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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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SUBCOMMITTEE ON FUTURE PLANT DESIGN

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MEETING

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WEDNESDAY, JANUARY 14, 2009

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ROCKVILLE, MD

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The Subcommittee was convened in Room T2B3 in the Headquarters of 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 CORRADINI, Chair
SAID ABDEL-KHALIK
J. SAM ARMIJO
GEORGE E. APOSTOLAKIS DENNIS C. BLEY
HAROLD B. RAY
WILLIAM J. SHACK

CONSULTANT TO THE SUBCOMMITTEE PRESENT:

THOMAS S. KRESS

NRC STAFF PRESENT:

MAITRI BANERJEE, Designated Federal Official
STEVE BAJOREK
SUD BASU
DONALD CARSON
HERMAN GRAVES
JOHN JOLICOEUR
JOSEPH KELLY
RICHARD LEE
ALLEN NOTAFRANCESCO
JAY PERSENSKY
SEAN PETERS
STUART RUBIN
ANTHONY ULSES

C-O-N-T-E-N-T-S

AGENDA ITEM PAGE

Adjourn

P R O C E E D I N G S

(8:30 a.m.)

CHAIR CORRADINI: Okay. Let's get started. The meeting will come to order.

This meeting is open to the members of the public. My name is Mike Corradini, chair of the Future Plant Design Subcommittee.

We have with us today ACRS members, or soon to have with us, Dr. Apostolakis, Dr. Bley, Dr. Shack, Dr. Armijo, Dr. Ray, Dr. Abdel-Khalik, and others will join us later in the day.

Tom Kress is our consultant in the area of advanced reactors is also present.

Ms. Maitri Banerjee of the ACRS staff is our designated federal official for this meeting.

ACRS INTRODUCTION

CHAIR CORRADINI: The purpose of today's meeting is to receive a briefing on and discuss with the staff the NRC's advanced reactor research program. The research program document has been updated recently to address the gaps in the NRC's analytical tools and infrastructure needed to independently verify NGNP VHTR design and its safety performance as well as other R&D needs, to review the NGNP application.

In the recent past the NRC performed a PIRT to develop an expert assessment of safety relevant NGNP phenomena, and the NRC R&D and infrastructure needs for the NGNP licensing. The results from these PIRT efforts and the joint NRC-DOE NGNP licensing strategy report provided input to the research program update.

In addition to NGNP the program document also provides a preliminary analysis of regulatory research needs for the staff's independent assessment of sodium cooled fast reactors.

Dr. Powers, now present, and I were members of the several PIRT panels, the NRC general counsel has advised us not to provide our views on the work of the specific panels we served on. Hence, I will not take part in any discussions specifically related to the thermal fluids panel.

We have up to 10 minutes for any member of the public who may want to ask questions to do so at the end of the meeting.

As a transcript of the meeting is being kept, we request that participants in the meeting use the microphones located near the meeting room when addressing the subcommittee. Participants should first identify themselves and speak with sufficient clarity and volume so that they can readily be heard.

We will proceed with the meeting. And I will call upon Stu Rubin, Stuart Rubin, of the Office of Nuclear Regulatory Research, to kick it off.

Stu.

MR. RUBIN: Okay, thank you. And -

MS. BANERJEE: Excuse me, Stu. This is Matri Banerjee. I just wanted to mention to the members that if you are missing any slides, because I anticipated only seven of you to come, and it looks like maybe, you know - if you are missing any slides, and there are going to be 17 sets of slides, please let me know, so I will go and fetch one for you.

CHAIR CORRADINI: So actually you reminded me of something I had talked to Stu ahead of time, and I'll ask the members and the staff. There are a number of parts to this presentation to try to lead us through the various parts of the advanced reactor research plan. So I would ask that we stick with our general plans. We give the speaker some time to develop their presentation. Unless there is a clarification question, try to hold them until something is just burning in us to clean it up.

And as we always have, about half of this is for discussion. So we should have ample time for discussion on any one of these topics.

Stu.

ARRP INTRODUCTION (OVERVIEW)

MR. RUBIN: Okay, again, good morning. Thank you, Dr. Corradini, and the ACRS members.

My name is Stu Rubin. I'm the senior technical adviser for advanced reactors in the Office of Research. And for this presentation I'd like to provide a very high level overview of the research plan with a focus on the R&D that we will have in the HTDR arena, and in the implementation as it exists today.

Research again is focused on safety R&D that we need to conduct to get ready to review the NGNP VHTR license application.

And so you know our strategy, for today is to start with a presentation at a fairly high level, this presentation. And then to work our way down as we go through the presentations, the next one being Joe Kelly who will then bring it down to a low level in terms of our evaluation model, development plans, and then following that we get into the ground level specific technical arena plans that participate in the development of that evaluation plan.

I think it would be most efficient as you mentioned to kind of hold those detailed questions to those detailed low level presentations.

The other point I wanted to make is that we started only a short time ago within the last year and a half, so we are just now starting to get our arms around what we need to do. We may not have all the detailed answers yet. We need to have those answers by the time the application comes in.

And the other point I'd make is that I would view this as a first meeting, in that I expect that over the next five years and beyond we will have follow up meetings in areas of focus, thermal fluids, nuclear fuels and the like. So we don't have to actually go through it all today. We are going to do more as time goes on in terms of meeting with the subcommittee.

As far as the focus of this presentation over these two days, first my purpose is to provide an overview of our R&D plans, and then to discuss and identify the technical issues and safety research that was identified within each of the technical arenas. And Joe Kelly will also provide a discussion of the accident analysis evaluation model, which brings together the disciplines of many technical arenas.

Third of course is we want to obtain feedback even over these two days from the subcommittee, in terms of our views and recommendations on how we ought to move forward with our plans.

And finally we want to support the work of this subcommittee to provide input and recommendations to the full committee on what we need to focus on and how we ought to proceed.

Just as a way of background I know Dr. Corradini covered it, but I'd like to give you some additional context, the first version of this plan was issued back in 2003 about five years ago, and it was done because of the HTGRs that were coming in at that time, PBMP principally. But by the time the ink dried on the plan, we actually shut down our R&D activities, because PBMR, or Exxon in that case, had decided to terminate the review. So we really didn't get anything going at that time.

But it was an approved plan at that time. But then following that, starting in 2005, a number of non-light water reactor design applicants came to the NRC and formally expressed an interest in licensing activities, and these of course were PBMR company, PBMR for design certification, and of course the NGMP and the EPact was a need for us to do a licensing action, and Toshiba 4S advanced burner reactor, with sodium fast reactor technical review, so we potentially would have to do. So in 2005 the Commission recognizing this issued a SRM to the staff to begin its development of the technical infrastructure for HTGRs and to a much limited amount for sodium fast reactors.

And so we began to revise the plan, bring it up to date to reflect the work that had been done and the like, and the new kinds of technical issues. And so we did that, and focused on HGTRs principally, and to some extent on sodium fast reactors. And in 2007 we provided that to what is called the Advanced Reactor Steering Committee within the NRC management structure for their review. They did review it and provided some comments back, and following that as was mentioned, we had some PIRTs, we had five PIRTs for the NGNP, in five technical arenas. So we had the additional input from that.

And also we met for the first time at INL out at the Idaho National Laboratories with DOE's contractors, and we got a very exhaustive briefing on all the work that they were doing to support design, development and licensing of the NGNP.

So with all that, we took that in and we revised the advanced reactor research plan, and we sent it back to the steering committee for their review and final approval.

And during this whole time, because of the Commission direction, we did initiate tasks in 2007, more in 2008, and we are initiating tasks today.

So while we don't have an approved plan formally, we are moving forward because of the time needs.

In terms of the infrastructure or the actual structure of this thing, it's two parts. One is what we would call an infrastructure needs assessment, which really applies the key technical and safety issues that come out of the licensing NHGR, and the second part of the actual plans themselves. These are plans that NRC plans to embark upon to do its regulatory research in meeting our goal.

And so the focus now is on HTGRs and - but there are generic aspects included as well that apply to all advanced reactors - human factors, digital INC, PRA, regulatory infrastructure. These are not specific to NGNP but certainly NGNP is a driver for their needs.

And so we have compiled our detailed plans in the document, and we've also included a limited infrastructure assessment, or what we would call a survey really, and R&D plans for SFRs.

Now again, the reason for the infrastructure is, we really want to understand what are the key, unique, and different technological issues and research needs for these designs. We also want to identify where are the gaps in what the NRC has in terms of data and information and modeling and know-how, and call that to the attention of our management in order to support a licensing review.

We also specifically identify what experimental data and models and code need to be developed, and what kind of technical knowledge and know-how does the staff need to develop in order to really be ready to do a review of something close to our expertise for light water reactors, hopefully at that level.

But having said all that, we do expect that the design of the applicant will be responsible for doing much of the R&D that we will need to look at.

MEMBER SHACK: Was there a formal process to figure out who does what?

MR. RUBIN: Yes, that's this next slide.

MEMBER SHACK: Okay.

MR. RUBIN: Okay, that's the role of research. And there was a lot of debate going on, what should be our plans for doing research. So we did have management meetings and we worked through what is our role as regulators. And this is what was agreed to within the Office of Research, and in the office of NRR and NRO. So this slide summarizes that.

First we conduct safety research to develop our technical know-how and expertise that we are going to need to review an application for an advanced reactor, and also the guidance, develop guidance and criteria for making decisions on these reactors.

We also do research to verify the adequacy of the technical bases for the safety requirements, and the safety criteria that are being proposed by the designer-applicant.

Third we conduct safety research to develop an independent analytical capability or analytical tools and methods, and Joe will start talking about that after me, for the purpose of confirming the safety performance and confirming the safety margins in the plant designs, and also to use to assess the designers' analytical tools and the designers' results that they provide in their safety analysis.

And the fourth, we do it to investigate issues, technical issues, that we have feel large uncertainty, such as the fluid flow phenomena of air and gas, or the emissivity of the reactor vessel wall during conduction cool down.

And finally we conduct safety research sufficiently to scope out and validate technical issues that have high risk importance, so we can turn it over to the applicant or designer to resolve.

CHAIR CORRADINI: So just to clarify that, because Bill asked the question, but I didn't see in the research plan this process laid out, or even a graphic to give some examples of what things would naturally fall in the NRC's role, would naturally fall in DOE's role as the applicant.

MR. RUBIN: Right.

CHAIR CORRADINI: And would be somewhere in the middle, and you guys are still in a matter of conversation. Will we get an example of that?

MR. RUBIN: I don't have it in front of me, but I thought we had a column in our R&D plans that we called bins or something. At least we did that in our graph. And those numbers corresponded to these bullets. So we justified reactor based on connecting to one or more of these responsibilities.

MEMBER ABDEL-KHALIK: If there is an issue missed by the PIRTs, when and where would that issue be captured?

MR. RUBIN: Well, as we're working, worldwide people are working, and we talk to each other, issues emerge. And they need to be looked at, and phenomenon need to be understood. So we view the PIRT we did as kind of a first major effort to get our arms around the issues, but we are always trying to learn about new issues.

And to be sure, in the HTR 2008 there were issues presented that may not have been fully explored in the PIRT. So it's not something where we actually go out and seek additional input, but we certainly are listening to everyone and are exchanging information all the time.

So if you -

MEMBER ABDEL-KHALIK: But where on this chart would the boundary between the NRC's role and the applicant's role in identifying and following up on those previously unidentified issues?

MR. RUBIN: Well, I mean, once an issue is identified, we would, if it has important implications in terms of the technical basis for the safety analysis, then we would expect that the applicant would do the R&D to develop the data and to develop the modeling to account for that new issue or -graphite dust would be an example I would point to. It came to our attention through a recent analysis in Germany at Julic that there was a view that there could be a large amount of metallic radionuclides, cesium, tied up in the dust that was circulating within the AVR, sufficiently high that it could result in a consequence that far exceeded what the safety analysis had presented in the licensing of that plant.

So that's an issue that we need to understand, get our arms around. But PBMR to our knowledge is already working that problem very much, and we are as well, okay. So because of its importance, we have a piece in understanding the phenomenon. And I'll talk about that in fuels as well.

But the primary responsibility is the applicant, that being an example.

But anyway, this chart is intended to show graphically all the amount of R&D and data and information that we will need in blue to do the application, and the small piece in red is really what we view as what our job is in terms of regulatory research.

CHAIR CORRADINI: But this is a very good graphic. So I guess to just repeat my question as we proceed through the two days, if the staff could be aware of where we are trying to understand what clearly is red, what clearly is blue, where they cross, and to add Said's point to it, where you thought it didn't even exist it's sitting out there in the dark blue, when you bring it in, what are those. So examples of those things would help us understand your process.

MR. RUBIN: Okay, okay. We certainly discuss this all the time with management when an issue comes up. We ask - the first question we ask is, why isn't the applicant responsible for this. So we have to really think that through.

The next graphic really is set up for the next two days. I put a graphic in here which is really the two reactor types, the prismatic block reactor on the left side, and a dynamic pebble bed core reactor on the other side. And I explain a little bit about them.

Basically on the left side on the prismatic block reactor side, we call them PMRs, they have a fixed central annular core which is comprised of about 1,000 prismatic fuel boxes that are vertically stacked on top of one another to form a tall thin wide circular cylinder, and within that cylinder are graphite blocks, and outside are graphite blocks.

And the core is periodically reloaded in a batch basis much like a live water reactor is. They're easy to understand.

The pebble bed reactor on the right side has also an annular core, but it involves moving fuel elements. And the annular core is combined - is comprised of a bed of about 400,000 pebble fuel elements, and I'll show you one later, and these are loaded into that annular space, and they all move down the core together and individually, slowly traveling from the top to the bottom by gravity. And when each gets to the bottom they are removed, looked at in terms of burn up, and if they are well below the design burnup they are returned to the top of the core and dropped back in. So this continues throughout the fuel cycle, and that's why it's called a continuous online refueling system.

In terms of the coolant flows, basically during power operation the vessel inlet, relatively cool helium comes in at the bottom, travels vertically up close to the vessel wall, then reverses direction and comes down through the core, picking up heat as it travels through either the circular channels on a prismatic fuel assembly or through the open spaces in a pebble bed type reactor, and having picked up that heat and exited below the core and then exits out through that same annular input duct where it came in initially.

So with that background you will have a little understanding of what we'll be talking about in our discussions. Just so you'll know -

CHAIR CORRADINI: Just to again, clarification on this one, so originally there was going to be a decision point as to which way to go. Is that decision point in terms of time still the same, or are you going to have to consider both designs through your safety - your preapplication phase?

MR. RUBIN: We are going to consider both designs until DOE makes a decision.

CHAIR CORRADINI: So has their decision point estimate changed?

MR. RUBIN: The feedback we are getting, and I could defer to DOE, is that we are looking at some time after - as defined by the licensing strategy, maybe later this summer or beyond, and we'd have to talk to DOE.

And the issue comes up, well, what is the application date?

CHAIR CORRADINI: It's still 2009-2010 timeframe?

MR. RUBIN: Yes, correct, correct. So until that time our strategy and plan is to move forward with research that really can be applied to both kinds of designs.

And again this slide lists some of the basic design facets and the safety approach taken by ACGRs. First of all there - the safety attributes and asterisks I would say are different than Fort St. Vrain. But basically the designs involve very high core outlet temperatures, perhaps as high as 900, 950 degrees. The core is annular, with a graphite center reflector, different than Fort St. Vrain. During normal operation they will use - the NGNP at least will utilize an intermediate heating strategy to exchange heat with a secondary plant, and there may be a direct cycle as well in which the helium directly goes to a helium tower turbine generator.

But there may also be steam generators in a design, which makes for more complex factor analysis issues for us. It utilizes coded fuel particles. It must have very low failure rates to meet the design acceptance criteria.

They are metallic pressure vessels instead of prestressed concrete, as Fort St. Vrain was. The reactor is designed to rely solely on passive systems, structures and components, and inherent characteristics to mitigate design basis accident; not necessarily beyond design basis, but for design basis.

And the dose consequences for these plants were based on mechanistic source terms, event specific, rather than a bounding source term. And as we all know, the license basis will be developed using the PRA and deterministic judgment in a risk-informed manner.

Again, these are the technical arenas. The ones that are in red asterisks have an important contribution or role in our evaluation model development. The green asterisk ones are the ones that are generic, and we added H2 production facility in this particular AARP because of the NGNP design, and again I mentioned sodium fast reactors were also included in terms of a survey of the infrastructure needs.

I'd like to point out in this slide what our priorities are for developing analytical methods. And they're listed in descending order.

Our first priority is to develop the tools for calculating the phenomena and the dose consequences of design basis accidents, and severe accidents.

Our second priority is to have tools that allow us to understand the performance and the integrity of the SSCs that are relied upon to mitigate those accidents. Examples would be confirming the integrity and performance of what's called the reactor cavity cooling system during these events, as well as the concrete structures that support everything during these events.

Third and lowest priority is development of tools that will allow us to understand failure potential during normal operation. This is a big focus for INL. They want a design equipment that is going to have a long term life expectancy, and they don't want early failures.

But we view that as more accident prevention, and our focus needs to be really on accident mitigation type and analytical tools.

This next slide was - is intended to show what are the targeted kinds of events that we want to be able to develop tools for, as well as what are the targeted figures of merit.

This was developed by several meetings with the evaluation model development team, and this is what we came up with basically. On the left side is the kinds of events, normal operation, pressurized core heat up events, pressurized core cool down events, depressurized core heat up events, which involve the failure of the heat and pressure boundary, and that with air ingress as another category. And then weather and steam ingress events, and reactivity type events. So that is the spectrum of the kinds of events that we want to be able to develop an evaluation model for.

And the figures of merit, as you see there, there are many more, but these are some principal ones that we feel our codes need to be able to display and understand so we can compare those with the applicant's analysis results.

CHAIR CORRADINI: Again, some clarification. Except for the pebble compaction, are these essentially the same list that Fort St. Vrain have to worry about?

MR. RUBIN: I think so. I think this

basically covers it. If you look in the categories of heat up, cool down, air ingress, water ingress, reactivity as the basic categories, I think they - all ACGRs will have events that fall into those basic categories. The details may be somewhat different.

I'll give you an example. You could have a water ingress event, okay, that could cause a reactivity event to occur, and also could raise pressure because of the forming of steam.

Down the road you could have a valve lift to prevent all the pressurization. So you could now have an event where you don't actually open the reactor, or you open the reactor later on. So you could have a reactivity slash water ingress event with a delayed kind of an opening of the reactor, and that could - so there are all kinds of combinations, but they fall into those categories.

CHAIR CORRADINI: Okay, but the reason I asked my question as I did is, besides the pebble bed design, put that off the table, if we just had prismatic, I want to understand that this list here is pretty much the same as Fort St. Vrain, which leads me to my next question, the high temperature operation of the NGNP does not change any of the characteristic accidents one would have to consider, or the factor of

- you are going to produce hydrogen offsite change any of the accidents you might consider on the reactor side?

MR. RUBIN: Okay, let me say that there is no road that is - hydrogen plant or process plant events, okay. The only reasons we don't have that is we don't have enough information yet to really understand it.

But basically if you look at it this way, a hydrogen plant is a load on the reactor. And you could lose your load. You could have load increases. Same as you have on fossil - excuse me, on light water reactors.

As far as that goes, those are small hydrogen plants, only 10 percent let's say of the full capacity of the reactor. So they are small load increase, decrease type events, heat up and cool down.

What are more interesting, of course, are the IHX failures. We might have some ingress of some sort of another media into the system. But before we start trying to model all that, we want to understand more about what is the design. So we are going to be meeting with NGNP to - excuse me, with INL and DOE to get more information on it.

But that is a role we'd like to add in

time.

MEMBER ABDEL-KHALIK: This may come out later, but how well do you think we know the core inlet flow distribution in either of these two designs?

MR. RUBIN: Well, we could have some people here who will talk about CFP analysis, what we're doing. It's not a formal part of our evaluation model development, but to understand some of the local effects that we may need to be concerned with in our evaluation model.

And to give you an example, it's not your example, exactly, but we believe that there will be a profile at the core exit which is not uniform in theta, okay. And so that's important to understand certainly for downstream mixing issues, for the balance of plant equipment failure issue.

But we also want to understand what is the temperatures in the graphite box, you know, nonuniformly distributed. So if you did have an event like an air ingress event, you may have this side of the core at a higher temperature than that side of the core in terms of oxidation rates and the like.

So we definitely are interested in those kinds of things. In terms of the inlet side, I'm not sure we have anything going on that, but on the outlet side we do have some CFD analysis that we are doing to understand those kind of distributions.

CHAIR CORRADINI: So Said's actual question leads me to the one where I like your priorities, but the design can feed back to potential radiological effects. And let's just take the distribution of temperature and push it further. How are you going to verify that you actually know how the graphite dimensionally changes as this core ages? If you were going to get to that later, that's fine. But this is just another step into the question, and I with all due respect to computers, what if I don't believe it? How are you going to know from some sort of in-service inspection about it?

So that's kind of where I hear his question potentially going. We can wait on it.

MR. RUBIN: Yes, we have someone who is going to talk about graphite and graphite aging and distortion with time, and the implications on thermal analysis and the like. So save those questions.

This is I would call an initial concept or preliminary concept of our evaluation model. I won't say much about it. I don't want to take the wind out of the sails of Joe Kelly. But basically we want to use this kind of a model which brings together really analytical tools and methods associated with nuclear analysis, thermal fluids analysis, fuels performance analysis, graphite behavior, and also fission product transport.. So it involves a team to work together to talk about the needs of each other, to make sure the models' inputs and outputs connects.

And I will let Joe talk about it. But this is quote our action analysis evaluation model concept at this point, and we can get more into it after Joe and beyond at the detail level.

Just to summarize, where we are in the advanced reactor research plan R&D, first of all our focus is on the NGNP VHTGR COL technical review aids. They are not showing us pebble bed at this point or prismatic, but that is really our focus.

We also want to be consistent in terms of high importance, low knowledge, type data needs for modeling in terms of the research that needs to be done, and we had parts for the NGNP, we had one several years ago for TRISO particle fuel, and we had one for human factors.

We also want to be consistent with our guidelines for the role of research, to make sure we are not doing what the applicant and DOE needs to be doing. And we watch that all the time.

We also want to utilize extensively the R&D that DOE is doing, and we are going to do that because it's expected, and there is an MOU that says as much, that we will have access to all their work. And they want to understand from us what exactly the environment set ups and data collection, and how you collect data, needs to be, so that it is good data that will serve both our purposes.

Again as I mentioned, for now we have both prismatic and pebble bed reactor designs. But when DOE makes that design selection, we are then going to focus clearly on that type of reactor and that specific design.

I will say we incorporated cooperative research into our R&D activities. We have already spoken to the European Union RAPHAELE program, people who have a program underway for HGTR type research in fuels, thermal fluids analysis and the like.

We recently talked to the Japanese atomic energy agency representative about potential research that they feel they would be willing to do with their HGTR, very useful type research I would add.

We need to talk to INL to see if we can identify some of those proposals that would really be very useful for both of us.

We have also been interacting with the OECD TAREF program, which is really a program to pull together worldwide what facilities exist for safety research for sodium transfer reactors, as well as for high-temperature reactors, and we are now at a point where we want to start talking really seriously about which of those facilities would the countries collectively try to get some research completed at.

And finally we need to support the timeline for the NGNP COR application. We can't do something that is going to be ready in 15 years; we need to do something that needs to be ready when the COR is submitted, which is 2013.

Now I put this in there because Dr. Corradini asked me to walk through the roll out of our presentations, but it's really a dupe of the agenda. And it's intended to really start out high, work our way down, and to do it in that way, and you can see by reading what will be covered at a high level in each case.

I will be coming back on fuels, and so we will just work our way down that onion. And that's it for me.

Are there any more questions? I guess we are - are we on schedule?

CHAIR CORRADINI: We're ahead. We want Joe badly.

MR. RUBIN: Joe, okay.

REACTOR PLANT SYSTEMS ANALYSIS (OVERVIEW)

MR. KELLY: Okay, I am Joe Kelly, and I'll be giving an overview presentation of our evaluation model for the NGNP at the level of the reactor plant system analysis.

A simple little roadmap, just what I said. I'll be giving - I'm so used to pointing, I'm an old style presenter, I want to stand up and point, so excuse me, I'm still trying to learn this.

So I'll be giving an overview of the evaluation model, and then below that will be five different presentations giving some of the technical details. Fuel analysis will be Stu, nuclear analysis will be given by Tony Ulses. Thermal fluids, Steve Bajorek. The accident analysis, which is more the MELCOR code, would be Allen Notafrancesco; and consequence analysis, Jocelyn Mitchell.

My contents are pretty short. The first, what is an evaluation model, what does it have to do.

The second, what is the one that we are putting together actually look like. And then the role of CFD analysis in this.

Then if time and your interest permits, I'll give a couple of short examples of some of the CFD work we've done to date.

Our evaluation model is straight from the reg guide. It's pretty simple. Calculational framework, typically consists of more than one computer code that all have to work together to go through a design basis accident. And also it includes the assumptions that go along with the use of those codes.

For the scope of the one that I'm responsible for the development of is the reactor plant systems analysis, and that includes primarily four areas: the nuclear analysis; thermo-fluids; fuel performance; and fission product transport.

At the moment it's going to apply to both pebble bed, that's the PBR, and the prismatic modular reactor, or PMR designs.

Once there is a design decision by the Department of Energy we will focus that down.

I'm going to talk in the way that it's like three separate evaluation models, although in reality it's one that covers three difference concepts. There are the normal operations; the initial release; and the delayed release.

So what are those? Normal operations, that's fairly obvious. What does the plant look like when it is sitting there operating for a long period of time?

And what we really need, this sets the source term for the initial release. So it's the generation and distribution of the fission products. What I'm talking about here now is actually within the coated fuel particles within the core. But you also have to worry about the fission products that have escaped the coated fuel particles, the ones that are played out, or absorbed within the matrix graphite. So all those within the helium pressure boundary; the circulating activity due to things like contamination in the helium coolant; or if specially if it's a Brayton cycle, the erosion products that have been activated. And the dust formed radionuclides.

MR. KRESS: Are you working on a dust source model?

MR. KELLY: Not yet. Not yet, but that is something that we obviously are going to have to do. And it's not necessarily how much dust is generated, but how much is there. It's the inventory of dust that is important. Where can it hang out?

MR. KRESS: But you need attenuator for it.

MR. KELLY: Right.

MR. KRESS: And you'll have to know what size it is.

MR. KELLY: And that is a huge uncertainty at the moment. You know based on the AVR results, the same people will tell you well, it might be six microns, or it might be point six; it depends on when we measure it. And that's a huge difference.

CHAIR CORRADINI: Do they know the magnitude of the inventory? They had a lot at the AVR.

MR. KELLY: At the AVR they had estimates. But the speculation is that from the HTR 2008 is that a lot of it had to do with oil ingress in vents, and now you got - it had to do with oil ingress events, and that was the shift from the six micron to the point six micron. They think that's what explains that. But you are getting me far outside of my area of expertise here.

CHAIR CORRADINI: What is the name of the person we can ask this of in the two days? Who is responsible for worrying about this?

MR. RUBIN: Okay, let me just use that as an example. We have a lot of players here. How much radionuclides actually gets out to the edges of the fuel - the pebble in that case. You have to understand the fission product transport within the particles and the matrix to understand that.

We may in fact be talking about on contemporary fuels very little in the way of cesium for example getting through a TRISO particle fuel layers, to get to that point where the dust is then generated.

So the first part of the puzzle is how much cesium is available to be bound up in the dust. And that is where the fuels program, and I'll talk about that, starts.

The next thing is, how much dust is actually generated, containing that very large amount of cesium, or very little cesium. That's a part that is in our graphite program to get our arms around that.

The next question is, how is that dust actually transported, and where does it go? So we have some analysis methods that we are thinking about, CFD analysis, to try to understand how that dust gets distributed and where it goes. There are some thoughts that it goes where it's below the velocity profiles, and that might be where the heat exchangers are, okay.

And then the next question is, what happens to that dust in an event where it can be blown out of the system? Other kinds of analysis. But if at the beginning of the process you conclude that there is not a lot of say radionucldes in that dust you can forget everything else.

So that's in my research plan, to get that.

CHAIR CORRADINI: Yes, I'm with you, but let me push that point. So let's say it's not a lot of radioactive material in it. All of a sudden I don't care about the dust?

MR. RUBIN: No, but you want to get your arms around the magnitude of it, because it could be the difference between requiring large filters or not requiring large filters. So we need to understand it; they need to understand it. This is in the venting of the system.

CHAIR CORRADINI: Okay.

MR. RUBIN: So how much rise or fall is the contribution of activity and dust will have a determination in whether or not you need to provide those kinds of mitigation type components in the system.

So want to know if it's a little addition or it's a big addition to that source. We need to know regardless.

MR. KRESS: Will that depend on the quality of the fuel actually?

MR. RUBIN: Well, a subcase in there is failure of particles due to elevated diffusion through intact coatings. And that is the issue for graphite dust as presented by the author of that issue.

MR. KRESS: We are not dealing with non-intact coatings, or too thin coatings?

MR. RUBIN: I will get into that. It has to do with the diffusion coefficient through cesium - excuse me, through silicon carbide at the temperatures we are talking about at the burnoffs we are talking about. And -

CHAIR CORRADINI: And it's only cesium? You keep on mentioning that.

MR. RUBIN: Well, because strontium tends to be tied up more in the kernel anyway, okay, and the cesium is much more mobile to come out of the kernel, and so that is the one that really is the dominant one in terms of being available for release.

MR. KRESS: Do you know what the chemical form of the cesium is yet from those kernels?

MR. RUBIN: Well, we will get to my presentation of it.

MR. KRESS: Okay, sorry.

MEMBER BLEY: Let me just sneak one in on that. Is it strictly a radiological problem, or is there enough dust in release that it could be an explosive issue, or a fouling of heat transfer surfaces be an issue?

MR. RUBIN: We'll go into those questions.

MEMBER BLEY: Okay, so you are looking at all of that.

MEMBER ABDEL-KHALIK: Let me just ask a basic question. What physical phenomenon determines the maximum allowable volumetric heat generation rate during normal operation at any point in the core?

MR. RUBIN: Okay, the goal, the goal is - what I should have talked about in my presentation - the goal is to have a passively cooled core for any accident. And so you need to do analysis of what is the maximum power generation or power density you can have in the reactor core, such that when you lose normal cooling and you start developing those processes for passive heat removal, you do not see the temperature rise that goes above some I'll call it design limit for the core.

MR. KRESS: Sixteen hundred?

MR. RUBIN: Sixteen hundred is used as a guide for that. And so you need to do that calculation to see what the - and that's why the power densities on modular ACGRs are so low. They are only about 5 to 10 percent power density compared to a modern light water reactor for that very reason, because you want to be able to passively cool the core in an accident.

MR. KRESS: That's also one of the reasons for the annular core, you get the fuel out to the periphery where it has a shorter distance to traverse radially to get the heat out.

CHAIR CORRADINI: Thank you.

MR. KELLY: And the initial release is simply when you have the break you release everything that is circulating in the helium, plus you can remobilize dust or plate-out. And the delayed release is what happens much later in time when you are doing a heat up, so you have to model the diffusion out of the intact coated fuel particles as well as the failed one, and you have to worry about either air or steam ingress, and what effects those can have.

And our model will have to model the hold up and the retention of the fission products within the confinement or containment.

Examples of transients to be analyzed, Stu already showed you his table. I was just going to go over the main five ones with the things you worry about.

So the pressurized loss of forced circulation which is - you know, you will hear people talk about P-LOFCs all the time. What you are really worried about now is the thermal plumes in what would be the inlet or upper plenum. So you are worried about the temperature of the components up there, and their integrity.

For depressurized loss of forced circulation, this is more like our standard LOCA analysis, that us light water people are more familiar with. And here you are worried about the peak fuel temperature. To calculate that you have to have a very good estimate of what is the effective thermal conductivity. I realize any nuclear analysis person looks at that and thinks about it's the reactivity coefficient, but so it will overlap.

So it's the effective fuel thermal conductivity, and also the performance, and if you will, the integrity of the reactor cavity cooling system.

Following that you go to higher consequence accidents, which would be like an air ingress following a D-LOFC. And here you have to worry about the graphite oxidation. That then leads you to the integrity of the core itself, or the supporting structures for the core. The damage that can occur to the coated fuel particles, causing additional fission particle release, as well as mobilization of the graphite layers, which would contain the absorbed fission products.

MR. KRESS: And with the water ingress you tend to get CO and CO2, will your models have to deal with those? And hydrogen, right.

MR. KELLY: That is one, when we get to the evaluation model, you will see we are using MELCOR. And MELCOR has a lot of capabilities there. And that's why we chose it.

Now the models will have to be adjusted or reimplemented to be more specific for graphite.

MR. KRESS: You will get countercurrent flows with multiple species of exothermic reactions?

MR. KELLY: Not in MELCOR -

MR. RUBIN: Can you come back to that question when we have our MELCOR expert here.

CHAIR CORRADINI: So can I ask you a non-MELCOR question about water ingress, if I'm allowed.

So where is the water - where are the sources of water in these point designs?

MR. KELLY: Well, part of it, is we don't know. And like if you noticed in the PIRT the water ingress was not covered. But it typically -

CHAIR CORRADINI: Well, in point of fact it was mentioned a whole lot. But not in detail.

MR. KELLY: But there are things like the shut down cooling system which will be a helium-to-water heat exchanger going directly into the core, the designs I've seen, and then Stu can tell you we are not sure what the NGNP design is going to be. You know you hear different things. Sometimes you hear there is always going to be an intermediate loop, but there may be a steam generator in place of an IHX now, in which case you have to worry about steam generative ruptures, and so on and so forth.

CHAIR CORRADINI: Thank you.

MR. KRESS: Will you need a CFD calculation for those thermal plumes you're talking about?

MR. KELLY: Probably. And that is certainly one of the areas where we would use CFD to take a look at.

And we have already kind of covered the reactivity events. And of course the pebble bed compaction has to do with seismic events.

So this is the NRC evaluation model as we envision it today.

MEMBER RAY: The last statement you said, the pebble bed compaction has to do with seismic events, is that what you said?

MR. KELLY: Yes. In the chemical industry, they actual shake pebble beds or pack beds in order to increase their density. And so you would worry about the density increasing, because the packing densities run around 60 percent, and it can go up to -

MEMBER RAY: I was just thinking, is there no analog in the prismatic? In other words is there no structural function performed by the graphite that might be affected by a seismic event?

MR. KELLY: I'm sure it can be affected, but I don't know how it can affect reactivity.

MEMBER RAY: Well, I think the issue, in my mind, you could have failures of the graphite core supports, and have the entire core moved -

MR. RUBIN: Correct.

MEMBER RAY: And then essentially you are moving away from the control rods, because they stay where they are and the core goes down. So you can have a reactivity addition that way, which is also true in pebble beds. So you have them from compaction. And also you are losing some of that negative reactivity for the rods, actually relatively moving away.

MR. RUBIN: That was the big problem we struggled with years ago, failure of the core supports.

MR. KRESS: Do the designs have a diverse redundant way to - like we introduced boron in the water reactors.

MR. KELLY: The ones I'm most familiar with have control rods which tend to be in the outer reflector region, and then they have a reserve shutdown system which are absorber spheres, that are dropped through bore holes and a central reflector.

And you can correct me, is there anything else? I think that's it.

MR. RUBIN: Yes, the absorber balls are equivalent to liquid injection in a LWR water. It's a diverse way of getting native radioactivity in the core.

MR. KELLY: And when we visited the PPMR facilities they were actually testing things like the absorber balls, the dropping of them through the bore holes, at prototypic pressure and temperature conditions.

MR. KRESS: The fuel itself, on negative temperature coefficients?

MR. KELLY: Yes.

MR. GRAVES: Excuse me, this is Herman Graves from the Office of Research. I'm going to be talking tomorrow about some of the structural and seismic concerns that we have with the seismic qualification on the fuel. We are looking at graphite prismatic core design.

MEMBER RAY: Okay, good, I would just then make the comment that I don't think seismic as an issue is limited to the pebble bed.

MR. KELLY: No, I am learning, thank you.

On the left-hand side I have the function of the individual components of the evaluation model, and on the right-hand side the code specific. In the top part of this, down through the steady state, that is all to get the cross sections and thermal conditions to set up the normal operating conditions.

Then the bottom half of the figure is

actually the transient analysis. And so the codes we will use, you will see, for the - well for doing the cross section processing, resonance processing, et cetera, is the scale AMPX code suite that you've seen before. It's used by both research and NMSS.

The reactor kinetics or reactor core simulator, that neutronics solution is by the PARCS code, which had already been adapted somewhat for gas reactors. We have more work to do on it, but it's already been used for a pebble bed.

The thermal fluids part of the core analysis is a code called AGREE, which is a module in PARCS. What it is is a new three-dimensional version of THERMICS direct.

MR. KRESS: I don't see TRACE in there anywhere. Does AGREE take the place of what TRACE would have been?

MR. KELLY: AGREE is more similar to a subchannel code if you will. MELCOR takes the place of TRACE here. When we get to the transient analysis, the role of MELCOR is the thermal fluid analysis on a system level, as well as the fission product transport and graphite oxidation.

CHAIR CORRADINI: So one more - because I actually was looking for this thing you call AGREE.

What is it again? Can you just repeat please?

MR. KELLY: Well it's - actually I've got just a little more detail on a future slide.

MEMBER ABDEL-KHALIK: But before we get there, let me go back to the question I raised earlier. At least in the prismatic design, there is really no cross flow. And therefore, it is very critical to know the inlet core flow distribution, because that will affect the radial distribution, it will affect all your physics parameters.

So where in this picture do you get the detailed radial and azimuthal variations of core in the flow distribution, given the fact that you only have one pipe bringing the flow in?

MR. KELLY: Well, once it goes through the plenum -

MEMBER ABDEL-KHALIK: Yes, I understand.

MR. KELLY: But from the plenum to the individual fuel elements is a good question. And the bypass flows in my mind, one of the largest uncertainties facing these. And of course that has to do with the question that Dr. Corradini raised about who is going to - how do you know how much the graphite dimensions are going to change. And that is -

MEMBER ABDEL-KHALIK: But even just the

basic physics issues, you don't have cross flow, whatever you start out with you'll likely end up with the same flow rate, and if you had highly nonuniform core inlet flow distribution, which you may not know very well, you will not know the core temperature distribution very well, and you will not know the core power distribution very well.

MR. KELLY: Well, if - you see at this point we don't know if the fuel elements are going to contain orifices or not, like in the older designs; they probably won't. So that helps. That removes one of the uncertainties.

There are cross-flows between the fuel element blocks, due to the graphite. But again you hope it's small. But there are uncertainties, and we may have to treat them as uncertainties, okay? And we may have to conservatively treat them as uncertainties.

But the - you know solving a 1-D momentum equation is not that hard.

MEMBER ABDEL-KHALIK: I mean this is not a trivial problem. We do not know the core inlet flow distribution for a PWR.

MR. RUBIN: Let me try to attack that question another way. I think you are right, we need to understand that. And I think I see that the modeling, we will get our arms around it. If it turns out it's significant in terms of creating an azimuthal power shift, and therefore a temperature effect on the graphite in the fuel, we may have - this I'm just talking out loud - some sort of hot channel factors so to speak to apply that to the action analysis in the normal operation analysis of particle temperatures and failure rates. And do a hot channel type of a concept, and handle it that way. I mean that can be done.

When you get into fuels analysis, in terms of fission product release during normal operation accidents, temperature is the key. The higher the temperature, the more fission products are mobile, the more failures you may see. You need to know those temperatures well.

But if you handle it like in a sector, where a high channel factor, I would imagine that we can handle that in that way, during normal operations to account for those high temperatures, and during accidents as well.

MEMBER ABDEL-KHALIK: As long as it's on your radar screen, that is the important thing.

MEMBER SHACK: But I guess the answer to

Said's question is, you are going to calculate this distribution. There are no plans for an experimental kind of validation of this.

MR. KELLY: Well, we do plan to do what we call an integral effects experiment. And you would not be measuring the flows inside it, but you certainly would be measuring the temperature distribution.

Now we are not going to have irradiated graphite with leakage channels in it. There may be predefined gaps to simulate what we think the graphite damage might be.

CHAIR CORRADINI: So let me turn this around. This is the one where if I were you guys, I'd put the heat on DOE. It seems to me that I would either demand a temperature decrement on the outlet gas temperature with this uncertainty, I'm not sure if that is directly a Q triple prime question that Said was asking. But it seems to me the outlet gas temperature solves all problems. If you go back to a Fort St. Vrain, thou shalt not go above 700 to 750C, a lot of these uncertainties, although there, become diminished in need, because you can put in hot channel factors, et cetera.

So my question really is, is that the

staff's approach? Are you going to turn to DOE and your partner cooperative meetings and say, until you show us better, we are going to assume a hot channel factor of X to do our accident analysis? Or how is this proceeding?

MR. RUBIN: Well, again, if you did it - like the role of research, there is a bullet that I talked about, there is a large uncertainty that has important implications. It's our job to really go after that. But it's also the job of the applicants. So between us we will have to figure out how we are going to get our arms around the importance of the risk implications. And I'll call it the source term applications of those higher temperatures if they are there.

So that is definitely on our radar as something that we would want to look at. But we will certainly encourage DOE to do as much as possible in terms of experimental.

MR. KELLY: And as we go through this process with DOE, there will be an information exchange, and they will know what we are worried about. Because certainly anything that we don't know about, we are going to conservatively bias. And permeate that conservative bias through our calculations and see what the effect of it is. And if the effect is such that the designers can't live with it, then they have to develop a knowledge base so that we can remove or reduce that bias.

MR. KRESS: Back during my gas cooled reactor days, which was a long time ago, we had trouble finding - this may be the wrong place to ask this - finding graphite of the right quality. The different sources of graphite had such a wide range of quality. Do you have - this may be the materials area.

MR. KELLY: Yes, I will defer this to Srini's presentation.

MR. RUBIN: I think we'll postpone you on this one.

MR. KRESS: All right, if you want to put that in your pocket for tomorrow.

MR. KELLY: So the last thing on this slide that I haven't really touched on is the PARFUME code. That's an INL developed mechanistic fuel performance code for coated fuel particles. We are not going to use it directly in our evaluation model and actually Stu will talk about it more. We are going to use it to help inform the selection of the fuel response surface for the coated fuel particle failure rates, which will primarily be based on the NGNP-specific fuel performance test data.

And of course once we actually get calculator release from the confinement or containment, it will go to the consequence analysis code next.

So what do we have to do in order to make this come to fruition? The first part is the code and model development. That's the phase we are in now.

The next one is code integration. There is a lot of different computer codes in that figure that have to work together. They have to pass data back and forth sequentially or in parallel. So we envision it as an automated workflow for that code suite.

The next step is we are going to perform uncertainty analysis for this plant. And that will be some type of statistical approach; we haven't decided exactly what yet, but it will be something like the Wilks method.

MR. KRESS: Is that the non-power method?

MR. KELLY: Yes, it goes by a lot of names, GRS, Wilks, nonparametric, et cetera. And there are various flavors of it, which I'm not an expert on.

And part of that is that we have to incorporate the model bias and uncertainty factors for those into all of the computer codes so we can actually do the analyses. We are fortunate in that MELCOR already has a lot of those. And we'll just have to make sure it has all the right ones, and that some of the other codes like PARCS and AGREE have them as well.

Then we have this great computer model, but we have to prove it. And that's the code validation phase. So that will be a PIRT-based code assessment matrix that will be performed.

MEMBER BLEY: Can you explain that a little bit?

MR. KELLY: I can, based on the light water reactor experience, okay? A year ago I was a TRACE developer.

So basically the PIRT has identified the high ranking - the high ranking phenomena. So for each of those you then determine the range of conditions over which that phenomena was important. I would say Reynolds numbers, pressures, that kind of thing. Then you go and look at the experimental database out there and see what experiments are applicable for that phenomena, or that range of conditions. And then you do the separate effects test, or excuse me, you use the code to simulate the separate effects test for that phenomenon.

And you do all of those for all the high ranking phenomenon that you can, and then you also do an integral calculation and hopefully the integral effects test data will be there so that you can show that all those models, not only are they validated individually, but they work together well.

And the final thing is a code applicability report, which I know some of you have seen ones for the AP-1000 and the ESBWR. We will be producing something similar for the NGNP.

CHAIR CORRADINI: For the codes that you have showed?

MR. KELLY: Yes.

Just a very brief, what are those codes and what do they do, and then they will be handed off to the people in a more detailed technical presentations.

MELCOR is our severe accident code which I know a lot of you have heard of. It solves 2-D flow and heat transfer in the core, as well as fission product transport. We are -

CHAIR CORRADINI: 2-D?

MR. KELLY: In the core, yes. It's radial and axial in the core.

The - it has been modified to include core heat transfer and fill models for the pebble bed and prismatic. We've also put graphite oxidation models into it. We will be extending the aerosol models to include the graphite dust. And then likewise we have to have fission product release models for the coated fuel particles.

SCALE and AMPX is our nuclear analysis suite. AMPX processes the in depth nuclear data into code useable libraries, whereas SCALE gives us the lattice physics and the depletion capability to get us our few group cross sections to K heat and the fission product inventory.

I mentioned PARFUME. TMAP4 is a separate code that has been incorporated into PARFUME. It gives you the INL developed mechanistic fuel performance codes. We will be using the NGNP specific fuel performance data to develop for our failure rate. This is a function of the fuel temperature and burn up. And we will be using PARFUME's sensitivity studies to help inform that.

The actual fission product transport that we will talk about now is the diffusion through the coated fuel particle individual layers in a graphite matrix. That is handled within PARFUME by the TMAP4 code. DOE has recently provided that code to us, and we will be looking at it to learn what's in it and either include it in its entirety within MELCOR, or a simplified version of it within MELCOR.

MEMBER SHACK: But the MELCOR will also do the passive containment cooling calculations?

MR. KELLY: Yes.

MR. KRESS: When we talk about fuel performance failure rate -

MR. RUBIN: I'm going to cover that next.

MR. KRESS: You are going to talk about that? Okay.

MR. KELLY: He already gave me a thing saying, you got five minutes.

MR. KELLY: Hey, I have never given a presentation in front of the HUSE in less than two hours. You are doing good.

So MACCS2 is our accident analysis code, and Jocelyn will be talking about that. PARCS is the core simulator, core neutronics simulator, reactor kinetics code. It's 3-dimensional. It had already been modified for both cylindrical coordinates and hexagonal. And it's been benchmarked for the pebble bed with the OECD PBMR-400 benchmark. The AGREE code, which stands for Advanced Gas Reactor Evaluation, is a 3-dimensional two-temperature porous body code. It's basically a rewritten version of the legacy THERMIX/DIREKT codes. It's a module with inside parts of the coupling is very tight, and it likewise has been benchmarked for the PBMR-400, but also against the sauna experimental test, which is basically what happens after a D-LOFC.

We have to extend it to the prismatic core. GenPMAX just reads the cross sections out of scale, and puts them in the format that PARCS needs.

Schedule: it's tight.

MEMBER ABDEL-KHALIK: Was THERMIX ever validated for natural convection?

MR. KELLY: I don't know. I can't answer that. But we will certainly have to validate AGREE slash MELCOR for that.

That is one of the things in the sauna test. You know those are D-LOFC conditions, where you are transmitting the heat radially from the center of the core out to the periphery to the reactor cavity cooling system. They ran those tests with both helium and nitrogen. The helium test, the calculations looked great. And it has to do with the models for the effect of thermal conductivity are pretty good. But when you do the nitrogen test, now you are also having a natural circulation cell within that, and you get a lot more - you smooth out the radial penetration because of that. And the codes didn't tend to do as well on that. That is something we have to look at.

MR. KRESS: What was the heat source of those experiments?

MR. KELLY: What they did, they had a graphite electrode in the center, pebble bed around it, and then the vessel wall. And then you know individual pebbles were instrumented so you could get the radial temperature profile at several elevations.

So on schedule, code development, the initial model development, we need it by September 2010. That's coming up soon.

CHAIR CORRADINI: You need everything you showed done at some level in a year and a half?

MR. KELLY: Yes.

But obviously code development will proceed in two stages. The second stage is after we've done some of the assessment, found out where our models are missing things. We need to improve those models, and finish the codes by May 2013.

Develop new data, any new data that we are going to use as part of model development and assessment, September, 2012, that's soon.

MR. KRESS: Is Research developing these models, or are you farming it out to the universities?

MR. KELLY: Well, for the most part we hope that we can select models that are already there that cover it. When we - and then just make sure we have a database to qualify those models, and to quantify their uncertainty. Like for example for a pebble bed you would always start with KTA rules. Start there, make sure the quantification of the uncertainties is right, and hopefully be able to move on. But you do need to make sure we revalidate it.

And the validation against existing data, September `12, against new data, May of `13, and that gives us a code adequacy report in December, 2013. It's tight; it's going to be very hard to meet that schedule.

The role of CFD: it's not part of the - it's not explicitly part of the evaluation model, but we will be using it to provide benchmarks as well as possibly develop or select models for use in the system codes.

Examples of places there it is just a natural fit, we have already talked about the inlet or upper plenum in a P-LOFC. We should also look at the lower plenum, the graphite oxidation during an air ingress event. Dust deposition and lift-off, perhaps in an IHX.

The reactor cavity cooling system, that's a natural one. Because you have a natural convection cells as well as the radiation heat transport from the vessel walls, the reactor cavity cooling system.

We are not going to model that in great detail in MELCOR. It's going to be a fairly simple model. But doing that with CFD we can make sure that a fairly simple model is good enough.

And we talked a little bit about core inlet flow distribution. While bypass is a huge uncertainty, numbers for pebble bed are as high as 30 percent. That is a lot of your flow to not be going through the pebble bed, so we need to understand that, what kind of gaps can develop. And that comes out of the graphite program.

And then we need to know what kind of loss coefficients to use for those gaps in an analysis with something like AGREE or MELCOR.

MR. KRESS: When you talk about graphite oxidation by air, you are not really talking about burning are you? In a strict sense you can define burning versus slower air oxidation?

MR. KELLY: Yes. I can't make that definition, but -

MR. RUBIN: Well, whether it's endothermic or exothermic really depends on the temperature and the availability of oxygen, and there is always a link. And you have to see what the actual oxygen availability is, and the temperatures to know if it's exothermic or endothermic.

MR. KELLY: But I think it is exothermic from what I've seen.

MR. KRESS: The reaction itself is exothermic, but there are heat sinks.

(Simultaneous speakers.)

MR. KELLY: This was - time and interest permitting I was going to talk about some of the ongoing studies. But since I am exactly on schedule at this point, I don't think I'm going to be showing the last few slides unless asked for.

CHAIR CORRADINI: Well, I have a question. Is there a philosophy about using CFD in these advanced reactors? That is, are you going to use commercial products, or are you going to develop open source models that allow for clear - what shall I say politely? - checking of it to make sure it makes sense. Because if you are going to use commercial products that would be an issue.

MR. RUBIN: Let me answer that question. That is a question that we could answer if we were interacting with an applicant.

CHAIR CORRADINI: If you were what?

MR. RUBIN: If we were interacting with an applicant. If we were in a pre-application review and could see what their plans are for doing a safety analysis.

I will say this: in the time that we were doing a pre-application with PBMR for design certification they did have CFD codes within the suite of codes for their safety analysis. So there is an indicator there - and I think they want to use it for things like distributions of dust during normal operation and perhaps even the transport during an accident.

So we are getting glimpses, but we really can't know for sure until we get that suite to look at. I think the answer has got to be yes. But we are not planning to use it within our evaluation model. We are going to use CFD as kind of a tool to better understand local phenomena and how it needs to be accounted for. But once we understand that, we'll go through things like scaling of temperatures and hot channel factors and that kind of approach.

CHAIR CORRADINI: Thank you.

Other questions? We are on break, so unless there are more questions from members, let's take a 15-minute break. We will be back at 10:00 o'clock.

(Whereupon, the above-entitled matter went off the record at 9:45 a.m. and resumed at 9:59 a.m.)

CHAIR CORRADINI: Okay, let us get back into session. You're next on the list, according to our list.

MR. RUBIN: Yes, I am. Are we read to go?

CHAIR CORRADINI: We are ready.

REACTOR FUELS ANALYSIS

MR. RUBIN: Okay, this first technical presentation is going to be on the R&D plan for HTGR and VHTR fuels performance. We are going to try to go over some of the key technical and safety licensing issues, and what our infrastructure development needs are. And also I'd like to mention that we plan to utilize the advanced gas reactor fuel R&D that DOE is conducting to support the licensing. We plan to use that extensively.

Now with regard to the objectives in the fuels analysis arena, basically we want to develop and validate independent fuels analysis methods, and develop data, and really insights into performance of the fuel that can bear on licensing decisions and the like.

We also want to integrate fuels performance in terms of particle failures and fission product release from the fuel into the accident analysis evaluation model, because that at the end of the day is the purpose of this whole exercise is to account for that, and then see where it goes in the dose implications.

We also want to develop an ability to inspect fuel fabrication facilities, because in these fuel designs the fuel plays such a central role in the safety case, and because fuel manufacture plays such an important role in the performance of the fuel that we need to make sure that it is consistently being made right. And we basically also want to have sufficient staff knowledge and know how to effectively review an application in the area of HGTR fuels.

MR. KRESS: If I were to draw an analysis between the fuel manufacture and software and development, you are looking at the process to ensure liability as opposed to the product?

MR. RUBIN: Well, I'll get to that. We are looking at both, because the state of the art in fuel fabrication to assure performance is I'd say 90 percent product acceptance, but 10 percent are process controls. Because you don't understand exactly how the process controls end up being a product to make a product specification. So very important to manage that as well.

Okay, as far as the key safety and licensing issues are concerned, especially as it relates to the evaluation model, first of all, we want to be able to predict fuel particle failure rates during normal operation and during core heat up. And we want to do this not only for those, but also understand the release in theory of other kinds of events like water ingress and potentially large reactivity associated events.

But then not only do you need to worry about particle failures, but you actually at the end of the day you need to know what is deficient in product releases from failed particles, and for that matter, particles that have not failed. So we need to be able to assure that those kinds of predictions, and the data on which it is based, are acceptable and conservative where they need to be.

We also wanted to understand enough about the fuel performance that we have a handle on changes in what I'll call particle failure fractions, or changes in important parameters, such as temperature, burn up, power density, fluids, so we understand that if we are going to see if we go past this value of temperature things really start to increase dramatically in terms of fission product transport of particle failures.

We talked about dust, and I'd put it this way: we want to determine the magnitude of metallic nuclides in mobile graphite dust, so the job of the fuel performance R&D guy is how much metallic radionuclides are in there anyway. And so that comes to the fuels and R&D program to try and pin down, and we'll be talking to DOE and others about how to really get at that answer.

And we also want to ensure that the methods that are used to qualify the fuels, and for that matter that they are modeling are appropriate; they do do things a little differently than the actual way the fuel will see its environment in the reactor, and we want to make sure that the way they test is still conservative.

And lastly the issue of making sure that the fuel is made to the quality standards, and the product and process specifications so it performs as it did in the fuel qualification program.

Now I've included this quote to try to kind of make clear that the fuel particle is where it's at in terms of the safety case. This is a quote from a DOE document in connection with the MHGTR, and basically it says that these are miniature containment vessels, and they need to stay intact, and they need to retain fission products.

CHAIR CORRADINI: I'm sure Sam is going to ask a technical question, so I'm going to ask a non-technical one. So couldn't I say the same thing about a fuel rod in al light water reactor?

MR. RUBIN: Well, when you combine this with the proposal to have a vented confinement -

MEMBER SHACK: This is true even during accidents, which isn't true in the -

MR. RUBIN: Right. Okay, what am I hanging my hat on now? Back to the fuel. So the fuel has to perform during normal operations and all these accidents because I don't have that additional barrier to additional barrier that we see in a light water reactor.

MEMBER ARMIJO: But if you had a containment on these things they wouldn't have to meet that point.

MR. RUBIN: Absolutely.

MEMBER ARMIJO: They'd have a much easier -

MR. RUBIN: Yes, they'd have a much more relaxed kind of requirements.

CHAIR CORRADINI: I am still, with all due respect, I'll let the members get on me now, I am still missing something, because I can have a different sort of failure and release mobile fission products in a light water reactor and I still have the oxide particles such that I'd have to get in a severe accident before I'd start talking about it any differently. So if I'm within a design basis accident space, where I have - I assume what Joe was talking about in terms of accidents, in terms of a pressurized loss of flow, a depressurized loss of flow, a depressurized loss of flow with air ingress, I'm still within DBA space. So I still would say that from a fuel rod standpoint, whether I'm here or there, it's still the first barrier to fission product release, not the only barrier. Because I have filtered vented containments at least in the current French designs for light water reactors above a certain -

MR. RUBIN: Yes. I will get into the credits that are taken for other hold up mechanisms and other barriers in an HGTR release analysis, so it's not only the fuel. There are other barriers. Those are definitely modeled.

But if you don't get the particle failure rates down to pre-load numbers, those are not going to work for you unless you put a big filter in the event path, or you make it a traditional containment.

CHAIR CORRADINI: All right, that helps.

MR. RUBIN: Bu9t it's really a statement that goes with the vented containment concept, and the barriers, and the hold up mechanisms, and how much they really provide for those attenuations of releases. This is the biggest attenuation by orders of magnitude.

CHAIR CORRADINI: Because of that importance you make a point in your research plan, the Japanese aren't confident that the silicon carbine coated particle will meet the requirements of temperature, burn up, and are actually pursuing a zirc carbide coating, another coating. And whereas DOE and the national labs have said, oh, silicon carbine ought to be okay, my question is, has the NRC staff reached that same conclusion that these particles, this type of fuel -

MR. RUBIN: I think they -

(Simultaneous speakers.)

MR. RUBIN: - several months ago, and he put on what he called a radar plot where he had burn up going this way, temperature going this way, power density going that way, fluence going that way, and the like, and his point was that the NGNP is going to push the envelope in all these dimensions, okay.

It is an advanced gas reactor program that in DOE's view that they can make silicon carbide particles that will meet those kinds of environments with the failure rates that they need to have.

MEMBER ARMIJO: But generally when you push those boundaries, you do something to improve the -

MR. RUBIN: I would call it an advanced particle design.

MEMBER ARMIJO: This is going to be a silicon carbide particle that is better than the previous ones?

MR. RUBIN: Well, we will talk about that.

MEMBER BLEY: They claim they are.

MR. RUBIN: I have a graph that shows that, at least in terms of preliminary tests that Dave Petty has reported on. But it's coming. It's coming.

MEMBER ARMIJO: The question is, is the NRC staff comfortable that that is going to work out?

MR. RUBIN: I mean pick your poison. You could pick the path of using the design, silicon carbide, for which there is a wealth of data, tests, to draw on and compare to, or you could say, I'm going for this advanced form for which there is very little. And if I'm proven wrong, I have perhaps wasted my time.

So I think that they have, through their analyses, through a PARFUME code and other kinds of evaluations, they feel with a oxycarbide kernel, where you suppress all CO release, your pressurization of the particle is going to be kept sufficiently low within the burnup envelope and the temperature envelope and the fluence envelope and the power density envelope that they have for the NGNP. Okay? The UCO is going to let them get there. UO2 I think they are not comfortable that they can get these particle integrity goals that they have.

CHAIR CORRADINI: Without derating the volumetric power or the exit temperature?

MR. RUBIN: Well, let me keep going,

because these are questions I have that I think you will see better clarity when we get there.

Okay, just - I have a little show and tell here, I'll get started with it.

MEMBER SHACK: Stu, so they would use UCO even for a pebble bed design then?

MR. RUBIN: Well, right now the path is UCO, and the reason they are going UCO is first and foremost for the burn ups they want to see they don't want to see early particle failures due to over-pressurization due to CO formation.

The other thing is they are at a higher power density, and when you get to higher power density in the particles, you introduce high temperature and other kinds of failure mechanisms. It's called the amoeba effect, where you actually start to move the kernel toward the silicon carbide, and you can actually degrade it that way.

CHAIR CORRADINI: Non-isotropically?

MR. RUBIN: No, it just - it moves across a temperature profile.

CHAIR CORRADINI: So independent of direction, it's not a gradient.

MR. RUBIN: UO2 fuel that those phenomena are going to be problematic. So UCO makes those kind of go away. And they have other issues then that may catch up with them with these higher burn ups and temperatures that they have to design to.

But anyway, here is a greatly magnified picture of a particle. It's actually the size of a poppy seed and I'm circulating some examples of the kernel, and believe it or not, there is another one that has the kernel coated with the coating. So there are two different sizes you will see int here.

It's called a TRISO particle because there are three high density isotropic layers. Each particle contains a center kernel, high density spherical, and it'll be either UCO or UO2 right now. DOE is pursuing a UCO because of the need to suppress carbon monoxide generation.

The layer is coated with a low density buffer to provide volume for fission gas releases from the kernel, and subsequently the coatings of inner pyrolytic carbon layer, a silicon carbide layer. Could have been a silicon carbide layer. And then an outer pyrolytic carbide.

And so I would point out even at this point that the fission product transport from particles does take credit for the fission product hold up and attenuation of each of those components separately. That's how they are modeled in the model test, and for modeling fission product releases from core-wide releases. So you need to keep in mind those high density layers, and the kernel for that matter, and how those are going to be approached in terms of developing fission product transport, models which really come down to the fusion coefficients.

MEMBER ARMIJO: What is the density of the UCO percent of theoretical?

MR. RUBIN: It's pretty close.

MEMBER ARMIJO: Like 97, 98?

MR. RUBIN: We could ask DOE what that is. It's up in that range. Yes.

Okay, just provide a little more background on what we are dealing with. An HGTR core will contain billions, perhaps five billion for a pebble bed, 10 billion for a prismatic reactor. These particles really need to maintain a very high integrity rate for all conditions, normal accidents, even design-base accidents, because they are the principal barrier and hold up mechanism for release, because the other barriers that we talked about within the reactor and within the confinement system, don't count for that much. They do count for some, but this is the biggie.

MR. KRESS: Do you have a number for that? Like how many particles -

MR. RUBIN: I have one, to back calculate what those numbers have to be.

MR. KRESS: Yes, you have to back calculate.

MR. RUBIN: Back calculate, right. So just to point out, a fuel manufacture has really the prime effect on coated particle properties, and those properties really drive the behavior, and then hence the performance of failure probabilities. And it probably also is effective release in terms of affecting the fusion coefficients and the like.

The operating conditions, we talked about temperature and burn up, and also about power density and fluids. And those also have an effect, and that is that radar plot. You start going too far into those dimensions, you are challenging the particle to fail.

The accident conditions, principally there what is going to change is temperature, and the peak temperature that the particle sees when the accident reaches its maximum point, and in that particular location, is going to determine whether or not that particle fails.

And so because of all this there is an approach and a requirement that they have design specific and manufacturing specific radiation qualification programs that test it both in radiation which is normal operation simulation, and the accident condition which is the heat up, and to collect data to actually see what the particle performance is during these environments.

And these tests are done at the design conditions, so you are actually seeing how the particles - it's going to be the highest particle for the longest amount of time, with the highest burn up, how that one worked. Okay, in terms of its failure probability. So that becomes very valuable data, and we'll talk about it later, for developing models, for a core-wide particle failure rate.

And again, we talked about because they are projecting I believe they are going to have low particle failure rates, so they'll be proving the proposed event in reactor confinement. Now, two kinds of fuel forms. Here is another show and tell. That is actually the size of a fuel sphere. There is no fuel in there anymore. So - it's all been burnt up.

(Laughter.)

The intention is design burn up.

(Laughter.)

Well, basically, this graphic shows a pebble. It's basically as you see the size of a billiard ball. There are about 15,000 particles in each billiard ball, or pebble as they call it, and there is about 400,000 of these things in a typical pebble bed reactor. So if you go through the math, 400,000 times 15,000 is billiards, okay, about five to six billion in a core.

I would say that the matrix is viewed as durable. It can be dropped many times into the reactor. It also provides a hold up mechanism, a diffusion, a coefficient of its own to release of especially metallic radionuclides. And that is taken credit for in the analysis.

But in the release of gaseous fission products, such as krypton, it doesn't provide much hold up if any at all.

So the designers will seek to take credit for each one of the layers, and the kernel, in modeling a fission product release from particles.

Okay just so you know, you have probably seen this, here is a prismatic block reactor. This is actually an hexagonal fuel element. And how they develop that is they take particles and they first put them in a fuel compact, each about a half-inch wide and diameter, and two inches long. And then they take the finished compacts and they insert them into bored holes in a hexagonal matrix in the box, and then they plug them on either end, and then interspersed between those fuel holes are the flow holes for cooling during normal operation.

Okay, we talked about the particle failure rates. What I've thrown up here is what has been -well, let me start by saying this. Potential owner-operators of HGTRs have asked the NGNPR designers to provide a plan in which the dose at the fission area boundary does not exceed one REM, with the intent to get a license which does not require significant emergency planning outside that.

So the owner specified request has resulted in a back calculation of what the particle performance needs to be. So this is kind of representative of what those back calculations turn out to be. And to do the back calculation, you have to know fission product transport outside the fuel. And I will go into how they model that. But they take credit for those kinds of hold up mechanisms. So you end up with a manufacturing defect rate of what is seen there, a normal operation failure rate of 6 X

10^-5, and then an accident failure rate of 10^-4, so these numbers are the goals that the design requirements for the fuel -

MEMBER BLEY: And what are they defining as a failure for this failure?

MR. RUBIN: Okay, I'm with you on that. But I just want to point out that these particle failure rates take credit for also all those other hold up mechanisms that are modeled in the fission product release calculation.

Okay. Here is another quote from the same document. We need to be able to predict performance; big surprise.

Okay, what I'd like to talk about is our approach for modeling fuel performance, and we really are looking at two kinds of models. The first model, it would be a stand-alone model which is a detailed mechanistic finite element computer code that models all the important phenomena that affects particle behavior and failure, and it's capable of predicting failure for individual particles.

And they also plan to use that model from studying the sensitivity studies to better understand the behavioral particles, and the influence, the sensitivity to temperature changes, to burn up changes, and the like, as a tool to understand where issues may lie, and also as a way of training ourselves to better understand fuel behavior.

The second model is an empirical failure probability model that we want to develop, and we would derive that directly from fuel qualification testing, where they irradiate the fuel and they heat it up and they measure how many particles fail, and they are able to get a failure probability based directly on empirical data and not based on trying to mechanistically predict particle failure.

MEMBER ARMIJO: When they do these fuel irradiations, do they do them with prototypic fuel - in prototypic radiation conditions. Or is it something where you have to say, well, it wasn't quite the right shape and size, and it wasn't quite the right fluence, and it wasn't really an HGTR that we irradiated in; it was a lightwater reactor. You get all these variables, and then you have to do a bunch of adjustments.

MR. RUBIN: Absolutely, I agree with you. Two sides to that question: when you do your testing, is the testing being done on particles which were made using the process and everything, just everything in terms of the inspections, the accepted criteria, the product - that's exactly the same as what you are going to use for the mass production, it's exactly the same thing. That's the approach they are going to take. They have to fix all that; they are not going to change it anymore. We're not going to change our process design; we are not going to change the process variable controls or anything. And we are going to make fuel, and we are going to make 20 batches, and then we are going to mix them up into larger lots, and we are going to create a particle distribution, because no particle is exactly the same as another one, which is representative of production variation.

So they will try to make the case that they are tests, which will be hundreds of thousands of individual particles in these tests, is representative and bounding of the production fuel that is actually going to go -

MEMBER ARMIJO: Future production.

MR. RUBIN: Future production, but they are going to fix it.

CHAIR CORRADINI: So the recipe will be fixed?

MR. RUBIN: The recipe will be fixed. Then you have the question of, well, are test reactor representative of the conditions that the fuel will see? Well, certainly they can control the burnup. They can control the temperatures very clearly. They can control fairly good at the ATR the fast flux, that will be accumulated in the particles, and they can control the power densities in the particles.

So I think with the ATR they will be very - specially in that center hull, will be able to very closely match up with what is projected to be the limiting locations in the VHTR core. So they will be simulating the limiting fuel in those limiting locations. Their test is going to be like 12, 1250. Well, that temperature is calculated to be the highest that any particle will receive with all kinds of uncertainties stacked up. So that's the approach they are taking.

MEMBER ARMIJO: So they are testing to make up for let's say statistics or something.

MR. RUBIN: Well, statistics will come out of this, and we will get into that.

MEMBER ARMIJO: Yes, but they are pushing this fuel to make sure that they are -

MR. RUBIN: Yes, they are pushing it to the envelope.

MEMBER SHACK: Yes, but your footnote says that accelerated testing could be conservative or nonconservative.

CHAIR CORRADINI: Well, that is exactly what I wanted to ask you. Because when Dave came up here last time -

MR. RUBIN: Oh, we already jumped ahead. Okay.

CHAIR CORRADINI: If you want us to wait, but Bill and I were thinking - when Petty came up last time. Dr. Petty came up last time, he inferred that after AGR-1 there would be an accelerated schedule of essentially testing, and to do that - compressing the time - and to do that, the way in which you do that would be modified. And my simple question is, have you guys reviewed that, and are you okay with it?

MR. RUBIN: We've reviewed it to the level of the qualitative units. The arguments are these. When you accelerate the testing you have a higher power in the particles. And the temperatures in the particles will increase. The mechanisms that depend on temperature will be enhanced, and so you could force those mechanisms to occur sooner.

However, on the flip side, you reduce the amount of the time. So you push it in faster, but you stop the test sooner. Now you have to look at, was that conservative? And you can accelerate tests sufficiently for let's say UO2 fuel where because of the amoeba effect, you will drive that amoeba effect to occur before, but because you stopped it so early, you may have in effect had a non-conservative type of test.

The way they approached that was, they used an individual seam particle code, PARFUME, to try to understand the effects, the sensitivity of faster tests, shorter time, on all the failure mechanisms. And they concluded that if they run faster, but within limits, they would still have a conservative accelerated tests.

If they went any faster than that, then they might not have a conservative test, and furthermore, they might actually fail more particles than would occur otherwise.

CHAIR CORRADINI: Are you comfortable that PARFUME models all of the failure mechanisms?

MR. RUBIN: We'll get into that.

CHAIR CORRADINI: But I guess I'm asking -- I guess --

MR. RUBIN: Yes and no, yes and no.

CHAIR CORRADINI: You politely took me through the thinking but I'm getting -- I'm asking a judgment or at least a process question which is what you said kind of reminds me of what Dave said in his presentation. But I'm kind of curious. Has the staff reviewed that? Because you're not going to go back and redo these tests. So are you okay with the process and the protocols so that we don't come two years later and you then all say hold out, time out.

MR. RUBIN: The agreement is in place. It's called the MOU for NRC participation in the NGNP project. And that calls for NRC staff to come and look from a regulatory mindset and a safety reviewer's mindset what their testing program looks like. And whether or not there are issues with it.

CHAIR CORRADINI: Okay.

MR. RUBIN: And so we haven't started that. They want us to do that. We want to do that. But it hasn't really started yet. And so -- but because the clock is ticking, and the design needs to move forward, they've already moved away.

Now I will say that, that what they are doing now is not on the prototypical fuel. Those tests, fuel qualification tests, come several years from now. Okay. So the acceleration was really for their benefit so that they can get the data they need to make some decisions to finalize the particle design.

But once you get to the fuel qualification tests -- which they are not there yet -- those are the ones we have to answer that question clearly.

CHAIR CORRADINI: So AGR-1, which is not following the compressed time --

MR. RUBIN: No.

CHAIR CORRADINI: -- and AGR-2, which is what you just discussed --

MR. RUBIN: Right.

CHAIR CORRADINI: -- are not fuel -- from where you consider to be fuel qualification tests. They are essentially background data tests that get them information.

MR. RUBIN: Speeding up the development process not the qualification.

CHAIR CORRADINI: Fine.

MR. KRESS: If you have to a have a quality of six times ten to the minus five failures, it looks to me like you have to use maybe 50 of those balls, those billiard balls in a test to get one kernel -- I mean one of your little spheres to fail if it is at that quality level. Can you really detect that?

MR. RUBIN: Well, yes. They can detect failures. Not question about it. They can detect failures.

The question is what kind of -- how many particles do you have to test --

MR. KRESS: That's what I --

MR. RUBIN: -- at what level of confidence to be able to make the statement --

MR. KRESS: -- that's exactly --

MR. RUBIN: -- yes, I just made fuel and proved that I met that.

MR. KRESS: Yes, that's the question.

MR. RUBIN: Okay. That's the question.

MR. KRESS: But you're asking that question thought.

MR. RUBIN: Well, what you have is I think it's called a one-sided beta test.

MR. KRESS: Yes.

MR. RUBIN: And it's the old story of you've got a swimming pool full of white balls and there's a few black balls. And if you reach in there 10,000 times and they're all white balls, you might conclude well, they're all white. Now there's a few in there that are black. Your sample wasn't large enough.

MR. KRESS: Yes.

MR. RUBIN: Well, you can do a sample --

and I'll say 300,000 is the number that they're probably going to use for that -- and so based on that sample size, they can do this one-sided beta analysis and make a statement as to at the 50 percentile, the 75 percentile, or the 95 percentile confidence that my failure rate was not above this.

MR. KRESS: This is 300,000 of the little coated particles?

MR. RUBIN: Right, right, right.

MR. KRESS: Okay.

MR. RUBIN: Now it's interesting. If you did a million --

MR. KRESS: Yes.

MR. RUBIN: -- or you did five million --

MR. KRESS: Your confidence level goes up.

MR. RUBIN: -- you could make a statement that is even tighter than what they have here. But it becomes an economic issue. Do they want to test a million and a half particles to drive down that number that they can make a statement of 95 percent .

MR. KRESS: I don't think you have room in one radiation test to do that.

MR. RUBIN: No, it's an economic question.

MR. KRESS: Yes, you have to do it over and over.

MR. RUBIN: But that's the bottom line is that the one-sided beta test, it gives them the statement at 95 percent confidence that we do not have more than five times ten to the minus six particle failures even though we saw none.

MR. KRESS: Right.

MEMBER BLEY: Stu, just for me, can I take you back to the question I asked you earlier? How do they decide there has been a fuel failure? You said they can detect them. What is a fuel failure? You always have some leakage, right, some diffusion.

MR. RUBIN: Yes.

MEMBER BLEY: So is it a fusion rate? Is it a visual inspection like the picture you showed us?

MR. RUBIN: Well, the thing that they are really measuring is fission gas. They have continuous online measurements of fission gas. And the one real one that they watch closely is krypton, okay, krypton gas. And there's something called and R over B ratio, release to birth ratio. The birth is at a certain number but how many get released is being measured.

Well, there is a signature for how much krypton would be released when one particle fails and so when it blips up to that, they say we have a particle failure. And you know that blip by having done prior tests with particles that fail -- that are made to fail. And it has that signature.

So they're waiting for that signature to occur. They say haven't seen that signature yet that would say particle failure.

MR. KRESS: They use krypton because it has a short half life? And that enters into this R over B ratio.

CHAIR CORRADINI: And it wouldn't be released -- it would not be released at all in a normal intact particle.

MR. KRESS: That's pretty much right. It's a low R over B.

MR. RUBIN: Yes, okay. This next slide is all the failure mechanisms that have been documented, for that matter, in the TRISO particle fuels PIRT. The first five, I would say, are mechanisms that are generally associated with normal operation. And the first and the last four are generally associated with accident conditions.

And this last mechanism, elevated fission product diffusion through intact coating layers, that is the mechanism that has been associated with graphite dust. That even with intact particles, there is a sufficient of metallic radionuclides, principally cesium, through intact silicon carbide layers to get out to the surface of the pebble and then to be removed in the form of dust and then to go travel through the system and eventually settle out and be available to, again, be released.

So that is the failure mechanisms. And I'll define a failure mechanism as an elevated release of fission products due to a failure of a particle or due to elevated diffusion rates.

MEMBER ARMIJO: Is palladium release --

MR. RUBIN: Which?

MEMBER ARMIJO: -- palladium that the Japanese are talking about, is that the same mechanism you are talking about here? Elevated fission product diffusion through an intact coating?

MR. RUBIN: Well, I mean you have things like Silver-110M --

MEMBER ARMIJO: Okay.

MR. RUBIN: -- Silver 110-M diffuses very quickly through intact particles. And it's then released into the system to plate out on low-temperature components like in the balance-of-plant. It becomes an occupational hazard for people who are maintenance workers and the like, okay.

But I said diffusion because it's not

clear that diffusion is the mechanism. People don't actually know why Silver 110-M is actually moving so rapidly through the silicon carbide.

But I'm not familiar with the palladium being another actor of that sort. Okay. And being a hazard.

MEMBER ARMIJO: Okay. Well, it was just mentioned in the report.

CHAIR CORRADINI: Harold hasn't had a chance. You go ahead, Harold. I'm sorry.

MEMBER RAY: I think it's better -- what my comment would be in our discussion at the end of the day rather than introduce --

PARTICIPANT: Stu?

MEMBER ARMIJO: Just as a -- how important is as-fabricated particle quality --

MR. RUBIN: Very important, very important.

MEMBER ARMIJO: And how do they actually measure it, you know, as opposed -- you know, all these mechanisms relate to intact particles that are --

MR. RUBIN: These are the mechanisms. These are the big ones that make a particle fail.

MEMBER ARMIJO: But if the particles is --

MR. RUBIN: The next one is the things you are measuring --

MEMBER ARMIJO: Yes, I'm kind of interested in the quality -- quality control stuff, yes. How do you measure --

MEMBER BLEY: You don't have the krypton then.

MEMBER ARMIJO: Right. How do you find --

MR. RUBIN: Go ahead -- who are you please?

MR. LEE: Questions on the palladium -- Richard Lee from Office of Research -- the palladium has to do with the fission products from the $_{UO2}$. And because this is a high burn up -- up to like 100 gigawatts say per tons, the plutonium used is higher for palladium. It's intact to silicon carbide.

MEMBER ARMIJO: Right. And --

MR. LEE: So that's the one --

MEMBER ARMIJO: -- you point that out in your research plan --

MR. LEE: -- correct.

MEMBER ARMIJO: -- that that is what the Japanese are concerned about. And then the question is ultimately will that become an NRC concern.

MR. RUBIN: Well, again it has to do on

the particle design, on the temperatures it sees. The Japanese fuel design, the fuel runs at a much higher temperature than the particles will be operating in the PBMR or the VHTR. It's just a function of their design.

And so --

MEMBER ARMIJO: I thought that both of them had a 950 outlet.

MR. RUBIN: No, I'm talking about the fuel, the fuel itself, the particle itself.

MEMBER ARMIJO: Okay.

MR. RUBIN: The particle itself sees -- its envelope, you know, is even bigger in temperature. Very low burn up, very low burn up for the HGTR because they can't run it very long because it's operating at a high temperature. So you're dealing with different service conditions. And because of that in their design they have other issues to design against, palladium being one of them, and the like. Okay.

Here are the things that -- getting down to the phenomena level, some of the more significant phenomena in terms of the particle itself, which is what you're talking about, you know, checking these characteristics.

I mean there are dimensional characteristics. There's material and physical properties and chemical properties. And I lost track. There may be 80 different parameters that are checked in manufacture of a particle. These ones are particularly important for particle failure, for the failure mechanisms I mentioned.

And so yes, they will statistically check all of these properties in manufacture that they have listed. However, there are variations. Because it is a process and it is a random coating process, there will be a spread in the coating layer thicknesses of silicon carbide from one particle to the next. And they will have to have distributions. And those distributions will have to be within tolerances.

But those distributions are really the important piece of predicting particle failure because it is the tails that stack up in some particle that is the one that is going to fail.

Well now if you were to program in your average particle, you probably wouldn't show that you'd ever had a failure. And that's why statistical analysis or Monte Carlo analysis with those variations are very important for these mechanistic codes.

MEMBER ARMIJO: Stu, we're still seeing in light water reactor fuel pellets, UO_2 , plain, garden vanilla fuel, we're seeing even today, manufacturing defects that previously were thought to be unimportant are contributing to failed fuel. Okay.

MR. RUBIN: Yes.

MEMBER ARMIJO: After all of these years. And this is a -- this fuel hasn't had as much experience. And we're going to rely on a batch process with certain quality control measurements to predict what the same batch process will put -- will produce two years later or three years later? It's -- at some point --

MR. RUBIN: Let me go --

MEMBER ARMIJO: -- I'd like -- maybe Mike should --

MR. RUBIN: -- let me just --

MEMBER ARMIJO: -- show us how the manufacturing -- as manufactured properties, actually can predict or assure that the in-reactor performance will be as expected.

MR. RUBIN: Right.

MEMBER ARMIJO: And that, to me, is a real tough problem. I've been trying to figure out how are they going to actually pull this off. What are they going to measure --

MR. RUBIN: Hey, listen.

MEMBER ARMIJO: -- to assure that --

MR. RUBIN: What they are missing may get through, it turns out to be the important contributor to particle failure rates. Okay.

MEMBER ARMIJO: Right.

MR. RUBIN: But to their credit, DOE did a study looking back at all the fuel that they have made, especially for the NPR, and looked at how they actually failed. They looked down at the PIE and saw that there were cases where they had separation of layers from the silicon carbide.

They saw that there were those initiated just by failure due to anisotropy, high anisotropy causing a local spot. They saw amoeba effects. And so they were able to learn a lot about particle performance and mechanisms of failure.

The PIRT added to that. Okay. They are using all that knowledge. And they're using their analytical tools to engineer a particle and engineer the tolerances. They're using PARFUME as a tool to actually say what are the tolerances to react? We have the statistical pack. Can we go this far? It would be great if we could go that far in terms of accepting.

But as I say, we can't go that far. But we still may have something that -- and it's called weak fuel -- I think somebody coined the term. There's something you missed, okay. And we can do sensitivity studies when we're done with this to impose weak fuel where we impose higher failure rates on particles. And we'll get to how we can do that and see what the effect is in terms of dose and the like.

MR. KRESS: I presume, in regulatory space, you'll have some sort of tech spec limit on the activity and the primary --

MR. RUBIN: That's for sure.

MR. KRESS: And if you go beyond that, you have to shutdown and do something.

MR. RUBIN: Yes.

MR. KRESS: That's the way you control the quality, after the fact.

MEMBER ARMIJO: Yes, but it's after the fact.

MR. RUBIN: The difficulty with that is you are monitoring failed particles.

MR. KRESS: Yes.

MR. RUBIN: And if you have the other failure mechanism where you have an intact particle and you have high diffusion through an intact particles, your activity is not going to pick that up because it is metallic, it's ground up in dust, it's going to plate-out, it's going to bypass those monitors.

And so you have an accumulation of fission products in the system and never know it because you are watching the wrong thing.

CHAIR CORRADINI: I think -- just to interject -- I think we need to move on but I think Sam's point is that when we get back together, since we will get back together, let's just talk about fuel manufacturing recipe and the QA related to is, I think is an issue that gets us all a bit --

MR. RUBIN: Yes, a big issue, in fact we've developed an inspection protocol, it's about 50 pages long, and it gets into every single aspect of making good fuel. So we can go in there and look.

MEMBER RAY: Mike, wait. On this issue of tech spec, though, it doesn't seem to me if we're talking about accident containment function that tech specs are a legitimate way to say well, if we exceed the tech spec, we'll just have to do something.

Unless you can correlate what you see during normal operation with the accident condition in some certain way, I'm not sure how you do that.

MR. RUBIN: Well, I mean you have to understand what all of the sources of radionuclides are in your system to keep on top of that. The fission gases are through the measurements that you talked about. But the other ones, the metallics, now in the AVR, they had some systems in place that were able to keep book on the amount of dust that was being generated and other metallics. It was a very intricate system to tell them what was going on there.

But even there they really were not able to understand the full amount of dust that was being generated in the plant. So it is a black box in many respects.

MEMBER RAY: In the light water reactor containment, you pressurize the damn thing every so often and you measure the leak rate. I mean that's a pretty straightforward way to do that.

MR. RUBIN: Okay, Don Carlson would probably like to jump in. And there's something called pulling fuel out from time to time and putting it into an actual condition test and doing the PIEs to actually see how the fuel is doing and seeing if it is within the envelope of the qualification program. Okay.

MEMBER BLEY: Stu, you said something that

I think is real interesting and important and that after you do all these -- after they do all these tests and there is sampling on the process looking for fuel, you have to look at all the uncertainties. And it is the tails that matter because you have so many of these things.

MR. RUBIN: That's right.

MEMBER BLEY: And the standard techniques for looking at QA and for looking at distributions do a good job with estimating the central tendency, the middle of the distributions, but do a lousy job out in the tails. I hope you're doing something to really convince yourselves that you are covering yourselves really well.

MR. RUBIN: I've lassoed one of our statistical people to kind of take a look at the statistics that they were going to do not only for the qualification testing but for the manufacturing side. That's an important issue to make sure they're doing the right statistics.

And from what I've read, they've evolved over the years in what they're doing to today, quote/unquote, we feel we're doing the right kind of sampling and statistical analysis to prove our case. But we haven't looked at that.

MEMBER BLEY: Okay. Sometimes for this kind of thing you need some kind of extreme value or something almost like PRA --

MR. RUBIN: Yes, I agree.

MEMBER BLEY: -- to find out the key things that are driving it.

MR. RUBIN: Okay.

CHAIR CORRADINI: We need to move him along.

MR. RUBIN: Move me along. Okay. So the first thing is I mentioned this PARFUME code, DOE has been developing it for many years. I would view it as one of the best that is around in terms of the mechanisms it models and the data that it has in it. And they are going to improve it with additional data.

And our plan is to ask the DOE -- we already have -- to obtain that code. And we want to use it again as a learning tool to do sensitivity studies to better understand the tails, to understand if the fuel is not made right, what would be the implications on fuel performance and the like. And we would use it in that way.

And finally, we would use it to help us understand how variations in temperature, burn up, and the like would effect core-wide changes in particle failure rates.

Now let me talk about that because that is a different model that we want to develop. PARFUME is just kind of impractical, in my mind, to just kind of link directly to MELCOR. It's a finite element. The run times are long. It has a statistical package in it.

And at the end of the day, you don't know if it is valid anyway. Okay. So we need to come up with another approach. And the approach we're taking is not any different really than the designers have used over the years. And that is to establish a failure fraction based on actual test data.

And that test data would come from the actual fuel qualification tests of the final product. This is the way we're going to make it. This is it. This is the irradiation particle failure rates. This is the accident condition particle failure rates.

And to use that data to back out a particle failure fraction as a function of temperature and burn up based upon data directly. It's more defensible that way.

But to use PARFUME because it let's you get below the surface to understand why things can change in that space, temperature burn up space, to help us shape, if you will, that map, that response surface that we plan to put together. And that's no different than applicants worldwide have used for generating particle failure rates.

And one can think of doing that two ways: as a conservative way and also a best estimate way. You can use the statistics. You can use PARFUME to come up with two different kinds of response surfaces. And depending on whether the Commissions says okay, it is okay to use the best estimate response surface for the BDBAs but we want to use the conservative one for the DBAs, you know, we can do that.

Or they may say no, I just want you to use the conservative one for both. And fine. Other best estimate mechanisms to work with but not the fuel.

And so we want to obtain it for that. Excuse me -- we want to develop this response surface so we can predict core-wide R, Z, and time for normal operation and transients. And we also feel we could use it to see what the applicants have come up with.

But in the near term, because we don't have that data, either the experimental data or data in PARFUME that drives the models, we would use data from the German fuel just to kind of get the code going. Okay.

Okay. Now so the idea would be --

MEMBER ABDEL-KHALIK: Are temperature and burn up the only independent variables that would characterize --

MR. RUBIN: No, no, I think I told you that there is fluence, there is power density, there are other variables. But if you bound those other ones, then you -- let's say you are conservative on those, you then can -- and that's how they are going to run their tests, okay, they're going to run their tests with a conservative fluence and a power density and the like. So you've already bounded that.

And now you just work off the variables of temperature and burn up to drive a response surface. Okay. That's the approach that is taken by applicants to say those other variables -- you've got a gazillion variables but we're going to cover those in the experiment in a conservative way.

And we're going to just limit ourselves to a couple of variables that we're going to input into our analysis tool. So the idea would be to --

MEMBER ABDEL-KHALIK: Does that make sense though?

MR. KRESS: Actually, this is the way the fission product release models for LWRs in MELCOR were developed. Almost exactly that way.

MR. RUBIN: Right.

MR. KRESS: And so it's almost a parallel process.

CHAIR CORRADINI: So it is an empirical input for the moment until the data gives you a better number for the empirical model you input.

MR. RUBIN: Well, you use the empirical model that is based on the representative tests that are the qualification tests, that are bounding tests. And that's the basis for your response surface. And there are particles in the core that will be less than that bounding test.

In any event, the idea would be to be able to come up with a failure fraction for normal operation based on the maximum fuel temperature and the burn up. And for particle failure fractures during the heat up would be also fuel temperature but that is changing in time, R, Z, and time, and burn up.

And so what you end up with -- and this is just for illustration -- is that kind of response surface, okay, which shows that as you increase in temperature moving from right to left, for particular burn up you're going to start to increase additional particle failure rates which then now have to be accounted for in your source term, time-dependent source term.

And this will be applied R and Z, so you're seeing sectors, in R and Z, changing in time, moving across this response surface, having additional particle fails and then going through the fission product release for now failed particles. So you have to keep inventory and book on how many more particles have failed in what location and do the source term analysis on that basis.

So the model is a response surface.

CHAIR CORRADINI: Okay. So let's just use this to illustrate. So down at the left, at 900, is essentially six times ten to the minus fifth?

MR. RUBIN: I'm doing this for illustration.

CHAIR CORRADINI: I understand. But the numbers seem to match up so I just want to make sure I'm not off base.

So for a fuel operating temperature in the range of 900 to 1100C, right--

MR. RUBIN: Yes.

CHAIR CORRADINI: -- the failure fraction is what you are shooting for.

MR. RUBIN: Yes, I tried to -- I did this over the weekend so it would be consistent with what their goals are, okay. But I don't have the data to say that that is the way it is yet, okay.

CHAIR CORRADINI: And then until that data is available, there would be a dummy set of data into the --

MR. RUBIN: Right.

CHAIR CORRADINI: -- MELCOR analysis.

MR. RUBIN: Right.

CHAIR CORRADINI: So let me ask. What is known -- what is the experience out of Fort St. Vrain that you can use in this --

MR. RUBIN: Well --

CHAIR CORRADINI: -- in terms of the type -- the fuel, the type of operating conditions in terms of exit gas temperature and volumetric heating.

MR. RUBIN: -- the methodology -- the methodology is much the same.

CHAIR CORRADINI: Okay.

MR. RUBIN: The plot is grossly different -- grossly different because they had BISO fuel and they had TRISO fuel. And some of their temperature conditions went to 100 percent. During heat-ups, I mean heat-ups went to like 3,000 degrees, okay, they went to 100 percent.

And they had to account for that 100 percent particle failure rates. If that sector of the core went that high, it went off the cliff. Okay. So the basic idea is the same but the shape will change dramatically with the fuel and the conditions it will see. Okay. But the methodology is the same.

MR. KRESS: Do you envision steady state tests with temperature to develop this empirical model?

MR. RUBIN: Well, this empirical one is let's say 1,200. In the case of NGNP, I think it is 1,250 that they are running their fuel testing at. So 1,250 would be the last temperature at which you'd have a flat kind of a response surface, not giving credit for any temperatures lower than that in the core.

But once they get above that, now you are into an accident heat up and then you start to see increases. So that last step is where their fuel qualification for irradiation is done at.

MR. KRESS: Yes. But when you run the test, you'll do it at constant temperature.

MR. RUBIN: Yes. However, however, for pebble bed, it is interesting, it is cyclic. It goes up and down because you are putting the pebble in at the top.

MR. KRESS: Oh, that's right.

MR. RUBIN: The top is the coldest spot because that's where the cold is.

MR. KRESS: Then you go around and come back again.

MR. RUBIN: As it travels down, it gets hotter and hotter and hotter. So you have a sawtooth.

MR. KRESS: Yes.

MR. RUBIN: And so their approach, I believe, is to do a sawtooth fuel qualification test. And also max steady. But you have to look at both.

Okay. This is particle failure. We haven't even gotten to fission product transport yet. But particle failures are what drive the big fission product transport piece. Okay.

I don't know how much time you want to give me. This is really the heart and soul -- that last graph was really the heart and soul of our source term right there.

MEMBER ARMIJO: Stu, what are the various mechanisms by which a particle would start it out, intact, meeting all the quality requirements, what are the mechanisms by which they fail? And if one fails, why don't thousands fail?

MR. RUBIN: That one, right there, that's the list.

MEMBER ARMIJO: If everything is the same and there is one mechanism or two, why don't all of them fail?

MR. RUBIN: Well, PARFUME actually has several built in. I think it has -- the first one, for sure, I believe it has the second one, I believe it has the third one. I believe it has the fourth one. I believe it has the fifth one. It may even have the sixth one.

It doesn't have the accident-related ones for oxidation effects and reactivity effects. And it will be able -- through the next code I'm going to be able to talk about -- calculate what the diffusions rates are. But it has all those models.

MEMBER ARMIJO: In one of the little figures in this handout, there's a picture showing a crack in the pyrolytic carbon layer --

MR. RUBIN: Sure.

MEMBER ARMIJO: -- but the silicon carbide doesn't seem to be cracked yet. Is that a mechanism that concentrates stress?

MR. RUBIN: Yes.

MEMBER ARMIJO: So it seems it me there

would be, you know, some finite number of mechanisms that cause these failures and people would understand how each of these works as a function of burn up --

MR. RUBIN: Well, it's not like a predictor/corrector. What they find is yes, this is a failure mechanism. What can we do to modify the way we make the particles so that that particular kind of phenomenon will not occur.

MEMBER ARMIJO: Or will happen less frequently because --

PARTICIPANT: And so they have engineered -- they have engineered their coating process to dramatically reduce the debonding and the cracking, okay, which were the failure mechanisms of the old NPR fuel.

MEMBER ARMIJO: And if they had a quality control test in fabrication that would confirm that that, in fact, is the case, that they're making much higher quality, then I'd be more comfortable with that.

MR. RUBIN: At the end of the day, the irradiation in the particle failures, probably zero. It's not the end of the story. You have to go do a PIE where you'll actually start to look at individual particles and you look to see what they look like.

The other thing they are going to do is they are going to run tests where fuel will be driven so hard that they will fail. And they will need that kind of data to --

MEMBER ARMIJO: I agree with that.

MR. RUBIN: -- okay -- and then they'll want to see what the mechanisms are in those tests. Okay.

And the reason you need those tests --

MEMBER ARMIJO: To get statistics for the PIE is going to be tough.

MR. RUBIN: -- the reason you need those tests is you need something to validate your code because if you have a test where no particles ever fail, how do you validate your failure model? So you have to drive them to fail particles and then simulate that to say that I was able to simulate that failure way beyond the design limits. Okay.

MEMBER ARMIJO: I agree conceptually. But I think it is really tough in PIE when it is on these tiny little particle basis to get the statistics, you know, something was leaking in let's say one sphere and then what do you do? How do you inspect to find how many were leaking?

MR. RUBIN: Yes, I agree with you.

MEMBER ARMIJO: I fail to understand how they are going to do that.

MR. RUBIN: They are looking at more than one particle. They're looking at dozens, if not -- I don't know that number in their PIE. But it is a massive effort into itself. But I think we need to move on. So that's the particle failure.

But now here is the fission product release part --

CHAIR CORRADINI: So may I give you a time check? In 15 minutes, you are to be done.

MR. RUBIN: Okay.

CHAIR CORRADINI: So I'll let you decide what you want to emphasize.

MR. RUBIN: Okay. Let me just say this slide --

CHAIR CORRADINI: I can blame Sam but we're all to blame.

MR. RUBIN: Right. No, but you're asking your questions in the right presentation. I'll give you that.

(Laughter.)

CHAIR CORRADINI: Thanks. Appreciate that. I must note that. Will we get our assessment back in 2009? Sorry, it was a joke.

MR. RUBIN: Okay. Here again is the summary of the components of a particle and the fuel element for that matter. And the idea is to model all those components. And to develop fission product transport data and fission product modeling of fission product transport for each of those models.

And if you look at how you would apply that, well, I would apply it for different kinds of particles -- there's something called contamination which is heavy metal that is in the fuel ball, let's say, from manufacture due to the fact that there is going to be some sort of heavy metal in there naturally but also because some of it gets in there in the process of making the particles.

So contamination, what can I take credit for? I can't take credit for the kernel, IPyC, SiC, or OPyC. I need to take credit for any hold up and delays in the matrix.

The next one is a failed silicon carbide layer. There are methods available in manufacture to determine how many of those you have. And in that case, do we want to model hold up in the kernel, IPyC -- no. No kind of hold up in the SiC and then hold up beyond.

Failed particles, you'd only be banking on the kernel providing some hold-up mechanisms. And then the matrix and graphite. Intact particles, you would model all of that.

Now how do you do that? Before I get to that, this is a part of diffusion coefficients versus temperature that were based on fuel that was made and tested in German, U.S.A., Japan, and Russia in many cases. And they were able to develop these coefficients. Okay.

So here you have the basic information you need to then plug into a model to calculate what the diffusion rates are through each of those layers. Okay. But then you need a tool to actually pull that all together.

And a code has been developed. It's called the TMAP4 code. Okay. And that stands for tritium migration analysis program. This is a code that was developed in the labs to actually do calculations of tritium for diffusion reactor for normal operation.

And the basic modeling in there, it's a basic kind of a diffusion code. And it can be then configured with data and geometries to actually do this -- to solve this problem. And so it solves the 1D diffusion equation. It also accounts for chaptering if needed in any and all layers.

You can, in principle, model intact particles, failed particles, and so forth, simply by how you set up the modeling in the particular run. You can specify the fission product generation rate on the inside and then it go. And based on temperatures and the like, it will calculate what the diffusion rates are for various species of radionuclides.

And you put in the -- for now we have just what I showed you. NGNP and DOE are going to develop that specific for the NGNP fuel. And so it can also model Soret diffusion in any layer, which is important for the buffer layer because there is a big delta T there. And that's probably the one that you would model there. And I think that that is the one that is modeled with the Soret diffusion.

And it can handle temperature profiles, which are cyclic or steady state, and keep book on temperatures in various layers at different times, and modified diffusion rates. So it's keeping track of the chugging along of different diffusion -- fission products through those layers.

And it can do this for normal operation and then transition to an accident heat up. Okay. And it is being used now as a powerful tool to actually analyze test data, okay, of fuel performance.

But what you end up with at the end of the day, as a key point, is that the fuel temperature is the most important parameter in all of this. There are other things but that is the key that drives the whole model. So you have to understand temperatures locally to know how much releases you are getting for all these mechanisms.

MR. KRESS: This sounds a whole lot like the Boothe model that's in the MELCOR now for light water reactors.

MR. RUBIN: Yes.

MR. KRESS: They use an effective diffusing coefficient, which is an arrhenius thing --

MR. RUBIN: Right.

MR. KRESS: -- and then it look to me like --

MR. RUBIN: This is how it is done for many years in Germany, in South Africa, and China. They do take credit for all of that.

The question is can you put a code like this into MELCOR and keep book on all those dimensions?

MR. KRESS: As long as you have the temperatures --

MR. RUBIN: Yes, as long as you have the temperatures --

MR. KRESS: -- and the transients, yes, you can do it.

MR. RUBIN: Right. So our plan is to obtain the code under the MOU. We already did get the code about two weeks ago and the manuals and some datasets that they've already put together.

So we could start using the code and understanding the mechanisms and become more familiar with fission product transport in particle fuel, conduct sensitivity studies on temperature and burn up and the like to try to see how things are going to change. Okay. Like cesium diffusion with higher temperatures and higher burns, with the models we have, which is an issue for dust generation.

And in the long term, to get the data from DOE to change the diffusion coefficients specially to our fuel. Okay. And that's part of that plan.

Now what are we going to do for the evaluation model? There's two choices there and we're starting that now. It's to evaluate using TMAP directly as kind of a brute-force addition the MELCOR code for calculating core-wide diffusion and release versus temperature and burn up and time for all these kinds of fuel, which you will know from the first part we did on failure rates, and for manufacture.

Or following that, we might -- I'll call it simplify the diffusion and release models. Some codes develop an effective diffusion model where they take the chain of diffusion models and the one over the effective one, and one over the first one, and one over the second one, and one over the third one, and you can generate one diffusion coefficient for all the layers. Okay. So that's the approach taken by one.

It is going to become managing the complexity of the time of the calculational scheme within MELCOR to see if it will work. But we're just getting started with that.

And so once we've made that decision on how to account for these various types of particles, we're going to utilize that together with the particle failure rate piece, which will tell us when we have to shift over to -- we've got more failed particles at this point in time, at this point in the reactor, we've got to go to a different TMAP calculation for those particles.

And so what we end up is a fission product release verses time or source term versus time for the entire from those two together. In the near term, we'll use those diffusion coefficients that came from the TECDOC for the old German fuel. And I, long term, will hopefully get the data from DOE for our fuel specific.

I'd like to quickly run through -- this was all for just helium in the system. I haven't talked about other kinds of events. The other three kinds of events we've talked about water ingress, air ingress, and reactivity events. These curves on the right show the effects of water ingress into the fuel.

And the principle effect is the mobilization of fission products out of failed particles. Okay. The phenomena of actually failing the particles is not as big an issue as actually mobilizing the release from failed particles.

And you see there when the steam hit the particles, it went up by an order of magnitude. And then settled down because all of -- in this case, I think it was krypton-88 was actually taken out so the number, it came down in time because it had just all been released.

So we need to be able to model his for water ingress events if -- if we see water ingress within the licensing basis as an important kind of event. Okay. Because it is expensive to do these tests.

And so if plants are going to have steam generators, we definitely to get data for NGNP fuel. Okay. Even without steam generators because water can get in from the shutdown cooling system and other heat exchangers, you will have some level of moisture in there.

And all the data you have now is based on fuel which is not really representative of the NGNP fuel, neither in burn up or temperatures. Some of it is UCO but we just don't see it -- I personally feel it's not necessarily representative of the fuel that was used to generate these curves.

So I believe we'll have to do some testing. DOE will have to do some testing. They, right now, are kind of not committed to doing these tests. They're going to look at it. I think that now -- if there are going to be plants with steam generators, then they're definitely going to start putting that into their plan.

So for now, again, the strategy is use the data we have as a means to kind of run the codes, MELCOR codes, to account for these phenomena. And in the long term, use the data that might come out of the NGNP program.

MEMBER RAY: I didn't ask this earlier but I thought about it. Why is it just a steam generator application that would have this greater probability of water ingress? Isn't the reactor cavity cooling system water --

MR. RUBIN: It is. But it is outside the reactor vessel.

MEMBER RAY: Well --

MR. RUBIN: You have to find a means to get that water into the reactor.

MEMBER RAY: And you're saying that's not credible?

MR. RUBIN: I think the PIRT didn't -- I think there was concern that those tubes could fail and then kind of leak over to the reactor vessel, hit the vessel wall, and maybe caused a local temperature change that could be a failure mechanism for the vessel.

But to actually see that get into the core, I don't think anybody saw that as a pathway.

MEMBER RAY: Okay.

MR. RUBIN: The pathways that are traditionally used are the heat exchangers that are --

MEMBER RAY: No, I understand. Nevertheless, I wondered about that.

CHAIR CORRADINI: So just to make sure I understand, so it's really just the mass fraction of water in whatever gas is near the graphite and the fuel.

MR. RUBIN: This thing shows it is a partial pressure --

CHAIR CORRADINI: Well, okay.

MR. RUBIN: -- partial pressure of the steam at the site of the particle.

CHAIR CORRADINI: Right.

MR. RUBIN: If you do that higher for more particles, you are going to force more release for more particles. So steam generators are a candidate to get you going higher on that partial pressure curve.

CHAIR CORRADINI: So is this a policy decision by the staff? Or is this something that you have communicated to the DOE that --

MR. RUBIN: No, I haven't communicated -- they're seeing this when you are seeing this.

CHAIR CORRADINI: Okay. So let me ask a different question then. If there is a steam generator, does water ingress go into the design basis.

MR. RUBIN: You've got that right.

CHAIR CORRADINI: Okay.

MR. RUBIN: Of course. I do believe for the M/HTGR with steam generators water ingress was the limiting event. Now from a risk point of view, the argument was it was not a high probability of having that many tubes fail. But from a sheer consequences point of view, it was the limiting event.

CHAIR CORRADINI: So which of the point designs has a steam generator in the point design?

MR. RUBIN: Well, if you want to talk to DOE in the hall, you probably can ask them that.

CHAIR CORRADINI: But there is one at least?

MR. RUBIN: Does DOE want to get up and answer that question?

MEMBER BLEY: Or kind of what is driving the thinking. Is it --

CHAIR CORRADINI: I would assume you guys know because you're always talking --

MR. RUBIN: I know but it is not public information.

CHAIR CORRADINI: Oh, excuse me.

MR. RUBIN: Okay. That's why I'm saying that.

CHAIR CORRADINI: Okay. Thank you.

MR. RUBIN: And they haven't made a decision. They may decide to choose a plant that don't have steam generators.

Okay. The same thing for air ingress, basically you have mechanisms that can fail particles in that case. One of the mechanisms is you oxidize the outer pyrolytic carbon layer. It kind of goes away. And it takes away its compressive function on the silicon carbide, drives the silicon carbide stresses up.

They go from negative to positive in any failed particles. And then you also can directly attack the silicon carbide and form SiO or SiO_2. SiO can be self sustaining and fail the particle that way. And SiO_2 tends to create a barrier for continued attack by the accident, depending on the temperature by and large.

But in any event, there is data -- limited data on the failure rates and the releases due to air ingress or air being exposed to the particles. And you can see those effects on these curves. They're basically done for fuel spheres, nine percent FIMA, and the temperatures were maybe not typical of what we would see in the NGNP.

So there is a big question mark in my

mind. It would be hard to make the case that this -- these test data could be used in a licensing application for air ingress events. You'd want to do at least a few tests to see what the effects would be on the fuel specific to your plant.

At this point, the technology program from DOE, they may include air ingress testing with irradiated fuel. I think -- we have not talked to them lately about that. So we don't know if they made that decision or not.

So in the meantime, we'll use the test data we have. In the long term, we'll work with DOE to get additional data to model these effects.

And finally, reactivity events, you can see from this part that depending on the level of the energy pulse into the particle, you could drive the particle failure right up to 100 percent.

The question came up very early on is, you know, what are the -- what are the effects of pebble compaction of the entire active core moving away from the control rods in terms of reactivity addition? So we need to do some analysis.

The pebble bed reactor, because it is continuous online fueling, it has very little, if any, excess reactivity. So the potential for a large reactivity addition in pebble bed is said to be small. So these events become nothing more than kind of heat up events.

If one were to postulate a rod ejection, those kinds of reactivity additions get you into these kinds of curves.

CHAIR CORRADINI: A rod ejection would.

MR. RUBIN: Yes. Okay. And at least for example in HGTR, that was one of our limiting events. They actually postulated that as part of their licensing basis, rod ejection accident. And it became a limiting event for them.

Now whether or not the risk informed approach to licensing the NGNP will, in fact, say with the deterministic bounding event and pose that, we don't have the answer to it yet. But it is something on our radar. Okay.

So this problem or this performance issue will rise and fall with the what the risk informed licensing event selection ends up with.

And so let me just wrap up here. Fuel fabrication, we talked about that. This part tries to make clear the differences in fuel performance, R over B ratio over a burn up for a different manufacturer. The blue, the lower part was the range of particle failures.

And by the way, if you take those numbers and divide them by .01, let's say, you get the failure rates. Probably .1 for the NGNP fuel because they are running it at higher temperatures.

But you can see that the old NPR fuel, the way it was made, performed relatively poorly -- really very poorly. The German fuel, the way they made it, was the gold standard for many years.

We're starting to see now in Japan and now in the AGR program that we are meeting and beating those standards with the particle failure rates in operation, which is very encouraging to meet those goals that I talked about in here.

So this makes clear that manufacture is important. And even when you fix manufacture, you can have variations from lot to lot. So we want to have a way to kind of have a regulatory oversight of that. And we've come up with the next inspection line.

But it's true. We're just inspecting what we know -- what they have concluded what they know. What about what we don't know? Then you have to look at other ways to monitor that in the reactor and the like.

So in summary, integrity and fission

product retention is the key to the HTGR safety case. Fuel behavior in fission product release depends on how the fuel is made, its operating history, and accident conditions.

We're developing, with the help of DOE, analytical tools and data to develop our expertise to assess all of that in fuel failure as well as fission product release. And we want to be able to integrate those both into the evaluation model. And we have some strategies to do that.

We need to pursue the issue of graphite dust in terms of the amount of metallic fission products that are bound up in all of that. That's the fuel performance guys' piece to answer.

And we do, if it's not already clear, plan to extensively utilize DOE's work products in helping us to build our databases. And we've already talked to a number of other international groups to see where we can supplement that and have kind of confirmatory data from others in developing our models.

And as I spoke about last, the ability to inspect the fuel production facility is something -- we've developed a kind of a template for that even now.

So that's it for me.

CHAIR CORRADINI: Further questions for Stu?

MEMBER ARMIJO: In use of these codes that are submitted by let's say Idaho, this TMAP4, would you, when you get into a licensing, start the regulatory work? Would you, if you chose to use those codes, would you go through the same review and analysis that, let's say, a utility or a vendor would submit. Here's our licensing topical report and then you review it?

MR. RUBIN: That's a code validation issue. And I'll defer to Joe Kelly. With his experience, the NRC doesn't impose requirements on ourselves.

MR. KELLY: No, that's correct.

MR. RUBIN: Yet what is our standard for --

MEMBER ARMIJO: Well, in this case it is an Idaho DOE code given to the NRC to use that they claim --

MR. RUBIN: Yes, it's a box, a black box.

MEMBER ARMIJO: Right. And then you would have to go through it and make sure that black box worked.

MR. RUBIN: Sure.

MR. KELLY: Yes. And what we're using TMAP4 for now is the MELCOR developers are looking at it to see what they may need to do within the MELCOR code, whether they can take their current model and then change it or whether they need to actually implement TMAP4.

And what we would do is the verification part. That we would, you know, find the data sources and do the code assessment against it. And then try to make sure we have an understanding of the uncertainties involved in using that code.

MR. RUBIN: Okay. Are we scheduled to do one more this morning?

CHAIR CORRADINI: We are.

MR. RUBIN: Okay. Tony Ulses, you are the man.

MR. ULSES: All right.

CHAIR CORRADINI: Could you take your seat over there, Stu, if you don't mind.

MR. RUBIN: Okay.

CHAIR CORRADINI: I doubt you are trying to block the screen so they can't see it.

MR. RUBIN: Okay.

CHAIR CORRADINI: You can stand and move around if you feel like it.

MR. RUBIN: That's okay.

CHAIR CORRADINI: Whatever you like.

MR. ULSES: I thank you, Stu. As was mentioned, my name is Tony Ulses. I'm in the Office of Research. And I'm going to be talking to you today about our advanced reactor research plans in the area of nuclear analysis.

As we go forward in this and, you know, as we discussed, obviously we're going to have many meetings on this topic. I expect you're going to hear Stu and I talking together quite a bit because we obviously recognize there is a real strong linkage here between these two technical areas. And it's going to be driving some of our thinking.

What I want to do today is I want to kind of walk you through our thinking, what we've done so far, and I want to also mention here as we get into this that this is an area that we are really just getting started on.

We have done some work that we were able to accomplish back in the -- back when we were doing the PBMR work before it stopped, as was mentioned this morning in the pre-application area. And that work we've done some very basic assessment of it. We're relatively comfortable with it. But we're just literally getting started and kind of formulating our plans.

This is a statement that is actually literally right out of the advanced reactor research plan. And this is obviously a guideline statement. This is an extremely high-level document.

But the way that we've been interpreting this is we've almost gotten to the point in light water reactor space where we can almost take nuclear analysis for granted. It is down to the point where we're so accurate, we can get, you know, the actual power and the fuel thing relatively accurately.

The expectation, as we go forward with the work related to the NGNP project, is we're intending to take those methods and try and move them forward so we can retain that same level of accuracy as we're trying to analyze this.

And it's really -- because we realize that the actual fuel performance of these systems is so critical. And obviously the power predictions, obviously, you know, one of prime inputs to that calculation. So we want to assure ourselves that we have methods that are accurate so that when we get to the licensing process, the actual tech staff, at that point, will have the ability to do proper sensitivity studies to be able to really have an opportunity to fully understand this system as we go forward.

All right.

CHAIR CORRADINI: But would that statement hold if I had a gas outlet temperature of 700 to 750C versus 900C? In other words, can I be sloppier?

MR. ULSES: Well, you know, that's the question really of margin versus accuracy. And that's a question that will obviously get fleshed out in the licensing process.

And that's ultimately up to the applicant. You know how accurate do they want to claim their methods are versus how much uncertainty are they willing to accept. And so that's an issue, you know, that will be fleshed out in that process.

What we're really thinking about here -- and then this actually goes to a question that was brought up earlier this morning -- is the question -- I mean how do we really assure ourselves that we fully understand the system? In other words, are we able to actually go into the system and do analysis where we can say, you know, vary the parameters, do sensitivity studies studies, make sure we understand the margins of the system and how it behaves.

That's really more where we're thinking

right now with trying to retain the same level of accuracy that we have. And your question is certainly valid and it's one that --

CHAIR CORRADINI: Well, that's fine.

MR. ULSES: -- would get nicely fleshed out on the license basis.

CHAIR CORRADINI: But let me term my question differently. Has the staff asked the applicant what sort of hot channel factors could you live with if it was 750C, 850C, 950C, or the heat generation rate was X, Y, or Z? So you know the space in which you can operate. It's based on what you are going to have to decide what an acceptable level of uncertainty is.

I mean have those trait study calculations been done that the staff is aware of and looked at?

MR. ULSES: Well, the short answer to that question is no. We have not engaged INL down to that level of detail at this point. And as I said, this is --

CHAIR CORRADINI: Okay.

MR. ULSES: -- an area we're just getting started on. And certainly one of the areas that, you know, we will discuss as we go forward within this technical area.

CHAIR CORRADINI: Okay.

MR. ULSES: This is basically kind of the picture of our code suite. We, you know, we have -- the plan that we have as we go forward, as we intend it, is we intend to leverage the systems that we already have. Within the SCALE code suite, over the past five or six years, we've developed extremely accurate methods with high fidelity which are not necessarily tied to any particular system.

What that really means if it allows us to use those systems with relatively little effort, frankly, and actually move them up into the HTGR arena. And, you know, I'll get into more specifics on this as we go forward because that's obviously, you know, a real high-level statement.

But the point I want to make on this is that we really have three areas of application here. We're going to be working within the SCALE code system itself to make the necessary modifications, be sure we have the validation data that we need to validate those tools.

We're going to be looking in the area here in yellow, which is really the area where we take the cross sections we calculate from the SCALE system. And we put them into a form that can be used within the evaluation model, which, in this case, is going to be PARCS code. And then obviously PARCS itself is what we use for our normal diffusion area solver.

And the AMPEX 2000 code is the one where we actually take the raw evaluated data and we go in and we actually process it to the point where we can work with it in SCALE. But since we're actually working -- within SCALE, we're actually working with actual continuous energy data now but there's actually not a lot of processing that goes out between AMPX down to SCALE.

We're actually able to work with extremely high resolution data at the level of what I would traditionally call a lattice physics calculation. But that's not necessarily appropriate, you know, for these systems, that word.

Now one other point to make on this slide is that all of these codes are currently under configuration control. They've all been updated to modern FORTRAN languages. And we don't anticipate that we're going to need a lot of new physics to PARCS. We already have an arc data Z solver in the code. We already -- the one area where we may have to work is in the actual cross-section parameterization.

And what I mean there is, you know, the

way that we model now is we model a fuel ascender in the light water reactor space. And we assume that it is an isolated ascender. That may or may not work for these HTGRs.

We may have to actually go in and add some additional physics as we try and couple those nodes together in the nodal diffusion theory solver. That is something that is going to be fleshed out as we go forward in our research plan.

So this is basically a discussion of the area that we have been focusing thus far. And this is, you know, one of the real strong challenges in these types of systems, how do we process the resonances? And the methodology that we've developed is, again, we're using the existing codes, existing tools that we have within SCALE.

You know right now we use a continuous energy, one-dimensional transport theory code to process resonances within SCALE. So what we've been able to do is we've been able to go in and actually handle the multiple layers of heterogeneity in this fuel by essentially leveraging that tool.

What we're doing is we start with an actual pebble -- well, we actually start with an actual kernel model. And we go in and we do a one-dimensional transport theory calculation on that kernel. And we use that to get a representative spectrum.

And then we use that spectrum to go in and reevaluate an actual -- a new spectrum, which we can then move out to the actual level of the pebble or the actual compact itself. Again, the idea there is we want to make sure, you know, we actually retain the necessary information as we go forward.

And then from there, once we get the information we need to model the pebble or the compact, then we're prepared to go and model what would be analogous to like a light water reactor fuel assembly, for example.

CHAIR CORRADINI: And the reason you need to do this level -- remind me since I'm not a good neutronics person -- is because of the heterogeneity of these small link scales?

MR. ULSES: Right. Basically what we're worried about there is the actual effect of spatial energy sub-shielding --

CHAIR CORRADINI: Okay.

MR. ULSES: -- on the resonances. And we want to retain this level of detail so, again, we'll have the ability to understand whether or not some of the other methods out there right now, which are actually simpler, whether or not they have the level of accuracy and fidelity to give us the kind of predictions that we need as we go forward with the system. And --

MEMBER ABDEL-KHALIK: What is the meaning of the path of the neutron in silicon carbide?

MR. ULSES: Wow, well, that's a good question. I couldn't answer that off the top of my head to be honest with you.

MEMBER ABDEL-KHALIK: It's ten centimeters.

MR. ULSES: It's pretty big, yes.

MEMBER ABDEL-KHALIK: A few centimeters at least.

MR. ULSES: Right.

MEMBER ABDEL-KHALIK: So why is this level of detail important.

MR. ULSES: Well, because we're not necessarily -- within the actual pebble itself, I expect that your point is well made. I mean we're not going to see a lot of power variation across the pebble itself.

But the question that we want to have the ability to answer is we want to be able to retain the ability to model the effects of the pebble to pebble, for example, so we see if I have a high burn-up pebble next to a low burn-up pebble, you know, what is the actual effect of the power within that node?

And also what you see here is that this work here has been able to be done with the existing tools that we have. So this really was -- all we had to do was go into SCALE and take the tools that we already have and rearrange them so the sequences we run such that we could retain this level of detail.

So it really wasn't that much work at all to actually accomplish this. It was more a question of -- we didn't have to add new physics or new tools to do this. We had it in there so we decided to leverage it and use it as we went forward.

CHAIR CORRADINI: But to answer Said's question a bit differently, if it weren't a pebble reactor, it was a prismatic, is it -- is your real technical concern is when you go from the core to the reflector and you cross that boundary that you can't accurately get those heterogeneities as well as if I go into the core region where I've got the coolant channel, the moderator, and then the equivalent of essentially the fuel rod, the compact, I can't get the right measurement of how I get absorption if I have a power change?

That's what I thought was the reason you had to go through this detail. That's where I'm still struggling.

MR. ULSES: Certainly. Well, the issue of, you know, you mentioned essentially the reflector interface with the core itself.

CHAIR CORRADINI: Right. That one I can see.

MR. ULSES: That's an area that we've been discussing considerably as the reason for the need to do this --

CHAIR CORRADINI: Okay.

MR. ULSES: -- in order to have the right spectrum. It's more an issue in my mind of we want to be able to retain the level of detail so we can appropriately assess applicant methods.

And if we have the fidelity in these tools, it gives the staff, when it gets down to the licensing phase, the ability to fully understand whether or not the simplifications that may or may not be imposed in an applicant method are actually appropriate.

CHAIR CORRADINI: So this is your method of experimental independent verification of what the applicant is going to show you?

MR. ULSES: I would -- well, obviously, you know, this isn't experimentation. This gives us the ability to fully --

CHAIR CORRADINI: Verification.

MR. ULSES: Sure, exactly. You know we are retaining a considerable amount of information.

Now I'll show you a summary on this slide. I'm just going to go through a couple of -- well, this is essentially a summary of what I just said here. Again, we're using the existing systems that we have.

What you'll see traditionally out there is the use of Dancoff factors to allow for the spatial effects when you are doing resonance processing. You know it is not an invalid method. It's been used for many years. That's what has been used traditionally in these HGTR systems.

But, again, our methods will give the staff the ability to assess those methods with a fully independent set of methods. That is the intent of what we're doing here.

We have added the ability into SCALE to handle the hexagonal boundary systems on the pebble or when we're looking at the prismatic block fuel. And we have added in a depletion and a branching capability for the double heterogenic systems, however we have not extensively tested that at this point. That's something that is ongoing right now.

I wanted to mention just a couple of sample calculations that we've done so far with these systems. And, again, these are extremely preliminary. This is work -- this particular problem here was one where we set up using some start-up testing from the HTR-10. This problem is available from the International Reactor Physics Evaluator Handbook.

And, you know, this gives us -- this is an example of what I said earlier that we have comfort that the methods are working effectively. You know this is a simple evaluation of the criticality of the system with a certain pebble height. And as you can see here, the actual calculation is one for this particular configuration when compared to the critical experiment.

And we are continuing to work on this problem and we're going to work on the control outlook calculations. And that work is currently underway.

And, again, this is just an example of one set of data that we currently have that we have been looking at.

We have another problem here, the HTTR --

MEMBER ABDEL-KHALIK: What is the pebble volume density that was used in the analysis part of it?

MR. ULSES: That's a level of detail that I can't actually answer. This is work that was done by Oak Ridge for us as evaluation. The actual detail of how they model would actually have been part of the input for the specification for the --

MEMBER ABDEL-KHALIK: I mean isn't that a knob that one can change to come up with whatever results you want?

MR. ULSES: Right. But one of the advantages of using a problem that has been accepted for the International Reactor Physics Evaluation Handbook is that it has gone through a large amount of vetting, it has been reviewed by at least two or three independent reviewers. And so all the information in there is assumed to be correct.

MEMBER ABDEL-KHALIK: So the volume fraction of the pebbles --

MR. ULSES: Is going to be an input to this problem obviously.

MEMBER ABDEL-KHALIK: -- is specified as part of the input?

MR. ULSES: It's going to be specified as part of the specification, exactly. And it is going to be specified by the information that was provided in the handbook.

MEMBER ABDEL-KHALIK: Okay.

MR. ULSES: And, again, the expectation of this handbook is that this information has been extremely well vetted. It has been reviewed by one or two individual people. And so we have a significant level of comfort in the information that is in there.

MEMBER ABDEL-KHALIK: Okay. Thank you.

MR. ULSES: It's not accepted until it reaches that level.

This is just another example. This is an example from HTTR. And, again, this particular problem has not been actually officially accepted into the handbook. But it is in the process of going through that evaluation.

And, again, this is just another example of where we have applied these methods to a set of experimental data. And we have comfort that what we've done thus far with the double-het methods is actually working as we expect. And, again, this work was actually done down at Texas A&M with the help of Oak Ridge, using the SCALE code system.

So we move on, if we go back to -- again, just to refresh your memory, this figure here, what I just talked about here was the work we've done on the SCALE system itself. And then I'm going to move into discussing what the actual current state of the GenPMAXS scale and the PARCS.

GenPMAX is basically just sort of a translator. It doesn't really do any physics. It just takes the processing out of SCALE and it puts them into a form that PARCS can use. It actually --

CHAIR CORRADINI: Code process.

MR. ULSES: Right. It uses a series of partial derivatives based on the relevant variables, those being, for this case, it's going to be like the fuel temperature, what the condition of the monitor is. So it can recreate the actual values of the collapsed cross-sections that it needs as it is going to a solution.

For PARCS, again, as I mentioned, we currently have a cylindrical solver in the code. It currently works with -- we currently have an N-group solver with upscattering. The bottom line on this is I think PARCS is, with the exception, again, of having to maybe having to assess what we may or may not need to additionally parameterize as we're going from, again, the fine detail calculation to what is essentially a lump of material, which is a nodal diffusion solver, how we can translate that information to make sure that we can recreate the relevant reaction rates. That is an area that we're going to be researching, looking at.

And that is currently the only area that we expect we're going to actually put a considerable amount of research on within the PARCS code itself. And just, again, this is a real quick sample problem of the application of PARCS. This is the PBMR-400 benchmark, which has been mentioned previously.

There are five different code calculations. And, again, this is a code-to-code test. This is not based on data. These are results that were presented at a conference last year. And this is a transient which was a withdrawal of 200 seconds. And, again, we're showing here that the code is performing as well as the others.

The little wiggles you see on here, those are artificial effects from the rod cusping models as the rod transitions from node to node. There are a couple of the codes that don't have a decusping model so that leaves those little wiggles in there but that's a numerical artifice of the calculation.

All right, let me move on here. All right. So now I'm going to move into a discussion of the PIRT itself. And, again, we're using the PIRT as a guide of our research. But I want to emphasize that we're not locking ourselves into the PIRT.

And actually you are going to see a couple of things in here where we've actually made some modifications based on some recent research. And so that's a point I want to definitely make as we move forward here.

This is not -- you know, we're not moving into this with tunnel vision on this. We're continuing to engage with the international community. We're continuing to engage with our partners. And obviously we'll be also engaging with INL considerably as we go forward here.

This is essentially the heart and soul of a nuclear analysis. You know the ability to predict the flux and the power. I mean if I can get this right, then I can get anything else right.

And so this is an area where we're going to be focusing a considerable amount of attention. Essentially the first bullet, I mean that's obviously a statement of the obvious. I mean, you know, we have to fundamentally understand this system.

And this is why I've been so concerned about trying to retain a large level of accuracy in these methods. As we go forward, I expect we're going to use what we call the TSUNAMI methods in SCALE, which is a sensitivity and uncertainty application tool suite within SCALE.

CHAIR CORRADINI: That's something that is just embedded in the model?

MR. ULSES: It's just another code sequence within SCALE. SCALE is not one code. It is a sequence of 20 or 30 different actual independent codes which work under a series or sequence of driver modules. And this is just another sequence within SCALE. It is already there. It preexists. And we we're going to try and utilize that tool to help us understand the sensitivities of these systems as we move forward.

We expect we're going to take a multi-tiered approach to this. We're going to start with some small-scale studies, which are actually currently underway. And, again, we're going to be looking at doing models that -- you know, modeling isolated pebbles, modeling compacts so we can understand the basic physics.

We're going to try and use the data that we currently have for this phase. And that's really -- we have the HTTR data, we have HTR-10 data, we have some data from the PROTEUS facility which was a PSI. And, again, this is all data that is available in the International Reactor Physics Handbook. And that is the data that we are going to use to essentially develop our understanding of the system.

We're going to develop very detailed models of what we expect the NGNP system to look like. Obviously the design, at this point, is not fixed. But the point of that is that we want to make sure that we understand that we haven't missed anything as we go forward in this system.

We want to be able to have a very detailed model of the system so we can look at the linkages between SCALE and PARCS, so we can look at the sensitivities of the system to make sure that we have a solid understanding of the physics, and that we have what we need in the tool set as we get down to the licensing phase.

And, again, as I mentioned, we're going to work on preparing the PARCS interface. And that's going to really go on in a couple of phases. We're going to start on developing a simplistic interface now so we can get that part of the project moving forward.

But as we get into it, it is very likely that we may find that we need to modify that again. And, again, in order to make sure that we can retain the necessary information that we would need to get the power out of that code, which obviously we're going to then give to the fuel guys so they can model the fuel.

And that leads into the next bullet, which is, you know, we certainly recognize there is a very strong linkage here between the fuel performance and the power and the fission product release. And that is an area that we are going to be working on as we go forward as well.

This is sort of my vision of the current expectations as we go forward on the system. I expect the pebble systems are definitely going to be much more complex. And that's given, you know, the general stochastic nature of the system. It is going to be very hard to define what is the burn up of a pebble at a given location in that system.

Now as we go forward in this, it may very well turn out that that is not a large contributor. But that is something we need the ability to retain the level of fidelity to understand that because it maybe something that as we go forward, that is important.

Certainly the ability to homogenize that information, in other words the pebbles, and then when we get into the PARCS level of analysis, to then pull out the specific detail. And what I mean there is kind of the analogue to what we call like a pin power reconstruction methodology. In current LWRs, we have the ability to actually model what we expect. You know the individual power in the individual fuel pin, we want to retain the ability to have that level of fidelity as we go forward.

One of the other challenges for pebble systems, it is going to be really hard to validate predictions because as hard as we've seen it thus far out in the international community, no one has been able to figure out a way to instrument a pebble to actually tell me what the individual power of the given pebble is within the system.

And that's going to be an where we are obviously going to be engaging with INL and, you know, with others in the international community to try and get our hands around it.

This goes back to the question you brought up when we get into the licensing phase -- you know, margin versus accuracy. Is that an area where we will need to add some margin on because we're unsure of the level of accuracy? Or maybe it is an area where it is not going to be a problem.

That is something that we haven't fleshed out yet at this point. But I just --

CHAIR CORRADINI: So in the past -- in the past operation of I guess it was the AGR, which is a pebble design, there's no in-core instrumentation that tells you what the flux is at a location?

MR. ULSES: That's correct. There was no in-core instrumentation in that reactor at all as we understand it.

You know -- what --

CHAIR CORRADINI: But you don't necessarily need it on the pebble. You just need it maybe spatially so that as the pebbles pass through that spatial location, that helps you?

MR. ULSES: Right. But as I understand it, there was no instrumentation on the pebble bed system.

MEMBER ARMIJO: We knew the burn up.

MR. ULSES: Right. And that was measured --

MEMBER ARMIJO: And if you did PIE, you

might be able to get some idea of the maximum temperatures --

MR. ULSES: Right.

MEMBER ARMIJO: -- but it's very qualitative.

MR. ULSES: The only real experiment that I'm aware of thus far that made an attempt to measure the local conditions in the pebble bed were the melt wire experiments that were run through the ADR.

MEMBER ARMIJO: Okay.

MR. ULSES: And as I understand it, those experiments didn't necessarily live up to expectations at this point. And that is another area that we're obviously going to continue to follow.

You know as for what the current plans of INL for this issue are -- again, this is an area where we haven't really actually engaged them yet. And it is something that is obviously going to be important to talk about. How we are going to be able to that? Okay, what we need to do to validate the prediction of the model.

MEMBER ARMIJO: It seems to me the real challenge is to find out what is the hottest pebble or groups of pebbles in this core as a function of it.

MR. ULSES: Right.

MEMBER ARMIJO: In normal or accident conditions. If you don't know exactly where they are and where they've been, that's

MR. ULSES: Right. And that's one of the reasons --

MEMBER ARMIJO: -- that's --

MR. ULSES: It's a problem.

MEMBER ARMIJO: -- it's so much different when -- in your core, you know where everything is.

MR. ULSES: Right.

MEMBER ARMIJO: It stays put.

MR. ULSES: It's not to say that it is an insurmountable challenge but --

MEMBER ARMIJO: Oh, I know. I'm just saying --

MR. ULSES: -- but it is an area where, again, we need to engage with INL and, obviously, any future applicant. I mean this also goes back to the point I tried to make earlier on this. That's one of the reasons why I want to attain a significant level of accuracy in our methods. So, you know, that may be an area that we can explore if it is an issue.

I want to talk -- I'm sorry --

MEMBER ABDEL-KHALIK: If you do have in-core instrumentation, what information would it give you?

MR. ULSES: Well, it's going to give me a measurement of the flux or the power at a given location. And then obviously we have to have the ability to predict which pebbles are there. You know we have pebble-flow models. They exist.

Obviously we're going to be using them in our evaluation models of any type of pebble system. But it gives me the analogue of say, for example, the tip that I have in an LWR or like an LPRM system.

MEMBER ABDEL-KHALIK: Right. But those essentially measure steady state data.

MR. ULSES: Right.

MEMBER ABDEL-KHALIK: But I'm just wondering if you would ever be able to measure steady state data in this system given the stochastic nature of the positioning of individual pellets.

MR. ULSES: Well, that's a very good question and one that I, right now, would say we don't have our hands around. I mean it is one that we're going to be continuing to engage INL on as we move forward.

CHAIR CORRADINI: All you need is a LaGragian flux meter.

(Laughter.)

MR. ULSES: Is that all?

CHAIR CORRADINI: Follow the particle.

MR. ULSES: You know, the point I want to make with this slide is this isn't something that we've lost track of. This is an area that is on our list of things to talk about. And we are going to engage in this discussion as we go forward because we're not sure exactly whether or not it is an issue.

And as you point out, it may not be something we can really measure. And we'll have to deal with it in licensing space in another way. Maybe it is not going to be a problem. But it is something that we need to make sure we engage in a discussion with INL and also any future applicant.

But the next bullet are the common challenges, again between a pebble versus a prismatic system. Again, the issue of neutron scattering on graphite. And that's really a properties issue. And I'll touch more on that in a little bit here.

And when you get into the top point of these systems, you have -- and also at the bottom -- you have some voided areas, which leads to a lot of neutron streaming. That's obviously a challenge to any type of nuclear analysis code suite.

We're going to be seeing enrichments that are larger than what we are used to in light water reactors. That's really more of a data validation issue to make sure that we have the data that we need to validate the tools. I don't see any real problems there. It's just an issue we have in the data.

And obviously the multi-layer heterogeneity, which is an issue that we've already discussed here today.

MEMBER ARMIJO: Are all these fuels in these pebbles, are they all the same enrichment? Or are there going to be different enrichments?

MR. ULSES: I guess right now as I understand it, they're going to be using one enrichment. That's really more a DOE question. I don' really have an answer to that right now.

MEMBER ARMIJO: You don't know?

MR. ULSES: We don't even know where all the red gum balls are. Can you imagine --

MR. CARLSON: I have a little extra information on that. The last I heard PBMR was going to fuel the initial core with a lower enrichment. And then go to a -- progress to an equilibrium enrichment that they use little by little. So that there will be in the early life of the core two different enrichments.

MR. ULSES: Well, but from a standpoint of actually being able to make sure we have the methods to handle the system is more a data validation question. But obviously it is also a question of having to track where this stuff is.

All right. Let's see here. So, again, I'm walking you through what came out of PIRT in this area. The other area that was highlighted was the ability to predict decay heat. What we're currently planning on doing in this area is we're going to stay involved in standards work.

But the next bullet is a statement that within SCALE, we use the ORIGIN code, which is what we use to do -- to actually do our depletion calculation of isotopics. As long as I can give ORIGIN a good spectrum, it's going to give me a relatively accurate prediction of what isotopics are there. So really this really goes back to the spectrum and the weighted cross sections is the key to a successful ORIGIN prediction.

And within this area, we would expect -- and, again, this is an area that we are going to have to discuss with INL and any applicant -- is that we would expect to see some relevant calorimetric data in order to assess any models. And this is kind of similar to what you would see in like an ANS 5.1-type standard, is that there is actually very little data there and most of that is code calculations. But there is some data to actually validate the basics of what the standard is telling you.

The next item that was raised is spatial xenon instability. Where I expect to go on this is we should be able to disposition this analytically similar to what we do right now in the operating fleet for BWRs. But obviously this is something that would have to be confirmed as part of any start up physics program just to assure ourselves that we're not going to have a xenon instability problem.

I'm not aware of any problem with xenon instability in an existing operating HGTRs or any past operating HGTRs. But that's something we need to consider.

Reactivity coefficients, this is certainly one of the other areas which is very significant that came out of the PIRT. And, again, this is essentially a statement of the obvious. You know we will require a fundamental understanding of phenomena here to make sure that, you know, we know how the system is going to behave.

We will require measured data in order to evaluate the code predictions. And, again, this is an area that I'll touch on a little later. But that is an area where we're going to be engaging INL to ensure that we have the necessary data that we will need.

My expectation is that the SCALE to PARCS interface will strongly influence these conditions. Again, this goes back to the discussion of, you know, have I properly captured all the physics in that linkage to ensure that I can recreate the relevant reaction rates within a calculation. And that is an area that we're working on.

Now this next bullet is an area where we have actually used some recent work to actually go beyond what we studying when we looked at the PIRT.

There is some work by a researcher by the name of Dagan. He's working in Germany right now. It's Karlsruhe. And he's done some work which indicates that essentially some of the basic assumptions that are in the way we treat neutron scattering resonances maybe non-conservative.

So what we're planning on doing is we're going to go in and modify the CENTRM code which is -- that's the name of our continuous energy one-dimensional transport code that we use to do resonance calculations to assess the impact of this. And if this turns out to be a problem, then it is an area where we're going to need some high temperature data to assess this.

Right now the work by Dagan suggests that it may have anywhere on the order of a ten percent impact on the fuel temperature coefficients. But, again, this is all very preliminary. It is something that we are just working on. But, again, this is an area where we have -- you know where we are reacting to what we see in the community out there. And we're making the necessary changes.

And, again, we expect that we are going to be doing a large amount of sensitivity and uncertainty calculations in this area to ensure that we understand system performance and behavior.

So this is kind of a wrap up really of all the slides which discuss the PIRT finding. I think the main issue I want to discuss here is the need for validation data. And that is really where we are focused right now.

We have been discussing amongst ourselves and we will be engaging with INL here really soon in discussing what data is there, what data we expect we are going to need, where we see that we may or may not have some holes in the database in order to validate these particular areas of analysis.

Again, we will be establishing very detailed models of pebble and prismatic systems to allow us to explore sensitivities and uncertainties and to look at the linkage, again, between the detailed calculations and the PARCS-type analysis.

And we will definitely be planning to take advantage of the large amount of international data which is currently out there within the community. And, again, that is an area where we will be discussing with INL as we go forward.

The next couple slides just sort of summarize what we see as the current sources of data. These are the facilities that are currently operating. So obviously they're going to be pretty high on our list of interests.

The HTTR in Japan, as has already been mentioned, is a very well documented facility that is currently operating. And they are -- you know they have done -- they have already released some data through the IAEA program and also through the International Reactor Physics Handbook program.

The HTR-10 is in China. And, again, they have also released data also. It is currently in operation. But, you know, we know that there is additional data at these facilities that we would be interested in. And, again, this is an area where we will be engaging with INL because obviously our data needs are going to be very similar from these facilities.

The ASTRA facility is in Russia. It is a critical facility. They are currently working with the PBMR folks in South Africa. It is a zero-power critical facility. But there is some relevant data from that as well.

These are examples of facilities that have operated but there is a considerable amount of data that exists. I've already mentioned the HTR-PROTEUS experiments that were done at PSI. Again, this is a zero-power critical facility.

One of the areas that we are interested in is they actually did some activation foil measurements within this core, within one of the cores, which would give us some spatial information. And that is an area that we intend to explore.

The VHTRC facility was a facility that was designed as a precursor to the Japanese HTTR. And, again, this is an example of a critical facility.

And then the DRAGON facility was one that was done under the auspices of the OECD. We know there is a considerable amount of data from this facility. The challenge is going to be to actually go out and recreate it.

There is a program underway through the OECD to try and capture the reports that were actually written as a part of this project. And actually trying to pull them together into a repository so they are usable by researchers and by regulators that want it.

The next slide is examples, again, of the prototypical facilities that we may be able to utilize some information from. The one issue with some of these is they use some pretty unique fuel cycles. For example, Fort St. Vrain used an HEU thorium-type fuel system. That doesn't mean that the data is worthless to us. But it is certainly not prototypical of what we are going to expect to see in the NGNP system.

And obviously pebble bed cores that have been operating, the AVR is definitely going to be of interest to us. That is a well-documented facility. There is a considerable amount of information out there on that. And we're going to be working actively to what we can from that facility on what we need.

Neutron scattering in graphite is another area where we are reacting to work that has been done recently in the community. There has been some work done at NC State which was funded by a DOE grant where they have actually gone out and tried to study the effect of radiation on graphite scattering properties. And they have concluded that there is an impact. And so we are continuing to follow this work.

And I know that they are planning to do some more work in this area. The studies have been preliminary at this point. They are actually planning to do some more research. And we will continue to follow these developments. And if we need to make code modifications, we will do so as necessary as we go forward.

But, again, I wanted to point this out as an area where we're not locked into our PIRT process here. We're staying engaged with the community. We are trying to follow relative developments and make the necessary changes as we go forward.

This is also more of a summary slide of most of the things I've already talked about. One thing that we are working on now is we know that right now we do not have access to any data on actually depleted fuel pebbles. And that is one area that we want to have the ability to evaluate our models.

So we are actually working on what is

going to be a code-to-code comparison, a standard problem that we're going to be presenting to the OECD next month. And we expect that that is going to give us a considerable amount of information to help us guide the assessment and also any further development that we need to make on those methods.

I mean, you know, obviously as we go forward with this, we will need to have access to data. But it is the kind of thing where we can't wait until we have the data because then the methods aren't going to be ready. And we have to have something to work with right now. So this is an example of a problem that is going to allow us to move forward. And then we'll assess as the data becomes available.

We're working to refine the list of data. And, again, this is an area where we are going to be engaging INL and we're going to make sure we try and leverage what is out there in the international community.

One of the areas we're going to be focusing on is trying to identify where we have holes in the database, areas that, you know, we may need to do some initial research on.

We're going to continue working on our scoping studies. And we're going to work on detailed model development. And, again, this is really driven to allow us to understand, again, the linkage from SCALE to PARCS because it is an area where we think we may not fully understand that.

And it is is an area that we want to make sure we have our hands around. And we're going to do those assessments based on what we currently have from the HTR-10 and from the HTTR.

And for the longer term, again, the main emphasis of this slide is data. We intend to get as much -- you know we intend to identify the data needs and we will use that data to validate our codes.

I mean that is the area where we are going to be spending most of our effort on over the next three or four years is in code validation. Because essentially most of the actual FORTRAN work is essentially done other than, obviously, going back and feeding back on what we learned from our assessments.

MEMBER ABDEL-KHALIK: What methods did the Japanese use to design HTTR and what methods did the Chinese use to design the HTR-10?

MR. ULSES: Well, that's a question that I actually can't answer to be honest with you. But that is an area where we will be engaging with them to figure that out. As was mentioned, we've already had a discussion with the JAEA folks about HTTR.

And we will work to continue those discussions in consultation with INL as we go forward to try and learn from their program and learn what they did. And also how they may have, you know, gone back and say traded off uncertainty versus accuracy.

You know but that is obviously the perennial question in licensing. You know how accurate do you need versus uncertainty and versus the margin in your system? So that is something that we will engage with them on as we go forward.

And I think that the Chinese used actually the German code suite that was used in the AVR program. I believe that is the code suite that they used for the HTR-10 program. But I'm not 100 percent sure about that.

CHAIR CORRADINI: The fact that the Chinese reactor, just for reactor physics purposes, I guess, I'm curious, the fact the Chinese reactor is not an annular core design but is a essentially cylindrical -- it's totally fueled all the way to the center as was, I thought, the AVR, how does that change things relative to the reactor physics?

I can understand it from a thermohydraulics standpoint but does it really much matter in terms of what you can gather from their experiments or their information?

MR. ULSES: No, I think the only that would be, you know, lacking is obviously the effect on the power distribution, you know, from the annular core. But from the basics of actually understanding the accuracy and the applicability of the physics methods, there really shouldn't be --

CHAIR CORRADINI: Okay, all right.

MR. ULSES: -- a problem.

CHAIR CORRADINI: I didn't think so. I was just curious.

MR. ULSES: You know that data should be directly applicable to the assessments.

So, again, as we go forward, we're going to work hard to use our sensitivity and uncertainty methods to ensure we understand this system.

We have to work a little bit on SCALE execution speed. It is a little slow right now. Again, you know, we have accurate methods. We're going to work on SCALE execution speed. We have plans in place to do that. And that work is actually ongoing.

And also, again, back to the SCALE to PARCS interface. That is is an area that we have to explore. We have to make sure we understand that when we are going from our detailed methods to the nodal diffusion theory methods that we don't lose any information in there which is relevant to the ability to recreate the power exclusions.

MEMBER ABDEL-KHALIK: How long does it take to run a problem?

MR. ULSES: In SCALE?

MEMBER ABDEL-KHALIK: Right.

MR. ULSES: Well, you know, for a series of a few pebbles, it is on the order of a couple of minutes. It is not a huge run time. But as we scale that calculation up to looking at actually trying to run with thousands of pebbles, obviously, you know, that run time is going to increase.

I don't have in mind right now what I would accept as an acceptable run time for a large system calculation. You know I'm usually comfortable with an overnighter myself. I'm not one for immediate satisfaction and gratification our of a code.

But, you know, if I can get the run time down to the order of a day or so for a calculation, I think I'll be satisfied with that.

MEMBER SHACK: Get a bigger computer.

MR. ULSES: Exactly. These methods run

pretty fast on modern CPUs. And, you know, when we're doing continuous energy calculation, we're talking about modeling 20, 30,000 energy groups within that system.

And, you know, we can achieve those calculations literally in like an order of minutes. It's not a huge computational burden.

So, again, in summary -- wow, I finished really early -- okay. We sort of recognize that this is a very important part in the ability of the evaluation model to support licensing units. And we are moving forward with that expectation.

We are working on -- we are certainly aware of the need to have a solid interface between the nuclear analysis methods and the fission product release. We need to have the ability to actively predict the flux of power profiles which obviously impact the ability to get the burnup. And also the isotopic distributions which are relevant to the fuel performance. So it is all kind of linked in a big circle.

But it all really gets down to the fuel. It actually always fundamentally gets down to the flux and the power. And if I can get that right, I can get the rest of it right. That's what we're after.

What we see as the key nuclear analysis challenges -- and, again, this is sort of kind of a summary of the PIRT -- we are going to have to validate our methods to be able to predict reactivity of the system. We are going to have to figure out a way to handle the stochastic nature of burnup. And obviously the ability to homogenize and then be able to recreate that information to a sufficient level of detail to do that analysis.

We have to be able to handle the multilayered heterogeneity. One area that I haven't talked about here but we're certainly aware of is the reactivity effects of moisture ingress.

From the standpoint of the codes, that's going to be more of an input in how we model what moisture is there. And if that's in the system, if I know that, then I can calculate the reactivity.

And then we have to be able to reliably predict fuel isotopics, which, again, is integrally linked to the fuel performance studies.

Where we're going on this is we're going to take a phased approach to this. We're going to start with small-scale studies. We're going to scale those up. And we're going to try and make sure we understand this system at every step along the way.

We are going to be working on the SCALE to PARCS interface. We have to work on the MELCOR to PARCS linkage. That's more of an issue of just handing data back and forth between the codes.

And then I think the key point I want to leave with you from this presentation is that we're definitely focused on the need for code assessment and for the need to get access to validation data as we go forward.

And then also as I mentioned, we are looking into the neutron scatter properties of graphite because that's obviously a very important part of the performance of the system.

And that's a summary of where we are in the area of nuclear analysis.

CHAIR CORRADINI: Questions?

MR. ULSES: Questions?

MEMBER ARMIJO: Where does the effect of changing thermal conductivity of graphite with irradiation, does that get into to your codes? Into your analyses? Or not?

MR. ULSES: Yes, basically I provide them an input. In other words, I'll provide them, you know, how much, how much neutron irradiation the actual graphite is going to see. So it is going to be one of those things where we are going to have an iterative-type solution.

Again, I'll give them the necessary fluence. And then that is going to go to the thermal people who are going to tell me the temperature. And then I know the temperature and I can them the power. So it's all one big circle.

MEMBER ARMIJO: Okay, so there will be -- okay. Right.

MR. KRESS: Doesn't it seep back though in the moderation?

MR. ULSES: Dust, definitely, yes.

MR. KRESS: Yes, okay. You need that in your --

MR. ULSES: Right. Right.

CHAIR CORRADINI: So this is more of a process question than a technical question. But I'm still back to core flow bypass or where does the gas go compared to where you think it goes?

So when I asked that, Stu said well, if I think I heard it right -- I could have been wrong -- well, are you asking about how big the channels are versus how big the bypass is? Well, that's a graphite growth question. Go ask the materials guys.

And what I'm kind of worried about is I

heard -- I could have misheard -- compartmentalization of a cross-cutting problem that I think would, even though it is a normal operation problem, would effect any sort of associated accident analysis. So I need to know where the gas goes.

Said asked about the plenum. So how are you guys handling what I would call cross-cutting issues that you need to know something that effects neutronics, effects fuel performance, effects materials? You all get in a room and argue about it and then somebody takes the lead? How is this done?

MR. ULSES: Well, I'll just take it real quick. See, from a process perspective, I know we meet rather frequently and we discuss what we are all doing. And make sure that we are lined up as we go forward.

I don't know if you want to add anything to that, Stu, or not. I mean --

MR. RUBIN: Well, you are very right. We don't want to be --

CHAIR CORRADINI: I never inferred that. I never inferred that.

MR. ULSES: I don't know that we argue too much but we do talk a lot.

MR. RUBIN: And our first step was to

create that chart: what are the events? What are the figures of merit we want to create? And so okay, that's an event, a figure of merit. What do I need from who to get what I need to put out to the next guy? Okay. And so that continuous communication will start to reveal. And we'll write those all down and make sure that we are not in silos because if we are, we're never going to get this job done.

CHAIR CORRADINI: Right.

MR. RUBIN: We have to explain what I need to give you, my fission product release, and I listed all those things. And there's time dependency and spatial dependency. And, okay, that's your assignment. You've got to do that.

Now if we miss a phenomena, then we're, you know, in trouble. But in terms of communicating those inputs and outputs, we're set up to have those working group meetings periodically and make sure we are all working to the same kind of sheet music of everybody is doing what they have to do to pass to the next person.

CHAIR CORRADINI: So the reason I asked a question such as that is then is somebody given -- let's just talk about core bypass phenomena and how it effects accident analysis and associated source term.

Is somebody given the lead that then, therefore, there is an appropriate lead on the DOE side that you guys are in communication?

Because then the question is all right, so this is an issue. It has a materials aspect, a fuels aspect, a thermal hydraulics aspect, what is DOE doing that we don't have to do or choose to verify or choose to duplicate to make sure we confirm their work? How is the connection made to then the DOE lead in this?

MR. RUBIN: Well, we're just setting up our communications channels to start that process of talking by peer to peer -- thermal hydraulics to thermal hydraulics, nuclear to nuclear, fuels to fuels. But we also have to get into that cross connect discussion that they have with our cross connect discussions. Okay.

It is a to-do. We know we have to do that. We are just getting started exchanging those relationships. And we will be attending or have already started to attend some of their periodic meetings where they will go through a methods review where we will hear and see what they are faced with. And make sure that we are recognizing those same issues.

It is a to-do. We haven't gotten started.

But that is on our list of got to do that. The only way to get smart is to talk to people and learn more about what they know.

CHAIR CORRADINI: Okay. All right.

MR. RUBIN: We're going to do that.

Do you want to add to that?

MR. JOLICOEUR: Yes, This is John Jolicoeur from Research.

CHAIR CORRADINI: Yes, just pull the mic to you.

MR. JOLICOEUR: John Jolicoeur from Research. We have signed an MOU with DOE for the cooperative work between the two agencies. But what we have not yet completed is implementing an interagency agreement. That's currently under review. And we expect it to be completed here in the very near future.

CHAIR CORRADINI: Could you repeat what you said? So you signed the MOU but what are you still completing?

MR. JOLICOEUR: Implementing an interagency agreement between the two agencies.

The MOU is just a big framework document. Then you have to have --

CHAIR CORRADINI: So at this point, if you call up somebody at DOE, they'll say time out. We don't have the implementation. I can't answer you.

MR. JOLICOEUR: Yes, they will talk to us but at this point we haven't shared peers, as it were. We don't have peers lined up with peers yet because we don't have the implementing agreement to start doing that work. We expect to start very soon.

CHAIR CORRADINI: Okay. Maybe I lack the appreciation of how much legal handshaking there has to be. Is that because of the applicant-regulator issue? Or is that what it comes down to? Or is it just management upon management?

MR. JOLICOEUR: It is the way the MOU is structured. I mean the MOU is a big framework document. And then the implementing agreement provide DOE funding for us so that we can then engage --

CHAIR CORRADINI: Okay, okay, now we get to money. Okay.

(Laughter.)

MR. RUBIN: Let me just say -- let me just say -- we have -- we have their planning documents --

CHAIR CORRADINI: Thank you.

MR. RUBIN: -- we have their planning documents for code development. Okay. With our integrated code development strategy or graphic is not locked up. Okay. And we understand what they have written down so far as to what their linkage issues are from one discipline to the next.

We get periodically -- monthly -- their monthly reports and part of that is their code development area. What we haven't really started yet is the face to face --

CHAIR CORRADINI: Okay.

MR. RUBIN: -- in real time. And we need to have peer-to-peer but we also need to have system level guys to system level guys.

CHAIR CORRADINI: No, I understand that.

MR. RUBIN: That's the part we haven't started yet.

CHAIR CORRADINI: But I mean just a process question. I don't want to take away from our early break but to get John to clarify. So you helped me a bit. Are you also saying that this -- the MOU essentially defines the method of interaction during a pre-application phase between the DOE and the NRC? Or even beyond?

MR. JOLICOEUR: Actually, the MOU is -- actually --

CHAIR CORRADINI: Or the implementation or whatever the hell the thing is?

MR. JOLICOEUR: Yes, the current MOU is really pre-application, if you will.

CHAIR CORRADINI: Pre-pre- or just pre-?

MR. JOLICOEUR: Just pre-pre-application.

CHAIR CORRADINI: Okay.

MR. JOLICOEUR: So a new one will come up when pre-application begins.

CHAIR CORRADINI: Okay. So we're in pre-pre-application protocol?

MR. JOLICOEUR: Right, right. This is just cooperative work between the two.

MR. RUBIN: Here is the genesis of this. The Energy Policy Act has a piece in there that said that the Secretary of DOE shall engage with the NRC to get the NRC's input into their activities so that they are doing their research in a way that is responsive to the safety requirements for this plant.

So based on that, I forget what the subsection was, we wrote an MOU that is going to allow us to participate in basically their R&D. That's the focus of it.

CHAIR CORRADINI: Fine.

MR. RUBIN: Okay.

CHAIR CORRADINI: That helps.

MR. RUBIN: And that now is in place. Now we have an interagency agreement that takes us to the next level. And the next level is what are the working points of contact? What is the periodicity? What are they sending us? What are we sending back?

CHAIR CORRADINI: You got it.

MR. RUBIN: Details to follow.

CHAIR CORRADINI: I'm happy now. Thank you.

Sorry. Other questions?

(No response.)

CHAIR CORRADINI: Okay. We're -- I want to thank the morning's presenters. And we have more this afternoon.

We'll break until our official start time of one-thirty. All right -- for lunch.

(Whereupon, the foregoing matter went off the record at 12:14 p.m. to be reconvened in the afternoon.)

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

1:30 p.m.

CHAIR CORRADINI: Why don't we get started.

Steve Bajorek will take us through discussions of thermal fluids research versus thermal hydraulics versus heat transfer.

MEMBER SHACK: With the momentum equation.

(Laughter.)

MR. BAJOREK: I wasn't sure whether that would come up. Now we know.

Thank you very much for that introduction. I'm Steve Bajorek from Office of Research. Good afternoon.

Yes, what I'd like to do is talk about our thermal fluids research. Yes, that is a word that we've stumbled over. We like to say thermal hydraulics although by design, we're trying to keep the hydraulics out of this. So we've been calling it thermal fluids or TF for abbreviations.

What I'd like to accomplish in like, you know, my 45 minutes are three different parts of the presentation.

First I'd like to describe the thermal hydraulics research objectives. One of the things we'd like to accomplish today in all of our presentations is to lay out a picture on how these various disciplines fit together in order to help us develop the regulatory framework and to develop the evaluation models. And I'm going to try to describe how thermal fluids fits into all of that.

I want to outline what we are considering the major thermal fluid issues for gas reactors. And as part of that, I want to talk a little bit about the PIRT rankings, which ones have given us the most concern, given us the most -- are most interesting to us, outline our overall approach to dealing with those.

And finally, point out what we think from the thermal fluid research, what are some of the products, how does it relate to the evaluation model development? You know how are we going to use this information?

Tony Ulses did a really nice job at the end of his presentation in kind of outlining one of the biggest concerns in several of our's work and that is in coming up with the right experimental data in order to benchmark our models, benchmark our codes or various parts of the evaluation model. And that's a big concern in the thermal fluids area.

We have a lot of processes, some fairly well understood, some of them being driven into new ranges of conditions which are going to give us larger uncertainties than we may have expected at the conditions where the correlations may have been developed.

So I want to outline where some of those data needs are, where we think we can get some of that experimental data, what are some of the facilities which are available for that.

First in terms of the objectives, the thermal fluids research is here to support the evaluation model development. And there are two elements of that. First, we're going to be looked up to obtain or generate the integral and the separate effects data that is either going to go into the code, the evaluation model assessment or into development for some of the new models.

In terms of the hierarchy on where we will get that experimental data. There are three different steps we're going to take in each one of these processes. And I'll try to outline this as we look at some of the issues.

First and foremost, we're going to look at Department of Energy and the applicant to supply that data for assessing the models, assessing the correlations.

We will be able to start interfacing with DOE here as soon as the interagency agreement is in place but we would look to work very closely with Department of Energy in order to make sure that the data that they are developing satisfies our needs as well as theirs.

We're also looking at collaborating and entering into agreement with international organizations. We've talked about a couple of those, the HTR integral facility in China, HTTR in Japan. We've started to talk with both of those groups about gaining better access to the experimental data.

Some of it has been released in part of the international IAEA cooperative research program. So we see a little bit of that and are convinced that pursuing more data from those facilities is going to be very useful and helpful to us. But we don't have all of that yet. And what we're going to do is pursue those international agreements.

We're also working with RAPHAELE, that project, in order to gain some of their work into the gas reactors. We are also working in the CSNI TAREF project, task on advanced reactor experimental facilities, where we've reviewed the experimental facilities that are available worldwide.

The next step in that process is to work with the roughly ten or 12 international groups that want to be part of the TAREF to outline what the tests are, share data, perhaps do some cooperative research with one or more of those facilities and make it available to all of the collaborating research organizations.

Third, if we don't get the data from Department of Energy that fulfills our needs and we can't get it from international partnerships, we would conduct some of our own independent experiments. We'd like to leave that go to the third level of, you know, as part of the decision.

We have two routes by which we could pursue that right now. One, we have our Thermal Hydraulic Institute. We've used this for TRACE development. Up until this point, almost everything has been light water related. But this is a mechanisms that would allow us to run small-scale experiments at a couple, three different universities, give us some data that we would need on a timely basis.

MEMBER SHACK: This is Purdue?

MR. BAJOREK: Thermal hydraulic? Yes.

There are some other universities which are associated with that but it's primarily Purdue that runs that.

We've also recently entered into a cooperative agreement with several universities that would help supply us with some work for PARCS, MELCOR, and, if necessary, running some of the experimental tests that we might find necessary.

The second element of the thermal fluids' objectives would be to take these data, look at the correlations, the models that are currently existing, and try to evaluate those to see whether those are suitable for MELCOR, determine what the uncertainties are compared to the existing and new data, and use that to be factored into the evaluation model as we do some of the either uncertainty calculations or make changes to that code.

MEMBER ABDEL-KHALIK: Just for reference, how large is this effort under the third bullet currently?

MR. BAJOREK: Right now, the Thermal Hydraulics Institute, with respect to gas reactors, is fairly small.

MEMBER ABDEL-KHALIK: No, in general, what is the size of this effort even though it is now focused on water reactors?

MR. BAJOREK: Typically for the Thermal Hydraulics Institute, there would be work to support three or four different experimental programs. The reason I'm hesitating -- and I'm not sure in a public format whether I could talk about the dollar value.

MEMBER ABDEL-KHALIK: Okay. Then we'll skip it.

MR. BAJOREK: The Thermal Hydraulic Institute, for example, we're looking at work for interfacial and area concentration. We've run some other large-diameter pipes for drift flux so there are usually two or three relatively small-scale experimental programs.

The second one, there are provisions in there for doing some integral test work or some separate effects test work. The decision on whether to pursue that and to go ahead is still yet to be made. But it is a mechanism to allow us to move forward in a timely fashion.

As I think Joe Kelly put up in one of his timelines, we need to have this model ready in 2013. If you start marching backwards in terms of assessing the data, developing the models, building facilities, the time to get going is on us if not already behind us.

MEMBER ARMIJO: Do either of these facilities -- organizations, I mean, have test facilities with medium- and high-temperature gas?

MR. BAJOREK: Not specifically, no. At the end of the presentation -- and if you flip back to the next to the last page -- I've put a table in there. It is two pages. And it shows the major thermal fluids facilities available for gas reactor processes that I am going to go over.

One, it's only two pages long. There aren't too many of them. And if you look at the organization that runs them, there aren't too many in the U.S. In fact, I don't think there are any in the U.S. outside of Idaho and Argonne on that list. So they are relatively few and far between.

One thing I would say for work that we have done with Oregon State is they have a one megawatt DC power supply, okay, and the steam requirements for doing a number of tests that were on the order of the APEX facility that we used for AP1000.

CHAIR CORRADINI: But just to be -- to say it differently, just point of information, so one is essentially the old PUMA -- oh, PUMA, I've got it wrong -- PANDA -- I'll get it right.

MR. BAJOREK: You were right the first time. PUMA.

CHAIR CORRADINI: I'm sorry, I got a P -- I got my Ps confused. The first one is the PUMA facility and derivatives thereof. And the second one is the APEX facility and derivatives thereof. Right?

MR. BAJOREK: Correct.

CHAIR CORRADINI: Okay.

MR. BAJOREK: And a lot of -- at least the thermal hydraulic work, having the steam, having the electrical supply, you know, DC current, high current, sitting in a low ripple power I think gives you a lot of capability. So that's, you know, one aspect that we've used at least in that work up until now.

MR. KRESS: With LWR integral experiments, we used a lot of electrical simulators for fuel.

MR. BAJOREK: Yes.

MR. KRESS: What are you going to do for pebble beds?

MR. BAJOREK: That's a tough one. We've talked about this. One idea -- there are two things that have been done. One has been to put in a graphite heater where the central reflector was, push the pebbles, and measure the temperatures on the other side. But that is instrumenting a few of the pebbles but not really heating the pebbles.

One idea that, you know, I've thrown out to a few people, is creating a heater that you might want to think of as meatballs on a shish kebab skewer. You can bring in the electrode, put the windings, and then build an encasement around each of those.

Of course, you don't get to shuffle the balls around and change the porosity very easy. Something like that might be feasible.

CHAIR CORRADINI: That has been done before for debris bed cooling --

MR. BAJOREK: Okay.

CHAIR CORRADINI: -- for many years --

MR. BAJOREK: Okay.

CHAIR CORRADINI: --in simulated experiments both for the LMFBR days and the LWRs.

MR. BAJOREK: Okay. But, you know, something like that would give us a way of giving power to the balls and instrumenting those. But, you know, I'd have to imagine at least compared to electrical fuel rod simulators for reflood experiments that it is certainly different and may be much more difficult to fabricate.

Something that I think we might have to take a look at, if we're looking at packed beds of some type of a size where conditions near the reflector, where bypass is going to have a major impact, they're going to give us much different heat transfer and pressure drops that we would out in the far field, out in the center of that.

But it is an area that we're interested in. We've talked about it. But with the preliminary nature of the development work at this point, we don't have an answer to how you do that yet.

MR. KRESS: Thanks. I appreciate that.

MR. BAJOREK: What I'm going to do on the next three or four slides is just outline the parameters or, excuse me, the phenomena and processes from the PIRT that were identified in thermal fluids areas as being highly important but having a fairly low knowledge level. And just a couple of the issues related to that.

What I'm going to do next then is I'm going to take each one of these four major issues and lay out what are the problems that we see in those and what is going to be our general approach to what those are. So I'll go through these next couple of slides relatively quickly just to save time and not duplicate the effort here.

Four areas, the first of which would be the core and the vessel thermal fluids area, we can talk about, you know, the core effect of thermal conductivity question --

MR. KRESS: Does that thermal conductivity include radiation heat transfer?

MR. BAJOREK: All three of them.

MR. KRESS: So it is a function of temperature then?

MR. BAJOREK: Yes.

MR. KRESS: Okay.

MR. BAJOREK: It is a function of temperature, emissivity of the surrounding media, the fluid properties as well. I'll jump ahead here because this is kind of useful to that question and the core and the vessel questions. Where do you get challenges in thermal fluids areas?

In each one of the major paths for heat flow from the core all the way out to the concrete, you will find that radiation, conduction, and convection are all important in various parts of that half. Now especially when you start to go to the loss of flow-types of conditions where natural convection is the dominant convective mechanism, now you start to find that radiation, convection, and conduction, they kind of compete with each other. It is a combined mode problem. In some cases, radiation could be dominant. In other cases, the convection can be dominant.

But because you are looking at relatively small differences between those two or three different processes, it is difficult to assert in your models whether you are compensating one or the other. Or whether you are getting all three of those processes correct at the same time.

And you see that not only in the core where for a depressurized loss of forced cooling, thermal radiation is carrying most of the heat -- 60, 70 percent or so. Conduction through the gas, most of the rest of that, pellet-to-pellet conduction relatively small amounts bu they are all in there.

And depending on the accident, one may be more important than the other.

MR. KRESS: Do pellets actually have a contact area?

MR. BAJOREK: Very small. In some of the work that we've done so far, they've looked at the -- those three different paths and that pellet to pellet is almost negligible compared to everything.

Some of the existing models, though, however, say that that term is dependent on I guess they call it the pellet pressure. It depends on how many pellets --

MR. KRESS: How many bottles are smashing down on it?

MR. BAJOREK: Oh, yes, so it is a scaling dependent parameter and those have been based on relatively small-scale beds.

Now we're looking at now something with several hundred thousand pellets, eight meters high. That parameter might be a little bit more important. But I think at this point in looking at it, we would still look at radiation and conduction as being those major contributors.

MR. KRESS: Those things will depend on the void fraction?

MR. BAJOREK: Yes, oh yes.

MR. KRESS: So you would need to know the packing fraction.

MR. BAJOREK: You've got to know the porosity, the emissivity, the gas thermal properties. There are five or six different parameters.

MEMBER ARMIJO: But the variability of the geometry of all those pebbles as a function of height from the top to the bottom, is that all included in your analysis? Is that what you are going to try and be able to do? How do you do that?

MR. BAJOREK: In the analysis --

MEMBER ARMIJO: Is there an input that says this is what you are going to have? Or --

MR. BAJOREK: In the evaluation model, at least as I understand it, as we model the reactor, the various rings or regions of that reactor could have different porosities. There will likely be a high porosity near the radial reflectors, near the walls, than there would be in the center.

How that varies from the top to bottom, I haven't heard.

MEMBER ARMIJO: Is there already a model existing that DOE has or Idaho or somebody that could be an input to yours? And you can verify it?

MR. BAJOREK: Yes, I don't know if it was on one of those earlier diagrams with the evaluation model. I think it is called Peb. Bed.

CHAIR CORRADINI: There is a South African model that people are using. Whether or not it is verified is --

MR. BAJOREK: They are using that model -- I mean there is a code that is under development to try to estimate the flow of pebbles in the local porosities in there. But --

MEMBER ABDEL-KHALIK: But the conduction part, these are all sort of mono-dispersed beds. And there must be, you know, a lot of old data for the conduction part which you can separate from the total effect of conductivity if you want to validate the data.

The radiation part, I can see will be very difficult because, you know, it is few-factor-dependent. And that will just depend on, you know, how the particles are arranged.

MR. BAJOREK: Yes, the correlations that I am familiar with generally use a porosity. And the emissivity as a couple of the major variables or uncertainty contributors. It's, you know, something we are aware of. We are going to have to look into that in the long term.

But you are right. There are models and correlations that are there. They have been developed not necessarily for helium and its conductivity -- usually for air, nitrogen, I think argon, things which are of more interest to the chemical industry, you know, and their use of packed beds.

So we have to make sure that those

correlations are applicable to much higher temperatures likely than they have been developed. But radiation could actually have a higher contribution.

MR. KELLY: This is Joe Kelly in Research. Maybe I can put that into perspective a little.

At the temperatures you see in a D-LOFC, now these are not exact numbers but they are close -- the radiation component would give you an effective thermal conductivity of 20. Conductivity through the pellets, through the pebbles, through the gas for the next one, about five.

And pebble-to-pebble contact, about one.

So the uncertainty -- I mean the value of the pebble-to-pebble is less than the uncertainty in the radiation part.

MEMBER ABDEL-KHALIK: It is sort of the same problem as the dry cask storage where you have to worry about both conduction and radiation.

MR. BAJOREK: And back to the issue of the porosity, there is a large database in the chemical process industry because they use packed beds all the time. And it kind of like a damped sine wave as you go away from a wall. And is, in effect, going in about five pebble widths.

Now in our case, we've got two walls. And if you look at the current PBMR-400 design, it is only 15 pebbles across the annular core. Okay.

Now you can take those models for the varying porosities, put that into your porous body code. But then you are not sure if your drag coefficient is right because those are developed for a bed as a whole, not for reaching of higher porosity.

And one of the things we've done at this point in CFD is to model the region of the porous bed near a wall. And what we get are loss coefficients that are significantly less in the KTA rules. So that's one of the things that we are going to have to look at to see what the radial profile of the flow rate is.

Okay, so to kind of move ahead, I think we've kind of covered the core and vessel. Properties are going to be important. We need to know the emissivity. We need to know the porosity because we are well aware that bypass, you know, what goes on near the wall and away from the wall can be considerably different and yield much different fuel temperatures, which is ultimately what we need to get at.

Air ingress, I'll talk about this a little bit more in our approach, a couple of the issues that are raised here are what we called duct exchange flow or lock exchange flow. That contributes with molecular diffusion in that things have changed a little bit over the past few years where it used to be people were considered mainly with diffusion effects, air diffusing into the lower plenum and throughout the system.

More recently I think it has kind of dawned on everybody that that way of thinking came about because the pipes were at the bottom of the vessel.

If the cross-connect pipes are over on the side, now we have this lock exchange flow which is a term comes from civil engineering, looking at cold water flowing underneath warm water in a stream or a river. In much the same way, we can get air moving into they system much rapidly as helium escapes.

So duct exchange flow is a phenomena that we're very interested in because now this brings air and oxygen in contact with the structures and potentially the fuel within several minutes following a break to the system as opposed to several hours as had been the viewpoint several years ago.

CHAIR CORRADINI: Is that independent of

the break size? I would think not.

MR. BAJOREK: Not, not necessarily. Could I hold off on that because I have a couple of figures that we'll talk about -- about what we're looking at in that area.

MEMBER ABDEL-KHALIK: And no thought had been given to the building being inerted.

MR. BAJOREK: Not that I am aware of. I haven't seen that suggestion.

So right now, because we can't always guarantee that and because there may be accident scenarios where you would have oxygen in the confinement, we're still going to need to build that into our evaluation models. Even if it were inert, we'd have to go there.

RCCS performance, this was another set of phenomena that were highly ranked but relatively low phenomena, again dominated by thermal radiation because of those properties and behavior of the RCCS, potentially a participating media.

If we have this graphite dust being blown out of the reactor vessel into the cavity, it is going to change the problem from one of surface-to-surface radiation with convection to one where that media would be participating and capturing some of the thermal radiation changing the flow.

RCCS failure assumptions which could lead to either a symmetry if we fail one out of the two RCCS tube banks, which are a part of the system, or if you fail both of those in a very much beyond-design basis event where now the concrete thermal response might come in to play.

MR. KRESS: Isn't the dust likely to be gone before you really need to calculate this?

MR. BAJOREK: I think so.

MR. KRESS: Okay.

MR. BAJOREK: I think it is going to be something early on.

MR. KRESS: Yes, a little bit early on.

MR. BAJOREK: By the time the fuel gets up to its maximum temperature --

MR. KRESS: So you're worried about the maximum temperature.

MR. BAJOREK: We think so but that's something that we're going to have to --

MR. KRESS: It may effect the transient early on.

MR. BAJOREK: Yes.

Internal side heat transfer, the RCCS processes that were identified were parallel channel interactions, instabilities in the tubing, and some of what I would call just normal uncertainties associated with boiling.

One where we've actually concerned ourselves a bit more over the last several months has been the one that we've referred to as graphite dust. I think you've heard at this point a lot of where this is fitting in.

From the fuel standpoint where graphite dust is a sink for the fission products, we are -- our question there is how much of the fission products diffuse through the pellets or the fuel and can become embedded in the graphite dust?

We would look to the graphite research to help us understand how quickly the dust is generated, what is the size of those particles, what is the shape of those particles? Okay. It could effect -- because what we're interested in is from the thermal fluids standpoint is how easily those particles are transported through and out the system.

So that's from the thermal fluids point of view, graphite dust is a twofold problem. One, its effect on circulation within the cavity and the participating media that we just talked about. But for us to determine either the correlations or develop the data that would help us develop models for MELCOR to tell us how much of that dust, once we know where it is at, is transported out into the confinement and throughout the system potentially into the cavity filter system.

CHAIR CORRADINI: What about a combustion hazard?

MEMBER BLEY: Explosion.

CHAIR CORRADINI: Well, let's just call it a combustion hazard.

MR. BAJOREK: Could I hold off on that just as a --

CHAIR CORRADINI: Well, the reason I asked the question is you've said this is just -- you called it a PBR? I don't remember what you called it.

MR. BAJOREK: Pebble bed.

CHAIR CORRADINI: Why is it just that?

MR. BAJOREK: Oh, we don't think there is going to be a whole lot of dust for a prismatic.

CHAIR CORRADINI: Why?

MR. BAJOREK: You don't have the relative motion between the graphite to the extent that you do in a pebble bed.

CHAIR CORRADINI: And that's the phenomenological dust generator? You're not going to have high velocity helium gas going through the duct work continually eroding, smoothing corners?

MR. BAJOREK: In taking a look at the AVR experiments, okay, there was evidence that there was a considerable amount of graphite dust. I don't think they have see that in the HTTR.

CHAIR CORRADINI: What is a considerable -- just so I -- I don't even know historically what did they consider a considerable amount? A kilogram? Ten kilograms? A hundred kilograms?

MR. BAJOREK: I think it is on the order of several dozen kilograms.

MR. RUBIN: It's like 20 or more I think.

MR. BAJOREK: Yes. It was several dozen kilograms. I don't remember the number.

Since you asked the question, I'll jump ahead on the graphite dust. What we have done so far is we've basically done a literature survey to help us characterize the amounts -- several kilograms. I think someone talked about the .6 to six, size distribution has been seen.

A lot of uncertainty on whether that was prototypical of the fuel that we are going to see, okay, but that is what we have to go on at this point. So we're at least looking at that as a starting point.

But as you pointed out, one of the things that has popped out of our initial literature survey is that of detonation or combustion. You kind of need three things for detonation.

You have to have a sufficient concentration of a combustible particle. Okay, coal dust, for example, graphite, sugar --

PARTICIPANT: Flour.

MR. KRESS: Yes, almost any burning material.

MR. BAJOREK: Yes, something with carbon in it. You need to have that. And you need to have an oxidizing agent, oxygen, okay, and you need to have an ignition temperature at least in to -- the question to the person who was in charge of this, can we rule this out? And his answer was well, not yet. You at least have all three of those.

Now whether that is a major issue or concern in the long run, we don't know. But it is something that we are going to have to address or at least we are going to have to go back to the applicant and ask them to address that because we have not been able to rule it out at this point.

MR. KRESS: When we transport aerosols and

LWRs, if they manage to touch each other, the particles, the assumption is that they stick together. Is that a good assumption for this graphite dust do you think?

MR. BAJOREK: They aglomerate. I don't know.

MEMBER BLEY: They are charged.

MR. KRESS: Yes, they are charged. That's why -- you would expect that would keep them from touching each other even. But I don't know. I don't know if there have been any experiments on that or not.

MR. BAJOREK: Okay.

CHAIR CORRADINI: The reason that I asked the original question though was the energy content of a few dozen kilograms of graphite dust is the equivalent of the pressurization of all of the helium. You can double your peak pressure in any building you build but you have to consider based on just a few dozen kilograms of graphite combusting.

The detonation doesn't worry me because you've got all of this helium buffer. It would be almost like a cold burning accident versus a cold detonation accident.

MR. BAJOREK: Right. But it is an issue

that I think has gained more visibility over the last couple of years. The group that went to South Africa reports that PBMR, Incorporated is looking -- actively looking into this.

So it is something -- it is on our radar screen. We're going to follow it. We're going to have to make sure our codes can at least transport and track the location of the graphite dust and incorporate its effects on the natural circulation and everything else that goes in the system.

With respect to core and vessel thermal fluids, our approach -- we've initiated a project now using CFD to look at existing correlations to examine some sensitivities in the core. I think Joe just mentioned this is how we've determined that there are near-wall and far-wall effects.

We've used CFD to help say that hey, this is a sensitivity that we are going to have to be very sensitive to. We've also taken a look at gas mixture properties.

Very early on we wanted to try to make sure -- we were looking at things which could be generic to a prismatic or a pebble bed. You know getting properties right, mixture rules for these various constituent gases. So we've identified those.

And I think those are going into MELCOR at this time.

Our next approach would be to take a look at applicant and DOE data in order to benchmark and assess the models that go into MELCOR. If those prove to be insufficient or come too late in the schedule, we would consider running our own separate effects tests.

Okay. I'm going to jump over that.

MEMBER ARMIJO: Good. I didn't understand that picture anyway.

MR. BAJOREK: Air ingress, we've already talked a little bit about lock exchange. This is the process where we are concerned about the counter flow of fluids with different densities, their ability to flow past one another.

As we mentioned, the initial view had been that air ingress was diffusion limited. But as we start to take a look at breaks of different orientation, principally horizontal, we've been finding that yes, we can get air into the system significantly early. Just recognize that this is a process that is relatively difficult to calculate.

Other issues with respect to air ingress is there's not a tremendous amount of information on natural circulation in a scaled facility. This might also feed back on concerns about flow distributions coming into and out of the core. Okay.

We have calculations that suggest there are certainly differences between near-wall and far-wall. You may be able to do CFD calculations for an upper plenum if you define the geometry.

But no one has been able to go and measure velocity distributions in tests like HTR, HTTR that gives us the ability to benchmark the codes and give us some of the assumptions that we might want to even bias our models in order to make sure they are conservative. So that's -- we recognize that is a major shortcoming in addition to getting similar types of natural circulation conditions and flow patterns in a reactor cavity so that we are able to evaluate the RCCS performance.

Graphite oxidation also identified as an issue in the evaluation model.

MEMBER ABDEL-KHALIK: Could you just explain to me this locks change process? And wouldn't you have to totally depressurize the system before --

MR. BAJOREK: Yes.

MEMBER ABDEL-KHALIK: -- this process takes place? So it really is much later --

MR. BAJOREK: It's early. It would be

right after what we would call a blow-down phase. We wouldn't -- you know, if there was a rupture to the system --

MEMBER ABDEL-KHALIK: Right.

MR. BAJOREK: -- you would vent down fairly rapidly depending on the size of the break. Once that has -- once you've reached an equilibrium pressure between the vessel and the confinement, then this lock exchange would occur.

MEMBER ABDEL-KHALIK: Okay.

MR. BAJOREK: If I recall the calculations, we're looking at minutes into an accident.

MEMBER ABDEL-KHALIK: But it is a concentration gradient-driven process.

MR. BAJOREK: Yes.

MEMBER ABDEL-KHALIK: So it is a diffusion process.

MR. BAJOREK: Diffusion but also density different.

MEMBER ABDEL-KHALIK: Oh, I see.

MR. BAJOREK: Okay, the helium is at say an outlet temperature of 900, 1000 degrees C. Well, the air is sitting in the confinement at 100 degrees C. And just because the difference in those fluids, there is a considerable density difference between the nitrogen or the air and the helium.

CHAIR CORRADINI: But back to my original question about this -- he brought it up -- it's his fault -- if I'm pointed down, it is purely diffusion. If I'm pointed up, the buoyancy-driven plume would augment it.

If I'm sideways, I would think that it is break size dependent. If I have a little break, frictional effects could shut it down then it just goes back to diffusion. If I have a big hole, then I could have essentially two counter-flowing streams.

MR. BAJOREK: Break area -- yes, break size is going to be part of it as well as break orientation.

MEMBER RAY: Is there no break --

CHAIR CORRADINI: I just want to make sure I understood, that's all.

MR. BAJOREK: Yes.

MEMBER RAY: Is there no break in the head area assumed?

MR. BAJOREK: That's a good point because what we have done is we've kind of run with that question a little bit. We've seen some results from other CFD. What happens if you have a break in the large counter-flow pipe.

Okay, well we go back to this classic lock exchange in a great big flow area. Well, one of the questions that we had following well, there is a lot of penetrations in the upper head. That's where the pebbles have to come in.

So we said well, is this also a concern? So part of our early approach in trying to understand the issues better is we used a -- well, we had somebody come and set up a CFD model and we asked him to make a prototypical-sized upper head. And we just knew the hemisphere, approximately volume, and dimensions.

Get some prototypical temperatures of what we might think is going on there. Assume that blow-down has ended, how quickly does air get into that system? Okay. And does it get into there with any kind of a significant amount? And could CFD kind of show what some limited experimental data shows?

And it is that you get the maximum of air ingress into the system not for a horizontal situation or a vertical situations. But it is about 60 degrees.

And in calculations, we are able to come fairly close to that. And what these figures here show is for -- and I can't remember what size of a break this was -- but, yes, if you do have a break in the upper head where you would have a control rod drive, you will have penetration of air in at least the calculations were showing it was of the several ten to 20 kilograms fairly early such that oxidation in the vessel of any fuel up in that region would be at least an issue or a concern to us.

MR. KRESS: Early on, I was assuming this lock exchange meant you had cold air coming in, reacting and getting hot, and hot air going out. In the long term, isn't that what you have?

MR. BAJOREK: Depending on where the break is, our concern would be that the air comes in, oxidizes the graphite structures, and that plume then goes up into the core.

MR. KRESS: And gets trapped up there somewhere, yes.

MR. BAJOREK: Well, I don't think it is trapped there but the circulation pattern would eventually go up through the core into the down-comer. It would reverse the natural direction or the initial direction of the flow.

But it wouldn't be one of the air coming into the lower plenum and going back out. It would be going elsewhere into the system.

In this set of calculations I had the -- she is a graduate student who did this -- model the rest of the vessel and try to follow the plume down -- actually going down the down-comer into the lower plenum and back up.

So we were able to at least use CFD to help get a handle on the problem and give us some indication that yes, break orientation, break size are going to be important on certainty contributors. And that we can't just write off breaks -- small breaks to the top of the vessel right off hand. We're going to have to do more work to rule those out of the design basis.

In terms of air ingress and kind of the work that we've been doing at this point, I talked about the exploratory CFD calculations to help us understand what is going on. We have started to use our thermal hydraulics institute to set up a small separate effects test where we would look at helium, this lock exchange with helium within a vessel, air outside of the vessel, and change the break area, the orientation, and the break shape itself.

When you set up these models in a code, do you often want to assume that it is circular? Well, we want to know what happens if it is a larger crack.

So we're trying to develop some of the database that we are eventually going to be able to use to go to MELCOR and give us what you might call a break model or an air ingress model, give us indication on how much air is going to get into the system if we know the conditions inside and outside the system. So we're starting to move in that direction.

Outside of that, we would want to talk with Department of Energy to deal with air ingress. We feel that there is going to be a need for some type of integral test system in order to look at air into the system. And how that contributes or augments the natural circulation and the processes within inside the vessel.

RCCS performance, issues that were identified in the PIRT were one, a lack of prototypic data for circulation within the cavity, how you would model thermal radiation, a lot of uncertainty as to what would be the emissivities of the vessel, the RCCS panels themselves.

Again, you see this, especially in the RCCS, but a number of the thermal fluids, lack of data, insufficient data. This is an area that our approach is first of all, we view this as being very crucial, very important in the overall success of licensing a gas reactor design because this is our -- you know in a way one of the major heat sinks to the system -- our intent here is to participate with the work that is being planned at Argonne where they have an RCCS test set up.

I know they are in the process of refurbishing that facility because of the size. And as far along as they are, it would be our intent to participate in those tests, helping to outline what needs to be -- what type of data we need to get out of that and we would look forward to the interagency agreement being in place so we could start dealing with them more directly.

And, of course, the third avenue there is if those tests were to go away or fall significantly behind schedule, we would look to other test data, possibly internationally or, unless we got forced into running our own RCSS tests.

CHAIR CORRADINI: So -- maybe this is the wrong time to ask this question so I'll register it then you can decide where to answer it.

At what point does the MOU allow for inter-visitation of information versus independent confirmatory information? I assume calculations have to be essentially separate and confirmatory.

Experiments are essentially shared by this process?

MR. BAJOREK: I believe that is what the memorandum would allow. That we would be sharing data. And it enables us to work jointly with Department of Energy.

Stu?

MR. RUBIN: Yes, I mean we have a common concern. And we believe that the experiment type Steve was talking about, when that's signed, they agree, we will collaborate on setting up that experiment, make sure it is set up right with proper instrumentation and so forth. And we'll have access to the data while we attend the tests.

CHAIR CORRADINI: Right. I guess my question is a technical question and also in some sense a licensing question about what sorts of things are clearly confirmatory because you have to make an independent judgment about safety adequacy versus doing it with them.

And I'm assuming calculations have to be separate and experiments can be shared.

MR. BAJOREK: Yes, well keep in mind that the suite of codes that they are using for their evaluations is different from ours.

CHAIR CORRADINI: Okay.

MR. BAJOREK: So what we would be doing is we would be taking these data, doing our own assessments. We aren't necessarily going to be using the same correlations that they are using. So we are going to have independent calculations. Those would be confirmatory but how good our correlations are may be pointing back to a jointly shared set of experimental data.

CHAIR CORRADINI: Thank you.

MR. BAJOREK: Okay.

Current progress with RCCS performance, not as much as in the other areas. We've done some preliminary CFD calculations to help us understand how we would model this gray gas of the participating media.

They are very preliminary. We don't really have results on those yet. And experimental plans have not be started yet. So we have to wait for that interagency agreement.

Graphite dust, I think we talked about some of this already. As we mentioned, during normal operation, abrasion, vibrations, could generate a significant amount of graphite particles with the fission products.

We don't have a whole lot of experimental data on this yet. We've tried to glean what we could out of the AVR. But as we mentioned, some of that graphite dust may have been due to, I guess, oil ingress into the system. And the pebbles and the graphite isn't necessarily the same as what we would be using in the VHTR at Idaho.

MEMBER RAY: But I guess you are still on graphite dust but --

MR. BAJOREK: Yes.

MEMBER RAY: -- I heard the exchange earlier just speculating -- combustion isn't the word I'm search for, Mike. What is it?

CHAIR CORRADINI: Detonation.

MEMBER RAY: Detonation wasn't thought to be an issue. I interpreted that to be within the vessel. But the blow-down transports this stuff into the confinement building presumably where it is not so obvious to me that it isn't a hazard there.

Is anything that you are doing going to look at that? You know in the classical flower silo explosion kind of model?

MR. BAJOREK: At this point, we've identified it as an issue. We don't have any concrete plans. The first thing we need to do is to understand how much is being generated and how much of it actually gets transported from the vessel on out.

MEMBER RAY: Okay. All right. But I guess the point is you would consider it not just within the vessel as a hazard.

MR. BAJOREK: Oh, no. No, actually the initial thought was this would be a problem in the reactor vessel cavity itself until we started to think that gee, you can actually have air ingress very early in time where you could have a higher concentration of the particles.

So we are going to have to take a look at in vessel and in the cavity and elsewhere within the system. So it's -- but it is a relatively new issue and we haven't thought it through.

MR. LEE: Steve, under the fission product transport part -- this is Richard Lee from Research -- the dust explosion issues is addressed and the peer reviewers have identified that as in the confinement.

So it is something that we will keep track of under MELCOR because in the containment, carbon dust explosion, that can be monitored easily. Just we need to know is what the size. The finer the particles, the easier you can combust it. So that can be evaluated.

MR. KRESS: I'll bet you have to have an

ignition source rather than self igniting. And if you do, I don't see that you get that inside the vessel.

MR. LEE: Not inside the vessel. This is in the confinement.

MR. KRESS: Oh, in the confinement, you'd probably have some ignition sources.

MR. LEE: That was considered by the experts.

MR. KRESS: Yes, I was just addressing his question about in the vessel. I can't see it happening in there.

MR. LEE: And earlier you also asked about the -- earlier someone asked about the content amount of dust in the system, if you look at page eight in the volume three report, it is between ten and 50 kilograms for the test reactor and the expert, the peer review -- I mean the PIRT members thinks that for the power reactor, it would be higher, maybe up to about a factor of ten.

For prismatic reactor, it is a factor of at least ten less. That's the estimate for the amount of dust in kilograms.

MR. BAJOREK: So, you know, the graphite dust and all of its issues, it is on our radar screen. We are trying to get our hands around it at this point. And it is clear that just on the preliminary information, there is a lot of uncertainty in all of these.

CHAIR CORRADINI: You are over your allotted time. But Al seems very calm. So I'm not --

MR. BAJOREK: Well, that's why I'm trying to jump.

CHAIR CORRADINI: That's fine.

MR. BAJOREK: We've covered some of these. I'm trying to be selective on -- I'm trying to pick out the slides where I get the easiest questions.

CHAIR CORRADINI: That's fine. I figured that.

MR. BAJOREK: Experimental database, one of the things that we have started is to compile what facilities would be very useful to us, what data could be available if we get the right agreements.

As I mentioned, we are trying to participate in a couple of international exercises. One, the TAREF to identify experimental facilities, try to gain access to some of that experimental data, RAPHAELE, another project that is ongoing.

MR. KRESS: Where is TAREF located? T-A-R-E-F, where is that located?

MR. BAJOREK: Oh, that's part of CSNI.

TAREF stands for Task on Advanced Reactor Experimental --

MR. KRESS: Yes, but CSNI is in Paris. But I don't know where the experiment zone is.

MR. BAJOREK: That's not a facility. It's a project.

MR. KRESS: Oh, it's a project. Okay.

MR. BAJOREK: It's a task.

MR. KRESS: I'm sorry. I thought we were looking at experimental facilities.

MR. BAJOREK: You were going to ask what the scaling of it was?

MR. KRESS: Yes.

(Laughter.)

MR. KRESS: Okay. Thank you.

MR. BAJOREK: Yes, this is basically the major facilities that have been either operated, run, or planned. And I think the point that I would emphasize that if we did this for light water reactors, we would go on for several pages. And for each one of those, we'd have lots of experimental data, a number of tests which would be available for us to develop evaluation models.

If you go through this list, you'll find basically there are -- you have tests at Idaho to help for CFD qualification, the Mear facility. And we've got the Argonne facility for RCCS.

Just about everything else on that list, unless I missed something, is international. It is overseas. We need a partnership with some of our colleagues there to make that data available to us.

MR. KRESS: This would be different from CSAR? Or would it follow under there?

MR. BAJOREK: We don' necessarily get that data through CSAR per some of those agreements. So we have to pursue that. But there are relatively few experimental facilities out there to generate the data even if everyone goes and starts to develop high temperature gas reactors.

But we are looking towards these to help us with potentially integral effects test, RCCS performance. There are a couple there which would help us for air ingress, several proposed by PBMR, Incorporated which would help us with some of the vessel thermal fluids. So we are looking at these as potential avenues to help us with our data and experimental needs.

MR. KRESS: On your previous slide, there are a lot of UTs out there. Which one is that?

(Laughter.)

MR. BAJOREK: This is like UT Western Basin. I know I don't have that right.

CHAIR CORRADINI: That's the reactor that will never get built.

MR. BAJOREK: Irving Basin -- I knew it was some basin. But that's the one, I think the idea was it might be a prismatic but it is in the very, very preliminary stages. It is proposed. I was debating whether to even keep it on this list at this point. But I just wanted it to be complete.

MEMBER ARMIJO: GA doesn't have any heating test facilities?

MR. BAJOREK: They have some facilities for looking at components, pumps, heat exchangers, along those lines. But nothing where we would be able to go and look at core thermal fluids or natural circulation in a large region, nothing that is going to really help us on the evaluation model development.

CHAIR CORRADINI: Do you plan to have all the -- let me reverse my last question since I'm making -- when I asked Stu about things relative to fuel, his answer was they haven't started the conversation about fluence and time and power for their tests. But eventually when there has to be fuel qualification, they are going to enter into the conversation.

I assume DOE will be invited into your conversation if you choose to do experiments about the scaling of the experiments you do so that they might share in the data so that there is an open discussion about scaling, et cetera.

MR. BAJOREK: Yes.

CHAIR CORRADINI: Is that correct?

MR. BAJOREK: Yes.

CHAIR CORRADINI: Okay. And then let's take one of the examples, the RCCS. Am I allowed to ask in open session is it a water design, an air design, or to be determined.

MR. RUBIN: Both.

CHAIR CORRADINI: Both right now?

MR. RUBIN: Both designs are being proposed.

CHAIR CORRADINI: Open possibilities.

MR. BAJOREK: I think they are being proposed but I thought the facility right now was water.

MR. RUBIN: Okay. But the vendors have different --

MR. KELLY: Joe Kelly from Research. When we went to Idaho last spring and they showed us their experimental program, for the natural conduction test facility, which is going to be the RCCS, they showed planned experiments for both the natural convection air and the water. So at the moment, they were planning on doing both.

But the status is they're just cleaning out the old experiment from 20 years ago.

MR. KRESS: General question on these facilities --

MR. BAJOREK: Yes?

MR. KRESS: -- I recall there was once a proposed look at the range of PIE values and the scaling analysis that would name a facility as an appropriate scale, did anything ever come of that?

MR. BAJOREK: Oh, the one with the light water reactor facilities?

MR. KRESS: Yes.

MR. BAJOREK: Yes, the basic conclusion out of that is after you do your scaling evaluation, the better approach would be to look at that range of PIE values for those higher-ranked values, set up a conceptual model and range those because some of those distortions --

MR. KRESS: Of course they wouldn't be general for all of them. It would be specific to a given application I would think.

MR. BAJOREK: Yes, yes.

MR. KRESS: Okay.

MR. BAJOREK: Yes. I mean --

MR. KRESS: Thank you.

MR. BAJOREK: -- we did it for a boiling water system but you could take that same general approach for pressurized water, light water system, you could do it for gas reactors. So it's --

MR. KRESS: I would assume there would be something like that come up at some point.

MR. BAJOREK: Yes. And the scaling will be an important question mark as we start to look at the integral facilities because it is clear that you don't want to have a facility full height and full radial scale. You don't have the power. How you scale pebbles to get the five pellets away from the wall and preserve everything.

And it is almost inevitable that when we scale this, there are going to have to be distortions that are going to have to be dealt with. And that PIE group ranging is probably the right way of investigating it.

Our outlook on the infrastructure or experimental data needs, we find that the separate effects data exists for a number of these processes but most of these are out of our reach. They are either planned by DOE, they're in the hands of international organizations. We are going to have to pursue that data.

We may need our own separate effects tests, possibly an interval test to fill in the blanks between the needs that we have, which are looking at regulatory criteria and in some cases looking at the CLFs associated with the system.

We are interested in those accident scenarios which are design basis but also those ones which go well beyond the design basis. The designer and the applicant is more focused on AOOs, anticipated transients, and the design basis.

So our needs overlap but there are some exclusive areas that we are going to have to take a look at.

The technical staff feels that we are going to need access to a well scaled integral effects facility in order to look at things like multiple system failures, CLF effects, system interactions.

The point that we like to make is that in every other design certification, the staff has relied upon usually not one but several scaled integral facilities in which to draw its regulatory decisions and develop evaluation models. And because of the first-of-a-kind engineering that is going into the gas reactor, we don't see that as being any different here.

So in summary, we have initiated some of the thermal fluids research. We are just scratching the surface on a lot of these issues. We are trying to identify what they are, what the data needs are going to be, and where we are going to have to go from here. Our primary focus is the evaluation model.

I haven't said a whole lot about CFD but just to close with this, we are using CFD to help guide our decisions. As Joe pointed out, we don't intend to make it an integral part of the evaluation model but depending on the issue, depending on the design, we may have to augment our experimental data needs in order to provide information to assess and quantify CFD if we get into situations where we need to know local details within the RCCS, a vessel wall, lower plenum structures.

So we're leaving that off right now. We're not forgetting about it. But that's primarily because we don't have enough design information in order identify which specific tests we would want to require for that situation or what might be the tool we might need.

MR. KRESS: In terms of your need for integral experiments, is the fact that you are going to have sort of a demonstration plant on a DOE facility change your perspective on that? Can it be used?

CHAIR CORRADINI: Can it be the experiment, is that what you are asking?

MR. BAJOREK: Well, we haven't talked about this and got the staff opinion. So I'll give you my two cents' worth on this. When you have a nuclear core, you are limited on your instrumentation and how risky you want to be.

With AP 1000 and the APEX facility, the electrically heated core, you could fail one valve after the other after the other and if you got a little bit too aggressive with the facility, we knew that John Groom, the operator, was very quickly going to go over there and hit that scram button and it would be no problem. You don't have that liberty if you are using HTR or HTTR.

If I'm looking at tests that might involve air ingress, you certainly can't use any kind of a nuclear core. But, you know, we're still going to need that type of experimental data.

And I think, especially for the pebble bed, it is that question on instrumentation that is going to be very, very difficult experimentally to deal with. We want to know what those bypass flows are, we want to know what the flow distributions, both into and out of the core, we are going to want to know what the flows are out on the reactor cavity.

Whether you go with an optical technique or hot wires or thermocouples, they've got their limitations on where you can effectively put those and under what conditions they are going to last without constant calibration.

CHAIR CORRADINI: Okay. Any other questions?

(No response.)

CHAIR CORRADINI: Since we're a bit behind, thank you, Steve.

We'll turn it over to Allen.

MR. NOTAFRANCESCO: We're not behind. We're okay. We just messed up the timing, that's all.

(Laughter.)

CHAIR CORRADINI: Ready? Go ahead. I'm sorry. I was just writing notes to myself.

MR. NOTAFRANCESCO: I'm Allen

Notafrancesco. I am going to give you the overview of the accident analysis section within the research plan.

We are at a point where we are going at a lower level and more detail. I am going to provide the status of the implementation of some of the details going into our analytical code.

Some of this stuff was discussed already as part of the evaluation model. Clearly we want to -- the first bullet leads to that. That we want to provide an evaluation model and develop validating, utilize the accident source term and fission transport analysis models, tools, knowledge, and support for licensing in the various areas of fission product release, dose assessment, and PRA analysis.

That's a big global evaluation model. The next bullet is really what I'm trying to do within code space, integrate the fuel nuclear, the thermal fluid models into an accident source term and fission product transport analysis models and tools for the evaluation of HTGR.

This is basically a diagram showing the complexity from the fuel kernel outside the break, the different processes and physics we need to capture in the code.

But the bottom line, we want to calculate normal operation and transient behavior for the entire system, core, vessel, confinement, integrating the thermal fluids and the fission product release transport processes, including the dust and the oxidation effects.

As mentioned earlier, we selected the MELCOR code. Basically we believe a lot of the models are there in place. And it won't take too much to modify. And this way we can do DBA and beyond DBA accidents in one code.

Okay, this slide, what this does is -- what I did is I took the PIRT on the left side -- these are important processes and cross referenced them against some of the MELCOR packages to show you that we have the modeling in place.

And we've discussing burning, possible detonation, there are models in MELCOR. Obviously they will have to be assessed based on the medium that we're dealing with.

To get the ball rolling in the HTGR analysis, we took on initial activities that we knew were deficient. And some of the key tasks we did was INEL had a MELCOR version to look at HTGR. Sandia, who is the developer, is also doing the development, which the HTGR neglected to mention.

So Sandia got the INEL code. They looked at the models. And that's one task. The other task was to look at the helium properties modeled in MELCOR.

CHAIR CORRADINI: Al, could you just repeat what you said? I guess I'm -- so there is a MELCOR 2.X that Idaho has as it was modified by Idaho. And Sandia is modifying the Idaho --

MR. NOTAFRANCESCO: No, no.

CHAIR CORRADINI: Okay.

MR. NOTAFRANCESCO: -- it is an old model so they are looking at it to see if there is any value to taking anything out of it.

CHAIR CORRADINI: Who is they?

MR. NOTAFRANCESCO: Sandia.

CHAIR CORRADINI: Okay.

MR. NOTAFRANCESCO: It's a 1.82.

CHAIR CORRADINI: Okay, so you're using MELCOR 1.82 modified by Idaho? Or I should say DOE is using --

MR. NOTAFRANCESCO: Right.

CHAIR CORRADINI: Okay.

MR. NOTAFRANCESCO: Our current model is 2.1. So --

CHAIR CORRADINI: And so the modifications or the tool that the NRC is using is not the Idaho MELCOR. It's the modified Sandia code.

MR. NOTAFRANCESCO: I'll get into --

CHAIR CORRADINI: Okay.

MR. NOTAFRANCESCO: -- because what happened is since it was an old MELCOR model, there were several tricks done to simulate things. And we think things could be done better.

CHAIR CORRADINI: Okay.

MR. NOTAFRANCESCO: For example, the second bullet is where we going to update the core package. And I'll get into a little detail on that.

CHAIR CORRADINI: Oh. Okay.

MR. NOTAFRANCESCO: Okay? And also incorporate the graphite oxidation models of steam and oxygen. So, again, those are the initial activities that have been pursued over the past year or so for both the pebble bed and the prismatic designs.

Now where we are today is these initial attempts, we've got the reports in house. We just received them. We're looking at them now. I'm trying to provide you some initial status of when I read it. They have to be peer reviewed and we'll have to get back with Sandia because we see some little problems we need to pursue.

But basically there were two models from the INEL modification that Sandia cited. And oxidation of graphite of heat structures and diffusion of the air and helium.

Right now we're not doing anything with that but it was identified. Nothing really useful. I think we may have -- they used the correlation that is in the literature for oxidation, for example, bu they applied it to heat structures, not to the core directly. But I'll get to that point.

The other thing is the helium properties in MELCOR. That was compared against NIST data and the ideal gas law modeling in MELCOR, trying to get the density of helium, showed reasonable results. So that was positive.

Just to expand the point on the updating of the MELCOR Corp. core package. Clearly from a light water reactor to what we see with these gas reactors, we needed to customize the core in the sense of geometry and materials pretty much, putting in graphite as a core model, and the reflectors and stuff like that. So we've customized something that could be nodalized specifically for that whereas the INEL work obviously we didn't have advantage of that.

This next slide, basically what I tried to do was to glean the important phenomena. And I put that on the left side based on the PIRT, provided the status of where we are and the approach that was taken. And you could tick off some of the progress that we're making in that area.

And, again, this phenomena was in that NUREG for the status and our approach.

CHAIR CORRADINI: The PIRT NUREG?

MR. NOTAFRANCESCO: The PIRT NUREG. So what I did is I took what was the initial activities we did, take the processes, and correlate our implementation.

MEMBER ABDEL-KHALIK: Which bed effective conductivity correlation or model has been added and tested. I mean that tells me that you're way ahead of where Steve was talking about.

MR. NOTAFRANCESCO: Well, we have a correlation in there and we have discussions about what type of correlation. So it's just a correlation of -- it needs to be -- when I say tested, it means that it is working in the code, not assessed against data, okay?

CHAIR CORRADINI: It functions.

MR. NOTAFRANCESCO: It functions.

MEMBER BLEY: The code generates stuff.

MR. NOTAFRANCESCO: I was careful. I said tested, not assessed.

MR. BAJOREK: Allan, this is Steve Bajork, one of the things that I think we want to do with MELCOR is you want to get it up and running and operating soon. That gives you a way of at least testing out the models.

I think what it is using right now is basically a debris bed porous media correlation. In comparison between that correlation and Zehner-Schl_nder, which is an effective thermal conductivity for packed beds, it's not too far off.

So at least at this point, it gives you a way of starting MELCOR. But I think those of us who have looked at the data would recommend that they put in something like a Zehner-Schl_nder or something similar to that --

MEMBER ABDEL-KHALIK: And it includes temperature effects because of radiation so it is highly nonlinear?

MR. BAJOREK: Which one? The German one?

The German one accounts for things like emissivity and porocity effects. The one in MELCOR, I believe it is only porocity. Oh, excuse me, that's right, it is only temperature. But the German one counts for several other parameters.

CHAIR CORRADINI: But to generalize what I think we're hearing is is that when you say this has been addressed, that is they made a model -- functional in MELCOR to be tuned to the appropriate data or basic information in the future. Is that a fair way of putting it? Okay.

MEMBER ABDEL-KHALIK: Yes. But I guess my concern is that in this case, if radiation is dominant, as you would say, then this correlation would be highly non-linear in terms of its dependence on temperature. And if you don't have the right temperature dependence, you might be testing the code and you may be getting conversions whereas if you have a higher order correlation, it may not.

MR. NOTAFRANCESCO: This has radiation in it, right. This modified Z-S has radiation, at least the one we chose.

MR. BAJOREK: Well, the one in MELCOR, I think it is in there. I think it is more of an empirical fit.

MR. NOTAFRANCESCO: Right. Conductivity is not the -- that came out of the PIRT but we are recognizing radiation as part of the process.

MR. BAJOREK: But I think you point is that we're getting MELCOR operating at this point. But, you know, selecting more appropriate correlations is still an open issue.

MR. NOTAFRANCESCO: Right. We want to put in the building blocks to build the plant at the end of the day, get it going, and then we'll go back and iterate. And then ultimately how we do a plant analysis.

So that was the early phase --

CHAIR CORRADINI: So can I torture you one last -- or ask one last question to follow Steve's? So here's where, I guess, I was going to ask -- here is a good place to ask when you use -- Steve used the term CFD to help guide, I assumed that somewhere in this you will do a CFD calculation to help guide what you might choose to do in this regard. Because then you would actually -- you can essentially put in geometries and various temperatures and see what the functional dependence would be.

MR. NOTAFRANCESCO: Yes.

CHAIR CORRADINI: That is a way to attack this, right? Not the right way necessarily. But a way.

MR. NOTAFRANCESCO: Well, again, we're

going to put the building blocks to make it work. We'll use CFD later for insights to see how good our models are. But as a minimum, we want to get a plant built.

CHAIR CORRADINI: Great. Fine.

MR. NOTAFRANCESCO: And get the building blocks in place. That's the theme which you will see here. And that's what we're doing -- is the initial phase and the phase we have now is to do the rest of the plant. And when I say plant, both the prismatic and the pebble bed.

Sandia is working with Texas A&M to set up the deck. These are some of the accident classes we're looking at. It's just we're taking a small subset for now just as a benchmark of reference. And obviously we'll conduct the assessments of relevant data when available.

Also where we are currently in the plans is to get Sandia PARFUME and TMAP4. They already have TMAP4. They are going to analyze it. And the bottom line with this and with MELCOR in general is we're going to take complex models and have it technically consistent within the MELCOR framework.

We don't want something too detailed and when the rest of the model is less detailed. So what we're going to take insights from other sources and embed it in MELCOR to get a calculation.

This was discussed before. The other thing that Texas A&M is to put some kind model for the reactor and cavity and cooling system. And these issues were discussed about the make up of the cooling.

Other issues we are going to go after is the plant components, heat exchangers, gas turbines. And this other issue about air ingress modeling, Sandia is pontificating now on how to model some sort counter-current flow.

CHAIR CORRADINI: That's a good word. I was going to say usually the noun in from of that is not that noun.

MR. NOTAFRANCESCO: Well, until I see results, I'll use words like that.

Other plant activities we're going to chase after is the fission product liftoff and resuspension modeling, identifying the areas of benchmarking experimental validation, that was touched on before.

These transients are going to be slow and long. So one of the issues we're also going to be pursing in MELCOR space is trying to look at different runtime optimizations, time steps, code parallelizations, and other schemes to make it run faster.

Again, what I've done here is just to summarize in PIRT format the phenomena I just discussed: the status and our plan of approach. And to be more organized in all the phenomena that is perking out there and demonstrate to you guys that were insistent with the PIRT.

In summary, we have made progress with MELCOR 2.1. And we're going to be consistent with the PIRT. And follow the assessment activities. And as mentioned before, we are going to have extensive coordination with the other programs to make sure we are a success.

So that ends my presentation.

CHAIR CORRADINI: Good. Questions?

Dr. Lee?

MR. LEE: Tom, you asked about the cesium form. Doing the PIRT we discussed about the cesium form. Basically in the reactor system itself, this will be a metallic form because it is a helium system. Once it gets out into confinement, it would be an oxide form.

CHAIR CORRADINI: And does that impact

what could be combustion and essentially would have been vaporized and be transported out of the particle?

MR. LEE: We can consider everything under MELCOR frameworks. It's not a problem as long as you have data to support it.

MR. KRESS: How is it that it was in metal form? Why doesn't it combine with the iodine?

MR. LEE: I think all of these things going to be considered to see what there is. Because the cesium also, how does it interacts with the graphite? That's a major questions that we have to answer. That's why we talked to the graphite research very closely.

Dana Powers mentioned about what he observed in the end reactors, how the graphites look like. There are some tunnelings appearing because of the behaviors. So we need to how we can account for all of these so we may do some detail modelings. And then try to take some simplified treatment under the Melcor framework.

MR. KRESS: Weren't there some resuspension tasks in the CSAR program?

MR. LEE: The resuspension, we are looking in the resuspension not just for gas reactor but for light water reactor, especially with the acoustic vibration type resuspension. And we are pursuing that with the PSI Porche Institute because they are doing some separate effects experiment.

So under the cooperative severe accident research framework, we are going to be discussing with them to do this resuspension experiment. So in the meantime, we can also ask them to put some carbon on those surfaces. And look at the in treatment and treatment. So it is the same thing. It's treatment as an aerosol. So we will be doing those.

CHAIR CORRADINI: Okay. Let's take a break if we might. Is that all right? Or do you want to move up the hydrogen analysis discussion?

Sud, do you want to make that call? Stu is pointing at you.

MR. BASU: I'm okay. Do you want to --

CHAIR CORRADINI: Well, I was going to suggest we take a break until 3:15 if that's all right.

MR. BASU: Yes, that's fine.

CHAIR CORRADINI: All right. Good. Let's take a break then.

(Whereupon, the foregoing matter went off the record at 2:56 p.m. and went back on the record at 3:17 p.m.)

CHAIR CORRADINI: Let's get started.

So Dr. Basu is the stand in for Mr. Hudson.

MR. BASU: Yes.

CHAIR CORRADINI: Sud?

MR. BASU: Thank you. I think somebody already designated two of us as odd couples because I'm sitting in for Nate Hudson and Jay will be sitting in for Valerie Barnes.

MR. KRESS: Well, they had another reason for calling you the odd couple.

(Laughter.)

MR. BASU: Yes, I'm sure. I'm sure.

(Laughter.)

CHAIR CORRADINI: And, you, too, George. Happy New Year.

MR. BASU: I'm wondering what happened to Professor Apostolakis? All right. Now we are in business.

Happy New Year, Jay. Happy New Year to you all.

Okay. So this is going to be a little short presentation. I'm not going to wade through the slides or go through all the slides.

Nate Hudson has a family emergency so he couldn't be here so I'm giving the presentation for him.

It's the research plan for hydrogen and process plant analysis. The title is a little bit misleading. We are actually not in the business of doing the hydrogen process plant analysis for that plant. We are in the business of doing hydrogen process plant analysis as to its impact on the reactor safety.

So that's what the focus of our research plan is about. The objective is very simple, to develop independent and confirmatory safety analysis tools to support the staff review of the safety implication of the hydrogen or any other process plant operations on the NGNP or the reactor safety.

And, of course, the tools and methods to be implemented should be accurate and adequate to perform the confirmatory safety analysis, not unduly conservative, but also for phenomena that are unknown, for processes that are unknown. And I'll come to those things, we'll work on those things that, you know, we like to assure ourselves that there are going to be safety margins in our analysis and in our predictive capability.

MEMBER ABDEL-KHALIK: What you are trying to do is essentially set the boundary conditions?

MR. BASU: Set the boundary conditions in a way. But as you go into it and analyze it -- as I go into it, you'll see that the boundary conditions themselves are not quite known at this point, okay.

MEMBER ABDEL-KHALIK: Is the word boundary conditions the right one?

MR. BASU: Well, the interface between the two.

MR. RUBIN: What are the hazards that it poses?

MR. BASU: Okay. So here is the cartoon that I'm going to spend time on, in fact the rest of my talk I'll just keep that in large part. You have the reactor plant here, the NGNP or the HTGR plant if you will.

And then you have the process plants. And here, of course, in this cartoon, there are two plants shown. For NGNP, if you recall, the focus is on hydrogen co-generation. And, again, to put things in perspective, the NGNP technology envelope definition, if you will, is that ten percent of the process goes to hydrogen generation.

So if you are talking about a 600 megawatt-thermal, roughly about 50 megawatt-thermal goes to hydrogen generation.

MEMBER APOSTOLAKIS: Is the second plant also producing hydrogen? Or it could be someplace else?

MR. BASU: Well, it could be any processing applications. Any application.

MEMBER APOSTOLAKIS: So what if you have some other hazardous materials there?

MR. BASU: Yes, you can. And that is going to be -- yes, exactly.

So, okay, so what are the issues? There are basically three categories. One is the -- during the operation of the process heat plant, if you will, the hydrogen co-generation being one of them bu then there are other applications, the operational characteristics of the plant will have some impact on the reactor plant in a couple of ways.

One is that the transient in the hydrogen plant, and I'll say hydrogen plant but it could be any of the processing plants, the transient in the hydrogen plant can actually impact the reactor operation or the mode that the reactor is going to see in terms of the mass balance and energy balance.

The upset conditions in the hydrogen plant can also impact the reactor plant. So what we did here is we kind of list a few things. Chemical release from a processing plant could effect the reactor safety in a number of ways. First of all through the mass and energy balance, as I mentioned. And then the effect of corrosive byproducts on materials, material performance. And then, of course, the effect of corrosive and toxic byproducts on the reactor operation in terms of the operator dose and operator exposure, et cetera.

The detonation was mentioned in the context of dust. We, of course, in a hydrogen plant which produces hydrogen, hydrogen detonation is an issue. Here, of course, we are thinking of the unconfined hydrogen explosion. And then, of course, if the byproduct is oxygen, as it may be from one particular hydrogen co-generation process that the high temperature -- that is high temperature electrolysis, the oxygen is a heavy ground-hugging gas.

And if it is generating in flammable concentrations, that could also have an impact on reactor safety.

The transport -- processing transport system, the transients -- and I mentioned that all the times in chemical plant that get reactor trip or component failures. And some of the components are the intermediate heat exchanger tube failures, the processing failure and piping factors, and so on and so forth.

The third category that has an impact and it is going on the other side is whatever is happening in the reactor plant is going to be -- the process plant and a particular issue here is the trace amount of tritium that is generated in the reactor plan which isn't transported through the intermediate loop to the process plan. And the possibility of that ending up in the consumer product, the ultimate consumer product.

So that is an area that we recognize and we need to be able to address that either in some form of administrative control, tech spec control, and so on and so forth.

So these are the three main categories of issues that are related to coupled, co-located processing to the high-temperature gas reactor.

If there are no questions on this, then I will -- yes?

CHAIR CORRADINI: There is a question.

MR. BASU: There is a question.

CHAIR CORRADINI: So I remember when you

first were discussing this in the context of license training, you and Stu were up, there was a distance beyond which it just becomes some industrial facility in the region thereof, all right, and within some distance it has to be considered both feed forward, which is essentially stuff that happens in the NGNP that can effect the hydrogen plant. And then the feed back, which is some sort of gaseous effluence or some sort of feed back of the process plant effecting the reactor.

Are you taking the -- are you trying to think independently of the DOE about these sort of initiators? Or are you waiting to see what your colleagues are thinking in this regard?

MR. BASU: I think you gave me the good segue to what I was doing.

CHAIR CORRADINI: Okay.

MEMBER APOSTOLAKIS: I have another question.

MR. BASU: So --

MEMBER APOSTOLAKIS: So when you say safety issues --

MR. BASU: Yes.

MEMBER APOSTOLAKIS: -- this list will help you develop your R&D program I suppose.

MR. BASU: Yes.

MEMBER APOSTOLAKIS: You want to understand those.

MR. BASU: Yes.

MEMBER APOSTOLAKIS: I'm wondering whether there are additional safety issues if you consider a major external event like an earthquake which may disable parts of both plants --

MR. BASU: Yes.

MEMBER APOSTOLAKIS: -- are there any safety issues that perhaps would be raised there and we have to understand?

MR. BASU: Okay. Let me see if I can answer your question. Earthquake, external flooding, external fire, those have already been incorporated into the traditional design and safety analysis of the reactor plant if the reactor plant was a standalone plant.

The issues that I brought up here are the issues that are unique to the couple and co-located plants, process plants to the reactor plant.

MEMBER APOSTOLAKIS: But it is unique to have a major earthquake effecting the reactor and a chemical plant.

MR. BASU: Absolutely. But that will be

taken care of in the complex external load from the earthquake to the reactor safety.

MEMBER RAY: What he is saying is have you thought about an earthquake at the reactor? Yes. How about an earthquake at the reactor combined with one of these --

MR. BASU: Earthquake damaging the hydrogen plant.

MEMBER APOSTOLAKIS: Well, most likely it will.

MR. BASU: It will.

MEMBER APOSTOLAKIS: If it damages the reactor, I assume.

MR. BASU: And that's through one of these three categories.

MEMBER APOSTOLAKIS: Well, I don't know about that.

MR. BASU: No? What am I missing?

MEMBER APOSTOLAKIS: I don't know.

(Laughter.)

MEMBER BLEY: Well, one thing you might be missing is you may have opened up air pathways into the plant that wouldn't normally be there if you'd look a the hydrogen plant in isolation.

MEMBER RAY: Yes, and our envelope for

toxic gases isn't seismically.

MEMBER APOSTOLAKIS: What I think --

MR. BASU: If I have an upset in the hydrogen plant, if I have an accident in the hydrogen plant, I open up that pathway anyway. Right?

MEMBER APOSTOLAKIS: I think it would behoove you --

MR. BASU: If there was the intermediary loop because of an accident --

MEMBER APOSTOLAKIS: All we're suggesting here, Sud, is it would be nice to have a little story.

MR. BASU: No, I --

MEMBER APOSTOLAKIS: Don't try to explain it now.

MR. RUBIN: Here is the rub. We're not going to license the hydrogen plant. We're not going to really regulate the plant. What oversight can we assure that the frequency of events is not caught -- what kind of --

MEMBER APOSTOLAKIS: No, that's not what I mean, Stu. That's not what I mean. I mean if I do a traditional seismic analysis for the nuclear reactor where you have a hell of a lot of authority, right, now I have to worry about the co-located facility suffering from the same earthquake and maybe releasing bad stuff or doing other things. Right?

And I'd like to understand what the possibilities are. That's all I'm saying. And whether there is a need for additional safety issues to be put there or to be investigated. That's all I'm saying because this is kind of unique here.

MR. BASU: No, your point is well taken. In terms of whether or not an earthquake or any other external load could cause damage to both plants and the possibility of that we need to look into.

Once that happens, phenomena-wise, it's not going to be -- at least in my mind, I haven't seen -- I'm not aware of anything that's going to be different from the phenomena that we have identified.

CHAIR CORRADINI: I think, though, you guys are in violent agreement. I think all George is asking you to do is to go away and at least make sure it is enveloped within what you are considering.

MEMBER APOSTOLAKIS: My agreement is grudging.

(Laughter.)

CHAIR CORRADINI: Good, George. I think as long as you determine its envelope.

MR. BASU: Okay.

MR. RUBIN: I think you can imagine the

failure modes and effects in the worst case for that plant. And we want to make sure we can accommodate that. Okay, we're not going to say you can't build it that way. But we want to make sure that the possibilities are enveloped in us looking at the hazards.

MEMBER APOSTOLAKIS: The people who will do the PRA will definitely have to worry about this.

MR. BASU: You are absolutely right. I agree with you --

MEMBER APOSTOLAKIS: Now the question is --

MR. BASU: -- quite strongly.

MEMBER APOSTOLAKIS: -- the question is whether they will have some issues, chronological issues or other issues that they would need answers to. And these answers should come from this program. That's all I'm saying. And if you say no, that's fine with me. But we'll wait and see what will be because that's really the phenomenological threat in my mind.

MR. BASU: Yes, if there are --

MEMBER APOSTOLAKIS: Seismic.

MR. BASU: -- we're in agreement, George.

MEMBER APOSTOLAKIS: Okay.

MR. BASU: If there are any new phenomenological issues that come up, we definitely are going to look into that. At this point, I've not. Okay, now how do we --

MEMBER ABDEL-KHALIK: In the second category of events that you are looking at, why is this any different than any other decreased heat removal event that may be caused by something within the plant itself?

MR. BASU: It is not in theory but now -- I mean you have already designed the coupled plant to deliver part of your process heat for the other operation. And now you have to find a heat sink if there is a load falling operation in the other plant or load rejection in the other plant you have to find.

So in that sense but in theory, transient-wise, it is not. I mean phenomena-wise, it's not.

I'm just trying to recognize that these are the issues that one has to look into.

MEMBER ABDEL-KHALIK: But I'm just wondering if you're spending a lot of time on something that --

MR. RUBIN: Here's something we're not privy to yet and this is why we have to talk to DOE, they are writing requirements for this plant for the various vendors. And one of the requirements that one could think of is a requirement to design a plant where events, transients that occur in the hydrogen or processing plant would be buffered in some way through dump systems, through control systems, so it would not perturb the reactor much at all, notwithstanding I do believe that those kinds of requirements are being looked at so that a plant -- this hydrogen production plant, which who knows what the reliability is going to be -- that they could be tripping off every day -- okay -- you don't want to have to deal with that in a full transient of that -- even though it won't be -- it will be ten percent, I believe.

MEMBER ABDEL-KHALIK: Right.

MR. RUBIN: I mean you want to not have that -- even that as an issue. And there are ways you can engineer away that kind -- there are 100 percent load reject systems available in nuclear plants.

MEMBER ABDEL-KHALIK: Right.

MR. RUBIN: And that's what we're talking about here.

MR. BASU: I think I'm going to answer your question, the second part of that in a minute or so because I'm going to go back to -- Mike was asking me now what. We have these phenomena identified, what do we do? Where do we go from here?

I'll tell you what is happening in the HTGR involving design work, which is evolving. In NGNP we define the technology envelope as ten percent processing going into hydrogen plant.

There is some kind of thinking going on in the industry to be able to utilize the processing for more than ten percent.

CHAIR CORRADINI: Say that again. I'm sorry. I didn't understand what you say.

MR. BASU: Industry is looking into the utilization of processes for more than ten percent. In other words, less than 90 percent for the nuclear electricity production. And more than ten percent for the licensing application. Okay? So that is a possibility. We don't know. We're not clear yet.

And it could be -- it could be as high as 80 percent processing --

CHAIR CORRADINI: Of a smaller plant.

MR. BASU: What?

CHAIR CORRADINI: Nothing.

MR. BASU: Now what happens, going back to your question, if it is at ten percent, it's kind of no, never mind what is happening in the processing plant. But if an 80 percent load is taken by the process plant, then any upset that is happening at he process plant and if it is a single process plant or any other transients, I think we need to --

MEMBER ABDEL-KHALIK: Why would that be any different than a turbine plant?

MEMBER BLEY: Terminally, I wouldn't. Besides, you've got a lot of graphite.

MEMBER ABDEL-KHALIK: I mean I'm raising the question because, you know, you want to devote your resources to things that actually are important.

MR. BASU: Right.

MEMBER ABDEL-KHALIK: And if this turns out to be irrelevant under any and all circumstances, then maybe you ought not spend a lot of time on this.

MEMBER BLEY: Except that the first one, the chemical release --

MEMBER ABDEL-KHALIK: Yes, I'm focusing only on the second part.

MEMBER BLEY: Yes.

MR. RUBIN: I think from a designers point of view, they're looking at trying to design the control system in ways to accept the full reject and not have the reactor trip. But from a sinking point of view, you are right. I think it is bounding in terms of the loss of load.

MEMBER APOSTOLAKIS: Is this the result of a PIRT?

MR. BASU: Yes.

MEMBER APOSTOLAKIS: Well, the PIRT was never wrong.

(Laughter.)

MEMBER APOSTOLAKIS: Okay.

CHAIR CORRADINI: This is a PIRT pride.

MR. BASU: It's a living PIRT.

MEMBER APOSTOLAKIS: It's a living PIRT?

MR. BASU: So we'll not -- we'll take into consideration your suggestion.

In terms of what we are doing or what we are planning to do -- and let me answer your question, in terms of the hydrogen explosion issue, we have a very large amount of database from LWR --

MEMBER ABDEL-KHALIK: That I agree is unique. And you need to look at.

MR. BASU: Well, we will look into it but I'm also saying that we will benefit from the database that we generated under the LWR program. We have a large amount of database on the chemical dispersion, the plume modeling, so on and so forth.

And then, again, we're going to reap the benefit of that database. This is in the context of light water reactor but it equally applies to this. And we're going to be looking to the applicability of this. So there may not be any new R&D coming in this regard.

In fact, we have RegGuide 1.78 that's on the control room habitability against the chemical and toxic release. A lot of that information then may be brought to bear.

The transients in chemical plant that ill lead to reactor -- potentially reactor trip, we will look into. So load facts has been brought up, earthquake, and others.

This point that I'm trying to make is that there is already a large amount of database on many of these phenomena that we generated under the LWR program. And we will look into those to inform ourselves.

And then if at that point we find that there are some data missing, some information missing and that the applicant or DOE are not going to generate, then we'll set up -- we'll let that then define our program coding.

So this is a work in progress. We're not doing anything at the moment. We have gathered all the necessary information that will inform us as to what needs to be done in the future. And we will sort of define our program and design our program.

So that's, in a nutshell, and you have the handout but I, you know, I think I basically mentioned everything that is in the handout.

CHAIR CORRADINI: Other questions?

(No response.)

CHAIR CORRADINI: Thank you.

MEMBER ABDEL-KHALIK: On the next slide --

MR. BASU: The next slide.

MEMBER ABDEL-KHALIK: -- you want to develop an evaluation model to predict response of a reactor to transients undertaking the hydrogen production plant and vice versa. Why the vice versa?

MR. BASU: Well, here it is. I already said that I did not intend to go through the slides. The slides were prepared by Nate Hudson. He had a perspective in mind. I really cannot -- you know, I cannot --

CHAIR CORRADINI: Reconstruct it?

MR. BASU: Yes, interpret what he may have in mind when he talked about vice versa. I don't think vice versa applies. But --

MEMBER ARMIJO: Well, that's the hydrogen plant's problem. They should evaluate what happens if they --

MEMBER APOSTOLAKIS: But it is our problem, too, though because --

MEMBER ARMIJO: No, I mean from their standpoint --

MEMBER APOSTOLAKIS: -- if something bad happens there --

MEMBER ARMIJO: -- no but from them coming back to the reactor is an issue but from them -- from the chemical plant's standpoint if the reactor shuts down, if they've got a problem, they should say that's a possibility and this is how we'll handle it.

MEMBER BLEY: Well, their reaction just stops. I mean --

MEMBER ARMIJO: Yes, well, it may not be so easy depending.

MEMBER APOSTOLAKIS: I remember that many, many years ago, the Midland plant was cancelled because the chemical owner refused to supply some information. Is that a correct recollection? Regarding what hazardous materials they would carry and so on?

MR. BASU: If I remember, vaguely something like that.

MEMBER APOSTOLAKIS: Something like that.

MR. BASU: Also there was this --

MEMBER APOSTOLAKIS: Have you guys -- is the situation not different? Do you expect that the operators and the owners of these facilities would be willing to cooperate with you and answer the questions you might have?

MR. BASU: Well, these facilities will be -- in the regulatory space will be controlled by agencies like EPA.

MEMBER APOSTOLAKIS: Well, I assume that --

MR. BASU: So we may have to -- we may have to initiate dialogue with the corresponding regulatory agency. I don't know whether we can go to the operator or owner of a chemical facility and demand some information and then expect that they will provide the information.

MEMBER APOSTOLAKIS: Well, who -- maybe it is not your problem but somebody should worry about it it seems to me. Are high level people worried about it?

MR. RUBIN: Well, we'll certainly communicate that. We need to know what are those hazards and make sure we have protection against those kinds of chemical hazards. And DOE is -- we'll look to them to provide that for us.

Other issues are what are the security requirements? Okay? And we don't have regulatory over those security arrangements. What will they be? They are what they are for chemical plants in the United States.

How good that is, I'm not privy o bu I suspect it is a little different than ours. And what are the implication?

CHAIR CORRADINI: Who is the regulatory agency that deals with --

MR. RUBIN: I think it is Homeland Security.

CHAIR CORRADINI: It's not -- okay -- I thought it was FEMA.

MEMBER APOSTOLAKIS: There is no CRC.

CHAIR CORRADINI: Okay.

MR. RUBIN: And that's another whole issue of security and the implications of that relationship.

CHAIR CORRADINI: Other questions for Sud?

(No response.)

CHAIR CORRADINI: Okay. Thank you.

MR. BASU: You're welcome.

CHAIR CORRADINI: Jay, are you up?

DR. PERSENSKY: I am up.

CHAIR CORRADINI: Okay.

DR. PERSENSKY: Good afternoon. It is always good to be the last person because it makes you want to get out of here faster and hurry up and not ask any questions. And besides that, you know, I'm going to start this off by asking for some sympathy. As Stu said, I'm here replacing Dr. Barnes or subbing for Dr. Barnes who messed up her knee skiing. So she can't be around.

And so they asked me to help out. And I actually postponed my trip to Hawaii for one day so I could do this. So let's have some sympathy here, George. What's this Jay, what are you doing here?

Okay, now that's over, let's move on. You're not going to get any sympathy from this group, I can tell.

I am -- one of the reasons George asked that question is because I am a re-employed annuit and I actually retired last January. But I'm back here through the end of March as a re-employed annuit to try and help out the staff with some knowledge transfer since I had been here for something like 30 years in the human factors area. And not too many of us have been here that long.

So anyway, the other thing I'd like to

start off with is I understand, you know, the focus has been on the NGNP but one of the things about human performance is that it really is a cross-cutting topic.

It's hard to focus on one particular design because so much of what we would be doing from the human factors standpoint would cross over any of the advanced reactor designs as well as some of the work that might be going on for new reactors and as we see PIRT plants upgrading or updating their control rooms.

So a lot of the work that we're going here does cross cut. And to be honest, we haven't done a lot that focuses directly on the NGNP. But hearing Sud's presentation, I think that there is some support here -- more support for some of the things I'll be talking about.

Now what do we plan to do here? And really a couple of things. One is that what we are seeing and what we have seen in the licensing of the new reactors is that there are a lot of new technologies even in the human factors area that are taking place and are being used for licensing purposes in terms of the human -- they're using human performance modeling.

They're using rapid prototype. So there are some things out there we haven't been able to -- we're trying to get a better handle on in terms of understanding how those tools might play into the kinds of evidence that we typically have looked at in the past.

The other is that we have to look at what are the new concepts of operation? I mean we've just talked a lot with Sud here about -- all right, well, you've got the nuclear plant over here. You've got the hydrogen plant over here. What kind of interactions are there? Are there any types of new transients? Is there something new that the operator is going to have to be doing?

Are there going to be new tools that he's going to -- issues that he is going to have to be addressing, different types of accident scenarios? And, again, thinking more broadly about all different types of advanced reactors.

We hear things from the PBMR people about one person operating several units by him or herself from his basement part-time. So there may be new concepts of operation that need to be considered. We expect that there will be.

And the current regulatory guidance we

have out there, though it is fairly consistent or fairly good for the new reactors, we're not sure that it is really going to be as good in all conditions for the advanced reactors. So we would be looking for changes.

Unfortunately I didn't get the new -- I did make a new slide where I combined some of these things so what you have in front of you really is -- I have a couple more slides that I pulled together here.

But, you know, what kinds of issues? Of course, the main one we are interested in is the potential for human error. Is there an increase? A decrease? How is it -- is it going to be different kinds of error?

This would also, of course, lead to some of the HRA work that is going on.

One of the big things that I look for from a human factors perspective is the lack of situation awareness, which is really a phenomena in the human factors area of basically knowing what is going on now, what has gone on in the past, and what you can expect in the future.

And as we've heard, I know from a lot of places that a seasoned operator can walk into a current control room, look around because he has all of his displays, he has all of his alarms, he has everything in front of him and can pretty well figure out what is going on at the plant when he walks into the plant, that he has a quick awareness of what is happening.

Whereas if you walk into a new type of control room and if you see the little picture down at the bottom there, what you have is a bunch of computer screens that may or may not be on the kind of information that you want at the time. And it is great because you can get all kinds of information.

But on the other hand, you get what is called the keyhole effect because you are only looking at one thing and you have to navigate through several screens to actually get to the information that you might want at the time.

MEMBER APOSTOLAKIS: Jay, coming back o your safety issues --

DR. PERSENSKY: Right.

MEMBER APOSTOLAKIS: -- where would you put -- or is it an issue that maybe two different groups of people will get to coordinate their efforts in an emergency.

DR. PERSENSKY: Well, actually one of the things, and you'll see it, in terms of the actual projects that we're talking about or topical areas is the concept of teamwork and communication. And one of those is, in fact, distributed decision-making. How you make decisions in that type of situation.

So, yes, that is the heart of it. Yes.

Another issue, and we hear this a lot from the industry, is the lack of adequate adequate staff out there, people that can actually operate these things with any kind of experience.

I saw Dave DeSonjas in the audience but I see he left. I mean right now we just put out -- last year, a rule -- a new fitness for duty rule. And part of that fitness for duty rule included fatigue requirements -- fatigue management requirements that we have before in terms of a requirement.

They have to apply those by I think October -- no, I forget the date now but sometime this -- I think it is October of this year. And we're already beginning to hear voices about not having sufficient staff to met what amounts to some reduced hours that would they would have to hire new people to actually fill in for that.

And, you know, I'm talking to operators, talking to plants. And they are concerned about with the new plants, taking people from existing plans. So there is still a need --- this is more of a sociological issue -- but a need to get out there and figure out how we could encourage the development of staff.

One of the licensing issues that has come up is the fact that we're now talking about depending on digital technology and computer technology as opposed o the analogue that is out there now. And the -- as we know, digital technology changes very rapidly. Buy a computer today, it's an antique tomorrow or the next day.

And our currently regulatory framework may not necessarily be able to adjust as rapidly. So those are some problems that we have been discussing. And also the training and development of NRC staff. As I said, I've been here for a long time. I'm leaving -- we have a few new people but without of a lot of experience and we're trying to bring them along but the rate both in terms of the research end and in the licensing end is not quite what we need.

MEMBER BLEY: Jay?

DR. PERSENSKY: Yes?

MEMBER BLEY: Before you leave that one --

DR. PERSENSKY: Yes?

MEMBER BLEY: -- you talked about the

reduction in situational awareness in some new design control rooms, have you seen the opposite effects anywhere? I've heard people talk about some of the new ones as -- operators talking about how much a better view they get of the plant.

DR. PERSENSKY: I think what we are seeing is with the large view -- the large overview display, that there may be -- a number of people have said that is better. But even with that, we don't have any guidance on how to evaluate those.

MEMBER BLEY: That's true, yes.

DR. PERSENSKY: So --

MEMBER BLEY: Is there any work in progress trying to figure out how to do that?

DR. PERSENSKY: Well, as you know, we participate in the Halden reactor project. And that is one of the things that we have encouraged them to put into their general program as a way of trying to assess that because they do have a facility to do that.

Anecdotally, I have heard that from actually some of the existing light water reactors where they have put something like that in as an adjunct so we didn't have to review it necessarily, the operators have been very happy with it and have learned to use it quickly. But they still have everything else at the same time. So there is a difference between having it and not having it at all. So --

MEMBER BLEY: Is it -- let me sneak in a question for you. I didn't see it. I skimmed through your slides. Is there a timetable for when you folks think you'll be coming together with some of the guidance on how you might review these things and understand what they need to be effective?

DR. PERSENSKY: Not really. I mean we're trying to develop a more precise plan for human factors. And we used to have a human factors research plan but that went by the wayside some years ago.

So there's now a push to begin to develop that again. And part of that would be, of course, having more schedule.

MEMBER BLEY: Right now you don't have a place in the advanced reactor plan?

DR. PERSENSKY: Yes, we're in there.

MR. RUBIN: But it is generic.

DR. PERSENSKY: It's very generic and it's kind of amorphous right now. But let me get to some of the other issues that might help because some of the things we are working on.

MEMBER APOSTOLAKIS: Is there a human factors branch now?

DR. PERSENSKY: There is a human factors and reliability branch in research. And I see Sean Peters is back there. He is the branch chief. And we're in the division of risk assessment.

MEMBER APOSTOLAKIS: And how many expert on human factors are in that group?

DR. PERSENSKY: We now have -- not counting me, in that branch, we have -- yes, you wouldn't consider me an expert anyway, I know that --

(Laughter.)

CHAIR CORRADINI: I'm glad you got that on.

(Laughter.)

MEMBER APOSTOLAKIS: I didn't say anything.

DR. PERSENSKY: We have four people on board -- five?

MR. PETERS: Yes, five. If you count Val.

DR. PERSENSKY: Oh, if you count Val, okay. Val -- she's not in the branch but as a senior level advisor, she's there. So there's five. One of them will be leaving for school under our development program. So she will be gone for a couple of years.

MEMBER APOSTOLAKIS: So the human reliability people are --

DR. PERSENSKY: The human reliability people, we have three of them now.

MEMBER APOSTOLAKIS: Okay.

DR. PERSENSKY: All right. In NRO, the new reactors, there's probably four plus Dave.

MEMBER APOSTOLAKIS: Okay.

DR. PERSENSKY: And NRR has I think four as well. So that is the total of human factors in the agency. We don't have anybody in NMSS or FSME at this point.

MEMBER APOSTOLAKIS: All right.

DR. PERSENSKY: Now what are we looking at here and you've probably seen something like this. We're going from the large, expansive control rooms to the more cockpit style where the crew interaction is much more defined with the analogue systems as opposed to going through some computer -- the physical versus virtual HSIs, parallel access, serial access, these are all the kinds of things that we see as differences.

So this is actually a modified control room. It has both digital and -- this is the Beznau. And this is a conceptual design from the PBMR.

Again, those are the kinds of things we're looking at, this major kind of change that is going to occur.

As far as developing our plan or the topics that are here, most of it actually comes from something called the human factor -- NUREG/CR-6947.

MEMBER BLEY: When was that done?

DR. PERSENSKY: That was published just about a month or two ago.

MEMBER BLEY: Okay.

DR. PERSENSKY: It was finally published. It was the results of a PIRT in human factors where we looked at a number of issues that had been collated from both looking at vendor documents, talking to vendors, talking to some of the users, looking at what is going on internationally as well as looking at what is going on in the digital world outside of the nuclear industry.

So we spent a lot of time with the petroleum industry, for instance. The other is the coal-fired industry or the fossil power industry. They've got a lot more digital systems already in place than we see in the nuclear industry.

MEMBER APOSTOLAKIS: Are our digital I&C experts involved in this work?

DR. PERSENSKY: We do coordinate quite

closely with Dan Santos, who is our digital I&C SL than we had in the past with Steve.

We've been also working on another thing that I'm going to bring up next. I just want to mention right now we have funded and under way a couple of projects, one on operations under degraded I&C conditions which is where you might have some faults in the I&C condition even to the extent of complete failure.

MEMBER APOSTOLAKIS: Do we understand those degraded conditions?

DR. PERSENSKY: What we used in this -- what we're using here is trying to use the work that the I&C people are doing to establish some categorization of those types of faults -- or whatever faults they come up with.

MEMBER APOSTOLAKIS: We have been asking the I&C people to identify failure modes of systems. So evidently they have been done.

DR. PERSENSKY: Yes, I think they are on tomorrow, aren't they?

MR. RUBIN: Yes.

MEMBER APOSTOLAKIS: Oh, they are?

MR. RUBIN: Yes, they are.

DR. PERSENSKY: So you can ask them some

more.

MEMBER BLEY: I didn't notice that.

MEMBER APOSTOLAKIS: Okay.

DR. PERSENSKY: That we got from both the PIRT and some other workshops that we have been involved with.

MEMBER BLEY: Is that work that is actually in progress? Or is it just slated --

DR. PERSENSKY: It is in progress right now. We've established a framework from the work that we've gotten from the I&C people in the Oak Ridge project that's going on. And we're now trying to fit more of the human factors aspects into it.

But I mentioned before the methods and tools are changing in terms of what human factors people can use, what designers are using to actually replace sometimes human factors people. Somehow we don't need that. We'll just use this model.

The other that we've got going on is looking at levels of automation, how levels of automation effect personnel. And, again, this gets into questions, particularly of situation awareness and workload.

One of the issues that, you know, somebody said some time ago when we started talking about advanced reactors, well, we don't need to worry about human factors anymore because everything is so slow, they don't have anything to do. And, you know, so don't worry about it.

And the concept of underload is also something that we've seen in other phenomena.

MEMBER APOSTOLAKIS: Can we get a copy of this NUREG, Maitri?

MS. BANERJEE: This NUREG/CR-6947?

MEMBER APOSTOLAKIS: Yes.

MS. BANERJEE: Okay.

MEMBER APOSTOLAKIS: Thank you.

DR. PERSENSKY: And to get back to -- somebody asked the question -- one of the things we're also working on in the human factors standpoint, and you've heard a couple of presentations from the steering committee on I&C for the new reactors, and where we have one of the task working groups on that and we've been working to develop guidance in the area of minimum inventory of the large controls and displays.

Operator manual action is credited in safety analysis and also computerized procedures, which we put out an interim staff guidance on all of these now but we are getting a lot of feedback on needs to improve, especially in the area of computerized procedures.

We do participate in the Halden reactor project. We just started a new three-year agreement with them. And one of the other issues and I think is that we work with the working group on human and organizational factors that is part of the NEA/CSNI Group. And they have just recently published a -- no, not yet published -- CSNI has approved a technical opinion paper that is not yet published. So I can't give you all the details on it.

But they have proposed in this technical opinion paper a set of research that should be done for advanced reactors as well. So we're looking at how we can merge these two things.

As far as what you would see in the plan that we published for the ARRP, the topics are these nine topics. I mentioned a couple of them before:

Concepts of operation, how you deal with concepts of operations, functions and tasks? What are the people going to be doing? How do you assess what they are doing, especially if you are dealing with numerous different areas?

The function allocation and automation? How do you balance automation with personnel review?

Another part of using the digital system is, in fact, they may be much more complex than the analogue systems because they could be almost like a black box in trying to know it. The other is the opacity of being able to understand what is behind some of the things. And that relates, of course, to training and procedures and other aspects of human factors.

Workload variations, I mentioned that, and transitions. And it gets to the question of staffing, you know, how many people do you need? What are the qualifications of those people?

Teamwork and communications, George asked about distributed decision-making. That's where this area would fit. There are a number of projects under each one of these overall topics.

Computer-based procedures, we see that as a fairly major issue. As I said, it is one of the ISGs that the industry has actually come back to us with a lot of questions on. And there are a lot of unanswered questions there.

We just had one of our new people look at -- do a little literature search and they came up with 30 different issues related to computerized procedures that we need to try to address in some way from the literature.

Alarm management has been a long-term issue to try to get away from the waterfall effect. And how does it really play out in a digital system? And, again, the human factors methods and tools.

Right now these are the projects for which we have funding in `09 or plan funding for `09 and `10. You'll see that one of these is the update of NUREGs 0711, and that is supposed to say 0700, which are the two primary documents that we use in the human factors -- that we and our regulator friends use in the human factors area.

One is the process -- the entire human factors engineering process. The other, which is 0700, is details on the HSI, the Human System Interface. And this gets into the colors and lengths of telephone cords. I'll bring it up before you do. You're wireless now. But a lot of the issues with regard to what does this thing really look at.

And we're also working with the standards committees as much as possible to try and get them to develop some of these standards that we can endorse. IEEE is working on a computerized procedure standard right now that they are trying to get out.

MEMBER APOSTOLAKIS: There seems to be a

lot of work going on, Jay. And I'm wondering does the staff seek ACRS advice on these things? Or they don't have to? Or what?

DR. PERSENSKY: No -- well, we have not -- because we have haven't had a plan, we have not had as many opportunities to interact with you. I think that that, again, is part of this overall planning process that the new management wants us to go through. I'm sure there will be more opportunities.

MEMBER APOSTOLAKIS: I mean these projects sound very interesting. So it would be interesting to have -- or useful maybe -- to get a supplement.

MEMBER BLEY: And, you know, that one you mentioned on operations under degraded I&C is one I think we would really be interested in hearing where you are headed.

MEMBER APOSTOLAKIS: That's also touching on our work with the I&C people with failure modes and so on. So who is the right person to talk to about this?

DR. PERSENSKY: That man right back there, Sean.

MEMBER APOSTOLAKIS: Okay.

DR. PERSENSKY: And in addition, EPRI has contacted us with regard to trying to do some collaborative work. We haven't defined what that is yet but there are some areas that they are interested in that we also have a common interest in.

Okay, now what are we going to do with all this when it is done? And part of it -- and this follows on from the TWG work, is making sure that the industry knows what they are getting themselves into. In a sense, what to expect. What do I need to do to get that license? And that is one of the ways we're trying to make it as transparent as possible.

What do we need to do to enhance safety or maintain safety and deal with any kind of regulatory action that is necessary? And really from a research perspective, what we do is we develop the technical basis for whatever tool we're using, whether it is a regulatory guide, and SRP change, or inspection guidance change. That's what our research is used for.

And that's what we, again, try and make sure that whenever we put out a new guide, that the basis for it is clear. So there's transparency there.

Sort of as an ending slide, I mentioned the CSNI work. What we are hoping to do is to actually -- and part of the reason for that CSNI-TOP -- and just, you know, for complete transparency, Dr.

Barnes and I played a role in writing that TOP, we hope to have more international cooperation, to be able to leverage some of the work because as George was kind of hinting at, I think, our staffing and if you really look at our budget, it is such that the more leveraging we can do, the better off we are.

Well, the Halden program is part of the EOCD so they are going to be taking advantages of that as well. And another topic that has come before -- I think has come before you as well -- is this issue of new research facilities. As I said right now, our primary research facility, in terms of having a full-scope simulator is Halden.

And the Commission has asked us in the past to look and see whether or not --

MEMBER APOSTOLAKIS: I thought we wrote a letter supporting that idea. This Committee wrote a letter two years ago.

DR. PERSENSKY: Supporting the -- and there's been a Commission paper that went out that we're doing a pilot test on that right now. But there's not much human factors involvement because one of the more expensive parts of that would be to develop a simulation research facility.

MEMBER APOSTOLAKIS: What is CSNI-TOP?

DR. PERSENSKY: Technical opinion paper. This is the one that I was mentioning that says they've developed this integrated research plan as well. And we want to integrate with them.

MEMBER APOSTOLAKIS: Who is our representative on this?

DR. PERSENSKY: Dr. Barnes.

And if you really want to know the future of control rooms, it's that guy sitting in his basement with a virtual control room and he can do it.

CHAIR CORRADINI: Is he NRC this guy?

(Laughter.)

DR. PERSENSKY: Actually he's at home. This is one of the Halden virtual settings.

And with that, if there are any questions, if not, you can go home.

(Laughter.)

MS. BANERJEE: That was sneaky.

CHAIR CORRADINI: Any questions for Jay?

MEMBER APOSTOLAKIS: Do we have a human factors subcommittee?

CHAIR CORRADINI: We'll discuss it at the retreat.

DR. PERSENSKY: According to the -- I looked that up, as a matter of fact.

MEMBER APOSTOLAKIS: Oh, okay.

DR. PERSENSKY: I noticed that there is no longer a human factors subcommittee. There used to be.

MEMBER SHACK: We trimmed it out.

CHAIR CORRADINI: Questions to Jay before we broaden the discussion?

(No response.)

CHAIR CORRADINI: Okay. Thank you very much.

DR. PERSENSKY: Thank you.

CHAIR CORRADINI: What I wanted to do was to see if the members and our consultant had any questions of anybody else during the day. And then I'd like to broaden -- just general comments from the folks for the day's events because we're going to have another full day tomorrow.

MEMBER APOSTOLAKIS: Are we writing a letter in February?

CHAIR CORRADINI: No, it turns out. But we are to write a letter. I was informed today that staff -- unnamed staff can't support a letter writing in February but -- so we will look -- take it upon ourselves to possibly March or April to write a letter on the research plan.

So I'm open to members' comments.

MEMBER APOSTOLAKIS: On what we've heard?

CHAIR CORRADINI: Well, if we have nothing about what we've heard, I want to broaden it because Harold and I talked briefly outside and I want to ask actually the staff since we've got them here about some policy issue -- questions that relate to the research plan.

MEMBER APOSTOLAKIS: Well, my only comment is that this issue of external events and like the research I think ought to be explored a little better.

CHAIR CORRADINI: So if I might --

MEMBER APOSTOLAKIS: Is that what you're asking for?

CHAIR CORRADINI: Well, before I even do that, Maitri reminded me that since this is an open meeting and I think we may have -- or we did at least at the beginning of the day, members of the public in attendance, if there was going to be any public comment.

(No response.)

CHAIR CORRADINI: The public has left the building.

So, George, I'm sorry.

MEMBER APOSTOLAKIS: Let me repeat. I

mean my only comment is that I'd like to see a better story on what safety issues may arise when you have a major external event, in particular an earthquake, that would effect both the reactor and the chemical facilities.

CHAIR CORRADINI: So some sort of common mode event that effects both.

MEMBER APOSTOLAKIS: Yes. And then explore what kinds of issues would arise. I mean you can't wait until PRA guys come in.

CHAIR CORRADINI: Other comments?

MEMBER RAY: Yes, I have -- do you want me to launch?

CHAIR CORRADINI: Well, before you launch where I think you are going to go, I want to see about presentations.

MEMBER ABDEL-KHALIK: I have a big picture question about how realistic is the timeline. When you talk about completing an evaluation model and verifying it so that you can actually use it by 2013 and an element of that is a possible set of NRC experiments, this is a dream world. How do you view the timeline?

CHAIR CORRADINI: I think he's addressing at the last staff member standing in front of the room

-- or sitting. Stu?

MR. RUBIN: Okay.

CHAIR CORRADINI: This is where you earn the big bucks. Please come to the front and help us with us.

MR. RUBIN: Okay. We're struggling with a number of issues. One is what is the timeline? What is the real COL application date? Is it still 2013? Or is going to start slipping as events between now and things that need to be decided in the future start to slip so we may have more time?

We don't know. That's one aspect.

Another aspect is our budgets, okay. We're operating under a continuing resolution. That causes us budgetary issues in terms of initiating work, okay.

Assuming it was the best case scenario, we had all the money, are we going to be able to get there? Right now I would say we don't -- we haven't identified something that is going to be a show-stopper. If you feel you just kind of vaguely think that it is just never going to come together in the time frame, you've got to help me out if you can point to what those specific issues are.

But right now --

CHAIR CORRADINI: Well, let me through one at you. Since I'm not allowed to use anything about TF, so I'll use fuel, the thing that concerns me most is is the fuel irradiations in ATR and how they are going to play out and if you are going to buy into -- staff that is -- is the staff going to buy into the protocol about compressing the irradiation time at the higher power.

And if that's not the case, what is going to have to be redone or what is going to have to be lengthened? And as soon as you start lengthen the fuel irradiations, I can't see you making the schedule that has been laid out to us by DOE and you guys are coordinating with that. So that's one that pops in my head.

MR. RUBIN: One thing you have to realize is if they cannot ultimately have their plant licensed because of those issues, then everything slips. And with that slippage, we have more time as well. Okay.

It's not like well we have to be done but they're going to have to stretch out. They're going to have to live with the date that we start out with.

In other words, we're all slipping in time. Okay. So there's that whole issue of schedule slippage due to any -- for any reason. If they are slipping, we're buying time at the same time.

But your technical issue of accelerated irradiation, we're going to have to look at that. For the fuel qualification program, I have not heard that that is part of the plan.

I know they are getting into that in some of the earlier tests but once you get into fuel qualification then the risks start to increase because you are actually pushing the fuel harder than you would otherwise. And if you start seeing particle failures, oops, we've really tripped over ourselves here by doing that.

CHAIR CORRADINI: So is a way of summarizing what you are saying to Said is that you are trying to -- you feel there is no show-stoppers that makes NRC the blockage to make the schedule if it is maintained? Is that a way of interpreting what I hear you saying?

MR. RUBIN: Well, in other words, we need this data for doing our modeling. But they need it, too. Okay. They need to provide the technical basis for their models. Okay. And if they can't deliver those in time, then they are slipping. Okay.

MEMBER ABDEL-KHALIK: But your job is to --

MR. RUBIN: It needs another application.

MEMBER ABDEL-KHALIK: -- do an independent assessment.

MR. RUBIN: But the data, we're looking for the data. We may not use the same models that they are going to incorporate but the basic data, if we feel that the tests were valid in terms of simulating the core in terms of burn up, in terms of power level, in terms of temperature, in terms of fluence, if we don't have any issues with that simulation for that qualification, the data is acceptable.

You go off and you model it how you want to. We'll go off and model it the way was want to.

MEMBER BLEY: I guess, though, where you first started -- let me just take it organizationally -- I haven't seen anything in the presentations that lays out a detailed project plan, how you get from where you are to the end, identifying all the key places where it could go awry.

And without that, I'd say categorically you don't have a chance to get there.

CHAIR CORRADINI: Just as a point of information --

MR. RUBIN: Let me respond to that.

CHAIR CORRADINI: -- yes you can -- but a point of information, you look at section five, there are dates on all of their bulleted points. So one could draw a PIRT chart or whatever the heck it is form that.

MR. RUBIN: It's more than a PIRT chart.

CHAIR CORRADINI: In each one of their points, they've got dates where certain things have to be complete.

MR. RUBIN: We need a project plan that has that kind of information.

MEMBER BLEY: Including the key places where things could go awry.

MR. RUBIN: Jennifer Ewell, our Division Director, has asked us for that. And we will get that together. You are absolutely correct.

MEMBER BLEY: Okay.

MR. RUBIN: We need to have a project schedule.

MR. KRESS: In the LWR work to develop the fission product release models, we had to fuel that had already been irradiated with fission products built up in it and we had to re-irradiate it to get some of the short lives back.

MR. RUBIN: Yes, and I pointed that out.

MR. KRESS: And then we would take those and stick them in a hot cell and heat them up and hold them at different temperatures corresponding to accident conditions. And then grab samples and correlate the rates at which fission products came out as a function of temperature and burnup and what else.

We could do about one or two tests a year with the small samples of fuel. Now I just can't -- you are going to have to have a lot of data on the fission product release from these particles and from the things. And I just can't see you getting that extent of data to make an empirical model which, by the way, I like, the empirical model, in that time frame. It's going to take a lot of data.

MR. RUBIN: We haven't challenged Dave Petty and his staff in terms of having the throughput capability to get all of that data we need. But we have heard that they want to buy additional furnaces for additional accident testing, heat-up testing, so they can run more irradiated fuel through those tests to get data faster. Okay.

MR. KRESS: Yes.

MR. RUBIN: But I don't know if there are any choke points where it's just not going to work out. But they recognize that.

MR. KRESS: Those are tough experiments to do.

MR. RUBIN: Sure. Sure. I think that would mean providing more equipment to PIE and to accident test that irradiated fuel for that very reason.

CHAIR CORRADINI: I held off Harold before because he is going to to take us --

MR. LEE: Mike, I think we did look at the -- the staff did look at INL, the fuel campaign that they are undertaking at ATR. And our concern is the same thing that Tom just mentioned. Is that how do I get the empirical data for the releases.

And I think we do have some comments that we have compiled but until the implementation agreement is in place, we can not convey them until then. So we kept those in mind.

The adequacy of that so-called fission -- studying the fission product releases, we looked at it already. So we will be discussing with them at the earliest possible chance.

MR. RUBIN: We believe that the licensing strategy for the NGNP also was looking at that very issue, the timeliness of data that you need to use in your models for licensing. And what is the strategy whereby you can take compensatory measures, okay, lower operating temperatures, restricting the burnups, things of that sort where you start to really lower particle failure rates, release rates, even perhaps adding filters to vent systems, really just -- I guess they are compensatory measures.

And just allowing the plant to operate at much lower power levels. Okay. So the amount of, you know, power being generated in the particles is much lower, for example.

So there are those thoughts that are coming to mind to meet the date. If we really absolutely must meet the date, there are things that you can do.

CHAIR CORRADINI: Harold, you had some questions.

MR. KRESS: Is the date somewhat arbitrary anyway?

MR. RUBIN: Yes, it is.

PARTICIPANT: It is written into law.

CHAIR CORRADINI: We've been known to break the law.

MEMBER RAY: On Christmas Eve, Maitri gave us a very comprehensive memo on this in advance of this meeting. And I just want to refer to two points here and then ask the question of the members actually. I don't expect to address it to any of the staff members here.

But in talking about the NGNP licensing strategy report basis document and licensing report to the Congress, she indicated that the top four issues included number one, defense in depth measures --

MS. BANERJEE: Policy issues.

MEMBER RAY: What?

MS. BANERJEE: Policy issues.

MEMBER RAY: What did I call it? Oh, technical policy issues. What did I call it? I thought I'd read that.

MS. BANERJEE: Oh, I'm sorry.

MEMBER RAY: Yes. And -- well, I may not have so -- it's a policy issue, right. I think we all agree on that.

But then it indicated further on in the memorandum that the third proposed milestone on developing regulatory guidance for implementation of Commission policy statement on defense in depth for advanced reactors may be on hold as the staff plans to recommend the Commission doesn't work on the policy statement -- be put on hold.

And then elsewhere either here or

someplace else -- at least I gathered the rationale for that was related for the need to see a comprehensive PRA for such reactors before making judgement about the policy statement. And we had some exchanges in e-mail among the members back and forth that I won't go into.

In any event, the question is at this subcommittee meeting, do we intend to have any discussion among the members or with staff on this question? I'll direct it to the Chairman but you'll direct it back to anybody else.

CHAIR CORRADINI: Well, let me add something -- fuel to the fire. I guess in the e-mail traffic we had to each other, it was my impression that we kind of broke up into two quasi-camps on this. I don't even know what they called the camps.

But from my perspective, I want to -- I kind of want to make the staff say something about this or at least understand how you are thinking because I am struggling. There were four policy issues.

Harold mentioned one but it kind of comes down to containment, performance -- the building performance criteria, the containment performance criteria, or the containment system performance criteria for this machine -- and how it may differ depending upon the licensing basis events that you are considering, what is in the design base, what is outside the design base.

And given that this defense in depth policy statement has been put on hold or is being delayed a bit, where does this leave you relative to your policy questions that you have for the NGNP? That's what I'm kind of struggling with myself because to me, the containment performance criteria -- the containment system performance criteria is quite important in this sort of design.

So not just the staff -- I guess the other -- I'm sorry, not just the members but I'm very curious what the staff thinks about this because we're going to have to wrestle with this as we go forward.

MR. RUBIN: Well, I don't want to speak for Mary Drouin who is going to be here tomorrow --

CHAIR CORRADINI: Oh, you are going to put it on Mary?

MR. RUBIN: Well, I mean her piece in this is the risk informed infrastructure. And a big piece of that is the defense in depth requirements. How do you construct defense in depth in a risk-informed environment.

And she has been spearheading the work we have done so far in developing a draft, if you will, of a defense in depth policy paper. And she's fully aware of the reasons why these decisions are being made.

So she's more on top of it. So tomorrow is the time to ask that question.

CHAIR CORRADINI: Okay. So then I'll turn to the members. So I'll throw out just one point to kind of feed this for Harold. And then Maitri.

I guess my feeling is is that if you don't have a containment system with this reactor, you are betting too much on the design, whatever the point design might end up to be. And so I looked back. There was some staff documents about what is going on in Fort St. Vrain and apparently with the PCRV and the BISO, TRISO whatever fuel it was, there was a confinement structure with certain requirements.

To me that is at least a minimum that has to be here. And regardless of what the policy is on defense in depth, particularly because you'd have a lot of passive systems that you'd yet to prove will actually function over the multi days.

MR. RUBIN: Well, the paper that Mary was preparing had in it as a very important piece the policy position on containment requirements for advance reactors. And that statement was very much parallel with what appeared in the technology-neutral framework under defense in depth. Okay.

And so that was the direction we were going in. Okay. And I think what you are dealing with there is postulated challenge events to the core to be defined and then go through an analysis of the fission product releases and to ensure that the containment can provide defense in depth for that challenge event. Okay. And that was the idea.

That might be beyond what you might -- well, you would be beyond what you would get from a PRA. Okay. And we'd all have to agree -- maybe it is five steam generator tubes failing or maybe it is that and a valve opening up. Or maybe the RCC doesn't work for two days, okay, you can find a lot of challenging events and we'd have to decide what that would be.

That was the concept in the technology-neutral framework. The challenge to core, in this case, particle failures heating up, caps failing due to a chemical attack or what have you, and making sure that your containment was okay for that.

And we'd all be happy with that containment if that kind of event were to occur. And that would be an engineering judgment.

MEMBER RAY: And is that the way a policy gets set?

MR. RUBIN: For defense in depth, it's a deterministic judgment.

MEMBER RAY: Well, I'm asking about the idea that there is this mandate to address a policy matter but we're going to put it on hold until something happens. It sounds like Mary will turn a crank and we'll get a lot of information --

MR. RUBIN: Well, she could talk to you privately as to the reasons behind that. But if you go back to the original paper of I think SECY-03-0059, it talked about the options for developing defense in depth for PBMR at that time and non-LWRs.

And one option was case by case. Okay. We can take each plant on its own and make a decision on that one case and we'll decide. We may not have a generic concept or policy at the end of the day but we have figured it out. So --

MEMBER RAY: Well, okay, then that is the policy then.

MR. RUBIN: We may have stepped away from the generic policy paper. But so there are other options.

MEMBER APOSTOLAKIS: A clarification question -- what is it that has been postponed?

MR. KRESS: The submittal of a policy --

CHAIR CORRADINI: The presentation we got last meeting where Mary made the presentation about their developing a policy paper on defense in depth, that activity is being postponed.

MEMBER APOSTOLAKIS: Postponed until when?

CHAIR CORRADINI: Maitri, I'll leave it to you.

MS. BANERJEE: Well, yes, what is happening is staff is writing a SECY paper to the Commission, expected towards the end of February where they are going to identify why it is premature to start working on a policy paper on defense and depth and how to go forward from here.

CHAIR CORRADINI: Oh, I see.

MS. BANERJEE: So we are going to get a copy of the draft SECY paper and hopefully then we can decide whether we want to take it up and want to talk to the staff, have another presentation or not.

MEMBER APOSTOLAKIS: Well, so this SECY will argue why they are postponing it.

MS. BANERJEE: Yes.

MEMBER APOSTOLAKIS: But it doesn't answer to the question until when.

MS. BANERJEE: I think they are also going to say, you know, tie up their schedule of developing this policy paper with some additional work that is going on in the risk-informed performance-based area with, you know, HTGR and all this work. And say this is -- you know, until a certain time. So I expect to see a logical --

MEMBER APOSTOLAKIS: Now a previous Commission told us explicitly not to get involved in policy issues. Is that still valid? Otherwise we can't get involved here at all.

MS. BANERJEE: No, my impression is these are areas that ACRS would like to get involved in. I'm not sure.

MEMBER APOSTOLAKIS: That was an explicit order.

MEMBER SHACK: Well, I think his is a technical policy issue.

(Laughter.)

MR. KRESS: Since when do you take orders?

MEMBER APOSTOLAKIS: It was policy. Come on. Unless we have a different Commission now.

MEMBER SHACK: We've certainly be involved in technical policy issues and that's been a long mission.

MR. KRESS: But containment is a technical matter.

MR. RUBIN: There have been many meetings on the technology-neutral framework. And all of that is fraught with policy issues. So we've been involved in it.

MEMBER RAY: I don't know how you stay out of it honestly on this level.

MEMBER BLEY: Well, you raised it in the context of that last meeting. My impression at the last meeting was staff was well on its way to organizing a process that would lead to a SECY that would put forward a policy decision.

CHAIR CORRADINI: Right.

MEMBER BLEY: And it seemed like they were, you know, on track. There was more to be done.

I don't quite get it but I guess I'd have to see the arguments they are making now about why it should be postponed. It seems -- it would be extremely useful, as the rest of this process goes forward, to have that defined.

CHAIR CORRADINI: Well, I mean -- I guess it is a cart before the horse sort of thing but it seems to me without that, to ad hoc develop something, the staff for the NGNP project.

MR. RUBIN: We will make regulatory decisions.

MEMBER APOSTOLAKIS: I don't see what the big deal is. All the review stuff, we do. What is the big deal?

MEMBER RAY: All right. Then the big deal -- since I started this -- would be you are going to make policy after you--

MEMBER APOSTOLAKIS: Do it.

MEMBER RAY: -- after you applied policy. In other words, you are applying policy but you don't know what it is. We'll figure it out after you've done it, I guess.

MEMBER APOSTOLAKIS: There are some real safety issues I submit. It really doesn't make a difference because we will review here whatever these guys are doing. And, you know, pass judgment.

Now what you are saying, Harold, is that sounds very odd that we establish policy after we have implemented something. I agree.

But in terms of real safety issue, I frankly don't see a difference.

MEMBER SHACK: I mean there was an SRM, too, that sort of said exercise the technology-neutral framework --

MEMBER APOSTOLAKIS: Yes.

MEMBER SHACK: -- including some of this defense in depth concept on a reactor concept just to see how it all worked out. And you can sort of argue that, you know, that's what we're going here is we're sort of going through that process to see how it really applies to a real case.

MEMBER APOSTOLAKIS: And the Commission may very reasonably wait until the results of this.

MEMBER SHACK: Well, I'm not sure, you know, that could be part of the argument for holding off is to just actually go through a more concrete case than trying to decide policy in the abstract.

MEMBER BLEY: This will no doubt arise again tomorrow in Mary's talk.

MR. RUBIN: I will advise Mary that she need to be ready.

(Laughter.)

MR. RUBIN: As I understand it, go from the letter that you signed April 30th -- if I read it anyway -- Mary will be talking about a partially risk-informed approach as the option that we are trying to implement here.

CHAIR CORRADINI: Correct. Out of four

options --

MR. RUBIN: I think we dropped partial. It is risk informed.

MEMBER RAY: I see. All right. Because option two was partially, option three was fully. And I was going to say --

CHAIR CORRADINI: We've managed to kind of -- we've landed in between the two I think.

MEMBER APOSTOLAKIS: What's the difference between a partial risk-informed and a full risk-informed?

CHAIR CORRADINI: It's like being a little pregnant.

MEMBER RAY: You know, George, we actually get into some debates, as we did in the e-mail over this very issue because to me the real question is between risk informed versus risk based which we never confuse that.

MEMBER APOSTOLAKIS: All right. That has been settled.

MEMBER RAY: That's correct.

MEMBER APOSTOLAKIS: It's not risk based. We know that.

MEMBER RAY: All right. Swell. Then I was simply going to ask what's the difference between partially and fully risk informed.

MEMBER APOSTOLAKIS: And I'm saying none.

MEMBER RAY: Good.

CHAIR CORRADINI: That settles that.

Boy, you are in a very certain mood these days. But let me just push -- let me just push the point because I think -- I thought I saw where Harold was going with this but let me tell you what worries me. What concerns me about at least this reactor, this design -- or not concerns me -- what I concern myself about in this design is not the long time behavior, which we seem to focus on but the short-time behavior of what is the limiting accident that is going to essentially cause a pressurization? And then how you handle that initial pressurization.

Because unless that is thought through, you can literally have opened the confinement building or the building, the system, and then any further failure down the line, you essentially have now a bypass. You have no --

MEMBER APOSTOLAKIS: And you think that the policy statement on this --

CHAIR CORRADINI: No, no, no. No, that isn't my point.

MEMBER RAY: Yes, just tell me what the

answer is and that's okay, we'll move on.

MEMBER APOSTOLAKIS: Between what?

MEMBER RAY: About whether -- you are basically saying it is not important or it is not timely or whatever to address this issue. Okay.

But, you know, I'm still hung up over the fact that I've watched us get to a place on another technical subject, and I won't mention what it is at this moment but you all know what I'm talking about, in which steps were taken, steps, steps, steps, every time looking back to the step before.

And then finally you get way down here where you are doing something that you think might be a bad idea but after all, you had all these precedents going back over time, each one just a little bit further down the road.

CHAIR CORRADINI: He's worried about a slippery slope is what I think he's saying.

MEMBER RAY: Okay. Fine. But if we can't have a policy on defense in depth now, okay.

But I think we ought to be aware that, you know, normally speaking people would think the Commission does have a policy on defense in depth. I think that is what they think on the 18th floor anyway.

And if we don't have one because we can't figure it out, that's as good as answer as any, I suppose.

CHAIR CORRADINI: I'm going to step back. You guys are having too much fun.

George, you're up.

MEMBER APOSTOLAKIS: I think we all feel better if we think of this exercise without the existence of a policy statement, like Bill said. As a first test of the technology-neural framework and the ideas behind defense in depth, we will have a lot of opportunities to influence that.

And then that may be will go to the Commission when they formulate their policy statement. And I'm pretty happy with that.

MEMBER RAY: Well, as I told you, we recently had an example here in another realm where statistical inferences were drawn about economic behavior which turned out to be dead wrong. More than once.

And I'm just concerned that we will all talk ourselves into the same mindset the way those geniuses did. So that is why I'm raising this issue here.

MEMBER APOSTOLAKIS: I would have to

understand better what you mean so maybe this is not the right place.

CHAIR CORRADINI: Invite him to dinner and you will.

MEMBER BLEY: I think something George just said resonates a bit with me. The idea that there's a de facto policy through the technology-neutral framework that can get its test here. And having a test before you actually anchor it in concrete isn't a bad idea.

And if it moves forward along the lines we heard the last time with that as something of a de facto way to do that, I think that is very good.

CHAIR CORRADINI: So if we went -- if Mary were here now I could ask her and she would say there's -- just if I might just push the point a bit -- if we were to ask at what level do I have fuel integrity, fuel rod or fuel pellet integrity that I can remove a barrier, the staff has an example of where that would be? Because I don't think I see it in 1860. It doesn't exist. And that's what I guess I'm getting it.

MEMBER APOSTOLAKIS: This committee will look at this issue on its own merits. Not because somebody said there is a policy to have an extra barrier. We are an independent group. So I don't know why you worry about it.

You think there is going to be a committee letter that says we really think there ought to be a barrier but there is a policy.

CHAIR CORRADINI: There's no policy.

MEMBER APOSTOLAKIS: It will be totally different added comments because somebody will write them.

(Laughter.)

MEMBER APOSTOLAKIS: I really don't see any issue. And I would have to understand better where Harold is coming from in order to feel comfortable if I understand where he is coming from. But everything else that has been discussed in my mind is a non-issue. Definitive.

MEMBER RAY: Well, George, precedent, I think, weighs more heavily here than you would suggest. In other words, as Dennis said, well, this is a test. We'll try it out and see how it works, implying that well, maybe we'll change our mind the next time.

But that's not the way it works. You make this decision, you've made it not only in this application but every one like it from now on.

MEMBER BLEY: I've seen it in some other areas.

MEMBER RAY: You're darn right.

MEMBER APOSTOLAKIS: But what has been tested here is, in fact, the whole DNF -- not just the defense in depth part, the whole technology-neutral framework. If you guys decide to use it, it would be the first time that somebody is trying seriously at least in a federal agency -- there are other places where it has already been tried.

CHAIR CORRADINI: Stu, you had a --

MR. RUBIN: Well, it was a management decision. It just didn't come out of thin air.

And one of the issues is the policy issue, as it was being crafted, was technology-neutral, okay, and you try to be all things to all technologies.

And when you do it at that level, it becomes difficult to kind of understand how it applies to specific technologies. And there are some technologies where the fuel is dissolved in the coolant. There is no particle, okay.

Now what is my defense in depth? Exactly, and so you start having different kinds of concepts. Is this universal statement, how does this really work for me?

So does it make sense to go forward with a technology-neutral statement or maybe we need to be technology specific. And that's maybe more tractable in this case.

And so I think that's the path we're going down is a more technology-specific case.

MEMBER APOSTOLAKIS: And that, in fact, if you are very careful with that formulation may take care of some Harold's concerns because then a decision here will not bear a precedent for other decisions. But we'll see. We'll see. I mean I'm willing to listen.

CHAIR CORRADINI: You are really?

MS. BANERJEE: Maitri again. What the Commission SRM said --

MEMBER APOSTOLAKIS: What did you say?

MS. BANERJEE: The Commission -- I said my name Maitri Banerjee -- I have to say my name.

MEMBER APOSTOLAKIS: Okay. I'm sorry. I heard something else.

MS. BANERJEE: What staff -- what I understood from attending this meeting is the staff is saying the Commission paper wanted the staff to consider the licensing -- the option development of licensing option paper -- a position paper for NGNP.

And then use the experience from the PBMR reactor pre-application review. And they are saying from development of licensing paper, it's not -- they haven't gotten much experience and PBMR work is on hold. So they need to do more work to come up with, you know, some ideas on that.

MEMBER RAY: That's where I read that the context of this was more PBMR work.

MS. BANERJEE: And in terms of option two or option three that, George, I think you asked, staff is still working on -- they are still struggling with it. And they are having meetings with INL and DOE on how to develop DBAs and beyond-DBAs from DBA --

MEMBER APOSTOLAKIS: They are -- not the DBAs.

MS. BANERJEE: LBEs -- LBEs comes from PRAs.

CHAIR CORRADINI: They're trying to decide where to draw the line once they get all their LBEs on a piece of paper, I think, is what she just said.

MS. BANERJEE: Right. And then, you know how do you --

CHAIR CORRADINI: Where do you draw the line? What is design basis? And what is beyond design basis?

MS. BANERJEE: So you have your LBEs from PRAs and then you are going to draw out your DBAs and beyond-DBAs and all those things -- design-basis events. And how to use option two versus option three. And the clear definition is -- what I saw that day -- was alluding a lot of people.

CHAIR CORRADINI: George, I think that as we understood it --

MEMBER APOSTOLAKIS: There is a concept of design basis in the TNF.

CHAIR CORRADINI: Well, there isn't. But there is in the licensing strategy for this machine. So to the extent --

MEMBER APOSTOLAKIS: So --

CHAIR CORRADINI: No, I guess my interpretation -- my understanding of the memo and what all that we've heard is when we had the discussions about NGNP is is that we will -- from the lessons learned of NGNP, we will take the TNF further.

But for the NGNP, there will be things that are in the design base and there will things that are out of the design base.

MEMBER APOSTOLAKIS: It will be a hybrid.

CHAIR CORRADINI: Yes, that's why it is 2-3 versus 4 or whatever.

MEMBER APOSTOLAKIS: By the way, when you say option two and three, these are not the ten years ago option two and three.

MS. BANERJEE: No these are the option two and three in the licensing strategy bulletin.

MEMBER APOSTOLAKIS: There is a strong record forgetting about options in this agency. So don't worry about it.

(Laughter.)

MR. RUBIN: Well, the basic difference between option two and option three in the selection of events is the concept of a deterministically selected bounding events. Okay.

MEMBER APOSTOLAKIS: For this reactor.

MR. RUBIN: For this reactor. For this license.

MEMBER APOSTOLAKIS: Supplement by the licensing basis events.

MR. RUBIN: Yes, from the PRA.

MEMBER APOSTOLAKIS: I've always wondered --

MR. RUBIN: And so you can continue with that as your licensing policy forever --

MEMBER APOSTOLAKIS: Oh, I hope not.

MR. RUBIN: -- or you can, as confidence

builds with the PRA, experience and the like, to relax that.

MEMBER APOSTOLAKIS: Again, we're getting into discussions here that require Mary.

MR. RUBIN: Yes.

MEMBER APOSTOLAKIS: But I've always wondered in the TNF what exactly -- how would the LBEs be scrutinized by the agency? It was never clear to me how that would happen.

MEMBER BLEY: Well, they didn't get that far to define it.

MEMBER APOSTOLAKIS: So it's not there.

MEMBER BLEY: But the idea was they would be scrutinized at the level of the DBA.

MEMBER APOSTOLAKIS: Okay. All right. That's my understanding.

MEMBER BLEY: That kind of detailed analysis --

MEMBER APOSTOLAKIS: That's what --

MEMBER BLEY: -- LBEs which were a limited set.

MEMBER APOSTOLAKIS: That's right. That's where the practical issues came up. But there is -- the TNF --

MEMBER SHACK: It was clear it was part of them. And as you said, the real question is do you pick those licensing basis events based on strictly the PRA? Or well, you know, we argued when we wanted the two and a half was to yes, okay, pick some deterministic ones but look at the PRA and see if there were additional licensing basis events that really ought to be -- you know, we didn't want the old LWR case where we picked out design basis events and found out we left out important things.

MR. RUBIN: No, we're not doing that.

MEMBER SHACK: That really was what we were trying to avoid here. And that is our risk-informed option two and a half.

MEMBER APOSTOLAKIS: That's correct. But there is also, because the staff is very clever, there is a long discussion on the LBE. Then at the end, it says and the staff is free to pick any sequence they like and declare it a design basis or an LBE. I like that. I love it. I really love it.

(Laughter.)

MEMBER APOSTOLAKIS: But let's wait until tomorrow.

CHAIR CORRADINI: Okay. Other comments? Questions?

MEMBER ARMIJO: I have a comment on the --

first of all, I thought the research plan was very well written and very comprehensive. But as I read through it I just kept -- you know, the cash register kept turning around.

(Laughter.)

MR. KRESS: It is an enormous set. You know unless a lot of that stuff is already available, it's going to take an enormous amount of time as well as money. And part of the -- so I don't think there is a chance that you will ever meet those dates. And that goes for DOE.

Because first of all, the design hasn't been selected. You don't know whether it is going to be prismatic or pebble. You don't know whether it is going to be a gas turbine or a steam generator.

There's -- fuel development takes a lot of time. And you're still what I would call like scoping irradiations on the fuel. And you are resurrecting a technology that was pretty well established when ABR was operating. But it is all being resurrected -- the graphite, all this stuff.

So I think the staff could push back to DOE and say you guys have got to make up your mind on what reactor you are going to build, what fuel you are going to make --

CHAIR CORRADINI: And the size of the machine.

MEMBER ARMIJO: -- and the size of the machine and back off on your 950 until we have some experience that we know that this fuel will work. Or else you'd better start developing some better fuel if you are insisting on the 950.

Because that's an enormous, enormous amount of work that is in that plan. I thought it was a good plan. But I don't think there is money behind it. I don't think there's even time even if you got all the money you wanted.

So that's my comment.

MEMBER SHACK: I would say, you know, the customer is always free to choose what he wants as long as the staff could say you have to give me enough evidence to convince me it will work.

CHAIR CORRADINI: Right.

MEMBER SHACK: And the longer he waits, the less -- to me, that's the customer's choice. If he wants to go for 750 or 950, that's his business. As long as the staff is willing to dig in and say if you want to go 950, I need all of the data that you want -- that I need to make that safety decision.

MR. RUBIN: It's a bargain we have on this strategy.

MEMBER APOSTOLAKIS: The staff cannot ask DOE to do anything. I mean no. Besides asking for data.

MEMBER ARMIJO: This is unusual. This isn't the licensee coming to the staff. This is a little bit co-development, government co-development.

MEMBER BLEY: Under law.

MEMBER ARMIJO: Under law, okay.

MEMBER BLEY: Yes.

MEMBER ARMIJO: And so the staff could simply say hey look, for 950, we're going to need a hell of a lot of data. And you want us to be ready by this time, this date, to license this machine, you know, time is running out. You have to make some decisions.

CHAIR CORRADINI: But it's my -- I don't disagree with your comments. I actually think they are very good. But it is my impression DOE is having those internal discussions now and has had them for the last couple years.

MEMBER ARMIJO: You could tell they hey, your licensing on this schedule is at risk.

CHAIR CORRADINI: No, it wasn't a slip of the tongue because they have been mulling over this for a while. Harold and I are quite aware of that for longer than a couple of years. My only worry is I'm not exactly sure if the staff has any dog in this fight. They can observe that they can't meet schedule. And that's about the only way into this discussion.

MEMBER APOSTOLAKIS: I think Stu made it very clear earlier. He said, you know --

MR. RUBIN: If they slip, we slip.

MEMBER APOSTOLAKIS: -- yes, if you slip --

MR. RUBIN: It's an agreement. You look to your part of the bargain of staying on schedule, we'll keep up with you. If they don't, the bargain is broken. But the question of temperature, the ENACT talked about a hydrogen plant. A hydrogen plant drives you to certain temperatures. The interest now may not be for hydrogen but may be for process heat that may not require those temperatures. Okay.

So there are some issues now. Can we lower them? And we're not sure if they are firm and final on that or they are still sticking with their hydrogen goals.

CHAIR CORRADINI: You can make hydrogen in any temperature. Electrolysis does very well --

electricity at ambien conditions.

MEMBER BLEY: I had one comment -- and Jay is gone -- that's too bad -- on the human performance presentation.

I'm disappointed that, you know, for many years the people in human performance have argued they really need to be involved up front as design and development go ahead. And I think so far we're missed a golden opportunity. While they are in the plan, it is more a catalogue of things -- what they know and what they don't know rather than a plan of how of how to move forward in the research to mesh up with the research plan. And I think they really need to get on the ball and lay out a plan for how the human performance work is going to integrate with the rest of the development.

CHAIR CORRADINI: Okay. Thank you.

MEMBER APOSTOLAKIS: Everyone can also make comments tomorrow, right?

CHAIR CORRADINI: Correct. I'm just trying to, you know, save us -- so that when it is fresh in your mind, I get I down.

MEMBER SHACK: Well, I would, just as a comment, I would support Steve's contention that, you know, you should not build this thing without an integral test for the thermal fluids part.

MR. KRESS: I second that motion.

CHAIR CORRADINI: Yes, but the integral test -- if we're going to get into that, the integral test, before you start picking it, it is going to be a very difficult integral test given --

MR. KRESS: It will be the most difficult one they have done.

CHAIR CORRADINI: Yes. All right. And I guess I think we have to see the scaling analysis of it before I'd buy into anything that I'd want to call integral.

MR. KRESS: That's right.

MEMBER ARMIJO: Bill didn't say bad integral test. He said integral test.

(Laughter.)

MEMBER APOSTOLAKIS: So you guys don't believe in simulation?

CHAIR CORRADINI: Anything else? So we will adjourn for the night. And pick up tomorrow at 8:30.

(Whereupon, the above-entitled meeting of the ACRS meeting was concluded at 4:58 p.m.)

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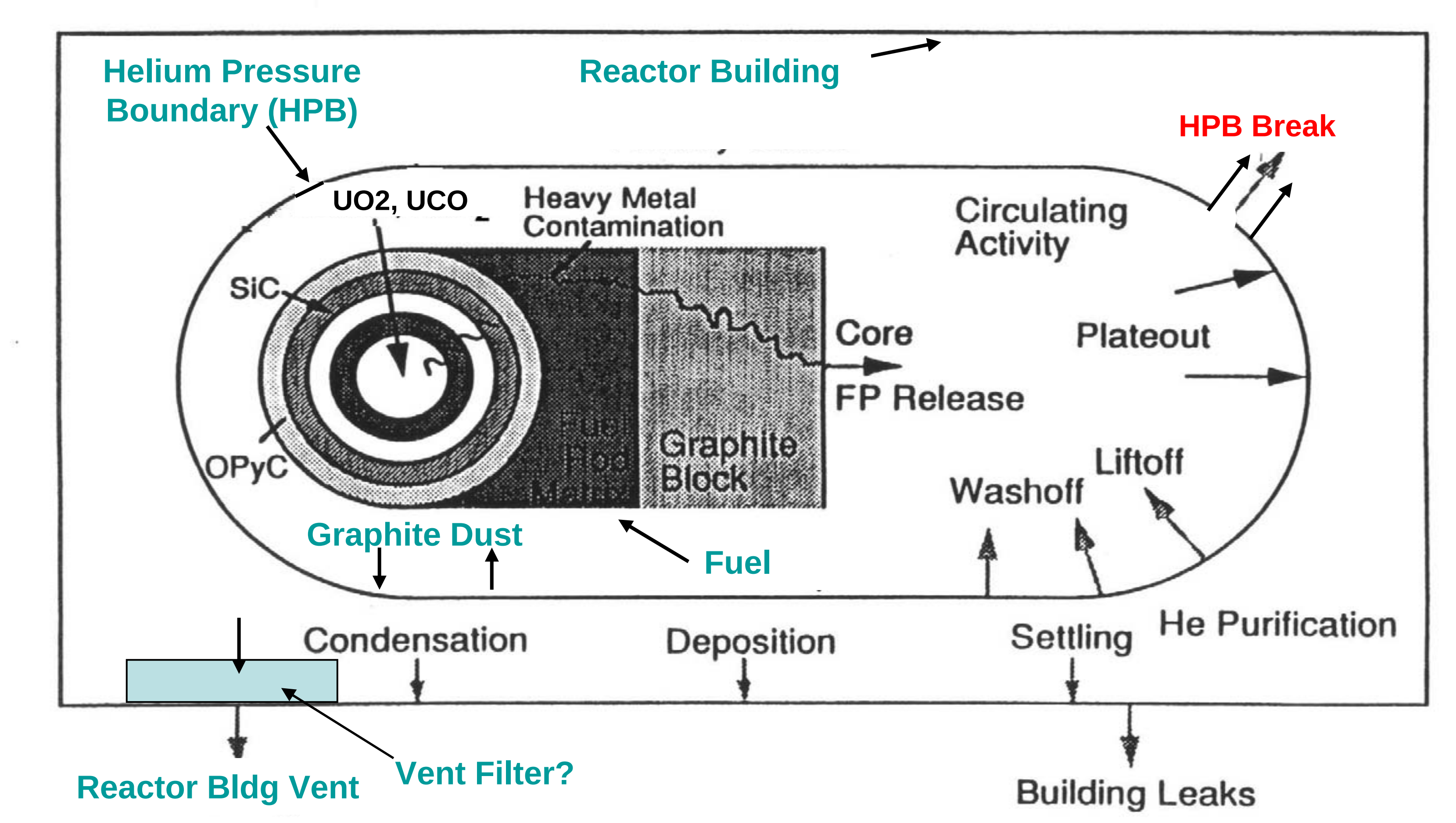
Advanced Reactor Research Plan for Accident Analysis

Allen Notafrancesco
Office of Nuclear Regulatory Research
January 14, 2009

Accident Analysis R&D Objectives

- Develop, validate and utilize accident source term and fission transport analysis models, tools and knowledge to support NRC licensing application reviews in the areas of HTGR source term, FP release, dose assessment and PRA analysis.
- Integrate the TRISO fuel, nuclear and T-F models into the accident source term and fission product transport analysis models and tools for the NRC HTGR accident evaluation.

HTGR Mechanistic S-T and FP Transport Calculation Must Model Many Complex Phenomena



Accident Analysis Methods

- Calculate normal operation and transient behavior for the entire system (core, vessel, confinement), integrating thermo-fluids and fission product release/transport processes including dust, and graphite oxidation.

Selected MELCOR Code

- Code includes most of the capability to build upon for HTGR analysis for Design Basis Accidents (DBA) and beyond DBA accidents events (e.g., air and water ingress)

Current MELCOR Modeling Capabilities

Phenomena from PIRT	MELCOR "Packages"
Decay Heat	Decay Heat
Aerosol Dust Deposition	Radionuclide (RN)
Cavity Filter Performance	Flow Path (filter model w/RN)
Combustion of Flammable Gas	Burn
Core Coolant Flow & Properties	Control Volume Hydrodynamics & Flow Path
Reactivity temperature feedback	Core

Initial Activities for PBR & PMR

- Review INL MELCOR version for HTGR and review He-Air thermal-physical data/correlations for expected conditions
- Update Core Package (COR) to model HTGR core fuel and structural material components
- Incorporate graphite oxidation (steam and air) models

Review of INL MELCOR Modifications and He-Air Data

- INL Modifications to MELCOR
  - Oxidation of graphite Heat Structures
  - Diffusion of air in helium
- He-Air Properties in MELCOR compared to NIST data (range is 300-1500K, 0.1-10MPa)
  - Ideal gas law modeling is reasonable

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Update MELCOR Core Package

- HTGR cores implemented as new reactor types PBR (pebble bed) and PMR (prismatic block) into MELCOR 2.1
- PBR pebble fueled and unfueled zones
- PMR fuel compacts and graphite prismatic blocks
- Graphite reflectors (inner and outer annular elements)

MELCOR Modeling Capabilities Related to Core

Phenomena from PIRT table	Status	Plan of Approach
Graphite Oxidation of Fuel Components	Added and tested	Added graphite oxidation in steam and air to MELCOR
Pebble Temperature Profile	Added and tested	Modify MELCOR fuel profile to add sphere fuel modeling
Bed Effective Conductivity	Added and tested	Added packed bed correlation for conduction and radiation
Fuel and Graphite Blocks Radial Conduction	Added, PBR tested. Graphite Blocks to be tested with PMR input file.	Expanded MELCOR core conduction model by adding radial heat transfer
Pebble Bed friction factor and heat transfer	Completed	Using packed bed friction factor and heat transfer
He coolant properties	Reviewed properties from NIST	MELCOR can model He adequately
CO/CO2 reaction products	Added oxidation, need to add the ratio model	Kim and NO model for CO/CO2 ratio will be implemented in MELCOR.
Point Kinetics	Preliminary testing performed	
Reflector components	Added and needs testing	

Accident Analysis Strategy

- Develop MELCOR input models for PMR and PBR designs (SNL in partnership with Texas A&M)
- Perform analyses of accident classes
  - loss-of-forced circulation (pressurized)
  - loss-of-forced circulation (depressurized with air ingress)
  - ATWS
  - water/steam ingress from secondary system
- Conduct code assessments against relevant plant benchmarks

Fission Product Release & Transport Modeling

- PARFUME and TMAP4 insights will be used for CFP failure rate predictions and fuel fission product releases
- Devise simplified models/methods to incorporate into MELCOR framework

Thermal-Fluids Improvements

- Implement Reactor Cavity Cooling System (RCCS) model
  - Removal of heat from the reactor vessel using either air or water as the RCCS cooling medium
  - Radiation and convection heat transfer with participating medium (gray gas and dust effect)
- Plant components
  - Heat exchangers
  - Secondary system components (gas turbine, compressor)
- Stratified flow air ingress modeling (counter current flow)

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Other Planned Activities

- FP lift-off and resuspension modeling
- Identify areas requiring benchmarking and experimental validation
- Improve code numerics for slow and long transients for HTGR analysis
  - Time-step optimization (e.g., convergence criteria, subcycling)
  - Code parallelization
  - Optimization of numerical schemes and solution strategies

Models to be Added to MELCOR for HTGR Modeling

Phenomena from PIRT table	Status	Plan of Approach
RCCS Modeling	TAMU is assigned to add an RCCS to the PBR core input	Use existing CVH, FP and HS radiation models in MELCOR
Air Ingress (Countercurrent Flow)	SNL is evaluating this problem	
Improved Balance of Plants components	SNL will try to use existing Mechanical and Heat Exchanger models in MELCOR	
Fission Product Release model	Awaiting review of INL codes	SNL will review the models in INL codes and devise a simplified model for fission product release.
Liftoff/Suspension of Dust	Plan to perform literature search on entrainment	Re-entrainment model to be built in MELCOR

Summary

- HTGR model extensions in MELCOR 2.1 are well underway
  - Development informed by past work and PIRT
  - Assessment activities will follow
  - Extensive coordination with other programs is required

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Advanced Reactor Research Plan for Reactor Consequence Analysis

Jocelyn Mitchell
Office of Nuclear Regulatory Research
January 14, 2009

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Reactor Consequence Analysis R&D Objective

- MACCS2 code itself is technology-neutral
- MACCS2 input now developed for LWR technology
- Objective to consider any important differences in input stemming from advanced reactor technologies

Licensing Issues related to Reactor Consequence Analysis

- Offsite consequence analysis is the final aspect of PRA
- Mix of radionuclides and the chemical forms may be different for advanced reactors

Technical and R&D Issues (Reactor Consequence Analysis)

- Other analyses would give the inventories of produced radionuclides
- Other analyses would provide the chemical forms of the released material
- This effort would determine if there are new biologically important nuclides and determine the dose conversion factors for the appropriate chemical forms for all nuclides

R&D to be started between now and FY 09

- None
- Await input from other areas
- Techniques well developed, so no need to start earlier

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Advanced Reactor Research Plan for Fuels Analysis

Stuart D. Rubin

Office of Nuclear Regulatory Research

January 14, 2009

HTGR Fuels Analysis

Objectives:

- Develop, validate and utilize HTGR fuel behavior and fuel fission product transport analysis models, methods and insights to support safety and licensing reviews.
- Use the HTGR fuel behavior and fuel fission product transport methods and data for developing an accident source term for normal operation and accident conditions for use in the NRC accident analysis evaluation model.
- Develop NRC inspection capability to independently assure the production fuel supply quality.
- Develop NRC staff technical knowledge and capability to effectively review the fuel performance aspects of an HTGR licensing application.

Key Fuel Safety and Licensing Issues

- Predicting fuel *particle failure rates* during:

  Normal operation, core heat-up, air ingress, water ingress, large reactivity insertion events
- Predicting fuel *fission product release* during:

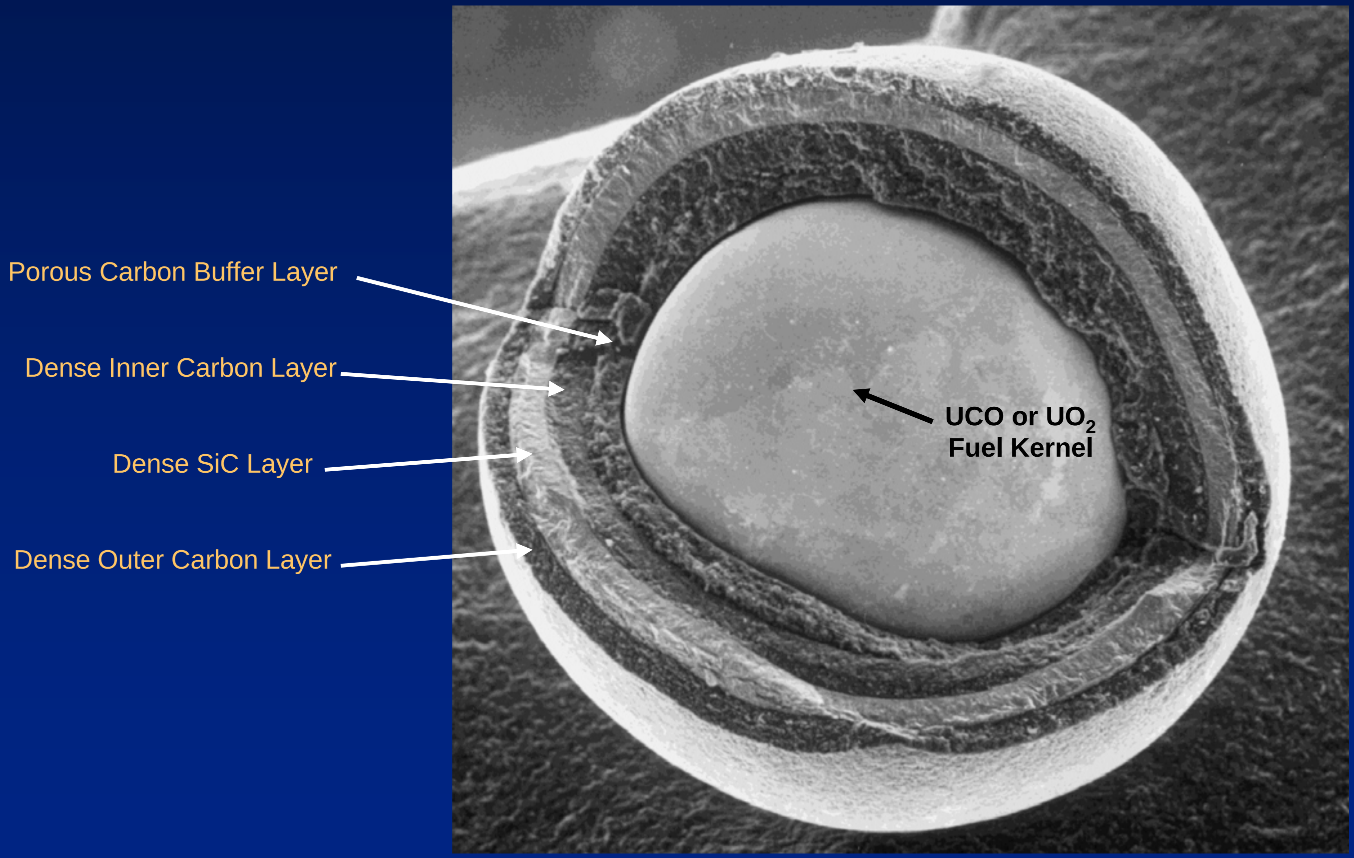
  Normal operation, core heat-up, air ingress, water ingress, large reactivity insertion events
- Establishing the *margins* to significantly increased particle failure rates and fuel fission product release during normal operation and accidents
- Determining the magnitude of metallic radionuclides in mobile *graphite dust*
- Confirming the adequacy of fuel qualification irradiation and accident condition *testing methods*
- Providing regulatory assurance of the *quality of the fuel* fabricated over fuel supply lifetime

Background

"The key (HTGR) concept is the coated fuel particle, which serves as a miniature fission product containment vessel." [1]

[1] DOE-HTGR - 90257

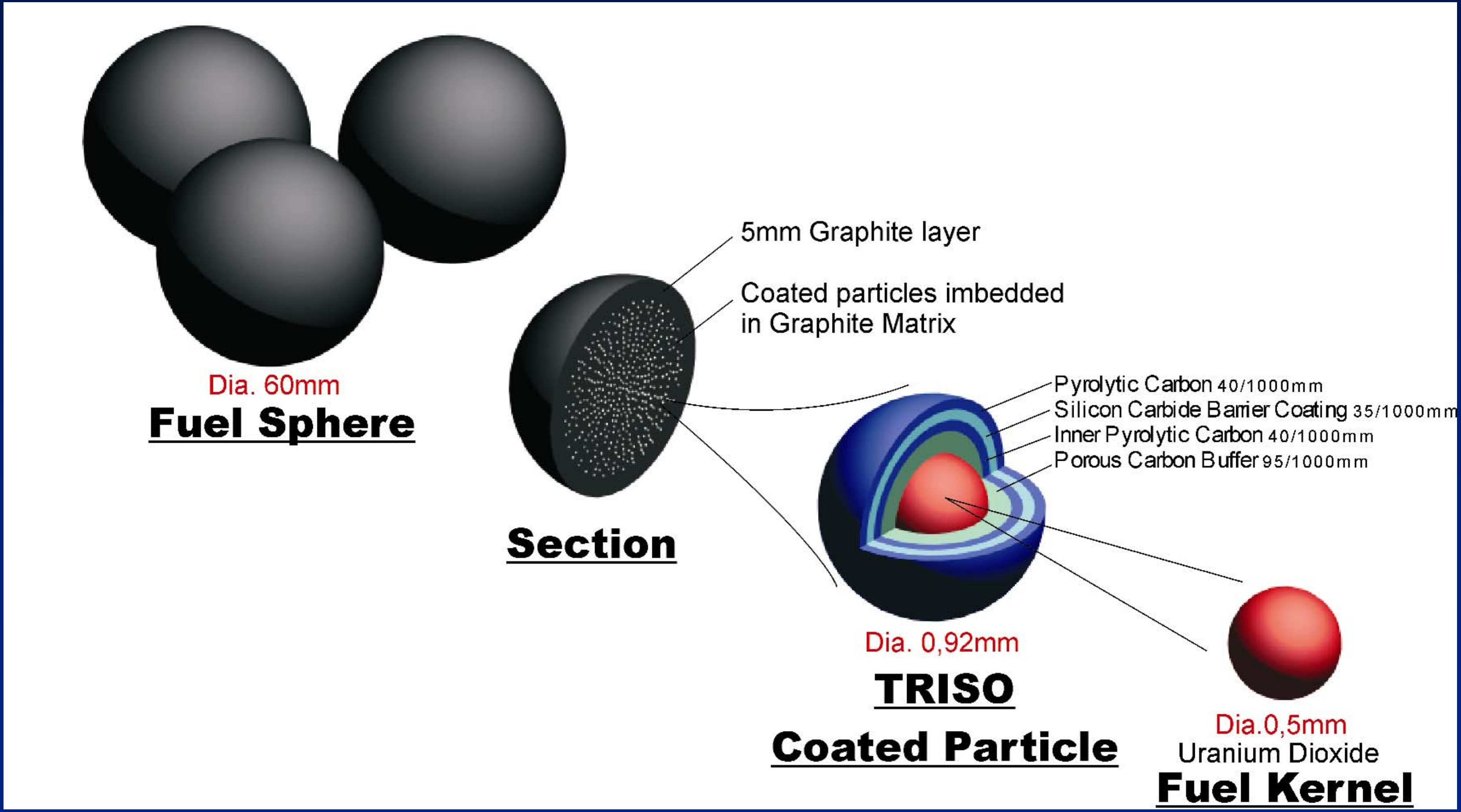
HTGR "TRISO" Coated Fuel Particle



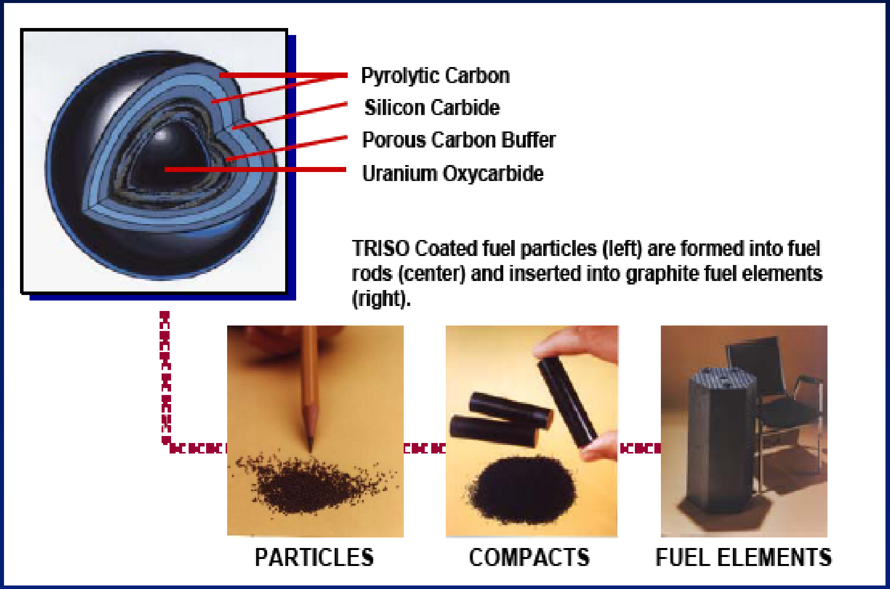
Background

- An HTGR core contains billions of coated fuel particles (CFPs)
- To meet dose acceptance limits: FP release from fuel heavy metal contamination, CFP defects from manufacture, CFP operational failures, CFP accident failures and, intact CFPs - must all be very low
- Fuel manufacture has a prime effect on: CFP properties, performance and FP release
- Fuel operating conditions have a strong effect on: CFP performance and FP release
- Fuel accident conditions have a strong effect on: CFP performance and FP release
- Design and manufacture-specific fuel irradiation and accident condition test data are needed to: develop and validate the fuel behavior and fuel FP transport models and to qualify the fuel for licensing
- Due to the projected low levels of fuel FP release and circulating activity, HTGR plant designers propose a low pressure vented reactor confinement building.

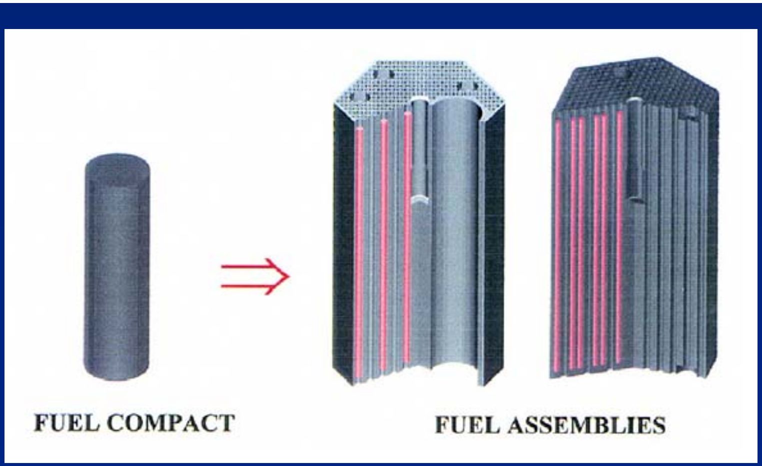
Pebble Bed Reactor Fuel Element



Prismatic Block Reactor Fuel Element



TRISO Coated fuel particles (left) are formed into fuel rods (center) and inserted into graphite fuel elements (right).



HTGR Fuel Particle Integrity Requirements

To meet dose acceptance criteria at the site boundary, CFP initial defects, irradiation failures and accident condition failures must not exceed (i.e., design limits) about….

$< 6X10^{-5}$ manufacturing (un-irradiated) defect rate
\+ $< 6X10^{-5}$ normal operations (irradiation) failure rate
\+ $< 1X10^{-4}$ accident (heat-up) failure rate

…..crediting fission product transport holdup and retention mechanisms within the fuel element, core graphite structures, helium pressure boundary surfaces, confinement building surfaces and release dispersion characteristics.

Background

“Successful operation (of the HTGR) is dependent on predictable performance of the fuel.” [1]

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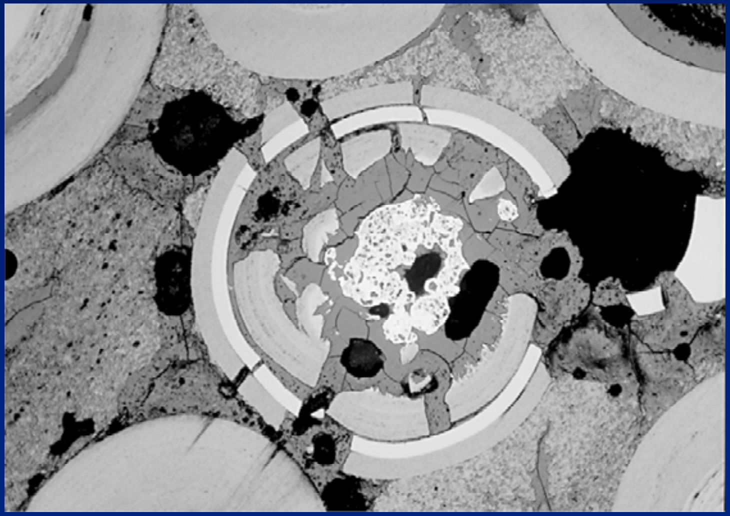
[1] DOE-HTGR - 90257

Fuel Particle Performance:
Single Particle Behavior/Failure Modeling



Particle Integrity: Failure Mechanisms*

CFP Failure Mechanisms:

- Pressure vessel failure (SiC layer rupture)
- PyC irradiation failure (dimensional change)
- PyC layer de-bonding from SiC layer (SiC local stress riser)
- Kernel migration (SiC layer degradation)
- SiC failure due to fission product attack
- SiC failure due to decomposition (elevated temperature)
- SiC failure due to oxidation (air ingress)
- Particle failure due to rapid energy deposition (reactivity insertion)
- Elevated fission product diffusion through intact coating layers

* TRISO-Coated Particle Fuel Phenomenon Identification and Ranking Tables (PIRTs) for Fission Product Transport Due to Manufacturing, Operations, and Accidents (NUREG/CR-6844)"

Particle Integrity: Important Phenomena

Particle Property Phenomena*

Kernel:
fission gas release; CO production; swelling during rapid reactivity events

Buffer layer:
interconnected void volume, cracking/failure

PyC layers:
anisotropy, Poisson's ratios (elastic and creep), strength, bonding to SiC, CTE, elastic modulus, irradiation-induced dimensional change, creep

SiC layer:
strength, elastic modulus, CTE, irradiation-induced swelling and creep

All of the Above:
Variation in dimensions and material properties

Operational and Accident Condition Phenomena

Normal operations:
Fuel element surface temperature and kernel power (to calculate CFP radial temperature gradient) fast fluence, kernel burn-up,

Heat-up accidents:
Fuel element max surface temperature, fast fluence, kernel burn-up, CFP irradiation temperature history

Reactivity events:
Kernel burn-up, irradiation temperature history; kernel energy deposition and rate, kernel max transient temperature

Oxidation events:
SiC oxygen or $H_2$0 partial pressure; SiC temperature; SiC time at temperature

* Property values can change with irradiation, temperature; CFP manufacture-specific irradiation and accident condition test data needed for most material properties

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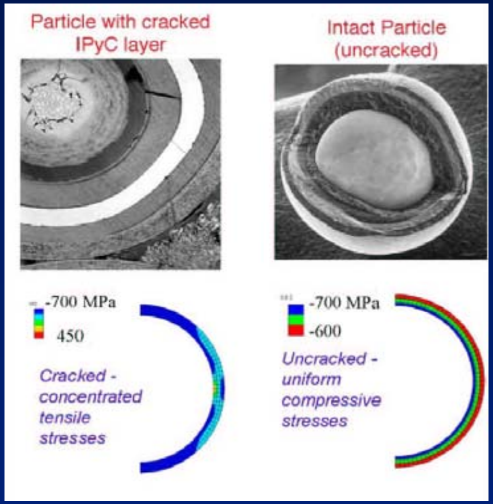
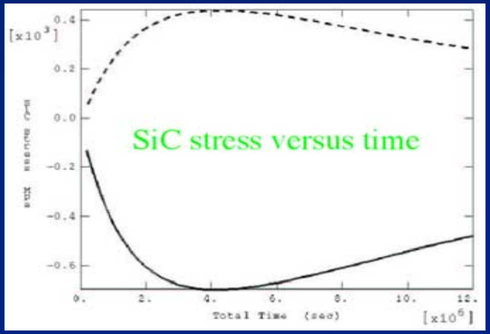
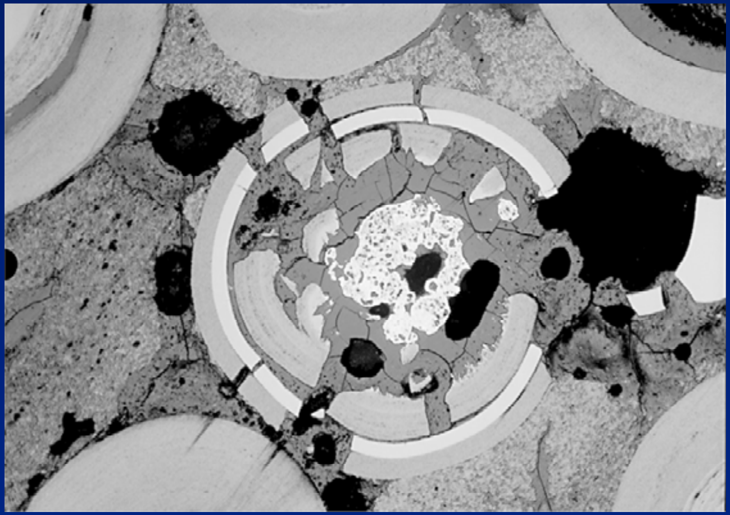
NRC Fuel Particle Performance Analysis Model Development and Use

- Obtain multi-dimensional behavior, finite element PARFUME code, models, data and manuals from DOE/INL
- Evaluate PARFUME via code-to-code and code-to-data benchmarks
- Conduct sensitivity studies to evaluate variations in important phenomena, qualification test program adequacy, etc
- Use PARFUME to develop NRC staff knowledge of CFP performance and behavior to prepare for licensing reviews
- Update PARFUME with NGNP-specific CFP materials data, irradiation test data, accident condition test data when available
- Use PARFUME sensitivity studies to inform selection of CFP failure rate vs. fuel temperature and B.U. to be used in NRC accident analysis evaluation model





Fuel Particle Performance:
Core-Wide Particle Failure Rate Modeling

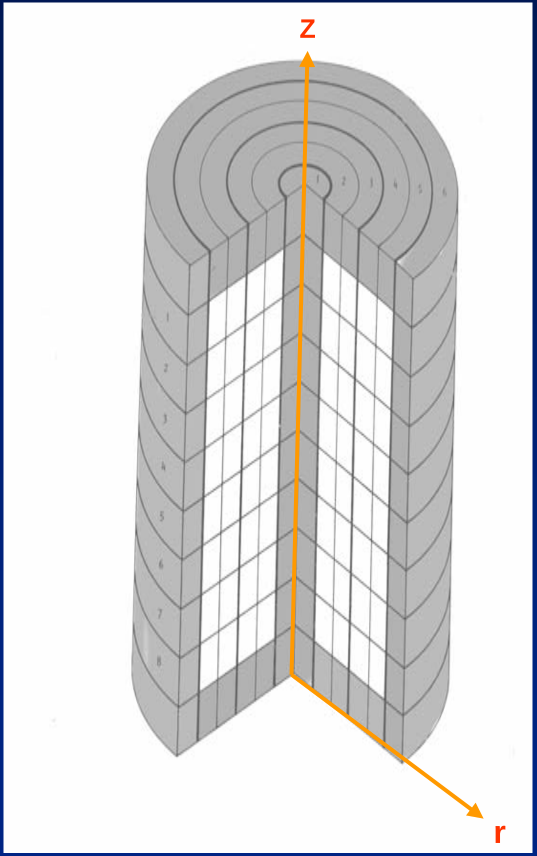


NRC Core-Wide Particle Failure Rate Model Development

NRC Accident Analysis Evaluation Model (EM)

- Establish CFP failure fraction based on NGNP CFP failure fraction design requirements and NGNP fuel qualification program CFP failure fraction data.
- Establish CFP failure fraction versus fuel temperature and burn-up based on the above NGNP failure fraction requirements and data
- Use PARFUME to inform the development of conservative and best estimate CFP failure fraction versus temperature and burn-up
- Commission decisions on mechanistic source term calculation and use will determine where conservative or best estimate CFP failure fraction versus temperature and burn-up will be used in EM for normal operation, transients, DBAs and BDBAs
- Utilize the selected CFP failure fraction function in the NRC accident evaluation model to predict number of CFP failures in the core vs. R, Z and time for normal operation, transients, DBAs and BDBAs
- Compare the NRC CFP failure fraction function to the NGNP COL applicant's CFP failure fraction function
- Near Term: Utilize a CFP failure fraction versus fuel temperature and burn-up based on German reference fuel qualification (irradiation and heat-up) test results

NRC Core-Wide Particle Failure Fraction Model*



Particle failure fraction (normal operation)

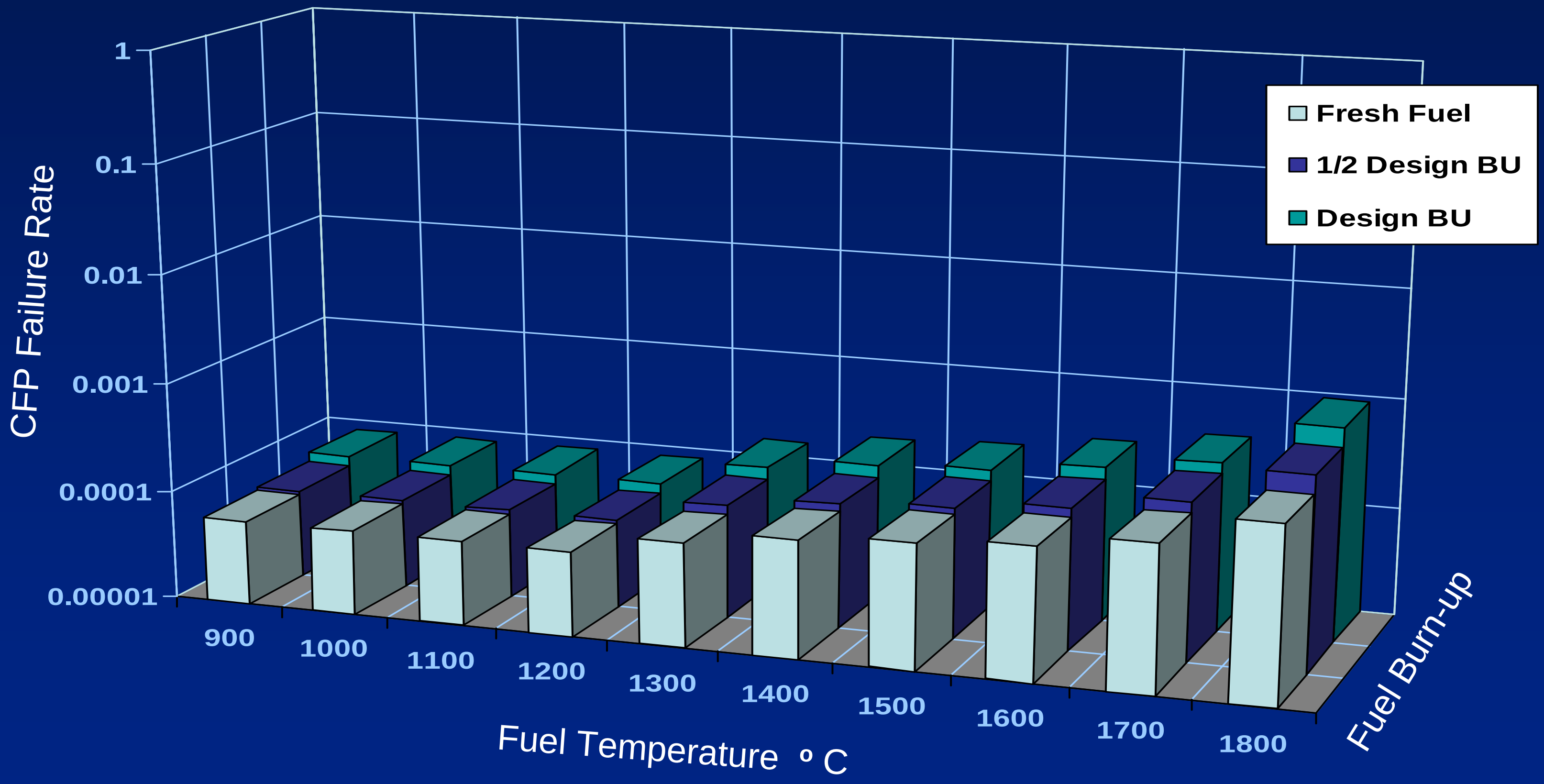
FF = **f** {max fuel operating temp, B.U.}

Particle failure fraction (accident heat-up)

FF (r, z, t) = **f** {fuel accident temp (r, z, t), B.U.}

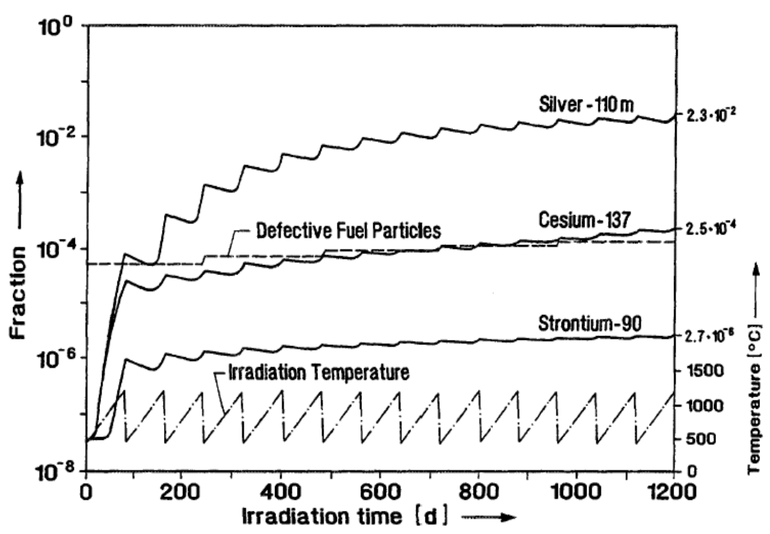
* To be based on NGNP fuel qualification test data

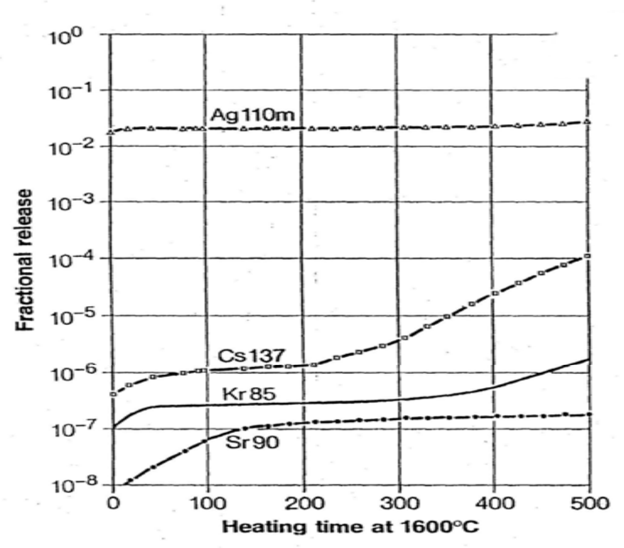
Particle Failure Fraction vs. Fuel Temperature and Burn-up* (Response Surface)



* Prototypical - for illustration only

Modeling Fuel Performance: Fission Product Transport and Release





Fuel Fission Product Transport Modeling

<u>Fuel element component</u>

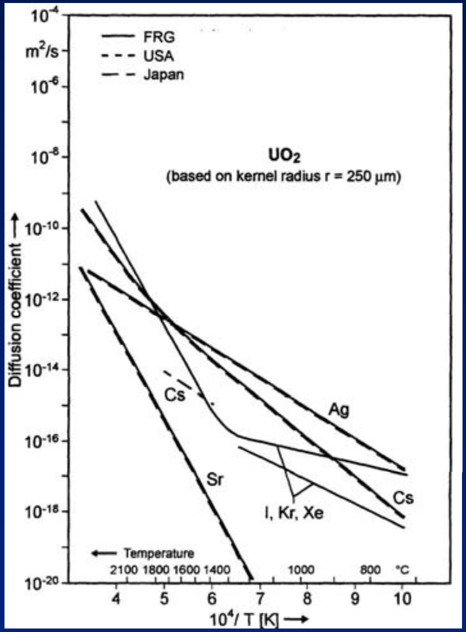
- Kernel
- Inner PyC layer
- SiC layer
- Outer PyC layer
- Fuel matrix (pebble or compact)
- Fuel graphite block (PMRs only)

Fuel Fission Product Transport Modeling

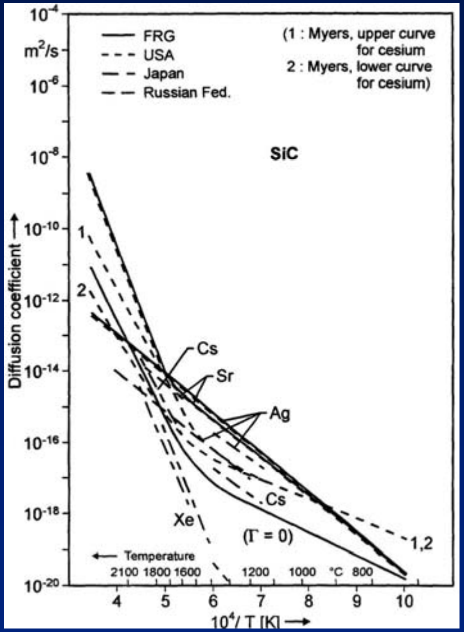
	Fuel Element Component					
Fission Prod. Source*	**Kernel**	**IPyC**	**SiC**	**OPyC**	**Matrix**	**Graphite**
Contamination	-	-	-	-	Yes	Yes
Failed SiC Layer	Yes	Yes	-	Yes	Yes	Yes
Failed Particles	Yes	-	-	-	Yes	Yes
Intact Particles	Yes	Yes	Yes	Yes	Yes	Yes

***Leach-burn-leach test provides distribution for fresh fuel**

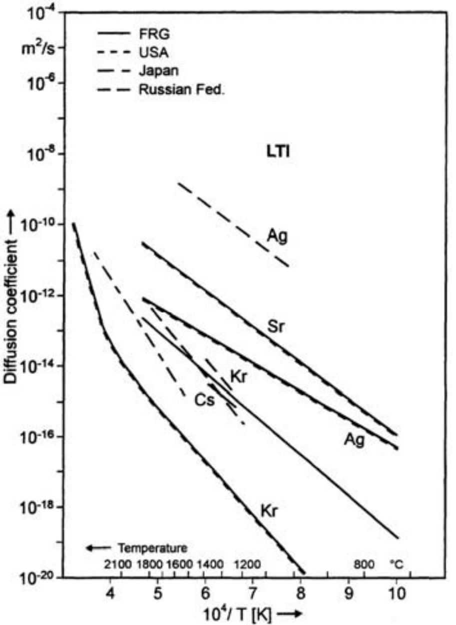
Fuel Effective Diffusion Coefficients*



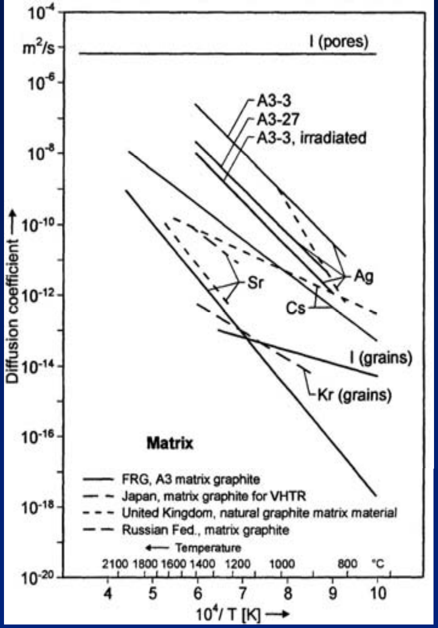
UO_2



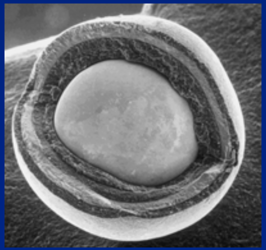
SiC



IPyC and OPyC



Matrix



* IAEA TECDOC 978

Fuel Fission Product Transport Modeling

<u>TMAP4 Code</u>

- FP transport in a TRISO coated particle and fuel matrix
- Solves 1-D diffusion equation, with trapping (if needed) for all layers
- Intact, failed, defective SiC, and matrix contamination can be modeled
- User-specified fission product generation rate in kernel vs. time
- Calculates temperature distribution from fuel element surface to kernel
- User-specified effective diffusivities for each component
- Effective diffusion coefficients for each component calculated
- Soret diffusion in any layer (e.g., large ΔT in buffer during normal operation)
- PBR cyclic or PMR steady irradiation temperatures can be input
- Normal operation/irradiation and accident heat-up FP transport

- *Fuel temp vs. time is <u>most</u> important to fuel FP transport and release*

NRC Fuel Fission Product Transport Model Development

- Obtain TMAP4 code from INL for fuel FP transport analysis
- Evaluate TMAP4 via code-to-code and code-to-data benchmarks
- Conduct sensitivity studies to evaluate variations in diffusivities, etc.
- Use TMAP4 to develop NRC fuel FP transport knowledge for the NGNP COL review
- Near-Term: Use available (IAEA TECDOC-978) effective diffusivities
- Long-Term: Update TMAP4 with NGNP fuel-specific effective diffusivities based on DOE/INL AGR test program results/data

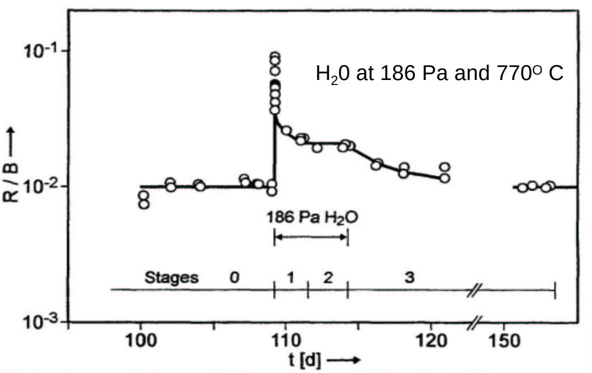
NRC Fuel Fission Product Transport Model Development

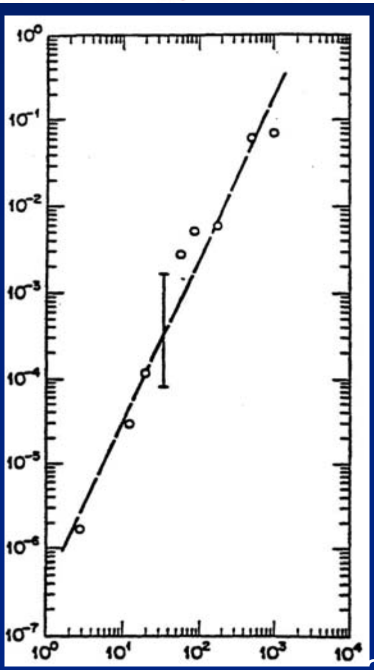
- Evaluate using TMAP4 for calculating core-wide fuel FP diffusion and release versus fuel temperature, burn-up and time for: contamination; failed particles; particles with failed SiC layers and; intact particles *or*,
- Develop alternative simplified fuel FP diffusion and release models for calculating core-wide fuel FP diffusion and release versus fuel temperature, burn-up and time for: contamination; failed particles; particles with failed SiC layers and; intact particles
- Utilize the selected particle failure fraction response surface together with the selected fuel FP diffusion and release models in the NRC accident analysis EM to calculate the core-wide fuel FP transport and release vs. R, Z and time for normal operation, transients, DBAs and BDBAs
- Near-term: utilize available (IAEA TECDOC) fuel FP diffusion and release rate data
- Long-term: utilize the fuel diffusion and release rate data developed by the NGNP fuel development and qualification program

Fuel Fission Product Release: Effects of Water Ingress

- Oxidants reaching exposed kernels can rapidly/significantly increase fuel particle fission product release
- Release fraction from exposed kernels depends on H_2O partial pressure and fuel temperature
- If NGNP design has steam generators, SG tube failure could significantly increase exposed kernel releases
- NGNP designs with no high pressure, high volume water sources, could limit/preclude increased kernel releases
- Limited fission product release data/models for irradiated compacts with UCO kernels and pebbles with UO_2 kernels
- Additional experimental data for NGNP fuel will be needed to reduce model uncertainties for H_2O ingress FP release
- DOE AGR fuel technology development program may test irradiated fuel with intact and failed particles for H_2O ingress
- NRC has access to DOE test data for developing NRC fuel fission product release models
- Near-term: Use available data/models (e.g., IAEA TECDOC) with uncertainty for NGNP fuel design

Stored ^{85}K Fission Gas Release as a Fraction of Kernel Inventory



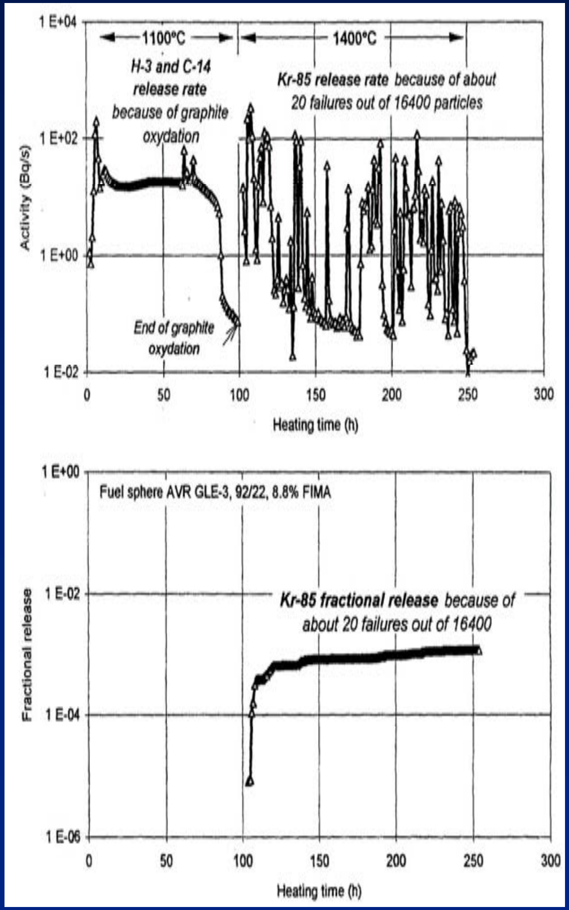


Stored ^{85}K Fission Gas Release as a Fraction of Kernel Inventory

H_2O Partial Pressure

Fuel Fission Product Release: Modeling Air Ingress

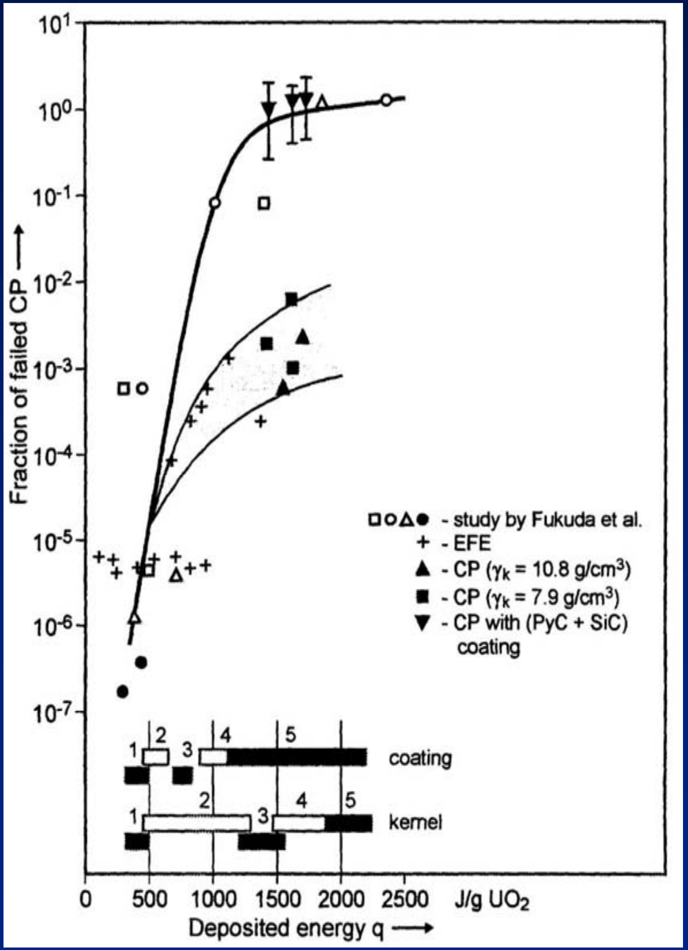
- Fuel matrix/OPyC oxidation can release FP by means other than diffusion
- Oxidation can fail particles by OPyC degradation and/or SiC oxidation ($SiC + O_2 \rightarrow SiO$ or SiO_2)
- Particle failure fraction depends on extent of air supply, particle temperature and can be much greater than heat-up without air ingress
- Low chemical reactivity of PMR nuclear-grade fuel blocks (vs. PBR fuel element matrix material) provides some protection of PMR fuel compacts and particles
- Air ingress provides a HPB opening and motive force for FP transport from HPB
- Existing irradiated fuel oxidation effects data/models are not typical of NGNP fuel design (e.g., burn-up, fluence)
- DOE AGR fuel technology development program may include air ingress testing of irradiated fuel
- NRC has access to DOE test data for developing NRC fuel fission product release models
- Near-term: Use available data/models (e.g., IAEA TECDOC) with uncertainty for NGNP fuel design



Oxidation of two similar fuel spheres in air.
Top: 9% FIMA; Bottom: 8.8% FIMA (IAEA TECDOC-978)

Fuel Fission Product Release: Modeling Reactivity Accidents

- Large/rapid power pulse can release kernel FP and melt kernel, potentially over-pressurizing/failing CFPs
- CFP failure rate depends on energy deposition, deposition rate and fuel kernel transient temp rise
- Severity of reactivity accidents depends on core excess reactivity
- Concurrent HPB failure (CR ejection) would provide a motive force for fuel FP transport outside the HPB
- Limited reactivity insertion test data/models exist for irradiated fuel and is not typical of NGNP fuel design
- Reactor type (PBR or PMR) and limiting RIA event selection will determine whether NGNP fuel-specific reactivity accident testing is needed
- Near-term: Use available data/models (e.g., IAEA TECDOC) with uncertainty for NGNP fuel design



Particle failure rate vs. pulse energy deposition (IAEA TECDOC-978)

Background

“Manufacturing and inspecting of the fuel are critical steps in assuring the performance necessary for the success of the reactor system.”[1]

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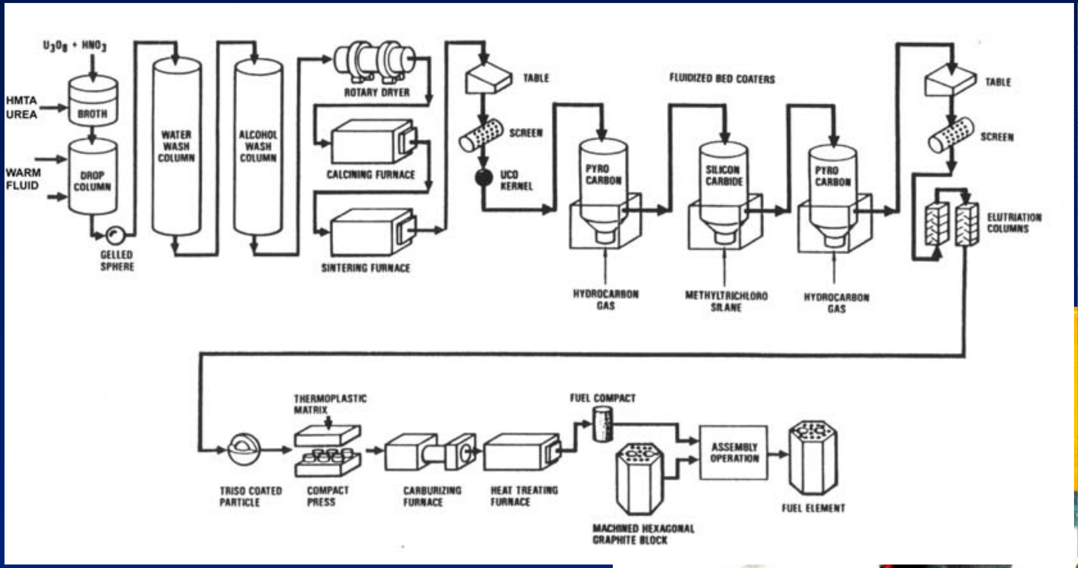
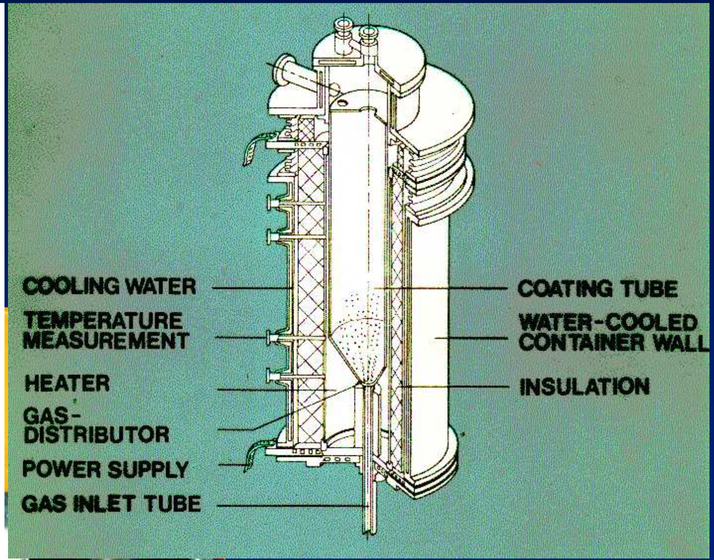
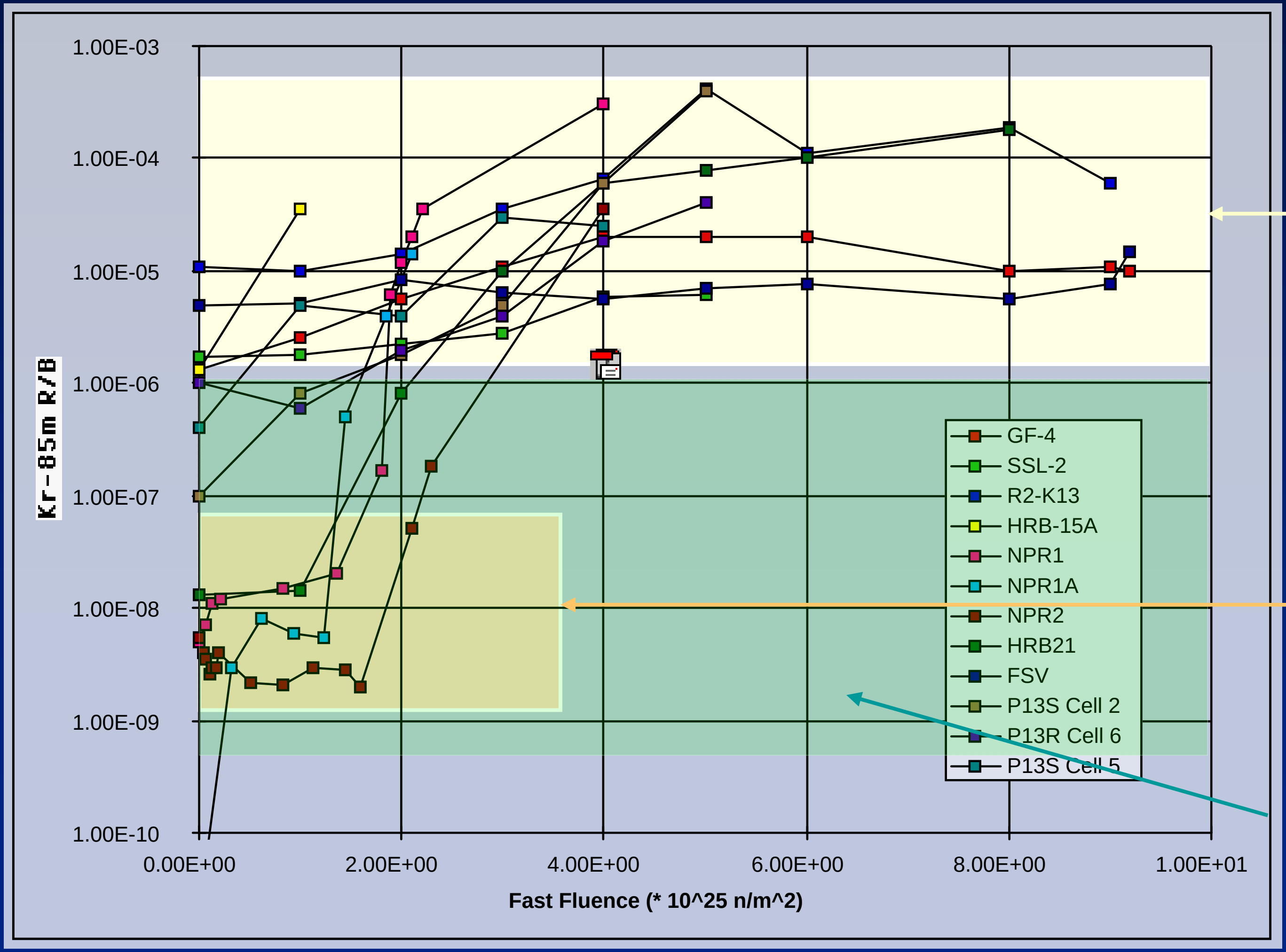
[1] DOE-HTGR -90257

Fuel Fabrication





U.S. and German Fuel Performance Experience



Range of *Old* (NPR) US Fuel Irradiation Data

Range of *New* (AGR1) US Fuel Irradiation Data

Range of German Fuel Irradiation Data

NRC Fuel Manufacture Quality Assurance Oversight Strategy

Develop an NRC inspection protocol for HTGR production fuel fabrication facilities addressing:

- Conformance with fuel product and process specifications to consistently meet fuel quality and performance requirements
- Fabrication process equipment and process parameters for fuel quality and performance
- Fuel characterization methods to ensure fuel product specifications are being met
- Needed calibration testing equipment and calibration inspection procedures for critical product and process parameters
- Maintenance procedures for fuel fabrication process equipment
- Sampling and Q/C statistical analysis methods
- Process equipment maintenance procedures, calibration and testing
- Procedures, training and qualification of fuel fabrication facility staff
- Automation of process controls and fuel characterizations methods

Summary

- CFP integrity and FP retention is the key to the HTGR safety case
- Fuel behavior and FP release depends on fuel fabrication, operating history and accident conditions
- NRC is developing analytical tools, data and expertise to assess CFP behavior and fuel fission product diffusion and release
- CFP behavior performance and fuel fission product release models are being evaluated for integration into the NRC accident evaluation model to predict the core-wide event-specific accident source term
- The contribution of matrix dust to the accident source term must be assessed and addressed
- NRC will extensively utilize the DOE AGR fuel development and qualification program work products to meet HTGR fuels R&D needs
- Cooperative research will also be used to supplement and assess DOE data, models and tools, as appropriate
- NRC is developing the basis for inspecting HTGR fuel production facilities

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Advanced Reactor Research Plan
Human Performance

J.J. Persensky, Ph.D.
Valerie E. Barnes, Ph.D.
Office of Nuclear Regulatory Research
January 14, 2009

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Human Performance R&D Objectives

- Establish the bases for new methods and tools for evaluation of human performance issues at advanced reactors
- Anticipate paradigm shifts in human performance issues because of new concepts of operations.
- Identify new, or any needed, changes to review guidance

Safety and Licensing Issues in the Human Performance Technical Area

Safety issues

- Potential for human error
- Reduction of situation awareness
- Availability of adequate qualified plant staff

Licensing issues

- Accommodation of rapidly changing technology in the current regulatory framework
- Training and development of NRC staff

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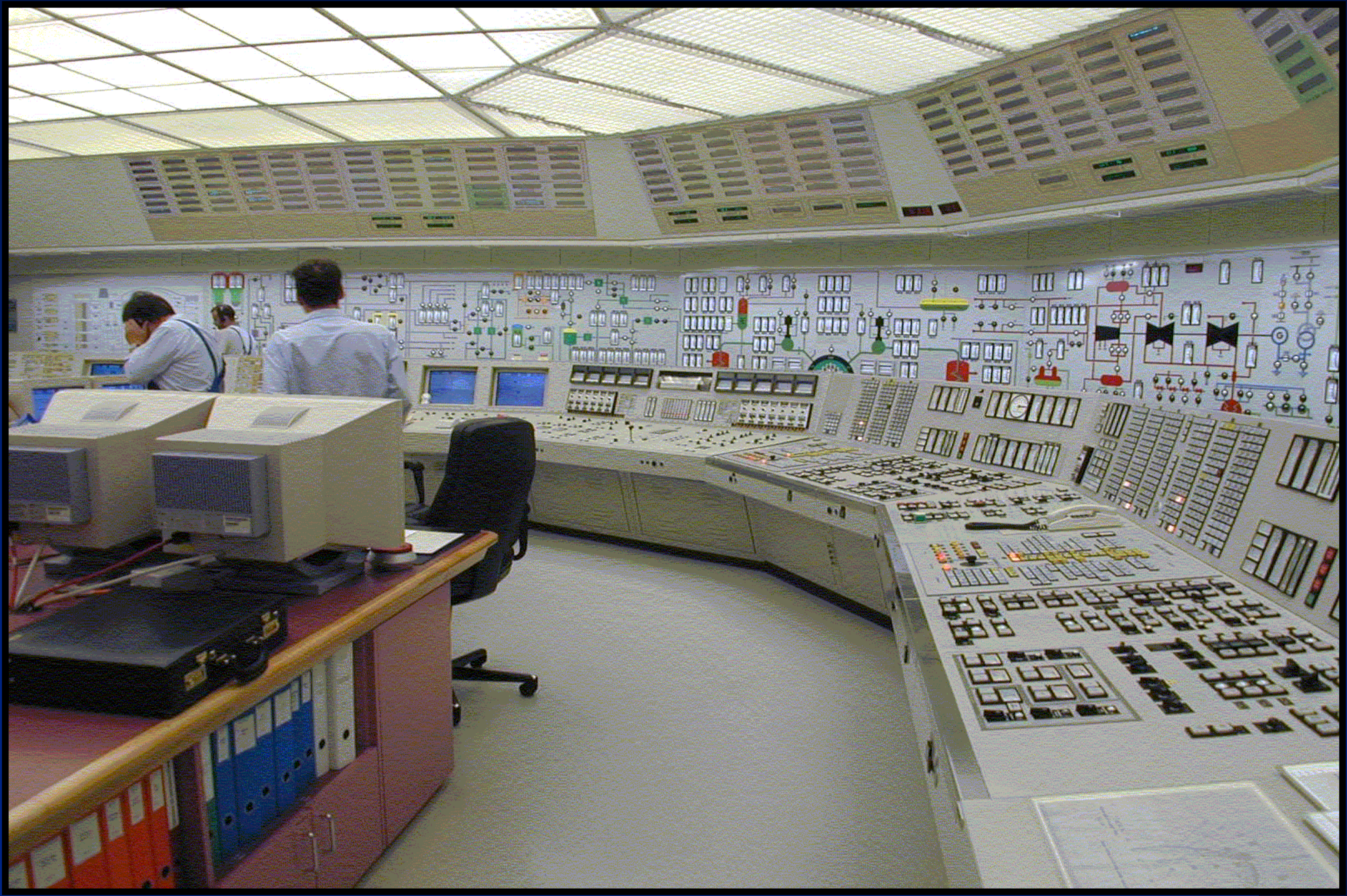
How HSIs at advanced control rooms may differ

Current LWR		Advanced Reactors
Large expansive control rooms	→	Centralization of HSIs into compact workstations and overview displays
Crew interaction with plant systems and components	→	Interaction through computer systems
Physical HSIs	→	Virtual HSIs
Parallel access to HSIs	→	Serial access to HSIs through view ports (keyholes)
Fixed HSIs	→	Flexible HSIs
Limited functionality	→	Expanding functionality of HSIs

Control Room
at Beznau



PBMR simulator in South Africa

Human Performance Plan Activities

- Basis document
  - “Human Factors Considerations with Respect to Emerging Technology in Nuclear Power Plants” (NUREG/CR-6947)
  - Ongoing research
    - Operations under degraded I&C conditions
    - Human factors methods and tools
    - Roles of personnel and automation

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Human Performance Plan Activities (Cont.)

- Related Activities
  - Develop long-term guidance for “Highly-Integrated Control Room - Human Factors” plan (TWG #5 of the Digital I&C Steering Committee)
  - Participate in the OECD Halden Reactor Project
  - Participate in the NEA/CSNI/Working Group on Human and Organizational Factors to implement the Technical Opinion Paper (TOP) on an integrated human factors research program for advanced reactors

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Human Performance Planned R&D Areas in ARRP

- New concepts of operation
- Operational designs and operator functions and tasks
- Function allocation - Automation
- Process complexity and opacity
- Workload variations, transitions, and staffing
- Teamwork and communication
- Computer-based procedures and intelligent automation
- Alarm management
- HFE methods and tools

Human Performance R&D to be started in FY 09 & FY 10

Project Title	FY09	FY10
Degraded I&C and computerized procedures	X	X
Update NUREGs-0711 & - 0711	X	X
Halden Reactor Program	X	X
Distributed decision-making		X
Operator modeling		X
Support HF standards		X
EPRI collaboration		X

Applications of Human Performance R & D

- Clear expectations for the evaluation of advanced control rooms with a well-defined path for advanced reactor licensing
- Identify the need for safety enhancements and regulatory action
- Technical basis and criteria for design acceptability reviews (e.g., input for regulatory guides, SRP enhancements, NUREGs, or inspection guidance)

Human Performance R & D Conclusions

- Good match between the NRC ARRP and the internationally recognized CSNI-TOP
- Opportunities for international collaboration – Leveraging and efficiency
- The Halden program will incorporate efforts related to the CSNI report
- The CSNI program could encourage the development of new research facilities and opportunities for field studies

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Advanced Reactor Control Room?

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Advanced Reactor Research Plan for Hydrogen and Process Plant Analysis

Nathan Hudson

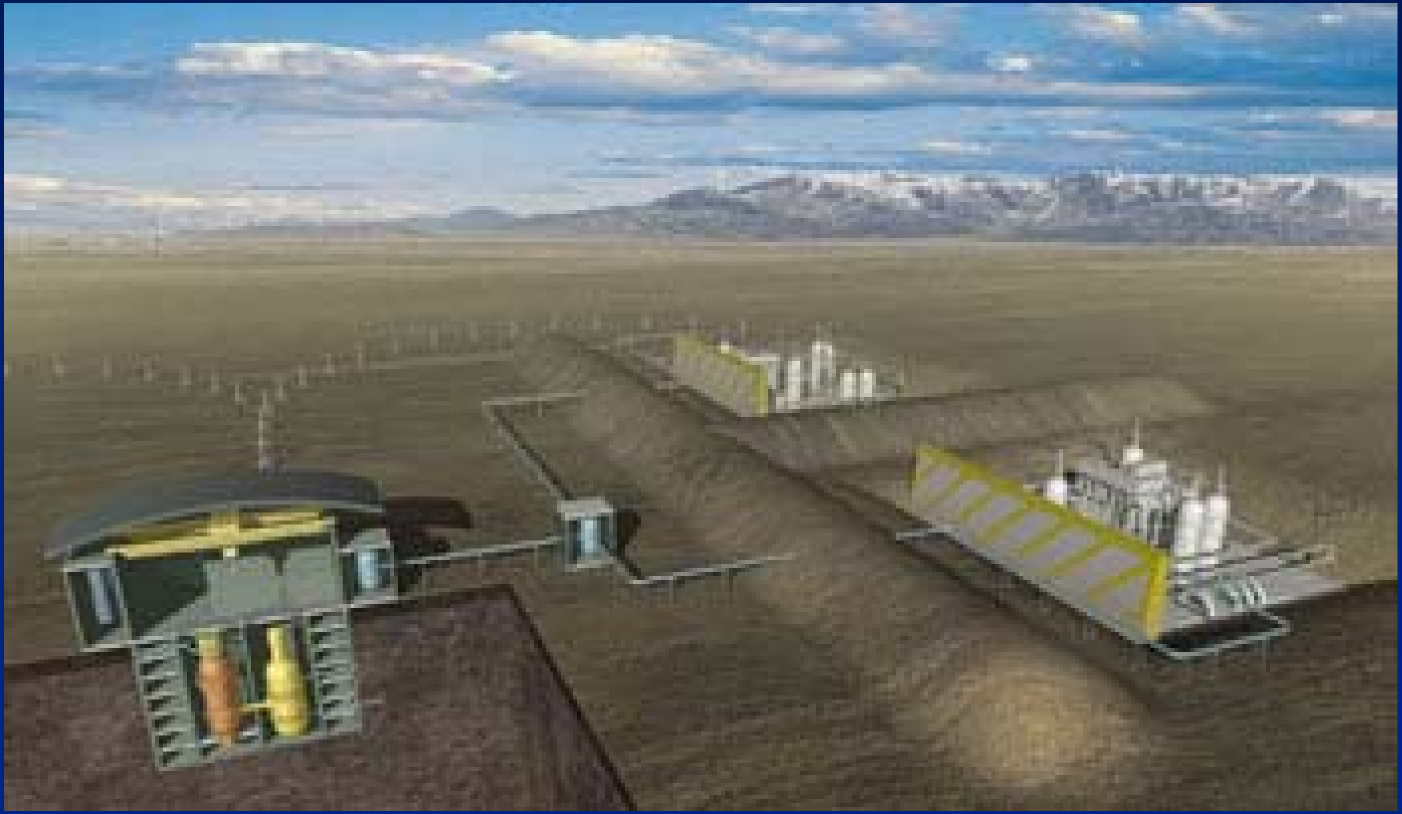
Office of Nuclear Regulatory Research

January 14-15, 2009

Hydrogen and Process Plant R&D Objectives

- To develop independent expertise, tools, and capabilities to support staff review of the safety implications on the VHTR posed by the NGNP hydrogen production facility.
- Tools & methods to be implemented should be accurate to the extent that they are not unnecessarily overly-conservative.

Hydrogen and Process Plant Analysis



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Hydrogen and Process Plant Performance Safety issues

Chemical Releases:

- Ground hugging heavy gas release (e.g., oxygen, suffocants, and toxic gases)
- Hydrogen gas detonation from H_2 plant
- Combustion of another flammable gas or liquid

Process Heat Transport System:

- Transients in chemical plant that lead to reactor trip or component failures
- IHX tube failures, PHX tube failures, piping failures

VHTR Events that Effect Hydrogen Plant

- Tritium transport

Hydrogen and Process Plant R&D Plans

- Develop an Evaluation Model (EM) to predict response of VHTR to transients undertaken in the hydrogen production plant and vice versa.
  - to be accomplished by extending the developing VHTR core EM to include the connecting heat exchangers and piping
  - will be necessary to couple this extended EM to existing chemical process software through a software interface.

- Develop detailed fluid flow and solid stress models for the connecting process heat exchangers and piping using existing tools.
- Develop EM for hydrogen deflagration & detonation events.
  - Hydrogen deserves a special treatment due to its highly buoyant & diffusive properties
  - EM to implement already existing analytical tools, correlations, or software.
  - EM to be able to predict the incident blast over-pressure loading on the reactor containment as a function of the separation distance between the containment and the hydrogen plant.

- Assess hydrogen EM against historical experimental data
- Develop EM for general deflagration and combustion events, excluding hydrogen at the hydrogen plant.
  - should be able to approximate radiative & convective heat flux projected upon the reactor building(s)
  - blast over-pressure & impulse shape from combustion event.

- Develop EM to approximate concentrations of a heavy gas release at specified distances from the reactor building(s)
- Establish a measurable regulatory activity of tritium to be detected in the intermediate coolant loop, through use of a radiation detector submerged within the gas during NGNP operations.

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Advanced Reactor Research for Nuclear Analysis

Anthony Ulses
Office of Nuclear Regulatory Research
January 14th, 2009

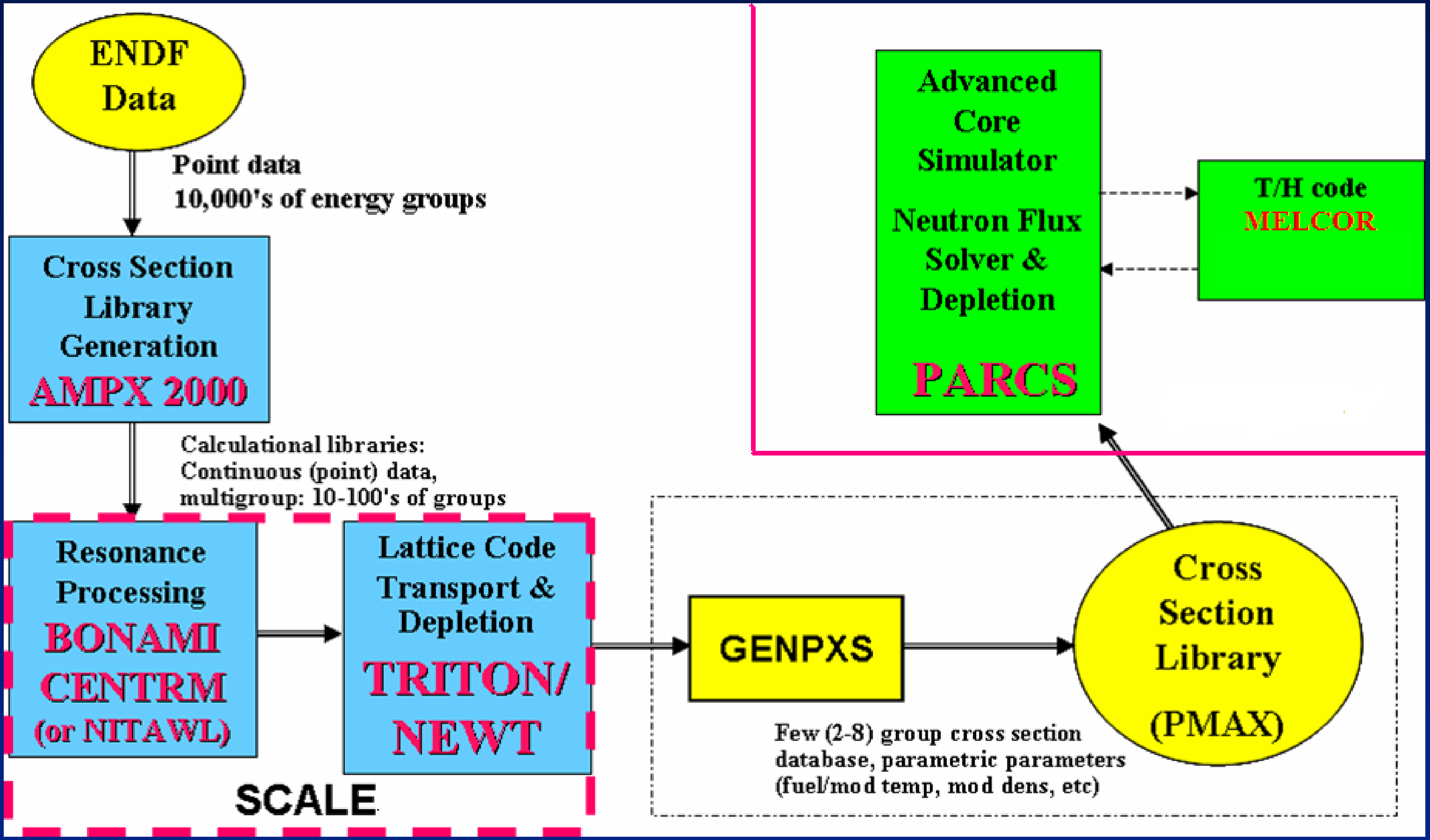
Introduction

- Objectives
- Summary of Current Status
- Review PIRT Findings
- Research Plans

Objective

- "…to establish and qualify the independent nuclear analysis capabilities and insights that may be needed to support the licensing evaluation of reactor safety analyses for PBR and PMR designs."

NRC Code Suite



ENDF Data

Point data
10,000's of energy groups

Cross Section Library Generation
AMPX 2000

Calculational libraries:
Continuous (point) data,
multigroup: 10-100's of groups

Resonance Processing
BONAMI
CENTRM
(or NITAWL)

Lattice Code Transport & Depletion
TRITON/ NEWT

SCALE

GENPXS

Cross Section Library
(PMAX)

Few (2-8) group cross section
database, parametric parameters
(fuel/mod temp, mod dens, etc)

Advanced Core Simulator

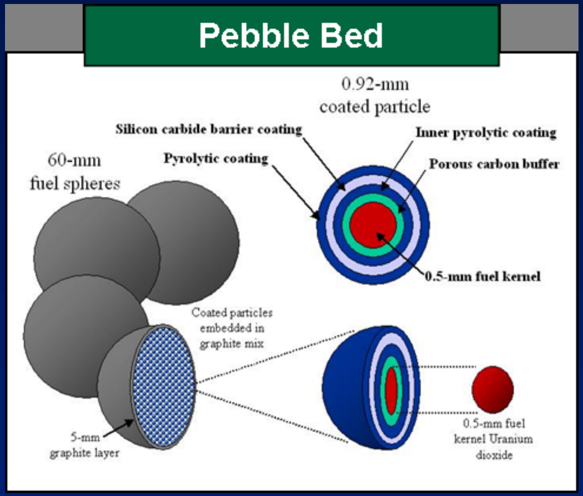
Neutron Flux Solver & Depletion

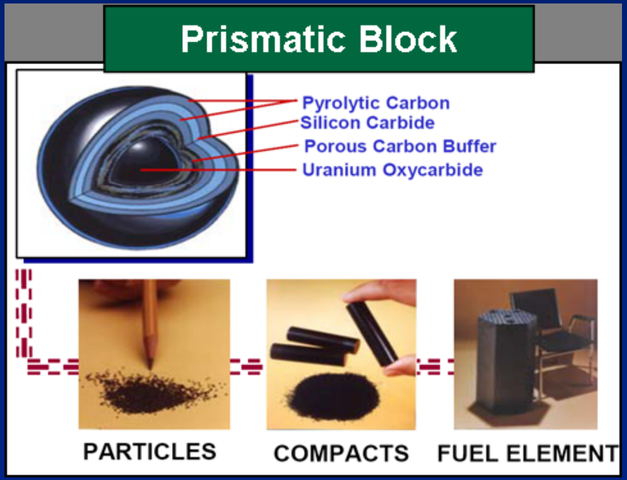
PARCS

T/H code
MELCOR

NRC Spectrum Analysis Capability

- TRISO
  - 1- D CE Transport Theory for Detailed Spectrum
- Fuel Sphere (or compact)
  - Uses TRISO averaged xsecs
  - 1-D CE Transport for Spectrum
- Assembly (or multiple pebbles)
  - Uses Sphere or Compact averaged xsecs
  - Multi-dimensional MG Transport Theory
- Makes Extensive use of pre-existing methods



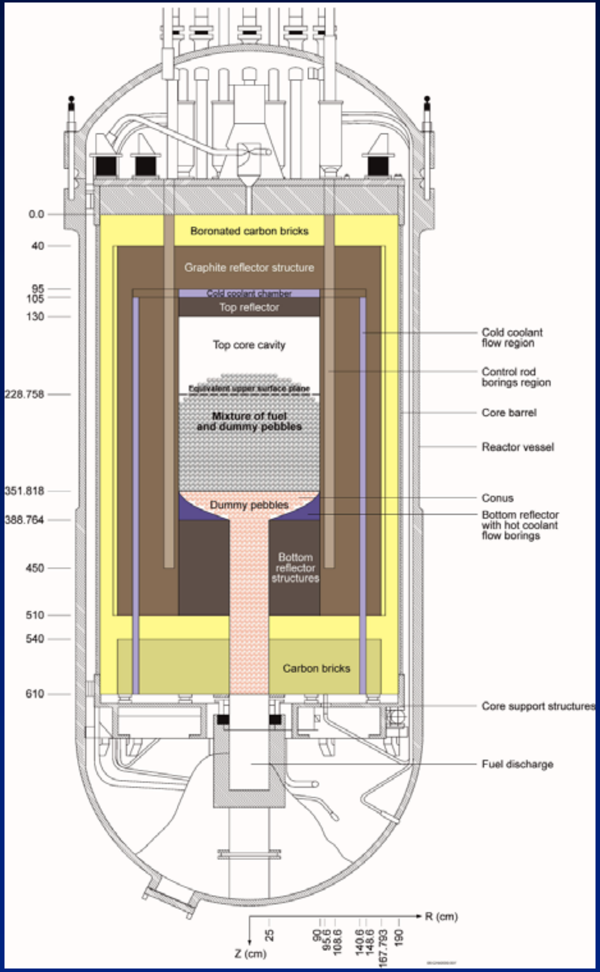


Summary of Current Status

- SCALE has working Double Heterogeneity Model Implemented
  - Uses layered continuous energy CENTRM calculations for self shielding
    - Calculated kernel specific disadvantage factors
    - Does not rely on Dancoff Factors
  - Initial Assessment is Promising
  - Applicable to both pebble and prismatic systems
- SCALE has general quadrature capable of modeling non-orthogonal boundaries
- Depletion and Branching of Double Het. Configurations implemented
  - Not extensively tested

HTR-10 Validation Model Development

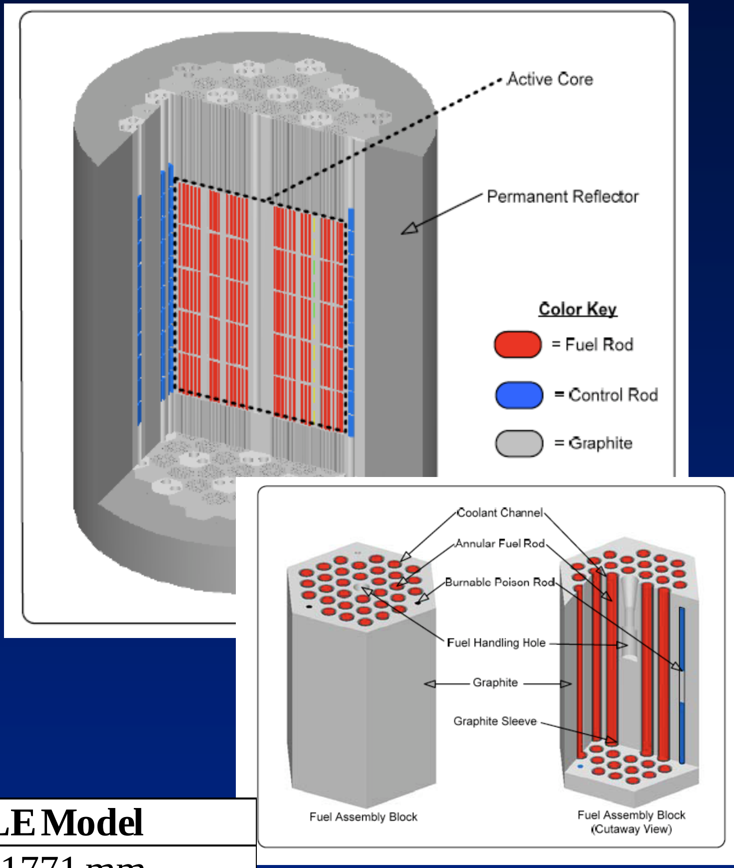
- Full model developed based on available specifications from IRPhEP Specifications
- Provides a validation case to support pebble-bed methods development.
- Used SCALE ENDF/B-VII cross section libraries, double-het capability and KENO Monte Carlo Code
- Benchmark configurations available for:
  - Initial criticality
  - Control rod worth
- Comparison of criticality at initial critical pebble height (123.06 cm)
  - SCALE keff = 1.0004±0.0007
- Control-rod worth calculations underway



DeHart, et .al., “Status Report on the Validation of the SCALE Code System for High-Temperature Gas-Cooled Reactor Analysis,” July 30, 2008.

HTTR Validation Model

- Full model developed based on IAEA CRP5 Documents.
- Provides a validation model for prismatic core methods
- Data Available for:
  - Critical configurations with differing number of fuel columns
  - Control rod worth and scram reactivity
  - Crticiality vs isothermal temperature (temperature coef)
- Full SCALE model developed (cross section processing/KENO)



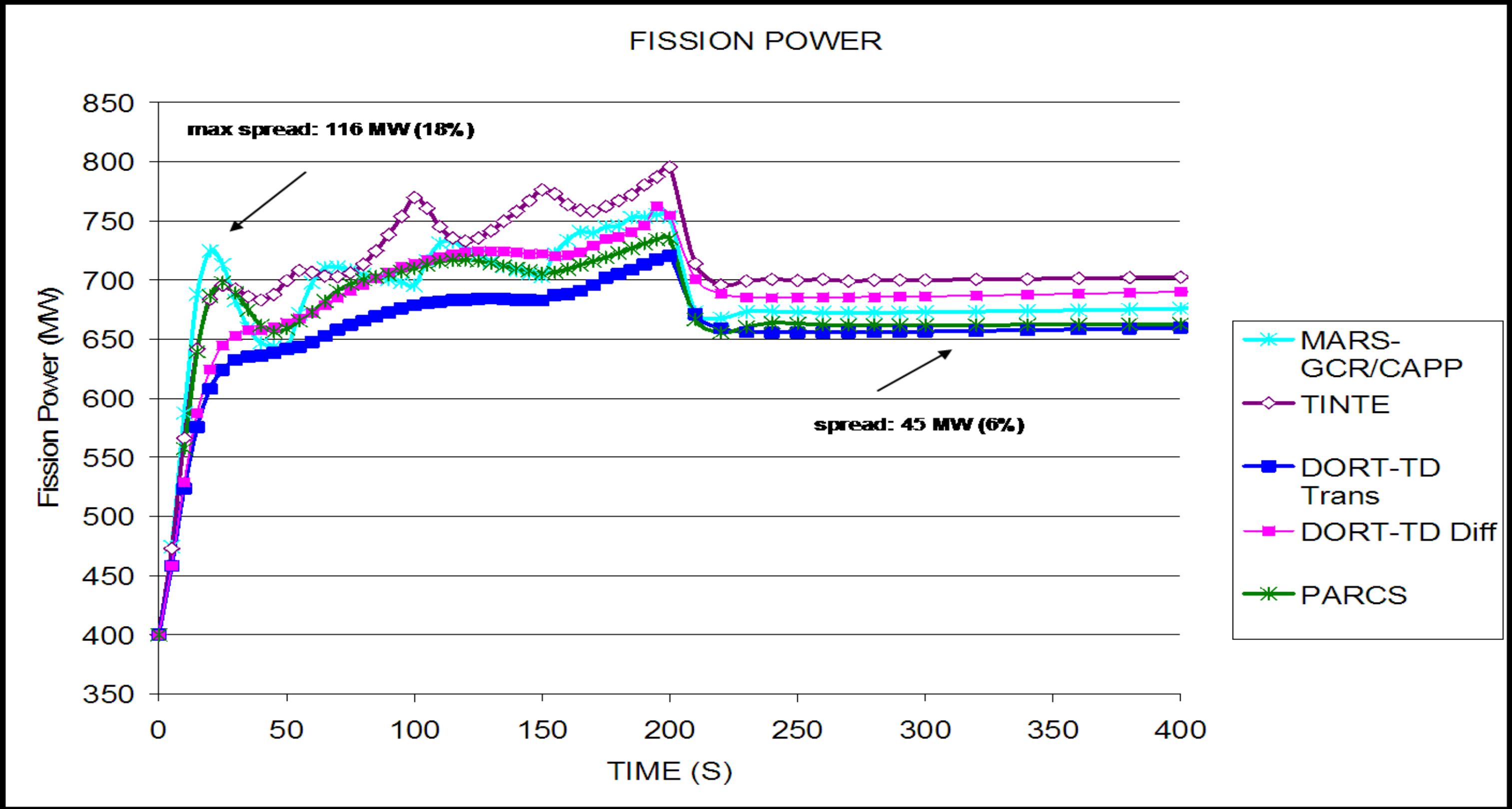
	HTTR Experiment	SCALE Model
Critical Control Rod Location (300K)	1775 ± 5 mm	1771 mm
Critical Control Location (418K)	1903 ± 5 mm	1899 mm
Control Rod Excess Reactivity	12.1 % Δk/k	11.9 % Δk/k
Control Rod SCRAM Reactivity	-46.3 % Δk/k	-45.9 % Δk/k

Ames, et. al. “BENCHMARK EFFORTS TO SUPPORT STUDIES OF VHTRs WITH TRUs,” HTR2008, Washington D.C., October 1, 2008.

NRC Reactor Analysis Capability

- GenPMAXS
  - Currently handles TRITON generated cross sections
- PARCS
  - Cylindrical coordinate solver implemented
  - N-group capability with upscattering

PBMR-400 Benchmark Slow Control Bank Withdrawal



Reitsma, et. al., "**OECD 400 MW PBMR BENCHMARK: TRANSIENT CASE 5a COMPARISON RESULTS," PHYSOR 2008, Interlaken, Switzerland, 2008.**

Review of PIRT Conclusions

- Nuclear Phenomena Ranked High or of Low or Medium Knowledge Level
  - Flux and Power Profiles
  - Decay Heat
  - Temperature Dependent Reactivity Feedback
  - Reactivity Insertion from Moisture Ingress
  - Spatial Xenon Stability

Research Plans - Flux and Power Profiles

- We need to develop a fundamental understanding of system behavior
  - TSUNAMI methods will be used to better understand uncertainties
- Multi-tiered approach envisioned
  - Small scale studies
    - Kernel and pebble (or compact) level
  - Study available measured data
    - HTTR, HTR-10, PROTEUS, etc.
  - Prepare detailed models of NGNP system for sensitivity and parametric studies
  - Identify focus areas
- Prepare PARCS interface
  - Research homogenization / de-homogenization techniques
- Prepare Interface for Fission Product Release Calculations

Current Expectations

- Pebble systems more complex than prismatic
  - – Stochastic nature of burnup
  - – Homogenization / de-homogenization effects
  - – Validating predictions difficult
    - Method to measure kernel (and pebble) power unavailable
- Common Challenges
  - – Neutron scattering and streaming
  - – Enrichment
  - – Multi layered heterogeneity

Research Plans - Decay Heat

- Stay involved with standards work
- Point depletion models such as ORIGEN should be valid
  - Properly weighted cross sections
  - Good predictions of power distribution
- Some applicable calorimetric data needed for validation

Research Plans - Spatial Xenon Instability

- Should be able to disposition analytically
  - – Assuming good prediction of core isotopics
- Confirm as part of startup physics program

Research Plans - Reactivity Coefficients

- Require fundamental understanding of phenomena
  - – Will require measured data
    - Ideally, we will have separate effects data
- SCALE to PARCS interface will strongly influence reactivity predictions
- Recent work by Dagan suggests problem with processing of scattering resonances
  - – CENTRM will be modified to assess impact
  - – High temperature data will be needed to complete assessment
- TSUNAMI will be used to assess uncertainties

Validation of Physics Methods

- ORNL has performed an initial review of available experimental data that can be used for validation of our physics methods
- Validation needed for:
  - Criticality
  - Power distribution
  - Reactivity control worth
  - Reactivity coefficients (fuel/moderator temperature)
  - Decay heat
  - Radionuclide source terms
- Initial focus on establishing a pebble-bed and prismatic core model to assess current methods and use for testing during methods development
- Take advantage of large amount of international data.

Sources of Experimental Data - Current Facilities

- High Temperature Test Reactor (HTTR)
  - 30MW prismatic reactor, JAEA, Japan
  - Currently operational
  - Well-documented startup experiments (IAEA CRP)
- High Temperature Gas-Cooled Reactor (HTR-10)
  - 10MWt pebble-bed reactor Tsinghua University, China
  - Currently operation
  - Well-documented startup experiments (IAEA CRP, OECD/NEA IRPHeP)
- ASTRA Critical Facility
  - Zero-power critical facility, RRC-Kurchatov Institute, Russia
  - Pebble-bed configuration supporting PBMR
  - Critical states available in evaluated experiment description

Sources of Experimental Data - Historical Facilities

- HTR-PROTEUS Critical Experiments
  - Zero-power critical experiments performed at PSI, Switzerland, in early 1990s
  - Pebble-bed configuration
  - Excellent documentation
- Very High Temperature Reactor Critical Assembly (VHTRC)
  - Critical assembly to support HTTR
  - Pin-in-block design
  - Documentation available
- DRAGON Reactor Experiment
  - 20MWt Experimental Reactor for OECD High Temperature Reactor Project, 1960s-1970s
  - Over 1000 archived reports available
  - Large amount of data to sort through and evaluate, some LEU experiments

Sources of Experimental Data - Prototype facilities

- Prototype facilities can provide useful information, but fuel enrichment (HEU) and type (U/Th) limits usefulness
- Prismatic cores:
  - Peach Bottom-1 (1967-1974)
  - Fort Saint Vrain (1977-1989)
- Pebble-bed cores:
  - AVR (1967-1988)
  - THTR (1983-1989)

Neutron Scattering in Graphite

- Recent NCSU work has raised some concerns about the adequacy of current scattering models
  - “Impact of Simple Carbon Interstitial Formations on Thermal Neutron Scattering in Graphite, ” Hawari, A. I., A. I. , Al-Qasir, I. I, and Ougouag, A. M, Nucl. Sci. Eng. 155, 449-462 (2007)
- Further work is planned
  - RES will continue to follow these developments and make code modifications as necessary

Near Term Actions (within the next several months)

- Develop OECD Standard Problem for Pebble Burnup
  - For presentation at February WPRS meeting
  - Intended to guide our assessment and development of burnup capability
- Refine list of data needs
- Continue scoping studies
- Begin detailed model development
  - Based on currently available HTR-10 and HTTR information

Expected work Scope for next Several Years

- Complete detailed assessment studies
  - Criticality
  - Power distribution
  - Reactivity control worth
  - Reactivity coefficients (fuel/moderator temperature)
  - Decay heat
  - Radionuclide source terms
- Update TSUNAMI as needed
- SCALE execution speed
  - It is expected that complex models will be needed as part of licensing
- Complete SCALE to PARCS interface
  - How to parameterize cross sections
  - Homogenization / de-homogenization

Summary

- Supports the NRC Evaluation Model development by developing, validating, and utilizing HTGR nuclear analysis models and methods
  - Nuclear analysis interface for fission product release calculations
  - Flux and power profiles, effects of burnup and isotopic distribution
  - Insights to support safety and licensing reviews
- Key Nuclear Analysis Challenges
  - Temperature-dependent reactivity feedback
  - Stochastic nature of burnup, homogenization/de-homogenization effects
  - Multilayered heterogeneity
  - Reactivity insertion from moisture ingress
  - Reliable prediction of fuel isotopics
- Ongoing and Planned R&D
  - Phased approach to SCALE and PARCS development for HTGRs
  - MELCOR-PARCS interface
  - Code assessment and validation
  - Neutron scattering properties of graphite

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Advanced Reactor Research Plan for Reactor-Plant Systems Analysis

J. M. Kelly

Office of Nuclear Regulatory Research
New and Advanced Reactors Branch

Reactor Plant Systems Analysis

- **Presentation Roadmap**
  - Overview of NRC Evaluation Model (this presentation)
  - Details of support for NRC Evaluation Model development by technical area:
    - Fuels Analysis: Stuart Rubin
    - Nuclear Analysis: Anthony Ulses
    - Thermal-Fluids Analysis: Stephen Bajorek
    - Accident Analysis: Allen Notafrancesco
    - Consequence Analysis: Jocelyn Mitchell

Reactor Plant Systems Analysis

- **Contents**
  - – Evaluation Model: Scope & Requirements
  - – NRC Evaluation Models for NGNP
  - – Role of CFD Analysis
    - Example of ongoing studies (time permitting)

Reactor Plant Systems Analysis

- **Evaluation Model**
  - Regulatory Guide (RG) 1.203:
    - *'An evaluation model (EM) is the calculational framework for evaluating the behavior of the reactor system during a postulated transient or design-basis accident. As such, the EM may include one or more computer programs, special models, and all other information needed to apply the calculational framework to a specific event.'*

Reactor Plant Systems Analysis

- **Scope**
  - Reactor/Plant System Analysis
    - FP Release from Confinement/Containment
      - Nuclear Analysis
      - Thermo-Fluids
      - Fuel Performance
      - Fission Product Transport
  - Applies to PBR and PMR designs
  - Consists of three EM’s
    - Normal Operations (Pre-Break)
    - Initial FP Release
    - Delayed FP Release

Reactor Plant Systems Analysis

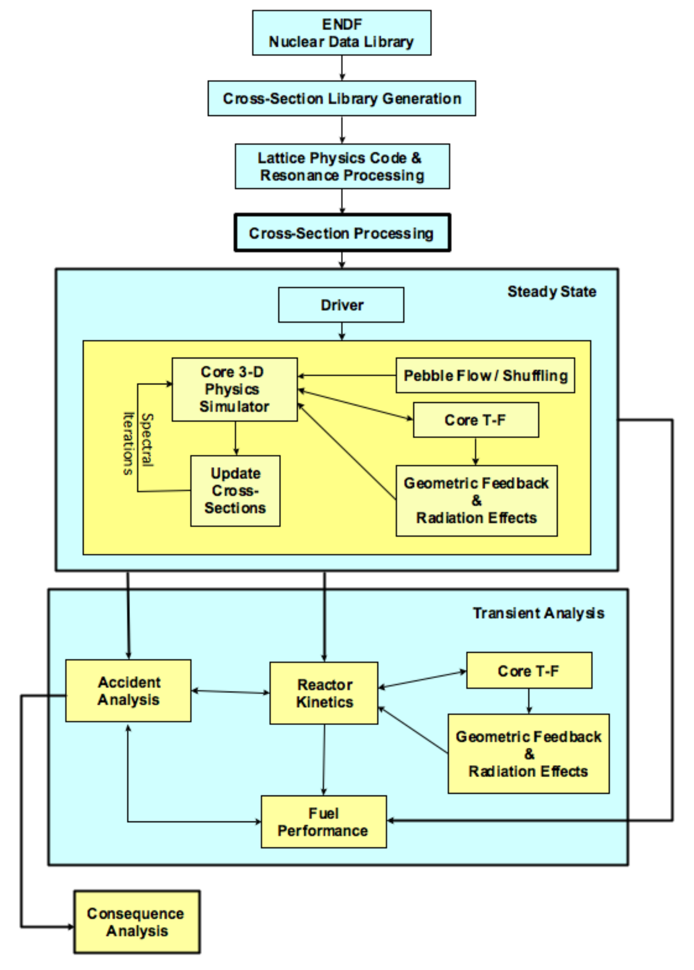
- **Evaluation Models**
  - Normal Operations
    - Determines the source term for the initial release.
      - i.e., the generation and distribution of FPs, magnitude and distribution of plate-out & absorbed FPs within He pressure boundary, circulating activity, coolant contaminant & erosion activation products, and dust-born radionuclides.
  - Initial Release
    - Models the release of circulating activity including dust mobilization and plate out lift-off; large/rapid reactivity events that result in CFP failures.
  - Delayed Release
    - Models the release of FPs from intact & failed CFPs during core heat up and with or without air or steam ingress; models FP hold-up and retention within the helium pressure boundary and the confinement.

Reactor Plant Systems Analysis

- **Examples of Transients to be Analyzed**
  - Pressurized loss-of-forced circulation (P-LOFC)
    - Temperature in upper vessel & associated components.
  - Depressurized loss-of-forced circulation (D-LOFC)
    - Peak fuel temperature; k_{eff} and RCCS performance.
  - Air Ingress following a D-LOFC
    - Graphite oxidation, integrity of core & support, CFP damage, release of fission products from graphite.
  - Reactivity Events, including ATWS
    - Control rod withdrawal, pebble-bed compaction, etc.
  - Water ingress
    - Reactivity insertion & chemical attack.

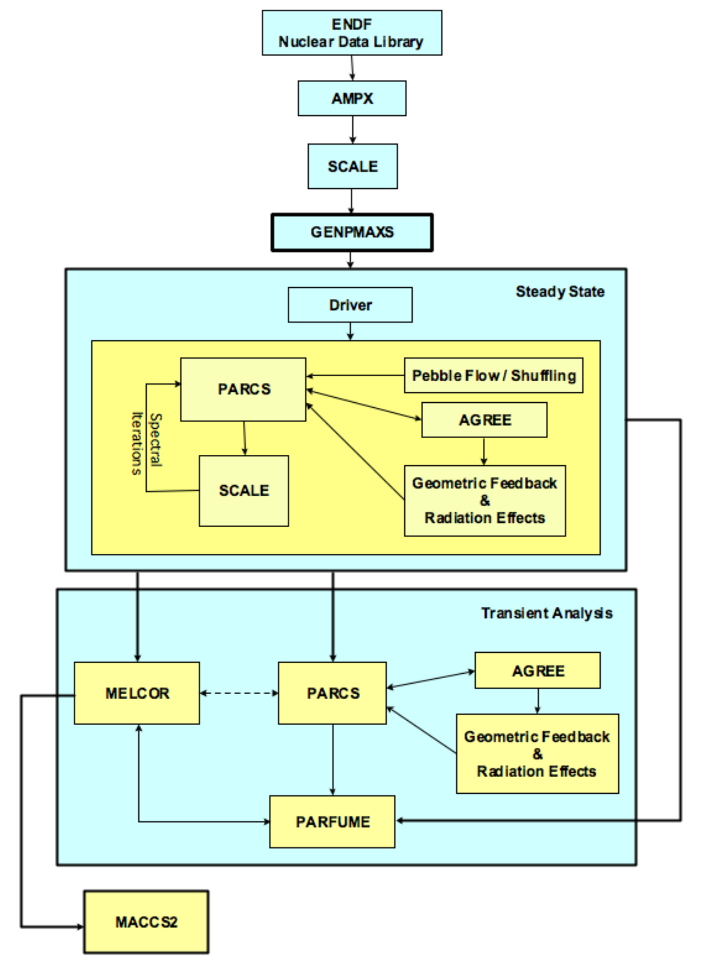
NGNP Evaluation Model

- By Function



ENDF Nuclear Data Library
Cross-Section Library Generation
Lattice Physics Code & Resonance Processing
Cross-Section Processing
Steady State
Driver
Core 3-D Physics Simulator
Pebble Flow / Shuffling
Core T-F
Spectral Iterations
Update Cross-Sections
Geometric Feedback & Radiation Effects
Transient Analysis
Accident Analysis
Reactor Kinetics
Core T-F
Geometric Feedback & Radiation Effects
Fuel Performance
Consequence Analysis

- Code Specific



ENDF Nuclear Data Library
AMPX
SCALE
GENPMAXS
Steady State
Driver
PARCS
Pebble Flow / Shuffling
AGREE
Spectral Iterations
SCALE
Geometric Feedback & Radiation Effects
Transient Analysis
MELCOR
PARCS
AGREE
Geometric Feedback & Radiation Effects
PARFUME
MACCS2

NGNP Evaluation Model

- **Development Tasks**
  - – Code & Model Development
  - – Code Integration
    - Automated workflow for EM code suite
  - – Uncertainty Analysis Methodology
    - Implementation of statistical approach
      - – e.g., Wilks’ method
    - Incorporation of model bias & uncertainty factors into codes
  - – PIRT Based Code Assessment
  - – Code Applicability Report

NGNP EM: Codes

- **MELCOR** - U.S. NRC Severe Accident Code
  - Solves 2D flow, heat transfer & fission product transport.
    - Core heat transfer & flow models: PBR & PMR
    - Graphite oxidation models
    - Extend aerosol models to graphite dust transport
    - Fission product release models for coated fuel particles
- **SCALE/AMPX** - U.S. NRC Nuclear Analysis Code Suite
  - AMPX processes ENDF nuclear data into code usable libraries
  - SCALE provides lattice physics and depletion capabilities to generate few-group cross-sections, decay heat and FP inventory.
- **PARFUME/TMAP4** - INL Mechanistic CFP Performance Codes
  - CFP failure rate vs. fuel temperature and BU from NGNP-specific CFP failure rate test data & PARFUME sensitivity studies
  - FP transport in a CFP, fuel matrix, and prismatic fuel block (TMAP4)
- **MACCS2** - U.S. NRC Accident Consequences Code
  - Estimates off-site consequences
  - Input source term, health, and site parameters

NGNP EM: Codes

- **PARCS** - U.S. NRC Advanced Reactor Core Neutronics Simulator
  - Solves 3D, Time Dependent Core Flux/Power Equations
  - Solves 3D Flux in both Cylindrical (PBR) and Hexagonal (PMR)
  - Benchmarked for PBR with OECD PBMR-400 Benchmark
- **AGREE** - **A**dvanced **G**as **RE**actor **E**valuation
  - 3D, two-temperature porous medium (PBR) approach based on the legacy THERMIX/DIREKT codes.
  - Coupled to PARCS to provide coupled time-dependent neutronics-thermo-fluid solution for gas reactors
  - Benchmarked with Julich SANA Test Experimental Data and OECD PBMR-400 Benchmark
  - Will be extended to model prismatic core.
- **GENPMAXS** - **GEN**erates **PMAXS** cross section files for PARCS
  - Reads SCALE/TRITON output at all burnup and temperature/fluid conditions and provides cross section library for PARCS

NGNP Evaluation Model

- Schedule
  - Code Development
    - Initial Model Development: Sept. 2010
    - Model Improvement
      - Based on Assessment Results: May 2013
  - Develop New Data: Sept. 2012
  - Validation:
    - Existing Data: Sept. 2012
    - New Data: May 2013
  - Code Adequacy Report: Dec. 2013

Role of CFD Analysis

- Not part of NRC EM, but used to
  - Provide benchmarks
  - Develop & select models for system level codes
- Examples of Potential Applications:
  - Lower Plenum:
    - Graphite oxidation during air ingress event.
  - Dust deposition and lift-off.
  - Reactor Cavity Cooling System:
    - Provide benchmark for MELCOR model: combined radiation & natural convection heat transfer.
    - Investigate effect of graphite dust on radiation heat transfer.
  - PMR & PBR Core
    - Bypass flow due to gaps between fuel/reflector blocks.

Role of CFD: Examples of Ongoing Studies

- Time & interest permitting

Role of CFD: Examples of Ongoing Studies

- Core Heat Transfer
  - – Pebble-Bed Reactors
    - Micro-Scale Model:
      - – Fuel kernel temperature distribution
      - – Effect of CFP clustering (hot spot factor)
    - CFD Modeling:
      - – Pressure Loss & Pebble-Gas Heat Transfer
        - » Randomly packed bed far from wall
        - » Randomly packed bed next to wall (reflector)
      - – Core Effective Thermal Conductivity
      - – Pebble Multi-Batch Modeling
      - – Whole Core Porous Body Model
        - » Provide benchmarks for MELCOR

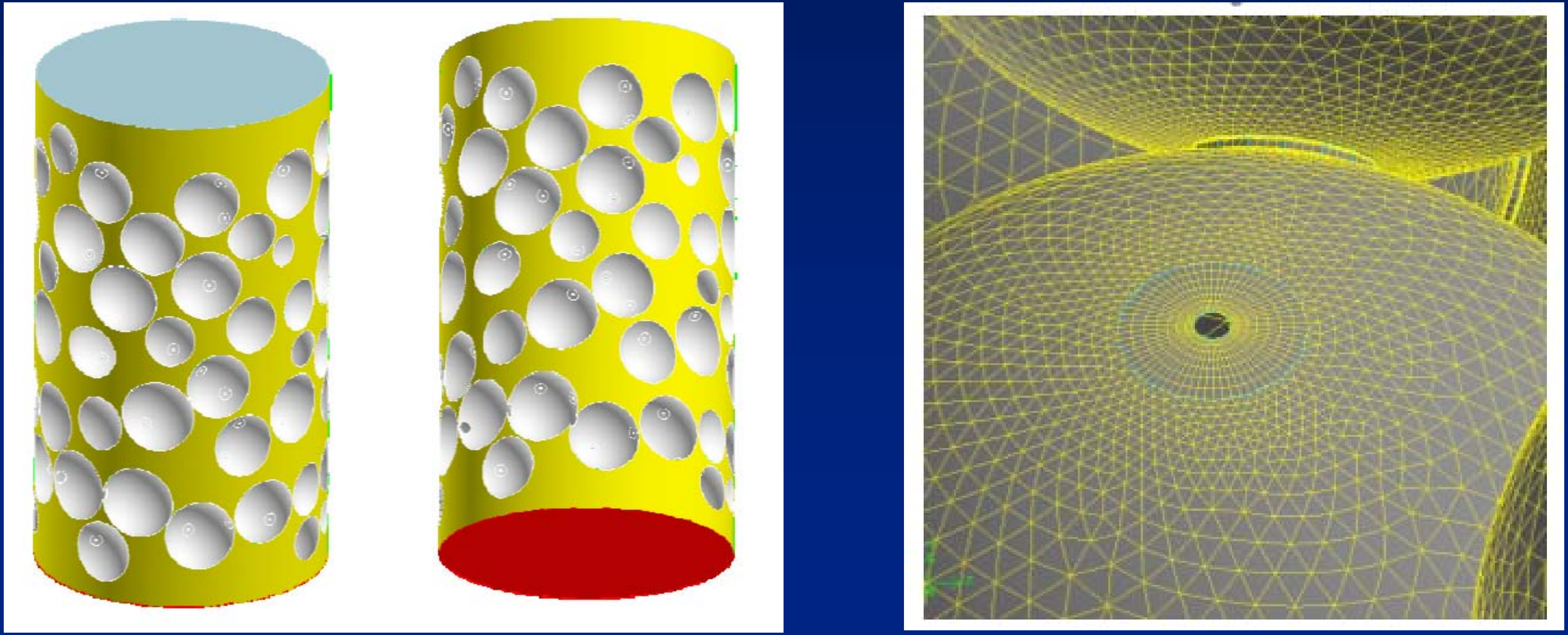
Role of CFD: Examples of Ongoing Studies

- Core Heat Transfer
  - – Prismatic Core Reactors
    - Meso-Scale Heat Transfer Model
      - – Temperature distribution within a fuel element
        - » Fuel compact surface & centerline temperatures
        - » Moderator (graphite block) temperature
        - » Coolant channel wall temperature
    - Macro-Scale Heat Transfer Model
      - – Effective thermal conductivity for heat transfer between fuel assemblies.

    - NOTE: meso-scale results have been used to develop a simplified model for MELCOR.

Role of CFD: Examples of Ongoing Studies

- Sample Results
  - – Meshing of a random packed pebble bed.
    - Remote from reflector wall (infinite medium)



Role of CFD: Examples of Ongoing Studies

- Sample Results: near reflector wall
  - Pressure Drop

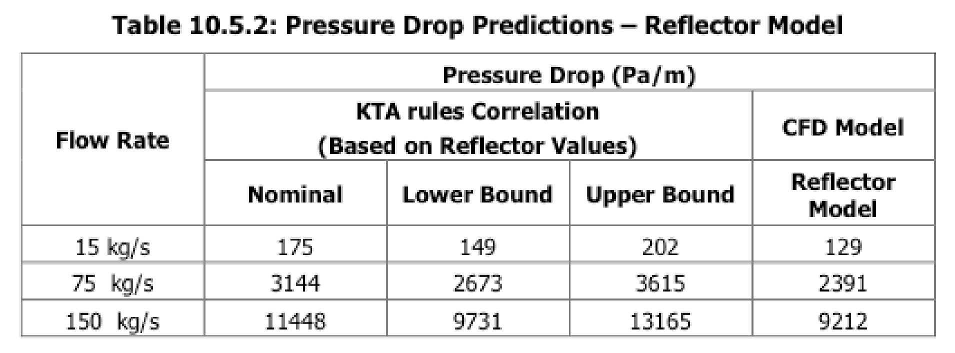
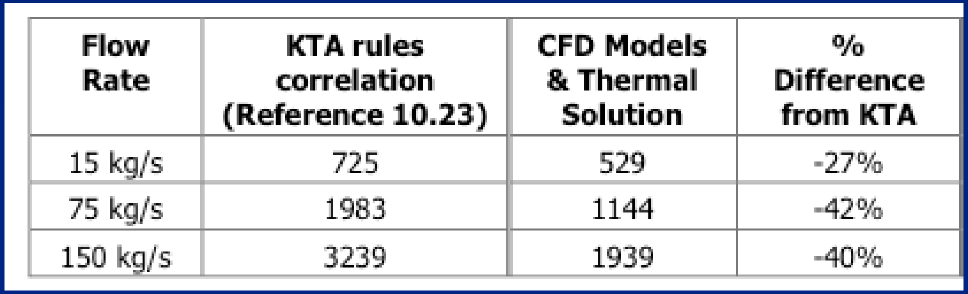


Table 10.5.2: Pressure Drop Predictions – Reflector Model

Flow Rate	Pressure Drop (Pa/m)			
	KTA rules Correlation (Based on Reflector Values)			CFD Model
	Nominal	Lower Bound	Upper Bound	Reflector Model
15 kg/s	175	149	202	129
75 kg/s	3144	2673	3615	2391
150 kg/s	11448	9731	13165	9212

  - Pebble-Gas HTC.



Flow Rate	KTA rules correlation (Reference 10.23)	CFD Models & Thermal Solution	% Difference from KTA
15 kg/s	725	529	-27%
75 kg/s	1983	1144	-42%
150 kg/s	3239	1939	-40%

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HTGR Thermal-Fluids Research

Stephen M. Bajorek, Ph.D.
Office of Nuclear Regulatory Research

Presentation to the Advisory Committee on Reactor Safeguards
Subcommittee on Future Plant Designs
January 14, 2009

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Introduction & Background

- Thermal-Fluids R&D Objectives

- Major HTGR Thermal-Fluid Issues
  - Thermal-Fluids PIRT Rankings
  - Approach
  - Products & Relation to EM Development

- Experimental Data & Facilities
  - Safety Significant Data Needs
  - Sources

Thermal-Fluids R&D Objectives

- Support the NRC Evaluation Model development by:
  - Obtain and/or generate integral and separate effects data suitable for code assessment & model development.
    - DOE & Applicant Data
    - Collaboration with international organizations.
    - Conduct independent experiments:
      - Thermal-Hydraulic Institute (THI)
      - OSU/TAMU/PU Cooperative Agreement
  - Develop or identify correlations for HTGR processes as necessary.

PIRT Identified Processes of Significant Interest

(Importance = H and Knowledge Level = M or L)

- Core & Vessel Thermal-Fluids
  - Core effective thermal conductivity (PBR)
  - Thermal properties
    - Vessel, Core Barrel & Reflector emissivities
    - Gas mixture properties
  - Bypass and coolant flow distribution
  - Heat transfer correlations
    - Mixed convection
    - Coolant property variation (viscosity, mixture effects)
- Air Ingress
  - Duct exchange flow
  - Molecular diffusion
  - Oxidation of core and supports

PIRT Identified Processes of Significant Interest

- RCCS Performance
  - Cavity air circulation & heat transfer
  - Thermal radiation
    - RCCS panel and vessel emissivities
    - Participating media (.i.e. “gray gas” effect)
  - RCCS failure assumptions
    - Failure of 1 of 2 channel (asymmetry)
    - Failure of both channels (concrete thermal response)
  - RCCS internal side heat transfer
    - Parallel channel interactions
    - Forced-natural circulation transitions
    - Boiling and two-phase phenomena

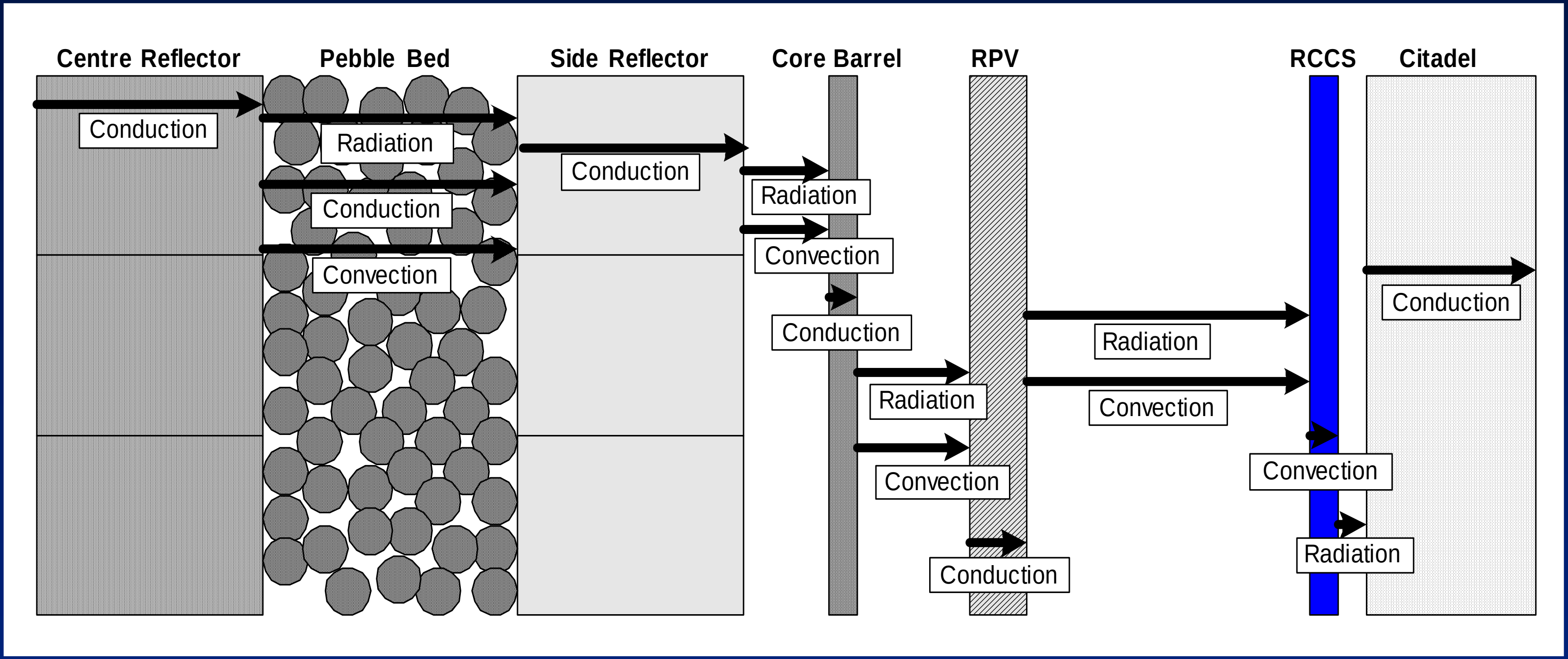
PIRT Identified Processes of Significant Interest

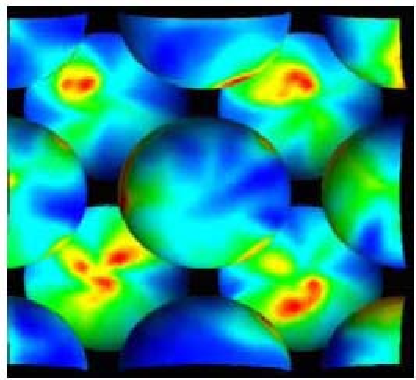
- Graphite “Dust” Phenomena
  - Hydrodynamic conditions for dust suspension.
    - Coolant velocity for liftoff
    - Suspension & carryover
  - Dust effect on coolant properties and flow.
  - Cavity filtering performance

Note: Graphite “Dust” is an issue primarily for PBR and with D-LOFC scenarios.

Note: Generation rate, FP content, size and shape distribution of graphite particles are also issues, but not specified in TF PIRT.

Introduction to Thermal-Fluid Technical Challenges





- Combined Mode Heat Transfer
- Bypass Flow

- Maximum Fuel Temperatures
- Local Temperature Variations

Core & Vessel Thermal-Fluids

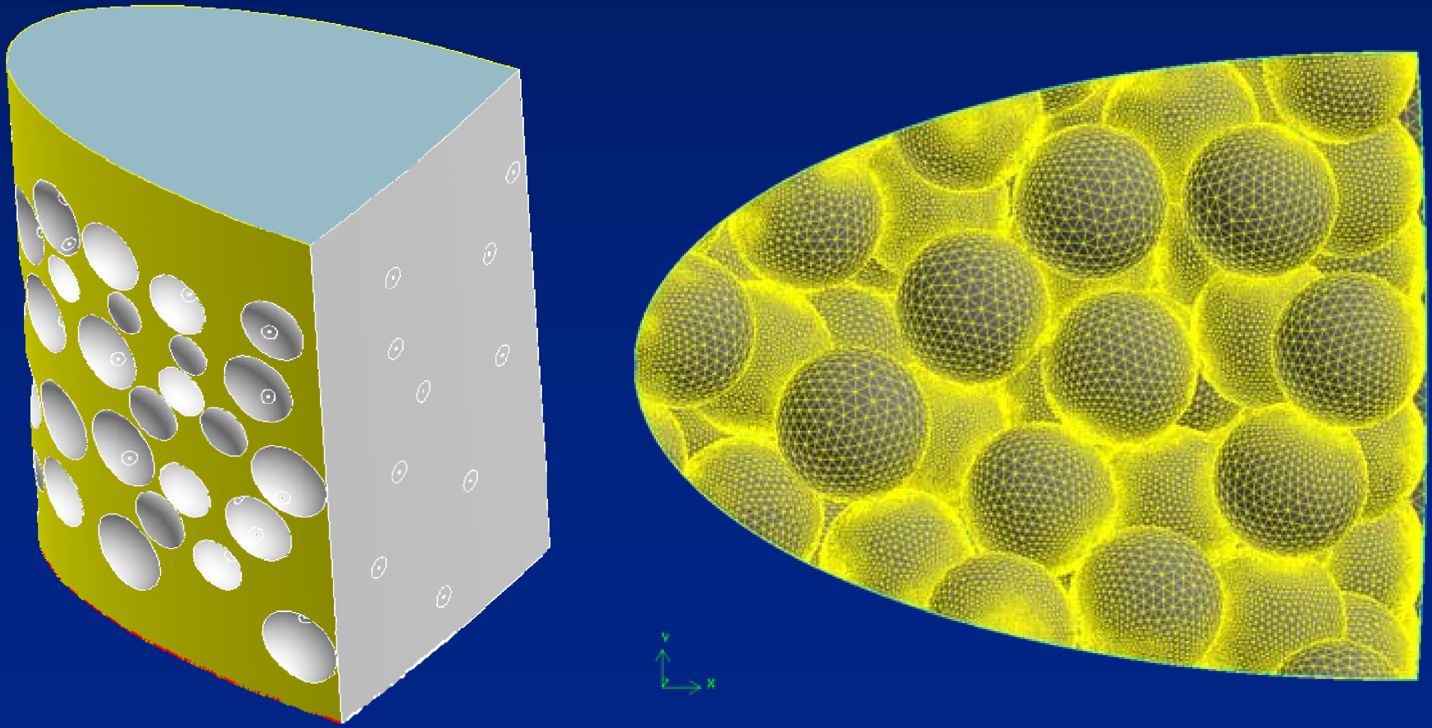
- Issues:
  - Limited convective heat transfer data exists at flow rates and temperatures expected in PBR or PMRs with helium as the coolant.
  - Properties of helium show large variations with temperature. Some uncertainty in properties for gas mixtures at high temperature.
  - Limited data to validate models for effective core thermal conductivity in PBR.
  - Bypass flows; flow along the reflectors (PBR) or through gaps in graphite (PMR), can account for a significant fraction of core flow.

Core & Vessel Thermal-Fluids

- Approach
  - Project initiated to review existing correlations for core effective thermal conductivity and use CFD to examine sensitivities (PBR). *- - - in progress*
  - Gas mixture properties reviewed, improved model recommended for MELCOR. *- - - in progress*
  - Make use of existing and/or applicant data (such as SANA or tests planned by PBMR, Inc.) to evaluate models for core convective heat transfer & bypass.
  - Conduct NRC sponsored SETs, if necessary.

Core Convective Heat Transfer

- Current Progress:
  - Assessing the several correlations for effective thermal conductivity and are attempting to validate CFD models.
  - Have examined effect of porosity (near- and far wall) on heat transfer and pressure drop.



Air Ingress

- Issues:
  - “Lock Exchange” Flow refers to the counter-flow of fluids with different densities past one another. Initial view was that air ingress was diffusion limited - which is incorrect for most break orientations of interest. Difficult process to calculate.
  - Data for natural circulation in a scaled facility is lacking. Confinement to reactor cavity air ingress data also lacking.
  - Graphite oxidation:
    - Where in core oxidation takes place
    - Oxidation kinetics, including graphite irradiation and O_2 content

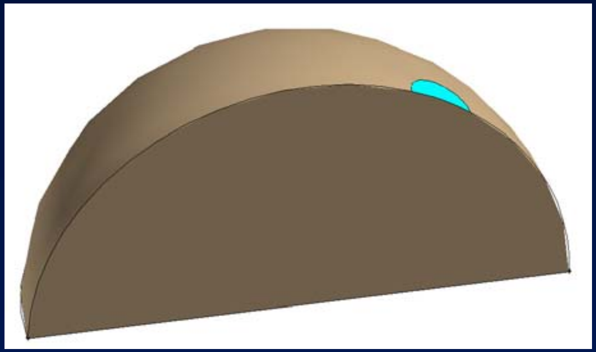
Air Ingress

- Approach:
  - Identified existing graphite oxidation rate models to be added to MELCOR. (Use existing models where applicable and evaluate on receipt of applicant data.)
  - Make use of existing and/or applicant data to evaluate modeling of air ingress and natural circulation in vessel.
  - NRC intends to conduct separate effects, and possibly integral effects tests to assist in model development and code assessment.

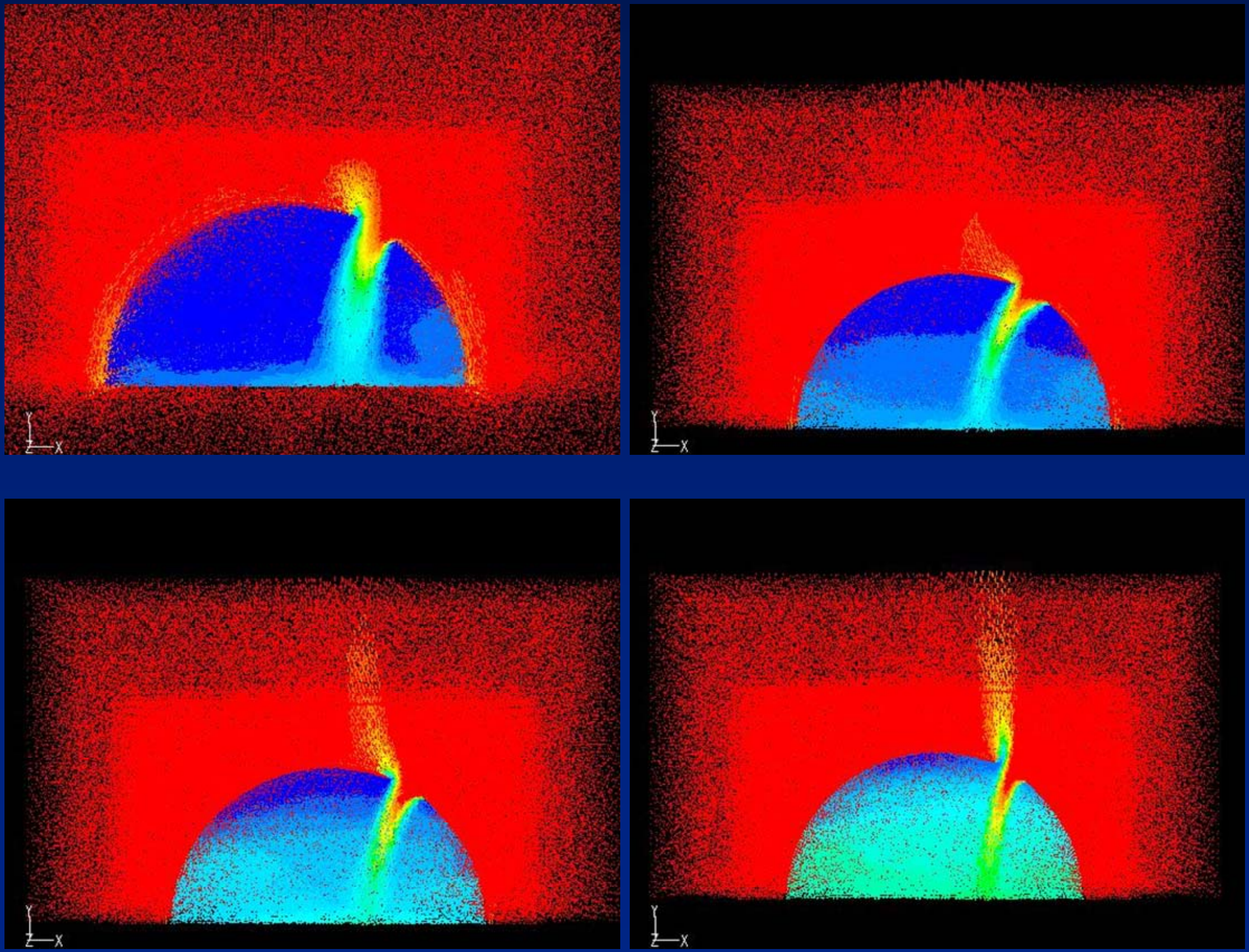
Air Ingress

- Current Progress:
  - Separate effects test currently being planned and test apparatus being designed. Data to provide air ingress flow rates for variety of break sizes, orientations, and geometries.
  - Exploratory CFD calculations made to confirm air ingress for top vessel breaks.
  - Plans for a small integral multi-purpose test rig to be considered. Intent would be a test loop to investigate natural circulation, air ingress, and particulate transport.

Air Ingress



Air ingress through vessel top break:
Blue = He / Red = Air



RCCS Performance

- Issues
  - Lack of prototypic data for vessel cavity air circulation & heat transfer. Difficult to benchmark codes for finding local hot spots.
  - Modeling of thermal radiation (including surface emissivities) and radiation-convention interactions.
  - Lack of data / modeling guidelines for RCCS performance with various failures. Asymmetric conditions may exist, affecting flows and heat transfer to cavity walls.
  - In-tube single phase and boiling heat transfer crucial to function. May be parallel channel interactions. Test data a major need.

RCCS Performance

- Approach:
  - RCCS performance is viewed as crucial in evaluation of a HTGR and licensing.
  - NRC will participate in experiments using the Natural Convection Shutdown Heat Removal Test Facility (NSTF) at ANL to investigate RCCS performance.
  - NRC would sponsor independent RCCS tests if necessary to meet schedule.

RCCS Performance

- Current Progress:
  - Preliminary CFD calculations initiated to explore modeling of “gray gas” in reactor cavity.
  - Experimental plans not started yet. Design information currently insufficient.

Graphite "Dust" Transport

- Issues
  - During normal operation, abrasion & vibration may generate graphite particles which can carry FP. These FP can escape the vessel through a break very early in an event.
  - Very little data available on graphite particle size/shape distribution, fluid conditions for lift-off, suspension and transport.
  - Graphite particles may impact heat transfer through effect on circulation and thermal radiation.

Graphite “Dust” Transport

- Approach:
  - Perform literature survey of graphite “dust” and its issues & identify existing applicable data.
  - NRC may need to conduct separate effects test(s) to develop models for MELCOR for graphite particle lift-off, transport, and deposition.

Graphite “Dust” Issues

- Current Progress
  - – Completed a literature survey on graphite dust issues; generation, size characterization, oxidation, etc.
  - – New issue that may be of concern is detonation.
  - – Test planning not started yet.

Experimental Database

- An extensive experimental database, including both integral and separate effects data is considered vital towards development.
- In preparation for EM development, NRC has compiled a survey of gas cooled reactor facilities that may be applicable to PBR or PMR.
- Participating in international (CSNI) activity (TAREF = Task on Advance Reactor Experimental Facilities) .

Experimental Database

Facility	Type	Status	Operator	Issue
HTTR	30 MW prismatic, nuclear core	Operating	JAERI	IET
HTR	10 MW, pebble bed, nuclear core	Operating	China	IET
HTTTR	Not specified.	Proposed	UT/GA	IET
NSTF	SET, non-nucl	Operating	ANL	RCCS
INWA	SET, non-nucl	Operating	Germany	RCCS
RCCS Fac.	SET, non-nucl	Planned	S.Korea	RCCS
Air Ingress	SET, non-nucl	Operating	JAERI	Air ingress

Experimental Database

Facility	Type	Status	Operator	Issue
NACOK	SET, non-nucl	Operating	Germany	Air ingress, natural circ.
SANA	SET, non-nucl	Operating	Germany	Pebble bed core heat transfer
MIR	SET, non-nucl	Operating	INL	LP streaking, turbulent mixing
AVR	pebble bed, nuclear core	Shutdown	Germany	IET
HTF	SET, non-nucl	Planned	PBMR, Inc.	Aux systems, misc.
PBMM	SET, non-nucl	Complete	PBMR, Inc.	Brayton cycle tests
HTTF	SET, non-nucl	Planned	PBMR, Inc.	Core TF
HELITE	He Loop	Operating	CEA	IHX, Component

Outlook on Infrastructure Needs

- Separate effects data exist for many of the HTGR TF processes. However, most of these data are currently unavailable to the staff. Cooperative agreements & access to existing data is crucial.

- The staff may need independent SET data for new model development where only Proprietary info will exist.

- The staff will need access to a well scaled integral effects facility for any design licensed in order to investigate multiple system failures and safety system performance.

Thermal-Fluids Research Summary

- Thermal-Fluids research has been initiated, with the intent to provide data for the staff's EM development and assessment.

- CFD is being used to help guide decisions on EM development and well as in identification of necessary test programs.