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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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X-ENERGY DESIGN CENTERED SUBCOMMITTEE

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TUESDAY

JUNE 3, 2025

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The Subcommittee met via Video Teleconference, at 8:30 a.m. EDT, Robert Martin, Chair, presiding.

COMMITTEE MEMBERS:

ROBERT P. MARTIN, Chair
DAVID A. PETTI
RONALD G. BALLINGER
VICKI M. BIER
VESNA B. DIMITRIJEVIC
CRAIG D. HARRINGTON
GREGORY H. HALNON
WALTER L. KIRCHNER
SCOTT P. PALMTAG
THOMAS E. ROBERTS

ACRS CONSULTANT:

DENNIS C. BLEY

DESIGNATED FEDERAL OFFICIAL:

DEREK A. WIDMAYER

ALSO PRESENT:

INSEOK BAEK, NRR
PAOLO BALESTRA, X-energy
TIM DRZEWIECKI, NRR
BRIAN FROESE, X-energy
BRIAN HALLEE, X-energy
MILAN HANUS, X-energy
RICHARD RIVERA, NRR
PRAVIN SAWANT, NRR
MATT THOMAS, X-energy
TRAVIS TATE, NRR

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

8:30 a.m.

CHAIR MARTIN: The time is 8:30. Thank you. The meeting will now come to order. This is a meeting of the X-Energy Design Center Subcommittee, the Advisory Committee on Reactor Safeguards.

I am Robert Martin, Chairman of today's Subcommittee meeting. ACRS Members in attendance are Ron Ballinger, Vicki Bier, Craig Harrington, Scott Palmtag, Dave Petty, Tom Roberts, Matt Sunseri, myself. We will also, oh, Walt's here. Walt Kirchner. Sorry, I thought you were out. And Greg might join us, should join us here a little bit later.

And ACRS Members in attendance virtually via Teams are Vesna Dimitrijevic. Sorry. We have two, oh, we only have one consultant that will be here, and not immediately. That will be Dennis Bley. He will show up for the source term TR here which that's going to be in the afternoon.

If I have missed anybody, either ACRS Members or Consultants, please speak up now. Derek Widmayer of the ACRS Staff is designated federal officer for this meeting. No member conflict of interest were identified for today's meeting. And we have a quorum.

During today's meeting the Subcommittee will receive a briefing on three X-Energy topical reports. And the Staff's draft safety evaluations for these reports.

Topical reports in order of our discussion today are Transient and Safety Analysis Methodology, Rev. 2, GOTHIC and Flownex Analysis Code Qualification, Rev. 3, the Mechanistic Source Term Approach, Rev. 3. These three topical reports are important to understand the safety basis for the Xe-100 small module reactor as we get closer to these reactors being deployed.

We're reviewing these topical reports because they serve as foundational analysis and qualifying approaches for the safety basis of the Xe-100 reactor.

The ACRS was established by statute and is governed by the Federal Advisory Committee Act, the FACA. The NRC implements FACA in accordance with our regulations. Per these regulations and the Committee's bylaws, the ACRS speaks only through its published letter reports. All Member comments should be regarded as only the official opinion of that Member, not a Committee position.

All relevant information related to ACRS activities, such as letters, rules for meeting participation and transcripts are located on the NRC public website and can be easily found by typing "about us ACRS" in the search field on NRC's homepage.

The ACRS consists of the Agency's value of public transparency and regulation of nuclear facilities provides opportunities for public input and comment during our proceedings. They have received no written statements or requests to make an oral statement from the public. We have also set aside time at the end of the meeting for public comments.

Portions of this meeting may be closed to protect sensitive information as required by FACA, and the Government and Sunshine Act. We have reserved a portion of this meeting at the end of each morning, and afternoon, actually, I think it's just, oh, we do have it posted for morning and the afternoon. Sorry. In the event that this is needed.

Attendance during the closed portion of the meeting will be limited to NRC Staff and its consultants. X-Energy Personnel and Consultants. And those individuals and organizations who have entered into appropriate confidential agreement. We have, we will confirm that only eligible individuals are in the closed portion of the meeting if they are needed.

ACRS will gather information, analyze relevant issues and facts and formally propose conclusions and recommendations as appropriate for deliberation by the Full Committee.

The transcript of the meeting is being kept and will be posted on our website. When addressing the Subcommittee participants should first identify themselves and speak with sufficient clarity and volume so they may be readily heard. If you are not speaking please mute your computer on Teams or by pressing *6 on the phone. Notice how close I am to the microphone, so use that as a guide.

Please do not use the Teams chat feature to conduct sidebar discussions related to the presentation, rather limit use of the meeting function to report IT problems.

For everyone in the room please put all your electronic devices in silent mode and mute your laptop computers. And your microphones and speakers.

In addition, please keep the sidebar discussions in the room to a minimum since the ceiling microphones, one behind me, are live. For the presenters, your table microphones are unidirectional and you'll need to speak into the front of the microphone to be heard.

Finally, if you have any feedback for the ACRS about today's meeting we encourage you to fill out public meeting feedback form on the NRC website.

We will now proceed with the meeting. And I call Travis Tate from the Office of Nuclear Reactor Regulation for opening remarks.

MR. TATE: Good morning. Can we get the opening remarks slide?

(Pause.)

MR. FROESE: I can stop sharing. These are my slides. X-Energy slides.

MR. TATE: I'll just go ahead. Go ahead, because I got them.

Good morning. Thank you, Chair Martin and Committee Members for the opportunity to present today on the evaluation model topical reports for the X-Energy's Xe-100 design. I'm Travis Tate, chief of Advance Reactor Technical Branch 1 in the Division of Advance Reactors and Non-power Production at Utility Facilities, or DANU, in the Office of Nuclear Reactor Regulations.

Next slide. Today you will hear X-Energy representatives who will a summary of each of the three of the four topical reports listed on this slide, followed by the NRC Staff who will discuss its review of the topical reports. The fourth topical reported, the reactor core design methods and analysis topical report is not included for ACRS review.

The NRC Staff documented its review with the three topical reports discussed today in a trial tip safety evaluation reports dated May the 6th, 2025. These topical reports are referenced in the recently docketed Long Mott Generating Station Construction Permit Application.

Next slide please. The Staff's review of these topical reports involve bring it together technical expertise from DANU, the Office of Research and contractor staff. The Staff review was focused on acceptability of the methodology which was used to ensure appropriate implementation to be performed as part of the separate licensing actions.

Today you will hear from only a few of the Staff listed in this, in the review. Involved in the review. But they represent the tremendous efforts of a highly skilled review team of technical reviewers reflected on this and the following slides.

Next slide. Thank you again for the opportunity to present today. And we look forward to the following discussions to hear your observations and feedback. And with that, now I will turn it over to X-Energy to begin their presentation.

(Pause.)

MR. FROESE: Okay. Good morning, everyone. Thank you all for joining. My name is Brian Froese. I am the project manager of our analysis integration team on Project Long Mott, which is our ARDP site.

Prior to going through the individual topical report presentations we first wanted to give just a high-level overview of our analysis topical report framework to kind of set the stage for the rest of the day. So with that we've got a lot to cover. I appreciate you all being here, and we'll go ahead and jump in.

So as I said, the objective, provide a high-level overview of X-Energy's safety analysis process background on our three topical reports. And a brief summary of the safety evaluations based on audits by the Staff. We've already gone through the names of the topical reports so I won't repeat those.

Regulatory basis. I'm sure we'll get into this more throughout the course of the day, but the main ones that we're working today, 10 CFR 50.34, primarily the parts that comprise the components of construction permit application. And that also sets design basis accident, offsite dose limits, 25 rem at the exclusionary boundary and low population zone. And also Reg Guide 1.203, which is our transient safety analysis methodology framework regulatory guide for development of those methods.

Wanted to give an overview of our safety analysis process. Generally what happens is there is a design freeze, either design milestone or self-imposed design freeze. Based on that design our PRA Team creates a series of licensing basis events in accordance with NEI 18-04.

(Off record comments.)

MR. FROESE: Our probabilistic risk assessment team develops a series of licensing basis events. Those are passed to the safety analysis team to do a thermal hydraulic analysis in both Flownex and GOTHIC. And we'll get into the difference in use between those codes later on in later presentations.

Key parameters from those thermal hydraulic evaluations are passed to the offsite dose calculation team where we used our in-house develop mechanistic source term code called XSTERM to determine offsite dose. Those offsite doses are then passed to the PRA team, back to the PRA team to do a technical adequacy determination and a licensing assessment mainly if we meet the 25 rem, 50.34 EAB and LPZ dose criteria. And then we pass through key parts back to the design.

It doesn't always work this perfectly. A lot of things are done in parallel, which is generally just the way that the process works.

The two boxes on the right-hand side highlighted in green are what three topical reports that we're going to talk about today primarily in this forum.

MR. TATE: I have my first question.

MR. FROESE: Yes, sir.

MR. TATE: How many times have you been through this cycle?

MR. FROESE: Approximately three.

MR. TATE: Approximately three. Okay. So you got a little bit of maturity, but you probably foresee a few more.

MR. FROESE: That's correct.

MR. TATE: So have, well. And you, of course you're here and you're supporting the construction permit application, so I'm thinking three is, three is appropriate at this stage. Typically five, six, seven is probably what you need.

MR. FROESE: Feels about right.

MR. TATE: Feels about right.

MR. FROESE: So prior to jumping into the individual topical reports I kind of wanted to anchor our discussion by highlighting a couple of the key safety features of the Xe-100. Three specifically, which also align with three of our required safety functions.

The first, control reactivity. The Xe-100 can shutdown passively just on inherent reactivity feedback without control rod insertion. Right? So if we ever had to, we can trip the circulators, the core temperature profile changes which changes the neutronics. And you can shutdown reactor power just on inherent reactivity feedback without rod insertion, unlike light water reactors.

Similar, control for control heat removal, the Xe-100 can passively remove decay heat through our, what we call our reactor cavity cooling system, or our RCCS. No active components and no operator reactions credibility.

So similarly, if we needed to we could trip the circulators, shutdown the reactor just on inherent reactivity feedback, and then decay heat can passively migrate from the pebbles, down to the reflectors, out to the reactor pressure vessel. And that radiates to out RCCS, which is a series of water filled stand pipes just passively boil off.

And the last one here, retain radionuclides, reutilize the functional containment, which I'm sure you're aware of. It's our TRISO particles. You retain a significant portion of radionuclides during normal operation, as well as licensing basis events. So unlike light water reactor, design basis accidents where you have a potential fuel melt, there is no credible accident for our TRISO, TRISO fuel to be able to melt. And as a result those radionuclides stay within the particles. And that leads to considerably lower offsite doses.

MEMBER PALMTAG: Before you move on. This is Scott Palmtag. This is, can you go back? This is always one of my questions. But it says it can shutdown passively on inherent reactivity feedback. What do you mean by that? Is that zero power or a new stable power?

MR. FROESE: It's, it goes down to decay heat.

MEMBER PALMTAG: Oh.

MR. FROESE: So yes, zero fission power.

MEMBER PALMTAG: So you're not going to find a new power balance that will balance out the reactivity feedback, it will actually go down to zero power?

MR. FROESE: That's my understanding.

MEMBER PALMTAG: Thanks, Brian.

MEMBER PETTI: Until xenon --

MR. FROESE: That's correct.

MEMBER PETTI: -- and it will go critical if you haven't put the rods in.

MR. FROESE: Yes.

MEMBER PETTI: In the gas chamber.

MR. FROESE: yes, that's correct.

MEMBER PALMTAG: It's usually with the feedback. I'm sorry. Your temperature goes up, your power is going to do down, but it's going to find a new equilibrium. So how do you go down to the zero?

MR. FROESE: Hey, Sonat, are you on, online? I think you are. Would you mind --

MR. SEN: Yes I am, Brian.

MR. FROESE: -- commenting?

MR. SEN: It all depends on how much the temperature increase. The temperature will increase and you will get to a certain equilibrium, a new power level, if it's not as much increase in the temperature. And you will get to normal operation conditions with the high power, with the similar temperatures or a little bit higher.

But if temperature increase, and there is no cooling, the temperature increases, you will get to zero power until the temperatures cool down significant, which is about 100, 130 hours. So then you will get to a new criticality. So that basically depends on the events.

MEMBER PALMTAG: Okay, thank you. I mean, we'll have to see the transient analysis before but it's going to, I'm not sure shutdown passively is the right word to use here. You got to go to a lower power usually.

MR. SEN: Yes. That's not exactly, it will go to lower power in every, it will, it's like a normal operating AOO. If you have an AOO you might get to a lower power, but usually like in the events that we analysis for the safety LBEs, that's credible, that usually goes to zero power. Zero fission power.

MEMBER PALMTAG: Okay, thank you.

MEMBER KIRCHNER: Because xenon builds in? You go to zero power because xenon builds in and heats up your excess reactivity.

MR. FROESE: That's correct.

MR. SEN: Yes, that's correct.

MEMBER KIRCHNER: But once you, once you

cool down it can come back to a different power level. It could be a lower power.

CHAIR MARTIN: Right. But --

MR. FROESE: It's varying.

CHAIR MARTIN: -- still --

MEMBER KIRCHNER: If it's not shutdown.

CHAIR MARTIN: -- it will stay pretty hot, you know.

MEMBER KIRCHNER: For a long time.

CHAIR MARTIN: Yes. And it probably exceeds the xenon effect so, which is, what, 12 hours? 24 hours. So yes. You know, you probably get a few days. The temperature will stay up, you know. I don't --

MEMBER PETTI: No, it stays hot.

MEMBER KIRCHNER: Yes. There is--

MEMBER PETTI: Yes. And then xenon runs out and you start to go critical, but it's a low critical. It's whatever the RCCS can remove --

MR. FROESE: That's correct. And we have seen that in our recalculations to look at, if it ever were to go recritical. Which is our safety related storing.

MEMBER PALMTAG: If there is no heat removal decay heat will add enough heat in there to keep the temperatures high to keep it shutdown, right? But if there is any heat removal it's going to come down in the power levels.

MR. FROESE: Yes, that's -- understood. Yes.

MEMBER PALMTAG: Okay.

MR. FROESE: Yes. And sorry, implicitly in talking about this, yes, as Sonat said, I was referring to design basis accidents where you get a higher temperature, core temperature profile. And so that keeps your reactor power lower, at least until xenon.

MEMBER PETTI: Can I just ask, is there any rationale to the ordering of this list? I would have thought pertaining to the nuclides would be number one and the other two would be subsidiary. But again, being a fuel person that's my perspective.

(Laughter.)

MR. FROESE: I appreciate that comment. Thank you.

So speaking of doses, I wanted to give a very high-level overview of the components that are including in our offsite dose calculations. That's this table on the left-hand side. We account for the circulating activity that's released and enhance liftoff of dust, particularly if there is a depressurization and there is dust that lifts off.

We account for activity release due to the fuel heating up during the accident. Right? So unlike light water reactors where you potentially melt through, we just have enhanced diffusion that comes out of the fuel as they heat up. And we account for that in both what we call the plant transient, or short-term, and long-term portions of the accident. We'll get into those in more detail in the upcoming presentations. But just trying to takeaway that it spans the entirety of the event.

And then if there is a steam generator tube rupture we also account for steam effects, as well as wash off effects.

The figure on the right-hand side is what we call our dose stack-up. This is essentially just the summation of all the different dose components. And the total of that is our offsite dose. We compare that to, we compare that to our offsite dose limits to make sure they're below the acceptance criteria.

This is an overview of our topical reports. As noted earlier, we use the NEI 18-04 process to determine licensing basis events, which are separated into anticipated operational occurrences, design basis events, beyond design basis events. And then the design basis accidents are prescriptively created from design basis events per NEI 18-04 by only crediting safety related equipment and using conservative inputs and assumptions.

Supporting the calculation and design basis accident offsite doses is our Reg Guide 1.203 design basis accident evaluation model. It's comprised of what will be four licensing topical reports. We have three of them so far today.

And so the main one is the TSAM. It primarily covers compliance with Reg Guide 1.203. And a summary of our safety analysis.

And supporting that is the GOTHIC Flownex topical report that covers the theory supporting the design basis accident evaluation model, model development, code qualification and code QA.

And also supporting the TSAM is our mechanistic source term licensing topical report that contains the MST theory. That will feed, what we intend to have, is a future XSTERM specific licensing topical report.

The reason that that's not in here today is because it's an in-house developed mechanistic source term code. It's still maturing and not quite ready for regulatory review. We're working hard towards that. And once it is we plan to submit a similar licensing topical report just on XSTERM that would feed methods, code qualification and code QA. But that will be the application of those MST methods that are described in the MST.

MEMBER PETTI: So what, how do I interpret the appendix to the source term topical event this afternoon?

Because it looks, looked to me like a partial theory there. Is that --

MR. FROESE: That's correct. It contains the --

MEMBER PETTI: So a lot of it would move into these formal LTRs?

MR. FROESE: Yes. The access term LTR is intended to be the application of the MST theory that's presented in that topical report.

One really quick clarification, just because it came up at the beginning of our audit with the NRC. Particularly that TSAM and the GOTHIC Flownex LTRs are written in such a way that we generically talk about all licensing basis events in those topical reports. The reason why we did that is because the methods and models we use for PSAR are the same between DBAs and non-DBAs, with the exception of the inputs and the assumptions that are used.

So we clarified in our outcome objectives of the topical report that we're specifically requesting approval to use these methods for preliminary analysis, but just for design basis accidents. Which is in alignment with NEI 18-04 that says to use Reg Guide 1.203 for only design basis accidents. So I just wanted to clarify that in case that question came up.

This is a summary of our draft safety evaluations. I'm sure we'll get into those in more detail with the staff, but our main takeaways for the per the mechanistic source term, licensing topical report, the NRC Staff concluded the topical report provides a reasonable plan for the development of the MST methodology. So we were very happy with the outcome of that.

There were no official limitations and conditions, but they did note that it's limited to the methods and not to the access term code.

The GOTHIC and Flownex topical report, main takeaway for us, the NRC Staff approves the use of the topical report for preliminary analysis of Xe-100 design basis accidents, but also aligns with our anticipated, our hopeful outcome. So that was good to see.

There was one limitation, and that was input parameters will be confirmed during the construction permit application review, which is what we excepted since this was focused on the methods and not on the inputs that were used.

And then for the TSAM topical report, there were three limitations and 14 conditions. Rather than going through all 17 I tried to boil these down into three main bullet points that were my, our takeaways.

The first is that these, this topical report is limited to preliminary analysis, preliminary design, and preliminary design basis accident selection.

The second is that if the existing data is not sufficient for compliance with Reg Guide 1.203, then we would need to fill that gap with research and development.

And the third main bullet, speaking of Reg Guide 1.203 is that compliance with that regulatory guide is still in progress. And the limitations and conditions capture that.

Key takeaway again here was, subject to

the limitations and conditions, use of the evaluation model described in the TSAM is acceptable for consequence evaluation, addressing PDC 19, 10 CFR 50.34 through preliminary safety analysis of the design and performance of Xe-100, and to describe a research plan as it's needed.

CHAIR MARTIN: Brian, this is Bob Martin. Is there a plan to submit a topical, maybe it's already been submitted, related to beyond design basis events? It says, you know, those related issues, cliff edge effects, such.

MR. FROESE: There is not currently planned a licensing topical report to be submitted on beyond design basis events.

MEMBER HARRINGTON: Yes, Brian, kind of a related question, similar to your unique limitation slide on DBEs versus DBAs. What you said made sense to me, which is, you know, use the same analysis methods but have different inputs for the different classes of training. But I'm wondering what else you would do because you still have a requirement to go produce the consequence curve for all the AOOs and the DBEs and, throughout the whole spectrum. You have to have some analysis methodology to believe those results.

So if you don't use the reg Guide 1.203 what do you use?

MR. FROESE: So for PRA there is the PRA technical adequacy standard that's used for non-light water reactors. As I described in the beginning of that, you know, let's circle how many times we go around.

The offside doses are feed back into the PRA team to do a technical adequacy determination. And we also do a licensing assessment for 50.34, which is for design basis accidents.

So it brings up a good point for, there is some additional analysis for certain PRA aspects to do longer distance max calculations that we're not doing for just the EAB and LPZ, but generally the methods for thermal hydraulics and mechanistic source term, just in the sense of, what is released from a reactor are effectively the same. Yes.

To answer your question, it's got to meet the PRA non-light water reactor steam --

MEMBER HARRINGTON: Okay, thanks. So instead of Reg Guide 1.203, the thermal hydraulic analysis quality is defined by the PRA standard?

MR. FROESE: That's correct.

MEMBER HARRINGTON: Okay, thank you.

MR. FROESE: Final takeaways. A tremendous amount of methodology development and analysis has been conducted by X-energy in preparation over the past, particularly over the past several years, in preparation for these topical reports and a construction permit application that was just recently submitted for Project Long Mott.

We're very proud of the work that we produced. We believe the methods support a strong safety case with considerable margin. But also recognizing, we are at the preliminary design phase and there is still work to be done. As an example, we plan on updating our PIRT to evolve based on our latest PSAR results.

So last thing, we just wanted to thank the NRC Staff for their guiding feedback and some really great review. You can tell that we put effort into this audit and into the review. Just very timely engagement, so just wanted to thank them for that.

If there are no more questions I think we can jump into the individual topical report sessions with TSAM and then GOTHIC, Flownex. That's all.

(Pause.)

MR. HALLEE: Good morning, everyone. It's a pleasure to be here with you, and thank you for having us. My name is Brian Hallee. I'm the CPA safety analysis manager for X-Energy for the Xe-100. And for this topic we'd like to walk through the licensing topical report covering the transient safety analysis methodology, or TSAM.

So how this presentation will flow. Forgive me for the front matter in setting up the stage here. I'll repeat some of the information Brian Froese just walked through. And then the intent of this is to walk through the TSAM report on how it aligns with the EMDAP elements and steps outlined in Reg Guide 1.203 primarily.

If there is time and interest for a closed session, we can walk through demonstration analysis. And then we'll wrap-up with the path forward for the TSAM.

So purpose of the TSAM report is primarily to define the evaluation model for the DBA transient safety analysis. We did demonstrate the analysis methodology at a high-level. For example, select example cases in the TSAM and its intended use as a basis for future licensing applications.

And in this presentation, primarily interested in outlining the TSAM as it applies to the DBA technology and highlighting alignment to the Reg

Guide 1.203, a 20 step, in-depth process.

Brian Froese, he mentioned this. Our guiding regulation is 10 CFR 50.34. Offsite dose EAB and LPZ limits and acceptance criteria outlined in that regulation. Key regulatory documents outlined in red here. Reg Guide 1.203 is the chief reg guide that we discuss and align to in the TSAM.

Reg Guide 1.233 is also mentioned. As Brian noted we have, we share the methodology in our approach to develop the PRA events for, that support the NEI 18-04 frequency-consequence curve.

As far as previous interactions with the NRC, we had a previous NRC safety evaluation written on the TSAM framework back in 2021. This TSAM attempts to address those limitations and conditions that were outlined on that framework.

We also have a safety evaluation report on the atmospheric dispersion methodology. So that specific aspect of the TSAM will not be mentioned here. And we have a safety evaluation report on the principle design criteria which were used to design our figures of merit and phenomena.

So just teeing up the Reg Guide 1.203 guidance. Reg Guide 1.203 is devised into four key elements described here. Establish the requirements of the evaluation model, develop the EMDAP base, assessment base, develop the actual evaluation model, and then assess its adequacy.

This figure was taken from the TSAM and just has a quick snapshot of where X-Energy was with the Xe-100 implementation at the time of developing the TSAM and the intent of this presentation as I'll walk through these in detail step-by-step and outline our current status and progress.

Just jumping right into Element 1. Step 1 is to define the analysis purpose, transient classes and power plant class. Our purpose is to evaluate the plant response for the DBAs, verify the safety-related SSCs meet their safety functions, as Brian mentioned, and comply with 10 CFR 50.34 criteria.

Noted here, the NEI 18-04 transient classifications, DBAs are defined as a subset of DBEs that rely only on safety related equipment. So that is primarily the topic for the DBA evaluation model.

Further, decomposing the transient classes. So these four groupings are the specific Xe-100 specific transient categories that we analyze to reactivity insertion events, loss of forced cooling, breach events and design basis hazard levels.

They can further be decomposed, as shown here. Status, or the purpose of this slide is noting that in the TSAM we were integrated, all the plant stays operating from full power to shutdown at the time the CPA analyses for these specific events.

MEMBER PETTI: Just a question, Brian.

MR. HALLEE: Sure.

MEMBER PETTI: The difference between overcooling and reactivity accountability and a loss of secondary cooling. The loss of secondary cooling could be an overcooling. And it's a LOCA in the secondary side I assume.

MR. HALLEE: Correct.

MEMBER PETTI: So in the reactivity one it's some sort of, just higher flow rate on the secondary side? That's how you differentiate that?

MR. HALLEE: That's correct.

MEMBER PETTI: Okay.

MR. HALLEE: Yes. That's a very good question. Yes, main steam line break would actually expand both categories. Yes, that's a good question.

I expect most people are familiar with this, but just for completeness here, so defining power plant class, Xe-100 is a 200 megawatt thermal pebble bed high-temperature gas-cooled reactor, helium cooled. It has online refueling pebbles circulating through the core. We utilize TRISO graphite matrix pebbles and decay heat removal via the radiated passive heat removal.

MEMBER PETTI: Just a question. So Xe-100, I always through 100 met 100 megawatts electric, and it's 80. Was it at one time 100 megawatts electric and the evolution things have evolved? This would be like a misnomer?

MR. HALLEE: Yes. Yes, that's my understanding, although it must have been several years ago. Before my time.

MEMBER PETTI: Yes. The other question I had was, if you could talk to your RCCS, it's now water cooled. You know, it's continual debate in the gas reactor community, air versus water. You know, like how did you settle on water?

MR. HALLEE: I think there were a variety of reasons. One of them was that the concrete temperatures in the reactor building were starting to become challenging with an air-cooled RCCS. And the design began to get more complicated.

And also from a shielding standpoint you had to punch some pretty large holes in the reactor building in order to make an air-cooled RCCS work. So we found the dose rates during normal operations coming out in the air-cooled RCCS were really challenging to design against. So that's how we landed on a water cooled RCCS.

MEMBER PETTI: Thank you.

MR. HALLEE: Speak to this a little bit further here in one of the future steps, but this just outlines the major systems of the Xe-100. And the functional containment concept, as Brian mentioned.

MEMBER PETTI: So, Brian, there is no shutdown coolant system. Some gas reactors have a shutdown coolant system in addition to RCCS. You don't have a shutdown system. Because your online fuel leg gets hot to do it just because all the pebble. But have you ever heard, probably --

(Simultaneously speaking.)

MEMBER PETTI: Never heard of it, yes.

MR. HALLEE: -- shutdown coolant system.

MEMBER PETTI: Because Maddox has another cooling system at the bottom of their vessel for when they fuel and then they, so it would be NS, non-safety related special treatment LMP. But I just don't think you guys have, physically have space to do it.

MR. FROESE: No, we don't have SSCs yet.

MEMBER PETTI: Okay.

MR. HALLEE: Just reiterating the

functional containment concept starts with the TRISO codings and PIC and SIC layers surrounding the fuel to maintain the fission gases. Then we have the pebble fuel graphite matrix, the core zone, and then the graphite kernel 3 zone.

Helium pressure boundary, which is a passive boundary it would assume normal leakage unless its breached. And then the reactor building infiltration on the building, which we do not credit at all in the DBA evaluation model.

MEMBER PETTI: So you have some sort of filters or it's just a generic --

MR. FROESE: It's just generic HVAC filters.

MEMBER PETTI: Okay.

MR. FROESE: During a depressurization event you're not putting that through a filtration system, it's coming out really fast.

MEMBER PETTI: And then --

MR. FROESE: But we don't take any credit at all for a reactor building hold-up for deposition like a light water reactor.

MEMBER PETTI: And then the kernel is also a barrier, correct? That's not listed here, right? Otherwise you have to assume all the fission products on the coatings, which I don't think you want to --

MR. FROESE: Yes, that's a good point.

MR. HALLEE: Good clarification.

CHAIR MARTIN: Another clarification. Your TRISO is proprietary version. I'd like to see that at some time. It's not -- it's listed right there.

MEMBER PETTI: It's an HEI 2, hot.

CHAIR MARTIN: Plus I'll let you say that it already aligns with, say the spider plot in the EPRI report in 2020.

MEMBER PETTI: I believe it. I believe their design would fit inside the --

CHAIR MARTIN: Okay.

(Simultaneously speaking.)

CHAIR MARTIN: But you could still consider it proprietary fuel product.

MR. HALLEE: So I reach out to Milan in the back if there is anything on the proprietary front.

MR. HANUS: Yes, I'll actually -- okay, so --

(Simultaneously speaking.)

CHAIR MARTIN: Please say your name first.

MR. HANUS: Yes. Yes. I'm Milan Hanus.

I'm the strategic manager of system analysis. And regarding the fuel, the spider plot, that describes the prime way of this chemical, the important capabilities of the fuel, that is proprietary. That is modified version of the HEI spider plots, but I saw the TRISO program. But our version of TRISO-X places us for proprietary.

CHAIR MARTIN: Okay. Thank you. It's available to be looked at by proprietary session?

MR. HANUS: Yes. We can, yes.

CHAIR MARTIN: I mean, we'll see a topical report on this at some point, correct?

MR. HALLEE: We do have a --

(Simultaneously speaking.)

MR. FROESE: The staff --

MR. HALLEE: We do have a fuel -- TRISO-X fuel qualification for --

MR. FROESE: Right, right.

(Simultaneously speaking.)

CHAIR MARTIN: -- that this a little bit different --

MR. HANUS: This is based on --

CHAIR MARTIN: -- and that we'll --

MR. HANUS: Yes, this is based on --

CHAIR MARTIN: -- see it again?

(Simultaneously speaking.)

MR. HANUS: -- but it's modified --

CHAIR MARTIN: Sure.

MR. HANUS: -- for our purposes.

CHAIR MARTIN: Okay, thank you.

MR. HALLEE: All right. So we can move into Step 2, which is specify figures of merit. And already mentioned that is our primary figure of merit is radiation dose, total effective dose equivalent of TEDE at EAB. That it tends to meet 10 CFR 50.34 requirements. Clearly spell it out is less than 25 rem. That also facilitates our comparison with the F-C targets that are defined for the other events. Non-DBA events for 18-04.

And Brian listed the figure earlier, in the earlier slides, our calculation components that comprise the figure of merit are listed here as we define them. Actually calculate them discreetly.

Some ancillary figures of merit were mentioned in the TSAM topical report. And I've listed them here. And these are largely for verification and demonstration that the assumptions outlined in our DBA model do hold true. So ensuring things like the ASME pressure vessel quantities limits are not breached. So on and so forth. But our primary figure of merit for the DBA EM is offsite dose.

Step 3 is the decomposition of the systems and components and to phases of geometries and processes. The decomposition that was used for the PIRT process is listed here. The phases, fields, geometries, transfer processes were not as discreetly outlined as noted in Reg Guide 1.203. These were largely and inherently delineated in the PIRT phenomena itself.

So our intent is another PIRT revision prior to the OLA that will more discreetly lay this step out. But just note that caveat that those transport processes and POs are largely reflected in the PIRT phenomena and result in the physics phenomena that we tend to model for the DBA EM listed here.

MEMBER PETTI: Just go back. Question. The combustible gas, it's both air and water, you can get combustible gas, right? Is it only steam generator?

MR. HALLEE: Technically yes.

MEMBER PETTI: Thank you. So you're going to look at both hydrogen but also carbon monoxide?

MR. HALLEE: That's correct.

MEMBER PETTI: All right.

MR. HALLEE: Step 4 is perform the PIRT

process with the phenomena identification ranking table. X-Energy used a traditional approach here. Expert panel with adverse experience. But we also build upon the work that was completed for the NGNP high temperature gas reactor.

We organized the phenomena by event categories, developed knowledge levels, ranked importances, and ranked them against our primary figure or merit, which is dose consequence.

The event categories listed. We had seven here that were evaluated for the PIRT. Six transient analyses and one normal operating condition analysis.

And not, the full PIRT is reflected in Appendix C of the TSAM report. Didn't have that reflected here, but some of the high importance phenomena examples that are associated with these event categories are listed here. Field temperature negative reactivity feedback for control rod withdrawal event for the loss of heat, secondary cooling scenarios, thermal conductivity heat capacity and decay heat generation. And steam-graphite oxidation or steam generator tube rupture events.

CHAIR MARTIN: Your PIRT methodology, as I'm sure you're aware that the NRC published a, you know, a temperature gas reactor PIRT, NUREG 6 something. You know.

But commonly cited, I believe it's cited here, it's in the document but I'm not a hundred percent sure, was it a delta review approach that the PIRT team took or did you kind of put that to the side and then try to kind of build the PIRT from scratch? What was the strategy there?

MR. HALLEE: Yes, so initially for Revision 1 of the PIRT it was a delta approach from the NGNP in the prior high temperature gas reactor PIRTs.

For Revision 2 X-Energy largely started from scratch, developed a PIRT specific working groups for each of these seven scenarios and largely built that from the ground up. While also paying knowledge to what was known to be important for the prior PIRT. Prior PIRT effort.

CHAIR MARTIN: Okay. So the answer was yes, basically to both.

MR. HALLEE: Yes.

(Laughter.)

CHAIR MARTIN: Now I have picked on another design center for not being transparent with the membership of the PIRT team. I guess it's okay for this stage of the thing, but the NRC is certainly on record of expecting that transparency. And so, I'm closer to, you know, a operating license application or standard design approval.

There is expectation, you know, to see these, you know, might understand that they don't have inherent biases. You know, understand the completeness of their expertise and the completeness of the group in general.

That you know at least I'm looking out for that. It's common criticism of PIRTs. That these were human, you know, expert. And often times the "expert" and they're subject to subjectivity. And we understand the checks and balances associated with that.

MR. HALLEE: Yes. Thank you for the comment. So that takes us to the end of Element 1.

So Element 2 of Reg Guide 1.203 is largely focused on development of the assessment base and the V&V back story.

So Step 5 is specify the assessment objectives of the V&V base. And the TSAM, we largely not that that is reflective of the reg Guide 1.203 intent and want to verify our codes capabilities model phenomena, identify the PIRT, validate those predictions against the data and quantify any biases or uncertainties. And as well, establish the applicability to Ex-100 specific geometry conditions.

So code specific assessment objectives, those will be covered in code specific V&V LTRs. And I'll just make kind of this high-level objective.

CHAIR MARTIN: Real quick. Obviously we have this GOTHIC and Flownex TR after this one. Was there anything else, any other peripheral tool sets, that are integrated with those primary codes or is that pretty much it? Do you have like automation, you know, like input transfers, I don't know. Anything else that might, you know, as an integrated product be subject to V&V?

MR. HALLEE: Yes, good question. Yes, so we'll actually touch on that a little bit here as we get into the Element 3 --

CHAIR MARTIN: Okay.

MR. HALLEE: -- and the definition of the evaluation model. We did use some data handling with XSTERM in order to hand off core, or conditions from the thermal hydraulic system codes to our dose code.

CHAIR MARTIN: Heat build temperatures and stuff like that.

MR. HALLEE: Exactly.

CHAIR MARTIN: But do you hand off the

whole transient or do you say, have some inherent conservatisms and just say, well, let's go with heat temperature or something like that? How do you deal with those kinds of uncertainties?

And maybe it's a little premature to ask the question like that, but --

MR. HALLEE: Yes. It depends a little bit on the stage of the event. And so, one of the things that we found is we can take a more conservative approach during the initial transient portion of the event and be more rigorous in our level of conservatism as you hit the peak fuel temperature out tens of hours into the event. So it kind of is situational in that sense.

CHAIR MARTIN: Yes. I mean, as I asked earlier, you've been through the cycle three times. You get good confidence. But still to hedge against, you know, what changes might come along in cycle 4, 5, 6, you know, you want to retain some of that conservatism and have something to give a little bit later if you have to. So that's what it sounds like you're doing.

MR. HALLEE: So Step 6 gets to the question of, how does the V&V assessment base scale to the Xe-100 prototypic geometry. And for that we outlined in the TSAM that we intend to follow the hierarchical two-two scaling approach. H2TS. It comes with a top-down and a bottom-up approach to scaling. And so there is a four-step process here where we've identified the relevant protocol phenomena in the PIRT. And then we'll perform the top-down scaling to find the dimension of the supply groups and quantify them as similarity between the data in the Xe-100 and then address any distortion factors as needed.

This is largely just a plan outlined in the TSAM. And X-Energy is really just commencing this work now. So that is reflective of the status that was outlined in the TSAM.

CHAIR MARTIN: I understand that you have no design specific testing planned. That, you know, and ultimately you do that to complete your assessment base. That is still true?

MR. HALLEE: Of course.

CHAIR MARTIN: Okay.

MR. HALLEE: That's true.

CHAIR MARTIN: And you want to say anything more about why you feel that that's appropriate or maybe it's, I know we have the other topical, but maybe at a high-level we can explore a little bit more the other, the other topical.

MR. HALLEE: Yes, I'll let Milan, when we get to the MST topical, I think there is some test data that we're looking to get for further qualification of our fuel type. But beyond that, yes. We have a helium test facility that is largely just focused on environment condition qualification of our components but no additional test data that we're seeking for validation of our codes. It's just, expect it's due to the availability of all of the data for this issue --

CHAIR MARTIN: That's --

(Simultaneously speaking.)

CHAIR MARTIN: -- you know, some uncertainties probably. Mostly on our operating conditions and somehow you can establish those uncertainties. But anyway, we'll see how that evolves. Again, it's still early.

MR. HALLEE: Okay. So wrapping up Element 2, the Step 7 through 9 largely are focused on treatment of the experimental data in the V&V tests. And then effects and the test distortions that come out of the scaling analysis.

And so, the experimental data piece of this will be discussed in the code specific LTR presentations as they apply to the V&V efforts there. And then as I just mentioned, the scaling activities are still in progress at the planning stage so no discussion on test distortions yet that were outlined in the TSAM LTR.

That takes us to Element 3 which is development, actually develop the evaluation model. And Step 10 notes, establishing the evaluation model development plan.

We have multiple work plans that outline the development of the V&V of all these, all the codes that comprise our evaluation model. And then an overall Reg Guide 1.203 plan that ties all these EMDAP activities together and defines our project schedule through OLA. And that plan is intended to be revised to incorporate the staff's feedback on our LTR and CPA as well.

And so, overall philosophy is, integrate the approach for Reg Guide 1.203 as we're noting, also with NEI 18-04, we have a system of codes that all work together to address the phenomena that are key to our safety analyses. And then all codes are V&V'd to develop X-Energy's 10 CFR 50 Appendix B, compliant Xe, or quality assurance program.

CHAIR MARTIN: One aspect of scaling is

that, you know, there is some consistency between, say your core design tools and your TH tools. Don't they go to C it's like a nodalization of your care in particular or are we at some point today? And then how that might align core design.

MR. BALESTRA: So can, I'll cover nodalization in the closed session.

CHAIR MARTIN: Oh, if we could.

MR. BALESTRA: Yes. I have some slides that show nodalization in the closed session.

CHAIR MARTIN: Okay. Okay, I will be interested in that. Just at a high-level, more of a confirmation statement, but there is a decent alignment between, say the multidimensional modeling of, from your core design tools and to the thermal hydraulic tools.

MR. BALESTRA: And so, as I will show, getting the colleagues' points of the report, you know, I'm going to make some examples of the evaluation case we have. And I'm going to, you know, how they align with the design that we have until it has been --

CHAIR MARTIN: Do we look, to say, at your peak fuel temperature? Is that at the hurdle level or is it more of an average with sort of multiplier or --

MR. HALLEE: Yes. Our Flownex model goes down to the kernel level. The GOTHIC model.

MR. BALESTRA: Yes. They model the fuel diagram. Then we'll come back over the model, you know, the, at a percent of the pebble in the mesh. And so, and then our, you know, some experiments we used to track the temperature. You know, like with pebble size pediments and make sure the temperature is the base temperature of the pebble in the span built. I'm not sure that --

CHAIR MARTIN: Well that can be a pebble temperature but really if you get down to the kernel --

MR. BALESTRA: Yes. That's --

CHAIR MARTIN: Yes. You have like a separate --

MR. BALESTRA: We have some verification for that, to validate temperature of the TRISO but, you know, measuring the TRISO temperature is not something that we get it's kind of a, I mean, Dave can confirm that but --

(Laughter.)

MR. BALESTRA: Yes. So point being is that if you measure the base temperature of the pebble you can, it's just conduction through the TRISO and then back to the core, and then the shell of the pebble. You know, the mechanical structure, you can barely --

CHAIR MARTIN: Well I mean, even with light water reactor fuel you don't measure the center line of --

MR. BALESTRA: Yes.

CHAIR MARTIN: -- the fuel temperature, right?

MR. BALESTRA: Yes.

CHAIR MARTIN: It's basically --

(Simultaneously speaking.)

CHAIR MARTIN: Okay. Well, I'll say, I never used Halden to benchmark. I was hoping, you know, my design basis accident --

MEMBER PETTI: But again, the physical size of the fuel that makes, you know, it practical.

CHAIR MARTIN: Right. Right.

MEMBER PETTI: I --

CHAIR MARTIN: But I mean, you can get the, you know, the pebble temperature. And because, like you said, it's conduction.

MEMBER PETTI: Yes.

CHAIR MARTIN: You know. And then basically back out, you know, of the fuel.

MEMBER PETTI: Yes.

CHAIR MARTIN: The peak fuel temperature within the pebble itself.

MR. HALLEE: All right. So moving on to Step 11 which is evaluate, or establish the evaluation model structure itself. We've taken a, like Brian alluded to this, we've taken a bit of a unique approach here to where we've divided the evaluation model into two phases.

One being the early phase, or what we call the plant transient. And the long-term cooling phase where we use Flownex, the early phase, seconds to hours, and GOTHIC, the long-term phase. Hours to day respectively.

So Flownex largely contains, because Flownex is capturing the active plant response, it contains the detailed system nodalization. Both the primary and the secondary contains all the detail model of the controllers. And then provides the boundary conditions for the other downstream codes.

GOTHIC is largely focused on the primary and focused on capturing that passive heat renewal that occurs over the many, many hours after the 30 days and demonstrating the effectiveness of the RCCS.

MEMBER PETTI: So in principle Flownex

couldn't do that longer phase?

MR. HALLEE: So in principle it could. There is a bit of a lack of efficiency on the subroutine structures of Flownex that make it just less efficient than GOTHIC.

MEMBER PETTI: So it takes longer then?

MR. HALLEE: Correct.

MEMBER PETTI: Okay.

CHAIR MARTIN: Or, you know, is there an actual handoff between Flownex and GOTHIC or, you know, do you run the early portion of the transient with GOTHIC and then there is a check? How do you do that?

MR. HALLEE: Good question. I actually have a slide on that. Maybe we can jump to that now.

So the way we've handled GOTHIC is that it's a bounding assessment of a long-term event that captures a set of Flownex over transient events. Early events.

So GOTHIC models the entire event from the initiating event. And we basically defined a limiting initial power or initial stored energy in the core. As well as astounding assumptions to basically ensure that early phase transients that are mapping to GOTHIC are covered entirely by the GOTHIC assessment.

So one practical example, that would be main steam line break, feed line break or loss of feedwater. Those would all be mapped to down to PLOFC where we would maximize the stored energy of PLOFC by way of GOTHIC.

CHAIR MARTIN: Just curious, but if Flownex is, you know, if there is not a code that NRC has ever seen? I mean, certainly it's been around a while and people in the community are familiar with it. Do you have a relationship with the developers of Flownex to, say communicate your challenges and maybe get special attention, features to add or are you doing that internally?

I mean, that's one option too, depending on your agreement with the Flownex people. I mean, certainly something like this challenge with maybe run times. That's, you know, your miracle method nerds out there should be able to tackle that, but, I mean, it's time consuming, it's challenging. It can't be done. Obviously others do it.

MR. HALLEE: Yes.

CHAIR MARTIN: What is that relationship like? Do you pick up the phone and first name basis kind of thing and --

MR. HALLEE: Yes, absolutely. You know,

we have a relationship with the client developers, we have people who worked on Flownex, like Herman in the back, worked at Flownex for a long time doing thermal hydraulic analysis. We have an ongoing contractual relationship with them where they help us with specifically what you're talking about. If there is ever a problem in modeling space, like runtime or --

CHAIR MARTIN: They're basically considered a partner on the project. All right, that's good to know. It's almost essential.

MEMBER HARRINGTON: Can you go back to Slide 22? So you have the TH systems code, which I assume is Flownex. To the next slide. And then it's got a hook, this spatial kinetics code.

The slide on Flownex has just point kinetics. So what is the role of point kinetics versus spatial kinetics? Is there another code that you're going to cover in some other topical report that does the spatial kinetic?

MR. HALLEE: Yes. So we've used, Brian used the code X-e. It's developed at the University of Michigan. And that code was used to verify the code that FT-100 is actually tightly coupled as a core. So we actually verified that spatial kinetics aren't necessary for the reactivity assertion transients evaluated by the DBA EM. And so that was our decision to use point kinetics going forward in our codes.

MEMBER HARRINGTON: Okay, thanks. If I might offer this, possible misleading. So this is basically what you did to come up with your method, but then your method itself doesn't have that hook off to do a spatial --

MR. HALLEE: Yes. Good comment. And then just wrapping up this slide, XSTERM, as we've noted, is our X-Energy in-house developed code that is the mechanistic source term calculator and evaluates our offsite dose consequences.

So this slide sort of pictorially attempts to describe what I just mentioned. And so we've got a branch, Flownex, which defines the source term temperatures. GOTHIC defines the long-term temperatures. But really as Mr. Martin asks, and it really redefines the whole separate analysis case starting from the initiating event. And then XSTERM is our mechanistic source term code.

What I'll jump into here next is the, this tool noted as the FSC tool which actually utilizes XSTERM. And this is our post processor which converts thermal hydraulics system core nodal fuel temperatures into offsite doses.

So how this is accomplished is, XSTERM is pre-evaluated to generate a number of single pebble evaluations at different time and temperatures. We created a database of those temperatures versus doses. And then when a safety analysis is run, be it Flownex or GOTHIC is performed, those peak fuel temperatures are mapped against that database and we generate the offsite dose that way.

There is a number of conservative assumptions built into that database we've developed. Things like downing dispersion factors that currently aren't site specific. The DBA's, fuel impurity and quality metrics are pegged at the design limit values. Time and temperature bounds and transient times, and then pebble power profiles are maximized. So all those conservative assumptions are baked into every DBA source term evaluation that gets mapped using this FSC data tool.

MEMBER PETTI: So just a question on, I think it's the previous slide. XSTERM is picking up the circulating and the time played out. It gets lifted off, but what was unclear to me was, there are fission products in the matrix, right?

And then under heat up, they may not come from the particles but it may come from fission products in the matrix. They got them doing the operation and then come out are worst in oxidation events. The particles may be okay, but you got that inventory, let's call it at-risk, in the matrix. Is that captioned? Because it wasn't really talked about in the documents.

MR. HALLEE: Yes. That's correct, yes. All the pre-compiled pebbles are evaluated up to a 60 effect of full power year. Well, evaluated to their limiting operating conditions. So we're starting from that condition. The pebble one that we performed the fuel.

MEMBER PETTI: It should be like a thousand days or whatever the present timing is.

MR. HALLEE: Correct. Correct. Good question.

CHAIR MARTIN: If I missed this, but regard to, you know, the circulation of the fission, the activation products, you have a step where you determine where they might otherwise accumulate. Steam generator for instance. And then is there some account for where they're located? Say in a depressurization event.

I expect most of them are either in the

core or steam generator. And you can kind of give a feel for what fraction kind of leaves the core?

MR. HALLEE: Yes. So we have a mechanistic XSTERM analysis that does look at where distributed throughout the primary system that is radionuclides. It played it out is the term that we used for that.

CHAIR MARTIN: Yes.

MR. HALLEE: Due to the temperature inversion that occurs in the steam generator, I said a majority of it would occur in the steam generator pressure vessel. And our intent actually is, we developed a tech spec SRTL which is intended to verify that as some periodicity throughout normal operation. But yes, the majority is occurring in the steam generator pressure vessel.

CHAIR MARTIN: Okay.

MEMBER PETTI: Just talking about steam generator I had a question that I couldn't find. Is the helium on the inside of the tubes or the outside of the tubes in the design?

MR. HALLEE: Outside of the tubes.

MEMBER PETTI: Outside. The steam is on the inside?

MR. HALLEE: Yes.

MEMBER PETTI: Thanks.

MR. HALLEE: We noted this. So then we can move on to Step 12, which is developing and incorporate the closure models. And for those not familiar with closure models, it's really just a simplistic model assessment of physics that either are too complicated to model or have diminishing returns if that detail is further, further achieved.

One example of that would be the porous media pebble bed assessment for heat transfer in the core. And so, our current status on this, as outlined in the TSAM, is that these are currently under development for all the codes. And I don't believe we're going to get into any details on this, the code specific LTRs, so really these are just largely defined but still undergoing development and assessment for accuracy.

CHAIR MARTIN: So when it comes to heat transfer in the core you might expect, at least at some point, you would do an experiment to consider porosity or versus the size of your pebble and what have you. It's a complicated geometry of course.

I certainly think the other in-tests previously, are you trying to stay within, say the applicability of those old tests with the size of your pebble or, I mean, do you really depart it much from, you know, the prior work with the pebble design and the core design? Core size.

I don't know if there is like a porosity type --

MR. BALESTRA: Yes, so --

CHAIR MARTIN: -- standard that you're trying to hit. What is your figure of merit as far as making sure your design is applicable to prior work?

MR. BALESTRA: That's a good. And I would say that, you know, that bullet itself didn't change much from the fuel program. It's still the same size. And so -- and the pebbles, you know, the pebble size is also comparable to some of the old design that is being deployed during the thermal program.

So the correlation, the board, you know, the correlation developed for those kind of reactors are pretty much obliged very well on the design we have.

CHAIR MARTIN: Okay. So that is --

MR. BALESTRA: Relatively speaking.

CHAIR MARTIN: -- you know, internal design spec, you know, to target some appropriate range based on prior work --

MR. BALESTRA: Yes.

CHAIR MARTIN: -- you know.

MR. BALESTRA: Yes.

MR. HALLEE: All right, that takes us to the last element which is assessing the evaluation model for its adequacy. And so, largely in the TSAM we noted that the components of Element 4 which are the code, the final code V&V input uncertainty treatment similarity and scale evaluations and ultimate quantification of the bias largely still in progress.

One key facet, or key component on the four that we did get, go into detail on is the model uncertainty and input at certain treatment. And so I'll spend of the rest of the discussion here outlining what did for uncertainty quantification.

So our uncertainty analysis methodology looked at lots of different types of uncertainty material properties for reactor physics, model specific scenarios, specific uncertainties and then kind of I&C control logic set point uncertainties.

We utilized a, I think a bit of a unique approach here to define our uncertainty. And then sort of come up with uncertainties by deduction, which is called a PK PIRT or phenomena and key parameter identification ranking table process which is really an extension of the traditional PIRT process. And we use it to identify what are the key code inputs or parameters that are effecting our figure of merit, which is outside dose.

CHAIR MARTIN: This PK PIRT approach, is this something invented or is this something that's been peer reviewed or --

MR. HALLEE: Our understanding, this is traditionally used in Canadian CNSC assessments for reactor applications.

CHAIR MARTIN: Something you can borrow?

MR. HALLEE: Yes.

CHAIR MARTIN: Okay.

MR. HALLEE: So what this has allowed us to do is to enable uncertainty quantification on a more targeted basis. Specifically that assisted our long-term heat-up case analysis uncertainty because of the just resource time consuming costs of running the 30-day evaluations. Past heat removal cases

This approach supported deterministic conservative or best estimate plus uncertainty approach. And I will get into how we achieved, how we pursued that further here.

So just to kind of step through how the PK process works. We start with the high and medium rank phenomena outlined in our PIRT. Link those to the models that are applicable to, the specific transient categories, and then decompose the phenomena into model parameters. Or what our actual inputs so we can tune into the code to qualify the code.

We then have an expert panel re-rank those parameters so that we're working with the high and potentially medium rank parameters that can be adjusted into code. Assign them in uncertainty distributions and then perform either individual sensitivities to understand how, what's the delta for a figure of merit for altering each of these parameters to their worst case tolerance or perform just a worst case stack up analysis for all the inputs. And estimate our uncertainty either way.

CHAIR MARTIN: So you highlight there in 1, identify high and medium ranked phenomena. Did you do state of knowledge evaluation as well and the how did that factor into this determination because ultimately you're looking for, I mean, if it's high, and there is also a high state of knowledge, you know, often times those are really the simple ones. It's the ones that are most state of knowledge in particular that end of being your risk guidance.

MR. HALLEE: Yes, that's a good question.

It was ultimately a judgment call, but state of knowledge was evaluated during this process.

CHAIR MARTIN: Okay. But you didn't come up with a term that I've used in the past, which are borrowed from Gary Wilson who I consider the father of PIRT to an extent, but is just risk perspective. And it's a metric that corporates the ranking of both the importance and state of knowledge. But did you use something like that or how did you integrate that state of knowledge into your evaluation?

MR. HALLEE: Yes. So the PK PIRT process was largely just expert panel driven. And so, there is a, we developed a report for each transient category and basically walked through the PIRT and had justification written for inclusion or exclusion of each phenomena. And that included the importance ranking and state of knowledge ranking. Just a judgment call by the expert panel.

MEMBER PALMTAG: This is Scott Palmtag. So you have an estimate overall uncertainty. I assume that's numerical calculations once you got your uncertainties out of each of your parameters and you run a whole bunch of numerical methods. Have you done this or is this something you're going to do?

MR. HALLEE: We have done this.

MEMBER PALMTAG: Okay.

MR. HALLEE: Yes, that is correct.

MEMBER PALMTAG: And that's a very expensive calculation. How many Monte Carlo cases have you run?

MR. HALLEE: So actually the, defining the PK PIRT process allows us to distill down, we distill down, that's the number seven input parameters that are key drivers for the particular event. What we would do is then run one case potentially with all seven of those parameters, get to their worst case tolerance limit and that becomes our conservative assessment for uncertainty. So it's actually --

MEMBER PALMTAG: But now --

(Simultaneously speaking.)

MEMBER PALMTAG: -- simplifies the analysis.

MEMBER PALMTAG: You can't always tell which ones, which direction things go on it. There are some transients that, you know, one parameter, you know, one direction is going to be bad, another one is, so what do you mean --

MR. HALLEE: So --

MEMBER PALMTAG: -- case? If you've picked seven parameters and worse case, so you didn't do like a Monte Carlo you just --

MR. HALLEE: No, we did not perform Monte Carlo analysis. And that's a good comment. So, as a way to backstop that we did perform individual sensitivity analysis for each --

MEMBER PALMTAG: Single parameter.

MR. HALLEE: -- parameter. And that also helped us identify what are any correlating parameters that, you know, might alter each other as we, if you were to alter them together. So we could define with each individual sensitivity analysis, what was the impact on temp, peak fuel temperature and then add all up and see how that compared to the overall worse case tolerance stack of analysis. If they aligned well we knew one. If there was limited correlation between parameters, and then two, we had sort of the worst case direction identified by performing those sensitivity analysis.

MEMBER PALMTAG: Can you do those separately for each transient?

MR. HALLEE: Correct.

MEMBER PALMTAG: Did you use a screening criteria to say, certain parameters don't need to be touched even if the PIRT team came back and, you know, hard to image they would say this is high and that something, you know, wasn't confirmed as high in the sensitivity, although it does happen. But did you come across those situations where you just said, ah, this particular parameter, this particular phenomena, you know, doesn't move the needle, we don't need to treat it?

And so as a consequence you reduce your set that you ultimately consider, yes. So --

MR. HALLEE: Yes.

MEMBER PALMTAG: -- what was that screening criteria?

MR. HALLEE: I hesitate to throw a hard number out. I know for the control rod withdrawal event that's one that comes to mind as I think we ended up with like 14 different parameters and ultimately found that there is really only four or five that drive that event.

MEMBER PALMTAG: Usually four or five. Whatever you're looking at --

MR. HALLEE: Yes.

MEMBER PALMTAG: -- it's only four or five.

MR. HALLEE: Yes. So there was, it's a bit of a judgment call, again, by the PK PIRT panel. I don't think we had a hard limit that said if it's more than three percent we're going to throw it out. It's a bit of a judgment call.

MEMBER PALMTAG: Okay. All right, I'll reserve what I'm thinking right now for later.

MR. HALLEE: So the last comment I want to make here is that that approach that I mentioned, where we take the worst case tolerance, stack-up and applied it, that applies to every single constituent of the offsite dose that we analyzed for the safety analysis with one exception, the DLOFC.

Since that's our limiting event we wanted to understand, maybe not so quite conservative, understanding of what the fuel temperature of that case would be. And so what we did was we applied a root some of squares method to understand what a 95th, 95th percentile would be for that event. And so we ran each of those individual sensitivity analyses to their two sigma value, and then get the statistical analysis to understand, you know, the combinatorial effect. What's the 95th percentile for that case since it is our limiting event.

MEMBER PETTI: So just to be clear, you didn't, you didn't run, you know, I've seen pebble bed stuff in the literature with a sister code where you ran with a wrapper around the codes and you do all of this. You didn't do that to come up with that?

MR. HALLEE: Correct.

MEMBER PETTI: I just worry that this approach isn't going to be conservative. I mean, everything at its worst condition, so --

MR. HALLEE: And --

MEMBER PETTI: -- that's good. It means it will probably have margin.

MR. HALLEE: Yes.

MEMBER PETTI: At least you can afford to do that. But sometimes I worry that it covers up, you know, it hides, there's more margin there than even that would suggest because crudeness, I guess, of the approach.

MR. HALLEE: That's a very --

(Simultaneously speaking.)

CHAIR MARTIN: To Dave's point. On about conservative. Not only you have conservatisms in your model parameters but you stylize these events, correct? In those categories, correct?

MR. HALLEE: Yes.

CHAIR MARTIN: And of course you have to take, you know, stylizing there are generally conservative assumptions that maybe combine, you know, a plant state conditions are similar but different, where you might have multiple failure type considerations. Yes. And so, you're nodding your heads, so I'm looking for that confirmation --

MR. HALLEE: That is correct.

CHAIR MARTIN: -- that even the stylized is our basis events.

If you really took those events as you articulate them for, you know, these design basis events and then went back to a PRA you might find that there, the likelihood of those particular ones you selected are maybe less likely than reality, may even fall into the category of beyond design events.

MR. HALLEE: Yes. That's exactly right.

CHAIR MARTIN: Have you done that exercise? I mean --

MR. HALLEE: Yes.

CHAIR MARTIN: -- that's kind of --

MR. HALLEE: I think one clear example of that would be for the DBA, CPA analysis, DBA. It will be assumed double ended guillotine break of this main steam line break for our main steam line break event. And PRA has demonstrated that as an incredible event that we would see some smaller size that would not necessarily see the effects that the main steam line break that we see in our DBA event. That's one example.

CHAIR MARTIN: And that depends on this one. I mean, you do cover like single-failure criteria. You really talk about that. But that's all, those are still classic deterministic treatments and state of analysis base you've covered?

MR. HALLEE: That's correct.

CHAIR MARTIN: And so then you would, for every category you've done a search for single-failure criteria?

MR. HALLEE: Yes. I guess the only thing I'd add is that NEI 18-04 --

CHAIR MARTIN: Doesn't --

MR. HALLEE: -- doesn't require additional failure --

(Simultaneously speaking.)

MR. HALLEE: It's rolled into the PRA.

CHAIR MARTIN: Right.

MEMBER PETTI: The PRA is correct. You've done multiple to figure out which one is the worst. And that would be, you know, you effectively get a single-failure rate.

CHAIR MARTIN: Right. Right.

MEMBER PETTI: I've had this argument with previous Members on this Committee about single-failure criteria.

CHAIR MARTIN: But you haven't with me.

(Laughter.)

MEMBER PETTI: No.

CHAIR MARTIN: I'm more deterministic than most, but --

MEMBER BIER: Do you plan to talk more about what the two bottom bullets on that slide or should I ask my questions now?

MR. HALLEE: No. There is an example application of this --

MEMBER BIER: Okay.

MR. HALLEE: -- in the closed session. If --

MEMBER BIER: Okay. So I'll hold the questions till then.

MR. HALLEE: Okay. All right, so that takes us to the wrap up. So, yes, the TSAM was largely focused on defining our evaluation model and aligning it with Reg Guide 1.203 while also noting that it's intended to be used for the NEI 18-04 methodology. And that we intend to validate the codes we've selected. And as I mentioned in the closed session, we can walk through an demonstration analysis that was outlined in the TSAM.

And going forward, we do plan to complete the V&V of all these codes, finalize the MST methodology, as Brian noted, deliver XSTERM specific LTR on that code, and address any NRC feedback on our methodologies and CPA to support the OLA. Thank you. Any questions?

MEMBER PALMTAG: You're running a little early here.

MEMBER PETTI: Well I had a question but I can't remember if it's in this topical or the appendix of the Flownex.

MR. HALLEE: It's easy to blur, that's why I wanted to put them back-to-back.

MEMBER PETTI: Yes.

(Simultaneously speaking.)

MEMBER PETTI: I think it was DLOFC calculated some peak temperatures that were outside of the lists, as I understand it, the historic database on U02 and the AGR database. So, and without having seen the fuel qualification topical, are there plans to do testing to cover that?

MR. HALLEE: Yes, that's where I'll defer to Milan, I think when we're going to discuss some of the MST --

MEMBER PETTI: We can talk about it later if that's better. In more context.

MR. HALLEE: That was an appendix in the TSAM.

MEMBER PETTI: It was?

MR. HALLEE: And we'll walk through that example in the closed session.

MEMBER PETTI: Right. And it's, the fuel may be fine but there is just no data to support it at this point.

MR. HALLEE: We'll visit that.

MEMBER PALMTAG: Bob, we're running early, but there is only 15 minutes. We're scheduling for a closed session so we might, it sounds like we may take more --

CHAIR MARTIN: Oh, we're good.

MEMBER PALMTAG: -- than 15 minutes.

CHAIR MARTIN: All right. I guess if there is, are there any other questions that we want to tackle here so we can save some for closed session? Just take a normal break.

You don't think we need, you really don't see the slack in the schedule --

MEMBER PETTI: There is no slack.

MR. HALLEE: No slack.

MEMBER PETTI: The GOTHIC and the Flownex are good to go in the next 20 minutes.

CHAIR MARTIN: Oh, okay. I'm sorry. I guess I was assuming that was over here. Oh. I'm reading it a little bit different.

MEMBER PALMTAG: You just got the whole thing in here.

MEMBER PETTI: You have a 24 slide presentation.

CHAIR MARTIN: Yes.

MR. HALLEE: Yes.

CHAIR MARTIN: I still think it's probably good break point to, okay. So let's get back together in 15 minutes. Let's call it 10:10. Meeting recessed.

(Whereupon, the above-entitled matter went off the record at 9:53 a.m. and resumed at 10:10 a.m.)

CHAIR MARTIN: Okay. Recess over. We're going to move onto the next topic of GOTHIC and Flownex. X-energy?

MR. BALESTRA: Good morning, everyone. I'm Paolo Balestra. I'm manager of nuclear safety at X-energy. It's an honor to be here today. Thank you, everyone, for listening, and I'm looking forward for your impressions.

So, today I'm going to talk about the

licensing topical report for Flownex and GOTHIC and the Flownex analysis code qualification. The presentation is going to go through the purpose of the LTR. Then we are going to do an overview on the regulatory requirements and guidance. And then, obviously, an overview on the safety analysis model. Then I will give more about the Flownex code qualification and the GOTHIC code qualifications. And then conclusions.

So the purpose of the LTR, as you may know, is to describe the methodology and theory behind GOTHIC and Flownex supporting the Xe-100 Safety Analysis Evaluation Models. Reference, the LTR reference code manuals and some of the validation and verification efforts, and the qualification plans of both tools. It does not detail any specific code executions or categorization of all analyses. So questions on specific (audio interference) discuss them in the closed session. And the conclusion of the LTR is that the two codes can support the transient and safety analysis for the Xe-100.

The outcome is that the NRC review and approve the GOTHIC and Flownex models for the use in DBA analysis evaluation for the Xe-100.

Okay. Now we go on the overview of the

regulatory requirements. So, we already discussed about --

MEMBER PALMTAG: This is Scott Palmtag. Before you get started, I didn't really see a good description in the TRs, but can you just tell us a little bit about GOTHIC and Flownex? I mean, obviously there are third-party software companies that support them. GOTHIC is pretty well known; Flownex maybe not so much, but they are a fairly large company. Are they all NQA-1? Are you relying on their NQA-1 or do you have your own commercial dedication or --

MR. BALESTRA: So -- for GOTHIC you know like we are relying on that. So we audited their NQA-1 procedures, you know, and they're compliant. So we are relying on their NQA-1. And the same goes then for Flownex. So, like, they've been developing the NQA-1 compliant procedures.

MEMBER PALMTAG: So they're both NQA-1 development. You're relying on their NQA-1, auditing, it, and then you did your own validation -- or verification and validation of their specific cases?

MR. BALESTRA: Yes, auditing GOTHIC and Flownex is just for (audio interference).

MEMBER PALMTAG: So there's a much -- what

I want to say, there's much broader validation and verification for other applications --

MR. BALESTRA: Yes, yes.

MEMBER PALMTAG: -- for both of these codes?

MR. BALESTRA: Yes.

MEMBER PALMTAG: All right. Thank you.

CHAIR MARTIN: Yes, one thing about the NQA-1 with GOTHIC, and it probably has evolved, but it was created initially for containment analysis in light water reactors. And its V&V was focused on that particular application. And I assume you're going to get into it, but if there are test problems that are specific to gas reactors, obviously that's -- maybe they even incorporated that into their V&Vs and it's really -- and part of its NQA-1, relates to its application here, but once upon a time high-temperature gas reactors was not part of their focus and it was -- and so it wouldn't necessarily translate and you'd have to do the commercial rededication for this application.

MR. BALESTRA: You are absolutely correct. There has been development in the last few years and as we are going to see in the next slides that -- some specific cases that will be performed in GOTHIC case, specific case for (audio interference) test reactor to complement the already big set that has been used to verify and validate in GOTHIC.

CHAIR MARTIN: Question?

MR. FROESE: Yes, I guess I'd also just tie in here that we're closely coupled with the Numerical team that develops the GOTHIC software. They're on the call today, so that would be the other resource.

MR. BALESTRA: So you have already seen the other presentation on the regulatory requirement that we are following and the guidance in Reg Guide 1.203. Just want to add that additional NRC guidance come from the advanced reactor application review roadmap and other HTGR licensing experience, like the General Atomics MHTGR, and the NGNP from -- NGNP from which we got the PIRT, starting point for our PIRT analysis, and Exelon/PBMR.

Okay. So, as has already been mentioned we use two codes for two different phases of the transients: So the short-term transient phase and the long-term transient phase. Short-term transient phase is defined as the period at which the SSCs are actively responding to an initiating event involving forced cooling or depressurization. The long-term transient phase is defined as the period at which passive heat transfer begins and no additional active plant response to the initiating event are considered.

So for the short-term, as we said before, we're going to use Flownex and it's used modeling primary system and key secondary systems coupled together. And GOTHIC is used for the long-term transient analysis supporting extended simulations and passive cooling requirements. So --

MEMBER PETTI: Paolo?

MR. BALESTRA: Yes?

MEMBER PETTI: Just a question that each of those -- was it seven LBEs, they use both? There are no transients that are short-term so that they would stay in the Flownex box early and you wouldn't use GOTHIC?

MR. BALESTRA: So I would say that yes, but not in the sense that there are some -- so, the one that you mentioned, yes, like, they all end in BOC or POC scenarios, right? But then there are also operational occurrence, you know, there are other transients that they end up with active cooling. So the Flownex is not because we don't go in the passive phase, so some LBEs. But for DBAs, yes.

MEMBER PETTI: So I'm thinking about the

steam generator tube rupture. Can Flownex handle the steam --

MR. BALESTRA: Yes. Yes, we do the short-term transient with Flownex and we model the rupture and the steam flowing through the primary system and mixing with helium.

MEMBER PETTI: And then outside of the primary system in the vault, the citadel, you know, the --

MR. BALESTRA: Yes, the way which we model it right now is -- which we model the reactor (audio interference) is like through a conservative boundary condition that is basically atmospheric pressure with -- filled with air so that we maximize the depressurization. And we also conservatively estimate the (audio interference) that happens after so that --

MEMBER PETTI: I'm more interested in the condensation of the steam, the model, when gets into the reactor building through the relief valve into whatever volume that is --

PARTICIPANT: So the design is -- no.

MR. BALESTRA: Yeah, we don't have a reactor building model (audio interference) with these models for DBAs.

MEMBER PETTI: It just may be important

for the source term. We'll get back to it when we talk about the source term. So I have a particular phenomenon in mind and that may be a phenomenon you maybe need to consider.

MR. BALESTRA: We can -- yes, we can (audio interference).

And so talking about Flownex, it models reactor kinetics and thermal-hydraulic phenomena through the point kinetics. It uses a combination of 1D finite volumes and 2D axi-symmetric discretization to model the reactor. And obviously it solves the partial differential equations for mass, energy, and momentum conservation using (audio interference). And it predicts basically the system response of the primary and secondary heat transport systems.

Going into the components of the model, pebble bed and the de-fueling chute are modeling using porous media approximation that is a very well-known approximation used for pebble bed, proven multiple times (audio interference). And the Kugeler-Schulten correlation is used for convective heat transfer when we have -- yes, for modeling, basically, the heat that moves from the pebble to the helium. And then we have effective pebble bed conductivity using Zehner-Schlunder correlation based on the A3-3 graphite as a conductive material. And, obviously, in the reactor we have also the point kinetic that us parameters calculated by VSOP for simulating the neutronic response.

Then moving into the steam generator, we have -- the steam generator is modeled with 1D components and it assumes uniform radial steam temperature. And that has been proved in previous design like THTR. And Xe-100 uses a very similar design to THTR steam generator, so we can assume (audio interference) assumption.

The Reactor Cavity Cooling System is modeled through some sort of -- some boundary conditions and it's designed to have at least 72 hours of boil-off volume. The material properties are obviously temperature-dependent. There is a particular attention to graphite that considers irradiation -- degradation-induced aging effect. So we map that and we take into account for (audio interference).

MEMBER BALLINGER: This is Ron Ballinger. I have a question. Are the material properties also time-dependent?

MR. BALESTRA: So time-dependent in the sense of --

MEMBER BALLINGER: On the steam generator side. Tubing, for example.

MR. BALESTRA: That's -- and, Richard, are you -- can you answer that question?

MR. RIVERA: Yes, I'm here. No, for the steam generator tubes you would not have a time-dependency involved. I assume you're talking about as you raise and lower temperatures and potential for cycling effects? Is that what you're getting into?

MEMBER BALLINGER: Yes, that for sure.

MR. RIVERA: Yes. No, that would be something that would have to be monitored independently. And then if there were a certain material property that we'd want to look at because a certain quantity of operational time has elapsed, then we'd have to plug in those specific properties in a material properties table to evaluate them.

MEMBER BALLINGER: Thank you.

MR. RIVERA: No problem.

CHAIR MARTIN: For clarification, so Flownex is run for 72 hours?

MR. BALESTRA: No, that's the -- that's just the RCCS, how it was designed.

CHAIR MARTIN: Okay.

MR. BALESTRA: But usually Flownex run for hours. That's the timeline.

CHAIR MARTIN: Hours meaning less than 12 or something?

MR. BALESTRA: No, like a few hours. One, two, three hours maximum.

(Simultaneous speaking.)

CHAIR MARTIN: -- short-term transient and a little heat-up.

MR. DERCHER: There's a defined set of criteria that we prescribe that ends the transition from the Flownex phase. Essentially, it's when the plant's not actively responding and it's unique to each event.

(Simultaneous speaking.)

MR. DERCHER: Two really quick things on that. Ron, just recall that we don't credit safety-related heat removal through our steam generator, right? Our safety-related means of heat removal are through RCCS. So just wanted to point that out.

And, Dave, to answer your question -- sorry, should have thought about this at the time -- if you have a tube rupture event, that gets piped directly out of the building so you're not going to have condensation inside the reactor building. We have a relief valve from the bottom of the steam generator that pipes directly out to the environment.

MEMBER PETTI: Oh, okay.

MR. BALESTRA: Thanks.

CHAIR MARTIN: One other little detail. Material properties, anything proprietary? Are these standard databases?

MR. BALESTRA: So --

CHAIR MARTIN: Like the BISON database or -- is there anything unique?

MR. BALESTRA: Andrew, do you know the answer to that question?

MR. DERCHER: As far as where material properties are coming from? Is that the question?

MR. BALESTRA: Yes, are they proprietary?

MR. DERCHER: For certain -- you know, I don't want to -- I want to err on the side of caution here because some might be proprietary. Honestly, I don't know that they all are, but as far as -- I'm just going to pick on the steam generator tube if we're going to grab a material property. The alloy that's used as far as the material properties when you're looking at thermal conductivity, heat capacitance, et cetera, we would go to let's say the vendor for that and ask for those properties. So we're plugging in real properties. But I -- because I'm not 100 percent sure about the proprietary nature of all the material properties, I don't want to go there.

MEMBER PETTI: I would say probably -- this is Dave -- some of the graphite stuff, even the testing results are proprietary in agreements between countries. There's a bunch of irradiations in Europe that you have to be part of to get access to it. I think the U.S. data tends to be more open.

MR. DERCHER: And you touched on graphite and that -- I specifically stayed away from that because -- yes, that's --

MEMBER PETTI: Yes, that one's -- it complicated.

CHAIR MARTIN: And I expected graphite. One challenge that I've seen in my experience with design projects like this is material properties -- the consistency of material properties being used within the design centers -- you'll have your design folks. They'll go off and find their own data that they'll use. And then the safety folks will use their own. And who knows -- you know, a partner will use their own. And so there's -- and it sounds like there's really no effort to standardize among the project.

MR. BALESTRA: Periodically I check, like, that all the groups use the same properties --

MR. DERCHER: And we do have a couple of generic material reports that we try to use throughout the X-energy design.

(Simultaneous speaking.)

MEMBER PETTI: With graphite it depends on the grade. Each company --

CHAIR MARTIN: It depends on the margin available, too, and kind of what your goal is. How granular do you want to get.

MR. DERCHER: I would also state that -- it's interesting that Scott brought up, because I presented at various ANS conferences for X-energy where we've been asked specifically about sharing material property data, standardizing it. And I'm usually directed to remain rather tight-lipped about that. So that's why I'm not going into too much detail about it.

CHAIR MARTIN: I think Oded wanted to make a quick remark here.

MR. DORON: Yes, hi. I'm Oded Doron, the VP of Engineering at X-energy. I want to just add a general point because you're making a good point. We are looking to actually centralize material data at X-energy, creating a dedicated materials team and moving toward having materials handling. So your concern is valid and being addressed.

MR. BALESTRA: Let's talk a little bit about GOTHIC. It's a hybrid code that bridges gap between CFD and one-dimensional thermal-hydraulic analysis. The purpose of this is to actually increase the level of accuracy just in selected region of your model so that you can keep the run time like fast enough for the scope of the calculations. And GOTHIC is very flexible and used also for RCCS performance evaluation and design and reactor building environmental conditions that as Bob pointed out was the original scope of the code.

The reactor use the same correlation used in Flownex. The reactor component has a little bit simplified to obviously run to -- up to 30 days of simulations. One example of simplification is that the cone region of the pebble bed is not explicitly modeled. But is a low-power region. It's not going to change the results significantly.

And the steam generator is uses the same approximation uniform radial heat transfer and use 30 axial subdivisions that has been defined using nodalization sensitivities.

The reactor cavity cooling system again is a boundary condition that is based on a stand-alone RCCS model that informed the reactor model for -- inform the boundary condition of the reactor model.

And reactor building, as I mentioned before, is not explicitly modeled. We have a boundary condition that impose atmospheric pressure and contains air to maximize the air ingress during the accident as a conservative approach.

Okay. Flownex code qualification. In the LTR the three manuals -- three most important manuals are reported. It is worth mentioning that Flownex is developed using NQA-1 quality standards and there's over 40 person-years dedicated of V&V. There's obviously ongoing improvement thanks to international conferences specific for HTGR analysis that will include the pedigree of the code.

There are some of the accident that we discussed before. And, obviously, all the phenomena on these accident are important for -- to be -- for defining the validation. And, obviously, the primary metric is the dose at exclusion area boundary, but, obviously, GOTHIC influence don't calculate that and we have to use the quantities and the significant impact of the subsequent dose. So we have assessed those quantities and one of them, for example, is the fuel temperature.

And these are some of the validation case that, Bob, you were talking about before. And for example, this is the verification effort for the pebble temperature. As we said, we cannot measure the TRISO temperature, so we have to use some numerical solutions to compare the model that we have in Flownex (audio interference) equation. And we use the step power increase in that yield 1D conduction model, and compared this to Flownex, and we saw that there's a bias from spatial discretization, how many (audio interference) from the center to the top of the pebble.

But we saw that that bias in the temperature of the fuel decreased with the power levels. And that's basically what happens after the shutdown. So we have low power, so the bias gets very small and (audio interference). So we come up with the best trade-off between like accuracy and fast downtime.

Another big case for -- another big exercise that we've been done for validating the

Flownex is HTR-10. And this will be used for validating heat transfer phenomena, you know, radiation, conduction, and convection. During the -- in the benchmarking, there are some ex-core location temperature measurement, and the simulation that has been done with Flownez already showed very good agreement with the results.

Another very important case is SANA, because like SANA actually measured the pebbles base temperature different axial location in the experiment during (audio interference) circulation condition. And that has been done with a wide range of temperature. And the pebble to the point that we did for is same size, six centimeter. And even in this case Flownex was comparing very well and we used as metrics L-infinity and L-2 models.

Other validation cases are --

MEMBER PETTI: Paolo?

MR. BALESTRA: Yes?

MEMBER PETTI: Just a question. On the HTR-10 benchmark besides -- the comparison to data you said was good. I assume it was also -- it compared very well with the other codes as well because it was an EIEA benchmark, right?

MR. BALESTRA: Yes. We did uncertainties

over like the other participants.

MEMBER PETTI: Sure. Right.

CHAIR MARTIN: Uncommon for us to see L-infinity, L-2 norms. Those are just the standard, simplest metrics, like rooting some squares and -- right?

MR. BALESTRA: Yes. Okay. Other cases to validate when we have a break, right? So we have to validate the pressure loss model. So we have a case in which a pressure vessel -- a valve in a pressure valve was open and the (audio interference) time was measured. And even in this case Flownex was -- matched the experimental data fairly well.

Other experiment -- another experiment is the Mass Flow in Compressible Gas Network. So it's complex gas networking which valves were change and were closed or open or regulated to change the flow configuration. And even in this case, Flownex was able to match both the C-state and the transient space between the opening and closing of the valve.

And then transient temperature in heat exchanger. This one is an experiment we did -- heat exchanger. The inlet temperature was changed from 26 to 60 degree. And even in this case Flownex was able to match closely the results. And these are just like some of them. There is more, I just wanted -- for sake of time, I didn't want to go through all of them.

GOTHIC code qualifications. Same here. In the LTR we have the two most important manual for GOTHIC. All the effort -- most of the effort for the validation and verification of GOTHIC is reported in the GOTHIC Qualification Report that is released together with every new version of the code and includes, obviously, comparison analytical solutions and experimental data from integral and separate effect test facilities. There is a wide range of phenomena covered in that report like natural convection, heat/mass transfer, aerosol behavior, and more.

The planned applications. Again, here we have SANA, HTR. In addition to those two, there's also NSTF. That's very, very old data that can be used to validate with the cooled RCCS. And additional applications. Not part of -- they not part of the current (audio interference). Texas A&M University, 1/28th scale of NGNP HTGR reactor building. Then we have the famous HTGR facility at Oregon State that can provide very good data for (audio interference) transients. And obviously worth mentioning, the Framatome Applied GOTHIC to evaluate HTGR design building -- and a building response.

CHAIR MARTIN: Very good may be a little of exaggeration, but it's been highly analyzed and assessed.

(Simultaneous speaking.)

CHAIR MARTIN: Sat in a lot of meetings with Robbie Kyle, so --

MR. BALESTRA: Okay. Yes, in conclusion we can say that these are to the two version of the code that are in use under NRC-approved Quality Assurance Program at X-energy that is conforming in 10 CFR 50, Appendix B, and the ASME NQA-1-2015. We thought in the LTR we discussed like the methodology and theoretical basis for the two codes. And in conclusion we would say that GOTHIC and Flownex will support the Xe-100 transient safety analysis evaluation model, pending NRC approval for the preliminary design.

CHAIR MARTIN: A question regarding the relative extent of V&V held by developer on high-temperature gas reactor applications between GOTHIC and Flownex. I would expect Flownex is maybe more extensive than GOTHIC when it comes to high-temperature gas reactor benchmarks. Or have you pulled and kind of aligned those two in a code-to-code comparisons?

MR. BALESTRA: So I would say that Flownex started earlier, so there's way more work. Also in the open literature, if you look at -- about it. But GOTHIC is catching up. So as you have seen like there is repetition, right? So all the cases that has been run for Flownex that we will be -- they will be run for GOTHIC too at X-energy. But also these specific cases, like Texas A&M, Oregon State, and -- these are 1. So (audio interference).

CHAIR MARTIN: But certainly more to be done. I had asked about code-to-code comparisons. Have you done some of those?

MR. BALESTRA: We have done some. Obviously, perfect match is impossible because discretization and so on, but we saw that the simplification that we introduced in GOTHIC make a more conservative solution of running (audio interference).

CHAIR MARTIN: That supports, say, a claim that your evaluation model, overall, is conservative against realistic-type simulations. I appreciate that.

What I didn't see was I guess a PIRT focus. I don't know if you feel like that's more of a proprietary content.

MR. BALESTRA: So, the scope of the LTR is -- you know, we have a V&V plan that is (audio interference) that's very detailed how we came up with all the cases. The LTR is more -- show that it's -- the codes are NQA-1 and the models can be used (audio interference). So we can discuss more.

CHAIR MARTIN: Okay. You said it was a company technical report that goes into those other details?

(No audible response.)

CHAIR MARTIN: Okay. Thanks. Further questions from the Committee?

Seeing none, I guess we can move on to the staff. We're going to have a quick changeover, so give us just a second while we get everything together for the staff.

MR. DRZEWIECKI: Okay. Are we ready to start?

CHAIR MARTIN: Yes.

MR. DRZEWIECKI: Yes, so I'm Tim Drzewiecki. I'm the leader of your Xe-100 design center. This morning we're going to over the staff's review of the transient safety analysis methodology, at least in this session, and then we'll over the

GOTHIC and Flownex qualification.

Could have the next slide, please? So as far as the staff's presentation first we're going to go over just some background on this topical report as well as some that are related to this, highlight the reg basis as identified by the staff.

Going to the staff's view approach, then we'll just summarize our findings associated with the EMDAP process. Then go into some other areas that were certain limitations associated that were inherited from other topical report that are disposition in this review as just kind of highlighting the scope of the consequence analysis as applied for this topical report. And then go into staff conclusions.

Can I have the next slide, please? So as far as background, there's a predecessor topical report to this. That was a safety analysis methodologies framework that was submitted in October '21. Staff's SC was issued in March '23. That SE had identified four limitations associated with being clear on the figures of merit, doing a finalized PIRT, as well as code assessment and just define the models used.

So this topical report that was submitted in April '24 and then resubmitted earlier this year, it does include a section which dispositions those four limitations. The updated topical report that was sent in in March, it included some of the markups that were identified during the course of the audit, but there were no RAIs issued either on this topical report or any of the ones that are at issue today. It was all handled through the audit process.

As far as scope, Section 1.5 of this topical report --

CHAIR MARTIN: Can you give us some insight on what they said about identification of figure of merit recently, your first bullet?

MR. DRZEWIECKI: Yes. Oh, you means in terms of what was stated inside of the topical report safety evaluation?

CHAIR MARTIN: Yes.

MR. DRZEWIECKI: Well, I would just say that it was carried over in terms of it was not clear what the figures of merit were when they first did that one framework. And I'll say that remains the case up to date --

CHAIR MARTIN: Oh, okay.

MR. DRZEWIECKI: -- as you will see in the course of this report.

CHAIR MARTIN: All right.

MR. DRZEWIECKI: So as far as the scope, Section 1.5 of the topical report, it does clarify that they were seeking approval to use the methodology for the preliminary analysis for the Xe-100 and particularly for design-basis accidents.

As stated before, this topical report is one of four and it's the high-level one that was submitted. So this was reviewed at the same time as the GOTHIC and Flownex qualification, which you will hear as part of this session this afternoon. We will discuss the source term topical report and then there is the core design methods which is -- that one is not subject to this meeting today, so it's not highlighted.

Any questions on the background so far?

(No audible response.)

MR. DRZEWIECKI: Next slide, please? So as far as the reg basis -- and again, this is identified by staff -- it's got a little more on fidelity than what was stated in the topical. The first one here is 50.34(a)(1)(ii)(D), which that requires an applicant for a construction permit to perform a postulated fission product release to evaluate some of the consequences. Then there is

50.34(a)(4) that requires preliminary analysis and evaluation of your design. And that is generally associated with some of the principle of design criteria and the design-basis that are derived from it.

So, staff identified several of the PDC 10, which is your reactor design startles, inherent feedback, things like that. So these were areas where we would expect that these kind of methodologies would be used to support findings in your -- that's part of your safety analysis.

CHAIR MARTIN: You'd also expect a unique figure of merit associated with every PDC or --

MR. DRZEWIECKI: Could be, yeah.

CHAIR MARTIN: -- RFDC.

MR. DRZEWIECKI: Yes. So that would be -- yeah. As we look at that process you'll see that we had the same observations.

But so as far as -- this is our first condition. So, because this was reg basis, it was identified based on the design description as provided inside of TSAM. So that was preliminary. So anybody who may (audio interference) this topical report will need to verify, you know, the reg basis using TSAM is still relevant here, just to kind of clarify what findings are going to be made or what findings are going to be supported by this methodology.

Can I have the next slide, please? So this one I want -- okay. So this one I think is kind of special to a construction permit, so I want to be clear on this one. 50.34(a)(8). This is what requires having an R&D Program such that any kind of safety questions on SSCs would be resolved for -- before you complete construction of the plant.

One part of that is that there is a rule, 50.43(e) about having sufficient data to assess the analytical tools that you use (audio interference) safety of your plant. That rule applies to almost everything. It applies to somebody who wants an operating license, really anything under 52, but it does not apply to a construction permit. The staff issued guidance. This is a part of the RCAP guidance, so Reg Guide 1.253, that tries to clarify this.

And so that language at the bottom that notes that for construction permit application the requirements under 40.53(e) to ensure that you have sufficient data on the safety features of your design and to assess analytical tools does not apply to a construction permit. Therefore, you don't necessarily need a fully-approved evaluation model, but there are findings that we do have to make. We want to have some feeling that there is adequate margin in your design, but they don't have to be with fully unassessed model.

MEMBER PETTI: That would have to happen in the OL submission?

MR. DRZEWIECKI: Yes. And the intention is to -- so why I bring this up here and why this is called out, because it's called out early in the safety evaluation. You can see that there's lots of staff conditions on the -- and they are tied to this regulation. But the intention that -- because at the CP stage we want to have confidence that there's going to be R&D plans in place to answer those questions so that when the OL comes in, we'll have the answers.

MEMBER PETTI: So can like -- for something like seismic sometimes at the CP the design is no even firm enough. Does that also apply like in the external event, the specificity that you don't necessarily have to have an analysis? The analysis could seriously evolve because the design could evolve.

MR. DRZEWIECKI: Yes, we think that -- so I'm hesitant to answer the question, but I'll tell you what my opinion is at this time. This is a subject that is going to evolve as we review the current CP. And that is certain features -- you can't change the site. And so we want to ensure that there is sufficient understanding of the design-basis that you're designing the plant to, similar to what we do like for Part 52 where we have a section where we know that you designed your plant a certain -- say peak ground accelerations or like response spectra. So we plan to pursue that information to know that what are you designing to and why do you think you have margin? So while we understand it's subject to change, we want to ensure that we at least have targets that are reasonable.

MEMBER PETTI: Because one of their events was seismic and it surprised me that you could do an analysis at the CP stage that you felt good about, just given the state of the design. I agree, you should be able to identify your peak ground acceleration and all of that, but through the actual analysis, at least the ones that we've seen, are fairly sophisticated by a lot of design information. Thanks.

MR. DRZEWIECKI: Are there any more questions on this particular slide? This is one thing that I thought may be somewhat new to this topic.

(No audible response.)

MR. DRZEWIECKI: Okay. Next slide, please? So as far as the review approach we followed the EMDAP process because it was clear that that's what they were using. EMDAP, the evaluation model of development and assessment process, is outlined in Regulatory Guide 1.203. And it was pretty clear that that's what they're using. EMDAP, so everyone knows, it's a 20-step systematic process broken up into four elements. So the staff's safety evaluation, what we tried to do was to map those elements and steps into certain portions of the SE.

And so going down to the last bullet here, Section 2.1 of the Tech Evaluation, it attempts to map information inside of TSAM to various section of the SE. The reason being is that we felt we were finding information that would address a certain step in various portions. So we're trying to move everything into that portion and then assess that one step into one spot. We hope that would improve readability, legibility of the SE. So if you have any feedback on that, we can use that going forward.

Section 2.2 of the SE. It does go back to that 50.34(a)(8) point as it was called over and over again. And then steps 2.3 through 2.6 follow the EMDAP elements. 2.7 goes into the limitations that were identified in the framework. And then 2.8, kind of just clarifies the scope for which the consequence analysis as described inside of TSAM is used or approved to try to set the limits on it versus what's in the actual source term document.

Next slide, please? Okay. So now we're going to step through all the EMDAP elements. I want to take a moment to try and describe what I'm trying to show with the color coding. So what's in the box is where staff thinks they are in the process. In the legend on the right, if it's green, we believe that was fully addressed. We can check that step off. If it's yellow, it's mostly there. There's significant information, significant work done. If it's orange, we think that they've started the process. And it's red, there's -- we didn't find anything in that time.

So going through it now, if I look at step 1, as far -- which is to go through and specify the purpose, transient class, and the power plant class, our plant class it's pretty clear that this is for the Xe-100. There is a list of events that are identified in Section 11.2. We would clarify that those were the -- I think the basis for the design-basis accidents.

That list is derived from a full power-up PRA. And so for reasons as described in the safety evaluation, that list did appear to be -- it wasn't clear it was final or if it was preliminary.

It's not the same list there as what is in the (audio interference) CPA. So we had a condition on that that anybody who would reference this should go through -- give us the list of DBAs and justify why this topical report is used there. And there's just -- also we have a first limitation just kind of clarifying that this is only for a construction permit.

CHAIR MARTIN: But yes, as a clarification, I mean you have these color-coded statements related to how complete it is, but this is not relative to what's necessary for a CP. It's relative to what we eventually hope to get with a --

MR. DRZEWIECKI: Yes, for an OL, for like a full design that could you use for a COL or an operating license.

CHAIR MARTIN: Hopefully, at this stage, that -- if it was just related to CP, the green, right? Yes?

MR. DRZEWIECKI: Well, I would say Regulatory Guide 1.203, it's not really construction permit guidance. So we're just -- evaluated it. It's really there for really something that would be even for -- I would say it definitely has like a LOCA-type tinge to it, but mostly from a hydraulics, but I would say it's really there for like design certifications and operating licenses. So this sets the path. I don't know if I want to -- would say that -- call it green because it would just change --

CHAIR MARTIN: Right. It really wasn't envisioned for this kind of --

MR. DRZEWIECKI: Yes.

CHAIR MARTIN: Yes. So I appreciate that.

MEMBER PETTI: That also implies there was a lot of flexibility in what's accepted at the CP stage.

MR. DRZEWIECKI: Yes. Yes.

MEMBER PETTI: It's that usual certainty versus flexibility problem.

MR. DRZEWIECKI: Yes.

CHAIR MARTIN: But you could probably take the regulatory basis statement that you highlighted a few slides back and extend it to some of these other elements an steps and come with a similar statement about level of completeness.

MR. DRZEWIECKI: Yes.

CHAIR MARTIN: And you said what -- relative to code V&V it was really looking at the plan moving forward to truly make all these steps green.

MR. DRZEWIECKI: Yes, yes.

CHAIR MARTIN: And so by taking a structured approach like Reg Guide 1.203, that obviously is a big part of establishing a plan.

MR. DRZEWIECKI: Okay. So as far as step 2, yes, those are for the figures of merit. It was clear that they were going to use acceptance criteria for dose and as far as that acceptance criteria is consistent with the regulation. There was other information that described figures of merit that didn't appear to be consistent through our topical report.

And then as well as standards -- as well as quantitative standards of acceptance, as you had mentioned, those were not provided whether or not you had the figures of merit say for example whether it was fuel temperature or structural temperature or things like that. Those were not there such that -- and it's called out that you may want to use surrogate figures of merit. For example, Flownex and GOTHIC, they don't actually calculate dose. So when you're trying to set the target to inform what your PIRT panel and things like that, are there other figures of merit they should be informed by?

So this led to our Condition 3, that an application referencing this topical report must subscribe how surrogate figures of merit will be assessed as part of a relevant R&D program, or justify that you don't need them.

CHAIR MARTIN: I mean, one thing we maybe should have covered with the applicant was like vessel temperature because more often than not that is more limiting than fuel with high-temperature gas reactors. So I take it you really didn't see that. Or to what extend did you press them on that as a figure of merit?

MR. DRZEWIECKI: I would say the conversation that happened during the audit -- yes, I mean, Pravin may want to weigh in here. Yeah, there was a lot of discussion on what's your actual figure of merit? And we never really, I don't think, got to a clear answer. But Pravin might be able to --

MR. SAWANT: Yeah, my name is Pravin Sawant. So, yes, we did talk about that, like dose is kind of a surrogate figure of merit, like where do your parameters start to -- that will calculate using, say, GOTHIC/Flownex, that goes into those analyses, that kind of -- those kind of parameters kind of becomes figures of merit for GOTHIC/Flownex, for example. So, looking at that, it appears that -- like those temperature distributions for materials in core, like fuel and reactor and reactor vessel would become a figure of merit for GOTHIC/Flownex type of calculations.

But I agree, like there was -- as our condition here indicates, it's still not very clear, but we can see that overall approach at this stage.

CHAIR MARTIN: Well, I mean, besides fuel, anything that you might be concerned with from a engineering standpoint, anything that could break, you know, core supports, obviously I mentioned the vessel, your control mechanisms or what have you, those are all figures of merit, right? Because once something breaks, the problem changes, right?

And so looking at the fuel particularly with this design, where we've seen lots of margin, you have to start looking at these other things because that really is the limit. It's not -- it may not be the fuel. It's when something breaks.

MEMBER PETTI: Could possibly pressurize the (audio interference). It's not the fuel. It's things like the control rod that drive mechanisms, how they're attached to the vessel that are ASME allowables. Because of the natural circulation you can get how helium in places that you don't hot helium. So it's things like that. And at this point they might need more than one figure of merit because they don't know until they get the design really finalized, which -- what's going to happen where.

MEMBER BALLINGER: With respect to the vessel outside the core, it's all defined by the codes. The ASME. If it's designed according to Division 5 or whatever the new Section 3, those are the figures of merit.

MEMBER PETTI: But which one will be limiting I guess is (audio interference).

MR. DRZEWIECKI: So I think (audio interference) would be because we did identify say PDC, which covers your design-basis for the pressure boundary. And so we would expect that that would kind of come in here and that would have its own acceptance criteria. So if you're going to use these methodologies to assess -- to show that you meet PDC 30 in a design-basis associated with it, then you would have to go through and identify those.

Can I have the next slide, please? So as far as step 3, this is the step to go through and identify the systems, components, phases, geometries, fields, processes that you should model. This is partially addressed through the PIRT process as described. We identified this through the audit, but we didn't see this information inside of this topical report itself. And there was a slight departure that we uncovered from Reg Guide 1.203 in the fact that it doesn't appear that they're doing a system B composition or a hierarchal system decomposition.

So this is one condition of a CP application that would reference TSAM. It must clarify systems, components, phases, geometries, fields, and processes that must be modeled in the EMS part of a relevant R&D Program.

And I'll say as far as this presentation we're not going into all the details in the safety evaluation for time's sake, but there's obviously more description for the bases of all these conditions in there.

Going onto step 4, which is the actual PIRT process. So we did see the importance levels called out for certain events inside of this topical report. Furthermore, it did describe the process. It described a seven-step process. Staff did compare this versus the NGNP PIRT. Staff were -- involved NRC and sponsored by the NRC in NUREG/CR-6944. That's a nine-step process. We noted a few differences in the SE. It wasn't the basis for our approval or not. It was just something to compare to.

But some of the reasons why this would not agree is because the first three steps are not fully addressed, and those were inputs into the PIRT process. We did not see a knowledge base described as well as knowledge levels described inside of the SE, which would inform what you need for your (audio interference).

CHAIR MARTIN: You did not see the state of knowledge?

DR. DRZEWIECKI: We did not, we did not.

CHAIR MARTIN: It's kind of contrary that I asked that question.

DR. DRZEWIECKI: Well, I think they did it. It was just not described in a topical report. So, it was -- yes, so, that's a different -- so, the information could be there, but it was just not in this.

CHAIR MARTIN: Yes, certainly a very important part of the process to identify the risk items.

DR. DRZEWIECKI: So, as far as -- and,

yes, and then, as column number four described, you know, to see if this methodology uses two characteristics in time periods. There's the short-term phase and then, the long-term phase.

And it wasn't clear, this was promulgated and used in the PIRTs. And it wasn't broken up there, so we didn't receive information.

So, some -- those are some of the reasons why this is -- how it's labeled like it is.

So, we have a condition that, you know, and if somebody who would reference this topical report wants to incorporate a suitable knowledge base, assess knowledge levels of associated phenomena, and address the characteristic time periods as part of a relevant R&D program.

Next slide, please?

Are there any questions on this part?

Okay, so, going into Step 2, this is the development of the assessment base. So then, Step 5 which specify the objectives of the assessment phase.

There's a high level of discussion in this topical report on the plans for some of the codes that are part of this suite. However, not a lot -- it wasn't clear whether it was going to be our -- based and information and TSAM. It is partially addressed in the GOTHIC and flux qualification and will be discussed in other presentation.

Going down to Step 6 which is to perform scaling analysis and identify similarity to criteria.

So, it is described that they're following the H2TS methodology which is referenced in Reg Guide 1.203.

It also clarifies that decode accuracy and validation activities and will be addressed on a case by case basis.

There are other sections that describe how, you know, a code could be assessed through being the base and similarity ratios. Staff didn't make any findings on those approaches because just similarity ratios, on their own, are not sufficient to demonstrate, but you have, you know, an evaluation model in order to quantify the uncertainty associated with it.

So, we have a condition here that somebody who would reference this topical report also assess the EM using a range of experimental data whose non-dimensional numbers bound the values applicable to this design or provide alternative justification for development R&D program.

And we also call out a limitation, but the approval is really just restricted to the use of the H2TS scaling methodology. But there's no specific scaling or associated data that was assessed.

Next slide, please?

Okay, so, continuing on, Step 7 is to identify existing data or perform integral effects testing or separate effects testing to complete the database.

That was generally not addressed in TSAM, but it is partially addressed because of Flownex and will be discussed in the following presentation.

Step 8 is to evaluate the effects of the IET distortions and SET scaleup capability.

Again, there offer the general H2TS scaling methodology which partially addresses this. There's no findings made on the distortion analysis as previously discussed.

And we didn't, you know, identify any information on the SET scaleup capability.

So, this is a condition here that, you know, somebody who would reference the topical report must include evaluation of effects of IET distortion, SET scaleup capability as part of the R&D program.

Step 9 to determine experimental uncertainties, this we didn't see information either in TSAM or in GOTHIC Flownex. So, this is the -- this is our tenth condition that you must, you know, evaluate experimental uncertainties associated with R&D program model assessment.

Next slide, please?

Okay, so, moving on to Element 3, this is to the actual to go through and develop the EM.

Step 10 is to have your plan. And so, essentially in 12, it clarifies that all the activities described in TSAM are performed in accordance with the Quality Assurance Program Description, or QAPD, which has been reviewed and approved by the NRC staff.

And so, as far as the information that is usually called out to address this step which is, you know, a documentation requirements, the programming standards, configuration control.

This is generally done under the QAPD. So, staff found this to be fully addressed.

Also, during the audit, we did see that they do have some procedures to address, you know, software QA and those items as well. So, that was called out in the audit summary.

Going down to Step 11 to establish the evaluation model structure, Figure 22 in this topical report, it shows some of the interfaces, the analysis methodology.

And Section 5 of this topical report summarizes the codes that are used within it, including the core design methodology, source term, stress GOTHIC and Flownex, as well as the Flownex screening criteria.

This topical report also states that the final sets of conditions and interfaces will be outlined in a future submittal. So, this is -- it appears to be preliminary.

They also have their own limitation in this topical report that it has to be used with the three other topical reports, specifically, to be used in combination with GOTHIC Flownex, the source term topical report, and with the core design and methods topical report.

CHAIR MARTIN: Question again, I can kind of relate both that Step 11 and 10, regarding kind of configuration for full procedures, did you see procedures for how to prepare modeling -- models with those?

And then, how to perform analyses?

Were there those kind of instructions that they could pass on to their analysts?

DR. DRZEWIECKI: Are you referring to kind of like ensure and calculation procedure type thing?

CHAIR MARTIN: Well, I did have -- I mean, there's always a high level calculation procedure, right, that's supposed to cover the whole organization.

But then, specific to performance and stage analysis, specific to the use of these codes, you know, there's the practice, you know, the practice, you know, goes back to how to establish a best estimate method. So, they can go back to, you know, CSAU code scaling for the uncertainty document in the late '80s, the expectation that you try to eliminate user errors. Right?

And some of the subjective decision making as much as, you know, practical.

So, the recommendation came -- that comes out of that is that you would have procedures that, you know, guide an analyst so that, you know, you can get a different analyst and still kind of get the same result.

Did you see that in their QA program?

DR. DRZEWIECKI: I did not, I did see V&V procedures.

CHAIR MARTIN: Okay.

DR. DRZEWIECKI: But we -- I don't -- well, they were not examined in detail. And as far as the execution of these procedures to actually do individual calculations, I would say that probably would not have planned to look at those as part of, you know, the methodology at this stage, maybe during like a QA inspection down the road, but I'll ask Pravin to see if he saw anything else.

MR. SAWANT: No, I mean, yes, for now, we relied upon their promise to follow their QA -- program. So, X-energy has already received approval of their QA approach and that's the QA process that you would follow. And that's what we limited our review to.

They did list these alternative calculation procedures, so that their other colleagues in the topical. But we didn't go beyond that point.

CHAIR MARTIN: Okay, I don't know if X-energy wanted to jump in? I'll give you the opportunity, in the interest of fairness.

MR. FROESE: Well, of course, there's procedures, for their guidelines, or instructions, you know, those things all kind of, we follow on configuration control.

We see the analysis performed for these

topical reports follows our analysis procedure 2AP3.2 which demonstrates compliance with that QA program. That's the --

CHAIR MARTIN: The analysis procedures that are kind of generic across the organization or --

MR. FROESE: Yes.

CHAIR MARTIN: Okay, so, it's -- okay.

You can kind of create a hierarchy and be specific to each discipline, but at this point, it's still kind of broadly applicable. So, kind of gives a feel for it?

MR. FROESE: Yes, that's correct. There's some --

(SIMULTANEOUS SPEAKING)

MR. FROESE: -- degrading like, for instance, there's scoping counts that we could do for design analysis versus the safety analysis calculations are considerably more compliant.

CHAIR MARTIN: Certainly, it needs some depth there.

MR. FROESE: Yes, consistent with, you know, other light water reactor in QA1 applications.

CHAIR MARTIN: I will tell you that more mature organizations that get to the OL stage, they take their QA program and it's hierarchal -- you start off at the high level that addresses, you know, NQA1 at its most basic.

But then, there'd be discipline usually has -- translates that into what they do. And you get a sharper look at that -- those processes.

Again, it's all about assuring that the user has the minimal effect on the outcome.

Go ahead.

DR. DRZEWIECKI: Yes, so, as far as the last bullet on this slide, it talks about, you know, as far as TR, it does clarify the fact there, you know, it was a planned transient phase that was discussed, that's evaluated with Flownex and then, the long-term of fast cooling phase which evaluated with GOTHIC as well as XSTERM.

Next slide, please?

Staying inside of Step 11, this goes to two Flownex screening criteria which is, you know, one aspect of this model. And so, it does describe the closed reading criteria as a response surface that converts to the Flownex calculated pool temperatures into the conservative dose estimate.

Staff does agree, you know, there's a reasonable of approach for estimating dose associated with a diffusion driven phenomena from the fuel, but it was unclear, based on information in its topical report, you know, what of the radionuclide of release mechanisms that are accounted for by the Flownex screening criteria.

Also, we did not see actual screening criteria. We just saw it described as a response surface.

So, we had two conditions associated with this that someone would use for screening criteria with TSAM, must provide a justification for their use on a case by case basis to ensure that they're covering the appropriate radionuclides release mechanisms for an event, as well as to clarify, you know, what are the screening criteria that are used that would justify the use of FSC in lieu of actually performing XSTERM calculations.

So, as far as staff did make a statement here that subject to conditions 11 and 12 as well as the limitations and conditions provided with inside of TSAM that we conclude that it address that this EMDAP or would address this step because the codes used in the evaluation model have been identified and the interface -- initial interfaces have been described.

Going on to Step 12, we did not see information inside of TSAM that would address this step. However, it is partially addressed in the GOTHIC and Flownex topical report.

During the audit, staff did note statements that there are a few closure models still under development or are being validated.

So, this has a condition 13 that someone could reference in this topical report must describe how enclosure models will be developed or incorporated into the evaluation model, either directly or by reference as part of a relevant R&D program.

Next slide, please?

We're going into Element 4. This is to assess model adequacy.

So, it is -- so, I'll just make clear that these are not addressed in this topical report, but they will be addressed in a future submittal.

There is a condition placed with inside of this topical report that states that the evaluation model are described cannot be used for a final safety analysis until the validation and verification of the code have been done and approved by NRC staff.

There is some information relevant to EMDAP Step 20 to determine evaluation of model biases and uncertainties. This is that one PK process that was described in X-energy's presentation.

Staff did not make any findings or determinations -- or I'll say, staff were unable to determine that that methodology is appropriate for reasons specified to the safety evaluation.

There were certain things that were screened out and, you know, maybe not justified. So, that's all described in detail in the SE what some of the concerns were there.

Condition 14 was added to address this. Basically, all of Element 4 that CP application referencing this topical report must describe how the evaluation model assessment will be addressed, either directly or incorporated by reference as part of a relevant R&D program.

So, that's the EMDAP steps. Are there any questions on the assessment against EMDAP at this point?

Okay, next slide, please?

So, as far -- essentially going back to the predecessor, this is an earlier frame work topical report that, again, it was submitted in October '21, SE was issued in March '23.

It had four limitations basically saying that you have go through and identify what are your figures of merit, you know, finalize your PIRT, do the verification and validation, and justify how the models are used.

So, in 2.5, it has information inside this topical report how those four limitations are addressed within TSAM.

NRC staff did determine that the -- report TSAM does not fully address those limitation. However, going forward, an applicant that would reference TSAM would not have to refer back to the previous topical report that all limitations and conditions are provided in TSAM supersede the old conditions.

Next slide, please?

So, this is going into the scope of the radiological consequence assessment. So, TSAM information associated with radiological consequences is pretty high level and, with the exception of the Flownex screening criteria, is really limited to thermal fluids assessment.

We did not identify information in this topical report to address radionuclide production, transport, dispersion, and conversion to radiological dose.

So, this is the staff's third limitation, just clarifying the approval of this TR for radiological consequence analysis is limited to the thermal fluids inputs used in radionuclide -- used in radiological consequence analysis and the general use of Flownex screening criteria.

CHAIR MARTIN: But we wouldn't expect that, though. I mean, really --

DR. DRZEWIECKI: Not really.

CHAIR MARTIN: -- I mean, that's all in XS term, right?

DR. DRZEWIECKI: It is, it is. And so, I'll say, now, some of this has to do with like how staff works to try to be efficient, you know, with the next person.

Because, generally, you know, whenever this is going to be referenced, a very easy thing to do is to go look at what are the conditions and limitations associated with this topical report without having to go through and read all the details of the safety evaluation.

So, this is, just to make it clear, so it's just so that anybody who would use this would not -- would know, you know, don't look for, you know, you know, any of the details here.

CHAIR MARTIN: And you mentioned thermal fluid assessment, do you expect temperatures and flow rates and pressure as being useful downstream?

DR. DRZEWIECKI: Yes.

CHAIR MARTIN: So, you can, of course, track or, you know, do the transport problem, but that should be more or less all that's necessary.

DR. DRZEWIECKI: Next slide, please?

So, as far as staff's conclusions, we do approve the use of this topical report for the preliminary analysis of DBAs for the Xe-100 subject to the 3 limitations and 14 conditions.

And the reasons for that is because of the use of this EM as described performed, you know, we inform radiological consequence analysis, so it can support findings associated PDC 19 as well as 50.34(a)(1).

And then, as well as it could be used to support findings associated with 50.34(a)(4) specifically, to the relevant PDC because CP applications, one, are not required to provide evaluations of safety margins using approved evaluation models in accordance with, you know, Reg Guide 1.203, pursuant to the limitations as described in this topical report 13.2, as well as staff's conditions.

Sufficient justification would be provided in a CP application or during the associated safety review to ensure that the codes used in the evaluation model are reasonably capable of analyzing DBAs for the Xe-100 design.

Additionally, and pursuant to the conditions 2 through 14, somebody who referenced this would be capable of meeting the requirements under 10 CFR 50.34(a)(8) to describe an R&D program to resolve any safety questions associated with the -- of the evaluation model applicability to the Xe-100 because it would comply with Reg Guide 1.203.

CHAIR MARTIN: Are you done?

DR. DRZEWIECKI: Well, just, I mean, the only thing I wanted to say was just, you know, was just this last bullet that we do expect that this topical report is going to make any kind of CPA application work, any kind of construction permit on review more efficient.

That's it.

MEMBER PETTI: So, I have a lot of philosophical questions.

This is the second non-light water review that we've seen of this approach.

Contrasted, we just finished NuScale with topical reports. Again, that's a COL application, so it's all there, everything's there.

My general concern with the advanced reactor models, it's nowhere near the amount of data and experiments for these advanced technologies with the water.

But I anticipate that they'll be monitored, and if there are smart designers out there, I hope significant monitoring.

Can that trade off in terms of meeting the details of 1.203?

You know, yes, this is good, I mean, it isn't perfect scaled. Yes, that doesn't work. But you know, I've got this big margin. I'm not sitting on the edge of something like, you know, an advanced light water reactor which is really where 1.203 kind of evolved from.

Are there those flexabilities in the structure? Because I just worry, we've talked about you, you read some of our letters, you'll see us hinting at this. But you are the guys that are going to end up making those discussions is that -- is that process, you know, okay that --

DR. DRZEWIECKI: Oh, yes, sir.

MEMBER PETTI: But the obviously, there's margin that compensates for the fact that they don't meet, you know, every little dot of this Reg Guide.

DR. DRZEWIECKI: Yes, that is true. And so, I would say that there are pieces of this Reg Guide that I don't think are overly prescriptive. Some pieces aren't, some pieces are.

But in terms of we're always going to apply, you know, all the risk informed approach. We're always going to consider is there margin? Is there performance pieces that could be done that could inform you? Things you could do such that you could monitor things.

So, we're always going to do that and we're always going to use those as we do these assessments.

So, but in terms of that, I mean, you know, there is some data out there that we think we can use, we actually use quite a bit here, at least for gas reactors and maybe, you know, some other designs. So, we do plan to leverage that to inform, you know, our understanding.

We also may need to do things as well like where we have uncertainty, maybe we can leverage our own research to see, you know, can we get to the same conclusions?

So, we have plans in place. We are aware of these challenges. And I'll say, in this area, I think we'll get into more of that during this first term discussion and what we plan to do going forward, at least near term.

But I'll say this, in terms of the construction permit phase, there is a lower bar, for sure. I mean, you don't need to have the assessment model --

(SIMULTANEOUS SPEAKING)

MEMBER PETTI: -- even at DOL that, you know, I mean --

DR. DRZEWIECKI: Yes, where you have the --

MEMBER PETTI: -- there's a 1,000 page topical report from NuScale on validating the LOCA methodology.

DR. DRZEWIECKI: Yes.

MEMBER PETTI: And it was, you know, plot after plot against data, you know, just endless against. You know, don't, you know, but I look at that and I think, you know, and they spent a lot of money.

And I look at that for these where, you know, there will be some much margin, although there was a lot of margin in NuScale.

I sometimes worry that I think, you know, that that -- the risk-benefit there. It might not have been, you know, in hindsight, but it should have been.

But that's what I worry about, you know, going forward.

MR. SAWANT: And consider, you know, it can also be a question on Reg Guide 1.203. We, in the case of us and Reg Guide 1.203, it is a highly scalable -- and one can look at it as abstract guidance that way.

There is a really large margin in Reg Guide 1.203 that allows the -- like high conductivity approach and, you know -- wants to, you know, make the margin really like tight and they can more link, you know, better regulations and better answers in the quantification.

So, that way, Reg Guide 1.203 is quite flexible. And what it uses is like complete guidance on thinking about methodology in complete sense.

MEMBER PETTI: A frame work in completeness, that sort of thing. That's good, thank you.

DR. DRZEWIECKI: Well, but, you know, I think we already noted that it doesn't give you something explicit relative to construction permit application study to this. Right?

(SIMULTANEOUS SPEAKING)

DR. DRZEWIECKI: And this --

CHAIR MARTIN: You know, you're kind of out there with that ambiguity trying to sift through what is necessary. I don't know if there's a lesson learned there that you might recommend as Reg Guide 1.203 needed to be updated to have something that helps reviewers like yourselves get through the challenge?

DR. DRZEWIECKI: Well, I -- that might -- yes, I would say with DANU, we are definitely talking about what we can do in this area. Now, because, okay, you know, you read a review for a valid topical report can take time. Right?

And so, we're trying to find ways that we can be perhaps more performance based, maybe do more things less in licensing space. And what I mean by that is, you know, we can do our safety reviews, that's one piece.

We can do LARs, we can inspection, we can do other things. So, maybe we can look at it at a higher level and then, look at the details through audits but not having to do everything and assess everything in safety evaluations.

Those are just some ideas. But I'll say, are we going to revise it? I think we're thinking about how we can accelerate it.

If you have thoughts there, it would, you know --

(SIMULTANEOUS SPEAKING)

MEMBER PETTI: -- you know, as a band aid. Right? And then, eventually, if you decide --

DR. DRZEWIECKI: Yes.

MEMBER PETTI: -- that you've got enough to make -- to change the Reg Guide, change the Reg Guide, whatever you -- you know, you have an ISG.

I think these, you know, the challenge and X-energy, there'll be a lot of lessons learned, I'm sure and you guys will capture them and filter them down.

MS. SAWANT: But at this stage, what we're doing is at least trying to see if our work is guaranteeable to address the elements in that and what is planned. So, that like it's not just like looking at what's there. We are also looking at what's planned. That gives us like the 10 CFR 50.34 request to see like if we are in really good confidence -- and it's like eventually are a reactor.

MEMBER PETTI: I'm glad you mentioned that early in the presentation.

MR. SAWANT: 34(e).

MEMBER PETTI: That's an important point.

MR. THOMAS: So, this is Matt, and I'm kind of responding to Dave here.

I guess in my mind, his -- I think of this, you know, how can you improve deficiency of 1,000 -- review a 1,000.

My question would be is, why do you have to have a 1,000 page report to document what they want to do? Is there regulatory efficiencies on the other end that the applicant doesn't have to provide a 1,000 page report to justify something that should be pretty -- a methodology that should be straightforward?

Yes, you don't have to answer that.

DR. DRZEWIECKI: Yes, I'll just say, I've been on both sides of the use of Reg Guide 1.203 and I do think that there could be ways to make it more clear and streamlined. Because I think that -- I believe that there's been some misinterpretations of it or maybe doing too much.

MR. SAWANT: I'll still argue that it's scalable Reg Guide and if agree really large margin, then you can -- really can address all the limits that are really small documentation.

It's all about like how much margin there is and how much confidence you want in your answers.

MEMBER PETTI: That's the right answer. I mean, so we should expect. The problem is, sometimes that doesn't flow to the top as you read the full Reg Guide. You look at everything.

We sometimes lose the forest for the trees. It's all about safety margin. Right? And it clearly, on both sides, whether it be the applicant might by having to address in this all the stuff, and even the SEs, you know. What's the high level summary here? What's the margin at the highest level?

DR. DRZEWIECKI: Can I have the next slide? This is just to kind of wrap things, if it's okay.

Richie, may I have the next slide?

Yes, this is just, you know, kind of a summary of where we think everything is today. So, and which, you know, what we're saying, that's okay for a CV and so, that's what we're saying.

And so, I'll stop there and then we can transition to the GOTHIC and Flownex review whenever we're ready.

CHAIR MARTIN: Go ahead.

MR. SAWANT: So, let me re-introduce myself. My name is Pravin Sawant, a Senior Nuclear Engineer in DANU.

I will talk about the evaluation of X-energy GOTHIC and Flownex --

CHAIR MARTIN: Oh, we've got the wrong slides.

MR. SAWANT: I'll just -- we can start.

Yes, so, it starts here, initial quantification topical.

The -- there it is there.

DR. RIVERA: Trying to get it to show the right screen, I apologize.

MR. SAWANT: Okay, this topical at this stage by our contractor -- on this -- and we have some contractor people also online, specifically, Roger Walsh participating in this review.

So, next slide?

So this is our presentation. I'll quickly go through the background, regulatory basis, and our evaluation approach -- Then, I'll talk about our evaluation of GOTHIC and Flownex codes and input models.

And then, GOTHIC and Flownex quantifications.

We'll briefly talk about GOTHIC and Flownex documentation, configuration control, and quality assurance.

And finally, the limitation and conditions, and conclusions.

Next?

So, the -- provides the quantification codes and describes preliminary Xe-100 input models that they have designed.

And we looked for the preliminary design basis accident analysis.

The topical also summarized completed and planned validations and also describes the quality assurance approach for these codes.

And this topical, which we are calling GFQ, our topical release, supports this TSAM methodology in this presentation.

And as we saw in the accelerator presentation, Flownex is used for short-term response and -- for long-term response. I'll not go through those details.

And external request to review, and I'll pull that this course on the preliminary DBA analysis.

So, this evaluation is focused on evaluating the adequacy of these codes for preliminary

DBA analysis.

Next slide?

I'll not go through the details of the regulatory specifics. It's the same as TSAM, 10 CFR 50.24 for a construction permit application preliminary analysis.

And Regulatory Guide 1.233 and 18-04 which all the risk informed performance based technology inclusive guidance for non -- reactors. Specifically as evaluation of limitation in the 18-04 states that DBA analysis are expected to satisfy Reg Guide 1.203 and that process. And that's what we followed in that guidance, again, for review of this topical report.

Next slide?

And our approach in like quality EMDAP steps and not all EMDAP steps are addressed in the topical. We saw in Tim's presentation that Element 1 is exclusively addressed in the TSAM topical.

And some steps under Element 2 and 3 are also addressed in the TSAM topical.

So, we will look at like only the steps that -- of Element 2 and Element 3 that were addressed in GOTHIC and Flownex topical, and Element 4, there is applicable review evaluation is essentially not addressed at this stage.

So, the scope of the review here is to review GOTHIC and Flownex codes and Xe-100 input models against Steps 11 and 12 of EMDAP, review of documentation, configuration control, and quality assurance approach of Step 10 of EMDAP.

And review of elements of GOTHIC and Flownex qualifications using EMDAP Steps 5 and 7.

And again, like review says, the review focused on evaluating the adequacy of GOTHIC and Flownex codes, input models, and validations for preliminary DBA analysis.

Next?

So, let's start with like evaluation of GOTHIC and Flownex codes and input models. And the object is to confirm adequacy of GOTHIC and Flownex codes and input models or preliminary analysis of DBAs Xe-100 design.

So, what we looked at is we wanted to confirm that the GOTHIC and Flownex codes are capable of modeling important phenomena -- transient phenomena for Xe-100 design and also to confirm the GOTHIC and Flownex input models represent important instances in Xe-100 of model and has adequate nodalization, boundary conditions, and initial plant state conditions and controls are specified consistent with preliminary nature of the design.

And again, like here, all these EMDAP steps, there is no specific -- coding that are used. Essentially, what we are looking is the other steps are addressed are preliminary DBA analysis.

Next?

This slide summarizes Flownex code and input model. So, X-energy already talked about some of that -- on Flownex code. As a summarization, the code is -- it's been there for a long time I think, since the 80s, but new to us.

It's not been, to my knowledge, not been reviewed by NRC for any methodology previously. But it appears that there is quite a bit of work done with Flownex in gas reactor work.

So, I will not go through the other details, but yes, the code itself has a standard closure models, you know, in single stage and friction and heat transfer closure models.

What we observed that they do have more specific closure models that are needed for preliminary pressure drop or heat transfer modeling analysis of porosity variations.

We didn't critically review these closure models in this review. But we did look at like they do have a unique closure models needed for their design.

For the Xe-100 Flownex input model, they, again, like because the core has the ability to use their network modeling approach that has node size limits that allows them to represent the whole plant as they have the ability to model the new products using the approach and I believe to model consistent response.

So, basically, Xe-100 design is represented entirely using Flownex. We have seen models from primary system, secondary system as well as balance of one side model and control systems.

And specifically for as a reflector and pressure vessel, they are representing at 2-d axial and radial nodalization. As X-energy presented earlier -- is represented as bounding condition at this stage and is the safety of model to derive this part of the condition.

Next slide?

For GOTHIC code and input model, GOTHIC code, as mentioned during earlier presentation, it's been widely used in nuclear safety analysis and in NRC has also approved many methodologies based on GOTHIC codes. So, it has wide range capabilities and can model lumped parameter approach to model three representation.

Again, like closing relations, other than standard closing relations, they do have pebble bed, pressure drop, and heat transfer specific closing relations.

Input model, again, like they have a presentation of primary and secondary systems, including cross over vessel of piping represented in GOTHIC model, steam generator model with some new details that allow them to model the steam generator rupture scenario.

Again, like core and reflector and vessel region modeled with the axillary mesh.

Let me see, and then, the whole core is represented using cylindrical geometry and they neglected kind of the conical sections in the core.

RCCS is, again, modeled as a bounding condition. It's like a heat flux temperature dependent on heat flux. They used GOTHIC stand-alone GOTHIC modeling for RCCS to derive this -- condition.

And as X-energy already talked about, like steam generator is modeled with 1-D approach just the axial nodalization put on primary and secondary side.

Next slide?

So, these are the conclusions that we reached and the conditions that we reached after making our GOTHIC and Flownex codes and input models.

So --

CHAIR MARTIN: So, the first bullet there, earlier, Tim noted in regard to the EMDAP, I think Step 3 where you do the kind of the decomposition and you had system components, constituent phases, field equations, you know.

So, clearly, the codes have those sort of things. But you didn't see the one to one mapping between their methodology and the outcomes of the PIRTs and whatever to code models and all of that?

Because, yes, this is also the phase of, well, I guess, when it comes to phases, you know, Dave asked the question earlier about, you know, steam generator ruptures or what have you.

Did you spend much time on that particular transient? And of course, how it solves that problem, you know, with basically two component helium water?

MR. SAWANT: So, for now, we didn't go into a lot more details. But what we have seen is that they have those event categories and risks and first sign of phenomena are inside of all those event categories.

Eventually, when they do address the relevant core of EMDAP where they have to, you know, stitch together all of these things like important phenomena, then core models correlations and then corresponding safety evaluations and make -- looking at all of these and make conclusions about capability and address any gaps and --

So, we expect that when they're addressing the input code, they would combine all these aspects. Right now, what we have seen, like looking at just input model and, in general, the code and what's happening in the code, that the code has a preliminary integrations and closure models that also they work for this type of design, their input model does have important necessary presenting a very good model.

So, it's a really high level review and observation at this stage, but we expect like when they address EMDAP code, they would, you know, combine all this understanding and inform the methodology like if there are any limitations, gaps, those would be addressed after the applicability evaluation.

But yes, for now, again, like our preliminary model, that's what we were looking for in like overall code and overall input models.

That basically covers this slide.

We did impose, again, like obvious limitations that we are offering codes only within the analysis and we are not offering and specific inputs for the -- that are in the model -- Xe-100 models.

Next slide?

So, looking at GOTHIC and Flownex evaluations, again, like Element 2 and that Element 2 has -- test, but GFQ topical -- addressed only two steps, the 5 and 7 like scaling analysis, distortion analysis, or determination of experimental uncertainties, did these steps like 6, 8, 9 which will really allow them to show the applicability of experimental data for their design, but not addressed at this stage.

So, we looked at only Steps 5 and 7 which is basically Step 5 is addressed by the evaluation metrics that they showed us in GFQ topical which kind of shows mapping of high ranked phenomena and selected SET, IETs and analytical validations they have.

And our observation is that, at least for GOTHIC, that measured validations are really part of the developmental assessments of these codes.

There is -- they do inform us that they plan to validate GOTHIC against more specific applicability for RCCS which is from the NSTF - .

But we -- like we'll talk about some of the validations that they're like very specific validations for gas reactors and specifically Flownex, but with GOTHIC we have seen plans for the validations.

Next slide?

So, for Flownex validations, again, like the validation metrics included a number of SETs, IETs, and analytical benchmarks. These are what I have shown on this slide are what we think that are important validations.

It appears that these validations for majority of high ranked phenomena in their validation metrics.

What is this high temperature gas cooled reactor test, HTR-10, which is really reactor, 10 megawatt reactor, so it's obviously a highly applicable -- test.

SANA SET has data related to the pebble bed heat transfer and pressure drop system preliminary test and highly applicable as a steady state and less transient data. And pebble bed micro model is more related to the single phase gas integral system models or single phase gas systems.

We do see like no coverage for some of the phenomena that -- their outlet plenum flow distribution or flow reversal in core as well as the phenomena that I think Tim had talked earlier in distribution and concentration of moisture in primary system.

For modeling, it appears that they are looking at like -- where it links of CMD.

For the distribution and concentration of moisture, they do point out some gas mixing type of validations but not any dedicated specific validation.

And they do plan to, again, perform additional validations against HTR-10 transient data. I think what they showed us in the topical was represented against tested HTR-10 data and some additional Flownex analytical simulations.

So, the determination is that the EMDAP Steps 5 and 7 are address for preliminary analysis. We see that the evaluation metrics is covering a lot of high ranked phenomena.

I mean, like we didn't do a critical review, it was more like we didn't critical review all these validations and tried to see what is the applicability range or preliminary range code of these validation or we expect that addressing Element 4, they will, you know, cover this analysis like to determine if there is any validation gap and address that validation gap.

Next?

For GOTHIC validations, again, like I think it's been there in the period for some time, there are a significant number of these. And right, the validation metrics is measured in options in legacy validations.

They do have -- a lot of those legacy validations do cover validations related to physics and related to the gas phase transport. So, it's -- many of them are quite relevant.

But what we see is they're applying validations against HTR-10, SANA and NSTF data are quite important. And these are -- at this stage, these are planned validations. And they, again, like similarly lack of coverage for those three phenomena that we saw for Flownex.

But overall, we determined that steps -- EMDAP Steps 5 and 7 are addressed for preliminary analysis because we saw some validations and we saw planned formulating against important data.

So, again, like we expect that when element core, we can see address the observations from those valuations.

Next slide?

On the GOTHIC and Flownex documentation, configuration and QA, our review was, again, at the high level. But we noted that what GOTHIC and Flownex codes are doing -- are following EM QA1 qualifications program and they also do have like upload quality assurance topical, NRC approved topical that they stipulated that they followed all these evaluation models based on GOTHIC and Flownex codes.

In terms of documentation, we did see documentation for evaluation modeling requirements, methodology and code and user manuals. Scaling report, uncertainty analysis and final assessment reports are currently not available.

Our overall determination is that the plan is to follow their approved X-energy quality assurance program and the current documentation is adequate for the preliminary CP applications.

And this is the limitations and conditions that staff imposed on the topical that GFQ TR is limited to the applicability of these codes in accordance with the modeling features described in the topical for preliminary analysis of Xe-100 design.

And the review of input parameters into these models is expected to be performed as part of the review of CP application.

And so, in conclusion, again, like we find that what Flownex and input models that are described in the topical addresses EMDAP Steps 11 and 12 adequately, again, like for preliminary approval.

We also determined that the, again, like documentation and their configuration control for a QA approach section for similar address EMDAP Step 10 for preliminary analysis.

And the nodalization, modeling assumptions, boundary conditions are having described consistent with preliminary nature of the Xe-100 design.

And validations against SET, IET, and analytical assessments have been described adequately for the preliminary approval and we do see their plan for completing important validations in the future.

So, this is our conclusion that GOTHIC and Flownex codes and input models and validations are adequate for preliminary analysis.

CHAIR MARTIN: Okay, that's it.

I've bitten my tongue because I think we'd like to have a closed session to, one, address the question I had on nodalization. I'm curious about that and offered that and maybe one or two PIRT questions.

MEMBER PETTI: Should we wrap up into that in a second?

MEMBER BIER: Yes.

CHAIR MARTIN: And just have one?

MEMBER PETTI: Just have one meeting.

CHAIR MARTIN: We can do that, I guess.

MEMBER PETTI: I think that, because, you know, it's such a -- as no one leaves or runs away. I think that'd be good.

CHAIR MARTIN: Okay, we can certainly do that as well.

Then, are there any other questions from the committee?

On the line, Vesna?

(NO AUDIBLE RESPONSE)

CHAIR MARTIN: Okay, I think then we can conclude.

MEMBER DMITRIJEVIC: I'm good, I'm sorry, I didn't really disconnect my microphone. But I'm good, I don't have any questions, thanks.

CHAIR MARTIN: Thank you, Vesna.

And I think we can conclude this morning session. And then, recess for lunch.

Given that we're going to postpone this

closed session, instead of the 1:15 that's listed here, we can go to 1:00 or are we tied to this 1:15, Larry?

MR. BURKHART: We can go to 1:00, if you -- do you want to take public comments at all?

CHAIR MARTIN: Well, I figured we'd just defer everything to the -- it's all -- I mean, we could.

Does anybody have --

(SIMULTANEOUS SPEAKING)

MR. BURKHART: I'll tell you what, let's give an opportunity and while we're on the subject.

CHAIR MARTIN: Certainly.

So, what I've been advised is that we give opportunity for public comment on the transient safety analysis methods report and on the GOTHIC and Flownex topical reports.

So, if there's anyone from the public, please use your -- raise your hand in the Teams function there. We'd be happy to listen to what you have to offer.

Okay, 15 seconds has gone by, is that enough?

Okay, so not hearing any public comments, I think we can then move to recess until after lunch and convening at 1:00 p.m.

(Whereupon, the above-entitled matter went off the record at 12:03 p.m. and resumed at 1:01 p.m.)

CHAIR MARTIN: Okay. All right. I'll try this again. We're back with X-energy. And now we are going to hear the third of three topicals that we are going to cover today. This one is mechanistic source term approach. Milan, is it you handling this presentation?

MR. HANUS: Yes. Good afternoon. I hope everybody had a good lunch and a good break. And I appreciate you coming back here and having me present the mechanistic source term approach for X-energy data for the safety analysis operation.

My name is Milan Hanus, and I am the strategy manager at X-energy. And as you have heard before, the recommendation of the mechanistic system models is part of a bit of the trend or movement, ask of X-energy. So that's why we're still working the hand of analysis, which I will be presenting.

So I appreciate all the -- as part of the Department of Energy project. And let's jump into the presentation.

And so I will start with an overview of the mechanistic system project that X-energy took and then develop into the models that we propound and questions and answers.

Before I start, just a reminder, there will be quite a bit of acronyms and abbreviations. You have the presentation. At the end of the presentation there is a list of acronyms so if you need to look at the back, just go to that last slide and it's an explanation of all the abbreviations.

And now let us include a little bit of what we are talking about. The particular point -- we submitted the particular point to ask for approval of models, mechanistic system models. The topical report does not include any core development and/or presentation details that will be part of the upcoming XSTERM Topical Report. So this topical report is based focusing solely on the models themselves.

The document, from looking at the phases, the mechanistic system topical report, obviously develop the risk-informed performance based-licensing basis report which defines the events that we ask input in from the system perspective. The design consent safety analysis methodology that is particularly a point that you've heard about in the morning.

And then we have the Xe-100 design

details. And we also mentioned the TRISO-ISO pebble fuel methodology, fuel quantification methodology part, which outlines the methodology for fuel prepared to be a version of the TRISO fuel.

And the last document is the atmospheric dispersion and dose calculation methodology, which basically discuss how we (audio interference) to these and convert it into the dose (audio interference).

The mechanistic source term approach is, as I mentioned, based on the performance-based design, based on the NEI 18-04 guideline. We follow some additional guidelines originally developed for the light-water reactors, but more recently adjusted or modified for advanced non-light-water reactors.

So, the regulatory guidance SECY-93-092 was one of the main guidelines that we followed. We are seeking approval of our approach to model the source term (audio interference) and transport to other radionuclide barriers and (audio interference) to get the diffusion coefficients and other important aspects of the source term.

The Xe-100 source terms are event-specific. So the source terms are built-up for each event depending on what systems are activated, basically, in those events. And they account for the passive design features of the Xe-100 reactor and model in detail the mechanistic release and transport of the radionuclides from the point of origin out to other radionuclide barriers and out of the plant (audio interference) for the environment.

CHAIR MARTIN: Milan?

MR. HANUS: Mm-hmm?

CHAIR MARTIN: With a mechanistic source term, as the name would otherwise suggest, you'd expect a mechanistic approach, but yet there is still some stylization, right, of the events and how you establish the initial conditions, boundary conditions. They incorporate some of the conservatisms or inherit some of the conservatisms from the conservatisms that are in the safety analysis and then broadly -- these are not, say, best estimate or is that treated -- it's still kind of a single calculation associated with a single calculation on the safety analysis side?

MR. HANUS: So the mechanistic source term is built from all the contributions to the source term. And they do assume that -- there are conservative assumptions based on the actual event itself. But they are built up from several contributions. It's not like one single value. It's a mechanistic way of simulating all the -- what we should release and potential pathways of the radionuclides depending on the conditions. And we --

CHAIR MARTIN: Depending on the conditions as predicted --

MR. HANUS: As predicted by --

(Simultaneous speaking.)

CHAIR MARTIN: Inheriting kind of the conservative aspects of the original safety analysis.

MR. HANUS: Yes.

CHAIR MARTIN: The thermal-hydraulics analysis.

MR. HANUS: Yes, that's correct.

CHAIR MARTIN: But then, after that, it's more out of best estimate or mechanistic -- I mean, I'm sure there are uncertainties you are going to treat. You know, you are going to treat some of those -- at least the more dominant ones, you know, in the appropriate conservative direction.

MR. HANUS: Yeah, that's correct.

So, as I mentioned, as we heard before, the safety case of Xe-100 is reliant on the functional containment metallurgy concept. So we have multiple radionuclide release barriers, starting from the fuel container to the left here to the TRISO coating barriers of the matrix that holds the particles in place, to the helium pressure boundary in the middle part of the left picture, to the reactor building. It's also a radionuclide release barrier even though we found out the majority of radionuclides is held within the first order of release barriers. So we don't credit the reactor building as a safety system.

The right picture shows more schematically the phenomena that these two potential release (audio interference) in case of accidents like breaks into the pressure boundary. And (audio interference) the potential addition to the source term release, the blue, condensation, deposition, settling, these are the other phenomena that could prevent the release out to the environment. But they are modeled as well in our methodology.

CHAIR MARTIN: I was just going to say, on the previous side there, I see dust, of course, mentioned. I would expect that to be a relatively low state-of-knowledge phenomena. And what are you doing about characterizing dust, specifically?

MR. HANUS: For dust, I have special slide. But I can state now that it's based on operational experience from mainly the AGR reactor. But we also found out that the dust activities are the major contributor to the whole source term, so.

So, the Topical Report describes in detail the mechanistic source term models in seven appendices, basically. The particular appendices are listed on the left, A through G. Each of the models is taking -- describing part of the source term.

So the FPM is a fuel performance model which describes the (audio interference) of particle failures due to increased temperatures or radiation. The thermodynamics model describes the temperature and the thermodynamic conditions that (audio interference), so the temperature, the flow rates, the pressure changes.

SOLM and the GASM models, these two models, are radionuclide release models. The first one, the SOLM, is a time-dependent concept model which basically retrieves all the diffusion equation for the release of the radionuclides from the spherical pebbles, of the particles and pebbles.

The GASM is a simpler steady-state model originally developed for gaseous radionuclides only. And we use that model to develop to kind of coordinate the diffusion coefficients for the SLRM model for the gases, which are not -- this data was missing from the original set of diffusion coefficients that you got from the IAEA documents. I'll get into more details later.

The DUSTM model is the model for the dust production in the core. And the HPBM model is the model that basically takes the radionuclides released from the pebbles and the dust and computes the transport to the pressure boundary. So all these phenomena are seen before the deposition, liftoff, and so on.

We also have a corrosion model for the gas events. And the last two models here, KSIM and TRITM, I also include it in our source term methodology, but we did not specifically ask the NRC to approve these models since they are not part of the DSEM.

The KSIM model is basically a plant simulator, which we can evaluate the point kinetics and fast transients.

The TRITM model is -- we use it more for scoping analysis, especially for the (audio interference) needs, because tritium is not a big dose contributor, but it's important for if you are trying to you get the heat for steam processes (audio interference) through the steam generator tubes.

All these models have some kind of (audio interference) in that they are codes that exist, legacy codes. But X-energy found that it's difficult to combine all these codes, and many of these codes are old codes that we don't have to contact of the original developers anymore. We needed to be more -- to have more control over the code, over the correlations for our purposes. So that's why we decided to develop our own source term analysis code called XSTERM, which is currently under development and implements the models that are presented in this Topical Report.

MEMBER PETTI: So let me ask my question. In terms of the fuel performance, which is really the heart of everything --

MR. HANUS: It is.

MEMBER PETTI: I have major problems with your approach in three areas. Let me talk about them. Most of the models are UO2-based. They don't happen in UCO. They have been engineered out of UCO.

For instance, the amoeba effect, the good and outlook model, there is no CO in these particles, so there is no CO corrosion. So I don't understand what validating a bunch of models that are applicable to this fuel system means or gets you for the down-the-road.

Even the one model that you are using that comes out, let's call it, the American lineage of fuel, the tracking, the IPYC tracking that's in PARFUME, has been engineered away. That mechanism is not what happens in UCO fuel.

Second, you talk about wanting to validate against the AGR data. You're not the first. There are others that have said the same thing. They were not designed -- those experiments weren't designed for validation. And the failure mechanism that was found common in both irradiations and heating tests, nobody models. There is no code today that can model it. In fact, DOE has taken it upon themselves to make it a challenge problem in their advanced modeling simulation program. And they're still -- it's incredibly difficult to model.

And, finally, some of the individual material properties that are in the models, thermal-mechanical properties, which determine the failure of the layers, the values you are using are coming out of the German lineage. The American data have, I call it, more functionality. You've got point estimates, and they just vary with fluence. The U.S. data is temperature-influenced. And you put those all together you get different -- you can get very different answers. Okay? So there's a lot of uncertainty.

The strength data that you talk about in the appendix, I have not seen, Martin, UCO TRISO have anywhere near that strength in salt and carbide.

So there's these differences when you pull from the historic that make it difficult. INL has done a lot of work looking at which material properties matter, and it's a handful. It's five properties. It's the strength of the layers. It's the shrinkage of the graphite. And it's the creep of the pyro-carbon. The creep of the pyro-carbon is highly uncertain. There is only seven data points made in the entire data set.

And so I put all that together, and I said, I think you are in a spot that you won't be able to validate these, or the validation you do may not constitute a true validation of what you are trying to model, which is your UCO TRISO.

It seems to me it would be easier to accept the failure fractions in the Topical Report, put some margin on it, and say, our service conditions are bounded by the tests. Here is my failure rates. That's my model. And then you go from there from fission product releases. I think you ought to at least consider it as Plan B going forward here.

Because I've thought about this for much longer than any of you guys have been involved in TRISO fuel. I've thought -- 15 years I have been thinking about this. And it is one of the reasons why the U.S. program looks the way it does. It is heavily empirical.

I had the same ideas when I started. I mean, PARFUME, which is, you know, I was one of the people working on it. Very mechanistic for its time. But the more you looked at it, the more you kept going, this is going to be really difficult, if not impossible. The AGR program tried to measure material properties again, and they failed. Tried multiple times, multiple institutions. It's just the scale of the samples. Okay, let's make a bigger sample. It doesn't look like a coating layer. Well, then you get an answer that isn't right. And there is enough data in the literature to convince yourself, you have got to do it on the real material, and that's really difficult.

How they did it in the old days is beyond me, but, you know, there is data out there. So I look at all of that, and I go, when you put on your licensing hat, this may be a very high risk with -- you know, when there is a simpler empirical approach that I think can get you to the same point. Because really what you care about is, you know, the modeling of the fission products and the diffusion, which is, in principle, a simpler task than modeling all the failures.

Similarly, just think about this statistically. You are going to calculate a failure probability of 10 to the minus 7. I heard pressure vessel failure. We never see pressure vessel failure. It never happens. It's engineered away.

For 10 to the minus 7, do you know how many particles you need to irradiate to validate 10 to the minus 7? It's more than we have ever irradiated in the world, probably. You know, so there's all these sort of problems that I see that, when you stack them up, step back and say, is that really the smartest approach? Or is there a way to do it simpler and still keep you moving forward? So that's sort of the recommendations.

MR. HANUS: I appreciate the comment. And you are right. It's very difficult to validate a diffusion fuel failure model. This is, you know, one of the reasons why we went back to some of our own quantification kind of testing, you know, the UCO particles under test now with INL.

But, yes, that would take time. The data that we have data available are UO2 pebbles or UCO capsules or compacts, which have different geometry. That's many uncertainties that (audio interference) in our approach.

And we will take this into account. I appreciate your suggestion. Yeah, (audio interference) model (audio interference) it certainly couldn't hurt to validate that approach as well. Thank you.

CHAIR MARTIN: I'll ask a much tamer question, on the previous slide. I appreciate this slide. It's one of the better ones, because it kind of relates to the phenomena you view as important. And you tie it into, of course, the historic database that is otherwise captured in these codes.

I wonder if, you know, UO2 aside, the correlations, models and correlations that you are using in XSTERM, ultimately do they fall back to maybe one of these codes one way or another? Maybe with the exception, of course, of dust. But you basically cherry-pick, you know, here are the codes that are similar? Because, of course, your code is not as old as all of these other codes that are on here. You have the benefit, of course, of looking -- and then some would be, you know, different among the ones that might otherwise apply to these different settings. Or did you go off on your own on some correlations that are really outside of a user experience base?

MR. HANUS: It is a mix of both. So, we did take into account the correlations used in some of these codes, especially PARFUME, PANAMA, these codes. We, in several cases, connect in more detail to (audio interference). We started with -- we used that correlation as a basis, but evaluated it in our operating conditions and found that -- or, you know, with other experimental data that it was originally not evaluated. And we found out that (audio interference) by modifying the correlation by using different coefficients but the same functional dependence, for example.

(Simultaneous speaking.)

CHAIR MARTIN: -- there's a lot of empiricism, and you've identified conditions that maybe your plant might be at and found the data that might be more appropriate to do the fitting and stuff like that.

MR. HANUS: We did. And (audio interference), many of our correlations are based on data fitting and digitization of the report (audio interference) releases or temperature dependencies as a form of just (audio interference) take of an experiment.

So, in many cases digitize those and convert it into a functional dependence and -- but it is basically a mixture. We have our own. And in some cases we have our own proprietary correlations. In many cases we used original correlations from previous old codes. And in some cases there are modifications on those, as well.

CHAIR MARTIN: Okay. Maybe save a question for the staff, but how they evaluated, you know, their methods to come up with new models and correlations. Thank you.

MR. HANUS: So, the XSTERM code, this is just a brief slide about the code itself. It's the evaluation model for quantification of Xe-100 source terms, implementing the methodology presented in this Topical Report. And it's developed under our QA program. The goal is to get NQA-1 qualification of the code and use it for the final safety analysis report and operations.

Currently, the code -- the functionality of the code has been developed, but at this point we are updating the verification and validation, uncertainty quantification, trying to get confidence in the results. Having (audio interference), you know, getting proper data, as was mentioned before, for the FPM model, for example.

And so the verification and validation is planned in four phases currently, to basically observe and validate the different main phenomena. Activity release and transport in Phase 1, reactor temperature and power in Phase 2, the dust production and dust settling in Phase 3. And Phase 4 is the last phase of validation, the corrosion as well as the tritium release and (audio interference).

So now we have model relating to the actual models. There are seven models. They are integrated to the most -- the basic model that influences all the others is the thermal-hydraulics model. Most of the other release mechanisms depend on temperature, so it's the THM model, so I start with that. It uses data from the VSOP, the neutronics data, as input, as well as the Flownex global, the flow rate from Flownex, to calculate boundary condition. And the THM model provides temperature distribution throughout the particle pebble and conditions through the reactor to basically all the other models.

The model is capable of creating

temperatures within a single fuel element or in the fuel core. These two models are used to (audio interference) of the model. When it was (audio interference) calculations, which is used, for example, in the FSC, Flownex Screening Criteria calculations where we take one pebble under given conditions and calculate the release rates from the pebble.

The full core calculation is part of a fully integrated XSTERM calculation, if I talk about the recommendation itself. This is used to obtain the steady state event basically in the plant from which the transients can start later on.

The single fuel in that calculation can use either the (audio interference) or the (audio interference), which is how we model the compacts, of AGR compacts, mainly for the validation purposes.

CHAIR MARTIN: Clarification. THF is the MOOSE-based code? THM?

MR. HANUS: No, THM is thermal-hydraulics model. It's just --

CHAIR MARTIN: So, I mean, MOOSE, their thermal-hydraulic module, they call it THM. It's just a coincidence?

MR. HANUS: It's a coincidence, yeah.

CHAIR MARTIN: Okay. That's unfortunate.

(Laughter.)

(Simultaneous speaking.)

MEMBER PETTI: We just figured that out.

MR. HANUS: So we are using the methods in the core. (Audio interference) can do about a mode of heat transfer, so we are using the conductive heat transfer models for pebbles, the Zehner-Bauer-Schluender model, the convection based on the Kugeler-Schulten correlation, as referred to in the previous presentations. Stefan-Boltzmann law for radiative heat transfer.

We take into account the decay heat using the German standard, DIN-25485. And the thermal-dynamic -- or the thermal calculations in our methodology issue from the single layer of the particle all the way through the reactor nodes, and we model the conduction and these other phenomena throughout, all the way to the reactor.

MEMBER PETTI: Just a question. In the particle, the buffer shrinks and a gap opens up. Do you model the heat resistance of that gap?

MR. HANUS: We don't. If --

MEMBER PETTI: Some do.

MR. HANUS: We don't. We model the -- the (audio interference) section we model, but not the buffer.

MEMBER PETTI: Shrinkage. And the net result is a gap.

(Simultaneous speaking.)

MEMBER ROBERTS: Well, I mean, you could some sort of effective thermal connectivity. I mean, as we've said a couple times, everything is empirical based.

(Simultaneous speaking.)

MEMBER ROBERTS: And if you got correlations from a database that, you know, had that condition, then --

MEMBER PETTI: At this power density the effect is not going to be as great. Prismatics, it's always about 50 degrees, 40 degrees. The lower power density is probably 50 to 30, which given the uncertainties, it's middle at least.

MEMBER BALLINGER: It's basically a statistical gap, in the sense that we're not dealing with a symmetric kernel here.

MEMBER PETTI: Correct.

MEMBER BALLINGER: So it's not --

MEMBER PETTI: You'll see them on one side, but not the --

CHAIR MARTIN: For thermal radiation, are there kind of standard view factors you use or do you, you know, explicitly calculate a view factor based on some assumptions of where the pebbles are? How sophisticated is that?

MR. HANUS: No, (audio interference).

CHAIR MARTIN: Is it pebble to pebble or pebble to wall?

MR. HANUS: Pebble to helium to wall, basically.

(Simultaneous speaking

MEMBER PETTI: I would imagine it can't be that large in the pebble bed, one pebble next to another, the temperature difference is not that large.

(Simultaneous speaking.)

CHAIR MARTIN: I mean, I guess, in theory, you could do it to the coolant itself, but that would be trivial. But, okay. So something there to capture maybe the effect between the pebbles closest to the wall.

MR. HANUS: Yes.

MEMBER PETTI: I just have to ask. Schulten is "the" Schulten, I'm assuming. The father of pebble beds. He must have been a young engineer that he worked on the convective heat transfer coefficient.

(Laughter.)

(Simultaneous speaking.)

MEMBER BALLINGER: He might be that old.

MEMBER PETTI: He might be one of the ones involved, yeah. It's great to have a correlation named after you.

(Laughter.)

MEMBER PETTI: He's a giant.

MR. HANUS: So as I mentioned before, the method of properties are based on similar the reports and the digitization of the cast that is just an example of further -- the conduction based on the feature and fluence.

But the point is that the methodological, the procedure is -- like I would refer you to the computations as dependence system here and the temperature of the properties of the failure temperature calculation are dependent on the temperature itself. So some limitations there.

And we use the VSOP data as an input. There is specific bodies actually of the data behind this and those sets mainly for -- leading to the next part to get the power and light densities.

But, you know, the VSOP nodalization is --

the VSOP uses a different number of axial layers. You know, the ideal rate. But the heat transfer equations in another model when of the same amount of axial layers to make it simpler and based on that being between the VSOP model and our model. But the size of that -- thatdata is from Flownex and that is due to the core mass and height. Everything else is computed is in the source system belt.

And that is the algorithm. It is very simple. We have completed the dynamic parameters so the temperature single nodes and the nodal conditions of the temperature surface only conditions where the pebble temperatures and the pebble matrix temperatures surface-only conditions for the trace particle temperatures and disintegrated over time to each steady state or next time step.

Now the particle failure probability model, it takes as an input the particle temperatures and provides the fair and accurate depictions back to the model. That's all into GASM. Here to make sure it's a failure, base particles based on all these models. And even before, some of the phenomena are not important for these two particles. But we still calculate and validate that. So it's an agreeable contributions.

We do include this model for our validation against order to experiments. So we perform some validations against HFR, public validations, in which case we want to be as close as possible to that experiment.

MEMBER PETTI: So on that model, it would be very interesting to validate against AGR2, UO2. There were capsules of UO2 in that experiment. And I would guarantee you that model would way underpredict what was observed.

There is significant CO corrosion in the destroys the carbon layer at 1,600 degrees. It's one of these oddities about the German pebble testing. It was fine. But it was not good. So let's call it modern UO2. The U.S. program never really spent a lot of time with it because UCO is the focus, but there's data out there published by the program that shows significant corrosion. It would be interesting to compare what the model said.

MR. HANUS: There is actually a validation plan. The plan to perform so far if the AGR found experiment.

MEMBER PETTI: But those are all UCL.

(Simultaneous speaking.)

MEMBER PETTI: This is one is the UO2.

Where you expect carbon monoxide so you can check that model against it. And I think it could give you a headache.

MR. HANUS: And there's also the models. We got to hold these models and in that particular board, I think, if anyone is interested to talk more into the position.

Now the fission, the phenomena of fission to go visit the temperature, surface inputs to these models, those results. In this case to the next kind of -- next transfer calculation in the HPBM.

Focusing on the SOLM model, this image because this model solves the direct fission equation. It must be a good geometry, and we are taking into account the direct fission recoil and the connective activation production terms and balances them with the HM terms by means of decay and activation and transformation to another guide.

And the equation in this model, there are equations for each of the isotopes set out in test. The risk of isotopes is based on the engine program. The most important classes of engine type has been identified particles consequence. So we have, again, a model time to put itself.

CHAIR MARTIN: You are stating it there

about your list of radionuclides from the NGMP program. So you did not do your own design specific evaluation to be dated? Okay.

MR. HANUS: Yes, given the product type that elevates the dose contributions from the isotopes. But it was based on -- the initial set was based on NGNP.

MEMBER PETTI: Which was based on kind of a synthesis both in U.S. and German, you know. What did the safety analyses find as being important?

MEMBER KIRCHNER: Could you go back two slides, please?

MR. HANUS: The slides here?

MEMBER KIRCHNER: The fission product model phenomenon. So I'm looking at all of that. What is dominant?

MR. HANUS: So it depends on the temperatures. At higher temperatures, the thermal decomposition usually is the ultimate effect --

MEMBER PETTI: Very high temperatures.

MEMBER BALLINGER: You've really got to get very --

MEMBER KIRCHNER: 2,000 degrees is very high.

MEMBER PETTI: Higher than you ever

dreamed of.

MR. HANUS: Otherwise --

MEMBER PETTI: Under normal operation, I think is where Walt is going, right?

MEMBER KIRCHNER: Is it defects or is it more failure of the --

MR. HANUS: Defects also have -- at the rate of -- so the --

MEMBER KIRCHNER: If it's defects, I don't see how you validate your models. That's predominantly from the mechanistic failure of the particle then you could validate your model. But if it is dominated by defects and other things, then you can't infer from -- you are not looking at this stuff microscopically. You are looking at it statistically. So if the latter one dominates, then your efforts on the former areas are better bounded --

MEMBER PETTI: My sense is that the defects and the cracking of pyro-carbon -- the defects come in. you get what you get out of each factor, right?

MEMBER KIRCHNER: Yeah, with each factor.

MEMBER PETTI: And so what's called the source term from that, and then you get some failures underirradiation, most likely cracking. All the others should be really small. And they tend to be kind of in the same neighborhood.

MR. HANUS: Yeah. So in normal rating conditions, we don't go beyond the manufacturing defects basically. Whatever, you know, is -- we are doing the best for the manufacturing defects. The failure factors don't go beyond that.

MEMBER PETTI: But because of the material properties they use, I agree with them. But if you use the U.S. material properties, you will get a different answer. You will get cracking at low temperature because the creep coefficient goes down so you can't relieve the stress. So this is what I'm talking about, some of the nuances of the models that look okay but are not necessarily conservative.

MEMBER KIRCHNER: But if the defects are dominating then --

MEMBER PETTI: Defects usually are dominating.

MEMBER KIRCHNER: Then you wouldn't be able to validate the model.

MEMBER BALLINGER: There's an old British saying called being too cute by half, which means you overspecify the problem to the extent that you should because you just don't know. And what you eventually have to do is just do irradiations, run it.

And that's so much margin. That's what allows you to do this because you have got a huge amount of margin so that even if you are too cute by half, you are okay.

MEMBER PETTI: That's why the AGR radiations contains over 300,000 particles. It is to demonstrate -- in the U.S. the approach was design away -- remove every failure mechanism you know through change in particle design, change in fabrication or limiting the surface conditions. So you cut the grass as low as you could.

Now you just need a large population to irradiate to convince yourself that that failure rate, that minimum statistical failure rate, you can live with. And that's what AGR did basically. It's an old GA design approach because they didn't want to live with some of the failure makers, particularly in a prismatic. There are hot spots in the core then. I call them bad neighborhoods where the particles don't want to live.

MEMBER BIER: I have kind of a follow-up question. This is Vicki Bier. A follow up broader version of Walt's question of what are the dominant failure modes? And I don't know if you guys are the right vehicle to answer it or somebody from this morning.

You mentioned that you were on roughly your third significant redesign and update of the PRA analysis. Have those changes been mostly because of safety problems, mostly because of, like, operational efficiency for the utility, mostly because of, you know, maintainability and configuration issues? Or what is kind of the big drivers of the evolutions?

MR. FROESE: This is Brian. I would say evolutions in design have driven a lot of the PRA iterations.

MR. HANUS: So just to complete the SOLM model, it calculates the ISO calculations throughout all the layers of the TRISO as well as the (audio interference). And for the safety evaluations, you calculate the release to birth ratios for all the releases of transients.

MEMBER PETTI: So just a question because it wasn't clear. For iodine and tellurium, there's no measurements out there. There's very few. You are going to assume that they are like noble gas.

MR. HANUS: For iodines --

MEMBER PETTI: For iodines and telluriums, right? Those are some of the isotopes on the list.

MR. HANUS: Yes. For tellurium, we assumed some various evidence, and we do have iodine coefficients IAEA tech doc.

MEMBER PETTI: The German data showed it was just like noble gas.

MR. HANUS: Then, yeah --

MEMBER PETTI: There's no --

MR. HANUS: It didn't -- that's what --

MEMBER PETTI: There's more data under most of those diffusion coefficients than the iodine, is just a handful.

MR. HANUS: Yeah, that's what we have seen.

MEMBER PETTI: I mean, the other -- well, you are going to get there in a couple slides.

MR. HANUS: So the diffusion coefficients are based most on the IAEA tech doc. We did additional research studies of two of different features kind of getting statistical evaluation of the coefficients of all the usual type of temperature dependence of diffusion coefficients but next is the IAEA tech doc.

And we use zero surface bounding conditions of sorption into -- from the gas.

CHAIR MARTIN: So that document is not

going to have diffusion coefficients for all the radionuclides?

MR. HANUS: No.

CHAIR MARTIN: So how did you fill in that gap?

MR. HANUS: We assumed the diffusion based on the chemical properties of the --

CHAIR MARTIN: Categories --

MEMBER PETTI: It's in my draft letter because there are groupings that are natural that I think you guys will probably use. But you are silent in the report. So it's worth -- if you read it, that one is going to get updated on the next one to be very explicit about how you are going to group fission products because everybody has to do that.

MR. HANUS: So for the (audio interference) basically methods I used to make a solution for in comparison I used BDF2 backwards difference method. And we had used the simplest, the main connector is also for the solution of these equations. For this vehicle we tried to use simple cross-examination of the methods we used for the more complicated geometries.

MEMBER PETTI: I just want to let you know that the U.S. program has looked at those diffusion coefficients, compared them to AGR measurements and also talked to the German folks who developed those diffusion coefficients. This was well over a decade ago.

And buried in some of those diffusion coefficients are particle failures, okay? So the cesium diffusion coefficient in silicon carbide has some particle failures in it, which means it is not pure diffusion. So it overestimates.

So there is all sorts of stuff hidden in the weeds there. But it just -- when you are trying to do this sort of an approach, they kind of took an empirical approach and backed out of diffusion coefficient that when you look at it you go, oh, there was some particle failures there, you know.

Because what they did is they used the code directly with their licensing body. They didn't try to build up, like what you are trying to do, which is what the U.S. was trying to do as well.

CHAIR MARTIN: It should be conservative.

MEMBER PETTI: It should be conservative, yeah, absolutely. But if you are close, then it's irritating, right? The U.S. is working really hard to try to get new diffusion coefficients, but it's painful. It's a lot of work.

MR. HANUS: So the GASM model has been originally developed for making the releases of the gases under steady-state conditions. It is based on semi developed solutions equations for the spheres. And you can see the nuclides.

It assumes that obviously that the gaseous isotopes have very short half-lives so it neglects the transfer to the intact coatings and it also takes into consideration the basis, failed particles and heavy metal contamination.

This model is kind of used in our methodology had to escape the SOLM model that we are trying to obtain the diffusion coefficients for the gases, which we did not have available because of the nature of the studies. So essentially solved the steady-states from GASM. And solved the steady-state -- the actions of steady-state in the SOLM as well and compared the results to get the definition for the SOLM model for gases.

The GASM model is based on two models, Rollig and Richards. And we obtained a temperature at which we switched models based on the experiment results.

In one temperature range, one model gets better matching the results of the experiment. In the other temperature range, the other model gives us better results. And so we combine these two models.

MEMBER PETTI: So let me just ask a question here. I was surprised that -- I know both those models. The Richards model is wonderful but it gets so many adjustable parameters that I think you could shoot a large cannon through it.

The Rollig model is simpler. And I am used to that.

But the U.S. program measured in AGR 34. You don't hear about it. It's published. It's out there. R/B as a function of temperature for failed particles for seven different noble gas isotopes. Really short-lived stuff to the stuff you are mostly worried about.

A, that's a data set that you might want to consider to validate or B, it's a correlation. You can just avoid again, avoid all this validation and go, whoops -- avoid all this validation and go directly to using the empirical correlation, which is a fit to the data.

So, again, that's out there. It's published. I will have the reference in the letter. But it's UCO data. It's not UO2 data, you know. And it's over a very wide range of temperatures, tons of data.

MR. HANUS: The dust production model is a very simple model based on the pictures provides the dust production data in the HPBM, the initial boundary. And as I mentioned, it is based on the measurements under the pebble-bed reactor AVR, the AVR German reactors.

And we have used this so the -- the AVR has also validated this calculation. So we used one data set to obtain the parameters needed for the model, that the AGR used to validate its values.

So the model, the graphite and the metallic dust production basically from AVR and to control the diffusion as well. And we modeled on the sizes of particles, the dust particles on the system.

And so the model is based on -- the main product is the dust production rate parameter at which is jointly dependent but acting and then so we are using the (audio interference). And the production of, of course, is temperature dependent. This is where we need to get the input from DHM. And load pressure on the pebbles and other parameter, which is based on the silo pressure formula which will record gains for the pebbles in other model.

The dust production rates in the

reactivity control system is based on the production rates of the -- we specify as an input. And give us the best production rate, which is essentially the amount of dust generated in each location of the core or the plant.

MEMBER PETTI: So in terms of -- you kind of normalized things to match AVR, which is great. But from a size perspective, do you model what the size is or do you just assume it's the same size as what was measured in AVR.

MR. HANUS: Yes, we model the same size as distribution.

MEMBER PETTI: Yeah, it makes sense to me.

MR. HANUS: It's more basically.

MEMBER KIRCHNER: So it scales? First, how big is your reactor diameter in height, vis-a-vis AVR? Just the first order.

MR. HANUS: So, if you know (audio interference) that information -- so 2.5 meters times almost 10 meters, the height of the reactor.

MEMBER KIRCHNER: Much bigger than AVR.

MR. HANUS: It is bigger. It's a different spec ratio from --

MEMBER KIRCHNER: So how would things like control rod abrasions scale given that you've got a much deeper pebble bed to push the control rods in? Is that the kind of abrasion you are talking about?

MR. FROESE: The rods don't go directly to the pebble bed of our reactor.

(Simultaneous speaking.)

MEMBER KIRCHNER: In the reflector.

MEMBER PETTI: There is also data on Fort St. Vrain.

MEMBER KIRCHNER: That's how I was going to say --

MEMBER PETTI: Which is a way bigger reactor than any of the -- so my sense is that the graphite dominates over the metal.

MEMBER KIRCHNER: What are the similarities in the graphite firing and coatings of the pebbles vis-a-vis AVR.

MR. HANUS: So we used the --

MEMBER KIRCHNER: Harder, is it basically a harder coating?

MEMBER PETTI: Same. Well, it depends on -- AVR had so many different pebbles, so many generations. And they did change the heating schedules that it is hard to, you know, they are all going to have one heating schedule for their pebbles. But I don't know if you guys are doing the lower temperature or the higher temperature heating of the pebbles and that may get into proprietary stuff.

You know, there is two different temperatures that the Germans use. And the higher temperature gets you better conductivity but potential damage to silicon carbide. So the U.S. program said no, we are going to stick with the lower one.

MR. HANUS: So to the question of graphite and metallic analysis and pick a value within the experiment, which states and reports the percentage of metallic dust to graphite dust. So this is how we estimated the metallic dust production rate increase. The prediction is based on the graphite dust production in the core.

And all these models, specifically dust production that results from the pebbles as well as the temperature in the core surface inputs to the pressure boundary model, which models a bunch of phenomena that accounts for nuclides to the UAM.

So we model the reads from the pebbles. SOLM model, deposition of components, rate to dust, for the initial containment of the dust for elemental radionuclides that have been taken out under surfaces back into the circulating helium for sorption and de-sorption of the radionuclides.

The model is one dimensional even though we allow the component nodes of all the different inputs so (audio interference) the model. But the equations are essentially one dimensional so a (audio interference) kind of system. And affecting the helium is the take back because that acquires all the dust from one nuclide to the other. And we have a model of all this. And then opposite these.

MEMBER PETTI: Let me ask a question here. Is the dust a dense aerosol or a really light aerosol or somewhere in between in terms of the grams per cubic meter that's suspended. Let me just say I ask it because this phenomenon that's not modeled, it seemed like each particle size doesn't know the other particle size exists. There is no particle to particle interactions so there is no agglomeration that occurs because if there is enough of them, they will agglomerate, and they will settle.

Similarly, if there is enough of them, there could be an electrostatic affect. Consider this -- I would call this a sparse aerosol model because they don't interact. They don't know that there are other particles around them. An element of node and size.

MR. HANUS: Yes. In our model they don't

even do -- even though earlier we performed -- we had accommodation model. And based on the returned backlog in there, and we found out it doesn't affect the overall results. So this will be --

MEMBER PETTI: It must be a very sparse aerosol.

MR. HANUS: And this occurrence complicated the result so --

MEMBER PETTI: For sure. For sure.

So the other question is back in the NGNP days, INL took the AVR dust and the size and put it into MELCOR. Never published it. Should have. And in fact you had a DLOFC. All of the dust came out and settled in what's called the citadel around the reactor.

And then the fission products came out in the second heat-up. And so it said to me that timing is everything in that it looked to me like at the time that you could do a lot of sensitivity studies and maybe convince yourself that the dust is not as important. It is a bogeyman potentially.

MR. FROESE: I was actually going to interject a little bit earlier, but I didn't want to interrupt Milan. That is one of the things that we are finding as well. Dave, it even kind of goes back to your point about how much margin is available under Reg. Guide 1.203.

And one of the things that we are seeing in our preliminary safety analysis is that even if you conservatively released all of the dust that is inside of the primary loop and it is considerably below, somehow that could even feasibly occur, it is released. It is still considerably over more than an order of magnitude less than the offsite dose limit, you know, what level of validation is required?

MEMBER PETTI: The other thing you could consider, which is another way to bound it, assume all the fission products are in a vapor phase. There is no dust. You run your calculations. You assume it's all dust when you run your calculations. If you don't get a big difference. It tells you all that dust stuff isn't really, really important.

MR. FROESE: That kind of goes back to my first slide when I said our PIRT is planning to evolve. That's one of the things we are going to be looking at.

MEMBER PETTI: Because this could be a deep hole.

MR. FROESE: It really can. And at the end of the day, it doesn't make a difference in terms of dose.

MEMBER PETTI: Exactly, exactly.

MR. FROESE: It's one of the simplifications that we're --

MEMBER KIRCHNER: I would be surprised that it would make a big difference. You are presenting very elegant models. And you are chasing this. I would bound it and just move on.

MR. FROESE: We have been --

MEMBER KIRCHNER: Don't complicate your system models with this.

MR. FROESE: I appreciate that comment. We have been having those exact same conversations.

MEMBER PETTI: You have a technical basis because you want your questions, right? So you looked at it.

The other thing I would say is that the liftoff models, there is a lot of data. You don't cite Comity. You are aware of the Comity experiments in France. Again, that's a no dust. I don't think there is any dust in Comity. But there is documents out there that have really good data as a function of flake size, how much was lifted off.

And then just generally suspension of metallic, maybe even -- the aerosol literature. I was also an aerosol guy in my past. There is tons of literature out there for data if you feel you need that to validate.

You know, simple pipe experiments. I will cite a couple to get you started, but there is a lot of data out there that wasn't talked about that if you feel you need to go there, there is non-nuclear stuff out there that can help.

MR. FROESE: Please do. Thank you.

MR. HANUS: I will, the particle mass transfer, as we alluded to earlier, is modeled in the (audio interference) and particle of the changes between the phases. The main phase that we use as a background, the helium gas secreting kind of depositing the dust and the dust secreting the isotopes and the whole model is multiphase model, multiphase exchanges as shown in the previous pictures. Again solved as a time dependent method, using the specific method for time stepping.

MEMBER PETTI: The sorption makes it pretty stiff, though.

MR. HANUS: Yes.

MEMBER PETTI: Very stiff.

MR. HANUS: And, again, sorption doesn't appear to be the main game changer as the results use a solution and the different sorptions.

And the last model presented here is the corrosion model, which is based on a simple rate equation and, again, here, the input guide the corrosion model depending on the temperatures and it provides the phases between the Oak Ridge bounding model.

And we do have models for all these conditions. So we modeled the enhanced releases from these two kernels, the pyro-carbon coating and the matrix. But as we found out, the strength has not affected the overall dose results. That's importantly.

MEMBER PETTI: Let me -- this is one where I disagree. The paper said you don't assume any particle failure on moisture ingress. There is no data to support that view.

Full stop, the U.S. has had this in their fuel development programs going back to MHTGR in 1993. They are finally, the U.S. program has its furnace. This is beyond the core furnace in Germany. Core just did fission gas. But that is not what we are worried about here. It's all about cesium and strontium and iodine. And well steam at the high pressures that can be predicted on a steam generator tube rupture cause particle failure. And so that is going to be tested experimentally. That is probably one thing that would really change how you have to think about this.

MR. FROESE: I can maybe add onto that. One of the things that we found in doing our steam generator tube rupture oxidation calculations was that the penetration depth through the fuel free zone, the steam wasn't getting to the particles past that 5 millimeter mark at the temperatures. We were seeing in tube rupture events. So that was one of the reasons why that statement was --

MEMBER PETTI: Okay. I mean, I could believe that if that were the case.

MR. FROESE: Yeah.

MEMBER PETTI: But there will be experimental data certainly, you know certainly not for your CP, but for your OL. And on UCO, again, in compact form from the U.S. program to look at that. Both air, although steam is probably higher.

MR. FROESE: We definitely would be interested in looking at that. But, yeah, that is the reason why.

MEMBER KIRCHNER: Can you repeat that because this is pretty important.

MR. FROESE: Yeah.

MEMBER KIRCHNER: You are saying that the 5 millimeter overcoat, pyrolytic carbon on the pebble does not fail in the accident scenarios you were looking at a high temperature with steam?

MR. FROESE: What I said was that steam diffuses in through the fuel free zone through the matrix and that it is going to get -- that it is going to react with the fuel free zone and not penetrate past the 5 millimeter fuel fee zone before it potentially reaches particles.

MEMBER PETTI: Because it is consumed?

MR. FROESE: Because it is consumed in the chemical reaction.

MEMBER KIRCHNER: The steam is consumed?

MR. FROESE: Yeah.

MEMBER KIRCHNER: But you have got a huge reservoir of steam in your system, in your steam generator. If you blew down, for example, the primary and then the steam generator tubes failed as a result or consequential failure or not, that steam generator, depending on how much inventory it has and the isolation valve closing time, et cetera, is going to backfill your primary system, and I don't think you are going to be lacking steam mortar.

MR. FROESE: We do that explicit

calculation in both Flownex and Gothic.

MEMBER KIRCHNER: Okay.

MR. FROESE: What helps us is that the circulators trip pretty quickly. And so if there is additional steam that gets into the --

MEMBER KIRCHNER: The steam can find its way through the whole system with or without the circulators.

MEMBER PETTI: To me the other issue is -- I know the story on air. Everything gets held up in the lower plenum. So I believe the. But even if you think you have calculated a lot of assumption, the partial pressure of oxygen -- let's say FZP, fuel free zone particle intervention of, will be very low. But at that low pressure, you get the oxidation of silicon carbide changes. So you don't get SIO2. You get SIO.

MR. FROESE: When you say oxygen, just to make sure I understand, do you mean steam?

MEMBER PETTI: Steam, yeah, but --

MR. FROESE: Okay.

MEMBER PETTI: It is oxygen that is going to be the reactive component, right?

MR. FROESE: And then you meant air --

MEMBER PETTI: No, this is true in air, too. But the oxygen that gets to the particles may be, you know, it's like six atmospheres of steam if I remember from MHTGR. You might have, you know, 0.1 atmosphere, so even lower.

There is a point at which you can start to react. It looks like it's zero because you started really high. It's a real small residual. But it can attack the silicon carbide and produce SIO instead of SIO2. SIO2 is a glass. Everything is protected. You go to SIO, and it evaporates.

The Japanese -- there is tons of papers out there in the literature on this. And this is a big deal. And it is really hard, I believe, to do something without looking at it experimentally to see whether or not you really can get there. What saves you is that the reaction kinetics vary with pressure to some power.

And so at those low pressures, the rate could be very slow. But then, again, you know, you only know fuel expended.

MR. FROESE: I guess the last thing I would just add is that the amount of steam that can get into the core relative to the total weight of graphite in the fuel is small, especially compared to what still stays inside the steam generator.

What we found is we hit -- potentially it would hit flammability limits before oxidizing a large portion of our pebble. It's the hydrogen generation that we are most concerned with.

MEMBER PETTI: I hope that's the case because MHTGR PRA looked at this extensively.

MR. FROESE: Yup. We're well aware of there.

MEMBER PETTI: What they told us that there is tons of sensitivity analyses that aren't in that document that show that you can go from it looks good to it looks bad. So you've got to really make sure you've mapped out the parameter space effectively, the connection space.

MR. HANUS: So, yes, this is the end of the presentation. And this our overall source term calculation methodology and anymore questions, please ask.

MEMBER PALMTAG: This is Scott Palmtag. You didn't mention point kinetics at all. It was in the topical report.

MR. HANUS: Yes, here, we do have point kinetics for submitting the transients and essentially getting this initial steady-state for the transient calculations.

In the topical report, we include that

model in a separate appendix. We do include it as an overall description in one of the sections.

MEMBER PALMTAG: It's a rather unique way of solving kinetics equations.

MR. HANUS: It is. I mean, it is a collection of kinetics models basically connected through --

MEMBER PALMTAG: I am not even sure that is going to work. I will hold my judgment until I see the results. But you may just want to put in a 2D kinetic model in there instead of trying to validate that this unique way of solving in point kinetics on a part-by-part basis is going to work.

I think you are going to spend more time trying to convince people that that works rather than just putting in the 2D diffusion.

MR. HANUS: Yes. And what we will achieve undoubtedly is that we don't even need that to do diffusion if we just use the simple kinetic approach.

This is mostly (audio interference). We had this model initially of, you know, and validate. And at this moment, we are advising (audio interference) to approve this model it was under --

MEMBER PALMTAG: It just seems like this

is going to be more -- more trouble to validate it.

MR. HANUS: At the moment that we submitted the topical report, it was under revision whether we need it or not. We felt the need to include it there just as a section because it makes the whole metallurgical piece the same (audio interference) that we mentioned at the TTM even though we do not ask approval because we don't use it in the safety evaluation calculations.

But you are right. We (audio interference) the diffusion model.

MEMBER PALMTAG: Okay. I still have another couple of general questions. So we talked about the uncertainties. And Dave has talked about that, the uncertainties in these models validating it. But when you started this reactor, it is sort of a first of its kind reactor, are you going to have -- what kind of monitoring are you going to have? Are you going to have some kind of dust monitoring, a plate monitor? How did you -- are you going to measure these things to know they're right?

MR. FROESE: This is Brian. I would say our played-out deposition or played-out and circulating activity is going to be controlled by our SARRDL, our specified acceptable radionuclide release limit. It's going to capture circulating and deposited activity.

The methodology or detection mechanism that we use to monitor the plate-out is still being, frankly still being finalized. We have a helium services system that would measure circulating activity.

MEMBER PALMTAG: Okay, and what about somewhere dust, are you going to announce some sort of measurement on dust, or?

MR. FROESE: We'll have dust filters and we're also planning to measure steam generator activity.

MEMBER PALMTAG: It's dust activity that matters, but if.

MR. FROESE: Yeah, we're planning to measure steam generator deposition activity. The exact means that we are going to use is still being finalized, whether that's a monitor placed outside the steam generator or probe or something. We're still in the process of finalizing that.

MEMBER PALMTAG: Okay, I'm glad to hear that. Only one other minor thing is your decay heat model is based on the German standard. Just a suggestion, you might want to put in the ANS standard.

It might make your NRC review a little better, because no one's really familiar with the German model but everyone's pretty familiar with the ANS standard.

Just a suggestion, you might want to consider replacing that model.

MEMBER PETTI: So you don't know yet, but you probably will have a plate-out file of some type to monitor metallic.

MR. FROESE: No. We are - so we are not committing to a plate-out probe right now. We are evaluating options for measurement of plate-out inside of the steam generator. At the top of the list is trying to use an external monitor to look inside of the steam generator.

MEMBER PETTI: Because yeah, because I mean, look, putting something on a purification system that's way too far away to get any answer that means anything. Okay.

MR. FROESE: Yeah, I agree.

MEMBER PALMTAG: So you may not have a plate-out probe, but you are going to have some way of measuring, is that my understanding?

MR. FROESE: That's correct.

MEMBER PETTI: The plate-out probes were like right above the core, as I remember it.

MR. FROESE: Yeah, I mean, we talked with a lot of folks that have past plate-out probe experiences, that there was troubles with that.

MEMBER PETTI: Absolutely. (Simultaneous speaking.)

MR. FROESE: Yeah, so we're trying to look at alternatives for that that are more practical.

MEMBER PETTI: You should be able to measure cesium and silver. Strontium, you can't, it's a beta, so.

MR. FROESE: Yeah, there - really in the weeds here - but I think there was some work of trying to measure some of the noble gasses using the daughter products as a predictor.

MEMBER PETTI: Yeah, but they decay so quickly compared to 90 it may not - yeah, there's a lot of old tricks.

MEMBER KIRCHNER: So can members ask other members questions

CHAIR MARTIN: Feel free, Walt.

MEMBER KIRCHNER: Well, Dave, you know, based on your experience, this is a very elegant model that's being proposed. But why I was asking the question about defects, if that dominates, or even if it's a significant fraction, then there's no way you can validate these detailed models for the other mechanics from a macro results, even when they start operating. So --

PARTICIPANT: Too many adjustable parameters.

MEMBER PETTI: Yeah, no.

MEMBER KIRCHNER: Yeah, so my sense is can't you simplify your life for yourself by taking a correlation, an empirical approach to bounding the performance based on AGR data of UCO kernel fuel with these specs as you're in the spec range? And then as a function of temperature and time, etc., then sort that out.

So the defects would be a function of --

MEMBER PETTI: Well, you fix it once you get out of QC.

MEMBER KIRCHNER: That's what you're going to get out of QC when you run --

MEMBER PETTI: So the staff would have

(Simultaneous speaking.)

MEMBER KIRCHNER: - production, yeah.

MEMBER PETTI: But whatever they're using bounds what you get.

MEMBER KIRCHNER: Right, so you hit that,

that's like a one input, and then put an empirical correlation in place for the time, temperature dependent performance.

MEMBER PETTI: That's what the purpose of --

MEMBER KIRCHNER: And burnup.

MEMBER PETTI: - of the EPRI topical was, which was here I empirically measure failure rates, live on bounds. Take some margin because there's always a design versus an expected, all that stuff, right.

MEMBER KIRCHNER: Right, take that margin --

MEMBER PETTI: And go. Now, what it makes us - the big, next big concern is dust. But it sounds like, I mean, if you actually have to validate all this, that's really complicated. If you can convince yourself that dust is not an issue, the problem is simple.

MEMBER KIRCHNER: Yeah. But then in Bob's swim lane, 1.2 over 3, I mean, how would you validate this?

MEMBER PETTI: Oh, again, this is my --

MEMBER KIRCHNER: At the microscopic mechanistic level.

MEMBER PETTI: 1.2 over 3 (Simultaneous speaking.) when applied to this technology.

MEMBER KIRCHNER: You mean you're really depending on batch-made fuel even in AGR or small batches.

MEMBER PETTI: AGR 2 was production, what is now considered production.

MEMBER KIRCHNER: Considered production.

MEMBER PETTI: But yeah, no, it's - as I said, I spent 10, 15 years thinking about it, and I said you just can't go there. But you can go back and read the earliest NGNP data, and it was all the radiation's plan for this. And they died when NGNP died. But I look at it now and I go there's got to be a better way.

MEMBER KIRCHNER: Forty years ago, we would have done just, we would have just bracketed the data correlation empirical --

MEMBER PETTI: Right, exactly.

MEMBER KIRCHNER: With the fuel form at hand, that would be become the input for your --. It's not up there. FTM module.

MEMBER PETTI: I mean, even the detailed diffusion equation that's by net element, you can use an analytic solution. It's not that difficult.

That's the thing, though, you know, it's simple booth diffusion. All you're doing is you're doing it numerically. I can write down the equation. It's the same diffusion coefficient.

You get answers that are, you know, the same. You know, all that precision is a little bit of an overkill relative to when you ask yourself what's the true uncertainty, you know, it's the fusion coefficients.

Yeah, so I always thought, similarly, all the pebble stuff, if it were up to me, I'd pick three pebbles. I'd pick the worst trajectory, assume it always, the pebble goes all the way down the worst trajectory, all this time.

Then pick an average, whatever that means, and then pick like a min or something, you know. And say those are my three pebbles the bottom of the core, and they just run three calculations. Something like that.

MR. FROESE: Yeah, it's a great point. I'd say it's a, one of the things that we're working through is the balance between, yes, dust in NEI-18-04, which we've been challenged to do to not excessively put in too much conservatism into our analyses, which could potentially drive, you know, drive costs on safety systems and such. Versus, you know, the fastest path to --

MEMBER KIRCHNER: But that very conservatism is the whole basis for the functional containment approach. So --

MEMBER PETTI: And again, the V&V burden, it should not be underestimated. For the time and cost getting to the OL. CP, yeah, not a problem. There's a lot there that if you just, you know, extract the relevant physics, put it on a piece of paper, I think it's more transparent to the regulator.

And I can tell you, you know, that there are other people using TRISO fuel, and some of them are going that way. And I think the micro guys are going to go to something simple too, because they're even smaller.

But I think actually these simpler versions can even be used here, even though it's a bigger reactor. I mean, just give you a number, all this plate-out stuff, do you know what the fourth same grain safety analysis assumed?

And this was approved. One percent of the gas activity plated it out for a pass. Now how many passes that gas goes, right. You could make it one one-hundredth that, you're going to get the same answer because there's so many passes.

That was what was done in, what, 1970s, I guess. That was considered acceptable. They don't have to model all that stuff, you know, particularly if you could -- if you could take a detailed model with all the absorption isotherms, and show that in the end, you know.

So you could do a side calculation that doesn't need all that validation, but then just do something really simple. Everybody loves models, I understand that.

CHAIR MARTIN: Okay, so have we exhausted questions for X-energy?

MEMBER PETTI: Let me just make sure I've hit on everything that I -- something letter that --. Oh, here's the other one. Again, this is why I was talking about steam condensation.

There are some fission products like inside -- there are some fission products in the matrix then when the steam gets in there, you will convert the cesium and strontium to cesium hydroxide and strontium hydroxide, which are volatile. They'll stay with the steam.

And I always argued, okay, it'll condense in the building or whatever it is. But now you tell me that you've got a line that is going to spew it outside the reactor.

MR. FROESE: Yeah, we do include the fission product from oxidized graphite as a result of steam generator 2 ruptures in our -- in --

MEMBER PETTI: So the fission products residing in the matrix are assumed to be full?

MR. FROESE: Yes.

MEMBER PETTI: Okay, because that wasn't clear. Okay. Oh, I can take that out.

MEMBER KIRCHNER: How much material at risk is there in that? In other words, fission product in the inventory. What contribution would that be?

MR. FROESE: Generally what we've seen in the amount of fission product inventory in the matrix material is low compared to offsite DBE dose limits. That's what we've seen thus far in our --

MEMBER PETTI: And you're saying like 25 rem?

MR. FROESE: Yeah, compared to 25 rem, it's --

MEMBER PETTI: One rem, when you have to do the.

MR. FROESE: Yeah, so it's below one rem, even compared to -.

MEMBER PETTI: Because that's the one that's going to --

MR. FROESE: For EPC -- yeah.

MEMBER PETTI: Limit with your EPC. And they're on the order of, let's say 10 to the minus 5, right. All the defects, put them together, all the incremental failure that you get after radiation accidents, you know, 3, 4, 5, 10 to the minus 5, something in that range. Worst case, 10 to the minus 4 of the inventory, you know. And a lot of that's out in the matrix because --

PARTICIPANT: In the matrix, yeah.

MEMBER PETTI: But again, if you do a detailed pebble, it might be in the matrix in the middle versus on the edge. So there's something there that probably helps you.

CHAIR MARTIN: What's the size of your site that you're have assuming for these preliminary calculations?

MR. FROESE: The preliminary boundary, low population zone and emergency planning zone are all currently set at 400 meters from the building lineup that would - that other credible events could occur.

MEMBER PETTI: MHTGR was either 400 or

450, I can't remember. And one rem was always iodine, but they had a lot of the tension of cesium and strontium in the graphite.

And they were worried about the steam wash, the wash-off effect. Because the strontium - cesium I think it would be okay. And the dose from the strontium may be a problem. But that's where - that's some of the higher uncertainties in the diffusion coefficients in strontium and cesium.

But you're a smaller core now. I mean, MHTGR was, you know, about 350 megawatts. This is 80. So well, yeah.

CHAIR MARTIN: You mentioned tritium earlier in the presentation. Wouldn't expect to be a huge contributor here, but if you want to follow up with that earlier thought.

MR. FROESE: Currently tritium is not included in our safety analysis dose calculation, similar to light water -- light water reactors. There's normally some estimate of the potential inventory, and we're still in the process of confirming that other activation-type products are minor contributors compared to offsite dose limits.

MEMBER PETTI: I guess that in terms of tritium, right, there's three sources, ternary fission, activation, the helium -- isn't helium four? No, there are only three. And then, impurities, the graphite. So they're worried about this in the old days, because graphite had a lot of impurities.

I don't believe today graphite has a lot of impurities. I used to hear about that all the time, it drove me crazy. Modern technology, the graphite's very good. And the others are very small contributors compared to the graphite because there's a lot of graphite.

MR. FROESE: Yeah, where a lot of this concern comes from is just for this particular reactor using the steam and making sure that (simultaneous speaking.) the tritium vibration --

MEMBER PETTI: So we looked at this in NGNP. Your outlet is 750, right?

MR. FROESE: Yes, 750.

MEMBER PETTI: Yeah, if you - your permeation rates will be really low unless you get a - you got to stop moving towards 850, 900 for sure. If you just - I don't remember what metallic alloy it was. But there's good data on permeation rates through those materials. Plus there'll probably be an oxide on the inside that'll be a barrier. Whether you can count on that.

MEMBER KIRCHNER: And this, with helium as a coolant, you don't get much of that reduction in --

MEMBER PETTI: Yeah, no, no, this is not like --

MEMBER KIRCHNER: Salt --

MEMBER PETTI: - salt systems, where you can get a lot, yeah. That's why I was surprised when I saw it, because it shouldn't be an issue.

CHAIR MARTIN: Okay, we exhausted questions? Ready for the staff. Okay, let's take a moment and switch over.

MR. DRZEWIECKI: Other members on the team are no longer with the NRC. People thought they were involved in this review. I will say that this is an area that we see as basically highly important because basically doing, you know, your dose calcs for your site are something that we want to basically flesh out as part of -- as part of the CP application.

But this is a risk that we're going to carry into CP application. So this topic report and staff's review did not fully address these areas, but we'll get into that in this presentation. Can I have the next slide, please?

So first I'll go through, you know, just some of the background in terms of, you know, where this report fits in with the other ones and how some of - and how some of the - some of the updates were done on this topical report.

Going to the reg basis, highlight the scope of the staff's review. Do a quick summary of the staff's review. And then just - and our conclusion. Can I have the next slide, please?

So this was a largely submitted in May '24 and was updated earlier this year. That update includes items that were - that were identified during an audit. That includes updates to Section 1.5, which introduction to 7.1, which is the conclusions. Just to clarify that this is just for a preliminary analysis.

They corrected typos. And then there was a update to this Appendix H, which shows all the model interfaces, which is on the next slide, please. So this wasn't updated, this wasn't changed. And so this was also shown in a previous presentation.

The model interfaces as described. It does appear to be a preliminary, somewhat simple change. For example, there are models that are described in this topical report. In the previous version they were in this figure, and then they were pulled out. But that's the kinetics model as well as the - as well as the tritium models.

So it's highlighting that this, it's unclear because this is the final version of these interfaces. Next slide, please.

Just some background. This is just, you know, some of the material that staff is very much aware of. There's been a lot of work done in the area of a source term analysis, especially on the gas reactors. I imagine these look very familiar, especially to, you know, Dr. Petti. Surely, you know all the NGNP PIRTs, both in accident analysis as well as for the fuel.

The white papers that came out of the Idaho, there's a EPRI threshold topical, a report. The one, I don't know if the committee is as familiar with the joint work that was done by the NRC and by the CNSC, that's the Canadian regulator, to effectively take the fuel qual - the fuel qual framework that was outlined on the new regulatory 246 and try to exercise that with the help of PNNL oversight.

But that being said, all the background information, it wasn't really brought to bear during the course of this review. But just highlighting that this is something that we're familiar with and we plan to carry this on as we go through on the CPA review to engage some of the details of the models. Next slide, please.

So this is going to the right basis. Again, this is the regulatory basis identified by staff, so it's somewhat different in the SC versus what is in the actual topical report. Just going to a higher level of fidelity maybe.

One is 50.34(a)(1), of course doing a partial interest product release for the offsite consequences. 50.34(a)(4) to do a preliminary evaluation. Of the systems, staff identified some of the PDC that are relevant to this area, including 10, that's the SARDDL specified several radiological release rates. Sixteen, that's your functional containment. Nineteen, that's your control room.

And then, again, bringing in 50.34(a)(8). This is about having a R&D program in place so that you can answer questions that have to be answered to pretty much assess available tools such that you'll have that information in place for the OL before you can begin construction. Next slide, please.

As far as the scope of the staff's review, Section 4.2 describes other models that are implemented into the excess term code are used to calculate dose consequence for licensee basis events. That's the LBEs, which also includes design-basis accidents, which are a subset of LBEs, in accordance with NEI-18-04.

The staff reviewed the MST modeling approach to address radionuclide transport to support preliminary analysis of the Xe-100. But the review is limited to and focused just on high-level physical phenomena of interest and whether the approach and methods could reasonably support a future licensing action.

Reasons for that is the design is preliminary. The development and assessment of the models is in progress or is planned. And the - so, yeah, so the evaluation models within the excess term for acceptability will be conducted during the review of an application that relies on this.

So right now, we're looking at the Long Mott generating station, within that CP review. So we're going to carry this review as far as some of the details of these models into that review. Next slide, please.

Yeah, so this should be old news here. This is just as far as, you know, some of the barriers to radionuclide release. Just want to highlight some things in case it wasn't made clear in the previous presentation. There's obviously with the fuel particle there on the left, actually it's the fuel pebble with the fuel particles inside of it.

That's the bulk of the functional containment, I would say. So within the fuel itself, you have the kernel. You have your -- or silicon carbide and your pick layers. And then you have the fuel matrix and the fuel-free zone outside of that.

And so that's also shown on the right figure there. Outside of there, you have the helium pressure boundary. And there is a reactor building, you know, with filtration and all that. But that is not credited in the safety analysis or as part of source term. Next slide, please.

Okay, so now going through the actual models, there are three that I'm going to talk a little more about or some of the things that were noticed by staff. The one thing, as far as thermodynamics calculation model, this is all the temperatures in the fuel, both in the pebbles and the particles. So you know, a multi levels of heat transfer there, as well as the core components.

So staff doesn't - this is seen as an area of high importance because, you know, this is going to calculate all your fuel temperatures, which, you know, some of the release mechanisms are going to be driven by diffusion, which is temperature-dependent. So this is an area that we're going to look at or plan to look at as of the PSAR on review.

I will state that over the course of this review, I think there was some misunderstanding as far as the role of this module, of this model versus what is done inside of the safety analysis methodology. What I mean by that is the use of GOTHIC and Flownex versus what is done here.

So there is some confusion there. And so that's why a detailed review was not done on this model as part of a - as part of this methodology. So we'll be looking at that basically over the PSAR.

MEMBER PALMTAG: My impression, of the THM is simpler, you know, because of course it's solving a different problem. They're just tracking more things because of loading and it doesn't need the same kind of TH that GOTHIC and Flownex would otherwise conduct.

MR. DRZEWIECKI: It was. As was brought up, as far as the point kinetics model this is KSEM. So it's described as 2-D axisymmetric geometry simulating transient behavior of the core.

It further states that you know, point kinetics is applied to each cell individually. There are many cells in the model and the flux profile is, you know, going to be reshaped between time shifts using A, B, the fusion kernel.

So that description of point kinetics, I'll just say it did appear somewhat different than what I'd be used to. I don't know what -- I venture different Palmtag here. But I think he brought that up. It does look a little novel to what we've seen before, which is kind of, you know, just having a zero-D model with a single eigenvalue value that, you know, wouldn't have, you know, that kind of coupling.

Surely aware of things like exact point kinetics, but I'm not sure if that's where this is going. Anyways, just wanted to highlight that the use of this model, it was relied upon, but I expect that to be justified for a number of issues. So it couldn't, you know, so we could have some questions there as basically a recipient view.

CHAIR MARTIN: Yeah, Scott, your ears should have been burning.

MR. DRZEWIECKI: So I'm not sure if my comments there resonate with kind of highlighting that. It did look like the way the point kinetics model was described was a little novel. That being said, we did not dig into any of the details of this model, so. Next slide, please.

Okay, third item, kind of talk about, you know, this is the - this is a tritium model. This was under development, so that wasn't, you know, a lot of details in here. And so just trying to highlighting the fact that it was just used, and you know, you're going to have to clarify.

The other models, which I won't go in, I won't read these off, but I'll just kind of highlight them. As far as particle failure to probability model, you know, solid transport modification model. Gas transport model. The dust model.

Then we have a pressure boundary model and a boric corrosion model. This is just kind of summarizing what those are. I think we went over those, so we can go to the next slide, kind of go into what staff said about that.

As far as those models, those last six models are highlighted here, and there's nine total. But these three. So the staff did make a - they did determine that these address phenomena that appeared - that we needed to predict the source term to support preliminary - to support preliminary analysis.

That's because the models rely on previous modeling experiments. I'm sorry, previous modeling operational experiments from the gas-cooled reactors, such as AVR. Based on staff's experiments -- based on staff's experience with LWR and non-LWR source term analysis, there were no gaps that were - that were seen.

However, there are sections of this topical report that seems like this model could be - are subject to change. So staff did not perform a detailed technical review on any of the models within this topical report, specifically access term. And so there's no conclusions made regarding the acceptability of any of these models as part of this topical report.

CHAIR MARTIN: Did it go ace as far as - use the word, you know, assess, verify, or what have you of the methods that they used to come up with some of their proprietary models and correlations? At least make sure that it was, you know, got the appropriate standard approach to the use of new information, new data.

MR. DRZEWIECKI: Yeah. So doing - it's hard for me to answer that question because some of the people that were involved in that are no longer here. And so I can state that what was kind of passed on didn't see a lot of detailed, you know, detailed assessment that was documented. And so this is what we had.

It was kind of a like a fail flaw review is what it looked like. And that was not seen. And so that's why we're going to carry this, yeah, into the CP review.

MEMBER HALNON: This is Greg Halnon. I wasn't in this morning for - I guess the burning question I have just from listening to the little I did is what value did this topical report provide to us if you can't make any conclusions. You got to read, look at all this stuff when it comes to the CP perspective anyway.

MR. DRZEWIECKI: So I'll say this: if in the previous presentation that was on TSAM, I did make a point to highlight that even though some information is - is preliminary, going through that exercise, at least for safety analysis methods, it did, I think it's going to give us some efficiencies when we go into the CP review.

Whether or not I can state that here because we didn't go into the details. For example, on the TSAM topical report, for the safety analysis methods, we had gone through and identified, you know, many conditions that we think are going to basically kind of streamline our ability to write our safety evaluation over the course of the CP review.

I can't make that same conclusion here because a lot is left undone. Other than it gave us a first look at these models. But I'm not making our conclusions. It's hard to say that we gained efficiencies in the CP review.

MEMBER HALNON: Given the fact that the people that did the review are no longer here, so the wisdom and thought processes that they used to make these non-conclusions don't even carry forward to your CP review. That's the impression I got.

MR. DRZEWIECKI: Next slide, please. Okay, yeah. And then as far as Section 6 of this topical report, it does clarify that the V&V is underway to ensure the excess term is qualified to support final safety analyses. Validation plans are developed to cover high- and medium-ranked phenomena that are identified through the PIRT process.

A phenomena model by XSTERM were extracted from an earlier version of the PIRT process. Staff does determine, you know, that that assessment process is acceptable because the identification of code requirements through a PIRT process, that's an established approach that's called out in Reg Guide 1.203.

However, staff was unable to assess the adequacy of the V&V plan because the plan is not based on the latest PIRT information. Again, we didn't see information describing the knowledge level of the phenomena identified in the PIRT. And the plan looked like it was preliminary and subject to change. Next slide please.

So as far as staff's conclusions, we stated that this topical report provides a reasonable plan for the development of the MST methodology for the source term methodology. That's because those six models, you know, failure probability model, sub-probability model, so on, that are within XSTERM, they appear to cover phenomena needed to predict the source term to support preliminary analysis and evaluation of the design.

The TR does describe an acceptable approach to V&V for code assessment based on the PIRT process. But the staff are making no conclusions regarding the acceptability of the models within XSTERM for the source term analysis because the models are still under development.

The detailed technical review of the individual models was not completed as part of this review. And the details regarding a key phenomena ID with the PIRT process are not provided in this topical report. And models and associated validation plans are preliminary and subject to change.

So staff expects that a detailed technical of the XSTERM models and its applicability to the Xe-100 reactor will be addressed as part of our review, the licensing part, as part of the licensing application that would reference this report. And that would include a Long Mott CPA.

CHAIR MARTIN: We mention it for, of course, you know, it's the CP's it's, you know, it created ambiguity about, you know, what exactly is the right, you know, what measure of completeness. You know, it's -- you can't expect 100% done at this stage. Obviously the more, the better.

And I do think statements of general applicability, I'll use the word fatal flaws, you saw no fatal flaws. Even though there's an expectation that -- but you know, design will change and be very -- prove their methods. I think you can look at, say, like their design models and then make a statement about their applicability today.

So you could strengthen a statement, say the SE, saying that, you know, we took a look at them. We pulled the thread a little bit to the data that they were based on. And there was no obvious flaws with it. Well, you can make an applicability statement, you know, without, you know, any more information, qualified by the fact that of course all is subject to change.

Going much beyond that obviously uncertainties just can't be quantified at this point. They can take conservative approaches. And of course there are degrees in which you can do that, we've discussed a few of those today.

But applicability really all, you know, I've been thinking about it as we go on it. You know, the applicability statement, about the only thing you can really do at this point and have decent confidence going forward.

Ultimately the risk is on the applicant, you know. That, you know, getting our shot at all this, and you know, it gets obviously more serious, you know, the farther along we go on this.

But through all those big events, you know, what I saw, you know, and general applicability, except, with your exception of that UO2 fuel, Dave.

But a lot of the things that, you know, that were presented look familiar in my own experience with gas reactors.

To some extent, and now I'm getting a little preachy, but you know, I look at the MST approach in general and I still feel like, you know, those, it's maybe still a better tool as a verification for simpler approaches.

That of course, you know, Dave, you were hitting on earlier, that there is a TRISO topical, EPRI topical out there that provides a firm foundation on you know, failure rates. And you could come up with a simpler model and then backstop it with the details that you have prepared in XSTERM.

I don't know, I guess I have nothing more to add on that. And I invite other members to -.

MEMBER KIRCHNER: Seems to me I'd like to make an observation, if I may. I appreciate the applicant in the staff's review and where you are. I mean, trying more and more to do things in parallel so we don't have a fully developed and accepted EN methodology for this source term.

So what does that mean for the CPA that's coming up? It seems to me the pebbles are the pebble. They're going to be made to the spec. So let's assume to first order that they can - they've got the quality assurance and control. So they make the pebble and the fuel, TRISO fuel, to the spec.

Then what do we do for the CPA? It seems to me you bound the problem with the maximum hypothetical accident release as the source term, and then demonstrate, based on design options, whatever figures merit, mainly time and temperature, that you're below that. And you can then meet whatever they set, like the 400 meter exclusionary boundary and so on at one rem, or whatever metrics are going to be used going forward with the CP.

Because you're not going to validate this stuff in that timeframe. And the CP application's at hand. So it seems to me at least that's where we are.

We or the staff would look at this bound, you know, but the potential at least might be look at the mechanisms that - the functional containment, how it performs. And then do an estimate of what the dose is at the boundary.

And then you iterate on your design choices. But the fuel is the fuel, that's a given. I don't expect that to change.

So Dave, am I missing something?

MEMBER PETTI: That's right. I mean, if

they're looking for and confidence that the dose is low --

MEMBER KIRCHNER: Low.

MEMBER PETTI: -- there was an expert opinion-based model that I -- we developed in NGNP which did in nuclear technology. It only went to curies, and it had prismatic pebble bed. Higher temperature, the old high temperature machines, the 750 machines.

You can look at those doses. There's an ion level report that goes all the way to dose. We just stopped at curies. And you can meet one rem.

MEMBER KIRCHNER: You could meet the one --

MEMBER PETTI: You could meet one rem.

MEMBER KIRCHNER: -- yeah.

MEMBER PETTI: So I believe I can. It's just a matter of, you know, you just don't want the death by a thousand splits to get there.

MEMBER KIRCHNER: No, that's what I'm saying.

MEMBER PETTI: The applicant, you know, I mean that's just, there's so many things you can down too many rabbit holes. And today I can write your four equations to show you what the answer is. And

I've been preaching this to the micro community about this is not rocket science, this can be done fairly simply.

So, and again, I think you can actually apply here because these machines are still, you know, they - I guess they're an SMR, but they're kind of, they're on the small side of SMR. Certainly about micros.

MEMBER KIRCHNER: So I guess I don't know where that ends up at. But at least from my perspective, it seems to me like we are so used to Part 52, where - where people come in with a design that's essentially complete. We don't know how to deal with one that's starting from a construction phase and going to like a Part 100, Part 50 approach, which always is in the open.

So unless there is some safety concern, which I haven't heard one today, then they're in their rights to go on with building the plant and then have all this stuff come together at the end when you get the operating license. Just like a Part 50 process does.

So you know, what's the release to the public and all that stuff? That comes later.

MEMBER PETTI: I think, you know, that was

- we have these same arguments with Kairos, right. It was just, you know, a CP, but it was a test reactor. So that's why some of the questions about where's the line for a CP for a power reactor. I had to have in my mind with the Kairos experience knowing what the answer is there. You know, how different.

And you know, my opinion is you go back to MHTGR days, design was well advanced beyond what we've seen here. And it seems like CPs are moving to less design completion and pushing more to the OL. Not just X-energy, all the - we've seen other applicants advance the same thing.

So you know, is there a line in which the staff feels, you know, uncomfortable. To me the question is, you know, what are your design criteria. You do those. What are the safety functions, what are the systems that implement those safety functions? Do they look reasonable?

And then, you know, the accident analysis. I mean, we haven't seen the details. But certainly the ones they identified are the ones identified in every gas reactor that I've ever seen.

So you know, I can see putting together a story for the CP that that's not an issue. I just was wondering if the staff had any red line. Because I think I can check off affirmative on that higher level stuff and the systems stuff.

MEMBER KIRCHNER: Well, I don't think we've seen the floor yet. I think it's -- can put the floor of detail and continue --

(Simultaneous speaking.)

MEMBER PETTI: Yeah, yeah.

MEMBER KIRCHNER: Rather than the other around. And then they started with NuScale, which was the design, and that's what we're used to. It's all online.

MEMBER PETTI: That's the POL --

(Simultaneous speaking.)

MEMBER HALNON: Why there's so many, you know, limitations and conditions in this thing, because, you know, those are promissory notes essentially for the applicant to, you know, do these things and demonstrate compliance and satisfactory results in the end, not at the beginning.

MEMBER KIRCHNER: Right, but if you're doing concurrent R&D, which we'll see in, I presume that the staff one more time for this application when it comes in, will build a so-called Appendix A, which lists the things that either have to be demonstrated experimentally or completed and so on.

The only danger I see here, Tim, is that I don't know that you can really get through with that matrix of models and V&V them by the time you want to build and license, the operating license. I'm worried about that.

PARTICIPANT: I don't think they have to.

MEMBER KIRCHNER: I don't think they have to either, I'm not saying that. But I'm saying that you put something up like this, with a very ambitious V&V challenge in front of you, you probably don't need it for making a adequate safety determination, if you can show that for a bounding set of events, that the public dose is acceptable, acceptably low.

And I'm just wondering where we are. Usually, you know, you want to have the box checked, that EM methodology checked. It's approved for going ahead and doing all your analyses. I just worry that they don't get there with this complicated presentation.

MR. DRZEWIECKI: Well, yeah, yeah. So one I thought was green actually the safety was basically, you know, like the overarching structure of the interfaces basically like the large codes that are being used, you know, whether BSOB, FUB, your GOTHIC, and you know, Flownex, all that stuff.

I do want to highlight, so one thing, you know, being handed, it would have been helpful if this methodology and the associated review had progressed further to retire perhaps some of the risks that we're taking into the CP review.

Because this is an NEI-18-04 review, which is a risk-informed review. So doing the calculation of the consequences, which is where this is being used, is going to be important. Because that's going to inform how you classify your SSCs, how you assess defense-in-depth, and that is being evaluated.

And so this is an area that we do see as something that, you know, we emphasized going into the CP review. And we have, you know, some plans in place, such that we can not only, you know, do this review, but do some of our own independent calculations using, you know, basically, you know, things like a scale and MELCOR, those kind of things. So just to make sure that we can assess these risks to give us a good feel that we're all on the same track.

MEMBER PETTI: Just remember that the MELCOR source term calculations that were done years ago for HTGRs had failure fractions that are a factor of 50 to a factor of 100 higher, you know. When I saw those numbers, I was like what planet are you on.

That's not what the database tells us. The database tells us a really good story.

So you know, don't spend time to figure out, it's right there, you know. I'm hoping everybody can calculation diffusion the same. It's not a difficult problem. So we've done benchmarks under the IAEA on that stuff, and everybody gets the same answer. It may not be the right answer, but they keep getting the same answer.

No, they do. They ran UO2 and it all worked well. Then they ran UCO and it didn't match the data because the data all derive from UO2.

CHAIR MARTIN: Somewhere we kind of touched on the tools, right, Tim. You mentioned scale and MELCOR. You know, earlier this year we wrapped up our review of, you know, the progress that Research has made, you know, to support these kind of rules, these kind of reviews.

So at what point would you kick off the preparation of kind of audit analyses with the tools that Research has come up with?

MR. DRZEWIECKI: Well, I'll say this. I mean, it started a while ago.

CHAIR MARTIN: Well, we would have like a MELCOR model and you have --

MR. DRZEWIECKI: Ah, yeah. In fact, so there were a couple, you know, there was, you know, public workshops going back a few years where there was a series of, you know, of generic models that were built of gas reactors and across the board with the intention of having those in place such that you could just go through and you know.

CHAIR MARTIN: Well, with design-specific information. So, like you've begun doing the tweaks for X-energy?

MR. DRZEWIECKI: Not yet because we don't have the, you know, any of that information, I think, of those tweaks yet. But those are stuff that we're planning on doing.

So yeah, because it basically was brought, you know, are we doing this review or when it starts. It has started. You know, it's been docketed, I think what, two weeks. So I mean, it was docketed. But the extent this letter went out, I think we already mailed. So we're rolling, and --

CHAIR MARTIN: So it would be kind of a part of the CPA review is to start having some of these kind of audit calculations done.

MR. DRZEWIECKI: We do have those plans in place. That is that we have, you know, a research assistance request in place, user need request in place. So we, you know, we have plans to leverage.

MEMBER PETTI: You have pebble bed models, as I recall, and they were benchmarked against the pebble bed benchmark that IAEA have. You know, they're designed really similar. So get a huge jumpstart on putting in the design specifics and their differences.

No, those have been invaluable, I think, for the staff. Even it's not the exact design, there's lot of commonality in each technology class that you see.

MR. DRZEWIECKI: Yeah. I'll say during the Kairos CP review for Hermes 1, they were used there. They were leveraged there. And it gave staff, you know, a lot of confidence having that - having that independent check.

CHAIR MARTIN: Kind of, yeah, we should do a public comments at this time. So if there's anybody online or of course in the room, representing yourself public in some matter. This is your opportunity to speak up and offer a comment to the committee.

So if you're interested, just raise your hand using the Teams function or tap me on the shoulder, or whatever. I'll give you 15 seconds. Is that too little?

Don't be shy. Okay, so it sounds like we haven't - we don't have any public comments here.

So I snuck in two of my questions that I thought would be in the closed and got the answers that I wanted related to phenomena specifically and related to the - from radiation and dust. I think she covered dust pretty well.

The only other thing was the, kind of the nodalization detail. For me, I can probably just pull the thread a little bit late on here. I don't have to have closed session.

MEMBER PETTI: I had just two questions that I'm not sure needs closed session if I don't talk about the specific numbers. But if I just talk about it in general. I will let X-energy decide if I ask the question.

The - in one of the appendices is the spec numbers. And they are significantly lower than what the Germans ever achieved and have ever been achieved in the U.S. The U.S.'s is a compact, high-packing fraction, very different geometry. Do you know which table I'm talking about?

MR. HANUS: What numbers are those?

MEMBER PETTI: Defect.

MR. HANUS: Oh, defect actions.

MEMBER PETTI: Yeah, you've got, it's the table that's got the AGR numbers. And then it's got X-energy. And of course the actual numbers are in brackets. But the numbers are significantly lower than the Germans ever achieved, that AGR ever achieved. And at a higher confidence level than is standard.

You know the table I'm talking --

MR. HANUS: Yes, I know, yeah.

MEMBER PETTI: Those imply, because it's at the higher confidence, that the mean has to be even lower. And I'm trying to -- I mean, if you've -- if TRISO X has done stuff and demonstrated it, like, great. And I can imagine, you know, in a pebble low packing fraction, that could have lower defects than a 40% packing fraction compact. That wouldn't surprise me in the least.

But I was just, you know, understand that they're significantly below anything that's been achieved, even in China today.

MR. HANUS: So this comes from another fuel development team. And I don't know if anyone is on the call who could comment on that for us. The system developers, it's an input.

MEMBER PETTI: Right, no, if you can get

there, that's going to help you a hell of a lot all the way down the line.

MR. FROESE: I think this is something we take back to the fuel committee.

MEMBER PETTI: I think that's fine, you know. Because I'm learning the same letters that the staff needs to check. I mean, that is everything that's on the defects, right. And so you got to be absolutely sure that they can consistently produce to that.

CHAIR MARTIN: Be careful.

MEMBER PETTI: My second question is something I forgot to ask. Do the models account for the breathing of the -- of the vessel? Understand what I say, right. In that DURC, you blow it out, right, and then there's still the core heats up, it's still expelling. And then the core starts to cool down and it pulls back.

And so the fission product release stops when the flow regresses. Do you guys credit that or take that into account?

MR. FROESE: Yes, that's correct. It's one of the reasons that supports a 72-hour safety-related duration on our CCS, is exactly from that phenomena. And after the core hits its peak temperatures, you start to get that volume, that's your contraction back in that keeps the fission products inside of the reactor.

MEMBER PETTI: Right, not --

MR. FROESE: That's the model that's GOTHIC.

MEMBER PETTI: Okay, because it didn't talk about that. But it's -- in this nuclear technology paper, we have people who were working for I think PBMR at the time. And the numbers were significant in terms of reduction as a physical phenomenon.

The problem comes with validating that behavior could again be something that could be challenging. I believe it. I mean, you can do - we're doing some simple calculations in teams to either show actually happens.

Okay, those are my questions.

CHAIR MARTIN: Satisfied ourselves we don't need a closed session?

MEMBER BIER: I think Bob, you may still want to have a closed session for the morning's topics, or?

CHAIR MARTIN: Well, like I said, mine were morning-related. And I snuck in.

MEMBER BIER: Yeah, I didn't really sneak mine in. I suppose we could come back to the earlier slide and see if people can answer the question in a non-proprietary environment, but.

CHAIR MARTIN: Ask.

MEMBER BIER: So this was with regard to the uncertainty methodology about extreme value analysis and mean squared error. And I can't remember who the presenter was at the time, I'll just look at the mic.

So I guess I had two questions. One is was that - was the extreme value analysis done using the statistical method of extreme value three theory, which is kind of a standard known method that extrapolates from data? Or is that just kind of an informal description of what was done, you picked some extreme values to test insensitivity or whatever?

MR. HALLEE: This Brian Hallee. It was the latter. So a straight value, meaning you take each input --

MEMBER BIER: Got it.

MR. HALLEE: - to its two-signal limit, and then it would just stack.

MEMBER BIER: Perfect, thank you. And the other question I had, which is not meant as a critique, I'm just trying to like figure out, but I'm wondering whether it makes sense to do something like mean squared error when the results are to begin with kind of arbitrarily conservative or whatever. Is it meaningful in that context?

And not that there's necessarily anything wrong with doing it, but it just seems kind of like well, maybe it - you know, I'm not sure what you get out of doing that if the results have, you know, varying levels of conservatism, etc., that you're combining.

MR. HALLEE: Yeah, I would agree with that. I think we're - it's little bit said 95 percentile, we're going to use that in floats and that it's a reduction of a conservative method but it's not a true 95-95 and how we're - and how that's being defined.

MEMBER BIER: Okay.

MR. HALLEE: Sort of a reduction of over-conservatism, if you will.

MEMBER BIER: Okay, so you did it kind ad hoc, just in order to have some way of bringing in the extremely wide bands to a more manageable level, but it's not like some validated methodology that you're hanging your hat on and going to use going forward necessarily or whatever.

MR. HALLEE: We're still exploring the exact statistical method we'll apply for the LRA, that's correct.

MEMBER BIER: Okay. And I guess that answers my questions and then I don't need a closed session for an example. Thanks.

MEMBER PETTI: I had another one, just, you had talked about it. In the example calculation in the DLOFC, the fuel got really hot, well above the database. Just no fig leaf for the staff that - it was a sample calculation so I didn't put a lot of weight in it. But if that number is what you get, that's problematic because you're outside the testing range.

PARTICIPANT: Yeah, with a sample, you could do just about anything and like the sample for the temperature is lower too. The question doesn't come up.

CHAIR MARTIN: All right. Not going to go to closed session, so maybe this is the last shot at questions.

MEMBER PETTI: Well, I think we're going to have some discussion about what letters we're going to write.

CHAIR MARTIN: Oh, of course. Remember,

this is a subcommittee, not full.

I think you've already tipped your hat about what you're going to do. I as far as the morning session, I think just a summary report would be sufficient. So but why don't you tell us what you're thinking --

MEMBER PETTI: Well --

CHAIR MARTIN: - this afternoon.

MEMBER PETTI: - to be consistent with the other applicants, we always write a letter on source term. So I plan to write a letter and encapsulate largely the concerns that identified and recommend that they look at, at least for the OL, I can't -- CP something -- something simpler. Whether they do that in parallel I'm not going to give a script, but you know.

I think they can get to the goal line in a lot easier way, is basically.

Point out other data sources that weren't in the paper so if they want to go start chasing things, this data --

CHAIR MARTIN: Yeah, it's kind of a --

MEMBER PETTI: - either the staff or the --

CHAIR MARTIN: -- unprecedented recommendation coming out of the ACRS that you could actually be simpler. I think there's probably more examples of the other direction.

MEMBER PETTI: I'm just here to help.

PARTICIPANT: I would suggest that we really should do that. I think it's - we should avoid excessive pontification because we know it.

MEMBER KIRCHNER: I think we have to be careful we don't get out of our swim lane, because if we recommend a certain path, they take that path, and we don't like the results, then we are culpable.

MEMBER HALNON: This fuel has enormous margin. There's a lot of data out there to start with, especially for gas reactor fuel. It's got a lot of margin. Is there a reason to suggest that very sophisticated models need to be applied when the uncertainty bounds on those models and the potential for verification are essentially zero?

And they don't need it. I mean, that's really the key thing I think, they don't need it.

MEMBER KIRCHNER: The key thing is going to be production quantities with low defects.

MEMBER HALNON: Yeah.

MEMBER PETTI: That's all been.

MEMBER KIRCHNER: I can tell you that firsthand because I've bought fuel from GA 40 years ago to the MHTGR spec. And be careful about your spec. Don't over-specify beyond what you need because you may put yourself in a situation where in front of the NRC you can't meet your spec.

MEMBER HALNON: And the EPRI document is quite good.

MEMBER KIRCHNER: I think that's an adequate spec. If you're going beyond that, you should have some reason perhaps economic which I don't know or some other design issue that you're addressing. Otherwise, over-spec'ing the fuel may be a trap for the actual manufacturing of production quantities of fuel.

CHAIR MARTIN: One thing I think Matt is touching is, we can't be in the consultant mode.

MEMBER KIRCHNER: No.

CHAIR MARTIN: And certainly provide some opinions on complexities and whatnot. But remember, we're looking at the TR that's in front of us, not what we hoped to have seen and/or the CP that's coming down the pike. So we just got to be careful that we're not providing indirect direction, if you will.

MEMBER PETTI: Pontification.

CHAIR MARTIN: I mean, the comments are on the record. They're listening to them. They can apply what they feel is required. But the onus to demonstrate safety is on the applicant and the NRC to verify, not for us to give a pathway forward. However, I hope that they've certainly taken your comments to heart.

MEMBER KIRCHNER: Well, the thing that's a little bit different here is this is, you know, this is the poster child for functional containment. So you really have to deliver on the particle fuel, and I guess that's enough said.

CHAIR MARTIN: Well said.

CHAIR MARTIN: We'll certainly see more fuel down the road.

Okay, have we covered everything?

MR. BURKHART: If I can just ask a question. So this is Larry Burkhart from the ACRS staff. So a letter on mechanistic source term? Do you want a presentation by the applicant and the staff, or no?

CHAIR MARTIN: I don't think - everybody's --

MEMBER PETTI: They can certainly just listen in now.

MR. BURKHART: Okay, I don't see.

PARTICIPANT: It's not like you're

traveling a long distance (Simultaneous speaking.)

PARTICIPANT: Opportunity to go through it and look at a draft for proprietary information.

PARTICIPANT: We won't catch you all cold.

MR. BURKHART: Exactly.

CHAIR MARTIN: Yeah, I just want to make it clear to the staff and the applicants that you're invited to listen in to the deliberations. You will get a version to clear for proprietary before we bring it up. And then if the committee has any questions for the staff or for the applicant during the deliberations.

PARTICIPANT: And you can actually, you can attend as well. I mean, it's a public meeting. You don't just have to listen in. In the proprietary, if you see factual - when you get it, if you see any factual errors, point that out to the ACRS staff members or the NRR staff members.

CHAIR MARTIN: Okay, well, I'd like to thank X-energy, and of course the staff for their presentations and the time and effort that they put in to create the presentations. With that, I'll adjourn the meeting.

(Whereupon, the above-entitled matter went off the record at 3:24 p.m.)

Xe-100 Analysis Overview

Brian Froese, Analysis Integration Project Manager

June 3, 2025

Department of Energy Acknowledgement and Disclaimer

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Objective & Regulatory Basis

Objective: Provide a high-level overview of X-energy's Safety Analysis process, background on the 3 Licensing Topical Reports (LTRs), and summary of each LTRs Safety Evaluation Report (SER) based on audits by the staff.

1. Transient and Safety Analysis Methodology
2. GOTHIC and Flownex Analysis Codes Qualification
3. Mechanistic Source Term Approach

Regulatory Basis:

In part: 10 CFR 50.34 and RG 1.203

Overview of the Safety Analysis Process

1) Design Freeze

2) PRA Develops Licensing Basis Events IAW NEI 18-04

LBEs

3) Thermal Hydraulic Analysis of LBEs in Flownex & GOTHIC

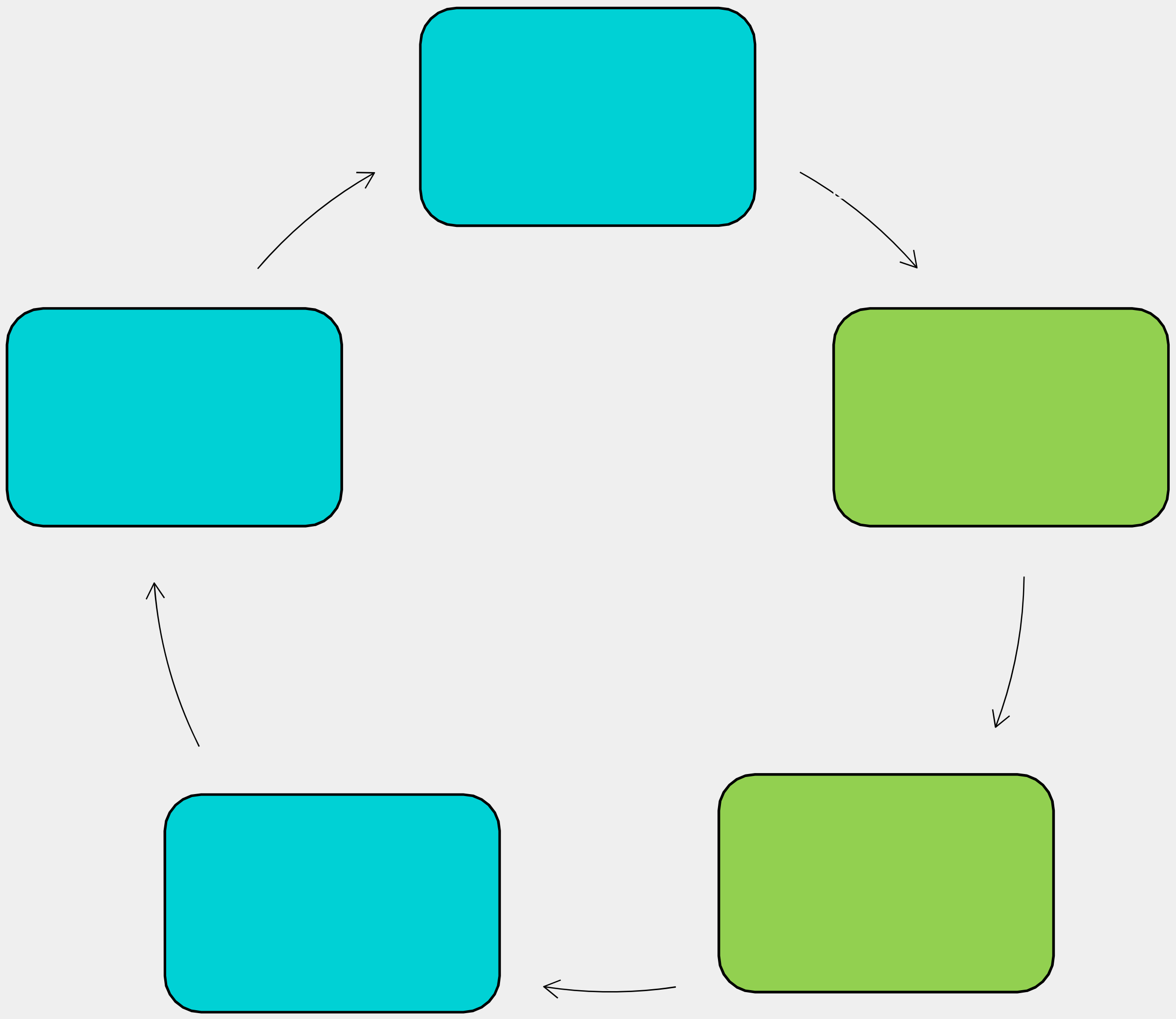
Core Temperatures vs. Time
Core Power vs. Time
Steam Ingress (if applicable)

4) Determine Offsite Dose in XSTERM

Doses

5) PRA Technical Adequacy Determination, Licensing Assessment

Capability & Reliability Targets
Special Treatment Reports
SSC Classifications



Xe-100 Key Safety Features

Control Reactivity

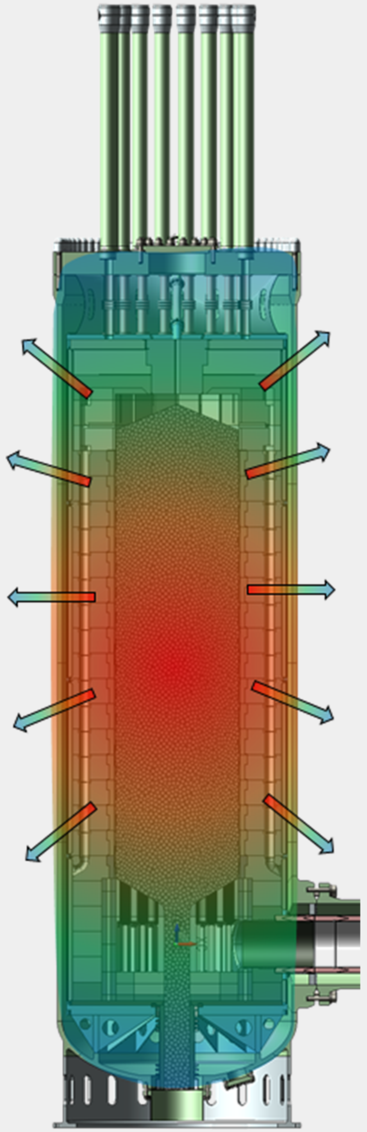
- The Xe-100 can shutdown passively on inherent reactivity feedback without control rod insertion

Control Heat Removal

- The Xe-100 can passively remove decay heat through RCCS with no active components and no operator actions credited, at least through 72 hours

Retain Radionuclides

- “Functional Containment” retains significant portion of radionuclides during normal operations and during LBEs



Overview of Dose Components

Dose Stack-up

- Circulating activity released
- Liftoff activity released*
- Fuel heat-up activity released Plant Transient
- Fuel Heat-up activity released Long-Term*
- Steam effects activity released*
- Wash-off activity released*

Sum = LBE Dose

Offsite Dose (TEDE) [Rem]

25 rem DBA Limit

Final result for this example case

* Steam-off/Wash-off contributions

* Liftoff contribution

** Long-term DLOFC Dose Contribution *(Additional release from fuel at high temperatures)*

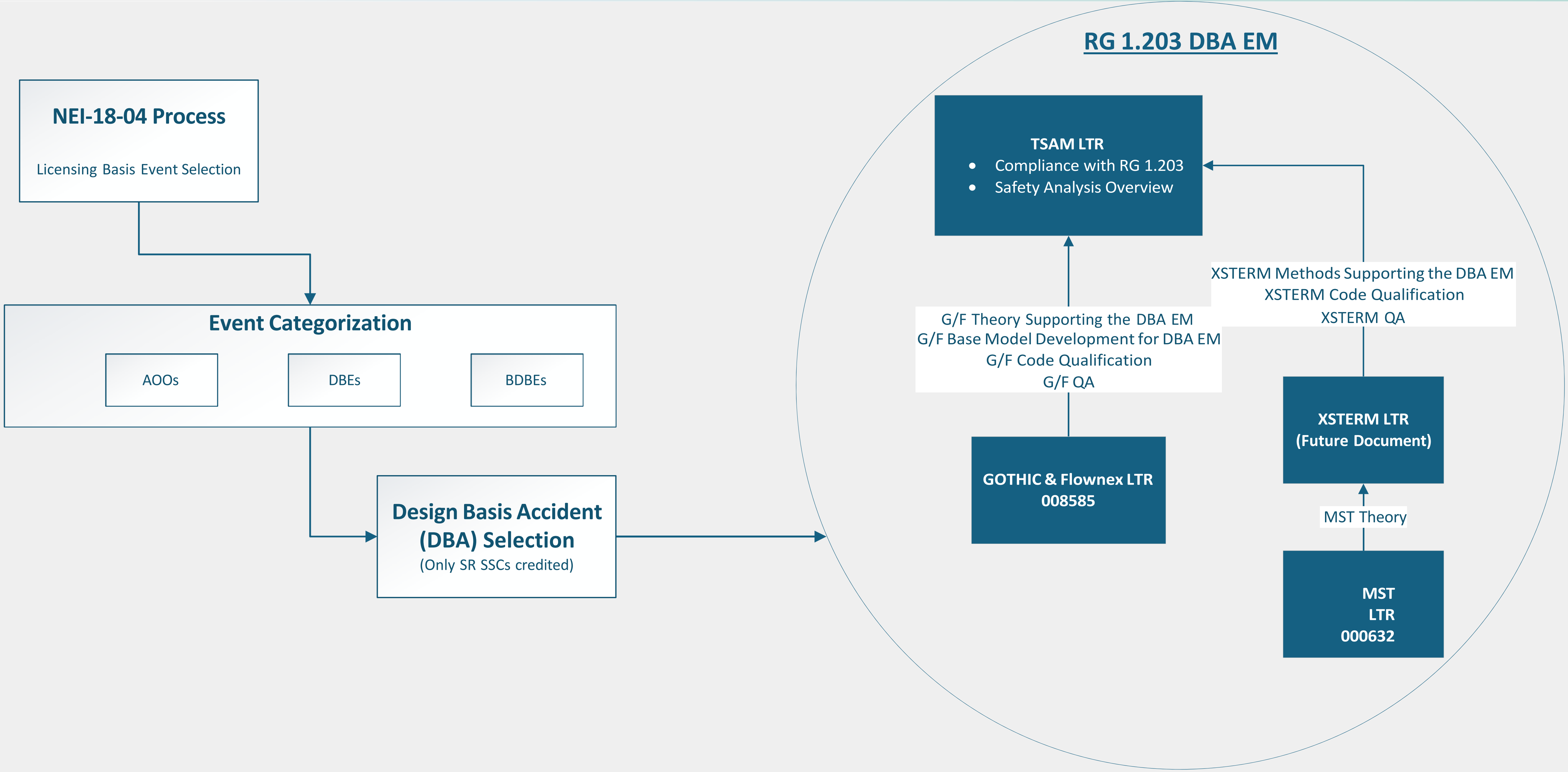
* Plant transient contribution (Flownex Screening Criteria) – *Release from fuel*

* Release of He circulating inventory

0.1 v/o leak per day

*If Applicable

LTR Overview



NEI-18-04 Process

Licensing Basis Event Selection

Event Categorization

AOOs

DBEs

BDBEs

Design Basis Accident (DBA) Selection

(Only SR SSCs credited)

RG 1.203 DBA EM

TSAM LTR

- Compliance with RG 1.203
- Safety Analysis Overview

G/F Theory Supporting the DBA EM
G/F Base Model Development for DBA EM
G/F Code Qualification
G/F QA

GOTHIC & Flownex LTR
008585

XSTERM Methods Supporting the DBA EM
XSTERM Code Qualification
XSTERM QA

XSTERM LTR
(Future Document)

MST Theory

MST
LTR
000632

One Unique Clarification

LBEs: Non-DBAs vs. DBAs

- Methods and models are the same for PSAR, but inputs are different
- This led to several technical discussions during the initial NRC review
- “Outcome Objectives” specifically requests approval to use these methods for preliminary analysis of Design Basis Accidents
- Application only to DBAs aligns with NEI 18-04

Draft Safety Evaluation Report Summaries

Safety Evaluation Report	Limitations & Conditions	Key Takeaways
Mechanistic Source Term Licensing Topical Report	None, noting this is limited to the methods and not XSTERM	"The NRC staff Concludes that X-energy's TR…provides a reasonable plan for the development of the MST methodology."
GOTHIC & Flownex Analysis Codes Qualification Licensing Topical Report	1 Limitation that input parameters will be confirmed during Construction Permit review Certain TSAM limitations also apply	"The NRC staff approves the use of TR…for the preliminary analysis of Xe-100 DBAs"
Transient and Safety Analysis Methodology Licensing Topical Report	3 Limitations, 14 Conditions: • Limited to preliminary analysis, design, DBA events, etc. • Research and development may be needed if existing data isn't sufficient • RG 1.203 compliance still in progress	Subject to the limitations and conditions, use of the EM described in the TSAM is acceptable: • For consequence evaluations addressing Xe-100 PDC 19 & 50.34 • For preliminary safety analysis of the design and performance of Xe-100 • To describe a research plan to resolve safety questions regarding EM applicability to the Xe-100

Final Takeaways

- A tremendous amount of methodology development and analysis has been conducted by X-energy in preparation for these topical reports and the Construction Permit Application
- We are proud of the work produced, and believe these methods will support a strong safety case with considerable margin to dose limits
- We are at the preliminary design phase and there is still work to be done
    - PIRT will evolve based on latest PSAR results
- Thank you to the staff for your guiding feedback, effort put into this review, and timely engagement

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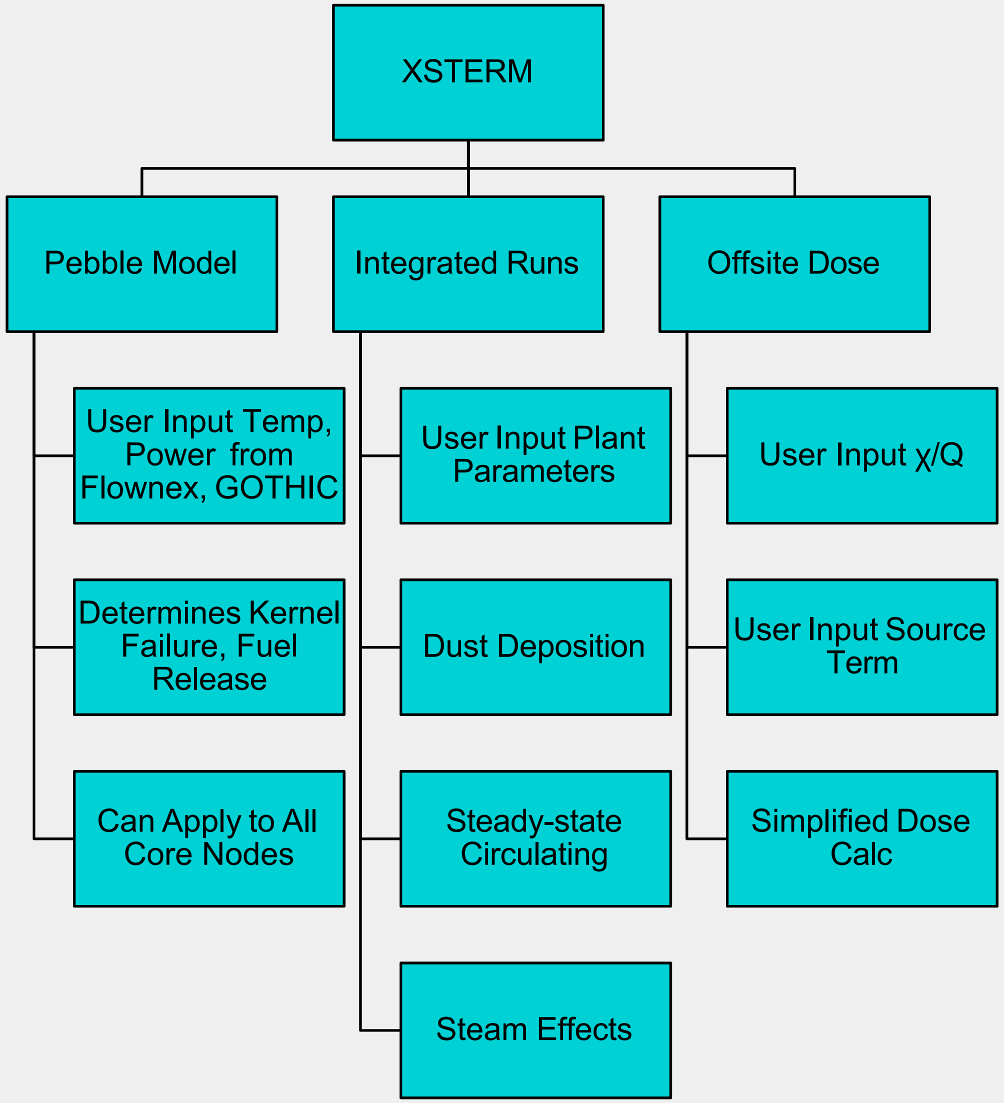
Additional Slides

Overview of Safety Analysis XSTERM Applications



- XSTERM
  - Pebble Model
    - User Input Temp, Power from Flownex, GOTHIC
    - Determines Kernel Failure, Fuel Release
    - Can Apply to All Core Nodes
  - Integrated Runs
    - User Input Plant Parameters
    - Dust Deposition
    - Steady-state Circulating
    - Steam Effects
  - Offsite Dose
    - User Input χ/Q
    - User Input Source Term
    - Simplified Dose Calc

Xe-100 Licensing Topical Report
Transient and Safety Analysis Methodology

ACRS X-Energy Design Center Subcommittee Meeting

June 3, 2025

Brian Hallee – X-energy CPA Safety Analysis Manager


energy

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Outline

1. Introduction & Purpose
2. Regulatory Framework
3. Evaluation Model Development Approach
4. Walk through Status of EMDAP Elements 1 -> 4
5. Demonstration Analysis
6. Conclusions & Path Forward
7. Questions

Introduction & Purpose

Purpose of the TSAM Report:

1. Define the evaluation model (EM) for DBA transient safety analysis of the Xe-100 reactor
2. Demonstrate analysis methodology for select example cases [proprietary]
3. Support future licensing applications

Presentation Objectives:

- Summarize X-energy’s methodology for DBA transient and safety analysis of the Xe-100 reactor
- Highlight regulatory alignment to RG 1.203

Regulatory Framework

Applicable Regulation:

- 10 CFR 50.34 - Contents of applications; technical information

Key Regulatory Documents:

- RG 1.203: "Transient and Accident Analysis Methods"
- RG 1.233: Endorses NEI 18-04 approach for licensing basis development

Previous Interactions with NRC:

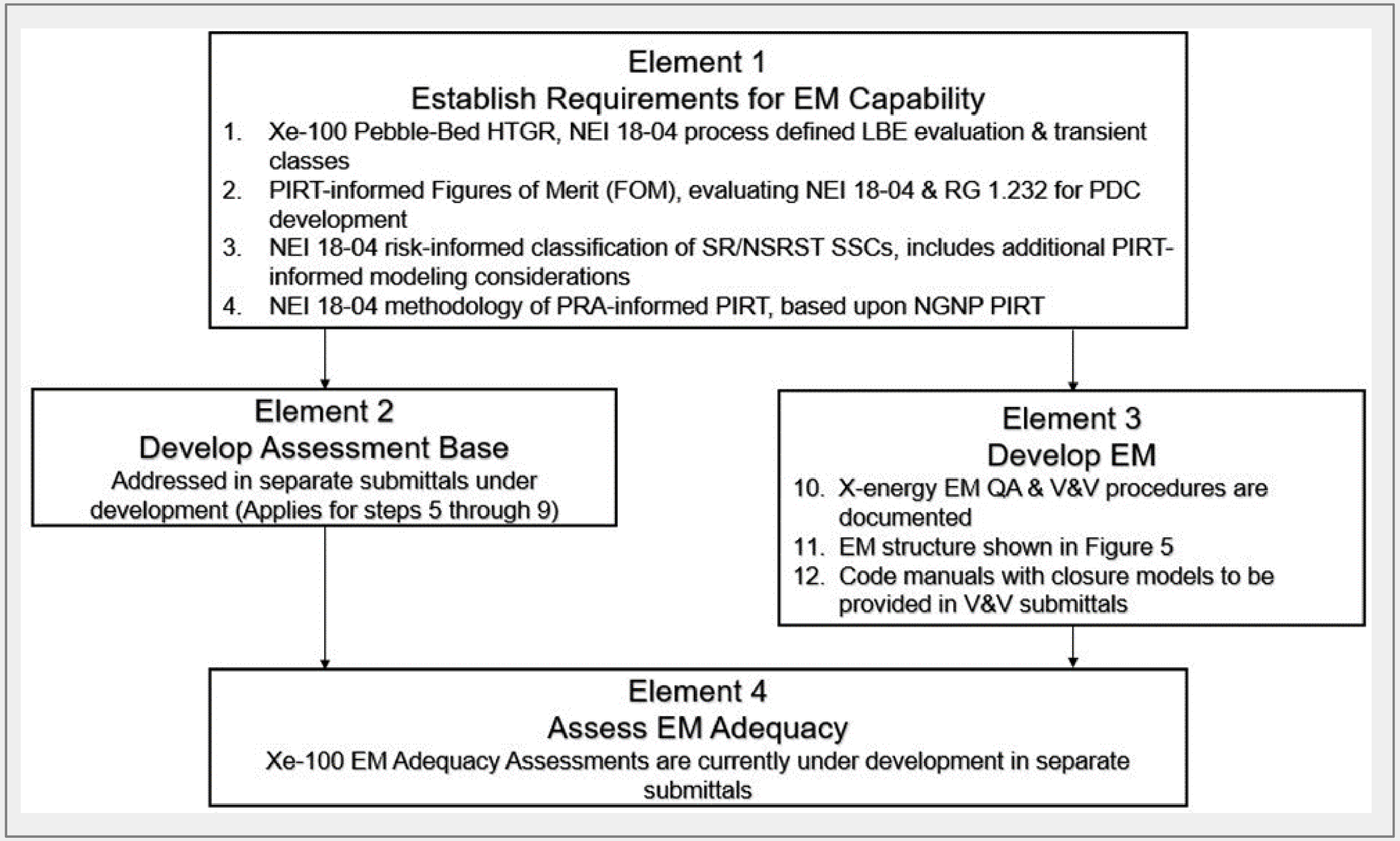
- NRC SE on Rev. 1 of TSAM framework (ML23086C082)
    - Previous limitations being addressed in current methodology
- NRC SE on Rev. 2 of Atmospheric Dispersion Methodology (ML24242A251)
- NRC SE on Rev. 3 of Xe-100 Principal Design Criteria (ML24284A012)

RG1.203 - Evaluation Model Development Approach

Evaluation Model Development and Assessment Process (EMDAP):

- RG 1.203 EMDAP implementation for Xe-100

- Four major elements:
  - Establish requirements for EM capability
  - Develop assessment base
  - Develop evaluation model
  - Assess EM adequacy



Element 1
Establish Requirements for EM Capability

1. Xe-100 Pebble-Bed HTGR, NEI 18-04 process defined LBE evaluation & transient classes
2. PIRT-informed Figures of Merit (FOM), evaluating NEI 18-04 & RG 1.232 for PDC development
3. NEI 18-04 risk-informed classification of SR/NSRST SSCs, includes additional PIRT-informed modeling considerations
4. NEI 18-04 methodology of PRA-informed PIRT, based upon NGNP PIRT

Element 2
Develop Assessment Base
Addressed in separate submittals under development (Applies for steps 5 through 9)

Element 3
Develop EM

10. X-energy EM QA & V&V procedures are documented
11. EM structure shown in Figure 5
12. Code manuals with closure models to be provided in V&V submittals

Element 4
Assess EM Adequacy
Xe-100 EM Adequacy Assessments are currently under development in separate submittals

Element 1
Establish Requirements for EM Capability

1. Xe-100 Pebble-Bed HTGR, NEI 18-04 process defined LBE evaluation & transient classes
2. PIRT-informed Figures of Merit (FOM), evaluating NEI 18-04 & RG 1.232 for PDC development
3. NEI 18-04 risk-informed classification of SR/NSRST SSCs, includes additional PIRT-informed modeling considerations
4. NEI 18-04 methodology of PRA-informed PIRT, based upon NGNP PIRT

Element 1 – Establish Requirements for EM

Element 1: Establish Requirements for EM

Step 1: Define Analysis Purpose and Transient Classes and Power plant Class

Analysis Purpose:

- Evaluate plant response for Design Basis Accidents (DBAs)
    - Verify performance of safety-related SSCs to meet required safety functions
- Demonstrate compliance with previously mentioned regulatory requirements and guidance
    - Quantify radiological consequences for comparison with 10CFR50.34 acceptance criteria

Transient Classification Approach:

- **NEI 18-04 Framework Implementation**:
    - AOOs: Anticipated events expected in plant lifetime ($>10^{-2}$ per plant-year)
    - DBEs: Unlikely events during plant lifetime (10^{-4} to 10^{-2} per plant-year)
        - DBAs: Deterministic events derived from DBEs with only SR SSCs credited
    - BDBEs: Very unlikely events (5×10^{-7} to 10^{-4} per plant-year)

Element 1: Establish Requirements for EM

Step 1: Define Analysis Purpose and Transient Classes

Xe-100 Specific DBA Transient Categories:

- **Reactivity-Initiated Events**:
  - Control rod withdrawals/ejections
  - Overcooling (via MSLB)
- **Loss of Forced Cooling Events**:
  - Pressurized loss of forced cooling (PLOFC)
  - Depressurized loss of forced cooling (DLOFC)
  - Loss (or degradation) of secondary cooling (LOSC)
- **Primary System Breach Events**:
  - Small, medium, and large depressurization events
  - Steam generator tube leaks/ruptures
- **Other Events**:
  - External hazards - Seismic

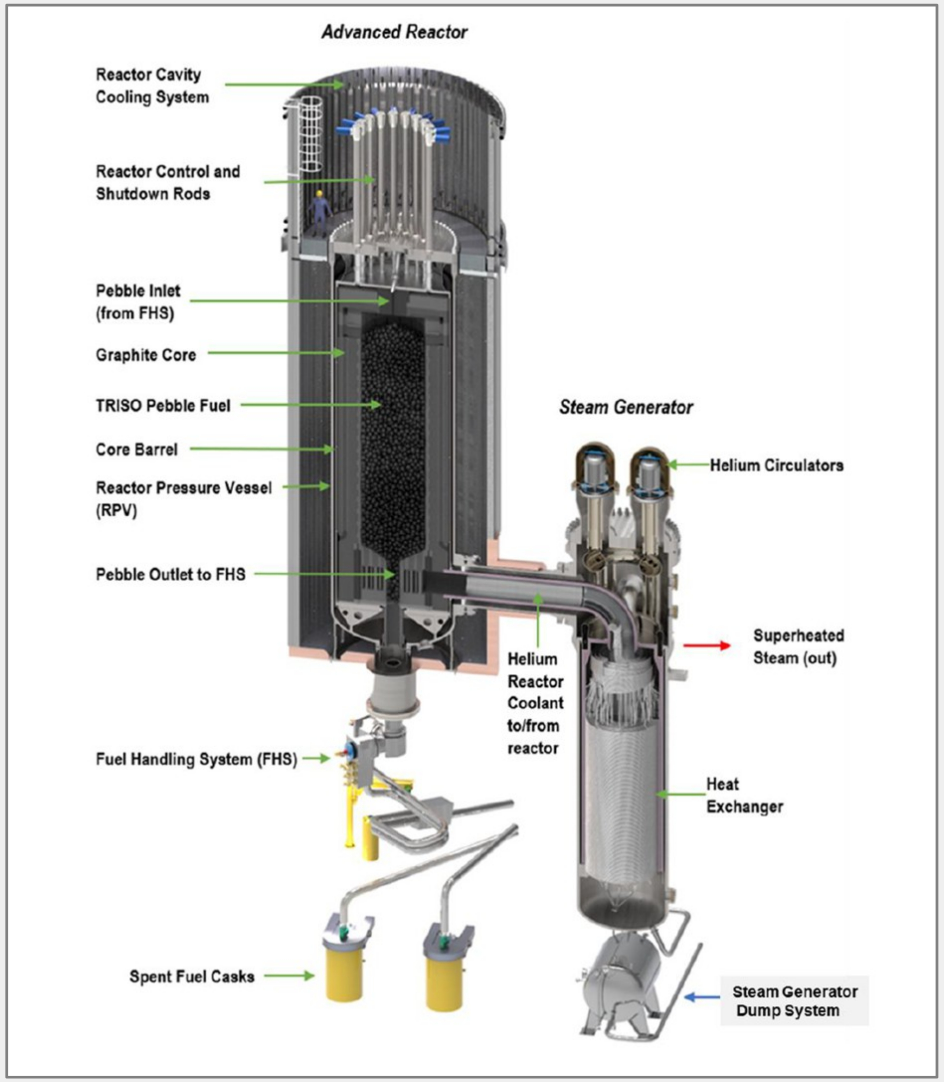
Integration with Plant States:

- Analysis covers all operating modes from full power to shutdown

Element 1: Establish Requirements for EM

Power Plant Class:

- 200 MWt (80 MWe) pebble bed high-temperature gas-cooled reactor
- Helium coolant at 6 MPa, 260°C inlet, 750°C outlet
- Online refueling with pebbles circulating through core
- TRISO fuel in graphite matrix pebbles
- Decay heat removal via passive systems

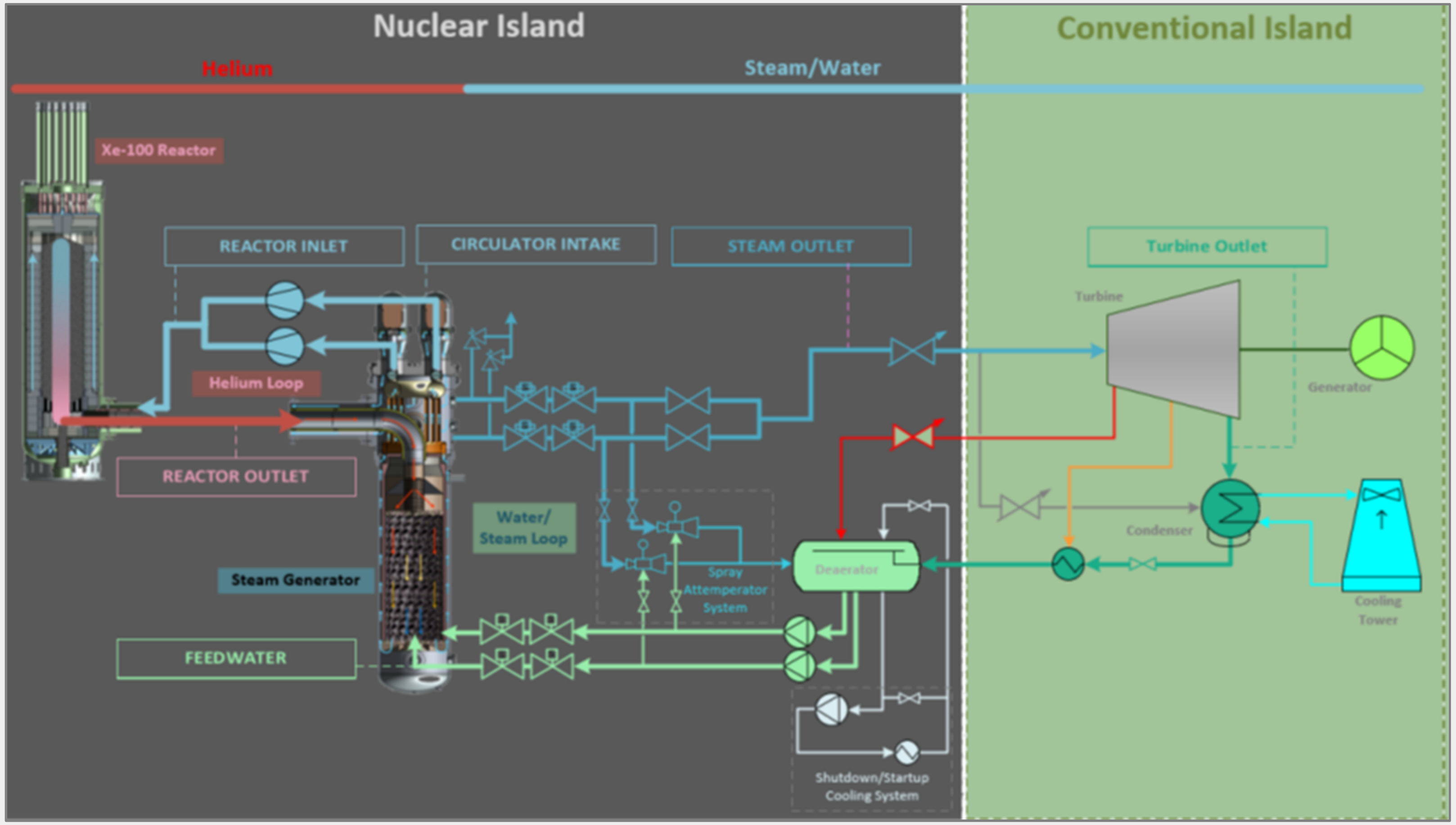


Element 1: Establish Requirements for EM

- **Power Plant Class:**

Major systems:

- Reactor System (RS)
- Steam Generator System (SGS)
- Helium Circulator System (HCS)
- Reactor Cavity Cooling System (RCCS)
- Fuel Handling System (FHS)



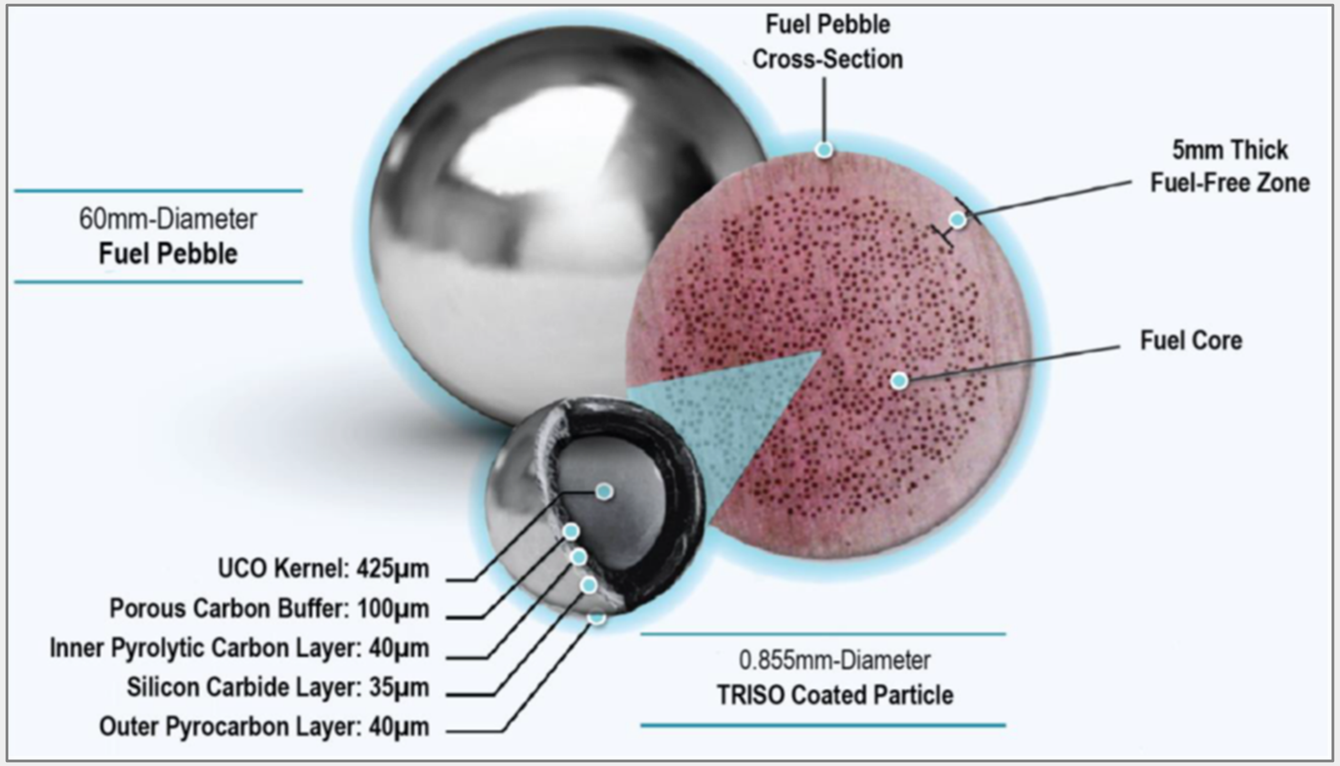
Element 1: Establish Requirements for EM

Power Plant Class:

Functional Containment:

- Multiple barriers to radionuclide release:

1. TRISO coatings
2. Pebble fuel matrix
    1. Fuel core
    2. Fuel-free zone
3. Helium pressure boundary (intact (normal leakage) unless breached)
4. Reactor building + filtration (not credited in DBA EM)



Element 1: Establish Requirements for EM

Step 2: Specify Figures of Merit

Primary FOM for Xe-100:

•**Radiation dose (TEDE)** at Exclusion Area Boundary (400m)

- Addresses 10 CFR 50.34 regulatory requirements (EAB Dose < 25 rem TEDE)
- Facilitates comparison with F-C targets from NEI 18-04

FOM Calculation Components:

- Initial HPB circulating inventory release
- Fuel heat-up induced releases
- Lift-off of plated-out activity
- Long-term passive cooling releases
- Event-specific mechanisms (e.g., steam-off/wash-off for SGTRs)

Element 1: Establish Requirements for EM

Step 2: Specify Figures of Merit

Supplementary DBA FOMs for Xe-100:

- **Environmental Conditions**
    - Informs environmental qualification for SR SSCs
- **Reactor Fuel Temperature**
    - Demonstrates compliance with qualified fuel temperature limits
- **Reactor Fuel Time-at-Temperature**
    - Ensures fuel doesn't exceed time-temperature limits
- **Total Core Reactivity**
    - Demonstrates subcriticality and reactivity control
- **Total Reactor Power**
    - Demonstrates controlled power and absence of oscillations
- **Flammable Gas Production**
    - For SGTR events to prevent flammable concentrations
- **ASME Pressure Vessel Quantities**
    - Demonstrates meeting ASME BPVC criteria

These FOMs assisted in defining PIRT phenomena and ensure
the assumptions / modelling decisions applied in the DBA EM are valid.

Element 1: Establish Requirements for EM

Step 3: Identify Systems, Components, Phases, Geometries, and Processes

Key Systems and Components Modeled:

- **Reactor System (RS)**
  - Fuel pebbles and TRISO particles
  - Graphite reflectors (side, top, bottom)
  - Reactor vessel metallics
  - Control and shutdown rod systems
  - Hot gas duct system
- **Heat Transport Systems**
  - Steam generator tube bundles
  - Helium circulators
  - Helium pressure boundary
  - Primary loop pressure relief system
  - Secondary side fluid systems
- **Safety-Related Passive Systems**
  - Reactor cavity cooling system
  - Reactor building structures (not credited for RN retention)
  - Functional containment barriers

Phases, geometries, fields, transport processes considered in PIRT phenomenon, although not explicitly delineated in TSAM.

- **Physics and Phenomena**
  - Neutronics (steady-state and point kinetics)
  - Thermal-hydraulics (forced and natural circulation)
  - Heat transfer (conduction, convection, radiation)
  - Fission product transport and retention
  - Chemical reactions (oxidation phenomena)

Element 1: Establish Requirements for EM

Step 4: Identify and Rank Key Phenomena (PIRT Process)

PIRT Methodology:

- Expert panel approach with diverse expertise, building upon work completed for NGNP
- Phenomena organized by event categories
- Ranked against Dose Consequence (FOM)
- Temporal phases defined for each event (OCTPs)
    - Table 9 in TSAM LTR
- Knowledge level assessment for each phenomenon

Event Categories Evaluated:

- Control Rod Withdrawal (CRW)
- Loss of Secondary Cooling (LOSC)
- Steam Generator Tube Rupture (SGTR)
- De-pressurized Loss of Forced Cooling (DLOFC)
- Pressurized Loss of Forced Cooling (PLOFC)
- Seismic
- Normal Operating Conditions (NOC)

High-Importance Phenomena Examples:

- Fuel temperature negative reactivity feedback
- Effective core thermal conductivity
- Core specific heat capacity
- Decay heat generation and distribution
- Steam-graphite oxidation reactions
- Fission product retention and transport

Element 2
Develop Assessment Base
Addressed in separate submittals under development (Applies for steps 5 through 9)

Element 2 – Develop Assessment Base

Element 2: Develop Assessment Base

Step 5: Specify Assessment Objectives

Assessment Approach:
Reflective of RG1.203 intent

1. Verify code capabilities to model key phenomena
2. Validate predictions against appropriate data
3. Quantify model biases and uncertainties
4. Establish applicability to Xe-100 design conditions

Code-specific Assessment Objectives will be discussed in the respective code LTR discussion later.

Element 2: Develop Assessment Base

Step 6: Perform Scaling Analysis

Scaling Methodology Overview:

- Follows H2TS methodology with top-down and bottom-up approaches
- Focuses on ensuring experimental data adequately represents Xe-100

Four-Step Scaling Process:

1. **Identify Relevant and Critical Phenomena**
2. **Define Key Characteristics and Dimensionless Groups**
3. **Assess Similarity Between Test Data and Xe-100**
4. **Address Distortion Factors**

Current Status:

- Methodology defined in Section 6.5 of TSAM report
  - More detail contained in standalone scaling analysis plan
- High and Medium ranked phenomena defined
- Initial identification of dimensionless groups in progress
- Planning for similarity assessment and accuracy scaling

Element 2: Develop Assessment Base

Steps 7-9: Experimental Data and Effects of Test Distortions

Notes:

1. Experimental data will be discussed during the respective code-specific LTR presentations

2. Scaling activities remain in progress – no discussion of distortions in LTRs

Element 3

Develop EM

10. X-energy EM QA & V&V procedures are documented
11. EM structure shown in Figure 5
12. Code manuals with closure models to be provided in V&V submittals

Element 3 – Develop Evaluation Model

Element 3: Develop Evaluation Model

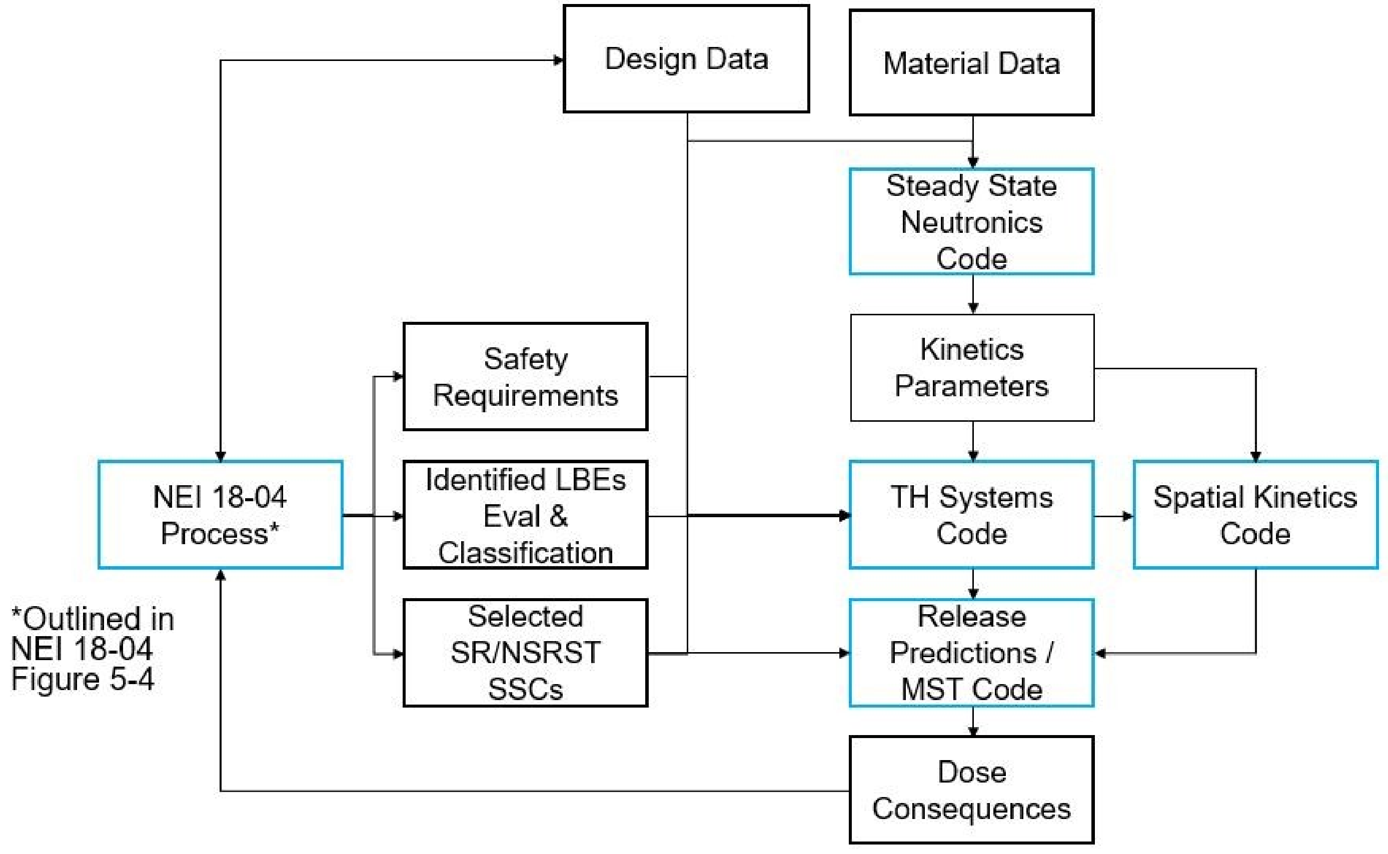
Step 10: Establish Evaluation Model Development Plan

Multiple work plans exists outlining the development and V&V of EM codes. An overall RG1.203 plan ties all EMDAP activities together, creates project schedule for completion.

Development Philosophy:

1. Integrated approach combining RG 1.203 methodology with NEI 18-04 framework
2. System of codes working together to address all necessary phenomena
3. Quality-assured development following X-energy's QAP (XEQAPD-NP, Rev. 3)

- **High-level LBE analysis flowchart →**



*Outlined in NEI 18-04 Figure 5-4

Element 3: Develop Evaluation Model

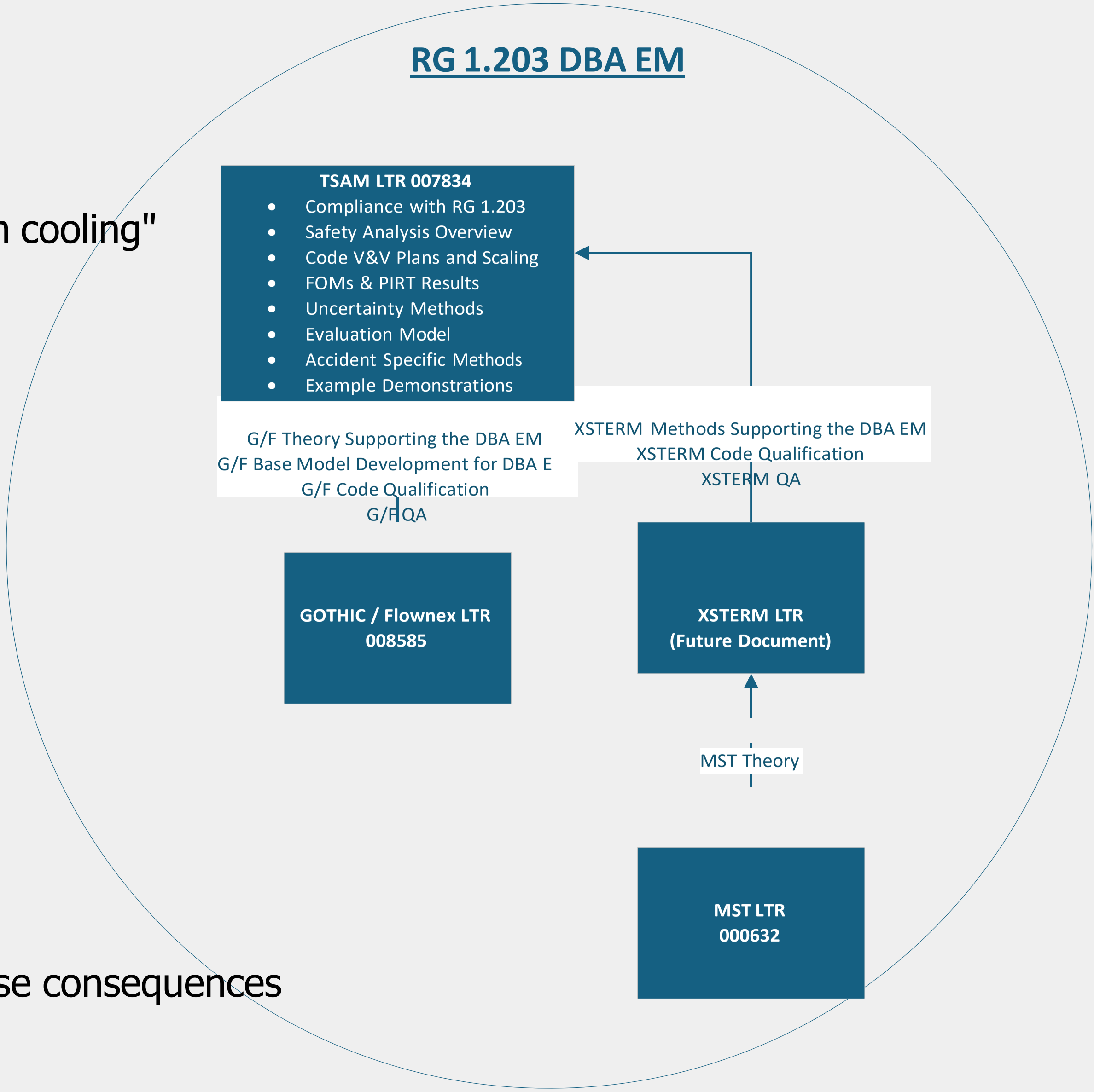
Step 11: Establish Evaluation Model Structure

Overall EM Structure:

- Integrated modeling approach with multiple specialized codes
- Two-phase analysis approach: "plant transient" and “long-term cooling"

Code Functions and Interfaces:

- **Flownex**: Models plant transient phase (seconds to hours)
  - Detailed system nodalization
  - Core, primary, and secondary system thermal-hydraulics
  - Point kinetics for reactivity effects
  - Provides boundary conditions for other codes
- **GOTHIC**: Models long-term cooling phase (hours to days)
  - Passive heat removal
  - Effectiveness of RCCS
- **XSTERM (X-e developed code)**: Calculates source term and dose consequences
  - Mechanistic source term calculations
  - Specialized models for specific release mechanisms



RG 1.203 DBA EM

TSAM LTR 007834
- Compliance with RG 1.203
- Safety Analysis Overview
- Code V&V Plans and Scaling
- FOMs & PIRT Results
- Uncertainty Methods
- Evaluation Model
- Accident Specific Methods
- Example Demonstrations

G/F Theory Supporting the DBA EM
G/F Base Model Development for DBA E
G/F Code Qualification
G/F QA

XSTERM Methods Supporting the DBA EM
XSTERM Code Qualification
XSTERM QA

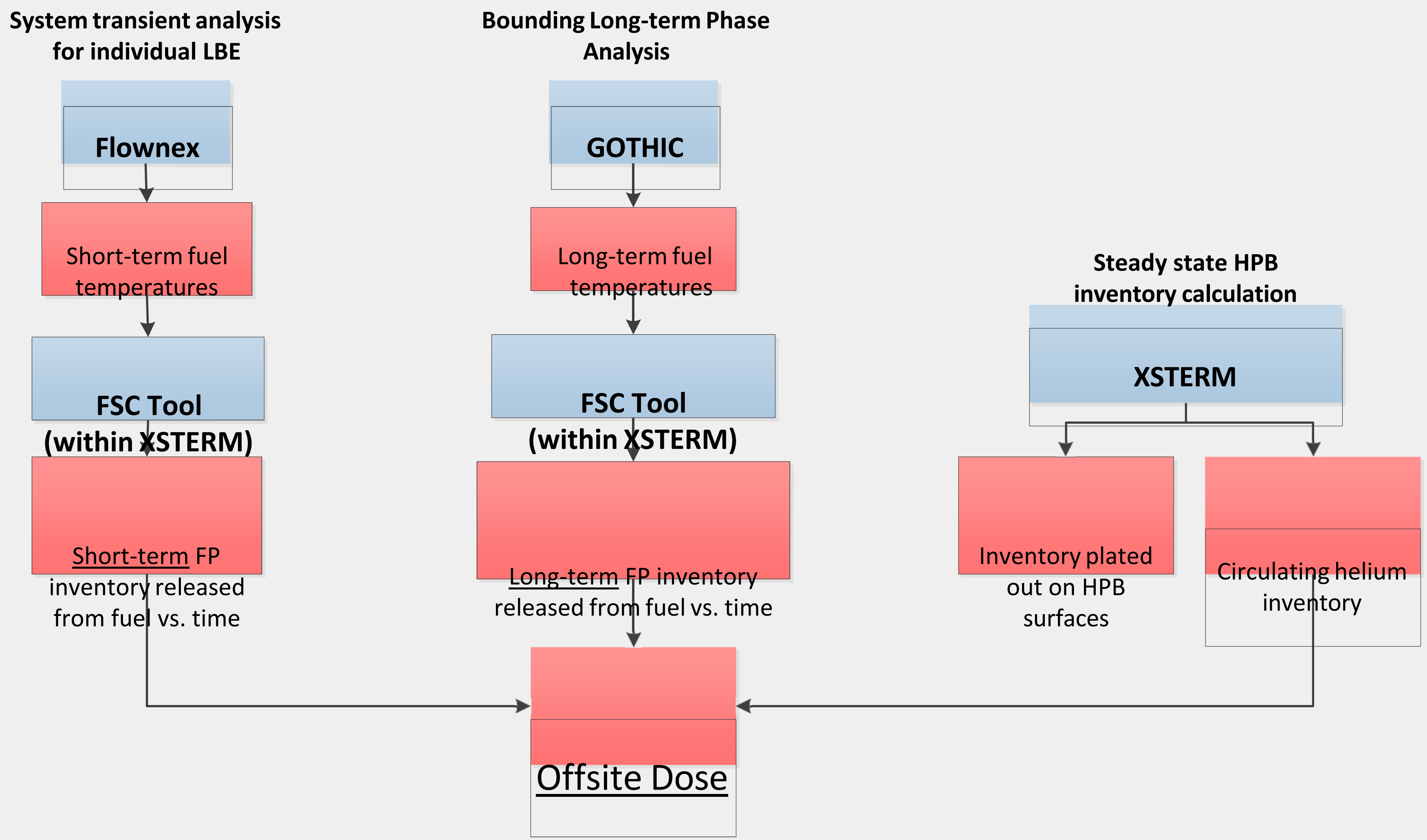
GOTHIC / Flownex LTR 008585

XSTERM LTR (Future Document)

MST Theory

MST LTR 000632

Element 3: Develop Evaluation Model



System transient analysis for individual LBE

Flownex

Short-term fuel temperatures

FSC Tool (within XSTERM)

Short-term FP inventory released from fuel vs. time

Bounding Long-term Phase Analysis

GOTHIC

Long-term fuel temperatures

FSC Tool (within XSTERM)

Long-term FP inventory released from fuel vs. time

Steady state HPB inventory calculation

XSTERM

Inventory plated out on HPB surfaces

Circulating helium inventory

Offsite Dose

XSTERM -- Flownex Screening Criteria (FSC) Tool

- Converts T/H system model nodal fuel temperatures into offsite doses
  - *Provides the fuel heatup (radionuclide diffusion) contribution to the offsite dose FOM*

Conservative assumptions built-in for DBAs:

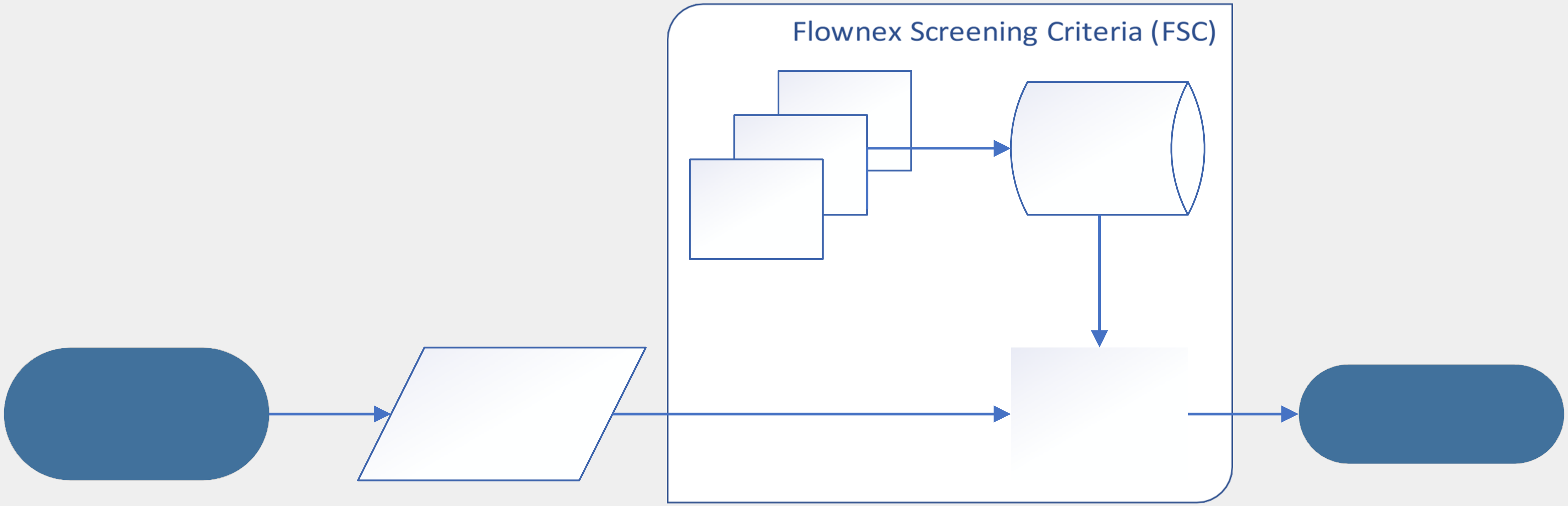
- *Dispersion factors* $(\chi\chi/QQ)$ *and fuel impurity/quality*
- *Time-at-temperature bounds transient times*
- *Pebble power profile under fission maximized*

Database of Avg. Pebble Temperature vs. Dose

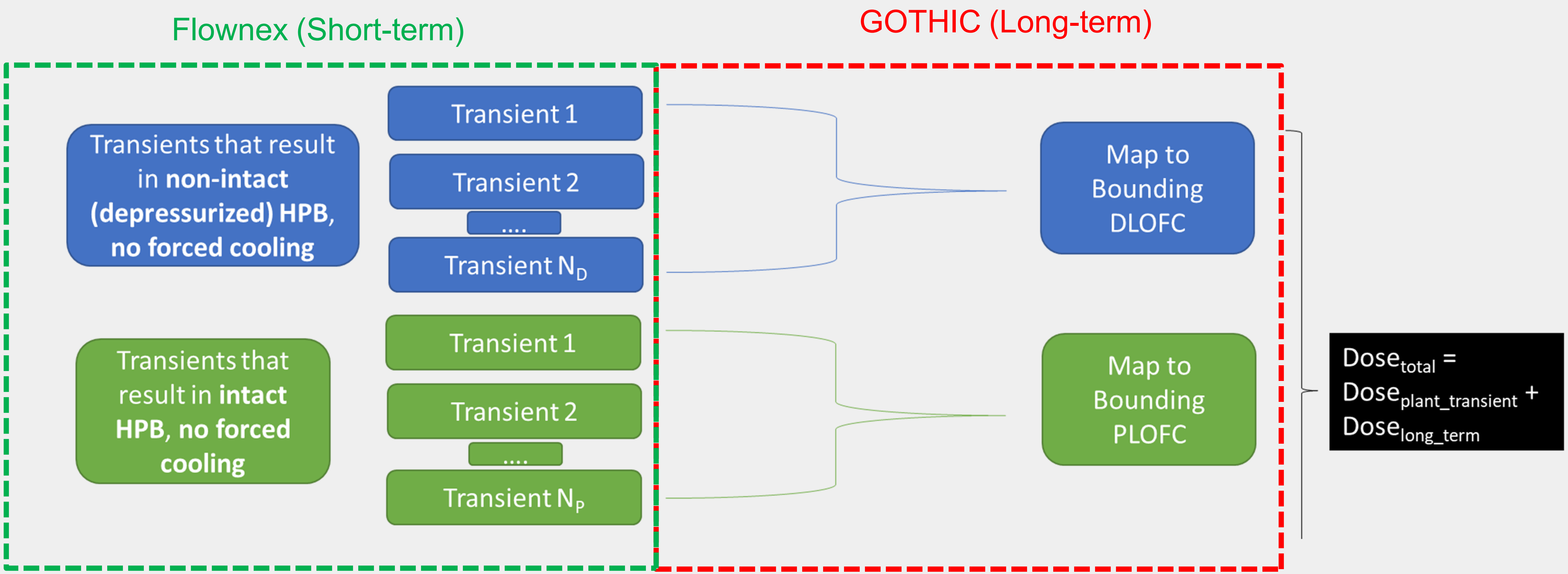
XSTERM Single Pebble Evaluations

Results: Peak Fuel Temperatures

FSC Data Recorder



GOTHIC Analysis Stream (Long-term Transients)



Flownex (Short-term)

GOTHIC (Long-term)

Transients that result in **non-intact (depressurized) HPB, no forced cooling**

Transient 1

Transient 2

....

Transient N_D

Transients that result in **intact HPB, no forced cooling**

Transient 1

Transient 2

....

Transient N_P

Map to Bounding DLOFC

Map to Bounding PLOFC

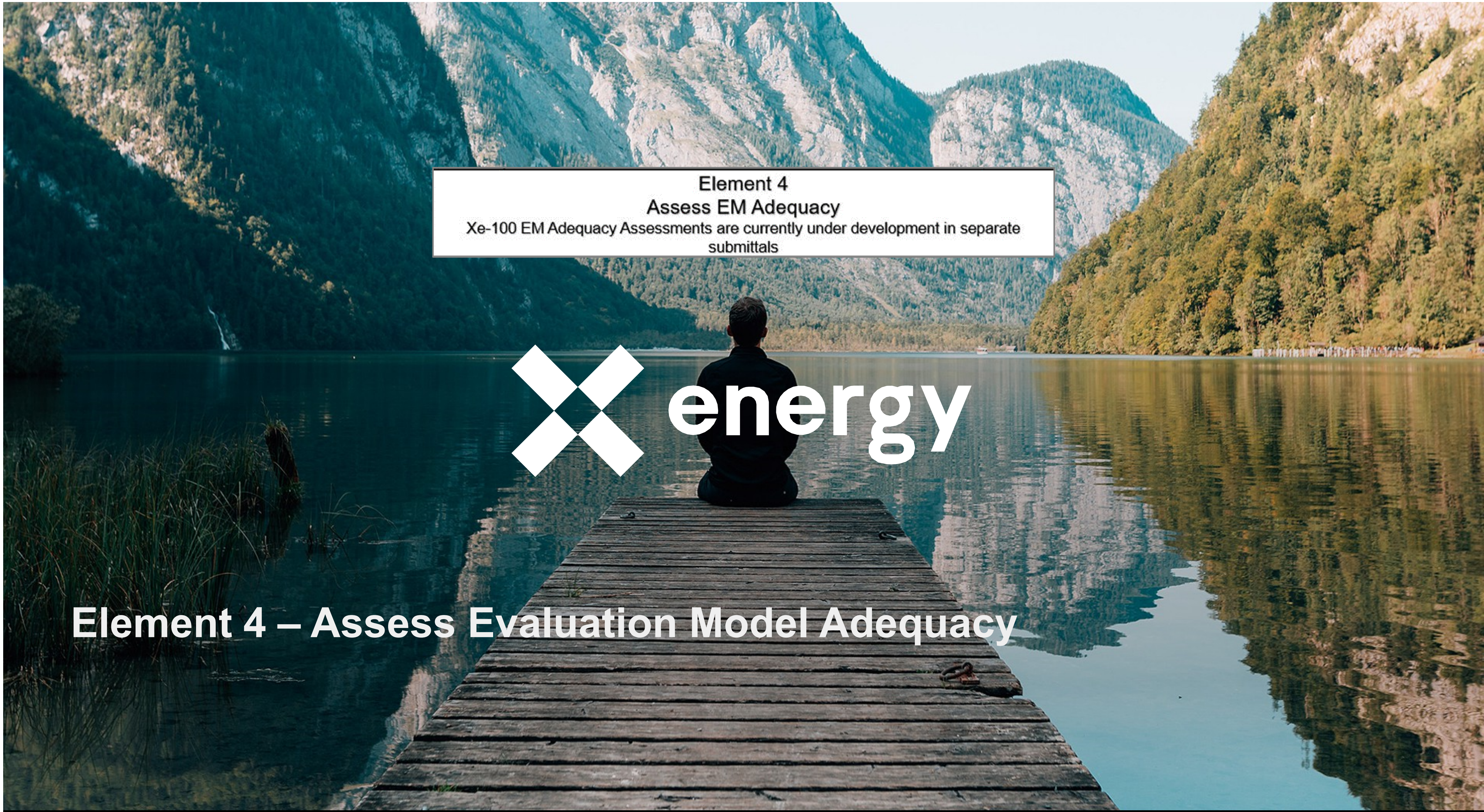
$Dose_{total}$ =
$Dose_{plant\_transient}$ +
$Dose_{long\_term}$

Element 3: Develop Evaluation Model

Step 12: Develop or Incorporate Closure Models

Current Status:

- While some closure models are specified, the closure models for the EM codes (XSTERM, Flownex, GOTHIC) are still under development and undergoing assessment for accuracy and capability



Element 4
Assess EM Adequacy
Xe-100 EM Adequacy Assessments are currently under development in separate submittals

Element 4 – Assess Evaluation Model Adequacy

Element 4 – Assess Evaluation Model Adequacy

Objective of Element 4

- Demonstrate that the Evaluation Model (EM) adequately models relevant plant behavior under transient and accident conditions.

Key Components of Element 4

- Code Verification and Validation (V&V)
    - Discussed in code-specific LTRs
- Model Uncertainty and Input Uncertainty Treatment
- Assessment Against Measured Data
    - Discussed in code-specific LTRs
- Scaling and Similarity Evaluations
    - Incomplete
- Quantification of Bias and Uncertainty
    - Incomplete

- Note: TSAM LTR indicates these steps are in-progress and will be supplemented in future submittals.

Element 4 – Assess Evaluation Model Adequacy

Uncertainty Analysis Methodology

Types of Uncertainties Addressed:

- Material Properties
- Reactor Physics
- Model and Scenario (e.g. HCS coastdown rate)
- Control Logic, setpoint, and measurement (e.g. Reactor power measurement)

Phenomena and Key Parameter Identification and Ranking Tables (PKPIRTs):

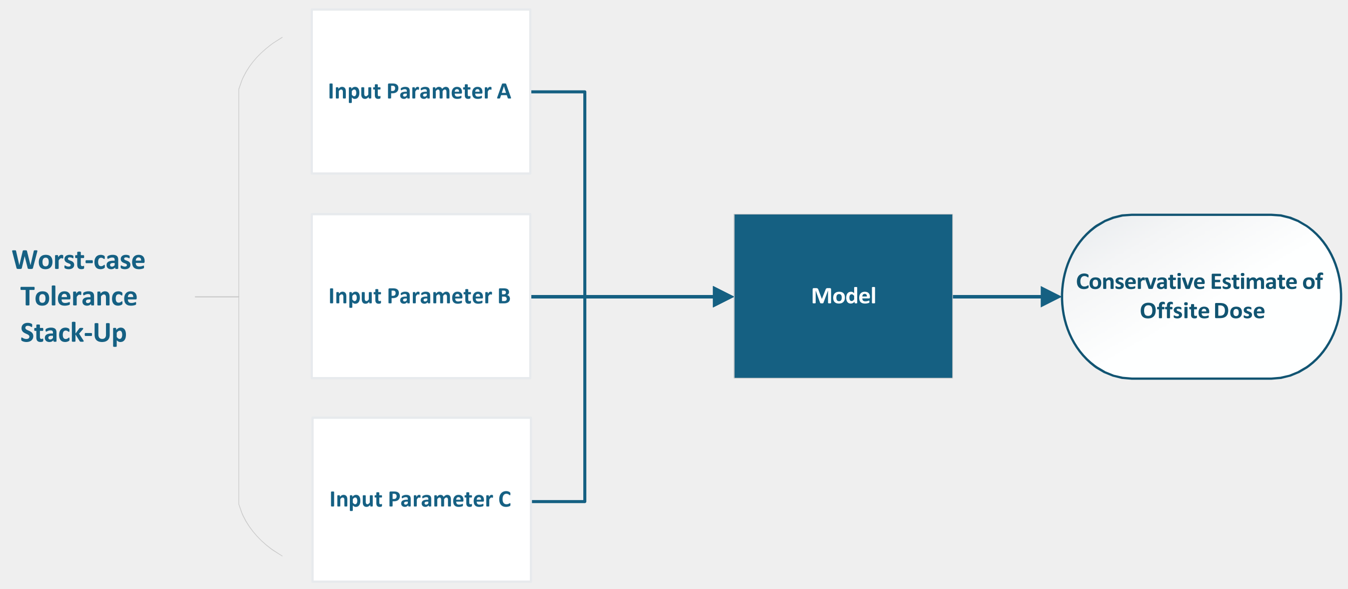
- Extension of traditional PIRT process
- Identifies key parameters (i.e. code inputs) affecting figures of merit
- Allows targeted uncertainty analysis
  - Enables UQ to be performed on time/resource-consuming long-term heatup cases
- Supports both deterministic-conservative and best-estimate-plus-uncertainty approaches

Element 4 – Assess Evaluation Model Adequacy

Uncertainty Analysis Methodology (cont.)

PKPIRT Process:

1. Identify high/medium ranked phenomena
2. Link to models in analysis code
3. Decompose into model parameters
4. Identify high ranked parameters
5. Assign uncertainty distributions
6. Perform individual sensitivity analyses or worst-case stack-up analysis
7. Estimate overall uncertainty



Approach:

- Apply extreme value analysis for key parameters
- Perform Root-sum-of-squares (RSS) Statistical combination of uncertainties for limiting long-term event (DLOFC)

Conclusions & Path Forward

Conclusions:

- Evaluation model defined and developed following RG 1.203 approach
- Integration with NEI 18-04 methodology
- Computer codes selected and being validated
- Demonstration analyses applied in TSAM LTR confirm methodology
    - Can be discussed in closed session

Path Forward:

- Complete V&V of all analysis codes
- Finalize mechanistic source term methodology, publish XSTERM code LTR
- Complete full suite of licensing basis event analyses
- Address NRC feedback on methodology for OLA

Questions

Acronym List

- **AOO** - Anticipated Operational Occurrence
- **ASME** - American Society of Mechanical Engineers
- **BDBE** - Beyond Design Basis Event
- **BPVC** - Boiler and Pressure Vessel Code
- **CFR** - Code of Federal Regulations
- **CPA** – Construction Permit Application
- **CRW** - Control Rod Withdrawal
- **DBA** - Design Basis Accident
- **DBE** - Design Basis Event
- **DLOFC** - Depressurized Loss of Forced Cooling
- **DOE** - Department of Energy
- **EAB** - Exclusion Area Boundary
- **EM** - Evaluation Model
- **EMDAP** - Evaluation Model Development and Assessment Process
- **F-C** - Frequency-Consequence
- **FHS** - Fuel Handling System
- **FOM** - Figure of Merit
- **FP** - Fission Product
- **FSC** - Flownex Screening Criteria
- **HCS** - Helium Circulator System
- **HPB** - Helium Pressure Boundary
- **HTGR** - High-Temperature Gas-cooled Reactor
- **H2TS** - Hierarchical Two-Tiered Scaling
- **LBE** - Licensing Basis Event
- **LOSC** - Loss of Secondary Cooling
- **LPZ** - Low Population Zone
- **LTR** - Licensing Topical Report
- **MSLB** - Main Steam Line Break
- **MST** - Mechanistic Source Term
- **MWe** - Megawatts electric
- **MWt** - Megawatts thermal
- **NEI** - Nuclear Energy Institute
- **NGNP** - Next Generation Nuclear Plant
- **NOC** - Normal Operating Conditions
- **NRC** - Nuclear Regulatory Commission
- **OCTP** – Operational Characteristic Time Period
- **OLA** - Operating License Application
- **PDC** - Principal Design Criteria
- **PIRT** - Phenomena Identification and Ranking Table
- **PKPIRT** - Phenomena and Key Parameter Identification and Ranking Table
- **PLOFC** - Pressurized Loss of Forced Cooling
- **PRA** - Probabilistic Risk Assessment
- **QA** - Quality Assurance
- **QAP** - Quality Assurance Program
- **RCCS** - Reactor Cavity Cooling System
- **RG** - Regulatory Guide
- **RN** - Radionuclide
- **RPV** - Reactor Pressure Vessel
- **RS** - Reactor System
- **RSS** - Root-Sum-of-Squares
- **SE** - Safety Evaluation
- **SGS** - Steam Generator System
- **SGTR** - Steam Generator Tube Rupture
- **SR** - Safety-Related
- **SSC** - Systems, Structures, and Components
- **T/H** - Thermal-Hydraulics
- **TEDE** - Total Effective Dose Equivalent
- **TRISO** - TRi-structural ISOtropic
- **TSAM** - Transient and Safety Analysis Methodology
- **UCO** - Uranium Oxycarbide
- **UQ** - Uncertainty Quantification
- **V&V** - Verification and Validation
- **XEQAPD-NP** - X-energy Quality Assurance Program Description - Non-Proprietary
- **XSTERM** - X-energy Source Term (code name)
- **χ/Q** - Chi over Q (atmospheric dispersion factor)

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Xe-100 Licensing Topical Report
GOTHIC and Flownex Analysis Codes Qualification

Paolo Balestra

June 3, 2025

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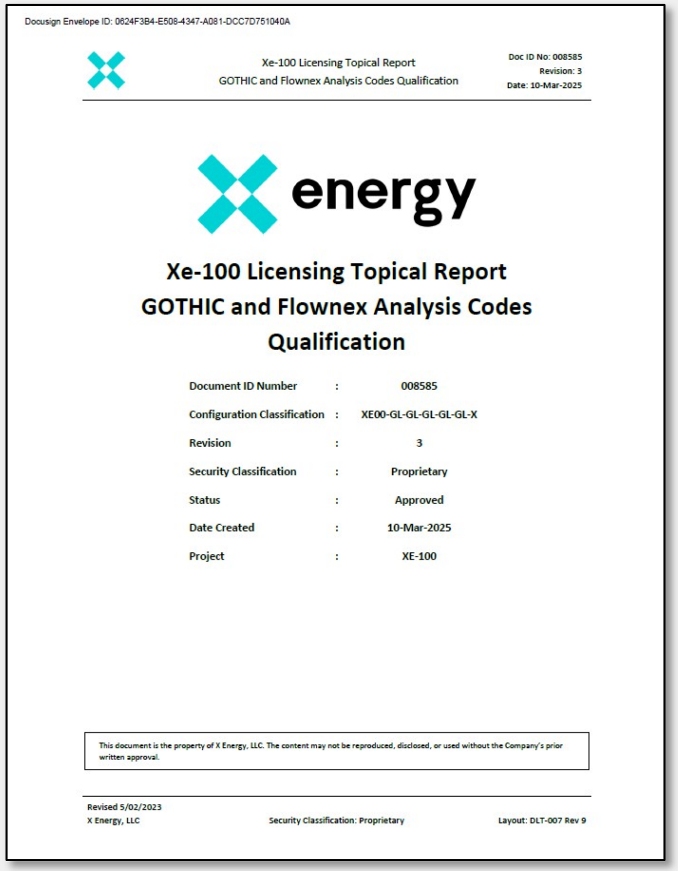

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GOTHIC and Flownex Analysis Codes Qualification

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Project	:	XE-100

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Purpose & Scope of the LTR

Purpose & Scope of the LTR

- Describes **methodology and theory** behind **GOTHIC** and **Flownex** analysis codes supporting the Xe-100 Safety Analysis Evaluation Model (EM)
- References **code manuals**, current **validation and verification** efforts, and **qualification** plans of both tools
- Does **not detail specific code executions** or categorization of all analyses
- The **conclusions** will support the **Transient and Safety Analysis** (TSA) of the Xe-100

Outcome Objective

- **NRC review and approval** of **GOTHIC and Flownex models** for use in Design Basis Accident (DBA) evaluation

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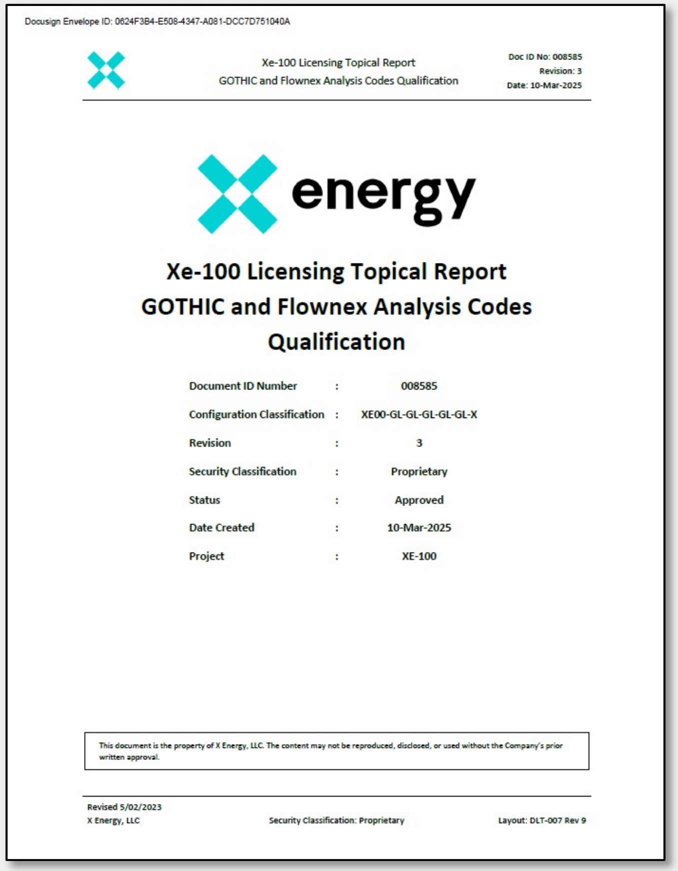

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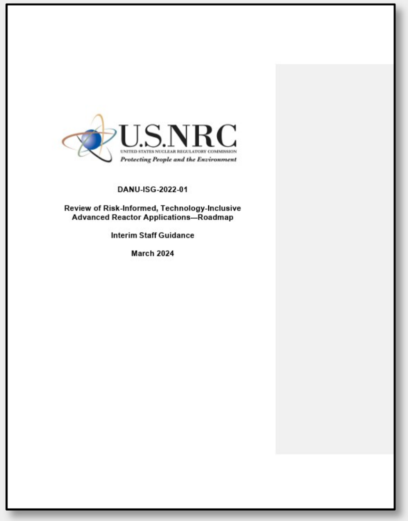
Overview of the Regulatory Requirements - Regulatory Guidance

Regulatory Requirements: GOTHIC and Flownex support **Xe-100 safety analyses** aligned with NRC **requirements** under 10 CFR Parts 50, 52, and 100 (e.g. Construction Permits, Early Site Permits, Reactor Site Criteria)

Key Regulatory Guidance: Policy Statement on the Regulation of Advanced Reactors, RG 1.203, RG 1.233, RG 1.253

Additional NRC Guidance: DANU-ISG-2022-01 – Advanced Reactor Application Review Roadmap, U.S. HTGR Licensing Precedents (GA-MHTGR, NGNP, Exelon/PBMR)



U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

DANU-ISG-2022-01

Review of Risk-Informed, Technology-Inclusive
Advanced Reactor Applications—Roadmap

Interim Staff Guidance

March 2024

INL/EXT-08-15118

The Next Generation
Nuclear Plant

January 2009

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance.

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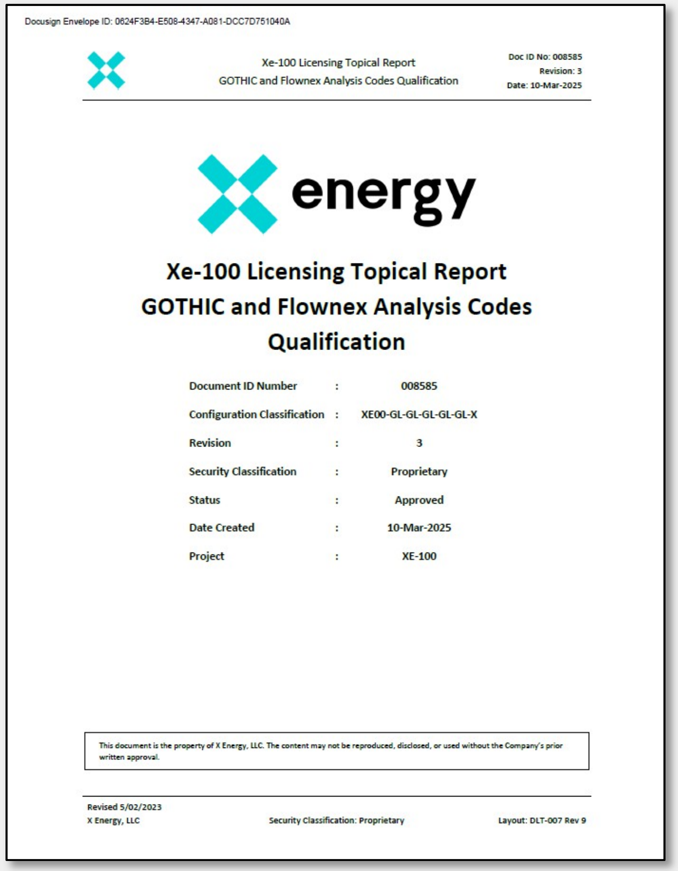

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Overview of Safety Analysis Models.

- The transient analysis is split in two phases, the **short-term transient phase** and **long-term transient phase** based on the system response:
  - **Short-term transient phase** is defined as the period at which **SSCs are actively responding** to an initiating event, involving **forced cooling or depressurization**
  - **Long-term transient phase** is defined as the period at which **passive heat transfer begins** and no additional active plant responses to the initiating event are considered
- **Flownex** is used for short-term transient analysis modeling **primary system and key secondary systems**
- **GOTHIC** is used for long-term transient analysis, supporting **extended simulations** and passive cooling requirements

Overview of Safety Analysis Models – Flownex Transient and Safety Analysis

Flownex

- Used for **Xe-100 safety analysis**, modeling **reactor kinetics** and **thermal-hydraulic phenomena**
- Uses a combination of **1D Finite Volume** and **2D axi-symmetric** discretization to model the reactor.
- Solves the partial differential equations for **mass, energy and momentum conservation** equations to obtain the mass flow, pressure, and temperature distributions
- It predicts the overall **system response** of the reactor when integrated with the **primary** and **secondary heat transport systems** for safety analyses

Overview of Safety Analysis Models – Flownex Transient and Safety Analysis

- **Reactor:** The pebble bed and the defueling chute are modeled using **porous media approximation**
  - The **Kugeler-Schulten** correlation is used for the **convective heat transfer** between pebbles and helium
  - For the **effective pebble bed conductivity,** the **Zehner-Schlünder** model is used with **A3-3** graphite as conductive material
  - **Point kinetics** with input parameters provided by VSOP to model the **neutronic response**

Overview of Safety Analysis Models – Flownex Transient and Safety Analysis

- **Steam Generator (SG):** The SG model relies on a design that produces a **uniform radial steam temperature**, enabling the use of a 1D discretized model. Uniform steam temperature was **demonstrated in the THTR**, which used a similar design
- **Reactor Cavity Cooling System (RCCS):** The RCCS is a passive, water-cooled system, providing **at least 72 hours of boil-off volume**.
- **Material Properties:** Material properties are **temperature** dependent, in addition graphite properties account for **irradiation-induced** aging effects

Overview of Safety Analysis Models – GOTHIC Transient and Safety Analysis

GOTHIC

- **Hybrid** code that **bridges gap between CFD and one-dimensional thermal-hydraulic analysis**, using multidimensional regions where needed while keeping simulations relatively fast
- Purpose of this model is to provide a **relatively fast running tool** to support long term transient phase **dose estimates**
- The code is currently used also to study the **RCCS Performances** as well as **Reactor Building environmental conditions** during the accident scenarios

Overview of Safety Analysis Models – GOTHIC Transient and Safety Analysis

- **Reactor: Same correlations** used in the **Flownex** model
  - **Simplified model** for running **30 days** simulations
  - E.g. the **cone region** of the pebble bed is **not explicitly modelled** since it is a low power production region
- **Steam Generator:** Helium and water/steam sides are modeled with **uniform radial heat transfer** using 30 axial subdivisions; determined based on **nodalization sensitivities**
- **Reactor Cavity Cooling System:** Heat removal from the RPV outer surface is modeled trough a **boundary condition** based on a stand-alone RCCS GOTHIC model results
- **Reactor Building:** The reactor building is not explicitly modeled; depressurization events assume **atmospheric pressure** to maximize depressurization and air ingress

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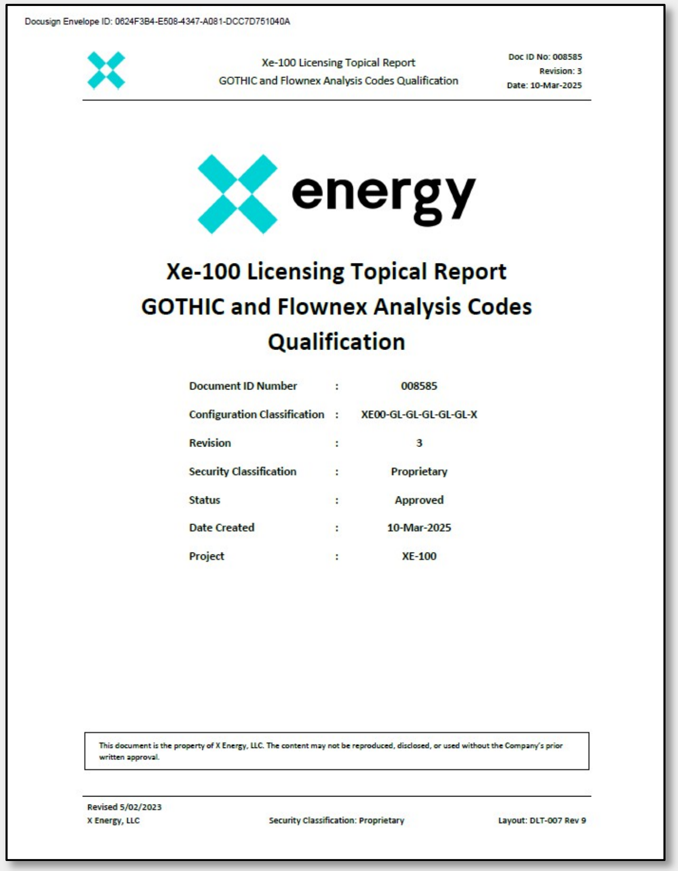

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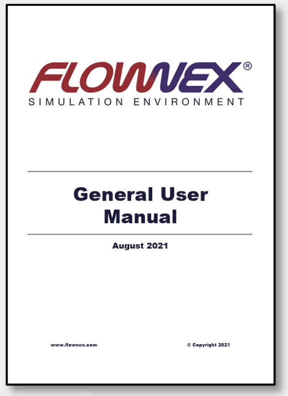
Flownex code qualification – Manuals

- **Manuals**: Flownex Simulation Environment Manual, Flownex Library Manual, Flownex Theory Manual
- **Flownex Development:** Developed under **NQA-1 quality standards,** Over 40-person years dedicated to V&V
- **Ongoing Improvement:** M-Tech actively participates in **international conferences** (CRP-5, ICAPP, HTR-TN) to enhance Flownex's capabilities and meet **HTGR analysis** requirements



FLOWNEX®
SIMULATION ENVIRONMENT

General User Manual

August 2021

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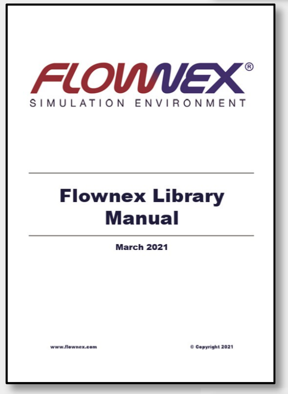

FLOWNEX®
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Flownex Library Manual

March 2021

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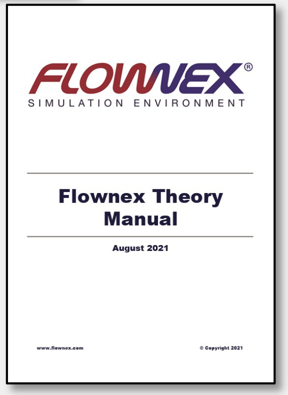

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SIMULATION ENVIRONMENT

Flownex Theory Manual

August 2021

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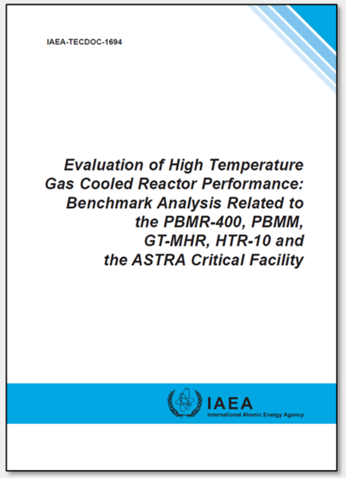
Flownex code qualification – X-energy Flownex Validation Plan

- The following **accident scenarios and associated phenomena** have been postulated for the validation of Flownex:
  - Loss of Feedwater (LOFW)
  - Circulator Trip or Loss of Forced Cooling (LOFC)
  - Primary Side Depressurization Events
  - Steam Generator Tube Rupture (SGTR)
  - Seismic Events (SE)
- **The primary metric is dose at the Exclusion Area Boundary (EAB).** Parameters predicted by Flownex which have a **significant impact on subsequent dose** assessments should therefore be considered as candidates for validation (e.g. Fuel Temperature)

Flownex code qualification – Flownex Fuel Temperature Validation Exercise Report

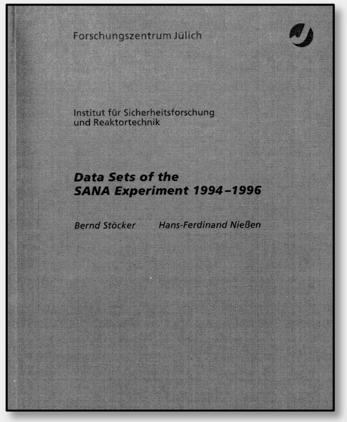
- **Pebble Temperature Verification:** A numerical problem based on the PBMR design pebble (similar to Xe-100) involving **step power increases**; fuel temperature prediction accuracy depends on **spatial discretization**, bias decreases at lower power levels such as post-reactor trip conditions.
- **HTR-10:** Validation focuses on **heat transfer phenomena** using temperature measurements at selected **ex-core locations**, which, despite differences in power, size, and flow conditions, is considered relevant to Xe-100 due to similar core design and operating conditions.
- **SANA: pebble surface temperature** predictions are validated across a **wide temperature range** and locations under steady and transient conditions using established pebble bed heat transfer and fluid resistance correlations, with accuracy assessed through $L\infty$ and L^2 norm metrics.



IAEA-TECDOC-1694

Evaluation of High Temperature Gas Cooled Reactor Performance: Benchmark Analysis Related to the PBMR-400, PBMM, GT-MHR, HTR-10 and the ASTRA Critical Facility

IAEA



Forschungszentrum Jülich

Institut für Sicherheitsforschung und Reaktortechnik

Data Sets of the SANA Experiment 1994–1996

Bernd Stöcker Hans-Ferdinand Nießen

Flownex code qualification – Other Validation cases

- **Pressure in Branched Network**: Validation involved **opening a valve** connected to a **pressure vessel** to generate a pressure wave in the downstream piping, measured from 387 kPa to atmospheric. Flownex predictions **matched experimental data**
- **Mass Flow in Compressible Gas Network:** An experiment validated mass flow predictions in a complex piping network using air **at 0.045 kg/s and 102.36 kPa**. Valve adjustments created **different flow configurations**, with simulation results closely matching measured pressures.
- **Transient Temperature in Heat Exchanger**: **Water temperature** was **increased** from 26°C to 60°C in one stream. Flownex predictions closely matched experimental data for both convective and conductive heat transfer

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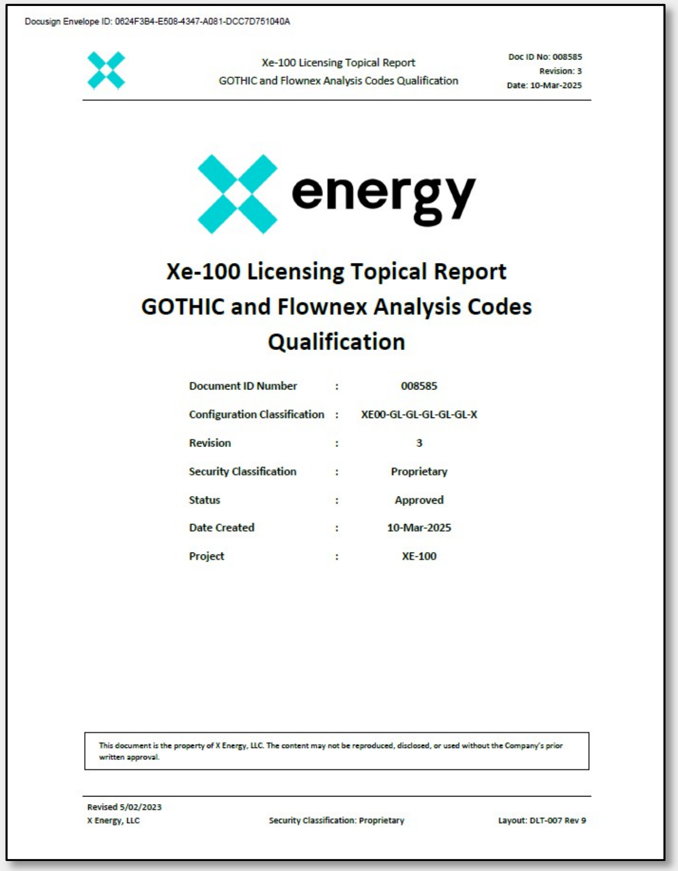

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GOTHIC code qualification – Manuals

- **Manuals:** GOTHIC Thermal Hydraulic Analysis Package User Manual, GOTHIC Thermal Hydraulic Analysis Package Technical Manual
- **GOTHIC Qualification Report** documents extensive V&V across single/two-phase flow cases and is updated with each release
- **Validation & Verification scope includes**:
    - Analytical solution comparisons (e.g., flow between plates, 1D conduction)
    - Experimental data from separate and integral effect tests facilities
- **Validation phenomena covered**: natural convection, stratification, heat/mass transfer, aerosol behavior,…

User Manual

GOTHIC Version 8.5(QA)

THERMAL HYDRAULIC ANALYSIS PACKAGE

Technical Manual

GOTHIC Version 8.5(QA)

THERMAL HYDRAULIC ANALYSIS PACKAGE

GOTHIC code qualification – Planned Applications

- **Planned Applications**
  - **SANA - Pebble Bed Temperature Prediction**
  - **HTR-10 - Integrated Effects Benchmark**
  - **Argonne NSTF - RCCS Validation**
- **Additional Applications:**
  - **Texas A&M University:** Modeled a **1/28-scale NGNP HTGR reactor building** test facility to analyze depressurization scenarios, including air ingress phenomena, validated against experimental data
  - **Oregon State University:** Benchmarked GOTHIC using asymmetric heating test data from the **High Temperature Test Facility** (HTTF) during pressurized conduction cooldown
  - **Framatome:** Applied GOTHIC to **evaluate HTGR** design and building response

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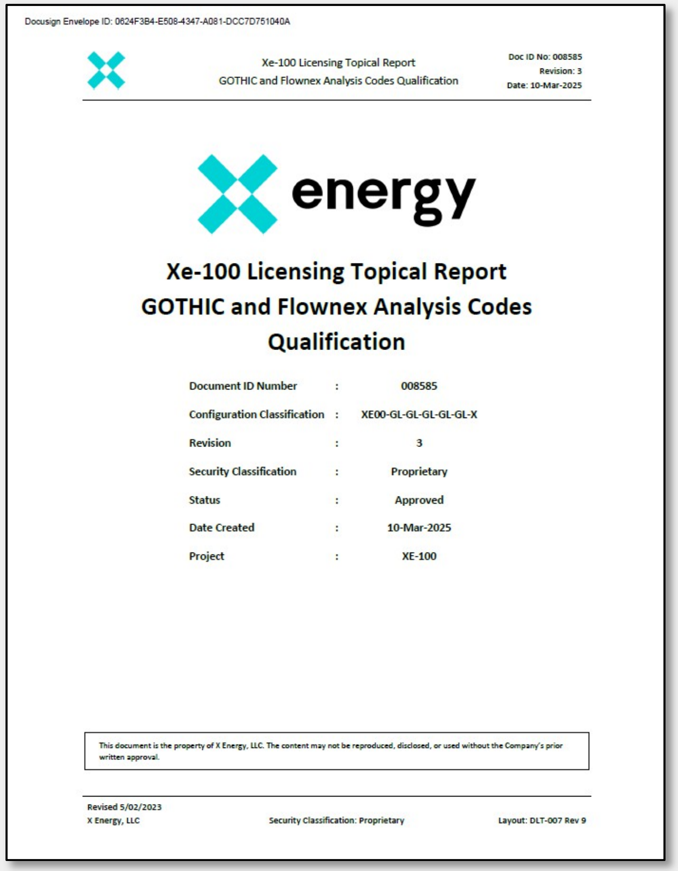
- Gothic Code Qualification
- **Conclusions**



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Xe-100 Licensing Topical Report
GOTHIC and Flownex Analysis Codes Qualification

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Revision: 3
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Xe-100 Licensing Topical Report
GOTHIC and Flownex Analysis Codes Qualification

Document ID Number	:	008585
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Revised 5/02/2023
X Energy, LLC
Security Classification: Proprietary
Layout: DLT-007 Rev 9

GOTHIC code qualification – Conclusions

- **GOTHIC v8.4a(QA)** and **Flownex v8.16.0.5518** are the software versions currently in use under **NRC-approved Quality Assurance Program** (QAP) based on **XEQAPD-NP Revision 3**, conforming to 10 CFR 50 Appendix B and ASME NQA-1-2015
- **Methodology and theoretical** basis are detailed in the LTR
- **GOTHIC and Flownex** will support the Xe-100 TSA **Evaluation Model**

Thanks for your attention… Questions?

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Xe-100 Evaluation Model Topical Reports
NRC Staff Opening Remarks

ACRS Meeting of the X-Energy Design Center Subcommittee
June 3, 2025

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https://www.nrc.gov/reactors/new-reactors/advanced.html

Scope and Use of Topical Reports

- Topical Reports:
  - Xe-100 Licensing Topical Report Transient and Safety Analysis Methodology
  - Xe-100 Licensing Topical Report GOTHIC and Flownex Analysis Codes Qualification
  - Xe-100 Licensing Topical Report Mechanistic Source Term Approach
  - *Xe-100 Licensing Topical Report Reactor Core Design Methods and Analysis* (Not included in ACRS review)
- Planned use:
  - These topical reports are referenced in the recently docketed Long Mott Generating Station Construction Permit Application

Review Team

- Transient and Safety Analysis
  - Tim Drzewiecki, Senior Reactor Systems Engineer, Xe-100 Review Lead
  - Tracy Radel, Senior Nuclear Engineer
  - Pravin Sawant, Senior Nuclear Engineer
  - Santosh Bhatt, Senior Nuclear Engineer
  - Denise McGovern, Senior Project Manager
  - Dan Beacon, Senior Project Engineer
  - Ian Jung, Senior Reliability and Risk Analyst
- GOTHIC/Flownex Qualification
  - Pravin Sawant, Senior Nuclear Engineer
  - Tim Drzewiecki, Senior Reactor Systems Engineer
  - Ashley Smith, Senior Nuclear Engineer
  - Denise McGovern, Senior Project Manager
  - Walter Touche, Energy Research Inc. (ERI)
  - Mohsen Khatib-Rahbar, ERI

Review Team

- Mechanistic Source Term
  - Inseok Baek, Reactor Engineer
  - Jason Schaperow, Senior Reactor Systems Engineer (Retired)
  - Tim Drzewiecki, Senior Reactor Systems Engineer
  - Michael Salay, Senior Reactor Systems Engineer, RES
  - Denise McGovern, Senior Project Manager

- Core Design Methods and Analysis (Not included in ACRS review)
  - Santosh Bhatt, Senior Nuclear Engineer
  - Inseok Baek, Reactor Engineer
  - Tim Drzewiecki, Senior Reactor Systems Engineer
  - Denise McGovern, Senior Project Manager

NRC Staff Review of Topical Report (TR) 007834 “Xe-100 Licensing Topical Report Transient and Safety Analysis Methodology” (TSAM)

ACRS Meeting of the X-Energy Design Center Subcommittee

June 3, 2025

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https://www.nrc.gov/reactors/new-reactors/advanced.html

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Outline

- Background on TSAM and related topical reports
- Regulatory Basis
- Review Approach
- Summary of Technical Review
- Other Limitations (Referenced Topical Report and Radiological Consequences)
- Conclusions

Background

- Xe-100 Topical Report: Transient and Safety Analysis Methodologies Framework, Revision 1 was submitted October 2021 (ML21288A173) and SE issued March 2023 (ML23086C082).
  - Limitations identified to address needs for (1) identification of figures of merit, (2) a finalized Phenomena Identification and Ranking Table (PIRT), (3) verification and validation, and (4) justification of the models used.
- TSAM originally submitted on April 30, 2024 (ML24121A285) with updated submittal on March 14, 2025 (ML25077A288)
  - Includes disposition of the limitations from "Transient and Safety Analysis Methodologies Framework”
  - Updated submittal includes markups identified during regulatory audit
  - Review leveraged the audit process to enable efficient identification of markups such that requests for additional information were not needed
- TSAM section 1.5 states, “X-energy requested review and approval of the evaluation model to analyze design basis accidents (***DBAs***) as defined in NEI 18-04 to support ***preliminary analysis and evaluation of the Xe-100***”
- TSAM is the top-level topical evaluation model report that used in combination with three other topical reports (TSAM section 13.2):
  - *Xe-100 Licensing Topical Report GOTHIC and Flownex Analysis Codes Qualification*
  - *Xe-100 Licensing Topical Report Mechanistic Source Term Approach*
  - Xe-100 Licensing Topical Report Reactor Core Design Methods and Analysis

Regulatory Basis

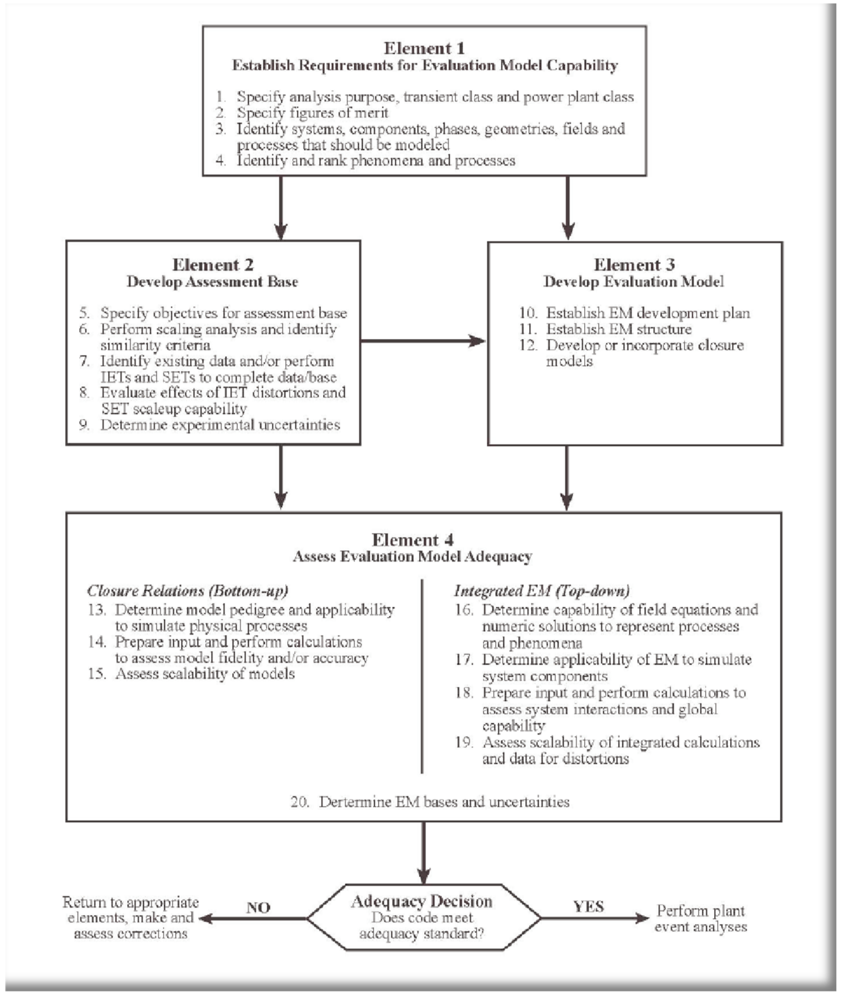
- Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34(a)(1)(ii)(D) requires, in part, that an applicant for a construction permit (CP) perform an evaluation and analysis of a **postulated fission product release** to evaluate the offsite radiological consequences.
- Under 10 CFR 50.34(a)(4) an applicant for a CP must perform a **preliminary analysis and evaluation of the design and performance of structures, systems, and components (SSCs)** with the objective of assessing the risk to public health and safety resulting from the operation of the facility and including the determination of margin of safety during normal operations and transient conditions anticipated during the life of the facility.
  - Staff identified relevant Principal Design Criteria (PDC): Xe-100 PDC 10, RFDC 11, RFDC 16, PDC 19, PDC 20, RFDC 26, PDC 28, RFDC 30, RFDC 34
  - Condition 1: A CP application referencing TSAM must confirm or update the regulatory basis relevant to the use of TSAM

Regulatory Basis

- Under 10 CFR 50.34(a)(8) an applicant for a CP must identify the systems, structures or components of the facility, if any, which require research and development to confirm the adequacy of their design and describe the **research program that will be conducted to resolve any safety questions associated with such systems, structures, or components**. Such research and development may include obtaining sufficient **data regarding the safety features of the design to assess the analytical tools** used for safety analysis in accordance with 10 CFR 50.43(e)(1)(iii).
- Section C.4 of Regulatory Guide (RG) 1.253, Revision 0, “Guidance for a Technology-Inclusive Content-of-Application Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors,”
  - *It is also important to note that for CP applicants, the requirements of 10 CFR 50.43(e)(1)(iii) to ensure that sufficient data exist on the safety features of the design to assess the analytical tools used for safety analyses do not apply. Accordingly, CP applicants are not required to provide evaluations of the safety margins using approved [Evaluation Models].*

Review Approach

- Review follows the steps outlined in RG 1.203, “Transient and Accident Analysis Methods”
  - TSAM sections 1.1 and 1.2 clarify that RG 1.203 is used to develop the methodology
- RG 1.203 describes an evaluation model (EM) development and assessment process (EMDAP)
  - 20 steps divided into 4 elements
- Technical Evaluation in Safety Evaluation (SE) maps relevant content of TSAM into the EMDAP steps
  - SE section 2.3 <- EMDAP Element 1
  - SE section 2.4 <- EMDAP Element 2
  - SE section 2.5 <- EMDAP Element 3
  - SE section 2.6 <- EMDAP Element 4
- Other portions of Technical Evaluation:
  - SE section 2.1: Introduction and Outline (Map TSAM content to SE)
  - SE section 2.2: Requirements under 10 CFR 50.34(a)(8) (Primary basis for conditions identified throughout the SE)
  - SE section 2.7: Limitations from Transient and Safety Analysis Methodologies Framework
  - SE section 2.8: Additional considerations on radiological assessment



Summary of Technical Review – EMDAP Element 1

Element 1

Establish Requirements for Evaluation Model Capability

1. Specify analysis purpose, transient class and power plant class
2. Specify figures of merit
3. Identify systems, components, phases, geometries, fields and processes that should be modeled
4. Identify and rank phenomena and processes

🟩 **Fully addressed**
🟨 **Mostly addressed**
🟧 **Partially addressed**
🟥 **Not addressed**

- Step 1:
  - TSAM is applicable to the Xe-100 reactor design as described in TSAM section 3
  - DBA EM addresses events listed in TSAM section 11.2
    - DBA list is derived from a full power probabilistic risk assessment and appears to be preliminary (e.g., DBA list in TSAM is different than DBA list in Long Mott Generating Station CPA)
    - Limitation 1: TSAM applicability is limited to preliminary safety analyses (i.e., construction permit)
    - Condition 2: An applicant referencing TSAM must justify how DBA events identified in preliminary safety analysis report are addressed by TSAM
- Step 2:
  - TSAM identifies radiological dose and as the figure of merit (FOM) and acceptance criteria that are consistent with NRC requirements (10 CFR 50.34(a)(1)(ii)(D)).
  - Other information in TSAM regarding FOMs is not consistent, quantitative standards of acceptance are not provided, TSAM does not clearly describe how FOMs are used in the EM development process (e.g., use in the PIRT process),and surrogate FOMs are not identified (e.g., Flownex and GOTHIC do not directly evaluate radiological consequences).
  - Condition 3: A CP application referencing TSAM must describe how surrogate FOMs will be assessed as part of a relevant research and development program or justify that they are not needed.

Summary of Technical Review – EMDAP Element 1

Element 1

Establish Requirements for Evaluation Model Capability

1. 🟨 Specify analysis purpose, transient class and power plant class
2. 🟧 Specify figures of merit
3. 🟧 Identify systems, components, phases, geometries, fields and processes that should be modeled
4. 🟧 Identify and rank phenomena and processes

🟩	**Fully addressed**
🟨	**Mostly addressed**
🟧	**Partially addressed**
🟥	**Not addressed**

- Step 3:
  - EMDAP step 3 partially addressed through PIRT process
  - TSAM does not contain information addressing step 3
  - TSAM appears to depart from RG 1.203 by not performing a hierarchal system decomposition
  - Condition 4: A CP application referencing TSAM must clearly identify the systems, components, phases, geometries, fields, and processes that must be modeled in their EM as part of a relevant research and development program.
- Step 4:
  - TSAM identifies importance levels for phenomena associated with particular events (TSAM section 8.5 identifies eight PIRTs including control rod withdrawal, loss of secondary cooling, steam generator tube rupture, …)
  - TSAM section 8.1 describes the seven steps that were taken to complete the PIRTs. NRC staff compared this against the nine-step process used to develop the PIRTs for the Next Generation Nuclear (NUREG/CR-6944) and noted several differences.
  - TSAM steps 1-3 are not fully addressed and these are input to the PIRT
  - Knowledge base is not described and knowledge levels are not provided
  - TSAM addresses transient and safety analyses using two characteristic time periods. These characteristic time periods do not appear to be reflected in the PIRTs.
  - Condition 5: A CP application referencing TSAM must describe how the PIRT methodology will incorporate a suitable knowledge base, assess knowledge levels of associated phenomena, and address characteristic time periods as part of a relevant research and development program.

Summary of Technical Review – EMDAP Element 2

Element 2 Develop Assessment Base
5. Specify objectives for assessment base (Partially addressed in GOTHIC/Flownex TR)
6. Perform scaling analysis and identify similarity criteria
7. Identify existing data and/or perform IETs and SETs to complete data/base (Partially addressed in GOTHIC/Flownex TR)
8. Evaluate the effects of IET distortions and SET scaleup capability
9. Determine experimental uncertainties

🟩	Fully addressed
🟨	Mostly addressed
🟧	Partially addressed
🟥	Not addressed

- Step 5:
  - – TSAM section 6 provides high-level discussions on verification and validation plans for VSOP90/95, Flownex, XSTERM, and GOTHIC but objectives are not provided (e.g., phenomena to be assessed, system interactions and global code capability assessment).
    - GOTHIC/Flownex TR partially addressing this step
  - – Condition 6: A CP application referencing TSAM must clearly state the objectives of the EM assessment base as part of a relevant research and development program.
- Step 6:
  - – TSAM section 6.5.1 describes use a scaling methodology that is consistent with the hierarchical two-tired scaling (H2TS) method that is referenced in RG 1.203.
    - TSAM section 6.5.2.4 clarifies that code accuracy from validation activities needs to be addressed on a case-by-case basis.
  - – TSAM sections 6.5.2.5 through 6.5.2.7 discusses verification and validation applicability based on similarity ratios
    - NRC staff are unable to make any determination on these approaches because similarity ratios are not sufficient to demonstrate EM applicability or quantify EM uncertainty
  - – Condition 7: A CP application referencing TSAM must assess the EM using a range of experimental data whose non-dimensional numbers bound the values applicable to the Xe-100 or provide alternative justification as part of a relevant research and development program.
  - – Limitation 2: The NRC staff's approval of the scaling approach described in this TR is limited to the general application of the H2TS scaling methodology. No approval of Xe-100 specific scaling or associated data applicability is provided.

Summary of Technical Review – EMDAP Element 2

Element 2 Develop Assessment Base
🟧 5. Specify objectives for assessment base (Partially addressed in GOTHIC/Flownex TR)
🟧 6. Perform scaling analysis and identify similarity criteria
🟧 7. Identify existing data and/or perform IETs and SETs to complete data/base (Partially addressed in GOTHIC/Flownex TR)
🟧 8. Evaluate the effects of IET distortions and SET scaleup capability
🟥 9. Determine experimental uncertainties

🟩	Fully addressed
🟨	Mostly addressed
🟧	Partially addressed
🟥	Not addressed

- Step 7:
  - NRC staff did not identify information in TSAM identifying existing data or assessing the need for integral effects tests (IETs) or separate effects tests (SETs).
    - GOTHIC/Flownex TR partially addressed this step
- Step 8:
  - TSAM provide general description of H2TS scaling methodology (see Step 6)
  - No findings made on distortion analysis (see Step 6)
  - NRC staff did not identify information on SET scaleup capability
  - Condition 9: A CP application referencing TSAM must include evaluation of effects of IET distortion and SET scaleup capability as part of a relevant research and development program.
- Step 9:
  - NRC staff did not identify information in TSAM addressing experimental uncertainties
  - Condition 10: A CP application referencing TSAM must include evaluation of experimental uncertainties associated with EM assessment data as part of a relevant research and development program.

Summary of Technical Review – EMDAP Element 3

Element 3 **Develop Evaluation Model**
🟩 10. Establish EM development plan
🟨 11. Establish EM structure
🟧 12. Develop or incorporate closure models (Partially addressed in GOTHIC/Flownex TR)

🟩	**Fully addressed**
🟨	**Mostly addressed**
🟧	**Partially addressed**
🟥	**Not addressed**

- Step 10:
  - – TSAM section 12 clarifies that activities described in TSAM are performed in accordance with the X-energy Quality Assurance Program Description which has been reviewed and approved by NRC staff.
    - Item identified in RG 1.203 for EMDAP step 10 are expected to be addressed by the quality assurance program (e.g., documentation requirements, programming standards and procedures, configuration control procedures)
- Step 11:
  - – TSAM Figure 22 shows EM interfaces and TSAM section 5 summarizes the codes and methods that are used in the EM (e.g., Reactor Core Design methodology, Mechanistic Source Term methodology, Flownex, GOTHIC, Flownex Screening Criteria (FSC))
    - TSAM section 10.2 states that the final sets of conditions and interfaces will be outlined in future submittals for NRC staff review
    - TSAM section 13.2 clarifies that the EM described in TSAM shall be used in combination with NRC approved versions of TR 008585, “GOTHIC and Flownex Analysis Codes Qualification,” (2) TR 000632, “Mechanistic Source Term Approach,” and (3) TR 006889, “Reactor Core Design Methods and Analysis.” “GOTHIC and Flownex Analysis Codes.
      - – NRC staff review of these methodologies is performed outside of TSAM review
  - – TSAM section 10.4 clarifies that analyses fall into two characteristic time periods:
    - Plant transient – evaluated with Flownex
    - Long-term passive cooling – evaluated with GOTHIC and XSTERM

Summary of Technical Review – EMDAP Element 3

Element 3 **Develop Evaluation Model**
🟩 10. Establish EM development plan
🟨 11. Establish EM structure
🟧 12. Develop or incorporate closure models (Partially addressed in GOTHIC/Flownex TR)

🟩	**Fully addressed**
🟨	**Mostly addressed**
🟧	**Partially addressed**
🟥	**Not addressed**

- Step 11 (cont):
  - – TSAM section 5.5 describes FSC as a response surface that converts Flownex calculated pebble temperatures into a conservative dose estimate
    - NRC staff agree that FSC appears reasonable for estimating dose associated with diffusion driven phenomena from the fuel, but TSAM does not describe what radionuclide release mechanisms are accounted for by the FSC
    - NRC staff did not identify screening criteria in TSAM
    - Condition 11: A CP application applying FSC in accordance with TSAM must provide justification for the use of FSC on a case-by-case basis.
    - Condition 12: A CP application applying FSC in accordance with this TR must provide screening criteria for justifying the use of FSC in lieu of performing XSTERM evaluations.
  - – Subject to SE conditions 11 and 12 and the limitations and conditions provided in TSAM section 13.2, the NRC staff concludes that TSAM addresses EMDAP step 11 because the codes used in the EM have been identified and initial interfaces are described.
- Step 12:
  - – NRC staff did not identify information in TSAM addressing EMDAP step 12.
  - – During a regulatory audit, the NRC staff noted that X-energy statements that there are few closure models still under development and/or are being validated.
    - Partially addressed in GOTHIC/Flownex TR
  - – Condition 13: A CP application referencing this TR must describe how closure models will be developed or incorporated into the EM, either directly or incorporated by reference, as part of a relevant research and development program.

Summary of Technical Review – EMDAP Element 4

Element 4 Assess Evaluation Model Adequacy	
🟥 13 - 15	Closure Relations (Bottom-up)
🟥 16 - 19	Integrated EM (Top-down)
🟧 20.	Determine EM biases and uncertainties

🟩	Fully addressed
🟨	Mostly addressed
🟧	Partially addressed
🟥	Not addressed

- Element 4:
  - X-energy states that EMDAP Element 4 (steps 13-20) is not addressed by TSAM (or any other TR)
  - TSAM section 13.2 states that the EM described in TSAM cannot be used to support a final safety analysis until validation and verification of the codes within the EM have been approved by the NRC.
  - TSAM contains some information relevant to EMDAP step 20
    - TSAM section 9 describes an uncertainty analysis methodology that includes a novel Phenomena and Key (PK)-PIRT process
    - NRC staff are unable to determine that the uncertainty analysis methodology is appropriate (reasons specified in SE)
  - Condition 14: A CP application referencing this TR must describe how EM assessment will be addressed, either directly or incorporated by reference, as part of a relevant research and development program.

Limitations from Referenced Topical Report

- Xe-100 Topical Report: Transient and Safety Analysis Methodologies Framework, Revision 1 was submitted October 2021 (ML21288A173) and SE issued March 2023 (ML23086C082).
  - Limitations identified to address needs for (1) identification of figures of merit, (2) a finalized PIRT, (3) verification and validation, and (4) justification of the models used.
- TSAM section 2.5 describes how TSAM addressed the four limitations provided in the NRC staff SE, dated March 29, 2023.
  - NRC staff determined that TSAM does not fully address the limitations in the NRC staff SE dated March 29, 2023
  - For an application that references TSAM, the limitations and conditions identified for TSAM supersede the limitations identified in the NRC staff’s SE dated March 29, 2023.

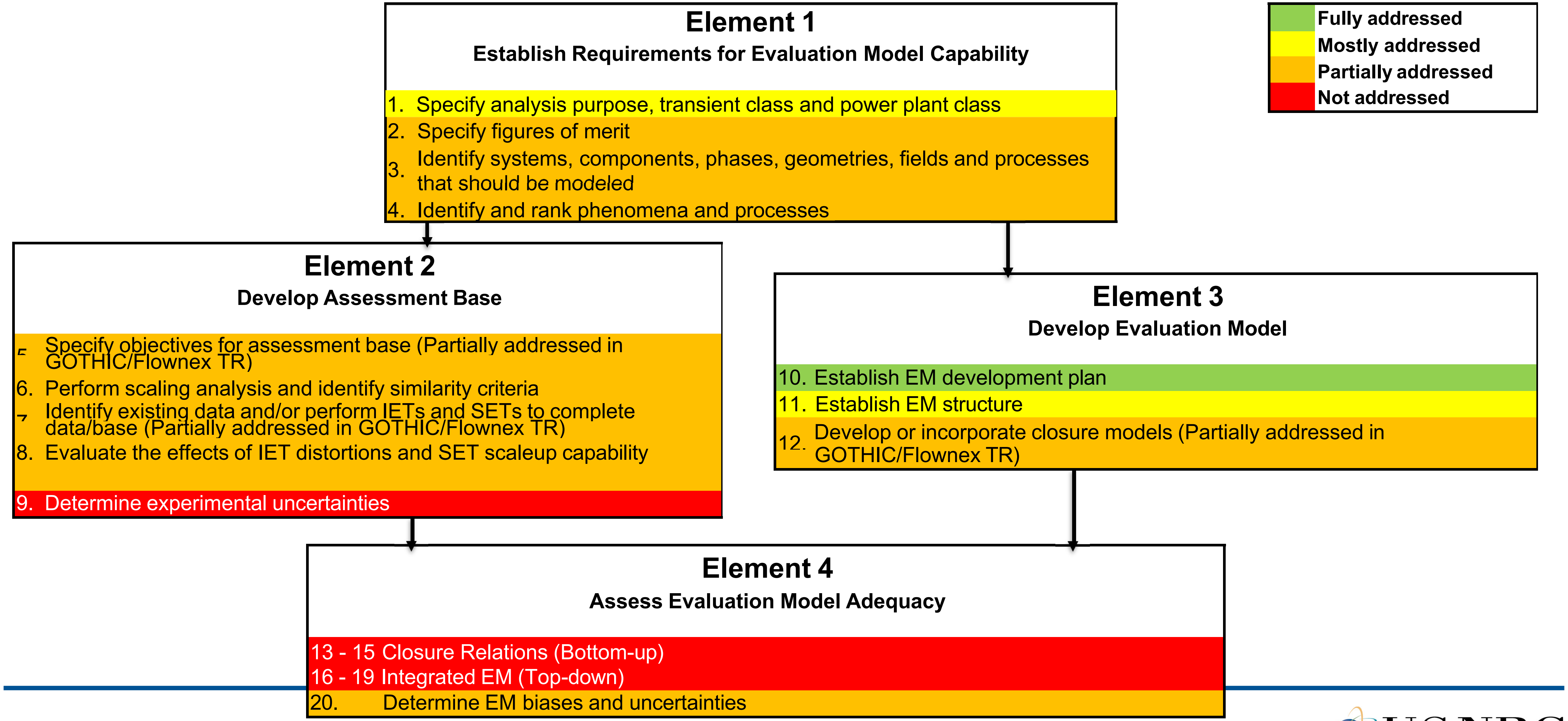
Additional Considerations Regarding Radiological Consequence Assessment

- TSAM information associated with the evaluation of offsite radiological consequences is high-level and, with the exception of FSC, in TSAM section 5 and section 10, is generally limited to thermal-fluid assessment.
    - NRC did not identify information in TSAM addressing radionuclide production, transport, dispersion, and conversion to radiological dose.
- Limitation 3: The NRC staff’s approval of this TR for radiological consequence analysis is limited to the thermal-fluid inputs used in radiological consequence analysis and the general use of FSC.

Conclusions

- NRC staff approves use of TR 007834, “Xe-100 Licensing Topical Report Transient and Safety Analysis Methodology,” Revision 2 for the preliminary analysis of DBAs for the Xe-100 subject to 3 Limitations and 14 Conditions (provided in section 3 of the SE)
  - The use of the EM as described in TSAM is acceptable for informing radiological consequence analysis evaluations to address **Xe-100 PDC 19 and 10 CFR 50.34(a)(1)(ii)(D)** because, pursuant to limitations described in TSAM section 13.2, SE condition 11, and SE condition 12, sufficient justification would be provided in a CP application or during the associated safety review to ensure that the codes used in the EM are reasonably capable of analyzing DBAs for the Xe-100.
  - The use of the EM as described in TSAM is acceptable for the preliminary analysis of the design and performance of Xe-100 SSCs in accordance with **10 CFR 50.34(a)(4)** and demonstrating, in part, preliminary compliance with **relevant PDC because** (1) CP applications are not required to provide evaluations of safety margins using approved EMs, and (2) pursuant to limitations described in TSAM section 13.2, SE condition 11, and SE condition 12, sufficient justification would be provided in a CP application or during the associated safety review to ensure that the codes used in the EM are reasonably capable of analyzing DBAs for the Xe-100.
  - The use of TSAM, pursuant to condition 2 through condition 14, is capable of addressing the requirements under **10 CFR 50.34(a)(8)** to describe a research plan to resolve safety questions associated with EM applicability to the Xe-100 because addressing those conditions would result in an EM that complies with the approved guidance in RG 1.203, “Transient and Analysis Methods.”
- NRC staff expects that the approval of TR007834, "Xe-100 Licensing Topical Report Transient and Safety Analysis Methodology,” Revision 2 for the preliminary analysis of DBAs for the Xe-100 subject to 3 Limitations and 14 Conditions" will provide efficiencies for licensing applications that incorporate it by reference.

EMDAP Status



- 🟩 Fully addressed
- 🟨 Mostly addressed
- 🟧 Partially addressed
- 🟥 Not addressed

Element 1

Establish Requirements for Evaluation Model Capability

1. Specify analysis purpose, transient class and power plant class
2. Specify figures of merit
3. Identify systems, components, phases, geometries, fields and processes that should be modeled
4. Identify and rank phenomena and processes

Element 2

Develop Assessment Base

5. Specify objectives for assessment base (Partially addressed in GOTHIC/Flownex TR)
6. Perform scaling analysis and identify similarity criteria
7. Identify existing data and/or perform IETs and SETs to complete data/base (Partially addressed in GOTHIC/Flownex TR)
8. Evaluate the effects of IET distortions and SET scaleup capability
9. Determine experimental uncertainties

Element 3

Develop Evaluation Model

10. Establish EM development plan
11. Establish EM structure
12. Develop or incorporate closure models (Partially addressed in GOTHIC/Flownex TR)

Element 4

Assess Evaluation Model Adequacy

13 - 15 Closure Relations (Bottom-up)

16 - 19 Integrated EM (Top-down)

20. Determine EM biases and uncertainties

Acronyms

CP	Construction Permit
DBA	Design Basis Accidents
EM	Evaluation Model
EMDAP	Evaluation Model Development and Assessment Process
FOM	Figure of Merit
FSC	Flownex Screening Criteria
IET	Integral Effects Tests
PDC	Principal Design Criteria
PIRT	Phenomena Identification and Ranking Table
PK	Phenomena and Key
PRA	Probabilistic Risk Assessment
PSAR	Preliminary Safety Analysis Report
QAPD	Quality Assurance Program Description
SET	Separate Effects Tests
TR	Topical Report
TSAM	Transient and Safety Analysis Methodology

Xe-100 GOTHIC And Flownex Code Qualifications (GFQ)
NRC Staff Review

ACRS Meeting of the X-Energy Design Center Subcommittee
June 3, 2025

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https://www.nrc.gov/reactors/new-reactors/advanced.html

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Outline

- Background
- Regulatory Basis
- Safety Evaluation Approach
- Evaluation of GOTHIC and Flownex codes and input models
  - Evaluation Model Development and Assessment Process (EMDAP) Element 3: Develop Evaluation Model (Steps 11 & 12)
- Evaluation of GOTHIC and Flownex qualifications
  - EMDAP Element 2: Develop Assessment Base (Steps 5 & 7)
- Documentation, Configuration Control, and Quality Assurance (QA)
  - EMDAP Element 3: Develop Evaluation Model (Step 10)
- Limitation and Condition
- Conclusion

Background

- Xe-100 Topical Report: GOTHIC and Flownex Analysis Codes Qualification, Revision 2 was submitted on May 22, 2024 (ML24143A192) with updated submittal of Revision 3 on March 13, 2025 (ML25076A053)
    - Provides overview of GOTHIC and Flownex computer codes
    - Describes preliminary Xe-100 input models developed for preliminary Design Basis Accident (DBA) analysis
    - Summarizes completed and planned verification and validation activities, and
    - Describes quality assurance approach for the codes
- GFQ TR supports Transient and Safety Analysis Methodology (TSAM) to perform preliminary analysis and evaluation of DBAs for the Xe-100 design
    - Flownex analyzes short-term transient response
        - Short-term transient period: systems, structures, and components (SSCs) are actively responding, forced cooling is available and primary system is actively depressurizing
    - GOTHIC analyzes long-term transient response
        - Long-term transient period: passive heat transfer begins and no additional active plant responses to the initiating event are considered
- X-energy requested review and approval of GOTHIC and Flownex codes and models to perform **preliminary DBA analysis** for Xe-100 design

Regulatory Basis

- **Under 10 CFR 50.34(a)(4)** an applicant for a Construction Permit (CP) must perform a **preliminary analysis and evaluation of the design and performance of SSCs** with the objective of assessing the risk to public health and safety resulting from the operation of the facility and including the determination of margin of safety during normal operations and transient conditions anticipated during the life of the facility.
- **Regulatory Guide (RG) 1.233**, Revision 0, "Guidance for Technology-Inclusive, Risk-Informed, and Performance-Based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors" (ML20091L698) endorses NEI 18-04, Revision 1, "Risk-Informed Performance-Based Technology-Inclusive Guidance for Non-Light Water Reactors," (ML19241A472) as one acceptable method to inform licenses, certifications, and approvals for non-light water reactors (LWRs).
- **NEI-18-04** states that codes and models used in DBA analysis are expected to satisfy RG 1.203, "Transient and Accident Analysis Methods," (ML053500170) requirements for evaluation models (EMs).
- Review of GFQ TR follows **RG 1.203** Evaluation Model Development and Assessment Process

Safety Evaluation Approach

- Many EMDAP Steps are addressed in TSAM TR
  - EMDAP Element 1, Establish Requirements for Evaluation Model Capability (PIRT) addressed in TSAM (partially)
  - EMDAP Elements 2, Develop Assessment Base and Element 3 , Develop Evaluation Model steps partially addressed in TSAM
  - GFQ TR addresses primarily steps under EMDAP Elements 2 and 3
- Scope for GFQ TR Review
  - Review of Flownex and GOTHIC codes and Xe-100 input models against EMDAP Element 3 Steps 11 and 12
  - Review of documentation, configuration control, and quality assurance approach for Flownex and GOTHIC codes against EMDAP Element 3 Step 10
  - Review of Flownex and GOTHIC qualifications (validations) against applicable steps under EMDAP Element 2 (Steps 5 and 7)
  - Review focuses on evaluating adequacy of Flownex and GOTHIC codes, input models, and validations for preliminary analysis of DBAs in Xe-100 design

Evaluation of GOTHIC & Flownex Codes & Input Models

EMDAP Element 3 Develop Evaluation Model		
10.	Establish EM development plan	TSAM and GFQ (partially)
11.	Establish EM structure	TSAM (partially) and GFQ (partially)
12.	Develop or incorporate closure models	GFQ

- Confirm adequacy of GOTHIC and Flownex codes and input model to support preliminary safety analysis of Xe-100 design consistent with EMDAP Steps 11 and 12
  - GOTHIC and Flownex codes are capable of modeling important transient phenomena for the Xe-100 design, and,
  - GOTHIC and Flownex input models represent the plant geometric input, nodalization, boundary conditions, initial plant state conditions and controls commensurate with the preliminary nature of the Xe-100 design.

Flownex Code and Input Model

- Flownex Code
  - Performs steady state and transient thermal-fluid simulation of plant with integrated reactor kinetics and control system model
  - 1-D finite difference equations for mass, momentum, and energy (multicomponent, compressible, homogeneous mixture model)
  - 1-D framework extended to 2-D axisymmetric representation of porous pebble bed core with 1-D conduction model for heat transfer in pebbles
  - Closure models include fluid properties, single- and two-phase friction including porous media pressure drop, two-phase flow related closures (e.g., boiling), heat transfer correlations such pebble to coolant and pebble to pebble effective conduction, porosity variation, etc.
- Xe-100 Flownex Input Model
  - Xe-100 components are represented with network of nodes (one-D control volumes) and elements (models) (GFQ TR Appendix C Figure 13,19)
  - Primary system, secondary system and power conversion cycle, control system modeled with Flownex
  - Model includes the pressure vessel, pebble bed core, fuel elements, core barrel structures, graphite reflectors, defueling chute, helium inlet and risers connected to the steam generator through the annular hot gas duct
  - Pressure vessel, pebble bed core, core barrel and graphite reflectors modeled with 2-D axial and radial elements. Junctions represent axial and radial helium flow between the fluid elements in the pebble bed core using the 2D Flownex formulation.
  - Reactor cavity cooling system (RCCS) represented as boundary condition

GOTHIC Code and Input Model

- GOTHIC Code
  - General purpose, thermal-hydraulic system analysis code, used extensively in nuclear safety analysis and in NRC approved methodologies (e.g., LWR LOCA and Containment Analysis)
  - Wide range of capabilities from lumped parameter approach to three-dimensional representations (multicomponent, compressible and multi-fields for liquid and gas)
  - Closing relations unique pebble bed application: pressure drop correlation (to be included), pebble-to-coolant convective heat transfer, effective thermal conductivity for pebble-to-pebble and pebble to reflector heat transfer
- GOTHIC Xe-100 Input Model
  - Primary and secondary systems including the reactor system, cross-over pipe, and steam generator represented with multiple control volumes, flow paths and heat structures (Figure 27 of GFQ TR)
  - Reactor model includes helium riser, upper head, core, outlet plenum, lower head, defueling chute, core bypass helium flow and control rod voids
  - The pebble bed core region is represented by a cylinder using a 2D axial-radial mesh with multiple axial levels and radial regions. The core outlet plenum is also represented by a cylinder with the same number of radial regions as the pebble bed core. Conical core sections neglected.
  - RCCS is modeled as a temperature dependent heat flux on reactor pressure vessel outer surface based on results from a stand-alone GOTHIC RCCS model
  - Detailed model for helical coil steam generator (SG) primary and secondary sides with ability to model SG tube rupture accident
  - Pebble bed fuel conductors represented as a single, spherical conductor with the average power of fuel pebbles in an axial and radial sub-volume, while the surface area represented by total surface area of pebbles in sub-volume.

∞

Determination on GOTHIC & Flownex Codes and Input Models

- Systems and components, constituents and phases, field equations, closure relations, and numerics for GOTHIC and Flownex are adequately described consistent with EMDAP Steps 11 and 12 for preliminary DBA analysis of Xe-100 design
- Major Xe-100 SSCs necessary to perform preliminary steady-state and DBA analysis are represented in plant input models consistent with EMDAP Step 11
- Closure models available within GOTHIC and Flownex, based on the NRC staff's high-level review and judgment, are adequate to support preliminary analysis of Xe-100 design consistent with EMDAP Step 12
- Evaluation of scalability and applicability of closure models to Xe-100 reactor design will be performed in future as part of review of EMDAP Element 4
- Current review for preliminary analysis is limited to the applicability of codes and general modeling capabilities and does not extend to or approve individual input parameters in the Xe-100 in models.
- Staff imposed Limitation 1 that limits approval of codes and input models, in accordance with modeling features described in GFQ TR, for preliminary analysis of Xe-100

Evaluation of GOTHIC & Flownex Qualifications

Element 2 **Develop Assessment Base**	
5. Specify objectives for assessment base	GFQ
6. Perform scaling analysis and identify similarity criteria	TSAM (partially)
7. Identify existing data and/or perform IETs and SETs to complete data/base	GFQ
8. Evaluate the effects of IET distortions and SET scaleup capability	TSAM (partially)
9. Determine experimental uncertainties	Not addressed

- Review Scope Limited to EMDAP Steps 5 & 7
  - Scaling analysis, distortion analysis, and determination of experimental uncertainties, required by EMDAP Steps 6, 8, and 9, are not addressed
  - Table 1 of GFQ TR “Validation Basis” provides (1) High importance PIRT phenomena for different DBA event categories, and (2) Validation matrix for Flownex and GOTHIC codes
  - Separate effects test (SET), integral effects test (IET), and analytical validations selected
  - Majority validations are part of GOTHIC and Flownex developmental assessments and use legacy data (i.e., existing data) except for planned validation of GOTHIC against future applicable Argonne National Laboratory (ANL) Natural Convection Shutdown Heat Removal Test Facility (NSTF) data

Flownex Qualifications

- Flownex validation matrix includes nine SETs, four IETs, and two analytical benchmarks
  - 10 MW High Temperature Gas-Cooled Reactor Test Module (HTR-10) steady state conditions (IET) (Chinese 10 MW reactor)
  - SANA pebble bed temperature (SET) (German facility, heated pebble bed)
  - Pebble bed micro model (PBMM)
- Shows coverage for all PIRT high-ranked phenomena except
  - Outlet plenum flow distribution (only for normal operation)
  - Flow reversal in core bringing hot core coolant into the inlet plenum
  - Distribution and concentration of moisture in primary system
- Planned validation
  - HTR-10 reactor power transient benchmark
  - Flownex analytical simulations
- EMDAP Steps 5 & 7 addressed for preliminary analysis with Flownex
- Applicability of assessment data to analysis of the Xe-100 reactor design will be evaluated as part of the considerations of EMDAP Element 4

GOTHIC Qualifications

- GOTHIC validation matrix includes 22 SETs, 10 IETs, and 14 analytical benchmarks
  - All are legacy validations
- Shows coverage for all PIRT high-ranked phenomena except
  - Outlet plenum flow distribution (only for normal operation)
  - Flow reversal in core bringing hot core coolant into the inlet plenum
  - Distribution and concentration of moisture in primary system
- Planned validation
  - HTR-10: steady state, LOFC without scram, and control rod withdrawal
  - SANA for pebble bed heat transfer
  - ANL NSTF data to validate performance of RCCS (important for long-term cooling)
- EMDAP Steps 5 & 7 addressed for preliminary analysis with GOTHIC
- Applicability of assessment data to the analysis of the Xe-100 reactor design will be evaluated as part of the considerations of EMDAP Element 4

Documentation, Configuration Control, and QA

- EMDAP Step 10 addresses requirements for documentation, QA, and configuration control for EM
- GOTHIC and Flownex EM development is performed under approved X-energy Quality Assurance Program (ML24218A128)
- Section 6 of GFQ TR provides description of selected X-energy quality assurance procedures related to software development
- Documentation of EM requirements, EM methodology, code theory and user manuals was provided. Scaling report, uncertainty analysis and final assessment report are not available.
- EMDAP Step 10 satisfied for preliminary analysis because
  - Activities described in GFQ TR are performed in accordance with an approved quality assurance program
  - Documentation is either available or its absence is reasonable for an EM supporting preliminary analysis for a CP application

Limitation and Condition

- The NRC staff’s approval of the GFQ TR is limited to the applicability of the Flownex and GOTHIC codes, in accordance with the modeling features described in the GFQ TR, for preliminary analysis of the Xe 100. The review of the input parameters into these models is expected to be performed as part of the review of a CP application.

Conclusion

- Review of Flownex and GOTHIC against EMDAP Steps 11 and 12 show that these codes have models to represent high importance phenomena to support preliminary Xe-100 DBA safety analysis in a Preliminary Safety Analysis Report for a CP application.
- Consistent with EMDAP Steps 11 and 12, Flownex and GOTHIC input models as described in GFQ TR indicate that all major Xe-100 SSCs are represented with sufficient level of detail to support the generation of a steady-state simulation necessary for preliminary DBA analysis for a CP application.
- The nodalization, modeling assumptions, boundary conditions, initial plant state conditions, and controls are commensurate with the preliminary nature of the Xe-100 design described in TSAM Section 3 (ML25077A285).
- Consistent with EMDAP Steps 5 and 7, the GFQ TR identifies SETs, IETs, and analytical assessments needed for validation of Flownex and GOTHIC codes. Preliminary validation results provide confidence that Flownex and GOTHIC can be used to perform preliminary Xe-100 DBA analysis in support of a CP application.

Acronyms

ANL	Argonne National Laboratory
CP	Construction Permit
DBA	Design Basis Accident
EM	Evaluation Model
EMDAP	Evaluation Model Development and Assessment Process
GFQ	GOTHIC And Flownex Code Qualifications
HTR-10	10 MW High Temperature Gas-Cooled Reactor Test Module
IET	Integral Effects Test
LWR	Light Water Reactors
NSTF	Natural Convection Shutdown Heat Removal Test Facility
PIRT	Phenomena Identification and Ranking Table
QA	Quality Assurance
RCCS	Reactor Cavity Cooling System
SANA	Selbsttätige Abfuhr der Nachwäre
SG	Steam Generator
TSAM	Transient and Safety Analysis Methodology

Xe-100 Licensing Topical Report Mechanistic Source Term Approach

Milan Hanus

June 3, 2025

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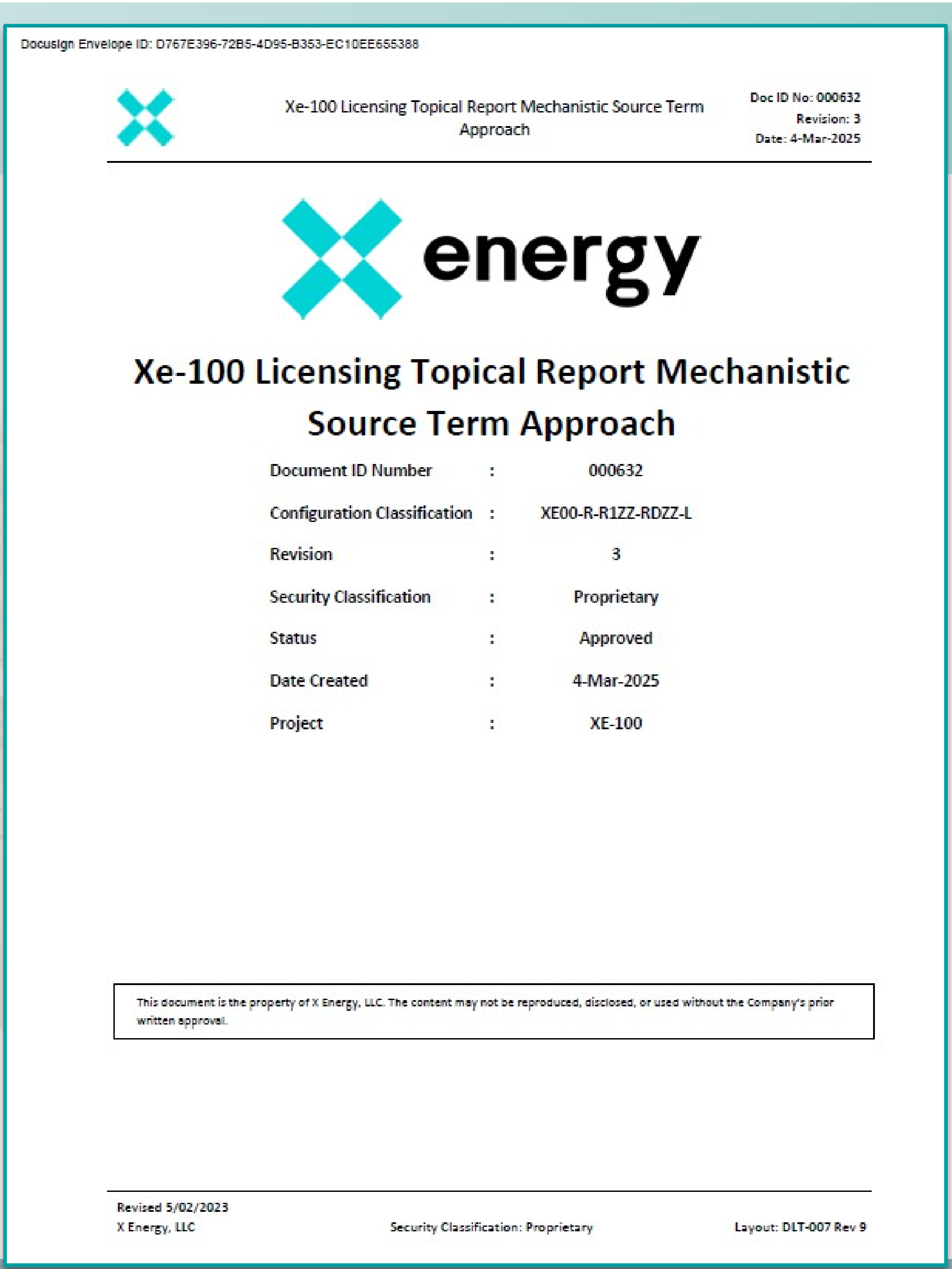
Outline

- X-energy’s Mechanistic Source Term (MST) Approach
- Mechanistic Source Term Models
- Q&A



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Xe-100 Licensing Topical Report Mechanistic Source Term Approach

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Xe-100 Licensing Topical Report Mechanistic Source Term Approach

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Mechanistic Source Term (MST) Approach

- **Scope:**
  - **Included:** Description of MST models used to determine radionuclide transport phenomena and estimate mechanistic source terms used to support the preliminary analysis and evaluation of the Xe-100
  - **Excluded:** Actual implementation evaluation cases and outputs (included in a future XSTERM Topical Report)

- **Interfacing Documents:**
  - Risk-Informed Performance-Based Licensing Basis Approach for the Xe-100 Reactor (ML21196A071)
  - Xe-100 Licensing Topical Report: Transient and Safety Analysis Methodology (ML25077A285)
  - Xe-100 Principal Design Criteria Licensing Topical Report (ML24047A310)
  - Xe-100 Licensing Topical Report TRISO-X Pebble Fuel Qualification Methodology (ML22216A179)
  - Xe-100 Licensing Topical Report Atmospheric Dispersion and Dose Calculation Methodology (ML23268A456)

Mechanistic Source Term (MST) Approach

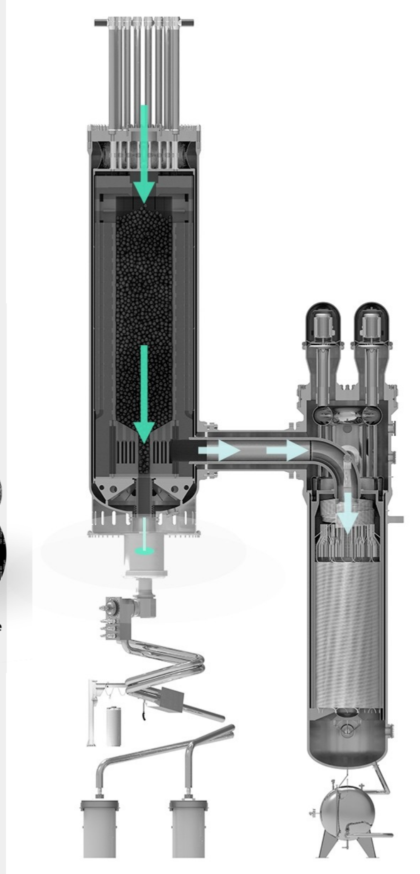
- Xe-100 MST methodology is part of the implementation of a **risk-informed, performance-based design and licensing basis** according to the Nuclear Energy Institute (NEI) 18-04 and Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.233
- **Regulatory Guidance (SECY-93-092):**
  - Reactor and fuel performance under normal and off-normal operating conditions is sufficiently well understood to permit a mechanistic analysis.
  - Sufficient data should exist on the reactor and fuel performance through the research, development, and testing programs to provide the adequate confidence in the mechanistic approach.
  - Transport of fission products can be adequately modelled for all barriers and pathways to the environs, including specific consideration of containment design. The calculations should be as realistic as possible so that the values and limitations of any mechanism or barrier are not obscured.
  - Events considered in the analyses to develop the set of source terms for each design are selected to bound severe accidents and design-dependent uncertainties.

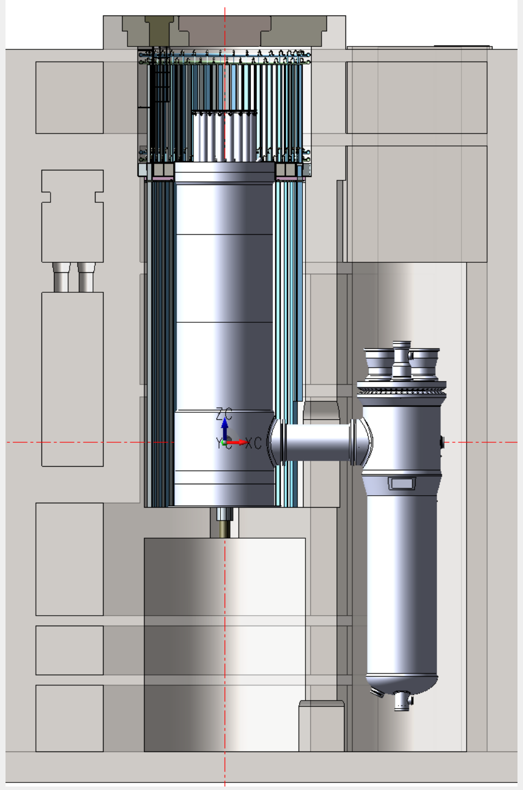
Mechanistic Source Term (MST) Approach

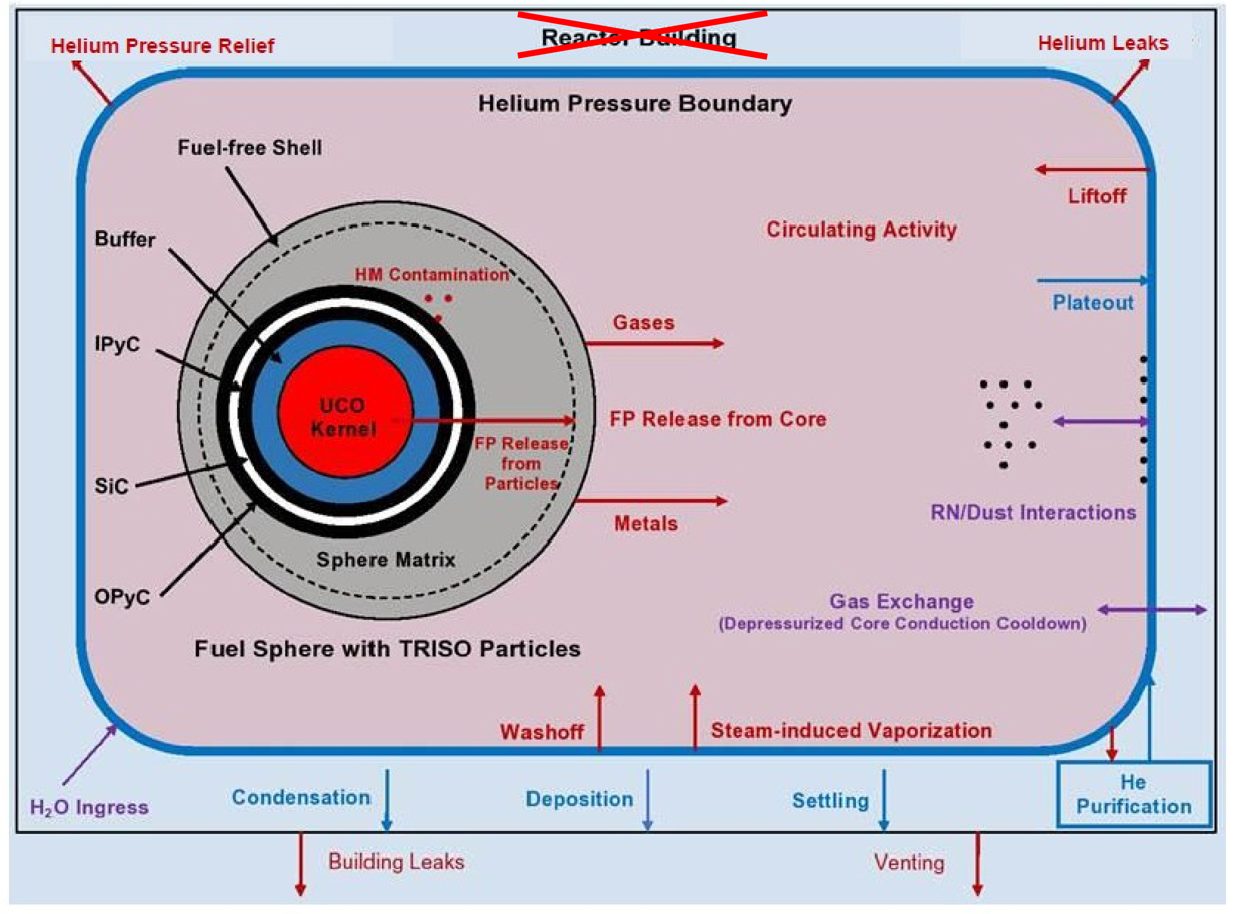
➢ **Xe-100 source terms** are:

- Event-specific
- Determined mechanistically using models of fission product (FP) generation and transport
- Accounting for the reactor’s inherent and passive design features and the performance of FP release barriers that constitute the functional containment
- Inclusive of the quantities, timing, physical and chemical forms, and thermal energy of the release
- Different from light water reactor source terms based on severe core damage event(s)

Mechanistic Source Term (MST) Approach







Radionuclide Release Barriers

Mechanistically Modelled Radionuclide Transport Phenomena

MST Models

LTR Appendix	*Model*	*Scope*	*Codes implementing similar capability*
A	FPM	Fuel Performance (particle failure fractions)	PARFUME (INL), PANAMA, STACY
B	THM	Thermodynamics	VSOP-THERMIX-KONVEK, AGREE (UMich), STAR-CCM+ (Siemens)
C	SOLM	Time-dependent radionuclide production, transport & release from fuel elements	PARFUME (INL), GETTER, FRESCO, STACY
D	GASM	Steady-state gaseous fission product release	PARFUME (INL), NOBLEG, STACY
E	DUSTM	Graphite / metallic dust production	N/A
F	HPBM	Dust, fission and activation product behavior in primary circuit	DAMD (PBMR), PADLOC (GA), RADAX, SPATRA, RADC (GA), MELCOR (Sandia)
G	CORRM	Air/water Ingress, fuel materials corrosion rates	OXIDE-4 (GA), TINTE, GRACE (FE), STAR-CCM+ (Siemens), Fluent (ANSYS)
	KSIM	Plant simulator using point-kinetics core model with spatial and thermo-dynamics coupling	MGT / TINTE, AGREE (UMich), RELAP-7 (INL), Flownex (M-Tech)
	TRITM	Tritium plant mass balance	TRITGO (GA), THYTAN (JAEA), TPAC (INL), TMAP (INL), ORIGEN-S (ORNL)
	Dispersion/Dose	Off-Site doses	MACCS (Sandia), HotSpot (LLNL), RASCAL (NRC), ADDAM (AECL)

Xe-100 Licensing Topical Report, Atmospheric Dispersion and Dose Calculation Methodology (ML23268A456)

XSTERM

US-DOE Code

German (Legacy) Code

Commercial NQA-1 Code

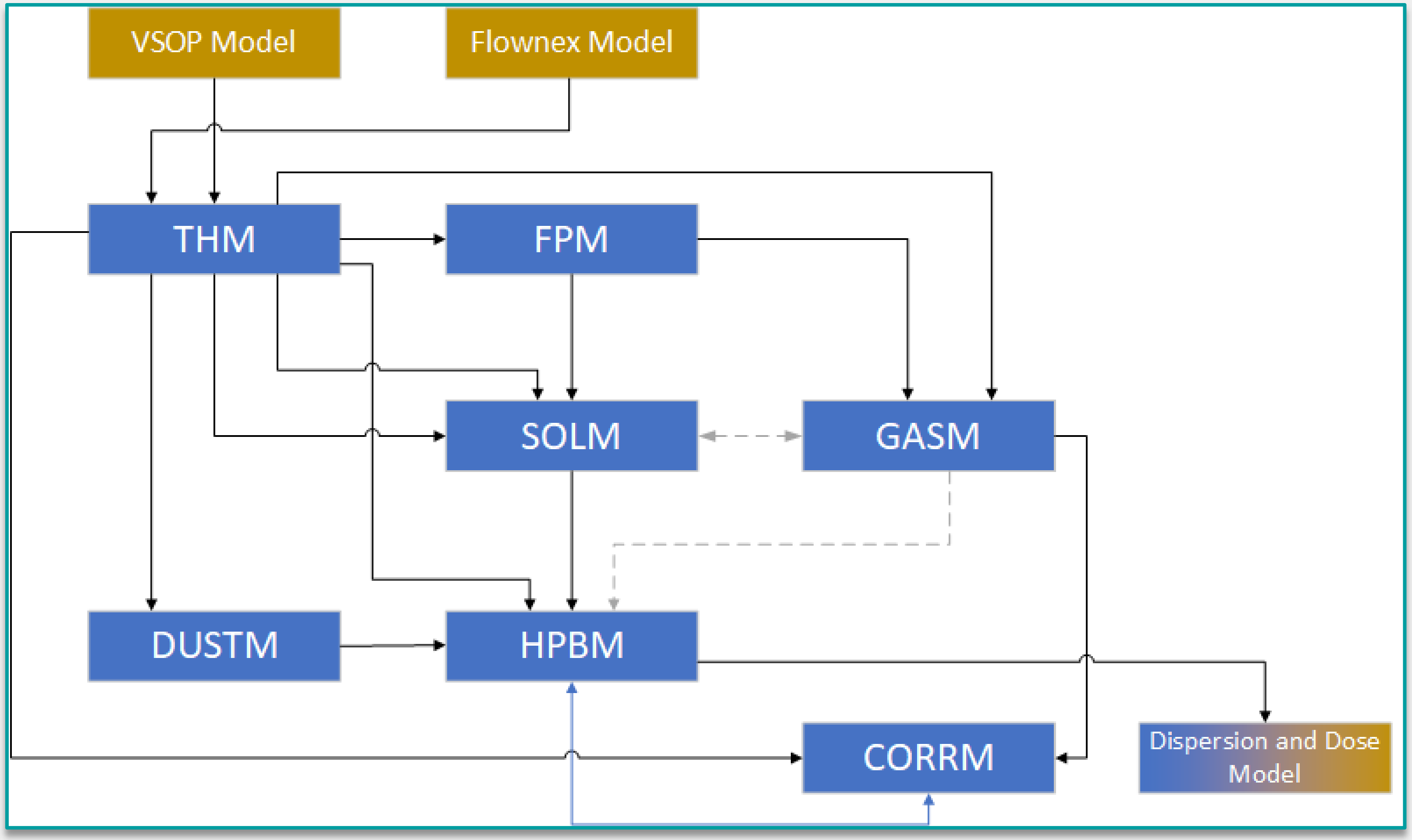
Other

XSTERM Code

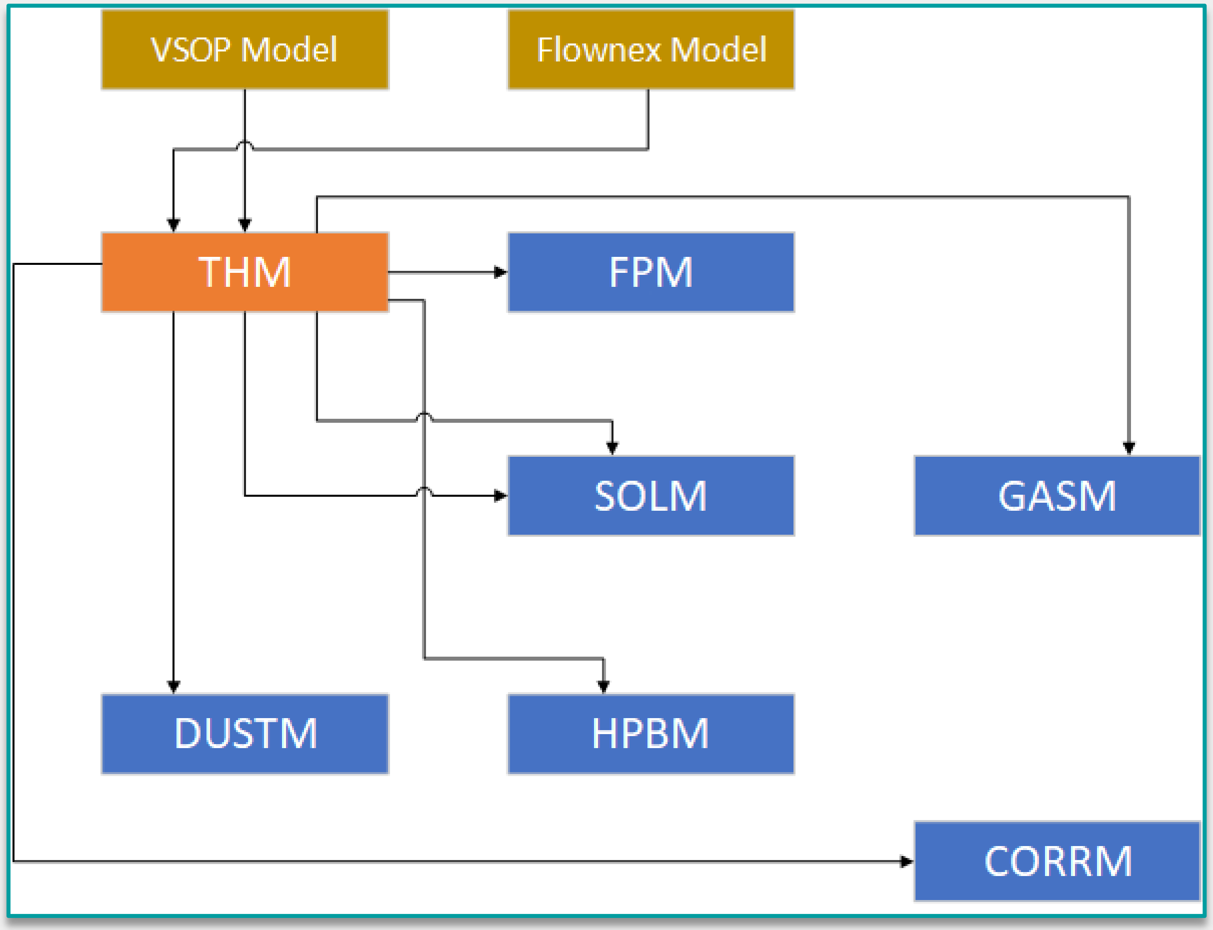
- **Evaluation Model for the quantification of Xe-100 source terms and dose calculations**
- Implementation of the MST models presented in this TR, part of X-energy safety analysis code suite
- Developed under X-energy Quality Assurance Program
- Goal: NQA-1 qualification

- **Verification and Validation, Uncertainty Quantification** in progress
  - Line-by-line code verification, comparison with analytical solutions, automated testing in the continuous-integration framework
  - Phased validation – each phase aims at validating a set of medium and high ranked phenomena from the Xe-100 Safety Analysis PIRT
    - Phase 1: Activity Release and Transport (FPM, GASM, SOLM, HPBM)
    - Phase 2: Reactor Temperature and Power (TDM, KSIM)
    - Phase 3: Dust Production (DUSTM)
    - Phase 4: Exposure to Oxidating Environments (CORRM, TRITM)
  - Uncertainty Quantification Plan based on the Xe-100 Safety Analysis PIRT

Core MST Models Relationship

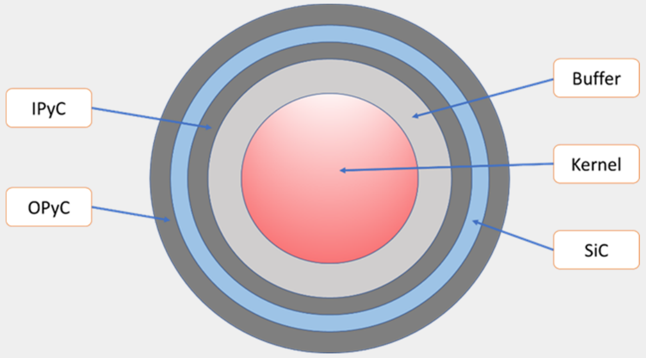


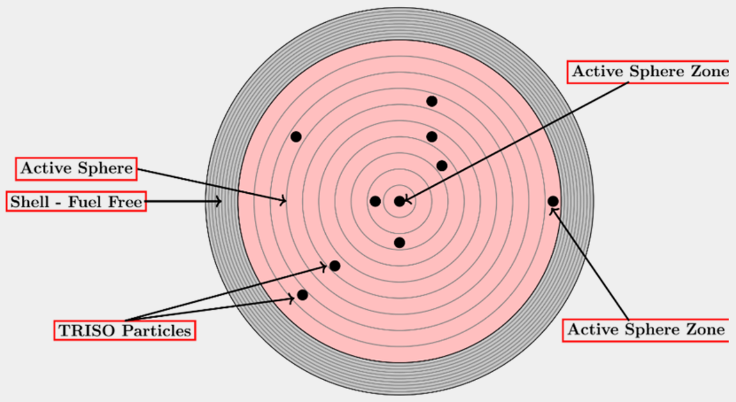
THM: Thermodynamics Model

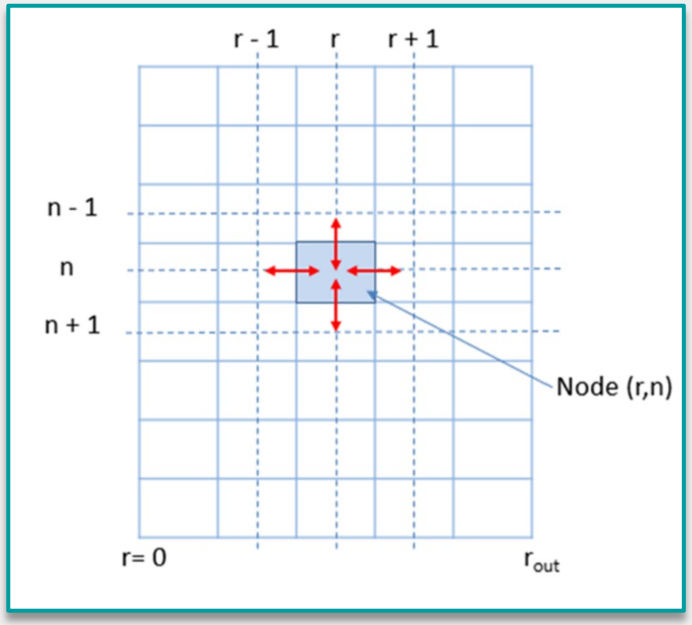


THM: Application Domain

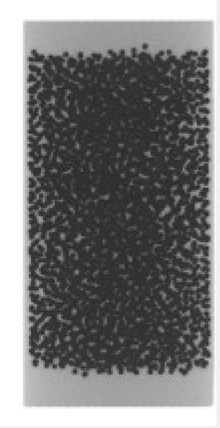
Xe-100 Single-Pebble / Core Calculations

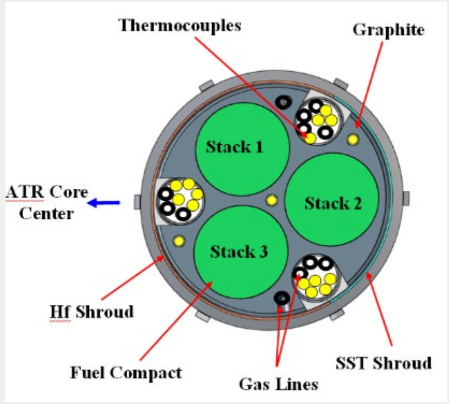






Fuel Compact Calculations (Validation)





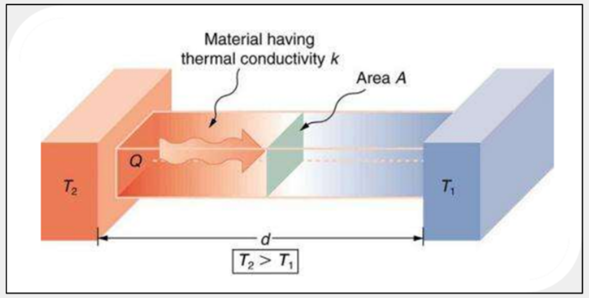
THM: Phenomena Modelled

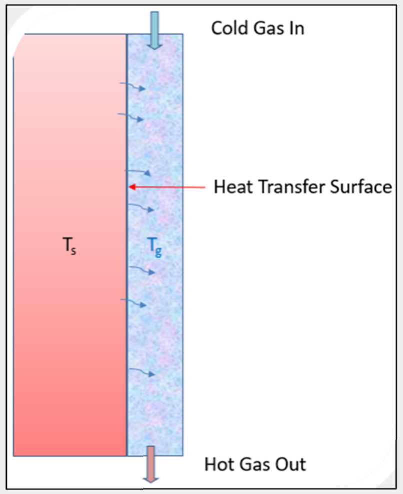
- Conductive Heat Transfer: Fourier law of heat conduction with space-, temperature- and dose-dependent conduction coefficients
    - Zehner-Bauer-Schlünder model in the pebble bed

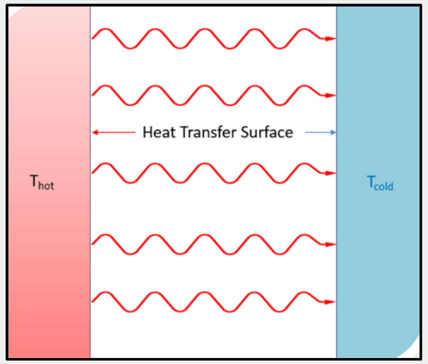
$$\lambda\lambda_{pppp} = \lambda\lambda_{ssss} + \lambda\lambda_{rr} + \lambda\lambda_{ff}$$

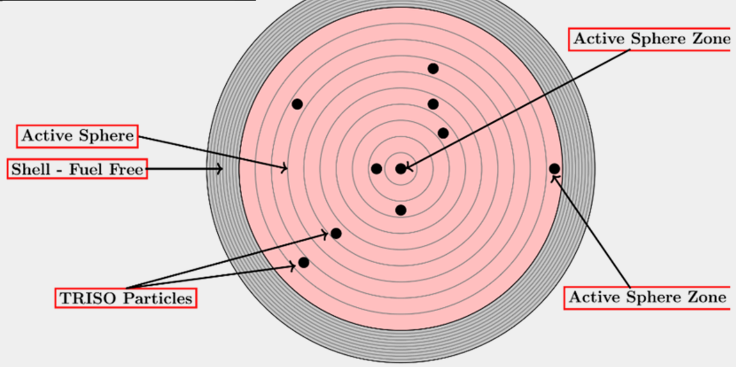
    - Reflector graphite model based on research of G. Haag
- Convective Heat Transfer: Kugeler-Schulten correlation
- Radiative Heat Transfer: Stefan-Boltzmann law
- Heat Sources: fission, gamma, decay heat (DIN-25485 standard)

- Pebble temperatures: 1D-radial heat conduction through pebble mesh zones with core node temperature as boundary condition – semi-analytic
- Particle temperatures: 1D-radial heat conduction through particle mesh zones with pebble zone temperature as boundary condition – semi-analytic
- Compact temperatures: 2D-axisymmetric heat conduction through compact zones with prescribed outer temperature – finite-difference discretization + successive-over-relaxation iterative method



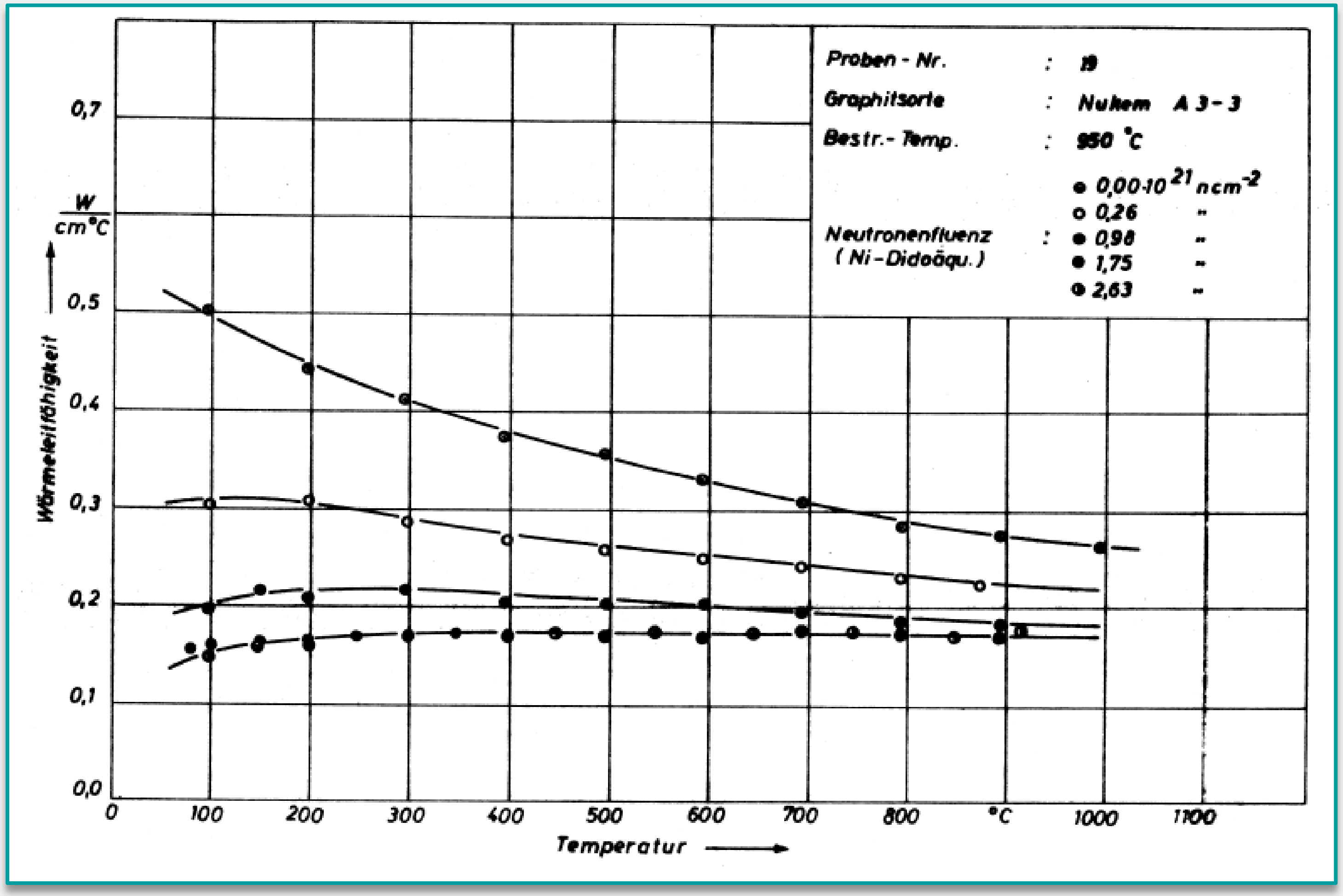






THM: Material Properties

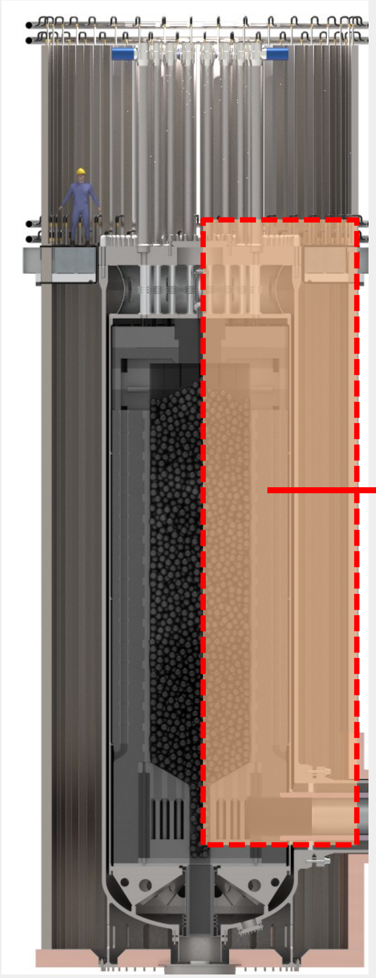
- Explicit correlations or data fits
- Generally temperature-dependent => iterations



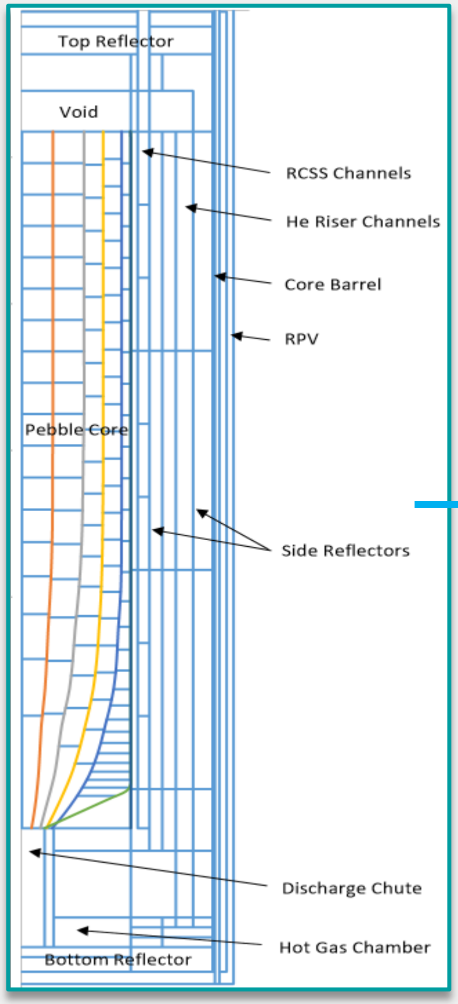
THM: Input Data and Boundary Conditions

- Second order least-squares mapping from VSOP grid to simplify heat transfer calculations

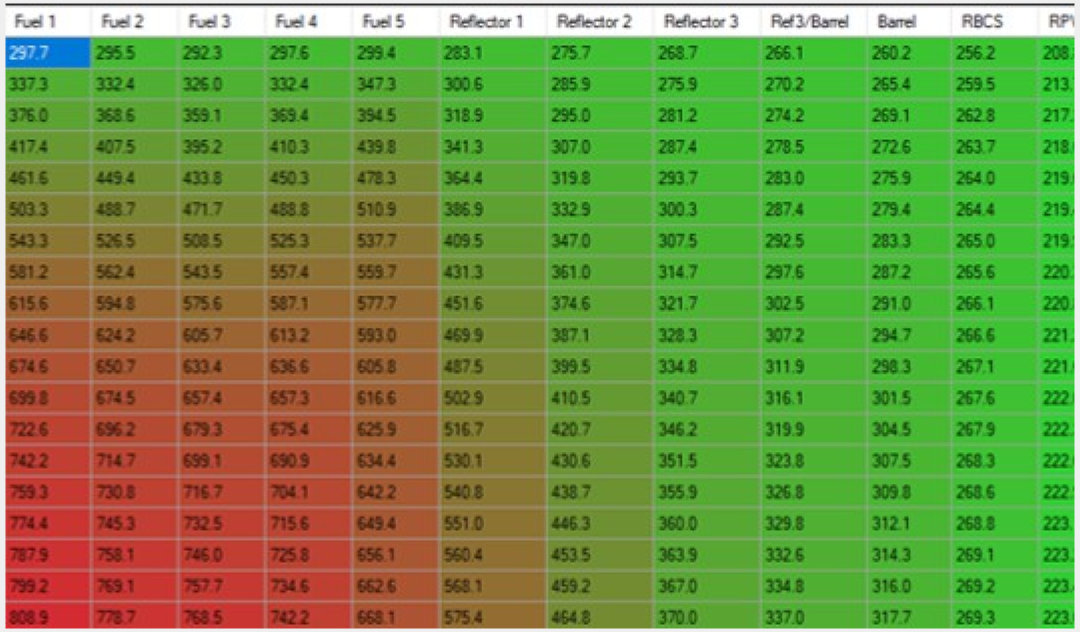
Xe-100 Reactor



VSOP Model



MST Model



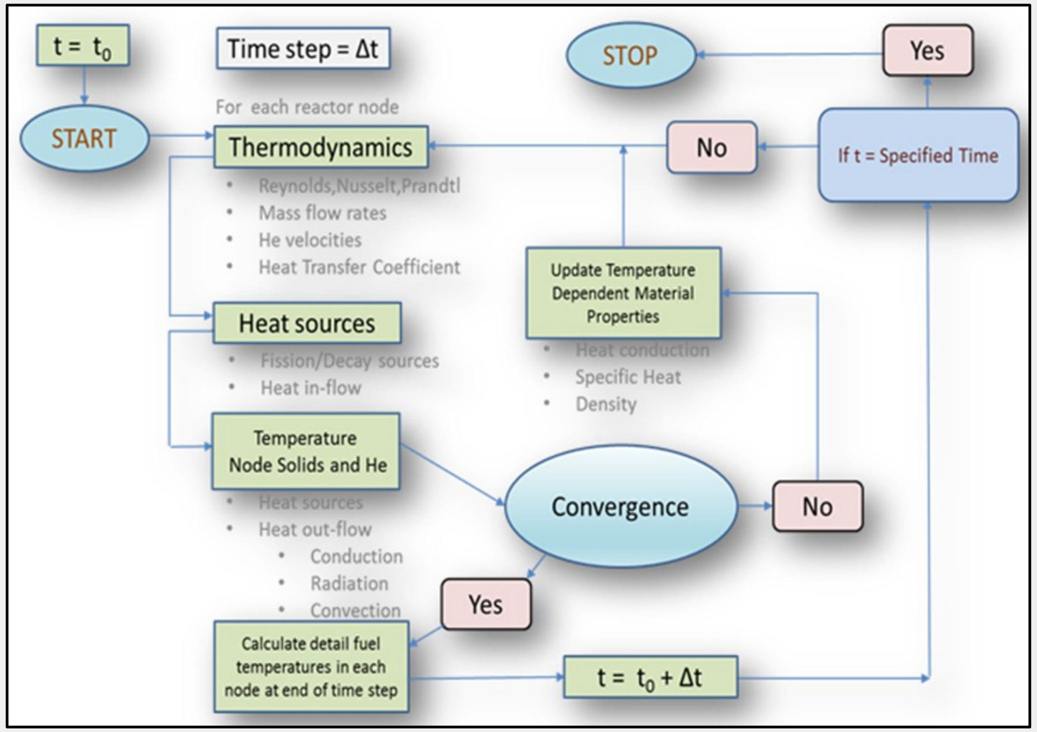
Fuel 1	Fuel 2	Fuel 3	Fuel 4	Fuel 5	Reflector 1	Reflector 2	Reflector 3	Ref3/Barrel	Barrel	RBCS	RP
297.7	295.5	292.3	297.6	299.4	283.1	275.7	268.7	266.1	260.2	256.2	208.
337.3	332.4	326.0	332.4	347.3	300.6	285.9	275.9	270.2	265.4	259.5	213.
376.0	368.6	359.1	369.4	394.5	318.9	295.0	281.2	274.2	269.1	262.8	217.
417.4	407.5	395.2	410.3	439.8	341.3	307.0	287.4	278.5	272.6	263.7	218
461.6	449.4	433.8	450.3	478.3	364.4	319.8	293.7	283.0	275.9	264.0	219
503.3	488.7	471.7	488.8	510.9	386.9	332.9	300.3	287.4	279.4	264.4	219.
543.3	526.5	508.5	525.3	537.7	409.5	347.0	307.5	292.5	283.3	265.0	219.
581.2	562.4	543.5	557.4	559.7	431.3	361.0	314.7	297.6	287.2	265.6	220.
615.6	594.8	575.6	587.1	577.7	451.6	374.6	321.7	302.5	291.0	266.1	220.
646.6	624.2	605.7	613.2	593.0	469.9	387.1	328.3	307.2	294.7	266.6	221.
674.6	650.7	633.4	636.6	605.8	487.5	399.5	334.8	311.9	298.3	267.1	221
699.8	674.5	657.4	657.3	616.6	502.9	410.5	340.7	316.1	301.5	267.6	222
722.6	696.2	679.3	675.4	625.9	516.7	420.7	346.2	319.9	304.5	267.9	222.
742.2	714.7	699.1	690.9	634.4	530.1	430.6	351.5	323.8	307.5	268.3	222
759.3	730.8	716.7	704.1	642.2	540.8	438.7	355.9	326.8	309.8	268.6	222.
774.4	745.3	732.5	715.6	649.4	551.0	446.3	360.0	329.8	312.1	268.8	223.
787.9	758.1	746.0	725.8	656.1	560.4	453.5	363.9	332.6	314.3	269.1	223.
799.2	769.1	757.7	734.6	662.6	568.1	459.2	367.0	334.8	316.0	269.2	223.
808.9	778.7	768.5	742.2	668.1	575.4	464.8	370.0	337.0	317.7	269.3	223.

Total core mass flow rate (Flownex)

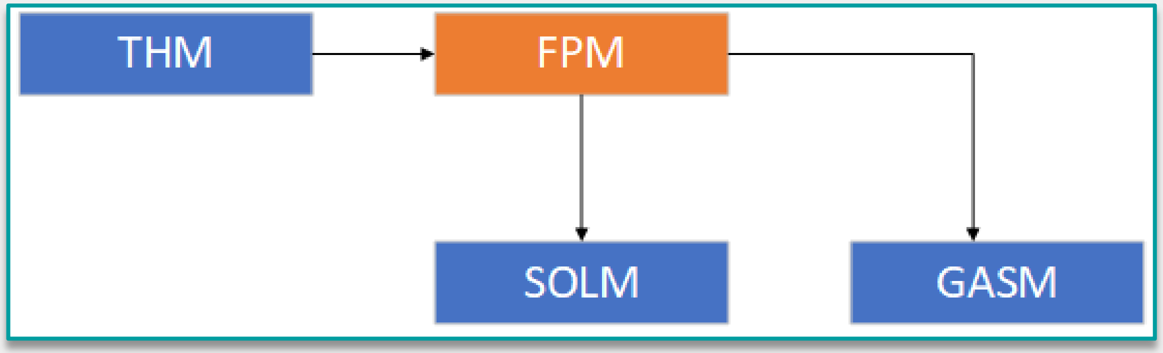
Disclaimer: Values shown above only for illustrative purposes

THM: Time-Stepping Algorithm

- Backward Implicit/Explicit Iterative Method
- Iterative calculation to converge reactor and coolant temperatures in each time-step
- Transient simulations
- Establishing steady state



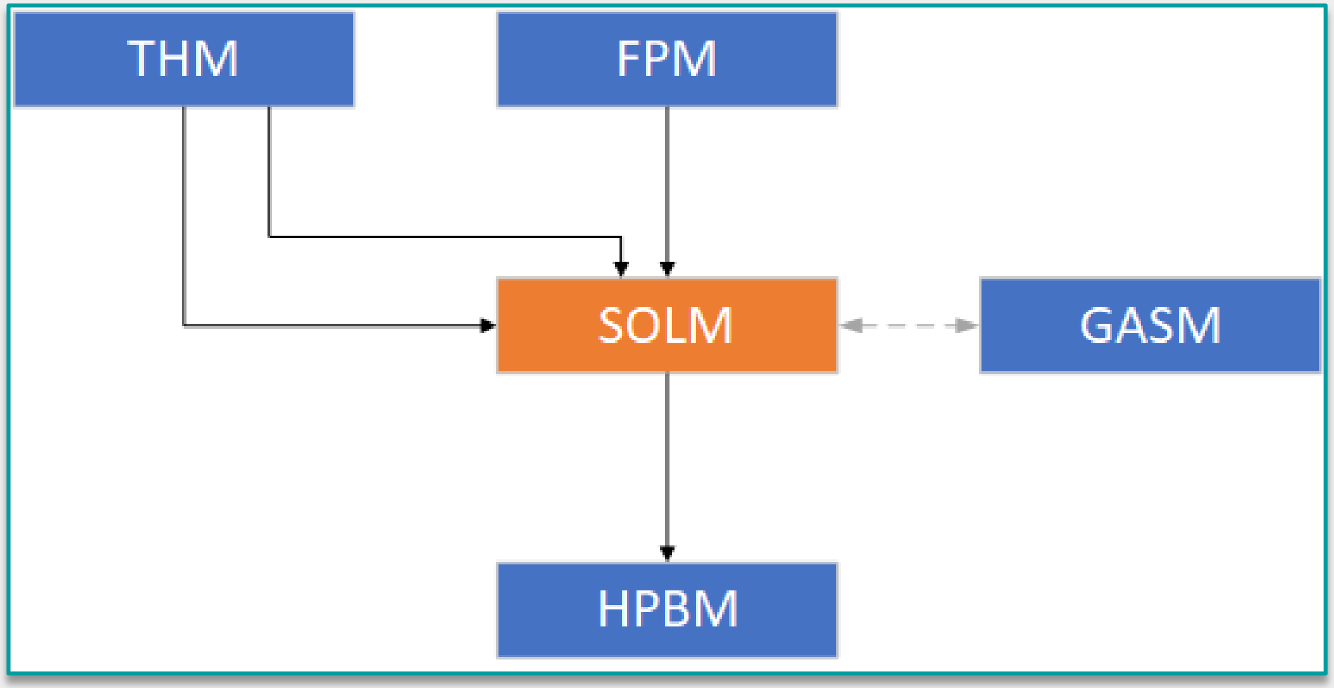
FPM (Particle Failure Probability Model)



FPM: Phenomena Modelled

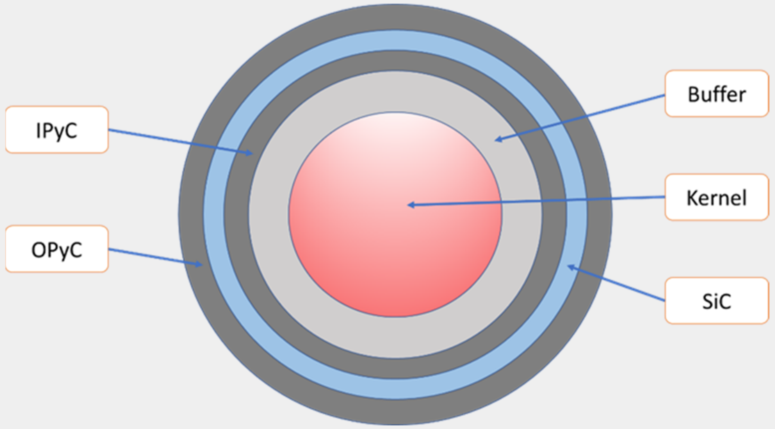
- **Pressure vessel failure** of TRISO particles
    - effects of pyro-carbon (PyC) irradiation-induced creep on the effective stress of the silicon-carbide (SiC) layer
    - Irradiation-Induced dimensional change of PyC layer
    - Fission gas pressure
    - Kernel irradiation swelling
    - Kernel thermal expansion
- **Kernel migration** (Amoeba)
- **Fission product corrosion**
- **SiC thermal decomposition**
- **Manufacturing defects**
    - Exposed kernel (i.e., defect of all coating layers)
    - SiC defect (i.e., defect of the SiC layer with at least one other coating layer intact)
    - Inner PyC layer defect
    - Dispersed heavy metal fraction

SOLM (Fission Product Transport Model)



SOLM: Phenomena Modelled

- Fission product production by **direct fission** in kernels, **recoil** from kernels to the buffer layer, **decay** and **activation**
- Fission product removal by means of **decay** and **activation**
- Transport and release of fission products from particles and fuel elements by means of **diffusion**
- Effects on isotope transport and retention from **as-manufactured particle defects**, **contamination** and **particle failures** that may occur during operation



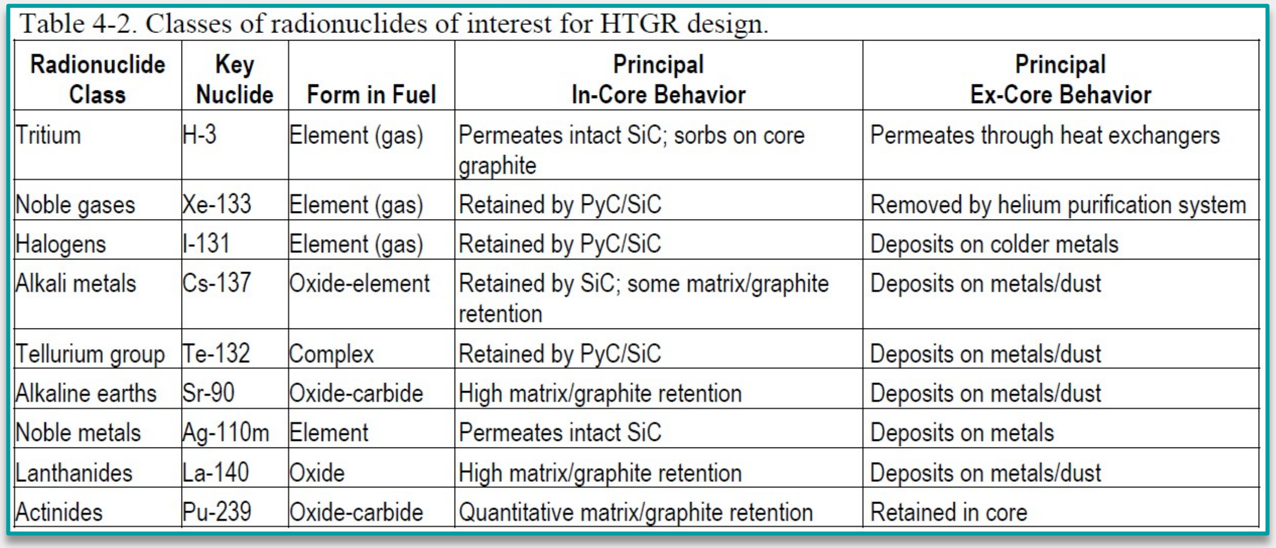


Table 4-2. Classes of radionuclides of interest for HTGR design.

Radionuclide Class	Key Nuclide	Form in Fuel	Principal In-Core Behavior	Principal Ex-Core Behavior
Tritium	H-3	Element (gas)	Permeates intact SiC; sorbs on core graphite	Permeates through heat exchangers
Noble gases	Xe-133	Element (gas)	Retained by PyC/SiC	Removed by helium purification system
Halogens	I-131	Element (gas)	Retained by PyC/SiC	Deposits on colder metals
Alkali metals	Cs-137	Oxide-element	Retained by SiC; some matrix/graphite retention	Deposits on metals/dust
Tellurium group	Te-132	Complex	Retained by PyC/SiC	Deposits on metals/dust
Alkaline earths	Sr-90	Oxide-carbide	High matrix/graphite retention	Deposits on metals/dust
Noble metals	Ag-110m	Element	Permeates intact SiC	Deposits on metals
Lanthanides	La-140	Oxide	High matrix/graphite retention	Deposits on metals/dust
Actinides	Pu-239	Oxide-carbide	Quantitative matrix/graphite retention	Retained in core

SOLM: Modelling Scope

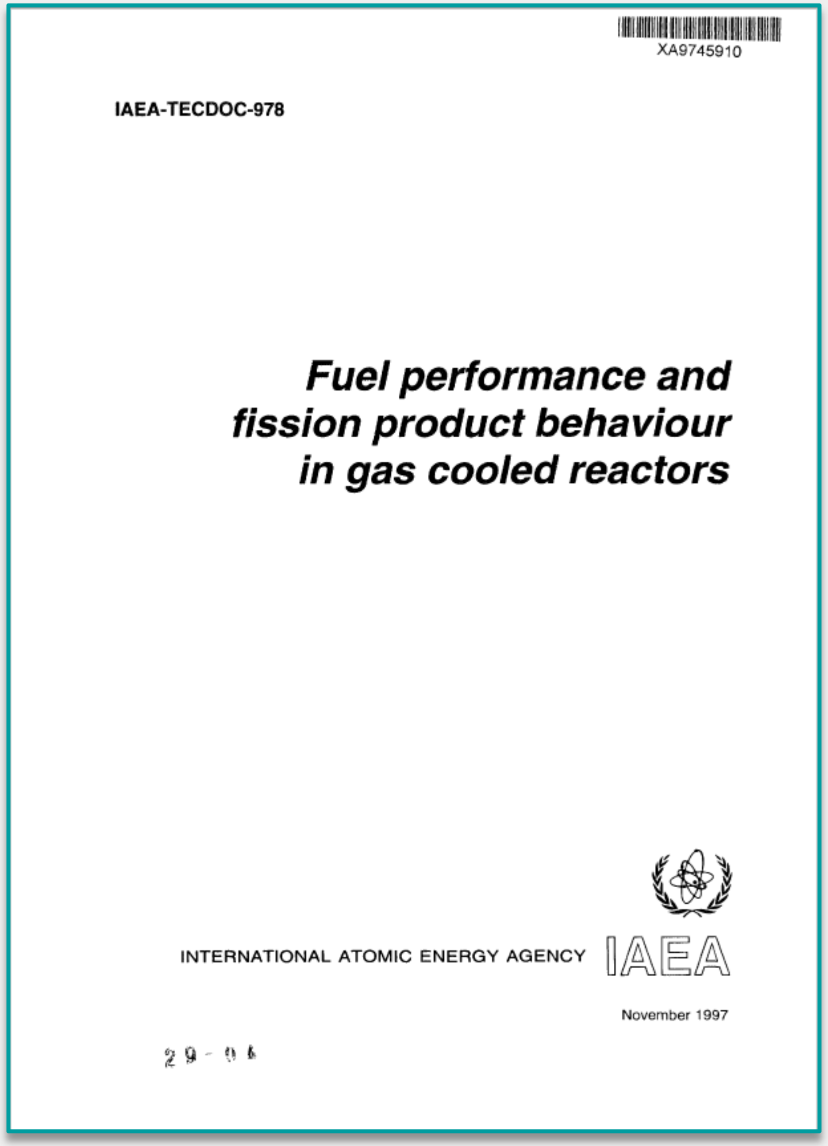
- Calculate **isotope concentrations** in fuel elements and particles
    - **for all core meshes**, following the multi-pass re-loading scheme to reach desired burnup to create an isotope library with the concentration distributions (initial condition for steady-state inventory and transient calculations)
    - **for a single sphere/compact** to model irradiation and safety (annealing) experiments (validation) and isolated fuel element calculations
- Calculate the **release over birth (R/B) ratios** for steady-state irradiations and **fractional releases** for transients

SOLM: Methodology

- Time-dependent heat conduction equation with temperature-dependent **effective diffusion coefficients**

$$DD_{eeffff} = DD_1{}^{eeeeee}\left\{-\frac{QQ_1}{RRRR}\right\} + DD_2{}^{eeeeee}\left\{-\frac{QQ_2}{RRRR}\right\}$$

- 1D radial (pebbles) or 2D axi-symmetric (compacts)
- Boundary conditions: **Zero surface concentration** or **sorption transfer** via iso-thermic exchange between pebble surface and thin gas layer



XA9745910

IAEA-TECDOC-978

Fuel performance and fission product behaviour in gas cooled reactors

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

November 1997

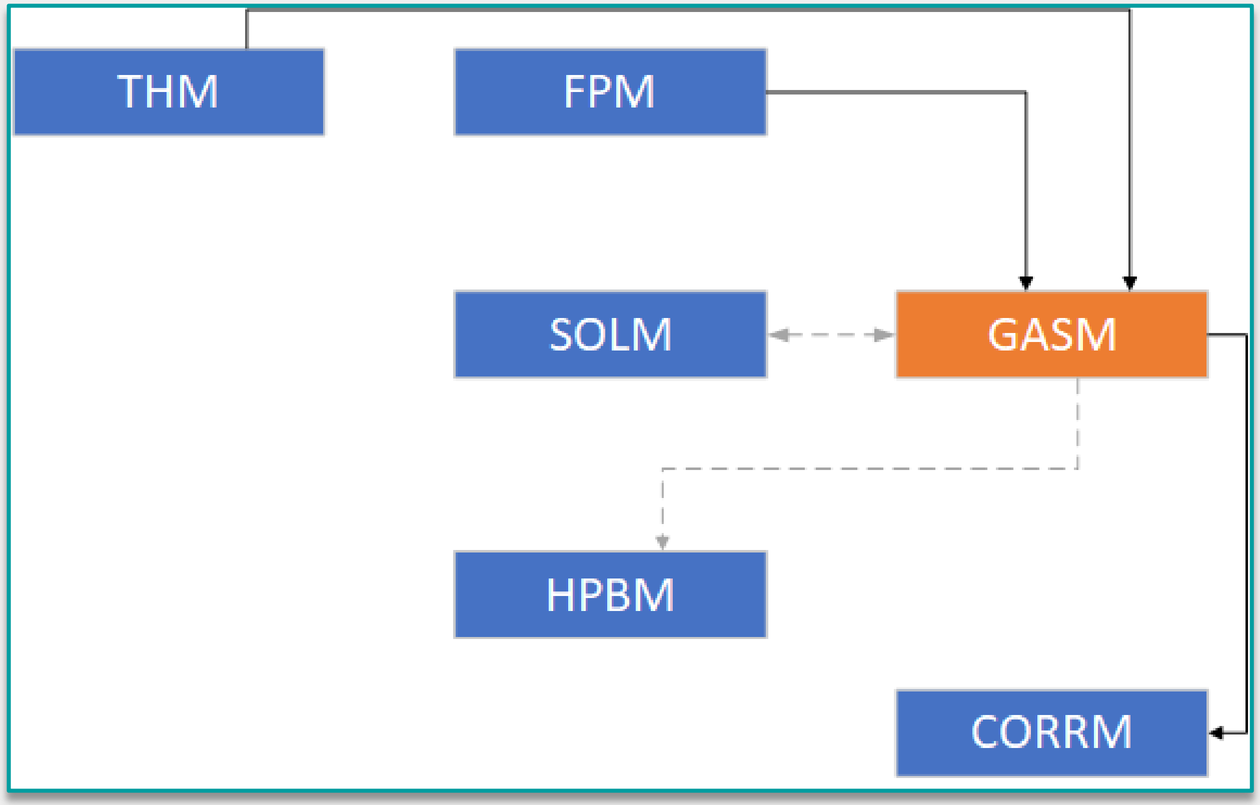
29 - 06

SOLM: Numerical Solution

- **Implicit Euler method** for time-stepping for pebbles and compacts, or **backward-difference method (BDF2)** for compacts

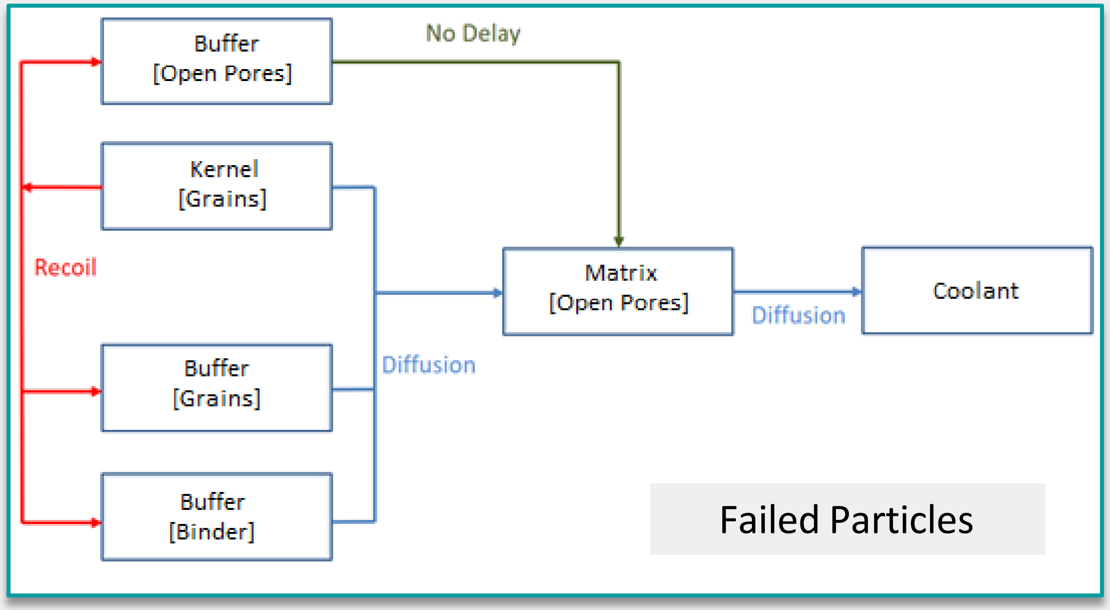
- At each time step, a **system of linear algebraic equations** arising from the **finite difference discretization** of the diffusion and source terms is solved:
  - ⇒ 3-diagonal matrix system for pebble geometries
    - – solved by Gaussian elimination
  - ⇒ 5-diagonal matrix system for compact geometries
    - – solved by the Gauss-Seidel iterations

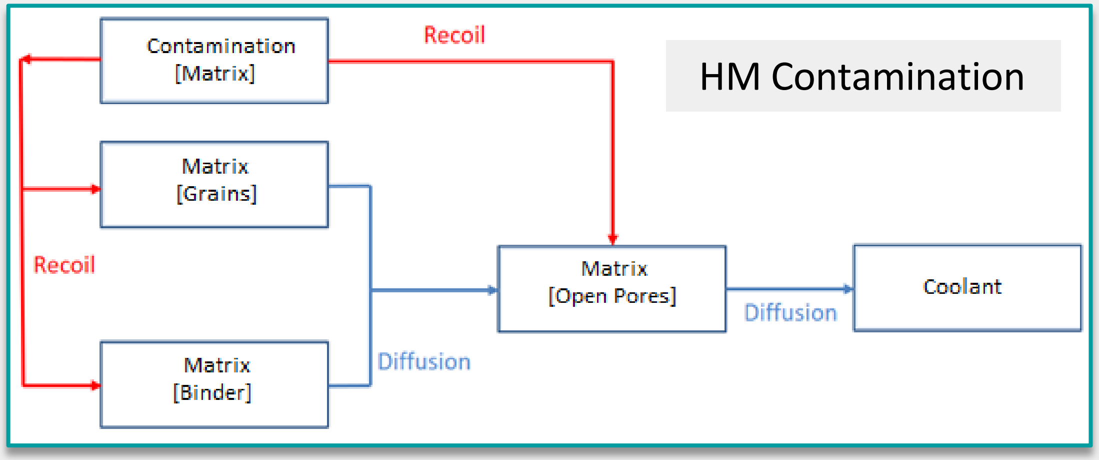
GASM (Gaseous Fission Product Transport Model)



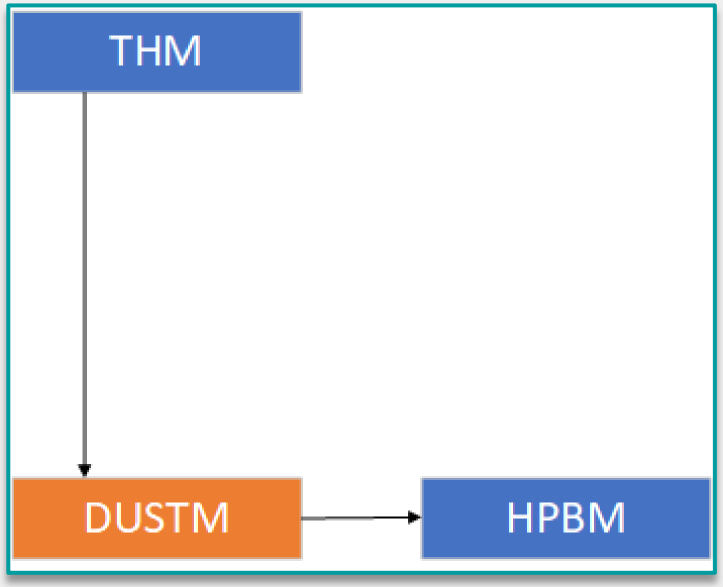
GASM: Phenomena Modelled

- Steady-state gaseous fission product (FP) release from particles and pebbles (R/B ratios)
- Short half-lives of the gas isotopes => transport from the fuel kernel through intact coatings can be neglected
- FP sources:
  - heavy metal (HM) contamination of matrix/outer PyC layers of particles
  - failed particles
- Two models dynamically switching based on fuel temperature: **Röllig Model** and **Richards Model**





DUSTM: Dust Production



THM

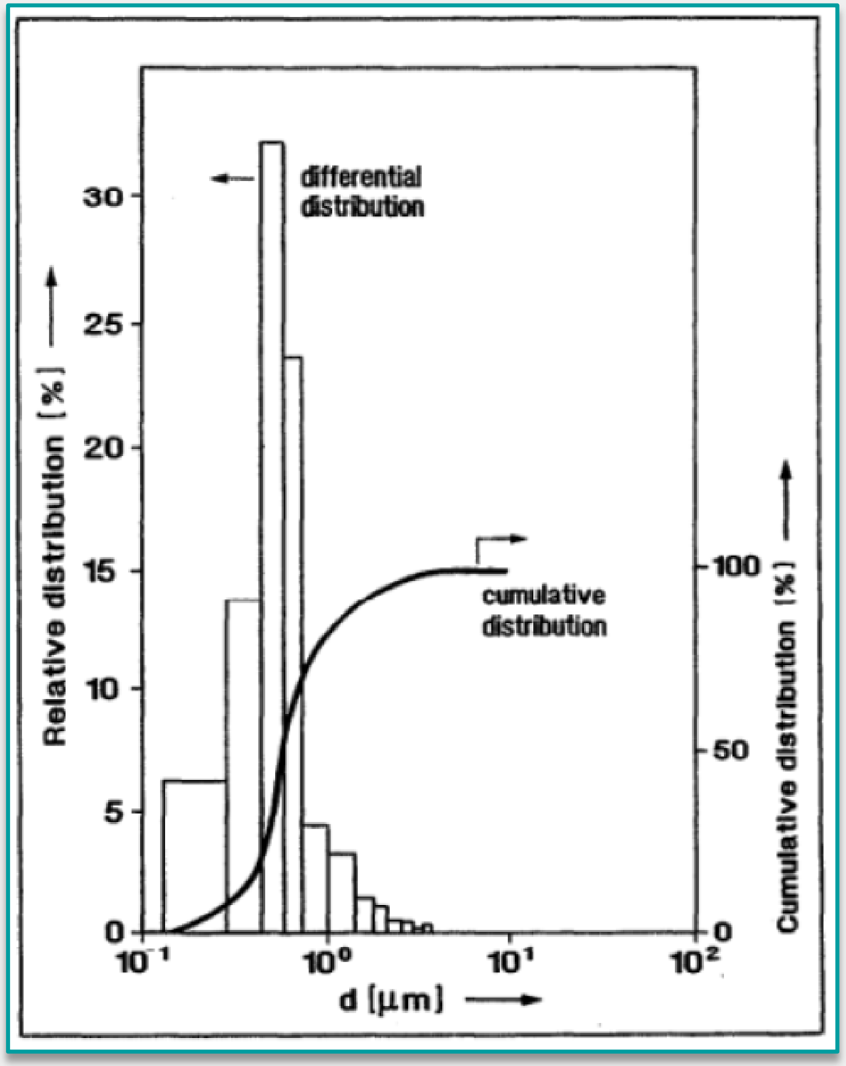
DUSTM

HPBM

DUSTM: Phenomena Modelled

- Graphite and metallic dust production from
    - pebble-pebble and pebble-reflector abrasion
    - pebble abrasion during its transport through the fuel handling system (FHS) piping
    - control rod abrasion during its movements over the operating period

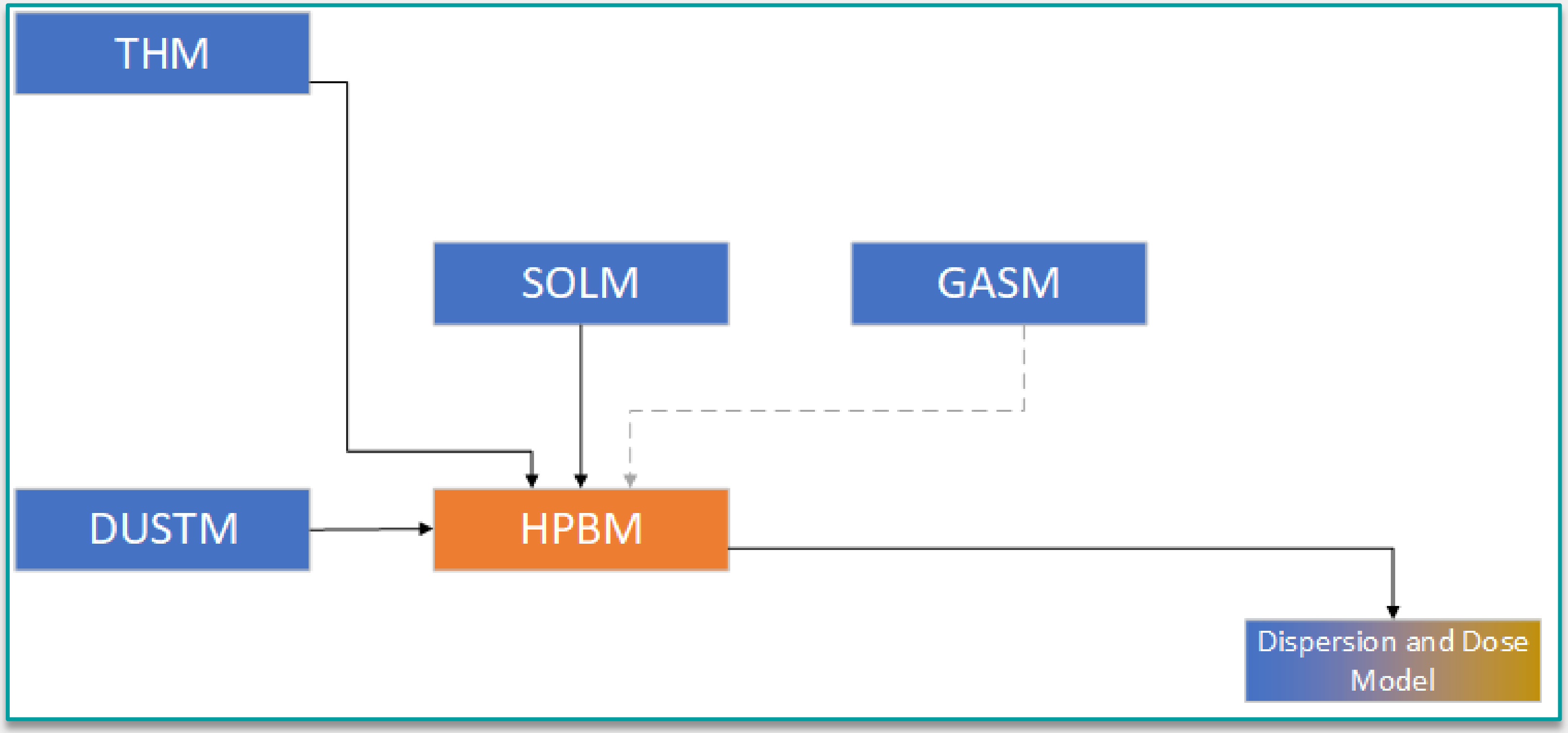
- Dust particle size spectrum lumped into bins, based on the historical measurements from the German pebble-bed reactor AVR



DUSTM: Methodology

- In-Core dust production
  - Wear from friction based on the theory of asperity contact
  - Total dust production proportional to geometry-dependent **dust production rate parameter** and **frictional force**
  - Frictional force proportional to temperature-dependent **friction coefficient** and height-dependent load pressure on the pebbles
  - **Load pressure** on the pebbles computed by modified Janssen's silo pressure formula including the effects of pressure drop
- Dust production in fuel handling system (FHS)
  - Proportional to empirically determined dust generation rate per meter of pebble movement in the FHS, number of fuel passes and length of the FHS pipe
- Dust production in the reactivity control system (RCS)
  - Proportional to empirically determined dust generation rate per meter of RCS rod motion and the total RCS rod distance travelled during the operation time
- **Dust production rate parameter** determined by applying the model on the AVR reactor operation data and adjusting the parameter to yield the measured total lifetime dust in AVR
  - Graphite/metallic dust ratio obtained from the Vampyr II experiment data

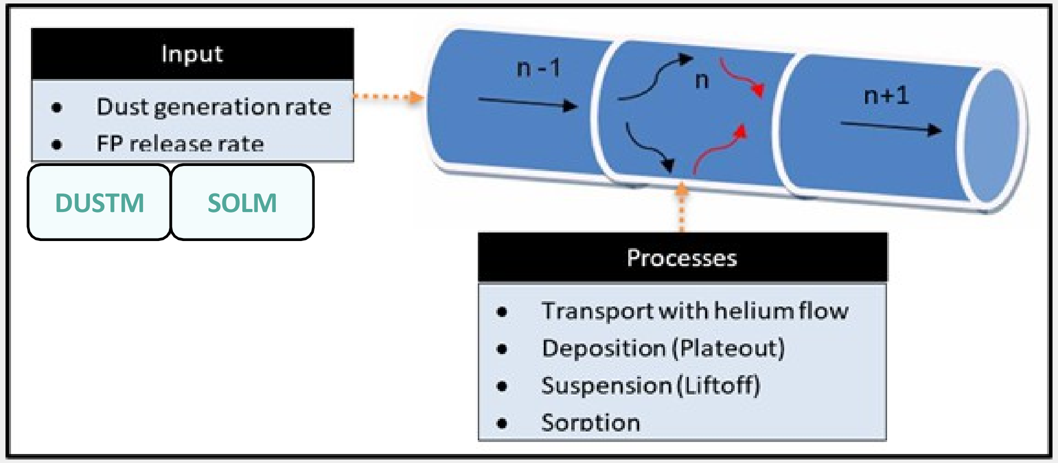
HPBM: Helium Pressure Boundary Model



HPBM: Phenomena Modelled

- radionuclide (RN) release from pebbles,
- deposition on component surfaces (RN, dust),
- plate-out on dust (RN)
- re-entrainment into circulating He (RN, dust),
- intra- and inter-component transport (RN, dust),
- RN transmutation through activation and radioactive decay
- RN removal through radioactive decay
- RN sorption into the graphite dust and de-sorption into circulating helium

HPBM: Phenomena Modelled

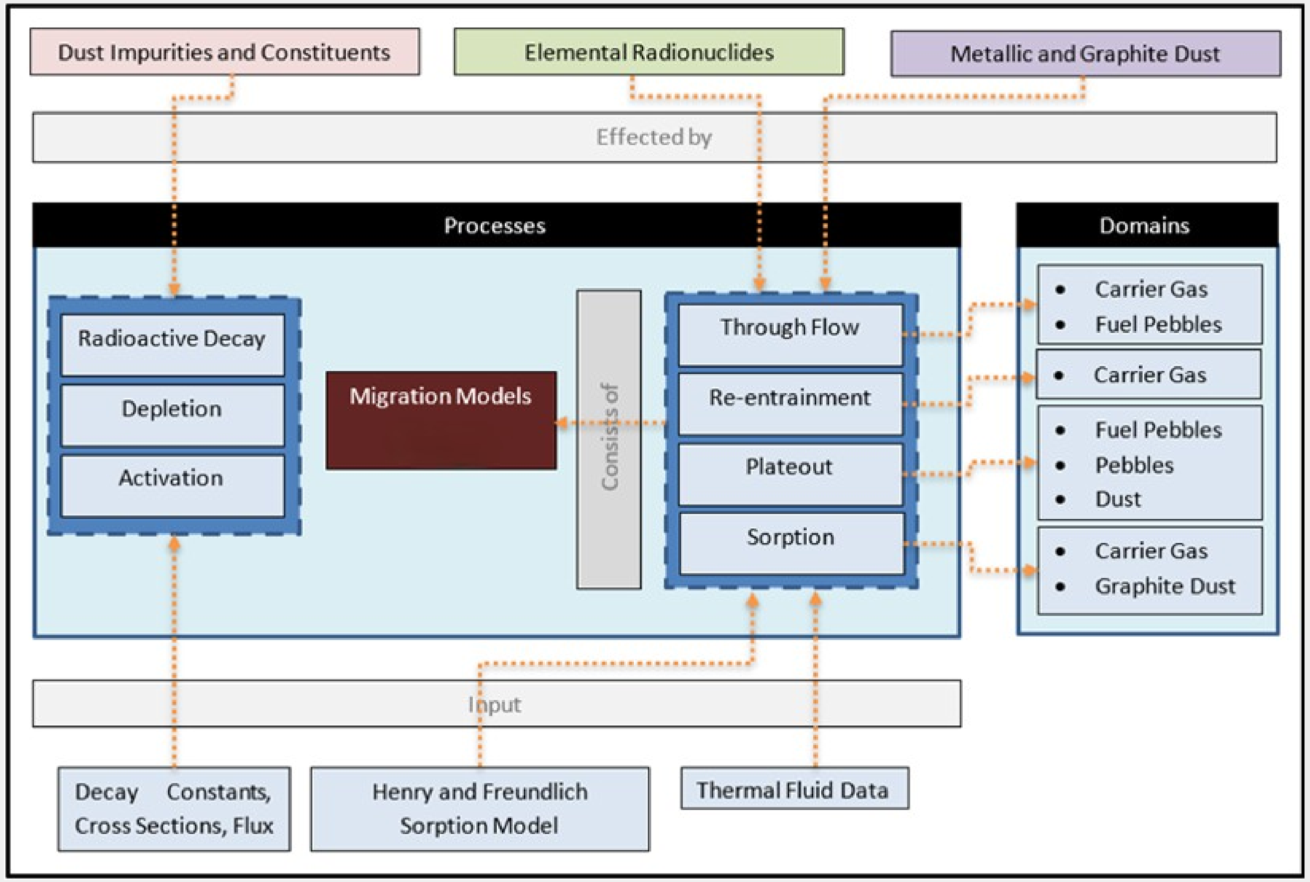


Input
- Dust generation rate
- FP release rate

DUSTM

SOLM

Processes
- Transport with helium flow
- Deposition (Plateout)
- Suspension (Liftoff)
- Sorption



Dust Impurities and Constituents

Elemental Radionuclides

Metallic and Graphite Dust

Effected by

Processes

- Radioactive Decay
- Depletion
- Activation

Migration Models

Consists of

- Through Flow
- Re-entrainment
- Plateout
- Sorption

Domains

- Carrier Gas
- Fuel Pebbles

- Carrier Gas

- Fuel Pebbles
- Pebbles
- Dust

- Carrier Gas
- Graphite Dust

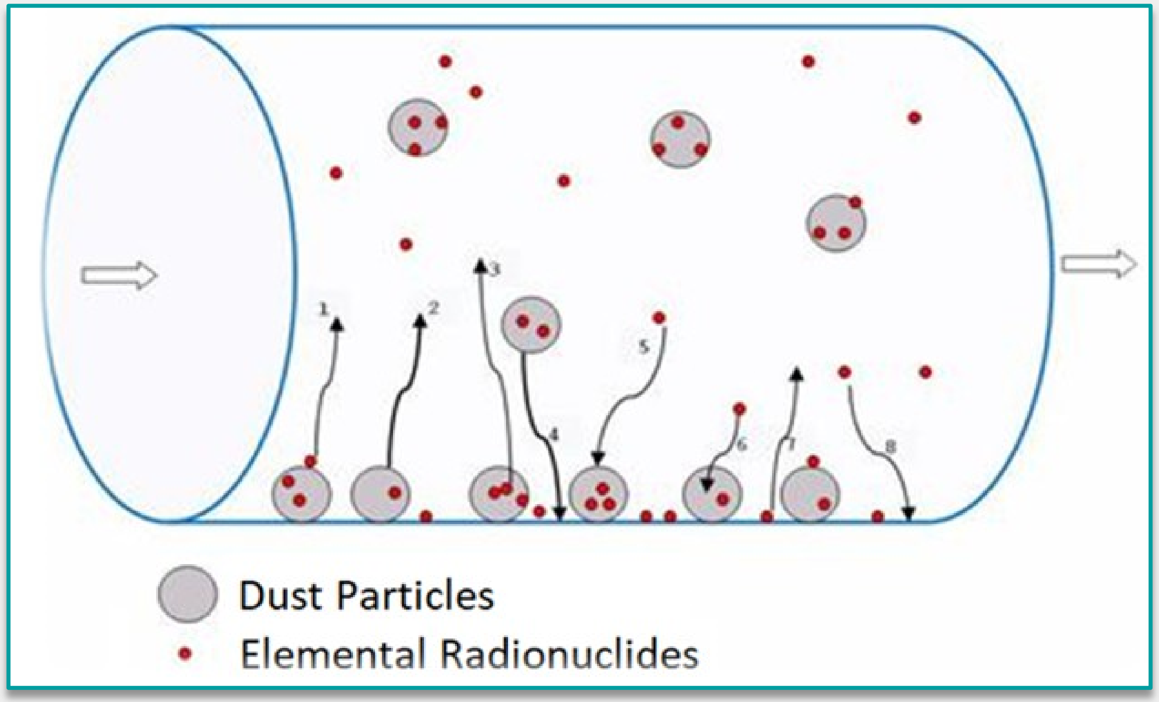
Input

Decay Constants, Cross Sections, Flux

Henry and Freundlich Sorption Model

Thermal Fluid Data

HPBM: Particle Mass Transfer



(1) Liftoff of elemental radionuclide from plated-out dust

(2) Liftoff of plated-out dust from component surface

(3) Sorption of elemental radionuclide from plated-out dust into helium

(4) Plateout of entrained dust onto component surface

(5) Plateout of entrained elemental radionuclide onto plated-out dust

(6) Sorption of entrained elemental radionuclide into plated-out dust

(7) Liftoff of elemental radionuclide from component surface

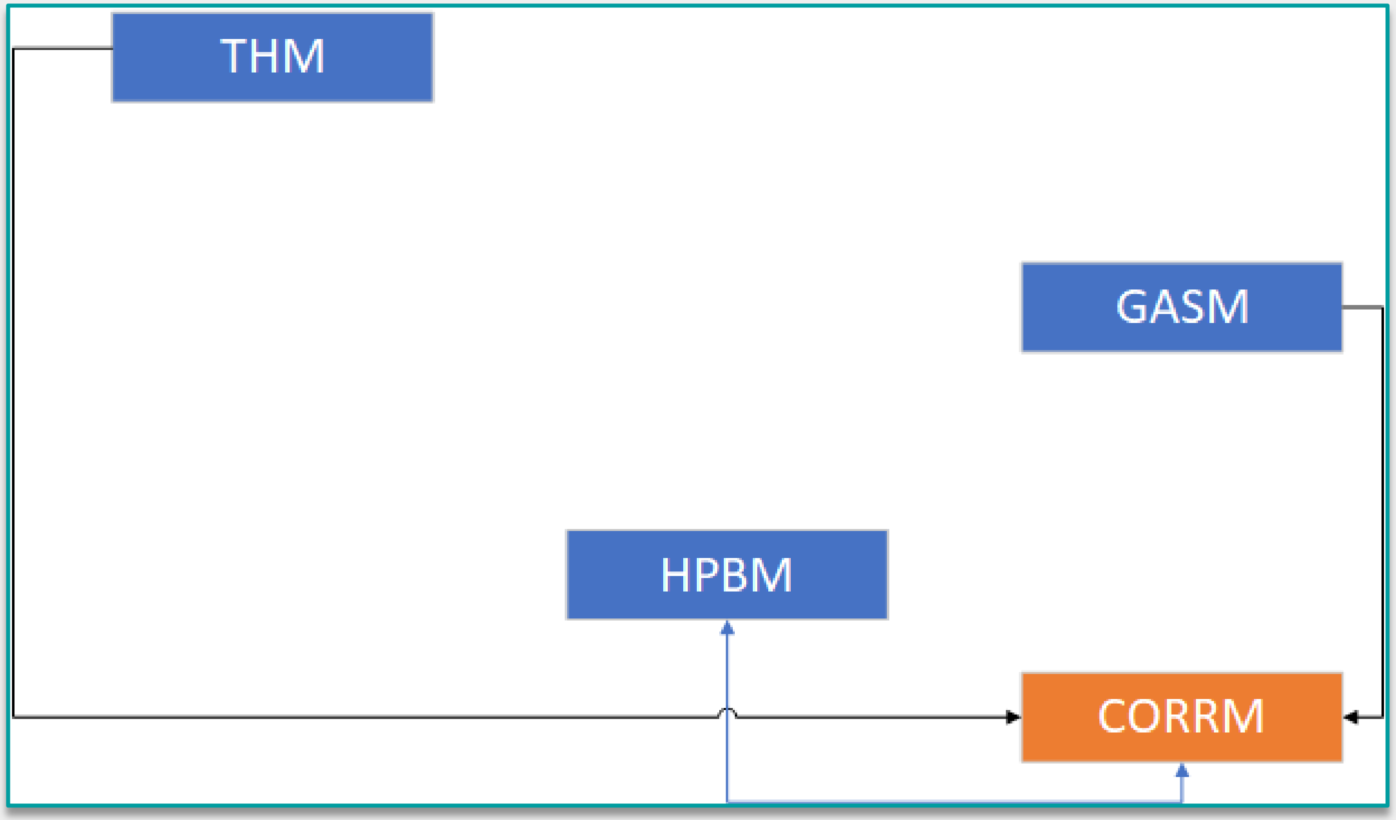
(8) Plateout of elemental radionuclide onto component surface

HPBM: Numerical Solution

- Coupled set of 2D partial differential equations for multi-phase flow and mass balance
- Phases:
  1. Helium gas
  2. Circulating dust
  3. Deposited dust
  4. Circulating isotopes
  5. Deposited isotopes

- Finite volume + Backward Implicit-Explicit Method (IMEX) discretization

CORRM: Core Corrosion Model



THM

GASM

HPBM

CORRM

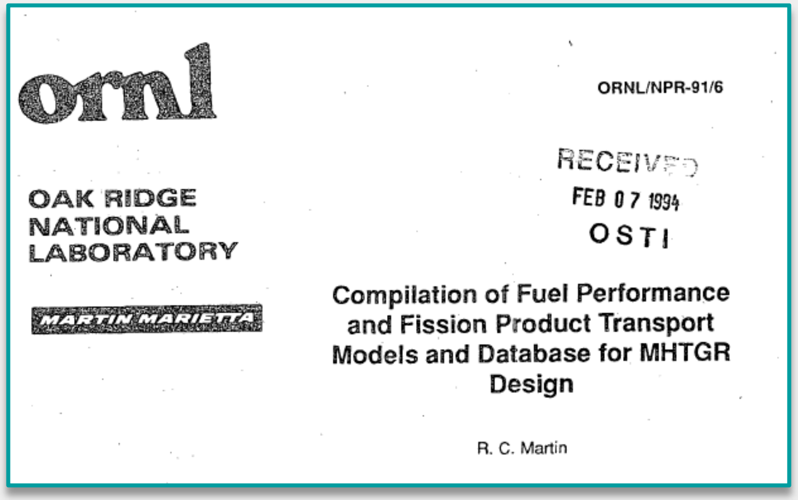
CORRM: Methodology

$$\text{Corrosion Rate} = \frac{(\text{Kinetic Factor})(\text{Driving Force})}{(\text{Adsorption Term})}$$

with temperature-dependency of kinetic factor and adsorption terms modelled by Arrhenius-type correlation

- Applied to fuel element graphite materials to determine the radionuclide release enhancement due to corrosion
- Based on correlation for H-451 fuel element graphite investigated at General Atomics

Material	State	Atmosphere
UCO kernel	Normal	Trace H_2O
	DLOFC	Air/He
PyC coating	H_2O ingress	H_2O/He
“US A3-3” matrix	Normal	Trace H_2O
	DLOFC	Air/He



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ORNL/NPR-91/6

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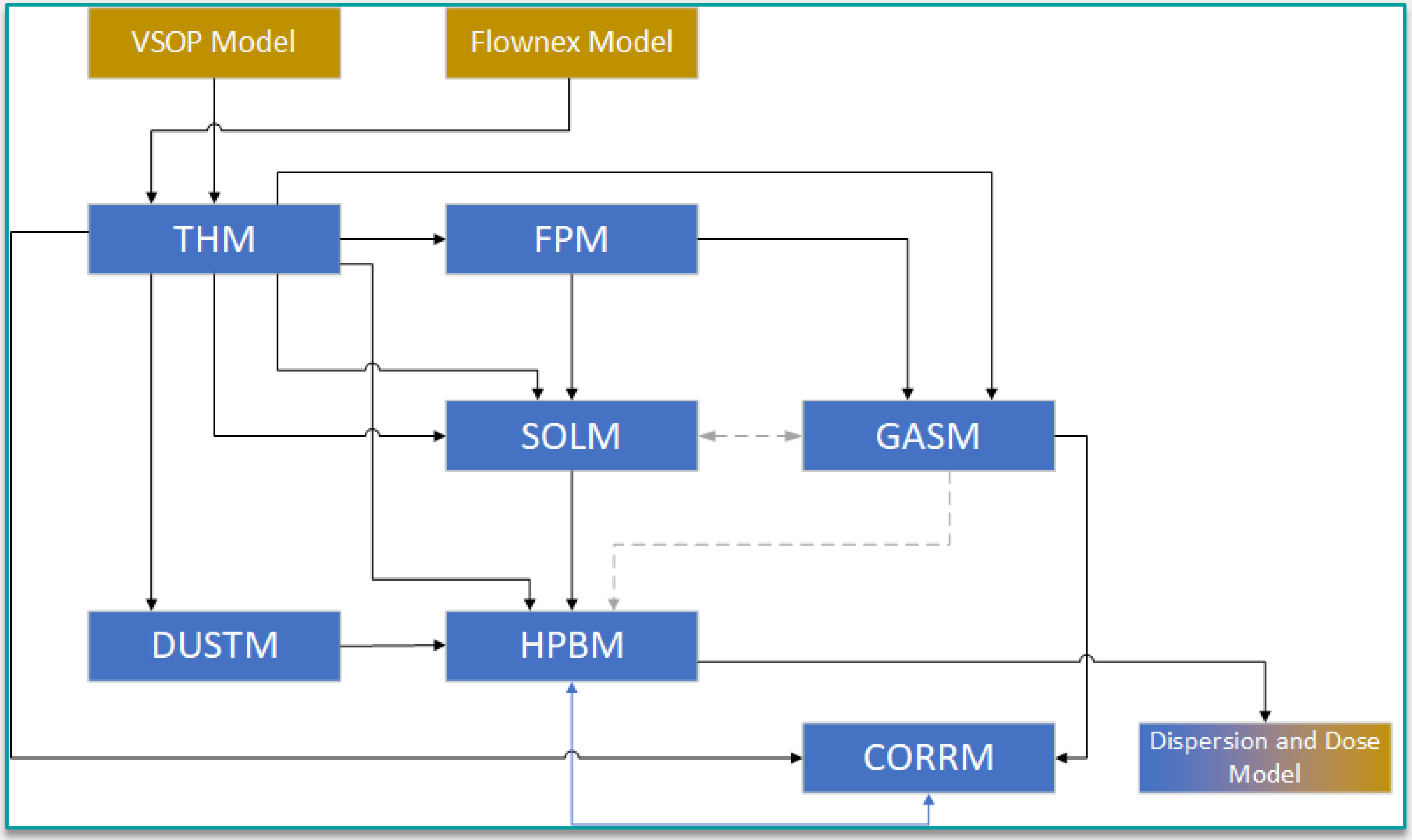
Compilation of Fuel Performance and Fission Product Transport Models and Database for MHTGR Design

R. C. Martin

Overall Mechanistic Source Term Calculation



VSOP Model

Flownex Model

THM

FPM

SOLM

GASM

DUSTM

HPBM

CORRM

Dispersion and Dose Model

Q & A

X Energy, LLC

Phone: 301.358.5600
530 Gaither Rd., Rockville, MD 20850

Milan Hanus
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x-energy.com @xenergynuclear

List of Acronyms

CORRM	Corrosion model	**PyC**	Pyrolytic-carbon
DLOFC	Depressurized loss of forced cooling	**Q&A**	Questions & answers
DOE	Department of Energy	**R/B**	Release to birth ratio
DUSTM	Dust production model	**RCS**	Reactivity control system
FHS	Fuel handling system	**RG**	Regulatory Guide
FP	Fission product	**RN**	Radionuclide
GASM	Gaseous FP release model	**SiC**	Silicon-Carbide
HM	Heavy metal	**SOLM**	RN diffusion and release model
HPBM	Helium pressure boundary model	**THM**	Thermo-hydraulics model
HTGR	High Temperature Gas-cooled Reactor	**TR**	Topical Report
KSIM	Neutron kinetics & plant simulation model	**TRISO**	Tristructural-Isotropic
MST	Mechanistic source term	**TRITM**	Tritium release model
NQA	Nuclear Quality Assurance	**UCO**	Uranium Oxycarbide
PIRT	Phenomena identification and ranking table	**XSTERM**	X-energy’s mechanistic source term code suite

NRC Staff Review of Topical Report (TR) 000632 “Xe-100 Licensing Topical Report Mechanistic Source Term Approach” (MST)

ACRS Meeting of the X-Energy Design Center Subcommittee
June 3, 2025

ADVANCED
REACTOR
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https://www.nrc.gov/reactors/new-reactors/advanced.html

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

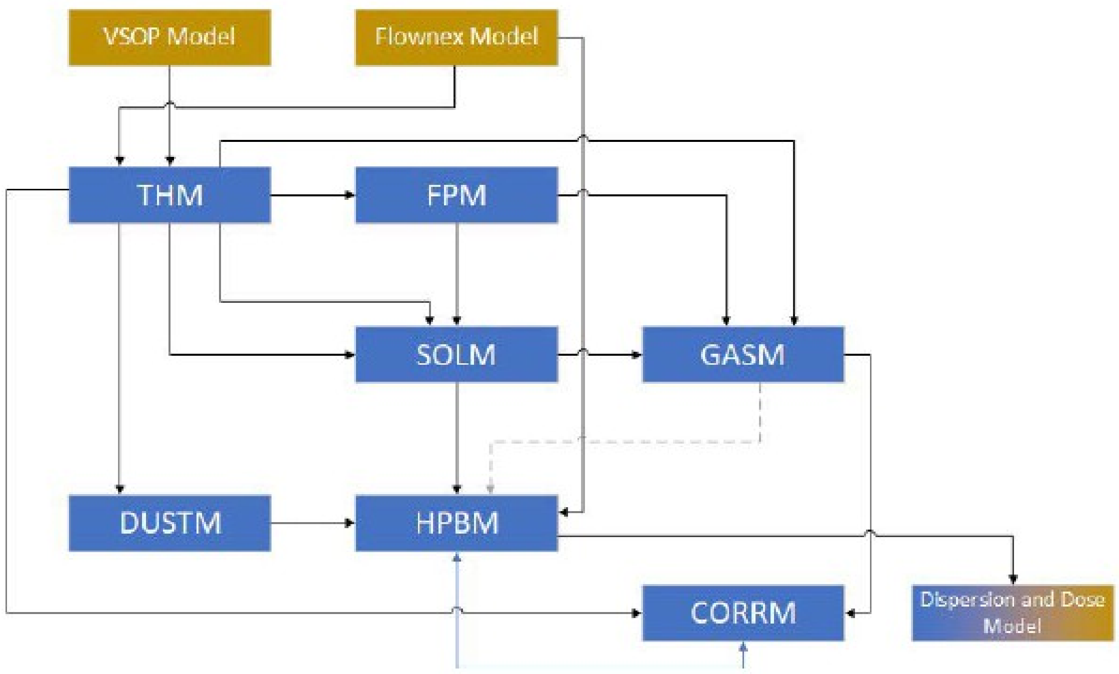
Outline

- Background
- Regulatory Basis
- Scope of NRC Staff Review
- Summary of Technical Review
- Conclusions

Background

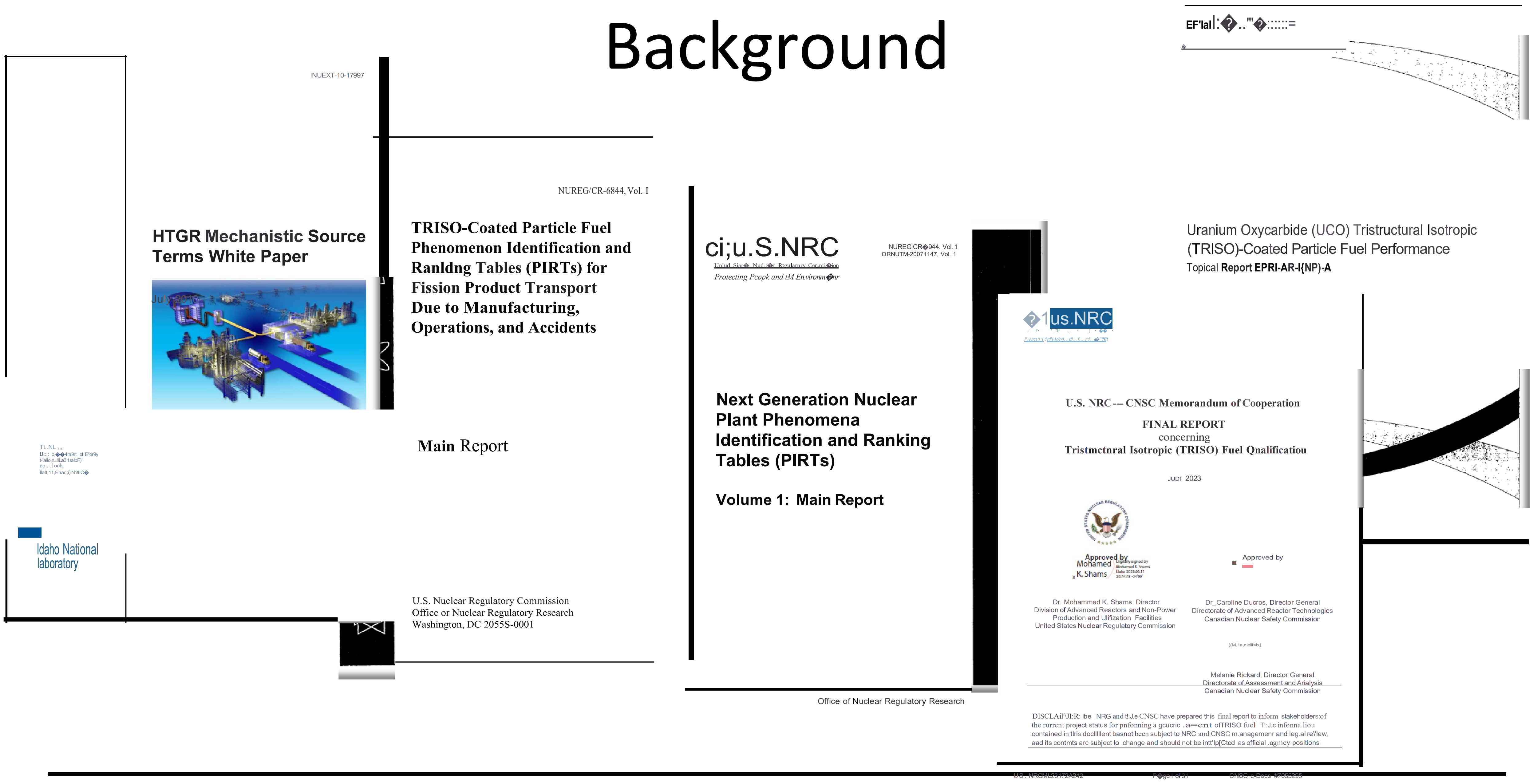
- MST TR originally submitted on May 10, 2024 (ML24131A146) with updated submittal on March 14, 2025 (ML25073A093)
  - Updated submittal includes updates identified during regulatory audit
    - Updates to MST TR sections 1.5 and 7.1 clarify that applicability is limited to preliminary analyses
    - Correction of typos
    - Updates to Appendix H showing MST model interfaces (next slide)

Background – Preliminary MST Model Interfaces



- Model interfaces, as described in the MST TR, appear to be preliminary and subject to change (e.g., Reactor Kinetics and Tritium models are described in MST TR but were removed from the interface chart in updated MST TR)

Background



INUEXT-10-17997

HTGR Mechanistic Source Terms White Paper

July 2010

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Idaho National laboratory

NUREG/CR-6844, Vol. I

TRISO-Coated Particle Fuel Phenomenon Identification and Ranldng Tables (PIRTs) for Fission Product Transport Due to Manufacturing, Operations, and Accidents

Main Report

U.S. Nuclear Regulatory Commission
Office or Nuclear Regulatory Research
Washington, DC 2055S-0001

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Protecting Pcopk and tM Environm�nr

NUREGICR�944, Vol. 1
ORNUTM-20071147, Vol. 1

Next Generation Nuclear Plant Phenomena Identification and Ranking Tables (PIRTs)

Volume 1: Main Report

Office of Nuclear Regulatory Research

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Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO)-Coated Particle Fuel Performance
Topical **Report EPRI-AR-I{NP)-A**

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U.S. NRC--- CNSC Memorandum of Cooperation

FINAL REPORT
concerning
Tristmctnral Isotropic (TRISO) Fuel Qnalificatiou

JUDf' 2023

Approved by
Mohamed K. Shams
Digitally signed by Mohamed K. Shams
Date: 2023.06.11 20:44:48 -04'00'

Dr. Mohammed K. Shams. Director
Division of Advanced Reactors and Non-Power Production and Ulifization Facilities
United States Nuclear Regulatory Commission

Approved by

Dr_Caroline Ducros, Director General
Directorate of Advanced Reactor Technologies
Canadian Nuclear Safety Commission

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Melanie Rickard, Director General
Directorate of Assessment and Arialysis
Canadian Nuclear Safety Commission

DISCLAil'\JI:R: lbe NRG and t!:J.e CNSC have prepared this final report to inform stakeholders:of the rurrcnt project status for pnfonning a gcucric .a=cnt ofTRISO fuel T!:J.c infonna.liou contained in tlris doclllllent basnot been subject to NRC and CNSC m.anagemenr and leg.al re\'lew, aad its contmts arc subject lo change and should not be intt'lp[Ctcd as official .agmcy positions

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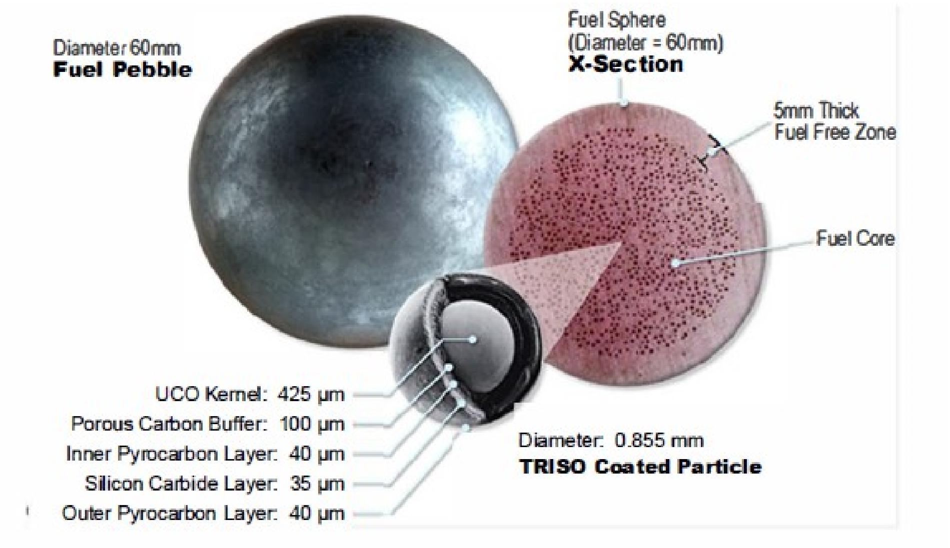
Regulatory Basis

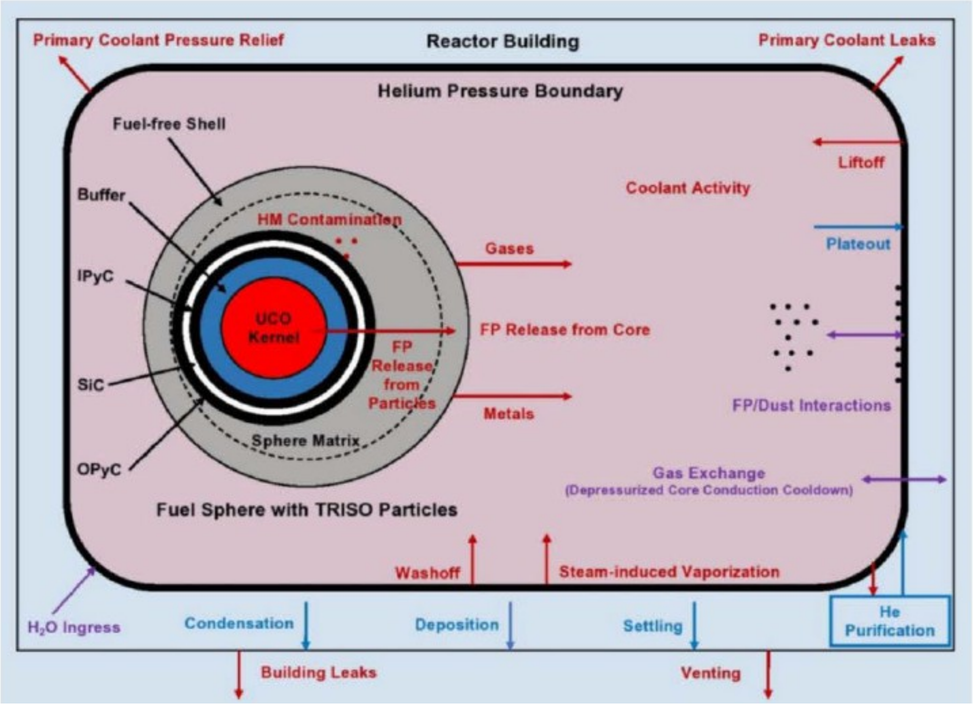
- Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34(a)(1)(ii)(D) requires, in part, that an applicant for a construction permit (CP) perform an evaluation and analysis of a **postulated fission product release** to evaluate the offsite radiological consequences.
- Under 10 CFR 50.34(a)(4) an applicant for a CP must perform a **preliminary analysis and evaluation of the design and performance of structures, systems, and components** with the objective of assessing the risk to public health and safety resulting from the operation of the facility and including the determination of margin of safety during normal operations and transient conditions anticipated during the life of the facility.
    - Staff identified relevant Principal Design Criteria (PDC): Xe-100 PDC 10, RFDC 16, PDC 19
- Under 10 CFR 50.34(a)(8) an applicant for a CP must identify the systems, structures or components of the facility, if any, which require research and development to confirm the adequacy of their design and describe the **research program that will be conducted to resolve any safety questions associated with such systems, structures, or components**. Such research and development may include obtaining sufficient **data regarding the safety features of the design to assess the analytical tools** used for safety analysis in accordance with 10 CFR 50.43(e)(1)(iii).

Scope of NRC Staff Review

- MST TR section 4.2 describes that MST models, implemented in the XSTERM code, are used to calculate dose consequences for licensing basis events, including the deterministic evaluation of design basis accidents
- NRC staff reviewed MST modeling approach to address radionuclide transport phenomena to support preliminary analysis of the Xe-100
- Review is limited to and focused on high-level physical phenomena of interest and whether the analysis approach and methods can reasonably support future licensing actions
  - Design is preliminary
  - Development and assessment of methods are in progress or planned
  - Evaluation of models within XSTERM for acceptability will be conducted during the review of an application that relies on the results of XSTERM evaluations

Barriers to Radionuclide Release





- Fuel
  - Fuel particle kernel (Uranium Oxycarbide (UCO)) within the TRISO fuel particles
  - Silicon Carbide and Pyrolytic Carbon coatings applied to the fuel kernel
  - Fuel matrix and fuel free zone of the fuel pebble
- Helium Pressure Boundary
- Reactor Building (Not credited)

XSTERM Models

- MST TR describes nine models in XSTERM:
  - Thermodynamics Calculation Model (THM) calculates detailed temperature distributions in fuel pebbles, TRISO-coated fuel particles, and all core components (reflectors, core barrel, and reactor pressure vessel)
    - NRC staff identifies this model to be of high importance because radionuclide release is expected to be diffusion dominant (temperature-dependent).
    - Use of THM for analyses supporting a Xe-100 licensing application requires justification by the applicant.
  - Point Kinetics Core Simulation Model (KSIM) is described as a modeling 2D axisymmetric geometry to simulate the transient behavior of the Xe-100 core.
    - TR section 5.1.9 further states that the point kinetics approach is applied to each cell individually (there are many cells in the model) and that the flux profile between timesteps can be reshaped using a diffusion kernel.
    - The description of point kinetics appears to be different than standard point kinetics approaches (i.e., 0D, single eigenvalue, lack diffusion coupling). Use of KSIM for analyses supporting a Xe-100 CP application requires justification by the applicant.

XSTERM Models

- MST TR describes nine models in XSTERM (cont):
  - Tritium Production and Transport Model calculates the overall tritium mass balance in the Xe-100. MST TR section 5.1.8 clarifies that this model is under development.
  - Remaining models:
    - TRISO Particle Failure Probability Model (FPM) calculates TRISO-coated particle failures probabilities
    - Solids Product Transport Calculations Model (SOLM) calculates the production, decay, transmutation, transport and leakage of gaseous and solid fission products from fuel pebbles to the helium pressure boundary
    - Steady-State Gaseous Fission Products Transport Calculations Model (GASM) calculates gaseous fractional release-to-birth ratios of fission product release from TRISO-coated fuel particles and pebbles into the primary circuit coolant gas.
    - Dust Production Rate Calculations Model (DUSTM) calculates the graphite and metallic dust production rates for the Xe-100.
    - Helium Pressure Boundary Model (HPBM) calculates the deposition and resuspension of fission products on helium pressure boundary surfaces and the release of fission products into the reactor building.
    - Core Corrosion Model (CORRM) simulates the mass transport and chemical reaction aspects of the core corrosion phenomena encountered during water or air ingress into the core of the Xe-100.

XSTERM Models

- MST TR describes nine models in XSTERM (cont):
  - The remaining models (FPM, SOLM, GASM, DUSTM, HPBM, CORRM) address phenomena needed to predict MST to support preliminary analysis:
    - Models rely on previous modeling and operational experience from gas-cooled reactor such as Arbeitsgemeinschaft Versuchs Reaktor (AVR)
    - Based on the NRC staff’s experience with light water reactor (LWR) and non-LWR source term analysis, the NRC staff did not identify significant gaps in the MST models.
    - MST TR section 4.2 states that the source term modeling described may be revised
      - NRC staff did not perform a detailed technical review for the models described in MST TR
      - NRC make no conclusions regarding the acceptability of these models

Assessment Plans (Verification and Validation (V&V))

- MST TR section 6 states that:
  1. V&V effort is underway to ensure that XSTERM is qualified to support final safety analyses
  2. Validation plans are developed to cover high and medium ranked phenomena that are identified through a Phenomena Identification and Ranking Table (PIRT) process
  3. The phenomena modeled by XSTERM were extracted from an earlier version of the PIRT
- NRC staff determined that the assessment process is acceptable because the identification of code assessment requirements through the PIRT process is an established approach (see RG 1.203)
- NRC staff are unable to assess the adequacy of the V&V plan:
  - Validation plan is not based on the latest PIRT information
  - MST TR does not contain information describing the knowledge level of the phenomena identified in the PIRT
  - The plan is preliminary and subject to change

Conclusions

- The NRC staff concludes that X-energy’s TR 000632, “Xe-100 Licensing Topical Report Mechanistic Source Term Approach,” Revision 3, provides a reasonable plan for the development of the MST methodology.
  - The FPM, SOLM, GASM, DUSTM, HPBM, CORRM models in XSTERM appear to cover the phenomena needed to predict the MST to support the preliminary analysis and evaluation of the Xe-100 design
  - The TR describes an acceptable approach to V&V
- NRC staff make no conclusions regarding the acceptability of the models in XSTERM for the MST analyses of the Xe-100 because:
  - Models within XSTERM are still under development
  - A detailed technical review of the individual models was not completed
  - Details regarding key phenomena identification and associated knowledge levels are not provided in MST TR
  - The models and associated validation plans are preliminary and subject to change
- The NRC staff expects that a detailed technical review of XSTERM model applicability to the Xe-100 reactor will be addressed as part of the review of a licensing application that references MST TR.

Acronyms

AVR	Arbeitsgemeinschaft Versuchs Reaktor
CORRM	Core Corrosion Model
CP	Construction Permit
DUSTM	Dust Production Rate Calculations Model
FPM	Failure Probability Model
GASM	Steady-State Gaseous Fission Products Transport Calculations Model
HPBM	Helium Pressure Boundary Model
KSIM	Point Kinetics Core Simulation Model
LWR	Light Water Reactor
MST	Mechanistic Source Term
PDC	Principal Design Criteria
PIRT	Phenomena Identification and Ranking Table
SOLM	Solids Product Transport Calculations Model
THM	Thermodynamics Calculation Model
TR	Topical Report
TRISO	Triple Coated Isotropic Particle
UCO	Uranium Oxycarbide
V&V	Verification and Validation
VSOP	Very Superior Old Programs

Meeting title X-Energy Topical Reports ACRS Subcommittee Meeting

Participants

Derek Widmayer
Thomas Dashiell
Larry Burkhart
Inseok Baek
Tammy Skov
Mark Paul
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Ben Chen
Christopher Brown
Stephen Philpott
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