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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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THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE

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OPEN SESSION

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FRIDAY

NOVEMBER 16, 2018

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear Regulatory Commission, Three White Flint North, Rooms 1C03, 1C04 and 1C05, 11601 Landsdown Street, North Bethesda, Maryland, at 8:30 a.m., Michael Corradini, Chairman, presiding.

COMMITTEE MEMBERS:

MICHAEL CORRADINI, Chairman

RONALD G. BALLINGER, Member

DENNIS BLEY, Member*

WALTER L. KIRCHNER, Member

JOSE A. MARCH-LEUBA, Member

JOY REMPE, Member

MATTHEW W. SUNSERI, Member

ACRS CONSULTANT:

STEPHEN SCHULTZ

DESIGNATED FEDERAL OFFICIAL:

WEIDONG WANG

ALSO PRESENT:

JOHN BOLIN, Public Participant
ALLYSON CALLAWAY, NuScale*
AMY CUBBAGE, NRO
JACOB DeWITTE, OKLO
RANDY GAUNTT, Sandia National Laboratories
MIRELA GAVRILAS, NRR
BRANDON HAUGH, Kairos Power
DON HELTON, NRR
ZESES KAROUTAS, Westinghouse
ANDREW LINGENFELTER, NuScale*
JOHN MONNINGER, NRO
ROBERT OELRICH, JR., Westinghouse
JOSHUA PARKER, Framatome
IAN PORTER, RES
ANDREW PROFFITT, NRR
EVERETT REDMOND, NEI
MARTIN VAN SKADEN, X-Energy
NICHOLAS SMITH, Southern Company/MSR
JEFF WHITT, Framatome*

*Present via telephone

A G E N D A

P R O C E E D I N G S

8:30 a.m.

CHAIRMAN CORRADINI: Okay. So, let's get started, then. So, this is a meeting of the Thermal-Hydraulic Phenomena Subcommittee of the ACRS.

My name is Mike Corradini, Chairman of today's Subcommittee meeting. ACRS members in attendance are Ron Ballinger, Jose March-Leuba, Matt Sunseri, Joy Rempe, and our consultant -- oh, I'm sorry, and Walt Kirchner, he just arrived. And our consultant Steve Schultz. Weidong Wang of the ACRS staff is the Designated Federal Official for today's meeting.

During today's meeting, the Subcommittee will receive information briefings on computer codes, with a focus on their use in light-water reactor accident safety analyses for accident-tolerant fuels and advanced reactors.

We appreciate the NRC staff's and external presenters' willingness to come to brief the Subcommittee.

Let me just go off script a bit, I want to emphasize how appreciative we are. This all started with a question we got from the Commission relative to the use of advanced codes in safety analysis and we appreciate the time and energy that both DOE, the industry, and the NRC staff has put into trying to brief us, so that we can potentially respond back to the Commission.

The information will certainly be useful as the ACRS prepares its review of regulatory actions associated with ATF in light-water reactors and advanced reactor designs, in terms of safety analyses.

Today's meeting is open to the public, unless we need to close the session in order to discuss and protect information that is proprietary, pursuant to 5 USC 552(b)(4).

I will note that we have been told by all the presenters there is nothing proprietary. We do have two 30-minute breaks, just in case we get into proprietary and want to get back to a question. It'll be a bit confusing, because we may have to excuse some people out of the room.

So, at this point, I don't expect any proprietary information. And I'll try to keep the Committee on task. If we delve into things like that, you can let us know and we can potentially deal with it in a different manner.

We will rely on the presenters to alert the Subcommittee if the discussion goes into any type of non-public information.

The ACRS was established by statute and is governed by the Federal Advisory Committee Act, or FACA. This means the Committee can only speak through its published letter reports. We hold meetings to gather information to support our deliberations.

What this really means is that the comments and questions conveyed during the meetings represent individual members' perspectives and not positions of the ACRS.

The ACRS section of the US NRC public website provides our charter, bylaws, letter reports, and transcripts of the meetings open to the public, including the slides presented at the open meetings.

The rules for participation at today's meeting were previously announced in the Federal Register. Interested parties who wish to provide comments can contact our office requesting time.

At this point, we've received no written comments, but we have requests for time to make oral statements from members of the public regarding today's meeting, at the end of the meeting.

That said, we also set a time for extemporaneous comments from members of the public attending or listening to our meetings. Written comments are also welcome.

As mentioned, we have a bridge line established for interested members listening in. Parenthetically, apparently, nobody is listening just let.

To preclude interruption of the meeting, the phone bridge line will be placed in a listen mode and muted for Committee discussions. We will unmute the bridge line at the designated time in accordance with a published agenda to afford the public an opportunity to make statements or provide comments.

A transcript of today's meeting is being kept. Therefore, we request that participants in this meeting use the microphones located in the meeting room when addressing the Subcommittee.

The speakers should first identify themselves and speak with sufficient clarity and volume so they be readily heard.

At this time, I'd ask that you silence all various appliances, phones, whatever, so there's no beeping and bopping going on during the meeting.

We'll now proceed with the meeting. John Monninger of the Office of New Reactors will start us in today's presentation. John?

MR. MONNINGER: Thank you, Dr. Corradini.

My name is John Monninger. I'm the Director of Safety Systems Risk Assessment in Advanced Reactors in NRC's Office of Nuclear Reactor Regulation.

The meeting today is a follow-up to the meeting that the ACRS Subcommittee had back on August 21, focused on, at that time, discussions with the Department of Energy on potential codes for accident-tolerant fuels and non-light water reactors.

My discussion, I'll cover two different areas, Section 3 and 4 on the agenda. Section 3 on the agenda, the role of computer codes in regulatory discussions is really intended to provide a broader perspective from the Agency on the use of codes.

It's not specific to NRO, it's intended to represent the practices of NRR, NMSS, the Agency in general and how we use codes in regulatory decisions.

And then, the second session will dive into non-light water reactors, or advanced reactors, which I'll use the term interchangeably there.

With that said, from the staff's perspective, in particular for non-light water reactors, we see this as a beginning of a series of discussions with the ACRS.

Our efforts today are closely aligned and supported by our experts within the Office of Nuclear

Regulatory Research and we're working very closely with Research, coming up with our plans.

So, if I could have the next slide, which is just the introduction section on NRC use of computer codes in general?

So, if you look at this slide, here, there are various codes that the NRC has developed and sponsored over the years. This slide doesn't list them all, but it covers representative examples of them.

And generally, they've been focused, with the staff's practice or focus being on existing light water reactors or large light water reactors. So, some of these codes are also used within the Office of Nuclear Material Safety and Safeguards.

But they cover a wide range of areas, be it fuel performance, reactor systems analysis, consequence analysis, radiation protection, chemical gases impacting the Control Room, et cetera.

They are used for an assessment of normal operations, off-normal operations, anticipated operational occurrences, design-basis accidents, beyond-design-basis accidents, and severe accidents.

So, there's a pretty healthy set of NRC-sponsored codes out there. And these codes are maintained by our Office of Nuclear Regulatory Research, in support of work done by the licensing organizations.

So, if I could have the next slide, please?

So, I think there's a lot, a lot of discussion with regards to confirmatory analysis and what is the NRC going to do about confirmatory analysis? But I think you have to step back a little bit and say the codes uses are much broader than just confirmatory analysis.

And if you think about analysis, who has the burden of responsibility? So, in certain areas, in regulatory practice, NRC bears the brunt of the burden of responsibility, improving what we want to do. In other areas, the licensees and the applicants do.

So, if you think about the NRC, areas that we are primarily accountable for that burden of proof is in our rulemakings, it's in our guidance developments, it's in plant-specific orders, generic orders, backfit analysis, regulatory analysis, generic safety studies, for example, the SOARCA study that the Agency did, the reactor oversight process.

If we decide to -- if we have a finding at a site and we decide to proceed with a performance deficiency, a white finding, a green findings, a yellow finding, a red finding, the burden on proof there is with the NRC, through our SPAR models, through our other analysis, to demonstrate -- we have the burden of proof to demonstrate the significance of that finding.

In a similar manner, in support of rulemakings. If we did -- if you go back to the efforts underway post-Fukushima, potential rulemakings on water addition, potential rulemakings on filter vents, the burden of proof there was on the staff to do the analysis.

And we use NRC's analytical codes to support all these areas on the left. In addition to that, we also use the codes for confirmatory analysis and supporting review on an application or an amendment.

But the primary responsibility, when it comes to the applications and amendments, the burden of proof then rests with the licensee, their analytical models.

We will use NRC analytical models for confirmatory analysis, but the burden of proof is with the applicants and the licensees.

CHAIRMAN CORRADINI: John, can I stop you there? Because I --

MR. MONNINGER: Yes, sir.

CHAIRMAN CORRADINI: -- think I know where you're going, which I think is a good overview. But it doesn't preclude that the licensee or the NRC might choose to use the same evaluation model --

MR. MONNINGER: Correct.

CHAIRMAN CORRADINI: -- it's then the user's burden to show that they are intelligent, excuse my words here, intelligent enough to use the evaluation model appropriately, with the appropriate assumptions, inputs, et cetera, et cetera?

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: Okay.

MR. MONNINGER: Yes, sir.

MEMBER REMPE: So, since you're interrupted, I know why you've made this list on the left, because you're talking about an application, but there's another responsibility of the regulator, and that's if you have yet another accident has occurred over the years.

MR. MONNINGER: Right.

MEMBER REMPE: And if one does go with the tools of the applicant for a unique new type of concept, what will be the backup?

I mean, we heard at the last meeting, oh, yes, DOE is going to maintain ownership of the software itself. The regulator needs to be ready in case of something happening, and how does that fit into what you've got here?

MR. MONNINGER: Yes. So, and I'm not fully appreciating probably the question, whether it's in the direct emergency response, the codes we may use in the Ops Center, or whether it's in a fact-finding or a lessons learned subsequent to an event?

MEMBER REMPE: Both of those things, but especially during the initial response actions that have to be taken, the regulator needs to give wise advice.

MR. MONNINGER: Yes. So, even today, for large light water reactors, NRC, in the assessment, we have some -- I'm the Director of NRC's -- I'm one of NRC's -- one of the positions I fill is the Director of the Reactor Safety Team.

And there's four or five or six of us, dependent upon when the event would potentially occur and who can respond first. I've had that position for probably the past 15 years and prior to that, I was a Severe Accident Analyst on the Reactor Safety Team, et cetera.

CHAIRMAN CORRADINI: I think we're trying to reconnect, sorry, I apologize.

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: So, keep going ahead.

MR. MONNINGER: So, with that said, you have to recognize, within the Ops Centers, the events go pretty quickly. So, the notion that the NRC, in the midst of an event, is doing detailed analysis, isn't there.

We have some simplified tools, and there are RASCAL calculations that are done, but given the progression of events, in the midst, it doesn't occur in the midst of events. There are --

MEMBER REMPE: Some of these unique designs are going to be so slow as they --

(Laughter.)

MR. MONNINGER: Yes.

MEMBER REMPE: Lots of time. But I just -- again, you need to keep in mind --

MR. MONNINGER: Yes.

MEMBER REMPE: -- that you've got to be prepared, as a regulator, for the unexpected, to give wise advice on --

MR. MONNINGER: Yes.

MEMBER REMPE: -- what needs to be done. And I hope that's being considered and factored in.

MR. MONNINGER: Yes. And I would -- so, I think part of our framework in proceeding, assuming an application comes in and is eventually granted and licensed, would be to ensure that our entire regulatory infrastructure, including the Ops Center, is prepared to deal with any potential upset of conditions.

And so, I think it is a fair point here, that I didn't list that, but it does make sense that our infrastructure for the Ops Center would need to appropriately be expanded also to cover non-light water reactors.

So, I put the green box there, the confirmatory analysis, when it does come to that legal finding, there's limited role in the actual legal finding of NRC's confirmatory analysis.

It's a very wonderful tool to focus the staff on areas of importance. It's a wonderful tool to provide additional confidence in the licensing analysis and the licensing model, but in the end, the decision that the NRC makes on granting a license is the licensee's model and approach.

The licensee's models and approach carry forward. They carry forward to day one in operation, day ten years, day 40 years, license renewal, subsequent renewal.

NRC confirmatory calculations don't carry forward. I mean, a question, could -- in support of ABWRs, so I was involved in the design certification review of ABWR, could the NRC recall any confirmatory analysis that we did for the ABWR?

And there's the potential we could, but that's not required in the Agency. However, for GE, they need to maintain those models. Post-licensing, it is based upon the applicant.

MEMBER MARCH-LEUBA: John? It's true that the staff confirmatory calculation has no legal standing --

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: -- correct?

MR. MONNINGER: Yes, sir.

MEMBER MARCH-LEUBA: However, the reason we perform confirmatory calculations, in my opinion, the primary value of it is to find out what mechanism the licensee forgot.

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: Is there a particular event? Is there a particular thing that you have to model?

MR. MONNINGER: Yes, sir.

MEMBER MARCH-LEUBA: And that, even though has no legal standing whatsoever --

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: -- it has tremendous value in the review. That's why we do it.

MR. MONNINGER: Yes. And I fully agree with you and that's a great segue to the next slide. And that would be the second bullet there, as to why we do it, it's to facilitate an effective and efficient review.

For the staff to focus on those areas of the application where there is the potential that the applicant's analysis isn't as robust, what are the areas of the application that are important to safety, what are the areas of the application that are risk-significant, where should the staff's line of questioning go through, where should the staff do audits, et cetera.

So, it's to do exactly what you're saying, and my thought is, that gives us an effective and efficient review, it focuses --

MEMBER MARCH-LEUBA: I think your third bullet, first bullet of the third bullet, says it all.

If we are reviewing a calculation for which we've seen 150 the last three months --

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: -- we don't need to do confirmatory, we're already experts on that.

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: But whenever you're doing a new type of transient or reactor or mechanism --

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: -- then, the fact that we're doing the confirmatory calculation, we are making experts out of our staff.

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: And they're learning what's important for the review.

MR. MONNINGER: Yes. And as you mentioned, experts are just for knowledge management or for training, as you mentioned. And then, first-of-a-kind operations, design features, et cetera, to focus the review, is really why we do do the confirmatory analysis.

The confirmatory analysis, there can be the view out there that it's the double-ended guillotine break for a LOCA, for ECCS analysis, for peak-containment design pressures.

And at times, we do do that, but in terms of the licensing staff, what we find to be potentially of more value isn't that one broad in-depth analysis of a particular accident sequence that the applicant did.

Rather, it's having a tool sitting next to the licensing reviewer or up in the Office of Research, where we can ask ourselves what if questions, what if questions, to determine then whether we need to engage the applicant.

So, I call these sort of mini, they're not really sensitivity studies, but you want a tool by your side so you can ask what is the impact of variation of a parameter, to know whether you need to engage the applicant.

So, there are the full-blown analyses, but then, there's these mini-tools that we use on the side.

MEMBER MARCH-LEUBA: If you ask me to convince somebody in management that that's valuable, I would have focused it on training the staff on what's important for this review.

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: I mean, you're making the staff an expert and maybe he wasn't an expert, nobody was an expert on this particular event.

MR. MONNINGER: Yes. And I would say, in terms of management support, interest, endorsement of ensuring we're ready, in terms of the codes, be it changes or modifications to NRC codes, or let me call it NRC-sponsored codes or DOE-sponsored codes, that support is currently there.

MR. SCHULTZ: John, of these examples, for the topics we're going to be discussing today, the first and the fourth element, first-of-a-kind and then, the opportunity to gain insights for those areas of application, those seem like the most important features.

We're bound to have -- we would hope to have fairly large safety margins, as we move forward --

MR. MONNINGER: Right.

MR. SCHULTZ: -- in these concepts. And of course, effective use of resources, okay.

MR. MONNINGER: Yes.

MR. SCHULTZ: But it's really the first and fourth element that we would focus on.

MR. MONNINGER: Yes, for non-light water reactors. And this first discussion was meant to be broader --

MR. SCHULTZ: Understood --

MR. MONNINGER: -- Agency-wide. So, the next slide.

In doing the confirmatory analysis -- so, last night, I corrected most of the slides, as opposed to saying NRC codes and DOE code, it should be NRC-sponsored codes versus DOE-sponsored codes.

Because in the end, the vast majority of the codes, be it NRC-sponsored codes or DOE-sponsored codes, are being performed by the National Labs. So, the notion that it's an NRC code versus a DOE code, it's more in terms of the direction and the sponsorship of it.

So, we can use various codes out there to conduct the confirmatory analysis. And one thing that has been very beneficial for the staff is even having the applicant's code to be able to run.

For the NuScale application, we found that to be of significant value, to be able to exercise their code.

MEMBER REMPE: And again, when you use this, there's, embedded into that first bullet, the fact that all of the codes should be validated with appropriate data?

MR. MONNINGER: Yes.

MEMBER REMPE: Okay.

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: Since she brought it up, and you can postpone us, because I'm going to be pretty strict about time, because we have so many speakers today.

Somewhere today, or later, I think it's got to be clearly identified, as Joy mentioned, that if we're going to choose Tool X, that there's a pedigree to Tool X, such that either the applicant show the pedigree, so we're clear about the validation of it relative to experiments or, we'll call it more conservative analyses or something, or the staff, if they're going to use it as their evaluation tool, have got to feel comfortable.

So, somewhere, maybe not today, I assume in the NRC program plan, there will be that element.

MR. MONNINGER: Yes. And the intent is, today would be the beginning of a series of discussions. And we do intend to come back to the ACRS with the staff's joint recommendations from the Office of Research and the NRR as to where we would like to proceed and what's the basis for that, et cetera.

CHAIRMAN CORRADINI: All right, thank you.

MR. MONNINGER: I think we covered the second one. So, and then, the last bullet there. So, NRC-initiated analysis, other than confirmatory analysis, even though the code is on confirmatory analysis.

So, this is intended to go back to the bullets on the previous slide, in terms of analysis we may do in support of rulemaking, backfit analysis, et cetera.

In those cases, we will come to the ACRS for formal -- many times, we will come to the ACRS for formal review of our analysis in support of that, be it our computer analysis, et cetera.

In terms of the staff's actual confirmatory analysis, when ACRS reviews an application, it is focused, it's mostly focused on the applicant's analysis and the staff's analysis is discussed in there.

However, when we come to proceed with a rulemaking, proceed with a generic safety issue, proceed with a SOARCA study, et cetera, the peer review and comment is on the staff's analysis.

We aren't presenting, when we come in to support a license application, we aren't putting in front of the ACRS the staff's confirmatory analysis for licensing decision, in terms of a peer review, in a similar manner that we would in support of a rulemaking, a backfit analysis, et cetera.

Rolling on, some various -- we have our SRP, Standard Review Plan, 0800. Of course, we would need different types of guidance for non-light water reactors.

In certain sections, it discusses the potential need for confirmatory analysis. Sometimes it calls it independent analysis, independent verification. We use different types of terminology.

And, there, it is, once again, to confirm the predictions, but in the end, it's to confirm what the applicant did.

And also, it's not required of the staff to do, it's optional, and it's based upon their insights of the design and discussions with their supervisor. Next slide.

So, broadly, we tried to pick some representative light water reactor areas where applicants depend upon modeling and simulation tools, computer codes, computational analysis, and to tie it to the regulatory requirements and then, to tie it to, be it the reactor design or the engineered safety features or support systems.

In many of these areas, dependent upon the particular design, the staff will do or will consider doing confirmatory analysis.

CHAIRMAN CORRADINI: This is an interesting graphic. I guess, my first reaction is, when you have a conversation with an applicant, is it clear what they're going to use in all these little boxes? Because --

MR. MONNINGER: So, some applicants --

CHAIRMAN CORRADINI: -- I was going to ask the applicants later today, do they have this graphical map like this for their various advanced reactors?

Because it seems to me, that, assuming it's not a proprietary issue that I can't talk about today --

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: -- but to me, this sort of mapping actually is pretty illustrative of what you need or what they need to do to make sure they're clear on their plan.

MR. MONNINGER: So, some applicants, and we're not talking about non-light water reactors --

CHAIRMAN CORRADINI: Yes.

MR. MONNINGER: -- just historically over the past 20 years, the level of engagement of various developers, designers, ranges across the spectrum.

Some applicants are in with the NRC multiple years in pre-application meetings. They talk about their proposed testing regimes, they talk about the potential codes, they talk about the validations of the codes.

Others, there's much, much more limited discussions, in terms of what their intent is. So, it really does run the spectrum.

With that said, there is no requirement for them to come in. But in terms of providing more certainty that the staff is prepared for the application, those pre-application discussions are definitely beneficial.

MEMBER REMPE: We heard about the regulatory engagement plans that the staff is encouraging these developers to provide. And is that one of the things you're suggesting be included in the regulatory engagement plans?

MR. MONNINGER: So, we don't have a chart or a figure like this, however, if an applicant would like to discuss their analytical codes, to have the NRC provide some level of feedback to that, they could develop a regulatory engagement plan for just that small, specific purpose.

Or they could develop a regulatory engagement plan much broader, to cover all pre-application type activities.

So, one of the potential designs has submitted a report on their approach to models and reactor analysis and the staff has been involved in discussions with one design out there. Next slide, please.

So, takeaways, for a summary slide or a conclusion. Codes are much broader than licensing confirmatory analysis. We have other responsibilities to support solid rulemakings, et cetera.

The scope and the tools varies widely. The third bullet is just, again, a reinforcement that in the end, the granting of a license and the codes and the methodologies and approaches that carry forward the applicant's.

And we do do, in support of licensing, the confirmatory analysis, to support an effective and efficient review.

MEMBER MARCH-LEUBA: Nobody has said this before, but this is a Subcommittee meeting, so what you're hearing is individual member's comments.

CHAIRMAN CORRADINI: So, you can ignore his.

(Laughter.)

MEMBER MARCH-LEUBA: I was -- this is not the ACRS speaking. I was left in charge of the minutiae and other annoying comments by John Stetkar when he retired.

So, on that sense, I see, in mathematical terms, there's a forcing function from management or NRC that is driving to making reviews shorter and cheaper.

And that forcing function is driving the solution towards minimizing the number of confirmatory calculations. I mean, you would agree that that is the case?

MR. MONNINGER: So, I don't think -- so, that's leading the witness, I would agree.

(Laughter.)

CHAIRMAN CORRADINI: That's a perfect analogy.

MR. MONNINGER: Yes. But I wouldn't agree with that. I think, so I'm within the Office of New Reactors and NRR has challenges, NMSS has challenges also with schedules. So, I think it's important for us to make timely decisions and to be predictable.

Our reviews of the advanced light water reactor designs, the AP600, the amendment to it, ESBWR, I think it is generally recognized that the time period it took those to be completed was well in excess of what it should be.

So, we did put a challenge to ourselves, for the KHNP APR1400 application to complete it within 42 months. But 42 months is also a long time, it's three and a half years.

So, there's time and then, there's resources out there. So, there's time and there's resources, as many resources as was needed to the KHNP application was applied. And where needed, we did do confirmatory calculations, recognizing that, to a large extent, it was an enhanced System 80+ design out there.

MEMBER MARCH-LEUBA: I'll 100 percent agree with you that we need to shorten the reviews --

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: -- and make them more predictable.

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: Especially more predictable.

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: It should not be rolling the dice. But with that in mind, I just wanted to defend the confirmatory, because I've worked on that and I like doing this.

I see two sources of value. One of them, you emphasized, which is the training of the staff. By forcing the staff to perform the calculations themselves, they know what the problems are with the calculations.

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: The other one, that you have not addressed, is it performs kind of a check on the uncertainty of the calculation.

By doing a completely independent calculation, and whether you get the number in the same order of magnitude or not, tells you what the uncertainty on the calculation is.

If you come up with a factor of two, suddenly you have to decide whether a factor of two is acceptable or not.

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: So, don't underestimate the value of the estimate of the uncertainty on the confirmatory calculations.

MR. MONNINGER: Okay.

MEMBER MARCH-LEUBA: And finally, I mean, I would like for us to continue to do confirmatory calculation, we just have to be smart on how we do that and how many we do.

If we already have staff that is familiar with LOCA and what all the pitfalls with a LOCA calculation, maybe we don't need to run a LOCA confirmatory, unless we're looking for the uncertainty on the calculation.

MR. MONNINGER: Yes. So, I agree with you. And I do have a slide, and we're going to roll into the non-light water reactors, and you may want to bring up the question again on schedule then, because I do put a challenge out there on non-light water reactors and schedules and confirmatory analysis.

So, the next discussion and the next slide. So, you're familiar with the NRC's Vision and Strategy, was issued in December of 2016, and we had several meetings with the ACRS on that.

CHAIRMAN CORRADINI: It's only been two weeks ago, so in theory, we remember.

(Laughter.)

MR. MONNINGER: Well, not --

CHAIRMAN CORRADINI: October 30 is when we had our last one on the LMP.

MR. MONNINGER: On the LMP, yes. Yes. And then, supporting that is the IAPs, the near-term. And within Strategy 2 is the plans to develop computer codes and review tools.

And that's what we're discussing today, our planning efforts for computer codes and review tools. The next slide just provides some of the discussion within the vision of the strategy.

And it was clearly stated, even back then, when we issued it in December of 2016, our intent is to leverage the experience from Department of Energy, international, academia, et cetera, in various areas.

Our intent here is to say, we are not fixated on just proceeding with NRC-sponsored codes of the past.

If there's a better way to do things, that achieves NRC's mission and can be done so in a cost-effective manner, we will use other codes out there, be it DOE-sponsored codes from NEAMS, CASL, or any other place.

And that's the IAP, our initial efforts are focused on evaluation of the potential codes out there and potentially down-selecting the codes that the staff would consider. And they'll be the discussions we'll have with the ACRS in the future.

CHAIRMAN CORRADINI: The way you phrase it, though, John, it strikes me that this is a conversation that's still in the midst of being had within the staff.

MR. MONNINGER: Yes. So, there's actually some very engaged discussions.

CHAIRMAN CORRADINI: Well, I've always known the staff to be very engaged.

MR. MONNINGER: Yes. So, I think it's actually good, I think it's very good for our staff, for the staff from the Office of Research to be very interested in the topic and to be engaged.

Because what we want to do is we want to ensure -- first off, we want to make sure we're ready. Congress, the administration, the Commission, they've given us the charge to be ready.

In addition to that, they've given us the funding. And it's not very often that Congress provides earmarked funding to the NRC to be ready. So, we want to do both those things.

So, the Office of Research and our staff are working very closely together on this. And once we're aligned, we'll come in with our draft recommendations to the ACRS.

So, even though a couple weeks ago, on the

LMP, when we originally rolled out the Vision and Strategy and the IAPs to the ACRS, it was early 2017. The ACRS wrote a letter, basically said, the most bang for the buck is on Strategies 3 and 5.

Strategy 3 being the flexible review processes, the LMP, the ARDC, the Advanced Reactor Design Criteria, that were originally -- the work on that originally sponsored by the Department of Energy, and also on the resolution of policy issues, such as emergency planning, such as security, such as siting, et cetera. So, that's where the vast -- a lot of our effort has been focused.

With that said, if you look at the potential resources to work on all the areas, resources-wise, cost-wise, the potential area that would be the most costly is on NRC computer code development within Strategy 2, if you were to look at it from a budget perspective.

CHAIRMAN CORRADINI: I sense that's the reason we got asked the question in front of the Commission.

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: Because I do think, as you're saying, you want to think about this from a planning standpoint, in a way that is efficient and effective, not just --

MR. MONNINGER: Right.

CHAIRMAN CORRADINI: So, that's all.

MR. MONNINGER: Yes. And when we developed the budget estimates for the various years, the number is relatively consistent over a five-year timeframe, and includes the work for the codes and the funding that has been provided by Congress covers that also.

So, this is just a summary of the ACRS letter. I assume you probably don't have any questions on your own letter.

CHAIRMAN CORRADINI: I love that slide.

MR. MONNINGER: You love that slide?

(Laughter.)

MR. MONNINGER: So, also, this year, in the Congressional, in the approval of the NRC's budget, was direction to the NRC. And the direction to the NRC was to prepare a report on CASL.

NRC's report discusses both CASL and NEAMS and came out of the 2018 Consolidated Appropriations Act and it asked the NRC to discuss the potential uses of CASL tools in our licensing and safety reviews.

MEMBER REMPE: John, actually, I guess I wanted to interrupt you on both of these two first bullets. I don't -- I actually tried last night to look up that act and could not find the specific text.

And then, I don't know if -- we weren't given, as part of our materials to read, the response back. And I'd be interested if you could provide that to Weidong, so we could see your response back?

MR. MONNINGER: Yes. So, I'll give a copy to Weidong. And then, I won't try to do the citation for the appropriate appropriations language, because I'll --

MEMBER REMPE: But you're -- this is --

MR. MONNINGER: -- I'll cite it --

MEMBER REMPE: -- pretty much a pretty good summary --

MR. MONNINGER: Yes.

MEMBER REMPE: -- of what they told you to do?

MR. MONNINGER: So, it's on Page 55, and this is within the NRC's budget authorization language. Modeling and simulation tools.

The Commission is directed to report to the Committees on Appropriations of both Houses of Congress, not later than 180 days after the enactment of this Act, the Commission's potential uses of the Consortium for Advanced Simulation of Light Water Reactors in licensing processes and safety reviews.

So, that's the first bullet. And I'll give a copy to Weidong.

And then, the NRC responded in a letter from the Chairman to the oversight committees in a letter dated September 27, 2018.

MEMBER REMPE: Okay.

MR. MONNINGER: And our response, even though the language asks us to address just CASL, we have been working very closely with DOE over the years also on NEAMS, and believed it was important to also discuss NEAMS and consideration for advanced reactors.

We highlighted in there our ongoing efforts to work with DOE and to leverage the programs and the supporting modeling and simulation codes to the best extent possible. We indicated that, where appropriate, we would use our codes and, where appropriate, we would use the DOE-sponsored codes.

In the end, we basically said, if we can meet NRC's mission and provide the functionality, we will look at, what is the most cost-effective means to do so?

So, then, some thoughts on codes for advanced reactors. I mentioned the regulatory infrastructure, funding provided by Congress.

So, one is, we need to be prepared. And

it's very important to us to be prepared to conduct the timely and effective licensing reviews.

We also believe that, given the special funding provided by Congress, it is important for us to provide focused oversight of that funding. We are asked to report -- so, this is internal within our division, it's nothing special coming from the Commission or Office Directors, et cetera.

But in terms of budget preparations, et cetera, over the past couple years, we get quite a few questions from Congress, where have you spent your funding, how prepared are you, et cetera.

So, we are placing additional emphasis on ensuring that we are effectively managing those funds and we can respond back to whoever may ask that question.

And we also want to be transparent on our rationale, recommendations, and decisions. And that extends to the codes and that extends to the proposed future engagement with the ACRS and future engagement with the industry.

We want the industry to be knowledgeable as to why we decided to go down X path. They don't have to agree with it. We'll of course listen to their comments and, as appropriate, consider changing our direction. But we want it to be well documented and provided out there.

So, with that, there's a very, very broad range of reactor designs out there. The three technology working groups and whether 20 different designs are under consideration, 40 different designs, 50 different designs. It's a very large landscape out there.

CHAIRMAN CORRADINI: What is the interaction between the staff, the NRC staff, and these technology working groups? Are -- is it observation or are staff engaged with these working groups to have a conversation?

MR. MONNINGER: So, we are not members of the technology working groups. The technology working groups are, Everett could correct me, but sponsored, chartered, funded, organized, under NEI, the three different technology working groups, and they have a lead and members.

With that said, we have our periodic stakeholder meetings and representatives from the TWGs are there.

They will have meetings and they will invite the staff to come and provide an update on X regulatory initiative. However, we don't sit in on their working level meetings. But there is very good communications with them and --

CHAIRMAN CORRADINI: So, it's a periodic -- does Everett want to say anything at this point? You're kind of acknowledging him, so I'm curious if you want help.

MR. MONNINGER: Yes, is that fair, Everett?

CHAIRMAN CORRADINI: You've got to come to the mic, Everett. Identify yourself with sufficient clarity and volume. There's a switch at the bottom of that mic, I think.

MR. REDMOND: Everett Redmond with NEI. That's accurate, John, description. We help support the technology-specific working groups. NRC engages with them at regular intervals.

They also engage with the Advanced Reactor Working Group, which NEI hosts. And then, as John, I think, mentioned, numerous public engagements throughout the year.

So, yes, NRC engages with the technology working groups, as well as the specific vendors on their specific activities.

CHAIRMAN CORRADINI: Thank you. You have to turn it off too, I'm sorry. We don't have the best A/V in here.

MR. MONNINGER: So, again, the effective and efficient licensing review. And in deciding the path forward on these, we really need to consider the life cycle costs of those.

So, it's not just a notion of NRC has a code on our computers, on our shelves, et cetera, but there's ongoing maintenance. There's the potential to transition the staff.

Say, for example, hypothetically, NRC sponsors 20 codes. Maybe it's those codes on Slide 2 or 3, or it could be more or less. Are we then going to potentially adopt five or ten more? And then, what does that do to our infrastructure, what does that do to our training, et cetera.

Or if we decide to adopt five or ten new codes, will we then decide to de-fund or to put on the shelf some of the existing codes? So, there's costs in terms of what we decide to do.

There would be -- say, for example, one of the -- and it probably isn't 20 on the previous slides, but we decide to use one of the codes on Slide 2. There would be -- on one of the previous slides.

There would be a certain cost to modify that code, to train the staff, and to get the infrastructure. There's more likely a different cost if we decide to adopt and use a DOE-sponsored code.

So, you just have to --

MR. SCHULTZ: So, John, your second bullet means, you're talking about, if NRC decides to develop codes themselves, then there are other costs that need to be considered in the life cycle, including development, verification, validation, maintenance, and training?

MR. MONNINGER: Yes.

MR. SCHULTZ: And then, the third bullet is a separate option or perhaps an option that could be used in addition, for certain --

MR. MONNINGER: So, I think the second one is -- whatever we decide to do, say, for example, we decide to use MELCOR going forward.

There's some incremental cost in modifying MELCOR to support the needs of non-light water reactors and training for staff and maybe some incremental yearly funded needed to support MELCOR for a broader range of applications. So, maybe that funding picture is this.

Maybe the NRC decides, well, no, we want a different severe accident integrated code. That cost would be significantly different than some type of delta off of MELCOR.

The third option would be, maybe there's another DOE-sponsored code out there. If that was the case, if we adopted that, we would most likely not have the cost associated with modification of the NRC's existing codes. However, there would be continuing base-level cost of having that within our infrastructure.

MR. SCHULTZ: That's right.

MR. MONNINGER: Okay.

MR. SCHULTZ: And, there, you would be talking about the training and some element of maintenance, but you would be depending upon whatever outside agency that would be to do the development, the validation, the verification, and so forth.

MR. MONNINGER: We would hope to. We would hope to. So, if we were to go -- and DOE has been very receptive, in terms of our interest. But in the end, DOE, they would control what does occur. To a certain extent, NRC has -- NRC has much more control over NRC-sponsored codes.

MR. SCHULTZ: Of course.

MR. MONNINGER: We can request Sandia to do something on a certain timeframe.

CHAIRMAN CORRADINI: But I think where Steve is going -- I see you have a backup slide that eventually I'm going to ask about, but maybe later.

I think where Steve is going is kind of where we're both worried, which is, if you choose X instead of Y, who's responsible for X, who has the validation portfolio for X, and if it's found wanting --

MR. MONNINGER: Right.

CHAIRMAN CORRADINI: -- who pays to properly upgrade it?

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: Okay.

MR. MONNINGER: And those are some of the ongoing thoughts and discussions, in coming up with our recommendation.

MEMBER REMPE: And as you think about that, there's other models. From my understanding, the SCALE is an example of a code that is jointly managed, is that a way of saying it?, by DOE and NRC, that you figure out what activities need to be done to keep it up to snuff and jointly decide who pays for those activities?

MR. MONNINGER: So, I can't go -- I'm not versed in the specifics of SCALE, but the answer would be, yes. We would have to work through all those details if the decision is to proceed with SCALE.

So, a lot of the same considerations previously and why we would do a confirmatory analysis. But then, I think, we do believe that there are other considerations out there.

The Commission has the policy statement for advanced reactors and has established certain expectations out there in terms of designs that are more robust, designs that are more forgiving, designs that aren't relying upon as much active systems, enhanced margins of safety, et cetera.

So, when the staff is proceeding with a proposed rulemaking, for example, for EP, for SMRs and other nuclear technology, or the staff is going in front of the Commission requesting permission to consider doing a proposed rulemaking on consequence-based security, behind a lot of these efforts is -- there is an underpinning of non-light water reactors, advanced reactors meeting these expectations.

And then, if you hear -- in our interactions with applicants and developers, there's a commitment to this. So, then, if that is then achieved, we do believe there should be consideration of that given to the extent of confirmatory analysis done.

It would need to be demonstrated by the

applicants that those margins are there, and in unique, novel areas, we may still proceed with doing confirmatory analysis.

But in a perfect world, if the baseline level of safety for the non-light water reactors is an order of magnitude or more lower, there should be less of a real need for NRC to do confirmatory analysis. How we factor this in, we haven't --

CHAIRMAN CORRADINI: I agree with you. I think that -- but I -- so, just to pick on where I think Jose was going, there's two ways to do it, now that I've been properly educated with the LMP.

One is that I have highly reliable or minimally needed safety systems that reduce the frequency of the event, or there's something unique about the design that reduces the potential dose --

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: -- or the, we'll call it the boundary dose. But you are going to need some sort of tool that can clearly identify what the source term is and how it leads from the tool through the, I'll call it the reactor system --

MR. MONNINGER: Right.

CHAIRMAN CORRADINI: -- to the larger system that can -- the building outside, that I won't use the C-word --

MR. MONNINGER: Right.

CHAIRMAN CORRADINI: -- all right?

MR. MONNINGER: Or the FC, functional containment.

CHAIRMAN CORRADINI: Thank you. Or the FC-word. Well, that hasn't --

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: -- I don't think the Commission's gone there yet, so I'm not going to --

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: -- but the outside building. So, there's -- that part of that has got to be known well enough or with high enough margin, so that one can say, essentially, come to the conclusion you've come to.

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: Okay.

MR. MONNINGER: And an applicant, in doing so, they could do that a couple different ways. One is, they could do it -- have some -- one is, they could propose a very conservative analysis, such that -- or they could try to be much more sharper, much more best estimate, which would then raise higher the level or higher the potential for NRC to do confirmatory analysis.

MEMBER MARCH-LEUBA: So, let me use the techniques of marketing, TV ads. Let's repeat, the purpose of the confirmatory calculations are training of the staff, the determination of uncertainty, and there's a third one, which is very important, especially for first-of-a-kind calculations, which is, what does the applicant mean? Is there an event that they didn't consider?

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: Is an event that progresses differently with different assumptions? That's where the staff should concentrate most on -- I mean, we don't want to reproduce the calculation and say, instead of ten to the minus seven, is 1.2 ten to the minus seven. That has no value.

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: We have to see if they miss something that was ten to the minus three.

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: And that's where the confirmatory and the becoming familiar with the process, which we are not. And I know nothing about molten salt, for example.

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: You have to become familiar to know what they missed.

MR. MONNINGER: Yes.

MR. SCHULTZ: John, I took it that your statement, quick and simple to explore -- that the explore sensitivities was where you were trying to capture that.

MR. MONNINGER: Yes.

MR. SCHULTZ: I would question, in any case, quick and simple. But to explore sensitivities would be the objective that would satisfy that need.

MR. MONNINGER: Yes. So, I would -- maybe we could delete, and simple. But I think, in terms of licensing, we want -- if we do the confirmatory analysis, we do want something that can be done in a timeframe to support the front end of the licensing review.

In reality, the staff front-end loads our review and Phase 1 is issuance of the RAIs. That is the time, prior to Phase 1 being complete, you want all your confirmatory calculations done, where we identify potential areas that we have questions on.

We want to raise those in the RAIs. We want to be conducting the audits based upon insights from the confirmatory analysis, within Phase 1.

So, to the extent that the calculations need to be fully representative of the design, versus -- yes. So, there is a need for quickness or timeliness in any calculations --

MR. SCHULTZ: Sure.

MR. MONNINGER: -- we do. And ideally, they'd be exercised by the Licensing Office. Currently, I would say, more than 50 percent, and it's not the right number, but the vast majority of the confirmatory analyses are currently done for our office by the Office of Research.

But I think in a best case world, you would want your licensing reviewer, your reactor systems engineer, to have that code for the training purposes, for the insights purposes --

MR. SCHULTZ: Yes, I was going to --

MR. MONNINGER: -- with the licensing side.

MR. SCHULTZ: -- re-emphasize the training of the staff, so that they would be prepared to do what you're describing.

MR. MONNINGER: Yes.

MR. SCHULTZ: Thank you.

MR. MONNINGER: So, and then, typical Phase 1 reviews, RAIs, and this will get into the issue of schedules, so 42 months, the APR1400, and schedule isn't scaled by power or source term, but if you were to do that, 1400 megawatt, APR1400 versus a micro-reactor, two megawatts, you would complete the review in 1.8 days.

So, there isn't a direct scaling between that. And there's not also a direct scaling between level of NRC resources to do it.

However, with that said, the NRC does need to be effective and efficient, making timely decisions, and we -- the level of resources need to be commiserate with the risk posed by the reactor designs.

So, you can't scale it directly to power, but both the schedule and resources need to be commiserate.

MEMBER MARCH-LEUBA: Yes, I agree that you cannot scale it by -- you have to scale it to risk --

MR. MONNINGER: Yes.

MEMBER MARCH-LEUBA: -- as you were saying. And unfortunately, to know what the risk is, you have to have a good PRA to start with.

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: And so, you need to understand what can go wrong --

MR. MONNINGER: Right.

MEMBER MARCH-LEUBA: -- and that's where you need your knowledge and your calculations.

MR. MONNINGER: Yes.

MEMBER BALLINGER: I'd be a little careful using the APR1400 as an example, since that was a System 80+ design and still took 42 months.

MR. MONNINGER: Right.

MEMBER BALLINGER: As opposed to, we reduced it to 42 months.

MR. MONNINGER: Right. And then, for the NuScale application, we established timelines that were even shorter than that, but I think, when you look at some of the micro-reactors, non-light water reactors, there's interest in even a much significantly shorter schedule out there. And --

CHAIRMAN CORRADINI: We're going to try to be quiet so you can get through your last set of slides.

MR. MONNINGER: Okay. So, the confirmatory -- in terms of cost and effort, if we do confirmatory analysis, it's got to be in line with the overall NRC review costs.

And the last one is, say, for example, our tools did not have the level of robustness in an area or we didn't have a model to explore a certain thing, and we still had a desire to do confirmatory analysis, but we didn't have a tool, the burden then to address that would be placed upon the applicants.

We would issue RAIs, we would do audits, we would discuss their testing, or in the end, we could put limitations on operations to address that area.

So, we mentioned Research leading the effort, with our staff in NRO. They're looking at it for a range of applications.

Here's some of the factors that are being considered. I believe Steve might have potentially, Dr. Steve Bajorek had potentially been to the ACRS in the past, discussing the CRAB suite. So, a lot of this is from the approach that they have discussed in the past.

CHAIRMAN CORRADINI: What -- can you repeat that? I don't think I understand.

MR. MONNINGER: So --

CHAIRMAN CORRADINI: Because I don't think Steve has said anything to us, at least in a formal meeting structure, that I'm aware of. Did he?

MR. MONNINGER: Yes.

MEMBER REMPE: He answered questions about, when we had -- there were two documents on that Vision and Strategy --

MR. MONNINGER: Yes.

MEMBER REMPE: -- and Steve was involved heavily, I think, in the second one.

CHAIRMAN CORRADINI: Oh, for Strategy --

MEMBER REMPE: And he answered some questions, yes.

CHAIRMAN CORRADINI: Okay, fine. Excuse me, I'm sorry.

MR. MONNINGER: Okay.

CHAIRMAN CORRADINI: Yes, Joy's right. Sorry.

MR. MONNINGER: So, I think a lot of the points here, I've addressed or you've asked question on, the verification validation. In terms of running the code, it would be much more beneficial to use if we could perform it in-house or have facilities available to run those.

Proceeding forward, in terms of doing an assessment of the codes and where the codes potentially have gaps or need to be further enhanced, the Office of Research is looking at the Predictive Capability Maturity Model, I guess was developed by Sandia.

And it characterizes the codes in these

six different areas. And it then asks you to assess where you are, in terms of these various areas. And this is currently being done by the Office of Research for us, and these are some of the areas we would engage with the ACRS in future meetings.

CHAIRMAN CORRADINI: Can I take you back? I told you we would be quiet, but then -- if you go back to Slide 19? Yes.

So, I work the problem backwards in my mind, maybe it's because I'm just a -- I was going to use the word lazy engineer, but as an engineer, you work the problem backwards.

You start with the big system and you work backwards. And so, the big system tells me, the thing that worries me is source term transport. And I was looking for that word somewhere in that slide and it isn't there. So, that's what leads me to your backup slide, which you used source term.

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: So, when the time is right, I want to get to the backup slides, because the concern I've got is, we, even as a Committee, have lost one of our experts and need that --

MR. MONNINGER: Right.

CHAIRMAN CORRADINI: -- so that we can have a timely review of what you present us, when it arrives.

MR. MONNINGER: Yes.

CHAIRMAN CORRADINI: So, source term, to me is the thing that drives a lot of this from a safety analysis standpoint.

MEMBER KIRCHNER: Mike, may I chime in at this --

CHAIRMAN CORRADINI: Sure.

MEMBER KIRCHNER: -- point.

CHAIRMAN CORRADINI: Go ahead, Walt.

MEMBER KIRCHNER: Yes. I have the same concern. I haven't heard about prioritization of your investments and efforts.

The first thing you're going to have to deal with, in my opinion, is the source term issue, because any of the applicants is going to want to address emergency planning.

So, you do have a draft Reg Guide that's part of rulemaking, but it's essentially silent on how to develop the source term.

So, there's both the procedural aspect of developing the source term, that would be adequate to convince you that PRA, classes of accidents, then subsequent failure or disruption of some kind, transport through multiple barriers, then dose consequence in the environment.

So, it would seem to me, that would come to the fore. I'm less concerned about physics, about reactor physics that is. Those codes are pretty mature. Cross-sections, that's pretty mature. Thermal-hydraulics is very well developed.

So, it seems to me, looking at your earlier chart, if you say to first order on Chart Number 8 that any of the new concepts are also going to have to demonstrate capability in all those areas that are on that diagram, I immediately go right to the source term, as an issue that will stymie a timely review, if the capability isn't there, the methodology, and the data, experimental data, to back it up, and the codes that are validated to make that case.

Otherwise, I think the applicants will have to fall back on some scaling, based on 0396, because this is a very difficult -- I mean, there's been a huge investment by both you, the DOE, the industry in getting to where we are.

And it seems to me that somehow, when you overlay the map of all the concepts that are out there, that you might have to review, you've got a very full plate.

And it seems to me, you've got to start thinking about prioritizing where you invest and where you perhaps rely on someone else. Maybe that's coming up in another slide.

But I see this source term, mechanistic source term, it's a term of art that's thrown out very lightly, but it's an extraordinarily difficult thing to do and back up with real data.

And that, again, since it will impact early on things like emergency planning, which will impact decisions about whether to go forward with the actual concept, I see some need to prioritize.

The other, since I've interrupted you, it seems to me the other thing that you need to consider as you look at the concepts and say, in each of these different concepts, where are the cliff effects? Where can things go -- it's a variant on what Jose was pointing out, the unknowns. Where can things go wrong with a major change in results?

And they're there for several of these concepts. And it's a different phenomena than what you would see in an LWR.

So that, to me, also would provide a means to start thinking through, well, we've got this large waterfront to cover, our resources are limited, where are we going to put our investments going forward? Thank you, Mike.

MR. MONNINGER: So, fully agree with you. And I think in our subsequent meetings, we'll cover source term, we'll cover beyond-design-basis accidents, et cetera. And we'll also cover the work that we want to prioritize.

MEMBER REMPE: Actually, would you put up Slide 23, that's your backup slide, since Mike mentioned it, which is hard to see with the lighting in here. No, this was the one I wanted.

MR. MONNINGER: Yes.

MEMBER REMPE: Okay. So, the fact that you have MELCOR on there with a dashed line means that, when you're looking under -- it says Comprehensive Reactor Analysis Bundle Under Evaluation, that means none of the DOE codes have been developed for evaluating source term. Is that what we should all conclude here?

MR. MONNINGER: Yes. So, it was deliberately put in backup slides, for one. So, the Office of Research is working through a set of potential recommendations for design-basis accidents, and on the next slide, for other areas, including severe accidents.

It's still under consideration. They're developing the report. We've iterated somewhat with them on the report and recommendations, but we haven't made any real decisions on going forward.

CHAIRMAN CORRADINI: This is what you were hinting at earlier?

MR. MONNINGER: Yes. So, this is what will come in the future meetings, to discuss with you. But we have to make sure we have something to share with you, we want to share our report and recommendations with you.

MEMBER REMPE: Yes, it's just kind of interesting with all the attention being placed on what DOE has done.

MR. MONNINGER: Right.

MEMBER REMPE: This meeting, that you're basically relying on what you have, I'm wondering, it's going to be curious to see what the different applicants are going to use. I mean, some of them may come in with the NRC --

MR. MONNINGER: Right.

MEMBER REMPE: -- tool for the source term.

CHAIRMAN CORRADINI: That's a good lead-in for your takeaways.

MR. MONNINGER: Yes. So, then, the takeaways. We will be back and we're looking forward to it.

(Laughter.)

MR. MONNINGER: It'll actually -- so, my presentation's actually easy, because I'm at the 40,000-foot level. So, the staff staff will be back at the next meeting.

So, we're assessing our needs, recommendations. It's really important to us to get the ACRS's feedback. We have really taken to heart the need to be ready.

And we want the best insights from Research, we want the best insights from our staff, we want the best insights from the ACRS, and we want the best insights from DOE, and we want industry to know where we're going and why.

And we will ask, eventually, for a letter on that.

CHAIRMAN CORRADINI: That actually -- to me, that's important. Because I want to make sure when we feedback, we feedback to the appropriate place with staff. So, I appreciate it.

Questions by the Committee for John before we switch to the next speaker? Okay. I think Andrew is next, is that -- do I have that correct? And you have a helper? Okay.

Okay. We have a big audience that's anxiously trying to get a copy of your slides. Why don't you go ahead, Andrew?

MR. PROFFITT: Okay, thank you. Good morning. I'm Andrew Proffitt, I'm the Project Manager for Accident-Tolerant Fuel in NRR. Thanks for having us here to talk about our plans for confirmatory analysis for ATF designs.

I don't think I could have asked for a better lead-in from John and some of the comments so far from the Committee. I think we're well aligned. So, next slide, please.

Outline of a few things I'll talk about. I'll just briefly touch on our approach to confirmatory analysis, I think John did a pretty good job of covering all that. We're completely aligned with his presentation, I just wanted to include it here for completeness for the slide deck.

Go through our confirmatory analysis strategy for ATF and what we plan to employ for confirmatory analysis.

And then, also touch on our coordination and interactions with the Department of Energy on their advanced modeling and simulation tools, as it applies to ATF. Next slide.

So, just very quickly, our approach to confirmatory analysis is generally informed by the phenomena important to safety.

And we are undergoing, as part of the ATF project plan, which we just finalized in September, we outline a strategy for conducting phenomena identification and ranking table exercises.

CHAIRMAN CORRADINI: If I might just interject, just for the Committee's sake, we did get a copy of that. That was part of what's on the G Drive for the Committee to look at.

MR. PROFFITT: Okay.

CHAIRMAN CORRADINI: Sorry.

MR. PROFFITT: Great. So, our evaluation can range from a number of things. It can include just a review of the information provided by the applicant or licensee, where the reviewer draws on previous knowledge and accumulated expertise to reach a safety determination.

We can employ confirmatory calculations, which could range from things like John mentioned, quick and simple, back of the envelope type things, to more complex, even coupled code systems to model significant portions of a reactor system.

And even it could, in some rare cases, maybe just pursue independent confirmatory testing in support of reaching a safety finding.

So, in general, for ATF, the staff expect that our approach for most designs will likely follow the middle bullet there, we'll use independent confirmatory calculations to assist us in reaching our safety finding in an efficient and effective manner.

And this goes to a lot of things that have been mentioned this morning, with ATF in some cases being first-of-a-kind, to understand sensitivities, to have the reviewers full understand the phenomena that are important. So, quite a few things, and I think a lot of that's been mentioned this morning. Next slide.

So, our strategy for ATF in seeking to support a most efficient and effective review, we considered several avenues.

We've considered enhancing NRC's existing NRC codes to model ATF concepts. We've also looked outside the NRC, at DOE, vendor, and commercial codes.

And we've used other codes besides NRC staff-sponsored codes in the past in certain areas, so there's been instances where we've run vendor codes in support of our safety analysis, there's been uses where we've used commercial codes in support of our safety analysis. And this also includes the DOE's advanced modeling and simulation capabilities.

Key factors for determining which approach would be appropriate for ATF would be the staff's experience and knowledge using the tool, along with any associated learning curve that would be required for the staff to become proficient with modeling in the code, and also, a full understanding of the assumptions and limitations of the tool. Yes?

MEMBER REMPE: Okay. So, I was very interested in the document and I looked through your slides. And so, a lot of my questions today are coming up spontaneously on different slides, because I don't know where else to put them --

MR. PROFFITT: Okay.

MEMBER REMPE: -- because there's a lot more content in that document.

MR. PROFFITT: Yes, absolutely.

MEMBER REMPE: For example, right now, in your document, you explicitly say, hey, in the near-term, we've been told the vendors are going to use their existing tools, because -- and you've made the conclusion, we're going to be also using our existing tools.

And I mean, last meeting, Shane Johnson said, well, he thinks it's because it's cheaper for them to continue on with their existing tools. And I figure you're doing it for the same reason.

MR. PROFFITT: Yes.

MEMBER REMPE: In light of that, are you in the driver's seat for working with the vendors on what data they need to modify their existing tools, so that they will be appropriately validated for this application?

And then, also, so you can use your tools to apply them for that application? Because it seems like there's some good cost savings to be done at this time.

The other thing is that I didn't see anywhere in your slides today that discusses the application that the vendor has in mind.

And my understanding from most recent discussions I've heard, is that the vendors have realized that the ATF will cost more. So, in order to deploy it, they have to have a good economic case.

And in your document, you identified some tasks that involved using the SPAR model to try and -- because, I mean, they want regulatory relief to have that economic benefit.

And it looks like you've been thinking along about, well, what are we going to have to be evaluating by having those tasks with the SPAR models?

And so, when I was looking at that, I was also thinking about, this would be great for a collaborative effort. The LWRS program has recently spent a lot of effort to focus on the economics of light water reactors.

And have you been discussing with the Department of Energy how this might be -- I mean, you've got the tools with the SPAR models.

I'm not sure, I think there's something in the risk MC stuff that might be usable, but it seems like to me that this would be a good collaborative DOE/NRC effort. Has that hit your radar yet?

MR. PROFFITT: Okay. Well, I'll try to start with, I guess, the first question on the data. So, we do have -- we've added an addenda to our Memorandum of Understanding with the Department of Energy, such that we can help with data sharing.

We've had heightened engagement with all the vendors. Currently, we're trying to understand their fuel qualification testing plans and their testing matrices, to see what data they anticipate gathering and we want to facilitate obtaining that data before licensing submittal, so that we can incorporate it into our codes.

I know in one example, for FeCrAl, we've been using DOE handbooks that have been published out of Oak Ridge to incorporate properties already into our FAST codes.

And the project plan, I think, acknowledges that fact, that the need for real-time data is very important to be able to ensure that our codes are developed in a timely manner.

MEMBER REMPE: So, are there some examples where you've identified some data that perhaps some of the vendors have forgotten about and that they are being receptive to your input and saying, yes, you're right and we'll make sure we get that data too? I mean, how is this interaction working?

MR. PROFFITT: So, I think we're a little bit early in that process. We have initiated for the coated cladding concept of ATF a PIRT exercise.

And so, certainly, we all have some ideas in our minds of what things may need to be addressed, but we definitely want to let that take its course.

We're expecting a preliminary report from that in early next year, maybe in the January timeframe. And then, an expert elicitation process to go through and have outside experts take a look at that preliminary report and provide us feedback.

And so, following the PIRT, I think we'll have a much better idea and a much more robust document, to be able to go down those avenues with the vendors. But we're certainly starting those conversations now, but I think we'll be in a better place once we complete that.

MEMBER REMPE: Okay.

MR. PROFFITT: And then, to the second, looking into the application that the vendors have in mind, we're certainly having those discussions.

One of the things, EPRI is working on a document called ATF 2.0, that we're expecting early next year. And that's looking at potential cost recovery, margin recovery efforts that they may be undertaking. So, they've done round one to that study, they didn't make it publicly available yet.

But we're certainly staying engaged and we're anxiously awaiting that, because we do want to be prepared for where -- the first step is, obviously, batch licensing under the current regulatory regime, essentially.

I mean, that's what we've heard from the vendors, that's the effort they want to go through, because they don't think they'll be able to take advantage of all the benefits of the ATF until they get a full core in anyway, so that will take a couple reloads.

So, our understanding of the process they're looking to follow is, get it in under the current paradigm and then, come later, a couple years later, and look to capitalize on some of those benefits, potentially.

MEMBER REMPE: In your task description, you actually specify, we need to do pilots. And I think that's a good point, because I don't think you can do a generic, oh, this is going to be more economical, I think it's going to be very plant specific.

And again, I think, if you can work with some other industry organizations or DOE to try and find that -- develop those insights and, if it's possible, I think that would be important to help facilitate this process.

MR. PROFFITT: Yes, absolutely. And I've got some of our risk folks here, I don't know if they wanted to speak more to the LWRS program or -- I'm not too familiar with our interaction there. Okay, I see, okay. We'll save that for later.

MEMBER REMPE: Thank you.

MR. PROFFITT: Thank you.

CHAIRMAN CORRADINI: Don, did you want to add something?

MR. HELTON: I can, unless you want to move on.

CHAIRMAN CORRADINI: Go ahead.

MR. HELTON: Okay. Don Helton, Office of Nuclear Reactor Regulation. I just want to point out, the Agency has been engaged with the Risk-Informed Safety Margins Characterization Pathway of Light Water Reactor Sustainability, so we are familiar with the risk tools that they're developing under that.

The pilots that were mentioned under the ATF plan are part of making sure that our PRA modeling is ready for the oversight function it needs to fill once these accident-tolerant fuels are actually in operation, to make sure we're modeling the as-operated as-built plant.

But to -- and I don't know if that's a sign from above --

(Laughter.)

MR. HELTON: It was well coordinated there with the lights going out.

CHAIRMAN CORRADINI: You can take that as a sign.

(Laughter.)

MR. HELTON: As my wife would tell you, I'm not good with picking up on subtleties. The only other point I would make is that, to Dr. March-Leuba's earlier point, we're aware of the fact that, as we proceed towards licensing, there are going to be questions about what the changes in risk are and how that should influence our prioritization of activities. And so, that is the other benefit of the pilots that you mentioned.

MR. PROFFITT: Okay.

CHAIRMAN CORRADINI: Feel free to move on.

MR. PROFFITT: All right, next slide. So, we've decided that, for near-term concepts, that the best approach will be to modify our existing codes, which will hopefully require minor modification.

CHAIRMAN CORRADINI: So, clarification, near-term means coated claddings and doped fuel?

MR. PROFFITT: And --

CHAIRMAN CORRADINI: What is --

MR. PROFFITT: -- FeCrAl, I would say, is on the edge of that. So, that's sort of one that we're considering. But, yes.

CHAIRMAN CORRADINI: So, it's a boundary?

MR. PROFFITT: It's more in a gray area, I guess, but yes, coated claddings and doped fuel.

So, those areas include fuel performance, thermal-hydraulics, neutronics, and severe accident source term progression.

So, the decision was based on several factors, with the highlights being, our codes are very tailored to evaluate the regulatory requirements, meaning they're more focused to the objective than tools seeking to model the entire system in greater fidelity.

The staff in the Licensing Offices and in the Office of Research are very familiar and comfortable using our existing suite of codes. There will be a very shallow learning codes to enable modeling of ATF and we believe we'll have high confidence in those results.

For the near-term ATF concepts, as I mentioned, it should be very minor modifications required and in some cases, we've already begun implementation of those modifications.

And then, the last bullet, there's no codes that are currently validated for AFT. So, all options would require the staff -- and for the staff to rely on an outside entity on this aggressive timeline would also involve some risk in that decision. So, that went into our thought process.

And also, in this consideration was the understanding that any development would need to precede licensing activity, so timeliness is very important to us in this. Next slide.

This is from the ATF project plan. It gives a graphical view of the process for updating these codes. And as I mentioned before, the PIRT exercise is our first step in this process. And as I mentioned, it's currently underway for coated claddings.

This will ensure that all new phenomena important to safety are identified and considered in the planning phases. The results will be used to inform the code development efforts.

The next step would be scoping studies, which have already been performed with the current knowledge base, but will be augmented following the completion of the PIRT.

Then, where necessary, the code architecture modifications will be made. For example, to move Zirc UO2 hardwired properties in the codes, or assumptions, and things similar to that, that have been based on the use of the current fuel technology for the past several decades, essentially.

Material properties will be added and new models will be developed where necessary. And this also -- these arrows back and forth indicate the interaction between the testing data, as it comes in, and the model development and how that moves forward.

And so, that's obviously very important and that's highlighted in the project plan, that near-term data acquisition will be very important in ensuring our readiness.

MEMBER MARCH-LEUBA: Do you consider the chemistry of these fuels in corrosion, iron transport, things like that, on your validations? Or would that be 100 percent experimental?

MR. PROFFITT: So, I think at this time, it will probably be experimental, it will probably be empirical in nature. But I don't know if Ian is with us this morning, our fuel performance, to maybe give any other --

CHAIRMAN CORRADINI: Everybody else is here, so --

(Laughter.)

MR. PROFFITT: Yes, that's right.

MEMBER MARCH-LEUBA: As Mike said before, we've lost our chemist in the membership.

CHAIRMAN CORRADINI: It goes beyond -- I think Jose's point is well taken, it goes beyond just source term, it goes beyond to chemistry effects relative to normal operation, as well as under accident situation. Oh, there he is.

MR. PORTER: Okay.

CHAIRMAN CORRADINI: You've got to turn a switch.

MR. PORTER: All right. Ian Porter, Office of Research. So, largely, we're going to be empirical at this point in time.

And most of the chemistry effects, we actually do not directly model a lot of chemistry in the fuel thermomechanical area. More so, I think, some of the source term guys probably deal with that more than we do.

So, it's largely going to be what the data, what comes out, what's shown, what models can we develop from that? We don't really -- so far, we haven't heard anything that's going to require significant changes to how we currently do the thermomechanical analysis.

Now, when we talk the longer terms, maybe the silicide fuels, some of the other metallic fuels, will have a very different behavior that we'll need to consider.

But so far, we haven't seen anything that's going to fundamentally significantly change how we do our review.

MEMBER MARCH-LEUBA: Hopefully, this corrosion and surface -- chemical effects on the surface of the fuel will be slow developing and can be catch as it happens.

MR. PORTER: Yes, that's what we're expecting. I think the one area is the FeCrAl, we've noticed the two different types of oxidation layers that can form.

That's going to be very different than how we've handled it with Zirc oxide, but other than that, we haven't seen anything yet that's been a concern.

MR. PROFFITT: Okay. I'm going to skip my next couple slides, they're on each of our capabilities, but they were really largely included here for reference, in case folks wanted to dig more into them. And they're also addressed in the project plan, in the reference material.

CHAIRMAN CORRADINI: Since you put them in --

(Laughter.)

CHAIRMAN CORRADINI: So, is FAST going to be the new FRAPCON, FRAPTRAN --

MR. PROFFITT: Yes.

CHAIRMAN CORRADINI: -- tool?

MR. PROFFITT: Yes, it's the combination --

CHAIRMAN CORRADINI: That's a clear decision by the staff?

MR. PROFFITT: Yes.

CHAIRMAN CORRADINI: Okay, because sometimes I've asked that in the past and it is a -- I got a fuzzy answer. So, it's a clear answer that FAST is the new form going forward?

MR. PROFFITT: Yes.

CHAIRMAN CORRADINI: Okay, fine.

MS. GAVRILAS: We've got thumbs up -- this is Mirela Gavrilas, Director for Safety Systems in NRR. We got thumbs up from Ian as he was sitting down that that is indeed the case.

MR. PROFFITT: Okay. So, I want to move to Slide 11 --

MEMBER REMPE: Actually --

MR. PROFFITT: Go ahead.

MEMBER REMPE: Since you did put them in --

(Laughter.)

MEMBER REMPE: I'd like to just get some

clarification on your thermal-hydraulics slide, because earlier, I brought up in prior meetings the fact that, if we believe the claims of accident-tolerant fuel, you'll be in a situation in the core where you have lost your control materials, but you still have the fuel and you're going to have to re-flood.

And TRACE does not have that capability. And so, is your plan to try and have something that's either a MELCOR, TRACE -- you've got to have thermal-hydraulic feedback and consider the effects of boron injection, or whatever they're going to do, unless somebody does accident-tolerant control rods.

And if you, again, if you want to get regulatory relief, it seems like you better understand that situation. And I'm not sure that the DOE codes or the vendor codes or your codes are doing that yet.

MR. PROFFITT: So, I think in the near-term, which is what we're really focused on here, now, is we don't expect that to necessarily be an issue, but certainly, in the longer-term, that would be a consideration we would need to consider with some of the more advanced, some of the longer-term concepts that are ATF, where that could potentially become an issue.

But I think, for the near-term concepts, we think our current suite of codes, with relatively minor modifications, will be able to adequately support the calculation we need to perform.

MEMBER REMPE: Okay, thank you.

MR. PROFFITT: Okay. So, our coordination with DOE on advanced modeling simulation. So, the project plan, again, which you guys have, acknowledges that potential to leverage DOE's advanced M&S tools, especially for the longer-term concepts.

But let me highlight a couple other things, though. There was a recent targeted effort to couple NRC's TRACE code with DOE's BISON fuel performance code through MOOSE, an independent solver, and that's given the staff a significantly greater understanding of the DOE codes.

So, this is just to highlight a couple of recent examples of where we've been interacting with them.

CHAIRMAN CORRADINI: This is a comment, which you can choose to ignore. Coupling codes sounds good, but it can create complications that I don't think -- to the chance that you actually get something out of it, in terms of feedback, is important.

But I think you want to not do this,

excuse my words, willy-nilly. Because it just creates -- it could create a nightmare, in terms of the ability to do a timely calculation, I won't use the word quick and simple, but I'll use the word timely calculation, to understand what's going on.

MR. PROFFITT: Yes, I would say, to your first point, it was an exercise for us to become more familiar, to have better understanding, and to increase our knowledge of the DOE systems. So, that's largely what we used it for.

We've also combined elements of -- oh, go ahead.

CHAIRMAN CORRADINI: And all I was going to say is, I'm not trying to say the tools are not appropriate, but sometimes, it's the connection that can cause an issue, not the individual tools, which could be quite robust.

MR. PROFFITT: Yes. So, we've also successfully combined elements of DOE codes under the CASL program and NRC's neutronics code, SCALE.

These efforts have demonstrated that specific opportunities exist to leverage elements of DOE codes to improve the NRC's analysis capabilities. So, we expect to continue to follow and continue coordination with DOE.

And onto the next bullet, to this effect, we've been coordinating with CASL on a focused ATF effort. This came out of, I think, the same appropriations bill that John was mentioning.

They had directed DOE to -- in the FY18 Omnibus Spending Bill, the CASL language includes, quote, collaboration with the NRC to evaluate the use of high fidelity modeling and simulation tools in the regulatory environment.

And so, CASL has chosen to center this collaboration on ATF. And so, they had proposed a program plan with some specific milestones and they provided that to the NRC for feedback.

We've provided them feedback on those milestones and we think it will end up being very valuable. So, we're actively working with DOE on that.

CHAIRMAN CORRADINI: So, let me ask you a loaded question there, is there actual experimental data that you can do what you just said?

MR. PROFFITT: Is there --

CHAIRMAN CORRADINI: I heard from her question that a lot of this would be potentially empirical, requiring experimental data. So, my next question is, if I get even more resolved in time and space, do I really have the experimental data to know what I'm doing is right?

MR. PROFFITT: So, that's currently underway. DOE is working with the vendor partners to produce data. They have experiments going on in ATR 1 and ATR 2, and I see some DOE folks, I don't know if they want to add any more. But there is data acquisition going on now, absolutely.

So, we actually have a kickoff meeting to discuss some of these milestones and some of the highlights are listed there in the sub-bullets on the bottom.

But one of the big things is, awareness for our end-users. Our staff in the Office of Research have largely been following these DOE advancements in modeling simulations. So, bringing some of this acknowledgment into NRR, the staff that will be performing these reviews.

One, to be aware of the capabilities for potential adoption, but also, aware of the capabilities for any use that the vendors or others may seek to use them for. So, it'll really help to increase our awareness and understanding of the capabilities.

Another one is, developing the uncertainty quantification and documentation of the BISON models for ATF concepts.

So, once of the big things here that we could do, while we may not adopt a DOE-sponsored code for near-term ATF concepts, we may be able to steal a model from their code and incorporate it into our code. So, that may be very well -- or use the way they model a code to sort of judge how a vendor may be modeling that phenomena in their code.

So, even if we don't fully adopt a DOE-sponsored code, there still could be great benefit to staying involved in that.

CHAIRMAN CORRADINI: So, let me pursue that, to make sure I understand. Because what I hear you say in a different manner is, you would establish with the vendors or the DOE or some team a set of standard problems that you would work on, to see where the uncertainties are, at least if I were to design it, where the uncertainties are, where I need empirical data.

Because I think Joy's point is quite important, that without the data that would either drive you to an empirical model, whether it be normal operation corrosion or oxidation under elevated temperatures, you'd almost need, like, a set of standard problems that you focus on and work on, to see where the uncertainties are. Am I getting close to what the plan is?

MR. PROFFITT: So, I don't know that we've fully proposed that in this area. We have, I think, have some proposals for that in other areas. And I don't know if anyone else wants to jump in to supplement my knowledge in that area, but that's certainly a good concept.

MEMBER REMPE: So, as you've mentioned earlier about, well, there's data coming from those ATR tests, most of that data will have to be cook and look obtained data, which means there's additional uncertainty.

And I would just be careful about trying to fine tune a bunch of models to something that has additional uncertainty in it, is a concern also I have.

MR. PROFFITT: Okay. Some of the other areas that we're looking is benchmark problems for ATF and transition cores.

And one of the areas here would be in neutronics, where if the DOE could use their codes to do sort of a benchmark problem or sample problem and the NRC tool, which is much simpler and has the methodology, has certain assumptions and limitations, if we could use that as a sort of benchmark, to give us a feeling that our methodology is appropriate, giving the high fidelity nature of the DOE codes, in that certain circumstance.

Some of the other areas, still on this same slide, is the development and demonstration for longer-term ATF concepts.

And one of the highlights there that I wanted to add is, it goes back to sort of one of our decision making tools for using our codes for near-term is that they're very tailored to the regulatory requirements and very easy to use for the staff.

And so, one of the things that the DOE is looking at doing here is improving the post-processing to incorporate fuel design limits during normal operation and AOOs and things like that. So, that would make it potentially easier for us to adopt in the longer-term.

So, basically, just to summarize some of the things that I've said there, and it may be repeating a bit, but get us up to speed on the capabilities of the codes, adopting models and NRC tools and sort of providing a warm fuzzy feeling that our methodologies are good in certain areas.

And then, also, for further consideration in the longer-term adaptation, these are certainly very good steps. And all these steps are just in the next year.

So, this was authorized, I think, in August 2018 and will go through August 2019. And so, we think these milestones that are laid out in the CASL program plan will go a long way in our coordination and help both sides get further along this continuum of moving towards potential use of advanced modeling and simulation.

And I think that was my last slide. Hopefully I didn't go too far.

CHAIRMAN CORRADINI: Okay, thank you. Members of the Committee, additional questions?

MR. SCHULTZ: Andrew, just on your last point, where you're talking, last couple of bullets, where you were talking about comparing the DOE codes, much more complicated perhaps than the NRC tools, to demonstrate or to see if you can continue to use the NRC tools.

Have you thought those types of comparisons through, so that if the comparison is insufficient, you've got a program plan identified, to address that issue?

What I would think you don't want to get into is, finding a result which causes you to feel that you need to enhance the NRC code and then, you've got parallel development ongoing, lots of resources, lots of expense.

So, hopefully, you're thinking about, what if these comparisons show, A, they're good to go, or, B, if they're not good to go, what is going to be the course of action?

MR. PROFFITT: Yes, absolutely. So, I mean, it can be a very slippery slope going down that path, but I think our specific objective here is in the more neutronics area, more well understood, a first principal code type area, where the DOE code that would be very high fidelity, very specific.

And we expect that it will confirm our methodologies and results, but that's sort of the very tailored area that we're looking at doing it. But I agree, I mean, I think we do need to consider --

MR. SCHULTZ: Just to be thinking, what will you do --

MR. PROFFITT: -- what would need to happen, yes.

MR. SCHULTZ: -- if you get into a circumstance where questions arise?

MR. PROFFITT: Absolutely.

MEMBER REMPE: So, I actually thought your plan was very prudent and practical. Is ACRS going to have any additional input on this? It says draft on the document, what's the planned future of that document and --

CHAIRMAN CORRADINI: I propose we take it up at the end.

MEMBER REMPE: Okay.

MR. PROFFITT: Okay.

CHAIRMAN CORRADINI: Because I think John also had some thoughts on that, too.

MR. PROFFITT: Okay.

CHAIRMAN CORRADINI: But I would think that's eventually where our input would fit in.

MR. PROFFITT: Okay.

CHAIRMAN CORRADINI: Anything else? Okay. We're going to take a ten minute break, because we're a little bit late and I want to keep us on track, since I have so many illustrious speakers that want to come in front and talk to us. So, back at 10:20.

(Whereupon, the above-entitled matter went off the record at 10:11 a.m. and resumed at 10:20 a.m.)

CHAIRMAN CORRADINI: Okay, why don't we get back together and let people settle in? Brandon, do you need somebody to help you run it or do you want to run the slides yourself? Christiana is being nice to you. There's a fee. Okay, we're ready to go. So, Brandon, you want to tell us about Kairos?

MR. HAUGH: Yes.

CHAIRMAN CORRADINI: Okay, the floor is yours.

MR. HAUGH: I appreciate that. So, Brandon Haugh, Kairos Power. I'm the Director of Modeling and Simulation, so the group that's responsible for the safety analysis tools, development, validation, and licensing.

So, we're going to go, a little introduction to Kairos, we're a non-light water reactor, advanced reactor company.

I'm going to give you a little bit of introduction to the design and then, we'll talk a little bit about some of the codes in terms for license-basis event modeling, really focused mainly on the ones that we're selecting from the more advanced, newer tools out of the DOE programs.

We have a whole other set of tools that are a combination of existing codes that have some pedigree and serve a certain purpose. I can answer questions to those, but it wasn't the focus of the presentation.

We always start all of our presentations with our mission statement. So, Kairos Power's mission is to enable the world's transition to clean energy, with the ultimate goal of dramatically improving people's quality of life while protecting the environment.

So, we take that to heart in all the work that we do at Kairos and we just wanted to share that with the group here.

So, Kairos is a fluoride high temperature reactor. So, it's an interesting combination of some unique technologies. So, we like to think of it as taking the best out of the three worlds, but we'll leave that up to the judgment at the end of the game.

So, we're taking coated particle fuel, the TRISO particle fuel, in a pebble form, in our reactor design. So, we get high integrity fuel that survives at very high temperatures.

We're combining that with a liquid fluoride salt coolant. So, the salt coolant we're using has a lot of intrinsic safety characteristics, in terms of being able to absorb fission products. So, we have very good control over our source term from the start through the coolant.

And then, we're also a low-pressure pool system, much like the sodium fast reactors. So, we eliminate a lot of the kinetics from an accident scenario by going to a low pressure system. Next slide.

So, I'll just give you a brief layout, since this is a open meeting. We'll give the loop cartoon here. So, we have three loops in our system.

We have a primary loop, which has, of course, the reactor pumps, a heat exchanger to an intermediate loop. The primary loop is a FLiBe salt, our own specification, but fluoride, lithium, beryllium salt eutectic.

The intermediate salt in the intermediate loop is a nitrate salt, very similar to the solar salts used in concentrated solar array systems.

And then, the power conversion system for the initial unit, we're looking at a steam conversion system here. But unlike a traditional light water reactor, this is a much higher pressure stream system, much like a fossil fired plant would be.

A little bit on that one is that at the end, in follow-on units, we predict as the maturity of other power conversion system matures and utilities' abilities to operate those, that there's a potential to change out that power conversion system for other types.

For the fuel system, we're taking advantage of the TRISO particles, multiple fission product barriers ingrained in the very small particle. So, you've got the silicon carbide layers, the pyro-carbon layers, and also, the long-term diffusion characteristics of all of that, at temperature.

Those are inside of a pebble, it's a little bit of a unique pebble design. It's designed to be actually buoyant in the salt, so it's actually neutrally buoyant in the salt at normal temperatures.

So, it has a matrix, carbon matrix ore, much like a graphite, surrounded by an actually annulus layer of TRISO particles that are embedded in a different type of matrix, and then, coated and then, with a graphite on the outside.

So, this is a little bit different than a traditional gas reactor type pebble form. And it actually has a lot of enhanced performance characteristics, in terms of very even fuel temperature distributions, and the neutral buoyancy gives us lots of good characteristics to be able to handle and predict the pebble flow within the reactor.

The particles do stay within the pebbles, in the reactor. The transit time is in the average of a couple of months. And of course, it does vary, it's a little bit stochastic.

When looking at our safety case, the design was really built around this combination of inherent safety features. So, we take advantage of the TRISO kernels and its multiple fission product barriers. We take advantage of the salt coolant and its ability to absorb fission products.

And then, we look at how that performs in our cover gas systems for the noble gases. And then, we have -- that system is within a reactor cavity, which then is within a reactor building, and then, to the environment.

So, when we look at the number of barriers available, there are definitely many of them to count. When we look at design-basis events, we're only going to take advantage of the two main fission product barriers and retention areas, and that's the particle and the salt.

So, that's, when you look at DBAs, we don't take a lot of credit for the building and all the hold up, because we get such good performance out of the kernel and the salt, in terms of fission product retention.

CHAIRMAN CORRADINI: So, what is the -- I guess, the one thing I was expecting to see in the cartoon is tritium and tritium control. Is it just understood that it's there and has to be considered on an operational basis and not an accident basis?

MR. HAUGH: Correct. It's an overall management strategy for the entire operation of the plant. So, we don't envision it being any different during normal operations than it would be during an accident, so that's why it's not called out here. But it's an important part of the design of the plant.

With any lithium based salt, of course, we're going to be producing tritium. Even -- no matter how much we enrich the lithium seven, we're still going to make tritium, so it's an inherent part of the operational scheme.

So, when we look at a very unique design like this, we have to take a fundamental look at all the phenomena associated with that. It's not a traditional light water reactor, the phenomenology is significantly different.

So, much like we talked about earlier this morning, with the PIRT process, we've engaged in that early in the design, approaching it in a slightly different fashion.

The initial PIRTs that we're doing internally are purely phenomenologically focused, based largely on disciplines. So, thermofluids, materials, fuel, and salt.

And in the next iterations, we're going to combine those in event space and combine them, and they'll be looking at evaluation model PIRTs, at the level of non-leak and leak type transients, mechanistic source term, as well as materials behaviors, because it's important in a high temperature reactor.

So, when we look at safety-related code development, I'm going to focus on kind of the four main sets of codes that we look at. And you'll notice, just like we talked about a little bit earlier, this one doesn't address necessarily source term migration out of the salt and into the environment.

So, we're looking at existing tools to do that, because they're actually fairly good and the phenomenology, once we exit the salt, isotopes are isotopes and as long as we understand the form that they're in, they'll be transported similarly.

CHAIRMAN CORRADINI: So, let me ask my

question here, because -- so, is there, perhaps it's company protected, is there an equivalent of what we saw in John's overview, in terms of how to meet the regulations and so, well, I don't want to say regulations, but how to meet the design, the alternate, the advanced reactor design criteria and what tools are necessary?

Because this looks like a limited set, compared to what we'd need. And your last comment made me think that you have other things in mind. So, is there an overall mapping of this that is available or is it still Kairos proprietary?

MR. HAUGH: It's still Kairos proprietary, we haven't released it yet, because we're still doing some due diligence on it.

And part of that is, as a non-light water reactor, we're submitting our PDCs, so our plant-specific design criteria that are adapted from the advanced reactor design criteria, plus other regulatory information.

And in that mapping, we'll follow our PDCs. And so, you'll see a very similar chart, it's just, we're waiting for the review of our PDCs, which will be coming up in a couple of months.

CHAIRMAN CORRADINI: So, these are -- this is, what I'll call a relevant list of the things we're interested in, but not the complete list.

MR. HAUGH: Correct.

CHAIRMAN CORRADINI: Nor a mapping of that.

MR. HAUGH: Correct.

CHAIRMAN CORRADINI: Okay.

MEMBER REMPE: So, I have a question that probably applies to everybody, but I'll start with you, since you're up here first.

MR. HAUGH: Okay.

MEMBER REMPE: You're planning to sell your reactor to people in the U.S., as well as overseas. We heard at our last meeting that DOE is going to maintain ownership of the source code.

How will you -- I mean, okay, you might be able to use these codes to get it licensed through the NRC, but what's the long-term plan for a business case, for using government-retained software to another country, there may be export controls -- I just, I'm puzzled here and it's not really an ACRS, because we advise the Commission and the staff, but I'm puzzled.

MR. HAUGH: I know, and I appreciate that. And what I would say is, correct, that we are looking initially at U.S. markets and potentially other markets.

And how we're approaching the code, yes, the DOE owns the code, but we'll have derivative technology. And so, it's understanding that. So, we have our own versions of these. So, we have KP-BISON, KP-SAM, and --

MEMBER REMPE: And you will own those versions and then, you can sell them to the world?

MR. HAUGH: It's an ongoing negotiation.

(Laughter.)

MEMBER REMPE: Okay.

CHAIRMAN CORRADINI: I think your initial comment, this is interesting, but not our direct concern, is --

MR. HAUGH: Correct.

CHAIRMAN CORRADINI: I'm fascinated, but let's move on.

MR. HAUGH: Yes. Great. And yes, so this is not the full snapshot of all the codes we would use to do the entire safety analysis.

So, the idea when I prepared this was focusing on the tools that we selected that relate to the Department of Energy Advanced Reactor and Simulation Programs, just to kind of tighten the focus.

And so, the important thing, I'll reiterate the phenomenology here. So, we have a fuel form that really doesn't release fission products if it's an intact form, until above 1600 degrees Celsius. The FLiBe coolant's boiling temperature is about 1430 degrees Celsius. And the coolant -- and its freezing temperature is about 460.

Then, we have the materials. So, if you look phenomenologically at high temperature reactors, most of the safety and concern is actually around the performance of the structural materials, because they're the most challenged in terms of their margin, to other types of phenomena, such as creep, creep-induced failure, and things like that.

And so, when we look at our combined safety case, we try to focus on that. And so, you'll see other codes come into play, really focused on structural materials. And there's more that we're evaluating beyond some of the list here, just to reiterate that.

So, in the systems code model, we've chosen the SAM code, developed out of Argonne National Lab, and it is based on the MOOSE framework, like the three top codes are on that list.

And we chose that for multiple reasons.

The first one being, we're a single-phase plant in a primary and intermediate systems.

And so, we didn't need the complexity of, like, a legacy code that had spent a lot of effort focusing on multi-phase flow phenomena. So, we have a lot less to worry about in terms of disturbing the code, when we're only focused on making changes for single-phase salt.

The other thing is, it's a modern programming language and in a modern programming framework. And so, actually getting young, energetic engineers who can rapidly get up to speed on the code and also rapidly adapt it to our design was a factor in the selection process.

As well as our ability to leverage the community in the Department of Energy, which has a lot of expertise in this area and has a strong willingness to support industrial application of these tools.

So, with these tools, we recognize they're not at a pedigree for licensing yet. So, we have code development activities that are actually ongoing and they're actually being co-developed with the labs.

So, we've identified phenomenologically, in our first set of PIRTs, what we need to add to the codes, based on what the code can do and based on what our reactor needs it to do.

We developed a Code Development Plan and we're implementing that right now.

CHAIRMAN CORRADINI: Can you just remind me what AGREE is? I know what PARCS is, what's AGREE? Is this for TRISO fuel?

MR. HAUGH: Yes, it's for pebble bed or a gas reactor. So, they have a hexagonal and a pebble form, so it's the thermofluids part of a full neutronics package. So, it's the thermal-hydraulic aspect of it.

CHAIRMAN CORRADINI: It's what you plug in and take out TRACE?

MR. HAUGH: Yes. Yes, or other codes. But it's just focused on the core, so for us, it's a porous media approximation to the pebble bed.

CHAIRMAN CORRADINI: But is it for both transient and steady-state analysis?

MR. HAUGH: We're just going to be using it, actually, for transient analysis. For steady-state analysis, we're using Serpent --

CHAIRMAN CORRADINI: Okay, fine.

MR. HAUGH: -- which is actually a Monte Carlo code, and then, we're actually coupling that, the thermal-hydraulic feedback, to other codes. There is a sequence there.

CHAIRMAN CORRADINI: Okay. Thank you.

MR. HAUGH: Yes. So, we're also going to use BISON for fuel performance modeling. Now, the initial BISON work was largely focused on light water reactor modeling, but they've already begun the TRISO implementation.

And we're accelerating the completion of that, by taking the knowledge base and phenomenology that's associated with what's in the PARFUM code and implementing a lot of those material models and everything into BISON, and then, using the solver in BISON to complete the analysis.

CHAIRMAN CORRADINI: So, well, I mean, this is out of my -- source term is not my area of expertise, but I want to make sure I understand. So, there's -- the physics package that really is being used and adopted is PARFUM?

MR. HAUGH: For the --

CHAIRMAN CORRADINI: Into BISON, which then would --

MR. HAUGH: Partially. So, the empirical closure models and material models are taken from PARFUM, that have been developed for the AGR program and the TRISO particles.

CHAIRMAN CORRADINI: Okay.

MR. HAUGH: But the actual mechanics modeling and everything is what's in BISON. And from a source term standpoint, the isotopic inventory is coming from really our steady-state physics code, which is Serpent Monte Carlo code and its depletion engine.

So, that generates the isotopic inventory that we use to validate the isotopic buildup that we put into the fuel particles in BISON.

CHAIRMAN CORRADINI: But let me take it through in a simple fashion, I think we have a couple minutes. So, PARFUM has, we'll call it empirical laws of inventory release as a function of temperature and chemistry.

Now, as I take myself through potential accident scenarios, best release is into the molten salt. What is used in the molten salt, in terms of fission product transport, then?

MR. HAUGH: Correct. And we're examining either implementing fission product transport in the salt, will be empirically modeled, in terms of the chemistry.

So, we're actually going to measure all the solubility characteristics and transport characteristics of all the isotopes or elements in the salt.

And then, those will be implemented into a systems code for the transport around the loop. And then, we'll have to deal with the interfaces to the gas areas, and potentially, if there's any wetting or aerosols that are developed.

CHAIRMAN CORRADINI: But if I put it crudely, it's to be determined?

MR. HAUGH: Correct.

CHAIRMAN CORRADINI: Okay. That's --

MEMBER MARCH-LEUBA: You're going to experimentally determine the solubility of every single element on your salt?

MR. HAUGH: Every element that's significant to source term.

MEMBER MARCH-LEUBA: And you have a plan to do that? I mean --

MR. HAUGH: Yes. And we'll start doing those measurements at the beginning of the year.

MEMBER MARCH-LEUBA: You, yourself?

MR. HAUGH: Yes.

MEMBER MARCH-LEUBA: It will be proprietary data?

MR. HAUGH: Yes.

MEMBER MARCH-LEUBA: Will it be funded by DOE?

MR. HAUGH: We're paying for it ourselves. Okay. And the last one to focus on is, we've chosen the GRIZZLY tool out of INL, which is an advance structural materials modeling code, finite element based, to use as a framework as we develop all the materials models and creep models for high temperature performance.

So, the team, the GRIZZLY team there is extending from their traditional light water reactor initial implementation into the appropriate modeling for high temperature reactors.

And we're actually working across three labs to develop material models. So, we're working with LANL, Argonne, and INL to do that.

There's also a recognition that there are environmental effects on the materials being in a salt environment and so, we actually have to develop environmental kind of aging models for the materials as well.

And then, for core physics transients, it's PARCS/AGREE. So, that's a nodal code, not necessarily one of the advanced tools, but I thought it was important to mention here, because that's also at tool potentially the NRC could be using as well.

MEMBER MARCH-LEUBA: What's this -- do you have control rods? How do you control reactivity?

MR. HAUGH: We have control rods, correct. Yes. In various locations.

MEMBER MARCH-LEUBA: Yet to be determined?

CHAIRMAN CORRADINI: Oh, no, I think it's determined --

MR. HAUGH: Yes, it's --

CHAIRMAN CORRADINI: -- yet to be talked about here.

MR. HAUGH: Correct.

MEMBER MARCH-LEUBA: Okay.

MR. HAUGH: Okay, thank you. And a little bit about our development paradigm. So, we have a full recognition, the amount of validation data needed for a new reactor of this type is significant.

And we're invested in that from the day one, when the company opened. It was actually initially mostly testing focused. So, the first people hired were, like, test engineers and things like that, because those are the long-lead items.

So, we look at the conventional nuclear development cycle, which has been lately maybe not so successful, as very much a: do a lot of planning and a lot of design, but not very much building and testing. It's expensive and, one, it's pretty hard to get somebody over that threshold to go spend the money on physical equipment.

We've taken it more in an accelerated pattern. What you'll look at is, a lot of technology development companies that have been more recently successful have embraced this rapid iteration process. And so, our process is very much the same: plan, design, build, test, just keep rinse and repeat.

And we do this at various scales, starting with simple, small materials that we can easily rapid prototype using salts and heat transfer oils for scaled analysis, and then, going all the way up to prototypic components in a FLiBe environment at full temperature.

CHAIRMAN CORRADINI: Just, so, I don't understand the difference. I see the same four boxes, you just --

MR. HAUGH: Yes.

CHAIRMAN CORRADINI: -- made them look three times --

MR. HAUGH: It's just, how much are you going to do it. So, if you think about a large light water reactor, how much did they ever build and test in the last ten years?

CHAIRMAN CORRADINI: Oh, well, I mean, but historically, you had Semiscale, you had LOBI, you had LOFT, so --

MR. HAUGH: Exactly.

CHAIRMAN CORRADINI: Okay.

MR. HAUGH: And so, that, we're just bringing that back to a non-light water reactor technology.

CHAIRMAN CORRADINI: Oh, okay. All right. So, they're regressing to the 1940s?

(Laughter.)

MR. HAUGH: Yes, but with enhanced measurement capabilities --

CHAIRMAN CORRADINI: Which is how they did it in the 1940s.

MR. HAUGH: Exactly, a little bit of brute force, because we need the data. So, we learn a lot about actually the component design as we actually build the validation database as well.

CHAIRMAN CORRADINI: So, let me, then -- okay. That helps me. So, are you already having conversations with the staff, relative to the fidelity and the scaling of the data you have to acquire, so that once you acquire it, it's not going to have to be reacquired?

MR. HAUGH: Correct, yes. So, the quality assurance program is coming in for a review, and that will directly address the test program as well. As long as our scaling analysis approach will be submitted very early next year for review.

CHAIRMAN CORRADINI: Okay. Thank you.

MR. HAUGH: And to accomplish that, we actually have multiple facilities. We're co-located, our headquarters in Alameda, California is actually co-located with the R-Lab facility and also a nitrate salt lab facility. So, it's 55,000 square feet of lab space.

We actually moved in two months ago and already started testing, component design testing. That will transition into a salt lab that we're constructing in another location. That's where we'll handle the FLiBe materials. So, the beryllium, really it's the beryllium hygiene is the important part of that.

And then, we'll actually be testing materials, corrosion, and characteristics of the components on small scales at the salt lab, and then, moving up in scale as we go to the test facility and the user facility in longer-term.

CHAIRMAN CORRADINI: All of this is intriguing. So, remind me the need for beryllium.

MR. HAUGH: Oh, okay. So --

CHAIRMAN CORRADINI: Because --

MR. HAUGH: -- it provides --

CHAIRMAN CORRADINI: -- I know, at university, one stays away from stuff like that, and if I had an operating system -- so, explain to me the requirement in the primary loop for the beryllium? I've forgotten. I'm sure there is one.

MR. HAUGH: So, the beryllium helps maintain the reducing environment, which it serves several aspects. One, it preserves the materials from corrosion characteristics, so it's not leaching ions out of the structural materials.

Also, it provides enhanced capability to manage fission products, such as iodine and things like that, in that reducing environment.

And also, the eutectic salt has unique optical characteristics. It's clear at temperature, which allows us to do other inspections that are much more difficult to do in other salts.

CHAIRMAN CORRADINI: All right, thank you.

MR. HAUGH: This is just some propaganda.

(Laughter.)

MR. HAUGH: That's our building we just moved into, it's an old aircraft hangar on Alameda Point. So, if you're ever out our way, give us a shout.

And then, we have a couple snapshots there of the high bay facility, where our integral effects test that are non-salt based will be. So, we actually will be doing some large scale ones in water and some large scale ones using DOWTHERM heating oil.

And then, you'll see, the smaller skids on those lower pictures there are actually our small separate effects test facilities. These are ones that are actually installed today. So, looking at hydrodynamics, as well as heat transfer.

So, we had a small time slot here, feel free to ask more questions. But basically, we're very committed to the application and validation of advanced modeling tools. That's what we kind of wanted to take away here.

And to support that effort, we're collaborating with the labs and the code owners at those labs to accelerate the remaining development. Our licensing plan for those codes is very aggressive, so we aim to have significant amount of that development done in the next 18 months.

Comprehensive testing program will be used to validate those tools for our application. And we're definitely ready to work with the NRC and ACRS to ensure a very transparent, ongoing interaction, to have an effective and efficient review process.

CHAIRMAN CORRADINI: Okay, thank you. Questions by the Committee?

MR. SCHULTZ: So, I assume if you're using these codes in the licensing arena, then these are all being developed under an approved Appendix B-like program?

MR. HAUGH: Correct. Yes.

MR. SCHULTZ: Okay.

MR. HAUGH: So, at Kairos, we have our own software quality program, that's fully compliant with Appendix B under NQA-12015, so the most recently endorsed standard. And we'll be commercially grade dedicating these codes from the lab.

So, the three main codes, actually, all four of those codes on that list, are developed under a QA program, it's just a different level of pedigree, because we have to carry it the rest of the way, and also the validation piece.

MR. SCHULTZ: And you're also doing verification, if you're doing code modification?

MR. HAUGH: Correct. Yes, our verification program is very extensive. It's actually done on the unit test level and on the integral test level. And then, we do continuous integration testing with all those changes.

MR. SCHULTZ: I'm thinking of verification, with regard to the QA program, the modeling to the --

MR. HAUGH: Correct, yes. And so, the modeling actually is implemented by multiple developers. So, there's an implementer, a reviewer, and an approver for all the models. And it also goes all the way down in the actual coding itself.

MR. SCHULTZ: I would hope so, yes. Both the coding, as well as the application of the model --

MR. HAUGH: Correct.

MR. SCHULTZ: -- element of verification. Thank you.

MR. HAUGH: Yes.

MEMBER BALLINGER: How important is it for you to control the potential in the salt? It comes back to the beryllium issue.

MR. HAUGH: Yes. And it's important, not super critical, I guess would be the best way to put it.

MEMBER BALLINGER: Does it affect the

source term?

MR. HAUGH: It can.

MEMBER BALLINGER: So, there's a band that you have to maintain?

MR. HAUGH: Correct. Yes, it's much like, even in LWR, right?, you have a chemistry control system, where you're going to be sampling and maintaining within the range, to ensure that you're within your validated safety-basis and also the operational characteristics of the materials, that's correct.

MEMBER BALLINGER: Thanks.

CHAIRMAN CORRADINI: Other questions? Okay. We're going to move on, thank you very much.

MR. HAUGH: Thank you.

CHAIRMAN CORRADINI: And we're going to turn into an ATF discussion, and Zeses Karoutas? Zeses is here somewhere. There he is. So, we'll switch from the world of non-light water reactors back to light water reactors with ATF fuel or cladding, or both.

MR. KAROUTAS: Okay. My name is Zeses Karoutas, Chief Engineer in Nuclear Fuel at Westinghouse. And I'm going to give you a presentation on our plans for using the DOE CASL and

NEAMS tools. Next slide.

First, I thought it would be useful just to give you a brief description of our accident-tolerant fuel, which we call EnCore, and describe some of the benefits, the physical benefits, the safety and economic benefits, just to give you an idea what benefits we're talking about and how we will develop models and implement and some of the tools that we have.

And I'll also talk briefly about some of the data needed for validation. And we need the data to validate the models that go into the tools.

Talk a little bit about the CASL and NEAMS tools to be used. The BISON code, which is going to be a key code for us, in terms of for accident-tolerant fuel.

And talk a little bit about the VERA core package for core simulation and also, applications for RIA and DNB. And then, talk a little bit about CRUD applications for an ATF core. And then, severe accident analysis.

A little bit about the Westinghouse EnCore product. We have, in terms of advanced cladding, we have the chromium coated zirconium and also, in terms of product evolution, after that would be silicon carbide.

And then, for the advanced fuel, we have doped pellets, which we call ADOPT. And it's doped with chromium and aluminum. And then, for the future, uranium silicide pellets.

In terms of implementation, we are in the process of implementing the chromium-coated cladding as lead test rods, with the ADOPT pellets in the Byron-2 plant, Exelon plant. And also, we have a segmented rod with uranium silicide pellets going into those, some of the lead test rods.

And in terms of the physical benefits, the ADOPT pellets, it's got a little higher density, about two percent, and that helps for fuel utilization. Better thermal stability and oxidation resistance, lower fission gas release in transients, and increased PCI margins at high temperatures.

The uranium silicide has a much higher density, about 17 percent, and this really helps the fuel cycle economics, for 18-month and 24-month cycles.

Also, has improvement in thermal conductivity, something on the order of five to ten times, which really helps for transients. And so far, from the ATR testing that we see, we see good irradiation behavior, in terms of swelling and fission gas release.

The coated claddings, it's coated with chromium. It's got higher accident temperature capability, something in the vicinity of 1300 to 1400 degrees C.

Reduced corrosion and hydrogen pickup. It's got good resistance to rod wear. It would have reduced exothermic reaction energy during high temperature transients.

We've bone burst testing, it has reduced balloon size and higher burst temperature, which could help in terms of fuel dispersal.

We also would see improved LOCA PCT margin, RIA deposition limits, and we're also looking at the possibility of staying in DNB for a short period of time.

CHAIRMAN CORRADINI: So, I don't want to go into the world of proprietary, but can I ask this question? These benefits of the coated cladding, is this irradiated claddings or is this unirradiated?

MR. KAROUTAS: Currently, it's unirradiated.

CHAIRMAN CORRADINI: Okay. Because --

MR. KAROUTAS: In terms of --

CHAIRMAN CORRADINI: Okay.

MR. KAROUTAS: -- like, for example, doing burst testing. And of course, we will have to get data, being irradiated in the future.

CHAIRMAN CORRADINI: So, this is maybe the wrong time to bring it up, but I can't think of a better time. Do you have a plan for that now with the Halden closure?

MR. KAROUTAS: Yes, we do. Of course, it does hurt that Halden has shut down. But we're doing our best, in terms of trying to perform testing elsewhere.

CHAIRMAN CORRADINI: Is this something that you would prefer not to discuss in public or can you tell us about the testing plan there?

MR. KAROUTAS: Well, I do have a slide on the --

CHAIRMAN CORRADINI: Oh, you do? Okay, fine.

MR. KAROUTAS: -- testing and --

CHAIRMAN CORRADINI: Okay, that's fine.

MR. KAROUTAS: -- I can give you a very brief idea.

CHAIRMAN CORRADINI: No, no, we can wait until you get to that.

MR. KAROUTAS: Okay.

CHAIRMAN CORRADINI: That's perfectly fine, thank you so much.

MR. KAROUTAS: And then, the ultimate cladding is silicon carbide, and there, the big benefit there is it's got no ballooning and bursting, it's got a high resistance to rod wear. It's almost have to worry about the spacer grid as opposed to the cladding.

And it eliminates oxidation-drive temperature spikes. We believe it has -- you can go up to near 2000 degrees C, that's where it really begins to decompose.

DNB and LOCA would be less of an issue with this cladding. And we also believe it would be a good fission product barrier at high temperatures, in a severe accident. It would minimize the potential for hydrogen generation to non-threatening levels.

Basically, we take all these benefits and we're going to try to develop models and put it in our codes, and that includes putting it in the DOE codes.

And this table here just kind of gives a qualitative comparison of some of these benefits, for the different designs here, relative to current fuel, where the yellow signifies some potential benefit and the green is a larger benefit.

If you go from left to right here, coated cladding with UO2 pellets, you have a certain benefit. With ADOPT pellets, it would be more. With uranium silicide, it would be even more. And then, with silicon carbide would be the best.

MEMBER REMPE: On this table, where is it that -- or do you have enough information yet to really say, yes, the benefit's going to offset the costs? Or is that going to be something, in your opinion, it is very plant-specific?

MR. KAROUTAS: Well, we're working on this and we're working together with EPRI on this ATF 2.0 program, to try to quantify the benefits.

We've also visited some of the plants, as part of that program. We've got to a couple sites, we've gone to the Vogtle site. And you are correct, each plant's a little bit different and so, the benefits will be based on that utility, what they're interested in.

One utility may be interested in 24-month cycles, for example. Another utility may be more interested in flexible power operation. And that kind of makes things a little bit different, in terms of how you utilize the benefits. Next slide.

In terms of the data, and maybe this answers your question a little bit, Mike, this is the type of tests that we need for validation. We've got to do autoclave testing for these materials.

We have to get test reactor data and we are going to other facilities, the MIT test reactor, the HFIR, ATR, and we still getting some data from Halden, even though the reactor is shut down, and they still have a program, a three-year program to 2020, where they are working with other facilities to try to get data.

CHAIRMAN CORRADINI: I'm sorry, we're talking other facilities within Europe?

MR. KAROUTAS: In Europe.

CHAIRMAN CORRADINI: The Belgium reactor?

MR. KAROUTAS: Yes, like the BR2 --

CHAIRMAN CORRADINI: BR2 is what I was --

MR. KAROUTAS: -- or Petten, as an example.

CHAIRMAN CORRADINI: Okay.

MR. KAROUTAS: So, I think we're --

CHAIRMAN CORRADINI: I apologize.

MR. KAROUTAS: Yes.

CHAIRMAN CORRADINI: Those are being upgraded to accept the -- because I thought some of those facilities needed some sort of upgrading to actually do this sort of testing.

MR. KAROUTAS: They do. They do, and some of this does delay maybe getting some of this data. But we do have a program here in the U.S., too. We're basically trying to work with all the facilities we can to get the data we need.

CHAIRMAN CORRADINI: Okay.

MEMBER BALLINGER: But not Bore-60? Not Bore-60?

MR. KAROUTAS: Say that again, Ron?

MEMBER BALLINGER: Not Bore-60?

CHAIRMAN CORRADINI: Not the Russian --

MR. KAROUTAS: No. No, not the Russian, yes.

MEMBER BALLINGER: Okay.

MR. KAROUTAS: So, in terms of other tests, there's in-reactor exposure and really, that's getting data from our commercial plants, in terms of PIE and hot cell.

We're doing burst tests, unirradiated power ramp tests. LOCA and RIA tests, with TREAT and information from Studsvik. Fretting tests at our own facility, including pressure drop.

We have the WALT Loop, in terms of looking at DNB and CRUD impact. Ultra-high temperature and

KIT tests, for severe accidents. And fuel mechanical behavior type tests.

So, this just kind of gives you a rough idea where all the test data is coming from.

MEMBER REMPE: So, at the last meeting, we were told, actually, for the reactive insertion valuations that, or the power ramping, it might be better to do those at ATR. Is that --

MR. KAROUTAS: We'd like to see if we could do it at ATR.

MEMBER REMPE: -- cycle and things like that?

MR. KAROUTAS: That's correct. Yes.

MEMBER REMPE: Okay.

MR. KAROUTAS: So, now, getting into the tools, this is a picture of the CASL and NEAMS tools. And the main focus here, at least for us, is the neutronics, MPACT, COBRA-TF, BISON for the fuel rod performance, and chemistry with MAMBA, where we're looking at CRUD impact.

And of course, a lot of these tools can link up to other tools too, like we can link up to RETRAN, TRACE, and RELAP7 for the system codes. CFD codes, we've been working with STAR-CCM+.

So, this is the package that we're looking at, in terms of trying to get more advanced modeling and simulation to help inform our design tools that we have.

CHAIRMAN CORRADINI: But -- I'm trying to come up with a way to ask this question. So, are these the mainline tools or are these things you're using for individual questions that you need to get more detail and you're going to use the already, I'll use the word preapproved Westinghouse tool set for light water reactors?

MR. KAROUTAS: That's exactly correct.

CHAIRMAN CORRADINI: Okay.

MR. KAROUTAS: That's our plan. We're really using these tools to maybe address some of the key performance issues, look at trends, do benchmarking with the tools that we have.

And of course, the BISON code, I think will really help out, in terms of trying to do more atomistic type of evaluations.

CHAIRMAN CORRADINI: Okay.

MEMBER REMPE: So, as preparation for this meeting, someone sent us your -- and you weren't a co-author, so I hope I'm not hitting you by surprise, but they sent us this top fuel CASL paper.

And there was a text in there, and it's

talking about the fuel, it's like in Section 4 of it, about the atomistic models, I'll see if I can find the title of it here, it was the Fuel Rod Applications of the CASL Tools.

And in there, it actually has a sentence in there about how they're adjusting, the models will be improved as more atomistic analysis of burnup effects are completed and updated models are incorporated into BISON and adjusted to best predict available, measured data.

And I'm just kind of wondering what that means, and maybe this is too detailed for you, but it sounds like, despite the fact that we've gone to atomistic effects in these models, that you're still kind of tuning the models to the data, which, again, if -- years ago, we talked about first order principles and how you wouldn't have to -- you could extrapolate those models and you could reduce testing.

But yet, they're still tuning the models. And that means you have to interpolate. And do you know what I'm talking about and do you have any thoughts about this?

MR. KAROUTAS: Yes. At least this is the way I look at it, first, you look at atomistic models for current fuel that you have and you have a lot of data for, and you see how well those models work for current, like looking at thermal conductivity degradation in UO2.

And if you do well there, then you take the next step and extrapolate outwards, say, for uranium silicide type fuel, and see what kind of behavior you get.

And then, you get some data on uranium silicide, and you get a few data points, and you see how it compares. And then, you inch your way up to getting more data, more comparisons. And maybe you're correct, there's still some empirical fittings.

MEMBER REMPE: It sure sounds like it.

MR. KAROUTAS: That's just my own opinion, and I --

MEMBER REMPE: Yes, I understand. Again, the staff will be looking at that more carefully.

MR. KAROUTAS: Right.

MEMBER REMPE: But it sure sounds like some folks are still tuning to me.

MR. KAROUTAS: And the atomistic models can really help out in terms of forecasting going forward, maybe helping out in terms of defining the test program that you need for getting more data. So, I think it can be very helpful.

MEMBER REMPE: Okay, thanks.

MR. KAROUTAS: Next slide. We'll be focusing on the BISON code quite a bit, because, really, that's the code that's going to be working with accident-tolerant fuel.

And there, we'll be providing predictions of expected fuel and cladding behaviors in advance of measurement data, to inform design decisions. We'll be looking at special performance issues for the code, that may be our current codes can't handle in detail.

We'll be looking at performance thresholds in the ATF material behaviors. And we'll be using these results to help confirm and guide the development of our own fuel performance codes.

CHAIRMAN CORRADINI: So, let me ask this question in this way, will BISON become W-BISON like GOTHIC became W-GOTHIC? Or will BISON be general and you'll use it and DOE will maintain it?

MR. KAROUTAS: I think, at this point, it will be general and DOE will maintain it. But at some point, there could be a point that we see a lot of value in the code and it makes sense to submit it.

CHAIRMAN CORRADINI: But not at this point?

MR. KAROUTAS: Not at this point.

CHAIRMAN CORRADINI: Okay.

MR. KAROUTAS: And I also want to mention that we are looking at the micro-reactors too, which have a different kind of fuel geometry, and advanced reactors, where a code like BISON may make a lot more sense. Next slide.

Just to give you an example, we just recently -- were putting some uranium silicide pellets in the lead test rods going into the Byron reactor. And we decided to make that a double-encapsulated segmented fuel design.

And we looked at the eccentricity of the uranium silicide pellet in this fuel rod, to look at fuel temperatures and fission gas release.

And it just gave us a good feeling that we're coming up with the right segmented rod design. So, we just used this recently. And so, it was very helpful to us. Next slide.

In terms of working with CASL and NEAMS, these are milestones that they have in their plan today. And so, we're working together with them, with BISON and ATF Clad concepts for PWR normal operation and LOCA conditions.

We're looking at the mechanical integrity and thermomechanical behavior of the coated cladding. We're looking at fission gas release for the doped oxide fuel, the plasticity and thermal creep of the doped oxide fuel. We're also looking at fission gas and creep in uranium silicide fuel.

And so, there's quite a bit of development going on, in terms of working together with CASL and NEAMS.

We're also, for the lead test rods and the lead test assemblies that are going in next spring, 2019, with the ATF materials, we are going to simulate that core, the whole core, with the VERA tool package.

And we'll be comparing some of the results to measurements. We'll be looking at the loading pattern for the cycle of ATF introduction. We'll be evaluating the results and comparing to our own core physics tools.

We'll be looking at 24-month and higher burnups. And this is something that some of the utilities are very interested in, in terms of the benefit of ATF, it can take us to 24 months and higher burnups and be more economical.

So, we'll be using the CASL and NEAMS tools for making those predictions. We'll be looking at RIA --

MEMBER REMPE: In your interactions with the staff, when you say -- I can get the thing about the longer cycle length, but when you want to go to higher burnups, it sure sounds to me like you need Halden data to -- I mean, they were the only ones who could do thermal conductivity degradation data.

MR. KAROUTAS: Yes, we still need -- you're absolutely right. We --

MEMBER REMPE: Okay, thank you.

MR. KAROUTAS: In order to go to higher burnup, and it kind of depends what burnup you're talking about, our peak rod burnup now is 62,000. I think as a next step, we're looking at, say, near 67,000. And then, another step, to go up to 75,000. So, we can get data as we go. And so, that's what we're looking at.

CHAIRMAN CORRADINI: Is the intent to -- because you had mentioned, and I can't remember now, there's already chromium coated cladding lead test rods being irradiated now? Or to be? That's what I can't remember now.

MR. KAROUTAS: Yes, they go into the core the spring of 2019.

CHAIRMAN CORRADINI: With UO2 or with U3Si2?

MR. KAROUTAS: They go in with uranium -- I'm sorry, they go in with the ADOPT pellets, doped pellets.

CHAIRMAN CORRADINI: Okay. All right.

MR. KAROUTAS: And we do have a segmented rod, which will have uranium silicide pellets.

CHAIRMAN CORRADINI: And then, the thought is, there -- you don't have to go back to your experimental slide. But the thought is, there, you would take them out, section them, and then, do PIE on them?

Would you do additional testing, LOCA testing, in terms of what has traditionally been done with, at some burnup levels, looking at essentially ductility failure with QUENCH?

MR. KAROUTAS: Well, we are putting samples in the ATR with the coated cladding and --

CHAIRMAN CORRADINI: And that's what -- those are the rodlet samples that will be used for --

MR. KAROUTAS: And doped pellets, we're also looking at uranium silicide and silicon carbide in ATR.

CHAIRMAN CORRADINI: Okay.

MR. KAROUTAS: And eventually, we want to take those and do LOCA and RIA testing.

CHAIRMAN CORRADINI: Okay, fine. All right. Thank you.

MR. KAROUTAS: Okay. And just to give you an example, we've been using the VERA tool package for, for example, AP1000.

And these were all blind predictions, before AP1000 started up, in terms of looking at hot zero power calculations and hot full power calculations.

And it's a heterogeneous-type core. We've got many different rod designs, different lattice geometries in the core, with different enrichments.

And the startup measurement comparison is actually, were very good. In terms of boron and isothermal temperature coefficient and rod worth, they're very close. Closer than our current tools. So, utilizing this actually helps us improve our current tools.

If you go to the next slide, we also did this with Watts Bar Unit 2 startup. And again, this was a blind prediction too, and we were looking at the measured minus predicted soluble boron during power ascension testing. And this came up very close.

And again, this helped our tools. ANC/PARAGON is what we use and so, it helped benchmark some of the tools that we have. And we also compared to the vanadium detector responses in the core, and that came out very close also.

We are looking at the RIA and DNB. And for RIA, the uranium silicide has higher thermal conductivity, which will be good in a transient, but it also has a lower melting temperature compared to UO2.

So, we want to look at different scenarios with various rod ejection strategies and look at the margin to melting for those transients. So, I think the VERA tool package will help with that.

And we're also looking at the locked rotor transient for DNB. And we'll be applying the tools for that too.

This is just an example for AP1000, where we've done a rod ejection analysis. And it was -- we modeled the entire core, with MPACT and COBRA-TF, and it performed very well.

It was very stable during the calculations, with an expected power pulse resulting from a super-prompt critical reactivity insertion and the resulting negative Doppler feedback.

And then, the other area that we'll be looking at is CRUD. As you know, with coated cladding and silicon carbide, it's got a different surface than our current cladding. And because it's a different surface, that could have an impact on CRUD deposition.

And we are performing some tests and so far, the tests look like the CRUD doesn't adhere more than our current cladding. But this is definitely a strong interest from customers, because having a lot of CRUD deposition can give you CRUD-induced power shift and could cause a lot of problems in the core design.

And so, we'll be looking at that with the MPACT, COBRA-TF, and MAMBA, which is part of the VERA tool package.

And in here, we explicitly include the feedback of boron on the power distribution. So, right now, we're in the process with CASL of trying to benchmark these tool to a lot of the data that we have in existing reactors, but we want to also apply this for the new ATF materials, which would have a different surface.

And there could be an impact on DNB or critical heat flux. And I think, based on pool boiling, we see, you can improve critical heat flux quite a bit by changing the surface. And we're trying to do our testing in the WALT Loop at the reactor-type conditions and flow rates, to see how that impacts DNB.

MR. SCHULTZ: So, you've been able -- these examples are for current reactor fuel and CRUD deposition?

MR. KAROUTAS: Right now, it's all current, yes. But we'd like to also apply it for the ATF materials, once we have good benchmarking with existing plants or existing fuel.

MR. SCHULTZ: Of course, thank you.

MR. KAROUTAS: In severe accidents, there, we've been using the MAAP code, so far, for these ATF materials, looking at coping time benefits, and also the use of FLEX equipment with ATF, for flow and passive heat mitigation strategies.

And DOE, they've been using the MELCOR code. So, we're trying to compare those results to what MELCOR provides.

And we also need to be able to put the latest ATF fuel mechanical behavior for these materials at high temperatures. And that's kind of a next step.

And I know CASL and NEAMS is working with the NRC, with a TRACE/BISON, to try to link up those two codes for LOCA capability. I think the project's called Blue CRAB or something like that. And so, we're very interested to see what kind of benefits you get when you couple TRACE and BISON together for ATF.

So, in summary, we're thinking that these DOE tools would definitely help us out, in terms of benchmarking and informing decisions for the next generation of advanced fuel designs.

And we are working on the eVinci micro-reactor, in Westinghouse, and also, the Lead Fast Reactor too. And I expect that we're going to be using the BISON code for those two applications. And so, it should help out there.

And so, our process is really to take the CASL and NEAMS tools and compare it to our tools that we use today. And that's really our benchmark that we want to do. Because the tools that we have are into our reload process, they're very fast, and this is the approach that we think is best, at this point.

And we're thinking the DOE tools could also help with getting a better understanding of the margin, and also the uncertainty. And so, we'll be looking at the uncertainty, compared to the data that we have.

CHAIRMAN CORRADINI: Questions by the Committee? Okay. So, we're going to -- since it's a Subcommittee meeting, we can potentially change things around. We were asked by one of the -- thank you, Zeses.

MR. KAROUTAS: Thank you.

CHAIRMAN CORRADINI: Thank you very much, Zeses. We were asked by one of the -- and this is Nick Smith from Southern, that you have a change in your travel plans.

So, if you want to come up now, we'll bring you in front of lunch, since we've not had a proprietary discussion yet. And then, we'll break for lunch. So, after this presentation, we'll break for lunch. It's all yours, Nick.

MR. SMITH: All right. I'm Nick Smith, I'm a Principal Engineer at Southern Company Services, I work in Advanced Reactor Research and Development, but I am presenting to you today in my capacity as the Chairman of the Molten Salt Reactor Technology Working Group.

CHAIRMAN CORRADINI: So, you're one of the three chairs that Everett mentioned?

MR. SMITH: That's correct, yes.

CHAIRMAN CORRADINI: Okay.

MR. SMITH: And Everett did a great job of kind of explaining the relationship. One thing to note is that, we're not directly funded or tied to NEI or EPRI or any other group, it's really an independent group of vendors that have no affiliation directly with NEI or any other working group like that. You can go to the next slide, here.

This is a quick run-through of the different companies that are represented in the TWG. We have seven different reactor technology developers and then, we also have participation from utilities, like Exelon and Duke, as well as NEI and EPRI attendants.

And I do want to say, I very much appreciate all the logistical support that NEI and EPRI have offered as we've been running through this process. Next one, here.

So, there's a lot of different design types in the MSR TWG. And I kind of plotted them here, so you can see just the difference in fuel cycles that you can go to with MSRs.

We have some thermal, thorium designs. We have fast uranium designs. And every permutation in-between there. So, it's a lot of different opportunities there.

CHAIRMAN CORRADINI: Kairos is not in it?

MR. SMITH: No, sir. The MSR Technology Working Group is a liquid fuel technology group only.

CHAIRMAN CORRADINI: Oh, okay. Thank you.

MR. SMITH: So, I just briefly want to make sure I cover what each of these technologies is focused on.

Terrestrial is leveraging the experience of the molten salt reactor experiment, thermal spectrum, graphite moderated, fluoride salt. If we go to the next one, here.

TerraPower is a fast spectrum molten chloride salt. It's an open core, there is no moderator in there. Next one, here.

FLiBe is another thermal spectrum design, but they are a thermal breeder. So, they're looking at two-fluid thorium breeding in their machine.

Muons, Inc. is an accelerator-driven molten salt reactor technology, thermal spectrum. Next.

Alpha Technology Corporation is another thorium-fueled breeder, two-fluid reactor.

And then, ThorCon is a company that's based on a MSR, they're trying to leverage shipyard construction techniques for their -- to lower costs.

And then, the last one here is Elysium Industries, which is another fast spectrum chloride salt design.

CHAIRMAN CORRADINI: Given the variety, I can't come up with a better word, given the variety of various concepts, is the working group -- well, let me not -- what is the working group's strategy to deal with that variety?

MR. SMITH: Well, we've got to stay flexible. I mean, we engage with people where it supports us as a group. There's a lot of different angles that have to be approached, and we try and leverage each other's experience, where it's possible.

CHAIRMAN CORRADINI: Well, let me ask my question, then, more specifically. Is the working group's, one of their objectives, to look for cross-cutting technical areas that require investigation with a majority of these concepts? What I'm trying to get at is, it seems like a lot of --

MR. SMITH: Yes. So, I've got a slide coming up here.

CHAIRMAN CORRADINI: Okay, that's fine. Why don't we just --

MR. SMITH: This is the one you're looking for. So, what do we work on? We work on things that are generically applicable to all of us.

Regulatory issues, like functional containment, something all of us want. Fuel qualification, whether you're a thermal or a fast spectrum core, that's going to be relevant.

We engage with DOE. So, we work with folks like Lou Qualls, who's the National Technical Director for the MSR Campaign. We work with Chris Stanek in the NEAMS group.

And then, we also engage on consensus standards. Stuff like the ASME boiler pressure vessel code and the high temperature alloys that are in there.

So, those are all different things that everybody wants to be able to design their reactor with, but they're not technology-specific, if that makes sense.

CHAIRMAN CORRADINI: Sure. So, where in this is source term?

MR. SMITH: Source term is in the end of my presentation.

CHAIRMAN CORRADINI: Okay.

MR. SMITH: But that's definitely something --

CHAIRMAN CORRADINI: That's fine.

MR. SMITH: -- we're very concerned with.

CHAIRMAN CORRADINI: Then I'll wait. I'll wait.

MR. SMITH: We'll just keep moving here.

So, just wanted to give an overview of the interactions we've had with DOE so far.

In April last year, DOE put together a chemistry workshop for us, which was three days of technical deep dive on chemistry issues associated with liquid fuel MSRs.

And they actually broke it down into analytical chemistry, computational chemistry, the chemistry of fission products, and what I think would be relevant for a source term calculation, and then, also, materials and salt chemistry interaction.

They developed a paper off of that, and I put the title in here, you can Google that and find it.

And that has been used to lead up to an NSF award on a molten salt center of excellence, that's looking more at the scientific aspects of understanding molten salts in nuclear applications than the applied things that most of the developers are looking at right now.

CHAIRMAN CORRADINI: And this is an awarded center of excellence?

MR. SMITH: Yes. Just very recently, in the last few months.

CHAIRMAN CORRADINI: And where is that?

MR. SMITH: So, it's not one center, but it's INL and Wisconsin, there's a few other groups that are on the team.

CHAIRMAN CORRADINI: INL is the lead then, if this is the one I'm thinking of.

MR. SMITH: Yes.

CHAIRMAN CORRADINI: Okay.

MEMBER REMPE: I have a question, since we've interrupted you. If you go back to that slide where you have the three circles?

MR. SMITH: Yes.

MEMBER REMPE: Are any of your, I don't know what you call them, members, are they ready to do a regulatory engagement plan with the NRC?

MR. SMITH: I think some of the members have engaged with the NRC --

MEMBER REMPE: No, I mean a regulatory -- as part of the Licensing Modernization Project, we have heard that the staff is trying to get a grasp, because of all the diverse, different folks coming forward.

And so, they're encouraging some of the developers to prepare a regulatory engagement plan, not just have a few discussions and meetings, but a serious, a document with serious thought behind it about how they're going to interact with the NRC to --

MR. SMITH: What are the white papers we're going to deliver and when are the milestones that we plan to meet?

MEMBER REMPE: Yes. Have any of them gotten to that stage yet in their development activities?

MR. SMITH: I know some of them are developing that regulatory engagement plan very seriously right now.

MEMBER REMPE: That's good, okay. Thank you.

MR. SMITH: So, the other thing I wanted to mention here is that we've had a lot of engagement and support from the GAIN initiative.

Especially when they're able to come to our meetings and we'll have developers asking questions or bringing up topics that they don't know much about, and GAIN has been able to tie them back to folks inside the National Lab complex that have that expertise.

And so, what ends up typically happening is that the MSR TWG will have meetings, we'll have presentations from people, and then, there will be these offline conversations between specific technology developers and the folks within the National Lab complex that can help them work towards a solution there.

We've also -- oh, hang on. So, we've got a -- the establishment of the MSR Campaign, which, up until two years ago, I don't believe we had any designated MSR research inside DOE. So, this is a new phenomenon, right?, it's a new thing. And we're really excited about that.

And then, the last thing I want to make sure I call attention to is the NEAMS software workshop that was put on in February, or the end of February, early March.

So, we had a lot of the developers asking questions about the NEAMS tools, we had seen presentations with kind of the results of modeling and simulation done with NEAMS tools, but there wasn't a clear on-ramp for the developers, how do you get access to the codes, how do you learn how to use them, because there's intricacies and subtleties to it that you don't always get from reading a manual.

And so, the NEAMS team put on a three-day workshop at Argonne, where everybody brought their laptops or had connections to the Blues Cluster at Argonne.

And we ran, ran on our own, the simulations that they had set up for us on different types of MSRs, using PROTEUS and NEK5000 and SAM and all of these exciting NEAMS tools that you've heard talked about.

So, that was a really good thing. And that's directly led to follow-on from the vendors, the reactor developers, to work with NEAMS on the things that they found that were really exciting.

So, we absolutely are planning on using modeling and simulation as a part of the licensing case for these different reactors, mechanical systems codes, neutronics, thermal-hydraulics.

And as it's been brought up early, you've got to have a V&V strategy around that. And I think the big gap for MSRs is on experimentation. There's a lack of data out there.

The thing I would say right now is, if you go and survey all the seven MSR companies inside of the MSR TWG, there isn't just one set of codes that they're all saying they're going to use. Some of them are going to use MCNP, some of them are going to use Serpent, some are using SAM, some are using RELAP.

And they're independently approaching the problem right now. But I think if there was a strong

V&V case behind one tool or set of tools, it would encourage them to use that tool specifically.

CHAIRMAN CORRADINI: So, let me ask you the same question that I guess I asked the Kairos folks. Let's forget about tools, let's just think about boxes that need a calculation to get to the next box, in terms of a plan, whether it be with what John Monninger suggested, with what I asked of the Kairos folks.

Does that exist for the molten salt liquid fuel systems? That is, I'm going to have to determine some reactor physics calculation, which leads to a temperature or a density reactivity estimate, which leads to a thermal-hydraulic estimate, which leads to essentially a set of accidents or a set of transients that I have to concern myself with about source term release, which then leads me to another set of calculations?

I'm looking for a logic diagram. Does it exist for the molten salt reactors?

MR. SMITH: I know it does for some companies.

CHAIRMAN CORRADINI: Is it proprietary or is it something that the working group needs to do regardless of the conceptual design?

MR. SMITH: I think there's enough differences between the designs of the companies that they each need to do it individually.

CHAIRMAN CORRADINI: So, they don't feel that there's enough commonality to do a cross-cutting thinking process? This is a thinking problem that doesn't need a code?

MR. SMITH: I think there's differences in things like, are you going to have a sealed core for the life of the run, where all the fission products that are volatile are in the same area as your liquid fuel? Or are you going to move those over to some other off-gas area and deal with them separately there?

And you start to look at design decisions like that and how you're going to approach modeling them and it's going to change your approach and what tools you would select for that.

CHAIRMAN CORRADINI: Okay. So, you're saying, there's enough diversity that, from a cross-cutting activity, the working group has not seen fit to do this?

MR. SMITH: I mean, it's not the working group's job to tell the developers how they should do their design, right?

CHAIRMAN CORRADINI: Oh, clearly, I would never -- I'm sure, yes. Yes.

MR. SMITH: But --

CHAIRMAN CORRADINI: But there's not a consensus among the working group that this is common activity that needs to be done by the working group?

MR. SMITH: Well, I think that, for example, the need for a source term code is something that has been clearly stated by the working group. That's something that's on my takeaway slide.

CHAIRMAN CORRADINI: Okay.

MR. SMITH: But the fact that, right now, if you try to go use MELCOR to model the source term, mechanistic source term, for any of these MSR designs, it's not ready and we don't have enough data, right? That's a problem and we've got to address that.

CHAIRMAN CORRADINI: Okay. Thank you.

MR. SMITH: Okay. So, experimental facilities. This is not specific to any one technology, but I think there's some pictures in here that I've borrowed from TerraPower, so I should probably give them credit.

But the way most of these vendors are approaching the collection of data that's lacking in order to do accurate modeling and simulation is, first, with small scale separate effects tests.

Things like, on the very far left, you see a micro-loop that's, like, a centimeter diameter tubing with naturally circulating salt in it. And you run that for a while, convince yourself that you understand the chemistry interactions with the salt.

And then, you can go to something like the next picture, which is, I don't know, a 20-GPM pumped isothermal loop with inch and a half tubing, and get some experience there.

And then, you go to something like an integrated effects test, where you're coupling loops together with heat exchangers and valves and you're integrating in that off-gas system.

It's electrically heated, so there's no radiation. Try and solve as many problems as you can before you bring neutrons and gammas into the equation, right?

One of the things that we've recently identified as an area that we're lacking is the MSR component ecosystem.

So, if you go to the vendors right now and you say, I want to buy a 300-horsepower pump that can handle 750 degrees Celsius uranium chloride salt, they're going to say, we don't have that in stock, but we can do an R&D project with you and over the next few years, we might come up with an answer.

That's not going to lead to a healthy molten salt reactor deployment timeline. And so, something Southern has a history of doing is creating these large component development facilities.

We did it a lot in the fossil energy space, where things like mercury-capture technology or carbon-capture technology, where you're at a skid scale, you're going to bring it in to the plant, you're going to try and run it with real flue gas, it's going to break, you're going to have some Brotherhood of Electrical Workers guy who presses the wrong button at the wrong time and tears it up, and you've got to repair it.

We need to go have those experiences as soon as possible, with at-scale molten salt reactor components: pumps, valves, heat exchangers.

In parallel to that, we need to also be doing as minimum scale as possible criticality experiments.

So, you've got a minimum diameter you can get to for any of these things to go critical, but we can do very low power experiments and verify the neutronics and collect data on things like, I'm going to use chlorine cross-section data as an example, where there's a lot of uncertainty there, actually.

You look at the difference between in-depth databases on chlorine-35 capture cross-section and it can change the reactivity of your core a few hundred PCM, depending on which database you use.

So, there's obviously this need for criticality experiments. And I think, the combination of those with, I'm going to say, some explicit source term experiments.

Can we take a few ounces of salt, put it next to HFIR, cook it for a while, and then, dump it out on a steel plate, with dissolved gas analysis, and see what comes off?

Does anything of concern come off? Is everything just staying bound up with these super electro-negative elements like chlorine and fluorine or do we need to be worried about some other things?

And I think that suite of experiments gets you the validation basis you need to run the modeling and simulations so you could go to a demonstration reactor.

I'd say, for the first-of-a-kind technologies, some people are talking about using the test reactor framework, NUREG-1537, which I think is being reviewed by NRC right now. But there's other companies that think they've got enough data --

CHAIRMAN CORRADINI: I'm sorry, can you say that again, please?

MR. SMITH: The NUREG-1537 --

CHAIRMAN CORRADINI: Well, I'm sure we can always find the number, but what was the thinking process, I'm sorry?

MR. SMITH: So, there's some test reactor that's the first time you're going to build the integrated machine, right?, with a power cycle integrated. And there's a pathway that NRC has that's less constraining --

CHAIRMAN CORRADINI: Okay, fine. I know what you're talking about.

MR. SMITH: -- than a commercial reactor. But you're not allowed to make a profit --

CHAIRMAN CORRADINI: So, you mean a prototype -- a prototype, is that your point?

MR. SMITH: I forget the word, there's a specific word for it, but it's the less constricted, you can make a profit off of this machine, pathway.

CHAIRMAN CORRADINI: Mirela?

MS. GAVRILAS: So, this is Mirela Gavrilas, again. We're talking about NUREG-1537, which is the guidance for research and test reactors.

CHAIRMAN CORRADINI: Okay.

MR. SMITH: There we go.

CHAIRMAN CORRADINI: Thank you.

MR. SMITH: Okay. So, a few other things I wanted to mention here. When you go and start using these DOE codes, some of them have really strong user support, like you can go to SCALE training ten times a year and there's a detailed manual, you can learn everything you ever wanted to know about SCALE.

But some of the other codes that are still in kind of a development phase don't have that pedigree or that history behind them, so they're a little bit more -- you've got to send an email or two to get up and running for the first time.

In order for these vendors to be able to use the codes, they've got to have a nice landing point, where you enter into the system, you download the code, you get access to it, and you learn how to use it. And that's not always as fleshed out as the industry would like it to be.

The other thing I want to say here is that the V&V of DOE codes, I feel like the responsibility is on DOE to pay to V&V those codes. And industry is going to be building these experiments and --

CHAIRMAN CORRADINI: And what does DOE say about that?

MR. SMITH: They've given me head nods in the background so far, I don't think they've said anything --

(Laughter.)

MR. SMITH: Yes. I mean, the point is, if industry is going to be paying to do all of these experiments, it makes sense that we collaborate together and bring in DOE to get access to the data to support the validation of their codes.

And I'd like to continue that public-private partnership in this space specifically, because we're seeing a lot of success in areas where you can have a technology developer in the driver seat, as far as where are we going and what are we trying to accomplish, and you fold in the National Labs as teammates, not as work-for-hire.

And you don't have to tell them explicitly, hey, we need you to go do X, they are looking around corners for us in a lot of these areas, and they really are acting like a teammate and not just somebody who is, do the task and send the report and forget about it.

That's the type of relationship we want to build with DOE going forward.

MEMBER REMPE: So, before you leave this slide, would you elaborate on your last bullet a bit?

MR. SMITH: So, I think, the caveat that all the developers asked me to put in here is that we don't need these codes from DOE if they are not going to accept the idea that we want them to V&V it and they would go pay for it themselves or do it themselves.

So, it's not an either/or, in terms of, like, DOE has to V&V these codes or we can't get licenses.

MEMBER REMPE: So, one probably needs some sort of an analytical method. Does that mean that the members of your group have their own backup software that they're working on, that they're validating on their own to bring in, to support any sort of license they get from NRC?

MR. SMITH: I think all of the credible vendors have multiple backup plans for every technology concern that they're currently addressing.

So, there's not just one all or nothing, if this doesn't work, then we're done, I think they're maintaining backup plans. But there's an optimum solution that they're hoping for.

MEMBER REMPE: Okay. Thank you.

MEMBER KIRCHNER: But, can we explore this a little bit more, because there are a lot of implications in this. Let's say you're depending on a code, therefore, it has to be a properly QA'd code. And I'm thinking Appendix B.

Let me back up from the bottom of your slide. Timing is an issue. For DOE, let's pick on some of the more generic DOE codes. The one that comes to mind is MCNP. It's kind of a workhorse, benchmark type code for difficult problems.

What does it mean here, if I take that next to the last bullet literally, DOE would pay for MCNP to be validated against your criticality experiments? Is that what you're expecting?

MR. SMITH: I think what I'm trying to convey, and I guess poorly, here, is different than that.

I would consider -- MCNP is not a development code, in my mind. MCNP is a code that has already been developed. And there might be tweaks to it or little changes to how it operates that you would need, but I wouldn't consider that a development code.

I'm saying, the commercialization timelines are such that you can't have DOE come back and say, we need a whole new tool, brand new code, from scratch, we're going to build it up with no background on it at all.

MEMBER KIRCHNER: Well, typically, the industry has taken codes that were derivative from, once upon a time, AEC, also NRC and DOE, and then, modified them and qualified them in the V&V sense, and put them under a rigorous QA program.

So, I'm missing something here. This would have to get very, very specific to suit your needs in the licensing arena.

Typically, the DOE-developed codes are, for lack of the right term, more generic, more flexible, more workhorse kind of thing, that could then be tailored to your specific needs. So, is that your expectation?

MR. SMITH: The expectation is that the DOE codes accurately model the physics and that a vendor could take them and integrate them in whatever fashion they need to to model their system.

MEMBER KIRCHNER: Right. And in your case, then, you would have the responsibility to meet the timeline necessary --

MR. SMITH: Yes.

MEMBER KIRCHNER: -- for your particular

business case?

MR. SMITH: Yes.

MEMBER KIRCHNER: I don't think the slide says that, or at least I'm misreading how you've put the slide together.

CHAIRMAN CORRADINI: Yes, the way you explained --

MEMBER KIRCHNER: It looks like, the illustration on the left looks like, is it a black hole or a cooling tower?

(Laughter.)

MR. SMITH: It's a cooling tower.

MEMBER KIRCHNER: Well, you could get into that kind of issue. But in all seriousness, I think you need to be a little bit more precise here and realistic about expectations.

And when you say that you want DOE to pay for the V&V, that means they have to go to Congress and get those funds. So, this is not as simple as just --

MR. SMITH: So, I --

MEMBER KIRCHNER: -- as you stated it here. And doing it in a timely manner to suit your needs, that's my concern.

CHAIRMAN CORRADINI: I think we're giving you advice that you can choose to accept or reject, but -- since it's a bit off topic.

But I think Walt's point is that, what I hear him say is, there's got to be a development plan with potential exit ramps and entry ramps that DOE has to be part of, I guess.

MR. SMITH: Absolutely.

CHAIRMAN CORRADINI: I'm trying to find a better word, but it's a partnership, as you said, but the words here didn't convey it. I think your explaining to us helped me.

MEMBER REMPE: So, we advise the staff and the Commissioners, not DOE, and my takeaway from this is that, with respect to your technology working group, it's not clear what you're planning to do with the DOE codes and that we should make sure that the staff and the Commission are aware of that.

MR. SMITH: It's an evolving story.

MEMBER REMPE: Yes.

MR. SMITH: Yes. Okay. So, only one slide left on what we're missing. Completely captures all the things that we're missing to make commercial MSRs happen.

One of the things that we are missing is a predictive chemistry code. So, this is something where, obviously, as the liquid fuel burns, you're going to have additional fission products that could change thermophysical properties, change how the source term would be affected.

And we don't really have a code that can do that right now. This would be the equivalent of a fuel performance code, but for molten salt reactors.

CHAIRMAN CORRADINI: So, let me investigate that. So, in the world of chemical engineering technology for reprocessing, there are things like that, I assume.

I'm looking at some of the folks in the room, in the labs that have that, for salt systems, or I'll call it -- so, is there something particular that's missing here?

Is it basic chemistry data that's missing? Essentially, chemistry potentials? What am I -- activity coefficients? I'm --

MR. SMITH: I think it's a combination of things. There's the missing chemistry data, right? I mean, we don't have a model that tells us how the thermophysical properties change as you change the chemistry.

We can accurately, pretty accurately predict what fission products are going to be in the salt as it burns, but the effect on viscosity, when you have a salt that's been burning for ten years, that's a question.

And that backs up into your safety case, because you designed your heat exchangers and your pumps and all of your heat rejection based on some heat capacity, viscosity, thermal conductivity, you need to know what changed about those as the salt burned up.

And if there's some chemistry management you're going to do, I mean, we do a lot of boiler feedwater chemistry management to prevent corrosion, if there's something like that that you're going to do, you need to understand the implications on that --

CHAIRMAN CORRADINI: Okay, I'm with you now.

MR. SMITH: -- with your chemistry.

CHAIRMAN CORRADINI: I'm with you now, thank you very much.

MR. SMITH: The next one I've got listed here is a couple --

MEMBER BALLINGER: Excuse me, but you're not starting from zero.

CHAIRMAN CORRADINI: Right, that was my point.

MEMBER BALLINGER: I mean, the molten salt reactor experiment, depends on how they control the potential, there's data there. And one of the original thermodynamic codes for calculating speciation was developed for the molten salt reactor experiment.

And I'm trying to remember the name of the darn thing, but it's an engine which is used all over the world now.

CHAIRMAN CORRADINI: You're talking about SOLGASMIX?

MEMBER BALLINGER: Yes. You got it.

CHAIRMAN CORRADINI: I think what he's getting at is, there are assumed activity coefficients, chemical potentials that have to be in SOLGASMIX, so that you can do the calculation. That's what I thought he was saying.

MR. SMITH: I think we've got to go do a lot of verification of the salt properties --

MEMBER BALLINGER: Yes.

MR. SMITH: -- and take those measurements.

MEMBER BALLINGER: Because it really depends on how you're controlling the potential. With the MSRE, they used a U4, uranium couple. But others will do -- beryllium is different.

MR. SMITH: And for a fast reactor, it would be different.

MEMBER BALLINGER: All right, thank you.

MR. SMITH: The next one is a coupled fast spectrum neutronics and thermal-hydraulics transient code.

I think today, you could go use VERA-MSR and do a transient for a liquid fuel thermal reactor, but there's been hang-ups on using that in the fast spectrum.

And so, that's something that we're already engaged with NEAMS on, but I figured it was worth mentioning, because that's something that's important to some of the MSR Working Group members.

And then, the third one you'll see listed is the MSR mechanistic source term code. And that's partly because, I think if you talk to the MELCOR folks, they would say, there's not a bunch of code aspects that are missing, but they don't have the right models for the MSRs that you would need in order to accurately do a source term calculation.

So, we've got to go do a combination of experiments and I imagine there's some subtleties to the implementation where there will be some tweaks that are needed, to use MELCOR for that. So, that's something that we've asked about, we're exploring, and we'll probably be exploring much more aggressively over the next year.

And then, I mentioned this earlier, but salt irradiation experiment data. We can do a lot with just the chemistry of the salt outside of neutrons and gamma fields, but at some point, you've got to get all three aspects of the chemistry at high temperature with materials and radiation.

And so, those experiments are being planned by different groups right now, but not all of them have taken place yet.

And then, the last one, I think would be, I put optimize, I don't know if optimize is the right word or predictable would be a better word, but an understanding of what it means to license an MSR. When you go fill out your Safety Analysis Report, a lot of understanding of what needs to be in that and what the expectations are there.

MEMBER REMPE: So, the expectations vary, whether they're going to go for a Part 50 or a Part 52. I'm guess you don't have any customers or sites that you got to go for a Part 52, right?

MR. SMITH: Not necessarily. I think a lot of people are concerned -- it's a business decision for the companies that are making the deal at the end of the day.

But I find it hard to believe that for a first-of-a-kind, you're going to be able to do the entire design and bank on being able to construct that and operate it at the start. You probably want something that looks closer to a Part 50.

MEMBER REMPE: I would think so. The prototype or demo or whatever you do first, yes, I would think so, that might be on a government site or something, I don't know.

But when you talk to the members, are they knowledgeable enough they understand that? Because a lot of times, I see a lot of the developers coming in thinking they want to get a certified design right off, and I think it's wise that you're saying, no, it's very hard to do that with a first-of-a-kind. And some of them are recognizing that and trying to think along the Part 50 way?

MR. SMITH: Yes. Some of the developers definitely have a dedicated licensing team and they're very knowledgeable and hesitant to make any commitments on a licensing pathway until they have a lot more information and have had a lot more meetings with NRC.

Others are more technically loaded, in terms of their staff, and so, there's not as much of a background on licensing.

MEMBER REMPE: Okay. Thank you.

MEMBER KIRCHNER: Let me -- may I just query you on your very last bullet? The -- I'm sure you're following what the staff is doing, with their Licensing Modernization Framework, with the generic, so to speak, advanced reactor general design criteria, et cetera.

So, are you expecting something that would be optimized for molten salt or are you participating with the, as an interested member of the public, with the staff on how they go forward with their technology-inclusive approach?

Because, at least what has been shared with us, doesn't -- it recognizes that that's one of the technologies out there, but it doesn't try and optimize for an MSR. What are you asking for there?

MR. SMITH: So, I think, whether you use the Licensing Modernization Project approach or not, if you went and tried to fill out your Safety Analysis Report for an MSR today, there would be gaps in the ability for the applicant to be as effective as possible.

Things that they would second-guess about putting in, that would probably lead to a lot of RAIs, and so, I guess what I'm saying here is, being able to have an open conversation about what should or shouldn't be included in an MSR --

MEMBER KIRCHNER: Okay.

MR. SMITH: -- application, even if it's using the technology-inclusive, technology-neutral framework, would be helpful.

MEMBER REMPE: I was involved in another conversation, actually, last week. And one of -- it wasn't one of your members of your groups, but one of the developers actually stated they thought the Licensing Modernization Project was hindering them.

And I said, well, how could that be? I mean, if you look at -- since you're from Southern, it's just one option that's being proposed and I know, from prior work I've done, that it could be helpful to several of those developers.

And when it finally -- we started exploring further, they finally admitted and said, yes, I guess we need to have more of the different technologies, micro-reactors or molten salt folks, participating in some of these discussions, maybe having a more active involvement by GAIN in those discussions.

Would that help your group, if, again, you were involved in some of these discussions? And is that an area where maybe the staff needs to try also and reach out more? Do you think there's a problem, I guess, because I was surprised when the developer stated that.

MR. SMITH: From my experience, the folks in the MSR TWG that I'm interacting with are much less focused on licensing and much more concerned with engineering a safe and viable product.

And it's almost taken for granted that if I really do engineer a safe product that can be verified, that the licensing piece will happen somehow or another. And that's kind of their stance.

CHAIRMAN CORRADINI: Or to put it differently, you're far away from the need for optimization at this moment, you have data gathering and --

MR. SMITH: We've got a lot of work --

CHAIRMAN CORRADINI: -- technology development?

MR. SMITH: That's correct.

CHAIRMAN CORRADINI: Okay.

MR. SMITH: As someone from Southern,

though, I do agree that the approach being taken by the LMP is absolutely going to help expedite the licensing process.

CHAIRMAN CORRADINI: Okay.

MEMBER REMPE: Yes, that's what I would think.

CHAIRMAN CORRADINI: Okay. Anything else?

MR. SMITH: That was it.

CHAIRMAN CORRADINI: Questions by the Committee? Okay. So, we're going to take an almost hour break. We'll be back at 12:45 to begin with Framatome. Okay?

(Whereupon, the above-entitled matter went off the record at 11:50 a.m. and resumed at 12:46 p.m.)

CHAIRMAN CORRADINI: Okay, why don't we get started? We have our next presenter, Josh Parker, from Framatome. Josh, welcome.

MR. PARKER: All right. Thank you.

CHAIRMAN CORRADINI: I think you were on.

MR. PARKER: Oh, I was on, there we go.

CHAIRMAN CORRADINI: Okay.

MR. PARKER: Sorry. Yes. Thank you for your time today. So, I'd like to present Framatome's ideas in terms of using DOE codes to support industry implementation of advanced concepts.

We've got a little bit of ATF, advanced fuels, as well as advanced reactors. We cover a little bit of everything there.

So, just a background on Framatome Innovation here, we often look at innovation in four buckets, most of you all are familiar with this, near-term, short-term, mid-term, long-term, as you bring things out to the market.

Clearly, one of the reasons we're here is, we need to do something differently than we've done before, or perhaps something we haven't done in a long time, and that's what we're considering, in terms of DOE codes and how they can be applied to bringing new products to the market.

Framatome's future, up here in a couple of bubble slides, we're looking at near-term ATF concepts here of doped pellet, along with a coated clad. We have advanced codes and methods that we are actively pursuing with the NRC approval.

Looking at a greater than five weight percent, as we start to head into some of the more advanced concepts, such as longer-term EATF of silicon carbide cladding or Lightbridge and a metallic fuel product.

So, these are kind of relatively where they're at in our development phases here, as we look at them.

CHAIRMAN CORRADINI: Let me ask a question.

MR. PARKER: Sure.

CHAIRMAN CORRADINI: So, within the French fleet, is chromium-doped fuel, has ASN approved its use or is it still in the process of being approved, within the French fleet?

MR. PARKER: I'm not aware of the French fleet. I do know that chromium doping has been approved for use in the BWRs in the U.S. fleet, as well as our German region has implemented the chromium-doped pellets as well --

CHAIRMAN CORRADINI: Okay.

MR. PARKER: -- in their products. Our French reactors tend to move a little slower.

CHAIRMAN CORRADINI: And just to complete my question, and I assume chromium-coated cladding is still being tested, but not implemented in any -- are there lead test rods in the French fleet?

MR. PARKER: There are not lead test rods in the French fleet, there are lead test rods in other reactors around the world, both in test reactors and commercial reactors. And the first leads, in terms of

U.S. fleet, will go in in spring of 2019, of this year.

CHAIRMAN CORRADINI: Okay. All right. Thank you.

MEMBER REMPE: When you say that there are lead test assemblies somewhere in the world with the chromium-doped cladding and the chromium-doped pellets, it's together, it's not just the tubes in one reactor test and the fuel in a different, you actually have them together?

MR. PARKER: We actually do have them together, yes.

MEMBER REMPE: Okay, good. Okay, thank you.

MR. PARKER: On the chromium-doped pellets, we've actually irradiated those for nearly 20 years in different forms. The chromium --

MEMBER REMPE: With different claddings?

MR. PARKER: With different claddings, it's really -- the newest thing is the chromium coating on top of it. So, we --

(Off microphone comments.)

CHAIRMAN CORRADINI: Excuse me, I thought I had a green light. If you're going to get to it later, I'll just wait, where you're doing the testing for the chromium-coated cladding?

MR. PARKER: So, ATR has some, both chrome-doped pellets and chrome-coated cladding.

CHAIRMAN CORRADINI: Yes.

MR. PARKER: Commercial reactor in Sweden has that rod combination and the lead assembly. And then, Vogtle has signed a contract to irradiate those in spring of 2019.

CHAIRMAN CORRADINI: Okay, thank you.

MR. PARKER: You're welcome. Just some background of why we need to do things differently. Historically, our product development is very linear and sequential. Most product evolutions, in terms of what we've seen in the market, take over a decade, from the concept to the first implementation.

And this is with things that we already understand, zirconium clad, UO2 oxide fuel, it still takes us well over a decade to bring something to market.

Just going down, and as you go, you go from the concept to the design to the testing and the validation, and you can end up in a cycle of where your testing or your validation needs you to go back and revisit your concept and come down.

After you get through that, you still get to the design requirements, the NRC review, and then, you get to the market implementation out there.

What we're looking at is the potential that the DOE codes could help streamline the process and help us out in this, and maybe make this more of a parallelized process, that we've kind of thrown up here, of where it makes sense to help drive with modeling and simulation the concept and the design process, to inform your testing, so that you're trying to compact the schedule here and bring new products that are both safe and economical to the market, in a quicker fashion.

So, our plants are aging out there, if we want to make a difference, we need to get the product out there sooner. So, we clearly see the benefit that modeling and simulation can have in that design process, as we move forward.

So, specifically, where we say the DOE can help. In the near-term, our short-term on the chrome-doped and chrome-coated cladding, we don't need any help with that.

We think it's an extension of our current code suite. It's a zirconium product with a coating on top of it, our extension of our current codes should be applicable.

We've had a large experience with dopants in fuel, both in the United States, as well as in Europe, with our background, so an extension of our current fuel performance codes there, we feel is applicable.

MEMBER MARCH-LEUBA: On the chromium-coated, have you made any CHF or CPR measurements? Does it affect the --

MR. PARKER: The performance?

MEMBER MARCH-LEUBA: -- the performance?

MR. PARKER: We've done some pressure drop type tests. We have not actually done a direct CHF, because the CHF is done with stainless steel rods or steel rods in a heater configuration. So, it's hard to get your chromium in that configuration to do a test.

MEMBER MARCH-LEUBA: But you have another way to do it?

MR. PARKER: What's that?

MEMBER MARCH-LEUBA: You have any other way to do it? Because CHF, the boil-off or the dry-out, depends on how you wet the surface.

MR. PARKER: Yes, so we have done wettability tests in the areas that we're able to do that.

MEMBER MARCH-LEUBA: So, you think that it doesn't have a negative impact?

MR. PARKER: No, we do not.

MEMBER MARCH-LEUBA: It may have a positive impact, then?

MR. PARKER: I think we're assuming if it does have a positive impact, we're not taking credit for it.

MEMBER MARCH-LEUBA: All right.

MR. PARKER: Mid-term effects, or mid-term items that we're looking at, silicon carbide cladding. We think that there could be some benefits here in the modeling and behavior of the material, in the fuel rod analysis codes. So, DOE could bring to bear some benefits in that.

Metallic fuel in LWRs, clearly, the DOE has a large experience base in terms of metallic fuels and their performance, so they could bring benchmarks, code-to-code comparisons, and codes to help aid the design, in terms of implementation in an LWR.

CHAIRMAN CORRADINI: So, I'm sorry that I don't remember, metallic fuel in LWRs --

MR. PARKER: We're --

CHAIRMAN CORRADINI: Oh, this is Lightbridge?

MR. PARKER: This is, yes, this is our Lightbridge --

CHAIRMAN CORRADINI: So, is Lightbridge --

MR. PARKER: -- fuel product.

CHAIRMAN CORRADINI: -- now wholly owned by or this is a collaborative effort?

MR. PARKER: It's a joint venture between Lightbridge and Framatome called Enfission.

CHAIRMAN CORRADINI: Ah, okay. All right.

MR. PARKER: Yes.

CHAIRMAN CORRADINI: Fine, sorry, I lost the thread there. Thank you.

MR. PARKER: That's all right. So, looking at these advanced products, we've got to go above five weight percent. The DOE, having benchmarks, helping us provide code validity up to the 20 weight percent, some of the areas that we could potentially benefit from.

MEMBER REMPE: So, my understanding of the DOE codes, a lot of the times, they've gone into this microscale or mesoscale stuff and they have, we were told, even fundamentally different equations than what's been traditionally in the vendor codes, as well as the NRC codes.

And when you say, well, they could help

us, I'm a little concerned, because they can't give all the data to validate those models for the mesoscale stuff.

And so, I'm wondering -- I mean, it's, I guess, okay if you want to get some insights, but when you -- if you're starting to think about extrapolating those codes, because you don't have high burnup data for higher synth-enriched fuels, I'm just wondering how that's going to work.

MR. PARKER: So, it goes back to the discussion I said in terms of parallelizing the process and using modeling and sim to inform.

We're not trying to take the place of testing out there, but we're trying to inform the design to stop or reduce the amount of iterations that we might have to do.

So, if there's anything available that helps us inform the design that says, this is a viable design versus a non-viable design, before we get into the expensive cost of testing and looking at higher burnups or specifically what's happening on an atomistic level of things, actually having models, that's -- computer power's cheap, so let's use that first, before we actually go out there and test, so we can inform the product design cycle.

MEMBER REMPE: Okay. Thank you.

MR. PARKER: Our long-term advanced reactors, there's a smattering of codes being used all over the industry.

This may be a little pie in the sky, but if we can condense that suite or availability to something that's industrial, easy to use, more robust, and has benchmarked with DOE, like reactors, many of the concepts out there come out of DOE-type reactors that were developed in the 1950s and 1960s or proposed, that would be very nice, I think, for our advanced reactor community.

So, to help finalize this, places we see that the DOE can help industry, clearly, in the area of the silicon carbide claddings on the accident-tolerant fuel, DOE can provide the independent fuel performance codes.

Metallic fuel in LWRs, definitely looking at an independent code suite would help, to have, like I said, before you have testing, if you have two codes that are in agreement and may have different models behind them, you have a higher confidence that your design may actually make it to implementation.

Clearly, code-to-code benchmarking suite would be very beneficial. We've used, in the past, the OECD/NEA benchmarks, anything like that that could be developed would be of benefit, we find, to the industry.

And clearly, on the advanced reactors, consolidating that code suite down and helping to reach a more industrial, ease of use concept, would help in those conceptual and design phases up front.

MEMBER MARCH-LEUBA: This is kind of a leading question, do you think, for this application, do you think these codes, these DOE codes need to be licensed by the NRC? Or are these only a helper to you?

MR. PARKER: So, we could see potentials in both of them. Clearly, and I'll get to it in my conclusion, if there's a business case to actually license the code, that would be something that we would consider. But we actually view it, right now, as possibly a helper, in terms of the design --

MEMBER MARCH-LEUBA: I wasn't asking you to license it --

MR. PARKER: Yes.

MEMBER MARCH-LEUBA: -- but them to license it. You could use their codes for these purposes without any license, because you will run the tests.

MR. PARKER: Yes, but what I would end up bringing to the NRC would be something that I would be asking them to license, and whether that's a DOE code or a self-developed code or a modification would be --

MEMBER MARCH-LEUBA: No, the way I see what you're proposing is, you use the code to scope your design. And then --

MR. PARKER: Yes.

MEMBER MARCH-LEUBA: -- you test it on a real experiment.

MR. PARKER: Exactly. So --

MEMBER MARCH-LEUBA: So, what you license is the experiment, not the code.

MR. PARKER: Well, we still have codes that we're going to license. We license our fuel performance code, in order to get to the end product.

MEMBER MARCH-LEUBA: But those, you will use with the results of your experiment, you would fine tune your existing codes to the final data.

MR. PARKER: Yes. We'd clearly benchmark against experimental data, in order to justify those.

MEMBER MARCH-LEUBA: Okay, just asking.

MR. PARKER: Yes.

CHAIRMAN CORRADINI: So, I guess, I understand qualitatively what you're saying, I'm still struggling as to, if I put it in its simplest terms, for short-term ATF, you see no need for anything other than the safety analysis tools you already have, that you either are thinking of asking for NRC permission or already have NRC approvals for use?

MR. PARKER: That is correct. So, we would ask for extensions of those --

CHAIRMAN CORRADINI: Okay.

MR. PARKER: -- current tools to the new materials.

CHAIRMAN CORRADINI: And then, in the second category, well actually, not the second category, in the category of silicon, SiC-SiC, I think I know what that stands for, one is fiber, one is embedded stuff --

MR. PARKER: Well, it's often considered a sandwich, but, yes.

CHAIRMAN CORRADINI: Fine, whatever.

MR. PARKER: Yes.

(Laughter.)

CHAIRMAN CORRADINI: For that, that's a long-term goal that requires still a good deal of experimentation. So, I sense computer tools can be of help, but until I have the experiments, I can't put the cart before the horse.

So, what are you saying there? Are you saying that you can use current DOE calculational tools to help design the experiments?

MR. PARKER: That is clearly one area that they could help, yes.

CHAIRMAN CORRADINI: So, give me an example of a tool that is robust enough to do that.

MR. PARKER: Currently, we have used CFD to help inform some of our testing, in terms of vanes on our grids.

CHAIRMAN CORRADINI: Ah, okay.

MR. PARKER: So, help design --

CHAIRMAN CORRADINI: But I'm --

MR. PARKER: Now, you're going back to the fuel performance aspects.

CHAIRMAN CORRADINI: Yes, I'm not going to let you off the hook.

MR. PARKER: Yes.

(Laughter.)

CHAIRMAN CORRADINI: I want, I guess I want you to name names, if they exist, in these three bullet areas, because I see where you're going, but if it's something that has yet to be determined, that's fine, I just want to understand, is it still in flux?

MR. PARKER: I don't think the codes are in flux, I think their capabilities, we still have yet to take a deep dive on some of them --

CHAIRMAN CORRADINI: Okay, fine.

MR. PARKER: -- to make sure that they're ready.

CHAIRMAN CORRADINI: Okay.

MR. PARKER: But if you want me to name names, BISON, MARMOT, there's things that are out --

CHAIRMAN CORRADINI: So, those are the two that you're thinking of, that would fit as an experimental design tool?

MR. PARKER: Exactly. NEK5000, in terms of thermal-hydraulics, CFD --

CHAIRMAN CORRADINI: Okay.

MR. PARKER: -- yes.

CHAIRMAN CORRADINI: Okay.

MR. PARKER: Yes.

CHAIRMAN CORRADINI: Thank you.

MR. PARKER: You're welcome.

CHAIRMAN CORRADINI: So, well, I'm not done yet.

MR. PARKER: Okay.

(Laughter.)

CHAIRMAN CORRADINI: So, there happens to be a tool that Framatome is developing with CEA called

ALCYONE. So, I'm surprised you're not picking tools that are already part of the mix that Framatome has with your partner, CEA, and EDF. Can you explain?

MR. PARKER: I will say that as the U.S. market, sometimes we're not aware of what is going on between Framatome in France --

CHAIRMAN CORRADINI: Seriously?

MR. PARKER: -- with EDF and CEA.

CHAIRMAN CORRADINI: Okay, fine.

MR. PARKER: Yes.

CHAIRMAN CORRADINI: All right. Okay. Thank you.

MR. PARKER: I would say, that's the first time I've heard that tool.

CHAIRMAN CORRADINI: Okay.

MR. PARKER: Yes. So, in conclusion, basically, we use a business case philosophy. So, in regards to the DOE tools, we look at it and where it best fits and meets our needs and can help us in the development project to help us bring technology to markets, we'll use it to its best advantage.

Clearly, the more advanced they become, we need the DOE to engage the industry and make sure that they're focusing their R&D in those efforts as well, and not just wasting time in other places that may not benefit us in the U.S. nuclear fleet.

MEMBER REMPE: So, my takeaway, since our job is again, to advise the Commission and the staff, is that the tools may be helpful for you, as you do things, but right now, it's unclear whether you're going to bring any of the tools to NRC at this time. So, it's not clear that the NRC needs to jump on the bandwagon yet.

MR. PARKER: The way that the NRC would see these tools is in regards to, like I said, code-to-code benchmarks, where we'd probably bring in our own code and we said, hey, the DOE ran these cases over here with X code, we ran them with our code, show that we get comparable results. So, in that case, we would want the NRC to be familiar with what the DOE has done.

MEMBER REMPE: But NRC, most likely, would be more familiar with your tool or you'd be bringing in your tool for NRC evaluation of whether -- and giving it some sort of Safety Evaluation Report, right?

MR. PARKER: That is correct.

MEMBER REMPE: Okay, thank you.

MR. PARKER: You're welcome.

CHAIRMAN CORRADINI: Other questions by

members? Okay. Hearing none, I'll thank you guys and we'll move on to the world of non-light water reactors. And X-Energy, I think, is coming up. Martin van Staden? Go ahead.

MR. VAN STADEN: Good afternoon and from X-Energy, thank you very much for the opportunity to discuss some of our modeling and simulation needs.

We thought it important just to vie a bit of background about our design, so that everybody understands where we're coming from.

Look at introducing some of the safety basis, because we believe that the modeling and simulation is really heavily dependent on the safety basis that we select.

And then, we'll go through some of the physics that drive that and look at the neutronics, thermal flow codes, and also, source term. And that's probably, if I had rearranged this earlier, I would have put source term first.

Just a note, obviously, there are a number of other areas where we use safety-related codes, but are not relevant to this Committee, such as structural codes, et cetera, so we won't be discussing those today.

We're looking at a pebble bed high

temperature reactor, using well proven UCO fuel that's been developed in the U.S. What we see, 200 megawatt thermal reactor, we're producing steam as our product, so we can produce electricity from that or use it for process heat.

So, those are just some basic parameters, not going to drive through those in detail.

MEMBER REMPE: Excuse me, I had a question --

MR. VAN STADEN: Sure.

MEMBER REMPE: -- when I saw this, and this is probably just my lack of a good memory, but you mention you're going to use the UCO TRISO fuel that's been proven with a lot of the tests that were done in the AGR program.

Did they do tests that would provide insights to validate the performance of that fuel for the type of transients that might occur if you're load following?

MR. VAN STADEN: Not at this stage, and X-Energy is planning to do validation testing, irradiation program with our fuel.

MEMBER REMPE: Okay. So, you'll be doing that in the future?

MR. VAN STADEN: We'll be testing that.

MEMBER REMPE: Okay, thanks.

MR. VAN STADEN: I think just maybe to follow up on that answer, some of the AGR tests did actually look at some design-to-fail fuel. And currently, I don't believe that those tests are going to be completed.

MEMBER REMPE: Well, isn't that, like, where they irradiated an ATF and then, they took it over to a hot cell and put it in a furnace? Or --

MR. VAN STADEN: Yes, so --

MEMBER REMPE: -- they didn't really bring the power up and down in ATR?

MR. VAN STADEN: Yes, those tests have been performed and we will be using that data and have been using what's been coming out of AGR so far. As well as historic data out of the German programs, that's been available, there's a lot of data for that.

MEMBER REMPE: So, you're using the German data?

MR. VAN STADEN: Yes.

MEMBER REMPE: Okay.

MR. VAN STADEN: So, what's really important here, sorry for the header being cut off there, is that our fuel provides the primary fission product barrier. And I say primary, because we've got multiple independent fission product barriers.

And what we see on the top left corner is the UCO kernel, which is about 4.25 millimeters in diameter there, really small, and that is coated with a number of layers.

We have a buffer layer, the larger layer, then pyrolytic carbon, silicon carbide, and outer pyrolytic carbon layer. And these layers together build up the key fission product barriers in the fuel itself.

We've got about 19,000 particles in a pebble. A pebble is about the size of a billiard ball and it's got a fuel zone in the center, which is the center 50 millimeters, and then, a five millimeter fuel-free zone, which makes up the fuel element.

And then, we've got 220,000 pebbles that fit in the core. What we see on the right-hand side is the reactor and steam generator; reactor on the left, steam generator on the right.

The pebbles are contained in the cylindrical volume that is formed by graphite blocks. The graphite, therefore, forms the core structures. Pebbles are dropped in at the top, under gravity, and they shuffle down to the bottom.

It takes about six to seven months for one pass of a pebble. We've got a multiple pass system. We measure burnup when the pebbles get to the bottom. If they still have life left, we'll put them back in. And on average, recycle them about six times.

Very important to note that, because we rely on the fuel quality and the barriers that the fuel quality provides us, the fuel is really an important aspect to understand and model.

And therefore, the analysis, one of the analysis challenges for us is to predict accurately the temperature of not just the pebble, but also, the fuel in itself and all the different layers.

So, just from a high level down, and I just wanted to go over what is the safety basis that drives some of the codes that we'll be using to support that.

And I've gotten the top, the safety functions. And these are not all the safety functions, they're the key ones relevant to thermodynamics, neutronics, and source term. We've got control criticality, control heat removal, and control fission products.

And what we've got in the boxes below those are some of the design features or design selections that we've made, to try and support those key safety functions.

Typically, design selections are things like low power density, low excess reactivity, strong negative temperature coefficient, et cetera.

Those are design features, they're there by design in the amount and the quantities that we've got them in there. Also, online refueling, very important, because it gives us a very low excess reactivity.

So, in each one of these safety functions, if we drive them down, we're supporting them either through thermodynamics analysis and thermal flow, or neutronics analysis. And then, also, source terms.

And I mentioned, I didn't put source term up front, because I've got a bit of a story to tell, how we go from the center of the coated particles, all the way out to the site boundary, and which analyses will support that.

So, if we look at -- I mentioned fuel temperature being very important and one of the key drivers affecting fuel performance. So, in order to model fuel temperature, we need to have a strong coupling between the neutronics and thermodynamics. So, that's a key physics coupling that we need.

Fuel burnup is also very important,

because of fission product buildup inside the kernels and the pressure buildup in the coated particles. So, understanding fuel depletion calculations is really important in order to be able to predict burnup.

And then, obviously, fuel quality, and we've got modeling in our source term code that really looks at how we affect fuel quality in various aspects.

And then, if we drill down a bit deeper and we look at what factors affect temperature, it's obviously the power, the power per coated particle and the power per pebble. And so, that's very important, we obtain that from neutronics codes coupled with thermodynamics.

The heat transfer phenomena involved in a pebble bed is an important aspect. It's a reasonably irregular geometry, so we need to model that in a great level of understanding.

And we're using CFD codes with simplified porous media models and go into a bit of how we're going to validate that with high fidelity modeling as well.

And then, material properties play a very important role in this whole process. Firstly, because they're strongly temperature-dependent in most cases, but also because they're affected by neutron radiation.

So, especially graphite material, thermal conductivity changes significantly over the life of the graphite. And that's both the graphite of the pebbles, as well as the graphite in the side reflectors.

So, I'm going to start off with a summary slide of the codes that we're using in various areas. So, the first couple of rows show the neutronics-related codes and then, the thermal flow codes and source term codes.

And what we have, we've had to rely initially on a lot of legacy codes. We have a number of key personnel that came out of the PBMR era and we're actually trained out in Germany with the AVR reactors. So, we had some of those in-house codes, such as VSOP and MGT.

So, we've been using those for conceptual design and they've been used to design reactors that have run and also, the HTRP, and that will be in operation, we hope, soon.

And then, we're looking at codes, commercial codes, like STAR-CCM+, as thermofluids code, and FLOWNEX Nuclear, which was also a code developed out of PBMR. Both of those codes are NQA-1, developed under NQA-1 Appendix B programs.

CHAIRMAN CORRADINI: I'm sorry. Again, which codes are developed under NQA-1?

MR. VAN STADEN: STAR-CCM+ and FLOWNEX, FLOWNEX Nuclear.

CHAIRMAN CORRADINI: Okay.

MR. VAN STADEN: So, we're relying a lot on those programs. In fact, we were involved in early days with, even with CD-adapco with STAR-CCM+ to move it towards getting NQA-1 compliance.

CHAIRMAN CORRADINI: Can you just remind me, I'm sorry, I know the name, but I don't remember, what is FLOWNEX again?

MR. VAN STADEN: FLOWNEX is a system analysis code, so it's similar to, most probably PARC or RELAP, is the easiest comparison.

And then, codes that we've been developing in-house, from scratch, is our XSTERM, which is our source term code. And I'll go through the various components of that in one of the later slides. And that looks at the source term from beginning to end, and we'll elaborate on that in one of the next slides.

We've also been working with the DOE labs and realize that some of the legacy codes, we don't have the support that we might need in the long-term.

So, looking at the DOE, we've developed a number of roadmaps in various areas. We have a neutronics roadmap, source term analysis roadmap, graphite roadmap, and a thermodynamics roadmap.

And then, we've used the insights of the DOE labs and various people have contributed to that, to help us understand which codes are available and how they would best suit our deployment timelines.

And that's a very important aspect, because there might be -- some people might say, well, we've got a code that can do this or that, but there might be only parts of those codes that are available.

And we've had to rely on something that we can drive the timelines to be in line with our deployment timeline. So, there might be some codes out there that we haven't got on this list and we've had to rely on DOE resources to help support us in identifying those.

And maybe just as a clarification note. We have grouped US/DOE codes, if you look at the legend at the bottom, as the ones marked in red. And I appreciate there's a lot of difference between maybe a US/DOE code for NRC or that's a NEAMS code, but we've just grouped those for this purpose as one set of US/DOE codes. So, please don't crucify us for that.

And then, the green, all the ones marked in green are in-house codes and the blue bolded ones are commercial NQA-1 codes.

CHAIRMAN CORRADINI: So, it's your plan to use things, use these tools -- I'm trying to understand, so I should focus on, in terms of what you want to use for safety analysis, the blue column?

MR. VAN STADEN: Yes. We're planning on using -- and that's what comes out of our roadmap, is primarily the codes in the blue column.

We are, and I'll show when we move to the next slides, in some areas, using a parallel path, where we are moving in parallel with legacy codes and US/DOE codes.

And we're fully aware that some of these codes need significant development work to be able to achieve what we need them to achieve for a pebble bed reactor that's got moving fuel.

So, that's what our roadmaps have been developed for, is to really outline the gaps and outline a plan on how we can achieve bringing these codes to a point where they're usable and can support our licensing process.

And then, we've listed the NEAMS codes there as well, and just to make clear, we are aware of those. We currently -- the only one we're using actively is NEK5000, through the support of Argonne, who are helping us with our verification and validation on our CFD codes.

But then, we've got the roadmap to develop some of these others within the next three years, to support the licensing.

So, if we move on to the neutronics roadmap. As mentioned, we've been using VSOP-A and VSOP-99, two independent versions of the German codes that were developed independently.

These are quasi-steady-state codes that perform the neutronics needed, as well as burnup and fuel shuffling; really, a complete suite of codes in that one code set.

And then, MGT looks at the transient part, fast transients. As mentioned, these have got a proven track record and we've used them for many years out of the PBMR program as well.

And then, worked with the different labs to develop our roadmaps, for neutronics specifically. Also, getting the support from the University of Michigan.

And we've put together these roadmaps that really help us drive the development work and we hope to start in all earnest next year, with developing these pieces of the codes that need to be enhanced to support our neutronics work.

If we look at the thermal flow roadmap, we've got two main needs for thermodynamic modeling. The one is looking at detail components and systems. So, whether it's the reactor system and the detail components, core barrel, RPV, et cetera. And we use CFD for that, and we've opted for commercial CFD codes, STAR-CCM+.

And then, we've got the system level analysis, which integrates all the components and systems and does full primary/secondary loop analyses, and transient mode. And that helps us develop our control systems, our transient responses, and et cetera.

And I mentioned both STAR-CCM+ and FLOWNEX are NQA-1 codes. We're developing an in-house porous media piece of user coding, that is linked to STAR-CCM+, to support the modeling of the pebbles themselves.

So, we have a porous media approach there, but we actually solve the energy equation within the pebbles to the center of the pebbles, so that we can actually integrate over the full domain and understand what the center pebble temperatures are. And in that way, we also can track the latent heat in the pebbles as well.

MEMBER BALLINGER: So, I'm not a code person, but I have some experience with VSOP. And which one of these other codes can deal with the moving core?

MR. VAN STADEN: Actually, none, at this stage.

MEMBER BALLINGER: Okay.

MR. VAN STADEN: And that's a key part of the roadmap, was to understand which of the DOE codes would be best suited to add the moving fuel modeling into it. And so, we've developed that and we'll most probably be addressing that in a white paper with the NRC staff.

MEMBER BALLINGER: So, none of these codes deal with the stochastic nature?

MR. VAN STADEN: None of the present codes.

MEMBER BALLINGER: Yes.

MR. VAN STADEN: Yes, that is correct.

MEMBER BALLINGER: Which of the future codes?

MR. VAN STADEN: Let me just go back to that. So, the future codes that we're looking at are SCALE with SHIFT, PARCS and AGREE, and I think the burnup in the moving core is done with ORIGEN and MIXICLE. So, MIXICLE looks at the shuffling of the pebbles.

So, these are pieces that we need to develop and integrate into these existing DOE codes, for that capability.

CHAIRMAN CORRADINI: So, I'm glad Ron asked the question, because I just assumed. So, what is MIXICLE?

MR. VAN STADEN: MIXICLE is the part -- so, our pebbles are shuffling down slowly --

CHAIRMAN CORRADINI: That part I've got.

MR. VAN STADEN: Yes. So, MIXICLE really takes that into account in the burnup calculations. So, you need to understand --

CHAIRMAN CORRADINI: But the physical location of them is based on what tool?

MR. VAN STADEN: Well, we're also doing discrete element modeling. So, discrete element modeling actually looks at the individual pebbles that are shuffling through the core.

And then, a lot of the VSOP, correlations in VSOP, are based on experimental testing that was done by the Germans.

CHAIRMAN CORRADINI: Okay.

MR. VAN STADEN: If I understood --

CHAIRMAN CORRADINI: So, there's an empirical connection to the spatial location of the pebbles?

MR. VAN STADEN: That's correct. And we're using discrete element modeling to -- almost as a validation tool to that, because we can actually change core geometry slightly in the bottom and get slightly different results. And we're using that as an update to some of those correlations as well.

MEMBER REMPE: Again, my memory's not so good, but I thought the South Africans funded some tests too, with the pebbles --

MR. VAN STADEN: Yes, we --

MEMBER REMPE: -- to try and show those, where the pebbles were, how they were flowing down and to validate some sort of software. Is this --

MR. VAN STADEN: Absolutely.

MEMBER REMPE: -- based on that, too?

MR. VAN STADEN: That's correct, yes. Actually, one of the people working with X-Energy was one of the engineers that was doing all those tests.

MEMBER BALLINGER: I think I recall some Japanese work, where they tried to make VSOP basically a Monte Carlo code, and they gave up when they ran out of computing power. They would have had the lights go dim in Japan to run it. But I think that data's still around.

MR. VAN STADEN: Okay. I'm not aware of that, thank you.

So, just to get back to the thermodynamic modeling. We're following a multilayer approach, which we see on the right-hand side.

So, we want to be using a porous media model that's got empirical model in there for modeling the heat transfer on pebbles, because that's a fast running code. We need to do long-term transients that take ten to 100 hours.

So, running explicit models of a pebble bed is not really feasible. So, we're using detailed RANS models and LES -- RANS meaning Reynolds-averaged Navier-Stokes, which is a typical CFD code, using one of those turbulence models embedded in the codes -- to understand some of the flow phenomena.

And we'll be validating that using higher fidelity models, such as LES and NEK5000. And then, as we go higher fidelity, we unfortunately most probably will need to reduce the size of the domain that we'll be modeling.

And we're really making a lot of use of the labs, Argonne, as well as Oak Ridge, to support us in those two areas.

MEMBER KIRCHNER: Are you going to have a number of internal control rods in the pebble?

MR. VAN STADEN: We actually do have control rods, and my apologies, I didn't point that out up front. But our control rods go into the side reflectors, so we don't --

MEMBER KIRCHNER: But they're in the reflector, not in the core?

MR. VAN STADEN: Yes.

MEMBER KIRCHNER: Okay. So, that's a design decision you already made.

MR. VAN STADEN: Absolutely.

MEMBER KIRCHNER: Okay.

MR. VAN STADEN: Yes.

MEMBER KIRCHNER: That simplifies this challenge.

MR. VAN STADEN: Definitely. Finally, the source term calculation chart, and my apologies, this is a bit of an eye chart, but I think it's an important chart, because it really brings together the majority of the modeling and simulation that supports our safety case into a summarized chart, to put it that way.

So, if we look on the left, we have these little pictures. The first one there being a coated particle.

And so, we've developed our source term code, XSTERM, and it will model each one of these steps, from the coated particle, all the various mechanisms for fission products to migrate coated particles, intact particles, as well as assumed failed particles.

Then, we go through into the pebble matrix and the graphite surrounding the coated particles, we refer to as pebble matrix. So, there's a certain retention ability of the matrix graphite as well.

And then, we go into a level, which we term circulating activity. And that's within the pressure boundary, so the gray there is the pressure boundary, which circulates.

And the top three are effectively your normal operation cases, where you don't have any failure of the pressure boundary.

And when you then go into potential failure modes, where you have leaks or breaks in the pressure boundary, we look at transport of all the fission products in the building, and finally, I wouldn't use the C-word, I'd use the F-word, the functional containment building, to then track the fission products to the site boundary.

And then, what we see in the various columns is just various isotopes, and by no means are those the only ones we track, I've just listed a couple.

The states in which they come out: gaseous, metallic, dust particles. The various mechanisms involved. The physical phenomena that get to be modeled there.

And then, the various codes involved in that. And as we can see on the right-hand side, the various codes, it's really a significant number of codes that we use to actually validate source term.

Our source term code, which we started developing about three years ago, we feel is really an important part of our safety basis, because it really models everything from the coated particle all the way to site boundary.

So, we looked at various pieces of codes that are available in DOE and there are pieces, like BISON, that we can be using and we will be using some of those for validation or benchmarking calculations.

But XSTERM can model everything in one suite, so that really helps us to do fast analyses and evaluation of different scenarios in a single code.

MEMBER REMPE: So, when I look at the phenomena, I don't see anything about water ingress or air ingress phenomena, is that going to be covered by XSTERM or MELCOR?

MR. VAN STADEN: Yes. We do cover air ingress and water ingress, as well as, in our case, we believe will be beyond-design-basis events, but --

MEMBER REMPE: You have that capability?

MR. VAN STADEN: Yes.

MEMBER REMPE: That's good.

MR. VAN STADEN: In summary, as mentioned, we needed to rely a lot on legacy codes and we'll, especially for conceptual designs, we'll continue using those as we don't have anything else in our arsenal at this stage.

We're moving out on exercising these roadmaps that we've developed with the DOE labs, to make sure that we can get some US/DOE codes that are capable of doing what we need.

We think it's really important for us to drive these from our side as well, because of our timelines. We want to be commercial and at a certain stage and we need to, therefore, take charge of that and drive those to fruition as soon as possible.

I think we really want to emphasize that we can't do this on our own, we need a strong commitment from the DOE and the various labs, to help us complete this, if we want to get these codes up and running in time to also achieve what we believe the DOE timelines are for deployment of advanced reactors.

And finally, I think collaborating with the NRC, as much as possible, early on and working through some of these roadmaps to make sure that there aren't disconnects in any of these, I think will be very valuable to us as well.

Thank you very much.

MEMBER MARCH-LEUBA: And what is the mechanism or plan that you have to obtain the commitment from DOE?

MR. VAN STADEN: Well, we want to place them under contract. So, in other words, contracting to do the development for us.

MEMBER MARCH-LEUBA: You paying them?

MR. VAN STADEN: Unfortunately, at this stage, this is the only option, we haven't had any other funding opportunity.

MEMBER REMPE: Okay. Back on Page 11, or Slide 11, just to be clear, MELCOR isn't really a US/DOE code, it's an NRC code, right?

MR. VAN STADEN: Yes.

MEMBER REMPE: And so, that will be something you might want to consider there. And then, do you have a regulatory engagement plan? I mean, I assume you're thinking of a Part 52?

MR. VAN STADEN: We actually have got both plans, a Part 50 and a Part 52, on our schedule boards. So, looking at which plan will get us deployed first.

But, yes, we have submitted a regulatory engagement plan and we will be moving out with a number of engagements in the next couple of months. I think our next one is the 5th of December.

MEMBER REMPE: Thank you.

CHAIRMAN CORRADINI: So, I want to make sure, though, that I'm with you. That in the previous summary column, you said what you want to use. In this one, these look like primarily your tools, supplemented by --

MR. VAN STADEN: Well, what I did mention up in the neutronics, on the neutronics side, we're going to run a parallel path for as long as we need to.

CHAIRMAN CORRADINI: Okay, fine.

MR. VAN STADEN: Meaning that once we've got a clear path to go with one or the other, we'll most probably focus more on the one than the other. But up until then, to mitigate risk, we've got a parallel path.

CHAIRMAN CORRADINI: Thank you. Other questions? Okay.

MR. VAN STADEN: Thank you very much.

CHAIRMAN CORRADINI: All right. So, we have -- our next speaker is at a distance. So, I think we're -- Andrew Lingenfelter? Andrew, are you on the line? Is Andrew supposed to be on the line?

MR. WANG: Supposed, I called him half hour back and he wasn't on the line at that time. And I told him we are earlier, so he should. But --

CHAIRMAN CORRADINI: He knows to come on at this time?

MR. WANG: He knows that 1:45.

CHAIRMAN CORRADINI: Oh, at 1:45?

MR. WANG: Yes.

CHAIRMAN CORRADINI: Oh, well then, why don't we take a ten minute break? Because I don't want to sit here and look at each other --

MR. WANG: I try to call him again, but he don't pick up the phone.

CHAIRMAN CORRADINI: All right. We'll come back in ten minutes.

(Whereupon, the above-entitled matter went off the record at 1:33 p.m. and resumed at 1:43 p.m.)

MEMBER CORRADINI: Okay. So, I'm trying to check to see if our NuScale representative is out there, Andrew?

Is Jacob DeWitte out there for OKLO?

MR. DEWITTE: Yes, I am.

MEMBER CORRADINI: Jacob, by process of elimination, we're going to take you now so we don't sit here looking for our NuScale representative.

MR. DEWITTE: That sounds good.

MEMBER CORRADINI: All right. So, why don't you go ahead and we will connect up with our NuScale folks in Oregon and they'll come after you.

MR. DEWITTE: Okay, thanks.

MEMBER CORRADINI: Okay.

MR. DEWITTE: Do you guys have my slides up?

MEMBER CORRADINI: We have your slides up. You'll just have to tell us Slide 1, Slide 2 or next slide, whatever you want, okay?

MR. DEWITTE: Okay. Thank you so much.

MEMBER CORRADINI: And can you speak a little bit louder, Jacob, please?

MR. DEWITTE: Yes. Is this better?

MEMBER CORRADINI: Yes.

MR. DEWITTE: Okay, great. Thank you guys. And unfortunately, my voice is a little bit hoarse so don't hesitate to do that. Between a cold and the smoke from the wildfires out here I'm a little bit, my throat is a little hoarse, so I'll try to speak pretty clearly and loudly. But if you can't hear me, please do interrupt.

So, first of all, thank you guys for having me. I'm excited to talk to you guys today. Sorry I had to be remote but between weather and some other conflicts I wasn't able to make it to D.C., so, appreciate you accommodating me for teleconference.

But basically, going to the next slide. So, Slide 2. I'm going to talk to you today mostly about fast reactor modeling and simulation tools and sort of provide a perspective of the different developers that are working on these technologies as indicated by the Fast Reactor Working Group, which is Chair.

So, basically there's a broad suite of

developers, as you can see, it's a pretty broad spectrum of technology that's covered. And that's kind of what's interesting about the modeling and simulation discussion here, is because of the fact that there is such a diverse set of technology with various coolants and various fuels, ranging from liquid metals to gases to salts as coolants, to fuels being in the form of metallics versus oxides or carbides or nitrides or even salts. You've quite a bit of different consideration.

And one thing that we've seen is what that looks like in terms of how different developers are pursuing or modeling a simulation approach. And also, the implications of that on a tool selection. As well as the needs and the gas being identified. So I'll be highlighting some of that today.

So this list, the developers you can see as well as the utility members that we have in the Fast Reactor Working Group, then also the general sort of independent parties such as EPRI and NEI.

And also, we're excited that we have supplier member here, including Studsvik Scandpower. Which I'll mention briefly in terms of some of the work they're doing. That could be beneficial to this group as well.

So with that, moving to the next slide, Slide 3. From a developer perspective, yes, there's different needs across the various phases of development and commercialization, which other speakers have talked about today and you've heard a decent amount.

But going from the conceptualization phase through design to licensing an operation, requires different capabilities, different tools and different codes.

And so, the focus I'll have today is mostly on where licensing is with a bit of the intersection between design. Because that's kind of, I think, the topic of interest in where some vendors or some of the developers are actually moving into. And so, that will be kind of what I highlight.

Moving to the next slide. In terms of fast reactor perspectives, there's various phenomenology of interests across the design. This is sort of amplified by the fact that the Fast Reactor Working Group encompasses technology that's spanned in quite a broad variety of different configurations that are all sort of united by their operation in the vast spectrum.

And a lot of that's motivated by the

various fuel cycle missions. Which range from long-lived cores to mission focused on used fuel consumption to breed and burn operations.

Generally speaking, all of these systems have a single-phase coolant behavior. So that's kind of the driving thermal hydraulics similarity, which is why when you'll see the thermal hydraulic codes being used and considered, it's actually got quite a broad set of overlap.

And then similarly, given the neutronic nature of these systems, and the fact that they're often generally very tightly-coupled core design, you'll see that reflected as well.

One thing we're noting though is the fact that some of these systems are operating, they're smaller design, smaller core design, that might have higher leakage components to what they do. So, that can, in some ways, challenge some of the legacy tools, which is why the advanced tools could be quite important for what we can do.

MEMBER CORRADINI: Can I --

MR. DEWITTE: And then there is also -- yes.

MEMBER CORRADINI: Can I just stop you for a minute, I want to make sure. So, under normal conditions a single-phase coolant behavior, but in off normal conditions, is it really clear for all range of potential accidents that I'm going to stay single-phase?

MR. DEWITTE: No. And that's pretty design dependent. But, you're right. In particular you're going to have effects that come into play here, especially in the severe accident phase where some may want to look at that.

However, generally speaking for most modern designs, and I say most because, again each design has unique specific considerations. It's pretty, you know, getting to the point of actual sodium boiling, which is the main phenomena you see for this spec coming into play, it's pretty unlikely given the overall global feedbacks that are going on across the rest of the system, as well as the localized feedback to different fuel levels.

That said, this is where some of the legacy tool capabilities are quite important, because there are sodium boiling models in SAS4A and SASSYS that are pretty important in terms of severe accident analysis and progression.

That said, pushing some of these designs though, even though severe accidents, you don't see sodium blowing really occur, frankly at all, in the accidents that they're looking at. But the capabilities do exist for the design where that may be relevant.

But that's kind of one of those areas where some of the legacy tools still have an important place to play, and will be used by some of the developers.

MEMBER CORRADINI: Okay, so let me say it briefly to make sure. So, there are legacy, I think the term you used was legacy, but we'll call it already existing tools that take into account what could occur under accident situations where I would have, I come to saturation and have a boiling of the liquid of metal?

MR. DEWITTE: Right. Yes.

MEMBER CORRADINI: Okay, fine. Thank you.

MR. DEWITTE: Yes. Specifically tasked for acceptance sodium boiling models, so yes.

MEMBER CORRADINI: Okay.

MR. DEWITTE: And then just to make the last little point here, then there are different considerations considering we have three developers working on a SASSYS fluoride system of the fluid fuel considerations and what that looks like in terms of the integration from the multi-physics level in the core.

With regards particularly to precursor drift which can be an amplified importance for some of the designs that have a plutonium consumption mission. Just because you reduce your delayed neutron fraction, you have a pretty fast neutron generation time, meaning pretty short, so things progress more quickly. And so you want to be able to capture those effects accurately because that can have a significant effect on your overall plant performance and safety analysis.

And so that's a gap that people are working on and are starting to get closed. Thankfully because of the tightly-coupled nature of fast reactors in general, particularly in regards to the fluid fuel considerations of the fast spectrum system, you don't have the local heterogeneous effect that you would see in some of the thermal salt systems where you can get variations in the power temperature coefficients that can be, create power and temperature coefficients that can be pretty variable.

So that at least helps and simplify the approach you have here, but nonetheless, that is a phenomena that's important to keep in mind. And especially as we look at the gap analysis and the different tools we can use to address it.

So, moving to the next slide, titled code options. Basically, there's a variety of tools that the developers and vendors are picking and choosing from.

Now, I can't get into the specifics for every developer and every vendor and what they're doing so this kind of encompasses and massages out all the details, but should hopefully provide enough clarity to provide some good insights about where people are going, just out of respect for the vendors proprietary interests.

But, the general views are, there's advanced tools. And I kind of bullet NEAMS because that's really the house where these tools are being developed.

That are, frankly some of them are being used to support licensing activities today by some vendors. Particularly around the fuel performance side. And I think we'll see that continued giving the state of maturity of those codes and their used case in the licensing process.

But then there is also legacy tools. So, as you said, might be sort of already existing tools that are out there, highlighted or course by SAS4A and

SASSY as I would say, kind of flagship severe accident fast reactor code suite available today.

As well as some others that are being used just to particular compliment where, basically build off the legacy that we build in terms of different codes that support the various fast reactor programs that this country has undertaken.

However, some of those codes are sort of, in some degrees, last a little bit so they need to be modernized. And that's an effort that the labs are doing, and also industry is picking up as well.

But nonetheless, I think what the common approach here is, is there's going to be a hybrid approach in the near-term and then in the longer-term I think you'll start to see that evolution of all these tools converge on the more advanced capability set.

There's also in-house codes. I highlight that this is a very important item because several vendors and developers are pursuing and developing their in-house tools that sometimes leverage legacy capabilities but also are establishing new capabilities to support their specific designs and need sets.

And that can range from fairly high-fidelity system level codes for accident analysis to fairly simply but important codes that compliment what we might already have in an electronic suite, to give it a better capability set for a specific design of interest.

MEMBER CORRADINI: Can I ask a question at this point?

MR. DEWITTE: Yes.

MEMBER CORRADINI: I want to make sure I'm clear. So, are the advanced tools being used to replace legacy, I guess when you say legacy, already existing either within the DOE to allow these potential vendors to use them, are they replacing the same physics with a more efficient way of analyzing or estimating the physical phenomena or are there gaps that these advanced tools are providing?

I'm, in at least --

MR. DEWITTE: Yes.

MEMBER CORRADINI: -- at least my limited memory of this there was a gap analysis run by the DOE for liquid metal systems, primarily sodium --

MR. DEWITTE: Right.

MEMBER CORRADINI: -- and that gap analysis is about five or six years old. And most of it was, I don't remember a strong, a large amount of gaps available, so I'm trying to understand where the advanced tools are being plugged in and for what reason.

MR. DEWITTE: Yes. That's a good question. And frankly, the answer is both of what you asked.

So, in large perspective there are not very many gaps on the sodium. There really aren't many at all from the different design.

You know, each design might have a specific consideration here, they may need something else on, but in general, there really aren't gaps in the tool set available from the existing tools today.

So, what the advance tools though are bringing to bear, are typically the tools, basically codes that are, frankly, both more useable, more flexible and more capable in how they operate, how they're used. So, it's kind of just a better overall package to use, which is why some are using it.

However, they're not all, you're not replacing all the legacy tools with some of these codes. So, just to give a more specific example, on the neutronics side, for example, PROTEUS, from the deterministic side for a particular sodium core, gives you some enhanced capabilities compared to, for example, what you could you do with DIF3D and REBUS.

So you can see the case where maybe DIF3D and REBUS is being used to support to good, new general design work but then you move to PROTEUS to support some of your licensing work. Or you use Monte Carlo tools similarly to support those high-fidelity analyses that you might need to do.

That basically just gives you a better overall answer. So, it's just an improvement, frankly, over some of what the existing tools are. But not for all tools.

So there is, in many cases, existing tools that don't have a current analog that's capable yet to fully replace the legacy tools so that's part of the element. The other challenge is though, some of these legacy tools are relatively difficult to use and somewhat hard to actually plug into the modern engineering environment that the developers are implementing.

So, when you think of sort of advanced program interfaces and different approaches that different developers are taking to automate how they do their analyses and support their quality assurance that they need to implement, there could be some challenges with that.

And so, there's some advantages that the modern tools give you in that framework. And I think Brandon mentioned that from the Kairos perspective. There's a similar story there.

So, it's sort of just a general evolution and modernization of some of these tools. So, you're going to see that mixed approach which is why.

Now, the other answer though, that's important here is, that gap analysis is true, there aren't gaps in existing tools with the sodium side, but when you get to the -- it becomes more gas enforced, when you get to the gas side, similar story, and when you get to the salt side, even more gas in terms of what's existing and what can be done.

So, in a lot of cases, these modern tools give you the flexibility to encompass the broader suite of technology.

MEMBER CORRADINI: But --

MR. DEWITTE: And again, just a good example of that is the work they've done on the electronic side where you have tools that now have higher fidelity capabilities and are flexible enough to support the different considerations that play for these different kind of reactor types.

MEMBER CORRADINI: So, let me stop you

there and ask a similar question I asked of the previous speakers. I'm not sure if you were listening.

MR. DEWITTE: Yes.

MEMBER CORRADINI: Is that, for all of these, I'm looking at some sort of boxology, forget about the name of the code, on where I would have to develop cross-sections, multi-group cross-sections that would lead to some sort of neutronics analysis which would lead to, essentially, fuel cycle performance, which would lead to reactivity feedback coefficients definitely necessary for the sodium for a liquid metal reactor. And then I would have to do transient analysis.

If I have that sort of makeup, I would think even though you have all these various potential vendors out there that you named as part of your working group, there's got to be some sort of logic to all of this that is cross-cutting. Has that been developed as part of the working group, the liquid metal working group?

MR. DEWITTE: I --

MEMBER CORRADINI: I know it existed 30 years when Clinch River was going up for licensing, so I'm sure it exists in some fashion now.

MR. DEWITTE: Yes.

MEMBER CORRADINI: Is that being used by the working group?

MR. DEWITTE: Yes, it exists for the liquid metal developers, but it doesn't exist for everyone announced in the group yet.

MEMBER CORRADINI: Right.

MR. DEWITTE: I think there's a vector on what we want to achieve, but yes, that does exist in how that approach go.

And the reality though is, different tools provide different capabilities. In that process you just described, a lot of the developers are integrating themselves, so their wrapping the codes together in-house. And that's an important capability at, that's where, for example, some of the usability features of the modern tools basically gives you an advantage if you want to use those.

But yes, that work flow, what you described, yes, that's basically what's being followed. And then being developed I would say, or at least that's the target objective to be developed, to support the other concepts that are out there.

MEMBER CORRADINI: Has --

MR. DEWITTE: When --

MEMBER CORRADINI: No, that's fine, I'll let you get on with your talk, but has this been discussed with the staff?

With the NRC Staff, because, from the standpoint of planning, again, I'm kind of more focused on the staff and what they need to plan, that would give them some idea of what is out there in terms of what needs to be out there, whether it be a legacy tool or a new NEAMS tool, et cetera.

MR. DEWITTE: Yes. I think to answer your question, I don't think the industry has communicated that very holistically, rather we've basically had, we've relied I should say, on the messages that have been communicated from DOE and the National Laboratory, based on some training that was done at different points in time over the last five or so years.

MEMBER CORRADINI: Okay. All right, thank you.

MR. DEWITTE: Now, that's being modernized. And each vendor, I can say for the vendor frankly that has been engaging with the NRC on the fast reactor side at this point, yes, we've outlined with the NRC and outlined our approach on how we intend to pursue this pathway --

MEMBER CORRADINI: Okay. All right.

MR. DEWITTE: -- given the unique considerations there.

MEMBER CORRADINI: All right, sorry to stop you. Go ahead.

MR. DEWITTE: No. No, the last little bullet is commercial code. I bring that up, it's an important piece here because there are certain capabilities between the commercial, FEA specifically, tool providers out there that will be used to support different points of the analyses.

And also, I think something that's very interesting that we're working with Studsvik Scandpower on, we meaning kind of the group of fast reactor developers is, is exploring what it would look like for them to develop effectively a CASMO simulate, if you will, for fast reactors. I think there would be a lot of power in having that tool exist on a commercial side --

MEMBER REMPE: Jacob, I'm having trouble --

MR. DEWITTE: -- to give us --

MEMBER REMPE: Jacob? I'm having trouble --

MR. DEWITTE: Yes.

MEMBER REMPE: -- understanding you, could you back up a couple of sentences and talk a bit slower? There's just a very fuzzy voice coming through, okay?

MR. DEWITTE: Yes, sorry. Again, having to deal with a cold and the wildfire smoke it kind of throttles the voice.

Yes, Joy, what I was saying was, we're also excited because we're exploring some options with Studsvik Scandpower to implement, to basically work with them to develop what would have looked like effectively a CASMO simulate type tool set for fast reactor core design and core analysis.

We can do good licensing analyses with the tools that are available, but we think there is some ways to be more efficient and more capable, but also help on the utility side to sort of, when you think about what future deployment looks like. If you have utilities who are running and operating some of these plants, being able to use tools that they're pretty familiar with but now can actually work in the fast reactor environment is a pretty helpful bridge.

And also of course, the QA that comes with that in terms of a product, given that it's a commercial dedicated product or commercial product with NQA-1 behind it versus commercial grade dedication that would go on with DOE tools or other tools that might be used.

So, does that kind of, could you understand me on that?

MEMBER REMPE: Okay. The fast reactor group is doing this, is what you're saying?

MR. DEWITTE: Yes.

MEMBER REMPE: Okay.

MR. DEWITTE: Yes. We're exploring that now with Studsvik Scandpower.

MEMBER CORRADINI: Keep on going, you're doing great.

MR. DEWITTE: The next slide, Slide 6, is, in terms of different analysis areas I just highlight those just to give you a preview of what I'm going to jump to. So, jumping to the next slide, which would be Slide 7, reactor physics.

I'm going to breeze through these for the sake of time. I know you've seen some of these before, but please interrupt me if you have any questions.

In general, I bucket these into three topics here. There's a cross-section generation aspect, which presents a unique consideration in the fast spectrum. And then tying, so there's a couple tools available for that and how they're going to be used to tie over to the deterministic option.

There's a number of options I present to cover different specific areas. In general, I list PROTEUS and Rattlesnake in percent kind of at the top, given that those are sort of the driving codes in general. And the others do support work, but they also provide alternative options.

And then I have the Monte Carlo bucket at the bottom left because some of the capabilities with modern Monte Carlo tools are providing some interesting ways to provide much more, well, a much higher fidelity approaches to calculating some of the core parameters that support the safety analysis. Or at least provide a verification, I'm sorry, validation or benchmark check to that.

MEMBER CORRADINI: So, just with Slide 7, there's a lot of names up there.

MR. DEWITTE: A ton.

MEMBER CORRADINI: So, are you telling me that, and pardon my simplicity, are you telling me from a deterministic route I can choose anyone of these to get the job done whether it's --

MR. DEWITTE: It depends on your design.

MEMBER CORRADINI: I'm sorry?

MR. DEWITTE: It depends on your design.

MEMBER CORRADINI: Okay, fine. Fine.

MR. DEWITTE: And your philosophy. So I would say that each designer has their own preference of these --

MEMBER CORRADINI: Okay.

MR. DEWITTE: -- that's why I list them.

MEMBER CORRADINI: Thank you.

MR. DEWITTE: Yes. Going to the next slide, Slide 8, thermal hydraulics. Basically a similar approach here where you've got a couple of different code packages where designers, based on their design and their preference, might be picking.

You see that in this space you've got sub-channel. There is the SE2, the SUPERENERGY2 code set. Kind of dedicates the legacy tools, but what we're seeing with SAM and PRONGHORN coming forward, could be fairly useful in terms of complimenting or maybe replacing that from the advanced tool side.

And then on the systems side you got SAM emerging as an advanced tool that has pretty high capabilities, but the sort of workhorse has been SAS4A and SASSYS. But there are some limitations of how easy that can be to integrate.

And I should highlight that, and again, I'm just picking for the sake for of time, I'll highlight on the system code level at the bottom. Some of the developers are also looking at FLOWNEX, which has some carryover with the gas reactor community, given its capabilities for single-phase flows from the system side analysis.

And then there is also, on the right-hand side, CFD. And I just bracket FEA because in some cases, these are being used to do more thermal mechanical solving.

But you've got the package of both NEK, NEK5000 to the various commercial codes that different developers are working with to do some of the high-fidelity analyses they need to support some of those localized phenomena or specific phenomena of detailed interests. Thermal stratification being an example in the liquid metal cooled system.

Moving to Slide 9. This kind of buckets a bunch of stuff up there, but in terms of fuel performance, Bison is emerging as the leading contender for, I would say advance fuel performance modeling and simulation.

Marmot can complement that, especially for certain evolution behaviors that we might want to explore more in-depth. But, in general, Bison is a pretty robust tool that I think its capabilities were probably, just frankly, maybe a little bit sort of under presented in terms of the metallic fuel space, given what they can do.

There are some gaps there of course that they're working on filling, but we've been very impressed with the capabilities they've demonstrated.

LIFE-METAL is sort of the existing tool that, I think what we're seeing vendors do is use both like metal inherent geometry limitations for what it could do, but it works very well for the more traditional space for like legacy design PIN spec specifications. So, thinking about what an EBR2 to a said PRISM or even back to an FFTF or a center type approach.

Like metals can give you a good example. Or works pretty well in that kind of configuration. But there are some limitations that Bison can help overcome.

So we're seeing those two sort of work together and some designers are pursuing Bison in preference just because of the capabilities.

And then I bucket SAS4A and SASSYS below given the transient capabilities of, for fuel performance in SAS4A. Specifically meaning there are transient fuel performance and fuel failure models. Very robust ones in SAS4A and SASSYS that are sort of, I think, being adopted in different forms and different flavors.

Meaning, either if they're not using SAS4A/SASSYS fully, they may be just using the fuel performance, in some cases, to do, to capture those analyses.

Structural/mechanical, similar story as I mentioned on the FEA side. Both bringing in a legacy tool, is NUBOW, or NUBOW, sorry, 3D, which is basically rod bowing.

And then Diablo, which is a high-fidelity structural mechanics code. And that Argonne has done quite a bit of work coupling with their various tools.

From the risk analysis side, I'll highlight this because I think it's important. We've seen fast reactor developers now implementing this.

Basically, ADAPT provides a dynamic probabilistic risk analysis platform that we see a lot of, what we see increasing interest and value in. Sandia and Argonne work together to actually couple that with a SAS4A/SASSYS.

And that provides a pretty powerful

coupling capability to actually do your source term calculations when you combine with your risk analysis. So I think that's going to be growing in use so I wanted to highlight it.

And then the source term side there's sort of the legacy tools, SAS4A/SASSYS, CONTAIN-LMR, which basically somewhat has been folded into MELCOR. There's a longer discussion there so for the sake of time we won't get into, but there are capabilities from that that are useful, but nonetheless, we think between SAS4A/SASSYS and then MELCOR and sort of the present codes to MELCOR like MACCS or RASCAL, are what give you basically the transport to the site boundary and dose analysis you need to do.

So we feel pretty confident in what those capabilities look like. With the idea that potentially SAM and other codes could develop in, and sort of combine with those or maybe replace those tools.

MEMBER REMPE: Tell me again a bit more about ADAPT. This is a new Argonne, Sandia effort?

MR. DEWITTE: This is --

MEMBER REMPE: Is this part of the, there was some award that Argonne had to do a risk assessment for a sodium reactor in the last few years from DOE, is that what this has come from or what is this?

MR. DEWITTE: It's actually not. This is actually a Sandia tool. It's a dynamic PRA simulator. So it's basically a dynamic --

MEMBER REMPE: Okay.

MR. DEWITTE: -- thriving tool. But you can then couple with an accident code such as SAS4A/SASSYS. Which is what Sandia worked with Argonne to do, to create sort of an all in one tool that you can propagate through your accident space and your event sequences without having to sort of structure yourself into those sequences, given the sort of inherent biases that come with building out your sort of event tree.

Basically, what it is a more robust way of doing a holistic probabilistic risk assessment on a plant. So, effectively, it just drives a bunch of SAS4A simulations at the different states, from the different states, and through the different states the plant will evolve to in a transient.

And that does so in a pretty powerful way that allows you to capture some interesting insights about what might you be missing in terms of your event tree analyses. So, it's interesting from a design side and it also has the power on the licensing side as well.

MEMBER REMPE: Does it require a --

MEMBER BLEY: Is --

MEMBER REMPE: detailed design? Like, do you have to -- oh, Dennis, did you have a question?

MEMBER BLEY: Yes, I did. Following up on your last one, because I haven't heard of ADAPT before. I don't think we've talked about it at the DOE meeting, the last one.

Does this fall under the work of -- Schmidt's over in Belgium 15 or 20 years ago? It sounds very similar.

MR. DEWITTE: You know, I don't know. I can look at that and get you an answer. I'm not familiar with that past work but I know --

MEMBER BLEY: I'd be interested because they really ran into problems with overload on the computers --

MR. DEWITTE: Yes. That's actually the interesting angle. So, it might be related because of that.

Because the, that's the cool thing is the advance of the computers today give us the capabilities to do this stuff now actually. Think about how computers have advanced in the last 15, 20 years, we're really not nearly as challenged.

And, Joy, to get to your question about how much detail you need, yes, that is an important aspect here, but it could be very useful in the design side of informing what actually really matters to the plant and then where you need to add the appropriate detail, so then support getting into these analyses sort of in a, through the design. Like, in a coupled way between the design process and the actual development process.

MEMBER CORRADINI: We have somebody in the room that I think can help Dennis a bit too.

MR. DEWITTE: Okay.

MR. GAUNTT: This is Randy Gauntt, Sandia Labs.

MR. DEWITTE: Oh, hey, Randy.

MR. GAUNTT: Yes. So, the ADAPT code is a dynamic event tree scheduler. And it's kind of co-diagnostics. You can drive pretty much any code with the ADAPT driver.

It's a joint effort between Sandia Labs and Ohio State University. And what it does is it walks your way through an event tree kind of a construct, making temporal, conditional decisions to spawn off two offshoots, at this point. And it kind of produces an event tree like collection of analyses that you can then come back and sort through.

MEMBER REMPE: So, I'm curious. So, let's explore this for a minute. So, the person has a design or they have to have an event tree as input to use ADAPT?

MR. GAUNTT: It's, like I say, it's kind of agnostic. You can hook this up to MELCOR, which we've done, you can hook this up to SAS4A.

The specifics of the design, I guess, would come back to the designs, the event tree decision points, say, if a pump works or a pump doesn't work or --

MEMBER REMPE: So, basically you define a transient, assuming the pump does or doesn't work, it does the analysis and then the analyst says, oh, it's better to have an extra pump here, something like that, so it feeds back to helping you design.

MR. GAUNTT: Yes, that might be a little simplified, but it just sort of accommodates things like operator decisions, timeliness of decisions. So it's got a definite temporal component to when this event tree branches off into one or more branches. And then those branches can branch --

MEMBER REMPE: Okay.

MR. GAUNTT: -- as you proceed through.

MEMBER REMPE: Thank you.

MEMBER CORRADINI: Dennis, does that help you?

MEMBER BLEY: It helped some. I'd be real interested in learning more about it.

MEMBER CORRADINI: Well, we'll take it --

MEMBER BLEY: Like I said, it's sounds like he'd be able to --

MEMBER CORRADINI: I'll make sure I capture Dr. Gauntt to get you a reference, okay?

MEMBER BLEY: Thank you.

MEMBER REMPE: Yes, in fact, several of us will be curious about it.

MEMBER CORRADINI: Yes. Yes, we'll get it for the Committee. So, Jacob, you have about three minutes.

MR. DEWITTE: Great. Well, thanks. Yes, thanks, Randy, for adding to that.

So, as you mentioned, there is some unique capabilities that that provides that I think are pretty powerful, especially given the fact that there's already been integration work with some of the tools that I mentioned before. So it gives you some pretty, I think it's going to give kind of a glimpse of where future design efforts go down that road of adopting that pretty early in the process.

So, moving on to the next slide, Slide 10. The validation. Basically, validation bases do exist to varying degrees for different designs that are out there.

I highlight varying degrees just because when you think of a sodium system, there is a very robust of data out there. Highlighted largely by EBR-II and the associated liquid metal development programs this country has undertaken.

And then there is some validation available but it's a little more limited for lead systems, for gas systems and for salt systems. So there is a lot of interesting work going on in terms of trying to expand the data available for that.

But the important part, I'll just spend a little more time to dive into here is, on the sodium side you've got a pretty rigorous case of fuel performance that's come from in pile, out of pile, as well as in tree. So, transient testing on metal fuel as well as off side fuel.

There's also been a vast spectrum of radiation done on carbides and nitrides, that there is some legacy data available on. And an important effort that we've been very appreciative of, from DOE, for working through with the labs on developing, and we urge them to sort accelerate this is, is archiving a lot of that data into sort of useable and searchable databases that can then support how that data is going to be used on the validation side.

So that's been an important ongoing effort and feeling that we continue to emphasize is one of the most important things they could do, because recreating this data just can't be done practically. So, that's helpful.

There is a lot of component data that's held in different plant databases that's been compiled under the NaSCoRD database, which has been very valuable. And that's a growing effort that I think is going to provide a lot of value for the designers.

And then there is, of course, the broad overall reactor operational data that has come from a number of different reactors in the lessons learned. They're go not just into design but different actual tests that were run, of course highlighted by the EBR-II shutdown heat removal that are going to be very valuable in terms of providing data and validation.

So, that kind of wraps up the presentation for me. The next slide, Slide 11, is just a general summary that basically kind of captures what I said. And for the sake of time, I'll just jump and see if there's any other questions left before I run out of time.

MEMBER CORRADINI: Okay, thank you, Jacob. Questions from the Committee?

MEMBER REMPE: So, I have one. I missed the very first part of your presentation because I was otherwise doing something else, but on Slide 2 you do list all these different members of your working group.

MR. DEWITTE: Yes.

MEMBER REMPE: And there's a diversity in the maturity of the designs that they're pursuing, and I, at least for the ones that are design developers of this working group. And I have been involved in other conversations regarding the licensee modernization project, which, by the way, I don't know if you're aware of it, but --

MR. DEWITTE: Yes.

MEMBER REMPE: -- it's just an option that's available to these different types of designs with different maturities.

MR. DEWITTE: Yes.

MEMBER REMPE: And I was puzzled to hear that some folks that are less matured designs are saying that it's hindering their efforts to move forward with getting their design license. And, do you have any insights you can give me on that and what is the problem, because, again, this is a little off topic but it's of interest to the ACRS?

MR. DEWITTE: Yes. I think that that question, yes, so, there are some insights I have on that.

I mean, in general, I think the broad consensus of the group is there's a lot of value in that work and where it goes in terms of what it's also doing as an option. I think there has been some, as the process has been matured, LMP has been matured and sort of evolved to the point of being, to some degree demonstrated and piloted.

There have been some concerns about how they approach certain aspects of the review, so, for example, I know the considerations around defense in-depth requirements that apply when there is really no source term or even any consequence of an event, does that make sense to evaluate some of the defense in-depth side if you're getting rid of all the consequence from that side throughout other means.

So, there's concerns about how that's approached. And I think the LMP group has actually, they've been taking steps to try to figure out how to approach that.

I think otherwise, I think there is some curiosity in about what this will ultimately mean in the design space for different vendors. I think there is just, people are learning and understanding how they can use this and what that looks like and what that would impact, how that would impact their design.

I haven't specifically heard really someone specifically say that it, itself, hinders their licensing strategy outside of some of the caveats I mentioned saying, hey, this seems to be interesting and could be probably very useful but seem to be, so maybe little bits of things, little gaps that we should fill in or better think about how we approach.

MEMBER REMPE: So --

MR. DEWITTE: So, you know, it's hard --

MEMBER REMPE: So, let me paraphrase what I think I'm hearing from you because, again, I'm having trouble with the fuzziness. But basically you're saying that, everyone does recognize it is just an option and the concerns are limited.

There is just certain aspects that haven't been fully flushed out. That no one thinks it's really hindering their ability to license their designs.

MR. DEWITTE: Yes. I haven't gotten the sense, explicitly from someone, that it's hindering their ability to license their designs.

MEMBER REMPE: Okay.

MR. DEWITTE: But, I don't know what everyone's thinking on that either. But that's at least the perspective that we've had when it's been discussed.

MEMBER REMPE: Okay, thank you.

MEMBER CORRADINI: Thank you. Other questions? Okay, Jacob, thank you very much. We're going to move on to NuScale. Is Andrew on line?

MR. LINGENFELTER: Yes. Andy Lingenfelter is here.

MEMBER CORRADINI: Good. Thank you, Andy.

MR. LINGENFELTER: Okay.

MEMBER CORRADINI: And we have your slides pulled up so feel free to begin --

MR. LINGENFELTER: Great.

MEMBER CORRADINI: -- when you're ready.

MR. LINGENFELTER: One second. Just let

you know I have Allyson Callaway here with me, he's a supervisor for corn fuel team. And Azat Galimov, he's also one of our sub-channel experts so we'll kind of be sharing the presentation.

So, first slide, agenda is Slide 3. It's what we're going to go through today sort of how we've interacted with CASL in the past. And some good work with NEAMS and then our suggestions on advanced ModSim going forward. So, that's what we'll cover.

So, on to Slide Number 4. I'll let Azat share what we've done with sub-channels. Go ahead, Azat.

MR. GALIMOV: Hello. During selection process of when we, in 2014, NuScale decided to select a sub-channel methodology and code to go on with the licensing. It was decided to just work with the several codes.

And one of those was COBRA and the second was VIPER. And the methodology and the collaboration with CASL at that time was very valuable because we was able to compare results and run some tests and historical experiments. NuScale specific type of phenomena like GE 3x3, PNNL.

And the CASL provides results, helped, to us, establish the path for the future development of our NuScale sub-channel methodology. Okay, next slide.

MR. LINGENFELTER: Okay.

MS. CALLAWAY: Okay. This is Allyson Callaway, I'm just speaking to Slide 5 quickly.

So, since some of the historical work that we've done with CASL in the past over the last few years --

MEMBER CORRADINI: I'm sorry, I don't mean to interrupt but you guys are hard to hear, so you're going to have to either speak slower and a little more clearly. What slide are you on?

MS. CALLAWAY: Slide 5.

MEMBER CORRADINI: Slide 5. Okay, thank you.

MS. CALLAWAY: So, since the last few years of historical work that we've done with CASL, and more recently in 2018 and at the end of 2017, we were engaged with CASL, mostly on looking at CRUD analysis. And I think that's going to come up later.

But CRUD analysis is a big thing that we were continued to be engaged with them on. And just the overall interests for the possibilities for the VERA tool at NuScale kept a lot of interests among our technical staff.

And so, in June of this year we had training. And we had somebody from CASL come out and conduct a two day training with our team.

And this is a really valuable step for NuScale because we got familiarity with the code, which is a lot more than just being able to get access to the code and use it. Familiarity with using it for NuScale applications and it got a lot of attention for the way that we should, could be able to apply the code in the future for NuScale. For a lot of future development that we can do and would get the leverage of this tool for hopefully.

So, the training was given to our systems and core thermal hydraulics team as well as to our code development team. So then a lot of exposure on the engineers that are going to be applying the code as well as engineers that would be doing code development and validation.

So, since then over the last four or five or six months, we've done a lot of thinking about the way that we'd like to continue to use the code and the way that we want to see the code continue to be developed for use.

So, on some of the near-term things that we've been interacting with the CASL team on, in terms of applications for NuScale, are further CRUD analyses. We're interested in looking at Guide 2 boiling analysis, flow distribution and boron mixing, alternate sub-channel methods, so perhaps using COBRA-TF. And then being able to use the code for validating other methods.

So, it was kind of a big jumping off point and we're hoping that we get to start taking it a lot further and a lot more ways going forward.

MEMBER CORRADINI: So, may I characterize what you just said in shorthand?

MS. CALLAWAY: Sure.

MEMBER CORRADINI: So, you're using this as backup analyses for potential future use?

MS. CALLAWAY: Yes.

MEMBER CORRADINI: Okay.

MS. CALLAWAY: That's fair.

MEMBER CORRADINI: Thank you.

MS. CALLAWAY: So, if there is no other questions on that we'll move on to the next slide.

MR. GALIMOV: This is Azat Galimov again. I want to talk about assessments of the CRUD build-up.

It was to perform a preliminary CRUD analysis to forecast the CRUD induced phenomena. I mean, to forecast operational CRUD behavior.

And the test stand activities included the development of the VERA model for the NuScale SMR. And then code-to-code comparisons and coupled neutronics and thermal-hydraulic simulations of eight fuel cycles to achieve equilibrium operating conditions for the CRUD analysis.

At the same time, it was the, VERA was compared against our in-house predictions for the neutronics and thermal hydraulic tools. And we tried to just compare what was the predictions again, thermal hydraulic predictions at the same time. We wanted to see what the specifics of the CRUD and the heat and the fuel phenomena is specific for our plant.

So, VERA demonstrated excellent capabilities to model that that NuScale core and consistency with the results from the multiple industry standard codes. And showed that some differences in the CRUD buildup in the core, because it was due to a different specific thermal hydraulic condition.

Next slide please. And then the future projects, what we actually are wanting to do in 2019 is a continued collaboration of the developments of the CRUD assessment methodology.

So, we're going to review the base model and review the results and find the path to future development of the CRUD assessment and methodology.

And the second path is, used a combination of computational fluid dynamics. And VERA core simulator too for multidimensional assessment of the reactor core flow, Guide 2 boiling, boron distribution.

And this is going to be very helpful because it's going to, as we already said, it's going to be part of the backup analysis. And maybe it's going to be a future methodology, sub-channel and system flow methodology.

MEMBER MARCH-LEUBA: Can I ask a question here? Hello?

MR. GALIMOV: Excuse me?

MEMBER MARCH-LEUBA: Yes. Okay, on the boron distribution, are you going to, are you planning to model the boron distribution in the vessel or you're also going to include the mixing of the boron you injected?

MR. GALIMOV: We will do a boron distribution in the vessel first.

MEMBER MARCH-LEUBA: Okay.

MR. GALIMOV: So, the planning is the preliminary and we actually want to do actually the, one of the transients in that. And maybe even the long-term cooling. However, all this just under planning.

MEMBER MARCH-LEUBA: Yes. Okay, so this effort with VERA is not going to include the boron mixing as you inject it?

MR. GALIMOV: Not yet.

MEMBER MARCH-LEUBA: Okay. But, okay. We'll talk about that when we have a NuScale specific meeting.

(Laughter.)

MEMBER CORRADINI: Keep on going.

MR. LINGENFELTER: Okay. The next topic is around NEAMS in particular. Many of you know we have a helical steam generator in the design.

And so, what was particularly helpful is -- NEAMS with the SHARP code. And since we didn't, it was limited research that was available on helical tube steam generators --

MEMBER CORRADINI: Can you speak a little bit, if this is Andrew --

MR. LINGENFELTER: Yes.

MEMBER CORRADINI: -- Andrew, can you speak a little bit louder please?

MR. LINGENFELTER: Yes. Yes, yes. How's

that, is that better?

MEMBER CORRADINI: Yes.

MR. LINGENFELTER: Okay, great. So the second bullet, what was a big help for the NuScale team was the experiments the folks did with NEAMS to help us with our helical test section predictions. And obviously the SHARP analysis.

So, that continues today. It was something that was done in the past and we're anxious to see it continue, the collaboration continue into the future.

So, maybe it wasn't specific to CASL but we wanted to mention that as part of the presentation. Okay.

And then I think when we look at Slide 9, which is the final slide that we have, about future recommendations, I think that what we would suggest is that there's got to be some industry benefits from, I don't know if it's an EPRI Department of Energy sponsored SER campaign with the NRC and the ACRS, around some section of VERA that would be, again, something that is industry, would benefit to the industry.

So, we put VERA-CS, which as we know, is a very large scope. But, maybe there's something we could all come to conclusion on that we could get it licensed with the NRC then we can all benefit from being able to use it as a benchmark.

MEMBER CORRADINI: So --

MR. LINGENFELTER: So, that was the one thing we wanted to take, one suggestion we had going forward. And Azat had two other ones at the bottom he just wanted to mention also.

MR. GALIMOV: Yes. A part of this -- effort, it could be beneficial for the developers to improve the codes by implementation of the generic and industry-specific proprietary modules.

For example, dynamically linked libraries for CHF and other modeling choices may actually be helpfully because that's, in that situation we can both, all include the basic installation and then develop our in-house too for CHF or, or CHF for whatever is applicable for the particular industry lender.

And that will significantly improve the usability of the software product. And also, there was also a discussion on the last industry and science council meeting at CASL.

Kind of a known, offered the idea of making the user group voting function, via using the user group. So basically, it's going to be like a feedback option from the industry to CASL and NEAMS.

And we can then choose what we vote. But that's, maybe it's too early for now. It needs some additional intermediate steps. However, it will be useful in the future.

And we use, it's not the first time introduction of this user group and the voting function. If, for example, is NuScale is actively participating in the VIPER user group and it's actually helping us to specialize the function to be implemented and set the priorities. So thank you.

MEMBER CORRADINI: Thank you. Let me, the last slide I was listening to as you went through it, I would characterize it that this slide is directed more towards DOE than to the NRC. So I'm going to take it under advisement but pass it on to DOE.

MR. LINGENFELTER: I mean, I think that, I think as I understood the mission of the HRS was in this, I heard, I thought, was that you folks were given the task of evaluating Department of Energy codes --

MEMBER CORRADINI: No.

MR. LINGENFELTER: -- to see how they would, is that right?

MEMBER CORRADINI: We were interested in your needs relative to safety analysis for licensing and what codes you, tools you're using. So I think all that you had given us before that was helpful for, at least for me, to understand where you think you could use it in the process.

Here these strike me as process steps that might be better served by providing to DOE how to improve the interaction with the industry. That's my interpretation.

MR. LINGENFELTER: Well, the other thought would be is that the, you know, I think it could be beneficial for the NRC, and the industry, if we had some generic topical reports on some very good codes and the inner agencies working together to benefit the industry.

MEMBER CORRADINI: Okay. All right, I think I see that point.

MR. LINGENFELTER: Thank you.

MEMBER REMPE: Well, there's another aspect that if the Commission is looking for whether they should consider these DOE codes, if DOE were to come in and submit a topical report for their approval, that might give the Commission more certainty before they stepped into them.

MEMBER CORRADINI: Okay, I'll let DOE take that under advisement. All right, thank you, Andrew and your other team members.

MR. LINGENFELTER: Thank you.

MEMBER CORRADINI: You can stay on the line. We're going to go now to public comments.

So, I was informed that some members of the audience wanted to make public comments. So the first question is, who in the room would like to make a comment relative to our topic at hand today? Come to the mic.

Whose ever out in the telephone world, can you put your phone on mute, your blinker is blinking? Thank you.

(Laughter.)

MR. BOLIN: So, my name is John Bolin, I'm from General Atomics. And I'm the manager for nuclear reactor design within the nuclear technologies and materials division of the energy group.

And General Atomics has a long history of development of advanced reactors. Starting with the Peach Bottom and Fort St. Vrain. Even before they were considered advance reactors.

With the post TMI focus on advanced reactors, GA sort of redesigned their effort toward a smaller reactor. The modular high temperature gas cooled reactor.

And over the years that's evolved into various other concepts. The new production reactor, the gas turbine modular healing reactor and the, we were one of the vendors associated with the next generation nuclear plant.

In 2009, we looked at the market and sort of made an evolution to our design where we started developing a gas cooled fast reactor. Which is called the Energy Multiplier Module.

And in that, we also worked on developing a southern carbide composite cladding. And that's now been, we've kind of leveraged that with the, under subcontract with Westinghouse as one of the ATF cladding concepts.

And in all this effort we have often used and relied on both DOE and NRC codes, what we refer to National Lab developed codes. Such as RELAP in the past, DIF-3D, NCMP, MELCOR, MACCS. And more recently we've been looking at FRAPCON and FRAPTRAN.

With the EM squared design, we're also looking at, how do we get this fuel qualified. And one of the efforts in that area is, we're looking at ways of accelerating fuel qualification.

So we're looking at leveraging some of the efforts that CASL and NEAMS have worked on, some of the codes they've worked on. Like, Shalottle and Bison. And along with some micro-capsule irradiation in HFIR, we plan on updating models to incorporate fuel swelling and fission gas release for our UC kernels.

And will also plan on interacting with the NRC in the near future, providing them with our preliminary fuel qualification plan.

MEMBER CORRADINI: Okay, thank you. Other members of the public, any other comments? I was told with this big audience I was going to have a lot of comments, so we planned for it. Okay.

And on the phone line, do we have any members of the public that want to make a comment? Can we take them off mute? I think you, can we take them off mute?

OPERATOR: The conference is now in silent mode.

MEMBER CORRADINI: No, the opposite.

(Laughter.)

OPERATOR: The conference is now in talk mode.

MEMBER CORRADINI: Okay, do we have any

members of the public that want to make a comment from the phone line?

Okay, with that, let me ask John Monninger to come up and sit over there by the mic.

(Laughter.)

MEMBER CORRADINI: Don't stand, sit. So, I want to make sure, I kind of want to get the remaining members comments but I can of want to --

OPERATOR: The conference is now in silent mode.

MEMBER CORRADINI: -- where to go from here. So, do Members have their comments? Joy.

MEMBER REMPE: My understanding is that the ATF project plan, even though the version we had said draft, has been finalized and released. So when you presented your presentation this morning and you talked about a letter, it is for the advanced reactor effort, right?

MR. MONNINGER: That's correct. For non-light water reactors, advanced reactors --

MEMBER REMPE: Right. The non-LWRs.

MR. MONNINGER: Yes.

MEMBER REMPE: And so, I wanted to make sure that we all understand that because there was a little confusion about that earlier today.

MR. MONNINGER: So, I think where we are within NRO is, there is considerable interest out there in the industry and support from Congress, support from DOE, et cetera. So, if the NRC is to proceed in undertaking it, we want to make sure we're ready and we get it right.

So, that's one of our desires to have the letter from the ACRS and to engage you explicitly in the plans and to take your feedback, recommendations, comments. In addition to engage with the industry and DOE et cetera.

If we proceed down the path, whichever direction we go, it could be considerable resources for the agency and we would want to use these tools and products, five, ten, 15 years down the road. So we want a good traceable, transparent record as to where we're going.

So that's the big push and desire for future engagement, a letter, resolve your comments, questions, concerns.

MEMBER CORRADINI: You go ahead, Joy.

MEMBER REMPE: I'm good. Yes.

MEMBER CORRADINI: You're happy?

MEMBER REMPE: Yes.

MEMBER CORRADINI: So, what I interpret

that to mean, at least going forward is, if and when we have, when we have the next subcommittee, we need to wait until you guys are, I'll use the word, on the same page within NRO and your support from research, so that we can see essentially a draft program plan of what the future holds.

MR. MONNINGER: Yes. And we could do it two different ways. I think the Office of Research, who we're working very closely with, they have three different reports out there they're pooling into one. And various revisions to it. We've digested certain aspects but not all of it.

A big question comes, we can interact with ACRS on multiple occasions through verbal briefings or we could push them out a little bit such that you would have a draft document, more to digest. A lot depends upon documentation.

You just want to hear the direction we're going and provide comments or is it more of review of a draft document. What happens then is we're further down the road and there would tend to be potential, more wetted in the path we are the further we get down.

MEMBER CORRADINI: Do other Members have, I know I have an opinion on this, but, Jose, do you have any comments you want to make?

MEMBER MARCH-LEUBA: Not really, but if we are going to write a letter, I would like to have a document that documents what we are suggesting, approving or recommending.

MEMBER REMPE: In your thought processes, I get this thing with the NuScale, the comment they had, a similar comment came up at our earlier meeting about the DOE codes, about, is anyone coming in to submit one for review. Which gives you a better feel for what the codes capability is and what its validation status is, et cetera.

Have you thought about trying to, before you go too far in this, I mean, you should, I like your little matrix where you're using this process to prioritize, but if there is some codes that your genuinely interested in and think have the most promise, to work with DOE, to have some sort of topical report submitted and have, or are they just not far enough along even to really even have the DOE submit a topical report?

MR. MONNINGER: From the developers?

MEMBER REMPE: Right.

MR. MONNINGER: Yes. I think it would be for them to really address where they are. You know, at a higher level, at least to discuss their plans. But in terms of whether they have anything solid to submit to us yet.

MEMBER REMPE: But before you decide that there is something of promise that you want to adopt, if the department, you know, if you have a higher list, I mean, they surely can't do all of them, but it just seems like it might facilitate the process. Frankly if someone comes in with a topical report, you charge it back to them or maybe you can take it out of the Congressional funding or something.

But, I'm just curious on, it seems like a more formal engagement with DOE on the --

MS. CUBBAGE: This is Amy Cubbage, NRO. I'm sorry.

MEMBER CORRADINI: You're on.

MS. CUBBAGE: Yes. I think you're conflating a little bit what the Applicants plan to do versus what we would do for independent calculations.

So, the individual developers, we're working with a number of them in pre-application status. Some of them do plan to submit topical reports explaining their plans in the area of codes and ultimately looking for our approval of what they plan to use.

Separately, we would be selecting what we plan to use. They may be the same, they may not be the same.

Certainly, the more we learn about the designs, that helps inform what we choose to use but it may or may not guide what models we plan to use. If that makes sense.

MEMBER REMPE: So, one, you've got uncertainty on which designs will come in, which effects your uncertainty on which codes you want to adopt.

MS. CUBBAGE: Right. And we do have a list of developers that we're engaging with and have expressed intent to engage.

And the extent that we have meetings with them, that always informs our evaluation of the potential tools out there and which ones we think have the most promise for developing for independent capability. But that there's an independent decision from what a developer chooses to do and submit to the NRC for approval.

And we would not be waiting for a developer to come in and say, I'm going to use Code X for us to make a decision because we need to be moving ahead in parallel.

MEMBER REMPE: So, then, if you are going to make a decision independent of which ones come in, what I was wondering is, if you could work with the Department of Energy, who is the person who developed this, and ask them to submit some sort of topical report instead of having to jump over the line and say, okay, I want to try and adopt this and get it to validation status that's required for the agency.

MS. CUBBAGE: We are working with the Department of Energy to help explain to them what our needs are. And if we see areas where we think Code X, Y or Z may need additional validation or something of that nature.

But we're not looking to the Department of Energy to submit codes to us for approval, because it would need to be the individual developer adopting the code explaining why it's appropriate for their use, why it's appropriately validated for their use. So the generic approval of a code like that is not something we've entered in. And it looks like Jose wants to jump in.

MEMBER MARCH-LEUBA: Yes. Help me with this. We never licensed code for Staff use.

MR. MONNINGER: Right.

MEMBER REMPE: Right.

MEMBER MARCH-LEUBA: The Staff can use any code they choose to license without a topical.

MEMBER REMPE: Okay.

MS. CUBBAGE: Right. I think Joy was implying that if developers X, Y and Z all want to use a DOE code, could we approve it generically for them.

MEMBER REMPE: Well, I'm thinking of the RELAP example, which, again, has specific applications for specific folks, but it just seems like since they're all depending on DOE is something could be worked out. But, again, I just kind of wondered.

MS. CUBBAGE: Extent to which they're all depending on DOE is up in the air right now.

MEMBER REMPE: Absolutely.

MS. CUBBAGE: You know, you heard from X-Energy here and they're not relying on a lot of the NEAMS code. So, it hasn't really been broached to us as a proposal from DOE nor the developers that we would do any type of generic approval of a code.

MEMBER CORRADINI: I guess I, unless I see DOE running up to the mic to say they're going to do it for five developers or five owner/operators or vendors --

MS. CUBBAGE: Right.

MEMBER CORRADINI: -- I doubt that path is going to be taken.

MEMBER REMPE: So then I guess I'm still kind of wondering, I mean, yes, you can review these things with DOE and identify gaps, there's still some uncertainty until you actually were to jump over the line if you decide to do that, and I'm just wondering if there is ways to minimize that uncertainty because you have very limited resources?

MS. CUBBAGE: Okay. If you're speaking specifically in terms of our capability versus the applicants --

MEMBER REMPE: Right.

MR. COMSTOCK: -- we're going to have to be in a continual learning mode, we're going to be pursuing models that we may find out new information about the designs that we may need to reevaluate and say, additional capability needs to be added in so we're not going to be able to declare victory in the near-term, this is going to be a multi-year process.

MEMBER CORRADINI: But if I might just use an example without using names. If Company X, Y, Z come in and said they'll all just thrilled to death about Tool A, DOE still is not going to be the one that comes in with Tool A, it's got to be up to Company X, Y, Z to come in and say, this is what we're going to use as part of our plan.

MS. CUBBAGE: That's typically in the model. Although, if DOE wanted to present something to our approval there's nothing that would preclude that.

MEMBER CORRADINI: No.

MS. CUBBAGE: But given the competitive nature of the advance reactor developer market, I don't know that there would be enough companies all using the same model. Because there is such variation in the types of designs and variations in the business models. And you heard X-Energy, for example, saying we have our in-house codes X, Y, Z. So, I think it's way too soon to tell if there's going to be that consensus among the developers on aligning on particular codes that they all want to come forward with.

MEMBER REMPE: But let's explore the thought about, why do you have to have an independent code from what the developers have. And so, if you want to use the same code that these developers have selected, then it seems like somebody should submit some sort of general document to give in or see competency that they should indeed use it instead of doing it on a case-by-case.

I was just kind of wondering, maybe the paradigm needs to change and there needs to be --

MS. CUBBAGE: We're trying to keep those decision points separate because we use codes for different purpose.

MEMBER REMPE: Absolutely.

MS. CUBBAGE: We're not responsible for the licensing. We may not need the same fidelity, we may not need the same qualification basis that an individual developer may need. So, there is --

MEMBER REMPE: But you need some confidence if you're --

MS. CUBBAGE: We do.

MEMBER REMPE: -- going to have that, say, okay, yes, we're not going to have our independent code, we're going to go with the same one. And so, you need some sort of confidence that costs money to get and staff resources.

And it seems like if you could push that off to the person who's trying to sell you the code that might be good. And then --

MS. CUBBAGE: To the extent that we intend to use a DOE developed code, we absolutely are looking for DOE to do the lifting on the qualification and the model development.

MEMBER REMPE: Which almost sounds like they need to submit some sort of topical report for it.

MS. CUBBAGE: It's a different process.

MEMBER CORRADINI: I think --

MEMBER REMPE: Yes.

MS. CUBBAGE: A topical report implies us reviewing and approving and we don't do that for our own capabilities.

MEMBER REMPE: Sure.

MEMBER SUNSERI: So I have maybe a question at a broader level because I think we're getting into like a specific code application.

MS. CUBBAGE: Yes.

MEMBER SUNSERI: So, on a broader level, you have this project planned to prepare the U.S. Regulatory for the effective licensing of accident power and fuel. And Task 4 is what we're talking about, I think, right? The confirmatory

MS. CUBBAGE: Except we're specifically not talking about ATF, that's the other folks that --

MEMBER CORRADINI: Mirela is here so she's --

MS. CUBBAGE: Yes, yes. Yes, Mirela is here. So, there's two different answers. Mirela already has a strategy in her report, and she can speak to that, our strategy is under development.

MEMBER SUNSERI: Okay. So, that's where I was going then. What is the details that supports that strategy?

MS. CUBBAGE: Yes.

MEMBER SUNSERI: I think that would help us if we understood --

MS. CUBBAGE: And that's the next meeting.

MEMBER SUNSERI: Okay.

MS. CUBBAGE: That's the next meeting.

MEMBER CORRADINI: I think I, just let me interject. I think the open discussion is good, but I'm hearing, I want to get back to, Joy asked the question, Mirela wasn't in the room, but we'll come back to that.

I think what I'm hearing is, from John and Staff -- Staff, a.k.a. Amy and others in the room -- is there preference might be for us to wait till they have a document that says, what's their path forward for non-light water reactors in terms of what their needs are for tools.

MS. CUBBAGE: Yes.

MEMBER CORRADINI: And then once we see that, we can react to that by a meeting and then write a letter report in response saying, great idea.

MS. CUBBAGE: And to the extent that that plan relies on DOE managed developed codes, we will absolutely be having closed discussions with DOE, it just won't be in the form of a topical report.

MEMBER CORRADINI: Right.

MEMBER REMPE: Strong words. I think we're in agreement on what needs to happen.

MS. CUBBAGE: We're in agreement on the comments.

MEMBER REMPE: And I think that he did, John answered the question. He said, no Mirela is already, she's separate. And that was my question.

MEMBER CORRADINI: Well, but I want to get further than that because what I'm hearing from Mirela is, if I might bring you up to speed is, I don't think, again, I'm speaking for myself, I don't think there's a need for the ACRS to comment on your program plan because you're going to go further than that with interim staff guidance relative to how you're going to deal with coded cladding or doped fuel. And until we see that, that's probably what we would need to comment on.

MS. GAVRILAS: That's exactly right. So, what we have now is a very high-level plan for all ATF concepts, near-term, long-term. And of course, it can only be as specific as a high-level plant can be.

But, as the plan says, we are going to have licensing strategies for each of the technologies that's going to come in front of the Staff. For example, for chromium coded, we're developing the licensing strategy as we speak.

As we said this morning, Andrew said, we're preparing the PIRT for coded cladding. We are looking at our codes to see what's needed.

So, we're sort of, we're interacting with the vendors to get the data that we need for our code and understand what codes they're going to use. And reviewing their qualification plan.

And all of that is going to come together into a licensing map, which right now we're thinking is going to be some sort of interim staff guidance in SRP4.2 that basically says, and this is how we are going to review chromium coded, or coded claddings in general. And similarly, a separate ISG for, this is how we're going to review.

MEMBER CORRADINI: But, the reason I wanted you to say that is to kind of get back to the question when she wasn't in the room. It's not just their plan, but they're going further than that. That would be the point where we would be able to look at it and comment on it.

MS. GAVRILAS: So, if you want to review the plan, we're here, just let us know. But our thought was that, these are coming soon. Soon as next year we're going to probably have preliminary engagement with the ACRS on that.

MEMBER CORRADINI: Okay, good. Other comments? John, are you happy?

MR. MONNINGER: We are very happy, thank you.

(Laughter.)

MEMBER CORRADINI: Okay. And I don't think we have any more public comments. So, unless I hear more from the Members, I'm going to thank everybody.

Let me circle back. So, the plan is, or the anticipated future is that until we hear from NRO as to where you're going and what the report might turn out to be, we'll wait and see. And at that point, that would be a good time to come back together and convene and talk about it.

MR. MONNINGER: Yes. And for interim planning purposes I would say four to six months. But we'll have to keep Chris and Weidong up to speed and have to work closely with our Office of Research. We want to make sure we're prepared and solid.

MEMBER CORRADINI: Okay, good. Anything else from the audience? This is your last chance. You are all here so quiet and polite. Okay, with that, we'll adjourn. Thank you very much.

(Whereupon, the above-entitled matter went off the record at 2:56 p.m.)

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ACRS Subcommittee on Thermal-Hydraulic Phenomena

3. Role of Computer Codes in Regulatory Decisions & 4. Computer Codes for Advanced Reactors

John Monninger, Director
Division of Safety Systems, Risk Assessment, and Advanced Reactors, NRO

November 16, 2018

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3. Role of Computer Codes in Regulatory Decisions

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Wide Range of NRC Sponsored Computer Codes

NRC sponsored codes have largely focused on light water reactor

- SAPHIRE
- FRAPCON
- FRAPTRAN
- PARCS
- TRACE
- SNAP
- RELAP5
- MELCOR
- MACCS
- RADTRAD
- RASCAL
- HABIT
- GALE
- Others

The Respective Role of Computer Codes by NRC and Applicants

There is a fundamental difference in NRC initiated actions and applicant initiated actions, and the party required to demonstrate the burden of proof.

NRC Responsibility

- Rulemakings
- Regulatory analysis
- Backfit analysis
- Reactor Oversight Process
- Safety studies
- Generic Issues Program

Applicant/Licensee Responsibility

- Technical/safety/compliance base for license applications and amendments
- Core reload analysis, design changes, methodology

The technical/safety basis to support a licensing decision must be demonstrated by the applicant. The applicant's analysis and models are part of the licensing basis and carry forward. NRC confirmatory analyses, if conducted, have a limited role in licensing applications.

NRC Confirmatory Analysis for License Applications

- Confirmatory analysis is not required; however, NRC may conduct limited confirmatory analysis in support of a licensing review
- Confirmatory analysis is supposed to facilitate an effective and efficient licensing review
- Examples of when and why we do confirmatory analyses
  - First-of-a-kind (or unique) designs, features, or operations
  - Safety margins are small
  - Effective use of NRC resources to focus the review (e.g., requests for additional information, areas to audit)
  - Gain insights on sensitivities and important areas of application

NRC Confirmatory Analysis for License Applications

- NRC confirmatory analysis may use NRC codes, DOE codes, applicant codes, or other codes

- Confirmatory analysis may be a complete re-analysis of an applicant's analysis, or it could be multiple mini-sensitivity studies to guide the overall review focus

- NRC initiated analysis (other than confirmatory analysis)
  - Generally use same codes developed to support confirmatory analysis
  - Generally subject to formal review and comment
  - Generally not used to establish licensing basis for a facility

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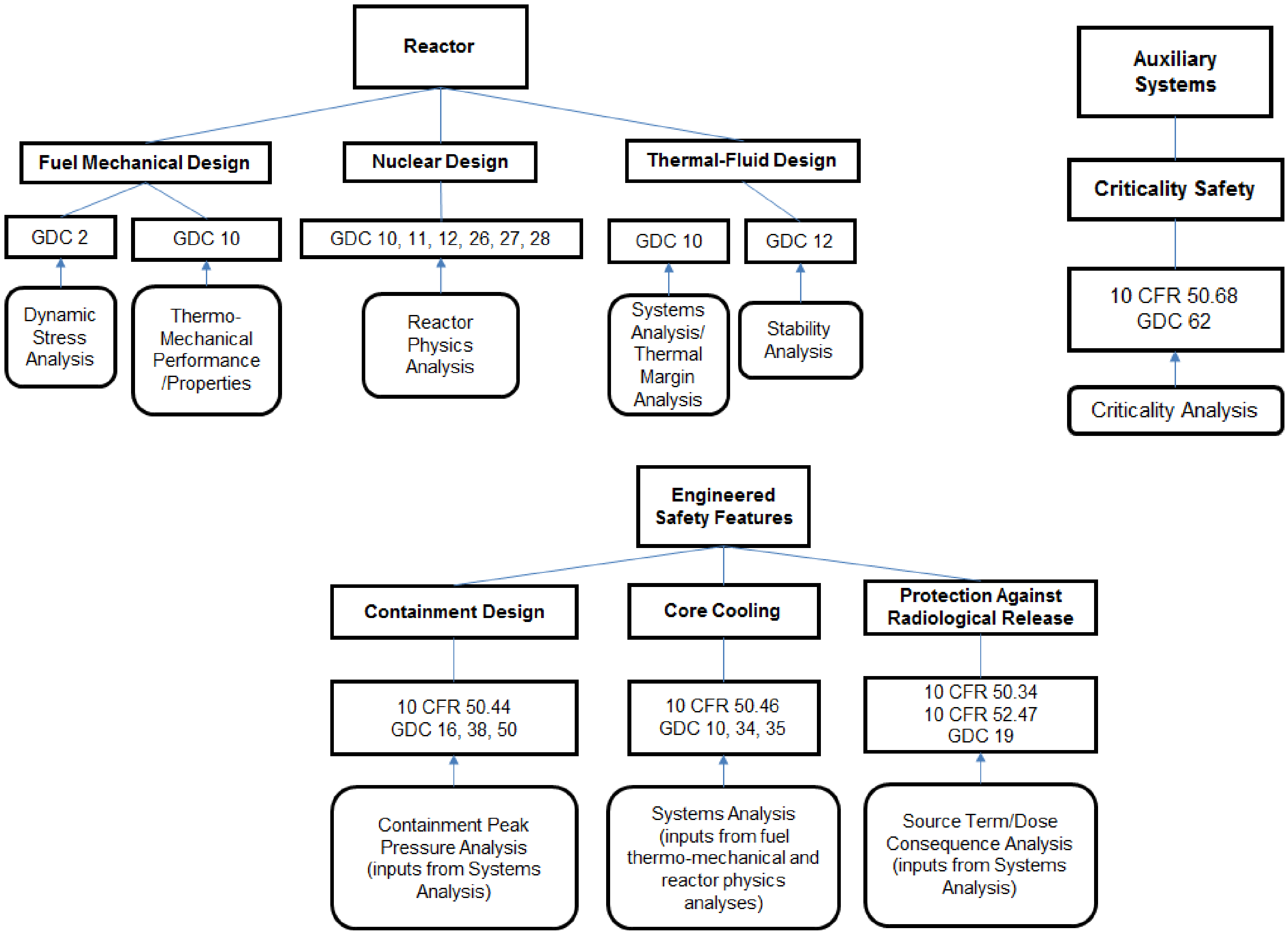
NRC Confirmatory Analysis for License Applications

- NRC regulatory guidance discusses confirmatory analysis
- SRP 6.2.1.2, Subcompartment Analysis
  - The reviewer may perform a confirmatory analysis of the blowdown mass and energy profiles within a subcompartment…The purpose of the analysis is to **confirm the predictions** of the mass and energy release rates appearing in the safety analysis report and to verify that the analysis considered an appropriate break location and size including LBB considerations.
- SRP 15.6.5, Loss-of-Coolant Accidents Resulting from Spectrum of Postulated Piping Breaks within the Reactor Coolant Pressure Boundary
  - New reactor designs may base their ECCS and reactor coolant system designs on prevention of core uncovery. Should that be the case, the reviewer should compare the applicant's analysis with the staff independent analysis to **determine if the predicted level of core coverage is consistent**.

Representative LWR Areas Where Applicants Depend Upon Computational Analysis



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Take Aways

- NRC uses of computer codes are broader than confirmatory analysis conducted for specific licensing applications
- The scope and tool used for confirmatory analysis varies
- The technical/safety basis to support a licensing decision must be demonstrated by the applicant. The applicant's analysis and models are part of the licensing basis and carry forward. NRC confirmatory analyses, if conducted, have a limited role in licensing applications.
- Confirmatory analysis is supposed to facilitate an effective and efficient licensing review

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4. Computer Codes for Advanced Reactors

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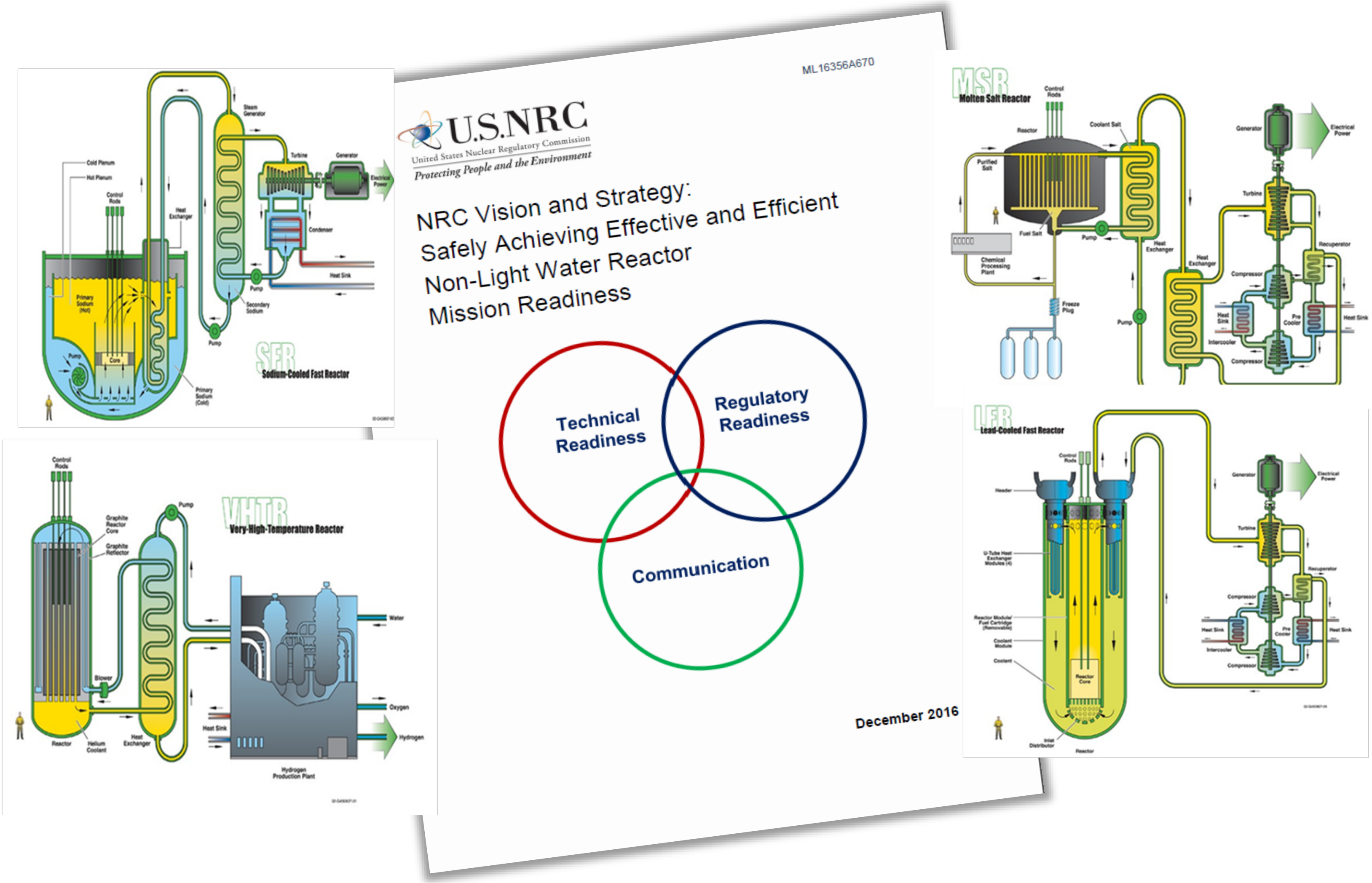
NRC Advanced Reactor Program Vision and Strategy



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Implementation Action Plans

Strategy 1
Knowledge, Skills and Capability
- ONRL Molten Salt Reactor Training
- Knowledge Management
- Competency Modeling
- Updated HTGR and Fast Reactor Training

Strategy 2
Computer Codes & Review Tools
- Identification & Assessment of Available Codes

Strategy 3
Flexible Review Processes
- Regulatory Roadmap
- Prototype Guidance
- Non-LWR Design Criteria
- Environmental Reviews
- Licensing Modernization Project

Strategy 4
Consensus Codes and Standards
- ASME BPVC Section III Division 5
- ANS Standards 20.1, 20.2 30.2, 54.1
- Non-LWR PRA Standard

Strategy 5
Policy and Key Technical Issues
- Siting near densely populated areas
- Insurance and Liability
- Consequence Based Security (SECY-18-0076)
- EP for SMRs and ONTs (SECY-18-0103)
- Functional Containment (SECY-18-0096)

Strategy 6
Communication
- NRC DOE Workshops
- Periodic Stakeholder Meetings
- NRC DOE GAIN MOU
- International Coordination

- Potential First Movers
- Micro-Reactors

NRC Approach for Advanced Reactor Computer Codes

- Vision & Strategy
  - Leverage the experience available from DOE, academia, international counterparts, and industry to acquire or develop non-LWR computer codes and tools in the following functional areas: Reactor Kinetics and Criticality; Fuel Performance; Thermal-Fluid Phenomena; Severe Accident Phenomena; and Materials and Component Integrity
- Implementation Action Plan 2
  - The staff's goal is to leverage, to the maximum extent practical, collaboration and cooperation with the domestic and international community interested in non-LWRs with the goal of establishing a set of tools and data that are commonly understood and accepted.
  - To perform these calculations, the staff will either need to develop or have access to existing analytical codes suitable for use with non-LWR applications. Currently, the staff has analysis codes that are applicable to conventional and advanced LWRs. For non-LWR reactor designs, the initial tasks for this strategy will include evaluation and down-selecting the codes for use by the staff.

Engagement with ACRS on Advanced Reactor Program

- Review of Advanced Reactor Vision and Strategy & Implementation Action Plans (February & March 2017)

- Supported overall approach and indicated that priority should be placed on Strategies 3 (flexible review processes) and 5 (resolution of policy issues)

- Indicated that Strategy 2 (computer codes) should focus on identifying data and knowledge gaps, rather than model and code development

- Discussed need for prioritization and to develop physical insights about new reactor concepts

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NRC Report on CASL & NEAMS

- 2018 Consolidated Appropriations Act directed NRC to report on potential uses of the CASL tools in licensing processes and safety reviews
- September 2018 response addressed CASL & NEAMS and considerations for advanced reactors
- NRC is working with DOE to determine how best to leverage the CASL and NEAMS programs
- Development and modification of NRC sponsored codes is an option, and DOE sponsored codes are also under consideration
- CASL and NEAMS capabilities could be adopted if they prove to be a cost-effective means of achieving the required functionality

Computer Codes for Advanced Reactors

- Congress provided funding to support modernizing the NRC's regulatory infrastructure for advanced reactors, including computer codes

- NRC needs to:
  - (1) be prepared to support timely and effective licensing reviews
  - (2) effectively manage our funds
  - (3) be transparent in our rationale, recommendations, and decisions

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Computer Codes for Advanced Reactors

- Desirable attributes of codes for NRC staff use
  - Computer codes need to be agile to support a range of regulatory uses and multiple reactor designs
  - Computer codes should be designed to facilitate an effective and efficient licensing review

- NRC's assessment needs to consider life cycle costs (development, maintenance, training)

- Could use existing NRC sponsored codes, DOE sponsored codes, or other codes

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NRC Confirmatory Analysis to Support Advanced Reactor Licensing

- Confirmatory analysis for licensing advanced reactors
  - Same as previous considerations (slides 5 & 6)
  - Need to also consider the extent to which the advanced reactor designs meet the Commission's expectations for advanced reactors (e.g., enhanced margins of safety)
  - Quick and simple to explore sensitivities
  - Ideally would be exercised by the licensing office
  - Needs to be timely to support the review (e.g., completed within Phase 1 to support RAI issuance, 3-6 months and could be less for micro-reactors)
  - Cost of any confirmatory analysis must be in line with overall NRC review costs
- In the absence of a given perceived need for confirmatory analysis, the applicant is responsible for resolving a given issue (e.g., RAIs, operational limitations, additional analysis or testing)

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Evaluation of Computer Codes for Advanced Reactors

- RES is leading the assessment for NRO
- Evaluating various codes for a range of applications – design basis, beyond design basis, severe accidents, and consequences
- Considering factors such as
  - Physics: Code suite must now or with development capture the correct physics to simulate advanced reactors. Selection of codes based on results of PIRTs.
  - Flexibility: Multiple reactor design concepts require flexibility within code suite. A goal has been to limit the number of new codes.
  - Code V&V: Code assessment is critical, especially assessment relative to advanced reactors
  - Computation Requirements: Codes must be able to run simulations on HPC platforms available to NRC
  - Cost avoidance: Minimize life cycle costs through potential leveraging DOE tools

RES is Using the Predictive Capability Maturity Model Characterization

- Using PCMM to characterize code readiness
  - Geometric Fidelity
  - Physics and Model Fidelity
  - Code Verification
  - Solution Verification
  - Code Validation
  - Uncertainty Quantification
- PCCM asks, …"Where are we today"
  - 0, little to no capability
  - 1,
  - 2,
  - 3, state of the art, with external peer review

Table 2: Predictive Capability Maturity Model (PCMM) Matrix

Element \ Maturity	Maturity Level 0	Maturity Level 1	Maturity Level 2	Maturity Level 3
Representation and Geometric Fidelity What features are neglected because of simplifications?	• Judgement only • Little or no representation or geometric fidelity for the system	• Significant simplification of the system	• Limited simplification of major components • Geometry is well defined for major components and some minor components • Some peer review conducted	• Essentially no simplifications made • Geometry of all components represented "as built" • Independent peer review conducted
Physics and Model Fidelity How fundamental are the physics and calibration of the models?	• Judgement only • Model forms are unknown or ad hoc • Few physics informed models • No coupling of models	• Some models and correlations are physics based and calibrated to data • Minimal or ad hoc coupling of models	• Physics based models and correlations for all important processes • Significant calibration using SETs and IETs • Some peer review conducted	• All models and correlations are physics based • Sound physical basis for extrapolation • Full coupling of models • Independent peer review conducted
Code Verification Are software errors and poor quality assurance practices?	• Judgement only • Minimum testing of software elements • Little or no SQA	• Code is managed by SQA procedures • Unit and regression testing performed	• Some algorithms are tested to determine convergence • Some features are tested with benchmark solutions • Some peer review conducted	• All of the important algorithms tested to determine convergence • All features and capabilities tested with rigorous benchmark solutions • Independent peer review conducted
Solution Verification Are numerical errors corrupting the results?	• Judgement only • Numerical errors are unknown or have large effect on results	• Numerical effects are qualitatively estimated • Input/output (I/O) verified only by analysis	• Numerical effects quantitatively estimated to be small • I/O independently verified • Some peer review conducted	• Numerical effects are determined to be small • Important simulations can be independently reproduced • Independent peer review conducted
Model Validation How carefully is the accuracy of the simulation and experimental results assessed?	• Judgement only • Few, if any comparisons to measurements in similar systems or applications	• Quantitative assessment of accuracy not directly relevant • Large or unknown experimental uncertainties	• Quantitative assessment of predictive accuracy for some key figures of merit from SETs and IETs • Experimental uncertainties well characterized • Some peer review conducted	• Quantitative assessment of predictive accuracy for all important figures of merit from SETs and IETs at conditions/geometries directly relevant to the application • Experimental uncertainties well characterized • Independent peer review conducted
Uncertainty Quantification and Sensitivity Analysis How thoroughly are uncertainties and sensitivities characterized?	• Judgement only • Only deterministic analyses conducted • Uncertainties and sensitivities not addressed.	• Aleatory and epistemic (A&E) uncertainties propagated, but without distinction • Informal sensitivity studies only	• A&E uncertainties propagated and identified • Quantitative sensitivity analyses conducted • Numerical propagation errors are estimated • Some strong assumptions made • Some peer review conducted	• A&E uncertainties comprehensively treated and properly interpreted • Comprehensive sensitivity analyses conducted • Numerical propagation demonstrated to be small • No significant assumptions • Independent peer review conducted

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Take Aways

- We will be back
- We are assessing needs and developing recommendations for advanced reactor codes
- NRC preparedness is vital and transparency is important
- We will present our recommendations to the ACRS in a subsequent meeting
- We will request an ACRS letter on those recommendations

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BACKUP SLIDES

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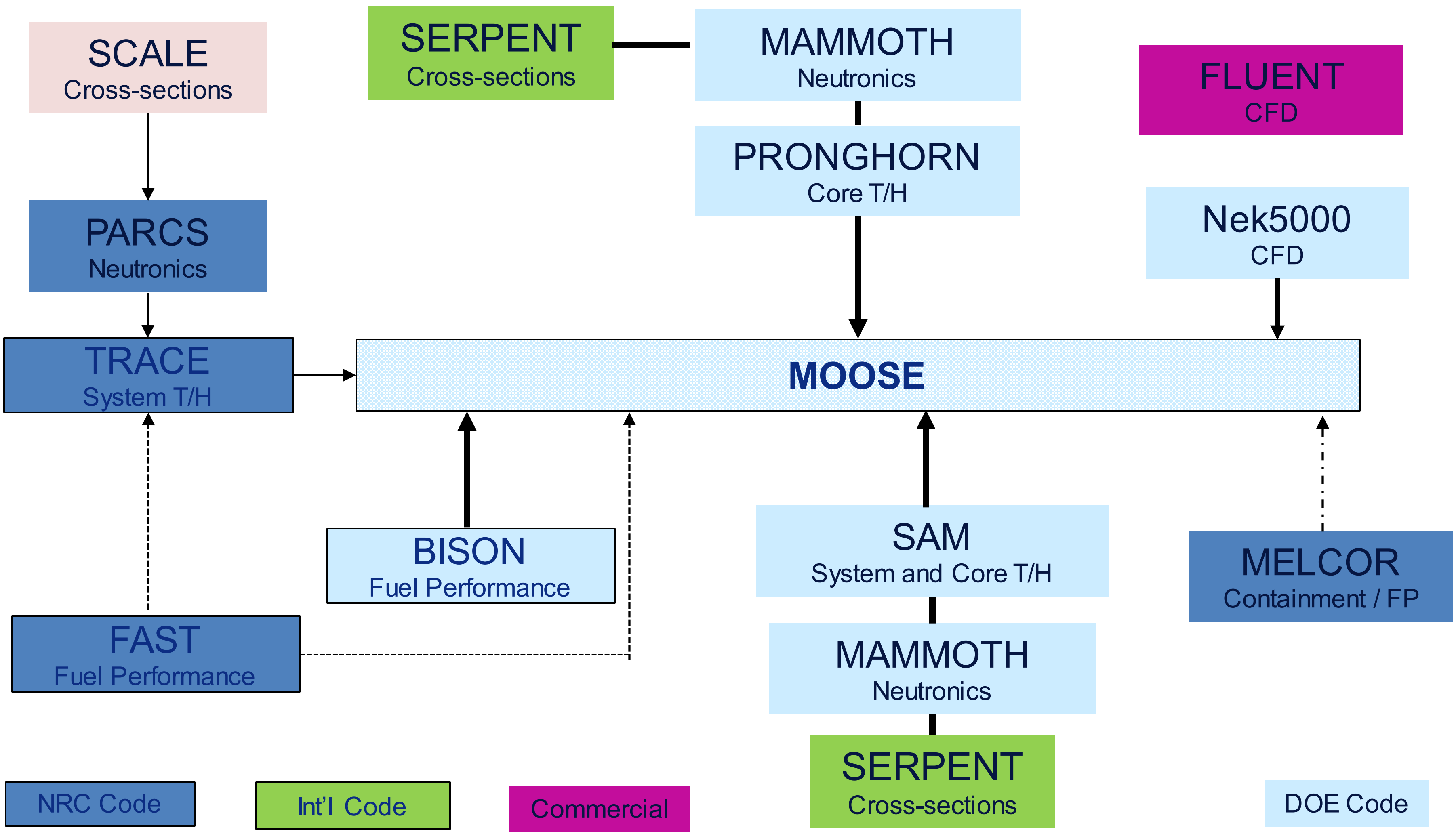
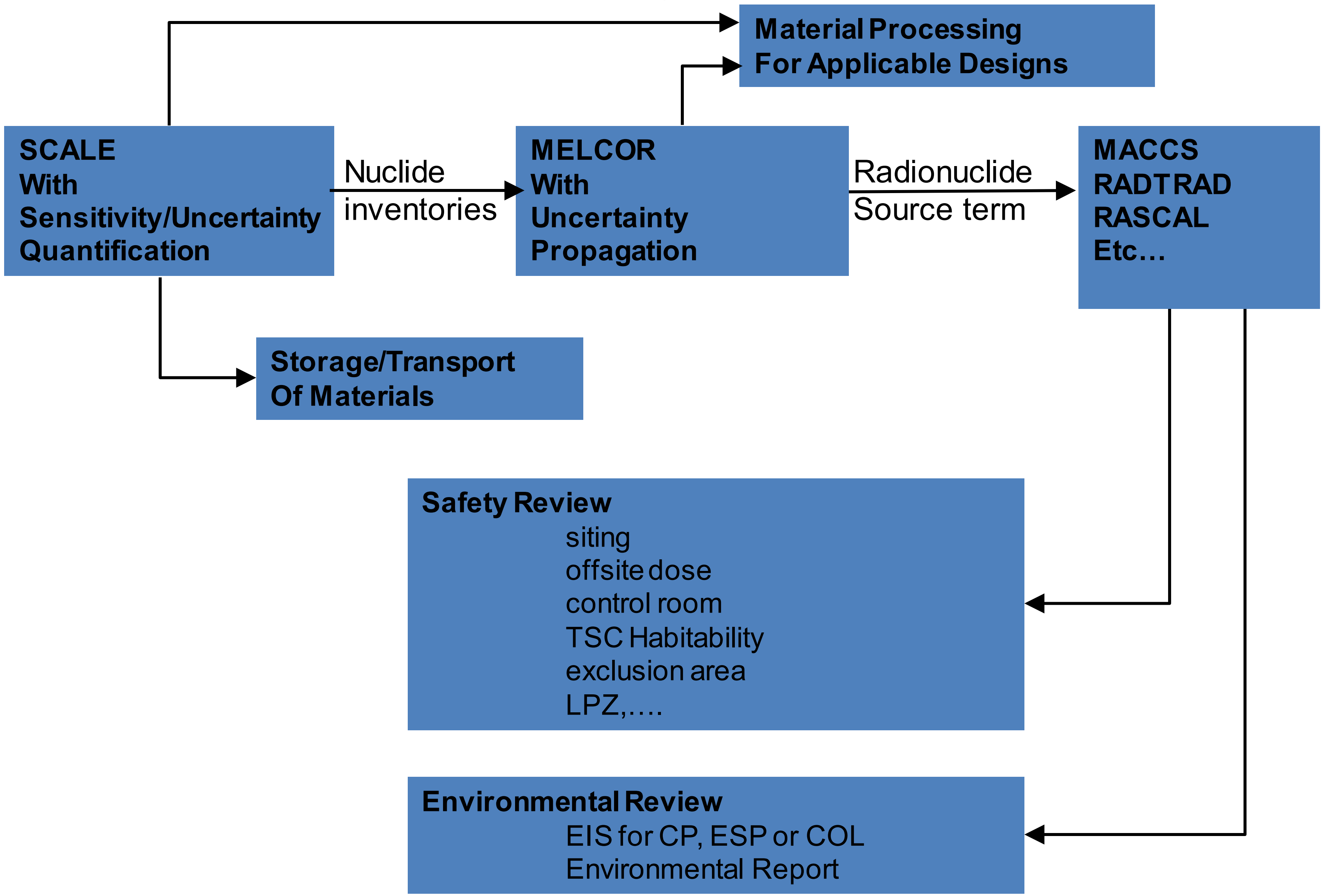
Comprehensive Reactor Analysis Bundle Under Evaluation



Source Term, Consequences, and Radiological Assessment



NRC Confirmatory Analysis of Accident Tolerant Fuel (ATF)

Andrew Proffitt, NRR

ACRS Thermal-Hydraulic Phenomena Subcommittee

November 16, 2018

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Outline

- NRC staff approach to confirmatory analysis
- Confirmatory analysis strategy for ATF
- Coordination with DOE on advanced modeling and simulation (M&S)

Approach to Confirmatory Analysis

- Informed by phenomena important to safety
  – safety significance
  – level of knowledge
- Staff evaluation can range from:
  – Review of information provided
  – Confirmatory calculations
  – Confirmatory testing

Confirmatory Analysis Strategy for ATF

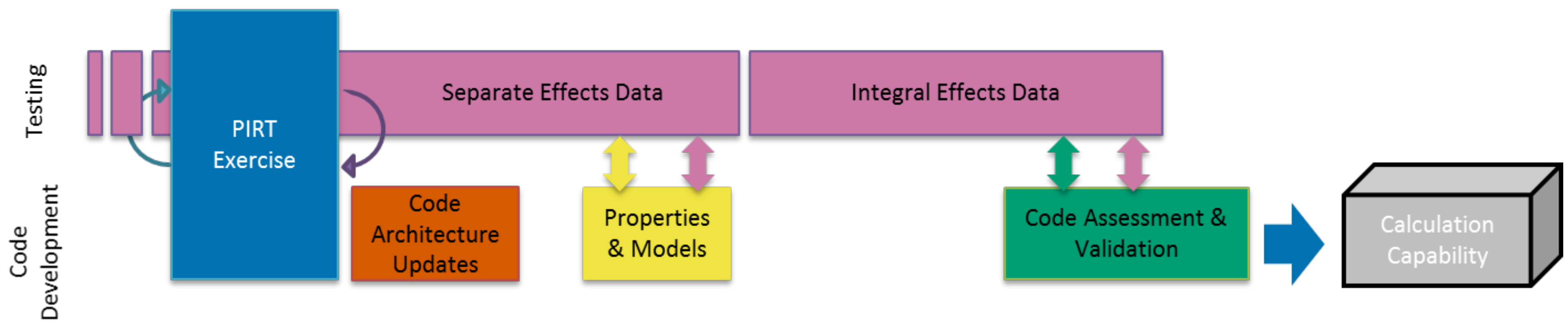
- To support effective and efficient ATF reviews, staff considered:
  - Modifying existing NRC codes
  - Use DOE/vendor/commercial codes, including advanced M&S tools

- Factors for consideration:
  - Staff experience using the tool
  - Development/V&V resources necessary

Use of NRC Codes to Model Near-term ATF Concepts

- Tailored to evaluate regulatory requirements
- Shallow learning curve
- Minor modifications required
- Need ATF specific validation

Development Process for Near-term ATF Calculation Capability



FAST

FRAP evolved

Fuel Performance

- What is it?
  - FAST (Fuel Analysis under Steady-state and Transients) calculates the thermal and mechanical response of nuclear fuel as a function of burnup under steady-state, AOOs and DBA transients.
  - FRAPCON + FRAPTRAN + ATF + (Significant code updates) = FAST
- Regulatory use:
  - Assess SAFDLs (NUREG 0800, Chapter 4) for new fuels, assess new/updated codes & methods, provide initial conditions to Chapter 15 analyses, assess spent fuel behavior
- Completed work:
  - Developed material library with ATF materials: FeCrAl, U_3Si_2, SiC, Cr-coating
  - Multi-layer cladding deformation model (coatings) [KAERI]
- Ongoing work:
  - Updates & assessment for doped fuels, high burnup, higher enrichment
  - 3-D solvers for non-cylindrical fuel, allow for fuel deformation
  - Coupling to TRACE and SCALE
- ATF work needed:
  - Models for appropriate compositions
  - * Assessment *

Thermal-Hydraulics

- What is it?
  - TRACE is a thermal-hydraulics systems safety analysis code with 3D reactor kinetics
- Regulatory use:
  - Analyses of LOCAs, operational transients, and other reactor accident scenarios
- Completed work:
  - Initial gap analyses of TRACE capabilities against ATF fuel forms
- Ongoing work:
  - Coupling with FAST and BISON fuel rod models
  - Select representative plant models and accident scenarios
- ATF work needed:
  - Generalize the fuel rod thermo-mechanical models
  - Add ATF fuel mechanical and thermal properties to TRACE including T_{min} for new cladding materials
  - Develop coupling with FAST & BISON fuel rod models
  - Assess new models and perform plant analysis

Neutronics

- What is it?
  - SCALE provides the capability to conduct neutronics analyses in such areas as lattice/core physics, transport, shielding, and criticality safety. SCALE data is also used to provide necessary information for FAST, PARCS, MELCOR and MAACS.
  - PARCS provides the capability to perform core simulation with thermal-hydraulic feedback
- Regulatory use:
  - Support licensing evaluations under GDC requirements through NUREG-800 Chapter 4 and 15 activities, including boron dilution accidents, rod ejection calculations, MELLLA+, etc
  - Support licensing evaluations under 10 CFR 50.68/70.24 criticality accidents, 10 CFR Part 71 packaging and transport, and 10 CFR Part 72 storage requirements. Activities may include burnup credit, criticality analyses, code validation against experiment reviews, etc.
- Completed work:
  - Initial gap analyses of SCALE and PARCS capabilities against ATF fuel forms and review of available validation data
- Ongoing work:
  - Development of detailed research plan for ATF fuel forms
  - Development of lattice level (SCALE/Polaris) and core level (PARCS) sensitivity models that will quantify how the changes presented by ATF fuel forms effect core level safety parameters in PARCS (reactivity coefficients, SDM, control rod worth)
  - Review of gap conductance schemes in the NRCs PARCS core simulator code
- ATF work needed:
  - * Assessment *

MELCOR Severe Accident/Source Term

- What is it?
  - MELCOR is NRC's computer code for predicting progression of severe accidents and source term
- Regulatory use:
  - Evaluate DBA accident source term to ensure designs meet radiological criteria in CFR (e.g., 10 CFR 100.11, 10 CFR 50.67, 10 CFR 50.34(a)(1)(iv), GDC 19).
  - Other regulatory source terms include equipment qualification source term and post-accident shielding source term (see for example SRP Sections 3.11 and 2.12)
- Completed work:
  - Initial gap analyses of MELCOR capabilities against ATF fuel forms
- Ongoing work:
  - Integrate FeCrAl module into latest version, complete benchmark, and begin sensitivity studies.
- ATF work needed:
  - Develop preliminary source term for a representative BWR and a PWR using FeCrAl for selected accident scenarios and compare the results to the current source term technical basis in NUREG-1465 (RG1.183), and to similar analysis for high burnup/MOX fuel.

Coordination with DOE on Advanced Modelling and Simulation

- NRC's ATF project plan acknowledges potential to leverage DOE's advanced M&S tools, especially for longer-term concepts

- Staff coordinating with CASL on focused ATF effort:
  – Familiarity, understanding, and training
  – Development of Bison models for ATF
    - Uncertainty quantification
  – Benchmark problems for ATF and transition cores (neutronics)
  – Development and demonstration for longer-term ATF concepts
    - Improved post-processing for regulatory criteria

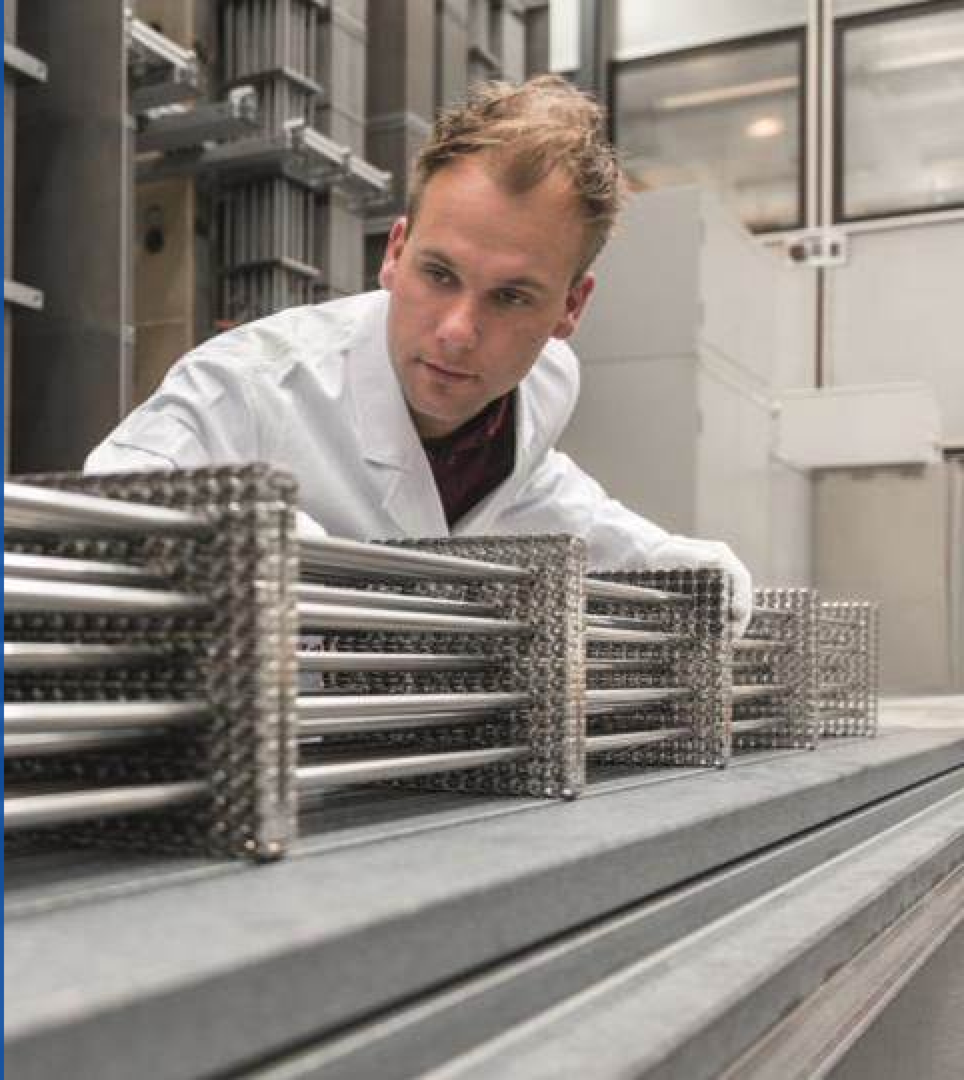
framatome

Use of DOE Codes to Support Industry Implementation of Advanced Concepts

Joshua L. Parker, P.E.

Framatome Inc.

Advisory Committee on Reactor Safeguards (ACRS)
Rockville, MD
16 November 2018



Framatome Innovation

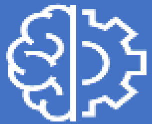
Pathway to Implementation

Near-Term
Innovations that can be brought to market in very short time

Short-Term
Innovations reaching market readiness within 2-3 years of development

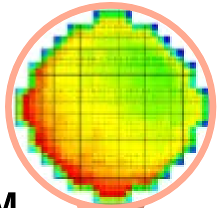
Mid-Term
Innovations that need >3 but <10 years of development

Long-Term
Ideas that need >10 years of development (still conceptual stage)



"Learning and innovation go hand in hand. The arrogance of success is to think that what you did yesterday will be sufficient for tomorrow." William Pollard

Framatome’s Future of Nuclear Fuel



Adv. C&M

>5%

>5 wt% U^{235}

- Enrichment in LWRs beyond 5wt% U^{235}
- Industry Effort Required

Near-Term EATF

- Cr-Doped Pellets
- Cr-Coated Cladding

Long-Term EATF

- SiC-SiC Cladding

Lightbridge

- Metallic fuel

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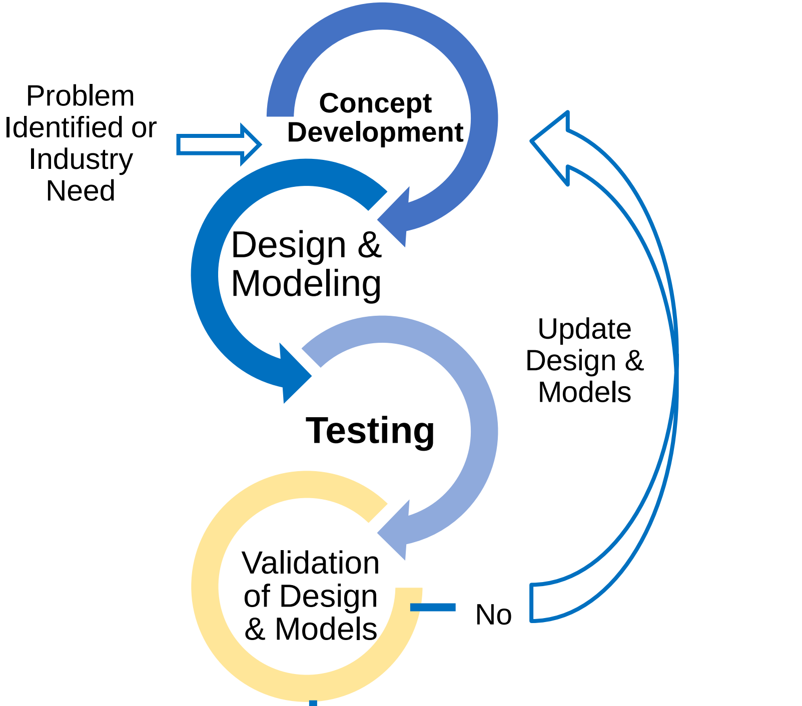
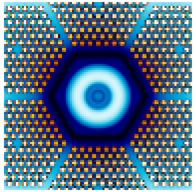
Product Development Cycle

framatome

Linear Product Cycle Development (Historical Model)

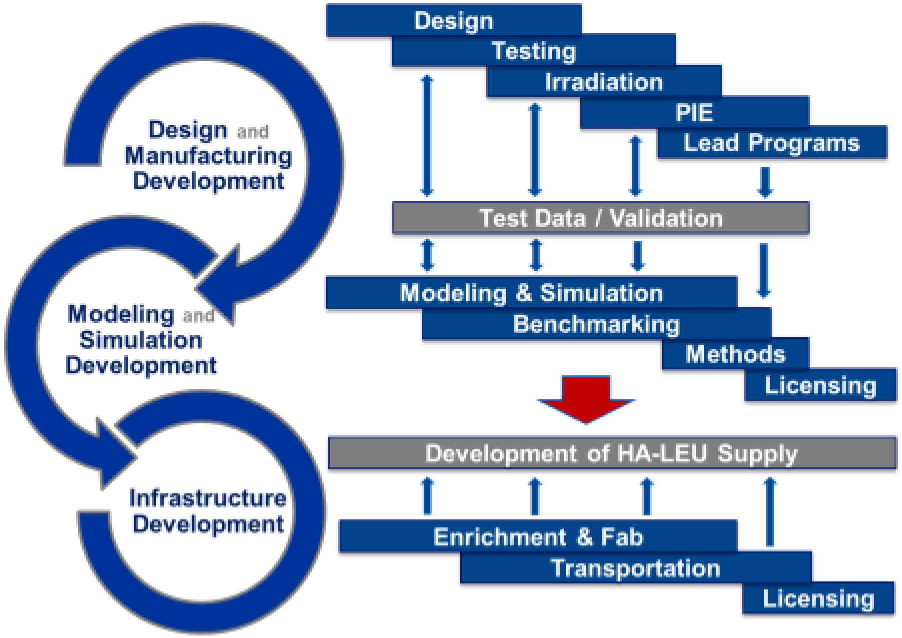
- **Historically product development is very linear and sequential**
  - Large product evolutions take 10+ years from concept to 1st implementation
  - We have a large understanding of Zirconium Cladding and UO_2 fuel and product implementation still takes a long time.
- **DOE codes could help streamline the process and help get products to market earlier to benefit the safety and economics of the industry**





Linear Product Cycle Development (Improved)

- Use parallelization where it makes sense to reduce the development cycle
- Leverage advancements in modeling and simulation to accelerate a parallelized product development
- DOE and Industry partnerships could help advance modeling and simulation capabilities resulting in earlier product implementation benefiting safety and reliability of the Nuclear Industry.



Where can DOE help?

DOE Help

Near/Short-Term

Cr-Doped
Cr-Coated
Nothing Needed

Mid-Term

- Si-C Cladding
  - Modeling and Behavior of material (Fuel rod analysis codes)
- Metallic Fuel in LWRs
  - Benchmarks
  - Code-to-code comparisons
  - Codes to aid design
- >5wt%
  - Benchmarks
  - Codes validated up to 20wt%

Long-Term

Adv. Reactors

- Single Code Suite for Adv. Reactor Design
  - Industrial
  - Easy to use
  - Robust QA
  - Benchmarked on DOE data with like reactors

Places DOE Can Help Industry

- **ATF (SiC-SiC)**
  - DOE can provide independent Fuel Performance Codes
- **Metallic Fuel in LWRs**
  - DOE can provide an independent Code Suite (Core Neutronics, Thermal-Hydraulics, Fuel Rod Performance
  - DOE could provide a new analytical code-to-code benchmarking suite for LWRs on metallic fuel similar to the OECD/NEA benchmarks for UO_2 fuel.
- **Advanced Reactor Fuel/Core Design**
  - DOE to consolidate or identify key codes and work with industry to develop a single industrial code suite for Adv. Reactor Development in the area of fuel and core performance that could be used for the Conceptual, Design and Licensing phase of these reactors

Conclusion

Framatome will determine each business case in regards to the use of DOE codes and where best to apply them to future technologies.

More advanced products and technologies need capabilities beyond the industry. DOE needs to continue to engage industry to advance these products through design, testing and licensing to provide safety and economic benefits to the US Nuclear Fleet, today and in the future.

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Westinghouse Plans for Using CASL/NEAMS Tools

Zeses Karoutas, Chief Engineer in Nuclear Fuel

ACRS Meeting in DC, November 16, 2018

Outline

- Westinghouse EnCore®[1] Fuel
- Physical Benefits of EnCore Fuel
- Safety and Economic Benefits
- Summary of Data Needed for Validation
- CASL / NEAMS Tools to be Used
- BISON ATF Applications
- VERA Core Applications for ATF
- VERA Applications for RIA & DNB
- CRUD Applications for an ATF Core
- Severe Accident Analysis Applications
- Summary

[1]**EnCore** is a registered trademark of Westinghouse Electric Company LLC, its affiliates and/or its subsidiaries in the United States of America and may be registered in other countries throughout the world. All rights reserved. Unauthorized use is strictly prohibited. Other names may be trademarks of their respective owners."

Westinghouse's EnCore® Fuel

EnCore® includes both incremental and game changing products to enable a sensible path to achieve full ATF benefits.

EnCore® Products:

- ✓ Advanced Cladding
  - ✓ Cr-coated zirconium
  - ✓ SiC
- ✓ Advanced Fuel
  - ✓ ADOPT™ doped fuel pellets
  - ✓ U_3Si_2 pellets

Chromium-Coated Zr Cladding

Silicon Carbide (SiC) Composite Cladding

Product Evolution

ADOPT™ Pellets

Uranium Silicide (U_3Si_2) Pellets

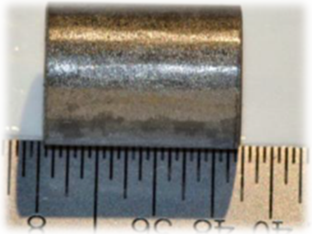


Photo courtesy of Idaho National Labs

EnCore Fuel Physical Benefits

- **ADOPT Pellets**
  - Higher density ~2%
  - Better thermal stability and oxidation resistance
  - Lower fission gas release in transients
  - Increased PCI margins at high temperatures
- **U_3Si_2 Pellets**
  - Higher uranium density ~17% improves fuel cycle economics for 18 and 24 month cycles
  - Increased thermal conductivity improves fuel thermal performance during transients
  - Good irradiation behavior (swelling, fission gas release)
- **Coated Claddings**
  - Higher accident temperature capability for accident conditions (1300 to 1400ºC)
  - Reduced corrosion and hydrogen pickup, and resistance to rod wear
  - Reduced exothermic reaction energy during high temperature transients,
  - Reduced balloon size, higher burst temperature and possible reduction in fuel dispersal
  - Improved LOCA PCT and RIA depositions limits and time in DNB for DBAs
- **SiC Cladding**
  - No ballooning and bursting, and resistance to rod wear
  - Eliminate oxidation driven temperature spikes
  - Maintain integrity under most severe beyond design basis accident conditions, decomposition near ~2000ºC
  - Fuel performance beyond DNB and during LOCA can increase design basis margins
  - Cladding provides fission product barrier to high temperatures
  - Minimizes potential hydrogen generation to non threatening levels

Westinghouse

These Physical Benefits can be used to assess Plant Benefits for Severe Accidents and DBAs

Safety and Economic Benefits

"Gen 1" (Cr-Coated Zr/ADOPT) "Gen 2" (SiC/U_3Si_2)

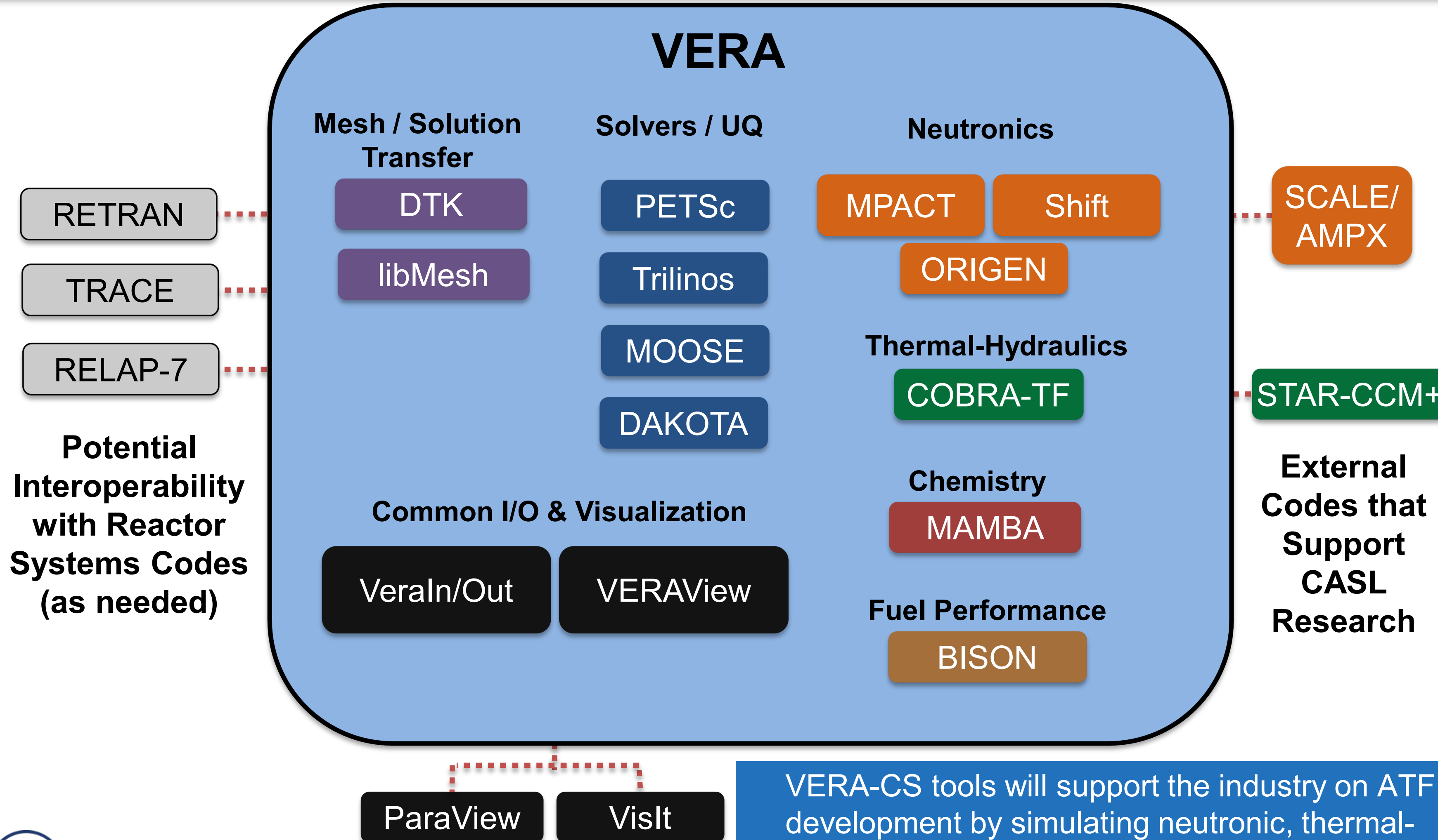
Benefit	Current Fuel Zr/UO_2	Cr-Coated Zr/UO_2	Cr-Coated Zr/ADOPT	Cr-Coated Zr/U_3Si_2	SiC/U_3Si_2
Pellet U loading			*+2.0%*	*+17%*	*+17%*
Fuel Utilization					
Grid-to-rod Fretting / Debris					
Load Follow / Flexibility					
Higher Burnup					
LOCA / DBA Margin					
DNB Margin					
Hydrogen (10CFR50.44 Margin)					
BDBA Margin/Operator Response Times					

Reference / No Benefit
Some / Potential Benefit
Large Benefit

Summary of Data Needed for Validation

- Autoclave testing
- Test Reactor (MITR, HFIR, ATR, Halden, etc)
- In-Rx Exposure (PIE, Hot Cell)
- Burst tests
- Power Ramp tests
- LOCA and RIA tests (TREAT, Studsvik, etc)
- Fretting tests
- Pressure Drop
- WALT Loop DNB and CRUD tests
- Ultra High Temperature, KIT tests
- Fuel Mechanical Behavior tests

CASL / NEAMS Tools to be Used



VERA-CS tools will support the industry on ATF development by simulating neutronic, thermal-hydraulic and fuel performance behavior of cores loaded with ATF

Westinghouse

BISON ATF Applications

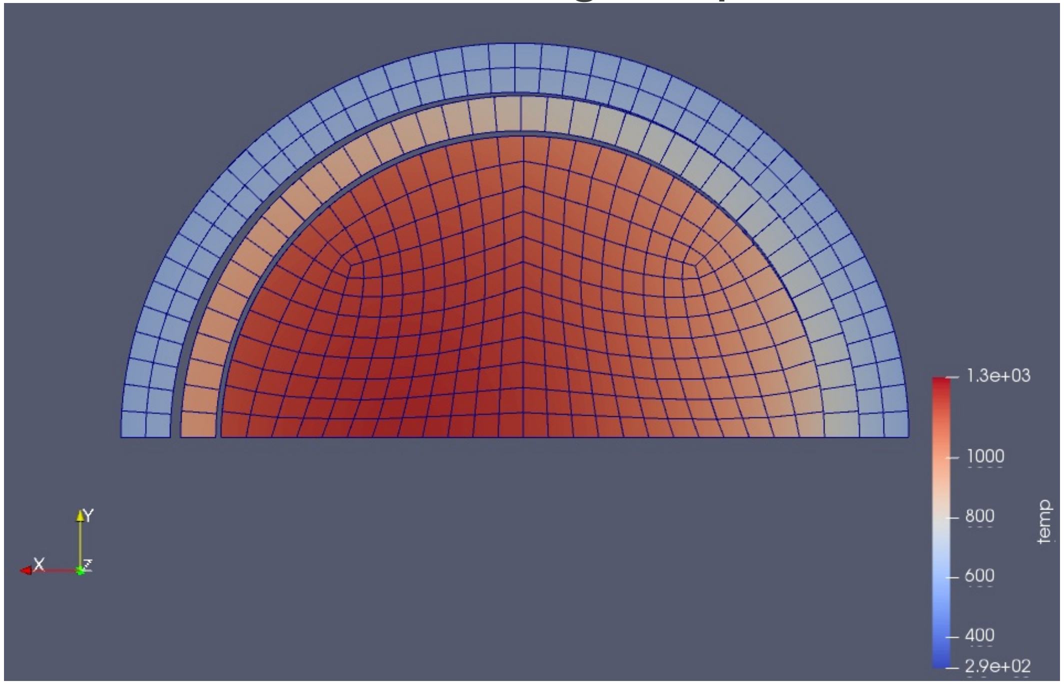
- BISON advanced fuel performance modeling will provide critical support for the design of accident tolerant fuel and cladding materials by:
  - Providing predictions of expected fuel and cladding behaviors in advance of measurement data to inform design decisions
  - Identifying potential performance issues and behavioral trends to inform planning for expensive ATF in-reactor testing
  - Providing advance indications of performance thresholds (or cliffs) in ATF materials behaviors
  - Providing supplemental results to confirm and guide the development of design fuel performance codes

BISON analyses will contribute to the basic understanding of ATF fuel and cladding material behaviors

Westinghouse

Example: BISON Application to EnCore® Accident Tolerant Fuel (ATF) Application

- BISON used to assess impact of eccentricity in postulated double encapsulated U_3Si_2 lead test rod design
  - Focused on fuel and cladding temperature distribution



BISON provides an important tool for evaluating ATF concepts where empirically based codes are limited in scope because of the limited availability of measured data

BISON Key Milestones

- BISON analysis of ATF Clad concepts during PWR normal operation and LOCA conditions
- Modeling of mechanical integrity and thermo-mechanical behavior of coated Zr-based cladding for ATF
- Modeling fission gas release from doped oxide nuclear fuel
- Modeling the plasticity and thermal creep of doped oxide nuclear fuel
- Fission gas and creep in uranium silicide fuel
- ATF material model development and validation for priority fuel concepts (Doped UO_2 and U_3Si_2)
- ATF Mesoscale Material Model Development for priority fuel concepts, use of Atomistic modeling & MARMOT (Doped UO2 and U_3Si_2)
- Application of BISON for evaluating PCI and Flexible Plant Operation
- Application of BISON for high burnup operation > 62 GWd/MTU

Westinghouse

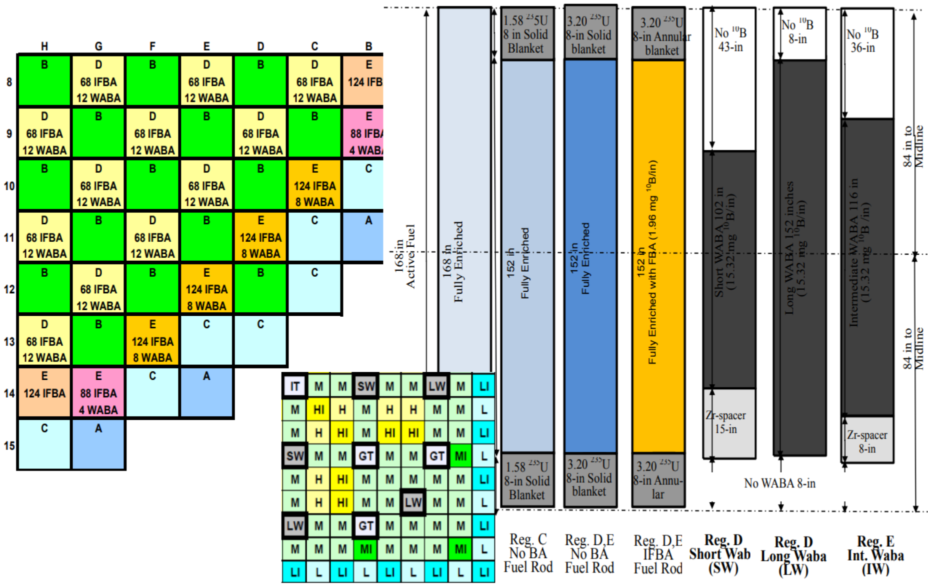
Westinghouse will work together with CASL / NEAMs on these key milestones

VERA Core Simulations for ATF

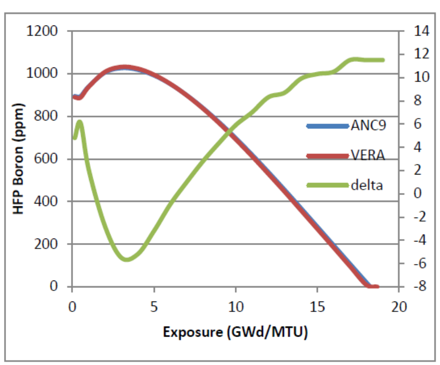
- Perform VERA core models for the Westinghouse ATF (Cr-coated cladding and U_3Si_2 fuel pellet) to support fuel implementation and licensing in commercial reactors, according to the following plan:
  - Setup past core models up to the actual cycle for the proposed plant for LTRs and LTAs implementation
  - Compare results to measurement for validation
  - Model core Loading Pattern for the cycle of ATF introduction, including ATF fuel assembly and fuel rod geometry
  - Evaluate results and compare to in-house core physics tools to ensure consistency
  - Model ATF region introduction until equilibrium cycle is achieved, including cycle length extension to 24-mo and higher burnups
  - Compare results to in-house predictions
  - Assess RIA for transition cores and eq. cycle
  - Perform economic analysis based on fuel requirements to assess fuel cycle savings from ATF introduction

Example: AP1000® PWR Analysis

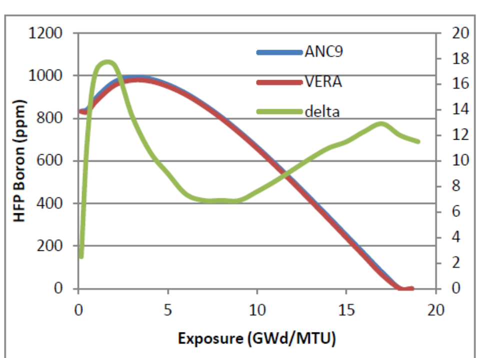
3D VERA-CS Model of the **AP1000** PWR First Core



Cycle 1 Hot Full Power (HFP) All Rods Out (ARO) Depletion



Cycle 1 HFP MSHIM™ Strategy Control Depletion

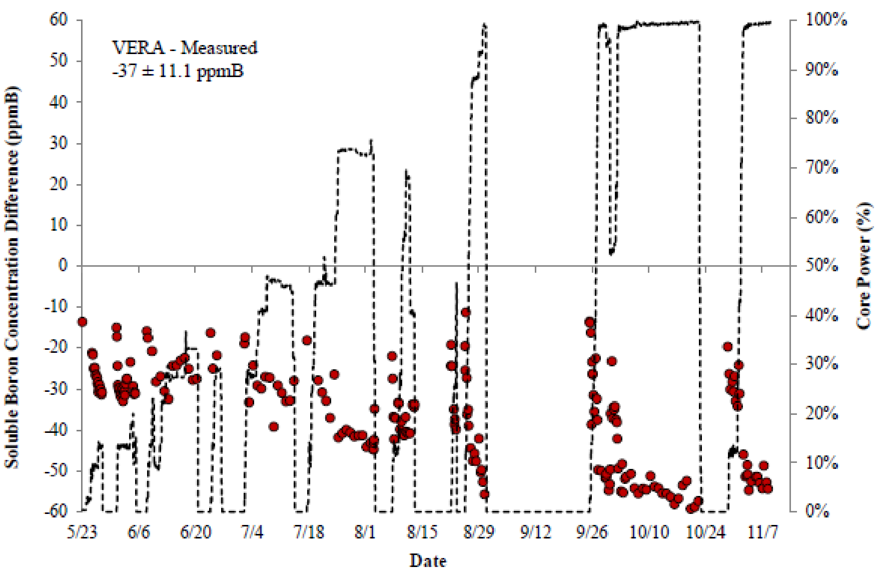


- HZP calculations
  - Comparison of global and local parameters indicated excellent numerical agreement between VERA-CS, Monte Carlo predictions, and ANC/PARAGON, reinforcing confidence in the startup predictions.
- HFP calculations
  - Lattice depletion simulations at HFP conditions with VERA-CS, PARAGON2, and Serpent showed excellent agreement
  - Core depletion simulations performed with VERA-CS and ANC/PARAGON2, demonstrating excellent agreement, confirming the Westinghouse design values for the AP1000 PWR first core.

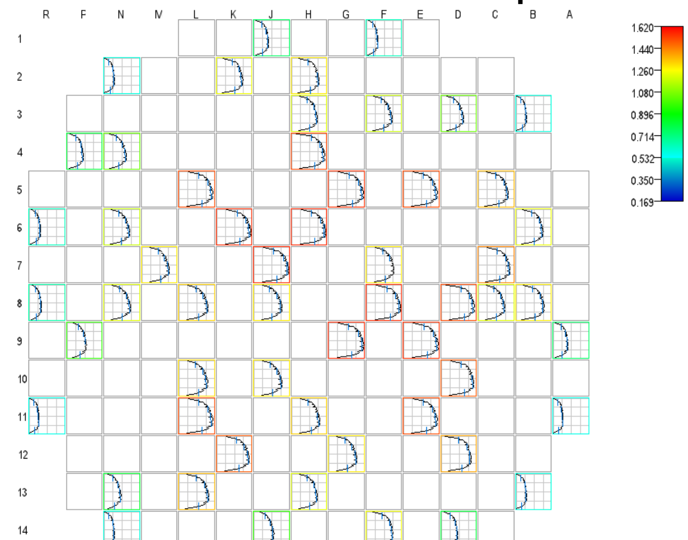
Startup Measurement Comparisons	
ARO Δ Boron	7 ppm
Δ ITC pcm/°F	0.5
Max/Min Rod Worth Δ % pcm	3.9%/-1.6%

Example: Watts Bar Unit 2 Startup Simulations

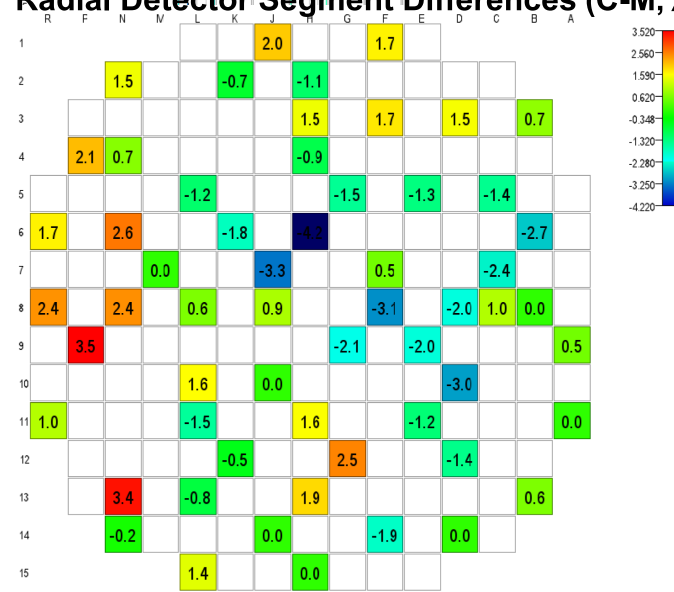
M-P Soluble Boron during Power Ascension Testing



Raw and Vanadium Detector Response



Radial Detector Segment Differences (C-M,%)



With the help of VERA results, Westinghouse was able to refine its in-house models (e.g., detailed explicit WABA, reflector constants, cross-section library based on ENDF/B-VII.1 data, etc.)

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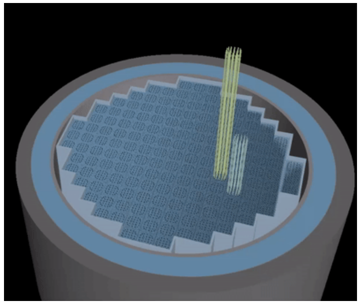
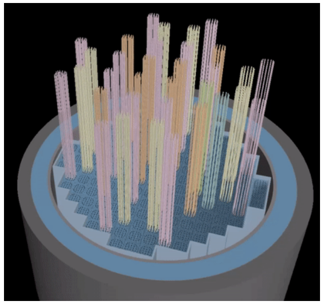
VERA Application for RIA & DNB

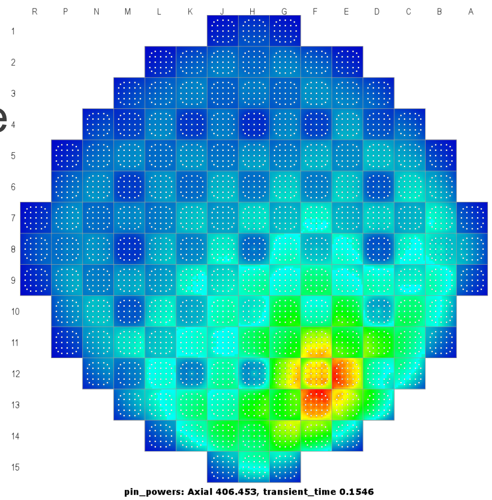
- An objective is to simulate RIA transients for cores with ATF. In particular, U_3Si_2 fuel with its higher thermal conductivity and lower melting temperature will be analyzed under various rod ejection scenarios to evaluate its performance (margin to melting temperatures) and its transient characteristics (e.g., impact of lower fuel temperatures on Doppler feedback).
- Another objective is to simulate locked rotor transients to evaluate improvements on reduction/prevention of rods-in-DNB fuel failure from ATF cladding features

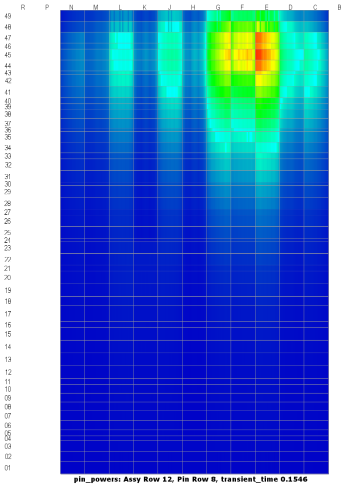
Example: AP1000 PWR Rod Ejection Analysis

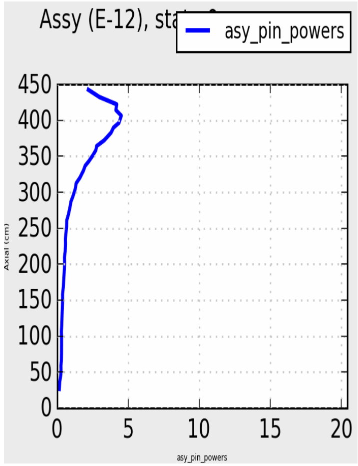
- REA simulated at End of Cycle (EOC) HZP, HFP, and part-power
- Full core geometry using MPACT coupled with CTF
- Highly asymmetric power distribution
- VERA-CS is capable of simulating full core geometry REA in a stable manner with the expected power pulse resulting from a superprompt critical reactivity insertion and the resulting negative Doppler reactivity feedback









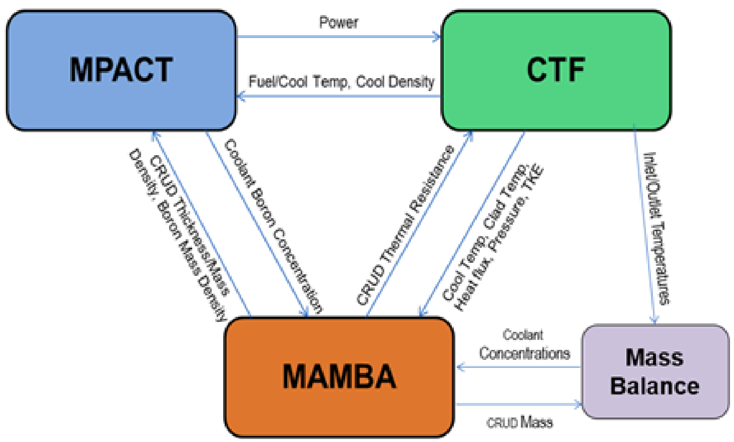


With high-fidelity simulation capabilities, VERA-CS is positioned to support the industry on analyzing reactivity initiated accidents for ATF, and to assist in responding to regulatory rule changes

Westinghouse

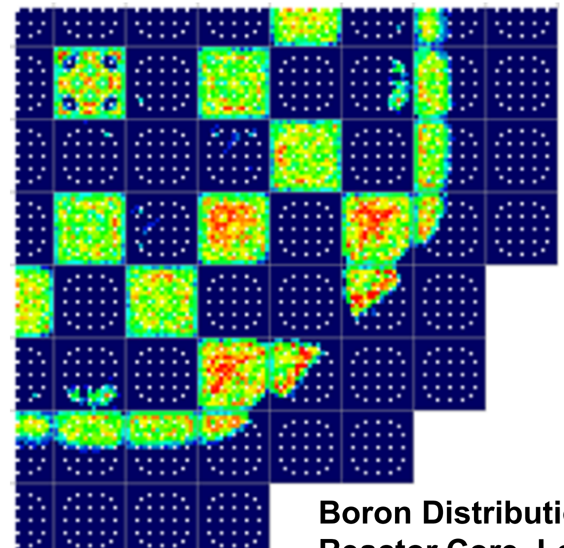
CRUD Application for an ATF Core

Advanced Analyses of CRUD



- Performed for each iteration until convergence between all three is achieved
- Repeated for each depletion step in simulation of plant operation

Use of VERA to predict Boron distribution in CRUD



Boron Distribution in a proposed Reactor Core Loading Pattern

- Explicitly including the feedback of boron on power distribution and calculating A/O

VERA-MAMBA will be performed for an ATF core to look at impact of cladding surface on CIPS, CILC and DNB

Westinghouse

Severe Accident Analysis Applications

- Westinghouse performing MAAP calculations to evaluate coping time benefits of ATF and use of FLEX equipment with ATF for flow and passive heat mitigation strategies
- Need to compare results to DOE calculations using MELCOR
- Implement latest ATF fuel mechanical behavior data and models into severe accident codes
- TRACE/BISON LOCA capability development for ATF

Summary

- With the help of the DOE tools, it is recognized that advanced M&S techniques can inform decisions for the next generation of advanced fuel designs and new generation reactors (e.g. eVinci micro-reactor and Lead Fast Reactor), as well as help in the resolution of any anomalous core behavior in existing LWRs

- Westinghouse plans to use DOE tools to help benchmark our design tools for ATF and better inform testing needed for validation

- The use of DOE tools together with validation data will help understand margin and uncertainty of ATF safety and economic benefits

Modeling and Simulation of MSRs MSR TWG

Southern Company

Nicholas Smith
Southern Company Services

Molten Salt Reactor TWG →

ONE

Terra Power

Fast
Breeder
Liquid Fuel
Salt Cooled
Uranium
(Could use Th)

TWO

Thorcon

Thermal
Burner
Liquid Fuel
Salt Cooled
Thorium

THREE

Terrestrial Energy

Thermal
Burner
Liquid Fuel
Salt Cooled
Uranium
(Could use Th)

FOUR

Flibe Energy

Thermal
Breeder
Liquid Fuel
Salt Cooled
Thorium

FIVE

Muons Inc.

Thermal
Burner
Liquid Fuel
Salt Cooled
Uranium

SIX

Elysium Industries

Fast
Breeder
Liquid Fuel
Salt Cooled
Uranium

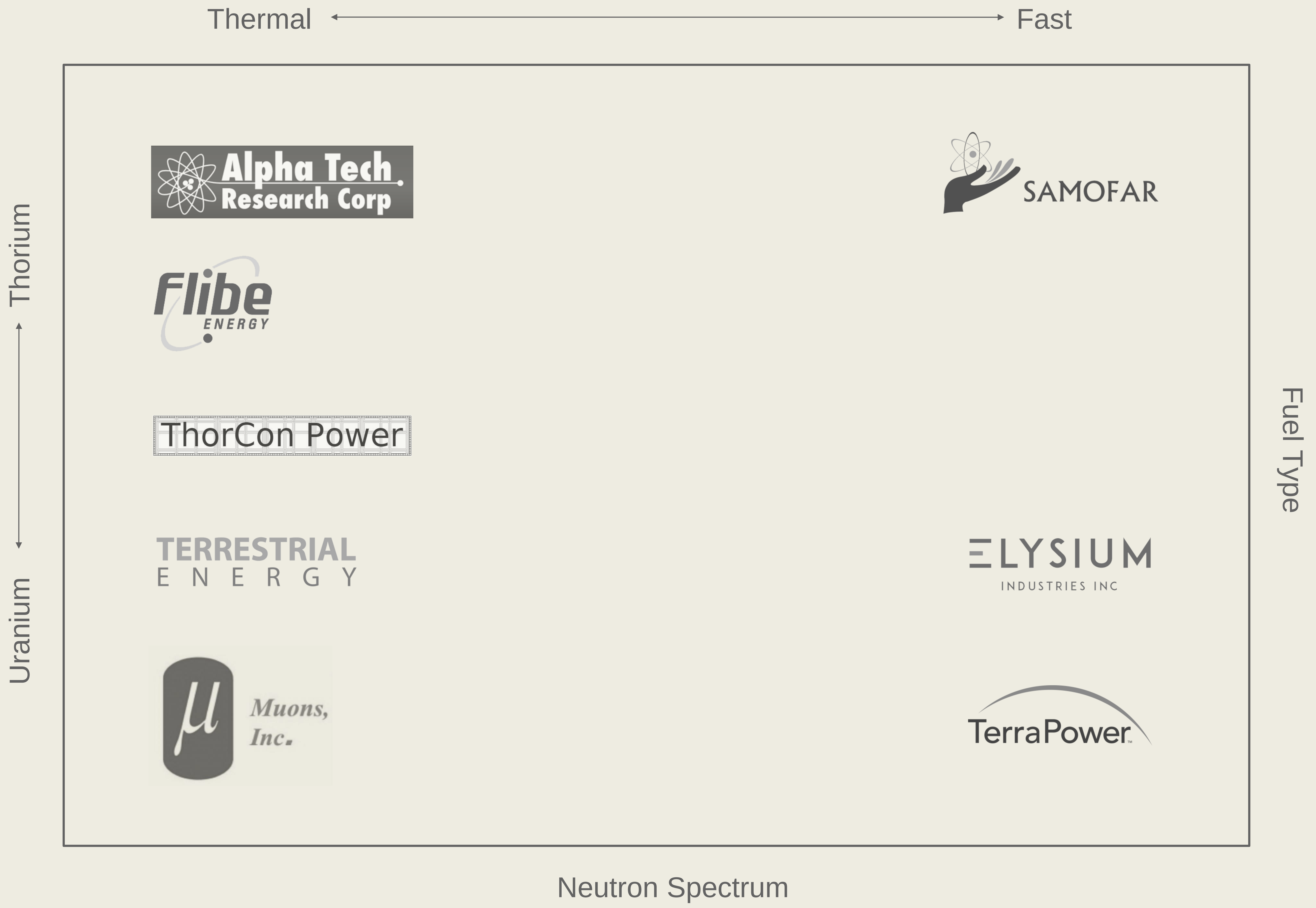
SEVEN

Alpha Technology Corporation

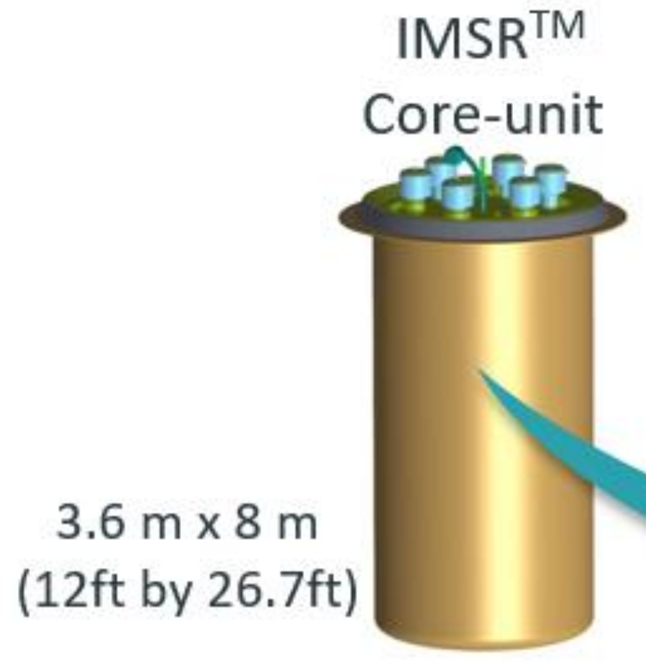
Thermal
Breeder
Liquid Fuel
Salt Cooled
Thorium

Exelon. NEI NUCLEAR ENERGY INSTITUTE DUKE ENERGY. EPRI

MSR Design Space

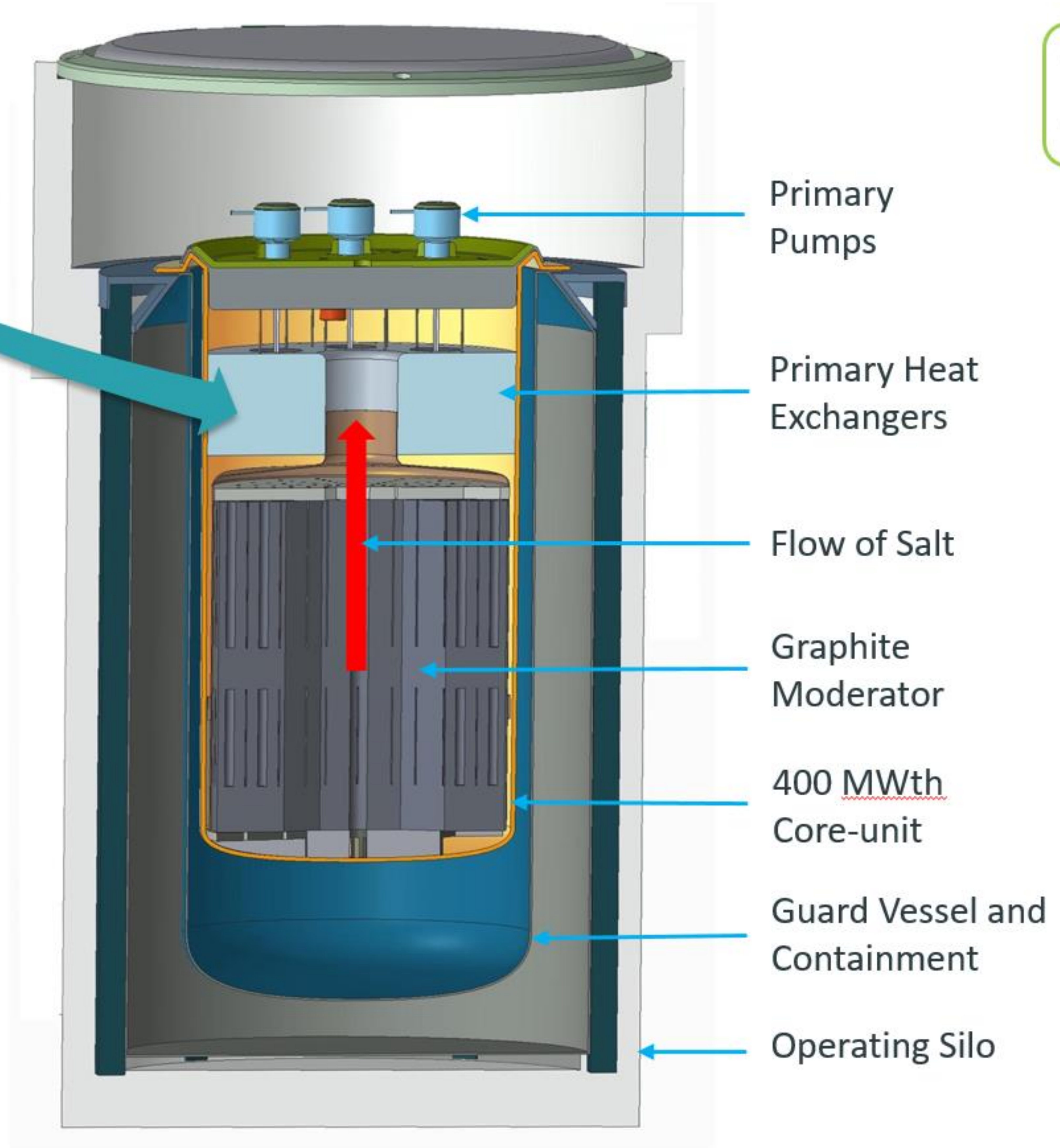


TERRESTRIAL ENERGY'S INTEGRAL MOLTEN SALT REACTOR – IMSR™



Cost-Focused Technology Innovation

- All primary reactor components integrated into a sealed, compact, and replaceable reactor vessel with a 7-year operational life
- Advanced, liquid fueled reactor
- Low pressure operation – 1 Atm
- High temperature output – 600°C
- 48% thermal efficiency
- Passive power management
- Passive decay heat removal
- Dynamic core and turbine load following
- IMSR™ power plant LCOE of ~4 to 5 c/kWh. LCO-BTU 5 to 6 $/MMBTU



Key commercial claim is that IMSR™ is a better way to generate heat than fossil fuel combustion and is being brought to market in the 2020s

Clean, Convenient, Cost Competitive, Scalable Energy

- Power and heat that is cost competitive with fossil fuel combustion
- IMSR™ heat easy to couple to industrial processes
- IMSR™ heat delivered by common industrial salt
- Dispatchable, on-demand heat and power for industrial processes and for electric power markets
- Factory production in support of rapid global deployment
- A Small Modular Reactor for lower project financing risks
- No NOX, SOX or CO_2

TERRESTRIAL ENERGY USA

TerraPower's Molten Chloride Fast Reactor (MCFR) advances nuclear in key areas

Enhance engineered safety

- No fuel fabrication
- Online refueling
- High temperature

Minimize energy costs

- Non-reactive coolant
- Strong negative temperature & void coefficients
- Near-zero excess reactivity

Offer new options for nuclear waste

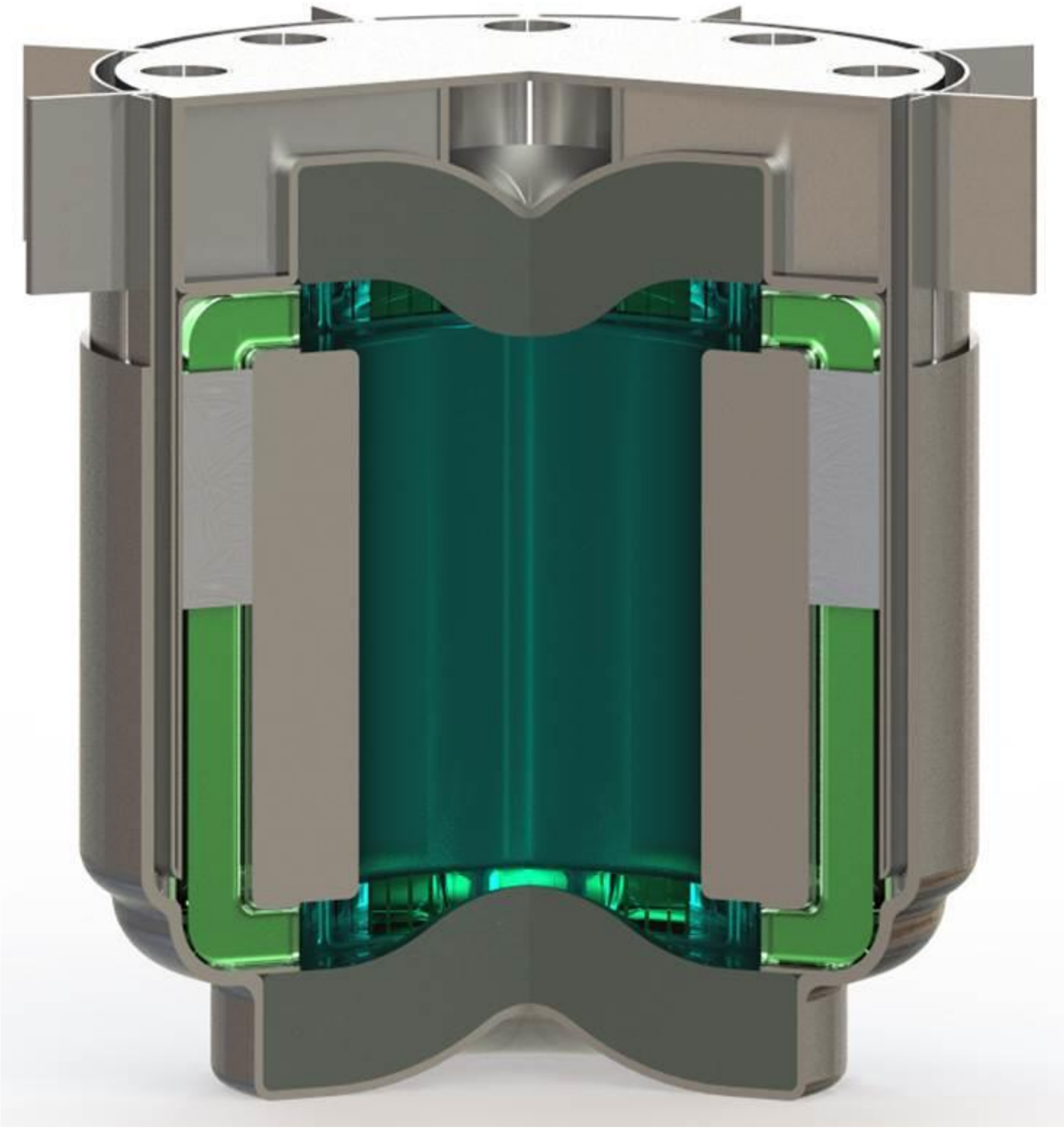
- Only startup enrichment
- Consume DU, NatU, and/or UNF
- Start with partial UNF load

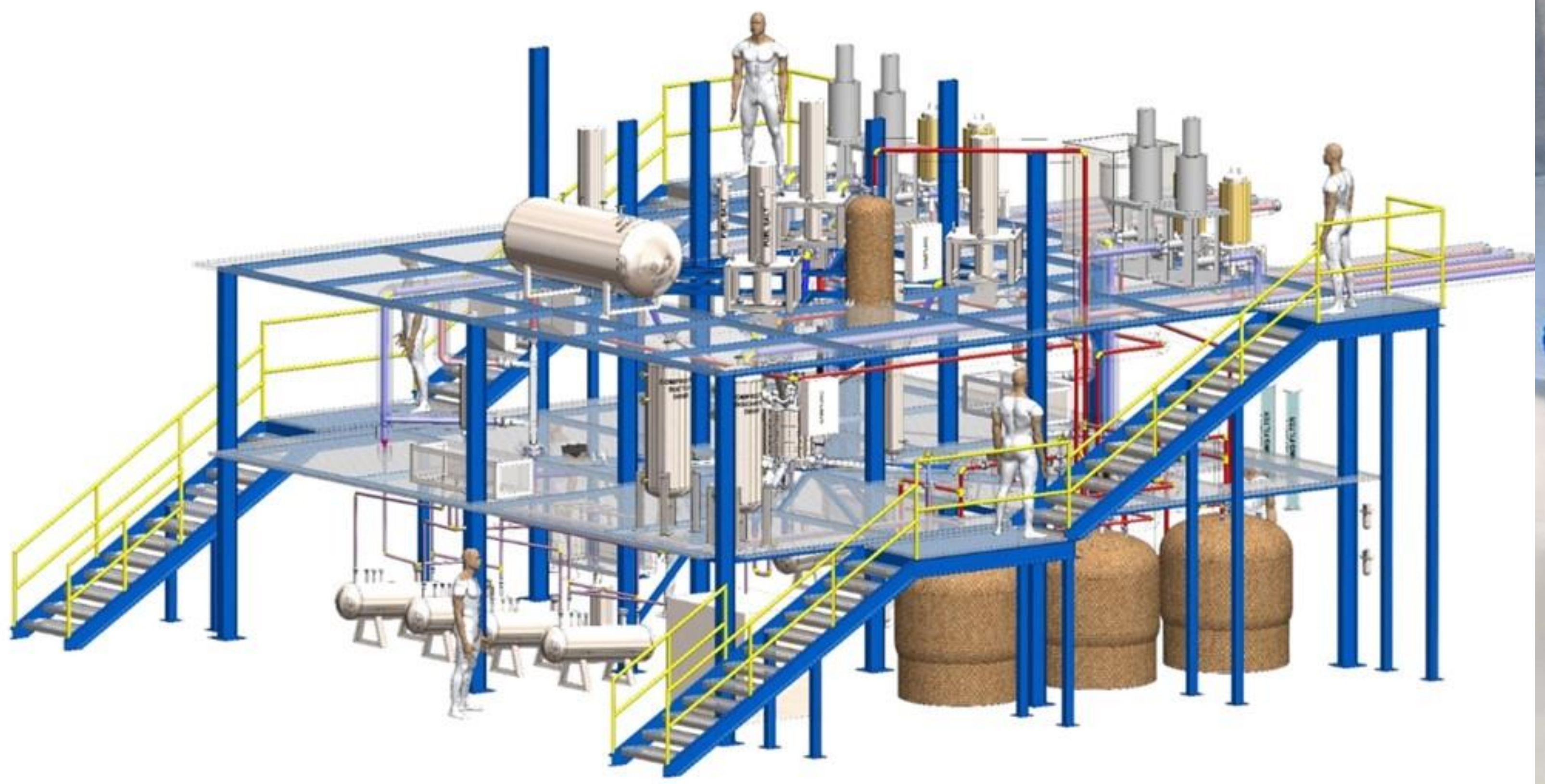
Provide reliable supply of energy to all nations

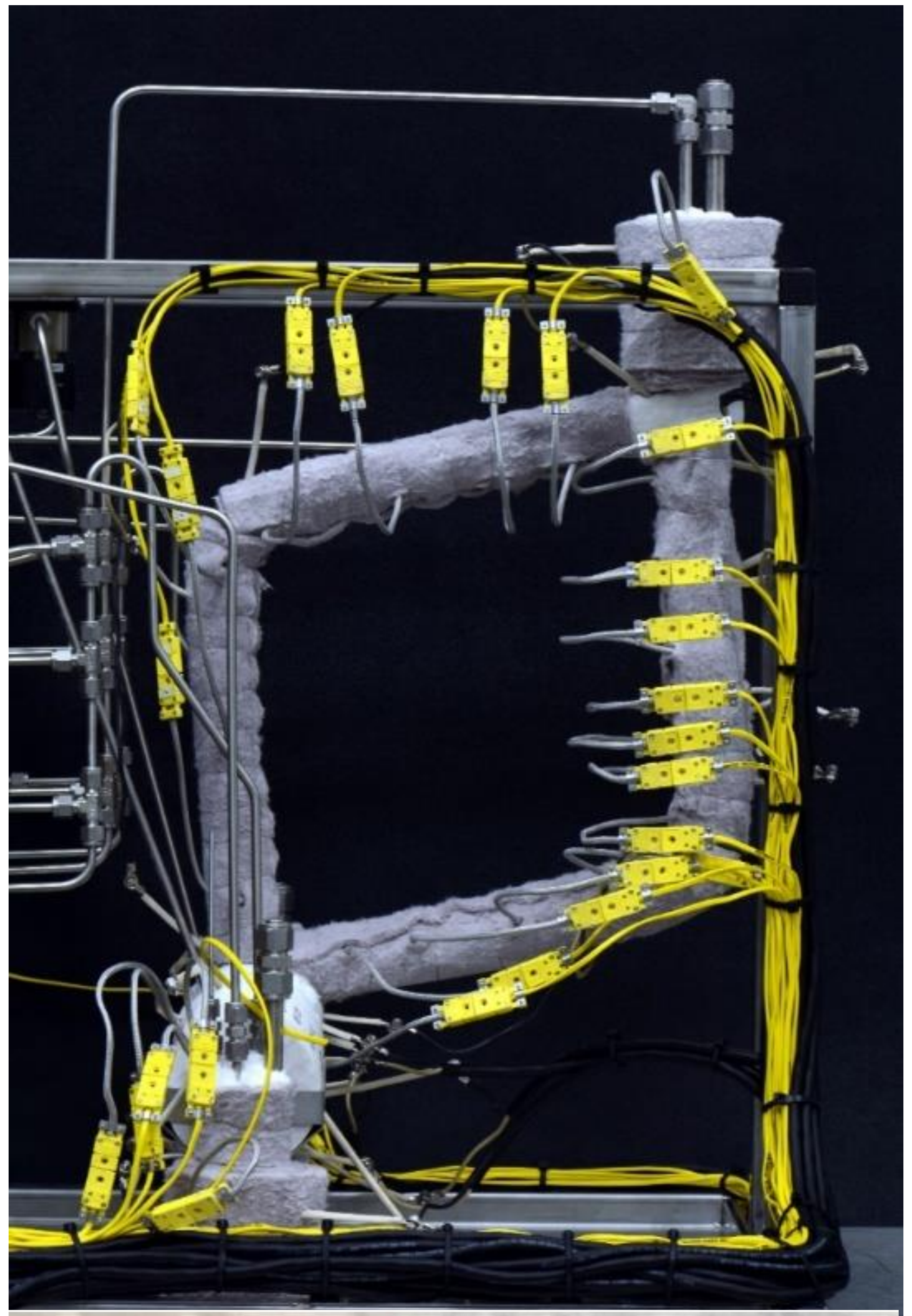
- No ongoing enrichment
- Strong non-proliferation traits
- Reduced water use
- Opens up non-electric markets

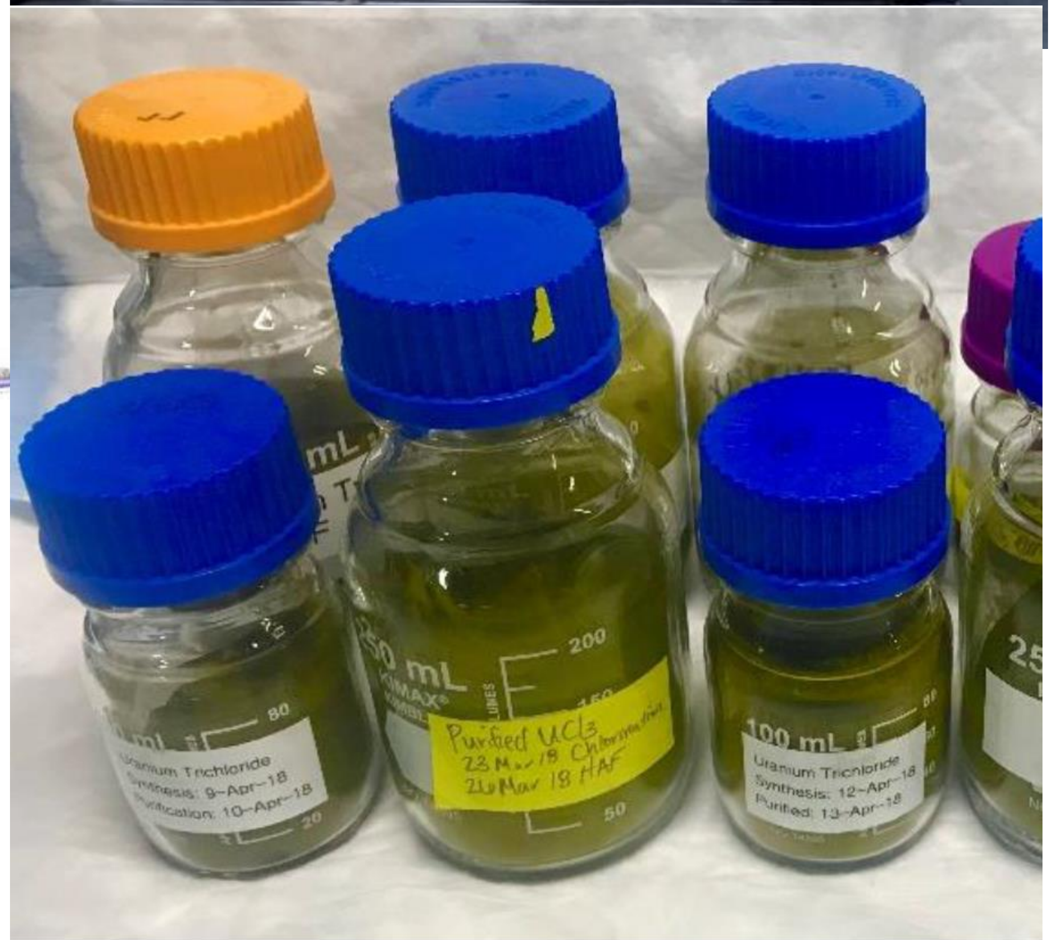
Maximize proliferation resistance

- Actinides stay in core, daughter core, or closely-coupled clean-up system
- Actinides always mixed with lanthanides





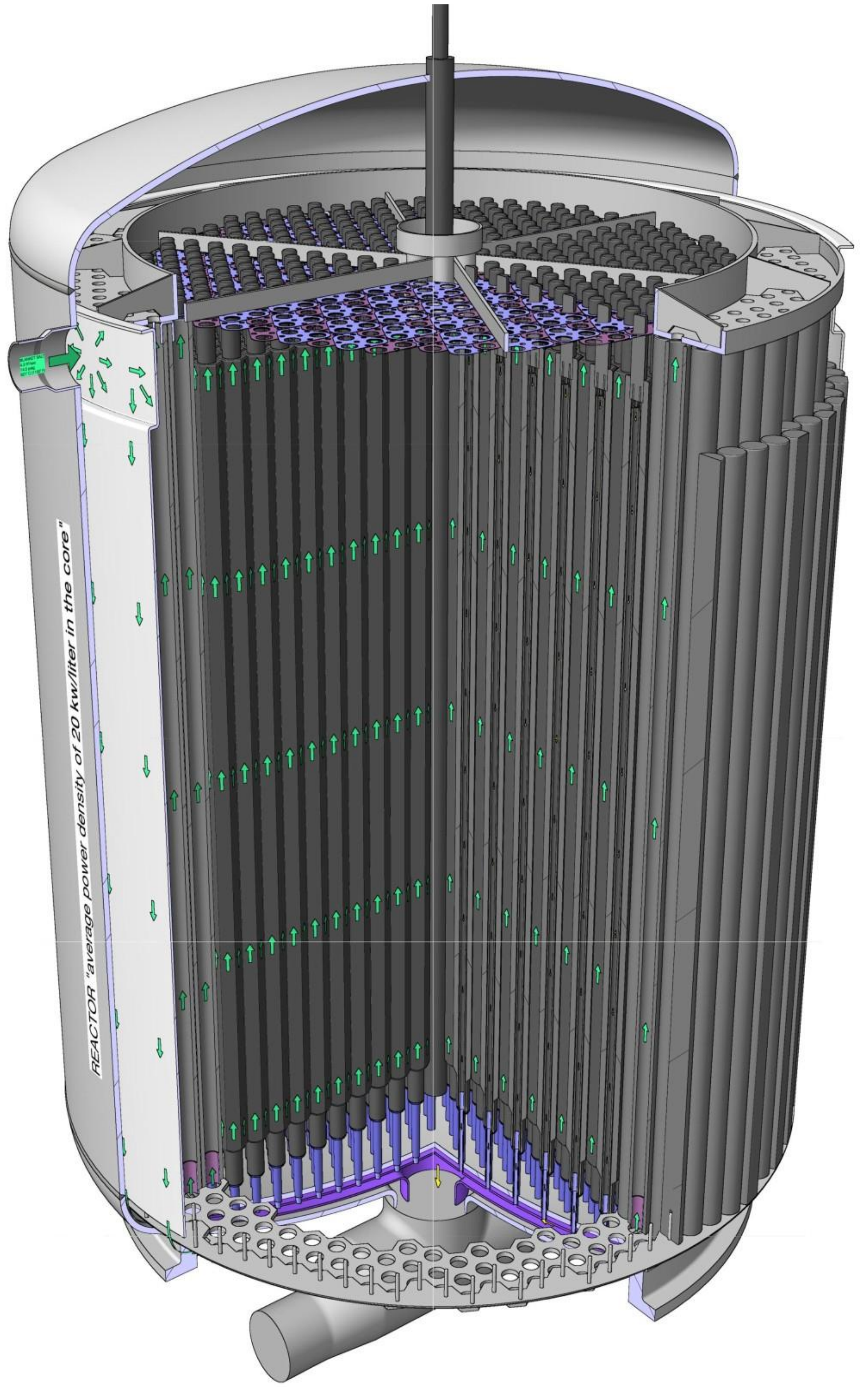




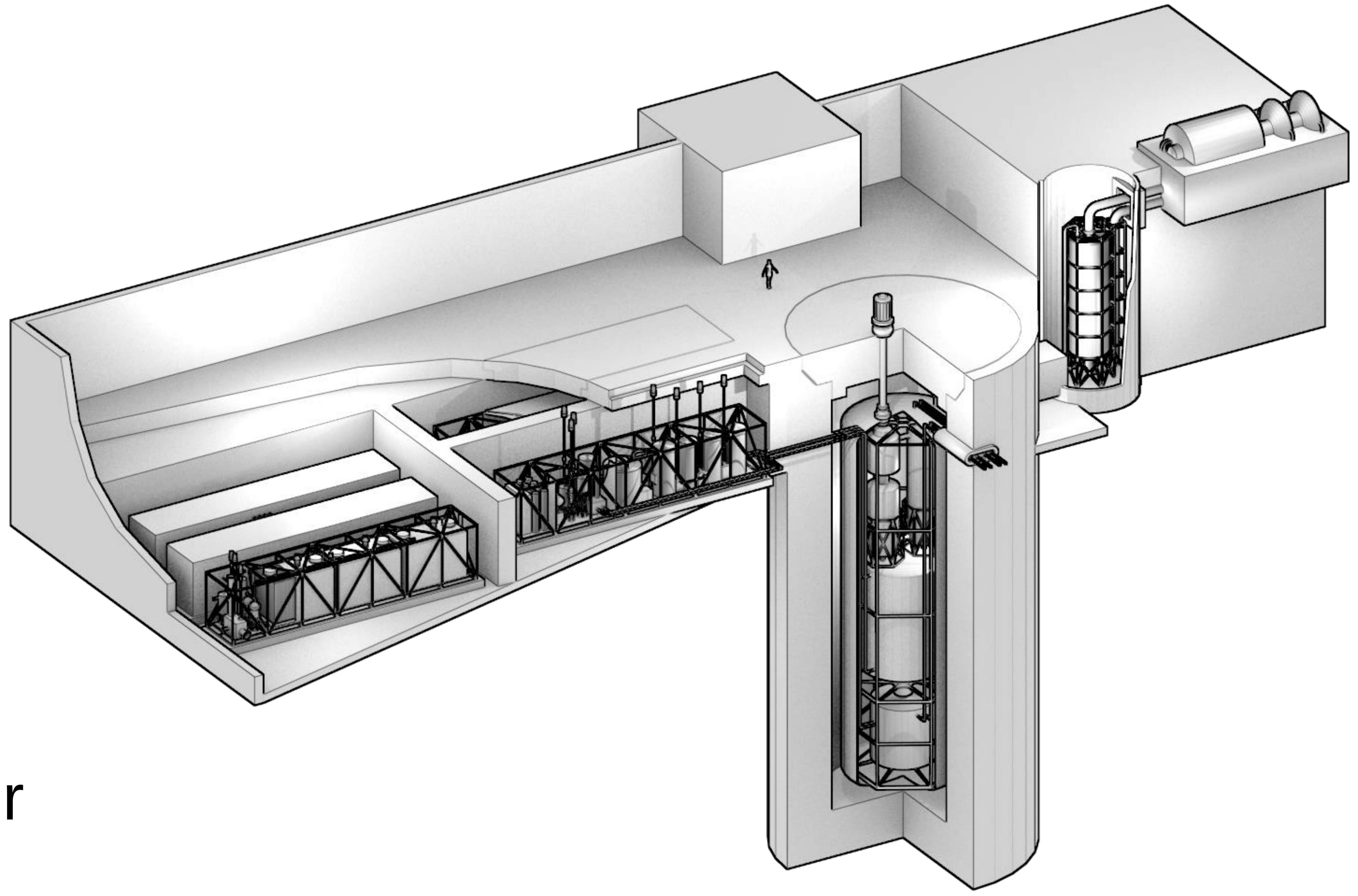
TerraPower

Flibe ENERGY

Liquid Fluoride Thorium Reactor (LFTR)



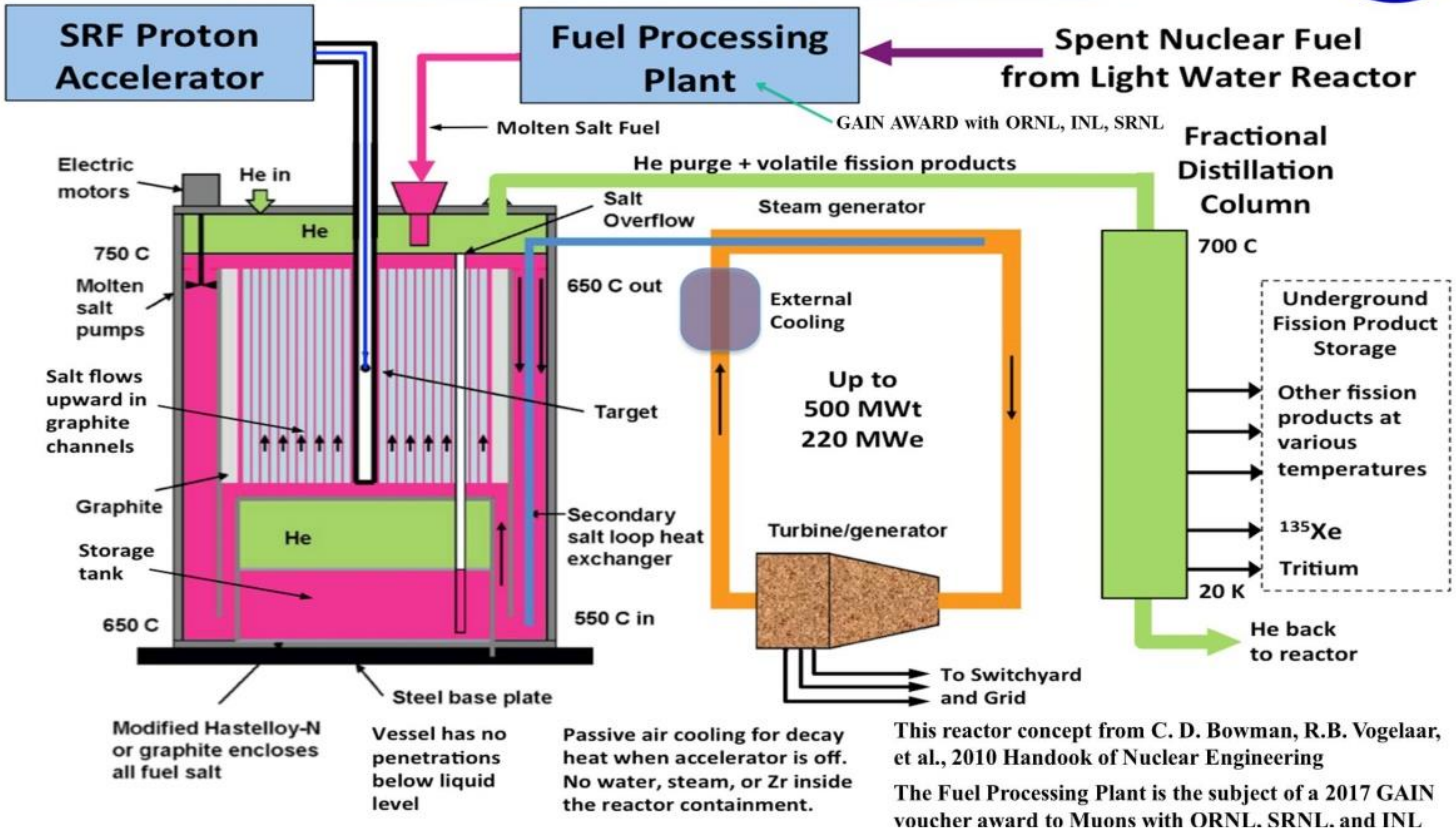
- Design objectives:
  - 600 MWt/250 MWe modular core
  - conversion ratio >= 1.0
  - Replaceable core internals
  - fuel salt in graphite tubes
  - Reactor vessel shielded by thorium blanket and graphite reflector
- Materials and fluids:
  - $^{7}LiF\text{-}BeF_2\text{-}UF_4$ fuel salt
  - $^{7}LiF\text{-}BeF_2\text{-}ThF_4$ blanket salt
  - $^{7}LiF\text{-}BeF_2$ coolant salt
  - Graphite moderator and reflector
  - Hastelloy-N reactor vessel and piping



Mu*STAR: Superconducting RF Linac Driving Molten-Salt Graphite-Moderated Subcritical Modular Reactors

Muons, Inc.

Mu*STAR System



A Mu*STAR system can be installed at each of 60 utility sites in the US to convert the SNF stored in pools and casks to fluoride salts, to burn it there for > 200 years, and to give new life to a reactor community while addressing many concerns of SNF storage and transport.

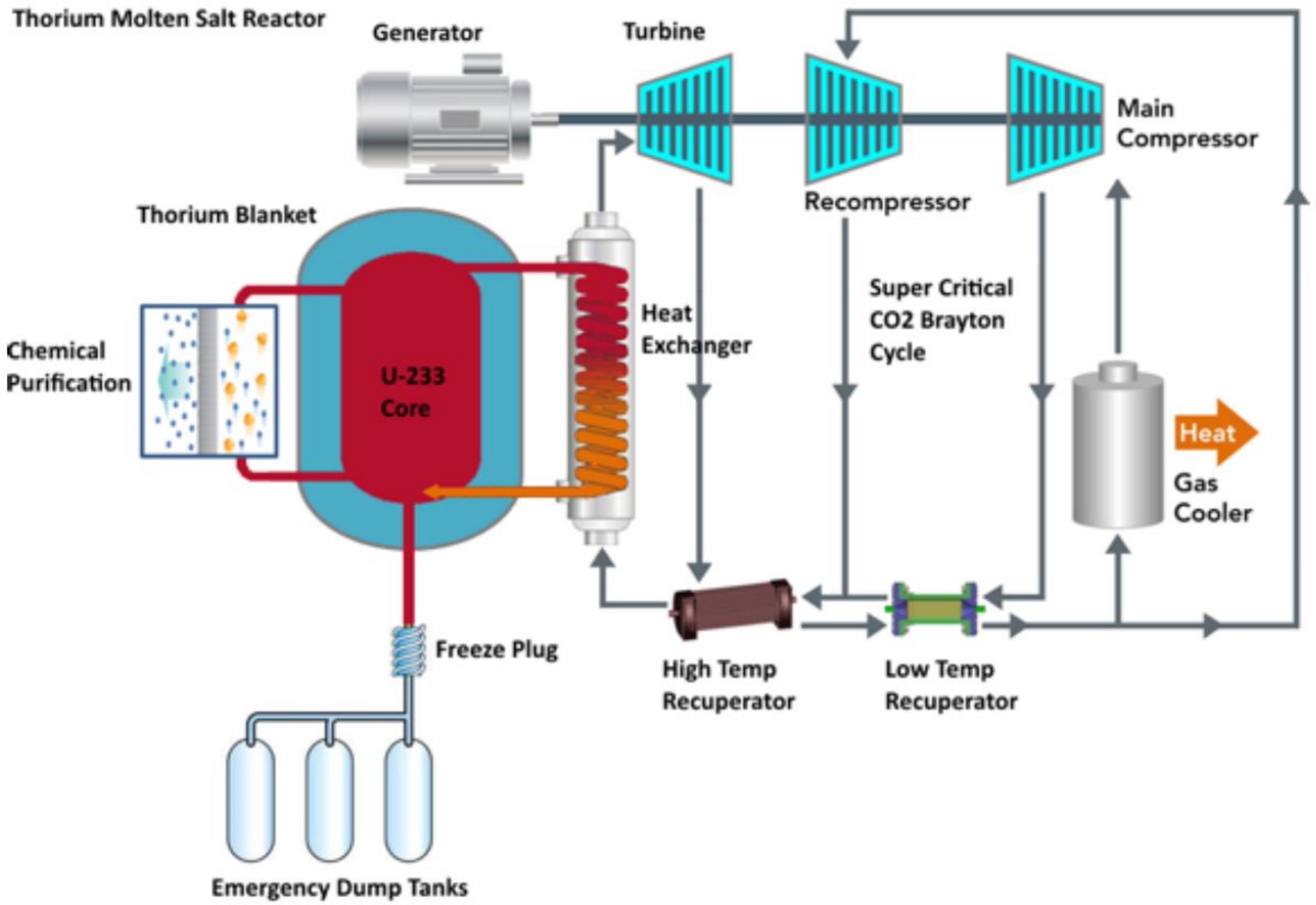
Alpha Tech Research Corp

Thorium Fueled

Fluoride Cooled

<300 MW

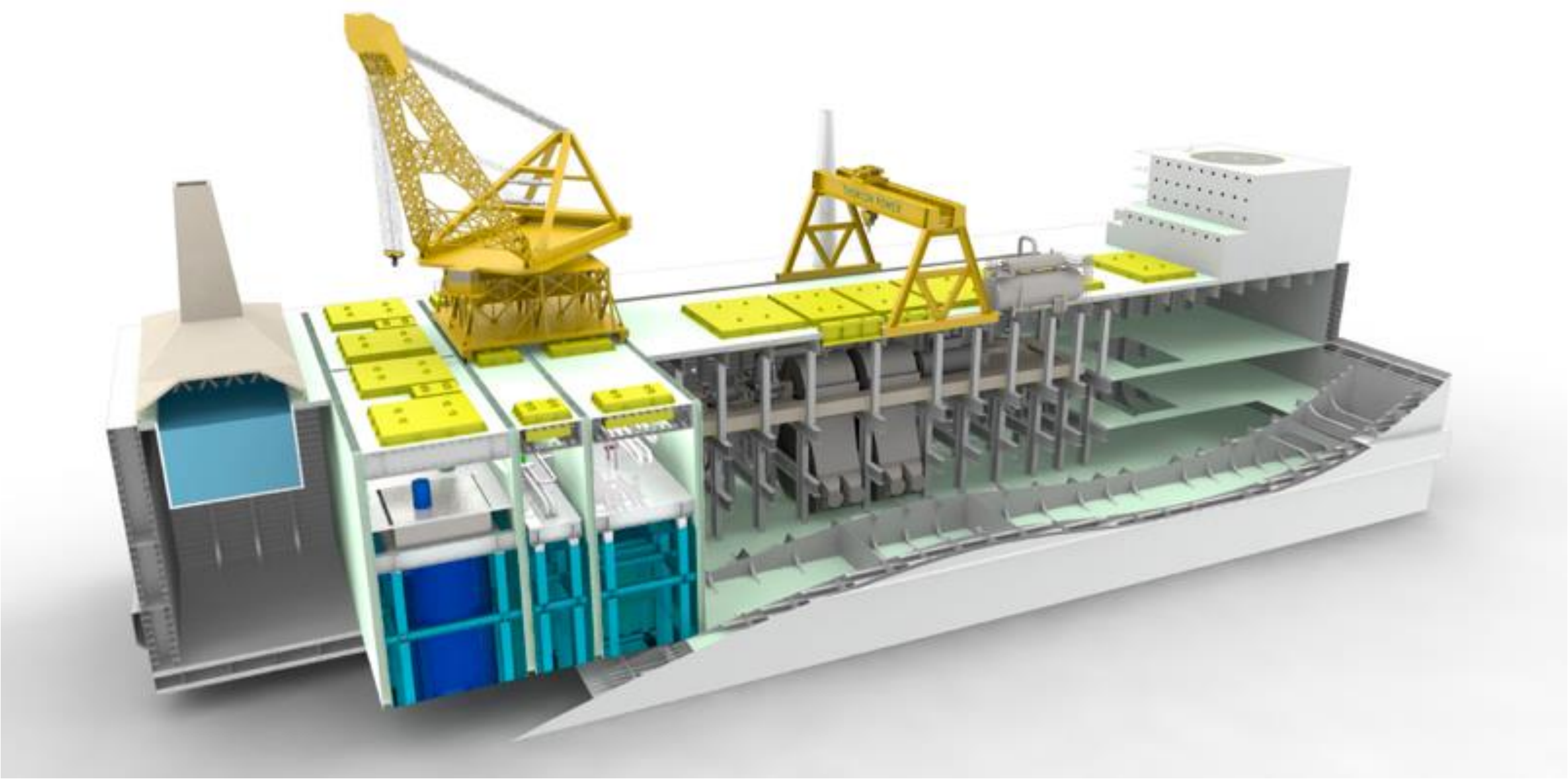
Partnering with Utah & Idaho universities on technology development



ThorCon Power

500 MWe MSR

- Thermal spectrum - Uranium Fluoride Salt
- Leverage shipyard construction techniques
- Build upon success of MSRE – Floating reactor towed to site
- Cost competitive with coal ($1.2B/GWe, 3 cents/kwhr). Targetting two years order to grid.



Elysium Industries

Molten Chloride Salt Fast Reactor (MCSFR)

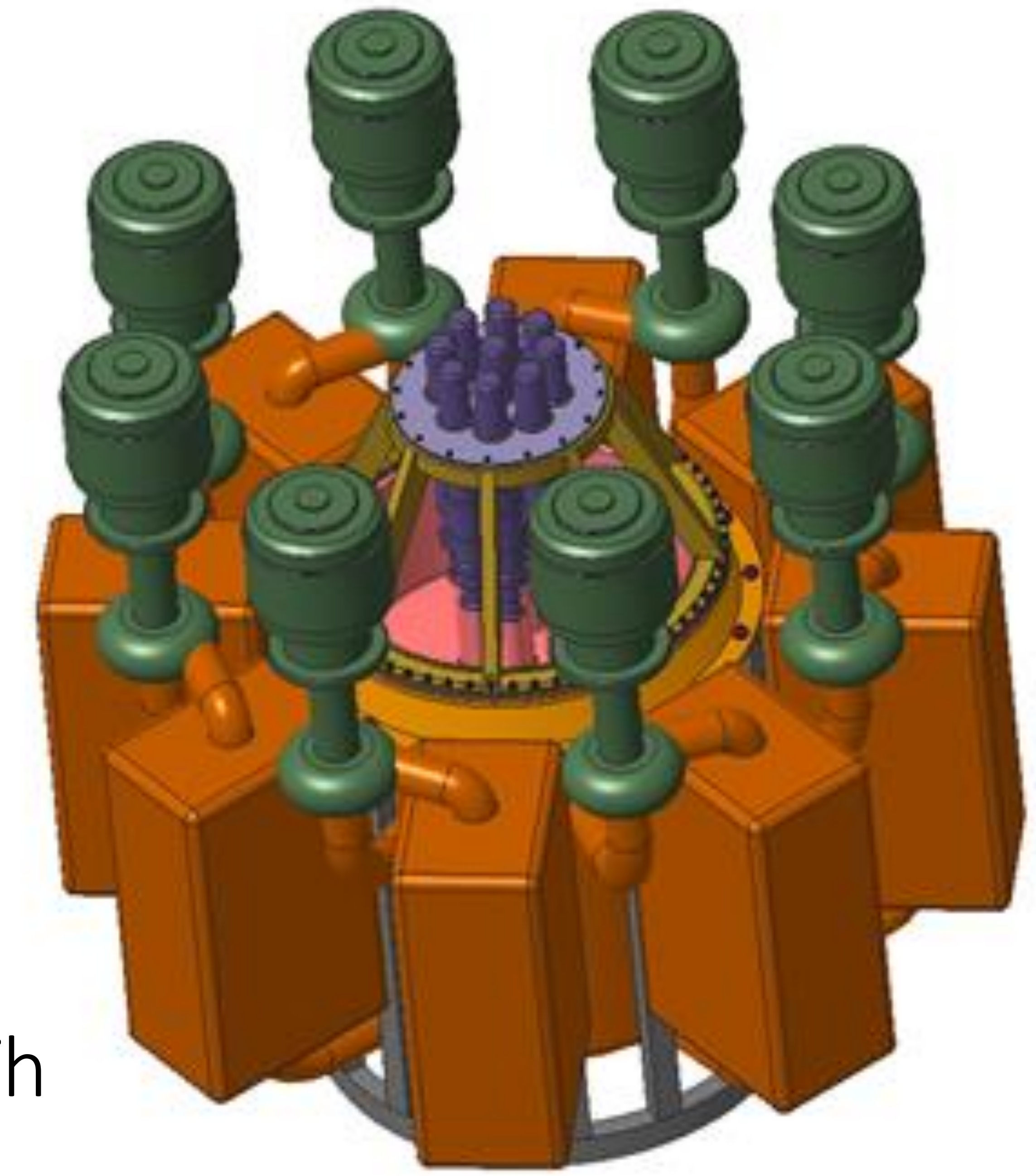
Design Objectives

Safety | *Economic Competitiveness* | *Low Environmental Impact*

Efficient Nuclear Fuel Use | *Enhance Non-Proliferation and Safeguards*

Plant Concept

- 1 GWe/2.5GWth
- Chloride fuel salts
- Fast spectrum neutron flux
- Breeding ratio ~1
- Core outlet: ~ 600 ºC
- Core inlet: ~ 500 ºC
- High TRL purification systems
- Design for maintainability
- Fuel Flexible: DU/LEU/SNF/RGPu/WGPu/Th

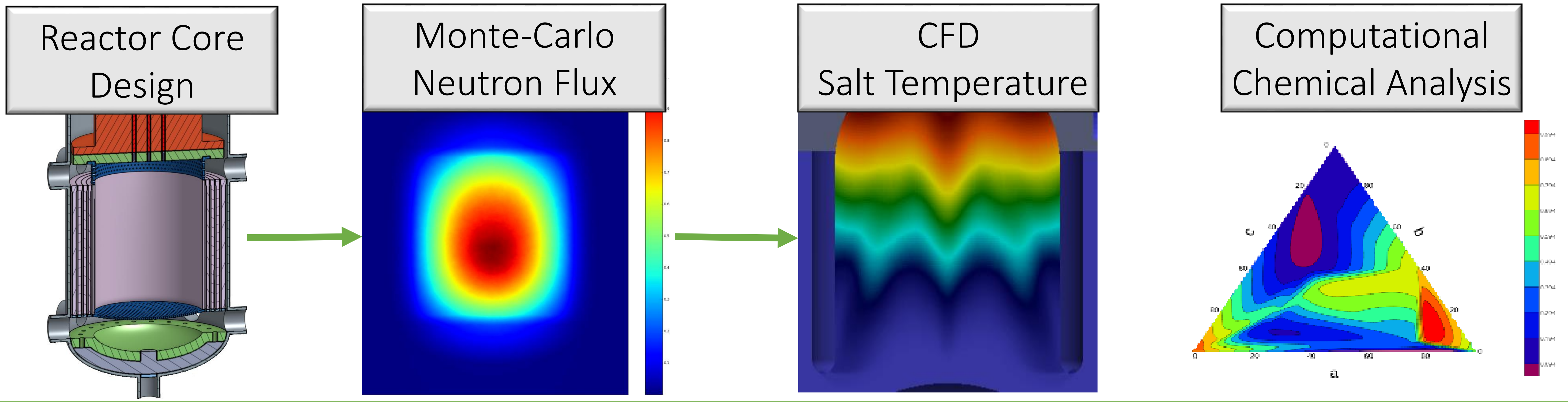


Safety & Proliferation Resistance

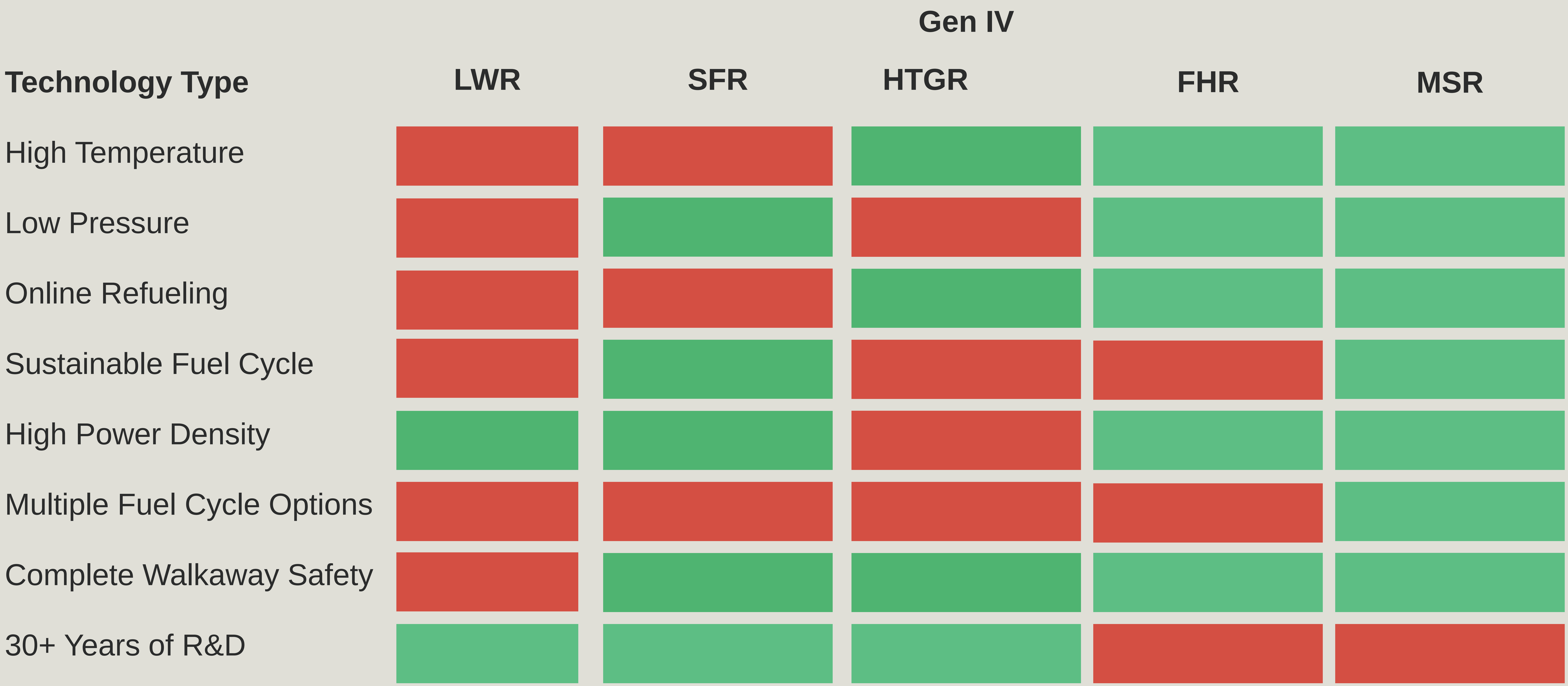
- Low operating pressure – Fuel < Secondary
- Secondary T_{cold} > Fuel $T_{m.p.}$
- Negative reactivity/void coefficients,
  - self regulating/shutdown
- **Fuel drain system**
- No actinide removal/separation
- Simple Chlorine based soluble fission product removal
- FP Vitrification with Cl recycling
- Passive corrosion control
- Passive safety, incl. decay heat removal
- No exothermic reactions
- Low excess reactivity

Design Approach

- Integrated Physics-Fluid design methodology
- Computational chemical analysis
- Test & validate



Technology Comparison ↘



Regulatory issues

Functional containment

Fuel qualification

Engagement with

DOE and National Labs

MSR National Campaign

NEAMS

Consensus standards related to MSRs

DOE has directly engaged the MSR TWG

- MSR Chemistry Workshop in April of 2017
- "Technology and Applied R&D Needs for Molten Salt Chemistry, Innovative Approaches to Accelerate MSR Development and Deployment" – Final Report

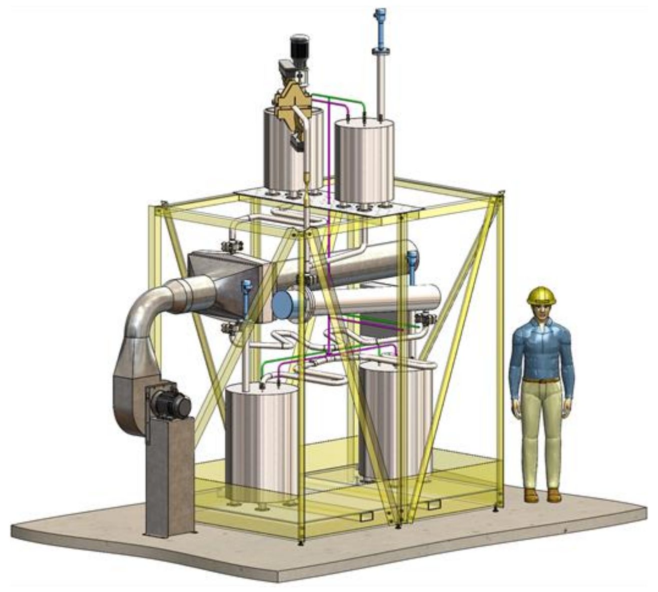
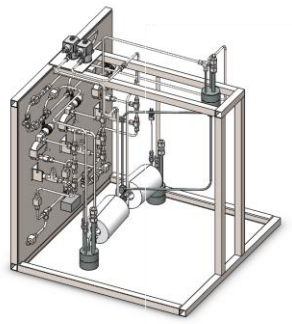
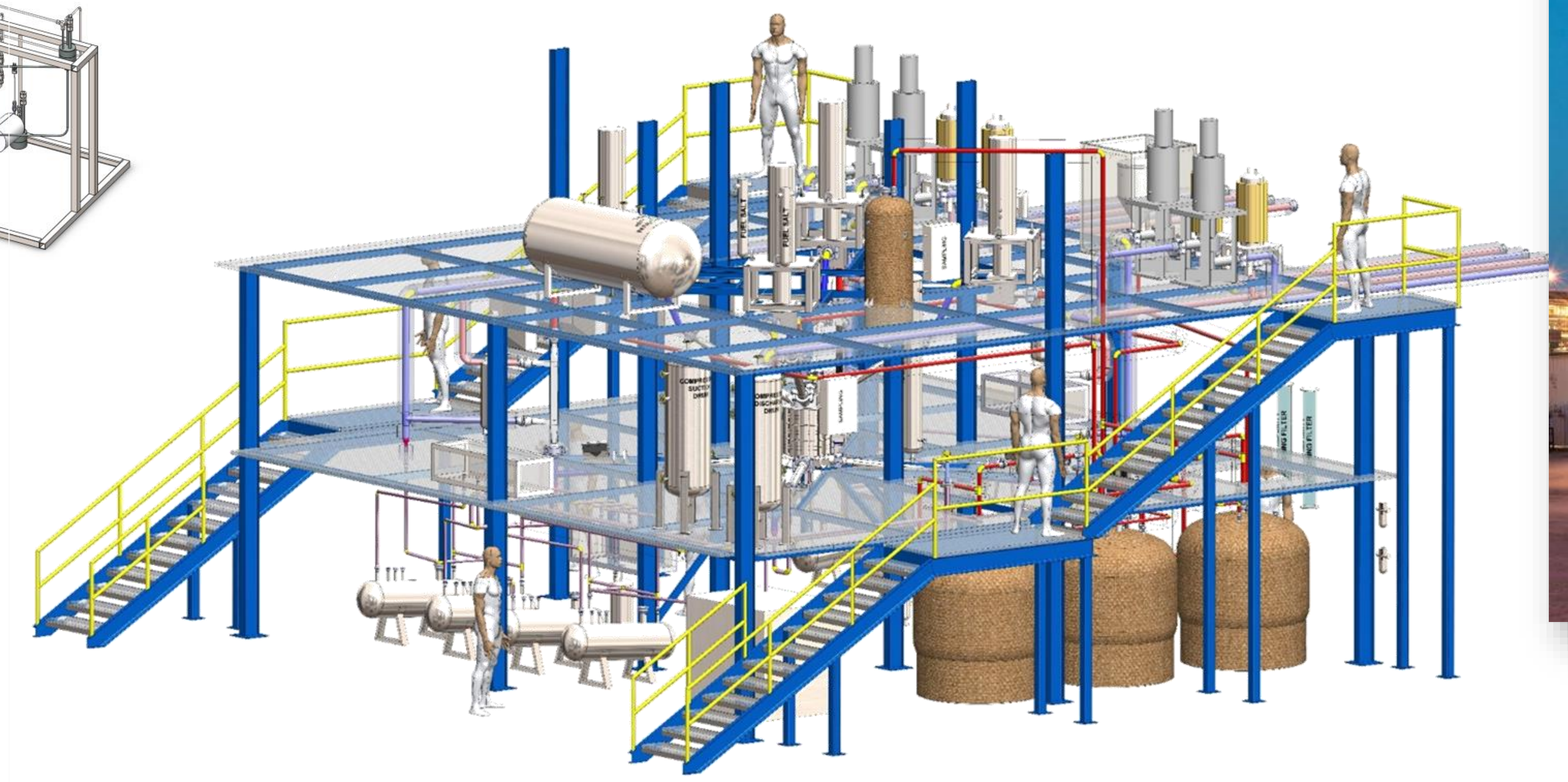
- GAIN support for MSR TWG activities – connection to SMEs within National Lab complex

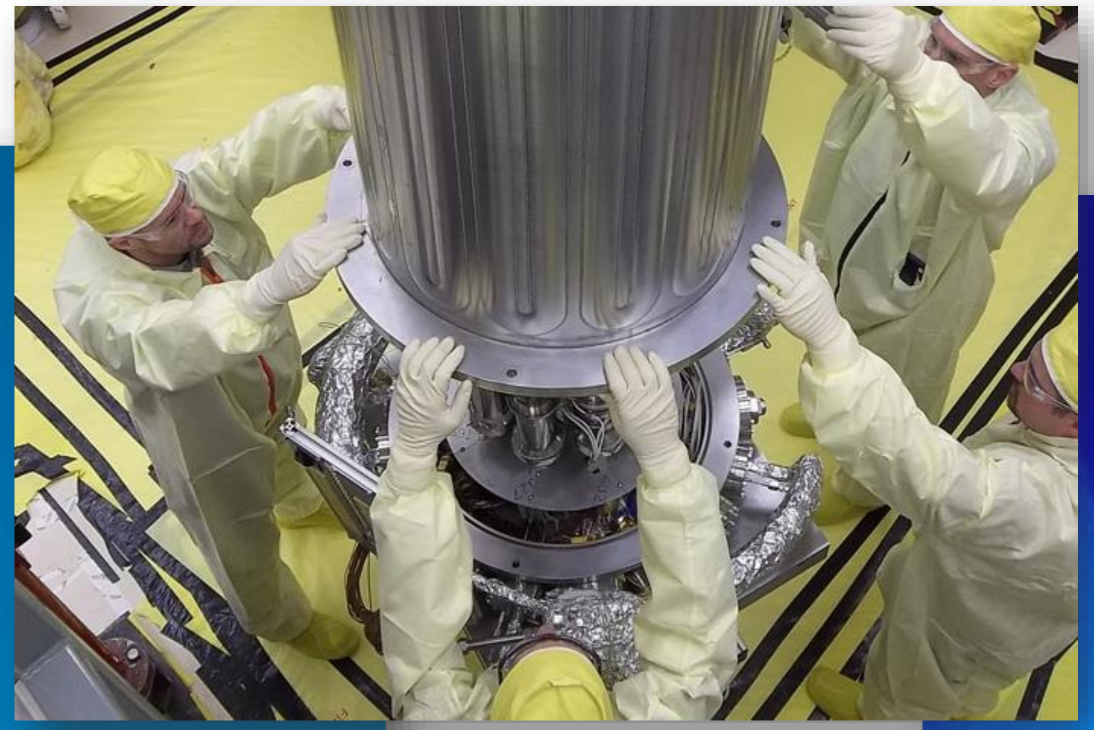
- Establishment of DOE Advanced Reactor Technologies (ART) MSR Campaign

- NEAMS Software Workshop for MSR TWG in March of 2018
- Led directly to GAIN voucher applications from industry to collaborate with NEAMS developers

- → MSR Developers intend on using neutronics, thermal hydraulics, structural mechanical, and systems codes based on features and V&V strategy
- → Each developer is approaching Mod/Sim independently – there is no “cookie cutter” set of tools
- → Code independence – can NRC and industry use the same codes?

Plans for experimental facilities →



Separate Effects Tests	Integrated Effects Tests	Large Component Test Facility	Criticality Experiments	Demonstration Reactor
2016-2019	2017-2020	2019-2022	2020-2024	2022-2027

MSR TWG Perspective on DOE Codes →

- Some DOE codes have strong user support while others require direct developer “hand holding” to utilize
- In order for industry to adopt these codes they must have similar usability and support to commercial codes
- We would like to see DOE pay to V&V their own codes against our experiments
- We have commercialization timelines that prevent DOE code development from being on critical path

What are
we missing?

- → Predictive chemistry and effective “MSR fuel performance code”
- → Coupled fast spectrum neutronics and thermal hydraulics transient code
- → MSR mechanistic source term code
- → Salt physical properties and chemistry data
- → Salt irradiation experiment data
- → Optimized MSR licensing pathway

Southern Company™

Kairos Power

KAIROS POWER MODELING AND SIMULATION PLANS

NOVEMBER 16, 2018

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

THERMAL HYDRAULIC SUBCOMMITTEE

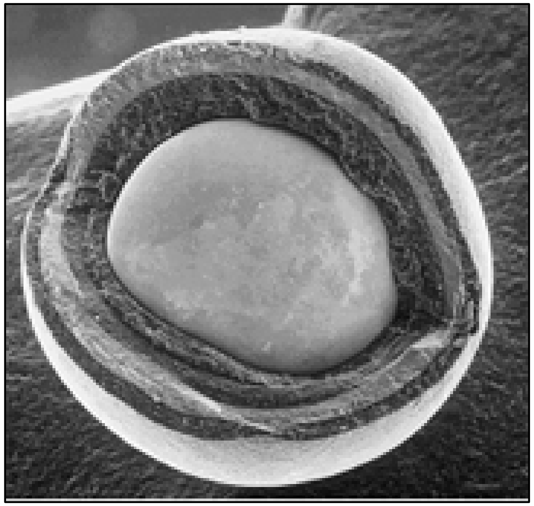
Agenda

- Introduction to the Kairos Power FHR Design
- Current Codes Selected for License Basis Event Modeling
- Ongoing Development and Testing to Prepare Codes for Licensing Interactions

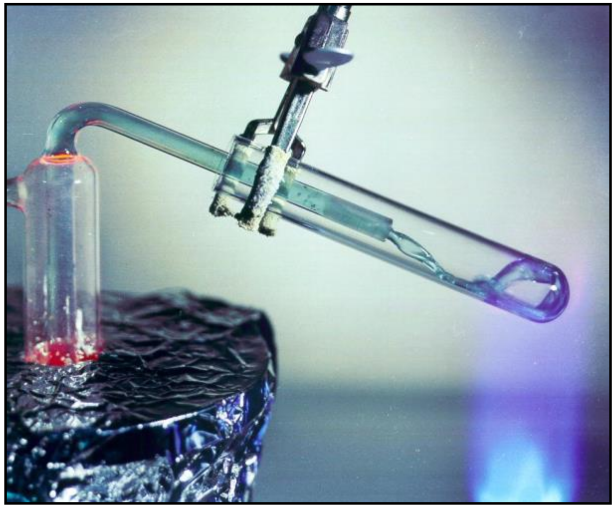
Kairos Power's mission is to enable the world's transition to clean energy, with the ultimate goal of dramatically improving people's quality of life while protecting the environment.

Kairos Power FHR Technology Basis

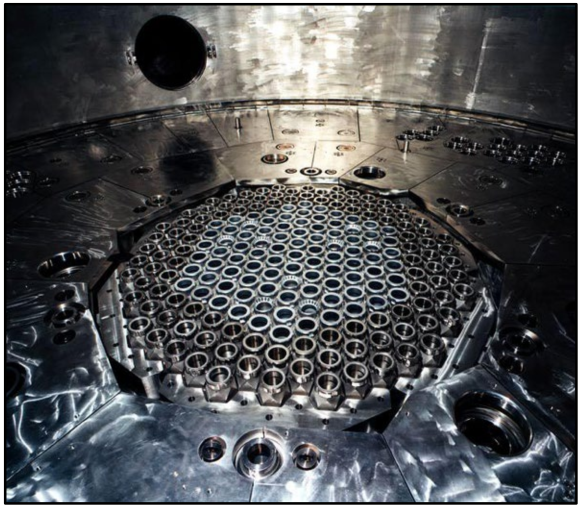
Coated Particle Fuel
[High Temperature Gas Reactors]



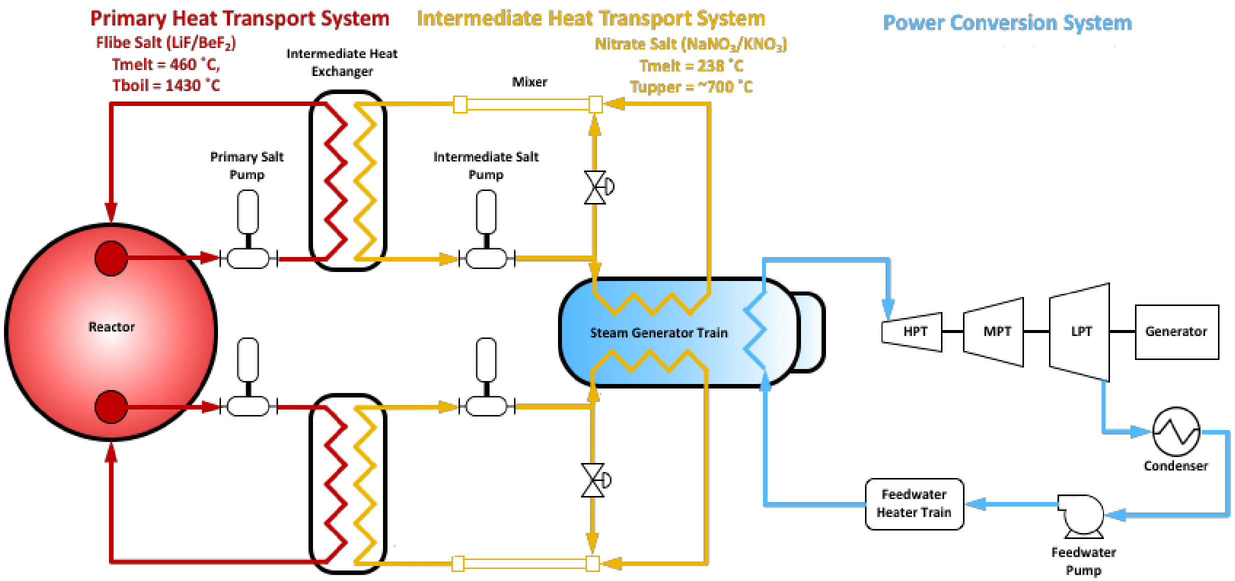
Liquid Fluoride Salt Coolants
[Molten Salt Reactors]



Low-Pressure Pool Vessel
[Sodium Fast Reactors]



Basic System Configuration with Steam Cycle

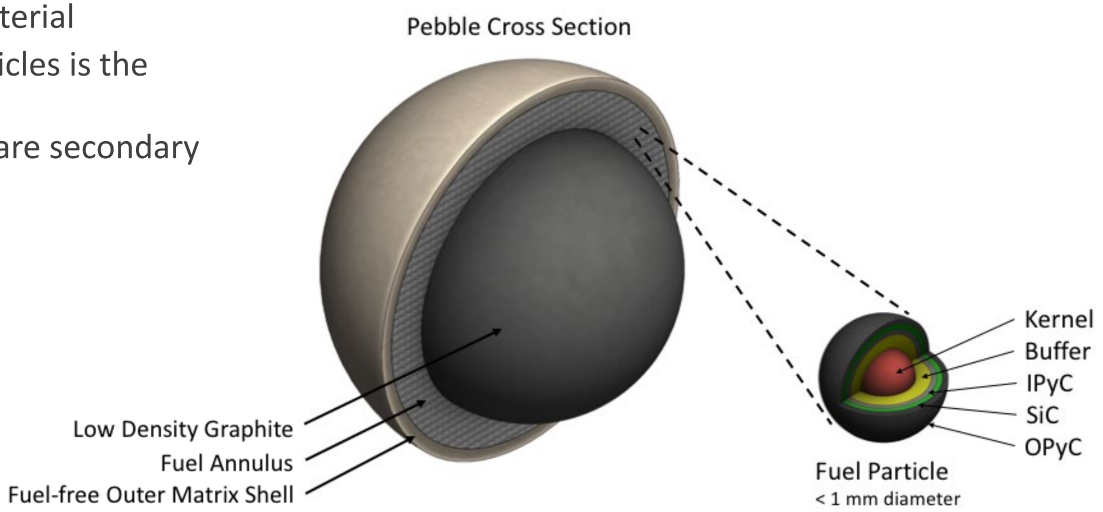


Highlights

- Minimal/no valves in primary
- Accommodate system heat up and cool down, with salt transfers
- Intermediate loop will leverage technology and suppliers of Concentrated Solar Power
- Enable multiple Ultimate Heat Sink options
- Tritium Management strategy is applied over the entire plant

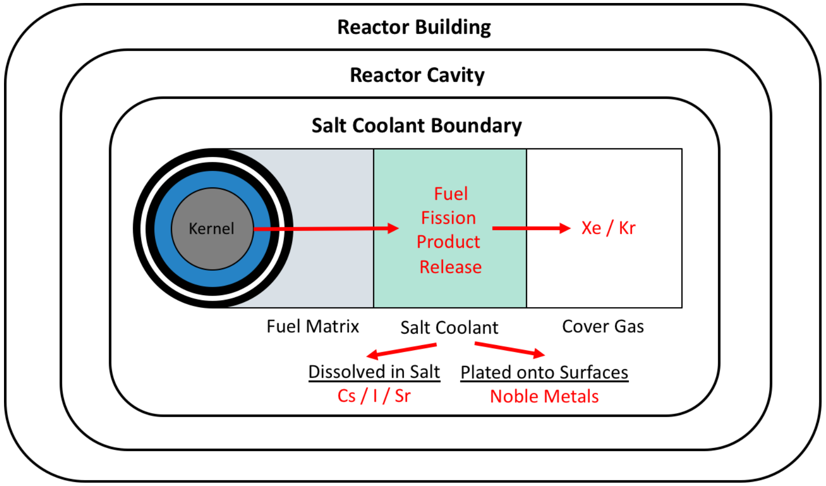
Fuel Particles and Pebbles

- Core design is a pebble bed concept within a graphite reflector
  - Pebbles are positively buoyant in Flibe
- Fuel particles:
  - Tri-structural isotropic (TRISO)-coated fuel particles embedded in a matrix material
  - Silicon carbide coating on fuel particles is the primary fission product barrier
  - Pyrolytic carbon layers and matrix are secondary barriers
- Pebble handling system monitors condition and burnup
  - Individual pebble transit is on the order of several months



FHR Safety Case is Rooted in the Robust Intrinsic Safety Characteristics of the Fuel and Coolant Combination

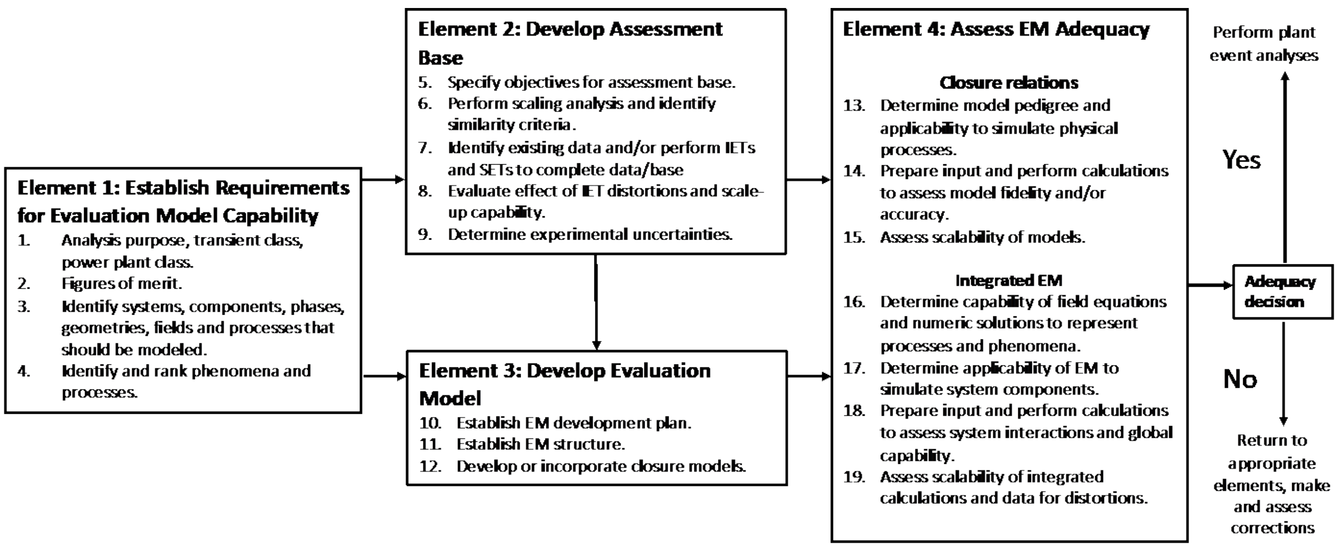
- **TRISO Fuel**
  - Demonstrated FP retention up to 1600° C
  - FHRs operate with uniquely large fuel temperature margins
  - No incremental fuel failure expected during postulated accidents
- **Flibe Coolant**
  - Demonstrated retention of solid fission products and iodine
    - MSRE ~ FHR Test with 100% Fuel Failure
  - Low pressure coolant reduces stored energy in reactor cavity and building
- **Low Pressure Primary System**
  - Loss of “pressure boundary” does not result in large pressure related energy releases
  - Additional defense-in-depth may be provided by retention of any fission products released from the primary circuit in low pressure reactor building structures.



11

Evaluation Model Development

- The aggressive timeline for deployment of the KP-FHR requires rapid maturity of the simulation tools used in the evaluation models.
  - Rapid down selection of possible tools
  - Use of internal Phenomena Identification and Ranking Table process to define early required modeling phenomena and inform the testing plan for validation.
- Leverage the extensive testing capability being developed at Kairos to fill in assessment base and generate validation data as needed.



Elements of an EMDAP (U.S. NRC RG 1.203).

Safety Related Code Development at Kairos

- The KP-FHR safety case is phenomenologically different than the current LWR fleet
- The robust TRISO fuel form with failure temperatures above 1600°C
  - Molten Salt (Flibe) as the primary coolant with a melting point of ~460°C and boiling point of ~1430°C
  - Structural SS316 Vessel

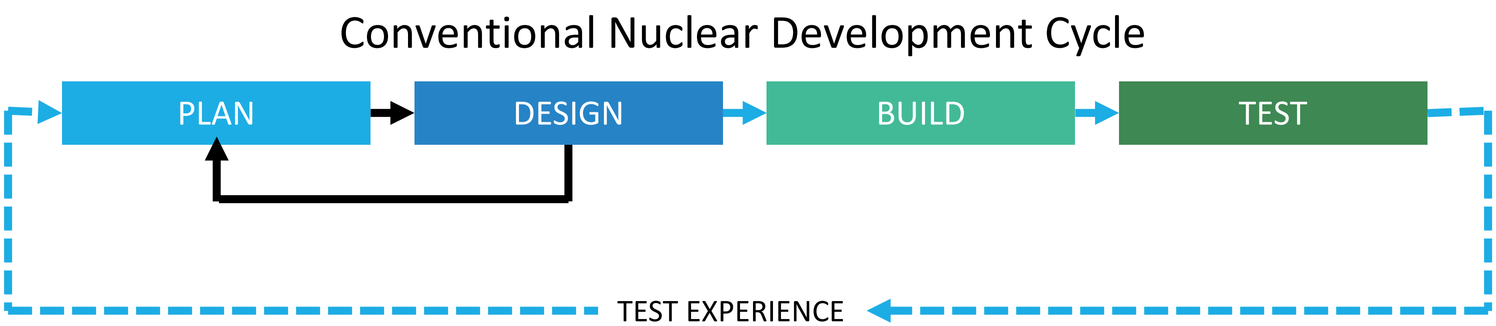
From the above phenomenology we chose the following key development efforts for safety related codes include:

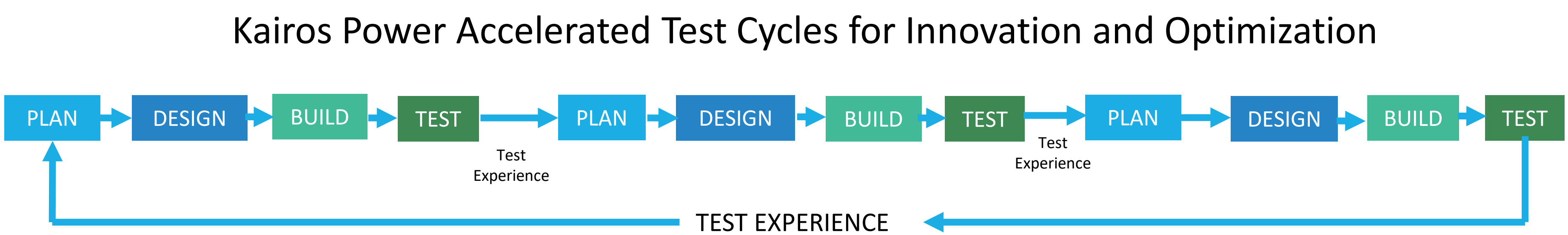
- **SAM: Dedicated safety related transient systems analysis tool being developed for KP-FHR.**
  - Co-development with Argonne National Laboratory.
  - Model Needs and Code Development Plan (CDP) in place and development underway.
- **BISON: TRISO fuel performance prediction tool.**
  - Co-Development with Idaho National Laboratory.
  - Model Needs and Code Development Plan (CDP) in place and development underway.
- **GRIZZLY: High temperature core structural materials analysis tool (Slide 14,15 Refs).**
  - Co-Development with Idaho National Laboratory.
  - Model Needs and CDP still to be created.
- **PARCS/AGREE: Porous media based thermal hydraulics code with coupled neutronics module for core transient analysis.**
  - Co-Development with the University of Michigan.
  - Model Needs established. CDP under development.

UNIVERSITY OF MICHIGAN

NEAMS
NUCLEAR ENERGY ADVANCED MODELING & SIMULATION PROGRAM

Kairos Power Nuclear Development Paradigm





Testing for Design, Safety, Validation

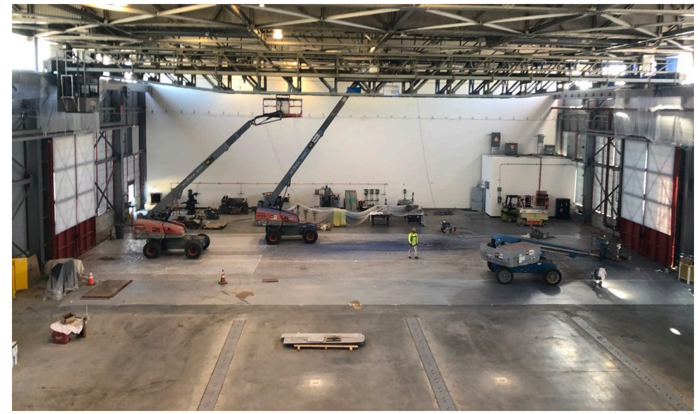
R RAPID LAB — Rapid Analysis, Prototyping, and Iterative Design Lab (R-LAB)

S SALT LAB — Salt Handling and Loop Testing Lab (S-LAB)

T TESTING FACILITY — Component Testing Facility (T-FACILITY)

U USER FACILITY — User Operations & Maintenance Training Facility (U-FACILITY)
Prototypic integrated systems test

Kairos Power’s RAPID-Lab for Iterative Testing for Design, Safety, Validation



Closing Remarks

- Kairos is committed to validation of advanced modeling and simulation tools applied to the KP-FHR.
- To support this effort we are collaborating with the DOE labs and code owners to accelerate the remaining development.
- Comprehensive testing program used in a unique way to support the design and validation of simulation tools.
- Ready to work with NRC and ACRS in a transparent fashion with ongoing interaction on code development and application.

Grizzly: Nuclear Power Plant Component Aging

- MOOSE-based simulation code for aging in nuclear power plant systems, components, and structures
- Used to model both aging processes and the ability of age-degraded components to safely function
- Intended to be used for a variety of components. Current applications:
  - LWR reactor pressure vessels
  - Concrete structures
- Areas of current development for advanced reactors:
  - High-temperature creep
  - Creep-fatigue and creep-fracture

Grizzly Engineering-Scale Applications:

LWR Reactor Pressure Vessels

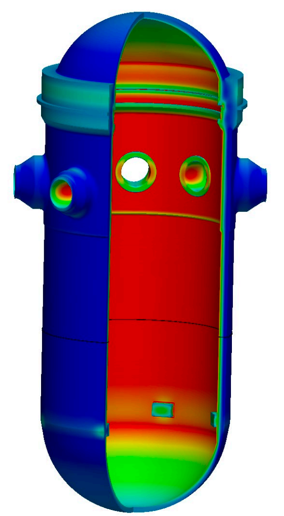
- Multidimensional modeling of global response during transients
- Fracture models with Monte Carlo sampling compute probability of fracture initiation

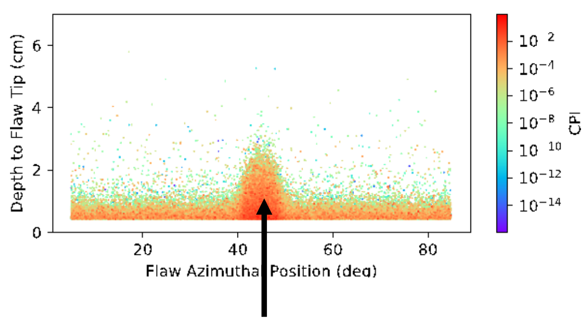
B. Spencer, W. Hoffman, and M. Backman. “Modular system for probabilistic fracture mechanics analysis of embrittled reactor pressure vessels in the Grizzly code,” Nuclear Engineering and Design, 341:25–37, Jan. 2019.

Concrete Structures

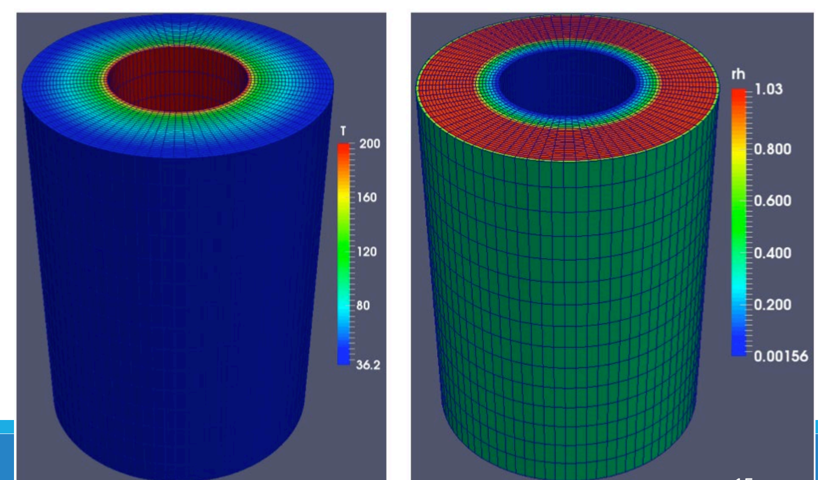
- Coupled physics models of heat & moisture transport and mechanics
- Models for volumetric expansion due to alkali-silica reaction (ASR) and radiation-induced volumetric expansion (RIVE)

H. Huang, B. W. Spencer, and G. Cai. Grizzly model of multi-species reactive diffusion, moisture/heat transfer and alkali-silica reaction in concrete. INL/EXT-15-36425, Idaho National Laboratory, Idaho Falls, ID, September 2015.





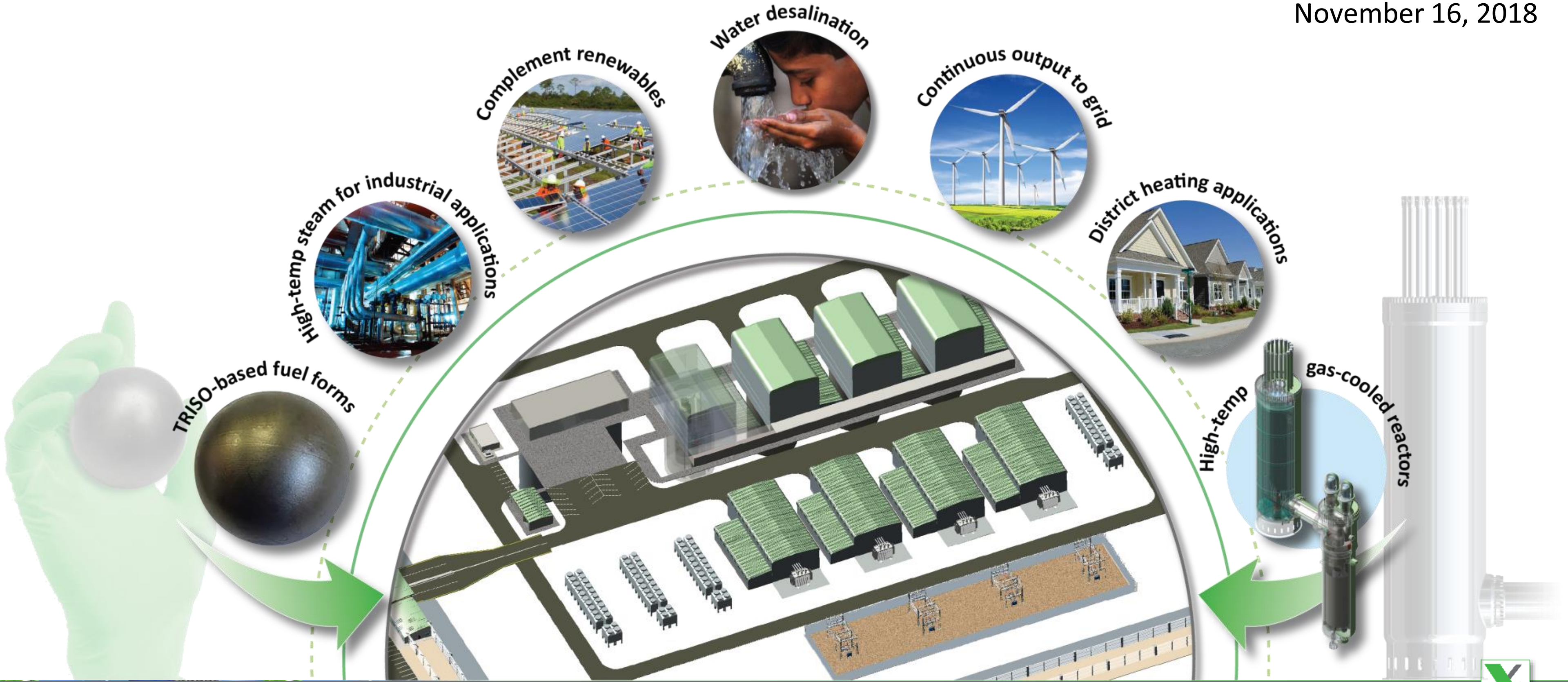
Increased failure probability at stress concentration



X-energy: Modelling & Simulation

Martin van Staden
VP Design Engineering

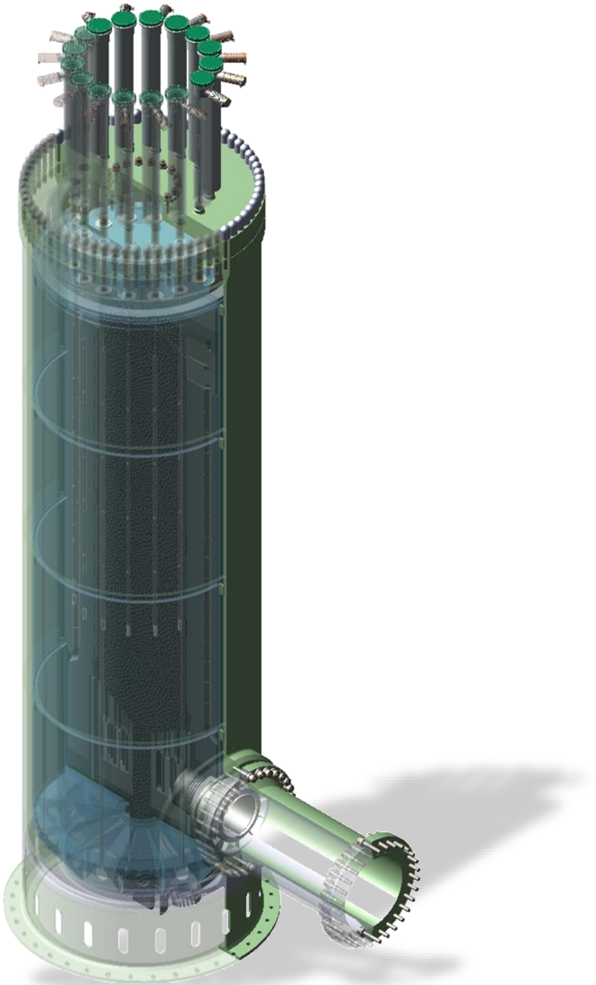
Computer Codes User Needs for Advanced (non-LWR) Reactor Safety Analysis and Accident Tolerant Fuels (ATF) in LWR Safety Analysis
November 16, 2018



Outline

- X-energy Design
- Introduction to our Design Safety Basis
- Main Physics to Support Safety Case
- Neutronics Codes
- Thermal / Flow Codes
- Source Term Codes
- Summary

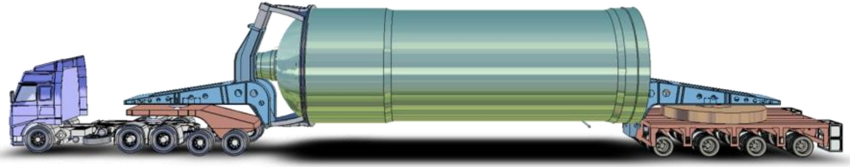
Note: This presentation only addresses codes of interest to the ACRS Thermal Hydraulics subcommittee (neutronics, thermal / flow analysis, and mechanistic source term). Structural and seismic analysis codes planned for use are not addressed herein.



Pebble Bed High Temperature Gas Reactor

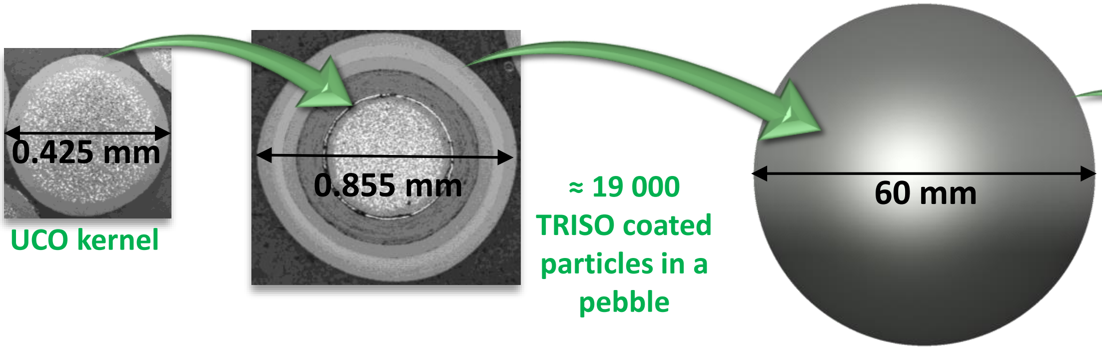
Plant features / attributes include:

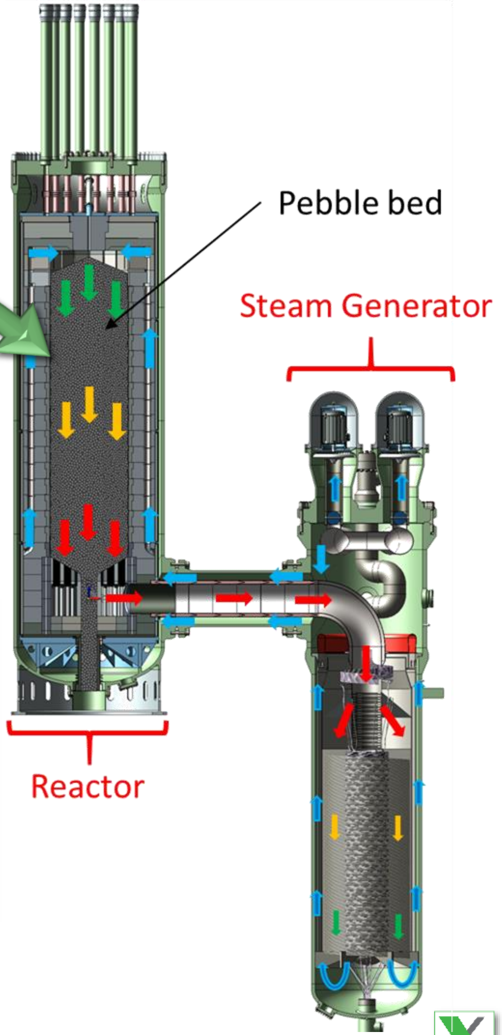
- Use of well proven UCO TRISO based fuel
- Proven intrinsic safety
- Operated without the need for a water source
- Load-following to 40% power within 15 minutes
- Continuous online fueling with passive on-site spent fuel storage
- Requires less time to construct (2.5 to 4 years)
- Factory assembled road transportable components/systems
- Deployable for electricity generation, process heat or co-generation



Thermal Output	Electric Output	Steam Pressure	Steam Temperature
200MWth	~75MWe	16.5MPa	565ºC

UCO TRISO Particle – Primary Fission Product Barrier





- Primary safety goal is to ensure that fission products are retained within the TRISO coated fuel particles to the maximum extent possible
- TRISO Fuel particle coatings provide multiple fission product barrier
- The analysis challenge is to predict fuel temperature and source term within a randomly packed pebble bed during normal operation and loss of forced flow conditions

Design Safety Basis – Supported by Analysis Tools

Safety Function	Control Criticality	Control Heat Removal	Contain Fission Products
Design Selection / Feature	• ***Low power density*** • ***Low excess reactivity*** • ***Strong negative temperature coefficient*** • ***Fixed phase moderator (graphite)*** • Online refueling • Large thermal inertia	• ***Low power density*** • ***Strong negative temperature coefficient*** • Fixed phase heat transport fluid • Large thermal inertia • Large pressure vessel surface area to remove heat passively	• ***High retention capability of fission products in coated particles (99.99%)*** • ***High temperature tolerance during loss of forced heat removal*** • ***Multiple independent physical barriers***
Analysis Tools	Neutronics analysis Thermal and flow analysis	Neutronics analysis Thermal and flow analysis	Neutronics analysis Thermal and flow analysis Fuel Performance analysis

Bold text indicates fuel design features

Main Factors Affecting Fuel Performance

Fuel Temperature

- Strong coupling between neutronics and thermal analysis needed

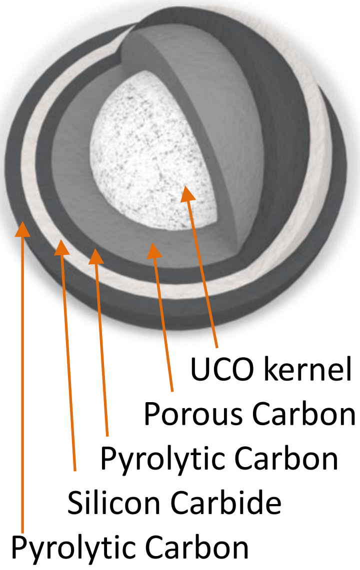
Fuel Burnup

- Moving fuel depletion calculations are needed to predict burnup

Fuel Quality

- Source term analysis takes fuel quality into account

TRISO Coated Particle



Factors Directly Impacting Fuel Temperature

Power

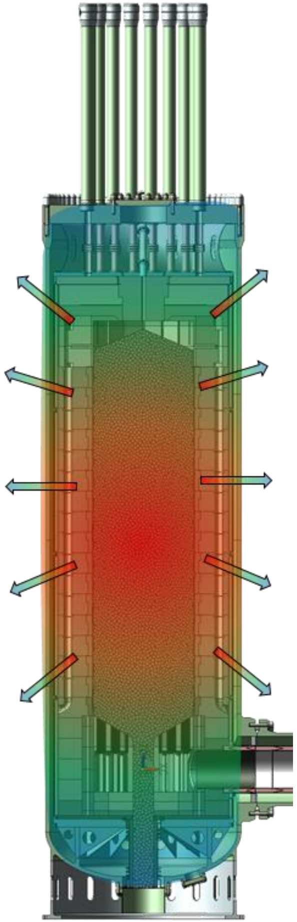
- Power profile obtained from neutronics codes coupled thermal flow calculations

Heat Transfer

- Calculated using CFD with validated porous media approach

Material Properties

- Use extensive material property data as a function of temperature and fluence



X-energy Neutronics / Thermal flow / Source term Codes

	Functionality	Currently used for Conceptual Design	Planned Code Development	NEAMS Codes
Neutronics	Cross-section generation for Full Core Analysis	ENDFB-IV,V, JEF-1 VSOP (GAM-ZUT-THERMOS)	ENDFB-VII.x SCALE (CENTRM-SHIFT)	ENDFB-VII.x MC2-3/PROTEUS
	2/3D steady state full core neutronics & thermal/flow	VSOP (CITATION,THERMIX-KONVEK)	PARCS-AGREE or PARCS-FLOWNEX or PARCS-STAR-CCM+	MC2-3/PROTEUS or MAMOTH-PRONGHORN
	Fuel Management and Burnup (i.e. fuel movement)	VSOP (ORIGEN-JUL, NAKURE)	ORIGEN 6.2 - MIXICLE	ORIGEN (pebble shuffling not supported)
	Time-dependent neutronics & thermal/flow	MGT, STAR-CCM+ and FLOWNEX	PARCS-AGREE or PARCS-FLOWNEX or PARCS-STAR-CCM+	RATTLESNAKE-PRONGHORN
	Higher order neutronics for shielding, verification, and UQ	MCNP	SHIFT MCNP	MC^2-3/PROTEUS/DIABLO
Thermal/flow	High fidelity thermal/flow for verification and UQ	STAR-CCM+	STAR-CCM+ NEK-5000	NEK-5000
	Graphite Corrosion	MGT, STAR-CCM+	XSTERM (XCORR)	
	System/Plant Analysis	FLOWNEX	FLOWNEX	SAM
Source term	Fuel performance and radionuclide release	XSTERM (XFP, XGAS, XOL)	XSTERM (XFP, XGAS, XOL)	BISON (limited TRISO capability)
	Tritium, dust deposition and resuspension, RN transport	XSTERM (XTRIT,XDUST, XHPB, XRB, XDIS)	XSTERM (XDUST, XHPB, XRB, XDIS)	

Color Legend: Legacy codes | US/DOE Codes | X-energy in house code | Commercial NQA-1 Code

Neutronics Codes Roadmap Development

- Conceptual design has utilized legacy pebble bed design codes – **VSOP-A**, **VSOP 99** (Quasi-Steady State) and **MGT** (Transient) - Proven track record but currently without technical support
- Worked with the DOE Labs (INL, ORNL, SNL, ANL) and University of Michigan to review existing US/ DOE codes in order to develop a comprehensive roadmap specifying the capability to simulate pebble bed reactors
- The Neutronics code Roadmap identifies two parallel paths:

Neutronics Road Map

Legacy codes (**VSOP-A**, **VSOP-99**, **MGT**)

- Complete Conceptual design
- Perform bench marks
- Ensure process to meet 10 CFR 50 Appendix B requirements

US/DOE codes (**SCALE, PARCS, ORIGEN 6.2, MIXICLE**)

- Develop required features for US/DOE Codes
- Link Codes using NEAMS work bench
- Ensure codes meet 10 CFR 50 Appendix B requirements

NRC License

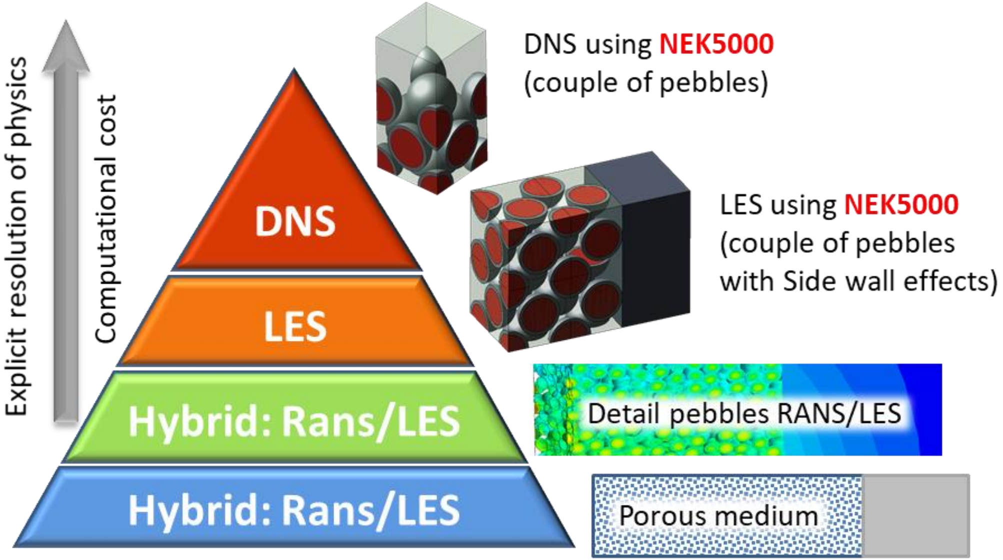
Color Legend:	**Legacy codes**	**US/DOE Codes**	**X-energy in house code**	**Commercial NQA-1 Code**

Thermal Flow Roadmap Development

- Two main requirements:
  - Component/sub system analysis : transient / steady state (i.e. core structures, reactor, etc.)
  - System level analysis: transient / steady state (entire primary & secondary loop)

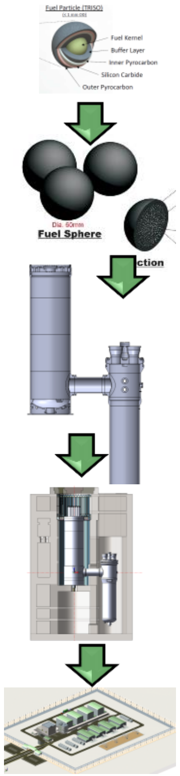
- Commercial NQA-1 codes for thermal and fluid flow:
  - **STAR-CCM+** detailed CFD subsystem and component analysis
    - Developed in house Porous Media Heat Transfer Approach (**PM-HTA**) user coding for STAR-CCM+
  - **FLOWNEX** Nuclear

- DOE Codes that will be used:
  - **NEK5000** - high fidelity verification and validation for pebble bed heat transfer
  - **AGREE** coupled to **PARCS** for thermal / gas flow - coupled neutronics



Color Legend: Legacy codes | US/DOE Codes | X-energy in house code | Commercial NQA-1 Code

Source Term Calculation



Source Term Path

Releases from TRISO fuel particles
↓
Releases from fuel elements (pebbles)
↓
Releases from Pressure boundary
↓
Releases from building
↓
Max dose at site boundary

Element / Isotope	Form / State	Mechanism	Physical Phenomena	Methods / Software Codes
Iodine Silver Strontium Cesium	Gaseous FPs Metallic FPs	- Release from TRISO particles into matrix graphite - Activation of impurities	Temperature, irradiation time, fast fluence, burnup, particle defects, contamination	VSOP-A, VSOP-99, MGT SCALE, PARCS, OREGIN FLOWNEX, STAR-CCM+ XS-Term
Iodine, Silver Strontium Cesium	Gaseous FPs Metallic FPs Dust Particles	- Diffusion from pebble into the helium stream - Activation of impurities	Temperature, irradiation time, fast fluence, burnup, contamination	VSOP-A, VSOP-99, MGT SCALE, PARCS, OREGIN FLOWNEX, STAR-CCM+ XS-Term
Iodine, Silver Strontium, Cesium	Gaseous FPs Metallic FPs Dust Particles	- Leakage from HPB into building and structures - Activation of impurities	Instrumentation line failure, small & large pipe breaks, plate-out, liftoff	ORIGEN XS-Term
Iodine, Silver Strontium, Cesium	Gaseous FPs Metallic FPs Dust Particles	- Transport throughout building to the environment	Plate-out, liftoff	XS-Term MELCOR
Iodine, Silver Strontium, Cesium	Gaseous FPs Metallic FPs Dust Particles	- Atmospheric dispersion - Ingestion	Postulates	XS-Term STAR-CCM+

Color Legend: **Legacy codes** **US/DOE Codes** **X-energy in house code** **Commercial NQA-1 Code**

Summary

- For conceptual design X-energy has had to rely on legacy neutronics codes as DOE codes with the ability to model moving fuel are not presently available and need to be developed
- X-energy has collaborated with the DOE labs to identify the gaps in existing DOE codes that need to be addressed in time to support final design and licensing of the Xe-100 reactor
- It is of extreme importance for X-energy to meet the time scales outlined in our code development roadmaps in order to achieve our target deployment date – these time scales have influenced choices made in the various road maps
- X-energy needs a commitment from DOE to support specific development of DOE codes to ensure DOE codes have the required capability to model pebble bed reactors
- We also need close collaboration and interaction with the NRC to move these roadmaps forward and to ensure regulatory requirements and expectations are met

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NuScale Collaboration with CASL & NEAMS

November 16th, 2018

Acknowledgement & Disclaimer

This material is based upon work supported by the Department of Energy under Award Number DE-NE0000633.

Agenda

- NuScale interactions with CASL to date
  - Support During the Subchannel Codes Selection
  - VERA Training
  - Assessment of CRUD build-up in NPM
  - Future Projects
- NuScale interactions with NEAMS to date
- NuScale observations on Advanced ModSim development

Support during Subchannel Codes Selection

- During subchannel codes and methodology strategy selection, (2014) collaboration with CASL was valuable
- CASL compared CTF (part of VERA-CS) results against historical experiments with NuScale-specific types of phenomena (e.g., GE 3x3, etc.)
- CASL-provided results helped establish the path for the development of NuScale subchannel methodology.

VERA Training

- In-house VERA training was successfully conducted by ORNL staff for 10 NuScale engineers in June of 2018
- The scope of the VERA training covered :
  - VERA-CS Overview
  - VERA_CS Input description
  - NuScale SMR-specific full core coupled simulation
- NuScale is currently working to define updated priorities and preferences for additional work/support to be provided under the CASL directive using the VERA-CS code.

Assessment of CRUD build-up in NPM

- The primary focus of the CRUD Test Stand activities was to perform a preliminary CRUD analysis to forecast the operational CRUD behavior.
- The Test Stand activities included the development of VERA model of the NuScale SMR, code-to-code comparisons, and coupled VERA neutronic and thermal-hydraulics simulations of eight fuel cycles to achieve equilibrium operating conditions for the CRUD analyses.
- VERA demonstrated excellent capabilities to model nuclear performance of the NuScale core and consistency with results from multiple industry standard codes such as MCNP, KENO-VI, CASMO5, and SIMULATE5.

Future Projects

- Use a combination of computational fluid dynamics (CFD) and VERA-CS for multidimensional assessment of the reactor core flow and boron distribution.
- Continue collaboration on the development of the CRUD assessment methodology

NuScale interactions with NEAMS to date

- The Reactor Product Line of the NEAMS project has developed flow-induced vibration (FIV) analysis capabilities to support industry and specifically integral, small modular reactors using the SHARP code (consists of Diablo for structural mechanics and Nek5000 for fluid mechanics).
- There is very limited research in the area of FIV for helical tube steam generators. The NEAMS project has performed in-air FIV experiments of helical coil test sections to increase the body of experimental results related to helical tubes and to benchmark the SHARP analysis methods. Having additional experimental data and alternate software tools and design analysis methods to perform FIV calculations are of great benefit to demonstrating the safety of the NuScale steam generator design.
- Continued development of the SHARP capabilities including two-way coupling is beneficial for NuScale, as the FIV mechanisms with the lowest safety margins for the NuScale design include strongly-coupled mechanisms such as vortex shedding and fluid elastic instability. Because NuScale is a natural circulation design, this represents a difference compared to most tradition reactor plant designs where turbulence is the primary focus of the Regulatory Guide 1.20 comprehensive vibration assessment program. Continued collaboration between NuScale and NEAMS as we generate modal and flow testing validation results will be useful to demonstrate the safety of the NuScale design and provide improved simulation methods for FIV.

NuScale Observations on Advanced ModSim Development

- Nuclear Industry (including NuScale) may get significant benefits from the usage of the advanced reactor modeling tools (ModSim).
- However, the positive impact could be more pronounced in case of applying ModSim suites nearer-term from a licensing standpoint rather than from the R&D standpoint. Therefore, the idea of considering step-by-step licensing of ModSim code suites like VERA CS and getting generic SER would be a great step forward for the industry.
- Participation of the NuScale and other companies in the Advanced ModSim commercialization effort can help to push the process forward. If needed, NuScale can participate in this effort.
- Code suites could be improved via implementation of generic and industry-specific proprietary modules. For example, dynamically linked libraries for CHF and other modeling choices could significantly improve the usability of the software products.
- Involvement of CASL & NEAMS in industry projects could improved via User Groups (e.g., using voting options within the groups).

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FRWG

Fast Reactor Working Group

Computer Codes User Needs for Advanced Reactor Safety Analysis

November 16, 2018

Fast Reactor Working Group

- Multiple developers working on multiple technologies
- Spans variety of fast reactor technologies in development
  - Various coolants, various fuels

ARC	Columbia Basin	Elysium Industries	Flibe Energy
General Atomics	GE	Hydromine	Oklo
TerraPower	Westinghouse	Duke	Exelon
Southern	Studsvik Scandpower	EPRI	NEI

Developer perspectives

- Different needs across the various stages of development and commercialization
  - Conceptualization
  - Design
  - Licensing
  - Operation

Fast reactor perspectives

FRWG Fast Reactor Working Group

- Various phenomenology of interest across designs
- Various fuel cycle missions
  - Long-lived cores
  - Used fuel consumption
  - Breed and burn
- Single phase coolant behavior
  - Heat transfer characteristics of liquid metals
- Generally tightly-coupled core designs
- Fluid fuel considerations

Code options

- Advanced tools
  - NEAMS
- Legacy tools
- In-house codes
- Commercial codes

- Each developer pursuing their own modeling and simulation strategy according to their respective designs

Analysis areas

Reactor physics

Thermal hydraulics

Fuel performance

Structural and mechanical analysis

Risk analysis

Source term analysis

Reactor physics

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Cross section generation
NJOY
MC^2-3
(Can use Monte Carlo XS gen)

Monte Carlo
MCNP
Serpent
OpenMC
Shift

Deterministic
PROTEUS
Rattlesnake
PERSENT
DIF3D
REBUS
ERANOS
PARCS
ORIGEN
Industry codes

Thermal hydraulics

Subchannel/channel
SE2-ANL
(SUPERENERGY)
SAM
COBRA
PRONGHORN

System
SAM
SAS4A/SASSYS
TRACE
RELAP
Flownex

CFD (FEA)
Nek5000
ANSYS
STAR-CCM+
ABAQUS

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Fuel performance

Bison
Marmot
LIFE-METAL
FRAPCON/FRAPTRAN

SAS4A/SASSYS

Structural/mechanical

NUBOW-3D
Diablo

ANSYS
ABAQUS
STAR-CCM+

Risk analysis

ADAPT

Source term

SAS4A/SASSYS
CONTAIN-LMR
GOTHIC
MELCOR

Validation

- Validation bases exist to varying degrees for the different designs
- Large experimental data sets for sodium cooled systems and metallic fuel
  - Highlighted by EBR-II and associated ALMR/IFR programs

General summary

- Diverse reactor designs and modeling and simulation considerations
- Variety of modeling and simulation options for design and licensing including legacy codes and advanced codes
- Varying degrees of validation bases
- Modern frameworks enable easier and more flexible integration and use
- Developers pursuing the best options to meet their needs
- Industry working with DOE and the national labs to advance these tools

Questions?

Appendix

Fuels

- Variety of fuels considered
  - Metal, oxide, nitride, carbide, salt
  - 7 developers considering metal fuel
- Robust fuel behavior can enhance the safety case
  - Fuel changing phase is not necessarily fuel failure, it can be a safety benefit
  - Coolant system can play an important role as a barrier to radionuclide release
- Operational considerations
  - Leakers do not necessarily impede operations

Metal Fuel Experience

- Metal fuel is a mature technology and the phenomena of interest are well characterized
- Over 130000 pins irradiated in EBR-II and over 1000 pins irradiated in FFTF
- In-core tests
  - 1986 SHRT tests
  - Also involved 40 startup cycles, 8 overpowers, 45 loss of flow tests
  - RBCB tests
- TREAT tests
- Out of pile tests
- Resilient to variations in manufacturing techniques and tolerant of impurities

Fuel Design Variations

- Extend operating envelope of metal fuels – e.g. advanced metal fuels
- Next generation cladding materials
- Alternative fuel materials
  - Carbides, nitrides, UZrH, cermets, etc.

Historical Reports and Data

- Metal fuel reports and data
  - Supporting documentation of applicable metallic fuel transient tests, including as-built data packages, as-run conditions, PIE results, and supporting documentation
- Legacy and modern fast reactor fuel experimental reports and data
  - Experimental data on UO_2, UN, UC, and advanced metal fuel irradiation performance
  - Experimental data on cladding materials
- NaSCoRD (formerly CREDO) database of component reliability for liquid metal reactors