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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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705TH MEETING

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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THURSDAY

MAY 4, 2023

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The Advisory Committee met, via teleconference at 8:30 a.m., Joy L. Rempe, Chairman, presiding.

COMMITTEE MEMBERS:

JOY L. REMPE, Chairman
WALTER L. KIRCHNER, Vice Chairman
DAVID A. PETTI, Member-at-Large
RONALD G. BALLINGER, Member
VICKI M. BIER, Member
CHARLES H. BROWN, JR., Member
VESNA B. DIMITRIJEVIC, Member
GREGORY H. HALNON, Member
JOSE A. MARCH-LEUBA, Member
MATTHEW W. SUNSERI, Member

ACRS CONSULTANTS:

DENNIS BLEY

STEPHEN SCHULTZ

DESIGNATED FEDERAL OFFICIAL:

WEIDONG WANG

CONTENTS

P R O C E E D I N G S

8:30 a.m.

CHAIRMAN REMPE: So, good morning. It's 8:30. This meeting will now come to order.

This is the second day of the 705th meeting of the Advisory Committee on Reactor Safeguards. I'm Joy Rempe, Chairman of the ACRS.

Other members who are in attendance are Ron Ballinger; Vicki Bier; Charles Brown; Vesna Dimitrijevic; Greg Halnon; Walt Kirchner; Jose March-Leuba, who will be joining us quickly, I'm sure; Dave Petti, and Matt Sunseri.

I note we do have a quorum. And similar to yesterday, the Committee's meeting is in-person and virtually.

A communications channel has been open to all members of the public to monitor the Committee discussion.

Mr. Weidong Wang is the DFO for today's meeting.

During today's meeting, the Committee will consider the following topics: the Kairos efforts to prepare a report for their Hermes Construction Permit; the Code Investment Plan that was developed by NRC's Office of Nuclear Regulatory Research, and the

X-energy Design Overview.

A transcript of the open portions of the meeting is being kept. It is requested that speakers identify themselves and speak with sufficient clarity and volume, so they can be readily heard. Additionally, participants should mute themselves when not speaking.

Periodically, we will open the meeting up to allow members of the public to make comments, as they wish.

And before we begin the first topic today, I'd like to ask other members if they have any opening remarks.

Not hearing any, then I'd like us to go off the record, and I'll ask the court reporter to return at 10:00 a.m.

(Whereupon, the above-entitled matter went off the record at 8:31 a.m. and resumed at 10:00 a.m.)

CHAIRMAN REMPE: It's 10:00 a.m. on the East Coast here. So, we're going to start.

Colleagues, I don't know if you followed, but in our last Research Review Report, we actually highlighted the fact that the Division of Safety Analysis in the Office of Research is developing an agencywide strategy for an integrated code development investment plan. And we did commit that we'd like to be briefed on it. So, we're really pleased today to welcome the Division of Safety Analysis in RES to come brief us this.

And at this time, I believe I'm supposed to turn over the presentation or the mic to Cinthya Roman who's on rotation from the Office of Research.

MS. ROMAN: Thank you.

Good morning, ACRS Members.

CHAIRMAN REMPE: Your microphone needs to go very close to you.

MS. ROMAN: Okay. Better? Okay. Okay. Better?

CHAIRMAN REMPE: Yes.

MS. ROMAN: Okay. As you mentioned, I'm Cinthya Roman and I'm the Acting Deputy Director for the Division of System Analysis in the Office of Regulatory Research. And we are pleased (audio interference) are used by the NRC, the industry, academia, and the international community to understand advances in technologies and support regulatory decisionmaking.

The NRC uses codes to support the development of an independent technical basis, along with any needed analysis, to confirm the safety of nuclear power plants, fuel cycle facilities, spent fuel storage and transportation packages, new applications, and amendment requests.

The staff collaborates with both domestic and international partners to leverage resources and ensure our computer codes are ready for the different types of technologies.

Next slide. For today's agenda, I will start off by giving you a quick overview of the Code Investment Plan. Then Kenneth Armstrong, the Chief of the Code and Reactor Analysis Branch, will discuss what we observed by looking across the agency's computer codes. He will also discuss the investment categories, resources considerations, and the process we used to obtain input from our computer code leads.

Matt Bernard, a code developer in our Division, will take a deeper dive in how we're planning work for the agency's thermal hydraulic computer code, TRACE. He will also describe future considerations and where we are likely headed with our computer codes.

Antony Calvo, an IT Specialist, will discuss our high-performance computing strategy, along with some concluding remarks.

So, why are we doing this? In 2019, as

part of the fiscal year 2021 budget review, the Commission requested a long-term investment plan to ensure the NRC inventory of computer codes were appropriately resourced.

In response, the staff developed this Code Investment Plan. It was a new process for research, and the staff embarked on a comprehensive review on identification of long-term needs for our codes. Although Research has the lead for the Code Investment Plan, the staff closely coordinated with the different program offices to ensure our priorities are aligned.

As a result of these efforts, we now have an integrated management tool for the NRC codes. Having the Code Investment Plan has facilitated our budget formulation process significantly. Therefore, this is helping us to have the necessary resources to maintain and modernize our codes and meet the agency's long-term goals.

Also, since the Code Investment Plan covers a seven-year period, it will help us to plan ahead and identify the staff expertise requirements for the long term. This plan is a living document with formal updates every year. And this is our second year formally using the investment strategy, and we expect to continue to refine this process over the coming years, as we gain experience using it.

I will now turn the presentation over to Kenneth Armstrong to go into more details about the Code Investment Plan.

Thank you.

MR. ARMSTRONG: Thanks, Cinthya.

And good morning, ACRS Members.

Again, I'm a Branch Chief over here, over in Research, and I'm here today to share with you some observations that we have looking across our suite of scientific computer codes.

With the breadth of the codes mission in this presentation, I'm going to try to give you an overview, and then, we'll take some deeper dives with Matt into TRACE and Antony into some of the high-performance computing platforms that we commonly utilize.

In putting this plan together, we found that each code has its own unique circumstances. However, we can make some general observations about the information collected from our code development leads.

Next slide, please.

The scope of this plan focuses on NRC's scientific codes, which are often used to perform a confirmatory analysis. The plan does not account for commercial, off-the-shelf products, such as Microsoft products and some of the Ansys tools that we commonly use across the agency. This is only going to concentrate on the codes that we either develop or co-develop with other entities.

For COTS software packages, the software vendors perform the maintenance and updates of these software packages when the agency purchases those through licenses. So, we don't, generally, have to worry about the development of those particular packages.

RES surveyed the NRC offices and identified 40 scientific codes which the agency was supporting for current and future development activities, pictured here in the table. Most of these codes are led by Research, but several fall under NMSS.

The table shown on this slide groups these codes by technical analysis area. These range from complex, integrated codes with close to a million lines of text that often take days or weeks to run to much simpler ones that run in seconds.

I'm going to try to expand on these bullets throughout my presentation. But, in summary, we found 15 of the codes are not expected to support near-term decisionmaking activities, but may be needed in the future. These codes are minimally maintained and placed in an archival status.

Twenty-five of the codes require ongoing investments to support expected regulatory decisionmaking. These codes require continual maintenance and development and represent the current pace of advancements made by industry. Three codes are currently undergoing code modernization and eight codes are being consolidated into three in the irradiation protection area.

Most of these codes are also supported by code-sharing programs, where resources provided by the participants assist the NRC in development, assessment, and training activities. We also share codes with domestic users and other federal agencies, like the DOE and DOE labs.

Next slide, please.

Yes, sir?

MEMBER BROWN: Since some of your codes take -- what, days or weeks? -- I've forgotten the actual timeframe you referred to. I'm asking how long the codes took?

I didn't get close enough to my mic;

didn't follow our own rules.

Days or weeks? And I was just curious, what platforms do you use? I mean, do you just use PC-type stuff? We don't have any high-level computing devices?

MR. ARMSTRONG: We do. I don't want to take too much of Antony's thunder later in the presentation about --

MEMBER BROWN: Oh, okay. Then, I'll wait. That's fine. I'll just hold off. Just go ahead and finish.

MR. ARMSTRONG: The answer is "all the above."

MEMBER BROWN: Okay.

MR. ARMSTRONG: So, we do have expanded capabilities past our normal --

MEMBER BROWN: Okay. I'll wait on those questions until later.

MR. ARMSTRONG: Perfect. Thank you.

Okay. Next slide.

By collecting data across the agency's suite of computer codes, we can profile and bin these codes into various categories.

The first chart depicts the agency's lead organizations for code development. Research leads most of the scientific codes developed by the agency. However, some are developed by NMSS. Many of these codes are currently in an archival status, awaiting long-term disposal for spent nuclear fuel.

The second chart shows that most of the codes are supported by the operating, new, and advanced reactor business lines since that's, basically, who's paying for the codes. We coordinate these closely with NRR.

The other codes depicted on the other two pie slices here are what we coordinate closely with NMSS.

The third chart indicates the majority of our scientific codes receive external funding through code-sharing programs. I have a slide on this next, but this includes most of the larger and more frequently used codes.

MEMBER MARCH-LEUBA: Yes, do you coordinate with the DOE RSICC, R-S-I-C-C? Because one thing I see missing here is the Monte Carlo, and SCALE has a Monte Carlo code.

MR. ARMSTRONG: You got it. So, the code set are in RSICC. We don't pay to maintain. We pay through -- actually, Matt is the COR for this. So, we do pay a yearly contract or we do support a yearly contract to RSICC that helps us with code distributions.

Those codes that are transferred to RSICC generally don't make the NRC's list because they aren't codes that we are maintaining and developing. But they are on RSICC's list and we do support that.

MEMBER MARCH-LEUBA: So, things like MCNP is regularly used by applicants and often by --

MR. BERNARD: Yes. Right. So, for staff and analysts who rely on those codes, they would request the code from RSICC. In the case of the Code Investment Plan, though, we don't capture the investments put into those codes by the labs.

MEMBER MARCH-LEUBA: But you're considering -- I mean, this presentation is money?

MR. BERNARD: Well, it's related to money and planning for code development.

MEMBER MARCH-LEUBA: So, as long as it's NRC, DOE takes care of it?

MR. BERNARD: MCNP is the prime example. That is the DOE-led code. And so, while we use the code and didn't have to pay for the code license, we don't pay directly for development usually. And so, we don't capture that directly in the plan right now.

MEMBER MARCH-LEUBA: The important thing

is you have not forgotten about it?

MR. BERNARD: That's right. No, we recognize that the DOE codes are critical to our success.

MR. ARMSTRONG: Yes, great question. There's other codes out there --

MEMBER MARCH-LEUBA: Is SCALE an NRC -- yes, NRC pays for SCALE?

MR. ARMSTRONG: You got it. It's on our list. We do pay the development. Actually, Oak Ridge pays to develop that as well.

MEMBER MARCH-LEUBA: Matt, say your name.

MR. BERNARD: Sorry about that. Yes, this is Matt Bernard. I had stepped in to supplement the answer.

Thank you.

MR. ARMSTRONG: Okay. Next slide.

Some NRC code investment resource requirements are supported by international programs. For example, the Code Application and Maintenance Program, the severe accident and research programs, these are in radiation protection computer code analysis and maintenance, this program grant, and helps foster and formalize cost-sharing arrangements.

CAMP membership contributions support

periodic user meetings, training, and related code support; participation in external programs to validate the codes, and support requests from domestic and international users for changes to codes beyond those supported by the NRC.

CAMP includes codes such as TRACE and PARCS for thermal hydraulics and neutronics analysis. CSARP includes codes such as MELCOR and MACCS for severe accident, source term, and consequence analysis. And RAMP includes a plethora of radiation protection codes. Some examples would be RASCAL, VARSKIN, and RESRAD. Other codes, such as FAST, FAVPRO, SNAP, SCALE, and xLPR, have other cooperative arrangements.

Finally, we also leverage codes from other organizations, like the DOE, EPA, and EPRI. In particular, codes from the DOE's Advanced Model and Simulation Program are expected to be utilized by the NRC for advanced non-LWR analysis.

Next slide, please.

The Computer Code Investment Plan provides a proactive approach for identifying funding over a seven-year timeframe. For active computer codes, major resource investments are depicted in this pyramid.

And looking at this from the ground up, first, we need to maintain our computer codes to ensure usability and distribute updated version to the user. We do this by fixing bugs identified by the user group and making sure that we are ready for the latest operating system and IT security requirements.

We have two maintenance categories defined in the Code Investment Plan: minimal maintenance and active maintenance.

Codes which are not actively used and are not projected to be needed for the regulatory decisionmaking activities within the next seven years, but may be needed later on, are placed in a long-term, minimal maintenance status to retain usability with nominal resource allocations.

Codes which are currently used to support regulatory decisionmaking activities undergo active maintenance to resolve issues; ensure stability/operability with the current operating systems; ensure IT security compliance, and improve IT architecture; portability, to improve performance in a cloud-based environment. The maintenance is performed on a continual basis and resources are captured in a budget each year to ensure usability of the codes.

Next, we develop these codes in line with regulatory drivers from industry and needs from the regulatory offices. Examples of this would be ensuring that we're able to model accident-tolerant fuel. These efforts continue to be closely aligned with NRC's licensing offices as future needs continue to evolve. We also enhance our codes through new features to improve analysis runtime and confidence in the models.

Finally, this approach allows us to plan large resource needs over time, like computer code modernization, where the code is fundamentally updated to take advantage of modern programming practices, and code consolidation, where multiple codes are combined.

Next slide.

MEMBER MARCH-LEUBA: Now, before you move on --

MR. ARMSTRONG: Yes, sir?

MEMBER MARCH-LEUBA: Now, often with codes, especially the ones you identify as not truly archival, but you don't plan to use in the next five years -- codes have a symbiotic relation between the code and the user, the trained user. Do you guys archive users, too, or --

MR. ARMSTRONG: That's a great question.

We do maintain points of contact for every code. So, when we go out on our annual review, we make sure somebody at least is going to raise their hand and say, "I'm responsible."

MEMBER MARCH-LEUBA: Yes, don't forget that. Because you have the FORTRAN lines of code you want, but if you don't know how to use it, it's useless.

MR. ARMSTRONG: That is a great comment. Thank you.

MEMBER BROWN: Question. We're now moving into the state with all these advanced reactors with some of the very unusual coolants to eliminate, you know, get rid of heat, as well as deliver power, is what they're doing. Most of the codes, at least in the time I've been on the Committee and we've listened to them for light water reactors in terms of thermal hydraulic and other type information, are very, very complex and comprehensive.

Have you all developed the ability to apply codes for the all these new configurations? Because we're getting information in the meetings from vendors, the applicants, but they're doing their analysis. And I just wonder, are you able to do the same level of validation for their analysis that you can do for the light water reactor? Yes? Or not at all? Or whatever?

(Laughter.)

MR. ARMSTRONG: That could probably be a presentation in and of itself. And we have, I think in the past, briefed you on some of our code development plans for non-LWR reactor analysis. So, I'll try to come up with the links for those.

But, for design basis space, we're heavily reliant upon NEAMS codes developed at the Department of --

MEMBER BROWN: I'm sorry, NEAMS code?

MR. ARMSTRONG: So, it's the Department of Energy's mod and sim program, where they have dedicated resources into it to advance codes such as Griffen for neutronics and SAM and Pronghorn for thermal fluids. And their goal for the development is primarily for non-LWR reactor analysis. So, we are following the development that they're doing there.

MEMBER BROWN: In some of these ones where we mix fuel with fluent, for instance, which is a whole new realm of distribution. And how do you know you've got a flat-tire profile, et cetera, et cetera? Or, if you don't care? I don't know the answer.

(Laughter.)

CHAIRMAN REMPE: Charlie, do you remember when we were briefed on the Code Action Plan? It was back during Dennis' time, and we wrote a letter about that, where there's like five volumes and it identifies the various tools they plan to use?

MEMBER BROWN: Are you asking me a question about --

CHAIRMAN REMPE: I was just asking, do you remember that? Uh-hum.

MEMBER BROWN: That was several years ago.

CHAIRMAN REMPE: Okay. So, anyway, I think that it would be worthwhile for you to go back and look at the letter and some of those documents.

The other thing, though, is they have reference plant evaluations, I've seen, with the MELCOR code, and it's been very helpful. And, in fact, we've used some of those insights in some of our evaluations that we're doing, or that the staff has been doing.

MR. ARMSTRONG: Perfect. Yes, MELCOR and SCALE have been developed to do exactly what you're talking about.

MEMBER BROWN: They're being adapted to --

MR. ARMSTRONG: They have. I know Hossein is in the back, if he wants to jump in.

But they have a Volume III planned for addressing accident scenarios. And I've forgotten -- MACCS. MACCS as well for consequence analysis. And Volume V in the volumes is front and back end of the fuel cycle.

We are developing our own tools. We are paying attention to what the DOE and industry are doing on this as far as their concerns.

MEMBER KIRCHNER: And while we've interrupted you, there's a prompt on this pyramid, "Code Consolidation." Can you just give us, in summary -- one of our recommendations two years running or over the course of many years, I guess, but two reports running, was in DSA to consolidate rad protection codes. Could you elaborate a little more on what's been done going from eight to three?

MR. ARMSTRONG: Yes, I have a slide on that.

MEMBER KIRCHNER: Or is that coming in a --

MR. ARMSTRONG: I have a slide on that, actually.

MEMBER KIRCHNER: Okay.

MR. ARMSTRONG: Thank you.

MEMBER KIRCHNER: Okay, I'll wait.

MR. ARMSTRONG: I won't keep you waiting too long.

Okay. Next slide, please.

Collecting information from our code development leads, vetting that information into various investment categories, we can collectively look at our code investments.

As shown previously, at the base of that pyramid, maintaining our codes and developing them towards regulatory drivers dominate the funding requirements. And you see that in the blue and the orange. I took, basically, a year and I looked at where the funding was headed in that given year.

Modernization and consolidation are generally significant efforts for those individual codes. But when you look at them collectively, they're only benefitting a few codes at a time. So, they're smaller pieces of the pie, although they are significant resource investments in those particular codes.

MEMBER BIER: And can I interrupt for a minute?

I'm trying to understand what "maintenance" really means compared to some of these other things. I mean, bug fixes, obviously, are part of it. But, like if you need to adapt to a new plant form, is that modernization or is that maintenance? You know, what comes under "maintenance" really, since it's such a big chunk?

MR. ARMSTRONG: Can we go back one slide?

That's a great question. And some of these, you know, when you talk to the code development leads, there's not a clean line that defines that. And where we group things, you know, is to help us in financial budget space to be able to justify.

So, typically, I view maintenance as keeping the codes -- doing distributions, fixing bugs. You know, a code like TRACE, we have a lot of analysts out there running them. And bug reports can be significant, as Matt knows. So, that is a significant resource, just keeping the code running; looking for areas to improve it lightly, not talking about a full modernization where you're, fundamentally, rewriting the code.

Does that help? We have some definitions in the Code Investment Plan, and we sent this out. This is now publicly available and we sent it out ahead of this meeting.

But think of keeping it running, your day-to-day work, annual resource requirements, training. So, obviously, we want to develop training tools that keep our newer staff members, that can help get them ready.

In codes like TRACE, MELCOR, and MACCS, we have international distribution programs, and we sponsor some training for them, as well as workshops.

So, that's all -- we characterize all that into maintenance package.

MEMBER BIER: So, another way to think about it might be it's not just like, quote-unquote, "repairs," but, also, just like normal operation of everything the group does, kind of?

MR. ARMSTRONG: Kind of what you just said, it kind of gets you into what we classify as new feature development as well. And that's when you're trying to take more applicability for a given code, or maybe I'm trying to better utilize it in a cloud-based environment, which Antony will talk about to you later.

But it's a good question, and the semantics -- you know, we try to talk with the code development leads and we try to group the stuff appropriately, but there's a big gray area between a lot of the Divisions.

Did I miss anything, Matt?

MR. BERNARD: No, I think that was good.

MR. ARMSTRONG: Okay. So, okay, yes, perfect. There we are.

Okay. As shown on the prior slide, code developments are significant code investment drivers -- I'm sorry. As shown on the prior slide, code developments are significant code investment drivers, and when looking across the codes, the majority of our current developments are focused here in the agency for accident power fuel, increased fuel burnup and enrichment, as well as preparing the agency to evaluate non-light water reactors and small modular reactor designs.

Here's a few notes on new feature development which I know you has asked about. New feature developments are, generally, much smaller resource-wise. And most of these resources go towards improving the code's robustness, enhancing uncertainty analysis capabilities.

As Matt and Antony will discuss later, we are also increasing the ability of our codes to communicate with one another and better utilize cloud-based computing environments.

MEMBER BIER: So, again, before you leave this slide -- if you can go back to it? There we go.

Again, I was thinking, when I saw preview slide, what are these? It sounds like state-of-practice; it kind of advances to the science. Like we need, you know, a new method for analyzing whatever, accident-tolerant fuel, or something. Whereas, new feature developments are more kind of on the computer science side, like what computational tools and rehab that weren't there before. Is that a fair description or --

MR. BERNARD: Yes, this is Matt Bernard.

Yes, that's definitely one of the categories in new feature development. They can also be slightly more overlooking, not necessarily driven by an immediate regulatory need. And so, they can include new physics, but they tend to be smaller and targeted features, as opposed to significant reactors.

MEMBER BIER: Thank you.

MR. ARMSTRONG: And another distinction would be, typically, state-of-practice developments are something that we're coordinating closely through the user need requests with the regulatory arms of the agency. New features are, generally, improvements that we're letting the regulatory arm know that we're doing, but, you know, they are progressions for the code that are much smaller, and typically, are not as documented as, say, these larger investments.

Next slide, please.

Okay. Code modernization is important for actively maintained scientific codes to ensure long-term stability. Code modernization efforts involve modifying, rewriting the fundamental code structure to incorporate new capabilities; address obsolescence issues; reduce analysis runtime, and for interoperability with other codes, and adhere to modern software development best practices.

One of the Code Investment Plan's largest benefits is the ability to plan out larger investments, like code modernization over time. Because it can be inefficient to start and stop things, based on a given factor.

As you can see by this slide, we expect to complete some rather large modernization efforts over the next five years. Somehow, this came out to about one per year. I'm not too sure how that came out, but that's for planning right now.

The top three are under active modernization right now. The next two, we have plans for those in the future; have requests through our partners.

And then, for TRACE and PARCS, we're

brainstorming on what we can do for those codes right now. So, those are the next ones that are to be evaluated. It looks like Matt and others are helping us brainstorm what's the next step that we can take for those particular codes.

CHAIRMAN REMPE: I think we've commented in our letter how we think it's great to be taking this longer-term outlook. And I heard you mention about justifying the budget. This has been going on for a while. Since we're in 2023, has your justification been successful and you get the budget you want for it?

MR. ARMSTRONG: It has.

CHAIRMAN REMPE: That's great.

MR. ARMSTRONG: So, generally speaking and overall, I think we've done a much better job of getting the base maintenance, any state-of-practice developments, and modernization efforts into our base request, as far as the budget is concerned. And that, to me, is the biggest benefit of the Code Investment Plan, is being able to make sure that we're not running around looking for midyear funding; that we're able to get the base amount of funding into the budget for these codes.

There can be urgent needs during a given financial year, and those will come. And we have ways of asking for that funding. But I think, as long as we're taking this long-term view, we have the right tools in place now to be able to get the majority of what we want to do for our base budget.

CHAIRMAN REMPE: Thank you.

MEMBER BIER: It's been a really long time since I've looked at SAPHIRE. The last time I did, it was pretty clunky and, like, functional, but very bare-bones compared to some of the industry-developed codes.

Can you hit, like, a few of the high points of what's planning in the SAPHIRE modernization?

MR. ARMSTRONG: I know it's in the documentation. That's a little bit outside my area.

CHAIRMAN REMPE: Well, actually, we also have these comprehensive briefings, and that's a better time to do this --

MEMBER BIER: Thank you. Fine.

CHAIRMAN REMPE: -- because of the time limitations today. So, I think that that's -- I'm going to rule out of scope on this.

MEMBER BIER: Yes.

CHAIRMAN REMPE: I mean, I ask you to

divert. Thank you.

MR. ARMSTRONG: Perfect.

Just to note that there is a general description here, but if you want more --

Okay. Next slide, please.

I know this was raised earlier. So, this is a slide on code consolidation. Code consolidation efforts improve the NRC's efficiency by reducing the number of individual codes maintained for a fewer number of codes that provide expanded capabilities.

Consolidation of similar codes can provide the following benefits:

Reduce functional redundancy between the codes.

Reduce overall code life-cycle development, maintenance, and distribution costs.

Standardize code programming.

Improve quality assurance.

And streamline analysis.

The efforts listed on this slide are all in the radiation protection area, where we have a number of smaller codes across various contractors and users that are ever trying to consolidate.

Next.

I'm sorry, do you want to go into more

detail here?

MEMBER KIRCHNER: No, this is exactly what I wanted to see.

MR. ARMSTRONG: Okay.

MEMBER HALNON: So, just a question. Do these timelines include the update of the NUREG or Reg Guide, or whatever user guide is out there for them?

MR. ARMSTRONG: I believe they do.

John, would you? So, would the consolidation of these codes include the user guidance and some of the --

MR. TOMON: Yes, this is John Tomon from the Radiation Protection Branch.

They're mostly my codes. They are all of my codes.

And first, we're, actually, like three-quarters to 90 percent of the way through the atmospheric ones. And in the same time, as we've done it, we've done verification, validation, and the user guide. And we've presented all of them to the program office, NRR, to evaluate, not only the code, but the user guide as well, because it has a new interface, as well as some of the new theory behind, you know, little bit different from the old ARCON, PAVON, and XOQDOQ codes.

MEMBER HALNON: You mean, to the timeline, fiscal year 2026 will be the end of the project and that includes all the necessary documentation as well, correct?

MR. TOMON: Yes, that's the plan.

MEMBER HALNON: Okay. That was the question. Thank you.

CHAIRMAN REMPE: So, while we have you at the mic, too, when we used to make those recommendations about validation, there was always pushback about, well, the individual users won't be so happy. Are the users doing okay about that you've consolidated this?

MR. TOMON: Yes and no.

CHAIRMAN REMPE: Okay.

MR. TOMON: You know, there's always hesitancies to change. They see the benefits, a lot of the benefits of what we're doing in what they've seen so far, at least the meteorologists have. But some of their hesitation lies in, okay, well, we have all this now, but we have to make sure the Regulatory Guides catch up with it, because the Regulatory Guides in some of these cases for ARCON, PAVON, and XOQDOQ haven't been rewritten since the 1970s.

So, they want to make sure we do that at the same time. And so, we're trying to figure out how we can get their time and our time to align, so that we can do that at the same time. But that's really been most of the hesitancy with this.

CHAIRMAN REMPE: Thank you.

MR. TOMON: Yes.

MR. ARMSTRONG: Okay. Next, I'm going to turn my presentation over to Matt Bernard, who's going to discuss the investment process; give an example what input looks like for a code like TRACE, and discuss where we're going across the agency's suite of computer codes in the future.

MR. BERNARD: Thank you, Kenneth.

My name is Matt Bernard and I work alongside Kenneth in the Division of Systems Analysis as a TRACE code developer. And so, today, I'm going to take you through how the Code Investment Plan applies to TRACE specifically, but also make a few comments about how many of our codes are adapting with this new plan.

So, the code investment process, functionally, begins in the summer prior to budget formulation. And so, within that process, the series of steps shown here on the left takes the code development leads from the initial stages of justifying the need for their codes. And for most NRC codes, their applications are very long-lived. And so, it's not an involved process, but just recognizing is there still an ongoing need for analysis tools in this area.

Following the justification of a need for that code, code leads are expected to, then, survey options, both within the NRC and externally, to see if there are comparable features or if there are ways in which the NRC code leads can leverage external packages to further improve their codes or to make user code improvements more efficient.

Once that survey is completed, the code leads identify maintenance and development needs -- maintenance and distribution needs for their codes. And this can be simple as simple bug fixes or more significant changes to the code.

Then, identifying development needs, and in this area, speaking, specifically, about new feature developments within state-of-practice development, and then, forecasting out for larger modernization efforts.

And then, finally, collecting all of that information, and then, loading that within the resource planning through the intake process. And that's done through this code intake chart, shown here on the right.

So, we now look at how this code investment chart is directly applied to TRACE specifically, and we can see that there is a lot of information here and it's extremely dense -- probably not the best use of a presentation slide, but it does really help in making the decisionmakers who are formulating budgets aware of what's going on with the code.

So, if we, then, strip away all of that information, and we step through how each section is directly applied, we can see that it really does provide a concise view of all of the codes. And so now, we step through and discuss the description of the current state. So, this is just a statement of what the code or technical area is within the code investment process.

Some codes, like TRACE, are long-lived, very large codes. And so, they don't need to have annual refreshers over what the feature is, but for codes that are more targeted, where they don't have a large budget, there can be a need to kind of refresh. The budget formulation needs to know what's going on.

So, for TRACE, TRACE is the NRC's thermal hydraulic analysis tool and has been in some form for about 40 years. The code is largely developed with FORTRAN 95 and 2003 features. We work to maintain the code at a state-of-practice, so adapting the code for any ongoing development needs. And we have the ability to couple directly to PARCS in order to perform many coupled thermal hydraulic, neutronic analysis.

MEMBER KIRCHNER: Matt, a minor correction. I was here in the front of the ACRS as part of the TRAC development team -- 45 years.

MR. BERNARD: Oh, my gosh.

(Laughter.)

MEMBER KIRCHNER: And I'm shocked that you're finding bugs in it.

(Laughter.)

CHAIRMAN REMPE: You were only five when you wrote it.

(Laughter.)

CHAIRMAN REMPE: Go ahead. Sorry.

MR. BERNARD: No, it's fine. No, I mean, I always love hearing about the history because it's definitely something which has been around for longer than I have. So, I try to understand, you know, the reason why some of these exist.

And so, then, with that description of the current state, then we actually move into moving through that intake process. And so, then, we get into justification for the need. And so, that's in this box the description of the activities that the code supports.

And so, again, for TRACE, the major driver for ongoing analysis is in the area of ATF, high burnup enrichment and the review of small modular reactors.

Secondarily, we keep the code ready to perform license amendment requests for light water reactors, and then, provide support for TRACE, in order to, like, we can supplement analysis capabilities within the non-light water reactor designs.

So, as Kenneth mentioned, we plan on utilizing or exploring the utilization of the DOE tools; specifically, the BlueCRAB code framework, but TRACE does perform a supporting role in doing some of the secondary-side analysis of some of these reactor designs. And so, ensuring that the code is ready in that area is important.

If we, then, move up the chart into the DOE requirements, this is where we get into identifying the code development, maintenance, and future needs. So, for TRACE, as TRACE is a living code supporting our ongoing licensing needs, TRACE requires ongoing maintenance.

And this is because the models which are being developed are continuously evolving. And often, evolution means becoming more details in their description of the planned models. And so, this pushes the code into areas where we weren't necessarily validating originally because of just limitations in the computer hardware.

But, then, accounting for that ongoing maintenance, then, we also need to implement new features. And so, we require some development, specifically, in the area of material additions and to support the ATF and high burnup needs; and also, preparing the code for additional small modular reactor designs, and then, potential new submittals of the existing designs which are already approved.

And then, finally, just more forward-looking, recognizing that TRACE is still evolving and still having features implemented which are outside of the direct state-of-practice development. And so, some of those, I'm actually the code lead on. And so, capturing those additional needs for better models to improve code uncertainty or improve the validation of the code.

Then, moving over into deliverables, this is really to begin to, additionally, justify the need for the code. And so, one of the areas that the regulatory arm of the NRC has requested from the TRACE development is that we develop and release assessed versions on a more regular basis. And so, this is an area where TRACE has evolved to become more responsive to our customers.

And so, in the past, we released major versions, which we call patches, based on some major feature limitation, not necessarily on a schedule. And so, we have moved into releasing major versions, major assessed versions of the code on a yearly basis.

And so, you can see here the projection of the next four years, five years of TRACE -- major patch releases, culminating with a potential release of TRACE Version 6. But, as this is a planning document, the Version 6 is something which is still being discussed.

And then, in the top here, we kind of see the proverbial stick within the code process, which is the impact of not resourcing the code appropriately. And so, like most NRC codes, the TRACE code, specifically, is a living code, but always remains functional. And so, really, the impact of not resourced is that we begin to really see deficits in our future and fail to maintain our code at state-of-practice for whatever new, potential submittals we're receiving.

And so, it really begins to insert, as time goes on, uncertainty in the review process, which could, ultimately, culminate in TRACE not being applicable to some applicant's design or feature at all, which would, then, require our regulatory staff to exclusively utilize the submittal's calculation, which will increase uncertainty in the review, and then, could potentially impact some of our schedules. And so, we don't really want to do that.

DR. BLEY: Excuse me. This is Dennis Bley.

And I apologize if you covered this. I missed the first one or two minutes of your presentation.

This is really interesting. I see that you're on Version 2 of this plan. I'm curious about when Version 1 was done and the evolution to Version 2, and things like that box you've just been talking about, the impact of not resourced. I suspect this showed up along the way because this became an important issue.

So, if you can explain a little bit about that, I'd appreciate it.

MR. ARMSTRONG: Sure. This is Kenneth Armstrong.

So, I'll touch a little bit about Version 1 versus Version 2. So, Version 1, we constructed not last summer, but the summer prior. And that helped inform FY24 budgeting. Last summer, we had what we call Version 2, and all the documentation helped inform FY25 formulation.

Some of the improvements that we made year over year, we talked about that a little bit earlier here in the discussion about common nomenclature between code investments. So, I'd say in the first version we weren't as clear in some of the definitions, and particularly, outlining the specific amount of resources that are going to one particular need versus another one.

So, some of the improvements that we've made in Version 2 are defining those resources a little bit better and breaking out the resources a little bit better as far as the maintenance and new feature development and state-of-practice development, particularly, the maintenance bins. That's probably one that we had shortcut a little bit in budget formulation in the past, and I think we did a pretty good job here in Version 2 of getting that properly spelled out, and getting as much of that maintenance, then, into the budget as possible. And I believe we were successful on that.

Some of the other improvements that we're looking at doing is bringing all this information. So, Matt's got a code investment chart up here. It lends itself to a dashboard sort of setting, particularly, on the financials.

DR. BLEY: Yes.

MR. ARMSTRONG: But you could think about the deliverables, too. So, in Research, we have an operating plan. So, those deliverables get, generally, they get put into an operating plan. The financials can be put into a dashboard, and that's where I can make some of the fancy charts that I made. I do that in Excel right now, but it can be done in probably a more powerful Access-based or Tableau, or something like that. That could be pretty neat.

So, year-over-year improvements. So, those are probably the few that I would highlight. I would say, in Version 2, we were probably even more successful with getting some of the priorities into the budget here, at least in our FY25 request.

DR. BLEY: Thanks. That's really helpful.

A little bit more, if I could. If you can say a little bit about the experience of the users and the people making the funding decisions with this and how they view this process. I find this really helpful. I haven't seen anything like it.

And the last question along that line is this is really clean for the single code I'm looking at. Do you have some kind of summary that lets the funding folks understand kind of the ranking across the different codes of the needs?

MR. ARMSTRONG: Yes, let me give that a try. So, you see Matt's summary sheet up here. We have one of these for each of our codes.

So, what this helps us do is, you know, when we're talking with NRR and NMSS -- it's a one-pager. So, we can share this with them, and then, discuss where we may be misaligned on state-of-practice needs or where we're heading in the future.

So, the utility in this sheet, you can get everything, at least in a summary view, on a page. You can get what's new and when, as far as the major deliverables go. You can look across all financial streams of where you're spending money and what you're doing with it, and get a brief outline of kind of where the code is.

So, if you are one of the business line leads over in NRR, you can ask for a bunch of these that may fit under your purview. For example, systems analysis, there's -- I'm venturing a guess here -- but half a dozen or so of these one-pagers that can fall under DSS over in NRR. So, it's a real easy, clean way to at least get that conversation started and see what's due when. So, that's helped us a lot.

Anything you want to add?

MR. BERNARD: Yes, I mean, maybe as a user of the chart and developing the investment chart, I think that there was definitely some growing pains in trying to make sure that you were concise. I don't know that we were prepared initially to fit all of TRACE in one chart. But I think, as time has -- you know, this is Version 2; this is the second year we have tried to exercise this plan -- we're definitely getting better.

And as I said, we are trying to be more responsive to the customers. And so, some of the feedback we get from these charts, we can directly implement both into development and future years of the chart.

So, as a user of the chart, it's definitely getting easier. And so, we --

CHAIRMAN REMPE: I'm going to also ask our consultants, as well as members, to realize that we're less than halfway -- or we're probably halfway through the presentation and we're over three-fifths of the way through the time. So, please hold the comments for a while to make sure we get through things and we'll have time at the end. Okay.

MR. ARMSTRONG: Okay. Thank you.

MR. BERNARD: And then, finally, all of that information has been collected into the resource requirements, where the code development leads break out all of these needs, requirements, and deliverables into how they support the different business lines.

For TRACE, because it is such a large code that is being used in so many different areas, that breakout is fairly large and complex.

But, ultimately, then, we then use -- we document the current year's budget, and then, we look forward five years to try to plan out where we're going to improve the code and support all of these different developments.

And so, the one note that I want to make here is that this financial input is done by the development piece. And so, not every item within this may initially be funded, and it's really just used as a planning tool to try to help inform the budget for future years.

So, as Kenneth said, we've done a much better job of documenting that and getting what we need when we need it. But I just wanted to note that the numbers that we insert here aren't necessarily permanent.

So, as I said, for TRACE, specifically, but, then, more generally across all of our codes, included in this plan, the new technologies which we are considering are definitely introducing in the need for significant change in our approach. And so, we recognize that from the code development leads that new nuclear technologies that are requiring us to modernize our approach to confirmatory analysis. And this is really spanning the whole process of code development.

So, our code development leads are integrating modern development tools to streamline their updates, improve their testing and validation. Some of our codes -- think of the more complex ones or the ones that are being used, intensively used for ATF and advanced reactors -- may require new physics models in order to be able to perform their confirmatory analysis, or even just to maintain the state-of-practice.

And then, finally, there's a recognition among the development leads that the breadth of these topics are so vast, that we may not be able to directly support all of these capabilities. And so, staff are recognizing that we can leverage the state-of-the-art capabilities developed at DOE in order to make our code improvements more efficient and more flexible in the future.

And so, based on that, then, I want to just highlight one area in which TRACE, specifically, is kind of satisfying all of these bets. So, I want to discuss just one specific new feature development entry.

So, as I mentioned, ATF and high burnup initiatives are really what's driving most of the improvements right now with TRACE. And within that initiative, there's a recognition that the plant models which are being developed are much more detailed than we originally used, requiring much more specification of individual fuel rod details in order to capture the effect of these new designs during the transients.

And then, secondarily, we recognize that TRACE also lacks some of the detailed models which may be important for analysis of these designs. And so, in order to make sure that TRACE is ready to support ATF analysis, what staff have developed is the form of explicit coupling, where TRACE is explicitly coupled to FAST using a series of scripts, where conditions are passed to TRACE at the beginning of transients, where FAST can, then, do steady-state execution to get realistic, precursor, initial conditions for TRACE. TRACE analyzes the transient, and then, important areas of the core can then be reinspected through TRACE, and fed into FAST to determine what the evolution of the fuel rods, individual fuel rods are within the transient.

But there's a limitation with this. The scripts which are developed by our staff are robust and capable of doing analysis now, but they require extensive knowledge of TRACE ASCII output, and that makes them brittle. Because if I, as a TRACE code developer, go in and change any one feature, that would have knock-down effects, which then breaks their scripts and impacts the overall timeline of the analysis. And so, that is definitely not ideal.

And then, also, explicit coupling of the transient may affect the prediction of that. Because TRACE doesn't have some of the models that FAST has, there might be differences in the way that the fuel behavior evolves between the codes, which may make us, potentially, miss some areas, some important areas of analysis.

And so, as a way to try to address this limitation, I am leading an effort to couple TRACE to FAST directly using the DOE code MOOSE. And so, MOOSE is the computational framework which underpins all of our advanced reactor tools. It provides a huge breadth of scientific capabilities from matrix solvers all the way through scientific codes that we're using for advanced reactors, like BISON and SAM.

But it also provides me, as a code developer, with a framework that is flexible enough to couple codes which aren't directly developed using MOOSE together to other codes. And so, I've been developing this coupling in order to simplify the NRC's overall analysis of methodology.

In doing this, our analysts can simply develop TRACE and FAST inputs, ignore the complexities of code output, and then, hopefully, be able to just have one single stream of analysis that yields useful results for regulatory activities.

And then, finally, maybe as a hope, we can, hopefully, with these more detailed models, improve the overall code predictions, although the validation of that prediction might be difficult, as the individual parameters which are being predicted may not be able to be validated on some tests.

So, to demonstrate this capability, what I was interested in was finding a test which was capable of exercising both TRACE and FAST for four conditions of interest. And so, the test which most naturally lends itself to testing this coupling capability was applying a coupled code to the LOFT tests operated at Idaho National Lab.

So, I'm sure all of you are aware LOFT was a test facility which mimicked a four-loop PWR. The LOFT itself aimed at two loops -- one broken loop, one intact loop -- and used nuclear fuel as a part of is experimental conditions.

The core design, shown here on the right, contains nine fuel assemblies, five rectangular and four triangular. And the important fuel parameters are shown here. But, importantly, the fuel used zirc cladding and was about 1.9 meters, and was, roughly, designed with the same parameters as what PWRs used at the time.

So, it's in here that I wanted to highlight this red box. The current coupling is limited to having FAST replace one modeled assembly from TRACE. And so, the overall comparison is useful for showing whether or not the capability can be applied to real reactor analysis.

But the final conclusions are difficult because of the interplay between replacing one single TRACE researcher component versus replacing everything in the core, and then, having the direct feedback of all the thermal hydraulic conditions. So, I just wanted to highlight that here.

And so, here is at least one snapshot of experimental data compared to the different codes for these frameworks. And so, shown here on this graph is a plot of the cladding temperature at 1.2 meters up the LOFT fuel rod at that coupled fuel location for this condition.

And so, we have a plot of temperature versus time. The red line with bullets is the experimental data. The black dashed line there is the TRACE Version 5.0 code, and the orange line is the coupled TRACE and FAST code.

So, again, we can't make final conclusions here, and some of the code behavior is affected by when this analysis was run. So, for TRACE standalone, some of the deficiencies in behavior are that the models which were selected for this model were used in the Version 5.0 assessment. Version 5.0 was released in 2008. And so, we have made a large number of strides in improving our fuel in models, but, as the purpose of this was to demonstrate the capability could be used, we directly used the Version 5 assessment. So, some of the deficiency and some of that behavior could be explained by feature selection.

But, for the TRACE-FAST coupling, the apparent, very precise, very accurate prediction could just be some compensating error, where, because TRACE-FAST is only modeling one single fuel assembly, the overall system behavior may not be as affected. And so, we can't draw firm conclusions, but the TRACE and FAST coupled code is able to very accurately predict both the peak clad temperature, as well as the transient leading to quench.

And so, the one comment to that is that the TRACE-FAST code is conservative, as far as quench time, and that has to do with the Tmin correlation used in TRACE as used for stainless steel, which predicts a lower Tmin and a later quench. So, it's conservative, but not necessarily the most accurate for this test for certain cladding.

But this prediction does show that the analysis, this analysis approach, could be used for real problems. And so, what we've demonstrated so far is that TRACE and FAST can be coupled together and be used on real reactor problems.

And so, moving forward, in the current fiscal year, what we want to do is to extend that coupling, so that an arbitrary number of FAST models can be used to replace TRACE key structures, so that we eventually map an arbitrary number of assemblies and fuel rods to a TRACE reactor core, and then, perform analysis based on that.

But this is an ongoing process. And so, this is a long-term goal that we want to apply. But it does show, as a final step, that leveraging these advanced reactor -- leveraging these state-of-the-art tools developed at DOE is something that maybe we can apply more generally to the entire agency, because they do appear to be very flexible in being able to potentially improve our analysis capabilities.

And so, with that, I wrap up how TRACE has fit within the Code Investment Plan.

And so, I want to pass it off now to my colleague, Antony Calvo, who's a Senior IT Specialist in the Division of Systems Analysis, and really ensures that resources that I need from an IT standpoint are available.

So, with that, Antony?

MEMBER MARCH-LEUBA: Before Antony, I guess the microphone, which you have turned green -- the beauty of the MOOSE approach is that it started doing power nuclear computing --

MR. BERNARD: Yes.

MEMBER MARCH-LEUBA: -- and you can take advantage of the cloud?

MR. BERNARD: Yes.

MEMBER MARCH-LEUBA: You must think about that in the future. Because I hear you are going to have a GPU with 112 volts.

MR. BERNARD: Right. Right. So, what is nice about applying the MOOSE approach to the TRACE-FAST coupling is that, once we extend beyond TRACE and FAST directly, we can assign every FAST fuel rod model to its own core. And so, we inherit, then, some of the parallelization, even if the individual codes TRACE and FAST aren't being used in a parallel sense.

MEMBER MARCH-LEUBA: Even when you get, like, factors of two, five, maybe even 10?

MR. BERNARD: I think that might be ambitious, but the fuel rod models in TRACE do utilize a significant amount of computational resources, but there's also the fluid side that is also very expensive. That's, right now, just being done serially.

MEMBER MARCH-LEUBA: I know it's done internally, but especially in BWRs, the channels are independent.

MR. BERNARD: But, yes, the independent channels might, hopefully, allow for a significant increase.

MEMBER MARCH-LEUBA: This goes back to the question of what hardware you're using it. Because the only way this is going to work (audio interference) a very tight nodalization is by run power.

MR. BERNARD: That's right.

MEMBER MARCH-LEUBA: We're limited. I mean, you have to wait two weeks when to run your (audio interference) then.

CHAIRMAN REMPE: I think the next presentation will talk about some of the capabilities.

So, let's let him have a chance.

MR. CALVO: So, good morning, everybody. My name is Antony Calvo. I work in the Division of Systems Analysis with Matt and Ken. And my role is really to ensure that Research has the high-performing resources needed to do the analytical tools and perform various types of analysis.

Next slide. So, I really want to kind of share with you a little bit about our hardware strategy, our high-performance computing strategy. I want to share with you a little bit where we were; where we currently are right now with our cloud computing environment, and then, kind of share with you all a little bit about where we want to go in the future.

So, before 2019, the Office of Research had about approximately 100-plus standalone high-performance computing systems that were currently in our environment. These devices did not have any approved configuration management plans or any sort of governance plans in order to manage these devices, which also made it very hard to manage these devices on an ongoing basis.

These devices were not in any sort of periodic, continuous monitoring state where IT security tasks could be implemented easily for an ongoing awareness of any new vulnerabilities or risks.

And you can probably guess, this caused some tremendous challenges around IT security compliance, managing outdated computers, which usually fell to many of the users, which really wasn't their role in an engineering capacity; and also ensuring that Research addressed any weaknesses and issues quickly to meet the Federal Information Security Management Act compliance that are known as FISMA.

So, in 2019, Research took on a plan to develop a plan and take a look at our existing computing environment to decrease our standalone high-performance computing systems in Research and looked at those devices that could easily be transitioned to the cloud.

So, at that time, we ended up working with the Office of the Chief Information Officer in developing a proof-of-concept to look at ways to migrate those devices to the cloud. At that time, we decided, in collaboration with OCIO, that the best solution at that time, looking at all the vendors that were currently out in the marketplace, was the Amazon Web Services GovCloud, which we have coined "RES GovCloud."

So, I also want to state that, with the onset of the COVID-19 pandemic, and the maximum mandatory work-at-home environment at that same time, the daily use and programmatic reliance on the RES GovCloud, which was no longer in a proof-of-concept -- it was completely operational at that time -- increased dramatically. And as a result of that, there was increased use by Research and NRR, and as well as NMSS.

I also want to state that RES GovCloud is essential for Research. It allows our staff to maintain, run, manage, and develop these codes in a very secure environment using virtual machines or instances, so that RES can review and perform confirmatory analysis to support our licensing activity -- all without the need for hardware.

But I want to also state that, over the course of time between 2019 and where we are right now, our footprint of these standalone high-performance computing systems are in the single digits now, because we have dramatically moved to the cloud, and it has been beneficial, not so much so -- and I think what precipitated all of that, I think, it's with the COVID-19 and the maximum work-at-home, people had to work at home. It was what was needed.

So, that kind of precipitated the whole use of the cloud.

Next slide.

So, I want to also kind of share with you a little bit about our strategy. As you could see, we have various users in Research. We have code developers, Matt being one. We have code analysts, and we also advanced reactor capability developers. So, all these individuals use different platforms, and many, as you can see, use the Amazon Web Services.

I also want to bring up at this point that we are exclusively using Amazon Web GovCloud. However, we are looking at other platforms right now to determine whether that other solutions can meet our need.

We also have another proof-of-concept ongoing right now with ICIO to look at Azure as a potential option. So, we're looking at it from an apples-to-apples perspective, and that's ongoing right now.

So, our whole goal, really, is to ensure that our users have the computational environment that is flexible, reliable, accessible, and secure.

So, I'm going to talk a little bit about the code developers and their need for custom hardware. Then, I'm going to talk about the code analysts, and then, the advanced reactor developers.

So, for our code developers to develop code using custom hardware, there's some very key beneficial reasons why this might happen.

And Matt can always chime in if there's any things I'm missing.

So, testing software on custom hardware is essential, that it allows our users to use various computing environments and allows them to do various -- the hardware allows them to use that environment appropriately.

There's greater control that is needed over the hardware components and configuration, enabling our developers to optimize code performance based on specific needs.

By testing on custom hardware, code developers can optimize their code to run more efficiently on a wider range of devices. And development of custom hardware provides our code developers with the ability to control the creation and distribution of executables that can be adapted and leveraged internationally through our various code programs, such as CAMP and CSARP.

So, I also want to state that, you know, AWS, as I alluded to earlier, not only are our code analysts using it, but everybody is using it to some degree. So, I also want to talk about the strengths of AWS.

One of the key strengths of AWS from our perspective is that it allows on-demand scalability based on need.

Flexibility to work from anywhere. As I had mentioned earlier, with the COVID-19, and we were all sent home, many of the users didn't have a lag in work because they were able to quickly spin up those instances and start using them.

So, as it is right now under AWS, we probably have approximately -- and I'll have to check the numbers later -- but it's approximately 110 to 140 users that are using at any one time.

MEMBER MARCH-LEUBA: Are those running the code or developing it?

MR. CALVO: They're mostly running the code right now.

MEMBER MARCH-LEUBA: The question I wanted to ask you is, if you are developing a new function, you need a compiler and debugger. Is that compatible with the cloud?

MR. BERNARD: Yes, it is.

This is Matt Bernard again.

MEMBER MARCH-LEUBA: You can run --

MR. BERNARD: So, we do have a development environment that does allow for direct code compilation on the cloud such --

MEMBER MARCH-LEUBA: You, basically, get a virtual machine?

MR. BERNARD: Yes, a true virtual machine that you can use. We have several developers who do use it periodically, but it's not usually the primary tool for code development.

MR. CALVO: And that's one of the reasons we're trying to do this new proof-of-concept with OCIO to look at Azure, to include a development environment that is robust and easy for developers such as Matt to use. So, that's something that we're trying to push hard on that.

MEMBER MARCH-LEUBA: Isn't it only code developed -- whenever you're running MELCOR or TRACE, it always runs at 122.5 seconds. So, you go back to the previous restart point, fire up the debugger, and see why it crashed. You need that capability even for the users.

MR. CALVO: Some of the other advantages with the cloud, and with AWS, in particular, is that you have access to some of the best technologies. You have the fastest CPUs. You have the fastest SSDs. You know, with the cloud, you can create your own environment. You can pick your CPU. You could pick how much space you're looking at, and just up an instance and have that ability.

And then, also, I want to bring up, all within the AWS environment are advanced security measures to protect our data and our code, such as secure firewall, encryption, multifactor authentication, and also, AWS is approved for use with export control information within the NRC.

So, for our advanced reactor capability developers, MacBook is essential for collaboration with the National Labs. For example, through the use of multiyear initiatives with INL, they provide NRC staff with support needed to use the Nuclear Energy Advanced Modeling and Simulation Program, the NEAMS, codes, such as Pronghorn, Griffin, BISON, Sockeye, and SAM, for the development of NRC's evaluation model for advanced non-light water designs.

So, in order to do that, that interconnection, and to remove the barriers, we ended up purchasing a limited amount of MacBook Pro devices for our advanced reactor capability developer team to interface with the Mac development environment at INL by creating a subnetwork called MacNET. And this allows us the ability to exchange computational computer codes to integrate their functionality. So, something that they're working with is -- and I'm working with Matt very closely -- to ensure for Matt and others to have that functionality in order to share those types of codes.

And one last example is regarding the DOE high-performance computing. In support of light water reactor-related activities using large sensitivity, uncertainty-type calculations at Oak Ridge National Lab, NRC staff have developed an approach using an authority to operate to gain access to Oak Ridge National Lab's high-performance computing environment that allows our staff the ability to have extremely high computational capabilities supercomputers in the area of 1,000 cores at a fraction of the cost that we would get with AWS.

So, our goals are really, No. 1, to maintain MacNET, so that advanced reactor capability developers in the agency can continue to develop DOE code interoperability capabilities. We want to maintain our cloud capabilities, and also, look for other options that would meet our needs. Develop models and perform scoping studies. And then, we want to extensively leverage the capabilities at the DOE Labs to analyze complete reactor system models and conduct uncertainty analysis.

MEMBER KIRCHNER: Tony or Matt, do you ever interact with the people who did what used to be called CASL at Oak Ridge? And they were running that on that ACCS Network.

CHAIRMAN REMPE: CASL was subsumed into the DOE MOOSE. It's subsumed and they don't exist anymore, is my understanding.

MR. CALVO: The CASL program is now a component within the larger NEAMS. And so, we do have staff who interact with the CASL group. We have NRC members who are part of the CTF User Group. And so, we do interact with them periodically, but we're not necessarily using their tools right now for the any analysis. But we are keeping track of where their capabilities are headed.

So, in conclusion, thank you for your time.

I want to say that the Code Investment Plan is a living document. As Ken had mentioned, and Matt, we're updating it annually, with most of our investment activity appendices in the back of the document. It is publically available. Here's the ML number.

The Code Investment Plan accounts for the scientific code needs and resource requirements enabling the NRC to continue to meet its safety and security mission, while also making the needed investment to be ready to regulate new and advanced technologies.

The Code Investment Plan works, No. 1, to provide the NRC with an integrated management tool for its scientific codes.

No. 1, it informs our budget formulations.

And three, it stabilizes scientific code annual resource requirements.

And four, identifies human capital, staff, and expertise requirements.

We want to thank you all very much for your time, and we have a couple of more minutes for some questions. And thank you again.

CHAIRMAN REMPE: Well, I have tried to make sure we made this time, and I may have cut some questions off. I have one, but do other members have any questions to bring?

(No response.)

CHAIRMAN REMPE: I appreciate that DOE is giving you great opportunity, but I always look for backup plans. How much of a risk would you be if something were to happen and Congress didn't give them the funding for some of those things? Have you of that concern?

MR. BERNARD: Well, I can speak specifically for the way that TRACE and FAST is progressing, and that, yes, we want to make sure that we don't over-leverage ourselves for any one capability or task.

And so, as I said, we can do ATF analysis right now using the scripts that our staff have developed. And so, we're really looking to use the DOE tools as a way to make us more efficient in the future. And so, it's not on the critical path, but it is something that, hopefully, will make us more agile.

CHAIRMAN REMPE: But, in your case, I actually wasn't as concerned because it sounds like it's just a framework with some good mathematical solvers, and surely, there are other ones out there you could have used.

But this thing with the Mac stuff that you were talking about, Antony, that's what I was wondering. What happens if that goes away? Because you, basically, are using a lot of the DOE systems with their development efforts. Is that going to be an issue?

MR. CALVO: I would say, well, we're primarily using the Macs to interact with INL and ANL and other DOE Labs for using the NEAMS base codes. If that need wasn't there, I think that those Macs would go into the -- actually, some of our developers could find other needs for them. But the primary goal for having this access is to be able to operate on a common platform that the developers, that the NEAMS developers are also utilizing.

So, if I'm reading your question correctly, if that need wasn't there --

CHAIRMAN REMPE: If the NEAMS codes would go away, what would you do?

MR. CALVO: Yes, this goes to, I think, one of the plans that we've presented to the ACRS in the past. And I don't know that I can speak with authority on that. I don't know if somebody else online can speak for how we would approach analyzing these plant designs if NEAMS zeroed-out this --

CHAIRMAN REMPE: Yes, again, I mean, it sounded like it was just even the tools, but it is, I guess, the tools and you're using that interface to deal with those tools. And I guess, if that were to happen -- again, you're using them for confirmative analysis -- the vendors will have to come up with something.

I guess I understand where it is at now. It sounded like a bit more that you were doing with it.

Thank you very much for coming and giving us this update. Again, I do understand that this is a living document and there will be future updates. And so, please do send us updated reports, as they come out. Because the one that we got yesterday was clearly a lot better than the one we had seen previously. And it would be good for us to be cognizant of it.

MR. CALVO: Sounds good. Thanks for letting us come today.

I think Dennis Bley --

CHAIRMAN REMPE: Dennis, yes, I see your hand up now.

Thank you very much.

Dennis, did you have a question?

DR. BLEY: Yes, I just wanted to thank them for this presentation and say, I was remembering back to the five volumes of the code plan for the Vision Program. And there was a lot of detail there that was really hard to kind of synthesize and see where we were. I think this is a great step forward.

CHAIRMAN REMPE: I agree.

And I know we had also recommended about having access to high-computing platforms. And so, the cloud stuff sounds really good, too.

I want to stop for a minute and offer the public stakeholders a chance to make comments.

If you're on a phone line, I guess you have to press *6. Otherwise, just unmute yourself on your computers.

Not hearing any, then I'm going to go off the record, and ask the court reporter to come back for a meeting that will start at 1:15.

(Whereupon, the above-entitled matter went off the record at 11:18 a.m. and resumed at 1:15 p.m.)

CHAIRMAN REMPE: It is now 1:15. So, we're back in session. And at this time, we're going to hear from X-energy about their plant design which uses a four pebble-bed gas-cooled reactors.

And I'm going to turn it over to Travis Chapman of X-energy.

MR. CHAPMAN: Good afternoon, everyone. I'm Travis Chapman from X-energy.

DR. BLEY: You need to put the mic really close.

MR. CHAPMAN: Really close?

DR. BLEY: There you go.

MR. CHAPMAN: Thank you. I appreciate the advice.

Thank you for having us here today. We're really grateful to introduce X-energy, the Xe-100 technology that we're discuss, as a company, and our first project funded under the Department of Energy's Advanced Reactor Demonstration Program, a four-unit demonstration with our partner Dow. And we'll discuss very briefly some particulars about that, but the focus today is certainly on the technology.

Ingrid, next slide.

CHAIRMAN REMPE: Travis, if I could just interrupt for a minute, this is our first interaction with you. And I just want to make sure that, although I gave some of these remarks at the beginning of our meeting, I think it's important to emphasize with new applicants that are coming through, even though you may be well aware of it, that, as you know, the ACRS was established by the Atomic Energy Act and it's governed by the Federal Advisory Committee Act.

And we issue our findings in public reports that are publically available, that are reports that provide the Commission independent advice on our reviews of the staff evaluations of the safety of proposed reactor facilities. It's required by the Atomic Energy Act that ACRS participate in reviews of these submittals of new licensees.

And as part of our review, we do consider not only the staff evaluations, but also the applications that are submitted to the NRC. And during this interaction, you'll hear members ask questions and sometimes offer their own opinions, but please be aware that those are just individual member opinions and our findings are documented in the letter reports.

And so, I just kind of think, with these new interactions, it's good to start off and kind of give some perspective on the groundrules, so that stakeholders from the public, as well as applicants, understand what's going on here. Okay?

MR. CHAPMAN: Appreciate that, Joy. Thank you so much.

Ingrid, if you could go to the next slide?

For our starting point, I want to do some introductions. So, I'm Travis Chapman, head of Licensing and Regulatory Affairs for X-energy. The last time I was in front of the ACRS was for

Generation III+ design and for the AP1000 COLA interactions when I was on the staff side. And since then, I've been involved in the advanced reactor side.

We've got with us Dr. Martin van Staden, Vice President of Engineering and Xe-100 Program Manager, and as well as one of the founding members of X-energy, to talk a little about our company's history with the background from PBMR, and Dr. Kyle Metzroth from MPR, but representing us here with X-energy today, who leads out our safety analysis efforts. We're going to talk about some of our licensing basis events.

He's also the lead for NEI 18-04 implementation. We look at that as a real challenge for us, is that we're one of the first to implement that methodology with the Advanced Non-Light Water PRA standard with all of its elements to it. I'll help lead up that effort and where it dovetails into the safety analysis side.

Thank you for having us. For our overview -- and thank you for the introduction, Joy -- what we're going to talk about today is the purpose that we have is to introduce you to X-energy.

We also have -- sorry, because I'm getting pointed this way -- from the X-energy staff side over here, Ingrid Nordby is going to be driving our presentation. She's one of our Project Managers and interface with Stephanie Devlin-Gill, our NRC Project Manager, as well as Mike Orenak here.

And then, whenever the subject of TRISO comes up, we're all going to look over at Ray Wang, who is the Manager of the Fuel System Design for X-energy on the reactor side of the house.

Our objective today is to introduce you to the company, to the technology for familiarity, with our development process leading into an ongoing series of engagements associated with our first project, as well as to discuss the licensing approach that we're taking for ARDP and how that will intersect with your oversight and advice activities.

We're going to talk about the technology and the company. We're going to talk about licensing. I'm going to shift over and Martin's going to describe the Xe-100 itself. We'll pick up for the safety design approach and some of our 18-04 implementation, and then, we'll close out the open portion of the meeting there.

In the closed portion of the meeting, we'll turn back over to Martin for a description of the Xe-100 structure, systems, and components. We tried to focus on the safety-significant elements that we think would generate discussion with you, as well as, in some cases, some construction and modularization aspects of the design.

We'll turn it over to Kyle for an overview of some licensing basis events; how we develop those LBEs; how we analyze them. We have a select set that we'll walk through some preliminary results for, so we can introduce the phenomena of interest, figures of merit, what we're analyzing for.

And then we'll close out with a discussion about our testing program, and specifically, the Helium Test Facility as a topic, and then, a little bit of an overview of some training program and simulator development.

Any questions on the agenda and the overview?

All right. Next slide, Ingrid. And one more. All right. So, X-energy is based here in Rockville. We're about one mile up the road where our headquarters is at, as well as a new facility in the Kings Farm area of Rockville.

The company was founded in 2009. As mentioned, a lot of pedigree that comes from the PBMR program and the technology development that was made there.

Right now, about three years into ARDP -- or excuse -- two and a half years into ARDP, we are over -- I think we're actually over 450 employees now. Every time I try to update the slide, I'm usually a couple behind.

An extensive number of PhDs, master's, folks from the National Labs, from new reactor companies, from construction experience, from Vogtle, Summer, other nuclear new builds, as well as a lot of non-nuclear talent that come out of other related industries. We look at our conventional island that we'll describe as commercial, off-the-shelf employment of steam components you would find at almost any other kind of power plant.

Most recently, I'd say the thing that we're known for is probably the Advanced Reactor Demonstration Program. We're one of the two demonstration projects selected by the Department of Energy in 2020 for a cost-share to deploy the first project, a four-unit planet. And we'll talk a little bit about the general details about that. And our aspiration is that that plant is in operation by the end of this decade. We do see that there is an achievable path to do that. We'll talk about certain of the technical elements of that.

The Xe-100, Martin will go into in more detail, but, for a general overview, a 200-megawatt, pebble-bed, helium gas-cooled reactor. Each unit in an electricity-generating configuration which is about 80 megawatts. We generally organize them into four-unit plants. We've found that to be an economically-attractive offering in the market. That produces 320 megawatts electric. For this particular project, we'll be demonstrating as a cogeneration plant to provide steam and electricity.

We don't require onsite or offsite power to perform any of the required safety functions. There's some safety-significant elements required, but no electric pumps, no electric blowers that are required for safety purposes.

And generally speaking, we would say a very simple plant compared to previous generations of reactors and the total numbers of systems, and the overall number of safety-significant systems in there.

We're fueled by TRISO-coated particle fuel in the form of a pebble. And Martin is going to have one that we can pass around here. In general, about 228,000 of those in the reactor at any given time.

Extensive testing and pedigree from the

Department of Energy's programs. We see Dr. Petti and others that work in those areas, as we've developed that program over decades of experience with the Department, and certainly, leverage a lot of that technology testing, development.

We have our own version of the TRISO-coated particle. We'll often refer to it as the TRISO-X particle or TRISO-X pebble. We have a facility in Oak Ridge, Tennessee that does that on a commercial scale of equipment as a pilot line. And we're expanding that in the form of Pellet TX-1, a commercial-scale facility that we can scale up the production for these reactors as we start deploying them.

Next slide. Of recent note, we had a change in the ARDP program that happened earlier this year. One of the aspirations, I guess I would say, from a commercial perspective, like other small modular reactors, we recognize it can increase electricity and sell to the various markets that are looking for it. We have a very flexible reactor that can load-follow. We'll discuss some of its particulars as we go on here.

But we've recognized that in the commercial industry there's a need for industrial application heat sources, energy sources, and the ability to provide industrial grade heat, superheated at capacity, would be significant to decarbonize the domestic industry, as well as internationally.

In 2022, we began some engagements with the Dow Chemical Company to look at what those opportunities might look like. Came into, as an early feasibility work that we did through 2022 into early 2023, and as we transitioned into 2023, the Department of Energy, X-energy, Dow agreed that they could join into the Advanced Reactor Demonstration Program as a subawardee, so that we could consider a project on the Gulf Coast for one of their facilities.

We look at this as kind of the future of small modular reactors in the advanced reactor communities, these kinds of projects going forward to work in these industries, decarbonize them, provide them the reliability and the energy sources that they are looking to do use.

Next slide. And speaking of ARDP, as an overview, in 2020, the Department announced the intention to have an award program for a cost-share to demonstrate two projects, to further develop several others, and then, some development awards of a lower tier.

We worked with several partners to come up with a proposal to say, "We think we can commercialize this technology in the window of time that ARDP was announced under, within the constraints of that program." Both got that proposal and were selected by the Department of Energy, along with TerraPower for their Natrium design, as a deployment and demonstration project.

So, under ARDP, X-energy has three main projects that we're running: the Xe-100 reactor technology program that Dr. van Staden leads; to develop, license, design, analyze the Xe-100 reactor, so that it is ready to deploy; the TRISO-X new facility in Oak Ridge, Tennessee, to produce the commercial quantities of TRISO fuel that we need for those reactors, and the ARDP Demonstration Reactor itself. A project at a site through a licensing pathway that achieves Class 103 Power Reactor Licenses for them.

As I mentioned, the project transitioned earlier this year -- in many ways, due to timing and need. Dow Chemical company was willing to step in and say, "We have a need for this energy. We're willing to partner with you for these steps, and let's look at what a project looks like to be deployed in the Gulf

Coast region."

The securing of that first customer commitment -- and we recognize that is an important step for any reactor, and certainly, in the advanced reactor community -- that this affirms our confidence that the technology is deployable in this period of time that we're looking at. And the funding match from the Department of Energy and the programs helps us to be able to do that and have these kinds of interactions.

CHAIRMAN REMPE: So, on the funding and the 50 percent, is it something where it has to occur simultaneously, or does DOE take a leader role and provides something upfront, and you just have to have something by the end of that process that's 50 percent?

MR. CHAPMAN: Sure. So, as we go along, all of the invoicing that we do for activities, we submit to the Department of Energy. They review it, and if it falls within the category of an allowable expense, they pay the 50 cents on the dollar from that. So, as we have progressed, we have done that.

The overall framing of the program began with the first couple of years being preapplication engagement, the construction permit development, the technology development analysis, supply chain development -- all of those activities. So, principally, an X-energy cost-share, and then, we'll eventually transition, as the project progresses, into a more construction-oriented activity.

Next slide.

DR. BLEY: This is Dennis Bley.

Is Dow asking -- I think you said this -- but is Dow asking you for a thermal supply, as well as an electrical supply? And if so, are you going to talk about that part of the design today.

MR. CHAPMAN: It is a cogeneration design. So, that's correct. There's both the steam supply and an electricity supply for their use case. We'll talk how we are capable of doing that. I don't think we're -- we're not discussing extensively the steam system and the layout for that. And I'm certain that that question is going to come up in the future for this particular project in its licensing package.

DR. BLEY: Sure. Thanks.

MR. CHAPMAN: You're welcome.

And then, leading into the technology discussion, we put together this viewgraph for many customers. Many of us have had experience in the light water technology, the deployment and the extensive maturation processes here in the United States. The high-temperature gas reactor community has a long pedigree. We've used these reactors in research facilities, test facilities, demonstration facilities, and commercially in the past. It has a long pedigree of use dating all the way back to Oak Ridge National Laboratory; deployments in the United Kingdom, and certainly, we have leveraged much of the experience base of graphite use in the AGR reactors there.

I would say that the bulk of the technical development occurred in Germany through the research and test reactor at ADR, testing a number of fuels, a number of design features, and many of the design principles that we follow for this design are based on the experience gained in ADR. To some extent, also, THTR had, while a shorter operating life, certainly many design lessons learned and operational lessons learned there as well.

And in the United States, Fort St. Vrain, we learned many lessons from that. We have that experience here in the United States, and we continue to see some of that experience in play with our spent fuel facility. We've gained many principles in how you store TRISO fuel for long periods of time and tons of configurations from that.

We leverage extensively the work done by NGNP, both from the TRISO fuel testing, graphite programs, as well as what I would say maybe is the best part of being an advanced reactor developer today is all the work in the regulatory matters to address things like how you select licensing basis events or the PRA in gaining risk insights; a risk-informed, performance-based manner of organizing your license application and the work that you do. How do you evaluate defense-in-depth in a holistic manner? The ASME codes. Basically, every element of the advanced reactor regulatory framework right now, I trace back in many ways to the work that was done during NGNP, and we want to leverage that, as we go forward.

With that, that's the introduction to X-energy. I'm going to turn it over Dr. van Staden to talk about the Xe-100.

Martin.

DR. VAN STADEN: Thanks, Travis.

And thank you, Joy and Committee, for having us here. It's a privilege for us to be here, and we are very excited to present this to you as well.

We can go to the next slide.

So, I think the heart of our design really starts off with the pebble fuel. I'll pass this around in a minute. This is a wooden flowerette. We didn't do a safety moment yet. So, let me take a minute to do one. Don't throw heavy objects around, but you can pass it around.

The fuel really allows us, as engineers, to think differently about how we design a nuclear reactor, the fact that our fuel is made up out of graphite as the container for the fuel TRISO-coated particles. And if we drill down, so if we look at the picture on the lefthand side, we have the cut-through section of a UCO fuel particle that shows the fuel kernel, which is the uranium content of the fuel.

And then, we have the next layer is a porous buffer layer that allows us to expand and absorb a lot of the nuclear fission products as they develop during the operational phase of the fuel.

And then, we have an inner pyrolytic carbon layer, a silicon carbon layer, and an outer pyrolytic carbon layer.

And those layered materials really are what provide us with these really small pressure vessels that can contain the pressure buildup in these particles during the life of the fuel, and provide us a very hardy structure that contains the fuel that is extremely temperature-resistant. All these materials have melting points of way above 2,000-3,000 degrees C, and obviously, graphite doesn't really melt; it sublimates. So, that allows us to think differently about things like decay heat and how we can remove heat from the core.

We can actually go to the next slide, please.

So, our reactor design was mentioned briefly by Travis. It's a proven pebble-bed reactor design. And I say, "proven," because we, actually, have about 25 to 30 years of operation, operational history, from the test reactors like the AVR, the THTR, and even some experience out of the HTR in China.

And really, the proven part there is how the core actually works; the fact that you can have a moveable fuel element where you randomly have pebbles that are packed together containing a cylindrical volume.

So that the image on the righthand side -- I'm sorry, for some reason, it's a motion that's not working. I don't know if we can click on it. It just shows the transport of the helium.

Ah, thank you, Ingrid.

So, the blue arrows there are showing the helium flow path from the circulators. We've got two circulators that move the helium through the reactor and steam generator. The outlet temperature of the circulator is about 250 degrees C.

The flow, then, goes through the reactor core, so up through the side reflector, which is a graphite side reflector, and then, through the pebble bed, which is a very good heat transfer mechanism, and heats the helium up to about 750 degrees C.

It, then, passes through our hot gas duct and into the steam general. We use a helical coil steam generator, and the steam is, then, generated by flowing water condensate up through the helical coil, and then, in a once-through steam generator, heating it to 565 degrees C and 16.5 MPa.

So, that gives us a really high-quality steam that allows us -- I'll get to the questions in a second -- to use high-efficiency turbo generator sets through which we can generate power. But it also allows us to operate and provide steam to probably about 80 percent of the process heat market. And that's a huge differentiator for our design that we purposely designed to, as part of our design envelope.

I have a question.

MEMBER MARCH-LEUBA: A couple of questions.

First, the control rod is going to the reflector --

DR. VAN STADEN: Correct.

MEMBER MARCH-LEUBA: -- through channels?

DR. VAN STADEN: We don't see very clearly, but back where the upward-flow arrows are, intermittently between the flow channels we, actually, have control rods. We have a total of nine control rods and nine shutdown rods, which are really very similar to each other.

MEMBER MARCH-LEUBA: I mean, it doesn't have to displace the pebble?

DR. VAN STADEN: It doesn't displace the pebble. Very important, that's a lesson learned from the THTR, where they, literally, when they scrammed, drove the pebbles right into the pebble bed.

And while we're on that topic, I'll mention, very briefly, what we did learn from that was that the structural integrity of the pebbles is, actually, not that important. Because even with the driving of these rods into the pebble bed, the rods had -- metal rods that had a cone at the bottom, which took the pebble and used the pebble as the nose to drive it through the core, but they ended up breaking a lot of pebbles in the THTR. But what was very interesting about that, the online monitoring of radionuclides did not spike during those events.

MEMBER MARCH-LEUBA: Now, the TRISO particles will be released as dust? They don't fly around?

DR. VAN STADEN: What we saw from that -- and we've actually got firsthand experience of one of our team members, Hans Chi, who was the operator that took that reactor through its first criticality, although the pebbles break, the TRISO-coated particles are extremely hard. These are silicon-coated particles, silicon-carbide-coated particles, and they're extremely hard. And Dr. Petti can probably also vouch for that.

And that allows you to maybe have, you could have coated particles in there. Our fuel-handling system will remove those, as part of operation. But the key there is that the pebble doesn't necessarily keep the fission products in there. There's small amounts of material that do get absorbed in the matrix of the graphite, but that doesn't necessarily get released, if you have any damage to the fuel.

MEMBER MARCH-LEUBA: So, I mean, this question is probably for Kyle. You have a total of 18 control rods, control rods/shutdown rods. If you reserve them all, is your (audio interference) big, small, medium? Certainly, you think you can handle it?

MR. CHAPMAN: Yes, we can handle it. We'll show some results in a little bit later on.

MEMBER MARCH-LEUBA: Are you talking 20 control rods, two control rods?

MR. CHAPMAN: It's not prompt-critical from my recollections.

MEMBER MARCH-LEUBA: All right. Yes, it's not a big axis we are creating?

MR. CHAPMAN: It's not, no. No, this is very low --

DR. VAN STADEN: Correct.

MEMBER MARCH-LEUBA: Okay. And the final question, and the one that I really want, any tube generators with the water inside are prone to density wave instabilities. Do you guys have a handle on that? Because that could be a serious problem.

DR. VAN STADEN: Yes, we've actually been very fortunate because our helical core bundle is almost a replica of the THTR steam bundle.

MEMBER MARCH-LEUBA: Uh-hum.

DR. VAN STADEN: And we have operational data from the THTR steam bundle. And we've been able to use that as a reference case for our analysis team to actually compare and validate some of the analyses that we are doing. So, we believe we've got a lot -- we've got margin there and understand --

MEMBER MARCH-LEUBA: Do you have a density wave methodology that can be used to experiment, and you do have experimental data?

DR. VAN STADEN: We're using actual operational data from THTR.

MEMBER MARCH-LEUBA: Uh-hum. Well --

DR. VAN STADEN: From the THTR reactor. The THTR actually had -- I think it's five steam generators -- 16 generators. So, they were spread around the reactor instead of one. And the single one of ours is about exactly the same size as --

MEMBER MARCH-LEUBA: And the same operating pressures and temperature?

DR. VAN STADEN: Correct.

MEMBER MARCH-LEUBA: That's good.

DR. VAN STADEN: The same tube diameter, the same inner and outer diameters as well.

MEMBER MARCH-LEUBA: That's a key parameter that will be very interesting.

DR. VAN STADEN: Yes.

MEMBER MARCH-LEUBA: So, if I can ask, what methods -- what code are you using to calculate?

DR. VAN STADEN: I'll hand it over to -- Kyle is going to do -- maybe you want to answer that when you go through the codes, the code.

MR. CHAPMAN: We have more discussion of the codes later on.

DR. VAN STADEN: Kyle discusses each of the codes.

CHAIRMAN REMPE: In the open session, do you want to talk about some improvements you've made to the pebble recirculation or handling system from what was in the THTR? Because I think that, when I was reading something, that there were some improvements, and I'm interested in that.

DR. VAN STADEN: Oh, yes. Yes. So, we were very fortunate. We're sitting with two of the key engineers that got taught by the German engineers that worked on THTR and on AVR. And they worked for BPMR. And they are our chief designer and chief system engineer for the fuel-handling system.

In South Africa, the premiere program also built a full-scale mockup of the fuel handling system, and we had a tremendous amount of lessons learned from that as well. And so, we've incorporated that, and we have got an extremely simplified version.

I've actually got a graphic, which is not in this deck, that compares something like the PBMR fuel-handling system to what we have today. And it's probably a tenth of the complexity in terms of number of pipes, number of valves, than what we had on the PBMR.

We, also, are going to cover -- I'm covering a small piece on the testing to show we are going to be building a helium test facility to test really the operational readiness of the helium, of the fuel-handling system. So, we can maybe cover that in a bit more detail when we get to that slide, if that's okay.

CHAIRMAN REMPE: Sure.

DR. BLEY: This is Dennis Bley.

You've decided you don't need or not to have an intermediate heat exchanger. Can you explain the logic?

DR. VAN STADEN: Well, we find we don't have -- we're using an 800H material for the steam generator tubes, which is very resilient to transfer of migration of fission products through that material.

Our tube wall thickness is, also, not what people are used to in the nuclear industry. If you compare -- I should have brought one of the samples here -- if you look at our tubes, they look more like gun barrels than they do tubes, because we've got a 4.5-millimeter wall thickness for the tubes. And that helps, obviously, with the retention of (audio interference) that could migrate right through the bundles. So, that's one of the main reasons -- we have so little that it's not feasible, really, to add, you know, an intermediate heat exchanger.

Does that answer the question? I hope so.

Okay. So, before we go with this slide, an important point there as well is that we use online refueling. So, when you look at the pebble bed -- I'm sorry, I don't have a pointer, so I can't point -- so, in the center of those arrows, we drop a fresh fuel pebble in. Pebbles take about six months to traverse from the top to the bottom. We have an auger at the bottom that removes pebbles.

And we do burnup measurements at the lower part, and then, the pebble gets immediately sent back to the top. If it's fully spent, it gets sent to a spent fuel canister. And if it hasn't been completely spent, it goes back into the core. On average, we pass a pebble through about six times before it's spent. And that really gives us a very high burnup, the ability to get a very high burnup and, also, have a low excess reactivity.

The last comment on this slide is really that, from day one, our team has also aimed to not venture into areas where we need to go to exotic materials. So, all the materials that we use in the core are covered by code cases. So, even the graphite, we have covered under the ASME Section III, Division 5. So, we've not ventured into the space, although it's a high-temperature reactor, where we are challenging any of the known material property boundaries.

MEMBER MARCH-LEUBA: Back to the excess reactivity, you have pebbles that have gone through 40 times, right? Is that --

DR. VAN STADEN: No, no, six times.

MEMBER MARCH-LEUBA: Six times?

DR. VAN STADEN: Yes, six times.

MEMBER MARCH-LEUBA: And it was fresh?

DR. VAN STADEN: Correct.

MEMBER MARCH-LEUBA: And you will be

mixing fresh balls and maybe graphite balls at the beginning?

DR. VAN STADEN: Correct.

MEMBER MARCH-LEUBA: And how do you make sure that you can get K-effective of 1? You measured it? You predicted it?

DR. VAN STADEN: So, we use codes -- first of all, a lot of experimental work was done by the Germans, as well as by the pebble-bed reactor teams of Africa. And during our pebble bed in South Africa, the worst core we had at that time, if I may admit, was dual-zone core where we had any graphite pebbles in the center and fuel pebbles on the outer annulus. And so, we did a lot of flow tests of pebbles to understand whether the pebbles mix, and et cetera.

And then, we also do a lot of what we call discrete element modeling today, where you model each and every pebble, the mechanics of them, shuffling through the core, dropping them in, looking at the random distributions.

And then, we've probably run a couple of years' worth of analysis, and we can really clearly show that, statistically, you get a general good mixture. And so, we've even taken some of these end results of these core models, so we can show which are first core, second -- first part, second part, et cetera. And we've done a couple C-of-D analyses at Argonne National Lab.

So, even if you have some grouping of, say, four or five ratio pebbles versus another grouping there of pebbles that have gone through a couple of times, we see very low, you know, temperature differences even within that. Because of the fact that the core has got such a strong negative temperature coefficient, even locally you'll see that, if you have a bit more reactivity in an area, the local temperature coefficient there will seem to moderate the reactivity directly in that area.

So, we don't see things like -- and I'm not sure if that's where you were on your way to -- hot spots or anything like that.

MEMBER MARCH-LEUBA: Unavailable reactivity axis.

DR. VAN STADEN: Yes. Okay.

MEMBER MARCH-LEUBA: You're trying to achieve K-effective 1.X?

DR. VAN STADEN: Yes.

MEMBER MARCH-LEUBA: -- by the mixture in your refueling, correct?

DR. VAN STADEN: Correct.

MEMBER MARCH-LEUBA: So, you will have six packets of pebble one that applies to that, fresh?

DR. VAN STADEN: Yes.

MEMBER MARCH-LEUBA: And you will dump one at a time, according to what you're measuring your K-effective is?

DR. VAN STADEN: Well, we're doing two things. First of all, when we remove the pebbles, we measure the amount of burnup, and that's the first point there where we make the decision to remove and replace with a fresh fuel pebble.

And then, we must realize, when you've got 220,000 pebbles in the core, adding one fresh pebble, there's a really small amount of excess reactivity you're putting in at a time.

MEMBER MARCH-LEUBA: You are in equilibrium.

DR. VAN STADEN: Yes.

MEMBER MARCH-LEUBA: From 20 years of operation, you can do that.

DR. VAN STADEN: Well, and we get equilibrium within the first year.

MEMBER MARCH-LEUBA: Within the first year?

DR. VAN STADEN: Correct.

MEMBER MARCH-LEUBA: How long does it take for a pebble to travel?

DR. VAN STADEN: About six months.

MEMBER MARCH-LEUBA: Six months? And on the second pass you are in equilibrium?

DR. VAN STADEN: No, no, no, no. It takes us just under a year to get to an equilibrium core. I mean, we don't discuss the startup regime here, but we use a variable approach to get to the first full power, where we use graphite pebbles, and then, we only start with some 4.95-enriched pebbles before we go to the LEU pebbles -- the HALEU pebbles.

So, it may be something we can discuss in the next --

MEMBER MARCH-LEUBA: We have plenty of time for you.

DR. VAN STADEN: Yes. Yes, definitely.

CHAIRMAN REMPE: Dennis, I see your hand up. Is this a holdover or did you have another question?

DR. BLEY: Sorry, it's left over.

CHAIRMAN REMPE: Go ahead, then.

DR. VAN STADEN: I think if there are no more questions on this slide, we can move to the next slide.

MEMBER KIRCHNER: I think you should tell everyone why you have down flow.

DR. VAN STADEN: And not up flow.

(Laughter.)

Well, you can actually do up and down flow, and we've investigated both. In fact, the AVR, which is the test reactor, had up flow. And they had the steam generator above the reactor, and that caused some problems. And we, obviously, learned our lessons from that as well.

But, fundamentally, we don't see whether you -- there's not really a big difference between up and down flow, but in a long core like this, you'll have lower fuel temperatures overall than when you have up flow, because your fresher fuel is in the top of the core.

We can go to -- oh, sorry, we're on the next slide.

So, what this slide depicts here is the segregation, really, of the nuclear island and the conventional island. So, we see on the lefthand side the nuclear island, marked blue, and then, the green part there being the conventional island.

Now, from day one, when we started with this design, we recognized from multiple STRIDE studies that we did that we're going to need to develop a reactor that is usable for both power and steam. And we wanted to ensure that we could either just provide steam to a process heat plant or power and steam, or just power.

And for that reason, we wanted to ensure a very clear segregation of the nuclear island, where we have nuclear safety-significant components and systems compared to a conventional island side, which we wanted to ensure had no safety-significant impact.

So, unfortunately, I don't have a pointer here. Ingrid, and then, if you can point to the nuclear island steam isolation valves in the most left box there?

So, our safety-related systems are all contained in that box. And those double -- you'll see two inline isolation valves are what isolate the nuclear side from the non-nuclear side.

The second box that we have, we can see some heat exchangers and a dump tank. That's really our startup and shutdown system, which can also provide a heat removal, a decay heat removal function. That is also on the nuclear island. It's not in the reactor building. It's in the nuclear island auxiliary building.

And so, we've segregated even our control system, because that's a very important part. We don't want any inputs and control variations on the conventional island to have to be monitored from the reactor side. So, we only need for our control system the temperature and pressure in the main steam line. So, if you have a conventional island that's got a turbine or a combined pressures heat plant, the reactor side doesn't see any difference. It sees a valve that opens and shuts for the turbine or for the process heat plant, and it will react to the pressure that feeds back into that line.

And obviously, on the common side, similarly, we measure the flows coming into the plant, and those are the indicators for the reactor control system and for the reactor protection system.

And so, you know, it's really, for us, a dream to have our first project be a combined process heat and power project, like we have now with Dow, because that really helps us demonstrate this versatility of the design.

And so, what you see on the conventional island side here is just a traditional steam turbine and generator set, and you can either take steam off the main steam line or actually use steam extraction from the turbine and have a specific turbine that brings the steam temperature down to the temperature and pressure required by a processes plant.

Any questions on this slide?

MEMBER PETTI: In the temperature of the reactor, the coolant is at 250 --

DR. VAN STADEN: At the reactor, it's about 260 degrees C. It's got about a 10-degree temperature rise over the M circulator. So, the outlet of the steam generator is 250.

And that's actually a very important aspect because our outlet temperature really flushes the entire pressure boundary. So, that's what gives us a very consistent temperature of the pressure boundary and, also, the core barrel internal metallic, so that we know that we're way within the ASME limits for those materials.

MEMBER PETTI: Because, historically, there was always this idea of very large delta T's across the core, which could cause some problems with the metallics.

DR. VAN STADEN: Correct. So, our metallics are, actually, very low stressed in terms of thermal stressing. Because the 250 degrees C goes up into the graphite risers. So, that sort of blankets the metallics.

And another design principle there is that we always -- in a graphite core, you've got a lot of leak flows because you don't glue these blocks together. So, the principle we use there is always leak from a high pressure/low temperature to the lower pressures at the high temperature.

MEMBER PETTI: Thank you.

MEMBER MARCH-LEUBA: And the control rods are inside the pressure boundary?

DR. VAN STADEN: Correct. Yes, they are.

Okay. I think we can go to the next slide.

So, just to follow on to the segregation part, this shows a plant view of a full reactor, four-turbine plant. This is an air-cooled layout with air-cooled condensers.

And what you see in the red box there is really the protected area boundary. And that also becomes the secure boundary. Whereas, on the conventional island side, we don't have the same level of -- the need for the same level of security.

We, literally, pass over the things. The steam lines go through there between the reactor buildings. They're not indicated on this slide.

Between the reactor and turbine buildings are really the interfaces, and as I said, the isolation valves are within the reactor building, which is, obviously, seismically-protected, as well as protected by an impact.

MEMBER MARCH-LEUBA: And they're designed, the formulas are designed to build one to start operating and be able to build the other three as it produces --

DR. VAN STADEN: So, our project timeline is -- our project is to build four. Our current schedule shows about a three-month schedule delay between the three -- between each reactor unit.

MEMBER MARCH-LEUBA: But you will be operating merely one when you finish using --

DR. VAN STADEN: Correct, but there's probably not going to be more than about three or four months prior to starting our --

MEMBER MARCH-LEUBA: And so, you have the same people all there.

DR. VAN STADEN: Of course.

MEMBER MARCH-LEUBA: So, you've considered the shielding and contamination issues?

DR. VAN STADEN: Correct. Yes, and the layout of the plant has actually been developed so that we can do the sequential construction. That's one of the reasons we don't have one large reactor building and one large turbine building. It's to enable sequential construction and starting one reactor up before we complete the next.

Okay. Any questions on this?

(No response.)

Go to the next slide.

The next slide is just a 3D rendering of the plant view there, a slightly different version of the plant view. My apologies. But it shows the spent fuel storage area. And I'll discuss that a little bit later in the closed session.

We have the four reactor buildings there, R1, R2, R3, R4. We've just opened up the model there showing some of the detail inside.

And then, the yellow buildings there being the turbine buildings; the four air-cooled condensers, and in the building on the most righthand side with the arrow pointing to (audio interference), the control and electrical building.

MEMBER MARCH-LEUBA: Just out of curiosity, the spent fuel, do you just dump it in 55-gallon drums or do something special with --

DR. VAN STADEN: Not quite. We have got

specially-designed spent fuel canisters. They're not casks. So, they hold, each one of them holds about 6,000 pebbles, and they are stored in a shielded vault area for the 60-year lifetime of the plant, before we, then, would remove those canisters and pull them up into a shielded cask for transportation.

MEMBER MARCH-LEUBA: So, those would be the transportation casks?

DR. VAN STADEN: They will be part of the transportation casks, but they will be inserted into the cask, which is really an overpack.

MEMBER MARCH-LEUBA: You don't have to manipulate any --

DR. VAN STADEN: Perfect. That's exactly what our philosophy is -- not to ever handle the pebbles individually again. Because when the spent fuel canister comes out of the reactor building, it gets seal-welded, and then, placed into the spent fuel storage facility.

MEMBER SUNSERI: Excuse me. What's the footprint size?

DR. VAN STADEN: Well, maybe this previous slide -- I think we've got a slide later on that shows it's about 400 meters in length and about 275 in the width of the pump.

Thanks. Next slide.

This is a bit of an animation that also gives you a bit of a view of the plant for reactor buildings, for turbines, and HVR. We also see up front there the electrical building and control building with the X-energy logo on. Then the four spent fuel storage units. Other buildings on the nuclear island side are helium storage facility as a separate building and then we also have a rad waste treatment facility within the predicted area boundary.

This just gives you an actual description or idea of the construction sequencing. This was a very early version done by some of our constructors to show how we would be constructing the plant.

MEMBER MARCH-LEUBA: The vessel is mostly above ground?

DR. VAN STADEN: No, the reactor is actually almost completely above ground. In fact, the reactor vessel head is basically at grade level.

MEMBER MARCH-LEUBA: Almost everything is underground?

DR. VAN STADEN: Correct. And in the conversation, we've got some further information on that. And that's it. I think I'll hand it over to Kyle now.

MEMBER HALNON: I didn't see a control room. Is that going to be a common control room?

DR. VAN STADEN: Great question, yes. The control room, the electrical building is rarely where the control room is located. We've done our human factors engineering design to enable us to actually operate up to 12 reactors from one control room, although the standard plant would be a full pack.

MEMBER HALNON: Thanks.

MR. CHAPMAN: All right, I'm going to walk through some licensing approach and then we'll carry on into the safety design approach with Kyle here.

Next slide.

As I mentioned, for the high temperature gas reactor technology, there has been a pretty extensive history in the U.S. market, as well as other markets in terms of regulatory interaction between domestic regulators, national activities. Right now, a series of pebble bed reactors are currently in operation. CRPM, both units. HCR10 in China are operating. We have that data right now and the technology works as it is.

For X-energy itself, we've entered into pre-application or pre-licensing engagements in several markets, here in the U.S. through the NRC, and

Canada in the vendor design review process. We're finishing up the combined Phase 1 and 2 VDR that should be issued this summer and proceeding into a targeted VDR Phase 3 for a couple of topics.

And then have expressed our interest to enter into the U.K. market, the Office of Nuclear Regulation and Environmental Assessment for Technology to deploy there as well. We consider all of them Tier 1 markets, Tier 1 regulators, and we see that from a company perspective, from a deployment perspective, as providing the credibility that we'll have for all of our international projects and expansion of our domestic projects going forward.

I would say like many advanced reactor companies, we're unique in this approach to conduct the application engagement with the staff so that we can align on technical, programmatic, policy matters as early as we can to introduce the technical subjects for their review so that when we are in application space and I'll show that in a few more slides, we've done the work ahead of time to introduce the things that we're going to be proposing and make the licensing process both efficient and effective in those areas.

MEMBER PETTI: Travis, a question. In

Canada and the U.K., is the interest more on the electricity side or co-gen as well?

MR. CHAPMAN: A little bit of both.

MEMBER PETTI: A little bit of both.

CHAIRMAN REMPE: I have a couple of questions. Since there has been all this work in the U.S. with the gas-cooled reactor, what's the remaining risk, the biggest remaining risk, and do you anticipate needing any exemptions?

MR. CHAPMAN: Yes, for the second part first. Absolutely. We'll try exemptions.

CHAIRMAN REMPE: A lot? What areas are you --

MR. CHAPMAN: Several. So from an approach perspective, trying to deploy this decade means that we can't wait for Part 53. The reason for Part 50 and 52, the specific elements of Part 50 is we've engaged with the staff in regulatory analysis. I would say to begin, the staff has actually identified several areas where specific language in the regulations would open itself up for either a determination of non-applicability or an understood need for you will need an exemption, but we understand why because your technology is different. They'll look at that as a barrier to overcome. It's simply a matter that we have to address.

CHAIRMAN REMPE: It sounds like paperwork. It ought to go fast.

MR. CHAPMAN: An example might be ECCS. We don't have an emergency core cooling system. The regulations associated with ECCS, I could say, don't directly apply. However, we absolutely remove core heat removal systems and we address the intent of that regulation there.

In working with the staff, will a specific exemption be required, or is this just a matter of determining applicability?

Criticality control. 5068, there's some exemption material there with respect to upper enrichment levels. Definitions, is it implemented in NEI 19-04? We use a different terminology for safety-related (audio interference) than is what is in the regulations. So a handful of areas. We introduced some of these in 2021 in a White Paper with the staff just to get some initial feedback on that one at the same time as their own applicability work was going on. We've kind of continued to progress through there. We don't see those as project risks in the sense of -- that's why -- really the basis for our -- really the basis for these early engagements, just to make sure we're aligned on it.

Entering into application review, we understand what interpretation of the regulations are we making and how will they address that going forward.

The earlier part -- I apologize, could you repeat the first part of -- the biggest challenges.

CHAIRMAN REMPE: Again, those seem pretty straight forward. We've had folks with other advanced designs where they wanted to have a non-safety grade shutdown system instead of two diverse ones or something like that. That's a bigger issue.

Do you have some bigger -- where do you think the big hitters will be in regulatory risk here in the U.S.?

MR. CHAPMAN: I think, and this is my opinion, and we're going to see some of the work that Kyle is going to show you if this one comes out, how we implement NEI-1804. We're going to use terminology that's going to come across different than what we've seen traditionally in the lightwater fleet, how we approach principle design criteria and how that intersects with things like safety related versus safety significant versus not safety related with no special treatment.

I think it's going to be largely a matter of just interpreting some of the terminology and the methods that we use, but nothing -- we practice all of the normal design principles you would expect, barriers, diversity, independence, redundancy, multi-barrier, defense-in-depth approaches, functional containment. That may be unique, but I feel like we've had years now of discussion about functional containment approaches. We implement it both on the reactor side, what might be new as we're exploring it more as how do we implement that on the spent fuel side? And I could say that it's not that novel -- distort the price of fuel all the time. So, some of those things we don't see as fundamental barriers, but I appreciate there's going to be -- there's going to be work to do.

CHAIRMAN REMPE: This helps. I appreciate your answer. The other question, since you are going to use the LMP here in the U.S., are you going to do this in other countries you're going to and is that going to be more of a hurdle to overcome in other countries, do you think, or is it going to go fairly easily?

MR. CHAPMAN: Our engagements with the Canadians have been very positive. I'd say that the results of the joint reviews and the activities between the NRC staff and the CNSC, they've mutually come into alignment on processes and approaches. They align with how they would go about doing a risk-informed, performance-based hierarchical kind of layout of your safety case. So I'd say we had positive traction in Canada and our work with OPG in 2020 and 2021, alignment with their review staff as part of a technology selection process that we're able to convince them that our graded approaches to quality assurance that aligns with safety classifications would pass muster with the CNSC.

In our early work in the U.K. with some of our partners there, Cavendish Nuclear -- This aligns with the safety case approach in the U.K. market very well with a coherent message about how you went about the classification processes. And so we see that as a positive attribute for those markets.

CHAIRMAN REMPE: Thank you.

MR. CHAPMAN: You're welcome.

MEMBER HALNON: Just a quick, maybe off the wall question. Did you ever explore with the staff the possibility of a site license rather than a core reactor license?

MR. CHAPMAN: We haven't explicitly looked at that and I naturally was inclined to keep individual unit licenses from the progressive deployment perspective.

MEMBER HALNON: But you could still do it. I mean thinking out of the box, but I understand that. If there are going to be, if you will cookie cutters, it might be a fruitful discussion.

MR. CHAPMAN: Thank you for that. The way that I review the individual licenses per unit, there are several -- no common safety systems, but there is common infrastructure that the site shares. So whatever the last license, in effect is, is going to be reliant on the rest of the site.

MEMBER HALNON: There's some barriers to overcome, length of license and modifications and that sort of thing. Something that we talked about early on with the SMRs back in the late 00s and it didn't go real far, but it was certainly an intriguing discussion.

MR. CHAPMAN: Appreciate that. Next slide. There we go.

X-energy began pre-application engagement with the staff back in 2018 with some introductory presentations about the technology, the technology development. Martin was great to pull up some of the history in our last ACRS engagement related to code development, code access term that we'll share a little bit later in the presentation.

To date, we've had a number of engagements. I look at these as activities and then the types of activities we try to select based on our licensing approach, licensing strategy.

In the lower written narrative, many subjects have been introduced in the form of White Papers so that we could get feedback in a more rapid iteration manner so that we could begin incorporating that work. And a handful of topical reports that we have explicitly asked for safety evaluations again related to our fuel qualifications program, our implementation of NEI-1904, a broad topical report that was related to our safety analysis methods, so this is not the individual methods on a specific accident sequence, but the over-arching -- I'd call it the scope, are we looking at the right scope of things that we need to be evaluating, looking at the right methods to develop under Reg. Guide 1.203 as part of that.

Similar to NuScale and other multi-modular vendors, we introduced control room staffing analysis form NUREG-1791, defensive human factors, engineering program that worked through a control room mock up, an engineering scale facility that's moving into our full-scale simulator to complete that HFE work.

Our current work in progress is principle design criteria, everyone’s favorite topic, how do I determine the shalls and shoulds in the appropriate places? This particular subject has been -- I'd say a challenge, but a good challenge. We're not only taking the Reg. Guide 1.232 work that was done to develop the advanced reactor and MHTGRDCs, we're trying to make sure that that lines up with the NEI-1904 process that would have been a more holistic, whole cloth, bottom up assessment. As you know, the required safety functions, the PRA safety functions, what are the design criteria that come out of that that you scope for normal operations, all the way through the spectrum developing needs, as well as our implementation of the NQA-1 quality standard.

MEMBER MARCH-LEUBA: Back to your line number one. Fuel verification is done for 20 percent rich in high burnup or is it only fabrication?

MR. CHAPMAN: So the fuel qualification program describes our use of fuel performance methodology and some of the fabrication elements. We love the work that was done under AGR1 and 2 and EPRI.

This topical report was trying to close the gap on the open items that remain from the EPRI report, what other things need to be addressed, specifically the pebble formation and any impact that pebble fabrication may have on the performance of the particles and the confirmatory tests that we're discuss later on.

MEMBER MARCH-LEUBA: Was the X in TRISO-X what does it mean? What's the difference?

MR. CHAPMAN: X-energy.

MEMBER MARCH-LEUBA: What is the characteristic of the fuel that makes it an X -- an existing --

MR. CHAPMAN: Our particular formula for how we get to the TRISO particle --

MEMBER MARCH-LEUBA: -- the fabrication?

MR. CHAPMAN: The fabrication methods that we would do.

MEMBER MARCH-LEUBA: But it's different and therefore, it's critical for the verification of the other fabrication method, is may or may not be applicable?

MR. CHAPMAN: It is applicable. Similar to some of the results of that effort. The idea that your manufacturing processes, as long as you can fabricate the particle to the specification, that specification is what gives us confidence that the performance is going to come out as expected.

MEMBER MARCH-LEUBA: And in an open session, I understand this is proprietary, what fraction of fuel is spilled out of the factory? What percentage of your particles leak?

MR. CHAPMAN: I think we discussed this later on in some of the analysis results. If we don't --

MEMBER MARCH-LEUBA: Is this proprietary, the number?

MR. CHAPMAN: We use fractions. We base all of it off of the AGR program.

MEMBER MARCH-LEUBA: Okay.

MEMBER PETTI: It's consistent sort of kind of potentially in the neighborhood of AGR.

MR. CHAPMAN: Thank you.

CHAIRMAN REMPE: So what's the status of the PDC? Has it been turned back into NRC?

MR. CHAPMAN: So, I will own this one. Look at me and say, Travis, hurry up.

CHAIRMAN REMPE: No, we have the meeting scheduled and I need to ask.

MR. CHAPMAN: The part that we leave and

someone intentionally helped us up on -- the staff's comments were frankly very easy to address and it was a good review to do the audit together. That also coincided with the cycle of our NEI-1804 processes. We had more results from the PRA that could give better definition to operational design criteria as opposed to licensing bases events ones. We wanted to make sure that we got the wording right. What we didn't want to do is come back in six months later and say we'd like to say those PDCs again after we went through the effort. That is in concurrence right now to get into the staff as I possibly can.

CHAIRMAN REMPE: It's posted because we have it on our planning and again, we'd rather you not have to come back again. I understand that. But it's good to let us know because there's other folks who do want to get in the queue.

MR. CHAPMAN: Yes. Next slide.

CHAIRMAN REMPE: Oh, and also if -- we tried to make sure that we have access to reports even if the staff SD isn't done and some of these reports we do have a copy and some we don't. Please -- this is not for you, this is for the staff -- make sure we have the proprietary version of it loaded on our SharePoint site that we can have access to it because it helps us have a better interaction with you --

(Simultaneous speaking.)

MR. CHAPMAN: Absolutely. Over the coming year and into 2024, under the Advance Reactor Demonstration Program, we proposed a series of pre-application engagements. The way I do that as well -- not just before the application goes in, these are discrete review activities that we've recognized a topical report or a technical report stand alone review would be the appropriate vehicle to pursue.

In the near term, really in support of a construction permit application that we'll describe in a moment, there are several methodologies that we're pulling together to make sure they can go in for review ahead of the construction permit. Some of the review, if our timing works the way we intend it to, it will be concurrent with the intent being the staff is looking at methods ahead of time.

Our atmospheric diversion methodology, how we use an internal code, a modular VSX turn code code, along with the ARCON code or offsite dose modeling is finished going through its proprietary review for submission. Mechanistic source term break up of one of our earlier reports, the methodology as well as the code verification/validation elements, transient safety analysis methods for the things that Kyle will show you here in a little bit, as well as a series related to codes we'll show you, our uncertainty analysis methodologies and some of the design methodologies. It’s very similar to other applicants in that area.

And then a follow on from there in the 2024, '25 time frame probably some topical reports that might be specific to programs or program methodologies that we did.

Next slide.

For that first project, it's a commercialization strategy at X-energy. We always had an intent, if we could help it, you try to find a project to demonstrate with first as opposed to going down the Part 52 path of certifying or approving the design, I'll call it in paper space. But before you've actively gotten into that project side, ADRP allows us to do that, the proposed licensing path was under Part 50, construction permit followed by an operating license. With that operating license, we would apply for the material licenses with the facility. In the construction permit phase, we've developed the environmental report that will address the requirements of NEPA under 10 CFR Part 51 for the staff. We also have some obligations under the Department of Energy to address NEPA across the broader range of -- (audio interference) -- the company.

The framework for a preliminary safety analysis report that has adapted a lot of different work that the staff and industry has done to bring forward an advanced reactor licensing approach. And as you can see on the bottom left there, if it's new and it's advanced reactors, we are probably trying to implement it in some way, shape, or form.

The advanced lightwater PRA standard and something like 1200 individual requirements we have to address for that, as well as it's endorsing Reg. Guide, not to mention the LNP methodology under the Reg. Guide 1.233. We are following an approach that I'll share here in a moment to structure the PSAR and then every other X-100 Safety Analysis Report going forward into a 12 chapter SAR. And we'll share with you what that looks like here.

So we are actively waiting -- the Draft Guide 1404, ARCAP work that the staff has done so we can make sure we've covered our bases.

Slightly different than was originally proposed under TICAP, we are not taking what was defined as the affirmative safety case. We did a regulatory compliance case and we’ve screened Parts 20, 50, 100, all of the regulations to make sure that we're addressing the appropriate regulations at the construction permit phase followed by the operating license phase. And we'll share that in the application, as well as performance-based EPZ methodology, the ASME code Section 3 Division 5, Section 11 Division 2 for RIM and in some cases, we desire to use our risk insights developing the PRA for flexibility and operational matters such as the security profile of the facility.

From ARDP, we leverage that first review of project one into what will become the standard design and whether that is a Part 52 application, a prospective Part 53 application, depending on how that rulemaking comes together remains future decisions for us.

Next slide.

Speaking of that PSAR, the 12 chapter layout. You've seen that over the past month with the staff. This began in 2020 with the earliest version of the TICAP discussion between the NRC Policy Branch, industry, effort led out by Southern Company into what could a SAR look like. And we had to pick up on that immediately because of the Department of Energy schedule to begin building the plans, where the data was going to come from, how we build that into a schedule, resource load that from a development perspective.

The titles, the names change a little bit depending on whatever iteration we've gone through. Now that we're in AI2107, generally landed here. Site characteristics is a chapter I would say that has been an open discussion still that we are doing the work. With that particular case, we're following NUREG 0800, but where that content lands, if I remember correctly, in 2107, actually is a subpart of Chapter 1 and then our methodologies would flow back into Chapter 2.

The information is organized in this manner because of our implementation of NEI-1804 that you get one giant chapter of safety related FSEs. Not that big because we don't have that many. Safety significant, or NSRST, non-safety related with no -- excuse me, with special treatment, SSEs and in one place the entire plant as described is actually in Chapter 1. So instead of individual chapters for each of the major systems in the plant, we see them combined together.

Next slide.

I'm going to close out. I pulled forward the principal design criteria developments because it felt more comfortable in this portion. As mentioned, we are trying to do the work to close what was done for the modular high temperature gas cooled reactor design criteria which I would say we have leveraged extensively not only here in the U.S., but in the international markets in Canada with the CNSC, and we're beginning to do that now with ONR as an activity that shows the NRC staff and U.S. industry has matured this concept significantly into more acceptable performance criteria, design criteria for these facilities.

And as mentioned, we're incorporating into their required safety functions, the PRA safety functions, the complementary design criteria, the operational design criteria, and required functional design criteria ascribed to the specific systems. And we want to make sure that that is clear because then in the review chapters themselves, we will be noting conformance to our PDCs as an important part of our 50.34 alpha compliance.

MEMBER PETTI: Can you give an example of ERA safety functions? Isn’t one of the required safety functions from the methodology?

MR. CHAPMAN: Sure. Start-up/shut-down system as a means of heat removal from the plant is modeled in the PRA but it's not a required safety function. Heat removal is a required safety function, but that function is performed by our reactor cabinet cooling system.

MEMBER PETTI: Okay, but is the shutdown system safety related or non-safety related special treatment? Okay. I understand.

MR. CHAPMAN: Next slide. We're going to transition over to Kyle.

MR. METZROTH: Okay, thanks, Travis. So in just a couple of slides here, we're going to talk a little bit about the safety design approach that a very high level. So later on in the presentation, we do go into say a little more about the methods and the tools that we're using, as well as a little bit more details on the implementation. But we're going to start here and talk about some of the core safety principles that have been built into the design since the start and it was really focused on ensuring that we wanted to have the required safety functions be performed by inherent and passive systems.

Go to the next slide, please.

So this picture is sort of a look at how

NEI-1804 is thinks of the world. So we start out with defining our required safety functions and it sort of starts in this hierarchical way. You ask -- you look at the PRA and say what are the SSEs that I'm relying on to ensure that I'm staying below my -- I'll say consequence limits. Those become your required safety functions, right? And then you can go and then define any defense-in-depth safety functions that you need.

So it starts off for us all up with fuel. The fuel is clearly the key part of the safety case and the retained radionuclides in fuel particles and pebbles is sort of our topic level safety function. But that decomposes down, and so there are other safety functions that support that. So the three key safety functions, and then kind of an overarching one for controlled reactivity, controlled heat removal, and limit water steam ingress and then all kind of supported by this maintained core geometry function.

So with regards to controlled reactivity, and you could also look at this as controlled heat generation. We manage primarily through reactor materials, core geometry, and low excess reactivity which is accomplished through the continuous refueling.

We don't rely on any kind of removable

poisons, no safety rods in order to rapidly respond to an event, but we can demonstrate that the reactor can shut itself down through inherent reactivity feedback in rapid response to the event. We do rely on the rods to maintain criticality control in the long term, but we can demonstrate that we don't require them in order to be able to rapidly respond to an event.

MEMBER MARCH-LEUBA: So you don't classify them as safety grade?

MR. METZROTH: They are safety grade. We classify them as safety --

MEMBER MARCH-LEUBA: But you don't need --

MR. METZROTH: The function that we need them for is long term reactivity control, not to rapidly respond. We don't need them to act quickly.

So the next one is controlled heat removal, also implemented in a passive and inherent way. So the core has a low-power density of about five kilowatts per cc and again, we leverage core geometry and materials such that the heat can be naturally removed via thermal radiation, conduction, and convection out to the reactor vessel wall which can then be transmitted to the reactor cavity cooling system into the ultimate heat sink, right? So it's all passive.

MEMBER MARCH-LEUBA: That's the long term decay heat rules.

MR. METZROTH: That's the long term decay heat rules.

MEMBER MARCH-LEUBA: Radiation containment --

MR. METZROTH: Yes, the building to the reactor cavity -- it's the reactor cavity cooling system.

MEMBER MARCH-LEUBA: And that is cooled how?

MR. METZROTH: That's just natural convection, natural air convection.

MEMBER MARCH-LEUBA: But eventually it has to get outside the walls.

MR. METZROTH: Yes.

MEMBER MARCH-LEUBA: Through the walls?

MR. METZROTH: No, it goes up and out of the building.

MEMBER MARCH-LEUBA: Okay.

MR. CHAPMAN: RCCS is similar to maybe RVACs end of the system. It's outside air through stem pipes, interior as it heats up, natural convection drive it back out through release. We have an image that shows --

MEMBER MARCH-LEUBA: So it's more containment you want to come up and share, somewhere in between?

MR. CHAPMAN: The reactor building is a pretty substantial structure, predominantly below grade SSC. The RCCS draws in, trends that down into the cavity area to pick up the heat before it's rejected out.

MEMBER MARCH-LEUBA: I haven't seen any chimneys. Is there sufficient draft inside the building to draw the circulation?

DR. VAN STADEN: Correct, and we'll cover that in the closed section. We have some more detail on that.

MEMBER PETTI: There have been experiments done on this. It’s really money DOE spent, well spent I think.

MR. METZROTH: The next safety function, limited water steam ingress, this is focused on ensuring that in the event of any kind of water ingress into the primary system, that we limit the amount of water ingress so that there's no fuel performance limits are violated.

And the source here is both through hypothetical rupture of a steam generator to -- that's the key water source. And so this -- the safety function is primarily accomplished through isolation and so we isolate and prevent water from getting into the core like if a limit is -- if an ingress is detected.

So this is a function of the reactor protection system, but it's a fairly simple function to isolate and there's no A/C power required in order to to accomplish it.

MEMBER MARCH-LEUBA: The valves are fail closed?

MR. METZROTH: Yes. And then again, there's this final safety function which kind of undercuts everything of maintaining geometry because a lot of the reactivity control, heat removal, right, it's dictated by the geometry. So maintaining geometry throughout all of those is kind of an undercurrent.

MEMBER PETTI: I know that in MHTGR it was not just water, but gas. Why is there not a safety function on limiting ingress?

MR. METZROTH: So there's -- the way that the -- I don't know if this is something they would get into the next session -- we'll get into that more.

Next slide, please.

So in addition to this, I would say overall safety design approach and the safety -- the core safety functions that we implement, we'll also talk a little bit about our overall containment philosophy. So we do implement the function containment approach where the primary containment role is performed by the fuel. So during normal operating conditions, accident conditions, the vast majority of fission products are retained by the fuel and it's the only -- it's the key boundary we rely upon to demonstrate acceptable performance. The building, the site play a role. It's the defense-in-depth barriers. And they play a role in safety, but they're not required in order to demonstrate acceptable performance.

MEMBER MARCH-LEUBA: So -- functional containment is the TRISO particle?

MR. METZROTH: Correct. In order to evaluate this, we leverage our mechanistic source term modeling. So we do have very detailed models of the behavior of the TRISO fuel, analyze it across a bunch of accidents. Look at the radionuclide transport that occurs from the particles into the helium pressure boundary and during any accident conditions into the building and out so we can accurately characterize what all the release paths look like and their magnitude and then we can feed that information back into the system design.

In addition, and as has been mentioned many times before, so we have these modeling tools that we use to evaluate this. We have the NEI-1804 framework which is used as sort of our overall framework to define the licensing basis events and develop safety design requirements.

So to say with NEI-1804 as our guide, right, to help us with determining how events are considered and developed and how safety requirements are developed, and then using our mechanistic modeling tools, we use these insights and it will feed all these insights back into the design process and ensure that they're captured. We'll get into a little bit more later about how we're actually doing that.

Okay, next slide. That's it.

CHAIRMAN REMPE: Travis, do you have another question or comment?

MR. CHAPMAN: That closes out the open portion of the meeting. I'm certainly happy to take any questions, discussion.

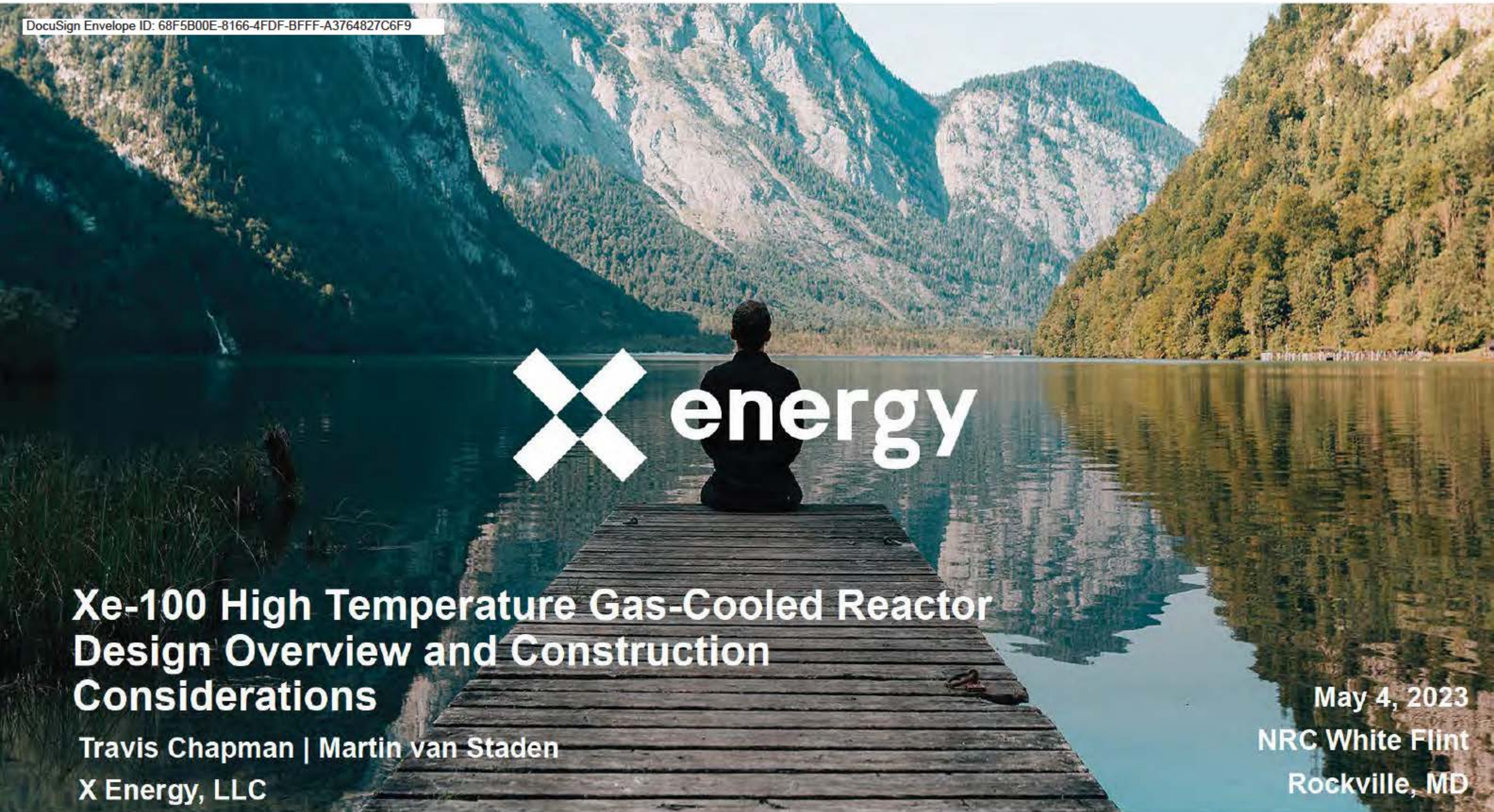
CHAIRMAN REMPE: Not hearing anything, we need to stop and have some time for public comments.

If you are on the line, the phone line, press star-six, unmute yourself. If you are on a computer, you can just unmute your mic.

Okay, I'm not hearing any and it looks like we're actually doing pretty well with respect to schedule which is amazing. Why don't we come back at -- let's still come back at 2:45, if you don't mind. You never know how these things are going to go. So anyone that needs to take a break, please do that and we're going to restart with a closed session. So I'm going to exit this and enter a different one. Okay?

Thank you very much.

(Whereupon, the above-entitled matter went off the record at 2:33 p.m.)



X energy

Xe-100 High Temperature Gas-Cooled Reactor Design Overview and Construction Considerations

Travis Chapman | Martin van Staden
X Energy, LLC

May 4, 2023
NRC White Flint
Rockville, MD

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Agenda & Objectives

Agenda:

- Overview of X-energy & the HTGR Technology
- Xe-100 Technology Overview
- ARDP Licensing Approach
- Safety Design Approach
- Xe-100 Principal Design Criteria & Development
- Safety-Significant Structures, Systems, and Components (SSCs)
- Construction and Modularization Strategy and Xe-100 Site Plans
- Xe-100 Testing Program & Helium Test Facility
- Xe-100 Training Program & Simulator Development
- Select Licensing Basis Event Overviews

Objectives:

- ACRS familiarity with the Xe-100 reactor design, technology development, and ARDP demonstration plant project
- Discuss the licensing approach for the ARDP demonstration plant project

X-energy Overview

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X-energy at a Glance

2009

Company Founded

Rockville, MD

Headquarters

440+

Employees
Including 40 PhDs and 38 Masters in Engineering / Science

$1.2B

Funding secured through ARDP

2029

Xe-100 commercial operation - ARDP

Xe-100

- 200 MWt pebble-bed helium gas-cooled reactor
- 80 MWe units, 320 MWe 4-pack
- No reliance on onsite or offsite power to perform any required safety functions
- 1/10th the components of a traditional nuclear plant

TRISO-X

- Ceramic encapsulated fuel that is safe (self-contained, radionuclide retention performance up to at least 1800C) & offers efficient burn-up
- Leverages long-term investment and testing by the U.S. DOE

Recent X-energy Developments & Announcements

Dow, X-energy to drive carbon emissions reductions through deployment of advanced small modular nuclear power (March 1, 2023)

- Dow and X-energy will construct Xe-100 unit at one of Dow's U.S. Gulf Coast facilities by ~2030 to provide process heat and power
- Dow is first manufacturer to announce intention to develop SMR technology options
- Dow has taken a minority equity stake in X-energy

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X-energy's Initial Xe-100 Deployment

X-energy was selected in 2020 by the US Department of Energy for its Advanced Reactor Development Program ("ARDP")

ARDP Overview

- In May 2020, the DOE announced the ARDP to speed the transition of next generation nuclear reactors from concept to demonstration through cost-share partnerships
- In October 2020, X-energy was selected to deliver a commercial a first-of-a-kind advanced nuclear plant as well as a commercial TRISO- X fuel fabrication facility, which will be delivered in partnership with Dow Chemical
- ***The program provides 50% cost share on all costs to deliver the first plant***

Our ARDP Project with Dow Chemical

Proposed Dow Chemical Project

4-reactor Xe-100 Co-generation Plant

What ARDP Selection Means to X-energy

✓ **Recognition from the DOE as an advanced reactor technology of choice**

- Selected out of ~50 applicants

✓ **Secures first customer deployment**

- Partnered with Dow Chemical to deploy the first advanced small modular nuclear reactor at an industrial site for cogeneration
- Customer also benefits from the 50% cost-share on their development and construction costs

✓ **Provides $1.2 billion in funding from the DOE**

- Fully funds all remaining design, licensing, and commercialization milestones of the reactor, including overnight CAPEX
- Funds the completion of the first TRISO-X fuel fabrication facility

✓ **Strengthens DOE's support of the advancement of TRISO fuel**

- Exemplifies the DOE's commitment to scaling TRISO fuel production in the U.S.

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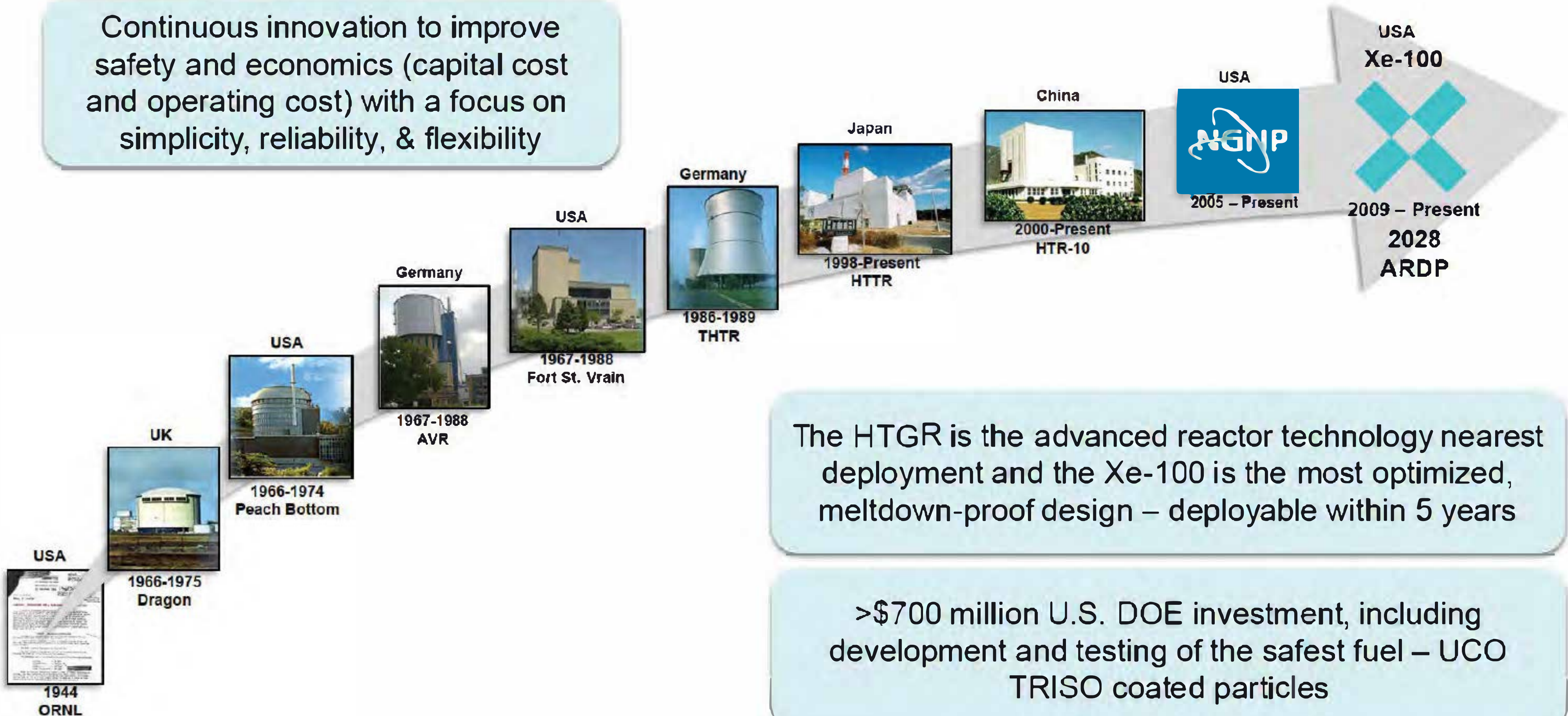
Operating Precedents for the HTGR Technology

Continuous innovation to improve safety and economics (capital cost and operating cost) with a focus on simplicity, reliability, & flexibility



The HTGR is the advanced reactor technology nearest deployment and the Xe-100 is the most optimized, meltdown-proof design – deployable within 5 years

>$700 million U.S. DOE investment, including development and testing of the safest fuel – UCO TRISO coated particles

Xe-100 Overview

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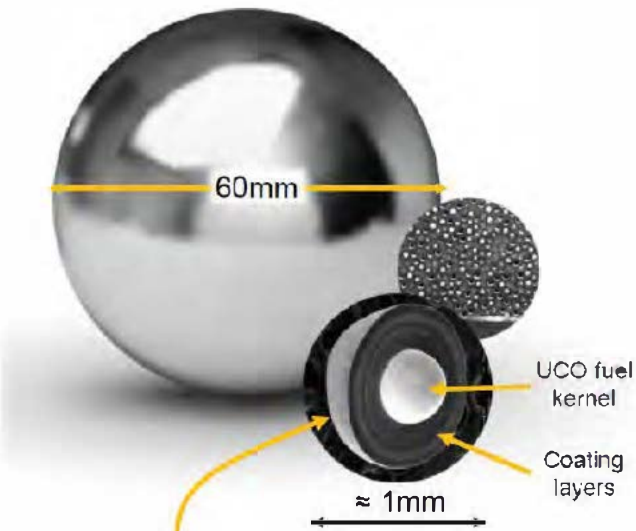
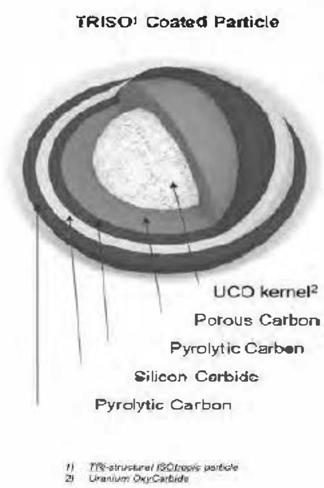
The Xe-100 Safety Case Starts with the Fuel

Graphitized Pebbles with embedded TRISO Coated fuel particles



≈19,000 TRISO Particles in a single pebble



TRISO / HALEU UCO

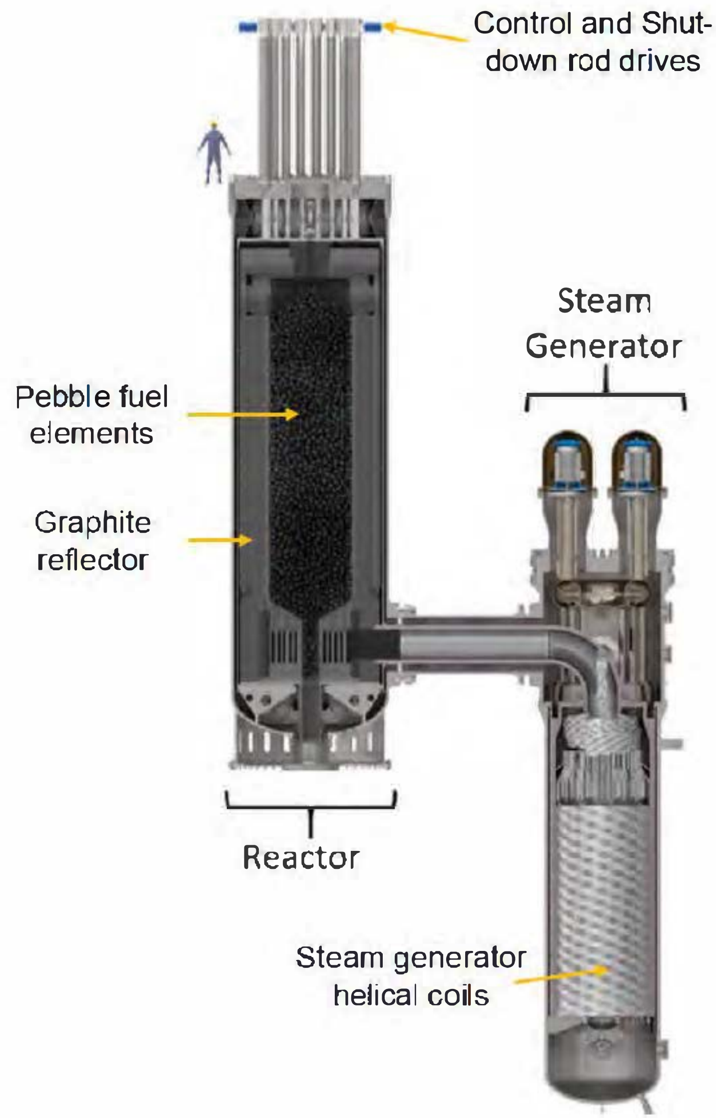
- HALEU UCO kernel coated with layers of carbon, pyrolytic carbon & silicon carbide to form a TRISO particle

TRISO-Coated Fuel Pebbles

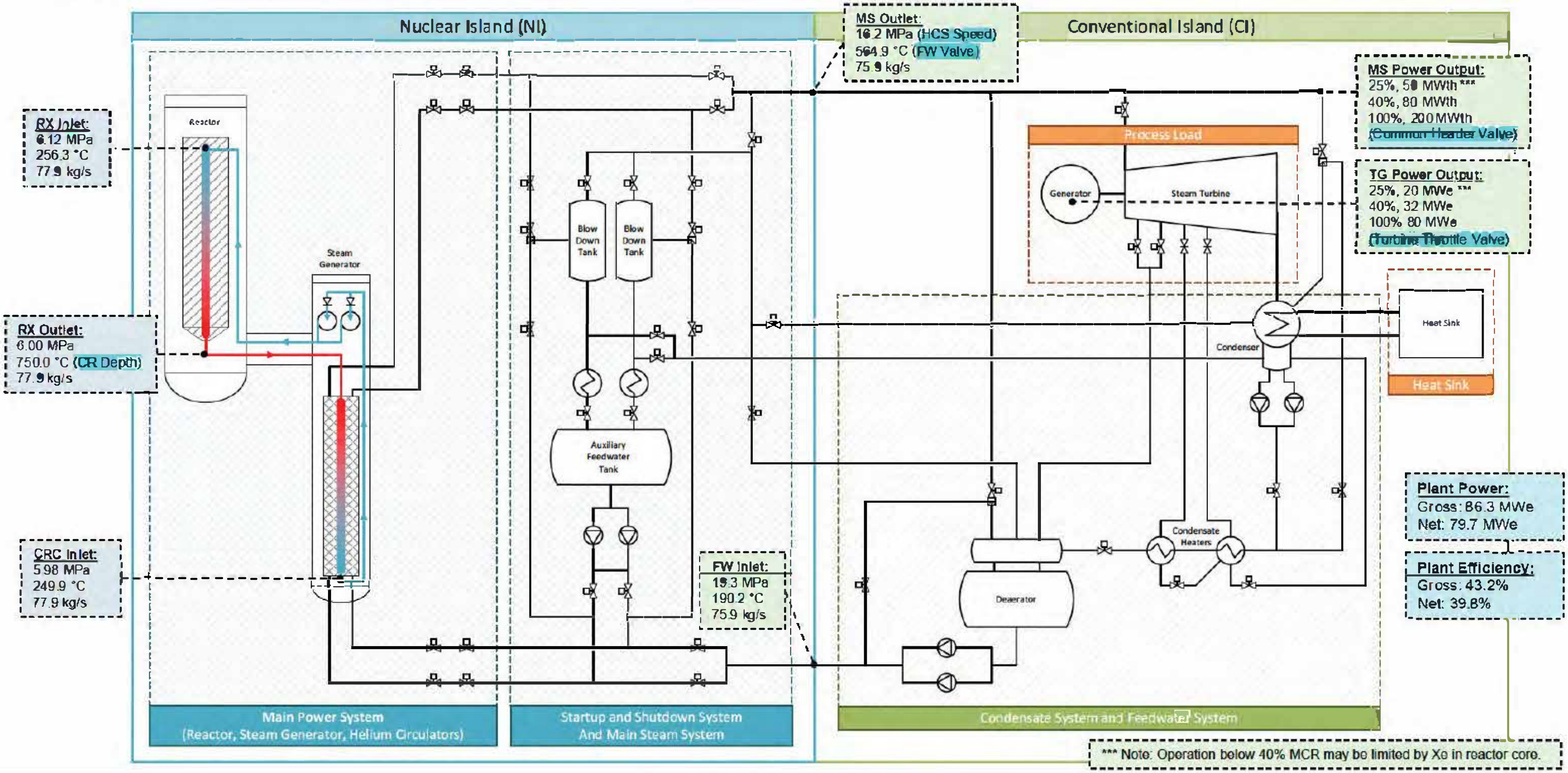
- TRISO-coated fuel provides robust, efficient containment of radionuclides within the TRISO particles, based on extensive development and testing through the DOE's Advanced Gas Reactor (AGR) program

The Xe-100 Design Solution

- Proven High Temperature Pebble Bed Reactor
- Derived from over 50 years of design and development to significantly reducing costs to enable competitive deployment
- Online refueling through automated continuous fuel handling system
- Versatile Nuclear Steam Supply System (NSSS) that can be deployed for electricity generation and/or process heat applications
- Conservative design that does not require new material development and or code cases
- Steam pressure and temperature designed to provide steam to multiple Commercially Off The Shelf (COTS) Steam Turbine / Generator sets (typically those used in Combined Cycle Power Plants)



Independent Nuclear Island with Variable Conventional Island



*** Note: Operation below 40% MCR may be limited by Xe in reactor core.

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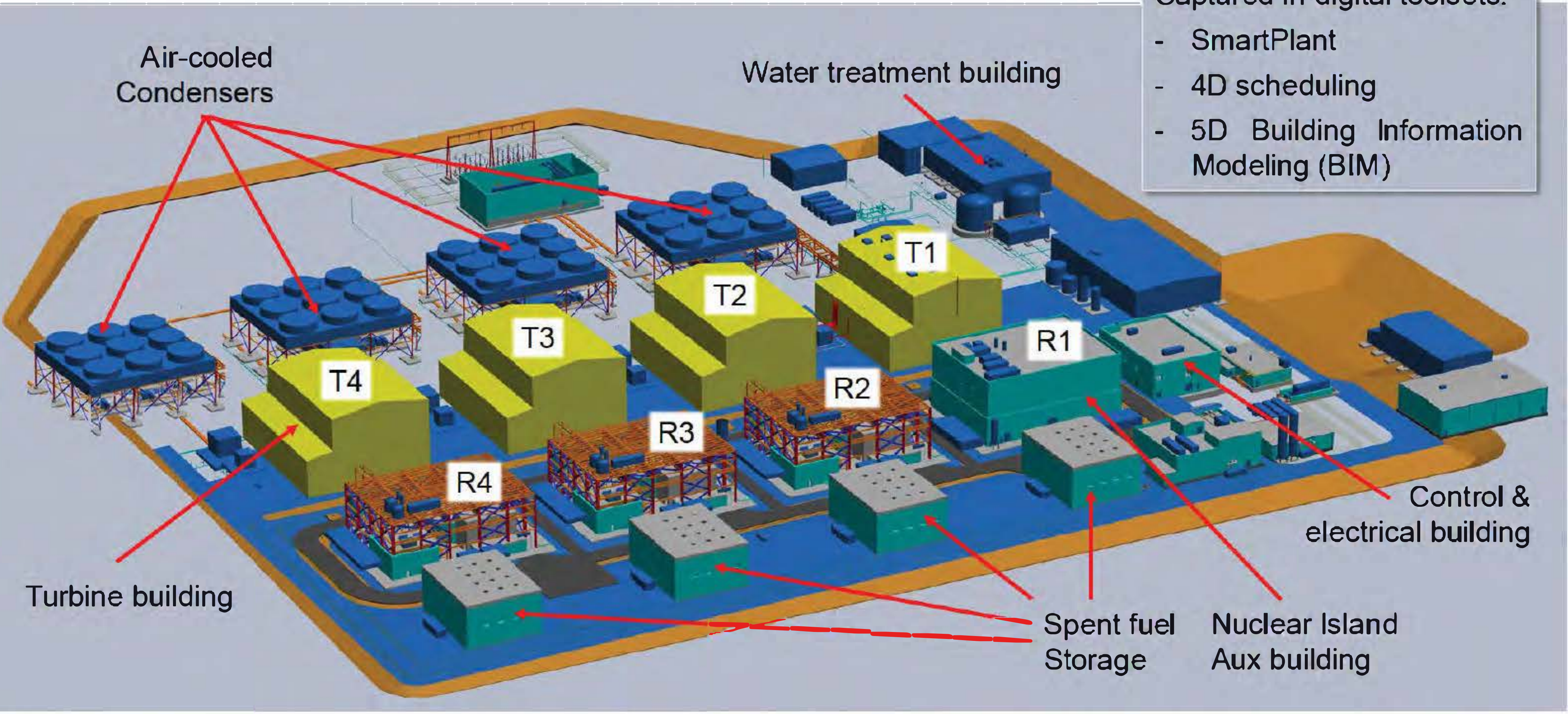
Site Layout | Key Features

Xe-100 Standard Air-Cooled Plant (4-Unit) Layout

Captured in digital toolsets:

- SmartPlant
- 4D scheduling
- 5D Building Information Modeling (BIM)




Xe-100
Day&Zimmermann
BURNS
McDONNELL.

Licensing Approach

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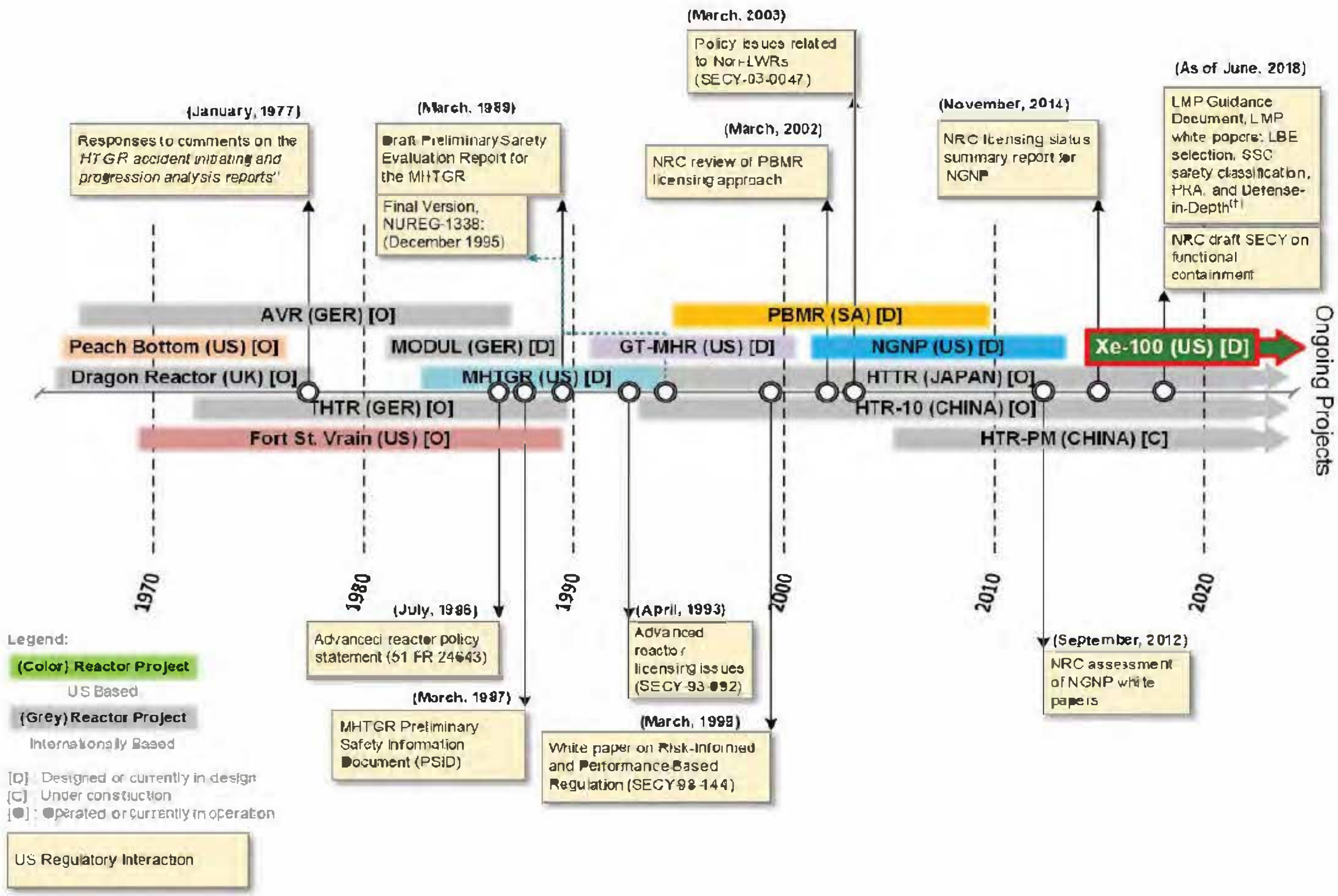
High Temperature Gas Reactor (HTGR) Regulatory Timeline

X-energy is working with the U.S. Nuclear Regulatory Commission (NRC), Canadian Nuclear Safety Commission (CNSC), and UK Office of Nuclear Regulation (ONR) to achieve acceptance of our designs for use in multiple markets. They are considered "Tier 1" regulators.

Our strategy in each country involves:

- *Progressively reducing regulatory risk for each project;*
- *Promoting company credibility through thoughtful public-industry participation in relevant topical areas;*
- *Using early engagement activities to identify and resolve technical, policy, and schedule challenges; and*
- *Working with the regulators to find mutually-agreeable solutions.*



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Pre-Application Engagements | Topical Reports

Topical Reports	In Progress?	Complete
TRISO-X Fuel Qualification Program		9 Mar 2023
NEI 18-04 Implementation		4 Aug 2022
Safety Analysis Methods Framework		29 Mar 2023
Control Room Staffing Analysis Methodology	Yes	
Principal Design Criteria	Yes	
Quality Assurance Program Description	Yes (Rv. 4)	

Engagements with white papers on Mechanistic Source Term, Bounding Design Values for Environmental Impacts, PRA Technical Adequacy, DI&C Design Approach, Seismic Design Approach, Regulatory Analysis of 10 CFR 50, RPV Construction Code, Security, Maintenance, and Operator Qualification & Training.

Pre-Application Engagements | Topical Reports in Development

Topical Reports in Development	Target
Atmospheric Dispersion Methodology	Q2 2023
Operator Training, Eligibility, and Qualification Methodology	Q3 2023
Mechanistic Source Term Methodology	Q3 2023
Transient & Safety Analysis Methods	Q4 2023
Uncertainty Analysis Methodology	Q4 2023
Code Qualification & Verification/Validation (Various)	Q3-Q4 2023
Core Design & Analysis Methods	Q4 2023

Engagements on other subjects and additional detail are contained in X-energy's 2023 Regulatory Engagement Plan Update.

ARDP Licensing Approach | 10 CFR 50

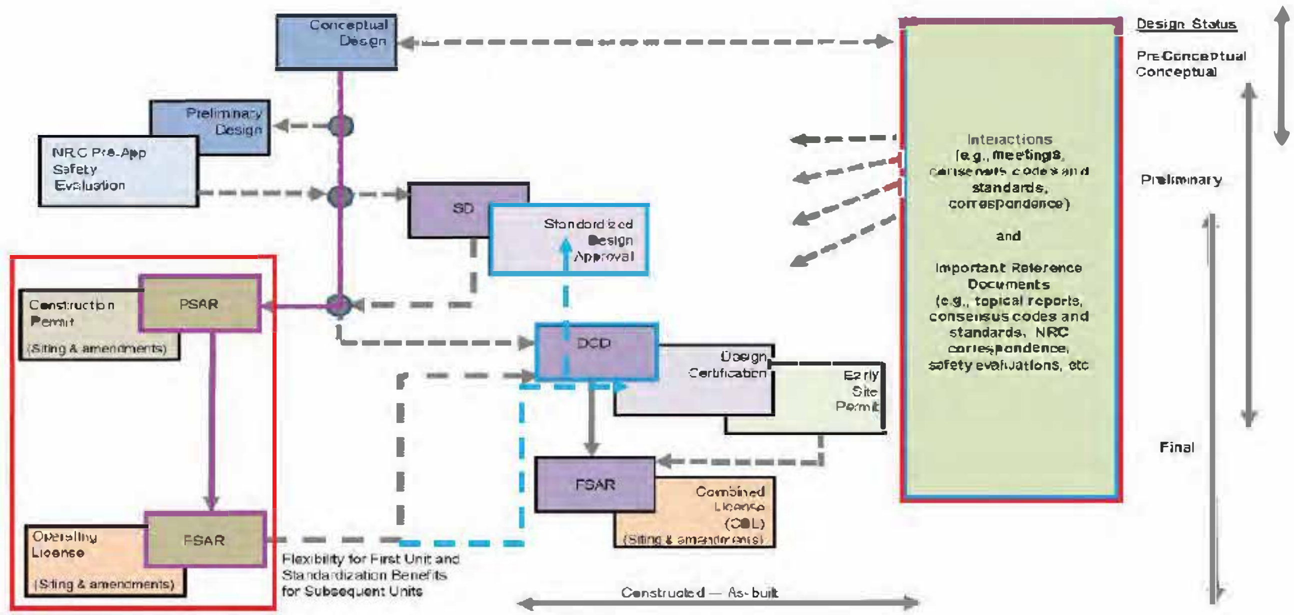
10 CFR Part 50 is a two-step licensing process that involves an application for:

- Construction Permit
- Operating License
- Material Licenses (Parts 30, 40 ,70) separately

The ARDP Project will also require an **Environmental Report** to describe the environmental impacts to comply with 10 CFR 51 requirements of NEPA, in addition to some DOE-OCED NEPA considerations (Federally-funded program)

X-energy is implementing many advanced reactor regulatory framework elements to demonstrate a commercial project in the near-term:

- ASME/ANS ANLWR PRA standard (RG 1.247)
- NEI 18-04 (LMP) (RG 1.233)
- NEI 21-07 (forthcoming DG-1404)
- Performance-based EPZ methodology (RG 1.242)
- Alternative consequence-based approach to security
- ASME Section III, Division 5 (RG 1.87 Rv. 2)
- ASME Section XI, Division 2 RIM (RG 1.249)



NRC's Regulatory Roadmap for Non-LWRs (2017)

Site-specific Xe-100 project

X-energy: Xe-100 Standard Design

Licensing Strategy

- *Preapplication interactions to de-risk overall project licensing approach (scope of application)*
- *Leverage ARDP CP/OL applications with site-specific details*
- *Fast-follower for ARDP reviews leverage NRC determinations for efficiency*

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NEI 21-07 Implementation | PSAR Structure (Part II)

- Chapter 1 - General Plant and Site Description
- Chapter 2 - Site Characteristics**
- Chapter 3 - Licensing Basis Events [including Methodologies and Analysis]
- Chapter 4 - Integrated Evaluations
- Chapter 5 - Safety Functions, Design Criteria, and SSC Classification
- Chapter 6 – Safety-Related SSC Criteria and Capabilities
- Chapter 7 - NSRST SSC Criteria and Capabilities
- Chapter 8 - Plant Programs
- Chapter 9 – Radioactive Waste Management
- Chapter 10 - Control of Occupational and Public Dose
- Chapter 11 – Conduct of Operations
- Chapter 12 – Initial Startup and Test Programs

** Subject to DG-1404 release

Safety Design Approach

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Design Analysis Approach

Our safety-by-design approach means the following:

- Identify functions that ensure the fuel remains intact for all operating conditions and licensing basis events
- Select design features that can <u>inherently</u> and <u>passively</u> perform all required safety functions

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Required Safety Functions (RSFs)

Safety Function	Control Reactivity	Control Heat Removal	Retain Radionuclides in Fuel Particles and Pebbles	Limit Water/Steam Ingress
	Control – Inherently/Passively	Cool - Passively	Contain - Passively	Control – Passive/Active
Design Selection / Feature	• *Low power density* • *Low excess reactivity* • *Strong negative temperature coefficient* • *Fixed phase moderator (graphite)* • *Online refueling* • *Large thermal inertia* • *Moveable poisons*	• *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 (99.999%)* • *High temperature tolerance during loss of forced heat removal* • *Multiple independent physical barriers*	• *Isolation is relatively simple and does not require a supply of electrical power* • *Prevention provided by material selection and robust design*
Analysis Tools	Neutronics AnalysisThermal and Flow Analysis	Neutronics Analysis Thermal and Flow Analysis	Neutronics Analysis Thermal and Flow Analysis Fuel Performance Analysis	Neutronics Analysis Thermal and Flow Analysis

Maintain Core Geometry

Main Factors Affecting Criticality (EM)

Negative Temperature Coefficient

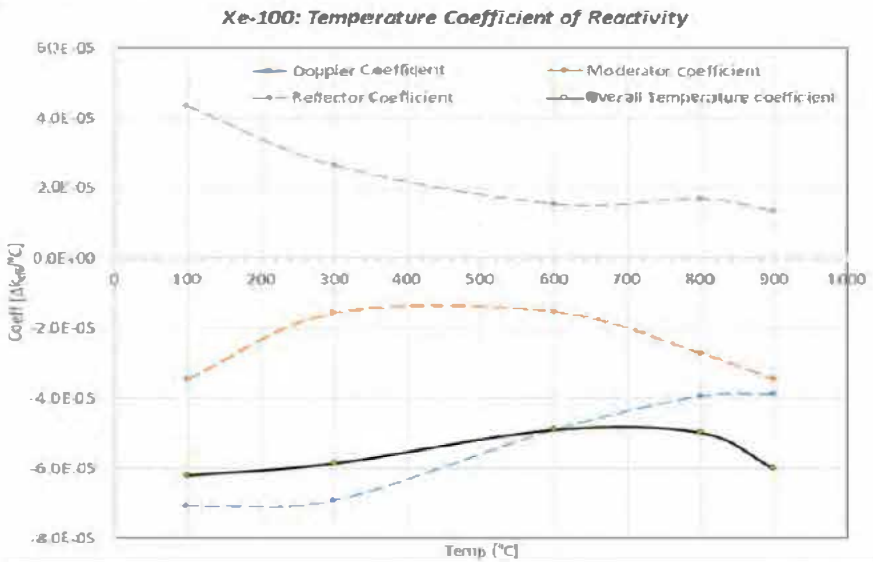
- Amount of fissile material per pebble
- U-238 as fertile material
- Moderation ratio (NC/NU)

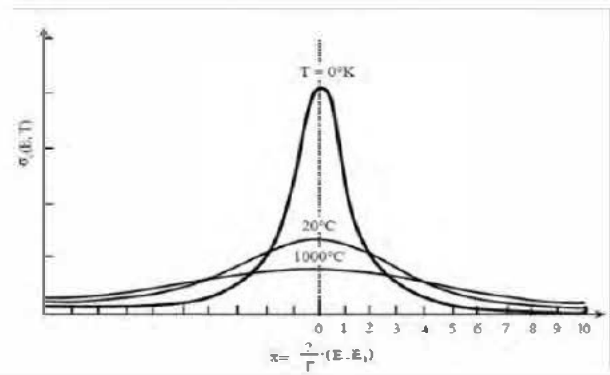
Low Core Power Density

- 4.83 MW/m3
- Low decay heat generation

Low Excess Reactivity

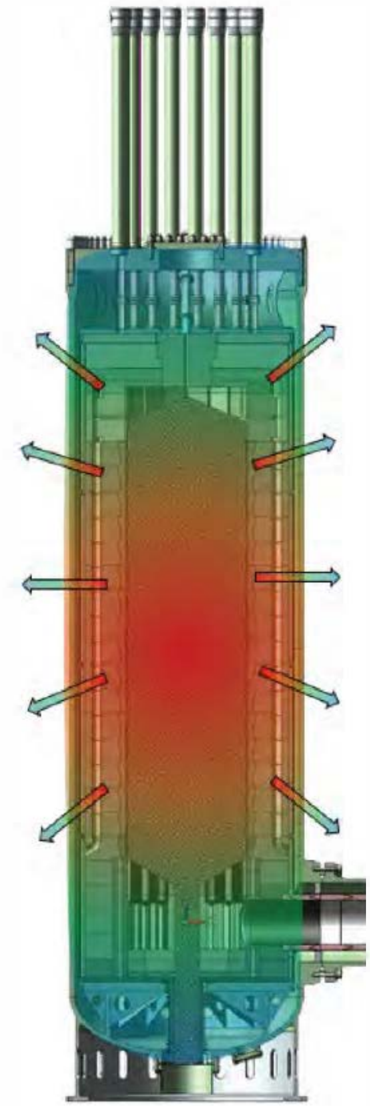
- Online refueling





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

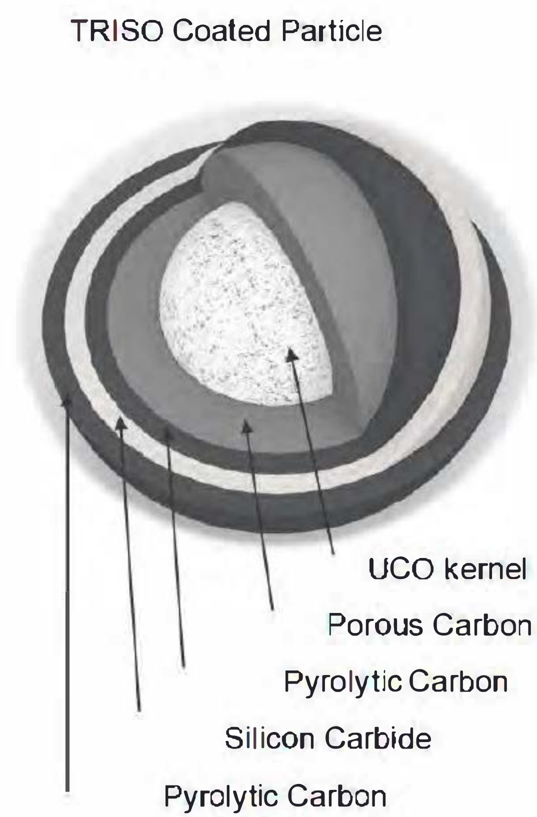


Main Factors Affecting Fuel Performance

Fuel Temperature
- Coupling between neutronics and thermal analysis needed

Fuel Burnup
- Continuous statistically-based fuel shuffling modeled to predict burnup
- Burnup measurement system

Fuel Quality
- Source term analysis accounts for manufactured fuel quality
- High quality fuel fabrication process



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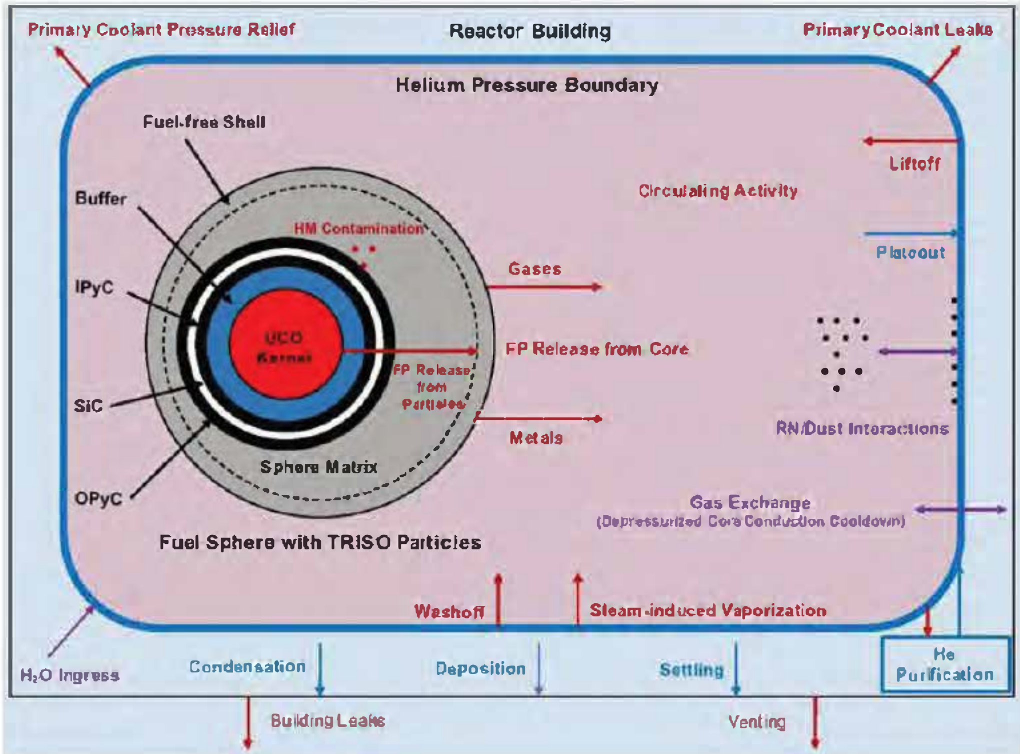
Functional Containment Approach

Our mechanistic source term development methods allow the Xe-100 to implement a functional containment approach:

- Relevant phenomena are modeled mechanistically
- Multiple barriers between the UCO kernel and receptors of interest
- X-energy's XSTERM code is a suite of modules that model these phenomena in an integration manner
- Informed by RG 1.233 / NEI 18-04 implementation



Principal Design Criteria

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Principal Design Criteria (PDC) Development

Xe-100 PDC development is a two-pronged approach and are derived from:

- RG 1.232, Appendix C "Modular High-Temperature Gas-Cooled Reactor Design Criteria (MHTGR-DC)
- NEI 18-04 and NEI 21-07 implementation activities, specifically the development of required safety functions (RSFs), required functional design criteria (RFDC), PRA safety functions (PSFs), and complementary design criteria (CDC)

The Xe-100 PDC can be categorized into three different groups:

- RFDC and CDC that perform RSFs and PSFs respectively
- Support the identification and implementation of Special Treatments
- Support normal operations

Closed Meeting Portion

Safety-Significant SSCs
PSAR Chapters 6 & 7

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Nuclear Fuel System

Xe-100 Fuel Performance Envelope:

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Xe-100 Fuel Required Safety Functions:

- Retain Radionuclides – Multi-barrier Functional Containment, high-temperature tolerance, high retention capability of fission products
- Control Reactivity – Strong negative DTC characteristics
- [[

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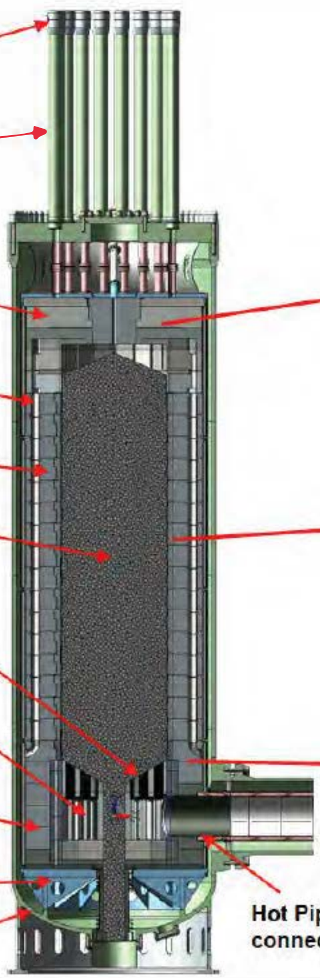
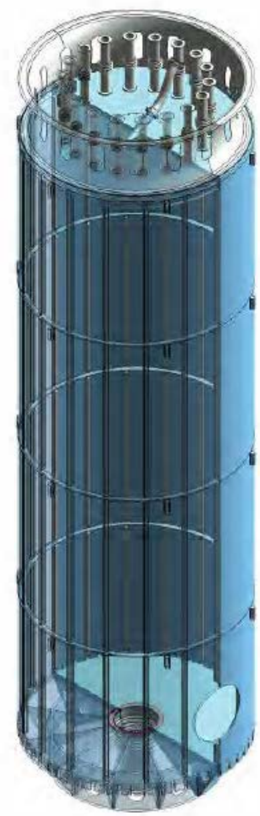
Main Power System (MPS) | Reactor System





MPS | Steam Generator

KEY DESIGN FEATURES:

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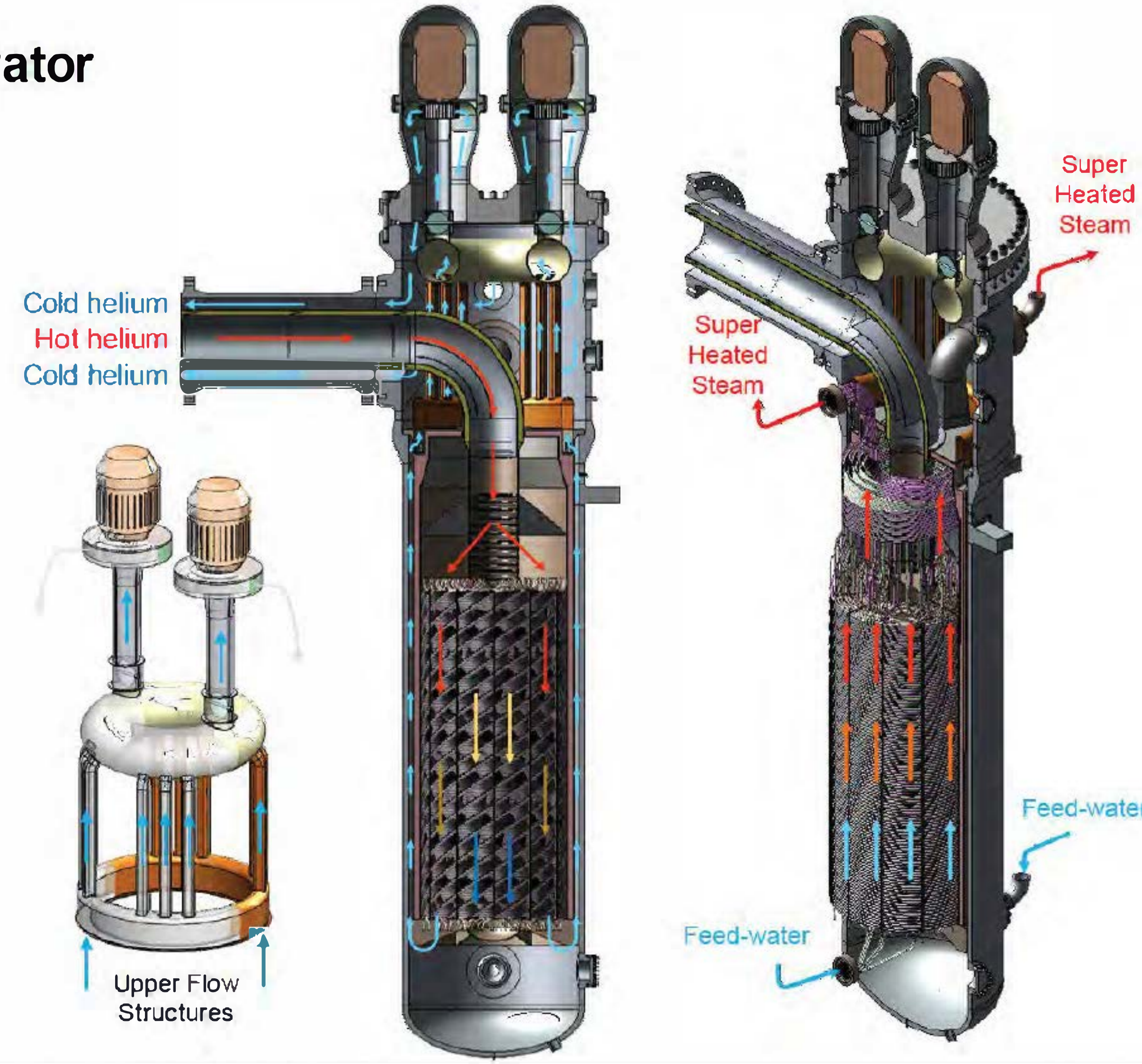

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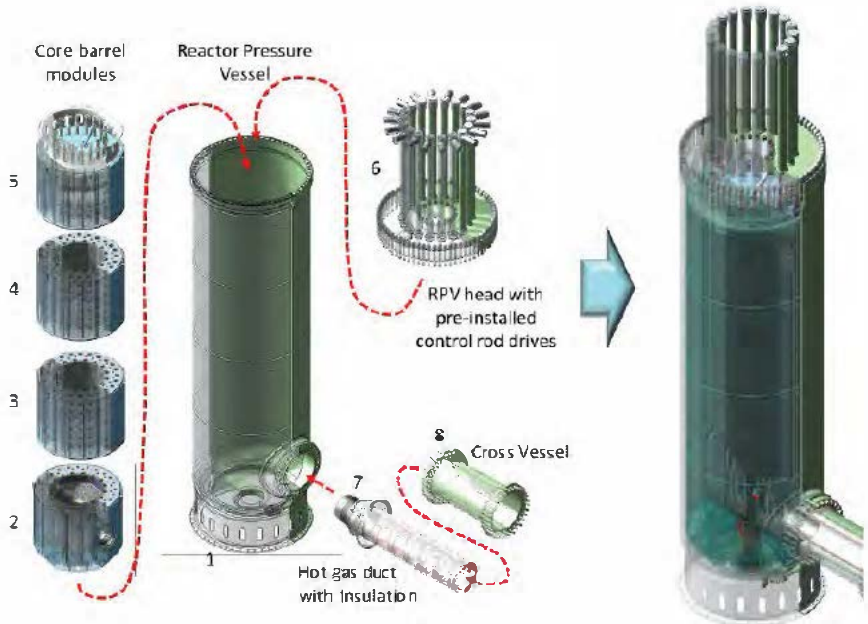
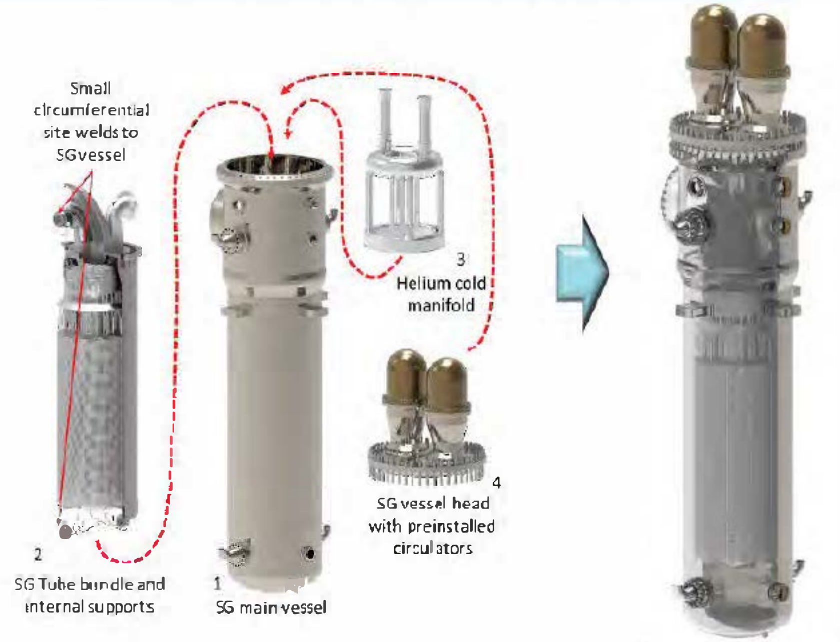
Construction and Modularization Strategy

- Overall strategy is to develop road transportable modules that can be assembled with minimal effort on-site
- Prefabricated modules can include pre-installed instrumentation harnesses for plug & play assembly on-site
- Concrete form structures can be prefabricated and installed onsite with preinstalled rebar

Reactor System Modules



Steam Generator System Modules



RCCS

KEY DESIGN FEATURES

Normal Operation

- The RCCS operates in one distinct mode to provide passive cooling. During all normal operating conditions, airflow is being provided through the inlet air plenum, and required cooling is achieved through natural convection
- Outside air enters the inlet ducts to the inlet plenum. Through natural convection (buoyancy force) the cooler outside air is forced down the downcomer and then upwards to the outlet plenum, collecting heat in the riser. Heated air is discharged back to the site atmosphere through the outlet ducts
- Maintains Reactor Cavity walls below code required 65°C

Required Safety Function

Control Heat Removal

- [[

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Components

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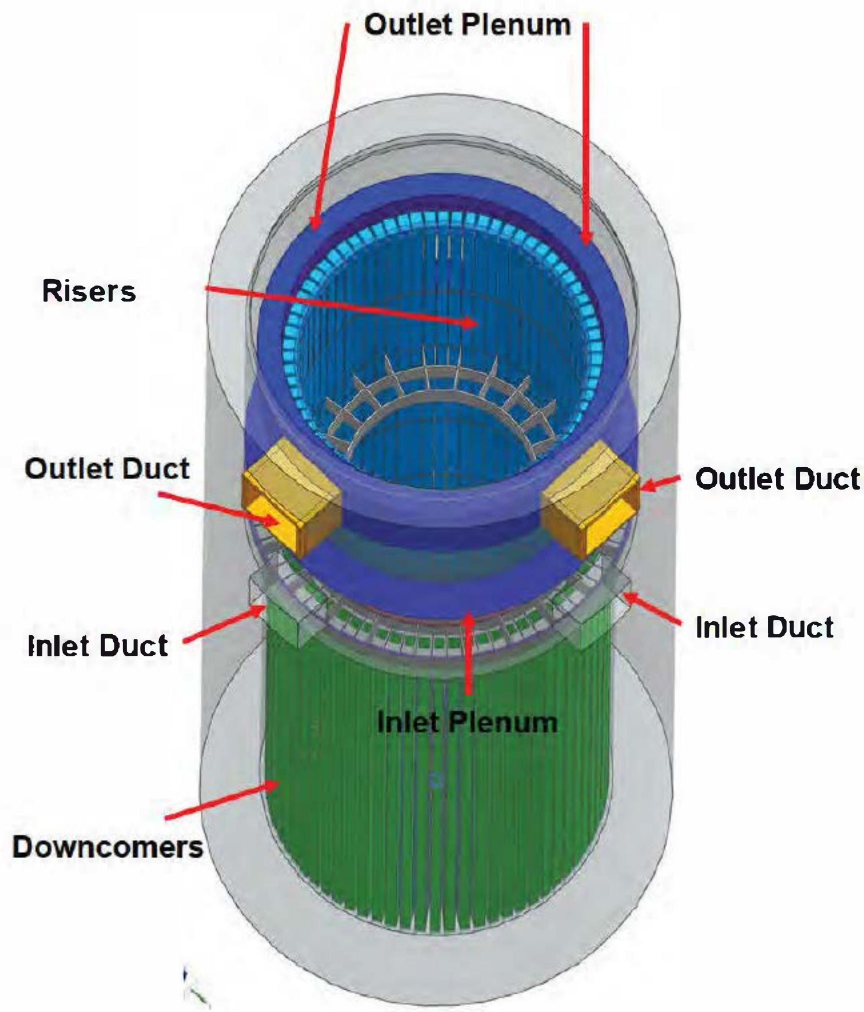
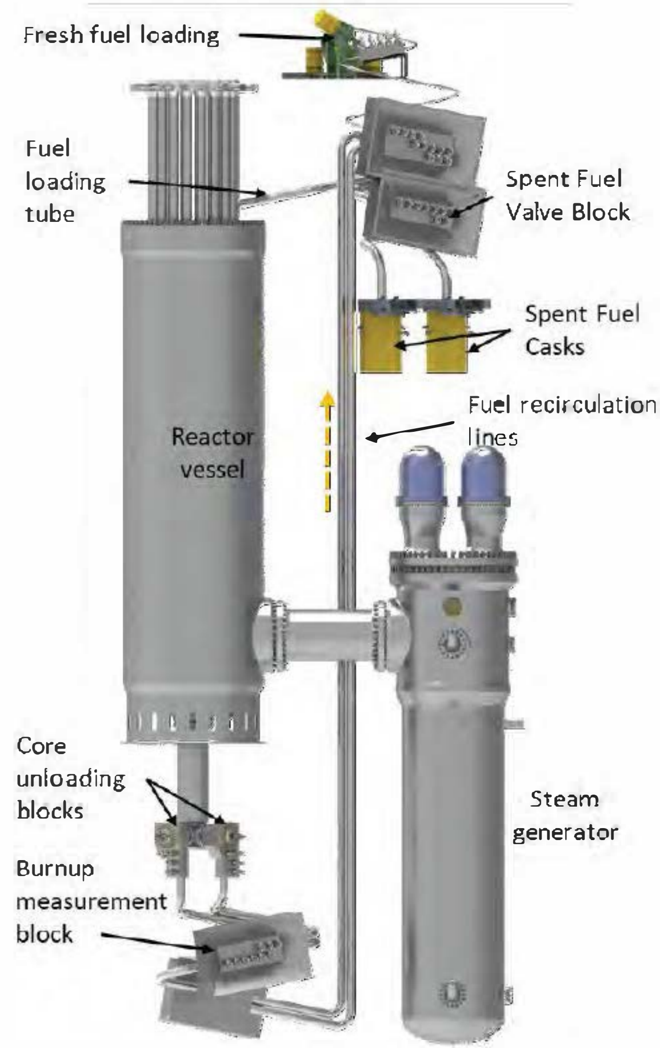


Fuel Handling System

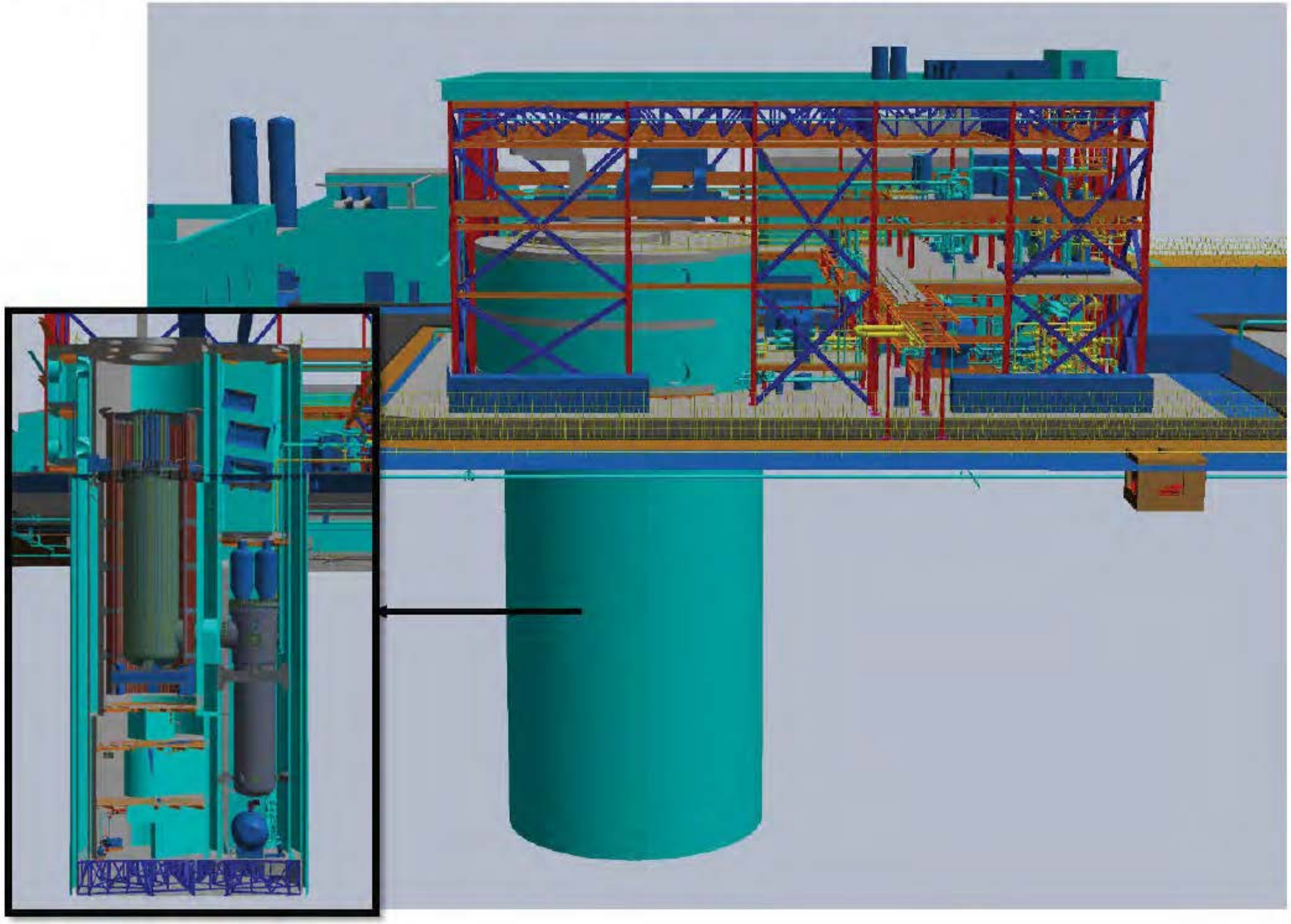
KEY DESIGN FEATURES

- The Xe-100 Fuel Handling System is a unique attribute of our plant that allows the reactor to operate continuously without the need for the traditional refueling outage every 18/24 months
- FHS is a non-safety related with special treatment system (NSRST)
- The pebble fuel form allows pebbles to be added to the top of the reactor, migrate to the bottom under gravity, and then be removed through the sphere unloading machine
- The fuel burnup is measured, and if it is not fully spent it goes through the reactor for the next pass
- On average, a fuel pebble will pass through the reactor six times over a period of about 36 months
- The FHS operates automatically without any direct operator interaction



Reactor Building & Nuclear Island Auxiliary Building

KEY DESIGN FEATURES



Spent Fuel Management

KEY DESIGN FEATURES

- [[

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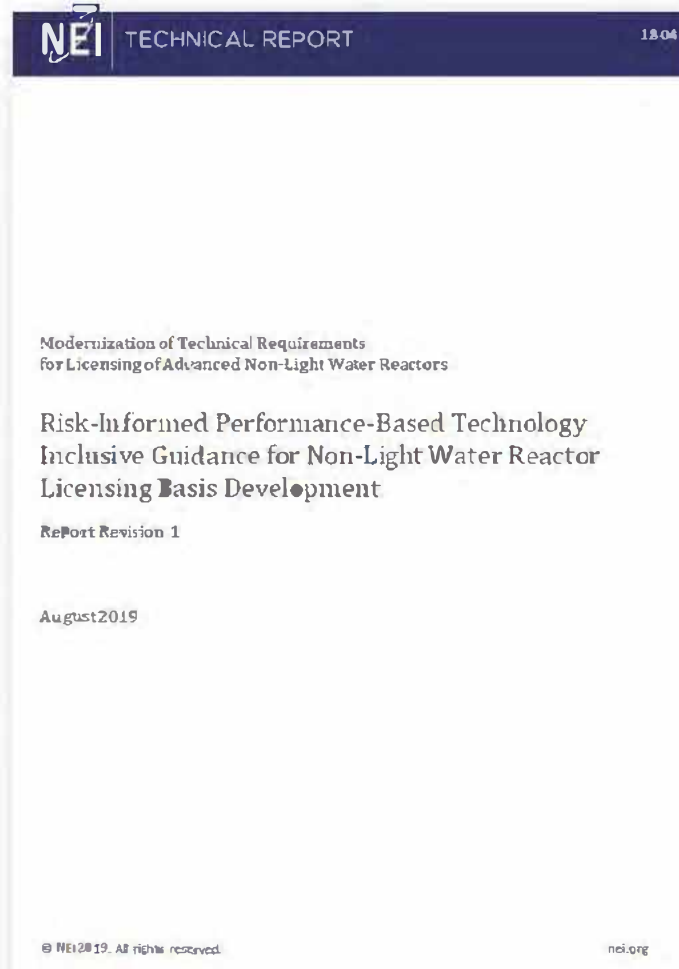
Licensing Basis Events

energy

Xe-100 Safety Design Approach | NEI 18-04

- NEI 18-04 is a risk-informed, performance-based process for:
  - Selecting Licensing Basis Events (LBEs)
  - Classifying Structures, Systems, and Components (SSCs) according to their safety significance
  - Evaluation of Defense-in-Depth
- Endorsed by the NRC with clarifications in RG 1.233
- Heavily leverages PRA and safety analysis information to inform design requirements for SSCs based on risk-insights
- The Xe-100 Program has developed guidance to implement NEI 18-04 activities, such as:
  - Integrated Decision-making Process Panel (IDPP) Charter
  - Integrated Decision-making Process (IDP) Implementation Guide with three supporting guides:
    - Xe-100 SSC Classification
    - Xe-100 Special Treatments
    - Xe-100 DID Adequacy Evaluation


NEI TECHNICAL REPORT 18-04

Modernization of Technical Requirements for Licensing of Advanced Non-Light Water Reactors

Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development

Report Revision 1

August 2019

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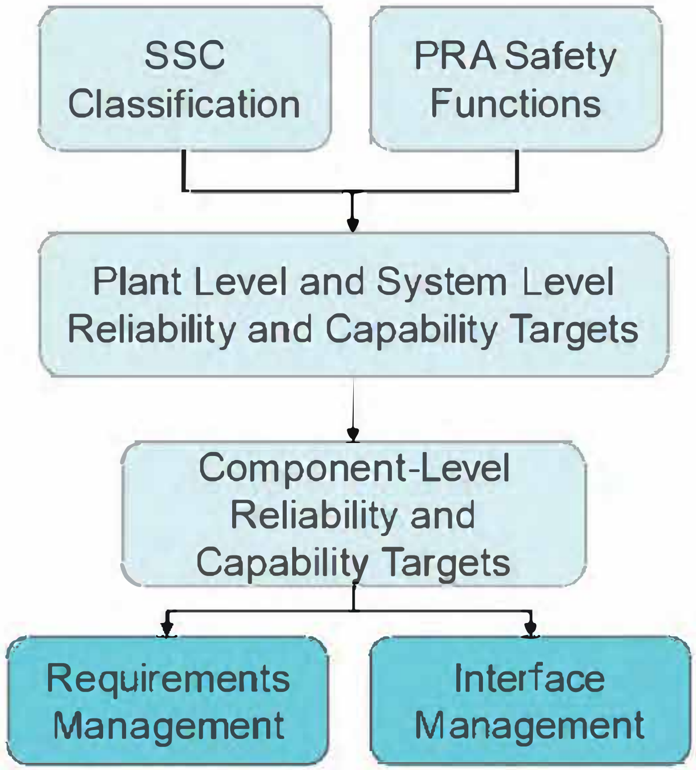
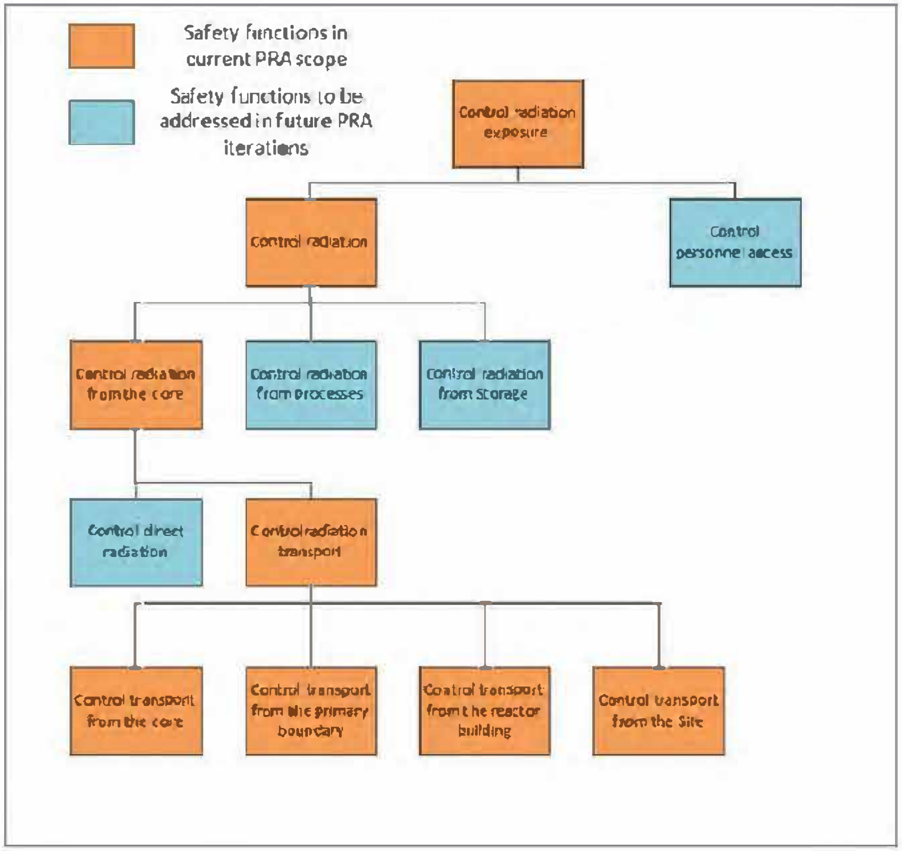
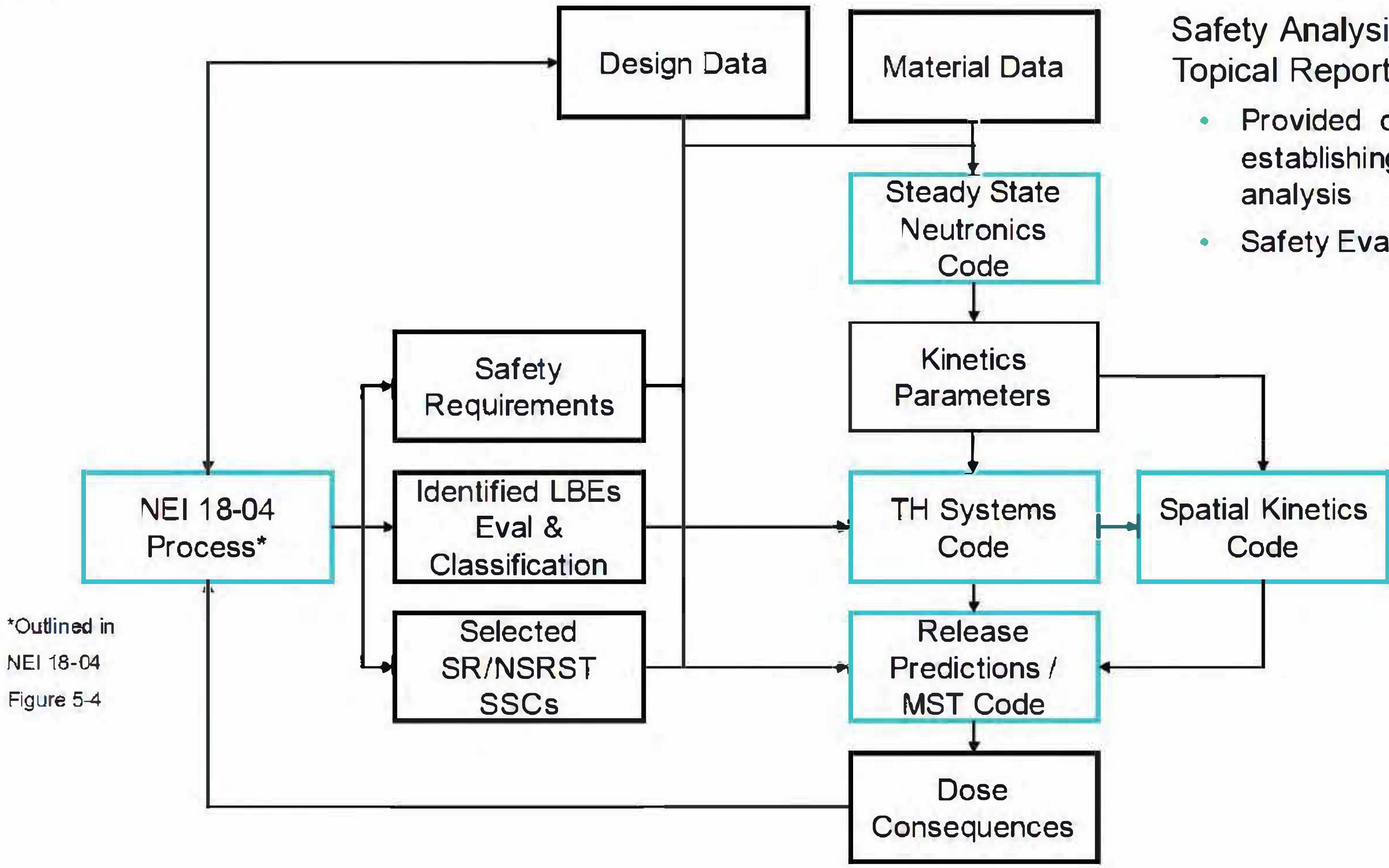
Safety Design Approach | Requirements Decomposition

Safety functions and design requirements derived from NEI 18-04 must be translated into a systems engineering process to ensure appropriate incorporation in the design.





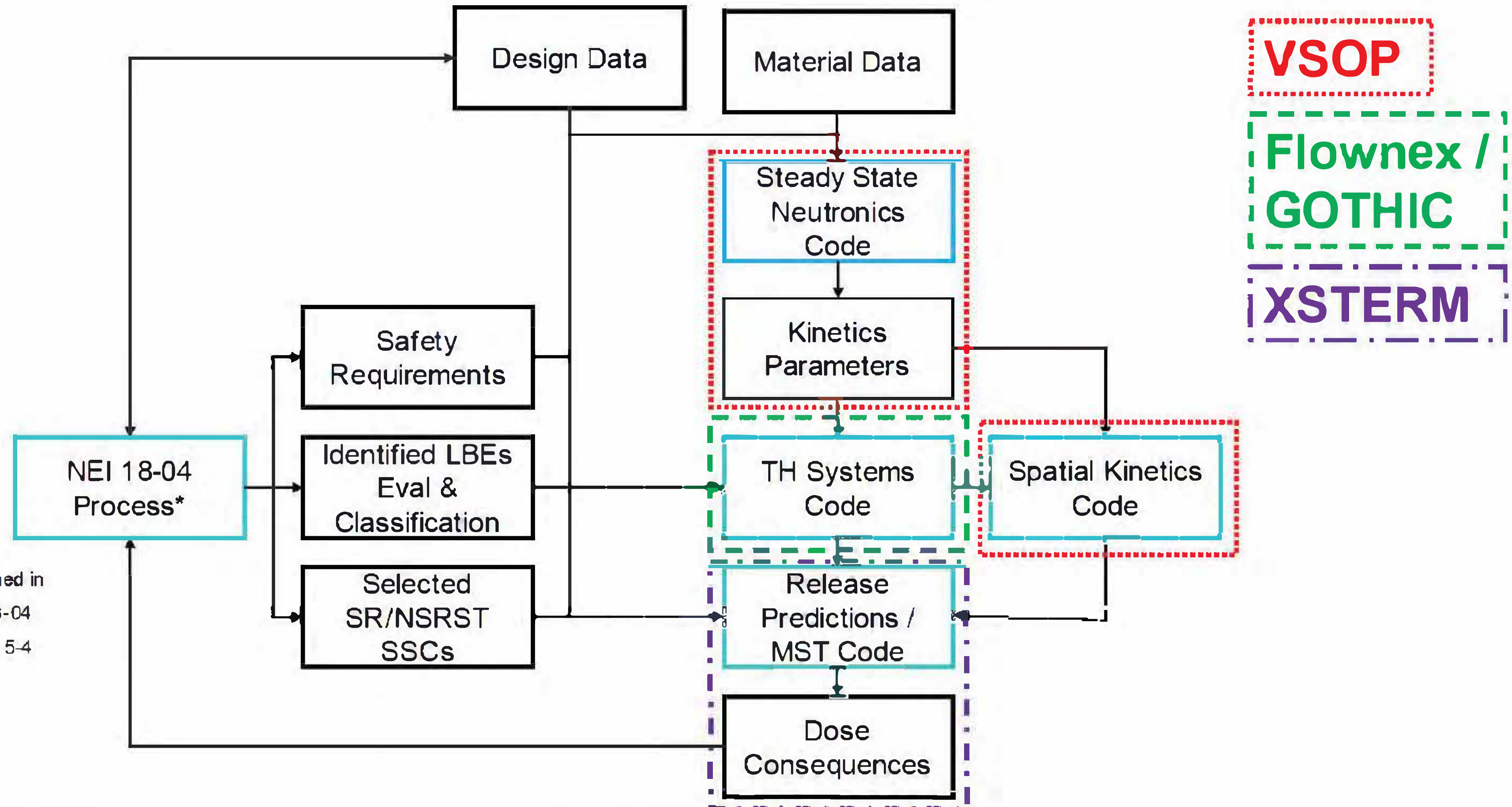
Safety Analysis Methods Framework



Safety Analysis Methods Framework Topical Report submitted 2021

- Provided overarching approach to establishing the scope of safety analysis
- Safety Evaluation issued in 2023

Safety Analysis Methods Framework | Main Computer Codes



*Outlined in NEI 18-04 Figure 5-4

energy

Flownex Overview

FLOWNEX® SIMULATION ENVIRONMENT

- Flownex is a thermodynamic, control volume-based simulation tool that can simulate a wide variety of working fluids and technologies
- Flownex is developed within a quality management system that is NQA-1 compliant

REACTOR & RCCS

- Reactor temperature and flow distribution
- Core power distribution profiles
- Point kinetic neutronics behavior
- Reactivity temperature feedback
- Control rod influence
- Natural circulation modelling

BALANCE OF PLANT

- Start-up, shut-down and load following
- Steam generator boiling and superheating
- Valve, pump & pipe sizing
- Comprehensive library of plant modeling components, fluids and materials

CONTROL SYSTEM

- Built-in Distributed Control System library of analogue and digital control components
- Integrated plant-control response modelling
- Control system testing & soft commissioning
- On-line simulation

ACCIDENT & SAFETY ANALYSES

- Natural circulation with full radiative and conjugate heat transfer
- Safety valve operations sizing & simulation
- LOCA, DLOFC, PLOFC, & other scenarios

3rd PARTY SOFTWARE

- User command coding
- RELAP for addition of established models
- MATLAB and Simulink coupling
- OPC server link for live control systems
- CAESAR II for pipe stress analyses
- Ansys Fluent for detailed 3D
- Ansys Mechanical for fluid-structure interaction

XSTERM Overview

Suite of code modules that mechanistically model the transport of radionuclides comprising the source term from their birth in fuel to potential release to the environment.

XSIM	XTDYN	XFP	XSOL	XGAS	XCORR
Flux, power, fluence & burnup, transient control	Fuel, helium & structure temperatures, gas flow rates	Fuel Performance (TRISO particle failure fractions)	Radionuclide, production, transport & release from fuel elements	Steady state gaseous radionuclide, production, transport & release from fuel elements	Fuel materials corrosion rates and radionuclide release rates due to corrosion

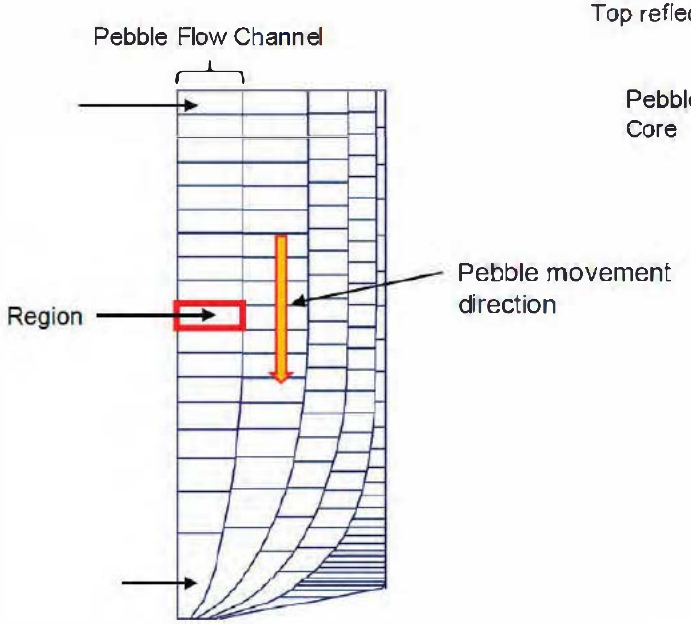
XTRIT	XDUST	XHPB	XRB	XDIS	XRAD
Production, transport in HPB and permeation of H-3 through SG tubes	Graphite and metallic dust production rates (one-time calculation)	Radionuclide & dust transport and distributions within the HPB	Radionuclide & dust transport and distributions within the RB	Radionuclide & dust dispersion into environment and public dose at EAB	Simple 0-D radionuclide plant mass balance (used for checks, not integrated runs)

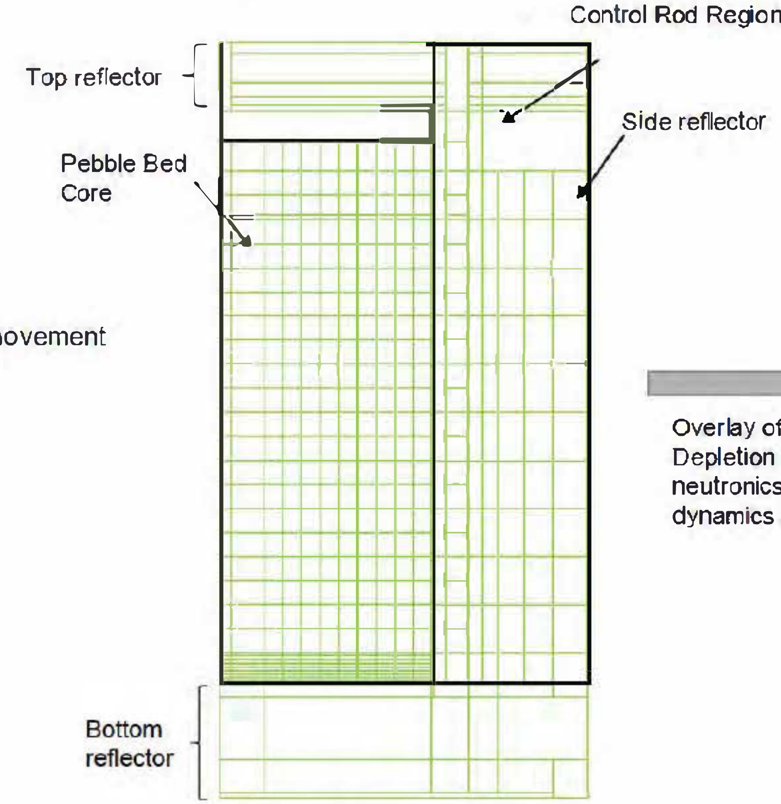
energy

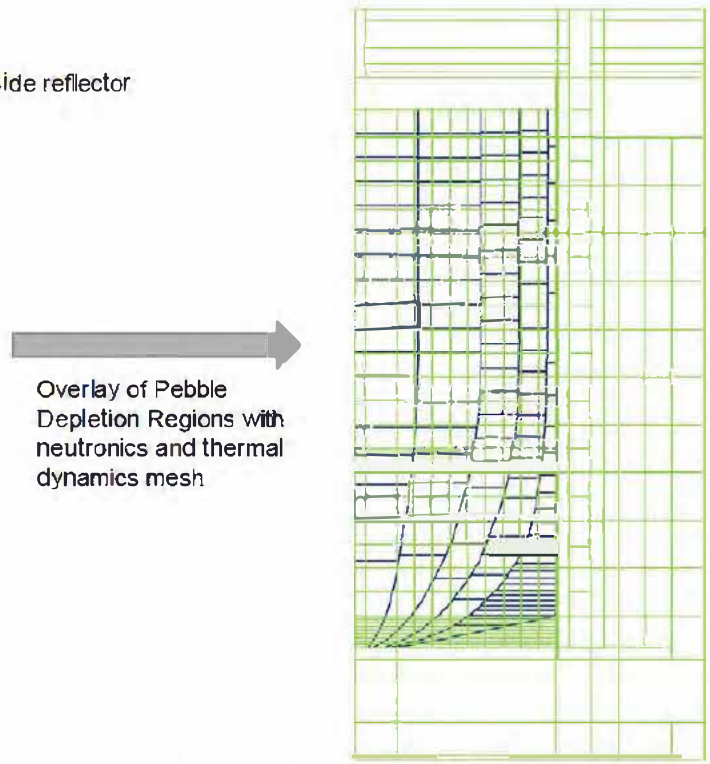
VSOP Overview

- VSOP stands for Very Superior Old Program
- What it does: Comprehensive numerical simulation of the physical processes of pebble bed reactors
  - Set up the reactor and its fuel elements
  - Process the relevant cross-sections
  - Evaluate the neutron spectrum
  - Perform the neutron diffusion calculation (2D or 3D), fuel burnup, fuel shuffling, reactor control, thermo-dynamics (2D) and fuel cycle costs
  - Simulates all phases of reactor operation from the initial start-up to the equilibrium
- For our analysis, we use 2D, R-Z geometry
- To perform equilibrium calculations:
  - Establish reactor geometry, fuel design, and nuclear data
  - Create fuel shuffling scheme
  - Set up helium flow paths and perform thermal dynamics calculations to account for feedback
  - Repeat calculations until equilibrium state (converged k-eff, flux profile, temperatures, pebble burnups from each pass in each region, etc.)

VSOP99 Multi-Physics Analysis







Depletion Regions

- Defines pebble velocity
- Flow channels are defined by discrete element methods (DEM) analysis
- Each region is a spectrum zone
- Each region has 6 batches to represent 6-pass fueling scheme

Neutronics and Thermal Dynamics Coarse Mesh

- Defines the spectrum zone outside of the pebble bed
- Dictates placement of materials and helium flow paths
- Flux, power, and temperatures reported in both coarse and fine mesh

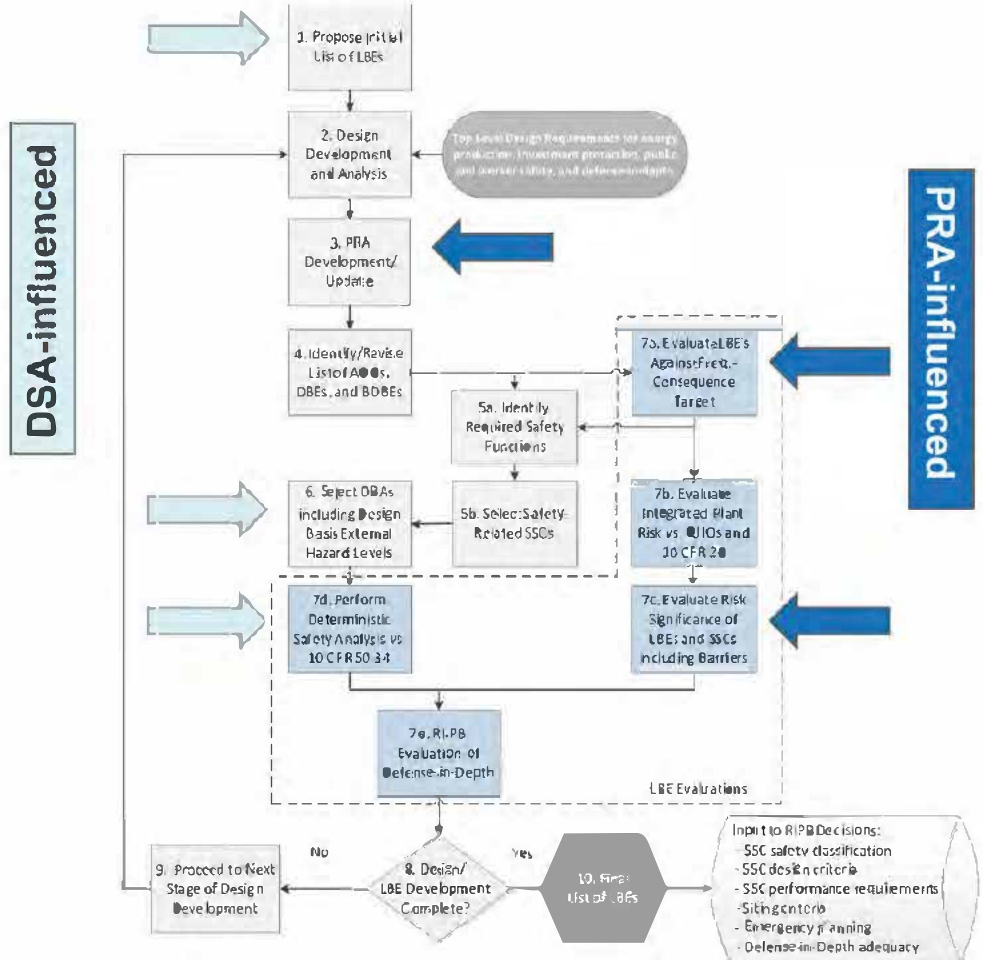
Feedback Mesh

- Flux, power, and temperatures mapped back to spectrum zones
- 6-pass pebbles in the core are treated separately in terms of fluence, power, and temperature feedback

Licensing Basis Event Selection

Approach that incorporates deterministic and probabilistic methods that is:

- Systematic and reproducible
- Sufficiently complete
- Available for timely input to design decisions
- Risk-informed and performance-based
- Reactor technology-inclusive
- Consistent with applicable regulatory requirements



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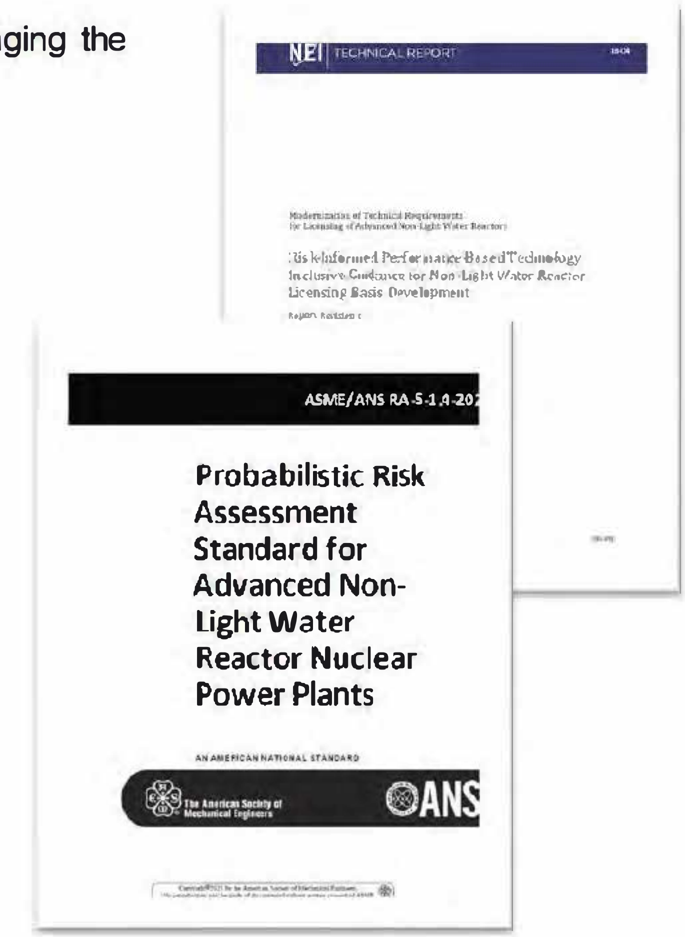
Licensing Basis Event Development

- Licensing Basis Events developed in accordance with NEI 18-04 process leveraging the Non-Light Water Reactor PRA Standard
- Overall strategy for PSAR
  - PRA covers LBEs for full-power internal events
  - Supplemental evaluations address (deterministic evaluations):
    - Low power modes
    - Non-core sources of radioactivity
- Major Internal Initiating Events
  - Depressurization events
  - Loss of secondary (loss of feedwater, steam/feed line break)
  - Rod withdrawal
  - Steam generator tube rupture
  - Transient events (turbine trip, reactor/circulator trip)
- Major design basis accident assumptions
  - No credit for reactor trip (shutdown on inherent reactivity)
  - No credit for active cooling systems (passive RCCS cooling)
  - No credit for retention or radionuclides in building



Licensing Basis Event Overviews

- The following slides provide an overview of several representative LBEs
  - Design Basis Accidents are shown (only safety-related SSCs are credited)
- Note: Results are preliminary
  - Based on preliminary methodologies
  - Many initial conservatisms included that are being refined
  - Based on preliminary design
- Organization
  - General event sequence
  - Phenomena of interest
  - FOM/Success criteria
  - Modeling results

Licensing Basis Event | [[

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Licensing Basis Event | [[ ]] P

Testing Programs

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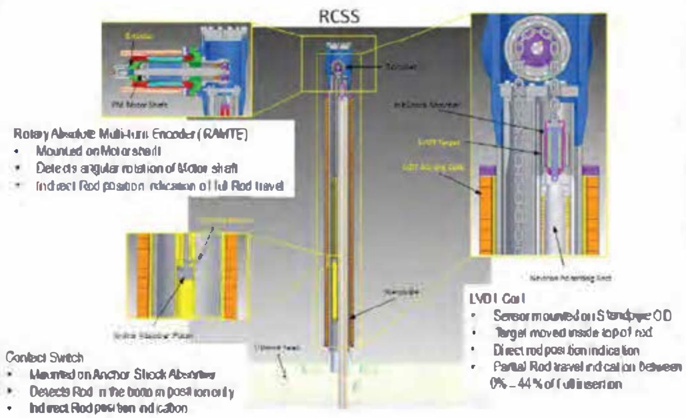
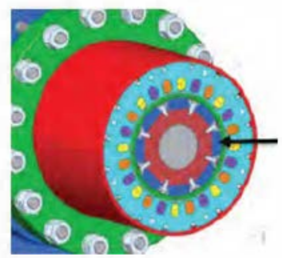
Key FOAK Implementation in Systems | Risks & Mitigations

FOAK System	Key Engineering Risks	Mitigation Measures
Helium Circulator System (HCS)	• [[	
Fuel Handling System (FHS)		
Burn-Up Measurement System (BUMS)		
Reactivity Control & Shutdown System (RCSS)		
Spent Fuel Storage System (SFSS)		]]P







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Helium Test Facility

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Helium Test Facility

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Other Test Programs

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Training Program & Simulator Development

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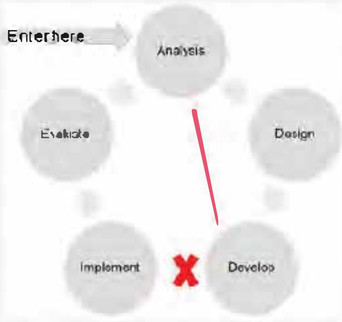
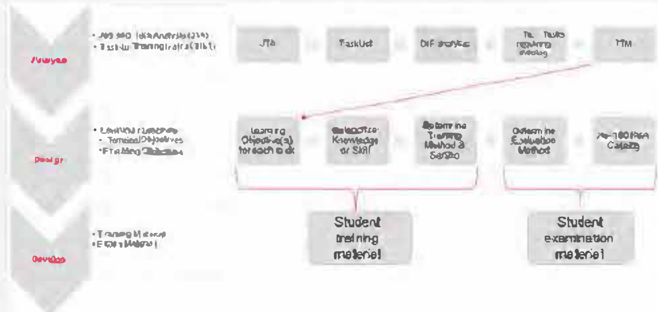
Training Update | Roadmap to 2030

SAT / ADDIE



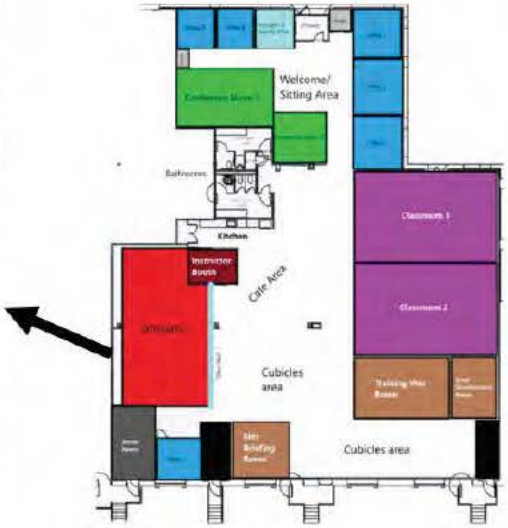


Schedule Constraints

- ❑ 10 CFR 50.120 (b)
- ❑ 10 CFR Part 73
- ❑ NUREG-0800 Ch.13.2.1.III.(f)

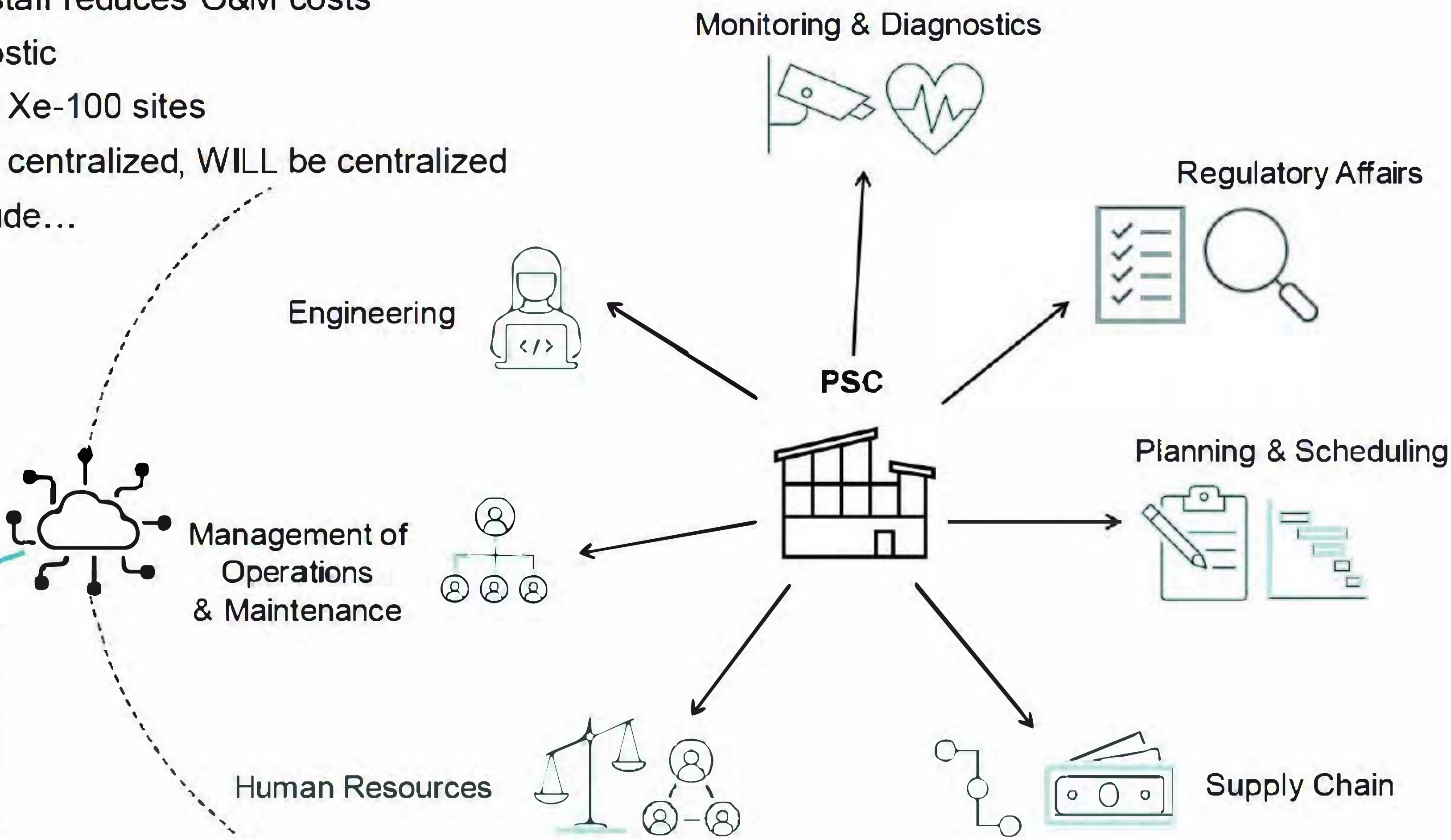
Xe-100 Operator Training Simulator & Facilities in Frederick Office

- Full scope Xe-100 Operator Training Simulator
- 2 x Classrooms for initial Operator Training (25 Desks Each)
- Space for 22 Employees plus students – Training, Simulator, HFE
- Q4 2023 Readiness
- Implementing SAT methodologies for all Xe-100 Training Programs



Centralized Staffing Philosophy with Plant Support Center (PSC)

- Centralizing certain staff reduces O&M costs
- PSC is location agnostic
- Can support multiple Xe-100 sites
- Any staff that can be centralized, WILL be centralized
- Responsibilities include…



Briefing on Scientific Computer Code Investment Plan

May 4, 2023

Scientific Computer Code Investment Plan

Cinthya Roman

Deputy Director (acting)

Division of Systems Analysis

Office of Nuclear Regulatory Research

Agenda

1. Introduction
2. NRC Computer Code Assessment
3. Investments and Resource Considerations
4. Intake Process
5. Where are we headed?
6. Tiered high performance computing strategy
7. Conclusion

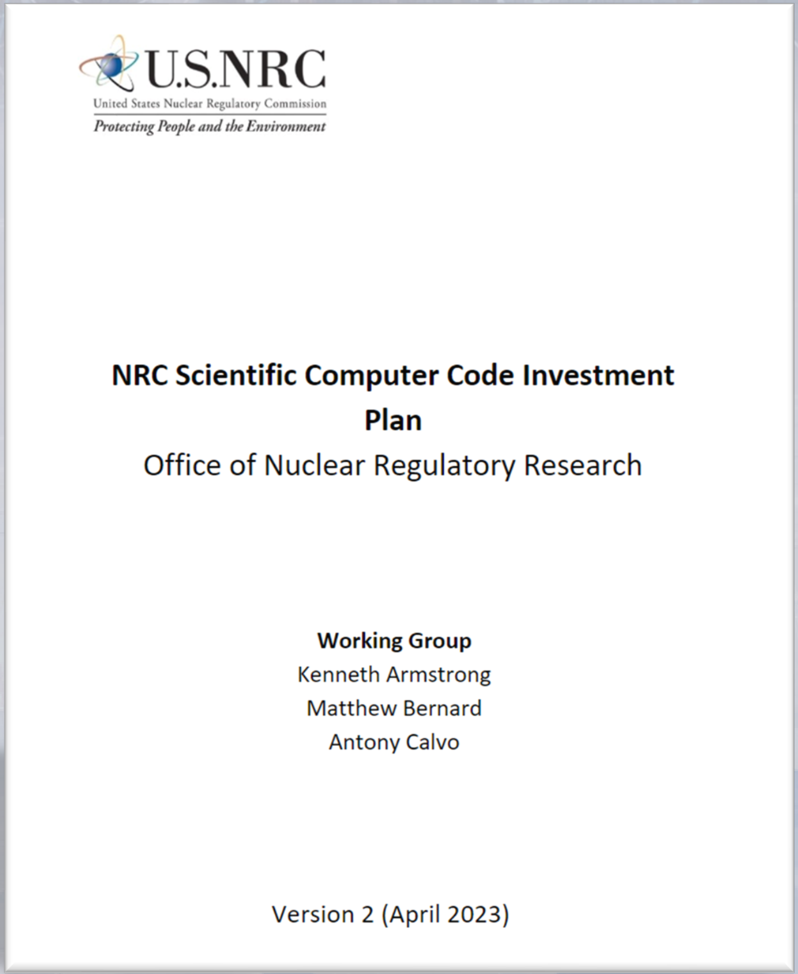
Ensuring Scientific Computer Code Capabilities

Request:

" … work with the technical offices to review in a holistic way the existing inventory of codes that the NRC uses to develop a long-term investment plan to support future use and resource requirements."

Success:

- Developed an integrated management tool
- Stabilized annual resources
- Informed budget formulation process
- Identified staff and contractor expertise requirements
- Documented process


U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

NRC Scientific Computer Code Investment Plan

Office of Nuclear Regulatory Research

Working Group
Kenneth Armstrong
Matthew Bernard
Antony Calvo

Version 2 (April 2023)

Scientific Computer Code Investment Plan

Kenneth Armstrong

Chief, Code and Reactor Analysis Branch II

Division of Systems Analysis

Office of Nuclear Regulatory Research

Assessing the NRC's Scientific Computer Codes

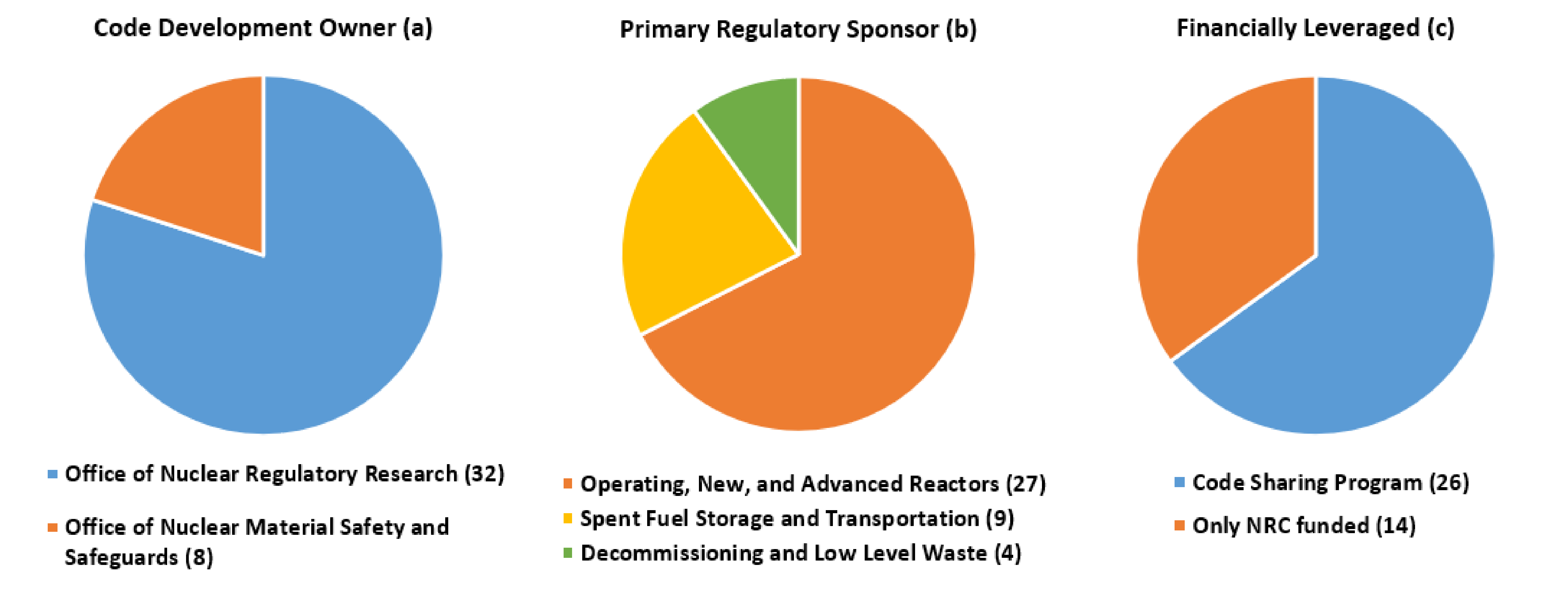
Total codes – 40

- Archived codes – 15
- Active codes – 25
  - Modernizing – 3
  - Consolidating – 8 into 3
- Most developed by RES and financially leveraged

Area of Analysis	Scientific Computer Code
Accident Progression and Source Term	MELCOR
	RTT
Atmospheric Dispersion	ARCON
	PAVAN
	TEPHRA
Chemical Dispersion	HABIT
Consequence	MACCS
Decommissioning	DandD
	GENII
	MILDOS
	RESRAD
	VSP
Dose Assessment	GALE
	NRCDose3
	RADTRAD
	NRC RADTRAN
	RASCAL
	VARSKIN+
External Hazards	PVHM-YM
Fuels	FAST

Area of Analysis	Scientific Computer Code
Geographic	OLYMPUS DISS
Graphical User Interface	PiMAL
	SNAP
Human Reliability	IDHEAS-ECA
	SACADA
Hydrology	BREATH
	MULTIFLO
	TPA
	xFlo
Materials	3D STRESS
	FAVPRO
	FES
	LEAPOR
Neutronics	SCALE
	PARCS
Probabilistic Risk Assessment	xLPR
	SAPHIRE
Record Database	Radiological Toolbox
Thermal-Hydraulics	RELAP5
	TRACE

Scientific Computer Code Portfolio



Cooperative Code Development Programs

Code Application and Maintenance Program (CAMP)

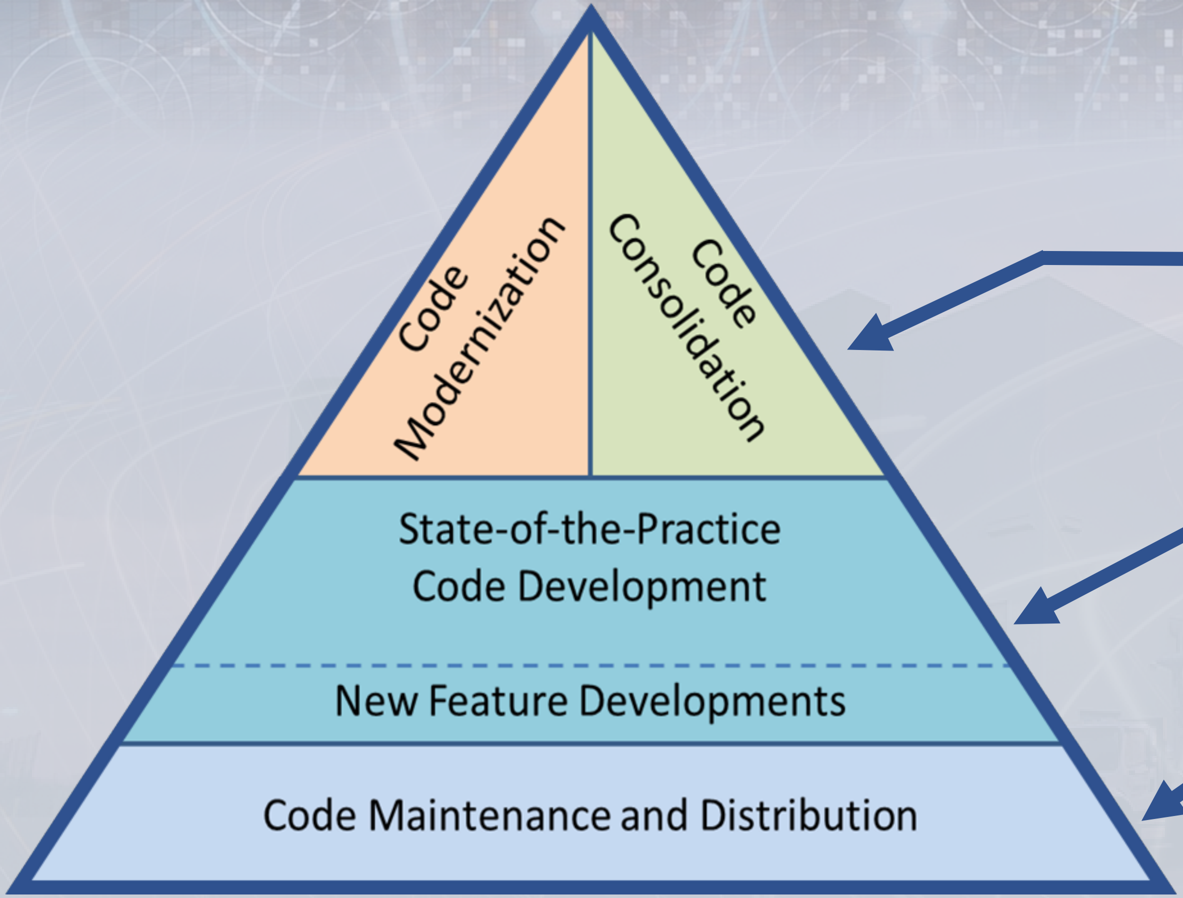
Cooperative Severe Accident Research Program (CSARP)

Radiation Protection Computer Code Analysis and Maintenance Program (RAMP)

Other cooperative arrangements exist with codes such as FAST, FAVPRO, SNAP, SCALE, and xLPR

Leveraging codes from partners such as DOE, EPA, and EPRI are beneficial

Applying Resources Strategically

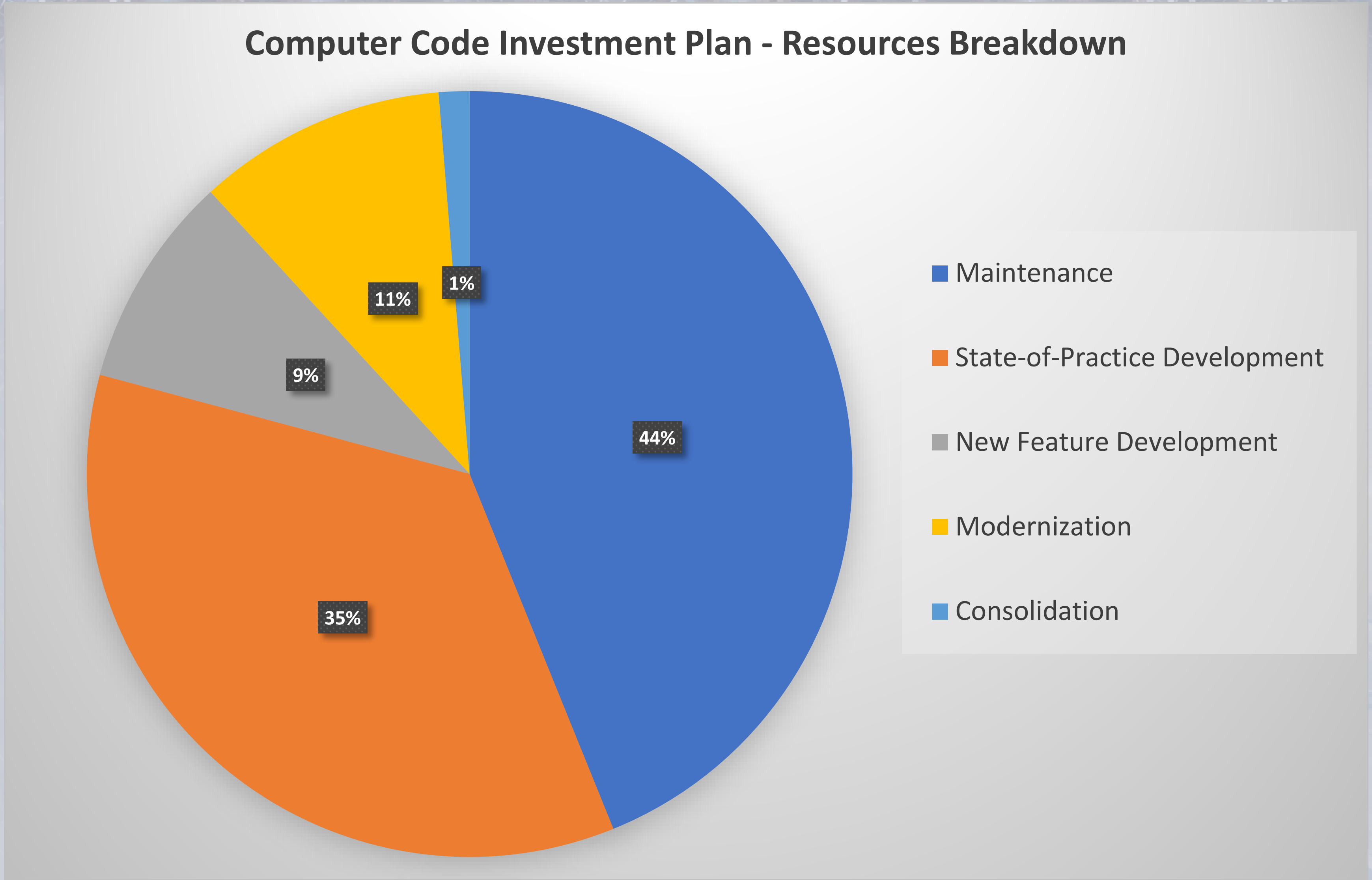


- Significant efforts, span multiple fiscal years
- Resources planned for the full scope of the project to ensure success of investment

- Updates to incorporate advancements made by industry
- Minor code changes that enhance the code usability or improve confidence in the model

- Recurring maintenance cost to fix bugs, ensure stability/operability with current operating systems
- Ensure IT security compliance

Financial Observations



Major Code Developments

State-of-Practice Developments

- Accident tolerant fuel (ATF)
- Fuel burnup and enrichment extensions
- Advanced non-LWR readiness
- Small modular reactors (SMRs)

New Feature Developments

- Uncertainty analysis
- Interoperability between codes
- Improve cloud-based computing

Modernization Investments

FAVPRO (fracture mechanics analysis)
- Timeline: FY20 – FY24

MELCOR (severe accident analysis)
- Timeline: FY18 – FY25

SAPHIRE (probabilistic risk assessments)
- Timeline: FY20 – FY26

MACCS (consequence analysis)
- Timeline: FY25 – FY27

RASCAL (dose analysis)
- Timeline: FY25 – FY28

Being evaluated – TRACE and PARCS

Consolidation Investments

SIERRA (atmospheric codes)

- Combine ARCON, PAVAN, and XOQDOQ into a single ATD module in SIERRA
- Combine GALE and NRCDose3 into additional SIERRA modules
- Timeline: FY21 – FY26

RABIT (habitability codes)

- Combine SNAP/RADTRAD and HABIT into a single code
- Timeline: FY25 – FY28

VARSKIN+ (dose codes)

- Combine VARSKIN+ and Radiological Toolbox into a single code
- Timeline: FY26 – FY28

Scientific Computer Code Investment Plan

Matthew Bernard

Reactor Systems Engineer (TRACE Development)

Division of Systems Analysis

Office of Nuclear Regulatory Research

Investment Process

- **Justify** — Justify Need for a Code
- **Survey** — Survey Options
- **Identify** — Identify Maintenance and Distribution Needs
- **Identify** — Identify Development Needs
- **Planning** — Resource Planning

Intake Process

Type of Development: Code(s)

DESCRIPTION OF CURRENT STATE	IMPACT IF NOT RESOURCED

NEED / REQUIREMENT

DELIVERABLE(S)

Major Deliverables (Code/Feature Releases)	**Date** (MM/DD/YYYY)

ACTIVITIES THE CODE SUPPORTS

RESOURCE REQUIREMENTS, $ K

Resource Requirements		FY21		FY22		FY23		FY24		FY25		FY26		FY27	
Activity	Business Line/Product	$K	FTE	$K	FTE	$K	FTE	$K	FTE	$K	FTE	$K	FTE	$K	FTE
Maintenance															

Lead :
UNR/RAR:

Code Investment Chart

Note: financial input (removed) is for planning purposes and depends on future funding request reviews and availability

Type of Development: TRACE

DESCRIPTION OF CURRENT STATE

TRACE models thermal-hydraulic phenomena in reactor systems. It is the agency's flagship tool for performing design basis as well as transient safety analysis and has been under development in one form or another for over 40 years. It is currently written in FORTRAN 2003 and C. It is state-of-the-practice in terms of modeling capabilities, is coupled to the PARCS code, and can be coupled with other codes, if necessary.

IMPACT IF NOT RESOURCED

- TRACE must be continually maintained to ensure useability/operability, maintain staff/contractor core capability, and provide training/code distribution.
- If TRACE is not developed to state-of-practice, then the NRC staff will not be able to keep pace with industry's development of new fuel and reactor designs.
- If new features are not integrated into TRACE, large areas of uncertainty won't be addressed which could cause over-conservatisms (e.g., safety margin penalties) in future reviews.

NEED / REQUIREMENT

- TRACE requires ongoing maintenance (e.g., fix bugs, operability with IT systems, V&V, distribution) to ensure useability and also modernize its training program.
- TRACE requires development to support confirmatory studies for new fuel designs (e.g., ATF and HBU) and small modular reactors.
- TRACE needs new feature development to reduce uncertainty in safety margins, improve uncertainty analysis/qualification, and improve code predictions from experimental results.

DELIVERABLE(S)

Major Deliverables (Code/Feature Releases)	**Date** (MM/DD/YYYY)
TRACE V5.0 Patch 7	3/31/2022
TRACE V5.0 Patch 8	3/31/2023
TRACE V5.0 Patch 9	3/31/2024
TRACE V6.0	3/31/2025

ACTIVITIES THE CODE SUPPORTS

TRACE supports many regulatory applications, including: 1) ATF rulemaking and licensing, 2) review of small modular reactor designs, 3) license amendment request for LWRs, and 4) potential review of advanced non-LWR designs.

RESOURCE REQUIREMENTS, $ K

Resource Requirements		FY22		FY23		FY24		FY25		FY26		FY27		FY28	
Activity	**Business Line/Product**	**$K**	**FTE**	**$K**	**FTE**	**$K**	**FTE**	**$K**	**FTE**	**$K**	**FTE**	**$K**	**FTE**	**$K**	**FTE**
Maintenance (active)	11-6-174-1145														
Develop Training Tools	11-6-174-1145														
Development (Fuels)	11-6-174-1145														
Development (SMR)	11-6-174-1145														
New Feature Development	11-6-174-1145														
CAMP	11-6-174-1145														
Modernization (consider)	11-6-174-1145														

Leads: Christopher Murray and Matt Bernard, RES/DSA/CRAB

UNR/RAR: NRR-2021-019, NRR-2021-001, NRR-2021-006, NRR-2021-013, NRR-2021-015

Where are we headed

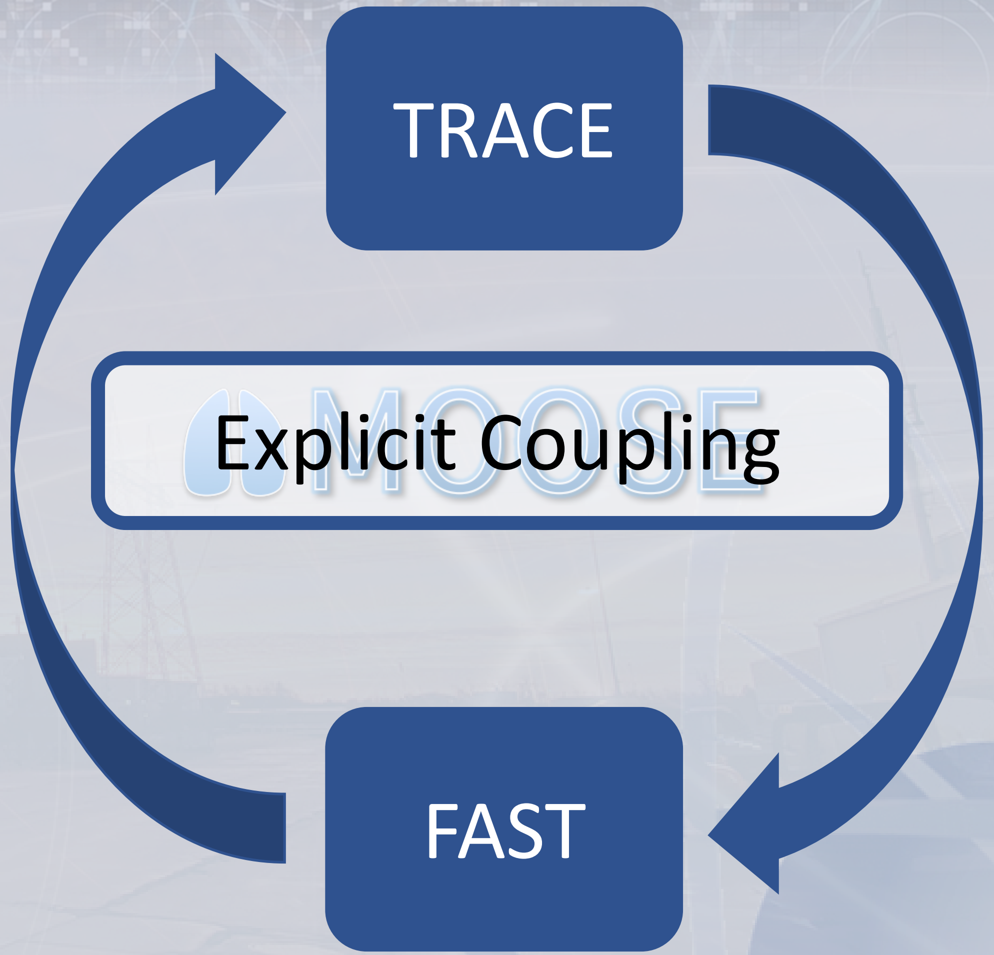
- New nuclear technologies require the NRC to modernize its approach to confirmatory analyses.
- Code development approach must integrate modern development tools to streamline updates.
- New physics models may be needed in NRC codes.
- State-of-the-art capabilities developed at the DOE Labs should be leveraged.

TRACE-New Feature Development

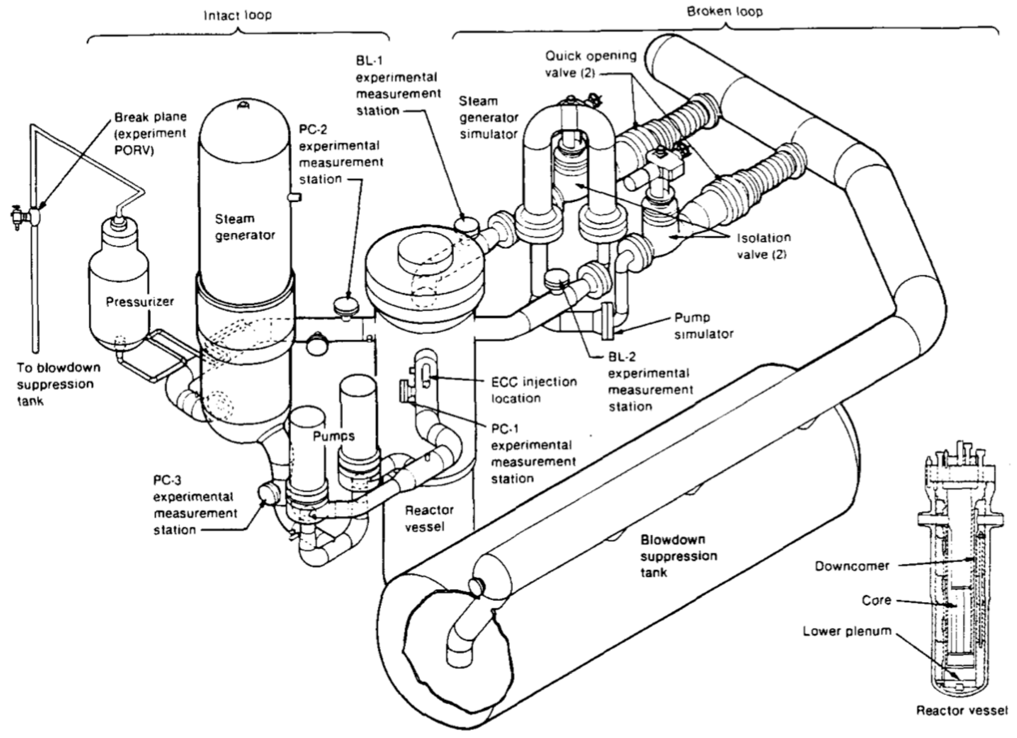
- ATF/HBU initiatives will require more detailed core models than traditionally used
- TRACE lacks some of the detailed fuel rod models in FAST

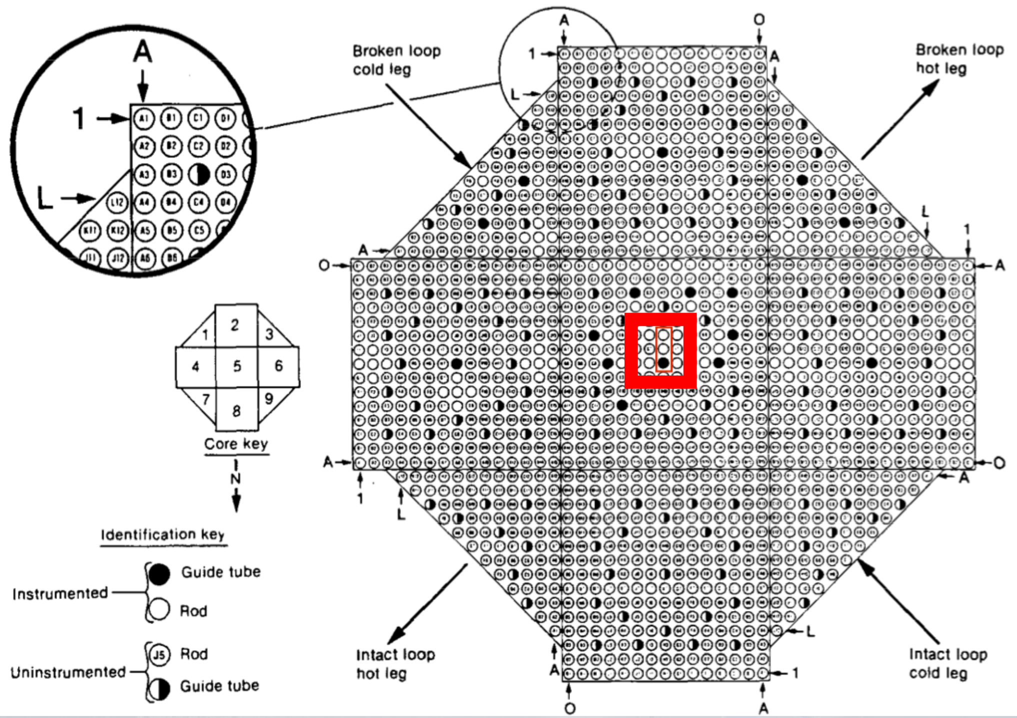
- Scripts require extensive knowledge of TRACE output
- Explicit coupling during the transient may affect fuel prediction behavior

- MOOSE code coupling simplifies analysis methodology
- MOOSE coupling provides TRACE with modern fuel models which could improve overall prediction



Coupling Demonstration Model - LOFT



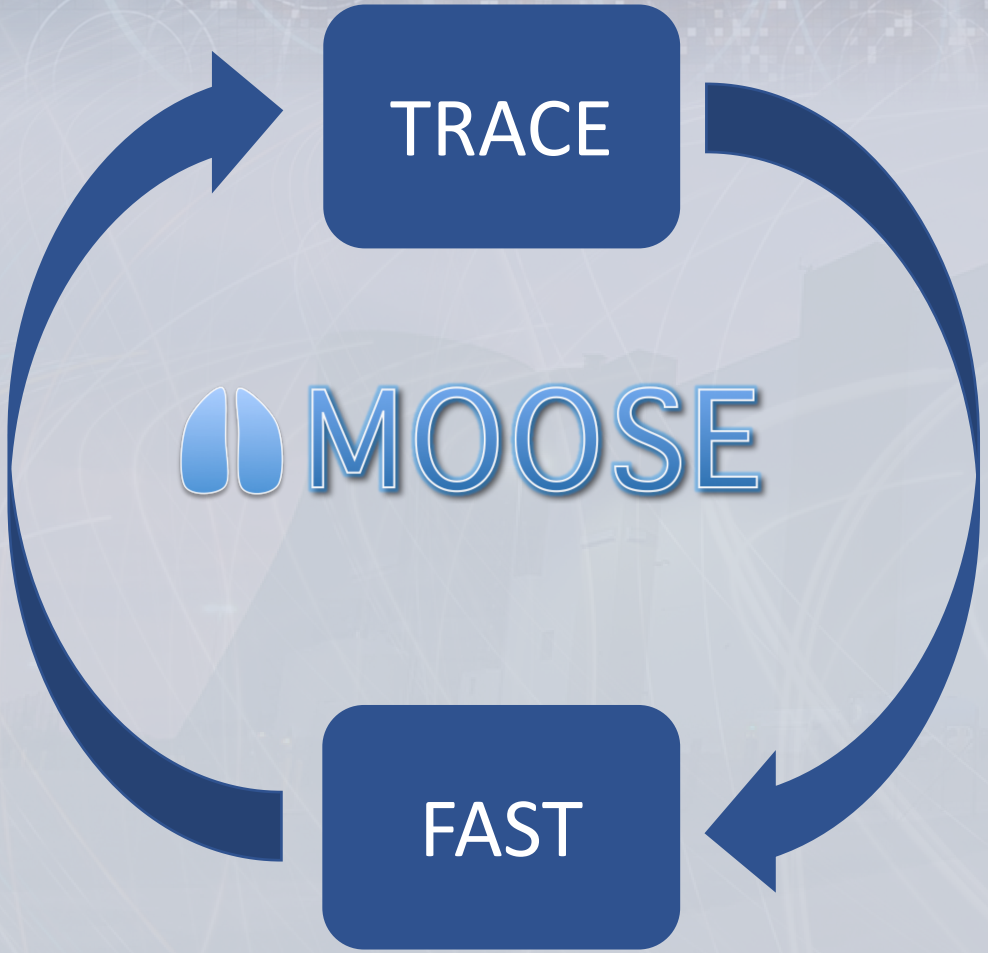


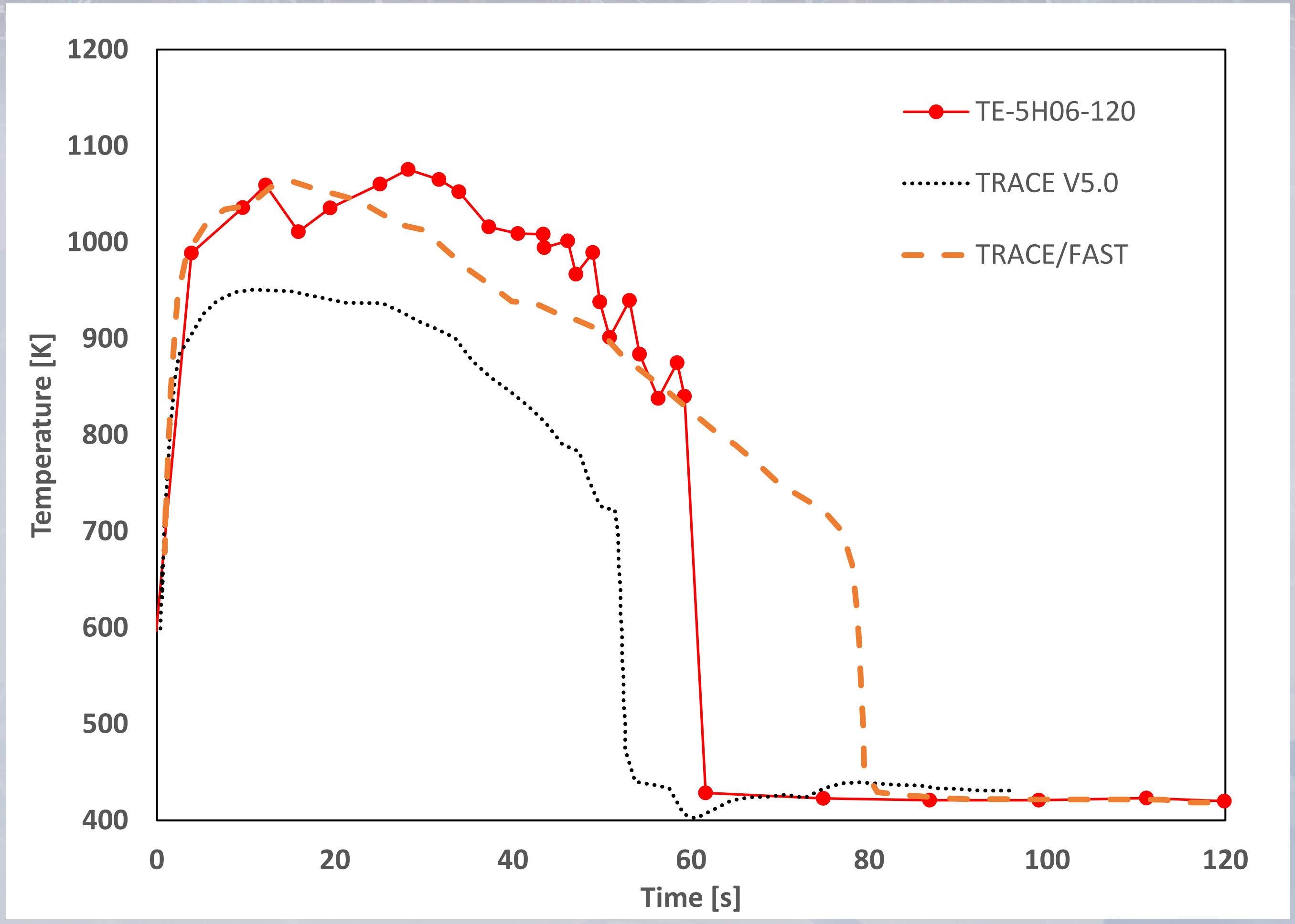
Fuel Assemblies		
Overall length	m	0.21
Fuel stack height	m	1.68
Rod pitch	m	1.43E-2
Plenum height	m	0.41952
Initial fill gas		He
Initial fill pressure	MPa	2.4

Fuel		
Material		UO_2
Enrichment	%	4.00
Density	% theoretical	93
Outer diameter	m	9.29E-3
Pellet Length	m	1.52E-2

Cladding		
Material		Zr-4
Outer diameter	m	1.07E-2
Inner diameter	m	9.48E-3
Wall thickness	m	6.2E-4
Diametral gap	m	1.9E-4

TRACE/MOOSE Coupling Development





TRACE/MOOSE Status and Next Steps

RES

- Current Status: TRACE/FAST coupling demonstrated that real reactor problems could be analyzed with state-of-the-practice tools
- Next Step: Demonstrate that TRACE/FAST can be coupled to model multiple TRACE heat structure components
- Next Step: Explore other areas where NRC can leverage modern computational frameworks to improve code capabilities

Scientific Computer Code Investment Plan

Antony Calvo

Senior IT Specialist

Division of Systems Analysis

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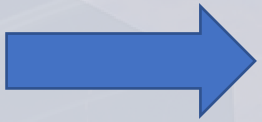
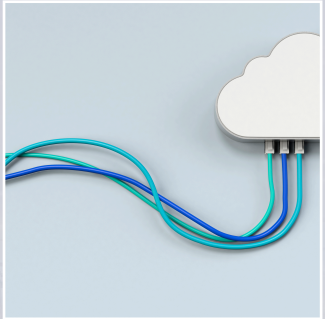
High Performance Computing System (HPCS) Hardware Strategy





Standalone HPCS Computers (prior environment)

Burdens with security compliance, necessity to be in-office, and outdated machines

Cloud Computing (current environment)

Scalable, flexible, reduced security burden on the NRC

High Performance Computing System (HPCS) Strategy

Code Developers

Code Analysts

Advanced Reactor Capability Developers

DOE HPCS

Custom hardware

aws

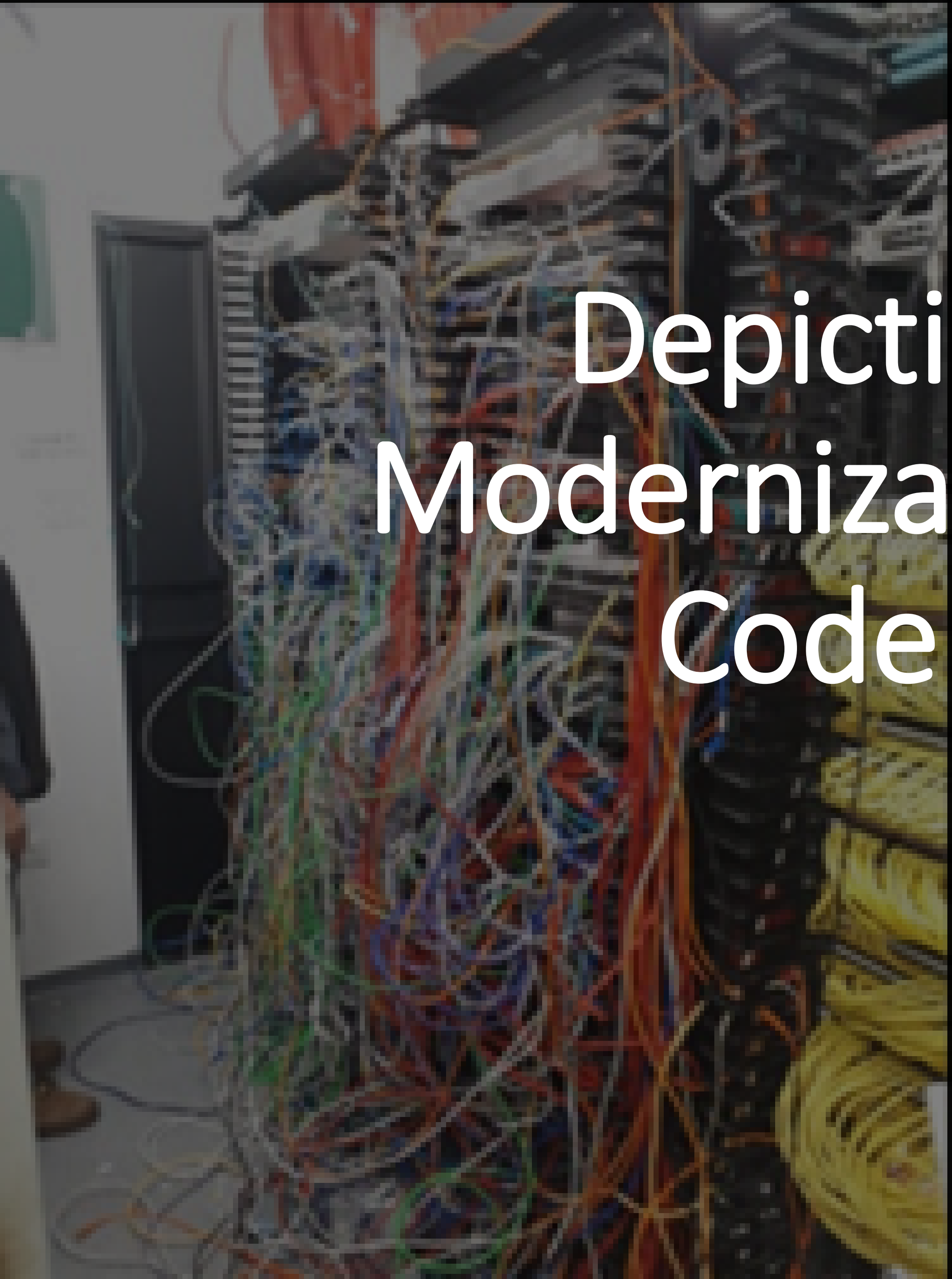
AWS is the current vendor, can change over time

MacBook Pros

Conclusions and Next Steps

- The CIP is a living document with formal updates to the investment activity appendices annually.
- This plan was recently updated and is available publicly here: ML23122A306.
- The CIP accounts for the scientific codes needs and the resource requirements, enabling the NRC to continue to meet its safety and security mission, while also making the needed investments to be ready to regulate new and advanced technologies.
- This CIP works to 1) provide the NRC with an integrated management tool for its scientific codes, 2) informs future budget formulations, 3) stabilizes scientific code annual resource requirements, and 4) identifies human capital and staff expertise requirements.

Extra Slides



Depiction of how Code Modernization can Streamline Code Infrastructure