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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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ACCIDENT ANALYSIS SUBCOMMITTEE

OPEN SESSION

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TUESDAY

MAY 6, 2025

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

SUBCOMMITTEE MEMBERS:

ROBERT P. MARTIN, Chair

RONALD G. BALLINGER

VICKI M. BIER

GREGORY H. HALNON

CRAIG D. HARRINGTON

WALT KIRCHNER

SCOTT P. PALMTAG

DAVID A. PETTI

THOMAS E. ROBERTS

MATTHEW W. SUNSERI

DESIGNATED FEDERAL OFFICIAL:

WEIDONG WANG

ALSO PRESENT:

VICTOR CUSUMANO, Deputy Director, DSS

ALAN MEGINNIS, Framatome

JARON SENECAL, Framatome

DAN TINKLER, Framatome

PAUL SMITH, Framatome

NGOLA OTTO, NRC

ASHLEY SMITH, NRC

ALEX COLLIER, NRC

KEVIN HELLER, NRC

LARRY BURKHART, NRC

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

8:30 a.m.

CHAIR MARTIN: Good morning. The meeting will now come to order. This is a meeting of the Accident Analysis Subcommittee of the Advisory Committee on Reactor Safeguards.

I am Robert Martin, chair of today's subcommittee meeting. ACRS members in attendance in person are Ron, Vicki Bier -- Greg is taking a pass as he gets prepared for another meeting -- we have Craig Harrington, Walt Kirchner, Scott Palmtag, Dave Petti, Tom Roberts, Matt Sunseri, and myself.

ACRS members in attendance virtually via Teams -- and I have to check, but I assume, Vesna, you're out there -- Vesna Dimitrijevic, and if I -- what's that?

MEMBER PETTI: I'm not sure she's on.

CHAIR MARTIN: Oh, you're not sure.

MEMBER KIRCHNER: And Ron's in transit.

CHAIR MARTIN: Okay. If I missed anyone, either ACRS members or consultants, please speak up now. I don’t believe we have any consultants today, Weidong Wang, of the ACRS staff is the designated federal officer for this meeting. No member conflicts of interest were identified for today's meeting, and we have a quorum.

During today's meeting, the subcommittee will receive a briefing on Framatome's topical report AMP-10350, Framatome methodology for boiling water reactors, valuation, and validation of APOLLO2-A/ARTEMIS-B, and the NRC staff's corresponding draft safety evaluation.

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The ACRS, consistent with the agency's value of public transparency in regulation of nuclear facilities, provides opportunity for public comment, and during the proceedings, we have received no written statements or requests to make an oral statement from the public. We have also set aside time at the end of this meeting for public comment.

Portions of this meeting may be closed to protect sensitive information, as required by FACA and the government in the Sunshine Act.

Attendance during the closed portion of this meeting will be limited to the NRC staff and consultants, the applicant, and those individuals, organizations, that have entered into an appropriate confidential agreement. We will confirm that only eligible individuals are in the closed portion of this meeting.

ACRS will gather information, analyze relevant issues and facts, and formulate proposed conclusions and recommendations, as appropriate for deliberation by the full committee.

The transcript of the meeting is being kept and will be posted on our website. The participants should first identify themselves and speak with sufficient clarity and volume so that they may be readily heard.

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Presenters, your table microphones are unidirectional and you'll need to speak into the front of the microphone to be heard.

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

The lead member for this meeting, on Topical Report ANP-10350, is Scott Palmtag, over here to my right. And I would like now to turn the meeting over to him.

MR. PALMTAG: Good morning. I'm Scott Palmtag and will lead this morning's discussion.

Topical Report ANP-10350P proposes a methodology for the steady state modeling of boiling water reactor cores using the APOLLO2-A/ARTEMIS-B code system.

Topical Report describes key aspects of the proposed methodology, its verification validation against experimental data and analytical benchmarks, and derived uncertainties for key core analysis parameters.

We are reviewing the topical report because the proposed ANP-10350 key methodology would establish initial conditions for parameters considered in reactor safety analysis, as well as their associated uncertainties.

To begin the meeting, I'd like to call on Victor Cusumano, the deputy director of the Division of Safety Systems in NRR, for opening remarks.

MR. CUSUMANO: Good morning, thank you. As he said, I'm Vic Cusumano. And we're here to present the staff's evaluation of Framatome's code system to model BWR physics. This is the first of many of expected submittals, Framatome to update the BWR methodology.

MR. BURKHART: Vic, excuse me. This is Larry Burkhart. Can you get closer to the mic?

MR. CUSUMANO: Bring the mic closer to me.

MR. BURKHART: Perfect.

MR. CUSUMANO: So, yeah, this the first of many expected submittals to update their methodology.

I will note that partway through their review, they submitted a supplement to the topical, to apply to increased enrichment and high burnup.

To be more efficient, the supplement is included as part of the topical report review, instead of as a separate review. This was agreed by Framatome and the staff together.

I do want to point out the staff and the vendor demonstrated exemplary levels of responsiveness to each other's needs, resulting in an efficient, satisfactory communication, with complex review, with no delays.

Thank you for your interest. And as Mr. Palmtag has mentioned, he's from North Carolina. I will not say anything. Not until we talk again.

MEMBER PALMTAG: That's good. All right, thank you. And next, we'll turn over to Alan Meginnis for opening statements from Framatome.

MR. MEGINNIS: Good morning. I am Alan Meginnis, I am licensing manager for Framatome.

I'd like to thank the ACRS for having us here today so that we can tell you about our APOLLO2-A/ARTEMIS-B Topical Report and safety evaluation.

APOLLO2-A/ARTEMIS-B is replacing

MICROBURN-B2/CASMO4 at the core simulator in our advanced analysis methods for boiling water reactors.

Previously, APOLLO2-A and ARTEMIS have been approved for use with the PWR reactor. And this topical report is extending this applicability for boiling water reactor.

This is the last upgrade of our advanced methods that Framatome is going to make for boiling water reactor, prior to our efforts to go to increased enrichment and increased burnup. Framatome calls that effort advanced fuel management, AFM.

So, in fact, this supplement, or this topical report, had supplemental information that was submitted, as Vic pointed out, to support AFM during the course of the topical report review.

So, this topical report is also the first of Framatome's boiling water reactor methodologies that is going to implement AFM before we submit the additional topical reports going forward.

Framatome appreciates the NRC's efforts in reviewing this topical report and we especially appreciate the flexibility they had in allowing us to submit the AFM supplement in the process of the topical report in order to accelerate our implementation of AFM. It probably shaved a year off of our implementation schedule, allowing us to do that, so we very much appreciate it.

Of course, we're anxious to get this topical report approved so that we can move forward with our AFM implementation to support industry needs. Thank you.

MEMBER PALMTAG: Thank you, Alan. I just had a quick question before we started. It sounds like this is going to be the first time that PWR and BWR methods are going to be combined for Framatome. Is that correct? Before, we had different codes for P's and B's?

MR. MEGINNIS: All right. So, the base methodology is going to be the same codes for the core simulator. But we have extensions that are only applicable for boiling water reactor in this topical report.

MEMBER PALMTAG: So, APOLLO2 will be used for both PWRs and BWRs?

MR. MEGINNIS: That is correct.

MEMBER PALMTAG: And ARTEMIS-B, is that a different code than the PWR one?

MR. MEGINNIS: That is the code -- it has extensions in it for boiling water reactor application. That's the B.

MEMBER PALMTAG: Okay, thank you. I think that's an important point.

CHAIR MARTIN: Since you're talking code -- I know we're jumping the gun a little bit on some of the slides, this is Bob Martin, so is there like an input parameter in the code that just says, this is for BEM, or something like a BWREM, and then it of course pulls into the solution? It follows correlations that are applicable, so in some ways it's kind of a merge code, rather than the same code?

MR. MEGINNIS: I'm going to have to refer that to Jaron.

MR. SENECAL: There'd be separate executables.

CHAIR MARTIN: Okay. So, the way you manage it, ARTEMIS-B is just its own standalone, while it has some foundational similarities with what we've seen before -- because I believe we looked at this about a years ago?

MR. SENECAL: A year or more.

CHAIR MARTIN: They share the same name. But as far as code management internally, they are separate codes.

MR. SENECAL: Yes, how we do leverage it, all our lessons learned across the organization, the vast majority of the coding is distinct.

CHAIR MARTIN: Sure. Okay. So, can I introduce our speakers?

MEMBER PALMTAG: Yes, please. Sorry to jump the gun.

MR. MEGINNIS: Okay. So, first we have on the left over here, far left, is Jaron Senecal. Jaron is the APOLLO2-A/ARTEMIS-B lead developer. Jaron earned a bachelor's of science from Walla Walla University, and went on to earn a doctorate in nuclear science and engineering from Rensselaer Polytechnic Institute.

Okay, Paul Smith is directly to my left. Paul is the Framatome's BWR neutronics codes and methods team leader. He has a master's of science in nuclear engineering from the University of New Mexico, and is a licensed professional engineer in the State of Washington. Thank you.

MR. SENECAL: All right, let’s get started. Is this volume okay?

MEMBER KIRCHNER: Just pull it up to you.

MR. SENECAL: Is that better? Okay. All right. So, we'll give an overview of the topical report in this open session and we'll leave some of the further details to the closed session.

For the next slide, we just have a brief overview of what we'll talk about. We'll go through the computer codes, and then describe the methods and models, and then list the various verification and validation efforts that are included in the topical report. Next slide.

Starting with computer codes, just to give a little background -- you can go to the next slide. Thanks.

Alan kind of touched on this already, but we're kind of inheriting, you could say, from two different approved methodologies.

On the BWR side, there was CASMO4/MICROBURN-B2, and we're inheriting some models from that -- I'll discuss that further -- and on the PWR side, the approved topical report is APOLLO2-A/ARTEMIS. And so, that's, as we mentioned, the backbone of the codes that we're building off of.

And so, in this topical report we're discussing APOLLO2-A/ARTEMIS-B, and this is the first in a series of topical reports for the next generation of codes/methods for BWRs. This topical report is applicable to steady state calculations, and it includes the supplement regarding increased enrichment and burnup. Next slide.

So, the APOLLO2-A code is a lattice physics code. It calculates the figure of cross-sections for the ARTEMIS-B core simulator. It solves the 2D neutron transport equation using a three-level computational scheme, it uses the SHEM281 energy group mesh for neutrons, and for gammas it uses 94 energy groups.

All of the physical data comes from the JEFF 3.1.1 cross-section library, with modifications that are described in the approved PWR topical report supplement.

As far as APOLLO2-A, the lattice physics code, it does not include any additional models specifically, for boiling water reactors. Go to the next slide.

In the middle, we have this HERMES-B code. It takes the cross-section data directly from the APOLLO2-A code and creates a multi-dimensional functional representation of the cross-sections.

And then this representation can be interpolated at arbitrary conditions for use in ARTEMIS.

So, the data that HERMES functionalizes for ARTEMIS includes microscopic cross-sections, as well as the macroscopic cross-sections for, like, all those residual cross-sections, for all the isotopes that are less-important, and the delta cross-section model for the control blade insertion.

It also includes the pin form factors, discontinuity factors, detector responses, and key deposition fractions.

Next, we'll go to ARTEMIS-B. It's the extension of ARTEMIS. So, the PWR code, we added on to it to be applicable to boiling water reactors. He uses much of the same methodology that's described in the ARCADIA Topical 10-297, and it contains the following modules: Flex Module, Fuel Rod, and thermal hydraulics modules, the dehomogenization modules -- think of that as pin power reconstruction -- and the depletion module. Go to the next slide.

CHAIR MARTIN: Point of clarification. The methodology overall, just looking at steady state transient accident conditions?

MR. SENECAL: Sure. Yeah, the scope of this topical report. So, we’ll go to methods and models, give an overview of that.

MEMBER PALMTAG: So, Bob, this is going to be steady states. But I assume this is going to feed the transient analysis in later topical reports.

MR. SENECAL: Yeah. Like he said, it was

just the initial conditions.

MEMBER PALMTAG: So, it's not directly kinetics now, but it's going to be very important for intra-kinetic.

While I'm talking, I just want to make a comment. But the APOLLO code's been around for quite a while and has, just from my impression, has a very good reputation, I would assume to be very similar results.

This MOC can be very similar results between the APOLLO2 and your previous CASMO4. That shouldn't be any surprises to the committee.

It is interesting that you picked the JEFF 3.1 library, just for pretty much familiar with most -- or I'd say, as far as I know, everyone in the U.S. is using the ENDF/B-VII data libraries, or maybe earlier.

So, this is going to be the first time that the JEFF 3.1.1 library's going to be used, which should be very similar, but it's a European library, as opposed to ENDF libraries, is the U.S. library. But just kind of jumping ahead of your validation, which tells us whether it's good or not. But it is kind of interesting as to the JEFF library instead of the ENDF library.

MR. SENECAL: Yeah, the APOLLO code is generally maintained in France. So, that's our French connection in our company. So, we'll start with the similarities to the ARCADIA Topical Report. In the ARTEMIS code, there's three modules that are essentially unchanged.

Flux solver, it uses the same semi-analytical nodal expansion method with coarse mesh rebalancing, the dehomogenization module calculates inter-nodal quantities, like pin powers and burnups, and the depletion module, which uses a Krylov subspace method for solving the depletion equations. Go to the next slide.

The Fuel Rod Module, it's solving the 1D Heat Transfer equation. It's presented here in radial coordinates. It's solved on a representative fuel rod in a lattice, and that calculates the effective fuel temperature for Doppler feedback.

Comparing it back to the PWR Topical Report, this is the same numerical solution method. We only changed the method behind it. But the properties have been updated to be consistent with the approved RODEX4 topical report, which we use for BWR thermal mechanic analysis.

So, these properties include the pellet

radial power distribution, the thermal conductivity, gap conductance and porosity tables. Next slide.

CHAIR MARTIN: Just another point of clarification. You say 1D, but you have axial nodes, or whatever you want to call them, and of course all individually drive the 1D. So, it's a pseudo-2D, in essence, right? There's just no axial conduction.

MR. SENECAL: Yeah, there's no axial component to it.

Then the thermal-hydraulic module is another change for the PWRs. It solves the fluid conditions in the core and gives feedback to the Flex Module in the boiling water reactors, with the fuel channels.

You basically have a system of parallel flow paths, the main one being the active coolant around the fuel rods inside the channel box, but there's also parallel flow paths for bypass and internal water channels, and all those are connected at the bottom and the top, so they experience the same pressure drops.

The ARTEMIS-B thermal-hydraulics module is very similar to the MICROBURN-B2 approved methodology. Next slide.

We'll discuss these more in the closed

session, but there's a variety of PWR-specific models that were implemented into ARTEMIS-B: variable axial nodalization module, we call that VAx, spacer grid and detector models, control blade depletion and control blade history models, the reflector models specific to BWRs, and we'll also discuss the jumpstart model.

CHAIR MARTIN: Real quick, probably on the previous slide I believe, to the thermal-hydraulics, so how do you model, say, non-uniform flows, with BWR core, I mean, the kind of radial subdivision of the core? It's bundle-by-bundle, or rings, or -- how do you deal with that inherent non-uniformity of flow through a core?

MR. SENECAL: Do you mean, like, different pressure drops between different assemblies?

CHAIR MARTIN: All of it. It's the core-wide, not just the bundle.

MR. SENECAL: So, each assembly is solved independent. We're not lumping assemblies together. So, each one is a flow path that's modeled exclusively.

CHAIR MARTIN: Okay. And then -- well obviously there's a bundle, so they're not cross-communicating. Okay. So then what feeds that initial condition of the flows through? Where does that information come from?

MR. SENECAL: Usually, it's plant data, where you have the re-circulation pump flow.

CHAIR MARTIN: Okay.

MR. SENECAL: Inlet flow. And so, along with pressure and inlet subcooling.

CHAIR MARTIN: Well, you look at it all kind of separately then. Regions. That would have to feed into your downstream codes.

MR. SENECAL: Each bundle's solved separately, but they're all uncoupled at the top and the bottom --

CHAIR MARTIN: Sure.

MR. SENECAL: -- so they ensure the crosstalk in that way.

CHAIR MARTIN: Okay.

MR. SENECAL: Does that answer your question?

CHAIR MARTIN: It does.

MR. SENECAL: So, go onto the next slide. So now, given overview of the verification and validation efforts that we did, for APOLLO2-A we had three different types of experiments or data that we compared against.

First is critical experiments. These all include reactivity, but some of them also include fission rate distributions. We have a variety of experiments that we included.

Listing them here, there's BASALA, EPICURE, Babcock & Wilcox, CAMELEON, and the ICSBEP. So, from each of those we have a select number of experiments that we include.

The next type of data is from spent fuel isotopic measurements. We have measurements from the Fukushima Daini, units 1 and 2, boiling water reactors, and we also included fuel pins from the REGAL experiments, which is a pressurized water reactor, but we included it because it has ten percent gadolinium in at least one of the fuel pins, and that was representative of boiling water reactors, in terms of gadolinium, so we included that as well.

And then finally, to fill in all the gaps between experimental data, we have Monte Carlo comparisons, which can be used to span arbitrary conditions and configurations. So, a wide variety of those, using them to validate reactivity, pin powers, burnup, and gamma transport as well.

CHAIR MARTIN: Just kind of a standard question for any of the V&V, particularly for an applicant like you all have been around a long time.

Just making the V&V program that you had for the prior methodology, and then reapplied it for the most part. So, are there new cases added? Were there some old cases removed? It's just a continuation of the same script. Applying it, of course, would make new models for all those old cases that you've used in prior methodology.

MR. SENECAL: So, the cases are all selected to represent boiling water reactors as much as possible. So, we're looking for things that have void, or simulated void, like the spent fuel. We selected as many boiling water reactors as possible. So, everything in the topical report is tailored to --

CHAIR MARTIN: That doesn't quite answer the question. So, you’ve been working with BWRs a long time, you have the prior methodology based on, say, microburn. Those, of course, had been V&Ved.

My question really was, have you just really taken the old V&V package for that methodology, and then converted into models and such to do your V&V for the APOLLO/ARTEMIS-B combination?

MR. SENECAL: I believe most of the validations run separate experiments. So, it's not primarily just translating, but it's more --

CHAIR MARTIN: So, the answer would have

been, if you said, yeah, a hundred percent, obviously there's an institutional memory here with -- well, agency-wide, with, of course, your methodologies in the past.

So, there were some additions, subtractions, from the old methodology V&V into this one. Okay. Well, that's important.

I guess you're still looking at, like, fifty or so different benchmarks. I mean, you've still got a significant package here. But there are some differences from the old methodologies.

MR. SENECAL: Yeah, and the CASMO microburn is twenty-six years old now. So, we're trying to use as many recent fuel types as possible.

CHAIR MARTIN: All right. Good point to know.

MR. SENECAL: For the ARTEMIS verification and validation for the next slide -- so we do verification of the Fuel Rod Module by comparing it against the RODEX4 results to show that the material properties have been implemented correctly.

We compared the reflector model using numerical validation against the SERPENT2 Monte Carlo code.

Next, we did the verification of the

ARTEMIS-B Pin Powers, using colorset calculations that are compared against APOLLO2-A.

And then for the Thermal-Hydraulics Module, we had validation for pressure drop and channel average void fraction data.

For more integral experiments, we have Core Follow data from 110 cycles from 8 different reactors. And additionally, we have Pin and Nodal Gamma Scan Results from three reactors, over five different cycles. Move to the next slide.

And then finally, we mentioned there's -- well, it's already been mentioned that there's a supplement regarding advanced fuel management, or AFM. We use this to signify increased enrichment Uranium 235 and increase in their maximum full length fuel rod average burnup limit.

We extended the verification and validation to this new regime by adding additional critical experiments, and in APOLLO2-A we also did additional numerical validation against SERPENT, and then we also, in ARTEMIS, did extensive verification of the pin powers against the fall. Next slide.

CHAIR MARTIN: This may be a time to ask about higher burnups. Obviously, there's a move industry-wide, looking at, so your new V&V starts looking at validation sets for higher burnups.

Maybe where did you get that data from? What's the background there?

MR. SENECAL: So, the first thing is we can -- again, SERPENT for the numerical validation, we can just simply run it out to higher burnups.

Some of the other verifications, same story against RODEX4 in the FRM, for example.

CHAIR MARTIN: You're kind of talking about code-to-code comparisons there?

MR. SENECAL: Yes.

CHAIR MARTIN: Right. I'd find more valuable from a verification standpoint, given certain amount of history, and what the prior organizations or personnel have done with those codes, talking about validation, when we're talking higher burnup.

MR. SMITH: Hi, this is Paul. So, I think to answer your question, a lot of what the validation is for this topical report would be code-to-code comparisons, as the data that maybe you're speaking of would be more applicable to, like, the RODEX4 supplement, where they're looking at physical phenomena, like issue gas, things like that.

The main important piece for ARTEMIS is the fuel temperature calculation. And so, we want to show that our fuel temperature calculation faithfully reproduces the RODEX4 temperature calculation, for instance.

So, that would be one aspect of how we extend burnup and show that we're okay in terms of our overall methodology. Does that make sense?

CHAIR MARTIN: Certainly it does. It makes it more difficult to quantify uncertainties if you're looking out there. And then, of course, it just puts the burden on how you handle uncertainties. So, I guess we're split here about that too. Right.

MEMBER PALMTAG: Can you go back one slide?

MR. SENECAL: Sure.

MEMBER PALMTAG: This is Scott Palmtag. To be more specific, when you did the higher burnups on isotopic. You're just comparing to SERPENT. But in the last slide, I can tell you there's something wrong with the library in terms of fission product. Are there any critical experiments that go to higher burnups/isotopics comparisons?

MR. SENECAL: Most critical experiments are going to be clean fuel.

MEMBER PALMTAG: Are there any isotopic measurements at higher exposures?

MR. SENECAL: I don't recall the burnup levels --

MEMBER PALMTAG: You've got a couple of BWRs in a previous slide -- Fukushima -- and then do you know what those burnups were?

MR. SENECAL: That would be included in the topical report.

MEMBER PALMTAG: Okay. I don't believe they're higher, over 62.

MR. SMITH: That's right. There's really a limited amount of data, in terms of what's actually out there.

So, again, when we talk to the NRC about this, they've asked questions in the RAIs and we were able to give them some additional code-to-code comparisons that they asked for, to deal with the isotopics.

MEMBER PALMTAG: Right. And you're not the only vendor who's got to deal with this as we go to the higher exposure.

Do you think there's a need for more experimental data to get the isotopics from higher? Or do you know of any planned experiments to get the higher isotopics for higher burnup?

MR. SENECAL: I'm not aware of any. But

it is something in terms of it could use improvement when that data comes in.

I think the goal, industry-wide, would be to get that data when it comes in, and ensure that we model things correctly. So, continuous validation as we go.

MEMBER PALMTAG: Okay, thank you.

MR. SENECAL: Are there further questions? We can wrap up with the conclusion.

Basically, we introduced the APOLLO2-A/ARTEMIS-B code system, given full review of the main code modules and models, and brief description of the verification and validation that's included in the topical report. Next slide.

CHAIR MARTIN: Okay, are there further questions for Framatome? Any of the members?

MEMBER PALMTAG: I should note, there'll be more questions in the closed session.

CHAIR MARTIN: Of course, there will be a closed session. I guess at this point we'll transition to the staff. So, we'll pause for a moment.

(Pause.)

CHAIR MARTIN: Feel free to take off here.

MR. OTTO: Good morning. I'm Ngola Otto,

I'm the project manager of Framatome Topical Reports and I would just like to start off by saying thank you for the ACRS Subcommittee for giving us the opportunity to present on the review of the Framatome's ANP-10350P, revision zero, Topical Report.

And the review team includes Ashley Smith, who's here, Alex Collier, and also we do have other review team members, Jack --

(Audio interference.)

MR. OTTO: -- at the back, and also Kevin Heller, who's supporting us remotely. And we do have other staff members here who are available to support today's meeting.

And so, as mentioned previously, we were able to conduct this review in an efficient manner by incorporating both the original submittal, plus the increased enrichment and higher burnup supplemental information, and we saved probably a one-year review time by doing that.

And so, we did issue four sets of RAIs and we did conduct two regular audits, and we held a number of public meetings to ask questions and get things resolved regarding review.

So, during this session, we'll be discussing our findings, and we'll probably get into more detail in the closed session that follows. So, with that, I'll turn it over to the staff to start the presentation.

MS. SMITH: Thanks, Ngola. Can you hear me? Should I move closer? That better?

As noted, I'm Ashley Smith from the Office of Nuclear Reactor Regulation, Division of Safety Systems, representing the Nuclear Methods and Fuel Analysis Branch. Here with me is Alex Collier, and we'll be presenting the staff review of ANP-10350P, the methodology for boiling water reactors, valuation and validation of APOLLO2-A/ARTEMIS-B. Next slide.

There's an agenda for the staff presentation in the open session, presenting some areas we thought would be of interest to you.

We'll give a brief introduction, talk a bit about our review timeline, discuss the regulatory requirements and guidance, areas of the technical evaluation, the supplement for increased enrichment and high burnup, staff limitations and conditions, and give a conclusion. Next slide.

Framatome's gone over this information, so I'm going to skim through it. Framatome proposed the APOLLO2-A/ARTEMIS-B code system to model core physics in BWRs.

This topical report describes the methodology and verification and validation applicable to steady state BWR core modeling.

As mentioned by Framatome, this is one of multiple reports expected to update their BWR methodology. Next slide.

APOLLO2-A/ARTEMIS-B is an extension of the ARCADIA code system to BWRs. It includes the APOLLO2-A spectral code, ARTEMIS-B core simulator, and the cross-section functionalization code HERMES-B.

ARTEMIS and HERMES codes were extended by adding BWR-specific models adapted from the MICROBURN-B2 BWR core simulator. As a note, APOLLO2-A was not modified. The flow chart here shows how these codes are incorporated. Next slide.

This is a review timeline of key activities throughout the review. The orange diamonds on the top of the timeline represent Framatome activities, and the green circles on the bottom represent NRC activities.

We've already mentioned a few other times, that about a year into the review, Framatome submitted a supplement to the topical report, to include increased enrichment and high burnup.

This path was agreed upon by NRC and

Framatome, prior to submitting the supplement, to increase the overall efficiency in the review process and support increased enrichment and high burnup industry initiatives.

There's also staff turnover during this time, so I want to mention that up front, that the lead reviewer left our branch midway through the review and is no longer with the agency. So, in some cases we may be relying on others to answer questions. Next slide.

NUREG-0800, also known as the Standard Review Plan, provides guidance for the NRC staff in reviewing safety analysis reports for nuclear power plants. Chapter 4.3 of this document focuses on the nuclear design aspects of a reactor core.

Primary objectives of this section are to ensure that fuel design limits are not exceeded during normal operations, or anticipated operational transients. Postulated reactivity accidents do not compromise the reactor coolant pressure boundary, and core coolability is maintained. Next slide.

Acceptance criteria outlined in SRP 4.3 are based on compliance with relevant general design criteria. Particularly, the GDCs that are listed here.

These criteria focus on ensuring Reactor Design safety, control of reactivity, and maintenance of core cooling activity. Next slide.

The NRC staff reviews the areas concerning analytical methods. These are: the descriptions of the analytical methods used in the nuclear design, including those for predicting criticality, reactivity coefficients, burnup, and stability; the database used for neutron cross-section data and other nuclear parameters; and the verification of analytical methods for comparison with measured data.

There are no specific criteria that must be met by analytical methods or data used by a vendor.

In general, the analytical methods and database should be representative of state-of-the-art and the experiments used to validate the analytical method should be adequate of fuel designs in the reactor, and encompass a sufficient range of variables and operating conditions.

I'm going to turn it over to Alex to discuss the neutronics.

MS. COLLIER: Thank you, Ashley. I'm Alex Collier, technical reviewer at the Nuclear Methods and Fuel Analysis Branch.

Framatome has already stated that no

changes were made to APOLLO2-A for its application to boiling water reactors.

Given the capabilities of the method and the validation that has been discussed previously by Framatome, and will be discussed further in future slides, the NRC staff finds APOLLO2-A acceptable for BWR applications.

Given that BWRs operate under different thermal-hydraulic conditions than PWRs, which is its original purpose, the NRC staff focused on how HERMES-B functionalized cross-sections.

The NRC staff asked an RAI and Framatome provided, a sensitivity steady using core-follow benchmarks from reactors operating under modern conditions with modern fuels.

Sensitivity studies showed that HERMES appropriately functionalizes cross-sections for downstream calculations. Next slide, please.

A lot of models for ARTEMIS-B were adapted from MICROBURN-B2, which has been previously reviewed and approved by the NRC staff. The sensitivity steady and the RAI that was mentioned in the previous slide supports the cross-section parameterization model in ARTEMIS.

The NRC staff reviewed the models that

Framatome has discussed previously, and have found them acceptable for boiling water reactor applications.

Ashley is going to be speaking next on the thermal-hydraulic and fuel rod module methodologies. Next slide, please.

MS. SMITH: Framatome's already discussed the thermal-hydraulic methodology in detail. So, to recap, the thermal-hydraulic methodology used by ARTEMIS-B is similar to the MICROBURN-B2 core simulator.

Minor improvements were made for ARTEMIS-B and the ARTEMIS-B thermal-hydraulic module used an iterative calculation scheme, which was shown by Framatome.

Staff found that the thermal-hydraulic methods were acceptable because they're consistent with approved methodologies, such as MICROBURN-B2. Next slide.

Again, Framatome's already discussed the information on this slide in detail. I'll recap that the ARTEMIS-B fuel rod module is comparable to the ARTEMIS fuel rod module approved by NRC staff.

The numerical solution of the heat transfer equation is the same as the method used in

ARTEMIS.

Physical properties in ARTEMIS-B are updated from ARTEMIS to be consistent with RODEX4, which is also approved by NRC staff.

Effective fuel temperature is the main output for the fuel rod module.

NRC staff determined the effective fuel temperature equation used in ARTEMIS-B is consistent with MICROBURN-B2.

The staff concluded that the fuel rod module methodology is acceptable, because it's consistent with industry standard codes that are approved by the NRC.

Alex will discuss validation and verification.

MS. COLLIER: Thank you. The NRC staff reviewed the validation and verification presented by Framatome. Staff focused on the databases that Framatome used and the methods covering the entire range of applicability, and the results that Framatome found and any present trends or biases.

The NRC staff found that the validation adequately assessed every area that the code is anticipated to assess, and found the predictive capability of the system acceptable. Next slide, please.

MEMBER PALMTAG: This is Scott Palmtag.

MS. COLLIER: Yes.

MEMBER PALMTAG: So, we asked this question earlier of Framatome. But really it’s a broader question for the industry. But as we go to these higher burnups, do you think there's experiments needed for isotopic measurements at high burnups?

MS. SMITH: I mean, whether or not it's needed -- we can speak about it more in the closed session, but I am aware of some spent fuel measurements that did go beyond the current limit, and the extension with numerical methods with a higher org code do kind of solidify the idea that the code is performing well.

MEMBER PALMTAG: The codes all use a common library. So, it's not going to tell you if you're missing something in the library. You mentioned we can talk about it further.

I wouldn't be surprised if the NRC does see a need for that, the more experimental data for isotopics at higher burnups.

MS. SMITH: Okay.

MEMBER PETTI: I've got a question.

MS. SMITH: Yes.

MEMBER PETTI: On the last slide. Previous slide. The last bullet, it's not a verification, it's a validation. But you say verification.

MS. SMITH: It's mostly validation.

MEMBER PETTI: Validation.

MS. SMITH: It's mostly validation.

MEMBER PETTI: It's data. Yes. Okay, thank you.

CHAIR MARTIN: I mean, we oftentimes get confused with the different words here. Verification, I look at anything that's the code comparison, because there's not validation. That's their verification, particularly when the codes that they're benchmarking against have been V&Ved before.

So, it's something that I would think -- on this list you have validation, but you also have, as Framatome said earlier, code-to-code comparisons that probably fall in the category of verification.

MEMBER PETTI: Right.

CHAIR MARTIN: And among the sets and under the category of V&V, is mostly -- is there good balance between say, what we'd call verification and validation?

We all would love to see more and more

validation -- you know, seeing-is-believing kind of thing. But what is your opinion, or assessment, of the balance of the code test cases that they selected and used?

MS. SMITH: I'm aware that Framatome did call the verification numerical validation, and I do kind of see it in that sense. It's comparing to a higher order of magnitude than SERPENT. It's a Monte Carlo code, which we all know is pretty solid.

They use a massive range of cases to extend kind of the range of applicability. And they went beyond what they were asking for. And they kept track of all the trends and took note of why there were any trends or any biases that were there.

So, we can talk about it more in the closed session, to get into details. But it's the staff's conclusion that it's adequate.

CHAIR MARTIN: Yeah. I do find it interesting -- and again as more maybe -- I have to defer to my colleagues that have more reactor physics experience -- but we do see more and more deference to SERPENT, where I don't believe it has been incorporated into any evaluation model for domestic applications.

And my experts not just here at the table, but that I have worked with in the past, there is this broad community acceptance for SERPENT, but it hasn't gone through that kind of vetting in the agency. Should it? I don't know. I look at Scott too. I mean, you ever have these kind of questions?

MEMBER PALMTAG: No, I agree. I think people at the top, Monte Carlo, and it used to be MCNP, everybody just used to trust MCNP. But I do want to note that the Monte Carlo that MCNP and SERPENT and Open MCs, have higher order of neutronic methods, but their depletion’s not really a higher order, it’s the same depletion matrix that everyone else is solving, has more isotopes. But I wouldn't really necessarily call the depletion part of SERPENT, a higher order method, than any other methods.

MS. COLLIER: I am aware that SERPENT uses the CRAM methodology for depletion, which --

MEMBER PALMTAG: Which is the exponential matrix you're solving, so there's nothing --

MS. COLLIER: Yeah.

MEMBER PALMTAG: -- it's not a higher order method than anyone else is using. They do use a lot more isotopes. That there's a problem in the library that's going to show up in all the codes. All the codes are going to have the same library.

MS. COLLIER: That's true. To note on the CRAM method, it is very robust and it's --

MEMBER PALMTAG: It's a numerical method, right?

MS. COLLIER: It is.

MEMBER PALMTAG: It's not going to tell you anything about whether the data's right or wrong.

MS. COLLIER: Correct. As mentioned in the timeline, Framatome submitted a supplement to the topical report to extend the range of applicability to include increased enrichment and higher burnup conditions.

Framatome has stated that they refer to this as advanced fuel management conditions. The supplement contains additional verification and validation to demonstrate the accuracy of the APOLLO2-A/ARTEMIS-B code system for these extended conditions.

The NRC staff concluded that the code system is acceptable for use at AFM conditions. Detailed discussion of the supplement will be in the closed session. Next slide, please.

There are three limitations and conditions in the staff's safety evaluation. First, the ARTEMIS-B methodology is applicable to steady state conditions associated with all reactor modes.

Second, the APOLLO2-A/ARTEMIS-B code system is limited to analyzing BWR fuel assemblies with square lattices and fuel designs validated within the topical report, such as ATRIUM-10 and ATRIUM-11 fuels.

However, this methodology may be validated for use with other fuel, based on the similarity to existing fuel product lines validated within the topical report.

Third, the ARTEMIS-B fuel rod module within APOLLO2-A/ARTEMIS-B is subject to relevant limitations and conditions contained with the current RODEX4 topical report and safety evaluation, which means burnup limitations for APOLLO2-A/ARTEMIS-B are based on the non-AFM limitations. As we’ll discuss further in the closed session. Next slide, please.

The NRC staff found the code system acceptable for application to steady and time design analysis of boiling water reactors. Staff’s conclusions are predicated upon licensee’s acceptably addressing the limitations and conditions in Section 4 of the NRC SE. Are there any additional questions?

CHAIR MARTIN: That's my line. Are there any additional questions from the members? Okay.

MEMBER PALMTAG: This is Scott Palmtag. I have one more question.

Going back to APOLLO2, you said there was no differences between -- there should, I asked Framatome -- but there's no differences between the previous submittal. Did the previous submittal actually have PWR geometry, or did -- I mean, they said there was no changes though. Is it to the methodologies, or to the geometry?

MS. COLLIER: I think it would be best if Framatome answered this question.

MEMBER PALMTAG: Someone from Framatome? When you said there was no changes to the APOLLO2, did you mean in geometry, or just the methodology? You can stand up right behind Bob, where that green line is. Yeah.

CHAIR MARTIN: Can you say your name?

MR. SENECAL: Jaron Senecal with Framatome. Could you repeat that question, please?

MEMBER PALMTAG: When you said that there was no changes to the APOLLO2 compared to the previous submittal, did the previous submittal have the PWR geometry in it, or are you referring just to the methodology --

MR. SENECAL: So, that's not a

methodological change. There's things like higher void and certain outputs that are necessary --

MEMBER PALMTAG: The channel -- this would be like the channel box to the BWR geometries. Was that included in the previous submittal?

MR. SENECAL: It would not have been presented in the previous submittal. I do not remember the version of the code in which these features came out and how that relates to the specific timeline.

MEMBER PALMTAG: So, on the verification, I assume you'd covered verification, including all the GE, the Westinghouse, the --

MR. SENECAL: Yes.

MEMBER PALMTAG: -- the new 11 x 11 BWR fuel solvent for -- okay. Thank you.

MS. COLLIER: Thank you.

CHAIR MARTIN: And any last questions from members? Okay, at the end of the open session we have an opportunity for public comment. If there's anyone in the room or online representing themselves, or an external public organization, you have an opportunity now to provide comments online, please, and raise your hand, the Teams function. Can anybody in the room just say something?

All right, not that we expected anything. So, I think the silence says that we're done with this open session.

So, at this point we will make a transition to the closed and our staff will make sure that everyone that should be in the room is otherwise vetted.

So, we're going to take a break here and let all that transpire.

(Whereupon, the above-entitled matter went off the record at 9:27 a.m.)

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

NRC Staff Review of Framatome Topical Report ANP-10350P, *Methodology for BWRs: Evaluation and Validation of APOLLO2-A/ARTEMIS-B*

Open Presentation to
Advisory Committee on Reactor Safeguards
Accident Analysis Subcommittee
May 6, 2025

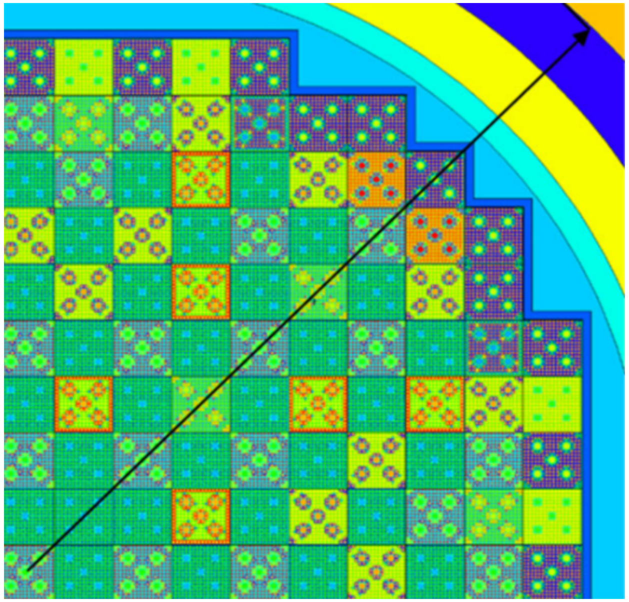
Ashley Smith, NRR   Alex Collier, NRR

Agenda

- Introduction
- Review Timeline
- Regulatory Requirements and Guidance
- Technical Evaluation (Open Session)
  - Neutronic Methodology
  - Thermal Hydraulic Methodology
  - Fuel Rod Module Methodology
  - Validation and Verification
  - Power Distribution Uncertainty
- Increased Enrichment and High Burnup Supplement
- Limitations and Conditions
- Conclusions

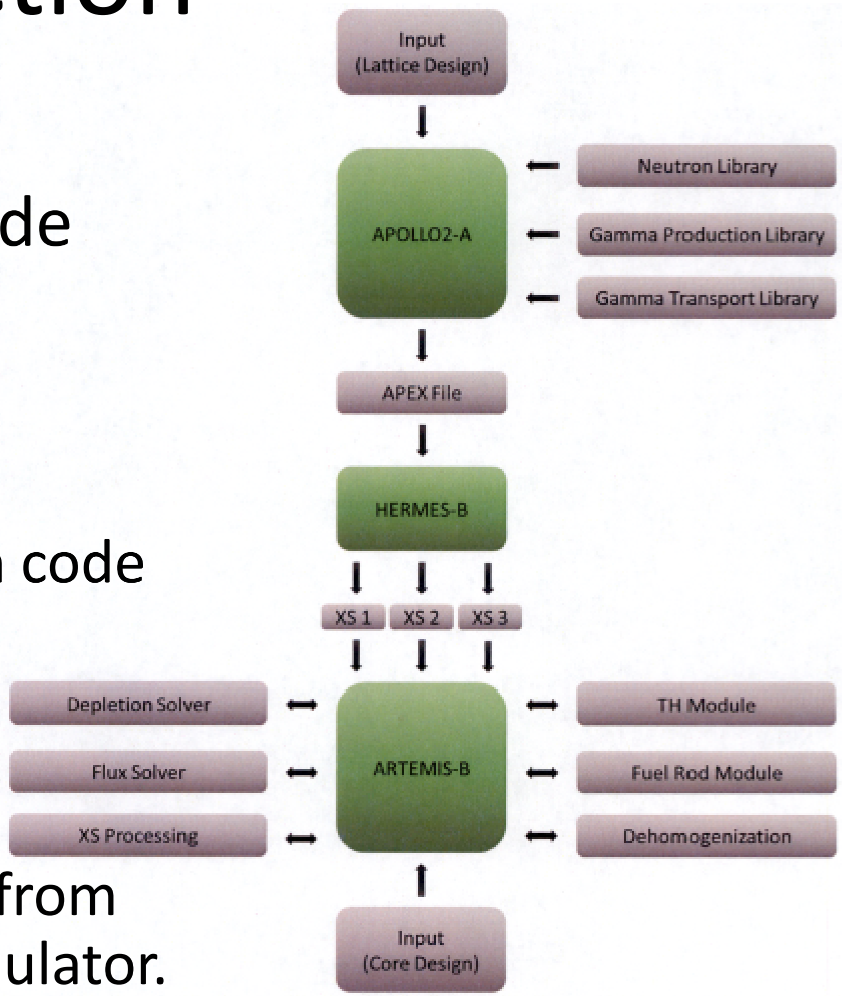
Introduction

- Framatome proposed the APOLLO2-A/ARTEMIS-B code system to model core physics in BWRs
- Applicable to steady state BWR core modeling
  - Methodology and V&V

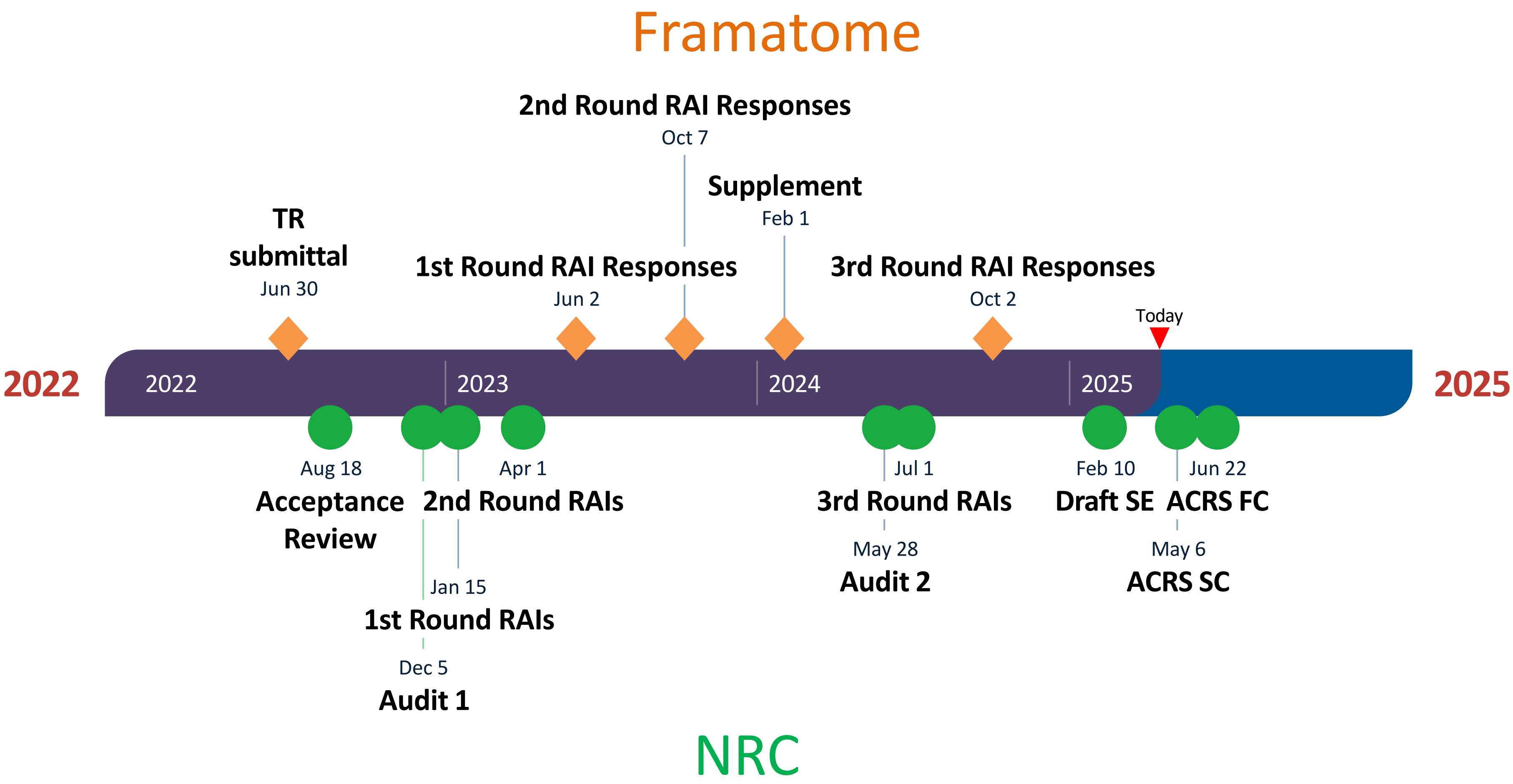


Introduction

- APOLLO2-A/ARTEMIS-B is an extension of the ARCADIA code system to BWRs including:
  - APOLLO2-A spectral code
  - ARTEMIS-B core simulator
  - Cross-section functionalization code HERMES-B
- ARTEMIS and HERMES codes extended
  - BWR specific models adapted from MICROBURN-B2 BWR core simulator.



Review Timeline



Regulatory Requirements and Guidance

- NUREG-0800, Standard Review Plan, Chapter 4.3, "Nuclear Design"
  - Fuel design limits will not be exceeded during normal operation or anticipated operational transients
  - Postulated reactivity accidents do not compromise reactor coolant pressure boundary
  - Core coolability is maintained

Regulatory Requirements and Guidance (Cont.)

- General Design Criteria 10
  - Reactor Design
- General Design Criteria 11
  - Reactor Inherent Protection
- General Design Criteria 12
  - Suppression of Reactor Power Oscillations
- General Design Criteria 13
  - Instrumentation and Control
- General Design Criteria 20
  - Protection System Functions
- General Design Criteria 25
  - Protection System Requirements for Reactivity Control Malfunctions
- General Design Criteria 26
  - Reactivity Control System Redundancy and Capability
- General Design Criteria 27
  - Combined Reactivity Control Systems Capability
- General Design criteria 28
  - Reactivity Limits

Regulatory Requirements and Guidance (Cont.)

The NRC staff reviews the areas concerning analytical methods. These are:

- Descriptions of the analytical methods used in the nuclear design, including those for predicting criticality, reactivity coefficients, burnup and stability.
- The database and/or nuclear data libraries used for neutron cross-section data and other nuclear parameters
- Verification of the analytical methods for comparison with measured data.

Neutronic Methodology

- APOLLO2-A
  - No computational models were added or changed since the ARCADIA® topical reports
  - The NRC staff considered the applicability of the current methodology to BWRs and found APOLLO2-A acceptable.
- HERMES-B
  - NRC staff reviewed cross section fitting functions and interpolation points in an RAI
  - The NRC staff found HERMES-B acceptable.

Neutronic Methodology (Cont.)

- ARTEMIS-B
  - The NRC staff focused its review on BWR-specific models.
  - Most of the added models are adapted from MICROBURN-B2, an NRC-approved core simulator.
  - Framatome provided sensitivity study in an RAI with reactors representative of modern operating states
  - The NRC staff found that the models added, and the overall methodology, are acceptable for BWR modelling.

Thermal Hydraulic Methodology

- Similar to MICROBURN-B2 core simulator
- Minor improvements made for ARTEMIS-B
- Uses an iterative calculation scheme

- NRC staff found that the TH methods were acceptable because they are consistent with approved methodologies and industry standards

Fuel Rod Module Methodology

- Comparable to ARTEMIS fuel rod module
- Physical properties consistent with RODEX4
- Effective fuel temperature equation consistent with MICROBURN-B2

- NRC staff concluded that the methodology is acceptable because it is consistent with approved industry standard codes

Validation and Verification

- APOLLO2-A V&V
  - Critical Experiments
  - Spent Fuel Measurements
  - Numerical Validation
- ARTEMIS-B V&V
  - Reflector Treatment
  - Pin Power Verification
  - Core Follow Benchmarks
  - Gamma Scans
- Thermal Hydraulic Verification
- Fuel Rod Module Verification
- The NRC staff found that the verification adequately assessed the range of applicability expected and demonstrated that the predictive capability of the code system is acceptable.

Increased Enrichment and Higher Burnup Supplement

- Framatome requested to extend the range of applicability to include increased enrichment and higher burnup conditions
  - Advanced Fuel Management (AFM) conditions
- Verification and validation of the extended conditions
- The NRC staff concluded that the APOLLO2-A/ARTEMIS-B methodology is acceptable for use at AFM conditions

Limitations and Conditions

1. Applicable to steady state operation
2. Limited to analyzing BWR fuel assemblies with square lattices and fuel designs validated within this TR
   – Can be used with similar fuel designs if modeling remains within capabilities of the methodology and validation is performed.
3. ARTEMIS-B FRM is subject to L&Cs in the current RODEX4 SE. Enrichment and burnup limits remain at non-AFM conditions until RODEX4 is approved by the NRC staff at the higher limits requested in the supplement.

Conclusions

- The NRC staff found the ANP-10350P/NP APOLLO2-A/ARTEMIS-B methodology an acceptable approach for application to steady state neutronic design analysis of BWRs.
- The NRC staff's conclusions are predicated upon licensees acceptably addressing limitations and conditions in Section 4.0 of the NRC staff's safety evaluation.

Acronyms

- AFM – Advanced Fuel Management
- BWR – Boiling Water Reactor
- FRM – Fuel Rod Module
- L&Cs – Limitations and Conditions
- RAI – Request for Additional Information
- SE – Safety Evaluation
- TH – Thermal Hydraulic
- V&V – Verification and Validation

framatome

Framatome Methodology for Boiling Water Reactors: Evaluation and Validation of APOLLO2-A/ ARTEMIS-B

ACRS Accident Analysis Subcommittee Meeting

Open Session, May 6, 2025

Jaron Senecal

Content

1. Computer Codes
2. Methods and Models
3. Verification and Validation

1 Computer Codes

Topical Report Background

- Approved methodologies
  - BWR: CASMO4/MICROBURN-B2, EMF-2158P-A
  - PWR: APOLLO2-A/ARTEMIS, ANP-10297P-A
- Methodology under consideration
  - BWR: APOLLO2-A/ARTEMIS-B, ANP-10350P
  - The first TR in a series of next generation codes and methods
  - Applicable to steady-state calculations
  - Includes supplement regarding increased enrichment and burnup

APOLLO2-A

- Lattice physics code
  - Calculates the few group cross sections (XS) for the ARTEMIS-B core simulator
- Solves the 2D neutron transport equation
  - Uses a 3 level computational scheme
  - Uses 281 neutron energy groups and 94 gamma energy groups
  - Uses the JEFF 3.1.1 cross sections with modifications
    - Modifications defined in ANP-10297 Supplement 1P-A (ARCADIA)

- No additional computational models were added since the ARCADIA topical reports

HERMES-B

- HERMES-B is a cross section functionalization code
  - The XS data are read directly from APOLLO2-A
  - Creates a multi-dimensional functional representation of the XS
  - Then the XS data can be calculated at any set of conditions
  - Based on HERMES (ANP-10297), but with additional parameters
- The following data is functionalized:
  - Microscopic XS
  - Macroscopic Residual and Delta XS
  - Pin Form Factors
  - Discontinuity Factors
  - Detector Reponses
  - Heat Deposition Fractions

ARTEMIS-B

- ARTEMIS-B is the extension of the ARTEMIS core simulator to BWRs
- ARTEMIS-B uses much of the same methodology described in ANP-10297
- ARTEMIS-B contains the following modules:
  - Flux Module
  - Fuel Rod Module
  - Thermal Hydraulic Module
  - Dehomogenization Module
  - Depletion Module

2

Methods and Models

Components From ARCADIA

- The methods of several modules are unchanged relative to ANP-10297 (and Supplement 1)
  - Flux solver
    - Uses the semi-analytical nodal expansion method with coarse mesh rebalancing
  - Dehomogenization module
    - Calculates the intra-nodal quantities such as pin powers and pin burnups
  - Depletion module
    - Uses a Krylov subspace method to solve the depletion matrix

Fuel Rod Module

- ARTEMIS-B Fuel Rod Module (FRM)
  - Solves the 1D heat transfer equation:
  - Solved for a representative fuel rod in a lattice
  - Calculates the effective fuel temperature

$$-\frac{1}{r}\frac{\delta}{\delta r}\left(r \cdot \lambda(r) \cdot \frac{\delta T(r)}{\delta r}\right) = q(r)$$

- Comparison to ANP-10297
  - Same numerical solution method
  - Properties have been updated to be consistent with RODEX4 (BAW-10247P-A)

- Properties
  - Pellet Radial Power Distribution
  - Thermal Conductivity
  - Gap Conductance
  - Porosity

Thermal Hydraulic Module

- The TH module solves the fluid conditions in the core
- Thermal hydraulic geometry
  - Equivalent to a system of parallel flow paths
  - Each flow path is connected at the top and bottom of the core
  - The main flow paths correspond to enclosed fuel assemblies
  - There are additional flow paths for the bypass and internal water channel flows
- The ARTEMIS-B TH methodology is similar to MICROBURN-B2

BWR-Specific Models

- Variable Axial Nodalization (VAX) Model
- Spacer Grid Model
- Detector Model
- Control Blade Depletion Model
- Control Blade History Model
- Reflector Model
- Jumpstart Model

3

Verification and Validation

APOLLO2-A V&V

- Three types of data are used:
  - Critical Experiments
    - Results: Reactivity and Fission Rate Distribution
    - Experiments: BASALA, EPICURE, B&W, CAMELEON, ICSBEP
  - Spent Fuel Measurements
    - Fukushima Daini 1 (BWR)
    - Fukushima Daini 2 (BWR)
    - REGAL (PWR, 10% Gadolinium)
  - Monte Carlo Comparisons
    - Used to span a much wider range of conditions and fuel types than experiments
    - Validates: reactivity, pin powers, burnup, and gamma transport

ARTEMIS-B V&V

- Verification of the Fuel Rod Module
  - Comparison made between the ARTEMIS-B FRM and RODEX4 to show consistency
- Reflector model numerical validation using SERPENT2
- Verification of the ARTEMIS-B Pin Power Predictions
  - Colorset calculations compared against APOLLO2-A
- Validation of the Thermal-Hydraulic Module
  - Pressure drop data
  - Channel average void fraction data
- Core Follow Results
  - 110 cycles from 8 different reactors
- Pin and Nodal Gamma Scan Results
  - 3 reactors / 5 cycles

Supplement Regarding AFM

- AFM - Advanced Fuel Management
  - Maximum U-235 enrichment is increased
  - Maximum full length fuel rod average burnup limit is increased

- V&V extended to AFM conditions
  - APOLLO2-A Critical Experiments
  - APOLLO2-A Numerical Validation
  - ARTEMIS-B Pin Power Verification

Conclusion

- The APOLLO2-A/ARTEMIS-B code system introduced
- An overview of the main code modules and models has been presented
- The verification and validation has been described

Thank you

Nomenclature

AFM	Advanced Fuel Management
BWR	Boiling Water Reactor
FRM	Fuel Rod Module
JEFF	Joint Evaluated Fission and Fusion File
PWR	Pressurized Water Reactor
TH	Thermal Hydraulic
TR	Topical Report
VAX	Variable Axial Nodalization
V&V	Verification and Validation
XS	Cross Section

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