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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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METALLURGY AND REACTOR FUELS SUBCOMMITTEE

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OPEN SESSION

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THURSDAY, SEPTEMBER 24, 2020

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The Subcommittee met via Video Teleconference, at 9:30 a.m. EDT, Jose March-Leuba, Chairman, presiding.

COMMITTEE MEMBERS:

JOSE MARCH-LEUBA, Chair

RONALD G. BALLINGER, Member

CHARLES H. BROWN, JR., Member

VESNA B. DIMITRIJEVIC, Member

WALTER L. KIRCHNER, Member

DAVE A. PETTI, Member

JOY L. REMPE, Member

PETE RICCARDELLA, Member

MATTHEW W. SUNSERI, Member

ACRS CONSULTANT:

STEPHEN P. SCHULTZ

DESIGNATED FEDERAL OFFICIAL:

ZENA ABDULLAHI

NRC STAFF PRESENT:

JOE DONOGHUE, NRR/DSS

MATHEW PANICKER, NRR/DSS/SFNB

ALSO PRESENT:

JERALD HOLM, Framatome

NGOLA OTTO, Framatome

P R O C E E D I N G S

9:30 a.m.

CHAIR MARCH-LEUBA: Okay, it's 9:30, this meeting will now come to order. This is a meeting of the ACRS Accident Analysis Thermal Hydraulics Subcommittee. I am Jose March-Leuba, the SC Chairman.

Because of COVID-19 concerns, this meeting is being conducted remotely. I see on the list of attendants we have Member Ron Ballinger, Charles Brown, Vesna Dimitrijevich, Walter Kirchner, David Petti, Joy Rempe, Pete Riccardella, Matt Sunseri.

Today's topic is Topical Report ANP-10323P, Revision 1, GALILEO Fuel Rod Thermomechanical Methodology for Pressurized Water Reactors. Portions of the meeting will be closed to the public to protect proprietary information. We will have an opportunity for public comments before we start the closed section of the meetings.

The ACRS was established by a statute and it's governed by the Federal Advisory Committee Act, FACA. As such, the Committee can only speak through its published letter reports. The ACRS section of the US NRC public website provides our charter, bylaws, agendas, letter reports, and full transcripts for the open portions of all full and subcommittee meetings, including the slides presented there.

The Designated Federal Official today is Zena Abdullahi.

A transcript of the meeting is being kept, therefore, please speak clearly and state your name for the benefit of the court reporter. Please keep the microphone on mute when not in use and don't use video feed to minimize bandwidth problems.

We know that we have scheduled a full Committee meeting on this topic in early October to write a letter. And I also wanted to note to the members that we have two topics. The main topic of this committee is the GALILEO fuel thermal properties methodology. But we will also have an information meeting on the best estimate Option III solution, which is a long-term stability solution that we already reviewed in plant-specific basis.

Now the staff is in the process of reviewing the Generic Topical Report that will be applicable to all plants. And they have asked us if we want to review it when it's done, which is expected the February time range, or not. And I made a decision that probably because we have already reviewed it in detail, we only needed a short information meeting where we see the differences between the generic and the plant-specific.

So at the end of this presentation, we will be hearing something about BEO-III, and we will ask the members if we want to have a full committee meeting on a letter, or this information is sufficient.

So at this point, let's request the NRC staff, Joe Donoghue, to make the introductory remarks.

Joe, you're in charge.

MR. DONOGHUE: Thank you, sir, this is Joe Donoghue. I'm a Director of the Division of Safety Systems in NRR.

Thank you for taking the time to let us present the Safety Evaluation that our staff's prepared on GALILEO. It's a methodology for a realistic evaluation of the performance of fuel rods in PWRs. And this is an important step in the vendors' suite of analysis methods and information they're going to provide related to ATF designs that they're pursuing.

So you're going to hear some details today about the thermal model, how it predicts the fuel swelling, densification, how it -- in other parts of the mechanical models. And then what licensing applications are expected -- that this would be expected to apply to.

So we've done a detailed review. We worked very closely with Framatome. I'm going to say out loud here that we've I think done a good job, the staff, working with Framatome. Framatome's done a good job being supportive of our needs to get to a Safety Evaluation that's before you.

So thanks very much, looking forward to a good meeting.

CHAIR MARCH-LEUBA: Thanks, Joe. At this point we give the floor to Framatome. I believe we're going to have a tag team of Jerald Holm and Chris Allison. And NRC will be providing the slides.

So Framatome, go ahead.

MR. HOLM: So good morning, my name is Jerry Holm, and I'm a Licensing Engineer for Framatome. We appreciate the opportunity to present Framatome's advanced fuel performance code for PWRs to the ACRS. The code GALILEO is a key element in our suite of advanced methods, and will be part of future submittals. I expect we may be back talking about GALILEO in support of these future submittals.

In particular, we appreciate the ACRS scheduling the full committee meeting on this topic for October 8 of 2020, so that the final SE may be issued in October.

With that, I'll turn it over to Chris.

MR. ALLISON: All right, thank you, Jerry. Can everybody hear me okay?

MEMBER SUNSERI: Yes.

MR. ALLISON: Okay, very good. Otto, do we -- excuse me, Ngola, do we have the slides available to bring up?

MR. OTTO: Yes, I'm loading them right now. So you should see them momentarily. Are you able to see the slides now?

CHAIR MARCH-LEUBA: I can.

MR. ALLISON: Yes, it has come up. Thank you.

So as introduced, my name is Chris Allison, I am the GALILEO project leader for the licensing in the United States. I'm in the Fuel Thermal Mechanics Department here at Framatome. If you go to slide 2, please.

Just a quick overview of the topics I'm going to discuss this morning in the open session. I'll give you some background to get you grounded in the history of GALILEO and its development. I'll provide a brief overview of the topical report and give some details on the GALILEO fuel performance code, and then the statistical evaluation methodology that it's paired with. And then I'll give a view of how GALILEO fits within our future plans for our advanced methods platform. Slide 3, please.

So, background. So the development of GALILEO was initiated with the goal to consolidate Framatome's worldwide expertise and experience into a single fuel performance code. And in doing so, we hoped to build upon all the best practices and techniques from our current generation of fuel performance codes.

And that includes COPERNIC, which is used in France and the United States for PWR applications. It includes RODEX4, which is used in the United States for BWR applications. And it includes CARO-3E, which comes from Germany.

The original development was to support a very broad range of applications, and that included PWR and BWR applications, and included UO2, gadolinia, and MOX fuels. During the process of the review, we submitted a revised topical report, and in that revision, we made a specific removal of the BWR applications and the MOX fuels. And that was consistent with our evolving priorities and strategies for where we wanted to go with our codes and methods.

And so the requested NRC approval that we have today is for PWR applications, it's for UO2 and gadolinia fuel types, with either M5 or Zr-4 cladding.

CHAIR MARCH-LEUBA: Chris, this is Jose. I -- can you give us a little background on why you decided to drop BWRs and MOX at this time? Because this approval has been going on for a long time. Was it an issue with being able to develop models inside the code, or the issue was validation against data? The timing, no need for it? Why did you do it?

MR. ALLISON: It was mostly an issue of timing and the strategy that we decided to employ for our codes and methods. We had already invested strongly in our BWR methods using RODEX4, and we decided that we did not want to repeat that process, to go again with GALILEO. And so we decided that RODEX4 was the better option there.

In terms of MOX fuel, that was more in terms of the, I would say the general dynamics of the MOX program in the United States. And then as that program kind of came to a stopping point or a, maybe an interim hold point, we decided it was better to wait and pursue that at a different time. So it's mostly just a timing issue and how it fit within our strategy.

MEMBER BALLINGER: This is Ron Ballinger. To my knowledge, there are no plants in the U.S. that are -- no PWRs that are using Zr-4 cladding anymore. So including Zr-4, is that as an afterthought?

MR. ALLISON: I would kind of --

MEMBER BALLINGER: Or is it the fact that COPERNIC already has it in it?

MR. ALLISON: I think from my perspective it's almost like a bit of a security blanket issue. It leaves that option open for us if, you know, if we ever had an emergency need where we needed to do an evaluation of an old fuel assembly with Zr-4 cladding, this approval would allow us to do that. But I do agree with your evaluation that Zr-4 cladding is basically an obsolete product in the market today.

MEMBER BALLINGER: Thank you.

CHAIR MARCH-LEUBA: Okay, thank you, proceed.

MR. ALLISON: Okay, slide 4, please. So in terms of the overview of the topical report, it does describe a methodology for the realistic evaluation of the thermal-mechanical performance of the fuel rods for PWR applications. And this is for demonstrating compliance with many of the fuel rod requirements that come from Section 4.2 of NUREG-0800.

The methodology is composed of two major components, the first being the GALILEO fuel performance code, and then the second being the statistical evaluation methodology that employs GALILEO. And the topical report describes the requirements and capabilities of the GALILEO fuel performance code.

It describes how the code is calibrated, validated, and the range of parameters over which that process was performed. It describes the uncertainty analyses and how those were selected and how they were developed based on the data. And then it provides a series of demonstration analyses to show how the code performs and how the methodology is applied to different plant types and fuel types. Slide 5, please.

So the GALILEO fuel performance code is a best estimate fuel rod performance code that simulates the thermal and mechanical response of the fuel rods in the reactor core as a function of their exposure for the local power and flow conditions. It's based on phenomenological rate-dependent models, and those were used to evaluate things like the temperatures, the strain, and exposure-dependent changes in the fuel and cladding materials and the fission gas releases that occur during operation.

It includes modeling of things like thermal conductivity degradation with burnup and irradiation damage. It has models for enhanced fission gas release at high burnup conditions and in transient conditions. And it also includes the formation of high burnup structure on the pellet rim and how that impacts the fuel behaviors at high burnup.

And maybe one of the more important things, or more advanced things, excuse me, is that it includes many new models in the pellet mechanic modeling and behavior that go a step beyond where our current generation of fuel performance codes are.

And then the -- go ahead.

CHAIR MARCH-LEUBA: Chris, when you say phenomenological rate-dependent model, what do you mean by that? What rate?

MR. ALLISON: So it could be many different things. One example would be a corrosion model where the model is developed to evaluate the corrosion rate over time, and then that performance is integrated to provide, you know, an oxide thickness at a given point in time.

It could also be a creep model, where the creep model is based on the rate of creep, given the conditions at a certain point in time. And then that behavior is integrated over the lifetime of the rod.

CHAIR MARCH-LEUBA: So for a mathematician, you are saying that you are modeling the non-linearities in the system and the histories if any are this history of the burnup.

MR. ALLISON: Yes, yes, that is correct.

CHAIR MARCH-LEUBA: Okay, thank you.

MEMBER BALLINGER: This is Ron Ballinger again. Am I to assume, I think I read it, that this -- you're assuming chromia-doped fuel as well?

MR. ALLISON: Chromia-doped fuel is a piece that will be addressed in a future step.

MEMBER BALLINGER: Okay, okay. Thank you.

MR. ALLISON: And then the last piece of this is that the fuel performance code is calibrated and validated using a very extensive database of measurements to both commercial rods and experimental test rods, both from in Europe and in the United States. And that really forms the backbone of the GALILEO fuel performance code and assessing its ability to predict rod performance.

MEMBER KIRCHNER: Chris, this is Walt Kirchner.

MR. ALLISON: Yes.

MEMBER KIRCHNER: How generic would you describe the models in this open session? And I'm anticipating future developments in claddings in particular. So you have a fairly generic base set of models that could be adapted for changes in cladding?

MR. ALLISON: I think that's a fair assessment. Generally the models are -- we try to base them on physics, so it's based on, you know, principles that are, that should be able to extend into different materials.

And then, you know, specific tuning is done to make that model work for a given material. But I do think the basis of the model does allow that we could make some application to a different material in the future, just needing to make some calibration of that model to the specific material.

MEMBER BALLINGER: Are you saying that this phenomenology or the generic model can be used for non-zirconium alloy tubing?

MR. ALLISON: I don't know that I would say it could be used for non-zirconium alloy tubing.

MEMBER BALLINGER: I didn't expect -- I didn't expect so, thanks.

MR. ALLISON: Okay, slide 6, please. So

the next piece of the topical report describes the statistical evaluation methodology. And the methodology is used to analyze rod performance during normal operating and AOO conditions for a given fuel reload and at a given power plant. It considers uncertainties over the projected range of operation of the rods in the core. And you should take that to mean the power histories for each rod.

And it includes the impact of measured and calculated power uncertainties, uncertainties in the manufactured fuel rod characteristics, and uncertainties in the GALILEO models. It employs a random sampling of those three uncertainty components that's similar to a Monte Carlo process, and it uses that with the best estimate GALILEO code, and then applies non-parametric order statistics to evaluate how those uncertainties propagate and influence the design analysis result.

And ultimately what we want to do is demonstrate that the fuel meets the design criteria with a quantified probability and confidence level. Slide 7, please.

So in closing, I'd like to give you a little perspective on where GALILEO fits in the future of our codes and methods suites and where it fits with our advanced technologies. And GALILEO really does fill a foundational role in that. You can start here at the first with a PWR rod ejection accident analysis.

This is a methodology that we've had approved by the NRC. It is -- it would be based on GALILEO, and that would be our foundation to support the new requirements and the new guidance that come from Regulatory Guide 1.236.

The next piece would be our advanced non-LOCA transient analysis methodology. And you may see that called the ARITA methodology. That is a topical report that's currently in review by the NRC, and it uses GALILEO for the evaluation of fuel melt and cladding strain during transient events.

The next piece would be our advanced LOCA analysis methods. And these would be using GALILEO to provide fuel rod input to the LOCA analysis. And you would expect to see -- you can expect to see that in a future submittal.

The next piece would be our advanced fuel management program. And this is targeting applications such as increasing our burnup limits. We're using higher enrichment in our fuel pellets, and you can expect to see those in future submittals as well. And GALILEO is a basis behind those.

And then the last piece would be the enhanced accident-tolerant fuel program, which you would also see in future submittals. And here GALILEO would be a supporting role for that, for the different types of technologies that we're exploring in that program.

MEMBER REMPE: So Chris, this is Joy Rempe. When you start thinking about what you're going to do when you go for new fuels and enhanced accident-tolerant fuels, and the fact that Halden has shut down, what's the plan for Framatome for getting data for extended burnup for these new fuels?

MR. ALLISON: I am maybe not the best person to comment on the plans for the accident-tolerant fuel program. I do know that there are plans of how they want to try to address different testing needs in the absence of Halden, and that might rely on more homegrown testing here in the United States, either out at Idaho or maybe at Oak Ridge. But the details of that plan I am not cognizant of.

MEMBER REMPE: So it's off-topic a bit, I'll grant you that, but I was reading your reports and the information we were given for this and thinking about the burnup limitations for various fuels. And I'd note that you can't really do it at Oak Ridge. And so yeah, maybe you could do something out at ATR, but they don't have the instrumentation capabilities they had at Halden.

Sometimes people talk about, well, the Jules Horowitz Reactor. And again, it's not up and running yet. But I think it's going to be hard to when you start talking about different things that are up for certain, up to certain burnups, what you're going to do in the future here. And I'm just curious what -- and you know, I think it's something that people need to think about.

MR. ALLISON: I agree completely with you. The loss of Halden is important for the industry as a whole, and specifically in terms of what it means for accident-tolerant fuel. And as you want to proceed into these ranges where we don't have data, it is going to be a substantial challenge.

MR. SCHULTZ: Chris, this is Steve Schultz. I have a general question on the additional submittals that you're anticipating. Are you expecting that you're going to have to make changes to GALILEO in these submittals, that there's going to be additional model changes that may be required for these future applications?

MR. ALLISON: I think that's a certainty, if you're speaking about accident-tolerant fuel. I think you would certainly see new modeling come in to handle those different materials and different fuel types that are being addressed there.

In terms of the advanced fuel management, I would not expect that to be the case.

MR. SCHULTZ: You already have information related to both increased -- well, to increased burnup at least, higher enrichment. I guess it depends where you intend to go with that, given what you presented in the GALILEO application.

MR. ALLISON: That's correct.

MR. SCHULTZ: So that would be a -- that could be a validation of what has already been presented to the NRC. Again, it depends where you're intending to go with that. Thank you.

MR. ALLISON: Yes, yes, I would agree with that statement. In future submittals, that would come up along those lines of increased burnup and higher enrichment, would certainly address how GALILEO and its methodology addresses those items, but it also includes many other items. And so those are much more --

MR. SCHULTZ: How are where you're --

excuse me, yeah, how about what will you expect -- where you expect to go with the LOCA analysis methods. Is what you have and what we're reviewing now as you see it satisfactory for what you're anticipating for your future submittal?

MR. ALLISON: I would have to defer that question because I am not involved with the LOCA analysis method. So I would have to defer that to someone more involved with that program.

MR. SCHULTZ: That's fine, thank you.

MEMBER BALLINGER: This is Ron again.

MEMBER PETTI: But to be clear, this, GALILEO, what we're really reviewing is the steady state.

MEMBER BALLINGER: Yeah, that's what I was about to say. It's not a transient code.

MEMBER PETTI: At least the transient capabilities we're not reviewing. We're really focusing on steady state.

CHAIR MARCH-LEUBA: Jerry, could you comment on that? Because when you do the non-LOCA transient analysis, which is currently under review, how is it coupled to the calculation?

MR. ALLISON: I'm sorry.

CHAIR MARCH-LEUBA: Do you understand the question? If you apply the GALILEO methodology to evaluate the results of a rod ejection or a non-LOCA transient, how do you do it? Do you do it in quasi-steady states like this?

MR. ALLISON: So for -- I can speak first to the PWR rod ejection. So the main application of GALILEO there would be more in terms of like initial conditions and the initiation of the accident. Providing things like an initial hydrogen content, for example.

In the non-LOCA transient analysis, GALILEO does include, I think I would go with your statement of quasi-steady, quasi-steady state or quasi-transient. And so it has the capability to make those transient types of predictions for fuel center line melt evaluations and clad strain evaluations.

CHAIR MARCH-LEUBA: So you would use ARITA to calculate the coolant conditions and the fuel power to each rod. And then every time step, you will do a steady state GALILEO calculation to calculate the center line temperature. Is that reasonable to say?

MR. ALLISON: That's a reasonable assessment, yes.

CHAIR MARCH-LEUBA: Okay.

MEMBER BALLINGER: This is Ron again,

it'll probably be a lot of agains. In part -- not to get into proprietary stuff, but does the non-LOCA transient part include accounting for liftoff of the cladding from the fuel?

MR. ALLISON: I think I would -- if I can defer that question to the closed session.

MEMBER BALLINGER: Okay, fine.

MR. ALLISON: I can answer it there.

MEMBER BALLINGER: Yep, thanks.

MEMBER KIRCHNER: Chris, this is Walt again. I had to ask rather a leading question, and some of your bullets here addressed where I was going with my question.

But when you describe this as a platform, or I'm sorry, a methodology, that has rate-dependent phenomena, what you're really talking about, the rates you're talking about are time at temperature, time exposure, burnup, not transient -- do you also mean transient performance as would be used for something like a LOCA analysis where you've got a quick transient and the dynamics that go with that?

Or maybe we save this for the closed session. You see what I'm saying?

MR. ALLISON: Yes.

MEMBER KIRCHNER: Things like pellet clad interaction under those LOCA kind of transients is a rate-dependent phenomenon as well. But that's very quick, not the -- I presume the rate-based phenomena that you're generally talking about are time, you know, exposure, burnup over a fuel cycle, not over a short-term transient.

MR. ALLISON: I believe that is a correct assessment. And we can -- we could go more detail on that in the closed session if you would like.

MEMBER KIRCHNER: The one I was reacting to was fission gas release in particular. Because for the rod ejection accident, that certainly is a rate-dependent phenomenon, but a very short -- and during a very short transient.

MR. ALLISON: Right. I think in terms of the speed of an event, we would say the rates we're talking about are for normal operations and for typical AOO-type of events, but --

MEMBER KIRCHNER: Right, so as one of my colleagues pointed out, more quasi-steady state, so to speak.

MR. ALLISON: Yes. And things like rod ejection and LOCA would bring in new sets of phenomena. And you address those types of rate dependencies in those specific methodologies.

CHAIR MARCH-LEUBA: Any more questions for Framatome before we transfer to the staff? Okay, thanks, Chris.

MR. ALLISON: Thank you.

CHAIR MARCH-LEUBA: We are going to start the presentation by the staff. It's going to be also a team of two, Mathew Panicker and Ken Geelhood.

So Mathew, are you going to talk?

MR. PANICKER: Yeah, this is an open session. Next up is a team of engineers from NRC and PNNL who were involved in the review of this GALILEO code, ANP-10323, Revision 1. The review was focused on the core, and the assessment of the individual models in the core, for example thermal model, fission gas release model, et cetera, mechanical models. Assessment of the integral core predictions.

The methodology consisted of assessing -- the review consisted of assessing proposed uncertainties, the statistical methodology Framatome used for various models and assessment, and assessment of fuel damage limits. Next please.

The Revision 0 of the methodology topical report was submitted in October 2013, and it is based on realistic evaluation of the thermal-mechanical performance of fuel rods for pressurized water reactor fuels, PWR fuels. And original submission was applicable to PWR, BWR, and MOX fuels, and later on NRC suspended -- requested the suspension of MOX and BWR fuels. It has got burnable absorbers, UO2 fuel. Originally it contained Zircaloy-2 for BWRs, Zircaloy-4 and M5 for PWRs.

The methodology provided for all of the thermal mechanical analysis, which is typical of a fuel performance core. Acceptance review was performed in March 2013, and we accepted the core. We give -- we had PNNL staff as consultants under a contract. And upon review, there were about 70 RAIs, including subparts, was issued. Next please.

CHAIR MARCH-LEUBA: Mathew, can you keep the slide 3? I see the cladding materials, Z-2, Z-4, and M5, that are quoted as the Framatome fabricated clads. And I don't remember seeing in the SER any mention of what we call mixed cores, when you have coresident fuel from a different vendor. How do we plan to handle that? Did I miss it in the SER?

MR. PANICKER: Mixed core analysis is done, and not as part of this but fuel performance core. That will be under different thermal hydraulics analysis.

CHAIR MARCH-LEUBA: So the plan will be to use the vendor number two thermal mechanical codes for the properties for their fuel?

MR. PANICKER: This is for the Framatome fuels.

CHAIR MARCH-LEUBA: So this is limited exclusively to analyze Framatome fuel, and if they have a mixed core with a transition with coresident fuel, we'll have to handle it separately?

MR. PANICKER: Yeah, that will be handled separately. There are other issues connected with mixed core, because DNBR values, mixed core thermal hydraulics, different pressure drops for different fuel assemblies.

CHAIR MARCH-LEUBA: Yeah.

MR. PANICKER: All those things are to be considered in the thermal hydraulic analysis.

CHAIR MARCH-LEUBA: Yeah, if we can make a recommendation that maybe the SER should -- well it's kind of late, but should be specific that this is only for Framatome fuels. Go ahead, Ron.

MEMBER BALLINGER: We need to be a little careful here. This fuel performance code doesn't care who made the fuel. All it cares about is the input parameters. So to the extent that another person's fuel is in the core, they can use this for that. It's just that the thermal hydraulics part would be different. So there's nothing in this code that deals with anything other than the surface temperature of the clad.

CHAIR MARCH-LEUBA: M5 is a proprietary alloy for Framatome. Nobody else can use it.

MEMBER BALLINGER: Yeah, sure.

CHAIR MARCH-LEUBA: And another vendors, I don't recall, SIRCLO (phonetic) --

MEMBER BALLINGER: Oh, you mean other vendors using this model. That's a different --

CHAIR MARCH-LEUBA: No, no, no. Framatome using this model to analyze a core that has coresident fuel from Westinghouse.

MEMBER BALLINGER: Sure, they don't need anything other than the input parameters for this code to run a fuel performance model.

MEMBER KIRCHNER: Yeah, that -- I agree, Ron. That's why I was asking the question about generic. As long as you're staying within the qualified, the validated basis for this methodology, it should not matter.

MEMBER RICCARDELLA: Right.

PARTICIPANT: But this code might not work for ZIRLO.

MR. GEELHOOD: This code doesn't have any models for other alloys such as ZIRLO.

MEMBER BALLINGER: Well, but it's not, you're not asking for approval for that, right?

CHAIR MARCH-LEUBA: Well, but if you want to balance a core that has both manufactured fuels, you will have to get a special dispensation to use mixed methods. It pays to think these things in advance before a plant has to do a reload in May --

MEMBER KIRCHNER: Well, I would think, Jose, that if you had such a mixed core, you might have to use GALILEO for the Framatome fuel and the XYZ methodology for the other fuel. But --

CHAIR MARCH-LEUBA: That sounds reasonable.

MEMBER KIRCHNER: It should still be valid for the fuel assemblies that are being analyzed with GALILEO.

CHAIR MARCH-LEUBA: Okay.

MEMBER KIRCHNER: It's more the thermal hydraulics domain and the spacer grids and other factors outside of the actual fuel rod mechanical model that would be substantially different when you change fuel bundles or mix fuel bundles.

CHAIR MARCH-LEUBA: And a fuel bundle with

M5 performs hydrogen-wise much better than one with Zr-4, or even certainly Zr-2.

MEMBER KIRCHNER: Yeah, I agree. So that the complexity would be you would have to use, like I said, the XYZ code for the other fuel.

CHAIR MARCH-LEUBA: I think so.

MEMBER KIRCHNER: Yeah.

MEMBER BALLINGER: I mean, it's the same dance that has to be done if you've got a BWR and you're evaluating instability and you got two different types of fuel.

CHAIR MARCH-LEUBA: Yeah, okay. I'm saying -- okay, I'll drop my comment. I was saying that the SER should be more specific that it's only applicable to the cladding of -- that it was intended for.

MR. PANICKER: Yes, this is Mathew Panicker, Fuel Analysis Group. For a mixed fuel, we usually have the specification from all the vendors, and they are to do a thermal hydraulic compatibility analysis including the friction factors, pressure drops, et cetera and come out with the margin for pressure drop which is acceptable for the operating and for that fuel to operate in the core, the mixed fuel.

And then there is another way of doing, solving the mixed core problem is characterization analysis. The compatibility of all the fuels with the configuration of the core. Like bypass flow, et cetera, et cetera.

CHAIR MARCH-LEUBA: Right, but for some of the acceptance criteria, you need to know how much hydrogen is in the clad. And for that you need to know who manufactured the clad, and you have to use the proper correlation. GALILEO cannot be used to calculate a SIRCLO hydrogen intake.

MR. PANICKER: That's right.

CHAIR MARCH-LEUBA: Yeah, okay, so I guess we'll cross that bridge -- maybe it's more applicable when we review the ARITA thermal hydraulic and non-LOCA transient. Probably the limitation or condition or at least bringing this up belongs more there than here. All right, continue.

MR. PANICKER: Next slide, please. The AREVA, as I said before, AREVA revised the scope of the topical report, suspended BWR and MOX fuels in November 2015. And then after that, in June of 2018, after they have looked at the RAIs and et cetera, et cetera, they revised the topical report Revision 1 of ANP-10323 after dropping the MOX and BWR fuels. And this is applicable to UO2 and gadolinia fuels, Zircaloy-4 and M5. The methodology provided limited set of thermal-mechanical analyses.

Because of the extensive nature of the RAIs, Framatome could deliver it in five installments, starting from December 18 through July 20th. The July 20, 2020 was to clarify a limitation condition, couple of limitation conditions in the Safety Evaluation. For review -- during the review, confirmatory calculation were performed using the analysis FRAPCON fuel performance code for comparison with GALILEO.

And most of the properties of the GALILEO has been compared with FRAPCON, and you might have seen, the members of the ACRS might have seen that in the Safety Evaluation. There were extensive graphical representation of those comparisons. Next please.

So this is some -- the GALILEO is actually built on the COPERNIC PWR cores that just been used in the U.S., and then the German TUV approved CARO-3. It has got models for thermal model and assessment, fission gas release, and its impact on internal pressure of RIP; cladding corrosion and hydriding model; cladding hydrogen pickup; fuel densification and swelling model; mechanical modeling and properties; fuel mechanical properties; rod volume and

-- rod volume model, void volume model and growth assessment; licensing applications.

It is not an improved statistical approach, 95% -- 95/95 or better. In most cases, it was 99.9/95 uncertainty calculations and other code applicabilities for fuel performance analysis. Next please.

These are the list of guidances and the regulations we used. GDC 10, which applied to SAFDL, which is not exceeding -- is not exceeded during the normal operation and AOOs. Provide emergency core cooling following LOCA, that is usually comes from what you call the fuel performance codes. But in this case, Framatome will submit another application for LOCA analysis. And also 10 CFR 50.46, acceptance criteria for ECCS.

10 CFR 50.34 talks about the -- provides guidance for the analysis and evaluation of design and performance of structures, systems, and components. SRP 4.2, which is the guideline for the fuel damage. No damage during AOOs. Fuel damage is not severe to prevent control rod insertion. Number of fuel rod failures not underestimated for proposed accidents. Core coolability should be maintained.

And also it -- there were complaints with

SRP 15.02. You cannot say complaints, the guidance in SRP 15.02 is followed because they have provided us with a lot of documentation including theory manual, V&V analysis, and all those things, the evaluation models. And a good explanation for the uncertainty analysis is included in the topical report. Next please.

The staff found that the GALILEO code and methodology as described in ANP-10323P Revision 1 and modified as discussed in the RAI responses are acceptable. There are several fuel limitations and conditions regarding the applicability rates, methodologies that are not approved, and documentation.

I think that should be the final slide.

CHAIR MARCH-LEUBA: Yes, it is. Thank you, Matt. Anybody has any questions for the staff on the open session? Remember that we'll be seeing details on the closed session in a moment.

So Mathew, I just wanted to say that this is a very good SER, very thorough work, very detailed. Lots and lots of confirmatory calculations, which is always good to see. And I congratulate you and your team on an excellent job.

MR. PANICKER: Thank you.

CHAIR MARCH-LEUBA: So we are moving now, changing topics completely, we are moving to the BWR division of Framatome. And we're going to be talking about the long-term stability solution for boiling water reactors that the staff has already approved and we reviewed for plant-specific implementation in Brunswick. And now they're submitting a generic topical report with a few modifications.

So this is an information meeting and the members will have to provide feedback if we want to issue a letter on it or are we satisfied with the original recommendation for Brunswick and this information meeting.

So Doug Pruitt, I believe you are on. You only have a few minutes for the introduction. Doug, I don't see you coming up.

MR. PRUITT: Can you hear me now?

CHAIR MARCH-LEUBA: Yes.

MR. PRUITT: Okay, I was muted from your side. Here we go. I'll unmute you, can you say something?

MR. OTTO: Can you see my screen?

CHAIR MARCH-LEUBA: I can see the screen. Doug, if you can speak a little louder, you come a little soft.

MR. PRUITT: Okay, can you hear me now?

CHAIR MARCH-LEUBA: Perfect, thank you.

MR. PRUITT: Okay. Good morning, I am Doug Pruitt, I would like to thank you for this opportunity to brief the changes to the best estimate enhanced Option III methodology from that client-specific methodology you reviewed in November.

I'm on slide 2, by the way. In this introduction, I will briefly touch on the BEO-III background, basically addressing why would we introduce statistical methodology; a summary of the BEO-III methodology; and a comparison of plant-specific and the generic methodology. That's slide 3.

The original BWR Owners' Group option III methodology and associated Detect and Suppress hardware was developed and implemented over 25 years ago. And that setpoint methodology was composed of several analytical components, each with its own conservative assumptions.

And part of that was because it was a generic methodology that addressed all vendors, and at the time obviously the methodologies and the computer capacity were limited.

The compounding of those conservatisms may result in a relatively small margin between normal operational noise and the trip setpoint for some plants. It consequently resulted in some spurious reactor scrams. The BEO-III statistical methodology aims to provide conservative reactor setpoints that provide greater operational flexibility to avoid spurious scrams and challenges to the safety systems. Slide 4, please.

BEO-III is based on a cycle-specific statistical analysis to determine the bounding 95/95 figures of merit criteria and establish the operating limit MCPR for reactor instabilities. Unique to the BEO-III methodology is the greater insight in core design due to the figures of merit. Of course, we do the core MCPR to demonstrate that the safety limit is not challenged at the time of oscillation suppression.

We go further and look at the limiting channel hydraulic response to demonstrate that the Detect and Suppress System was not challenged by independent channel oscillations. Slide 5.

So what's changed between the plant-specific that we talked about last year and the generic LTR? The correlations, nodalization, numerical solutions, validation against measured data, derivation of modeling uncertainties, statistical analysis, and capability that supports plant-specific

Detect and Suppress hardware are identical.

The changes include one, revision to the numerical basis for ICO, independent channel oscillations. Two, introduction of an exposure pre-filter to disposition non-limiting exposures from the statistical evaluation. Implementation of a more robust determination of oscillation decay ratios, and an additional analysis step to assess operational flexibility.

And that's the conclusion of my open presentation. Any comments, questions?

CHAIR MARCH-LEUBA: Hearing none, I just want to say that I've reviewed the BEO-III when we all reviewed it back in the Brunswick application, and I like the fact that it gives more insight into the whole core operation, the whole cycle.

Because it analyzes the whole cycle ahead of time and tells you when you may have a problem and when you don't have a problem. As opposed to the old, the 1980s methodologies, which we had to calculate in very conservative numbers and too much conservatism.

So I like the -- I want to say thank you for submitting this methodology because I think it's an improvement. Makes the reactor safer and improves the operability.

MEMBER BROWN: Jose, can I ask a question?

CHAIR MARCH-LEUBA: Please, go ahead.

MEMBER BROWN: Back on slide 3. Second bullet.

MR. PRUITT: Yes.

MEMBER BROWN: The compounding of conservatisms results in a relatively small margin between normal operational noise and setpoints for some plants and have resulted in spurious scrams. I understand that statement.

In my past battles in my old program, the Naval Nuclear Program, we normally based what I would call removal of -- or having better knowledge of the level of our conservatisms, they were based on data, not on just the desire to redo, you know, to redo the analysis.

Is this, when we -- when you talk about removing conservatisms, I understand the desire to prevent spurious scrams. Are they based on test empirical data from fuel performance, or is it just, it is better instrumentation that you know where you are better? As opposed to a ten percent error instrumentation, you now have stuff that's good to one or two percent or four percent?

I'm just looking for what's the basis for being able to improve this performance aspect.

MR. PRUITT: Yes, the primary change that results the conservatism of the old method. The old method basically assumes that to arrive at natural circulation at equilibrium conditions, so the feedwater, there's no time element associated with it.

And it also assumes that basically you start out the oscillation at some growth ratio. And it was a distribution maybe between 1.0 and 1.4 or 5, I can't remember exactly. And that was what established the hot-channel oscillation magnitude.

By going to a full simulation of the pump trip and the feedwater temperature equilibration, you start your detection of oscillations at a much lower magnitude, basically when it's becoming unstable. And so your system is able to respond much faster in a real transient simulation than it is in the conservative kind of steady state approximations.

MEMBER BROWN: Well, okay, but how are you able to get it lower? Is that because your measurements allow you to do that?

MR. PRUITT: Well, the other system assumes that you start detecting the oscillations when you're at a growth ratio of 1.1, 1.2, 1.3, whatever would be at that equilibrium condition. And so you still then have to wait for it to get to the number of counts in the oscillation magnitude in order to trip the system. In reality, it starts counting oscillations and monitoring when you cross the boundary.

And it's a much slower process where you start out at 1.0 and it slowly increases in growth rate as the feedwater equilibrates. And so basically the protection system is armed and ready to trip the reactor at a much lower or much earlier in the oscillation growth.

CHAIR MARCH-LEUBA: Doug, would you say that -- I mean, the detection system has not changed. We have the same detection system --

MR. PRUITT: Right.

CHAIR MARCH-LEUBA: -- before and after. The main difference is that now you're doing a best estimate calculation of what actually happens in the reactor, versus assuming the worst possible scenario.

MEMBER BROWN: Okay, I got that. So but is that -- is the best estimate then being used for design basis accident considerations or for beyond design basis considerations?

MR. PRUITT: Well, this is treated as a regular AOO, so this is --

CHAIR MARCH-LEUBA: It is always a pump trip, correct, Doug?

MR. PRUITT: Correct, yeah.

CHAIR MARCH-LEUBA: So it's a recirculation pump trip.

MEMBER KIRCHNER: Yeah, Charlie, this is in an AOO category of events for BWR.

MR. PRUITT: Yeah, we treat it as an Anticipated Operational Occurrence. We have separate methodologies based on the same code for anticipated transients without scram and an instability.

MEMBER BROWN: Okay, thanks.

CHAIR MARCH-LEUBA: Excellent. Any more comments in the open session? I'll count to five. I'll say no, so can we open the public line. Any members participating in the conference, in the Skype conference or the public line, could you, if you want to make a comment, please do so right now.

Can we have a confirmation the public line is open, Thomas? I don't hear anything. Anybody at all that wants to make a comment, please do so now, the next five seconds.

Good, so this concludes the open session of the meeting. We're going to transfer to the closed session to discuss proprietary information to

Framatome. And we are going to try to use a different process today than we've used in the past.

The closed meeting is being controlled by some gatekeepers, and they are the ones that will let you in if they determine that you belong inside, that you have a need to know for this proprietary information.

So we will reconvene at 10:35, which is seven minutes from now, on the closed session. And it will take a little while to let everybody through the log-in. So thank you very much for --

MEMBER KIRCHNER: Jose, could we have a few more minutes than seven minutes?

CHAIR MARCH-LEUBA: Yeah, I just didn't want to run over one, but you're right. Let's start at 10:45. Because it will take that long to let everybody in.

MEMBER KIRCHNER: Much obliged.

MEMBER BALLINGER: This is Ron, we have a second invitation, is that correct?

CHAIR MARCH-LEUBA: That is correct. And it starts with capitals closed meeting.

MEMBER BALLINGER: Yeah, yeah, okay.

CHAIR MARCH-LEUBA: Yeah, okay, so this phone line should go dead because there is no business to be had here. So everybody that belongs in the closed meeting, please move to the closed meeting. So we are temporarily recessed, and we will reopen the meeting later on, at 10:45.

MEMBER BROWN: So we'll reopen this meeting later also after? We're going to have another open session, or is the rest of the day on closed?

CHAIR MARCH-LEUBA: We, ACRS, will have a completely different topic this afternoon at 2:00 p.m.

MEMBER BROWN: Oh, no, I understand that, but for your purposes, we're going to be in closed for your subcommittee meeting.

CHAIR MARCH-LEUBA: We will be closed for the rest of the morning, until 1:00.

MEMBER BROWN: Okay, thank you, thank you.

(Whereupon, the above-entitled matter went off the record at 10:29 a.m.)

ACRS Sub-committee Meeting
Topical Report ANP-10323P GALILEO

Chris Allison

September 24, 2020

Topics

- Background
- Overview of Topical Report
- GALILEO Fuel Performance Code
- Statistical Evaluation Methodology
- Advanced Methods Platform

Background

- Development of GALILEO initiated to consolidate Framatome's worldwide expertise and experience into a single fuel performance code
- Builds upon the best practices and techniques from Framatome's current generation of fuel performance codes and methods, including:
  - COPERNIC (France and US)
  - RODEX4 (US)
  - CARO-3E (Germany)
- Originally developed to support PWR and BWR applications for UO_2, gadolinia and MOX fuels
- Requested NRC approval for
  - PWR applications
  - UO_2 and gadolinia fuel types
  - M5 and Zr-4 cladding

Overview of Topical Report

- Describes a methodology for the realistic evaluation of the thermal-mechanical performance of fuel rods for PWR applications
- The methodology is for demonstrating compliance with many of the fuel rod requirements of Section 4.2 of NUREG-0800
- Two major components:
  - GALILEO fuel performance code
  - Statistical evaluation methodology
- Topical report describes the following aspects
  - Requirements and capabilities
  - GALILEO calibration, validation, and range of parameters
  - Uncertainty analyses
  - Demonstration analyses

GALILEO Fuel Performance Code

- Best-estimate fuel rod performance code
- Simulates the thermal and mechanical response of a fuel rod in a reactor core as a function of exposure for the local power and flow conditions encountered during reactor operation
- Phenomenological rate dependent models evaluate the temperature, strain, exposure dependent changes in the state of the fuel and cladding materials, and the release of fission gas products
- Includes modeling of
  - Thermal conductivity degradation with burnup
  - Enhanced fission gas release in transients and at high burnup
  - Formation of high burnup structure on pellet rim
  - Advanced pellet mechanical models
- Calibrated and validated to an extensive fuel performance database consisting of European and U.S. data

Statistical Evaluation Methodology

- Analyze fuel rod performance during normal operating and AOO conditions for a given fuel reload and power plant
- Considers the uncertainties over the projected range of fuel operation for the rods in the core (power histories), the measured and calculated power uncertainties, the manufactured fuel rod characteristic uncertainties, and the GALILEO model uncertainties
- Employs a random sampling of the power, manufacturing, and model uncertainties, similar to Monte Carlo, with the best-estimate GALILEO code in conjunction with non-parametric statistics to evaluate the propagation of the uncertainties to the design analysis results

Demonstrate that the fuel meets the design criteria with a quantified probability

Advanced Methods Platform

- GALILEO is a foundational piece in Framatome's platform of advanced technologies and methods, including
  - PWR Rod Ejection Accident (REA) analysis – NRC approved methodology
    - Supports RG 1.236
  - Non-LOCA transient analysis – in NRC review
  - LOCA analysis methods – future submittal
  - Advanced Fuel Management (AFM) – future submittal(s)
    - Increased burnup
    - Higher enrichment
  - Enhanced Accident Tolerant Fuel (EATF) – future submittal(s)

Acronyms

ACRS – Advisory Committee on Reactor Safeguards

AFM – Advanced Fuel Management

AOO – Anticipated Operational Occurrence

BWR – Boiling Water Reactor

EATF – Enhanced Accident Tolerant Fuel

LOCA – Loss of Coolant Accident

MOX – Mixed Oxide

PWR – Pressurized Water Reactor

REA – Rod Ejection Accident

RG – Regulatory Guide

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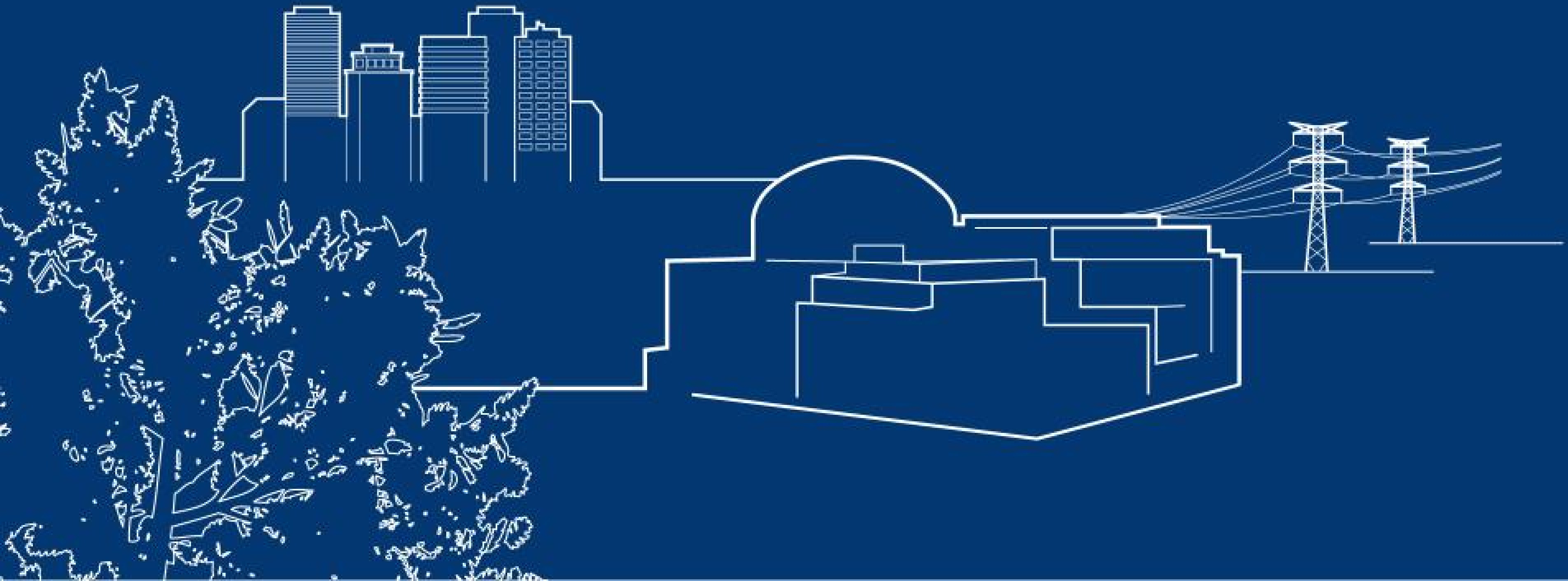
Thank you



NRC EVALUATION OF GALILEO CODE AND METHODOLOGY
TOPICAL REPORT ANP-10323 REVISION 1

OPEN SESSION

Mathew Panicker Ph.D., P.E.
Nuclear Methods and Fuel Analysis Branch
NRR/DSS/SFNB
ACRS Subcommittee Meeting
September 24, 2020

Review of GALILEO Fuel Rod Thermal-Mechanical Code and Methods

- Mathew Panicker (NRC)
- Technical Review provided by PNNL under contract with NRC
  - Ken Geelhood
  - Dion Sunderland
  - Christine Goodson
  - Carl Beyer
  - Robert Montgomery
- Review focus
  - GALILEO Code
    - Assessment of individual models
    - Assessment of integral code predictions
  - GALILEO Methodology
    - Assessment of proposed uncertainties
    - Assessment of statistical methodology
    - Assessment of fuel damage limits

Overview and History

- Revision 0 of ANP-10323 (GALILEO) submitted in October 2013
- Realistic evaluation of the thermal-mechanical performance of fuel rods for Pressurized Water Reactors (PWRs).
  - Applicable to PWR, BWR and MOX fuels
  - UO_2, burnable absorbers
  - Zircaloy-2, Zircaloy-4, M5
  - Methodology provided for all thermal-mechanical analyses
- Acceptance review was performed by NRC staff, March 2014
- PNNL staff supported the technical review under contract NRC-HQ-20-14-T-0009 under technical supervision of NRC staff
- Upon review, over 70 RAIs (including sub-parts) were issued

Overview and History (Contd.)

- AREVA revised the scope of TR, suspended BWR and MOX fuels, November 2015
- Framatome submitted ANP-10323 Revision 1 for PWR fuels June 2018 (Applicable to PWR fuel, UO_2 and UO_2-Gd_2O_3 , Zircaloy-4 and M5, Methodology provided for limited set of thermal-mechanical analyses
- Framatome responded to RAIs in five installments; 12/18, 1/19, 6/19, 9/19,, 5/20, and 7/20
- For the review confirmatory calculations were performed using the NRC's FRAPCON fuel performance code for comparison to GALILEO

Areas Covered in GALILEO

- Areva (Framatome) submitted GALILEO topical report in August 2013
- GALILEO is Built upon NRC-approved COPERNIC and German TUV approved CARO-3
  - Thermal model and assessment
  - Fission gas release (FGR) model and its impact on internal pressure (RIP) model
  - Cladding corrosion and hydriding model
  - Cladding hydrogen pickup
  - Fuel densification and swelling model
  - Mechanical modeling and properties; Fuel Mechanical properties
  - Rod void volume model and growth assessment
  - Licensing applications
  - Improved statistical approach
  - 95%/95% or better approach for uncertainty calculations
  - Code applicability

Regulatory Evaluation

- GDC 10: SAFDLs not exceeded during NO and AOOs
- GDC 35: Provide emergency core cooling following LOCA
- 10 CFR 50.46 Acceptance criteria for ECCS
- 10 CFR 50.34 Analysis and evaluation of design and performance of structures, systems, and components
- SRP 4.2: No damage to fuel during NO and AOOs
  - Fuel damage not severe to prevent control rod insertion
  - Number of fuel rod failures not underestimated for PAs
  - Core coolability is maintained
- Compliance with SRP 15.02; documentation, code verification and validation, evaluation model, uncertainty analysis included

Conclusions in SE

- NRC finds GALILEO code and methodology as described in ANP-10323P Revision 1 and modified as discussed in RAI responses to be acceptable
- Several limitations and conditions were stated regarding applicability range, methodologies that are not approved, and documentation

Acronyms

AOO - Anticipated Operational Occurrences

BWR - Boiling Water Reactor

ECCS - Emergency Core Cooling Systems

LOCA – Loss of Coolant Accident

MOX - Mixed Oxide

NO – Normal Operations

RAI – Request for Additional Information

SAFDLs - Specified Acceptable Fuel Design Limits

UO_2 - Uranium Dioxide

Best-estimate Enhanced Option III (BEO-III) Open-Session

Doug Pruitt

ACRS Information Meeting – September 24, 2020

Outline

- BEO-III Background
- Summary of BEO-III Methodology
- Comparison of Plant-Specific and Generic Methodology

BEO-III Background

- The original BWROG Option III methodology and associated Detect and Suppress (D&S) hardware were developed and implemented over 25 years ago.
  - The setpoint methodology was composed of several analytical components each with its own conservative assumptions.
- The compounding of conservatisms result in a relatively small margin between normal operational noise and the trip setpoint for some plants and consequently have resulted in spurious reactor scrams.
- The BEO-III statistical methodology aims to provide conservative reactor setpoints that provide greater operational flexibility to avoid spurious reactor scrams and challenges to the safety systems.

Summary of BEO-III Methodology

- BEO-III is based on cycle-specific statistical analyses to determine the bounding 95/95 figures of merit (FoM) and establish the OLMCPR for reactor instabilities
- Unique to the BEO-III methodology is the greater insight into the core design due to the selected FoM.
  - Core MCPR to demonstrate that the Safety Limit is not challenged at the time of oscillation suppression
  - Limiting channel hydraulic response to demonstrate that the D&S system is not challenged by independent channel oscillations (ICO)
- The BEO-III methodology has been reviewed previously as a plant specific methodology

Comparison of Plant-specific and Generic Method

- Correlations, nodalization, numerical solutions are identical.
- Validation against measured data and derivation of modeling uncertainties is identical
- Statistical analysis is identical
- Both support plant specific D&S hardware
- Changes include:
  - Revision to the numerical basis for ICO
  - Introduction of an exposure pre-filter to disposition non-limiting exposures from the statistical evaluation
  - Implementation of a more robust determination of oscillation decay ratios
  - Additional analyses step to assess operational flexibility