Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

Title: Advisory Committee on Reactive Safeguards
Materials, Metallurgy, and Reactor Fuels
Open Session

Docket Number: (n/a)

Location: teleconference

Date: Tuesday, October 4, 2022

Work Order No.: NRC-2115 Pages 1-22

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UNITED STATES NUCLEAR REGULATORY COMMISSION'S 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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MATERIAL, METALLURGY, AND REACTOR FUEL SUBCOMMITTEE

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OPEN SESSION

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TUESDAY

OCTOBER 4, 2022

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The Subcommittee met via Video-Teleconference, at 1:00 p.m. EDT, David Petti, Chairman, presiding.

COMMITTEE MEMBERS:

DAVID PETTI, Chair

VICKI BIER, Member

GREGORY HALNON, Member

WALTER KIRCHNER, Member

JOSE MARCH-LEUBA, Member

JOY REMPE, Member

MATTHEW SUNSERI, Member

ACRS CONSULTANT:

STEPHEN SCHULTZ

DESIGNATED FEDERAL OFFICIAL:

WEIDONG WANG

ALSO PRESENT:

ANDREW ATWOOD, Westinghouse

KEVIN BARBER, Westinghouse

ZACH HARPER, Westinghouse

SCOTT KREPEL, NRR

YUN LONG, Westinghouse

JOSEPH MESSINA, NRR

GUIRONG PAN, Westinghouse

MATHEW PANICKER, NRR

P R O C E E D I N G S

1:00 p.m.

CHAIR PETTI: Okay, this meeting will now come to order. This is a meeting of the Materials, Metallurgy, and Reactor Fuel Subcommittee of the Advisory Committee on Reactive Safeguards. I'm Dave Petti, chairman of today's subcommittee meeting, pinch-hitting for Member Ballinger who can't be with us. ACRS members in attendance are Jose March-Leuba, Matt Sunseri, Walt Kirchner, Vicki Bier, Greg Halnon, and Vesna, are you out there? No.

Consultants Dennis Bley and Steve Schultz, are you out there? Thanks, Dave. Okay. Weidong Wang of the ACRS staff is the Designated Federal Official for this meeting.

During today's meeting, the subcommittee will review the staff safety evaluation on WCAP 18546-P entitled Westinghouse AXIOM Cladding for Use in Pressurized Water Reactor Fuel, Enclosure 2, Revision 0.

The subcommittee will hear presentations by and hold discussions with the NRC staff, Westinghouse Electric Company representatives, and other interested persons regarding this matter.

The parts of the presentation by the

applicant and the NRC staff may be closed in order to discussion information that is proprietary to the licensee and its contractors pursuant to 5 USC 552(b)(c)(iv).

Attendance at the meeting that deal with such information will be limited to the NRC staff and its consultants, Westinghouse, and those individuals and organizations who have entered into an appropriate confidentiality agreement with them. Consequently, we need to confirm that we have only eligible observers and participants in the closed part of the meeting.

The rules for participation in all ACRS meetings including today and so announced in the Federal Register on June 13th, 2019, the ACRS section of the US NRC public website provides our charter, bylaws, agendas, letter reports, and full transcript of all full and subcommittee meetings, including slides presented there.

The meeting notice and agenda for this meeting were posted there as well.

We have received no written statements or requests to make oral statements from the public.

The subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions as appropriate for

deliberation by the full committee.

The rules for participation in today's meeting have been announced as part of a notice of this meeting previously published in the Federal Register.

A transcript of the meeting is being kept and will be made available, as stated, in the Federal Register notice.

Due to the COVID pandemic, today's meeting is being held both at NRC headquarters and over Microsoft Teams for ACRS, NRC staff, and licensee attendees. There is also a telephone bridge line allowing participation of the public over the phone.

When addressing the subcommittee, the participants should first identify themselves and speak with sufficient clarity and volume so they may be readily heard. When not speaking, we request that participants mute their computer microphone or phone by pressing star-6.

With that, we'll now proceed with the meeting and I'd like to start by calling upon NRR management to make an opening statement.

MR. KREPEL: (through an interpreter) Hello, everyone. This is Scott Krepel. I'm the Branch Chief for the Nuclear Methods and Fuel Analysis

Branch and it is my staff, Joey Messina and Matthew Panicker who have both performed the review and will be giving that presentation today.

I understand that Westinghouse has some good responses to all of the questions that the staff has had, as well as has conducted fellow reviews. I look forward to hearing more about it since I just became their branch chief about two months ago. So I've not heard all of the details yet about this particular review.

Thank you so much.

CHAIR PETTI: Thank you, Scott. So I call on Westinghouse to begin, please.

MR. ATWOOD: Thank you, Mr. Chairman. My name is Andrew Atwood. I'm the manager of the Materials and Fuel Rod Design Group for Westinghouse and I'm going to be providing the open session overview of our AXIOM topical which is WCAP 18546 which is seeking use for AXIOM in fresh water reactor applications.

CHAIR PETTI: Can you pull the microphone a little closer to you? I think people online here will hear better.

MEMBER MARCH-LEUBA: Let me interrupt you. If we can blow up the slides, too, it would be easier

to see in the presentation mode or --

MR. ATWOOD: So AXIOM fuel cladding is Westinghouse's next evolution of zirconium based PWR fuel materials. AXIOM builds on our successful history with ZIRLO niobium-10 cladding where we've further refined that with AXIOM by reducing the tin content and also adding copper and vanadium along with a refined final heat treatment to deliver a number of material performance improvements, specifically improved corrosion resistance with a reduced hydrogen pickup fraction as a result of that; reduction in cladding creep rates in normal operation; excellent dimensional stability, and we have proven operating experience in a number of test campaigns in various test reactors and power reactors around the world.

So our intent is to use AXIOM in region applications for all of our pressurized water reactor customers. AXIOM is fully compatible with conventional and ADOPT doped pellet CO2 fuel.

WCAP 18546 was submitted in March of last year, requesting approval for the use of AXIOM in all currently approved PWR fuel designs. Our nickel burnup limit is 62 gigawatt days per MTU and the topical includes new fuel performance models for AXIOM including strength, fuel rod growth, cladding creep

behavior, and corrosion.

These models and benefits enable improved performance by providing lower corrosion and hydro pickup, at higher duties and higher burnups while maintaining improved dimensional stability. And the properties and performance models for AXIOM cladding has been incorporated into existing NRC-approved analytical methods for use in plant-specific safety analyses.

MEMBER MARCH-LEUBA: Let me interrupt you for a moment. I've read ahead on the proprietary section, you are going to discuss more about the 62 gigawatt --

(Simultaneous speaking.)

MEMBER MARCH-LEUBA: Is there something you can say to the public about why you chose 62 and what are your plans to increase it?

MR. ATWOOD: 62 is our current burnup limit for our existing fuel designs, so we thought first to maintain that with AXIOM. We have operated AXIOM to burnups in excess of 70,000 gigawatts -- megawatt days per MTU and so we are going to be seeking an increase in the burnup limit in the future. It will be a separate submittal.

MEMBER MARCH-LEUBA: And there will be a

future topical report or just a license amendment?

MR. ATWOOD: It's going to be its own submission. It actually ties in a number of different things, so I want to make sure my licensing colleagues have the opportunity to weigh in on that.

MR. HARPER: Yes, Zach Harper, Westinghouse. So it will be a future submittal, future topical to the extent of burnup.

MEMBER MARCH-LEUBA: Thank you.

MR. ATWOOD: Thank you for the question. So the status of the topical to date, the NRC has conducted a technical audit in October of last year, October and November. A supplement has been submitted to provide the necessary data for using AXIOM with our ADOPT fuel. We have provided responses to several requests for additional information in areas including the material properties and performance models, the fuel rod design models that we used with AXIOM, and the criterion methods that we used for our LOCA analysis as well as reactivity insertion accidents, seismic, and other types of accidents.

The draft safety evaluation report for the WCAP was received beginning of September of this year, and we thank the NRC for the opportunity to review that draft. We have provided some comments and we're

working on resolution of those now.

In summary, AXIOM is in the process of being licensed and implemented for PWR fuel. We have completed the AXIOM material development program based on our experience gained with the development and operation of both serial and optimized ZIRLO claddings. The topical is presently under NRC review and we do anticipate the final SER this year, if all goes according to plan. And we do anticipate on including a supplemental on AXIOM for higher burnups in the future.

MEMBER MARCH-LEUBA: Something that my interest on this slide is "full region." You mean all the domains where you ask -- there is no limitations on the domain, you ask for performance or --

MR. ATWOOD: Well, I guess region in this sense would be complete reloads of fuel, but we're seeking to operate it according to our methods that are already licensed --

MEMBER MARCH-LEUBA: You can load a full 100 percent --

MR. ATWOOD: Yes.

MEMBER HALNON: This is Greg. The comments that are turned back to the NRC, any show stoppers in those or are you guys okay with what's

included in the SE?

MR. HARPER: Again, this is Zach Harper, Westinghouse Licensing. Yes, no show stoppers. It is largely editorial, changing proprietary brackets, things like that. Limits, conditions, all that is fine. I'm just trying to make sure that the final SCR that goes and gets attached to the topic (audio interference). Nothing significant.

MR. ATWOOD: Steve, go ahead.

MR. SCHULTZ: This is Steve Schultz. A couple of questions. The first was if you -- again, for the benefit of the public that are listening since this is the open session, you mention on your first slide that you're achieving enhanced dimensional stability and that there's an opportunity to provide better performance with regard to fuel rod growth. At least that's my interpretation of it.

Can you provide perhaps a more detailed qualitative description of what you are achieving with regard to the dimensional stability compared to the current fuel design? That's one question. I'll ask my other one here, too.

Can you provide a little more information about the experience base that you do have with this fuel as compared to what you have had in place for

previous design changes for the cladding that you have licensed previously?

MR. ATWOOD: Yes, first as far as growth is concerned, we have irradiated AXIOM in both prototypic fuel rod configurations as well as unfueled samples to burnups that exceed our 62 gigawatt day limit that we currently have. And we see good linear behavior as a function of accumulated burnup. I think even in equivalent burnups up to more 80 gigawatt days.

MS. PAN: This is Guirong Pan. I'm the technical lead for AXIOM developmental program. So I'll answer the question about the growth. We have some publications, including AXIOM growth compared with (indiscernible due to accent) ZIRLO and the ZIRLO cladding. You can see that the AXIOM growth is relatively flat. There's no accelerated growth, even at high burnup, like above 70 gigawatt days per metric tons uranium. So one advantage for AXIOM compared to current product is at higher burnup the growth is lower.

MEMBER HALNON: This is Greg. Does that include fuel assembly warping or twisting of any kind that would make refueling more difficult?

MR. ATWOOD: We've had some experience

with lead test assemblies that are quote fully AXIOM fuel clad. Those are at burnups that still compliant with the current license limits. We've certainly not seen any issues with dimensional stability in the fuel, and we anticipate that remaining true for AXIOM as well, given that it is -- it's not prone to breakaway growth. You're not going to have a lot of interactions with the fuel rods and the fuel assembly.

A lot of our very high burnup data is on lead test rod applications for --

(Simultaneous speaking.)

MR. ATWOOD: But all indication is that it's at least better than what we have.

MR. SCHULTZ: That's good news. Thank you. This is Steve Schultz.

MR. HARPER: Steve, you may have to restate your second question.

MR. ATWOOD: Oh, I believe the second question was what -- can we elaborate on our experience phase of test radiations. I have to be pretty careful of what's proprietary and the partners we've worked with.

We have irradiated both samples of AXIOM and some prototypic fuel rod forms in both test reactors as well as a number of power reactors in the

U.S. and in Europe, in a variety of different conditions, to include both varying chemistry as well as operating cycle rates.

Dr. Pan, I don't know if you happen to have the rough numbers off the top of your head, but I believe in the topical there's a table that outlines the different menus where we've gained our test radiation experience.

CHAIR PETTI: So, just to clarify, there's all these data plots I remember in the report and comparisons to your previous to cladding, ZIRLO and Optimized ZIRLO. But I guess the question I'd be most interested because I assume that some of that is actual licensed fuel that's in reactors. If you ask yourself when you came in to the NRC to get ZIRLO approved and optimized ZIRLO approved, you've got a certain amount of data. You have more data for AXIOM or about the same amount as you had for those products when you came?

MR. ATWOOD: I would say in terms of AXIOM, we have more data than what we had brought for optimized ZIRLO. I'd have to go back and actually quantify what the differences are, but AXIOM is a new alloy because of the additions of the copper and the vanadium, so we did make a deliberate review of all

the different types of data that we would have to bring knowing that we couldn't just rely on it being an extension of the existing ZIRLO family.

CHAIR PETTI: Thanks. That's helps. Other questions, members? No? Okay. Thank you very much.

MR. PANICKER: This is Matthew Panicker. I am in the Nuclear Methods and Fuel Analysis Group. Me and Joseph Messina did the overall review of the topical report that we are presenting in the open session. A few slides on the review results of the topical report, WCAP 18546PNP, Materials, AXIOM cladding for use in the pressurized water reactor fuel.

Next slide, please. This slide has -- Westinghouse submitted the AXIOM topical report on March 2021 and we reviewed, and from that, the topical (indiscernible due to accent) micro-structure of AXIOM, which is an alloy of zirconium alloy, thermal properties, mechanical properties that just (indiscernible due to accent), et cetera. Radiation programs and operating experience (indiscernible due to accent) and the results were from the (indiscernible due to accent) reactors where AXIOM was exposed to. AXIOM cladding behavior, corrosion

(indiscernible due to accent), AXIOM growth, cladding irradiation creep, (indiscernible due to accent) rejection accident in accordance with the (indiscernible due to accent) 1.236.

Irradiated mechanical properties are just AXIOM and (indiscernible due to accent) tensile strength test. Licensing criteria for fuel rod design. All of the safety analysis is done with the full (indiscernible due to accent) of AXIOM fuel. Loss of coolant accident, non-LOCA, containment integrity (indiscernible due to accent). And the seismic irradiation for both beginning of life and end of life, combined with LOCA evaluation, (indiscernible due to accent) thermal-hydraulic design, and (indiscernible due to accent) analysis. These are the topics which we reviewed.

Next, please. (Indiscernible due to accent) acceptance review, accepted the topical report, sometime early 2021. A regulatory audit was conducted on all the available documents related to performance, related to testing, LTAs, et cetera, of AXIOM fuel in European and American reactors. And that was done through the electronic (indiscernible due to accent) group, which lasted for several weeks. During the audit (indiscernible due to accent) interim

responses were received. At the end of the audit and also requests for additional information (indiscernible due to accent). RIA responses were received in February 2022. And before the end of the review, in December 2021, Westinghouse submitted a supplement to the WCAP 18546 to extend the applicability to adopt fuel rod because the original AXIOM topical report was meant for (indiscernible due to accent) without any additives. So (indiscernible due to accent) with an additive.

Next, please. This slide shows some of the basic review based on these regulatory evaluations EDC 10 which designs the (indiscernible due to accent). Design limits (indiscernible due to accent) pressure (indiscernible due to accent) LOCA analysis. The (indiscernible due to accent) A11 (indiscernible due to accent) that is regarding the acceptance criteria of the loss-of-coolant accident. And also Appendix K, evaluation for LOCA, (indiscernible due to accent) and these are the main regulatory aspects based on which we did the review.

Next, please. These are some of the -- these are the (indiscernible due to accent) 546 proprietary information on all these details. And also the details are not there in the topical report,

we asked for expanding them to RAA (phonetic) and their responses.

Micro-structure, micro-hardness, phased transition (indiscernible due to accent) ratio, specifically thermal (indiscernible due to accent), melting temperature (indiscernible due to accent) thermal expansion, these are the thermal properties. The elastic modeling (indiscernible due to accent) high temperature (indiscernible due to accent) reaction (indiscernible due to accent) orientation, radiation programs and (indiscernible due to accent) experience. So those are the mechanical and characterization of the (indiscernible due to accent) fuel.

Next, please. These are some of the characterizations of the AXIOM fuel or the licensing criteria. (indiscernible due to accent) accident limits according to RG 1.236. Fuel performance and licensing aspects (indiscernible due to accent), fuel loading(indiscernible due to accent) pressure, RAP, (indiscernible due to accent) clad wear, cladding fatigue, cladding oxidation, cladding (indiscernible due to accent), cladding fatigue, cladding freestanding, (indiscernible due to accent), cladding (indiscernible due to accent) PCA, (indiscernible due

to accent) LOCA and non-LOCA, rad incidents, and (indiscernible due to accent) analysis. These are the various aspects with respect to the licensing criteria of the (indiscernible due to accent).

Next, please. (Indiscernible due to accent) NRC staff has determined that the (indiscernible due to accent) approach (indiscernible due to accent). The staff reviewed AXIOM fuel load (indiscernible due to accent) interior and safety analysis for both LOCA and non-LOCA methodologies. (Indiscernible due to accent) regarding the (indiscernible due to accent) of this TR will be discussed during the closed session. That's all we have for the open session.

CHAIR PETTI: Thank you. Questions, staff, members?

MEMBER KIRCHNER: Matthew, this is Walt Kirchner. When you get -- this is more a little bit of process rather than details of AXIOM. When you get an application like this, usually a TR for new fuel form, do you typically run confirmatory calculations with your -- well, it used to be FRAPCON. I think it's called FRAS now. Do you put in some of the key properties or the delta change in properties for Zirc cladding families and then run any of your in-house

codes with the assistance of research to kind of benchmark the applicant's submittal?

MR. PANICKER: Generally speaking, most of the fuel performance and fuel or fuels like AXIOM or (indiscernible due to accent) we do confirmatory calculations. But in this case, AXIOM, we used the first code to confirm some of the results presented to us by Westinghouse and thus, most likely will be a person like my colleague, Joseph Messina.

MR. MESSINA: Yes, Joseph Messina from the staff. So we contracted out with PNNL to update to a proprietary version of FRAS and with that we did some confirmatory calculations that may be discussed more in the proprietary session.

MEMBER KIRCHNER: Right. I just wanted to get this on the record. But it's not just a -- what shall I call it, a review of the submittal, but actually do some independent confirmatory work to -- can you suggest in a public forum what the key areas you looked at?

MR. MESSINA: Yes. So we looked -- we ran similar cases with optimized ZIRLO and AXIOM and ensured that (a) that AXIOM behaved similar to what was presented in the topical report and that it behaved not largely different, that the difference

wasn't detrimental compared to optimized ZIRLO. It behaved similar or better and in the cases that it would behave maybe slightly worse, but not to any significant --

MEMBER KIRCHNER: I think key ones that I would look at would be honestly the activity insertion accidents and Reg. Guide 1.256 is probably one of the more important ones simply because that's one of the most stressful events scenarios for a cladding fuel system to be subjected to. So okay, I just wanted something on the public record that it was more than a literature review. Thank you.

CHAIR PETTI: Steve, go ahead.

MR. SCHULTZ: Just to go one step further in terms of the transient analyses and accident analyses that were performed, did you do side by side or any evaluations associated with the LOCA analysis?

MR. PANICKER: No, we didn't do that. We reviewed the applicability of the (indiscernible due to accent) LOCA and the (indiscernible due to accent) LOCA at Westinghouse. (indiscernible due to accent) and then we came to some conclusions.

MR. SCHULTZ: So you looked at the -- you had a long list of fuel mechanical and thermal properties changes that were done and so you evaluated

those by examining the Westinghouse analyses associated with those accidents?

MR. PANICKER: Right.

MR. SCHULTZ: I understand.

MR. PANICKER: Yes.

MR. SCHULTZ: Thank you.

CHAIR PETTI: Okay, so let's open for public comments before actually going to a closed session. Does any member of the public that has a comment, please state your name for the record and your comment?

Hearing none, then this ends the open session and we will now move to closed session. Thank you.

(Whereupon, the above-entitled matter went off the record at 1:34 p.m.)

Enclosure 2

Westinghouse Open Session Slide Package for the ACRS Subcommittee Meeting on WCAP-18546-P/NP

(Non-Proprietary)

September 2022

Westinghouse Electric Company
1000 Westinghouse Drive
Cranberry Township, PA 16066

Westinghouse AXIOM® Cladding for Use in Pressurized Water Reactor Fuel, WCAP-18546-P/NP

Andrew Atwood,
Manager, Materials and Fuel Rod Design

October 4, 2022

Westinghouse

AXIOM Fuel Cladding

Zircaloy-4 → ZIRLO → Optimized ZIRLO → **AXIOM**

- **AXIOM®** Cladding is Westinghouse's next evolution of zirconium-based PWR fuel cladding materials
- **AXIOM** builds on the Zr-Nb-Sn alloy system from the **ZIRLO®** family of alloys via a further reduction in Sn and the addition of Cu and V along with an alloy-specific final heat treatment providing:
  - Improved corrosion resistance and reduced hydrogen pickup
  - Reduced cladding creep rates
  - Excellent dimensional stability
  - Proven operating experience
- Intended for use in region applications of fuel for all PWR customers
- Compatible with conventional and **ADOPT™** doped pellet UO_2 fuel

Westinghouse

Topical Report WCAP-18546-P

- WCAP-18546-P was submitted in March 2021 to request approval for use of **AXIOM** cladding in all currently approved PWR fuel designs.
  - Initial Burnup Limits up to 62 GWd/MTU
  - Includes new fuel performance models for **AXIOM** cladding strength, fuel rod growth, cladding creep and fuel rod corrosion.
  - Enables performance benefits by providing:
    - Lower corrosion and hydrogen pickup at higher burnup
    - Enhanced dimensional stability
  - Properties and performance of **AXIOM** cladding incorporated into existing NRC-approved analytical methods for use in plant-specific safety analyses.

Westinghouse

Topical Report WCAP-18546-P Status

- NRC reviewers conducted a technical audit in October and November of 2021
- A supplement was submitted to provide the necessary data for use of **AXIOM** cladding with **ADOPT** fuel
- Westinghouse provided responses to Requests for Additional Information (RAI's) on the following areas:
  - **AXIOM** material properties and performance
  - Fuel rod design models
  - Criteria and methods used for LOCA, reactivity insertion accident (RIA), seismic and other accidents
- The draft Safety Evaluation Report for WCAP-18546 was received on September 2, 2022 and Westinghouse has provided comments

Westinghouse

Summary

- Westinghouse has completed **AXIOM** cladding material development based on **ZIRLO** and **Optimized ZIRLO** cladding
- Topical report is under NRC review. Final SER is expected in 2022 in support of full region implementation
- Supplement on **AXIOM** cladding for higher burnups to be submitted

AXIOM is in the process of being licensed and implemented for PWR fuel

Westinghouse

U. S. NUCLEAR REGULATORY COMMISSION STAFF'S EVALUATION OF WESTINGHOUSE ELECTRIC COMPANY TOPICAL REPORT WCAP-18546-P/NP, "WESTINGHOUSE AXIOM® CLADDING FOR USE IN PRESSURIZED WATER REACTOR FUEL"

Mathew Panicker, Joseph Messina
Nuclear Methods and Fuel Analysis
Division of Safety Systems

Advisory Committee on Reactor Safeguards
Subcommittee Meeting Open Session
October 4, 2022

Background

- WEC submitted WCAP-18546-P/NP, “Westinghouse AXIOM® Cladding for Use in Pressurized Water Reactor Fuel” topical report (TR) to the U. S. Nuclear Regulatory Commission (NRC) in March 2021

- The TR includes:
  - Density and microstructure of AXIOM cladding
  - Thermal properties
  - Mechanical properties
  - Irradiation programs and operating experience
  - AXIOM cladding behavior: corrosion, hydrogen pickup, rod axial growth, cladding irradiation creep, Impact on rod ejection accident (REA)
  - Irradiated mechanical properties: axial and ring tensile tests
  - Licensing Criteria: fuel rod design, safety analyses – loss-of-coolant accident (LOCA), non-LOCA, containment integrity
  - Beginning of life (BOL) and end of life (EOL) seismic-LOCA evaluation
  - Nuclear design, thermal-hydraulic design
  - Radiological consequence analysis

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Overview and History

- Acceptance review was performed by the NRC staff
- Regulatory audit (virtual) was conducted in October 2021 through the electronic reading room
- During the audit open items were generated, interim responses were received, and requests for additional information (RAIs) preparations started
- RAI responses were received in February 2022
- Westinghouse submitted a supplement to WCAP-18546-P/NP to extend the applicability to ADOPT fuel in December 2021

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Regulatory Evaluation

- GDC 10: acceptable fuel design limits not exceeded during normal operation and anticipated operational occurrences
- 10 CFR 50.46(a)(1)(i): “Each boiling or pressurized light-water nuclear power reactor fueled with uranium oxide pellets within cylindrical zircaloy or ZIRLO cladding must be provided with an emergency core cooling system (ECCS) that must be designed so that its calculated cooling performance following postulated loss-of-coolant accidents conforms to the criteria set forth in paragraph (b) of this section”
- Requirements for analyzing the design-basis loss-of-coolant accident (LOCA) are contained within Appendix K to 10 CFR Part 50, 10 CFR 50.46, and GDC 35
- GDC 35: abundant core cooling sufficient to (1) prevent fuel and cladding damage that could interfere with effective core cooling and (2) limit the metal-water reaction on the fuel cladding to negligible amounts

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AXIOM Cladding Fuel Thermal and Mechanical Properties

- WCAP-18546-P/NP TR provides information on:
  - Microstructure
  - Microhardness
  - Phase transition temperatures
  - Texture and contractile strain ratio
  - Specific heat
  - Thermal conductivity
  - Melting temperature
  - Thermal expansion
  - Elastic moduli, Poisson's ratio
  - Creep and hardening, Fatigue
  - Emissivity
  - High temperature metal-water reaction, Hydride reorientation
  - Irradiation programs and experience

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Characterization of AXIOM Cladding Fuel Performance and Licensing Criteria

- Fuel rod axial growth
- Corrosion Models, hydrogen pickup
- Impact on REA limits
- Fuel performance and licensing
  - Cladding stress
  - Cladding strain
  - Fuel rod internal pressure
  - Fuel Clad Wear
  - Cladding fatigue
  - Cladding oxidation
  - Cladding hydrogen pickup
  - Cladding flattening
  - Cladding free standing
  - Pellet overheating
  - Pellet-cladding interaction
  - Interface to other safety analyses: LOCA, non-LOCA, radiological consequences

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AXIOM Fuel Conclusions

- TR provides sufficient information on properties and characterization of AXIOM cladding fuel
- The NRC staff reviewed AXIOM fuel rod design criteria, and safety analyses for both LOCA and non-LOCA methodologies