UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 14, 2021

Mr. David P. Rhoades
Senior Vice President
Exelon Generation Company, LLC
President and Chief Nuclear Officer
Exelon Nuclear
4300 Winfield Road
Warrenville, IL 60555

SUBJECT: CALVERT CLIFFS NUCLEAR POWER PLANT, UNITS 1 AND 2 – REGULATORY AUDIT SUMMARY RE: LICENSE AMENDMENT REQUEST FOR ACCIDENT TOLERANT FUEL LEAD TEST ASSEMBLIES (EPID L-2019-LLA-0282)

Dear Mr. Rhoades:

By letter dated December 12, 2019 (Agencywide Documents Access and Management System Accession No. ML19347A779), Exelon Generation Company, LLC submitted a license amendment request for Calvert Cliffs Nuclear Power Plant, Units 1 and 2 (Calvert Cliffs). The proposed amendments would modify the renewed facility operating licenses to permit the use of accident tolerant fuel lead test assemblies and make an administrative change to the technical specifications. Up to two lead test assemblies of the Framatome PROtect™ fuel design would be loaded into the Calvert Cliffs reactors for up to three cycles, commencing with the approval of the license amendment request. The key features of the PROtect™ lead test assemblies are the chromium-coated M5® cladding and Chromia-doped fuel pellets.

To support its review of the license amendment request, the U.S. Nuclear Regulatory Commission staff conducted a regulatory audit. The audit was conducted from June 15, 2020, to June 19, 2020. A summary of the regulatory audit is enclosed.

NOTICE: Enclosure 2 to this letter contains Proprietary Information. Upon separation from Enclosure 2, this letter is DECONTROLLED.

If you have any questions, please contact me at (301) 415-2871 or Michael.Marshall@nrc.gov.

Sincerely,

/RA/

Michael L. Marshall, Jr., Senior Project Manager
Plant Licensing Branch I
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket Nos. 50-317 and 50-318

Enclosure:
1. Audit Summary (Non-Proprietary)
2. Audit Summary (Proprietary)

cc: Listserv

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

OFFICE OF NUCLEAR REACTOR REGULATION

REGULATORY AUDIT SUMMARY

LICENSE AMENDMENT REQUEST

RE: ACCIDENT TOLERANT FUEL LEAD TEST ASSEMBLIES

EXELON GENERATION COMPANY, LLC

CALVERT CLIFFS NUCLEAR POWER PLANT, UNITS 1 AND 2

DOCKET NOS. 50-317 AND 50-318

1.0 BACKGROUND

By letter dated December 12, 2019 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML19347A779), Exelon Generation Company, LLC (Exelon, the licensee) submitted a license amendment request (LAR) for Calvert Cliffs Nuclear Power Plant, Units 1 and 2 (Calvert Cliffs). The proposed amendments would modify the renewed facility operating licenses to permit the use of accident tolerant fuel lead test assemblies (LTAs) and make an administrative change to the technical specifications. Up to two LTAs of the Framatome PROtect™ fuel design would be loaded into the Calvert Cliffs reactors for up to three cycles, commencing with the approval of this request. The key features of the PROtect™ LTAs are the chromium-coated M5® cladding and Chromia-doped fuel pellets.

A regulatory audit is a planned activity that includes the examination and evaluation of primarily non-docketed information. The audit is conducted with the intent to gain understanding, to verify information, and to identify information that will require docketing to support the basis of a licensing or regulatory decision. Performing a regulatory audit is expected to assist the U.S. Nuclear Regulatory Commission (NRC) staff in efficiently conducting its review and gaining insights to the licensee's processes and procedures. Information that the NRC staff relies upon to make the safety determination must be submitted on the docket.

2.0 AUDIT OBJECTIVES

The purpose of this audit was to ensure that modifications to approved models and methods were consistent with the descriptions provided in the LAR and to obtain information needed to complete the NRC staff's independent, confirmatory Fuel Analysis under Steady-state and Transients (FAST) code calculations. The scope and objectives of this audit were defined in the NRC staff's audit plan (ADAMS Accession No. ML20098G965). The audit was conducted remotely using an ePortal to access proprietary Framatome material and multiple webinars to facilitate discussions. The audit took place over 3 weeks in June 2020. Participants in the audit are listed in Table 1 below.

Table 1: Audit Participants

NAME	ORGANIZATION
Paul Clifford	NRC
Andrew Proffitt	NRC
Michael Marshall	NRC
John Lehning	NRC
Ken Geelhood	PNNL
William Gassmann	Exelon
Philip Wengloski	Exelon
Tim Schearer	Exelon
Price Collins	Exelon
Enrique Villar	Exelon
Rachel Love	Framatome
Jerald Holm	Framatome
Jeff Reed	Framatome
Calvin Ritchey	Framatome
Graeme Leitch	Framatome
Miao Sun	Framatome
Mike Bingham	Framatome
Wanda Roman	Framatome
Nathan Hottle	Framatome
Mayur Patel	Framatome
John Adams	Framatome
Lisa Gerken	Framatome
Chris Conrad	Framatome
Christina Jones	Framatome
Chris Molseed	Framatome
Scott D'Orio	Framatome
John Sankoorikal	Framatome
Mohsin Reza	Framatome
Tammy Natour	Framatome
Brian Painter	Framatome
Glen Thomas	Framatome
Philippe Bellanger	Framatome
Yusen Qi	Framatome
Jeff Moore	Framatome
Rick Williamson	Framatome

3.0 DISCUSSIONS

Attachment 2 (i.e., technical basis report) of the LAR documents the technical justification in a Framatome report entitled "PROtect™ Lead Test Assemblies for Calvert Cliffs, Licensing Report." In accordance with the audit plan, the NRC staff reviewed several of the underlying Framatome engineering calculations supporting the technical justification for the Calvert Cliff's PROtect™ LTAs.

Nuclear Cross-Section Libraries and Core Physics Predictions

The goal of this portion of the audit was to better understand how the nuclear properties of the PROtect™ LTAs were captured and their impact on core physics predictions. During the audit, the NRC staff reviewed Framatome engineering calculation **[[**
]]. The main purpose of this calculation was to generate CASMO cross-section and PRISM models for Unit 2 Cycle 24, accounting for the up to two LTAs. The calculation also performed depletions and benchmarking, confirmed reload checklist items, and verified power peaking factor and burnup restrictions were satisfied. This calculation was completed in accordance with Framatome's quality assurance (QA) procedures.

No new assumptions or modeling simplifications were used. **[[**

]]
These modeling techniques are reasonable and capture the impact of Chromia dopant and chromium (Cr)-coating on the nuclear properties of the fuel.

Exelon has imposed a limit on the LTA design and placement such that the LTA fuel rod's peak total integrated radial peaking factor (Fr^T) will remain at least 2 percent lower than the core leading value throughout the cycles. During the audit, Framatome presented predicted Fr^T from the Calvert Cliffs Unit 2 Cycle 24 depletion analysis. The LTA maintained at least **[[**
]] margin throughout Cycle 24, which exceeds the 2.0 percent target margin. While fuel management for subsequent cycles is not firmly established, Framatome did perform depletion analyses on probable core locations. These depletions show that the LTA maintains greater than **[[** **]]** and **[[** **]]** margins for Cycles 25 and 26, respectively **[[**
]].

All the reload checklist parameters and requirements (e.g., peaking, moderator temperature coefficient, burnup, residence time along periphery) were satisfied.

COPERNIC Modifications and Benchmarks

To support the Calvert Cliffs LTA program, Framatome intends to use the approved COPERNIC fuel rod thermal-mechanical code and application methodology, modified as appropriate to capture the behavior and performance of the Chromia-doped pellets and chrome-coated M5 cladding, to demonstrate that all existing fuel design and performance requirements remain satisfied.

During the audit, the NRC staff reviewed Framatome engineering calculation **[[**
]]. The purpose of this calculation was to develop a modified version of COPERNIC that considers the unique physical properties of Chromia-doped uranium dioxide (UO_2) fuel (relative to standard UO_2): fuel density, fuel thermal conductivity, and melt temperature. The fission gas release (FGR) and fuel swelling models were also modified to match the empirical database. Revision 2 expands the applicability to all pressurized-water reactor LTA programs. This calculation was completed in accordance with Framatome's QA procedures.

Section 3.3 of the technical basis report describes the modifications made to the COPERNIC code to account for the Chromia dopant. The report states: "Modifications made to COPERNIC code are consistent with the Chromia-doped fuel properties and behaviors as described in the USNRC-approved topical report [[ ]]." [[ ]] describes the following modifications:

- The calculated theoretical density based on]] parts per million (ppm) Chromia is [[ ]] compared with [[ ]] for standard UO_2. This density is consistent with ANP-10340P-A.

- The thermal conductivity model was modified. [[ ]] A reduced thermal conductivity agrees with ANP-10340P-A.

- The FGR model was modified. [[ ]] ANP-10340P-A concluded that the existing FGR and FGR uncertainty remain applicable to Chromia-doped fuel.

- The gaseous swelling model was modified. [[ ]]. ANP-10340P-A introduced a new intragranular gaseous swelling model. Post irradiation examination data on Chromia-doped fuel rods show larger cladding deformation following both steady-state and power ramp irradiations, which indicates an increased fuel pellet deformation in comparison to standard fuel.

- The fuel melting temperature was [[ ]] to account for Chromia dopant. This change is consistent with ANP-10340P-A.

[[ ]] documents verification cases run to confirm that these changes were correctly coded into COPERNIC and that COPERNIC predictions are reasonable relative to the existing irradiation database. ANP-10340P-A lists the Chromia-doped irradiation database used to calibrate and validate RODEX4 (boiling-water reactor only). This listing is summarized below (extracted from the NRC staff's safety evaluation). This same database was used to verify the modifications to the COPERNIC code.

[[

]]

During the audit, the NRC staff, Exelon representatives, and Framatome representatives discussed COPERNIC predictions versus experimental measurements of **[[** **]]** The modified COPERNIC code provides a reasonable, best-estimate prediction of these important fuel parameters relative to the empirical database.

In order to understand the relative change in COPERNIC models and their impacts on COPERNIC predictions, the NRC staff requested to see benchmark calculations based on the approved version of COPERNIC (Version 2.1-L). The following observations capture the differences between the licensed COPERNIC 2.1-L and the modified 2.1-C relative to the Chromia-doped empirical database:

- Compared against online centerline temperature measurements, both code versions predict fuel temperature trends accurately. The change to the thermal conductivity model in 2.1-C results in approximately **[[** **]]** increase in fuel temperature and more precisely matches the data.
- The steady-state FGR database consists of multiple measurements from **[[** **]]** test rods with measured FGR ranging from **[[** **]]**. The change to the FGR model in 2.1-C results in **[[** **]]**. Framatome also presented its bounding models **[[** **]]**.
- The transient FGR database consists of **[[** **]]** test rods with measured gas release ranging from nearly **[[** **]]** **[[** **]]** The change to the FGR model in 2.1-C results in **[[** **]]**, which is conservative.
- The steady-state rod diameter change (RDC) database consists of multiple measurements from **[[** **]]** test rods with measured RDC ranging from **[[** **]]** microns. Both code versions accurately predict steady-state RDC.
- The transient RDC database consists of multiple measurements from **[[** **]]** test rods with measured RDC ranging from **[[** **]]**. **[[** **]]**. The change to the gaseous swelling model in 2.1-C results in **[[** **]]**.

These discussions and presentations show that the model updates were appropriate, and the modified COPERNIC code (Version 2.1-C) reasonably predicts important fuel parameters as described in the technical basis report, given the relative risk from the limited number of LTA rods.

<u>Fuel Rod Thermal-Mechanical Design Calculations</u>

The goal of this portion of the audit was to review the LTA fuel rod thermal-mechanical design calculations to confirm that Framatome's modified models and methods are capable of accurately or conservatively capturing the behavior and performance of the Chromia-doped pellets and chrome-coated M5 cladding in order to demonstrate compliance to applicable regulatory criteria as described in the LAR. During the audit, the NRC staff reviewed Framatome engineering calculation **[[**

]] The purpose of this calculation was to verify that the peak cladding corrosion thickness remained below the **[[** **]]** limit. This calculation was completed in accordance with Framatome's QA procedures.

The predicted best-estimate peak cladding oxide thickness was **[[** **]]** microns. A bounding power envelope, which represents three 24-month cycles, was assumed. The total exposure under the bounding power envelope equates to **[[**

]]. COPERNIC Version 2.1-C conservatively ignores the enhanced corrosion resistance of the Chromium coating.

During the audit, the NRC staff reviewed Framatome engineering calculation **[[**

]] The purpose of this calculation was to perform the stated fuel rod thermal-mechanical design calculations and demonstrate that the LTAs meet applicable performance requirements. This calculation was completed in accordance with Framatome's QA procedures.

As described above, the potential impacts of Chromia dopant on the material properties and performance of the fuel pellets is specifically modeled in the modified version of COPERNIC (Version 2.1-C). **[[**

]] In Section 4.7.2 of **[[** **]]**, Framatome states that the performance of Cr-coated clad may be modeled using the M5 behavior laws with the following exceptions: **[[**

]]

[[**]]** is the only performance characteristics that impact the fuel rod design calculations. Framatome stated that based on **[[**

]]. **[[**

]] would have some degree of impact on many of the design criteria. In some cases, it may be beneficial **[[** **]]**, and in others it may be detrimental (e.g., delayed pellet-clad gap closure). Therefore, in the evaluation of each design criterion, the impact of a **[[** **]]** must be considered.

In addition to the review and audit of Framatome's COPERNIC modifications and resulting design calculations, the NRC staff also performed sensitivity calculations with the NRC's FAST code. The base code, validated against UO_2 and zirconium-based cladding alloys (including Framatome's M5), was modified similarly to COPERNIC 2.1-C to account for the Chromia-doped UO_2 fuel pellets: **[[**

]]

The specific sensitivity calculations and any additional modifications to the FAST code or input biases are discussed in the following sections.

Rod Internal Pressure

The predicted maximum rod internal pressure was **[[**

]]. The COPERNIC application methodology is based on a best-estimate prediction plus uncertainty allowance to account for code uncertainties and manufacturing tolerances. The impact of each uncertainty and tolerance is independently estimated and then combined using a square root of the summation of squares technique. The calculation is based on **[[**

]]. Results of the LTA evaluation exhibit significant margin to the acceptance criterion **[[**
]].

The predicted limiting spent fuel pool (SFP) rod internal pressure was **[[** **]]**, compared with a design acceptance criterion of **[[** **]]**. In the COPERNIC application methodology, **[[**

]]. Results of the LTA evaluation exhibit significant margin to the acceptance criterion.

Section 7.2.4.3 evaluates the impact of Cr-coated clad on the rod internal pressure acceptance criterion and design calculations. With respect to the **[[** **]]** acceptance criterion, Framatome states that this criterion remains applicable for the following reasons: **[[**

With respect to the design analysis, Framatome states that a [[

]]. The impact from either aspect is expected to be small, but the exact magnitude is not known. To investigate the impact, FRAMATOME re-ran the bounding rod internal pressure and SFP pressure cases with **[[**
]]. The maximum rod internal pressure changed from **[[** **]]** and the SFP pressure changed from **[[** **]]**. Comparison of the results reveals that **[[**
]].

The NRC staff also performed FAST calculations to further understand the impacts of the PROtect LTA features on rod internal pressure. A nominal case was run first to establish a baseline with the modified FAST code, as described above, using the fuel properties and dimensions provided by Framatome for the PROtect LTAs and the same bounding power history used by COPERNIC. The nominal case resulted in a maximum rod internal pressure of **[[** **]]**, which is reasonably consistent with the COPERNIC result of **[[** **]]**.

The NRC staff then performed additional FAST calculations to further understand the sensitivity of rod internal pressure to **[[** **]]** due to the **[[** **]]**, due to the potential impacts of the chrome-coated cladding. The NRC staff performed a calculation with the **[[** **]]** biased an additional **[[** **]]**. Additionally, the NRC staff ran several cases biasing the **[[** **]]** in the positive and negative direction with the impacts being relatively benign, between **[[** **]]**, given the margin to the limits.

<u>Transient Cladding Strain</u>

For the transient cladding strain (TCS) calculation, COPERNIC iterates on predicted peak local linear heat generating rates (LHGR) until achieving a 1.0 percent cladding strain. **[[** **]]**.

TCS calculations confirm that for fuel rod burnup below **[[** **]]**, fuel temperature would reach T_{melt} prior to achieving a 1 percent cladding strain criterion. This is consistent with the standard design and past analyses. The COPERNIC TCS prediction of peak LHGR at 1.0 percent cladding strain is shown below, along with the maximum AOO over-power LHGR. Consistent with the discussion I the technical basis report, these results show significant margin to the 1.0 percent cladding strain criterion.

[[

]]

For the standard COPERNIC application methodology, **[[** **]]**. For Chromia-doped UO_2 fuel, data shows **[[** **]]**. Given that there are no specific test data to prove that **[[**

]]. The resulting predicted cladding strains for the five AOO over-power scenarios are listed below.

[[

]]

Accounting for the enhanced gaseous swelling of Chromia-doped pellets results in a significant reduction in margin to the 1.0 percent cladding strain criterion. For example, at the 50 gigawatt-days per metric ton of uranium (GWd/MTU) AOO over-power scenario, the COPERNIC TCS margin equates to [[

]].

In general, the cladding strain analytical limit is based on uniform elongation measurements from mechanical testing conducted on irradiated segments of cladding. The 1.0 percent criterion was originally based on testing of Zircaloy-4 (Zry-4) cladding segments. Degradation mechanisms impacting cladding ductility include irradiation-induced damage (hardening), cladding oxidation (wall thinning), and hydrogen uptake (formation of brittle zirconium hydrides). Since irradiation hardening saturates, progressive oxidation and hydrogen uptake dictate the end-of-life cladding ductility. M5 cladding exhibits superior corrosion resistance (relative to Zry-4 cladding), which limits wall thinning and hydrogen uptake. The Cr-coating is expected to improve water-side corrosion resistance. As such, end-of-life cladding oxide thickness and hydrogen content should be minimal. It is even reasonable to assume that cladding hydrogen content will remain below the solubility limit (70-80 weight parts per million) during normal operations. Hence, the detrimental effect of zirconium hydrides would not be present. The net result is that Cr-coated M5 would likely retain greater than 1.0 percent strain capability.

The NRC staff also performed TCS calculations with the FAST code. The tables above were reproduced using FAST in a similar manner to COPERNIC. [[

]] As expected, FAST, which includes a modern UO_2 based gaseous swelling model, predicts [[

]]. However, all the FAST calculational results remain well above the AOO peak LHGR for the core.

[[

]]

The NRC staff also ran FAST to mimic the analysis performed in Table 2. The Framatome results in this table were produced using a modified COPERNIC version that **[[**

]].

[[

]]

In this table, FAST nominal, using the UO_2 gaseous swelling model, underpredicts TCS for the **[[**

]].

This led the NRC staff to request additional characteristics of Framatome's Chromia-doped UO_2 fuel strain data such that the FAST UO_2 gaseous swelling model could be modified to better predict the increased swelling observed in Chromia-doped fuel.

Based on this information, the NRC staff compiled a modified version of FAST that **[[**

]].

The final column in the above table reports the FAST results using the same code modifications as described earlier and the addition of the modified gaseous swelling model. All the results remain below the licensing limit of 1 percent. In addition, the NRC staff performed a sensitivity analysis of **[[** **]]** on the most limiting TCS case at end-of-life conditions to determine if differences in the **[[** **]]** could significantly alter the results. Biasing the **[[** **]]** did not cause the FAST-calculated values to exceed 1 percent strain. When **[[** **]]** which is the expected impact of the chrome coating, the total TCS was actually reduced, providing more margin to the limit.

Section 7.3.5 evaluates the impact of Cr-coated clad on the TCS acceptance criterion and design calculations. With respect to the 1.0 percent cladding strain acceptance criterion, Framatome states that this criterion remains applicable since the cladding will maintain ductility at higher burnup due to significantly reduced oxidation and hydrogen uptake of protective Cr-coating.

With respect to the design analysis, Framatome states that the impact of a **[[** **]]** on TCS calculations is expected to be small, but the exact magnitude is not known. To investigate the impact, FRAMATOME **[[** **]]**. The results show no difference in predicted LHGR to the 1.0 percent cladding strain limit.

<u>Fuel Centerline Melt</u>

For the fuel centerline melt (FCM) calculation, COPERNIC iterates on predicted peak local LHGR until achieving fuel temperature in excess of melting conditions. **[[** **]]**. COPERNIC FCM predicted peak LHGR at incipient fuel melting are listed below.

[[

]]

During the audit, Framatome presented calculations which showed that at all burnup intervals, [[ ]]. As burnup on the LTA rods increases into second and third reload cycle, [[ ]]. Hence, the margin to FCM continues to increase.

Section 7.4.3 evaluates the impact of Cr-coated clad on the FCM acceptance criterion and design calculations. With respect to the FCM limits, Cr-coating does not directly impact the thermal properties (e.g., conductivity) of the fuel pellet. Therefore, the modified Chromia-doped properties are not impacted by the presence of chrome coating.

With respect to the design analysis, Framatome states that the impact of [[ ]] on FCM calculations is expected to be small, but the exact magnitude is not known. To investigate the impact, FRAMATOME re-ran the limiting burnup cases, [[ ]]. The results show no difference in predicted LHGR to the FCM limit.

In addition, the NRC staff performed calculations of FCM using the modified FAST code. The graph below shows the results obtained using FAST, along with an added trendline, compared to Framatome's COPERNIC results.

[[

]]

In addition, the NRC staff performed sensitivity runs to investigate the impact of [[ ]] postulated due to the impact of the Cr-coated cladding on FCM. FAST's [[ ]] was biased [[ ]] at several burnup steps. No impact was observed to the power at which melt was observed for any of the runs.

Based on the excellent agreement of the FAST and COPERNIC results, along with the NRC staff's additional review of the COPERNIC modifications and representative results, the NRC staff has reasonable assurance that Framatome can appropriately model the PROtect™ LTAs regarding FCM.

Loss-of-Coolant Accident Calculations and Assessments

The goal of this portion of the audit was to better understand the anticipated performance of PROtect™ LTAs under loss-of-coolant accident (LOCA) conditions and confirm Framatome's ability to demonstrate that the LTAs satisfy applicable regulatory requirements. During the audit, the NRC staff reviewed Framatome engineering calculation **[[**

]]. The purpose of this calculation was to assess the impact of the Chromia-doped pellets and Cr-coated M5 cladding on the initial conditions of the fuel rod (just prior to a postulated LOCA). Using a modified version of COPERNIC (see discussion above), Framatome ran the following sensitivity studies to investigate the potential impacts of the LTA rods on the initial condition of the fuel rods: **[[**

]]

Case #2 was run to separate potential effects of the **[[ ]]** from the Chromia dopant. The impact of differences in initial conditions to the Calvert Cliffs LOCA analyses-of-record (AOR) are based on Case #1 and Case #3. **[[**

]]

During the audit, the NRC staff reviewed Framatome engineering calculation **[[**
]]. The purpose of this calculation was to assess the impact and performance of the LTAs under small-break LOCA and large-break LOCA conditions and estimate the delta-peak clad temperature (PCT) relative to the Advanced Combustion Engineering 14×14 HTP reload assemblies considered in the existing AOR.

Section 7 of **[[ ]]** describes the potential impacts of the Chromia-doped pellets and chrome-coated cladding as follows: **[[**

]]

Based on initial conditions predicted using the COPERNIC code, as well as other information concerning the PROtect™ LTAs, Framatome estimated the potential impacts of the Chromia-doped pellets and chrome-coated cladding on the large- and small-break LOCA events by performing sensitivity analyses using the S-RELAP5 code. Based on its analyses, Framatome calculated [[ ]] for the large-break LOCA analysis [[ ]] for the small-break LOCA analysis.

Of the potential impacts of the Chromia-doped pellets and chrome-coated cladding described in Section 7 of [[ ]] and summarized above, the [[ ]] calculated by Framatome for the Calvert Cliffs LTAs for both the large- and small-break LOCA analyses were driven primarily by the change [[ ]]. Although the effect of [[ ]] was apparent in the large-break LOCA sensitivity analysis, this phenomenon affected [[ ]], whereas the more significant impact from the change in [[ ]] was most apparent in scenarios involving [[ ]].

For both the large- and small-break LOCA events analyzed for Calvert Cliffs, Framatome calculated that any impacts from the LTA design on [[ ]] would not have a significant impact on the calculated PCT. While the NRC staff agreed with this conclusion for the small-break LOCA analysis with respect to the large-break LOCA analysis, the NRC staff's assessment of the sensitivity calculations during the audit indicated that, for cases with PCTs occurring within [[ ]] of event initiation, [[ ]]. However, as noted above, the [[ ]] was driven by cases where the PCT [[ ]]. According to the calculations performed by Framatome, the impact of a [[ ]] would continue to bound the impact to early blowdown PCT cases, even with an additional [[ ]] to account for the potential for delayed rupture behavior.

For the small-break LOCA analysis, the [[ ]] was determined by cases at the upper end of the small-break size range, where [[ ]]. Although the impact of [[ ]], these breaks remained non-limiting for Calvert Cliffs, even after the larger [[ ]] of approximately [[ ]] was considered.

Finally, the NRC staff observed that the impact **[[** **]]** was neglected in the sensitivity calculations for Calvert Cliffs. The **[[** **]]** included in the calculations that is discussed above was solely due to **[[** **]]** While **[[** **]]** in a pressurized-water reactor is not a dominant phenomenon (e.g., as in a boiling-water reactor), it nevertheless tends **[[** **]]**. Thus, explicit modeling of the **[[** **]]** for the cladding surface of the LTA rods would be expected to **[[** **]]**. While a large impact is not expected, particularly at the temperatures relevant to Calvert Cliffs, its impact could not be definitively quantified during the audit due to its omission from the licensee's sensitivity studies.

<u>Non-Loss-of-Coolant Accidents Calculations and Assessments</u>

The goal of this portion of the audit was to better understand the anticipated performance of PROtect^{TM} LTAs under a variety of non-LOCA conditions and validate the applicability of the current updated final safety analysis report (UFSAR) Chapter 14 safety AOR. During the audit, Framatome described the process that would be used to ensure that the UFSAR Chapter 14 safety analyses remain bounding and applicable. For a majority of the safety analyses, it is expected that the placement of the LTAs in un-rodded core positions and the reduced rod power allowance will provide margin to offset any potential negative aspects of the Chromia-doped UO_2 pellets or chrome-coated M5 cladding.

For events such as control element assembly (CEA) drop, inadvertent CEA bank withdrawal, CEA ejection, and return-to-power main steam line break where proximity to a CEA directly impacts the accident progression, the placement of the LTA in an un-rodded core location is clearly a non-limiting location.

General Design Criterion 10, "Reactor design," in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," requires that specified acceptable fuel design limits (SAFDLs) are not exceeded during any condition of normal operation, including the effects of AOOs. With respect to the departure from nucleate boiling ratio SAFDL, the applicability of the safety limit and the rate of DNB thermal margin degradation during transients will be verified. During the audit, Framatome stated that the critical heat flux (CHF) experiments used to develop the CHF correlation employ electrically heated rods with Inconel cladding. These CHF experimental results have been accepted as applicable to different alloying compositions (e.g., M5), as well as cladding with an oxide layer. Hence, there is no reason to believe that a thin layer of chrome would significantly alter the applicability of these CHF correlations. Surface roughness has been shown to impact cladding-to-coolant heat transfer. Framatome stated that **[[** **]]**.

With respect to the fuel melting SAFDL and cladding strain SAFDL, explicit analyses have been performed to demonstrate that the LTA rods will not exceed these SAFDLs during AOO over-power scenarios (see discussion above).

During the audit, Framatome explained the process for verifying the applicability of the bounding CEA ejection AOR. First, for each reload cycle, explicit core physics analyses would confirm that the AOR bounding physics inputs (e.g., CEA ejected worth, reactor kinetics, peaking factors) remain applicable. Second, a temperature penalty would be calculated that explicitly accounts for the detrimental effects of Chromia dopant on fuel thermal conductivity and melting temperature. Then, it will be confirmed that the CEA ejection AOR predicted fuel temperatures remain below the Chromia-doped UO_2 melting temperature.

Fuel Handling and Storage

The goal of this portion of the audit was to better understand the anticipated performance of PROtect™ LTAs under fuel handling and storage conditions. However, no specific material on this subject matter was provided during the audit.

4.0 CONCLUSIONS AND FINDINGS

All the regulatory audit objectives listed in Section 2 were completed. No requests for additional information were needed to provide further information.

SUBJECT: CALVERT CLIFFS NUCLEAR POWER PLANT, UNITS 1 AND 2 – REGULATORY AUDIT SUMMARY RE: LICENSE AMENDMENT REQUEST FOR ACCIDENT TOLERANT FUEL LEAD TEST ASSEMBLIES (EPID L-2019-LLA-0282) DATED JANUARY 14, 2021

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