ATTACHMENT 20

Browns Ferry Nuclear Plant (BFN)
Units 1, 2, and 3

Technical Specifications (TS) Change 478

Addition of Analytical Methodologies to Technical Specification 5.6.5.b for Browns Ferry 1, 2, & 3, and Revision of Technical Specification 2.1.1.2 for Browns Ferry Unit 2, in Support of ATRIUM-10 XM Fuel Use at Browns Ferry

Thermal Conductivity Degradation Report
(Non-Proprietary)

Attached is the non proprietary version of a report prepared by AREVA discussing the impacts of thermal conductivity degradation in RODEX2 on core and safety analyses for Browns Ferry.

ANP-3170NP
Revision 0

Evaluation of Fuel Conductivity Degradation for ATRIUM 10XM Fuel for Browns Ferry Units 1, 2 and 3

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AREVA

AREVA NP Inc.

AREVA NP Inc.

ANP-3170NP
Revision 0

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Nature of Changes

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1.	All	New document

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NOMENCLATURE

AOO	Anticipated Operational Occurrence
ATWS	Anticipated Transient Without Scram
BOL	Beginning of Life
CHF	Critical Heat Flux
CRs	Condition Reports
IN	Information Notice
LOCA	Loss of Coolant Accidents
LTRs	Licensing Topical Reports
MAPLHGR	Maximum Average Planar Linear Heat Generation Rate
MWR	Metal Water Reaction
NRC	U.S. Nuclear Regulatory Commission
PCT	Peak Cladding Temperature
TCD	Thermal Conductivity Degradation

1.0 Introduction

The U.S. Nuclear Regulatory Commission (NRC) issued Information Notice (IN) 2009-23 (No. ML091550527), dated October 8, 2009 for concerns regarding the use of historical fuel thermal conductivity models in the safety analysis of operating reactor plants. IN 2009-23 discusses how historical fuel thermal mechanical codes may over predict fuel rod thermal conductivity at higher burn-ups based on new experimental data. This new experimental data showed significant degradation of fuel pellet thermal conductivity with exposure. The NRC staff concluded that the use of the older legacy fuel models will result in predicted fuel pellet conductivities that are higher than the expected values.

AREVA NP has had numerous meetings and correspondence with the NRC to quantify the impact of IN 2009-23 on current licensing safety analyses. As a result of this investigation, the issue and evaluations have been entered into and are tracked by the AREVA NP corrective action system. In addition, AREVA NP has informed licensees using AREVA evaluation models of any analytical changes resulting from the investigation in compliance with the regulations of 10 CFR 50.46.

The purpose of this document is to summarize the impact and treatment of fuel conductivity degradation for licensing safety analyses supporting the ATRIUM™ 10XM* fuel that is being introduced to Browns Ferry Units 1, 2 and 3.

* ATRIUM is a trademark of AREVA NP.

2.0 Disposition of Licensing Safety Analysis for Browns Ferry ATRIUM 10XM Fuel

RODEX2 and RODEX2A codes were approved by the NRC in the early and mid 1980's, respectively. At that time, thermal conductivity degradation (TCD) with exposure was not well characterized by irradiation tests or post-irradiation specific-effects tests at high burnups. The fuel codes developed at that time did not accurately account for this phenomenon. Analyses performed with RODEX2/2A are impacted by the lack of an accurate thermal conductivity degradation model. Likewise conductivity models in the transient codes COTRANSA2 and XCOBRA-T do not account for thermal conductivity degradation.

The NRC recently approved the RODEX4 fuel code and associated best-estimate BWR methodology. RODEX4 is a best-estimate, state-of-the-art fuel code that fully accounts for burnup degradation of fuel thermal conductivity. RODEX4, therefore, can be used to quantify the impact of burnup-dependent fuel thermal conductivity degradation and its effect on key analysis parameters.

Thermal-mechanical licensing safety analyses for the Browns Ferry ATRIUM 10XM are performed with RODEX4 and therefore explicitly account for thermal conductivity degradation. No additional assessment is needed for those analyses. For thermal-hydraulic and safety analyses an evaluation is needed. The following analysis methodologies use RODEX2 and/or include a separate UO_2 thermal conductivity correlation:

- Anticipated Operational Occurrence (AOO) analysis based on COTRANSA2/RODEX2/XCOBRA-T codes;
- Loss of Coolant Accidents (LOCA) analyses based on RELAX/RODEX2/HUXY codes;
- Overpressurization analyses based on COTRANSA2/RODEX2 codes;
- Stability analyses based on STAIF/RAMONA5-FA codes; and
- Fire event analyses based on RELAX/RODEX2/HUXY codes.

3.0 Assessment of Analyses for Browns Ferry ATRIUM 10XM Fuel

The issues identified in IN 2009-23 were entered into AREVA NP corrective action program in 2009. A summary of the investigation was provided to the NRC in a white paper (Reference 1). The white paper was an extensive evaluation; specifically for BWRs, the assessments consisted primarily of ATRIUM-10 fuel. A summary of that evaluation is provided as follows for the items noted in the previous section. In addition, to include the assessment of the ATRIUM 10XM fuel being introduced at Browns Ferry, each sub section ends with a discussion of the impact and treatment of thermal conductivity degradation for ATRIUM 10XM fuel.

The NRC reviewed Reference 1 and provided requests in Reference 2. AREVA provided responses to the requests in Reference 3. Items relevant from References 2 and 3 are also discussed in the following sub sections.

Note that the assessments presented in the following sub sections are interim corrective actions and were performed in accordance with AREVA NP's corrective action program and are archived within condition reports (CRs). Long term corrective actions are discussed in Section 4.0.

3.1 *Anticipated Operational Occurrence Analyses*

The computer codes COTRANSA2 and XCOBRA-T are used in AOO analyses. Both codes use UO_2 thermal conductivity correlations that do not include exposure degradation. In addition, the core average gap conductance used in the COTRANSA2 system calculations and the hot channel gap conductance used in XCOBRA-T hot channel calculations are obtained from RODEX2 calculations. In general, the sensitivity to conductivity and gap conductance for AOO analyses is in the opposite direction for the core and hot channel, i.e., putting more energy into the coolant (higher thermal conductivity/higher gap conductance) is non-conservative for the system calculation but conservative for the hot channel calculation. The competing effects between the core and hot channel calculation minimize the overall impact of thermal conductivity degradation.

The assessment of Reference 1 demonstrated that COTRANSA2 uses several conservative assumptions, which results in conservatism relative to the Peach Bottom turbine trip qualification database. The COTRANSA2 methodology results in predicted integral power increases that are bounding relative to the Peach Bottom benchmark tests. With the 110% integral power multiplier used in the methodology, the COTRANSA2 predicted to measured mean integral power is [ ] for the Peach Bottom turbine trip tests. The COTRANSA2 benchmark testing was performed using the same UO_2 conductivity model as used in the current licensing analyses. Therefore, the benchmarking comparisons inherently include any impact of UO_2 conductivity degradation with exposure exhibited in the Peach Bottom tests. The results from the benchmarking analyses demonstrate that the methodology has adequate conservatism to offset the potential impact of UO_2 conductivity degradation with exposure.

The prior assessment was based on fuel designs current at the time of the Peach Bottom tests. To supplement the assessment with modern fuel, calculations were performed using the as-submitted AURORA-B code (Reference 4). AURORA-B is built from previous NRC approved methods. These methods include codes RODEX4, MICROBURN-B2, and S-RELAP5; UO2 thermal conductivity degradation is correctly modeled. It is noted that the AURORA-B methodology and application have not yet been approved by the NRC; however, the staff accepted its use for sensitivity calculations for this assessment (Reference 2). The AURORA-B sensitivity studies show that the impact of fuel thermal conductivity degradation with exposure results in changes in the ΔCPR of [ ] increase in the transient LHGR excursion. Relative to the conservatism in the AOO methodology, these increases are considered small.

Based on the inherent conservatisms associated with the transient analysis codes and the small impact of thermal conductivity degradation with exposure for the AOO analysis, it is concluded that MCPR and LHGR operating limits based on the AOO methodology are not impacted.

The application of the methodology for ATRIUM 10XM fuel does not change the conservatisms nor invalidate the sensitivity; therefore, the AOO methodology remains applicable for ATRIUM 10XM fuel. It should be noted that transient LHGR analyses are performed with the RODEX4 code for the ATRIUM 10XM fuel, which correctly accounts for thermal conductivity degradation.

3.2 *Loss of Coolant Accident Analyses*

LOCA analyses are performed using the EXEM BWR-2000 methodology and include the use of the RODEX2, RELAX and HUXY computer codes. In addition to the initial stored energy, the RODEX2 code is used to calculate fuel mechanical parameters for use in the HUXY computer code that potentially impact the clad ballooning and rupture models. Clad ballooning has a small impact on Peak Cladding Temperature (PCT) and metal water reaction (MWR), but clad rupture can have a significant impact on PCT, depending on event timing.

The LOCA event is divided into two phases: the blowdown and refill/reflood phases. During the initial or blowdown portion of a LOCA, good cooling conditions exist, and the initial stored energy in the fuel is removed. While a decrease in the thermal conductivity increases the overall thermal resistance, heat transfer conditions remain sufficient to remove the initial stored energy. Numerous sensitivity studies have been performed to demonstrate that BWR LOCA analyses are insensitive to initial stored energy. After the initial phase of a LOCA, the heat transfer coefficient at the cladding surface is degraded due to the loss of coolant (low flow and high quality). As a result, the heat transfer from the fuel is primarily controlled by the surface heat flux, and the temperature profile across the pellet is very flat. When compared to the rod surface thermal resistance, the pellet thermal conductivity is not a significant portion of the fuel rod total thermal resistance. Therefore, LOCA calculations are not sensitive to the UO2 thermal conductivity used in RELAX and HUXY.

To demonstrate that LOCA calculations were not sensitive to UO_2 thermal conductivity, assessments were performed for multiple BWRs. Most LOCA analyses of record are limiting at beginning of life (BOL) conditions. For these cases, increases in PCT at later exposures remained non-limiting. Thermal conductivity degradation may impact calculated PCTs and oxidation at higher exposures; however, since the MAPLHGR limit decreases linearly following 15 GWd/MTU, significant margin is gained that offsets any decrease in margin associated with thermal conductivity degradation.

Assessments of the potential impact of exposure degradation of UO_2 thermal conductivity on the fuel mechanical parameters were made using the RODEX4 computer code. The RODEX4 code explicitly incorporates the impact of UO_2 thermal conductivity degradation with exposure. The

assessment based on the RODEX4 computer code was used to make adjustments to input for RODEX2 to reflect the impact of the UO_2 thermal conductivity degradation with exposure; HUXY sensitivity studies were performed with the adjustments made to the input of RODEX2. The change in PCT for cases without rupture at the break point exposure of 15 GWd/MTU was [ ]; the Browns Ferry ATRIUM-10 result was within this range and did not have fuel rupture, the BOL results remained limiting. The assessment did include a BWR case where the limiting PCT was not at BOL and included early CHF lockout and rupture. The PCT increased [ ], the change in metal water reaction (MWR) was small relative to the remaining margin to the oxidation limit. Therefore, even with rupture the increase in PCT is relatively small.

For the Browns Ferry ATRIUM 10XM fuel, the sensitivity studies were performed at the exposure break point of 15 GWd/MTU. The change in PCT at this exposure was approximately [ ], the change in MWR was [ ]. This exposure point has significant margin to the limiting PCT at BOL. Additional analyses were performed at later exposures to demonstrate higher exposures remained non-limiting, refer to Table 3-1. Limiting LOCA analyses specific to Browns Ferry do not have early boiling transition, nor fuel rupture.

Based on the assessment describe above, the potential impact of UO_2 thermal conductivity degradation with exposure on calculated PCT and MWR for the Browns Ferry ATRIUM 10XM fuel is not significant relative to existing margins to limits.

From the NRC's review of Reference 1, the additional information was requested in Reference 2. The requests and responses to the requests are provided as follows:

> *A detailed explanation of the source of the heat transfer coefficients utilized in the HUXY calculation*
>
> This request is answered in Reference 3.
>
> *A description of how LOCA analyses are initialized in terms of power distribution; specifically, how thermal limits (such as MLHGR or OLMCPR) are considered in the initialization*

This request is answered in Reference 3.

A characterization of the PCT sensitivity to fuel conductivity for plants where early boiling transition is predicted to occur during the early stages of LOCA

Specifically for Browns Ferry analyses, early boiling transition is not predicted to occur in the assessment. To ensure that this observation remains true for the entire break spectrum analyses, the Browns Ferry ATRIUM 10XM break spectrum analyses were reviewed to identify the case that was closest to early boiling transition. The case closest to early boiling transition was repeated with corrections to model UO_2 thermal conductivity degradation at 15 GWd/MTU. The new analysis did not result in early boiling transition, despite an increase in stored energy from conductivity degradation.

The change in stored energy from UO_2 thermal conductivity degradation is of primary concern for the LOCA analyses; however, it is important to note that maximum stored energy would occur between 0 – 15 GWd/MTU. Within this range, maximum stored energy occurs from pellet densification when the gap between the cladding and pellet is at its maximum. This usually occurs before 5 GWd/MTU – an exposure region that is not an issue for conductivity degradation. At later exposures where conductivity degradation is significant, the reduction in power by the MAPLHGR limit after 15 GWd/MTU would prevent this exposure region from being limiting in terms of stored energy. The RELAX system and RELAX hot channel analyses are performed with stored energy determined from the earlier exposure region. As noted in Reference 1, RODEX2 has an over-prediction of fuel centerline temperature to at least 10 GWd/MTU, therefore stored energy used in the RELAX analyses is conservative.

3.3 *Overpressurization Analyses*

The COTRANSA2 code is used to perform analyses to demonstrate that the reactor vessel pressure will not exceed the ASME vessel pressure limit during specified events. COTRANSA2 is also used to demonstrate that the vessel pressure does not exceed the acceptance criterion for an anticipated transient without scram (ATWS) event.

Analyses using COTRANSA2 are potentially affected by UO_2 thermal conductivity degradation with exposure, as described in Section 3.1 for AOO analyses. As discussed in Reference 1, the impact on overpressurization analysis was assessed in two ways: using AURORA-B to assess the relative impact of using UO_2 thermal conductivity with exposure degradation; and decreasing the core average thermal conductivity input into COTRANSA2 to account for the effects of exposure degradation. Reference 1 summarized the increase in pressure as less than a **[** **]** pressure rise (peak pressure – initial pressure) for the AURORA-B assessment and a pressure rise of **[** **]** for COTRANSA2 when the core average thermal conductivity

assumed a 30% reduction. The Reference 1 evaluations concluded that the impact of UO_2 thermal conductivity degradation with exposure on the peak vessel pressure in overpressurization analyses was a small increase, the increase is less than the existing margins to the acceptance criteria (Note: Section 3.3.1 below addresses all stacked pressure penalties).

The impact was specifically evaluated for ATRIUM 10XM fuel. A bounding bias for Browns Ferry ATRIUM 10XM was determined to be [ ] of the pressure rise (peak pressure – initial pressure) for both ASME and ATWS overpressurization analyses. For each cycle, based on AREVA's corrective action system, this bias is addressed for the ASME and ATWS overpressurization analyses to demonstrate that the pressure limits are not exceeded.

As an example, the bias for the ATRIUM 10XM transition core for Browns Ferry Unit 2 Cycle 19 is [ ]. Table 3-2 provides a summary of all the biases associated with the overpressurization analyses as discussed in Section 3.3.1.

From the NRC's review of Reference 1, the additional information was requested in Reference 2. The requests and responses to the requests are provided as follows:

> *A comprehensive list of the identified nonconservative biases in the AREVA overpressure analysis methods*
>
> The comprehensive list of items was provided in Reference 3. The biases applicable for Browns Ferry ATRIUM 10XM are summarized as follows. These biases are addressed for each cycle to ensure that the pressure limits are not exceeded.
>
> Void-Quality Correlation: The bias is [ ] for ASME and [ ] for ATWS calculations.
>
> Thermal Conductivity Degradation: The bias is [ ] of the calculated pressure rise from steady-state conditions for both ASME and ATWS calculations.
>
> Doppler Model Mismatch Between MICROBURN-B2 and COTRANSA2: The bias is [ ] of the calculated pressure rise from steady-state conditions for the ASME calculation and [ ] for the ATWS calculation.
>
> *Verification that the nonconservative biases are considered in an integral sense in the safety analyses.*

Reference 3 demonstrated that it is conservative to add the biases together from separate effect assessments. The integral study demonstrated a decrease in total bias pressure.

3.4 *Stability Analyses*

As summarized in Reference 1, the computer codes STAIF and RAMONA5-FA are used in stability analyses. Both of these codes have fuel models that include UO_2 thermal conductivity degradation with exposure. Therefore, there is no impact on AREVA NP stability analyses.

3.5 *Fire Event Analyses*

The analyses to demonstrate compliance with Appendix R criteria and the newer NFPA 805 criteria are performed using the LOCA analysis codes. For these analyses, the calculated PCT is much lower than for LOCA analyses. As detailed in Section 3.2 for the LOCA analyses, the impact of UO_2 thermal conductivity degradation with exposure has only a small impact on calculated PCT. Like the Browns Ferry LOCA analyses, the fire protection analyses are limiting at BOL. Therefore, the conclusions from these analyses would not be affected by UO_2 thermal conductivity degradation with exposure.

Table 3-1 Browns Ferry ATRIUM 10XM LOCA Sensitivity Analyses for Thermal Conductivity Degradation

[ ]

Table 3-2 Browns Ferry Unit 2 Cycle 19 Overpressurization Biases and Results

[ ]

4.0 Plan for Formal Resolution of Fuel Conductivity Degradation

[

] In the interim, the summary provided in this report is intended to support the application of ATRIUM 10XM fuel at Browns Ferry Units 1, 2 and 3.

1. Letter, R. Gardner to NRC, "Informational Transmittal Regarding Requested White Papers on the Treatment of Exposure Dependent Fuel Thermal Conductivity Degradation in Legacy Fuel Performance Codes and Methods," NRC:09:069, ML092010160, July 14, 2009.

2. Letter, T. J. McGinty (NRC) to P. Salas (AREVA), "Nuclear Fuel Thermal Conductivity Degradation Evaluation for Light Water Reactors Using AREVA Codes and Methods (TAC No. ME5178)," March 23, 2012.

3. Letter, P. Salas (AREVA) to NRC, "Response to NRC Letter Regarding Nuclear Fuel Thermal Conductivity Degradation Evaluation for Light Water Reactors Using AREVA Codes and Methods," NRC:12:023, April 27, 2012.

4. ANP-10300P, Revision 0, *AURORA-B: An Evaluation Model for Boiling Water Reactors; Application to Transient and Accident Scenarios*, AREVA NP, December 2009.