AUDIT REPORT FOR AREVA INC.

TOPICAL REPORT BAW-10192PA-00, SUPPLEMENT 1, REVISION 0

"BWNT LOCA - BWNT LOSS-OF-COOLANT ACCIDENT

EVALUATION MODEL FOR ONCE-THROUGH STEAM GENERATOR PLANTS"

PROJECT NO. 728

TAC NO. MF7145

1.0 INTRODUCTION

By letter dated November 25, 2015, AREVA Inc. (AREVA) submitted a topical report (TR) supplement to its US Nuclear Regulatory Commission (NRC)-approved evaluation model (EM) that is used to evaluate emergency core cooling system (ECCS) performance under postulated loss-of-coolant accidents (LOCA) at Babcock and Wilcox (B&W) designed nuclear power plants. The TR is entitled, "BWNT [Babcock and Wilcox Nuclear Technologies] LOCA – Loss-of-Coolant Accident Evaluation Model for Once-Through Steam Generator Plants," and can be identified either by TR number, BAW-10192PA-00, or by it abbreviated title, BWNT LOCA. The present submittal is Supplement 1P to Revision 0 of the NRC-approved TR, and is referred to as BAW-10192PA-R0-S1P-R0.

The original EM, BWNT LOCA, was developed in conformance with Appendix K, "ECCS Evaluation Models," to Part 50 of Title 10 of the US *Code of Federal Regulations* (10 CFR Part 50). The EM is used by NRC licensees to demonstrate compliance with the requirements contained in 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors." In particular, BWNT LOCA is used to show that the predicted ECCS performance following a postulated LOCA remains within the acceptance criteria provided in 10 CFR 50.46(b)(1) through (b)(3). These criteria impose limits on the calculated fuel peak cladding temperature (PCT), the calculated fuel cladding oxidation, and the core-wide hydrogen generated during the event.

The TR supplement was submitted to document, and obtain NRC approval for, an approach that AREVA has developed to account for a phenomenon known as nuclear fuel thermal conductivity degradation (TCD). The original EM does not account for TCD. The effects of TCD are summarized in NRC Information Notice (IN) 2009-23, "Nuclear Fuel Thermal Conductivity Degradation."

AREVA determined that the EM under-predicts the PCT because the BWNT LOCA does not account for TCD. This determination was documented in a report that AREVA submitted to the NRC on November 25, 2014, under 10 CFR Part 21, "Reporting of Defects and

Non-Compliances." To ensure that the affected NRC licensees continued to operate safely, the vendor recommended that each facility affected by the issue implement a reduction in the peak allowable fuel linear heat rate. Each NRC-licensed B&W designed nuclear power plant affected by the TCD issue implemented AREVA's recommendation. This interim measure ensured that the plants continued to operate safely with sufficient margin to offset the under-prediction in PCT resulting from the fact that BAW-10192PA does not account for the effects of TCD.

The information contained in BAW-10192PA-R0-S1P-R0 describes several modeling changes to account for TCD. Following NRC review of the TR supplement, and if acceptable, approval for use, the licensees using BAW-10192 would adopt the changes described in BAW-10192PA-R0-S1P-R0 in order to re-evaluate ECCS performance. The adoption of these changes would allow the affected NRC licensees potential relief from the interim reductions in peak allowable linear heat rates while remaining in compliance with the requirements of 10 CFR 50.46.

The NRC staff has determined that an audit, following Office of Nuclear Reactor Regulation Office Instruction LIC-111, "Regulatory Audits," would be beneficial in identifying additional information required to complete the review. The audit plan is documented at Agencywide Documents Accession and Management System (ADAMS) Accession No. ML16111B077. The audit was conducted on April 25 and 26, 2016, at the Marriott North Bethesda Conference Center, located at 5701 Marinelli Road, Rockville, Maryland.

2.0 REGULATORY AUDIT BASES

The BWNT-LOCA EM was developed in accordance with the regulatory requirements established in Title 10, "Energy," of the CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," Section 46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors" (10 CFR 50.46). The EM conforms to the required and acceptable features of ECCS EMs set forth in Appendix K to 10 CFR Part 50, consistent with the passage in 10 CFR 50.46(a)(1)(ii), which states, "Alternatively, an evaluation model may be developed in conformance with the required and acceptable features of Appendix K ECCS Evaluation Models."

The NRC staff, along with its consultants from the Brookhaven National Laboratory (BNL), audited BAW-10192PA-R0-S1P-R0 and supporting documentation, to identify appropriate additional information to request for submittal. Such information is required to determine (1) whether the changes are conformant to the requirements set forth in Appendix K to 10 CFR Part 50, specifically, those contained in paragraph I.A.1, "The Initial Stored Energy in the Fuel," and (2) whether the EM, as modified to account for TCD, remains more generally in conformance with the remaining required and acceptable features of ECCS EMs contained in Appendix K to 10 CFR Part 50, and the requirements for ECCS performance contained in 10 CFR 50.46.

3.0 REGULATORY AUDIT SCOPE/OBJECTIVES

The audit addressed the following five topics below.

3.1. OVERVIEW OF BAW-10192PA-R0-S1P-R0

AREVA presented an overview of BAW-10192PA-R0-S1P-R0. The presentation summarized the adjustments necessary to the BWNT-LOCA input to address the effects of TCD. The focus of the audit discussion was on the approach, implementation, and qualification of the adjustments to confirm that AREVA adequately models TCD as a function of burnup. The presentation also showed a comparison of the RELAP5/MOD2-B&W with modified inputs to prior analyses.

3.2. DISCUSSION OF QUESTIONS NOT ADDRESSED DURING OVERVIEW

Following the overview presentation, the NRC staff and its consultants from BNL, reviewed questions which were included as an attachment to the audit plan. The vendor provided the NRC staff a draft response to the questions, which the NRC staff discussed with AREVA. As appropriate, these questions will be formalized into requests for additional information (RAIs) and formally transmitted to the vendor. As is the process with a regulatory audit, the NRC staff did not retain the draft information, but understands that such information would be formally submitted in response to RAIs, as appropriate.

3.3. REVIEW OF INPUT PROCESSING PROCEDURES AND ANALYSIS PROCESS

The NRC staff and BNL audited the typical process of running the analysis computer codes during the audit. During this portion of the audit, AREVA addressed the methods by which RELAP5/MOD2-B&W initial conditions are set after running TACO3 or GDTACO and determining the appropriate volume-average fuel temperature with a TCD bias. The process for determining the fuel thermal conductivity and the fission gas gap multipliers, along with procedures for setting downstream code initial conditions, such as REFLOD3B and BEACH, was also addressed.

During this discussion, the vendor explained how some of the values in Tables 5-1 through 5-4 of the TR were calculated.

3.4. REVIEW OF SPECIFIC BAW-10192PA-R0-S1P-R0 CALCULATIONS AND ANALYSES

The NRC staff and BNL audited calculation files for the analyses that support the concluding chapters of BAW-10192PA-R0-S1P-R0.

3.5. ADDITIONAL DISCUSSION AND EXIT MEETING

At the conclusion of the audit, an exit meeting was held to summarize significant open items, which will form the focus of the ongoing review. Appropriate next steps, including an update to the licensing TR review schedule, were discussed, as well.

Team Assignments

The following personnel supported the audit:

NAME	AFFILIATION
Jonathan Rowley	Project Manager, NRC/Office of Nuclear Reactor Regulation (NRR)/Division of Policy and Rulemaking
Benjamin Parks	Technical Reviewer, NRC/NRR/Division of Safety Systems
Joshua Borromeo	Technical Reviewer, NRC/NRR/Division of Safety Systems
Lap-Yan Cheng	Technical Consultant, BNL
Joo Seok Baek	Technical Consultant, BNL

4.0 OPEN ITEMS

The following topics were discussed with the vendor and identified as open items. These topics are likely to appear within a future RAI that will be transmitted from the NRC to the vendor under separate correspondence.

4.1. BACKGROUND INFORMATION

During the audit, the NRC staff observed that BAW-10192PA-R0-S1P-R0 lacks a detailed description of the analytic process associated with BWNT-LOCA, and how this process is modified to perform the input adjustments necessary to account for the effects of TCD within the BWNT-LOCA evaluation model. Such a description would provide a methodology roadmap that would be a useful review resource.

4.2. TCD BIAS FUNCTION DEVELOPMENT AND QUALIFICATION

Discussion during the audit revealed that additional information regarding the development and qualification of the TCD bias function would likely benefit the NRC staff review.

- The NRC staff reviewed calculation notes that provided a detailed discussion of the characteristics of each fuel performance code case that was used to determine the TCD bias function that is applied to the TACO3 and GDTACO initialization parameters (i.e., initialization parameters that are supplied to RELAP5/MOD2-B&W). These descriptions are important to justify that the adjustment is based on a sufficient set of cases to provide a bounding representation of cycle operation, as are accompanying power history limits (LHR limits). The TR does not provide any discussion of the cases and the LHR limits shown in Figures 3.1 through 3.6 and Figure 3.8.

- The applicability limits provided in Table 3-4 are based on calculation files supporting the development of the TR. The basis for these limits will be requested, so that the NRC staff can evaluate their adequacy for and applicability to production safety analysis. One aspect of the evaluation will be to compare the basis against the applicability range of the computer codes (COPERNIC2, TACO3, and GDTACO) and experimental data used in the development of the TCD bias functions.

- The trending illustrated in Figure 3-10 indicates a direct proportionality between **[ ]** and measured data. The NRC staff anticipates requesting evidence that this trending is reasonably expected, and does not suggest a tendency for the bias to be under-predicted for fuel operating at higher linear heat rates.

- The NRC staff indicated that information sufficient to compare the validating data used in BAW-10192PA-R0-S1P-R0 to current-generation fuel designs in use at B&W designed nuclear power plants would be necessary. AREVA suggested that such data, regarding the B-HTP fuel design, is available in the current revision of BAW-10179. The staff will request AREVA to explain how the data varies for the B&W designed nuclear power plants.

- The TR utilized a comparison between calculated **[ ]** plus TCD bias function and measured **[ ]** to conclude that the TCD bias functions have adequately penalized the TACO3/GDTACO fuel temperature predictions. It was not readily apparent to the NRC staff that such a comparison leads to the conclusion in the TR. The NRC staff intends to request additional justification that applying a bias function based on the volume-average fuel temperature sufficiently augments the entire radial pellet temperature profile for the LOCA initialization.

4.3. MODELING APPROACH

The NRC staff identified a couple of topics related to the TCD modeling approach that are likely to warrant additional information. These included the "**[ ]**" modeling option employed in TACO3 and GDTACO, and the approach used to obtain a gas gap heat transfer multiplier close to unity. The **[**

]. Refer to Section 3.1.1 of the TR for additional discussion. In order to obtain a gas gap heat transfer multiplier close to unity, AREVA adjusts the fuel pellet and clad inside surface roughness as described in TR Section 4.2.

4.3.1. TACO3 and GDTACO **[ ]** Modeling

In order to perform a sufficiently complete evaluation of the **[ ]** modeling option employed for LOCA initializations using TACO3 and GDTACO, which were added after NRC staff approval of the TACO3 and GDTACO fuel performance methods, the NRC staff will request that the vendor provide comparisons among TACO3 and GDTACO, TACO3 and GDTACO with **[ ]**, and COPERNIC2 at middle-of-life and end-of-life conditions, as well as experimental data if available, for LOCA-initialized fuel pins. The NRC staff will request that the comparisons include radial power distribution, volume-average fuel temperatures, cladding inner radii, fuel outer radii, pin pressure, pin gas composition, oxide thickness, and final plenum volume.

4.3.2. Fuel Rod **[ ]**

With regard to the fuel pellet and clad **[ ]**, the NRC staff determined that the following additional information will be requested in order to continue its review:

- Sensitivity studies varying the gas gap multiplier across the range of target values (i.e., **[ ]**), showing the following results: predicted cladding temperature behavior including the PCT, gap conductance, and gap dimension

- Consideration, within the sensitivity studies discussed above, for variability in fuel cladding plastic deformation and rupture behavior, and for varying Gadolinia concentrations.

- Additional clarification is needed to support assertion in the TR that "**[**

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- Additional description of the adjustment process, including the as-adjusted fuel rod parameters, analogous to the information provided in Tables 5-7 and 7-5 of Audit Document **[ ]**."

- Additional specificity, such as modeling guidelines, to confirm that analysts **[**

] obtained from the LBLOCA analysis.

- For a given fuel rod, **[**

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- **[**

] as well as in the other fuel rods, of which there may be as many as six, modeled in the core region. In some cases the PCT occurs above or below the hot cell (the peak power location). The NRC staff will request AREVA to confirm that the PCT is either predicted **[**

], or that the **[**

] at the PCT location is appropriately confirmed, checked, or justified.

4.4. APPLICATION OF THE TCD BIAS FUNCTION

- The approach used to apply a **[** **]** should be described in more detail and illustrated by comparing the following volume-averaged fuel temperatures across the core axial elevation for the hot pin: TACO3 best-estimate, TACO3 upper tolerance limit, COPERNIC2 best-estimate, COPERNIC2 upper tolerance limit, TACO3 adjusted additively, and TACO3 with the TCD bias ratio applied.

- Descriptions and comparisons similar to the above should also be provided, comparing the hot pin adjustment to the hot bundle adjustment.

- Apparently, TACO3, GDTACO, and COPERNIC2 do not use common temperature units. While TACO3 and GDTACO use degrees Fahrenheit, COPERNIC2 uses degrees Celsius. Clarity will be requested in explaining the temperature units used in computation, and those used in developing bias functions. The NRC staff may also request justification for applying ratios that are based on non-absolute temperature units (i.e., Celsius and Fahrenheit have arbitrary zero values, whereas Kelvin and Rankine are the corresponding absolute units). It is noted that the use of different temperature units will result in different values for the volume-averaged fuel temperature axial adjustment ratio.

- The information presented in Tables 5-1 through 5-4 of the TR should be supplemented to include peak rod burnup and the TACO3/GDTACO best-estimate initial peak volume-average fuel temperature as determined using the **[ ]** LOCA initialization.

4.5. LOCA METHODOLOGY

- During the audit, AREVA explained how the analysis computer codes are used and how the results of one code are passed as input to another code in much more detail than the discussion given in the TR. The NRC staff will ask AREVA to provide such a detailed description of the LBLOCA EM computer code interface including data transfer between the codes, which can provide a road map to the methodology.

- Uncertainties are added to the temperatures (VAFT) predicted by TACO3/GDTACO for the hot pin and hot bundles. The NRC staff will request AREVA to provide detailed discussions of the development and qualification of the uncertainties. In particular the discussion should highlight the application of uncertainties in the modified LOCA methodology that deviates from the previously approved methodology.

4.6. TIL LBLOCA TCD DEMONSTRATION CASES

- Some labels in the figures of the TR are ambiguous and may lead to wrong interpretations. One example is “RELAP w/o TCD” in Figure 4-4. This represents the RELAP5 initial temperature with TCD bias but without considering the burnup-dependent fuel thermal conductivity. AREVA will be requested to clarify the labels with appropriate discussions.

- Section 5 of the TR shows the changes in the PCT predictions with and without TCD adjustments. In all the cases analyzed a core inlet skewed axial peak at 2.506 feet was assumed. The basis for this selection will be requested.

- AREVA needs to explain the basis for the LHR limits in Figures 3-1 through 3-5 and why the limits shown in Figure 5-18 are different.

5.0 LIST OF DOCUMENTS AUDITED

DOCUMENT ID	TITLE
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