U.S. NUCLEAR REGULATORY COMMISSION

FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

FOR TOPICAL REPORT WCAP-17202-P/WCAP-17202-NP, REVISION 0-1,

"SUPPLEMENT 4 TO BISON TOPICAL REPORT RPA 90-90-P-A"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION

By letter dated June 30, 2010 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML101830265), South Texas Project Nuclear Operating Company submitted to U.S. Nuclear Regulatory Commission (NRC) staff review Topical Report (TR) WCAP-17202-P/WCAP-17202-NP, Revision 0, "Supplement 4 to BISON Topical Report RPA 90-90-P-A" (Reference 1). Subsequent to this initial request, a revised version of the TR was submitted that incorporated issues resolved via staff requests for additional information (RAIs). The current revision, Revision 0-1, was submitted for staff review and approval by letter dated September 30, 2014 (Reference 2). WCAP-17202-P/WCAP-17202-NP, Revision 0-1, is the fourth supplement to the BISON TR RPA 90-90-P-A (Reference 3), and in its submittal, Westinghouse stated that the main purpose of WCAP-17202-P/WCAP-17202-NP, Revision 0-1, is to address restriction 2 of the RPA 90-90-P-A Safety Evaluation (SE). In addition to addressing this restriction, the WCAP-17202-P/WCAP-17202-NP, Revision 0-1, TR details new models and methods that have been incorporated into the BISON code in order to extend its capabilities and provide more robust analyses. Westinghouse Electric Company (Westinghouse) is seeking NRC approval of the WCAP-17202-P/WCAP-17202-NP, Revision 0-1, TR for boiling water reactor (BWR) product lines 2-6 (BWR/2-6) and advanced boiling water reactors (ABWR). As a result, some of the methods and models discussed in the submittal are only applicable to the ABWR while others have dual applicability. This SE intends to address the applicability of the WCAP-17202-P/WCAP-17202-NP, Revision 0-1, TR to BWRs/2-6 only. The Office of New Reactors (NRO) is to address applicability of the TR to ABWRs in a separate SE.

Presently, the BISON code is used for reload applications and other plant changes that only require limiting transients to be evaluated. The additional methods and models presented in the TR are intended to expand the scope of BISON to include all limiting and non-limiting transients required for a first-time transient analysis application. The new methods and models discussed in the TR are:

New Recirculation Pump Model: A condition in the SE for the original BISON TR requires justification for use of the existing recirculation pump model when transients are outside the first quadrant of the Karman-Knapp Diagram. The updated model describes pump operation outside of the first quadrant, and it is intended for the ABWR only.

The Advanced Control Rod Hydraulic Insertion Model: This model is used to model ABWR plant SCRAM velocity versus time instead of using user-defined tables of control rod position versus time. This model is only applicable to the ABWR.

Improved Method for Cross-Section Collapsing: This is an improved method of cross-section collapsing that utilizes input from POLCA7 (Ref. 4) to produce more accurate results in 1D.

POLCA7 is a steady-state, three-dimensional diffusion theory code used to predict core and pin-wise power distribution. This method was developed after the approval of POLCA7, and it is intended for BWRs/2-6 and the ABWR.

Asynchronous Pump Motor Model: This pump motor model changes pump speed in response to signals from control system models and is intended for use with SAFIR-generated control systems to model recirculation pumps. SAFIR is a code package containing a selection of standard control components and logical functions that can be coupled to any transient code to simulate most types of analog or digital control systems (Ref. 5). This model is intended for BWRs/2-6 and the ABWR.

BISON/SAFIR Interface for Level Measurement Model: This model calculates the water level in the reactor vessel as measured by a plant's instrumentation. The model can be used to represent several water measurements systems for a plant, such as narrow range level and wide range level. This model is intended for BWRs/2-6 and the ABWR.

Steam Dome Water Surface Condensation Model: This model is used to capture phenomena related to steam condensation on the water surface of the bulk water when subcooled water interacts with a steam environment. This model was intended for BWRs/2-6 and the ABWR, but it was withdrawn by Westinghouse (see Section 3.6).

Post Dryout and Rewet Model: This model is used to determine the peak cladding temperature (PCT) during events where fuel rods are determined to experience boiling transition and experience cladding failure. This is particularly important for accident events that require radiological consequences for cladding failure to be evaluated. This model is intended for BWRs/2-6 and the ABWR.

1.1 Background

In the years since BISON's approval in December of 1991, a number of supplemental TRs that expand upon and modify the original version of the code have been submitted to and subsequently approved by the NRC. The SEs that were written for the original BISON TR and the supplemental TRs each contain conditions and limitations that have been imposed and/or modified. In order to inform the technical discussion and evaluation that is to follow, it is beneficial to briefly discuss the original BISON TR, each of its supplemental TRs, and the conditions and limitations associated with them. The conditions and limitations presented below are numbered as they were in the applicable SE.

1.1.1 BISON

The BISON transient analysis code for BWR analysis (Ref. 3) is a one-dimensional code that includes models for simulating a BWR (e.g., the reactor core, recirculation loops, steam separators, feedwater, steam dome, and steam lines, and a number of balance-of-plant systems). BISON models the reactor coolant thermal-hydraulics, core neutron kinetics, fuel heat transfer, steam line pressure dynamics, and auxiliary plant systems. BISON also includes a single-channel model, SLAVE, for transient hot channel analyses. The SE associated with the original TR allowed BISON to be referenced in submittals supporting BWR reload transient analysis subject to the following conditions and limitations:

(1) Justification of the core flow when an unbalance from either recirculation loop can cause a thermal-hydraulic gradient across the core.
(2) Justification for use of the recirculation pump model when transients are in a quadrant other than the first quadrant of the Karman-Knapp diagram.

(3) Justification for use of the recirculation pump model when two-phase flow conditions are calculated.

(4) Justification of the slip and void correlation used (AA78 or Bryce-Holmes) if the core pressure exceeds 1305 psia while the quality exceeds 40 percent or if the pressure exceeds 1450 psia.

(5) Justification of the isentropic coefficient used during a depressurization event.

(6) A staff-approved model is required when modeling is necessary to simulate control systems.

Although not explicitly listed alongside the aforementioned conditions, an additional condition regarding BISON's cross-section collapsing methods was imposed in the main body of the SE. This condition stated that of the three methods described in BISONS's TR, Method C, was the preferred and accepted methodology to be used in the final licensing analyses of limiting transients. The two remaining methods, Methods A and B, were found to be acceptable for sensitivity studies and non-limiting transients. The oversight of excluding this condition from the comprehensive list is corrected in Section 4.0 of this draft SE.

1.1.2. Supplement 1 to the BISON Topical Report RPA 90-90-P-A

In 1996, the original BISON TR, RPA 90-90-P-A, was supplemented by CENPD-292-P-A, "BISON - One Dimensional Dynamic Analysis Code for Boiling Water Reactors: Supplement 1 to Code Description and Qualification" (Ref. 6). Supplement 1 made several modifications and additions to the BISON code in order to allow for explicitly simulating single loop operations, enabling core reload analyses that utilize the SVEA-96 fuel design and improving modeling of BWR reactor components (i.e., steam line and separators). Specifically, the improvements include:

- the implementation of XL-S96, a critical quality boiling-length Critical Power Ratio (CPR) correlation for the SVEA-96 fuel,

- advanced steam line modeling (PARA) enabling steam dynamic calculation in separate steam lines, steam bypass lines, and steam cross flows between different steam lines,

- individual recirculation loop dynamics enabling explicit simulation of single loop operation (addresses condition 1 from RPA 90-90-P-A),

- core boiling and condensation based on the Electric Power Research Institute (EPRI) (Lellouche-Zolotar) model,

- allow input of fuel rod thermal data from the fuel performance code STAV6.2, and
- the use of a geometric representation of the steam separator length-over-area ratio rather than an effective ratio.

As with the original BISON TR, the SE approving Supplement 1 included following list of conditions and limitations:

(1) Justification for the performance of user-modeled valves and control system functions within the PARA steamline model to ensure conservatism in licensing applications.

(2) The original BISON TR SE condition regarding the pump model remains unchanged. Similarly, the other SE conditions with respect to the simulation of the control system and the use of the slip and void correlation in the range of applicability also remain unchanged.

(3) The use of the EPRI (Lellouche-Zolotar) boiling/condensation model for licensing analysis must be demonstrated to be used within its range of applicability for each such application.

(4) The use of the turbine assembly model is restricted until qualified.

Condition 2 in the above list indicates that Conditions 2, 3, 4, and 6 from the SE for the original BISON TR, RPA 90-90-P-A, remain unchanged. Condition 4 in the above list was the result of Westinghouse stating that the turbine assembly model would not be used, and it was therefore not qualified in Supplement 1.

Although not explicitly listed alongside the above conditions and limitations, a brief discussion included in the SE for Supplement 1 implicitly placed a restriction on the applicability of the neutron cross-section collapsing methods. The discussion indicated that while Methods B and C both showed reasonable agreement of predictions for BWR/5 generator load rejection without bypass, it was Method C that had been demonstrated to be reasonably conservative for limiting transients with respect to the SVEA-96 fuel.

1.1.3. Supplement 2 to the BISON Topical Report RPA 90-90-P-A

In 2008, the original BISON TR, RPA 90-90-P-A, was further supplemented by WCAP-16606-P-A, “Supplement 2 to BISON TR RPA 90-90-P-A” (Ref. 7). The purpose of Supplement 2 was to extend the applicability of the BISON code to include the analysis of anticipated transient without scram (ATWS) sequences beyond peak pressures calculations and to determine the mass and energy release to the containment during the boron injection phase of the ATWS. To achieve this, the following code modifications were made:

- extension of the maximum approved upper pressure and steam quality limit for the AA78 slip/void correlation,
- modeling the reactivity impact from boron injection during an ATWS transient, and

- providing a description of an example ATWS calculations during the boron injection phase with the BISON code.

The AA78 slip/void correlation was previously qualified up to a pressure of 10 MPa (1450 psia) in the original BISON TR, RPA 90-90-P-A (Ref. 3). In seeking to extend the qualification beyond this limit, Supplement 2 was addressing Condition 4 of the SE for RPA 90-90-P-A (as described in Section 1.1.1 above). In the SE associated with Supplement 2, the NRC staff approved of the maximum upper pressure extension and steam quality limits for the correlation with the following condition:

(1) For reactor dome pressures less than 10 MPa, there are no limitations on the use of the AA78 slip/void correlation. But for pressures greater than 10 MPa during an ATWS event, if the quality exceeds the upper limit identified in WCAP-16606-P, Revision 0, then use of the TR is not approved.

As such, Condition 4 from the SE of the original BISON TR has been superseded by the above Condition 1 from the SE for Supplement 2.

1.1.4. Supplement 3 to the BISON Topical Report RPA 90-90-P-A

In 2013, BISON TR RPA 90-90-P-A was supplemented a third time by WCAP-17079-P-A, “Supplement 3 to BISON Topical Report RPA 90-90-P-A SAFIR Control System Simulator” (Ref. 5). Supplement 3 documents the use of SAFIR, a code package to simulate analog and digital control systems, in conjunction with BISON to model plant systems important to the balance-of-plant response. Supplement 3 sought to address Condition 6 in the SE of the original BISON TR by demonstrating that SAFIR is capable of modeling control systems consistent with the provisions of CENPD-300-P-A, "Reference Safety Report for Boiling Water Reactor Reload Fuel" (Ref. 8).

Approval of Supplement 3 was requested by Westinghouse for both BWRs/2-6 and the ABWR. As such, Supplement 3 was jointly reviewed by the Office of Nuclear Reactor Regulation (NRR) and NRO, and two separate SEs were written.

In the SE written by NRR, which focused on the applicability of Supplement 3 to BWRs/2-6, the staff concluded that SAFIR, in conjunction with an NRC-approved system code such as BISON, was acceptable for performing licensing-basis analyses for BWRs/2-6, and that Condition 6 of the SE for the original BISON TR could be removed. Although not explicitly stated as a condition, the SE only permits use of Supplement 3 in conjunction with “an NRC-approved system code” (in this case, BISON). Aside from this, no new conditions or limitations beyond those already identified within Supplement 3 itself were imposed.

In the SE written by NRO, which focused on the applicability of Supplement 3 to ABWRs, the staff concluded that SAFIR, when integrated into BISON, was an acceptable method of simulating control systems of the ABWR for the purpose of conducting reactor safety analysis, and that Condition 6 of the SE for the original BISON TR could be removed with regards to the code’s application to ABWRs. The NRO staff also identified two new conditions and limitations:

(1) Approval of SAFIR is limited to use in combination with NRC-approved BISON, but other dynamic BWR codes may be used as described in other licensing TRs and subject to NRC approval on a code-by-code basis, and

(2) SAFIR shall model control systems consistent with the provisions of CENPD-300-P-A.

The NRO SE also stated that conditions and limitations imposed upon the use of BISON in submittals prior to Supplement 3 continued to remain in effect.

2.0 REGULATORY EVALUATION

Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34, "Contents of Applications; Technical Information," requires that the licensee/applicant provide safety analysis reports to the NRC detailing the performance of systems, structures, and components provided for the prevention or mitigation of potential accidents.

General Design Criterion (GDC) 10, "Reactor Design," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," requires that the “reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to ensure that specified acceptable fuel design limits (SAFDL) are not exceeded during any condition of normal operation, including the effects of Anticipated Operational Occurrences (AOO).”

The acceptance criteria for AOO events are defined in Chapter 15 of the Standard Review Plan (SRP), otherwise known as NUREG-800 (Ref. 9). Satisfying these acceptance criteria is necessary for AOO events to meet the requirements of the GDC. Specifically, SRP Chapter 15 Section I.2.A states the acceptance criteria are:

(1) Pressure in the reactor coolant and main steam systems should be maintained below 110 percent of the design values in accordance with the American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code*.

(2) Fuel cladding integrity shall be maintained by ensuring that the minimum departure from nucleate boiling ratio (DNBR) remains above the 95/95 DNBR limit for PWRs and that the critical power ratio (CPR) remains above the minimum CPR (MCPR) safety limit for BWRs.

(3) An AOO should not generate a postulated accident without other faults occurring independently or result in a consequential loss of function of the reactor coolant system (RCS) or reactor containment barriers.

However, WCAP-17202-P/WCAP-17202-NP, Revision 0-1, (Supplement 4) is an application for the use of new and revised models to an existing NRC-approved transient code and does not present any analyses that require the use of these SRP criteria. As such, guidance for the evaluation of Supplement 4 may be found in SRP Chapter 15.0.2, “Review of Transient and Accident Analysis Methods,” Section III.5 (Ref. 9). This section includes provisions for the review of submittals that constitute small changes to existing approved evaluation models (EMs). When only small changes are made, the following attributes of the EM should be considered when determining the extent to which the full review process may be applied:

(1) Novelty of the revised EM compared to the currently acceptable model: Small changes to an EM component may only need evaluation against a small subset of the entire code assessment matrix to adequately test the phenomena that are affected rather that a full review of the entire EM.

(2) The complexity of the event being analyzed: The level of effort involved in the review process should be commensurate with the complexity of the EM.

(3) The degree of conservatism in the EM: The review process may be simplified if there is a large documented degree of conservatism in the EM.

(4) The extent of any plant design changes or operational changes that would require a reanalysis: If the changes to plant design or operations are small, then the required scope of the review process is also likely to be small. This is because most of the changes to plant equipment or operations do not cause the plant to operate outside the range of validity of the EM.

In summary, the NRC staff used the review guidance in SRP Chapter 15.0.2 in conducting its review of Supplement 4. The review covered the areas of: (1) documentation, (2) EM, (3) accident scenario identification process, (4) code assessment, (5) uncertainty analysis, and (6) quality assurance plan. Additionally, as per SRP Chapter 15.0.2 Section III.5, the level of effort applied to the review of these areas was commensurate with the changes made to the existing approved EM and their impact on relevant phenomena.

3.0 TECHNICAL EVALUATION

Supplement 4 is an application for the use of new and revised models to an existing NRC-approved transient code, BISON. The submittal is therefore comprised of a variety of smaller sections where each new or improved model is detailed in turn. The breakdown of these sections is:

(1) Description and qualification of the new BISON recirculating pump model designed to address Condition 2 of the SE associated with the original BISON TR.

(2) Description and qualification of new/updated code models:

- Advanced hydraulic control rod insertion model,
- Improved method for cross-section collapsing,
- Asynchronous pump motor model
- Steam dome water surface condensation model (note, Westinghouse has withdrawn the request for review and approval of this model. Therefore, this model is not evaluated in this SE), and
- Post-dryout and rewet model.

(3) Comparison of BISON simulations with the new/improved models against the Hamaoka-5 startup tests.

Hamaoka-5 is an ABWR that began commercial operation on January 18, 2005. Therefore, the comparison of BISON simulations to the Hamaoka-5 startup data is appropriate for demonstrating the applicability of the updated code to ABWRs. However, because Westinghouse is also seeking approval of Supplement 4 for BWRs/2-6, NRR staff has, when considered necessary, requested additional justification for the applicability of the new/improved models to BWRs/2-6.

Each of the sections within Supplement 4 that provide descriptions and qualifications of new/updated models will be discussed and evaluated in the following subsections.

3.1 Recirculation Pump Model Restriction

Condition 2 in the SE for the original BISON TR, RPA 90-90-P-A, states that justification is required for use of the recirculation pump model when transients are in a quadrant other than the first quadrant of the Karman-Knapp diagram. In the case of an ABWR, a trip of a limited number (not all) recirculation pumps can be included as part of the reactor protections system. A transient where a limited number of recirculation pumps trip can cause the flow in the tripped pumps to become reversed and result in the pumps operating outside the first quadrant of the Karman-Knapp diagram. Therefore, in order for BISON to be applicable to ABWRs, Condition 2 in the SE for the original BISON TR must be addressed. To that end, Westinghouse has provided a new recirculation pump model.

However, the new recirculation pump model is intended for internal recirculation pumps found in ABWR applications only. Westinghouse has indicated that it is not seeking approval of the new recirculation pump model for BWRs/2-6. As such, the adequacy and acceptability of the new model is outside the scope of this SE. Therefore, NRR staff finds that Condition 2 of the SE for the original BISON TR remains in effect for BWRs/2-6 applications.

3.2 Advanced Control Rod Hydraulic Insertion Model

For U.S. reactor licensing applications, the original BISON TR utilized a user-supplied input table of control rod position versus time data to simulate a reactor scram. Supplement 4 seeks to improve upon this existing method by presenting an advanced control rod hydraulic insertion model that includes modeling of the gas tanks, water tanks, scram valves, control rods, and piping within the control rod drive system. Given user input of these components' physical properties, the model simulates a scram by **[**

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However, the advanced control rod hydraulic insertion model is intended for ABWR applications only. As such, its adequacy and acceptability is outside the scope of this SE. Therefore, NRR staff finds that the user-supplied input table of control rod position versus time method to simulating a reactor scram should continue to be employed for U.S. reactor licensing applications of BWRs/2-6.

3.3 Improved Method for Cross-Section Collapsing

In Appendix A of the original BISON TR, three different methods were described for calculating coefficients for the macroscopic cross-section polynomial equations that represent how the macroscopic cross-sections for a given core axial node change as a function of **[**

] The three methods of cross-section collapsing are:

- Method A – "Single Fuel Type." This method uses the properties of the dominant fuel type in the core, with some adjustments to the final BISON model, to match core reactivity coefficients to a static three-dimensional model.

- Method B – “Multiple Fuel Types.” This method is a simplified form of collapse from a three-dimensional model in that it uses a single 3D state point rather than a series of state points. Cross-section calculations and, subsequently, polynomial coefficients are calculated for each axial node of each of the major fuel types in the core. Fuel type volume fraction weighting factors are then used to determine average cross-section values for a collapsed “single-channel core”.

- Method C – “Collapse from 3D Model.” This method uses a set of state points, around the initial conditions for a transient, modeled in a steady-state 3D core simulator. At each state point, average cross-sections are calculated for each horizontal plane in the core. The use of multiple state points allows for varying void fraction and fuel temperature. Flux-weighted averaging is then used when determining the cross-sections for a collapsed “single-channel core.”

In the original BISON TR, Westinghouse indicated that Method C was the preferred method of cross-section collapsing for the licensing of limiting transients. In the associated SE, NRC staff agreed with this position and approved only Method C for limiting transient analyses. The NRC staff also indicated that Methods A and B may be used for sensitivity studies and non-limiting transients.

Supplement 4 presents improvements that have been made to the Method B cross-section collapsing. The improvements involve the use of input from an NRC-approved 3D nodal code, in this case POLCA7 (Ref. 4). In the original Method B cross-section collapsing routine, the value of the void history was considered constant. This would introduce an axial power shape deviation that was compensated for by performing an axial burnup or control rod density distribution search. This search would match results to a user-specified power distribution and/or k_{eff} and help correct the axial power shape (Ref. 3). The Improved Method B uses **[**

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Westinghouse states that these improvements allow the axial power profile to be obtained directly and eliminates the need for the axial power shape fitting procedure.

The Improved Method B incorporates these changes into its weighting factors. In the original Method B, weighting factors that accounted for the volume fraction of each fuel type in the core were used for calculation of average cross-section values during the collapse from 3D to 1D. In the Improved Method B, the weighting factors instead consider, on a nodal basis, the **[**
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While comparing the Improved Method B to the original, NRR staff observed a difference between the terminology used in Supplement 4 and the original BISON TR, RPA 90-90-P-A. The NRR staff issued NRR RAI-01 (Ref. 10) seeking clarification to ensure proper understanding of the improvements made to Method B. The response to NRR RAI-01 clarifies the terminology between the two TRs and results in several changes incorporated into the text of Supplement 4, Revision 0-1. These changes only clarify the terminology used and do not alter the methodology.

The NRR staff noted that in the original Method B, weighting factors used volume fractions (fractions of each fuel type in the core) for a given node when collapsing from 3D to 1D while the improved method’s weighting factors, described by Equation 3-38 of Supplement 4, utilize

[**]** However, no justification was given for the use of **[** **]** in the weighting factors, nor was an explanation given for how the **[** **]** would be obtained. Respectively, NRR RAI-02 (Ref. 11) and NRR RAI-03 (Ref. 12) requested this information.

In the response to NRR RAI-02, Westinghouse explained that while volume fraction (flux-volume) weighting is the most physical and most frequently used weighting factor for collapsing cross-sections, **[** **]** To justify this, Westinghouse presented a comparison between axial power profiles generated for the Peach Bottom 2 Turbine Trip 1 test using the two weighting methods. The results are nearly identical. The NRR staff therefore finds the response of **[** **]** acceptable.

In the response to NRR RAI-03, Westinghouse stated that the **[** **]** used in the weighting factors described by Equation 3-38 come from the **[** **]** calculated by a 3D core simulator (in this case, POLCA7) for each assembly at a given operating state-point. The 3D core simulators provide a 3D representation of the core and thus produce a more accurate representation of **[** **]** compared to 1D or 2D methods, therefore, the NRR staff finds this response acceptable.

As validation of the Improved Method B, Supplement 4 provides results comparing BISON to the 3D core simulator POLCA7 and to a series of Peach Bottom 2 Turbine Trip Tests. Figures 3-4 and 3-5 of Supplement 4 compare BISON and POLCA7 axial power profiles while Figures 3-6 through 3-8 compare the axial power profiles predicted by BISON to those measured from the Peach Bottom 2 turbine trip tests. The NRR staff noted that Figure 3-5 was a comparison of axial power profiles for a mixed core representative of an ABWR. As a result, NRR RAI-04 (Ref. 10) requested information to better validate the Improved Method B for BWRs/2-6. In its response, Westinghouse provided an updated axial profile figure representative of a BWR/2-6 mixed core and a comparison of a reactivity change due to a change in recirculation flow. For a **[** **]** change in recirculation flow, the corresponding reactivity change in POLCA7 was **[** **]** and the corresponding BISON reactivity change was **[** **]** The NRR staff finds the magnitudes of the reactivity changes and the level of agreement between the two results to be acceptable.

However, while the updated axial power profile plot demonstrates reasonable agreement between BISON and POLCA7, there are some discrepancies between the results. Figures 3-6 through 3-8 of Supplement 4 also exhibit this behavior; major trends are captured by the BISON results but some discrepancies do exist. NRO RAI 15.00.02-22 (Ref. 13) requested information on how any biases and uncertainties that manifest these discrepancies are considered when utilizing BISON results to determine whether acceptance criteria have been satisfied.

In its response, Westinghouse emphasized that while Figures 3-4 through 3-8 were obtained without any axial power shape fitting procedure (in order to demonstrate the accuracy of the Improved Method B and that an axial power shape fitting procedure is not needed), the uncertainties in the model were quantified by employing one. Westinghouse further clarified this in a subsequent teleconference discussion stating that the axial power shape fitting procedure is used to evaluate biases and uncertainties only, and it is not performed as part of the transient analysis. According to Westinghouse, when the axial power shape fitting process is utilized it ensures that the BISON axial profile matches the one obtained from POLCA7. The process **[ ]** The original mismatch between the power profiles, and thus the uncertainty, is captured by this term. The power profile uncertainty is subsequently carried into the transient simulation by this term, thereby influencing the core reactivity.

To determine the uncertainties in BISON's transient core reactivity, comparisons are then made to the measured Peach Bottom 2 turbine trip tests transient data. **[ ]** The average power range monitor (APRM) responses for the turbine trip transient cases are then calculated. **[ ]** Westinghouse indicates that the adjustments made to **[ ]** This parameter is ultimately included in the uncertainty analysis performed according to the "Fast Transient and ATWS Methodology" (Ref. 14).

Key to this approach is the use of **[ ]** to represent model core reactivity uncertainty. The parameter **[ ]** was described in the original BISON TR RPA 90-90-P-A (Ref. 3) as **[ ]** Hence, this parameter can be tuned to determine a transient **[ ]** As such, it is an indicator of core reactivity, and a change in it to produce a different reactivity response could be used to represent the difference (and thus the uncertainty) between model and measurement data. Because of this, NRR staff finds the approach of using **[ ]** to capture model core reactivity uncertainty to be reasonable.

Because the Improved Method B relies on data from a 3D nodal code such as POLCA7, the question arises of how any biases and uncertainties that exist in the POLCA7 data are accounted for in BISON analyses. NRO RAI 15.00.02-24 (Ref. 13) requested this information with regards to axial power profile and core reactivity. For uncertainties in the axial power profile, Westinghouse stated that if a best estimate approach is chosen, then the **[ ]** For uncertainties in the core reactivity, Westinghouse stated that the uncertainty in core reactivity from POLCA7 is implicitly included in the parameter **[ ]** This is because **[ ]**

Hence, the adjustments made to **[ ]** during comparison to experimental data (as described above in the response to NRO RAI 15.00.02-22) includes core reactivity uncertainties associated with both POLCA7 and those introduced by BISON during the Improved Method B core collapse. The NRR staff finds these responses acceptable.

NRO RAI 15.00.02-21 (Ref. 15) requested information about the improved Method B that demonstrates its validation for the broad range of conditions that it will need to support analyses of first core and limiting transients. Westinghouse responded by supplying comparisons between BISON and POLCA7 of axial power shape and reactivity change from a **[ ]** change in recirculation flow. The ranges of test cases for the BISON to POLCA7 comparisons spanned between **[ ]** Three of the cases presented are based on Peach Bottom turbine trip test data, where the turbine trip test axial power shapes are modeled in POLCA7 before simulating a flow perturbation. For comparisons of axial power shape, the results between the codes show that the average of absolute deviation and standard deviation are consistently within **[ ]** respectively, and show no trends. For comparisons of the reactivity change due to a flow perturbation, the results of the codes also show a consistency with respect to each other; the differences between their magnitudes is less than **[ ]** for all cases save one, which shows BISON under-predicts POLCA7 by **[ ]** This datum appears to be an outlier as another case with similar test conditions produces results within **[ ]** Regardless, the difference of **[ ]** for the single case is still considered acceptable by the NRR staff as this is not generally considered to be a significant difference in reactivity when comparing results such as these. The staff anticipates that there will be some discrepancy between the results produced by a 1D code like BISON and a more complex 3D code like POLCA7. Moreover, the overall results show no trends of increasing disagreement between BISON with its Improved Method B and POLCA7.

Westinghouse's response to NRO RAI 15.00.02-21 also points to results presented in the TR that compare the BISON-predicted APRM responses and the measured APRM responses for the Peach Bottom turbine trip. The results show that BISON consistently **[ ]** the peak APRM response. To better evaluate the predicted results, NRR RAI-05 (Ref. 10) requested quantification of the differences in the peaks. Westinghouse responded with a table that indicated the predicted APRM peaks come within **[ ]** of matching the measured peaks. The APRM comparisons, presented in Figures 3-9 through 3-14 of the TR, also include plots of the time-integrated APRM responses, which can be used as a measure of the energy released in the fuel bundles during the turbine trips. Although BISON **[ ]** Additionally, Westinghouse referenced NRO RAIs 15.00.02-22 and 15.00.02-24, indicating that the **[ ]** Since the conservative nature of the BISON-predicted energy release and because the peak APRM response **[ ]** NRR staff finds the response acceptable.

The NRR staff has concluded that in light of the BISON-predicted and measured APRM results and the comparisons between BISON and the Peach Bottom 2 turbine trip tests axial power profiles, BISON using the Improved Method B can acceptably replicate the turbine trip transients described in the TR. However, a turbine trip transient may not be the limiting transient for all BWRs/2-6. Additionally, Westinghouse provided results that compare BISON to POLCA7, but did not provide BISON results in the TR comparing the Improved Method B to the previously approved Method C to demonstrate its acceptability for the analysis of limiting transients.

In response to discussions with NRR staff on these points, Westinghouse voluntarily submitted additional information and results to satisfy staff concerns (Ref. 16). The additional information submitted provides qualitative justification for the application of the Improved Method B to a wide array of limiting transients by illustrating that while the initiating event may change from case to case (e.g. feedwater controller failure high, load rejection, inadvertent high pressure coolant injection), they all ultimately result in the fast transient response of a turbine trip. Regardless of the initiating event, once the fast transient response of a turbine trip occurs, the physical models within BISON will be exercised is the same fashion as in the Peach Bottom turbine trip transients presented in the TR. For those limiting transients that are slower in nature and do not result in a turbine trip, such as closure of the main steam line isolate valves (MSIVs), the additional information provides quantitative justification through the comparison of BISON results for the Improved Method B and the previously approved Method C. Presented are the APRM and Integrated APRM results for a MSIV closure transient wherein the automatic scram on MSIV position is conservatively assumed not to occur. Both the Improved Method B and the previously approved Method C produced nearly identical results wherein the only differences are slight variations (less than 1%) in the predicted peak APRM and integrated APRM responses. The NRR staff finds the additional information acceptable.

As a result of the BISON-predicted and measured APRM results, the comparisons between BISON and the Peach Bottom 2 turbine trip tests axial power profiles, the illustration of the exercising of BISON's physical models, and the quantitative comparison of the Improved Method B with the previously approved Method C, NRR staff find that BISON using the Improved Method B can acceptably replicate limiting transients. However, while NRR staff finds the approach of using **[ ]** to characterize model core reactivity uncertainty to be reasonable, the manner in which this parameter is ultimately utilized in an uncertainty analysis to determine whether acceptance criteria for safety parameters have been satisfied is discussed in a separate TR that has not yet received NRR approval for BWRs/2-6. For these reasons, the NRR staff has concluded that the previously held regulatory position, that Method C shall be used for limiting transients, should be continued pending approval of WCAP-17203-P/WCAP-17203-NP, "Fast Transient and ATWS Methodology" (Ref. 14), which details the uncertainty analysis methodology. Should WCAP-17203-P/WCAP-17203-NP, receive approval, the NRR staff finds the Improved Method B applicable for limiting and non-limiting transients provided that the transient analysis and the associated uncertainty analysis are performed subject to any limitations and conditions established in the SE for WCAP-17203-P/WCAP-17203-NP.

The NRR staff also finds that BISON Supplement 4, Section 3.2 and the associated RAI responses demonstrate that the Improved Method B calculates the steady-state axial power profile without the need for any power shape fitting procedure with an acceptable accuracy for applicability to non-limiting transients and sensitivity studies. As such, the Improved Method B may be used for analyses as previously allowed for the original Method B.

3.4 Asynchronous Pump Motor Model

The original BISON TR describes a single recirculation flow control model that represents the entire pump. The pump speed may be prescribed by the user or calculated by the model, but because the model is an integrated part of the BISON code, it is not possible to control the model via simulated control systems. In Supplement 4, Westinghouse introduces an asynchronous pump motor model that can respond to signals from a SAFIR control model (Ref. 5), making it possible to have a more general control system for the recirculation flow.

Specifically, the asynchronous pump motor model can receive signals from a frequency converter model generated in SAFIR and then calculate the speed of the pump.

The asynchronous motor model presented in Supplement 4 accepts stator voltage, the frequency of the magnetic field in the stator, and the rotational frequency of the rotor as inputs and converts them at the output to a torque on the pump. As mentioned previously, the inputs may be generated by SAFIR, but they may also be given directly from the user. The output is correlated by considering the moment of inertia of the pump and by accounting for the opposing torques due to water head and friction. The pump motor model as described is constructed to be connected to three phase electrical power, thus mimicking the actual electrical setup in an operating plant, and incorporates a slip factor to describe the asynchronous behavior between the magnetic field in the stator and the angular frequency of the rotor. An asynchronous motor consumes a great deal of reactive power because of its need for magnetization current in the stator, and this is represented in the new pump model by defining the current with both reactive (imaginary) and active (real) components.

The slip factor as originally defined in Supplement 4 (Ref. 1) departed from the familiar definition used by the NRR staff. The response to NRO RAI 15.00.02-25 (Ref. 17) indicated that the definition is a typographical error, and Westinghouse incorporated the correction into Revision 0-1 of the TR (Ref. 2). The updated definition of the slip factor agrees with the definition NRR staff is familiar with, and the staff therefore finds the response acceptable.

Validation of the asynchronous pump model is provided by comparisons between BISON-predicted and measured results for two tests performed at the Hamaoka Unit 5 ABWR. The tests include a recirculation flow change and a closure of all MSIVs.

For the recirculation flow change test, a ±10 percent ramp change to the reactor power setpoint was performed. Because power level in a BWR is adjusted via changes to the total core flow, a power change of -10 percent should cause a corresponding reduction in the speed of the recirculation pumps and the total core flow. The core flow would behave in a reverse manner for a ramp increase in power. Both total core flow rate and reactor water level as calculated by BISON were in excellent agreement with the Hamaoka-5 measurements; all major trends and peaks were captured by the BISON results for a power decrease and a power increase.

The second test demonstrates a closure of all the MSIVs. The MSIVs closure causes a pressure increase in the reactor and initiates a reactor scram in response to the valve position signal inputs to the reactor protection system. Core flow will initially decrease due to runbacks of the recirculation pumps in response to the reactor scram, and water level in the reactor vessel will experience a relatively large drop due to void collapse, which results from the increase in reactor pressure. When comparing the BISON calculated results to the Hamaoka-5 measured results, the expected changes in total core flow due to pump runback and the decrease in water level due to void collapse are both seen. There is excellent agreement between the results with all major trends and peaks captured by the BISON results.

To further explore the adequacy of the asynchronous pump model, NRC staff, via NRO RAI 15.00.02-26 (Ref. 13), inquired if any comparisons between the model and pump manufacturer data or data for pumps with similar motor and performance characteristics have been made. In its response to NRO RAI 15.00.02-26, Westinghouse indicated that no such comparisons are available, but Westinghouse did clarify that the values used to define the

various components of the pump motor model (**[**
]) for the tests presented in Supplement 4 come from pump manufacturer data. Additionally, Westinghouse provided plots comparing the behaviors of the stator frequency, the relative pump speed, and the slip coefficient resulting from a step perturbation to the pump driver setpoint. Examining the plots for the three parameters reveals they respond as expected to a step disturbance; the stator frequency follows the setpoint, the relative pump speed follows the stator frequency with an as-expected slight delay due to the time it takes for the pump to come to the proper speed (a result of the slip and the pump's moment of inertia), and slip peaks occur from the change in the stator magnetic field frequency rapidly differing from the actual rotational speed of the pump. Since these plots demonstrate the behavior of the motor model behavior in response to electrical signals, the NRR staff finds the response acceptable.

Although the tests presented in Supplement 4 represent an ABWR with reactor internal pump (RIPs), the NRR staff finds the new asynchronous pump model acceptable for BWRs/2-6 analyses for the following reasons: 1) At the core of these tests is the demonstration of the model's ability to alter pump rotational speed in response to a change in the pump motor's stator frequency via a control signal and cause a corresponding change in total core flow and water level. The ability to cause a change in recirculation pump speed is not unique to ABWR RIPs. Most BWRs/2-6 utilize recirculation pumps that are controlled by a fluid-coupled motor-generator (M-G) set. In this set, a motor at constant speed drives a generator via a fluid coupler (torque converter), and the speed of the generator, which is connected to the pump motor, is adjusted by adding or removing fluid from the fluid coupling. This will in turn adjust the recirculation pump motor speed and the pump flow. The asynchronous pump model presented in Supplement 4 captures these effects; the frequency converter signal that drives the motor stator frequency is representative of the generator in the M-G set, and the control signal is representative of adjustments made in the fluid coupling. Those BWRs/2-6 that do not have M-G sets utilize recirculation pumps whose speed is adjusted in a manner similar to the ABWR RIPs, 2) Many of the trends seen in the changes of total core flow and water level are similar to those expected in BWRs/2-6, 3) The values used to define the various components of the pump model come directly from manufacturer data. This data is application-specific for both ABWRs and BWRs/2-6, and 4) The response to NRO RAI 15.00.02-26 illustrates the behavior of various pump parameters due to a step perturbation on an electrical and frequency level. This demonstrates the behavior of the pump independent of the application, and the presented results are as expected.

3.5 BISON/SAFIR Interface for Level Measurement Model

In the original BISON code, calculation of the water level in the reactor pressure vessel (RPV) is based on water and steam mass balances in the upper plenum and downcomer. The first cell with water is assumed to contain the two-phase level and the location within the cell is derived from cell height in relation to the calculated steam and water volumes. However, this two-phase water level is not the same level as measured by reactor instrumentation, which utilizes two RPV connections and a pressure differential transmitter. Additionally, the calculation of the two-phase water level does not take into consideration the pressure drop through the steam dryer, and it is therefore expected to be lower than the actual water level. To determine the water level as measured by instrumentation, Supplement 4 introduces a model that simulates the various water level measurements systems found in operating plants, such as narrow range level and wide range level, and accounts for the pressure drop across the steam dryer. Supplement 4 states that determining the water level as measured by the plant instrumentation system is necessary for more flexible non-limiting transient modeling.

The RPV water level measurement model presented in Supplement 4 uses pressure differences from two locations in the RPV to calculate water level, just as the actual measurement instrumentation in an operating plant does. In order to accomplish this, a portion of the RPV water level measurement model is implemented in BISON and the remainder is implemented in SAFIR. Within BISON, two nozzle components are used to generate pressure signals in the RPV. These signals are then sent to SAFIR for use in calculating the measured water level. The nozzle components make it possible to have a user-defined position of evaluating pressure that is not limited to RPV model node limits.

To obtain the pressures at the nozzles, the model performs a linear interpolation of the pressures from the adjacent node limits by using node height and height of the nozzle within the node. As mentioned above, the pressure drop through the steam dryer is not accounted for in the previously approved BISON code, and this causes the initial calculation of the two-phase water level to be lower than expected. Thus, after interpolating the nozzle pressures, the model calculates the corrected two-phase water level due to the pressure drop across the steam dryer. If one of the nozzle locations is located beneath the new water level, the model adjusts the nozzle pressure in response to the higher water level. The pressure drop across the steam dryer is modeled by a simple loss-based pressure drop correlation.

Equation 3-48 in Supplement 4 describes how pressure is adjusted for the nozzle found below the corrected RPV water level and contains a density term that is not adequately defined. NRO RAI 15.00.02-28 (Ref. 17) asked for clarification on this item. In its response, Westinghouse indicated that the density term is a mixture density taking into account both the steam density and the water density. Westinghouse incorporated this clarification into Revision 0-1 of Supplement 4. The NRR staff finds the response acceptable because considering both the steam density and water density within the node where a nozzle resides would be necessary for an accurate pressure calculation.

NRO RAI 15.00.02-31 (Ref. 13) expressed the concern that the linear interpolation performed when determining the nozzle pressures may not be applicable when pressure drops occur due to flow obstructions. Westinghouse responded that of the two nozzles, **[**

] However, Westinghouse conceded that a **[**

] Westinghouse also responded that, due to differences in plant-specific components, the impact of the linear interpolation of pressure for a given nodalization will be evaluated at the first-time application for the specific water level measurement system. The NRR staff finds these responses acceptable on the basis that Westinghouse will be active in investigating the accuracy of the water level measurement system for first-time applications.

As mentioned above, a portion of the water level measurement model is implemented in BISON and the remaining portion is implemented in SAFIR. Validation of the model therefore requires results generated from the two codes working in unison. However, Section 3.4.3 of Supplement 4 defers presentation of validation data, stating that "the SAFIR model is validated for the first-time application in connection with a License Amendment Request by comparing to plant data" and that an example to illustrate the process of validating the model is presented in the SAFIR supplement (Ref. 5). It is unclear if the example referenced utilizes the level measurement model described in Supplement 4 or if it is only to illustrate the process by which validation will occur. Therefore, NRO RAI 15.00.02-30 (Ref. 18) requested validation of the BISON/SAFIR level measurement model by comparing its performance to experimental data. In its response, Westinghouse stated that the BISON/SAFIR interface is qualified by comparing its performance against integral plant measurement data from the Hamaoka-5 startup tests. Westinghouse further clarified that the water level measurement system algorithm will be implemented in the SAFIR code on a plant-specific basis and in accordance with procedures described in WCAP-17079-P-A, Revision 0, "Supplement 3 to BISON Topical Report RPA 90-90-P-A, SAFIR Control System Simulator" (Ref. 5), and that the plant-specific implementation will be submitted for NRC review and approval as part of a licensee submittal.

Based on a quantitative assessment of the equations being used to model nozzle pressures in BISON and the responses provided to NRO RAI 15.00.02-30, the NRR staff finds the BISON/SAFIR interface for RPV water level measurement model acceptable for BWRs/2-6 analyses provided that the BISON/SAFIR water level measurement system model is validated for the first-time application in connection with a License Amendment Request by comparing to plant-specific data.

3.6 Steam Dome Water Surface Condensation Model

In the current approved BISON TR, there are models that describe the condensation in liquid due to changes in pressure and temperature or when subcooled water interacts with the steam environment. However, steam condensation on the surface of the bulk water was not considered. This model is intended to take into account the steam condensation on the surface of the bulk water in order to obtain better steam dome pressure and water level calculations at times long after scram.

During the initial review of Revision 0 of Supplement 4, request for approval of this model was withdrawn by Westinghouse in response to NRO supplemental RAIs 15.00.02-32, 34, 35, and 38 (Ref. 19). According to Westinghouse, since steam condensation on the bulk water surface is a phenomenon noticeable in the long-term, this model will not have any effect on the results of fast pressurization transients. The NRR staff agreed with this explanation. Additionally, Westinghouse stated that the model provides very minor benefits and only in long term results. Since the model's withdrawal, Westinghouse revised Appendix A in Revision 0-1 of Supplement 4 to present results without the steam dome water surface condensation model (this impacts Figures 3, 4, 7, and 8).

3.7 Post Dryout Heat Transfer Correlation and Rewet Model

The currently approved BISON TR includes a method for calculating PCT. This method uses a combination of the Bromley and Groeneveld heat transfer correlations for determining the fully-developed post-dryout heat transfer coefficient. The Bromley correlation is used to determine the heat transfer for low mass-flow in the stable vapor-film boiling regime (specifically, inverted annular flow) while the Groeneveld correlation is used for the high pressure (P > 23.8 bar / 350 psia), liquid deficient dispersed flow regime. The transition boiling regime that exists between the dryout point and the Leidenfrost point, in which partial vapor film boiling occurs, is not currently modeled. To improve upon this method, Supplement 4 presents an updated post-dryout heat transfer correlation that models the transition boiling regime. A rewetting/quench model, which describes how a rod is “recoated” with water when exiting the post-dryout heat transfer regime, is also presented.

According to Supplement 4, the BISON model for determining cladding temperature consists of three parts: determination of time for dryout and rewet, determination of the heat transfer between the cladding and the coolant in the post dryout regime, and determination of the rewetting velocity. The first of these is fuel type dependent and uses the applicable NRC-approved CPR correlation for the given fuel type when determining the times to dryout and rewet. The CPR correlation is not addressed in Supplement 4 because it is approved during the licensing process for a new fuel type. The remaining two parts for determining cladding temperature are discussed separately within Supplement 4 and are addressed below.

3.7.1 Post Dryout Heat Transfer Correlation

Supplement 4 presents a heat transfer correlation referred to as “the modified Groeneveld heat transfer correlation.” The purpose of this correlation is to determine the heat transfer coefficient between the fuel rod cladding and the coolant in the post-dryout regime, which is comprised of the transition boiling (partial vapor film boiling), fully-developed vapor film boiling, and dispersed flow regimes. This is accomplished by summing the contributions from multiple heat transfer correlations that describe the various heat transfer phenomena present across the multiple regimes. These include the general radiation heat transfer correlation, the Bromley and Groeneveld heat transfer correlations, and the Dittus-Boelter correlation. The NRR staff made observations concerning each of these terms. These observations were captured in NRO RAI 15.00.02-39 (Ref. 13). To facilitate discussion, each correlation and Westinghouse’s responses to NRC staff observations shall be discussed in turn.

The general radiation heat transfer coefficient accounts for radiative heat transfer. As presented in Supplement 4, it is the same in form as that found within the literature and in previous NRC-approved methodologies (Ref. 20). However, the term’s contribution to overall heat transfer is summed with that of the Groeneveld heat transfer correlation, which already implicitly accounts for radiative heat transfer in addition to convection. This could potentially lead to a non-conservative estimation of the total heat transfer coefficient for the regime in which the Groeneveld correlation is used. Westinghouse responded to this concern in NRO RAI 15.00.02-39 stating that **[**

] This necessitated determining the term’s overall influence on the total heat transfer coefficient. It was found that the relative contribution to the overall heat transfer coefficient due to the explicit radiation term is small, less than 2 percent; **[**

] The NRR staff finds this response acceptable because the contribution of radiation heat transfer does not have a significant impact on the predicted PCT.

The Bromley and Groeneveld heat transfer correlations account for heat transfer from the fuel rod cladding to the steam in the fully-developed vapor film boiling and dispersed flow regimes, respectively. These regimes exist in the fully-developed post-dryout conditions at fuel cladding superheat temperatures higher than the Leidenfrost point. As presented in Supplement 4, the correlations are the same in form as that found within the literature and in previous

NRC-approved methodologies (Ref. 20). However, [ ] This seems to be non-conservative for the calculation of PCT since [ ] In response to this concern as raised in NRO RAI 15.00.02-39, Westighouse indicated that [ ] The NRR staff finds this response acceptable because it ensures the correlations are being correctly applied in the proper flow regimes.

As presented in Supplement 4, the Dittus-Boelter heat transfer correlation is being utilized in the overall heat transfer correlation to model the transition boiling regime, and it accounts for the heat transfer contribution from the fuel rod cladding to the water droplets found in the partial film flow. The correlation is written in the form for fluid flow and is the same as that found within the literature and in previous NRC-approved methodologies (Ref. 20). Within the overall heat transfer correlation, the Dittus-Boelter correlation [ ] However, the Dittus-Boelter correlation was developed for single-phase fully developed turbulent flow in a smooth circular tube, and transition boiling is characterized by intermittent rewetting of the heated surface by liquid. Additionally, the Reynold's number used assumes full liquid phase is flowing, which does not reflect the conditions during partial film boiling. This raises the question of whether it is appropriate to use this correlation in the transition boiling regime. In providing justification for use of the correlation, Westinghouse responded to NRO RAI 15.00.02-39 by saying that directly following the occurrence of dryout, broken liquid film with substantial entrainment and deposition still exists, making the assumption of fully developed post-dryout conditions unjustified, and [ ] NRR staff recognizes this is a highly empirical approach to modeling heat transfer in the transition boiling regime. With this in mind, NRR staff finds Westinghouse's response acceptable because it indicates an attempt to model real phenomena with a conservative approach and because the correlation is ultimately compared to experimental data as discussed below.

3.7.2 Rewet Model

Rewetting of the fuel rod cladding is a process that occurs when the temperature difference between the fuel rod cladding and the saturation temperature of the coolant is reduced sufficiently enough that a stable liquid film can once again coat the fuel rod. This “return” from the post-dryout heat transfer regime is characterized by a quench front that moves along the length of the fuel rod. The rewet model presented in Supplement 4 is an empirically derived correlation using experimental data obtained from the **[** **]** The correlation describes the quench front’s **[** **]** Though comprised of several different curves, the overall correlation produces a continuous response spanning the anticipated range of cladding wall superheat. The exact nature of how the correlation was used and the conditions under which the fuel rod was considered to be fully rewetted was unclear in the TR. Clarification was provided in Westinghouse’s response to NRR RAI-10 (Ref. 10), which states that when the **[** **]** The NRR staff finds this response acceptable because it simulates the realistic progression of the rewetting phenomenon.

3.7.3 Validation of the Post-Dryout Heat Transfer Correlation and Rewet Model

Validation for the rewet model is supplied by comparison of predicted results to experimental data in Figure 3-21. There is a large amount of scatter in the experimental results and some of the data points have large uncertainties. **[** **]** Overall, the model moderately approximates the trends seen in the experimental data, and it produces non-conservative results for nearly half of the tested conditions. However, Figure 3-21 also shows predictions using a conservative multiplier of **[** **]** and these results bound all the experimental data points and the vast majority of the range of uncertainty. Westinghouse’s response to NRO RAI 15.00.02-40 (Ref. 13) provides an explanation for the conservative multiplier stating that it was specifically included to account for the uncertainties in the model and to ensure a conservative result. Westinghouse also stated that the multiplier will be used in applications of the rewet model. The NRR staff finds these responses acceptable because of the conservative approach.

Validation for the modified Groeneveld heat transfer correlation is provided by comparisons of predicted versus measured PCT increases using data obtained from the **[** **]** for two different fuel types: **[** **]** Figure 3-22 of Supplement 4 shows the results for the first of these two fuel types. There is a large amount of scatter in the data with nearly equal amounts of over prediction and under prediction, especially when compared to the results from the second fuel type presented in Figures 3-24 through 3-26. Supplement 4 does not discuss the nature of this scatter, and this concern was raised in NRO RAI 15.00.02-41 (Ref. 21). Westinghouse’s response indicated that the scatter is due to the **[** **]** when calculating PCT increases. According to Westinghouse, both of the fuel types underwent the same dryout testing procedures in the same experimental facility. The only real differences between the experiments were [ ] The NRR staff notes that as of the writing of this SE, only the first of the two fuel types and its [ ] have received NRC approval; the [ ] have not. The review of these is beyond the scope of this SE. Therefore, the NRR staff performed its review of the heat transfer correlation and rewet model under the assumption that if the [ ] receive NRC approval, the validation data will remain as presented in Supplement 4.

While NRR staff finds that Westinghouse's response to NRO RAI 15.00.02-41 adequately explains why there is significantly more scatter observed in data for the first fuel type versus the second, it does not address how this scatter will be considered when performing PCT calculations. However, Figure 3-23 in Supplement 4 presents additional supporting data for the first fuel type using a conservative method for PCT calculation, and indeed the majority of the data presented is conservatively predicted. This suggests a conservative methodology was developed to account for the scatter seen in Figure 3-22, but no description is provided in Supplement 4 detailing the methodology or the manner in which it would be applied. Westinghouse's response to NRO RAI 15.00.02-42 (Ref. 15) addresses this concern. The response indicates that two methodologies exist for determining the PCT, a conservative methodology and an unbiased methodology. How a methodology is chosen depends on processes described in WCAP-17203 (Ref. 14). When utilizing the conservative methodology (Figure 3-23), the overall heat transfer coefficient calculated by the modified Groeneveld heat transfer correlation is multiplied by a factor of [ ] and the rewet model uses the aforementioned (see above) conservative multiplier of [ ] According to the response, these multipliers are both employed to conservatively bound their respective correlation's uncertainty, thus conservatively biasing the PCT results. In the unbiased methodology (Figure 3-22), these multipliers are not strictly applied. Instead, the uncertainties in the modified Groeneveld heat transfer correlation and the rewet model are accounted for in the overall uncertainty evaluation described in WCAP-17203-P/WCAP-17203-NP. [ ] Additionally, the conditions under which the modified Groeneveld heat transfer correlation is used differs between the methodologies. [ ] NRR staff finds these responses acceptable because they illustrate how the uncertainty in the correlations is captured, either by applying a bounding conservative bias or incorporating the uncertainties into an overall uncertainty analysis.

It should be noted that the results presented for both fuel types were generated with the inclusion of the rewet model discussed in Section 3.7.2. Consequently, there was concern over the potential of compensating errors/uncertainties between the heat transfer correlation and the rewet model affecting predictions of the PCT. Westinghouse addressed this in its response to NRO RAI 15.00.02-41S01 (Ref. 19), which stated that a sensitivity study was performed to determine the contribution from each model to the scatter observed in Figure 3-22. **[** **]** The results show that while the rewet model influenced the average bias, its effect on the standard deviation, which is a measure of the scatter in the predictions, was small. Compared to the data presented in Figure 3-22, the standard deviation changed **[** **]** Likewise, the influence on the standard deviation due to the heat transfer correlation was also small, changing within **[** **]** Based on these results, Westinghouse reaffirms that the scatter observed in Figure 3-22 is primarily due to **[** **]** The NRR staff finds this response acceptable because the changes in standard deviation during the sensitivity study were minimal.

The NRR staff has considered the information presented in Supplement 4 and in the RAI responses for the post-dryout heat transfer correlation and the rewet model. While both the heat transfer correlation and the rewet model are highly empirical in nature, they are based on existing data and correlations, and the NRR staff finds they are reasonably supported by the predicted versus measured data peak cladding temperature results. The RAI responses demonstrate the primary source of scatter for the heat transfer correlation and how two methodologies exist to account for it during calculation of the PCT, a conservative biased methdology and an unbiased methodology. However, the uncertainty analysis used in the unbiased methodology of PCT calculation is described in WCAP-17203-P/WCAP-17203-NP, which has not yet received NRC approval. Because of this, the NRR staff finds the modified Groeneveld heat transfer correlation and the rewet model, as presented in Supplement 4 and explained in responses to RAIs, acceptable for application to BWR/2-6 analyses provided they are applied using the conservative methodology. Should WCAP-17203-P/WCAP-17203-NP, receive approval, the NRR staff finds the unbiased methodology applicable to BWR/2-6 analyses provided the analyses and the associated uncertainty analyses are performed subject to any limitations and conditions established in the associated SE. The application of either methodology may only be used in conjunction with the two fuel types for which data has been presented in Supplement 4, **[** **]** In the case of the second fuel type, which has not received NRC approval at the time of writing this SE, the application of either methodology may only be used if the **[** **]** receive NRC approval and only if the associated PCT increases validation data remains as presented in Supplement 4. If the validation data changes, updated results must be supplied to the NRC for review. When using other than these two fuel designs, justification is required for the conservative methodology's bounding multiplier and the unbiased methodology's range of multipliers.

4.0 CONDITIONS AND LIMITATIONS

As discussed previously in this report, conditions and limitations have been applied to BISON and its supplements. In some cases, conditions and limitations established in a prior supplement have been repealed or modified by a later supplement, and in other cases, their wording and meaning has evolved over time. For purposes of clarity, the following table (Table 4.1) demonstrates the relationships that exist between previous conditions and limitations and the comprehensive list provided herein for BWRs/2-6. Any conditions and limitations applicable to ABWRs will be addressed by NRO in a separate SE.

Table 4-1: BISON EM Conditions and Limitations for BWRs/2-6 Applied by Series of SEs

RPA 90-90-P-A	Supplement 1	Supplement 2	Supplement 3	Supplement 4
(1) We require justification of the core flow when an unbalance from either recirculation loop can cause a thermal-hydraulic gradient across the core.	Removed			
(2) We require justification for use of the recirculation pump model when transients are in other than the first quadrants of the Karman-Knapp diagram.	Applicability retained	Applicability retained	Applicability retained	(2) Applicability retained
(3) We require justification for use of the recirculation pump model when two-phase flow conditions are calculated.	Applicability retained	Applicability retained	Applicability retained	(3) Applicability retained
(4) We require justification of the slip and void correlation used if the core pressure exceeds 1305 psia while the quality exceeds 40 percent or if the pressure exceeds 1450 psia.	Applicability retained	For reactor dome pressures less than 10 MPa, there are no limitations on the use of the AA78 correlation, as this correlation has been approved by the NRC staff previously. For pressures higher than 10 MPa during an ATWS event, if the quality exceeds the upper limit identified in TR WCAP-16606-P, Revision 0, then use of the TR is not approved.	Applicability retained	(4) Applicability retained

Table 4-1: BISON EM Conditions and Limitations for BWRs/2-6 Applied by Series of SEs (Continued)

RPA 90-90-P-A	Supplement 1	Supplement 2	Supplement 3	Supplement 4
(5) We require justification of the isentropic coefficient used during a depressurization event.	(1) With use of the PARA steamline model, the user has flexibility of modeling valves and control system functions through the use of user supplied table and control systems. Modeling of these systems greatly affects the amount of conservatism in the transient outcome in certain event analysis. Therefore, as required in the original SE for BISON, it is recommended that ABB/CE be required to provide justification for these user controlled items, which include valve performance, to assure conservatism in licensing applications.	Applicability retained	Applicability retained	Applicability retained However, SAFIR is now used in conjunction with BISON. Therefore, this condition is not directly applicable when BWRs use the SAFIR control system.
(6) We require a staff-approved model when modeling is necessary to simulate control systems	Applicability retained	Applicability retained	(2) SAFIR shall model control systems consistent with the provisions of CENPD- 300-P-A.	Applicability retained However, SAFIR is now used in conjunction with BISON and is a staff-approved model for control systems. Therefore, this condition is not directly applicable.

Table 4-1: BISON EM Conditions and Limitations for BWRs/2-6 Applied by Series of SEs (Continued)

RPA 90-90-P-A	Supplement 1	Supplement 2	Supplement 3	Supplement 4
	(2) The modeling changes or upgrades did not affect the basic modeling of the recirculation pump model. Therefore, the SE condition regarding the pump model remains unchanged. Similarly, the other SE conditions with respect to the simulation of the control system and the use of the slip and void correlation in the range of applicability are not affected by this submittal, and therefore remain unchanged.	Applicability retained	Applicability retained	Applicability retained However, SAFIR is now used in conjunction with BISON. Therefore, this condition is not applicable to BWRs when the SAFIR control system is used.
	(3) The use of the EPRI void model for licensing analysis must be demonstrated to be used within its range of applicability for each such application.	Applicability retained	Applicability retained	(7) Applicability retained
	(4) ABB stated that the turbine assembly model will not be used thus the model was not qualified in this report. The use of the turbine assembly model is restricted until qualified.	Applicability retained	Applicability retained	Applicability retained

Table 4-1: BISON EM Conditions and Limitations for BWRs/2-6 Applied by Series of SEs (Continued)

RPA 90-90-P-A	Supplement 1	Supplement 2	Supplement 3	Supplement 4
			(1) Approval of SAFIR is limited to use in combination with NRC-approved BISON. BISON is the transient code interacting with SAFIR, but other dynamic BWR codes may be used as described in other licensing topical reports and subject to NRC approval on a code- by-code basis.	Applicability retained However, because Supplement 4 primarily addresses BISON, this condition is not applicable.
(The following condition was stated in the SE, but not listed in the summary) Of the three cross section collapsing methods described, Method C is the preferred and accepted methodology to be used in the final licensing analyses of limiting transients. The two remaining methods, Methods A and B, were found to be acceptable for sensitivity studies and non-limiting transients.	Applicability retained	Applicability retained	Applicability retained	(8) Only cross-section collapsing Method C is approved for limiting transients pending approval of WCAP-17203-P/ WCAP-17203-NP, whereupon Improved Method B may be used for limiting transients provided the analyses are performed according to the SE for WCAP-17203-P/ WCAP-17203-NP.

Table 4-1: BISON EM Conditions and Limitations for BWRs/2-6 Applied by Series of SEs (Continued)

RPA 90-90-P-A	Supplement 1	Supplement 2	Supplement 3	Supplement 4
				(9) The BISON/SAFIR water level measurement system model shall be validated for first-time application in connection with a License Amendment Request by comparing to plant-specific data.
				(10) Justification is required for the multipliers or range of multipliers used in the revised post-dryout heat transfer and rewet models for fuel designs other than those discussed in Supplement 4. (11) Only the conservative methodology for calculation of PCT increases may be used pending approval of WCAP-17203-P/WCAP-17203-NP, whereupon the unbiased methodology may be used provided analyses are performed according to the SE for WCAP-17203-P/WCAP-17203-NP. (12) Neither methodology for calculation of PCT increases may be used with the **[ ]** fuel until it **[ ]** receive NRC approval and only if the validation data remains unchanged.

4.1 Conditions and Limitations Applicable to Supplement 4

The summary of all conditions and limitations applicable to BISON BWR/2-6 analyses are restated below. Captions in italics indicate the source. The numbering scheme uses the BISON RPA 90-90-P-A condition numbers (1-6) that are still applicable (2-4) supplemented by those that need to be brought forward by Supplements 1, 2, and 3 and this report for Supplement 4 (7–11):

2) Justification is required for use of the recirculation pump model when transients are in a quadrant other than the first quadrant of the Karman-Knapp diagram. *(This is Condition 2 of the SE for the original BISON TR, RPA 90-90-P-A. It remains applicable to BWRs/2-6).*

3) Justification is required for use of the recirculation pump model when two-phase flow conditions are calculated. *(This is Condition 3 of the SE for the original BISON TR, RPA 90-90-P-A. It remains applicable to BWRs/2-6).*

4) Justification of the slip and void correlation used if the core pressure exceeds 1305 psia while the quality exceeds 40 percent or if the pressure exceeds 1450 psia. *(This is a condition from the SE for RPA 90-90-P-A and updated by Supplement 2 that continues to be applicable to BWRs/2-6).*

7) The use of the EPRI void model for licensing analysis must be demonstrated to be used within its range of applicability for each such application. *(This is Condition 3 of the SE for Supplement 1 to the original BISON TR. It remains applicable to BWRs/2-6).*

8) Of the three cross section collapsing methods described, Method C is the preferred and accepted methodology to be used in the final licensing analyses of limiting transients. The two remaining methods, Methods A and B, are found to be acceptable for sensitivity studies and non-limiting transients. *(This is a clarification to the conditions and limitations stated in the original BISON SE, RPA 90-90-P-A. This condition is stated in the SE, but was omitted from the list of conditions and limitations).*

   The use of Method C for limiting transients shall continue pending approval of WCAP-17203-P/WCAP-17203-NP. Should WCAP-17203-P/WCAP-17203-NP, receive approval, Improved Method B as presented in Supplement 4 is found applicable for limiting transients provided that the transient analysis and the associated uncertainty analysis are performed subject to any conditions and limitations established in the SE for WCAP-17203-P/WCAP-17203-NP. *(This is a modification to the condition from the SE from BISON RPA 90-90-P-A and is a new condition from this report).*

9) The BISON/SAFIR water level measurement system model shall be validated for first-time application in connection with a License Amendment Request by comparing to plant-specific data. *(This is a new condition from this report).*

10) Use of the modified Groeneveld heat transfer correlation and rewet model's conservative and unbiased analysis methodologies for fuels other than those for which data has been presented in Supplement 4, **[ ]** require justification for the conservative methodology's bounding multiplier and the unbiased methodology's range of multipliers. *(This is a new condition from this report).*

11) Only the conservative methodology for calculation of PCT increases is found applicable to BWR/2-6 analyses pending approval of WCAP-17203-P/WCAP-17203-NP. Should WCAP-17203-P/WCAP-17203-NP receive approval, the unbiased methodology for calculation of PCT is found applicable to BWR/2-6 analyses provided the analyses and the associated uncertainty analyses are performed subject to any conditions and limitations established in the associated SE. *(This is a new condition from this report).*

12) Neither the conservative nor the unbiased methodology for calculation of PCT increases may be used in conjunction with the **[** **]** fuel until it **[** **]** receive NRC approval and only if the associated PCT increases validation data remains as presented in Supplement 4. If the validation data changes, updated results must be supplied to the NRC for review. *(This is a new condition from this report).*

5.0 CONCLUSIONS

In Supplement 4, Westinghouse presented new models and methods to extend the applicability of BISON for evaluation of limiting and non-limiting transients including those required for a first core analysis of BWRs/2-6. The extension of BISON also included its application to ABWR analyses. This SE addresses the application of the TR only to BWRs/2-6. NRO is to address applicability of the TR to ABWRs in a separate SE. The following conclusions are provided here in summary as they apply to BWR/2-6 submittals.

Recirculation Pump Model Restriction:

The new recirculation pump model is intended for internal recirculation pumps found in ABWR applications only. Westinghouse has indicated that it is not seeking approval of the new recirculation pump model for BWR/2-6. As such, the adequacy and acceptability of the new model is outside the scope of this SE. Therefore, the NRR staff finds that Condition 2 of the SE for the original BISON TR remains in effect for BWR/2-6 applications (see Section 3.1).

Advanced Control Rod Hydraulic Insertion Model:

The advanced control rod hydraulic insertion model is intended for ABWR applications only. As such, its adequacy and acceptability is outside the scope of this SE. Therefore, the NRR staff finds that the user-supplied input table of control rod position versus time method to simulating a reactor scram should continue to be employed for U.S. reactor licensing applications of BWRs/2-6 (see Section 3.2).

Improved Method for Cross Section Collapsing:

The NRR staff finds that the Improved Method B for cross section collapsing calculates the steady-state axial power profile without the need for any power shape fitting procedure with an acceptable accuracy for applicability to non-limiting transients and sensitivity studies. As such, the Improved Method B may be used for analyses as previously allowed for the original Method B. However, the previously held regulatory position, that Method C shall be used for limiting transients, should be continued pending approval of WCAP-17203-P/WCAP-17203-NP. Should WCAP-17203-P/WCAP-17203-NP receive approval, the NRR staff finds the Improved Method B applicable for limiting transients provided that the transient analysis and the associated uncertainty analysis are performed subject to any limitations and conditions established in the SE for WCAP-17203-P/WCAP-17203-NP (see Section 3.3).

Asynchronous Pump Motor Model:

The NRR staff finds the new asynchronous pump motor model as presented in Supplement 4 and explained in the responses to the RAIs acceptable for BWR/2-6 analyses with no conditions or limitations (see Section 3.4).

BISON/SAFIR Interface for Level Measurements:

The NRR staff finds the BISON/SAFIR Interface for RPV water level measurement model acceptable for BWR/2-6 analyses provided that the BISON/SAFIR water level measurement system model is validated for the first-time application in connection with a License Amendment Request by comparing to plant-specific data (see Section 3.5).

Steam Dome Water Surface Condensation Model:

During the review of Supplement 4, request for approval of this model was withdrawn by Westinghouse in response to NRO supplemental RAIs 15.00.02-32, 34, 35, and 38 (Ref. 18). Westinghouse stated that the text and test results in Supplement 4 regarding this model will be removed (see Section 3.6).

Post-Dryout and Rewet Model:

The NRR staff finds the modified Groeneveld heat transfer correlation and the rewet model, as presented in Supplement 4 and explained in responses to RAIs, acceptable for application to BWR/2-6 analyses provided they are applied using the conservative methodology for calculation of PCT. Should WCAP-17203-P/WCAP-17203-NP, receive approval, the NRR staff finds the unbiased methodology for calculation of PCT applicable to BWR/2-6 analyses provided the analyses and the associated uncertainty analyses are performed subject to any limitations and conditions established in the associated SE. The application of either methodology may only be used in conjunction with the two fuel types for which data has been presented in Supplement 4, **[** **]** When using other fuel designs, justification is required for the conservative methodology's bounding multiplier and the unbiased methodology's range of multipliers (see Section 3.7).

6.0 REFERENCES

1. WCAP-17202-P/WCAP-17202-NP, Revision 0, “Supplement 4 to BISON Topical Report RPA 90-90-P-A,” June 2010 (ADAMS Package Accession No. ML101830265).
2. WCAP-17202-P/WCAP-17202-NP, Revision 0-1, “Supplement 4 to BISON Topical Report RPA 90-90-P-A,” September 2014 (ADAMS Package Accession No. ML14276A445).
3. RPA 90-90-P-A, “BISON-One Dimensional Dynamic Analysis Code for Boiling Water Reactors,” (Proprietary), December 1991.
4. CENPD-390-P-A, Revision 0, “The Advanced PHOENIX and POLCA Codes for Nuclear Design of Boiling Water Reactors,” December 2000 (ADAMS Accession No. ML003676050).
5. WCAP-17079-P-A, Revision 0, “Supplement 3 to BISON Topical Report RPA 90-90-P-A, SAFIR Control System Simulator,” February 2013 (ADAMS Accession No. ML14052A084).
6. CENPD-292-P-A, “BISON – One Dimensional Dynamic Analysis Code for Boiling Water Reactors: Supplement 1 to Code Description and Qualification,” (Proprietary), July 1996.
7. WCAP-16606-P-A, Revision 0, “Supplement 2 to BISON Topical Report RPA 90-90-P-A,” January 2008 (ADAMS Accession No. ML081280714).
8. CENPD-300-P-A, Revision 0, “Reference Safety Report for Boiling Water Reactor Reload Fuel,” July 1996 (ADAMS Accession No. ML110260388).
9. NUREG-0800, “Standard Review Plan (SRP) for the Review of Safety Analysis Reports: LWR Edition,” March 2007 (ADAMS Accession No. ML070810350).
10. Letter, U7-C-NINA-NRC-120070, “South Texas Project, Units 3 and 4, Response to Request for Additional Information re: Topical Report WCAP 17202-P, ‘Supplement 4 to BISON Topical Report 90-90-A’,” (Proprietary), Docket No. PROJ0772, November 2012.
11. Letter, U7-C-NINA-NRC-130006, “South Texas Project, Units 3 and 4, Attachments 1 and 2, Response to Request for Additional Information on NRR RAI-02 and NRR RAI-07,” (Proprietary), Docket No. PROJ0772, January 2013.
12. Letter, U7-C-NINA-NRC-120070, “South Texas Project, Units 3 and 4, Response to Request for Additional Information,” Topical Report WCAP 17202-P, ‘Supplement 4 to BISON Topical Report 90-90-A’,” (Proprietary), Docket No. PROJ0772, November 2012.
13. Letter, U7-C-NINA-NRC-110128, “South Texas Project, Units 3 and 4, Responses to Request for Additional Information,” Topical Report WCAP-17202-P, ‘Supplement 4 to BISON Topical Report RPA 90-90-P-A’,” (Proprietary), October 2011.
14. WCAP-17203-P/ WCAP-17203-NP, Revision 0-2, “Fast Transient and ATWS Methodology,” (ADAMS Accession No. ML14301A279), October 2014.
15. Letter, U7-C-NINA-NRC-110094, “South Texas Project, Units 3 and 4, Responses to Request for Additional Information” Topical Report WCAP-17202-P, ‘Supplement 4 to BISON Topical Report RPA 90-90-P-A’,” (Proprietary), July 2011.
16. Westinghouse Comments Regarding Draft NRC Safety Evaluation (by NRR) for WCAP-17202-P/WCAP-17202-NP, Revision 0, “Supplement 4 to BISON Topical Report RPA 90-90-P-A’,” (Proprietary), June 2016.
17. Letter, U7-C-NINA-NRC-110080, “South Texas Project, Units 3 and 4, Responses to Request for Additional Information,” Topical Report WCAP-17202-P, ‘Supplement 4 to BISON Topical Report RPA 90-90-P-A’,” June 2011 (ADAMS Accession No. ML11173A190).
18. Letter, U7-C-NINA-NRC-110094, “South Texas Project, Units 3 and 4, Responses to Request for Additional Information,” Topical Report WCAP-17202-P, ‘Supplement 4 to BISON Topical Report RPA 90-90-P-A’,” (Proprietary), July 2011.

19. Letter, U7-C-NINA-NRC-130056, “South Texas Project Units 3 and 4, Responses to Request for Additional Information, ‘Supplement 4 to BISON Topical Report RPA 90-90-P-A’,” (Proprietary), October 2013.
20. WCAP-11284-P-A/RPB 90-93-P-A, Revision 0, “Westinghouse Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Description and Qualification,” (Proprietary), October 30, 1989.
21. Letter, U7-C-NINA-NRC-110080, “South Texas Project, Units 3 and 4, Responses to Request for Additional Information, Topical Report WCAP-17202-P, ‘Supplement 4 to BISON Topical Report RPA 90-90-P-A’,” (Proprietary), June 2011.

Attachment: Resolution of Comments

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