Westinghouse Non-Proprietary Class 3

WCAP-16078-NP-A

November 2004

Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel

Westinghouse

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WCAP-16078-NP-A

Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel

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U.S. BWR Reload Analysis

November 2004

Approved: Official record electronically approved in EDMS
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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

October 15, 2004

Mr. James A. Gresham, Manager
Regulatory and Licensing Engineering
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: FINAL SAFETY EVALUATION FOR TOPICAL REPORT WCAP-16078-P, "WESTINGHOUSE BWR ECCS EVALUATION MODEL: SUPPLEMENT 3 TO CODE DESCRIPTION, QUALIFICATION AND APPLICATION TO SVEA-96 OPTIMA2 FUEL" (TAC NO. MB8908)

Dear Mr. Gresham:

On April 30, 2003, Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16078-P, "Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel," to the staff for review. On September 13, 2004, an NRC draft safety evaluation (SE) regarding our approval of the TR was provided for your review and comments. By letter dated September 23, 2004, Westinghouse commented on the draft SE. The staff's disposition of Westinghouse's comments on the draft SE are discussed in the attachment to the final SE enclosed with this letter. The proprietary information contained in the proprietary SE is indicated in bold type.

The staff has found that WCAP-16078-P is acceptable for referencing in licensing applications for boiling water reactors to the extent specified and under the limitations delineated in the TR and in the enclosed SE. The SE defines the basis for acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that Westinghouse publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed SE between the title page and the abstract. They must be well indexed such that information is readily located. Also, they must contain historical review information, such as questions and accepted responses, draft SE comments, and original TR pages that were replaced. The accepted versions shall include a "-A" (designating accepted) following the TR identification symbol.

Enclosure 1 transmitted herewith contains sensitive unclassified information. When separated from Enclosure 1, this document is decontrolled.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, Westinghouse and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 700

Enclosures: 1. Proprietary Safety Evaluation
2. Non-proprietary Safety Evaluation

cc w/encl 2:
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UNITED STATES
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WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-16078-P, "WESTINGHOUSE BWR ECCS EVALUATION

MODEL: SUPPLEMENT 3 TO CODE DESCRIPTION, QUALIFICATION AND

APPLICATION TO SVEA-96 OPTIMA2 FUEL"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION

By letter dated April 30, 2003 (Reference 1), Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16078-P, "Westinghouse BWR ECCS Evaluation Model: Supplement 3 To Code Description, Qualification and Application to SVEA-96 OPTIMA2 Fuel," to the staff for review. By letters dated June 30 (Reference 2) and December 12, 2003 (Reference 3), April 22 (Reference 4), May 28 (Reference 5), June 23 (Reference 6), and August 28, 2004 (Reference 7), Westinghouse responded to the staff's requests for additional information (RAIs). The objective of this TR is to introduce the modified counter-current flow limit correlation, a fuel rod plenum model that is applicable to part-length fuel rods, the applicable features of the improved STAV7.2 fuel performance model and the basis of applying this version of the model to the SVEA-96 Optima2 fuel design.

WCAP-16078-P describes changes to the Westinghouse emergency core cooling system (ECCS) evaluation model (EM) for boiling water reactors (BWRs). This version of the EM is identified as USA5. The differences between the USA5 and the previously approved USA4 version are:

- A change to the counter-current flow limit (CCFL) correlation to apply a conservative bias such that it bounds all the scatter in the correlation database,
- Addition of a fuel rod plenum model applicable to part-length fuel rods,
- Incorporation of the applicable features of the improved STAV7.2 fuel performance model, and
- Provides the analytical basis for applying USA5 to the SVEA-96 Optima2 fuel design.

The original Westinghouse ECCS EM (Reference 8) and version USA4 (Reference 9) were previously submitted, reviewed, and approved by the staff. This safety evaluation documents the staff's review of the modifications to the GOBLIN/CHACHA-3D series of codes supplementing the approved methods described and qualified in Reference 8. In addition, the staff reviewed the application of this methodology to the mixed core reload analysis. The staff's evaluation of these changes and the mixed core application methodology is discussed below.

2.0 REGULATORY EVALUATION

10 CFR 50.46

A loss-of-coolant accident (LOCA), as defined in Title 10 of the *Code of Federal Regulations*, Section 50.46 (10 CFR 50.46), "Acceptance criteria for emergency core cooling systems for light-water nuclear reactors," is a postulated accident to determine the design acceptance criteria for a plant's ECCS. There are five specific design acceptance criteria for the plant defined in 10 CFR 50.46:

- Peak Cladding Temperature - "The calculated maximum fuel element cladding temperature shall not exceed 2200°F."
- Maximum Cladding Oxidation - "The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation."
- Maximum Hydrogen Generation - "The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react."
- Coolable Geometry - "Calculated changes in core geometry shall be such that the core remains amenable to cooling."
- Long-term Cooling - "After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core."

10 CFR Part 50, Appendix K

Section A.1 of 10 CFR Part 50, Appendix K, "ECCS Evaluation Models," notes:

> *1. The Initial Stored Energy in the Fuel:*
>
> The steady-state temperature distribution and stored energy in the fuel before the hypothetical accident shall be calculated for the burn-up that yields the highest calculated cladding temperature (or, optionally, the highest calculated stored energy.)

Section D.6 and D.7 of 10 CFR 50, Appendix K, notes:

> *D.6 Convective Heat Transfer Coefficients for Boiling Water Reactor Fuel Rods Under Spray Cooling*
>
> Following the blowdown period, convective heat transfer shall be calculated using coefficients based on appropriate experimental data.
>
> *D.7 The Boiling Water Reactor Channel Box Under Spray Cooling*
>
> Following the blowdown period, heat transfer from, and wetting of, the channel box shall be based on appropriate experimental data.

3.0 TECHNICAL EVALUATION

3.1 General LOCA ECCS Model Features

ECCS Model Framework

The Westinghouse BWR ECCS LOCA method consists of two computer codes, GOBLIN/DRAGON and CHACHA-3D. The GOBLIN and DRAGON computer codes are essentially the same code. The GOBLIN code is used to analyze the response of the reactor system to a LOCA. It models the break flow, and the actuation of automatic features such as main steam isolation valve (MSIV) closure, reactor scram, and the ECCS. GOBLIN would also determine the boundary conditions that are applied to the hot channel analysis. Based on the GOBLIN analysis results (i.e., the plenum to plenum flow boundary conditions), the GOBLIN code is used to analyze the response of hot channel/assembly in a mode referred to as DRAGON. The hot channel analysis determines the response of the hot channel to the LOCA event (e.g., boiling transition, dryout, and refill). These results and the calculated thermal hydraulic conditions in the hot assembly are used to establish the heat transfer coefficients and boundary conditions that are applied to the limiting hot bundle cross section. The response of the limiting cross section of the hot assembly is then calculated using the CHACHA-3D computer code. CHACHA-3D determines the detailed temperature distribution for all components at the limiting cross section. It includes the effects of cladding oxidation and fuel rod swell and rupture.

When applying this methodology to a new fuel bundle design, new CPR models are needed for the GOBLIN/DRAGON code. The nodalization needs to capture the geometrical characteristics of the fuel design that are important to the key phenomena of a LOCA event. The critical power ratio (CPR) correlation for the new fuel bundle design needs to be developed and approved by the NRC. Both the CCFL correlation and the ECCS spray cooling heat transfer coefficient need to demonstrate that the new bundle expected responses are conservatively bounded. Otherwise, new correlations are needed.

The framework of this method and the generic application procedures remain the same as version USA4 and previous versions approved by the NRC. The staff found that the new changes implemented into the code package do not have an impact on the general framework and the application procedures; therefore, the overall methodology structure is acceptable. The evaluation of detailed physics model changes and their applications to SVEA-96 Optima2 fuel are provided below.

CPR Correlation And General Implementation Procedures

Following the same approach as USA4, the USA5 version uses a CPR correlation to conservatively predict boiling transition in the hot assembly. Specifically, the CPR correlation is used to determine the initial power of the hot assembly and verify whether the core is operating at or outside the boundary for acceptable operating conditions. For a LOCA analysis, it determines the time to switch to boiling transition during the blowdown phase of the LOCA. Several CPR correlations have been implemented into the GOBLIN code. The user has the option to choose the NRC-approved CPR correlations applicable to either SVEA-96 or SVEA-96+.

A new fuel design normally requires a specific CPR correlation approved by the NRC. The implementation of a new CPR correlation into GOBLIN has become a routine code update process, which includes the source code development, new CPR correlation validation and non-Westinghouse fuel justifications. Westinghouse requested that this process be evaluated through the 10 CFR 50.46 annual report process. Therefore, the staff does not necessarily review the details of the implementation process. The staff has previously reviewed the proposed process from Reference 8 and determined that the requested process is acceptable as long as the new CPR correlation has been approved by the NRC and the change to the LOCA method is reported to the NRC through the 10 CFR 50.46 reporting process. For version USA5, the currently approved CPR correlations (i.e., XL-S96, ABBD1.0 and ABBD2.0) can still be used within the approved ranges of applicability. However, the new CPR correlation for SVEA-96 Optima2 fuel has not yet been approved by the NRC. Therefore, the current version of the SVEA-96 Optima2 fuel CPR correlation in USA5 cannot be used until it has received the approval of the staff.

Level Tracking Model

[

] The level tracking model was part of the physics model package of USA4 which was approved by the staff. Extending the USA4 version, Westinghouse performed the sensitivity studies in this TR to explore the application of the level tracking model [

] Therefore, the use of the model [ ] does not alter the analysis results or the conclusions.

The staff reviewed the results of the sensitivity cases listed in Table 5-1 of Reference 1 and found that both the use or non-use of level tracking [ ] are acceptable.

3.2 SVEA96 Optima 2 Fuel Design and Modeling Features

3.2.1 General Design Features

The introduction of the Optima2 fuel design in the SVEA-96 fuel family was driven by the need for improved nuclear performance, particularly in the shutdown margin. This resulted in the use of part-length rods. In addition, the new fuel design has improved the CPR performance, stability performance, and reduced two-phase pressure drop. Evolving from the SVEA-96+ fuel design, the Optima2 design employs two 2/3-length part-length rods and one 1/3-length rod for each of the four sub-assemblies. The two 2/3-length part-length rods are placed adjacent to the central channel, while the one 1/3-length rod is placed in the outer corner of the sub-assembly.

The Optima2 and SVEA-96+ fuel assembly designs use the same handle with spring and transition piece. The fuel channels have the same outer dimensions. All four sub-assemblies have the same general structural design. Each sub-bundle of the Optima2 fuel is constructed as a separate unit with its own bottom tie plate and is equipped with two tie rods. Spacers are used to hold the rods in the radial positions. [ ] The Zircaloy channel consists of an outer channel with a square cross-section and an internal double-walled, cruciform structure (water-cross) that forms gaps containing non-boiling water. The water-cross has a square central water channel and smaller water channels in each of the four wings.

Table 4-1 of Reference 1 compares various parameters for the 10x10 SVEA fuel designs and shows that the fuel rod outer diameter is [ ], while the pellet diameter is [ ]. Instead of using a uniform pitch, the Optima2 design employs [ ]. The hydraulic diameter varies [ ]. Overall, the Optima2 design evolves from the SVEA-96+ design with the use of part-length rods, small fuel rod dimension changes and radial layout changes.

The new features of the Optima2 fuel design requires updating the ECCS LOCA methodology. Westinghouse applied the qualification process for new fuel designs as described in RPB 90-94-P-A and CENPD-283-P-A (References 10 and 11) which were approved by the NRC and identified the following necessary modifications:

- Plenum model for part-length rod
- New GOBLIN and DRAGON input models
- New CPR correlation

In addition, Westinghouse reviewed the applicability of their existing codes.

The staff reviewed the qualification process and found the new model updates identified by Westinghouse to be acceptable.

3.2.2 CCFL Correlation Change

One of the essential aspects of the Westinghouse BWR ECCS EM is the modeling of the performance of the core spray system. Following a LOCA, cooling water is injected into the upper plenum of a BWR via the core spray header above the core. The path that this cooling water takes is affected by the CCFL, which represents the maximum rate at which water can flow downward for a given upward steam flow. The CCFL correlation, therefore, is a limiting curve defining the operating region where a counter-current flow can exist. As such, the axial transport of energy along the fuel bundle and the occurrences of key LOCA events, such as fuel bundle midplane dryout and midplane reflood, can be accurately predicted.

The CCFL correlation presently used by Westinghouse in its approved EM has a restriction. In the qualification of the CCFL correlation (Reference 12) for use in EM version USA2, it was predicted that plant system responses were shown to be insensitive to the CCFL in analyses with resulting peak cladding temperatures (PCTs) in the 1500–1600°F temperature range. However, in demonstrating the acceptability of the CCFL for instances when the PCT approached the 10 CFR 50.46 limit (2200°F), Westinghouse submitted data showing that as the peak linear heat generation rate approached 36 KW/m, there existed a 100°F temperature difference between the plant-specific sensitivity case and the base case. Therefore, in the SE relating to CENPD-283-P-A (Reference 11), Westinghouse is required to include a conservative bias in the CCFL correlation when the calculated PCT is close to the 10 CFR 50.46 limit. This bias was to conservatively bound the database predictions of all fuel assembly components that were used to derive the basic CCFL correlation, thereby diminishing the probability of non-conservative predictions due to plant-specific influences.

The present CCFL correlation contains [

] The more restrictive effective diameter relation would better represent the observed data and would eliminate the restriction placed on earlier versions of the EM.

To qualify the validity of the CCFL correlation change, Westinghouse presented a comparison between the CCFL correlation prediction and the experimental data. [

] The curve generated by Westinghouse using the modified CCFL correlation for the SVEA-64 fuel design bounds all of the relevant experimental data points, and therefore, performs in the same manner as the imposed restriction. To confirm this assertion, the staff duplicated the curve and found that the effective diameter modification to the [ ] regime is acceptable. The staff also found, given that the modified CCFL correlation acts in the same manner as the imposed restriction, that there is no justification for the continued use of a separate conservative bias when the calculated PCT approaches the 10 CFR 50.46 limit.

To qualify the applicability of the modified CCFL model to SVEA-96 Optima2 fuel, Westinghouse performed a sensitivity study demonstrating the effect of the new fuel design and the modified CCFL correlation on the overall LOCA response. In the study, LOCA analyses were conducted using a base case, where the modified correlation and SVEA-96 Optima2 fuel were incorporated, and a sensitivity case, where the effective diameter of the fuel's upper tie plate was reduced by over 10 percent. The occurrences of key events following the LOCA were compared. The results showed negligible changes in the limiting occurrence of midplane boiling transition, midplane dryout, lower plenum refill, and midplane reflood. The staff reviewed the results of this sensitivity study, the sensitivity study conducted in CENPD-283-P-A, and the thermal hydraulic parameter differences between SVEA-64, SVEA-96, and SVEA-96 Optima2 fuel assembly design parameters. The staff found that the CCFL model with appropriate geometric parameters is acceptable for applications involving SVEA-96, SVEA-96+, and SVEA-96 Optima2 fuel.

3.2.3 <u>Gas Plenum Model for Part-length Fuel Rods</u>

The use of the part-length rods in the SVEA-96 Optima2 design results in the part-length rod gas plenum being located inside the reactor core. Unlike the gas plenum of a full length fuel rod, the part-length rod gas plenum will receive radiation heat transfer from adjacent fuel rods during the heat-up process. Therefore, the previous version of the CHACHA-3D code cannot be directly applied to Optima2 fuel.

Westinghouse applied a simple two step conservative approach to calculate the part-length rod gas plenum temperature. [

] In this way, the development of a sophisticated part-length rod plenum model was not necessary. In order to demonstrate that the acceptability of the two-step approach, Westinghouse applied the approach to the Optima2 fuel and found that the part-length rod plenum pressure and temperature were higher than that of the hot rod. This approach is judged to be conservative.

The staff reviewed the simplified conservative approach and found that the part-length rod plenum model is acceptable.

3.2.4 Application to SVEA-96 Optima2 Fuel

Nodalization

Applying the USA5 version EM to the SVEA-96 Optima2 fuel design requires input model changes for both the GOBLIN and DRAGON codes. Westinghouse also developed specific input models for the SVEA-96 Optima2 fuel. The previous SVEA-96 GOBLIN system input model was used to model the Optima2 fuel with changes in the core region. The core model of SVEA-96 Optima2 fuel has very similar nodalization to the SVEA-96+ fuel, which was reviewed previously by the staff. [

]

[

] A minor nodalization change was made by Westinghouse for modeling the Optima2 fuel design due to the existence of part-length rod gas plenum.

The CHACHA-3D code is used to perform a detailed fuel rod mechanical and thermal response calculation at a specified axial level of the hot assembly or sub-assembly. Because of the similarity between the SVEA-96/96+ design and the SVEA-96 Optima2 design, Westinghouse did not change the nodalization to model the Optima2 fuel design.

The staff reviewed the nodalization changes of the SVEA-96/96+ input models for the GOBLIN and DRAGON codes and found that the changes are acceptable to model the Optima2 fuel.

Applicability of Core Spray Cooling Convective Heat Transfer Coefficient

Core spray cooling convective heat transfer coefficients are used by the CHACHA-3D code to calculate the fuel rod heat-up at the limiting plane starting from the time the spray pump reaches the rated flow to the time of two-phase recovery in the core. [

] The staff questioned the validity of these spray coefficients for the Optima2 fuel part-length rods. In response (Reference 5), Westinghouse indicated that the spray cooling heat transfer coefficients required by 10 CFR Part 50, Appendix K, are applied only in the rod heat-up calculation. The same set of spray cooling heat transfer coefficients are applied to the axial plane being analyzed. If the lattice being analyzed was in the lower third of the core, the 1/3-length rods would be analyzed using the spray heat transfer coefficient for the corner rods.

Comparing the hydraulic diameters of three zones of Optima2 fuel, Westinghouse found that the Optima2 fuel hydraulic diameters for Zone 2 and 3 are greater than the hydraulic diameter of the SVEA-96/96+ fuel but less than that of the SVEA-64 fuel type. Therefore, the spray cooling coefficients should be between the coefficients of these two fuel types. Conservatively, Westinghouse decided to use the coefficients of the SVEA-64 fuel design. Although the Zone 1 hydraulic diameter is slightly less than that of SVEA-96/96+ by about 1.3 percent, it is considered reasonable to apply the coefficients for the SVEA-64 fuel design.

Because of the similarity of the lattice layout to the SVEA-96/96+ fuel design, the staff finds applying SVEA-64 spray coefficients to the Optima2 fuel to be conservative and acceptable.

Radiation Heat Transfer Model

Correctly modeling the radiation heat transfer phenomenon is essential for a LOCA ECCS evaluation model. The phenomenon is analyzed by both codes, GOBLIN/DRAGON and CHACHA-3D. The impact of radiation heat transfer on the system response, hot channel analysis and hot plane was evaluated. Westinghouse applied the same methodology to the SVEA-96 Optima2 fuel without modifications. The SVEA-96 Optima2 fuel design has three axial zones, 24 rods in the lower zone, 23 rods in the middle zone, and 21 rods in the upper zone of each sub-assembly. Each zone is surrounded on two sides by the water-cross and on the other two sides by the fuel channel. Applying the radiation model to Optima2 fuel, Westinghouse calculated the radiation heat transfer between each rod and its surrounding components. In order to be conservative, the smallest pitch of three radial zones is used to calculate the view factors.

The staff reviewed the application of the radiation model to the Optima2 fuel and found the approach to be conservative and acceptable.

3.3 Transition Core Application

When a utility changes fuel vendors, the reactor core can be loaded with different types of fuel bundles. These reload cycles are referred to as mixed, or transition cores. The presence of non-Westinghouse fuel invalidates the approach proposed by version USA5, which assumes the entire core is loaded with the same type of Westinghouse fuel; e.g., SVEA-96 Optima2 fuel, no matter what the legacy fuels are. The staff questioned the applicability of version USA5 in the following two aspects:

- Different fuel designs can have different mass and thermal hydraulic characteristics. These differences, coupled with different initial power distribution profiles, can cause different initial stored energy and LOCA event timing. If the dryout or the reflood occur at different times due to these differences, the uniform fuel loading approach may not be bounding or conservative.

- One of the major trends of the latest fuel designs from different fuel vendors is the use of burnable poisons. Depending on the burnable poison concentrations, some of the fuel/core design may result in hot assemblies that are twice-burned. Therefore, a non-Westinghouse fuel bundle may become the limiting bundle for a transition core. This may require other vendors to recalculate the maximum average planar linear heat generation rate (MAPLHGR) limit based on the new core design configuration.

In response to these two issues (References 5, 6, and 7), Westinghouse indicated that comparisons were made between a full core of GE 8x8 fuel, a full core of QUAD+, and a mixed core comprised of QUAD+ and GE 8x8 fuel for the limiting break using the GOBLIN code (Section 9 of RPB 90-94-P-A). The key phenomenon examined were the core inlet flow rate during blowdown, the vessel depressurization rate, and the time of core reflood. [

] Westinghouse also cited the experimental results of Dix (Reference 12) which showed that water pooling exists above the core for all BWR designs. This ensures an even distribution of ECCS spray water between all fuel assemblies because the QUAD+ fuel was designed to have similar upper assembly and bail handle to that of GE 8x8 fuel.

Based on the analyses performed for QUAD+ and GE 8x8 fuel during the limiting LOCA, Westinghouse concluded that the introduction of QUAD+ fuel in a transition core with GE 8x8 fuel would not adversely impact the specific fuel type LOCA MAPLHGR limits based on a full core of the respective fuel type. Extrapolating from this conclusion, Westinghouse has been assuming that all other Westinghouse fuel designs would be similar to other vendor fuel designs so that a full core of a given Westinghouse fuel would bound a transition core.

The staff found this approach does not have a sufficient basis and considered it a deficiency of the methodology for two reasons. First, the fuel designs from different vendors have changed significantly from the time of the QUAD+ and GE 8x8 fuel design. The introduction of the water rods, the part-length fuel rods, and other improvements among fuel designs have altered the fuel thermal-hydraulic and neutronic characteristics. The justification of a full core QUAD+ as the bounding fuel loading is no longer valid without specific analysis for a transition core. Second, it is questionable to assume that the fuel type specific LOCA MAPLHGR cannot be adversely affected during the mixed core operation, because the MAPLHGR limits might be subject to change during the transition core operation and other vendors may need to determine cycle specific MAPLHGR for their fuel designs. In response to the staff's concerns, Westinghouse agrees that an evaluation will be performed to determine applicability of this approach. Specifically, Westinghouse will compare a system analysis of a core containing a full load of SVEA-96 Optima2 fuel to a mixed core containing approximately one-third SVEA-96 Optima2 fuel and two-thirds legacy fuel. If this simplification is not justified, the mixed core model will be used for the system response analysis to determine the MAPLHGR limits for the Westinghouse fuel. For another vendor's legacy fuel, Westinghouse will obtain the MAPLHGR limits from the other vendor regardless whether these limits are cycle dependent or not.

Considering that version USA5 can be applied to other previously approved Westinghouse fuel designs, the staff believes the following requirements need to be satisfied when the method is applied to a first transition cycle with the introduction of Westinghouse fuel:

- A multi-channel mixed core analysis is needed to determine the system response and examine the applicability of the full core Westinghouse fuel model. Proper nodalizations are needed for modeling the legacy fuel.
- The Westinghouse USA5 version cannot be used to determine MAPLHGR limits of other vendors' fuel, since these limits may be cycle-specific.

3.4 Fuel Performance Model Modification

As part of the version USA5 submittal, the heat-up computer code (CHACHA-3D) has been modified to use a consistent set of inputs and models from the STAV7.2 fuel performance code. The following is a brief list of these modeling features added to the code:

- The STAV7.2 pellet conductivity model, which considers the burn-up-induced degradation, has been implemented into the CHACHA-3D code to replace the STAV6.2 fuel pellet conductivity model.
- The pellet radial power distribution model has been modified to take into account power generation by plutonium isotopes and treat the pellet rim region.
- CHACHA-3D uses the oxidation and crud thickness from STAV7.2 as input to account for the thermal resistance of the crud layer and the oxide layer.
- CHACHA-3D is enabled to receive STAV7.2 gap size and gas composition information at the beginning of the transient to determine the gap heat transfer coefficient.

However, STAV7.2 is currently under review by the NRC and has not yet been approved. Prior to the approval of STAV7.2, the applicability of any modeling features implemented into the CHACHA-3D code from STAV7.2 cannot be determined. Therefore, USA5 can only be used with modeling features from the currently approved STAV6.2 while the staff completes its review of STAV7.2.

Although the CHACHA-3D code has the STAV6.2 type of models, which was approved as part of the USA4 version, the STAV6.2 code has not been demonstrated to be applicable to the SVEA-96 Optima2 fuel design as a stand-alone fuel performance code. Westinghouse evaluated the differences between the SVEA-96 and the Optima2 fuel design and concluded in Reference 7 that the CHACHA-3D code with the STAV6.2 type of models is applicable to Optima2 fuel. The only limitation identified is that the rod average burnup is less than 50 MWd/kgU. The staff reviewed the Westinghouse evaluation and concluded that it is acceptable to apply the CHACHA-3D code with STAV6.2 type of models to the Optima2 fuel LOCA analysis.

4.0 CONDITIONS AND LIMITATIONS

The staff finds that Westinghouse has adequately demonstrated the reasonably conservative nature of its modified ECCS methodology except for the implementation of STAV 7.2 modeling features which are currently under review by the staff. Therefore, the approval of the entire USA5 package and the use of it are subject to the following limitations:

1. All of the STAV7.2 features cannot be used pending completion of the staff review and approval of the STAV7.2 code. The previously approved STAV 6.2 model in the CHACHA-3D code can continue to be used for LOCA analysis. Upon receipt of staff approval of STAV7.2, Westinghouse shall provide written notification that STAV7.2 models are now being used in their ECCS methods and shall submit a revision to WCAP-10678-P, if it is determined necessary by the NRC staff, to document any changes in the STAV7.2 models, methods, or implementation currently described in this TR.

2. A mixed core GOBLIN model shall be developed during the first reload analysis of a transition core to verify the validity of the full core Westinghouse fuel approach. If it is confirmed that the analysis with a full core of Westinghouse fuel is bounding, then the LOCA ECCS evaluation can be performed using the full core Westinghouse fuel approach. Otherwise, the mixed core model shall be used.

3. The USA5 EM cannot be used to calculate the MAPLHGR limits for non-Westinghouse fuel for a mixed core analysis. If the transition core analysis indicates that the system performance of the mixed core is more limiting than the full core analysis of legacy fuel, Westinghouse will request the utility to contact the legacy fuel vendor for an evaluation of the impact of the mixed core on the MAPLHGR limits for their fuel.

4. The methodology cannot be used until the SVEA-96 Optima 2 fuel CPR correlation is approved by NRC.

5. The overall acceptability of the Westinghouse BWR ECCS methodology remains subject to the restrictions and limitations of all other governing SEs of relevant computer codes, models, and fuel designs, as previously approved.

5.0 CONCLUSION

The staff reviewed the incremental changes from the previously approved USA4 version to USA5 and found that the differences between these two versions do not alter the major framework of the EM. The currently approved capability for analyzing BWR LOCA events in accordance with the requirements of 10 CFR 50.46 is improved by the proposed changes with respect to applying the EM to the SVEA-96 Optima2 fuel design, and the staff finds these changes are acceptable. The staff also reviewed the USA4 CCFL model change, the spray cooling model, and their applications to SVEA-96 Optima2 fuel according to the 10 CFR Part 50, Appendix K, requirements and finds these changes are acceptable. The staff finds that the overall conservatism and the framework of the original USA4 version are preserved through this set of proposed changes for USA5. The evaluation results for each of the specific model changes are summarized below:

1. The SVEA-96 Optima2 CPR correlation is currently being reviewed by the staff. After it is approved, Westinghouse may implement it into the USA5 EM model and report to the NRC through the 10 CFR 50.46 annual report process.

2. Use of the optional level tracking model [ ] of the GOBLIN vessel model is acceptable.

3. The CCFL correlation with appropriate geometric parameters is qualified for applications involving SVEA-96 Optima2 fuel.

4. The plenum model for part-length rods reflects the physical locations of the gas plenum and was found to be conservative and acceptable for calculating plenum gas temperature and pressure.

5. The SVEA-96 Optima2 GOBLIN/DRAGON/CHACHA-3D models have been evaluated. The models evolved from the SVEA-96+ model with specific changes for the Optima2 fuel. These model changes and the extension of the core spray cooling model and the radiation heat transfer model to Optima2 fuel are considered to be acceptable.

6.0 <u>REFERENCES</u>

1. Letter from H.A. Sepp (Westinghouse) to NRC, "Submittal of WCAP-16078-P, Revision 0 and WCAP-16078-NP, Revision 0, 'Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel' (Proprietary/Non-proprietary)," LTR-NRC-03-17, dated April 30, 2003. (Accession No. ML031220211)

2. Letter from H.A. Sepp (Westinghouse) to B.J. Benney (NRC), "Requested Information in Support of the NRC Review of WCAP-16078-P 'Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel' (Proprietary)," LTR-NRC-03-33, dated June 30, 2003.

3. Letter from B.F. Maurer (Westinghouse) to J.S. Wermiel (NRC), "Response to Round 1 Request for Additional Information Regarding WCAP-16078-P & -NP, 'Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel' (Proprietary/Non-proprietary)," LTR-NRC-03-74, dated December 19, 2003. (Accession No. ML033600246)

4. Letter from J.A. Gresham (Westinghouse) to NRC, "Response to Round 2 Request for Additional Information for WCAP-16078-P, 'Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel' (Proprietary/Non-proprietary)," LTR-NRC-04-24, dated April 22, 2004. (Accession No. ML041170286)

5. Letter from J.A. Gresham (Westinghouse) to NRC, "Response to Round 3 Request for Additional Information for WCAP-16078-P, 'Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel' (Proprietary/Non-proprietary)," LTR-NRC-04-33, dated May 28, 2004. (Accession No. ML042510098)

6. Letter from J.A. Gresham (Westinghouse) to NRC, "Response to Round 4 Request for Additional Information for WCAP-16078-P, 'Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel' (Proprietary/Non-proprietary)," LTR-NRC-04-39, dated June 23, 2004. (Accession No. ML042510042)

7. Letter from J.A. Gresham (Westinghouse) to NRC, "Revision 1 to the Responses to Round 4 NRC Request for Additional Information for WCAP-16078-P, "Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel" (Proprietary/Non-proprietary)," LTR-NRC-04-51, dated August 24, 2004. (Accession No. ML042400336)

8. Westinghouse Report RPB-90-93-P-A (Proprietary) and RPB-90-91-NP-A (Nonproprietary), "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Description and Qualification," dated October 1991.

9. Letter from H.A. Sepp (Westinghouse) to NRC, "Submittal of WCAP-15682-P-A, Rev. 0 and WCAP-15682-NP-A, Rev. 0, 'Westinghouse BWR ECCS Evaluation Model: Supplement 2 to Code Description, Qualification and Application' (Proprietary/Non-proprietary)," dated May 30, 2003. (Accession No. ML031540688)

10. Westinghouse Report RPB 90-94-A, "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity," dated October 1991.

11. Westinghouse Report CENPD-283-P-A, "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity for SVEA-96 Fuel," dated July 1996.

12. G. Dix, "BWR Loss of Coolant Technology Review," International Topical Meeting on Nuclear Reactor Thermal-hydraulic (ANS), Santa Barbara, CA, USA, January 11, 1983.

Attachment: Resolution of Comments

Principal Contributor: S. Lu, NRR

Date: October 15, 2004

RESOLUTION OF COMMENTS

DRAFT SAFETY EVALUATION FOR TOPICAL REPORT WCAP-16078-P,

"WESTINGHOUSE BWR ECCS EVALUATION MODEL: SUPPLEMENT 3 TO CODE

DESCRIPTION, QUALIFICATION AND APPLICATION TO SVEA-96 OPTIMA2 FUEL"

By letter dated September 23, 2004, Westinghouse provided comments on the draft safety evaluation (SE) for WCAP-16078-P, "Westinghouse BWR ECCS Evaluation Model: Supplement 3 To Code Description, Qualification and Application to SVEA-96 OPTIMA2 Fuel." The following is the staff's resolution of those comments.

1. Westinghouse Comment: Section 1.0, "INTRODUCTION," indicates that the change to the counter-current flow correlation is to accommodate the implementation of SVEA-96 fuel.

   Westinghouse Proposed Resolution: "A change to the counter-current flow limit (CCFL) correlation to apply a conservative bias such that it bounds all the scatter in the correlation database."

   NRC Action: The comment was fully adopted into the final SE.

2. Westinghouse Comment: Item D.7 in Section 2.0 should be revised.

   Westinghouse Proposed Resolution: "D.7 The Boiling Water Reactor Channel Box Under Spray Cooling."

   NRC Action: The comment was fully adopted into the final SE.

3. Westinghouse Comment: The first sentence of the second paragraph of Section 3.1, "General LOCA ECCS Model Features," should be revised.

   Westinghouse Proposed Resolution: "When applying this methodology to a new fuel bundle design, new CPR models are needed for the GOBLIN/DRAGON code."

   NRC Action: The comment was fully adopted into the final SE.

4. Westinghouse Comment: The next to last sentence in the last paragraph of Section 3.1, "General LOCA ECCS Model Features," should be revised.

   Westinghouse Proposed Resolution: "The staff reviewed the results of the sensitivity cases listed in Table 5-1 of Reference 1 and found that both the use or non-use of level tracking in [ ] are acceptable."

   NRC Action: The comment was fully adopted into the final SE.

5. Westinghouse Comment: The word "assembly" in the third sentence of the second paragraph of Section 3.2.1, "General Design Features," be replaced.

   Westinghouse Proposed Resolution: Replace "assembly" with "sub-bundle."

   NRC Action: The comment was adopted into the final SE.

6. Westinghouse Comment: The fifth sentence of the second paragraph of Section 3.2.1, "General Design Features," be replaced.

   Westinghouse Proposed Resolution: [

   ]

   NRC Action: The comment was fully adopted into the final SE.

7. Westinghouse Comment: The last sentence in the third paragraph of Section 3.2.1, "General Design Features," should be revised.

   Westinghouse Proposed Resolution: Delete the word "Thus."

   NRC Action: The comment was fully adopted into the final SE.

8. Westinghouse Comment: Section 3.2.1, "General Design Features," regarding the CCFL correlation changes should be revised.

   Westinghouse Proposed Resolution: Delete the first bullet item.

   NRC Action: The comment was fully adopted into the final SE.

9. Westinghouse Comment: The word "to" should be replaced with the word "for" in the third sentence of the first paragraph of Section 3.2.2, "CCFL Correlation Change".

   Westinghouse Proposed Resolution: "... flow downward for a given upward stream flow."

   NRC Action: The comment was fully adopted into the final SE.

10. Westinghouse Comment: The last sentence of the last paragraph of Section 3.2.2, "CCFL Correlation Change," should be modified.

    Westinghouse Proposed Resolution: "The staff found that the CCFL model with appropriate geometric parameters is acceptable for applications involving SVEA-96, SVEA-96+ and SVEA-96 Optima2 fuel."

    NRC Action: The comment was fully adopted into the final SE.

11. Westinghouse Comment: The next to last sentence in the first paragraph of Section 3.2.4, "Application to SVEA-96 Optima2 Fuel," should be revised.

    Westinghouse Proposed Resolution: [ ]

    NRC Action: The comment was fully adopted into the final SE.

12. Westinghouse Comment: The first sentence of the third paragraph in Section 3.2.4, "Application to SVEA-96 Optima2 Fuel," should be revised.

    Westinghouse Proposed Resolution: "The CHACHA-3D code is used to perform a detailed fuel rod mechanical and thermal response calculation at a specified axial level of the hot assembly or sub-assembly."

    NRC Action: The comment was fully adopted into the final SE.

13. Westinghouse Comment: The last sentence of the next to last paragraph in Section 3.2.4, "Application to SVEA-96 Optima2 Fuel," should be revised.

    Westinghouse Proposed Resolution: Delete the word "ratio."

    NRC Action: The comment was fully adopted into the final SE.

14. Westinghouse Comment: The second sentence of the third item in the number list of Section 4.0, "CONDITIONS AND LIMITATIONS," should be revised.

    Westinghouse Proposed Resolution: "If the transition core analysis indicates that the system performance of the mixed-core is more limiting than the full-core analysis of legacy fuel, Westinghouse will request the utility to contact the legacy fuel vendor for an evaluation of the impact of the mixed core on the MAPLHGR limits for their fuel.

    NRC Action: The comment was fully adopted into the final SE.

15. Westinghouse Comment: The name of the fuel design indicated in the first item in the number list of Section 5.0, "CONCLUSION," should be corrected.

    Westinghouse Proposed Resolution: Replace "SVEA-96+" with "SVEA-96 Optima2."

    NRC Action: The comment was fully adopted into the final SE.

16. Westinghouse Comment: The second item in the number list of Section 5.0, "CONCLUSION," should be modified.

    Westinghouse Proposed Resolution: "Use of the level-tracking model [ ] of the GOBLIN vessel model is optional."

NRC Action: The comment was adopted into the final SE with minor wording change. Proprietary information was marked consistent with comment 4 above.

17. Westinghouse Comment: The description of the CCFL correlation in paragraph 3 of Section 3.2.2, "CCFL Correlation Change," should be marked proprietary.

    Westinghouse Proposed Resolution: Westinghouse provided a markup.

    NRC Action: The comment was fully adopted into the final SE.

18. Westinghouse Comment: The description of the CCFL correlation in paragraph 4 of Section 3.2.2, "CCFL Correlation Change," should be marked proprietary.

    Westinghouse Proposed Resolution: Westinghouse provided a markup.

    NRC Action: The comment was fully adopted into the final SE.

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ABSTRACT

This Licensing Topical Report describes changes to the Westinghouse Emergency Core Cooling System Evaluation Model for BWRs. This version of the Evaluation Model is identified as USA5. The differences between this version of the Evaluation Model and the previously approved Evaluation Model (USA4) are (1) a change to the counter-current flow limit correlation, (2) the addition of a fuel rod plenum model that is applicable to part-length fuel rods, and (3) incorporation of the applicable features of the improved STAV7.2 fuel performance model. This report also provides the basis for applying the USA5 Evaluation Model to the SVEA-96 Optima2 fuel design.

1 INTRODUCTION

The objective of this Licensing Topical Report Supplement is to describe changes made to the BWR LOCA Emergency Core Cooling System (ECCS) Evaluation Model and to extend its applicability to SVEA-96 Optima2 fuel. The resulting version of the BWR LOCA ECCS Evaluation Model is identified as the USA5 Evaluation Model.

The changes to the Evaluation Model include:

- A change to the Counter-Current Flow Limit (CCFL) correlation in the thermal-hydraulic code (GOBLIN) is made to eliminate a restriction placed on earlier versions of the Evaluation Model. This change is described in Section 5.4.2.

- A change to the fuel rod plenum model in the fuel heat-up code (CHACHA-3D) is made to extend the applicability of the Evaluation Model to the SVEA-96 Optima2 fuel design. This change is described in Section 5.1.1

- A change to the fuel performance models in the fuel heat-up code (CHACHA-3D) to incorporate the relevant fuel performance models from the STAV7.2 fuel performance code (under NRC review). These changes are described in Section 5.5.2

In addition to describing changes to the Evaluation Model, this report provides a basis for applying the USA5 Evaluation Model to the SVEA-96 Optima2 fuel design (Section 6) and updates the compliance of the Evaluation Model with the requirements of 10CFR50, Appendix K (Section 7).

1.1 BACKGROUND

The licensing of the Westinghouse BWR reload fuel safety analysis methodology for U.S. applications started in 1982 with the submittal of various licensing topical reports by the Westinghouse Electric Corporation. These reports described codes and methodology developed by Westinghouse Atom AB, formerly known as ABB Atom (and ASEA Atom) of Sweden.

In 1988, ABB Atom continued the licensing of the BWR reload methodology, started by Westinghouse, directly with the NRC. The transfer of the licensing effort was formally facilitated by ABB resubmitting NRC approved licensing topical reports under the ABB ownership. The NRC acknowledged the transfer of the Licensing Topical Report approvals in 1992 (Reference 1).

After acquisition of Combustion Engineering by the parent company of ABB Atom, the U.S. operations of ABB Atom were consolidated within ABB Combustion Engineering. ABB Combustion Engineering became the cognizant organization for BWR reload fuel application in the U.S. Reference 2 describes the ABB BWR reload methodology that is currently used for the U.S. reload and plant operational modification applications.

ABB nuclear businesses were acquired by Westinghouse Electric Company (the successor company of the Westinghouse Electric Corporation nuclear businesses) in April 2000. The cognizant organization responsible for the U.S. application and development of the BWR reload fuel safety analysis methodology within the Westinghouse Electric Company remains unchanged.

The Westinghouse BWR LOCA ECCS Evaluation Model of References 3, 4 and 5 has been accepted by the NRC and applied in numerous U.S. reload and lead fuel assembly applications.

2. SUMMARY AND CONCLUSIONS

2.1 SUMMARY

The original BWR LOCA Evaluation Model (USA1), which was approved by the NRC in 1987, is described in RPB-90-93-P-A and RPB-90-94-P-A (Reference 3). This methodology was revised in 1996 with the USA2 Evaluation Model, which is described in CENPD-283-P-A and CENPD-293-P-A (Reference 4) and in 2003 with the USA4 Evaluation Model, which is described in WCAP-15682-P-A (Reference 5).

This licensing topical report describes changes to the Westinghouse BWR LOCA Evaluation Model that are identified as the USA5 Evaluation Model. The USA5 model contains only four changes that require NRC review and approval:

1. A change to the counter-current flow limit (CCFL) correlation in the GOBLIN code to remove the restriction that was placed on the previous Evaluation Model when peak cladding temperatures were calculated in excess of 2100°F.

2. The addition of a new fuel rod plenum model in the CHACHA-3D code to permit analysis of fuel designs containing part-length fuel rods.

3. The addition of the applicable fuel performance models from STAV7.2 fuel performance code (currently under NRC review).

4. The applicability of the USA5 Evaluation Model for analyses of reactor cores containing the SVEA-96 Optima2 fuel design.

NRC review and acceptance of these changes are requested.

2.2 CONCLUSIONS

The USA5 Evaluation Model is an acceptable methodology for establishing BWR MAPLHGR operating limits and demonstrating Emergency Core Cooling System (ECCS) performance for Appendix K reload fuel applications. The USA5 Evaluation Model is a straightforward and fully justified extension of the previously accepted USA1, USA2, and USA4 Evaluation Models.

CCFL Correlation – The technical basis for the proposed change to the CCFL correlation is based on the same data that were used to qualify the original CCFL correlation. The revised correlation is an improvement relative to the original correlation in that it is conservative with respect to all of the measured data.

Part-Length Fuel Rod Plenum Model – The new plenum model for part-length fuel rods provides a conservative determination of the gas temperature within the plenum of part-length fuel rods. This model change is necessary to account for the location of the part-length rod plena being adjacent to active fuel.

STAV7.2 Fuel Performance Model – Incorporation of the [

]^a These changes along with the conservative initial fuel performance parameters derived using the STAV7.2 fuel performance code ensure a conservative treatment of fuel stored energy over the entire range of exposures. These changes are applied consistent with the NRC acceptance of the STAV7.2 code.

Applicability of USA5 to SVEA-96 Optima2 – The only model change that was necessary to apply the USA5 model to SVEA-96 Optima2 fuel is the part-length rod plenum model in CHACHA-3D. The other design features of SVEA-96 Optima2 fuel are accommodated by nodalization and design-specific inputs. The changes to the SVEA-96 Optima2 fuel mechanical design that can affect the hydraulic performance of the fuel assembly relative to the SVEA-96/96+ assembly designs are the introduction of [

]^a and the introduction of part-length rods.

3 BWR ECCS EVALUATION MODEL METHODOLOGY OVERVIEW

This section provides an overview of the application of the methodology to a typical reload. The overview of the BWR ECCS Evaluation Model is presented by summarizing:

- The ECCS design bases,
- Major features of the Westinghouse BWR LOCA Evaluation Model, and
- The LOCA Evaluation Model analysis process.

3.1 ECCS DESIGN BASES

LOCA is a postulated accident, presented in the Code of Federal Regulations Title 10 Part 50.46 (Reference 6), to determine the design acceptance criteria for the plant Emergency Core Cooling System (ECCS). 10CFR50.46 prescribes five specific design acceptance criteria for the plant:

1. Peak Cladding Temperature – "The calculated maximum fuel rod cladding temperature shall not exceed 2200°F."

2. Local Oxidation – "The calculated local oxidation of the cladding shall nowhere exceed 0.17 times the local cladding thickness before oxidation."

3. Total Hydrogen Generation – "The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, except the cladding surrounding the plenum volume, were to react."

4. Coolable Geometry – "Calculated changes in core geometry shall be such that the core remains amenable to cooling."

5. Long Term Cooling – "After any calculated successful operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core."

As described in Reference 2, the Westinghouse BWR ECCS reload fuel licensing methodology requires demonstration of compliance with the first three acceptance criteria for each new fuel type introduced in a specific plant. Criterion 4 is assured by meeting Criteria 1 and 2. Criterion 5 is demonstrated during the initial review of the plant's ECCS design.

3.2 MAJOR FEATURES OF THE WESTINGHOUSE BWR LOCA EVALUATION MODEL

The GOBLIN series of computer codes uses one-dimensional assumptions and solution techniques to calculate the BWR transient response to both large and small break LOCAs. The series is composed of three major computer codes – GOBLIN, DRAGON, and CHACHA-3D.

GOBLIN performs the analysis of the LOCA blowdown and reflood thermal hydraulic transient for the entire reactor, including the interaction with various control and safety systems.

DRAGON performs the hot fuel assembly thermal hydraulic transient calculation-using boundary conditions from the GOBLIN calculation. DRAGON is virtually identical to GOBLIN except that features that are not required are bypassed in DRAGON. Occasionally, it is more convenient to perform the hot assembly analysis in parallel with the system analysis. This is accomplished by running a two channel GOBLIN model in which one of the channels represents the hot assembly. In this case, there is no need to drive the DRAGON analysis with boundary conditions from the GOBLIN system analysis.

CHACHA-3D performs detailed fuel rod mechanical and thermal response calculations at a specified axial level within the hot fuel assembly previously analyzed by DRAGON. All necessary fluid boundary conditions are obtained from the DRAGON calculation. [ ][a] These results are used to determine the peak cladding temperature and cladding oxidation at the axial plane under investigation. CHACHA-3D also provides input for the calculation of total hydrogen generation.

The flow of information between these codes is shown in Figure 3-1. RPB 90-93-P-A (Reference 3), CENPD-293-P-A (Reference 4) and WCAP-15682-P (Reference 5) provide detailed descriptions for these three computer codes.

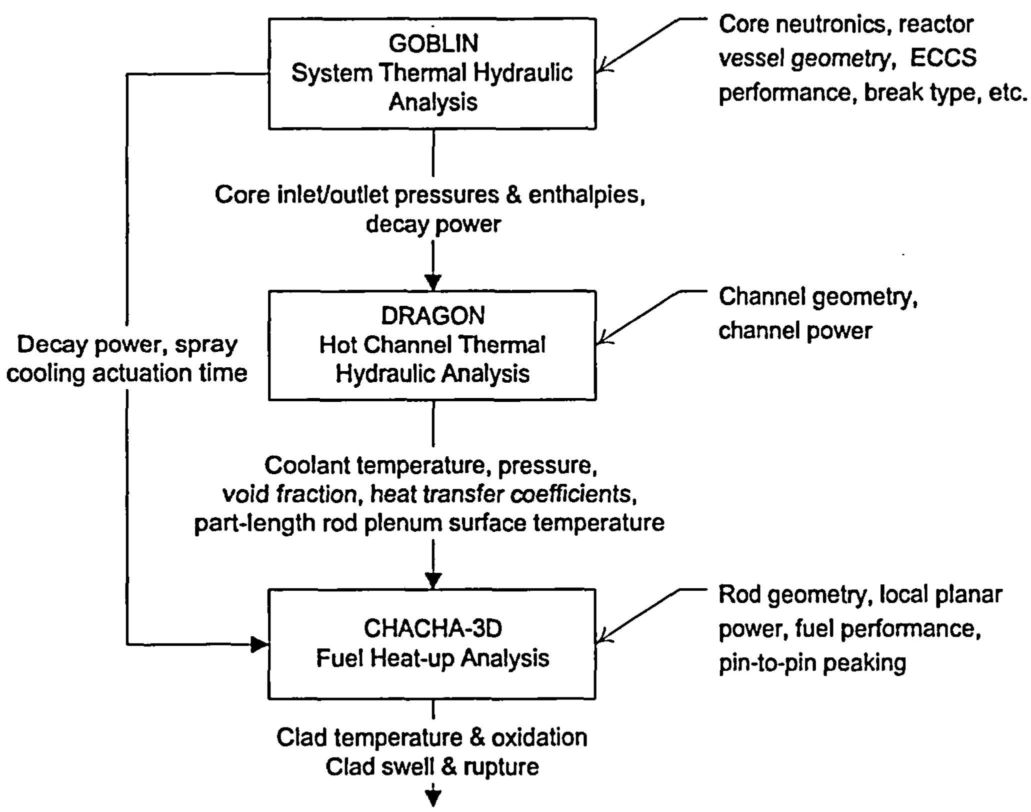

Figure 3-1 Flow of Information Between Computer Codes

3.3 LOCA EVALUATION MODEL ANALYSIS PROCESS

The U.S. version of the Westinghouse BWR ECCS Evaluation Model has been qualified and approved for application to several fuel designs. The specific designs are QUAD+, SVEA-96 and SVEA-96+. The general evaluation methodology has been applied in Europe to the following additional fuel designs: open lattice 8x8, SVEA-64, SVEA-100, SVEA-96 Optima, and SVEA-96 Optima2 designs.

The qualification process described for various fuel designs, which is discussed in References 3 and 4, is shown in Figure 3-2 and summarized below.

3.3.1 Methodology

If all the qualification criteria are met, the ECCS Evaluation Model is acceptable for application to the specific fuel mechanical design. If any step described below does not fulfill the qualification criteria, then the LOCA ECCS Evaluation Model may not be applied for the new fuel mechanical design prior to specific NRC review and approval.

1. Nodalization – Fuel design-specific models are developed for the GOBLIN, DRAGON and CHACHA-3D codes that capture the geometrical characteristics of the fuel design that are important to the key phenomena of a LOCA event.

2. CPR Correlation – The Critical Power Ratio (CPR) correlation used is an NRC-approved CPR correlation that has been shown to conservatively predict boiling transition for the specific fuel design.

3. CCFL Correlation – The Counter-Current Flow Limit (CCFL) model used is demonstrated as conservative relative to applicable experimental data for the specific mechanical fuel design.

4. Spray Cooling Convective HTC – The spray cooling heat transfer coefficients used are demonstrated as conservative relative to applicable experimental data for the specific mechanical fuel design.

5. Transition Cores – A full core configuration of the specific fuel design is used in LOCA ECCS performance evaluation applications. Acceptability for transition cores is confirmed by comparing the following reactor system responses for analyses performed assuming a full core of the applicable co-resident fuel designs:

   a. time of reactor trip,
   b. time of boiling transition at the midplane of the hot assembly,
   c. time of dryout at the midplane of the hot assembly,
   d. times of actuation of the ECCS, and
   e. time of reflood of the midplane of the hot assembly.

3.3.2 Discussion

3.3.2.1 Nodalization

The GOBLIN reactor core and DRAGON hot channel nodalization are selected to represent the fuel design features important to ECCS performance analysis. These features include the fuel assembly active cross-sectional flow areas, locations of inter- and intra- assembly flow paths, grid spacers, tie plate elevations and fuel rod dimensions. Axial node size in the GOBLIN and DRAGON models is selected to ensure there is sufficient detail to characterize thermal/hydraulic conditions along the channel and at the hot plane. When it is impractical to reduce axial node size sufficiently to capture important mixture level dynamics, GOBLIN's level tracking feature may be used to determine the position of the mixture level more precisely.

The CHACHA-3D geometric model is selected to represent fuel design specific rod or rod lattice configuration, channel configuration, fuel pellet, cladding and gap dimensions, and fuel rod plenum dimensions.

3.3.2.2 CPR Correlation

The CPR correlation is used to 1) determine the initial power of the hot assembly that will have it operating at or outside the boundary of actual operating conditions and 2) determine the time of boiling transition during the blowdown phase of the LOCA. GOBLIN has several CPR correlations available to the user. The CPR correlation that is applicable to the fuel design being evaluated or demonstrated to be conservative relative to a NRC-approved correlation for that fuel design is selected by the analyst to ensure that the hot assembly power and the time of dryout are predicted conservatively. The appropriate NRC-approved CPR correlation must be used to assess ECCS performance in a licensing application. The following NRC-approved CPR correlations are currently available to the user:

CPR Correlation	*Application*
XL-S96	SVEA-96
ABBD1.0	SVEA-96
ABBD2.0	SVEA-96+

CPR correlations are applicable to specific fuel designs or a group of fuel designs. The Safety Evaluation Report (SER) for RPB 90-93-P-A (Reference 3) requires that an appropriate NRC-approved CPR correlation be used when GOBLIN is used in a licensing analysis. The NRC-approved correlation may be one that has been developed specifically for the fuel design, or shown to be conservative relative to a NRC-approved correlation for that fuel design. Changes to GOBLIN are necessary when a new CPR correlation is implemented. The process described below is used by Westinghouse to install and test NRC-approved CPR correlations. Changes to GOBLIN following this process do not require a specific NRC review and approval. Such changes will be communicated to the NRC via the 10CFR50.46 annual reporting process.

The process used to install and qualify a CPR correlation in GOBLIN is as follows:

1. Develop coding to represent the new correlation. The coding includes checks on correlation parameters to ensure that inputs to the correlation are within valid ranges of those parameters. If a parameter is outside its range of validity, the [ ][a]

2. Validation of the implemented CPR correlation is performed by:

   a. [

   b.][a]

3. Ensure NRC approval of CPR correlation for the fuel design prior to its use in licensing applications.

4. Inform NRC of the change to GOBLIN via the 10CFR50.46 annual reporting process.

If a LOCA analysis of non-Westinghouse fuel is required, Westinghouse may not have direct access to the accepted correlation for the resident fuel. In this case, sufficient information is obtained from the utility to either:

1. Allow re-normalization of an NRC-approved Westinghouse CPR correlation for Westinghouse fuel to describe the CPR performance of the fuel, or

2. Show that the NRC-approved Westinghouse CPR correlation for Westinghouse fuel is conservative.

CPR correlations are valid within specified ranges of parameters (e.g., system pressure, core mass flux, inlet subcooling). When a CPR correlation is implemented in GOBLIN, it is only applied when conditions in the core are within its range of applicability. If any parameter is outside its valid range, [ ][a]. Since the system pressure and core flow decrease very rapidly following a large break LOCA, the prediction of boiling transition is often the result of exceeding the [ ][a]. Experience has shown that the fuel-specific CPR correlation selected [ ][a,c]

The process for developing the re-normalized CPR correlation is described in Section 5.3.2.5 of Reference 2. Implementation of the re-normalized CPR correlation in GOBLIN follows the process outlined above.

The CPR correlation for SVEA-96 Optima2 was not approved by NRC at the time this topical report was written. Therefore, it will be installed and tested after it has been approved before using the USA5 Evaluation Model for a licensing application involving SVEA-96 Optima2 fuel. NRC will be informed of this change to the GOBLIN code via the 10CFR50.46 reporting process.

3.3.2.3 CCFL Model

The CCFL model has been approved for a variety of fuel designs. In accordance with CENPD 283-P-A (Reference 4), this correlation will not be extended to fuel designs outside the range of approved applicability without being supported by experimental data. NRC review and approval of the new CCFL model is required prior to its use in licensing applications.

The change to the CCFL model in GOBLIN that is described in Section 5.4.2 is intended to remove a restriction placed on the USA2 Evaluation Model.[1]

3.3.2.4 Spray Cooling Convective Heat Transfer

A methodology to extrapolate spray cooling heat transfer coefficients for application to a variety of fuel designs has been approved. In accordance with CENPD-283-P-A (Reference 4), this methodology will not be extended to fuel designs outside the range of applicability without being supported by experimental data. If the spray cooling heat transfer coefficients can not be demonstrated as applicable, spray cooling heat transfer coefficients must be determined either from a detailed analysis that has been validated by experimental data or directly from applicable data. NRC review and approval of the new spray cooling heat transfer coefficients are required prior to their use in licensing applications.

3.3.2.5 Transition Cores

The BWR fuel channel and fuel mechanical designs are established to ensure hydraulic compatibility with co-resident fuel. This results in the system response to a LOCA event for one core of mixed fuel designs to be very similar hydraulically to that of a full core of a single fuel design. This observation has been demonstrated for several fuel designs in References 3 and 4.

---

1 In responding to a request for additional information relative to the NRC review of CENPD-283-P-A (Reference 4) Westinghouse committed to applying a conservative bias to the CCFL correlation to bound all the scatter in the correlation database for LOCA applications where the calculated peak cladding temperature exceeded 2100°F.

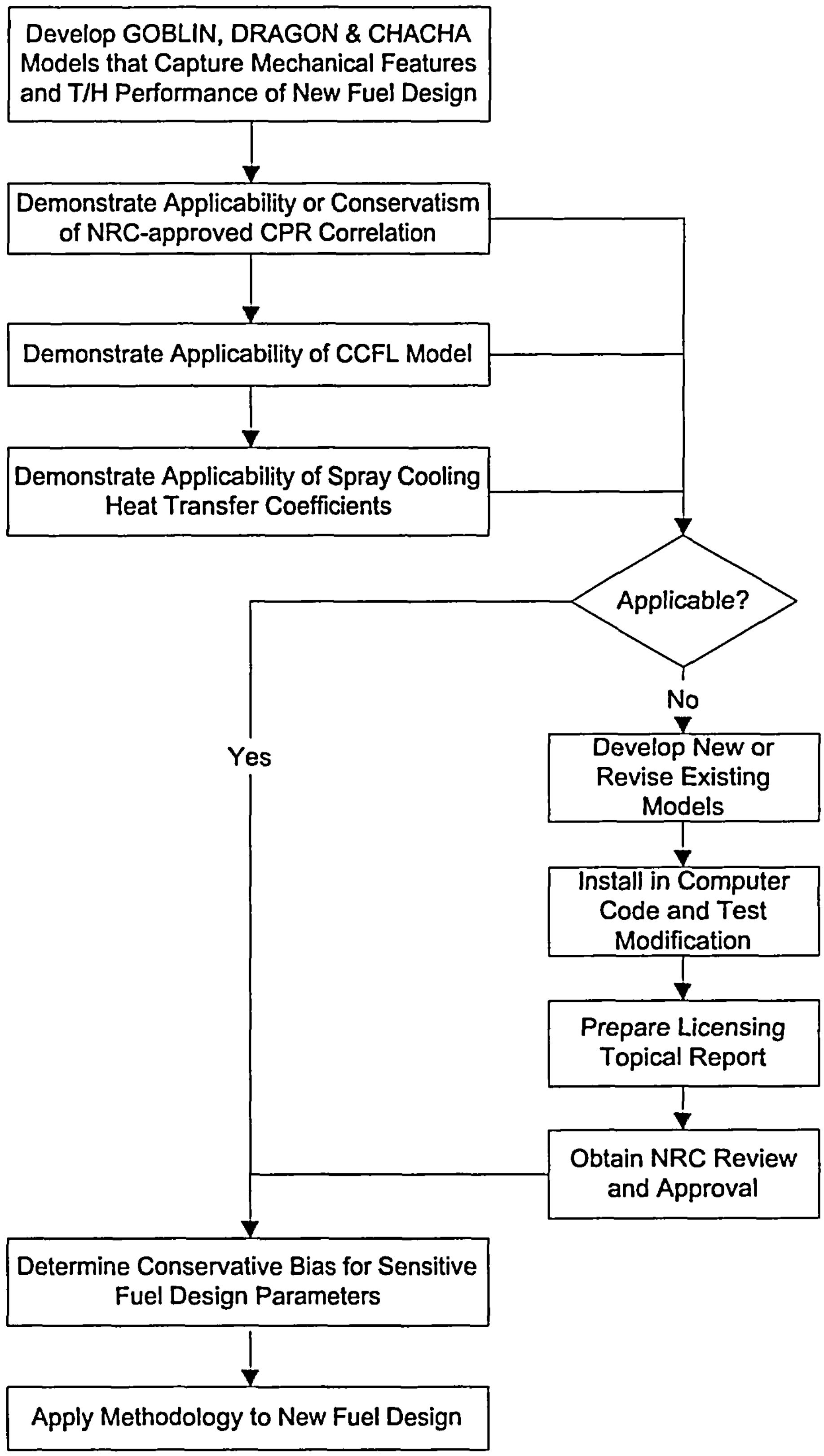

Figure 3-2 Process for Applying Evaluation Model to New Fuel Mechanical Design

4 SVEA-96 OPTIMA2 FUEL ASSEMBLY

Similar to the SVEA-96 and SVEA-96+ designs, the SVEA-96 Optima2 assembly consists of 96 fuel rods arranged in four sub-assemblies. The sub-assemblies are separated by a double-walled cross in the channel that forms nine parallel flow channels – one square center channel (water cross), four identical rectangular gaps in the cross wings (water wings), and four geometrically identical sub-assemblies. Each sub-assembly consists of 24 fuel rods in a 5x5-1 lattice. The SVEA-96 Optima2 fuel assembly is shown in Figure 4-1.

4.1 GENERAL DESCRIPTION

The general objectives for the design of the SVEA-96 Optima2 fuel are improved nuclear performance, in particular shutdown margin, by the use of part-length rods. In addition, the SVEA-96 Optima2 design has been optimized to provide improved CPR performance, stability performance and reduced two-phase pressure drop. The major difference between the SVEA-96 Optima2 fuel and the SVEA-96+ fuel assembly designs is the use of part-length fuel rods. The two fuel assembly designs have the same handle with spring and transition piece. The fuel channels have the same outer dimensions, and both designs have four sub-assemblies with a total of 96 fuel rods standing in the channel. The sub-assemblies have the same general structural design. As shown in Figure 4-2, three of the rods in each sub-bundle are part-length. Two of the part-length rods are two-thirds of the length of the full-length rods. These are placed adjacent to the central channel. The third part-length rod, which is one-third of the length of the full-length rods, is placed in the outer corner of the sub-assembly. Consequently, the lower part of the fuel assembly (Zone 1) consists of 96 fuel rods, the middle part (Zone 2) consists of 92 fuel rods and the upper part (Zone 3) consists of 84 fuel rods.

The part-length rod positions are chosen to maximize the shutdown margin with a minimum number of part-length rods. All rods have the same outer diameter, which is slightly larger than the diameter of the SVEA-96+ design. Each sub-assembly is constructed as a separate unit with its own bottom tie plate and is equipped with two tie rods. There are eight tie rods that are connected to the bottom tie plate by threaded end plugs, extending through the plate, and nuts. A spacer capture rod secures the axial positions of the spacers through heads welded to the cladding tube above each spacer level. The radial positioning of the fuel rods is determined by the spacers. Also, the rods are located axially but the lower tie plate. The tops of the rods are supported radially by an additional spacer in the plenum region or an upper tie plate.

[

][a]

The Zircaloy channel consists of an outer channel with a square cross section and an internal double-walled, cruciform structure (water cross) that forms gaps for non-boiling water. The water cross has a square central water channel and smaller water channels in each of the four wings. The outer channel forms, together with the water cross structure, four sub-channels for the subassemblies. [

]^{a,c}

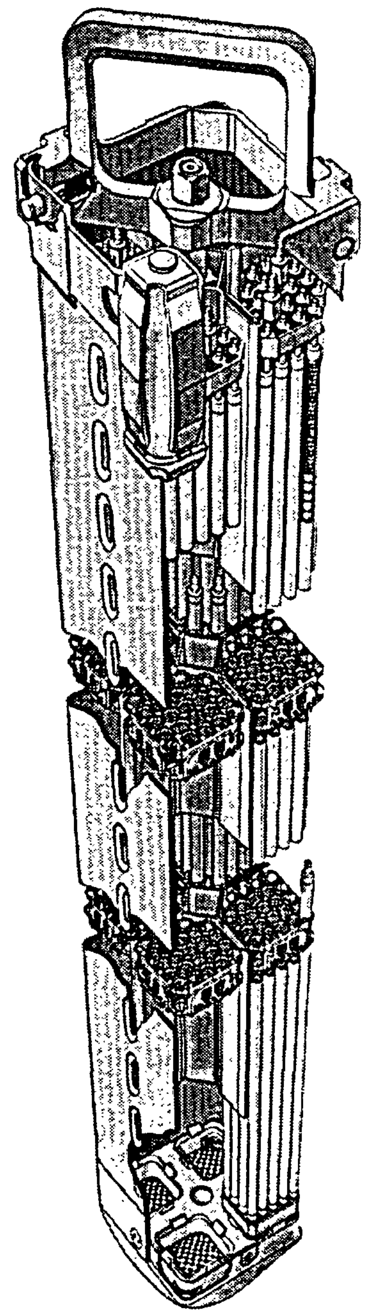

Figure 4-1 SVEA-96 Optima2 Fuel Assembly

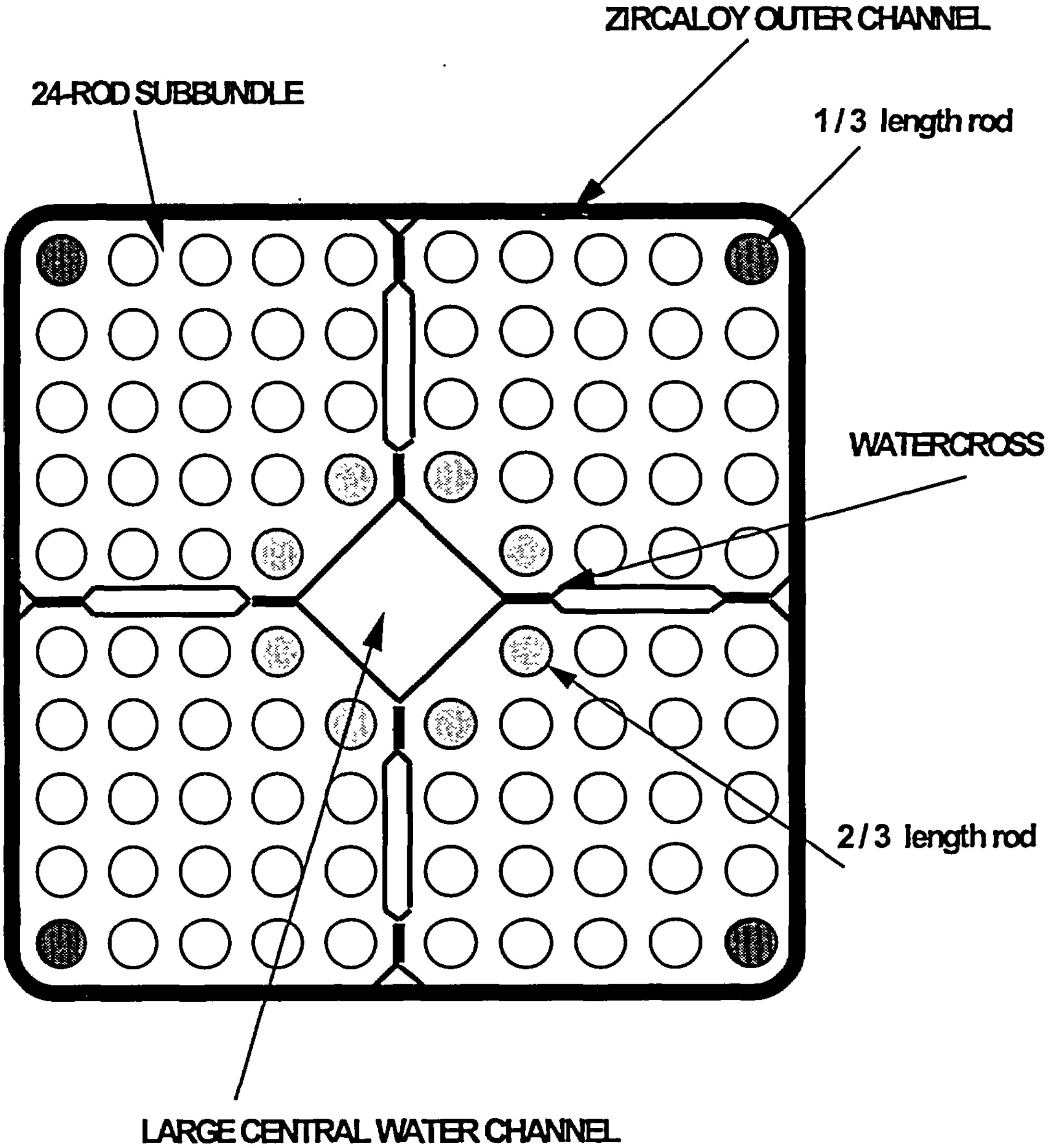

Figure 4-2 Cross Section of SVEA-96 Optima2 Sub-Assembly

4.2 COMPARISON OF SVEA-96 OPTIMA2 FUEL TO OTHER SVEA FUEL DESIGNS

Table 4-1 compares various parameters for the 8x8 and 10x10 SVEA fuel designs. As shown, the [

][a].

Table 4-1 Comparison of SVEA Fuel Assembly Design Parameters

[a]

5 EVALUATION MODEL MODIFICATIONS

5.1 GOBLIN NODALIZATION

5.1.1 Level Tracking

[

]a,c

Table 5-1 Timing of Key Events With Level Tracking Activated and Deactivated

a,c

5.1.2 GOBLIN Nodalization for SVEA-96 Optima2 Fuel

The nodalization for SVEA-96 Optima2 fuel is very similar to the nodalization for SVEA-96+ fuel. As discussed in Section 5.5.1, the hot plane heat-up model has been revised to permit a more accurate determination of the plenum temperature of the part-length rods. The new plenum model requires [

]a,c

[

][a,c].

a,c

Figure 5-1 GOBLIN Overall Nodalization for SVEA-96 Optima2 Fuel

[ ][a,c]

Figure 5-2 GOBLIN Core Noding for SVEA-96 Optima2 Fuel

5.2 DRAGON NODALIZATION FOR SVEA-96 OPTIMA2 FUEL

DRAGON is used to determine the thermal-hydraulic response of the hot assembly. The transient fluid boundary conditions [ ][a,c] The nodalization used for SVEA-96 Optima2 fuel is similar to the model that has been used for other SVEA fuel designs except for the minor changes that are discussed in Section 5.1 above. The nodalization diagram is shown in Figure 5-3.

a,c

Figure 5-3 DRAGON Nodalization for SVEA-96 Optima2 Fuel

5.3 CHACHA-3D NODALIZATION FOR SVEA-96 OPTIMA2 FUEL

Because of the similarity between the SVEA-96/96+ design and the SVEA-96 Optima2 design, the nodalization for the CHACHA-3D model is unchanged. Previous sensitivity studies (Section 4.3.1 of RPB 90-94-P-A (Reference 3) and Section 6.3.1 of CENPD-283-P-A (Reference 4)) have showed little sensitivity to fuel rod noding. The standard fuel rod noding is also used for SVEA-96 Optima2 fuel, which consists of [

]a,c

5.4 THERMAL-HYDRAULIC ANALYSIS CODE MODIFICATIONS

5.4.1 CPR Correlation for SVEA-96 Optima2 Fuel

5.4.1.1 Methodology

Critical Power Ratio (CPR) correlations are part of the heat transfer model in GOBLIN and DRAGON. The CPR correlation is used to determine the initial power of the hot assembly. The CPR correlation may also determine when boiling transition occurs during the LOCA transient if the fluid conditions are within the range of applicability of the correlation. The Westinghouse USA5 BWR ECCS Evaluation Model will use the SVEA-96 Optima2 CPR correlation that is approved by the NRC for applications involving the SVEA-96 Optima2 fuel design.

5.4.1.2 Discussion

An NRC-approved CPR correlation that is applicable to the fuel-design being analyzed is used in the ECCS Evaluation Model (RPB 90-93-P-A , Reference 3). At the time this topical report was written, the CPR correlation for SVEA-96 Optima2 had not been submitted to NRC for review and approval. Qualification of the SVEA-96 Optima2 CPR correlation will be provided in that topical report. The CPR correlation will be installed in the GOBLIN code in accordance with the process described in Section 3.3.2.2 and used for licensing applications after the correlation has been approved by NRC. NRC will be informed of the resulting change to the GOBLIN code via the 10CFR50.46 reporting process.

5.4.1.3 Qualification

The CPR correlation is used to establish a conservative hot assembly initial power. The CPR correlation may also be used to establish the time of boiling transition during the LOCA transient. Since the implementation of the CPR correlation in GOBLIN requires that it be used only over the range of parameters covered by its database, the system pressure or core mass flux may be out of range of the correlation at the time of boiling transition. As a result, the onset of boiling transition may be predicted by an appropriate critical heat flux correlation (e.g., GOBLIN's [

]a,c

[

]a,c

5.4.2 Counter-Current Flow Limit

5.4.2.1 Methodology

The CCFL correlation in the USA5 Evaluation Model has been modified to conservatively encompass all of the data in the correlation database as discussed below. Westinghouse will use the following expression to determine the effective diameter (D_e) in a flow channel. This term is used in the CCFL correlation in the [

]a,c

$$\left[\qquad \right]^{a,c} \qquad [5\text{-}1]$$

5.4.2.2 Discussion

There is a limit to the quantity of water that can flow counter-current to a given upward steam flow. This phenomenon, which is called the counter-current flow limit, has an effect on the path taken by cooling water that is injected into the upper plenum of a BWR via the core spray header. The sensitivity of the predicted peak cladding temperature is discussed in detail in the response to the request for additional information (Question 7) during the NRC review of CENPD-283-P-A (Reference 4). This study concluded that CCFL [

]a,c However, since the CCFL correlation did not bound the correlation database over the full range of flow rates, Westinghouse committed to applying a bias to the CCFL correlation, as required to maintain conservative results relative to experimental data when the predicted peak cladding temperature is in excess of 2100°F.

The CCFL is determined by a correlation that was developed from experimental data. The correlation is expressed in terms of basic geometrical parameters that enable the correlation to be applied to a variety of geometries (e.g., circular channels, square channels, and fuel assemblies). The objective of the change described below is to revise one of the geometrical parameters used in the correlation to one that better represents the observed phenomena and bounds the experimental database.

The Westinghouse BWR CCFL correlation, which is documented in Section 3.3 of RPB 90-93-P-A (Reference 3), is based on works of J. A. Holmes (Reference 7), G. B. Wallis (Reference 8) and R. V. Bailey (Reference 9). The CCFL correlation expresses the limiting downward volumetric flux of liquid ($-j_f$) in terms of the upward volumetric flux of vapor (j_g).

The constants in the correlation were formulated in terms of [

]a,c

[

]a,c

5.4.2.3 Qualification

The QUAD+ CCFL data is used to qualify the validity of this change. As shown in Figure 5-5, when the CCFL correlation is based on the [

]a,c

[

]a,c This is discussed in more detail in Section 6.3.

5.5 ROD HEAT-UP ANALYSIS CODE MODIFICATIONS

5.5.1 Gas Plenum Model for Part-Length Fuel Rods

5.5.1.1 Methodology

The detailed fuel heat-up computer code (CHACHA-3D) has been revised to provide a new plenum type that permits a conservative prediction of the plenum temperature of the part-length rods. For this plenum type, the gas temperature in the rod plenum is determined conservatively by equating it to the [

]a.

5.5.1.2 Discussion

The plenum sections of the part-length rods are located within the active core. Hence, they will receive radiation heat transfer from other rods during the heat-up phase of the LOCA. The conventional plenum model in CHACHA-3D, which is described in RPB 90-93-P-A (Reference 3), is not in this environment and does not completely address part-length fuel rods.

The methodology used to determine the plenum gas temperature for a part-length rod, such as those in the SVEA-96 Optima2 design, is different from the methodology used for a full-length rod. To apply the part-length rod plenum option, [

]a,c

a,c

Figure 5-4 Westinghouse CCFL Correlation (high void fraction regime)

a,b,c

Figure 5-5 Comparison of CCFL Correlation to QUAD+ CCFL Test Data

a,c

Figure 5-6 Comparison of Plenum Temperatures and Pressures

5.5.2 Fuel Performance Model

5.5.2.1 Methodology

The heat-up computer code (CHACHA-3D) shall use a consistent set of inputs and models from an NRC-approved fuel performance code. The USA5 Evaluation Model uses these new models and conservative inputs from the STAV7.2 fuel performance code.

5.5.2.2 Discussion

CENPD-293-P-A (Reference 4) describes the implementation of the relevant STAV6.2 fuel performance models in the CHACHA-3D code. This section describes the changes to CHACHA-3D that were made to incorporate the relevant STAV7.2 models.

The STAV7.2 code is the latest version of the STAV fuel performance code series developed and used at Westinghouse. The STAV7.2 fuel performance code is described in Reference 10. The STAV7.2 code is currently under review at the NRC.

5.5.2.3 Qualification

The new models that have been introduced in the STAV7.2 code to obtain improved predictions of various fuel properties throughout the design life of the fuel rod and to extend the fuel rod burn-up range are summarized below. How these new models have been incorporated into the USA5 BWR ECCS Evaluation Model is also described:

[

]a,c

[[redacted]]a,c

[

]a,c

a,c

Figure 5-7 Comparison of UO_2 Fuel Pellet Thermal Conductivity

a,c

Figure 5-8 Comparison of Radial Power Distributions

6 APPLICABILITY OF EVALUATION MODEL TO SVEA-96 OPTIMA2 FUEL

6.1 APPLICABILITY OF THE SPRAY HEAT TRANSFER MODEL TO SVEA-96 OPTIMA2 FUEL

6.1.1 Methodology

[

]a,c

Table 6-1 SVEA-96 Optima2 Spray Cooling Heat Transfer Coefficients

a,c

6.1.2 Qualification

Although the channel size has not changed significantly since the 1970's, the BWR fuel assembly designs have changed in many ways. These changes have resulted in a larger number of smaller diameter fuel rods as well as various non-boiling water channel designs. Figure 6-1 illustrates how the [

]a

Spray heat transfer tests have been performed (e.g., the BWR FLECHT test program) from which convective spray heat transfer coefficients have been derived. CENPD-283-P-A (Reference 4) provides a summary of these tests and describes how the spray cooling heat transfer coefficients are applied to various fuel geometries. [

]a,c

The BWR FLECHT tests, which simulated a 7x7 array, showed that the convective coefficients are dependent on the location of the fuel rod relative to its proximity to the channel enclosure (corner rod, outer row rod, or interior rod). Table 6-2 lists the heat transfer coefficients that are acceptable for use in an Appendix K analysis of 7x7 fuel.

Table 6-2 Appendix K Spray Cooling Heat Transfer Coefficients (W/m²-K)			
Corner Rods	Side Rods	Inner Rods	Channel
17.0	19.9	8.5	28.4

The use of these values requires the use of a radiation model that is consistent with the methodology that was used to generate them. The values in Table 6-2 were generated using a radiation heat transfer model that assumed [

]^{a,c}

The following discussion is a summary of how the BWR FLECHT spray heat transfer coefficients have been converted so that they can be used with an [

]^{a,c}

8x8 Geometry – As shown in Figure 6-1, the 8x8 designs have a ~ 7.7% smaller hydraulic diameter than the 7x7 design. This is due primarily to the increased fuel rod surface area due to the larger number of fuel rods. Test data from the [

]^{a,c} Table 6-3 shows the resulting convective heat transfer coefficients that are applied to the 8x8 geometry:

Table 6-3 8x8 Spray Cooling Heat Transfer Coefficients (W/m²-K)			

a,c

SVEA-64 Geometry – The SVEA-64 assembly, which is described qualitatively in Section 3.2 of Reference 4, is made up of four 4x4 sub-assemblies. [

]^{a,c}

[

]a,c Table 6-4 compares the heat transfer coefficients derived in this manner to convective heat transfer coefficients that yield a more realistic prediction of the Reference 12 data.

Table 6-4 SVEA-64 Spray Cooling Heat Transfer Coefficients (W/m²-K)				

a,b,c

The heat transfer coefficients generated from both the BWR FLECHT and the SVEA-64 spray cooling tests show that the rods [

]a,c

SVEA-96/96+ Geometry – The SVEA-96 fuel assembly, which is described in Section 3 of CENPD-283-P-A (Reference 4), consists of four sub-assemblies – each consisting of 24 fuel rods in a 5x5-1 array. The sub-assemblies are separated from each other by a cruciform internal structure (water cross) with a square center channel and cross wings with gaps for non-boiling water during normal operation. Except for closer grid spacing above the midplane, the SVEA-96+ geometry is identical to the SVEA-96 assembly. The basis for the convective spray heat transfer coefficients for the SVEA-96/96+ geometry was developed in CENPD-283-P-A (Reference 4). [

]a,c

Table 6-5 SVEA-96/96+ Spray Cooling Heat Transfer Coefficients (W/m²-K)				

a,c

SVEA-96 Optima2 Geometry – As discussed in Section 4.2, with regard to rod diameter and hydraulic diameter, the [

]^{a,c}

Table 6-6 Extrapolated Spray Cooling Heat Transfer Coefficients (W/m^2-K)

a,c

[

]^{a,c}

[ ] [a]

Figure 6-1 Hydraulic Diameters for Various BWR Fuel Designs

a,c

Figure 6-2 Effect of Spray Cooling Heat Transfer Coefficient of Cladding Temperature

a,c

Figure 6-3 Radiative and Convective Heat Transfer from Central Rod

6.2 APPLICABILITY OF THE RADIATION HEAT TRANSFER MODEL TO SVEA-96 OPTIMA2 FUEL

6.2.1 Methodology

The thermal radiation model in CHACHA-3D, which is the same as described in RPB 90-93-P-A (Reference 3), is applied without change. The [

]a,c

6.2.2 Qualification

As shown in Figure 6-4, the [

]a,c

[ ]a,c

Figure 6-4 SVEA-96 Optima2 Sub-Assembly Cross Section

[ ]a,c

Figure 6-5 View Factors Between Rod #8 and Other Surface Groups

a,c

Figure 6-6 Results of Sensitivity Study on Rod Pitch

6.3 APPLICABILITY OF THE CCFL MODEL TO SVEA-96 OPTIMA2 FUEL

6.3.1 Methodology

The CCFL methodology is described in Section 5.4.2, which presents a change to the CCFL model that increases its conservative bias with respect to its database. Since the CCFL methodology accounts for the relevant geometrical parameters associated with a fuel design, the CCFL methodology as described in this topical report will be applied to analyses of the SVEA-96 Optima2 fuel design using the appropriate geometric parameters for the fuel design.

6.3.2 Qualification

The CCFL [

]a,c

Table 6-7 CCFL Sensitivity Study Results

a,c

7 COMPLIANCE WITH 10CFR50, APPENDIX K

The changes to the Westinghouse BWR ECCS Evaluation Model described in this report are:

- A modification of the CCFL correlation such that it conservatively predicts the entire database of the correlation.
- The addition of a fuel rod plenum model for application to part-length fuel rods
- Incorporation of an improved fuel performance model to account for important burn-up dependent fuel properties and a more accurate description of the pellet radial power distribution.

Only the fuel performance aspect of the change to the Evaluation Model affects previous statements of compliance of the Westinghouse BWR Evaluation Model with 10CFR50, Appendix K. Descriptions of the compliance of the Westinghouse BWR ECCS Evaluation Model with Title 10, Code of Federal Regulations, Part 50, Appendix K are given in Chapter 5 of RPB 90-93-P-A (Reference 3), Chapter 6 of CNEPD-293-P-A (Reference 4) and Chapter 5 of WCAP-15682-P (Reference 5). The descriptions of compliance in References 3 and 4 are revised as described below. The description of compliance in Reference 5 is unchanged.

7.1 APPENDIX K SECTION I.A – SOURCES OF HEAT DURING THE LOCA

Section I.A reads as follows:

> *"For the heat sources listed in paragraphs I.A.1 to 4 of this appendix it must be assumed that the reactor has been operating continuously at a power level at least 1.02 times the licensed power level (to allow for instrumentation error), with the maximum peaking factor allowed by the technical specifications. An assumed power level lower than the level specified in this paragraph (but not less than the licensed power level) may be used provided the proposed alternative value has been demonstrated to account for uncertainties due to power level instrumentation error. A range of power distribution shapes and peaking factors representing power distributions that may occur over the core lifetime must be studied. The selected combination of power distribution shape and peaking factor should be the one that results in the most severe calculated consequences for the spectrum of postulated breaks and single failures that are analyzed."*

Westinghouse Evaluation Model Compliance with Section I.A:

> Section I.A of Appendix K has changed relative to Westinghouse's statement of compliance in Reference 4 in that an assumed power level less than 1.02 times the licensed power level may be used provided the proposed alternative value has been demonstrated to account for uncertainties due to power level instrumentation error. Westinghouse may account for power level instrumentation uncertainties less than 2 percent, but no less than the power level uncertainty that has been demonstrated.

7.2 APPENDIX K SECTION I.A.1 – THE INITIAL STORED ENERGY IN THE FUEL

Section I.A.1 reads as follows:

> *"The steady-state temperature distribution and stored energy in the fuel before the hypothetical accident shall be calculated for the burn-up that yields the highest calculated cladding temperature (or, optionally, the highest calculated stored energy.) To accomplish this, the thermal conductivity of the UO2 shall be evaluated as a function of burn-up and temperature, taking into consideration differences in initial density, and the thermal conductance of the gap between the UO2 and the cladding shall be evaluated as a function of the burn-up, taking into consideration fuel densification and expansion, the composition and pressure of the gases within the fuel rod, the initial cold gap dimension with its tolerances, and cladding creep."*

Westinghouse Evaluation Model compliance with Section I.A.1:

> The revised model for the [
>
>]^{a,c}

7.3 APPENDIX K SECTION I.C.4 – CRITICAL HEAT FLUX

A full statement of Section I.C.4 of Appendix K is given in 10CFR50, Appendix K.

The Westinghouse BWR ECCS Evaluation Model compliance with Section I.C.4 of Appendix K is summarized as follows:

> The critical heat flux in the system and hot assembly analyses is determined using an NRC-approved CPR correlation that is applicable to the fuel design. For SVEA-96 Optima2 fuel, that correlation will be will be submitted to NRC for approval prior to its use for ECCS performance analyses. The implementation of the CPR correlation in the GOBLIN code is described in Section 3.3.2.2.

8 REFERENCES

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3. Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Description and Qualification," Westinghouse Report RPB 90-93-P-A (Proprietary), RPB 90-91-NP-A (Non-Proprietary), October 1991.

   "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity," Westinghouse Report RPB 90-94-P-A (Proprietary), RPB 90-92-NP-A (Non-Proprietary), October 1991.

   Thadani, A. C., "Acceptance for Referencing of Licensing Topical Reports WCAP-11284 and WCAP-11427 Regarding the Westinghouse Boiling Water Reactor Emergency Core Cooling System Evaluation Model," August 22, 1989.

4. "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity for SVEA-96 Fuel," Westinghouse Report CENPD-283-P-A (Proprietary), CENPD-283-NP-A (Non-Proprietary), July 1996.

   "BWR ECCS Evaluation Model: Supplement 1 to Code Description and Qualification," Westinghouse Report CENPD-293-P-A (Proprietary), CENPD-293-NP-A (Non-Proprietary), July 1996.

5. "Westinghouse BWR ECCS Evaluation Model: Supplement 2 to Code Description, Qualification and Application," Westinghouse Report WCAP-15682-P-A (Proprietary), WCAP-15682-NP-A (Non-Proprietary), April 2003.

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11. Petterson, R. "GÖTA Data Analysis. Comparisons Between Test Data and Calculations," RCC-79-68, May 1979.

12. O. Nylund, R. Eklund, H. Wijkström, "Spray Cooling Experiments on SVEA Water Cross BWR Fuel," Paper presented to the 1988 European Two-Phase Flow Group Meeting.

APPENDIX A
RESPONSES TO REQUESTS FOR ADDITIONAL INFORMATION

A.1 INTRODUCTION

This Appendix contains the responses to NRC Requests for Additional Information (RAIs). The responses to the RAIs were made in References A-8 through A-11. The following is a compilation of that information.

Question 1:

WCAP-16078-P is a LTR documenting the new incremental changes of the Westinghouse BWR ECCS Evaluation Model Version USA4.0. The methodology consists of three computer codes: GOBLIN, DRAGON and CHACHA-3D and relevant input models. Please provide qualification reports, user input manuals and theory manuals of these three computer codes. (Already provided partially.)

Response to Question 1:

Qualification reports, theory manuals and other supporting documents have been provided on the GOBLIN and CHACHA computer codes in LTR-NRC-03-33 dated June 30, 2003. User manuals for GOBLIN and CHACHA were provided in LTR-NRC-03-67 dated November 18, 2003. Since the GOBLIN user manual provided contained several missing pages, a corrected GOBLIN user manual is provided with this submittal. Note that DRAGON is a subset of GOBLIN and is described in the GOBLIN documentation provided.

Question 2:

As part of this LTR, please provide engineering drawings of the proposed SVEA-96 Optima2 fuel design. (Already provided.)

Response to Question 2:

As indicated, engineering drawings of the SVEA-96 Optima2 fuel design were provided in LTR-NRC-03-40 dated July 25, 2003 as requested.

Question 3:

Please provide the new versions of these three codes. The source codes, executables and plant input decks. In addition, please also provide the executables of USA version 4 for comparison purposed. Please specify the computer platforms on which these codes are compiled and executed, also, the compiler version number. If there are some other graphics tools used to extract the plotting data for graphic purposes, please provide the executables.

Response to Question 3:

Executables of the following computer codes, which are located on an ALPHA processor running operating system OSF1 version 1885 release V5.1, have been provided on a CD provided with this submittal:

GOBLIN-3.12 – This computer code is used to calculate the thermal-hydraulic system performance and thermal-hydraulic hot assembly performance (when the logical variable DRAGON is specified as true).

CHACHA-3D.6 – This computer code is used to perform a detailed temperature analysis of an axial cross section in a BWR fuel bundle following a loss of coolant accident. This version of CHACHA contains a special model for determining the plenum pressure of part-length fuel rods, an improved optional fuel pellet radial power distribution model and improved fuel pellet conductivity models.

HOBIT-3.12 – This computer code is used to preprocess GOBLIN input data.

FRODO-3.12 – This computer code is used to change input data previously defined and to restart GOBLIN (e.g., initiate a break).

SUPERB-1.21a – This computer code is the plotting routine used to extract information from the binary output files from GOBLIN, DRAGON and CHACHA.

The only GOBLIN computer code currently available is version 3.12. A new version of GOBLIN will be used for SVEA-96 Optima2 licensing applications. The new version will contain the CPR correlation for SVEA-96 Optima2 fuel D4.1.1 documented in WCAP-16081, which is currently under review by the NRC, and run on the LINUX operating system.

Except for the CPR correlation, GOBLIN-3.12 may be used for evaluating the USA5 Evaluation Model by using appropriate inputs for the CCFL correlation.[1] GOBLIN 3.12 was used to respond to questions 4 and 5 herein, as well as the studies performed in support of WCAP-16078-P.

Since the USA4 version of CHACHA (3D.5) does not provide the capability to model the [ ]^{a,c} only version 3D.6 is provided. The modifications in CHACHA-3D.6 compared to CHACHA-3D.5 are the following:

- The implementation of the STAV7.2 [ ]^{a,c} The use of this model is optional.
- The implementation of the STAV7.2 [ ]^{a,c} The use of this model is not optional.

1 The CCFL coefficient that has been changed is input to GOBLIN under keyword FLOWPA as the variable PWFLOW. For the USA4 methodology, this term was input as the [ ]^{a,c}

- The introduction of a new [

]^{a,c} The use of this model is optional.

An overview of the information provided on the CD is provided in a file called INSTRUCTION.txt in the main directory. Additional detailed instructions for performing certain tasks are provided in README files in the various subdirectories on the CD. Input files for GOBLIN, DRAGON and CHACHA are provided for a BWR4 with 764 SVEA-96 Optima2 fuel assemblies. The rated thermal power and core flow rate for this plant are 3339 MWt and 1 x 10^8 lb/hr. A sample large break LOCA is provided on the CD for this plant initiated from conditions of 102.7% of rated thermal power and 105% of rated core flow.

Question 4:

It was indicated that the improved CCFL model alters the predictions of the PCT. Is there a plant LOCA analysis to show the comparison before and after the improvement of the CCFL model.

Response to Question 4:

Section 6.3.2 of WCAP-16078-P provides the results of a sensitivity study in which the CCFL restriction of the 'upper tie plate' was increased by over 10%. This study showed that the impact of the change was [

]^{a,c}

An additional sensitivity study was performed in response to this request. In this study, the CCFL model that is described in RPB 90-93-P-A (Reference 3 of WCAP-16078-P) was applied to all flow paths in both the system and the hot assembly models. This study also [

]^{a,c}

Question 5:

According to the engineering drawings and the fuel design descriptions, it appears that there are cross-flow areas among sub-channels within the fuel bundle. Therefore, during the LOCA, one would expect that the "hotter" subchannel would experience localized flow starvation due to the sub-channel cross-flow. If this physical process is considered credible, is the 1-D approach used by DRAGON sufficient to model Optima 2 fuel?

Response to Question 5:

The DRAGON analysis of the hot assembly is used to determine boundary conditions for the detailed heat-up calculations of the limiting plane. The most important of the boundary conditions are the convective heat transfer coefficients.

The results from DRAGON primarily determine the [

]^{a,c} As required by Appendix K, a convective heat transfer coefficient of zero is applied from the time of dryout until the core spray pumps achieve rated flow. After the adiabatic period and until two-phase conditions are predicted to return to the midplane, constant 'spray cooling' convective heat transfer coefficients are applied, also as required by Appendix K. After two-phase recovery of the midplane, a constant heat transfer coefficient of 25 Btu/(hr-ft^2-°F) is applied to all fuel rods, also as required by Appendix K.

Thus, the convective heat transfer coefficients that are applied to the heat-up analysis are, for the most part, prescribed by Appendix K. Any variability in the predicted heat transfer coefficients prior to the time of dryout would have a [

]^{a,c}

The channel power used in the DRAGON analysis of the hot assembly is a conservative estimate of the power that would [

]^{a,c} Therefore, the fuel assembly power in DRAGON is set conservatively to a value that is higher than would be allowed during operation.

Figure A-1 shows for a typical design that the limiting assemblies [

]^{a,c}

The expected effect of the cross-flow paths is a [

]^{a,c}

A special DRAGON model was created to [

]^{a,c}

[

]a,c

[ ]a,c

Figure A-1 Variation Maximum Sub-assembly Power Peaking with Assembly Peaking

Question 6:

Figure 3-1 shows the flow of information between computer codes. Please clarify whether all three code run independently during every time step of calculation. In other words, does DRAGON and CHACHA-3D provide feedback to the GOBLIN to affect the system wise solution schemes. If DRAGON and CHACHA-3D only perform side calculations based on the boundary conditions provided by GOBLIN, how is the energy generation due to metal-water reaction considered in the GOBLIN?

Response to Question 6:

As indicated in Figure 3-1 of WCAP-16078-P, GOBLIN is run to determine the boundary conditions for the hot channel analysis (DRAGON). Then DRAGON is run to determine the boundary conditions for the fuel heat-up analysis (CHACHA). There is [

]a,c

[

]a,c

Question 7:

It was indicated on Page 22 of the LTR, the CCFL correlation has been validated for SVEA-64 (QUAD+) geometry by comparison to nitrogen/water tests. First, please provide some geometry data or drawing to show the similarity of SVEA-96 Optimal 2 fuel. Second, when the new CCFL correlation effective diameter is used, has the code DRAGON been used to calculate the liquid and vapor fluxes? If it was, was the nodalization used same as that for SVEA-96?

Response to Question 7:

Geometry Data – The CCFL facility, which is described in the response to Question 8 in RPB 90-93-P-A (Reference A-1), was designed using prototypical SVEA-64 hardware. Table 4.1 of WCAP-16078-P compares the several design parameters of the SVEA-64 (QUAD+) fuel design to the SVEA-96 Optima2 fuel design. As shown in Table 4.1, the active flow areas of the [

]a,c Figure 4.2 of WCAP-16078-P shows a cross-sectional sketch of the SVEA-96 Optima2 fuel design. Figure 3.3 of CENPD-283-P-A (Reference A-3) shows a cross-sectional sketch of the SVEA-64 fuel design.

Application of Correlation – When the new CCFL correlation [

]a,c in GOBLIN and DRAGON is provided in Section 3.3.1 of RPB 90-93-P-A (Reference A-1).

Nodalization – [

]a,c Boundary conditions are applied from the GOBLIN system analysis to the upper and lower plenum nodes and to the bypass channel. This general nodalization scheme is identical for both the SVEA-96 and SVEA-96 Optima2 fuel designs. However, there are slight differences in sub-node heights in the active fuel assembly between the two models. For example, it was necessary for the [ ]a,c

[

]a,c

Question 8:

It was stated that SVEA-96 Optima 2 fuel used non-uniform pitch ratio and part length rods. Please explain why the new effective diameter would still result in conservative results for those fuel pins with minimum pitch ratio and away from the empty spots created by the part length rods.

Response to Question 8:

The fundamental quantities of the CCFL are the [

]a,c These quantities are correctly accounted for in GOBLIN / DRAGON by the use of the [

]a,c

It is also important to keep in perspective the quantities provided by the DRAGON hot assembly analysis. These quantities are:

[ ]a,c
[ ]a,c
[ ]a,c

The only heat transfer coefficients calculated by DRAGON that are used directly in the CHACHA heatup [

]a,c For the remainder of the transient, the convective heat transfer coefficients are prescribed by Appendix K. Since this is not a best-estimate methodology, a [

]a,c

Question 9:

How does the DRAGON hot channel model handle the spacers and smooth rod sections? Does the code explicitly model all the spacers? Was the CCFL option turned on at each cell face? How was the CCFL handled at the end of the part length rods?

Response to Question 9:

The DRAGON hot channel model and the GOBLIN system analysis models account for the form pressure drop of the spacers and the frictional pressure drop of smooth rod sections. The frictional and form pressure drop models are described in Sections 3.3.3 and 3.3.4 of RPB 90-93-P-A (Reference A-1).

[

]a,c

As described in Section 3.3.1 of RPB 90-93-P-A (Reference A-1), the [

]a,c

Question 10:

On Page 7, the transition core was discussed and several acceptability criteria were discussed. First, please clarify why the midplane of the hot assembly is particular of Interest. If the core has an axial power peaking at upper 1/3 of the core, is the plane at the power peak more limiting than the midplane?

Response to Question 10:

The Westinghouse BWR methodology [

]a,c Hence, the overall ECCS evaluation model remains acceptably conservative.

Assessment of Conservatisms – An assessment of the conservatism in the Westinghouse BWR ECCS methodology was presented in Appendix D of CENPD-300-P-A (Reference A-7). Two features of the methodology were identified as being very conservative. They are the [

]a,c

[

]a,c

Effect of Axial Power Shapes – The axial power shape of the hot assembly in a BWR is typically bottom-peaked at the beginning of cycle. This is due to the coolant void distribution in a BWR, which causes more moderation in the lower part of the core. Thus, the fuel in the lower part of the core is depleted more quickly than the fuel at the top of the core. The bottom-peaked power shape persists until near the end of the cycle, when the power transitions to a symmetrical shape and finally a top-peaked shape.

The sensitivity of the ECCS performance analysis to axial power distribution was studied in Section 6.2 of RPB 90-94-P-A (Reference A-2). This sensitivity study included three cases with an axial peaking factor of [

]a,c

[

]a,c

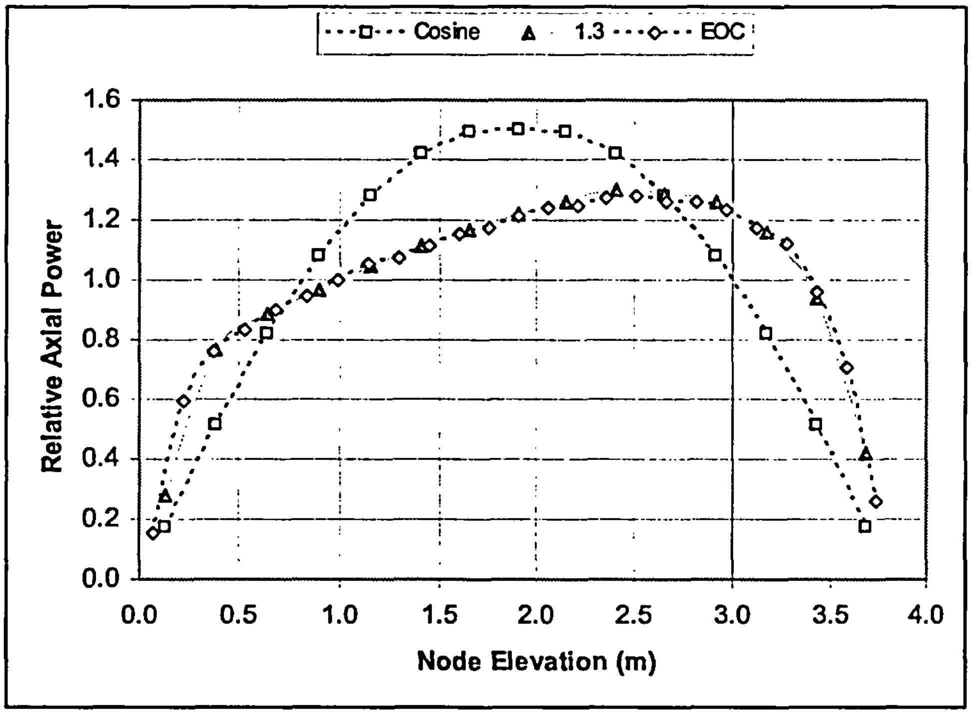

Figure A-2 Comparison of Axial Power Shapes

a,c

Figure A-3 Comparison of Predicted Hot Rod Response for Different Axial Power Shapes

Question 11:

For a transition core with SVEA-96 Optima 2 fuel, has the GOBLIN [code] been demonstrated to calculate the conservative spray distribution on top of the hot channel? Has the methodology taken into account the situation that, due to the difference of mechanical design, the spray of LPCI would cause some bundle more limiting than the hot channel even when its power peaking factor is less than that of hot channel?

Response to Question 11:

The Westinghouse ECCS methodology [

]a,c

[

]a,c

a,c

Figure A-4 Reference Case – Peak Cladding Temperature Distribution

a,c

Figure A-5 Influence of Assembly Spray Flow Rate on Peak Rod Temperature

Question 12:

When will CPR for SVEA-96 Optimum 2 fuel be submitted to NRC? Without the specific CPR, this methodology cannot be used for SVEA-96 Optima 2 fuel LOCA applications.

Response to Question 12:

The topical report describing the CPR correlation for SVEA-96 Optima2 fuel (D4.1.1) was submitted to NRC for review in WCAP-16081-P (Reference A-4). Westinghouse is currently responding to NRC questions relative to the review. The SER for RPB 90-93-P-A (Reference A-1), requires an NRC-approved CPR correlation to be implemented in the Westinghouse BWR ECCS methodology for licensing applications. Pursuant to that requirement, the approved CPR correlation for SVEA-96 Optima2 fuel will be implemented in the GOBLIN code prior to its application to that fuel design.

Question 13:

The level tracking model was tested for application to lower plenum. The sensitivity study shown that the timing of key events was not sensitive to the use of the model. Therefore, please explain why this part of discussion is included in this LTR if there is no difference between USA5 and USA4. In addition, please explain what the statement on Page 16 means, "... unless warranted by the specific application.."

Response to Question 13:

It is recognized that this change to the methodology has no impact on the results. However, since prior licensing topical reports (LTRs) (e.g., CENPD-283-P-A) indicated that level tracking would be used in the lower plenum, it was considered prudent to provide a formal justification for flexibility in the use of level tracking in the lower plenum in future analyses. The sensitivity study contained in WCAP-16078 provides justification for flexibility in the use of the level-tracking feature.

The statement "...unless warranted by the specific application" is included to indicate that there may be a plant-specific application where the use of level tracking in the lower plenum is necessary to maintain accuracy for a specific plant design where it is important to accurately capture the physical phenomenon associated with the location of the two-phase level interface.

Question 14:

Please explain how was the core average channel being modeled for a mixed core; i.e., how to determine the averaged local loss coefficients, flow area, hydraulic diameter and spacer locations, if different spacer locations exist in different bundle designs?

Response to Question 14:

The Westinghouse methodology is to [

]a,c

A comparison was presented in Section 9.3 of RPB 90-94-P-A of system response analyses performed with a full core of SVEA-64 fuel and a mixed core containing two-thirds SVEA-64 fuel and one-third 8x8 fuel. The SVEA-64 fuel is an 8x8 water-cross design and the 8x8 fuel was an open lattice design. The results showed [

]a,c

A similar result is expected for applications involving the introduction of SVEA-96 Optima2 fuel, which is also a 10x10-4 water-cross design with part-length fuel rods. However, Westinghouse will perform an evaluation to determine if this approach can continue to be applied during future applications of the evaluation model. This evaluation will compare a system analysis of a core containing a full core of SVEA-96 Optima2 fuel to a mixed core containing approximately one-third SVEA-96 Optima2 fuel and two-thirds legacy fuel. In the event this simplification is not justified, the mixed core model will be used for the system response analysis.

Clarification to Question 14 Response:

The GOBLIN code is fully capable of modeling a mixed core as a series of parallel channels having different characteristics (i.e., loss coefficients, flow areas, hydraulic diameters, spacer locations, fuel rod dimensions, etc.). The Westinghouse methodology is to [

]a,c

ECCS core-wide system response has been demonstrated in numerous U.S. and European applications not to be very sensitive to the unique fuel design features. For example, a comparison was presented in Section 9.3 of RPB 90-94-P-A of system response analyses performed with a full core of SVEA-64 fuel and a mixed core containing two-thirds SVEA-64 fuel and one-third 8x8 fuel of an open lattice design. The SVEA-64 fuel is an 8x8 water-cross design. The results showed [

]a,c

A similar result is expected for applications involving the introduction of SVEA-96 Optima2 fuel, which is also a 10x10-4 water-cross design with part-length fuel rods. However, Westinghouse will perform an evaluation to determine if this approach can continue to be applied for future applications of the evaluation model. This evaluation will compare a system analysis of a core containing a full load of SVEA-96 Optima2 fuel to a mixed core containing approximately one-third SVEA-96 Optima2 fuel and two-thirds legacy fuel (e.g., GE14). In the event this simplification is not justified, the mixed core model will be used for the system response analysis that is used to determine the MAPLHGR limits for the Westinghouse fuel.

If the mixed core model is determined to be limiting for the first transition cycle, it is anticipated that the system response would improve in subsequent reload cycles as the legacy fuel is replaced by Westinghouse fuel. Therefore, the MAPLHGR limits determined for the Westinghouse fuel during the first transition cycle and subsequent is expected to remain conservative to the end of life if based on the system response determined by the mixed core model.

Westinghouse performed a review of the previous Safety Evaluation Reports (SERs) performed by the NRC on previous BWR LOCA evaluation models. No restrictions were identified that would prevent using GOBLIN to derive the system response using a mixed core model that contained fuel manufactured by another fuel vendor. The information necessary to develop a mixed core model is provided by the utility. In addition, the individual constitutive models in GOBLIN are sufficiently general that non-Westinghouse fuel can be represented adequately.

Question 15:

Please explain how the bounding radial power distribution is developed in the average channel of GOBLIN code to maximize the sensible heat and stored energy? Is it defined on a cycle specific basis?

Response to Question 15:

The normal procedure is to use the boundary conditions from the GOBLIN system analysis to drive the analysis of the hot assembly. The radial peaking used for the hot assembly is established such that [

]a,c. As the GOBLIN system analysis usually represents the [

]a,c. Sensitivity studies have been performed using GOBLIN models with several parallel channels to represent the low power regions around the core periphery, intermediate interior power assemblies and the hot assembly. These studies showed that the [

]^{a,c}.

In the event a mixed core model is used to perform the GOBLIN system analysis, there would be two or more parallel channels to represent the different fuel assembly designs. The radial power factor used for each channel would be based on the core design.

The initial fuel stored energy in the GOBLIN average channel analysis is conservatively maximized by using an initial power level that includes the power measurement uncertainty and lower bound fuel rod performance conditions that minimize the cladding to pellet gap heat transfer.

Question 16:

Last sentence of Page 20 seems to be incomplete. Please clarify.

Response to Question 16:

The last sentence on page 20 continues on to page 21 where it is completed.

Question 17:

Page 26 and 27 discussed seven new modeling features added from STAV7.2 code into the CHACHA-3D code. How is the ballooning effect modeled by CHACHA-3D code in terms of flow area change during the ballooning process? What is its impact on the PCT and the release of decay heat/stored energy.

Response to Question 17:

As indicated on page 27 of WCAP-16078, only two of the fuel performance models in STAV will be installed in CHACHA-3D. These are [

]^{a,c}. Both of these models have been improved in STAV7.2 relative to STAV6.2. As discussed in the response to Question #18, additional parameters supporting the temperature calculation are input from STAV as part of the LOCA analysis initialization.

The fuel cladding strain and rupture models in the CHACHA-3D code are not being changed. These models are described in Section 5.6 of CENPD-293-P-A. Section 7.2 of this report provides comparisons of predicted rupture strains with data. Although ballooning of the cladding will reduce the flow area, the evaluation model uses spray heat transfer coefficients as prescribed by Appendix K when the cladding is predicted to balloon. The effect of increased steam velocity at the ballooned locations is not modeled since these coefficients are constant throughout the 'spray cooling' interval. Although ballooning of the cladding has a beneficial effect on heat transfer by convection due to the increased outer surface area, this effect is conservatively neglected in CHACHA-3D.

With regard to the impact of ballooning on the peak cladding temperature (PCT), the overall effect of ballooning is normally to increase the PCT. Since ballooning usually develops into rod rupture for the fuel rod exhibiting the PCT, the double-sided metal-water reaction clearly increases the PCT. The ballooning of the cladding also influences the heat transfer between the fuel pellet and the cladding. The change in gap dimensions decreases the gap heat transfer coefficient, which leads to an increase of the fuel pellet temperature relative to the cladding surface temperature. [

]^{a,c}

Question 18:

Item #4 on Page 26 stated that the time scale involved with gas release is at least an order of magnitude slower. Therefore, CHACHA-3D does not model additional gas release during the transient. Only the STAV7.2 results are used as the input. Please clarify what results of STAV7.2 are used, at what stage of the LOCA.

<u>Response to Question 18:</u>

The CHACHA-3D code is used to evaluate the performance of each lattice type for its entire burnup history. In addition to the thermal-hydraulic conditions exterior to the cladding, which are determined from the GOBLIN and DRAGON analyses, the initial conditions within the fuel rod are derived from the STAV7.2 code. These initial conditions are generated by running a STAV7.2 from beginning to end of life for a bounding power history using assumptions that produce conservative initial stored energies. In addition to the [

]^{a,c}

[

]a,c

Question 19:

Page 27 #5 and #4 on Page 26 seems to be duplications of the information. Please clarify.

Response to Question 19:

Item 4 on page 26 describes the athermal fission gas release model. Item 5 on page 27 describes the thermal fission gas release model. The fission product gas release (FGR) model consists of an athermal and a thermal release component.

The athermal FGR model accounts for [

]a,c

The thermal FGR model is [

]a,c

Question 20:

Page 27 item #6. Please provide a sample list of input parameters from STAV7.2 and explain any differences between the input of STAV7.2 and STAV6.2. If they are just inputs, other than outputs from STAV7.2, do they make a difference?

Response to Question 20:

The list of eleven input parameters from STAV7.2 is provided in the response to Question #18. The same parameters were provided by STAV6.2. Since the two fuel performance codes will predict a different variation of these input parameters with burnup, the [

]a,c These changes will affect the predicted cladding temperature response.

Question 21:

Page 27 item #7. Please briefly summarize the revised BWR crud build-up model in STAV7.2 and explain its impact on LOCA. Please provide more details about how CHACHA-3D defines the thermal resistance of the crud layer and the oxide layer. How is the metal water reaction modeled by CHACHA-3D code with the existence of crud?

Response to Question 21:

Crud model - Corrosion products released from various plant surfaces can deposit on the cladding surface. This material is referred to as crud. The previous crud correlation in STAV6.2 described the deposition of crud on the cladding surface as a [

]^{a,c}

Oxide model - The cladding oxidation model in STAV is made up of [

]^{a,c}

Metal-water reaction model - Section 4.4 of RPB 90-93-P-A describes how the metal-water reaction is modeled. Since the Baker-Just model is used, the rate of oxidation decreases as the thickness of the oxide increases. [

]^{a,c}

Question 22:

Page 27 item #8, does gap heat transfer coefficient used by CHACHA-3D subject to change during LOCA? What is the impact to PCT and other three LOCA criteria?

Response to Question 22:

The information from STAV shown in the response to Question #18 is used in CHACHA-3D to establish an initial gap heat transfer coefficient. Since the cladding balloons during the transient, small changes in the initial gap dimensions have a small impact on the overall thermal response of the cladding.

As described in Section 5.5 of CENPD-293-P-A, the gap heat transfer coefficient in CHACHA-3D is calculated dynamically during the LOCA event to account for the change in cladding dimensions during the transient. Except for the initial condition inputs from the fuel performance code, the CHACHA-3D model is unchanged. Since the revised initial dimensional information from STAV7.2 do not change significantly, they will have a very small effect on the predicted transient gap heat transfer coefficient. Therefore, Westinghouse expects that these changes will have a small impact on the predicted cladding responses (i.e., peak temperature, maximum local oxidation and core wide oxidation).

Question 23:

Under the title of "UO2 and Gadolinia Fuel Pellet Thermal Conductivity," it is stated that "The thermal conductivity for UO2 and Gadolinia fuel pellets are now calculated in accordance with STAV 7.2 fuel performance code." Does "in accordance with" mean that identical models and data are used?

Response to Question 23:

The thermal conductivity model for the UO_2 and Gadolinia fuel pellets in the version of CHACHA-3D used for licensing applications will be identical to the corresponding correlations in the approved fuel performance code.

Westinghouse expects that the approval of WCAP-16078 will be contingent upon using initial conditions and models for fuel pellet conductivity and power distribution from an approved fuel performance code. The installation of the approved thermal conductivity and pellet power distribution models in CHACHA-3D will follow the process described in the response to Question #25 (below). Therefore, the initial conditions for CHACHA-3D will be obtained from an approved fuel performance code and the applicable correlations from an approved fuel performance code will be installed correctly in CHACHA-3D.

Question 24:

Page 27. Does 62 MWd/kgU set the limit of this methodology for exposure? For thermal conductivity only?

Response to Question 24:

The STAV7.2 code, as described in WCAP-15836, is currently under review by the Staff as part of the Westinghouse program to obtain NRC acceptance of Westinghouse fuel assembly mechanical design methods used for BWR licensing analysis to a rod-average burnup of 62 MWd/kgU. The Westinghouse request for approval to 62 MWd/kgU is based on:

1. The understanding that the NRC is entertaining requests currently only to this burnup until additional high burnup data and support for higher burnup operation are available.

2. The Westinghouse fuel performance models, methods, and databases support fuel rod burnups in excess of 62 MWd/kgU rod-average.

The limit of 62 MWd/kgU on rod-average burnup is not based on limitations in the ECCS model. Acceptance of the fuel performance models (e.g., STAV) beyond the 62 MWd/kgU limit would be adequate justification for applying the ECCS model beyond 62 MWd/kgU.

Question 25:

A total of eight new modeling features from STAV7.2 are implemented into CHACHA-3D code. Please provide evidence that the implemented models in CHACHA-3D can reproduce the same results as that of STAV7.2.

Response to Question 25:

As indicated in Section 5.5.2.3 of WCAP-16078, only two of the new modeling features from STAV7.2 will be installed in the CHACHA-3D code. These features are the new models for [ ]^{a,c}.

Because of recent improvements to the STAV7.2 code, the [ ]^{a,c} have not been implemented into CHACHA-3D. However, the models that are implemented into CHACHA-3D, will be identical to the corresponding models in the approved fuel performance code. As part of the implementation process, sample calculations will be performed to verify consistency between these two codes after the final models are installed in CHACHA-3D. These calculations will be performed for a UO_2 fuel rod and a $UO_2 + Gd_2O_3$ as a function of nodal burnup. Similar to the validation presented in Section 7.3.2 of CENPD-293-P-A, these calculations will compare the predictions from the approved fuel performance code to the predictions by CHACHA-3D. The following quantities will be compared to ensure that the models are installed correctly:

- fuel centerline temperature,
- fuel average temperature, and
- gap heat transfer coefficient.

Question 26:

Section 6.1.1 discussed the applicability of the spray heat transfer model to SVEA-96 OPTIMA2 fuel. It is not stated in CENPD-283-P-A about how the coefficients are used. Therefore, please explain how this coefficient is being used inside the code for different rods and channel wall. For a mixed core, does this coefficient apply to the average channel? The corner rod is a 1/3 length rod. Is it necessary to even calculate the 1/3 length rod temperature profile? In addition, do the coefficients subject to change along the axial direction? Because of the use of part length rods, the radiation heat transfer view factors change along the axial direction. Does this variation affect the spray coefficients? Why?

Response to Question 26:

Application of spray heat transfer coefficients - The application of the spray heat transfer coefficients in the CHACHA-3D heat-up code is described in Section 4.5.3 of RPB 90-93-P-A. These coefficients are consistent with the 10 CFR 50.46 Appendix K requirements and are applied only in the heat-up analysis. The GOBLIN system and hot channel analyses use a different heat transfer model, which is described in Section 3.5 of RPB 90-93-P-A.

The spray heat transfer coefficients are input to the CHACHA-3D code as a table. The convective heat transfer coefficients used in the CHACHA-3D code from the beginning of the transient until the time of uncovery are taken from the [

]a,c are replaced by the spray heat transfer coefficients required by Appendix K. After two-phase recovery is predicted and until the end of the transient, the heat transfer coefficients predicted by the hot assembly analysis are replaced by the 'reflood' heat transfer coefficient (25 Btu/hr-ft^2-°F) required by Appendix K.

As indicated above, the spray heat transfer coefficients are applied as a table of values. The figure below is a typical example.

[ ]a,c

Application to average channel of a mixed core – The treatment of mixed cores is described in the response to Question #14. The spray cooling heat transfer coefficients that are required by Appendix K are applied only in the rod heat-up calculation (CHACHA-3D). The average core system response is determined using GOBLIN, which uses the heat transfer package described in Section 3.5 of RPB 90-93-P-A.

Application to the 1/3-length rods – The spray cooling heat transfer coefficients are applied at whatever axial plane is being analyzed. If the lattice being analyzed were from the lower third of the core, the 1/3-length rods would be analyzed using a spray heat transfer coefficient that is applicable to "corner" rods, as that is the location of the 1/3-length rods. [

]^{a,c}

Axial variability of the spray heat transfer coefficients – Although a [

]^{a,c}

Effect of radiation view factors on spray heat transfer coefficients – The radiation view factors are applied based on the actual cross-section being evaluated. The spray heat transfer coefficients are based on Appendix K requirements and are independent from the radiation view factors. As discussed above, a single set of spray heat transfer coefficients is used.

Question 27:

Page 33 mentioned the extrapolation process to define the SVEA-96 Optima 2 spray coefficient. Please explain how the extrapolation was done. What is the independent variable to extrapolate? Diameter? Or rod layout?

<u>Response to Question 27:</u>

The extrapolation process is based on [

]^{a,c}

[ ]^{a,c}

[ ]a,c

[ ]a,c

[ ]a,c

[ ]a,c

[ ]a,c

[ ]a,c

[ ]a,c

[ ]a,c

[ ]a,c

The same scaling procedure is used to derive heat transfer coefficients for the different SVEA designs. For the SVEA-96 Optima2 design (midplane), the comparable scaling factor is derived as follows:

[ ]a,c

As indicated in the WCAP-16078, it is proposed that [

]a,c.

Question 28:

Section 6.2 discussed the application of the radiation heat transfer model to SVEA-96 OPTIMA2 fuel. It is stated that the smallest pitch is used to perform the radiation heat transfer calculation. Please explain how are the different rod diameter and part length rods considered in the radiation heat transfer calculation.

Response to Question 28:

As described in Section 4.2 of the WCAP-16078, the fuel rods in the SVEA-96 Optima2 fuel design have a single rod diameter (9.84 mm). Radiation heat transfer is modeled in the system analysis, the hot channel analysis and in the hot rod heat-up analysis.

The radiation heat transfer model for the GOBLIN system analysis and hot assembly analysis, which is described in Section 3.5 of RPB 90-93-P-A, uses [

]a,c

[ ]a,c

is used to calculate the radiative heat transfer between components at each axial node within the fuel channel. The SVEA-96 Optima2 fuel design has three axial zones (i.e., there are 24 rods in the lower zone, 23 rods in the middle zone and 21 rods in the upper zone of each sub-assembly). Each zone is surrounded on two sides by the water-cross and on the other two sides by the fuel channel. [

]a,c

The radiation heat transfer model in CHACHA-3D, which is described in Section 4.5 of RPB 90-93-P-A and Section 5.4 of CENPD-293-P-A, is similar to the model in GOBLIN except that the [

]a,c

Question 29:

The Safety Evaluation Report and the accompanying Technical Evaluation Report, ITS/NRC/95-1, both related to CENPD-283-P, state that the CCFL coefficient values (K1 and Ku) for SVEA-96 fuel, which were shown to have little effect on predicted system and core behavior, should not be extended further to other fuels without being directly supported and validated by experimental data for those particular fuels. While it is noted that the effective diameter formulation has been shown to be more conservative based on the QUAD+ experimental data depicted in Figure 5-5, WCAP-16078-P, explain how the previous SER limitation has been addressed and overcome in demonstrating the appropriateness of the GOBLIN/DRAGON CCFL correlation for SVEA-96 Optima2 fuel.

Response to Question 29:

As indicated in the Safety Evaluation Report (SER) related to CENPD-283-P-A, the CCFL correlation was approved for applications to SVEA-96 fuel. Since the correlation was originally validated using CCFL data taken on QUAD+ CCFL test facility, the correlation should be applicable to fuel designs like QUAD+ (same as SVEA-64) and SVEA-96. Table 4-1 of WCAP-16078-P compares the key thermal hydraulic parameters associated with the SVEA fuel designs (e.g., fuel rod diameter, active flow area, hydraulic diameter, etc.). As shown, the hydraulic diameter, fuel rod diameter and active flow area of the SVEA-96 Optima2 fuel design fall between the SVEA-64 design and the SVEA-96/96+ designs. Therefore, it is concluded that the SVEA-96 Optima2 fuel design falls between the SVEA-64 and SVEA-96/96+ fuel designs from a thermal-hydraulic perspective, and within the range of applicability of the CCFL correlation.

In addition, the CCFL correlation is expressed in terms of physical quantities (e.g., vapor and liquid fluxes, hydraulic diameter, effective channel diameter, etc.). Since the CCFL correlation is expressed in terms of these physical quantities, it can accommodate the differences between the fuel designs.

Question 30:

As stated in the SER related to CENPD-283-P, the conservative bias for the base CCFL correlation was prescribed based on vendor-supplied data submitted by facsimiles dated September 19, 1995, and September 27, 1995. The data showed that the CCFL correlation had a 100 F sensitivity in the temperature range of the Appendix K limit and that the limit was exceeded as the APLHGR approached 36 KW/m. Demonstrate how the effective diameter formulation affects the CCFL correlation in the Appendix K limit (1800 F to 2200 F) temperature range by making a direct comparison with the results displayed in Figure A7-1, Appendix A, CENPD-283-P-A.

Response to Question 30:

The sensitivity study presented in Appendix A of CENPD-283-P-A was in response to NRC Question No. 7 regarding the review of that licensing topical report (LTR). The results of the sensitivity study presented in Section 7.1 of that LTR were extended to show the impact on peak cladding temperature. The sensitivity study presented in CENPD-283-P-A consisted of making an arbitrary 30% increase in the CCFL liquid flow restriction at the upper tie plate and fuel spacers for a particular plant model. Figure A7-1 in CENPD-283-P-A shows that the difference in predicted peak cladding temperature (PCT) increases as the average planar linear heat generation rate (APLHGR) increases. Near the acceptance limit, the difference in PCT was approximately [ ]^{a,c}.

The result of a sensitivity study showing the impact of using the CCFL model proposed in WCAP-16078-P was presented in the response to Question 4. This sensitivity study, which was performed at an APLHGR of 33.9 kW/m, showed a difference in PCT of approximately [ ]^{a,c} relative to an identical case using the existing CCFL model. In response to this question, this study was extended to show the impact of the proposed change to the CCFL model for a range of APLHGRs to obtain the sensitivity near the 10 CFR 50.46 acceptance limit. The results from this study are presented in the following figure. As shown, the difference in PCT increases as the APLHGR increase. Near the acceptance limit, the difference for the reference plant is approximately [ ]^{a,c}. This sensitivity study further supports the previous conclusion that small variations in fuel design geometric parameters that impact CCFL have a very small impact on the LOCA PCT results.

Note that the magnitude of the sensitivity to the change to the CCFL model depends in part on the blowdown and reflood performance of the reference plant (e.g., the timing of dryout, the timing of core spray actuation, the timing of reflood, etc.). Therefore, a simple comparison between the results presented in CENPD-283-P-A and the results presented here can be misleading, as the reference plants used for these two sensitivity studies are different.

[ ] a,c

A.2 REFERENCES

A-1. RPB 90-93-P-A, "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Description and Qualification," October 1991.

A-2. RPB 90-94-P-A, "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity," October 1991.

A-3. CENPD-283-P-A, "Boiling Water Reactor Emergency Core Cooling System Evaluation Model: Code Sensitivity for SVEA-96 Fuel," July 1996.

A-4. WCAP-16081-P, "10x10 SVEA Fuel Critical Power Experiments and CPR Correlation: SVEA-96 Optima2," May 2003.

A-5. RP 87-04 / SVEA 87-09, "SVEA Spray Cooling Test. Test Results and Evaluation," March 30, 1987.

A-6. Nagasaka et al, "Characteristics of Residual Two-Phase Pool in Upper Plenum During Refill-Reflood Phase of BWR LOCA," Proceedings of International Nuclear Power Plant Thermal Hydraulics and Operations Topical Meeting, October 1984.

A-7. CENPD-300-P-A, "Reference Safety Report for Boiling Water Reactor Reload Fuel," July 1996.

A-8. LTR-NRC-03-74, "Response to Round 1 Request for Additional Information Regarding WCAP-16078 P & NP, "Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel" (Proprietary / Non proprietary)," December 19, 2003.

A-9. LTR-NRC-04-24, "Response to Round 2 Request for Additional Information for WCAP-16078-P, "Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel"," April 22, 2004.

A-10. LTR-NRC-04-33, "Round 3 Response to NRC RAIs on WCAP-16078," May 28, 2004.

A-11. LTR-NRC-04-39, "Response to Round 4 Request for Additional Information for WCAP-16078-P, "Westinghouse BWR ECCS Evaluation Model: Supplement 3 to Code Description, Qualification and Application to SVEA-96 Optima2 Fuel" (Proprietary)," June 23, 2004.