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

Westinghouse

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

April 2003

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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.

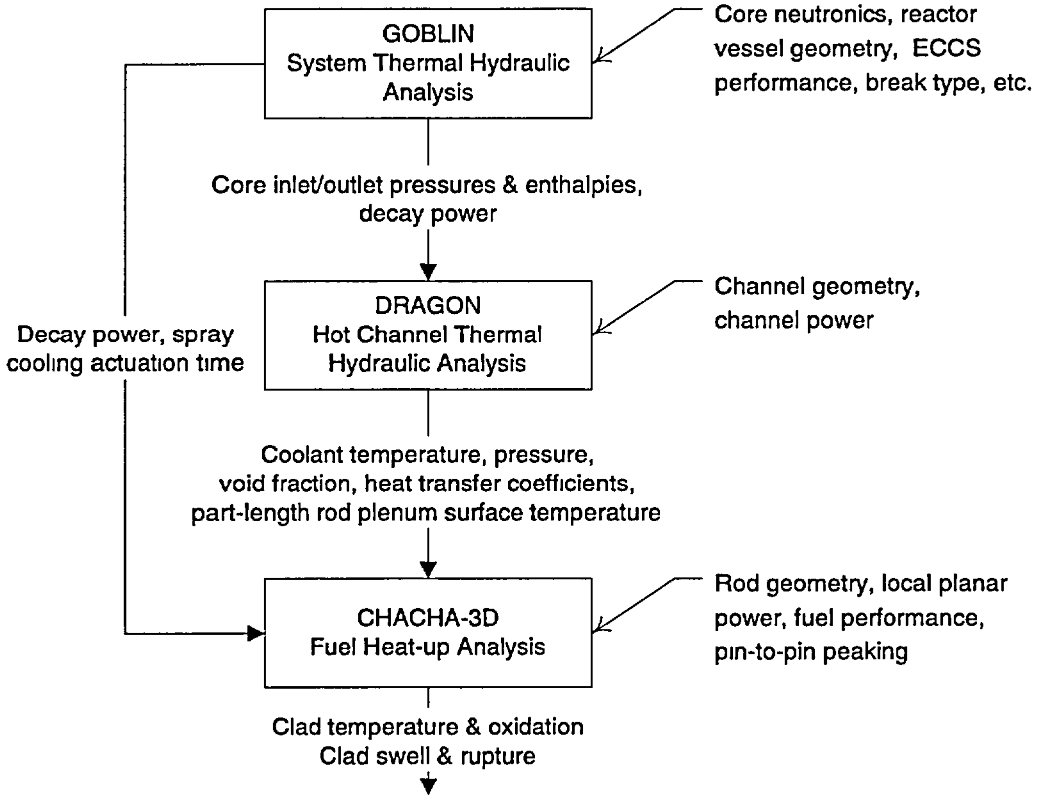

Figure 3-1 Flow of Information Between Computer Codes

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.

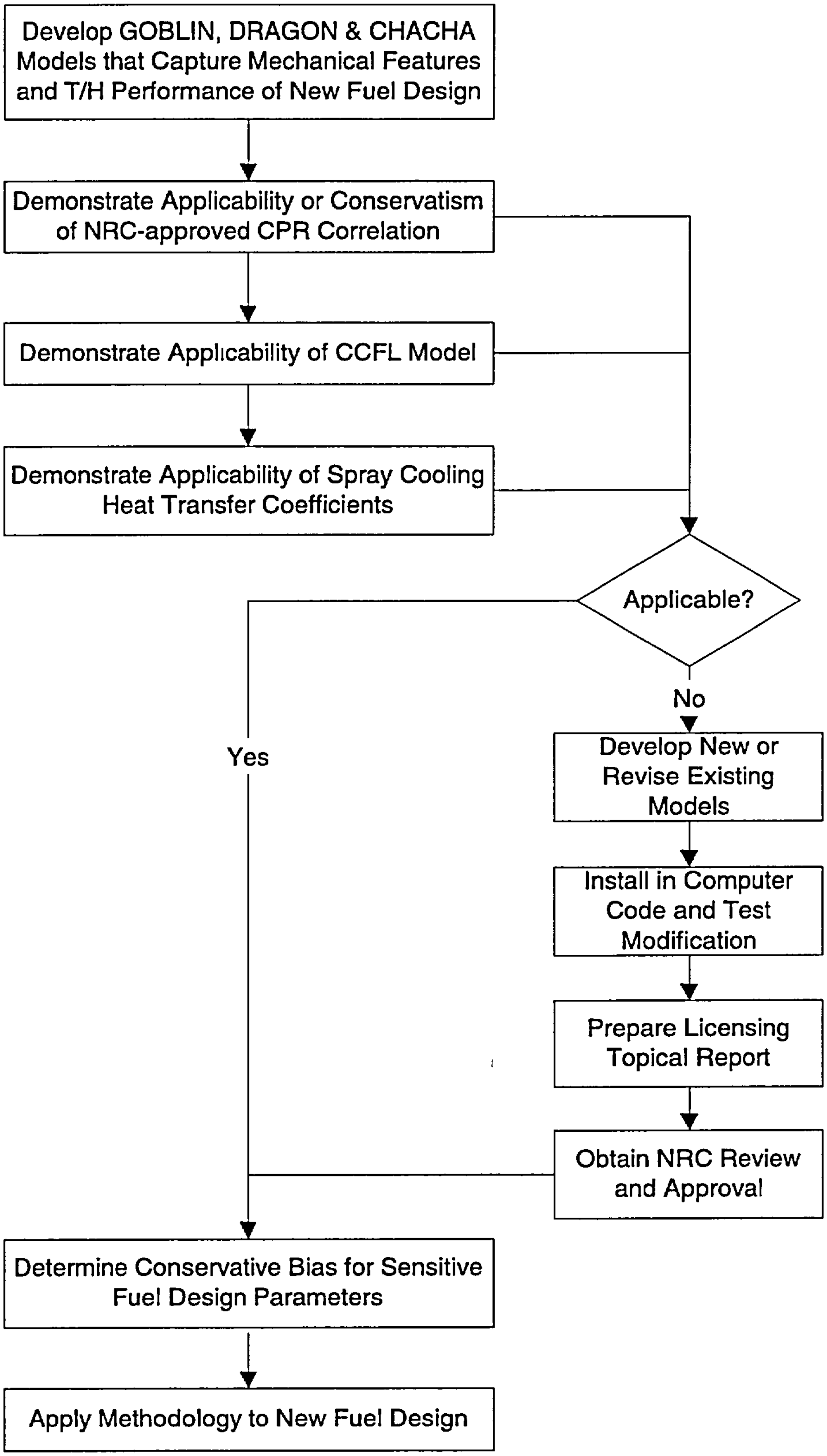

Figure 3-2 Process for Applying Evaluation Model to New Fuel Mechanical Design

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}

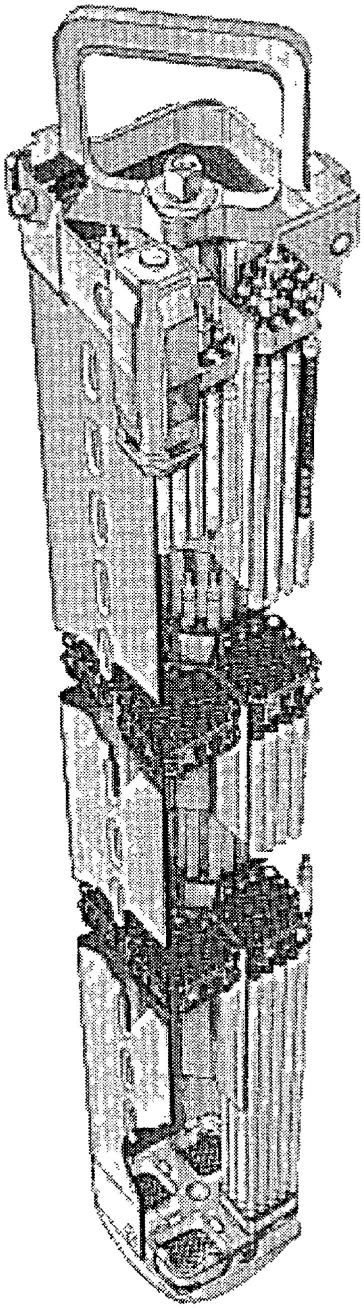

Figure 4-1 SVEA-96 Optima2 Fuel Assembly

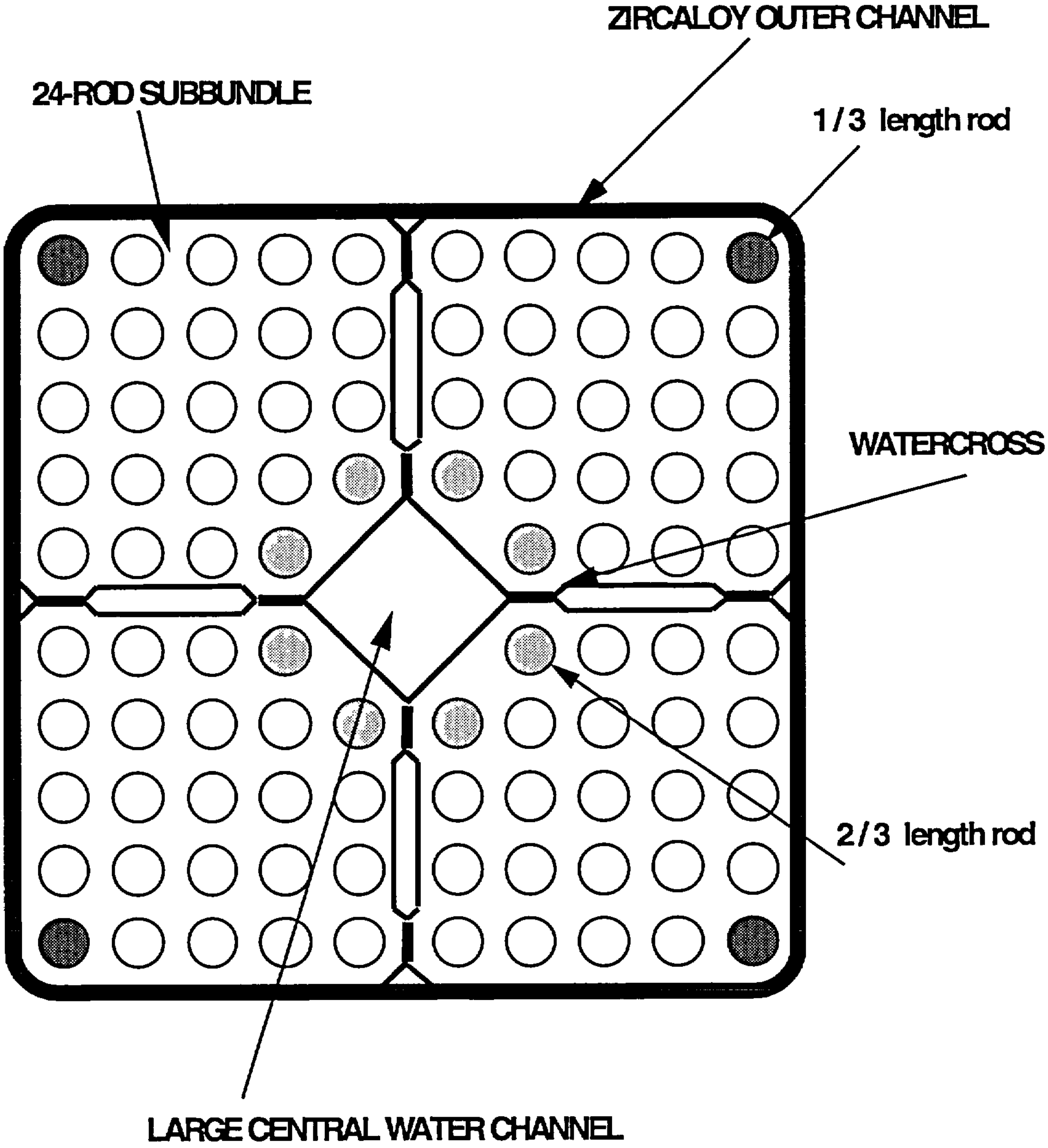

Figure 4-2 Cross Section of SVEA-96 Optima2 Sub-Assembly

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}

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

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}

[

]^{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/m^2-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/m^2-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/m^2-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/m^2-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.

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