August 18, 2016

Mr. W. Anthony Nowinowski, Program Manager
PWR Owners Group, Program Management Office
Westinghouse Electric Company
1000 Westinghouse Drive, Suite 380
Cranberry Township, PA 16066

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION REGARDING PRESSURIZED WATER REACTOR OWNERS GROUP TOPICAL REPORT WCAP-17788, "COMPREHENSIVE ANALYSIS AND TEST PROGRAM FOR GSI-191 CLOSURE" (TAC NO. MF6536)

Dear Mr. Nowinowski:

By letter dated July 17, 2015 (Agencywide Documents Access and Management System Accession No. ML15210A668), the Pressurized Water Reactor Owners Group (PWROG) submitted Topical Report WCAP-17788, "Comprehensive Analysis and Test Program for GSI-191 [Generic Safety Issue-191] Closure," to the U.S. Nuclear Regulatory Commission (NRC) staff for review. Upon review of the information provided, the NRC staff has determined that additional information is needed to complete the review of Volume 4. On July 12, 2016, Jay Boardman, PWROG Project Manager, and I agreed that the NRC staff will receive the response to the enclosed request for additional information (RAI) questions for Volume 4 within 120 days from the date of this letter.

If you have any questions regarding the enclosed RAI questions, please contact me at 301-415-4053.

Sincerely,

/RA/

Jonathan G. Rowley, Project Manager
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 694

Enclosure:
WCAP-17788, Volume 4 RAI
Questions (Non-Proprietary)

August 18, 2016

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ADAMS Accession No.: ML16228A527 ***concurrence via e-mail** **NRC-088**

OFFICE	NRR/DPR/PLPB/PM	NRR/DPR/PLPB/LA*	NRR/DSS/SSIB/BC	NRR/DPR/PLPB/BC	NRR/DPR/PLPB/PM
NAME	JRowley	DHarrison (ELee for)	VCusumano	KHsueh	JRowley
DATE	08/15/2016	08/17/2016	07/25/2016	08/3/2016	08/18/2016

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REQUEST FOR ADDITIONAL INFORMATION

RELATED TO VOLUME 4 OF TOPICAL REPORT WCAP-17788,

"COMPREHENSIVE ANALYSIS AND TEST PROGRAM FOR GSI-191 CLOSURE"

PRESSURIZED WATER REACTOR OWNERS GROUP

TAC NO. MF6536

RAI-1, Vol 4

General Design Criterion (GDC) 35, "Emergency Core Cooling," in Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, requires that a single failure be assumed when analyzing safety system performance. Sections 8.2, 9.2, 10.2, and 11.2 present safety system performance analysis results for four different plant categories.

a. Describe the single failure assumptions implemented in the analyses of the safety system performance for the four analyzed plant categories. Identify the single failure assumption(s) applied in the modeling of the reactor coolant system (RCS) response including the performance of the emergency core cooling system (ECCS). Justify the assumptions by describing pertinent conditions, supporting considerations, and applicable analyses.

b. The analyses for the Combustion Engineering (CE) plant category were performed with the containment backpressure computed by a coupled containment code. Demonstrate how the single failure assumptions implemented in the RCS response analysis for this plant category, as well as any additional and related assumptions, were considered for the purposes of calculating the containment backpressure response. Verify that treatment is consistent with Assumption No. 6 in Section 4.1, "Major Assumptions," and Input No. 6 in Section 4.2, "Critical Inputs."

c. Provide information that demonstrates whether plant-specific considerations are necessary to address GDC 35 when considering safety system performance on a plant-specific basis. Explain how the single failure assumptions implemented in the T-H analyses in Sections 8.2, 9.2, 10.2, and 11.2, as considered in the response to Items a and b above, remain valid for each plant category. Describe how it was determined whether additional single failure assumptions and applicable supporting considerations were required for plant-specific T-H analyses. If necessary, identify the types of plant specific information related to systems, conditions, parameters, and other relevant items that will need to be considered for adequate implementation of the topical report (TR) with respect to GDC 35 on a plant-specific basis.

RAI-2, Vol 4

Section 6.1 states that "a method was developed to calculate appropriate BB [Barrel/Baffle] flow resistances for use in this analysis" so that all Westinghouse upflow plants in operation in the

United States (U.S.) are represented. The section further clarifies that "the method and supporting calculations are contained in Reference 6-2, which confirms that the BB flow resistances shown in Table 6-1 bound all Westinghouse upflow plants." With regard to the Westinghouse downflow plant design category, Section 6.2 explains that "a method was developed to calculate appropriate UHSN [Upper Head Spray Nozzle] flow resistances for use in this analysis" and that "the method and supporting calculations are contained in Reference 6-2, which confirms that the UHSN flow resistances shown in Table 6-2 bound all Westinghouse downflow plants." Reference 6-2 is identified in Section 6.5, as follows.

Reference 6-2: **[**

].

a. Provide a copy of Reference 6-2.

b. Include a description of the assumptions used in the maximum and minimum BB flow resistance calculations given in Table 6-1.

c. Include a description of the assumptions used in the maximum and minimum UHSN calculations provided in Table 6-2.

d. For Items a and b, describe whether the flow passages between the downcomer and upper plenum regions via the hot leg nozzle gaps were modeled and provide a justification for the modeling approach.

e. For each Westinghouse unit considered in determining the BB and UHSN resistances in Tables 6-1 and 6-2, provide the following information in a table format, separately for both Westinghouse upflow and downflow plant category. In individual columns, include a description for each of the following items:

    i. Name and rated power
    ii. Identification numbers of design drawings, including the name of the unit for which they were produced, containing the geometric data to calculate the resistance associated with the

        (1) lower core plate to baffle region gap
        (2) former holes including the number of former plates with holes
        (3) upper core plate to baffle region gap
        (4) UHSNs

    iii. For each category of flow passage, identify all types and sizes of openings that are credited in the resistance calculation. As a minimum, include

        (1) the number of holes or gaps
        (2) hole diameter or gap width and perimeter length
        (3) individual hole or gap flow area for each type of holes/gaps
        (4) total resulting flow area

iv. Loss coefficients associated with each category of passage along with the reference flow area

v. Total unadjusted and adjusted BB/UHSN resistances along with the units

vi. Assumptions related to the way geometric data in the drawings was treated for the purpose of calculating resistances and assumptions related to the consideration of any other existing flow passages such as pressure relief holes in the baffle plates.

f. For each table in Item e, include a figure that illustrates the BB region and UHSN region geometries for each Westinghouse plant category and a separate figure showing an example of a BB former region top view for one-quarter of the core region. (Appropriate examples of such figures appear as Figures 1 and 2 in a March 26, 2001, letter by Exelon Generation Company, LLC, Agencywide Documents Access and Management System Accession No. ML010890050.)

g. During the U.S. Nuclear Regulatory Commission (NRC) staff audit of supporting Westinghouse documents and drawings on February 2-4, 2016, it was observed, for the upflow BB plant category, former plate holes of Type 1 were assigned a loss coefficient of **[ ]** and those of Type 2 were assigned a loss coefficient of **[ ]**. The staff could not determine the basis for those values. Provide the calculations and supporting documentation for each of these loss coefficients, as well as for other loss coefficients identified in the response to Item e.iv above.

h. During the NRC staff audit of supporting Westinghouse documents and drawings on February 2-4, 2016, the average loss coefficient for the upflow plant category, K_{AVG}, from former plate holes of Type 1 and Type 2 was computed from the individual loss coefficients, K_i, **[ ]**. Explain the rationale for using an averaging equation to obtain an equivalent loss coefficient value and demonstrate whether physical parameters are preserved by using this method (e.g., flow or pressure loss). Examine the effects of the averaging method on the resulting resistances for both maximum and minimum resistance cases. If the averaging method is found inconsistent, implement an appropriate approach and update the BB resistance results for the Westinghouse upflow and downflow plant categories.

RAI-3, Vol 4

Section 6.3, “Combustion Engineering Plant Model,” states that a method and supporting calculations for calculating appropriate BB flow resistances that represent all CE plants in operation in the U.S. are contained in Reference 6-3 and Reference 6-4. These two references are identified in Section 6.5 and updated in Letter OG-16-42 dated February 12, 2016, as follows.

Reference 6-3: **[ ]**.

Reference 6-4: **[**

].

a. Provide copies of References 6-3 and 6-4 listed above.

b. Provide a description of the assumptions used in the maximum and minimum BB flow resistance calculations provided in Table 6-3.

c. Identify the physical units for the BB flow resistances in Table 6-3.

d. Describe whether or not the flow passages between the downcomer and upper plenum regions via the hot leg nozzle gaps were modeled. If they were not, provide a justification for the omission.

e. Provide the information requested in Items e, f, g, and h in RAI 4.2 as it applies to the CE plant category. As both AREVA and Westinghouse performed BB flow resistance calculation for CE plant units, all requested information from each vendor for the analyzed plant units should be provided.

f. During the NRC audit of supporting AREVA documents and drawings on March 1-4, 2016, it was found in document **[** **]**" that two different values for the maximum BB flow resistance case, **[** **]**, were reported for **[** **]**. During the audit, it was explained that the values resulted from the calculations performed by AREVA and Westinghouse. This significant difference in resistances is a concern regarding the limiting representative resistances determined for the CE plant category. Provide an explanation for the difference in the BB resistance results for **[** **]**. Since both results may be incorrect, examine the methods used by AREVA and Westinghouse. Identify whether deficiencies in the calculational methodologies or differences in geometrical plant data related to the BB region were involved in both analyses. If deficiencies are discovered, provide a description and results of any changes to the methods for the corrected BB resistance calculation(s). Provide full calculations and final results for **[** **]** using both methods with applicable modifications. Provide the input derived from geometrical plant data related to the BB region for this unit as used in both analyses.

g. Verify that the issues associated with Item f above do not affect the other plant categories.

RAI-4, Vol 4

Section 6.4, "Babcock and Wilcox [(B&W)] Plant Model," states that "the BB design for all B&W plants is the same" and explains that the BB flow resistance shown in Table 6-4 is representative of all B&W plants. It is also explained that the method and supporting calculations confirming the provided BB flow resistance value are contained in Reference 6-3, which is identified in Section 6.5 and updated with Letter OG-16-42 dated February 12, 2016, as follows.

Reference 6-3: **[**

]

a. The above identified document appears to be related to the CE plant category. Confirm whether this is the proper reference for B&W plants. If a reference other than Reference 6-3 was used for B&W plants, provide a copy of the document.

b. Include a description of the assumptions used in the calculation of the BB total flow resistance value provided in Table 6-4.

c. Identify the physical units for the BB flow resistance shown in Table 6-4.

d. State whether any other flow passages between the downcomer and upper head/plenum regions were modeled in the analyses. If they were, provide a description of these additional passages and how they are evaluated.

e. Provide the information requested in Items e, f, g, and h in RAI 4.2 as it applies to the B&W plant design category.

f. During the NRC staff audit of AREVA documents and drawings on March 1-4, 2016, the NRC staff encountered difficultly in interpreting, following, and confirming calculations and results pertaining to the BB resistance calculations for the B&W plant design category. Therefore, ensure that the information provided in response to Items a through e above include all necessary clarifying and supporting information to support an independent review of the BB resistance calculation methodology and the results documented for the B&W plant category.

RAI-5, Vol 4

Tables 6-1 through 6-4 provide a summary of key inputs for each plant category. Provide the following information related to the key inputs for the HLB methodology:

a. Justify that the values for the parameters listed in Tables 6-1 through 6-4 are bounding or demonstrate that these values can be considered appropriate and applicable for all of the plant units covered by the TR. If certain key input values have not been validated as bounding, state how the use of the TR methodology will ensure that the applicable acceptance criteria are met for the specific plant application. Include enough information for each key parameter so that the NRC staff can verify that they are bounding for the plants intended to use the TR. Ensure that the information includes, as necessary, plant specific characteristics, operating conditions, licensing basis assumptions (including single failure), regulatory limits, operating procedures, technical specifications limits, uncertainties, and full ranges of the inputs and variables that could affect the evaluation. If it is determined that these parameters are valid for plants using the methodology, how will the plants ensure the variables that can affect these parameters are maintained at acceptable values?

b. Provide graphs of the physical axial power profiles implemented in the plant design analyses in Sections 8 through 11. Provide each physical axial power profile on a separate plot and for each profile show its nodal approximation based on the core axial nodalization.

i. Specify the elevation of the axial peak power location associated with the profile described in Table 6-3 for the CE plant design analysis.

c. Clarify the approach to determining the axial power shapes simulated in the loss-of-coolant accident (LOCA) analyses. Explain if any bounding, or otherwise considered appropriate, assumptions were introduced to define the shapes requested in Item a. Explain if any physical axial power shapes, representative of individual units for each of the NSSS plant design categories included in Table 3-1 were considered in analyzing and determining the applicability of the simulated axial power profiles. Describe and justify the basis on which a single axial power profile, applied in the analyses for each plant category, can be considered valid and applicable to reactor core conditions across various units represented by each NSSS design category. An axial power profile applied for the purpose of a small-break LOCA analysis using a model based on 10 CFR Part 50, Appendix K, would represent an acceptable axial power profile on a plant specific basis.

RAI-6, Vol 4

The evaluation models (EMs) used for the LOCA T-H computational analyses are described in Section 5. The plant models used to perform the analyses for each plant category presented in Sections 8 through 11 are described in Section 6. Table 1 below summarizes the computer codes and models used in these analyses.

Table 1: Identification of Computer Codes and Plant Models Used in the Thermal-Hydraulic Computational Analyses

Code and Plant Model Used	**Plant Category**			
	Westinghouse Upflow BB Plant Category	**Westinghouse Downflow BB Plant Category**	**CE Plant Design**	**B&W Plant Category**
System Code	WCOBRA/TRAC MOD7A	WCOBRA/TRAC MOD7A	S-RELAP5	RELAP5/MOD2-B&W
Code Version	Not provided	Not provided	Provided	Provided
EM Topical Report	WCAP-14747 (CQD), WCAP-16009-NP-A (ASTRUM)	WCAP-14747 (CQD), WCAP-16009-NP-A (ASTRUM)	[ ]	[ ]
Code Modified for WCAP-17788 Methodology	Yes (see Section 5.1)	Yes (see Section 5.1)	Yes	No
Base Plant Model	Westinghouse four-loop BE plant model	Westinghouse three-loop BE plant model	CE high-power BE plant model	B&W high-power Appendix K plant model (SBLOCA)

Provide the following information:

a. Identify the code version of WCOBRA/TRAC MOD7A used in the analyses in Sections 8 and 9.

b. Clarify if NRC staff approval of subsequent TRs related to WCOBRA/TRAC, S-RELAP5, and RELAP5/MOD2-B&W can have an impact on the EMs applicability or validity of the T-H analysis results presented in WCAP-17788-P.

c. As seen in Table 1 above, code modifications were made to both WCOBRA/TRAC and S-RELAP5 for the analyses presented in Volume 4 of WCAP-17788-P. Section 5.1 explains that "in order to simulate transient resistance at the core inlet due to the build-up of debris, it was necessary to modify the baseline WCOBRA/TRAC version." Letter OG-16-42 dated February 12, 2016, described a modification of the baseline S-RELAP5 code version to produce "a development version of S-RELAP5" that was used to obtain the updated analyses submitted with OG-16-42 to replace the original results in Section 10 of Volume 4. Describe briefly the code changes and provide the validation and verification results for the "single-application" WCOBRA/TRAC code version and the S-RELAP5 "development version." Confirm that the code modifications were performed in conformance with applicable quality assurance procedures and provide references to related documents for both code modifications.

RAI-7, Vol 4

Section 4 states "it was determined that all computer codes and methods utilized have the ability to accurately predict the RCS response to simulated core inlet blockage during the sump recirculation phase of the post-LOCA transient." Describe the technical basis for this determination for each code methodology used in the analyses. Include identification and description of key governing processes and explain how the code capabilities were evaluated in terms of adequacy for the modeling of such processes. Explain how the code capabilities and accuracy in predicting the system and core response, including important parameters associated with the consequences of core inlet blockage, were evaluated. Include comparisons and assessments using experimental data as applicable.

RAI-8, Vol 4

Adequate prediction of the two-phase mixture level swell under core pool boiling conditions at atmospheric or close to atmospheric pressures during the long term core cooling (LTCC) phase of a PWR LOCA is of primary importance for demonstrating adequate core cooling in association with core inlet blockage. Sections 6.1 and 6.2 state "it is known that the version of WCOBRA/TRAC utilized tends to over predict two-phase mixture level swell in the core under low pressure pool boiling conditions (Reference 6-1). To account for this, a multiplier on the core axial interfacial drag is applied consistent with the approach taken in Reference 6-1." Reference 6-1 is listed in Section 6.5 as follows.

Reference 6-1: WCAP-15644-P, Rev. 2 (Proprietary) and WCAP-15644-NP, Rev. 2 (Non-Proprietary), "AP1000 Code Applicability Report," March 2004.

Revised Section 7.1.1, "Debris Collection at the Core Inlet," of WCAP-17788-P Vol. 1, provided with Letter CAW-15-4339 dated November 24, 2015, further clarifies that an "interfacial drag multiplier of 0.8 x nominal" was used to analyze a double-ended cold leg break in a three-loop Westinghouse plant "consistent with Westinghouse NSSS analyses in WCAP-17788, Volume 4." Sections 8 through 11 of Vol. 4 provide no information relative to the capabilities of the other codes used for the analyses to predict two-phase mixture level swell in the core under low pressure pool boiling conditions. Also, Reference 6-1 has not been approved by the NRC.

a. Provide assessment results that demonstrate the codes used for the analyses documented in Sections 8 through 11 adequately predict two-phase mixture level swell under core pool boiling conditions at pressures close to atmospheric. These results should be based on level swell test data relevant to the analyzed plant conditions. Provide figures comparing code predictions to low pressure test data. Include tables identifying the test facilities, test runs, test flow conditions, measured void fractions, and predicted void fractions for the code assessments performed.

b. Clarify whether the "interfacial drag multiplier of 0.8 x nominal" identified in revised Section 7.1.1 was used in the HLB LOCA analyses in WCAP-17788-P Vol. 4 performed with WCOBRA/TRAC. If the multiplier was used in the analyses presented in Vol. 4:

    i. Describe the basis for determining the multiplier value.
    ii. Provide data assessments and the established range for this multiplier.
    iii. Demonstrate the applicability of the multiplier value to near-atmospheric pressure conditions
    iv. Explain whether the multiplier has a significant impact on t_{block}, K_{max}, K_{split}, and m_{split}. Use results of sensitivity studies, if necessary, to demonstrate the acceptability of the results in Section 8 and 9 in this regard.

c. Explain how interfacial drag was treated in the codes used for the CE and B&W analyses in Sections 10 and 11, respectively. Provide the information requested in Item b above as it applies to the EMs used for the analyses of the CE and B&W design categories.

RAI-9, Vol 4

Sections 8 through 11 provide LOCA T-H analysis results for determining the earliest transient point in time, t_{block}. T_{block} is defined so that the acceptance criteria for maintaining LTCC would be satisfied should complete core inlet blockage occur at or after this point in time following a HLB LOCA. Figures 8-16 (Case 1B), 9-15 (Case 1A), 10-13 (Case 1), and 11-9 (Case 1) show the core peak cladding temperature (PCT) responses following the application of complete core inlet blockage with temperature excursions being observed in Figures 8-16 and 9-15. Provide the following information in a table format (where applicable) for the limiting analyses. For example, Case 1B in Section 8 and Case 1A in Section 9 for each plant category. Include the axial void fraction profile results (Item c) in separate tables. If a parameter exhibits an oscillatory behavior within the vicinity of the time point of interest, include the parameter's variation range along with the observed predicted value itself.

a. Provide the following prediction results relative to the PCT excursions:

    i. Time of PCT (relative to break opening)
    ii. PCT
    iii. The core channel and axial elevation associated with the PCT location

b. Provide the following results relative to the axial elevation in the channel where the PCT was observed and the timing of PCT:

    i. Fuel rod local linear heat generation rate

ii. Predicted two-phase flow regime
iii. Vapor/liquid mass flow rates and mass fluxes for predicted continuous/dispersed flow fields (axial and cross-flow)
iv. Vapor/liquid phase velocities for predicted continuous/ dispersed flow fields (axial and cross-flow)
v. Wall heat transfer mode
vi. Fuel rod heat transfer fluxes to continuous/dispersed flow fields (clarify if any radiation heat transfer of significance was predicted)
vii. Heat transfer coefficients to continuous/dispersed flow fields.

c. Provide the axial void fraction distribution in the channel where the PCT was observed at the time when the PCT occurred and corresponding predicted two-phase mixture level in the channel.

d. Identify the closure heat transfer correlations associated with the heat transfer regimes identified as controlling with regard to the PCT values in Figures 8-16 and 9-15. Provide the ranges of applicability of these correlations and compare them against the predicted core limiting T-H parameters.

e. Identify the constitutive correlations for computing void fraction and any predicted entrained droplets/liquid film fields, as applicable, associated with the two-phase flow regime predicted at the PCT location and time of its occurrence. Provide their ranges of applicability and compare them against the predicted core limiting T-H parameters.

RAI-10, Vol 4

Provide plots showing the heat generation rates from the decay heat models that were used in the LOCA T-H analyses documented in Sections 8 through 11. Show the decay heat rates as a function of transient time with time zero corresponding to the break opening. Display the decay heat rate in relative dimensionless units using a linear scale with a range from null to 1.2. Plot the time axis in a logarithmic scale in units of seconds. Use a common time range that starts at one second after break opening and ends when the longest analyzed LOCA transient case ends.

RAI-11, Vol 4

Section 5.4 states that "the analysis completed by AREVA using S-RELAP5 produced results that compared reasonably well to those predicted by WCOBRA/TRAC, which are described in Section 9." The section also explains that "the plant and transient condition analyzed was identical to that used by Westinghouse;" however, "the plant models used for each analysis were developed independently following different methods and techniques." Section 5.4 concludes that "irrespective of the computer codes and methods used, the resulting code predictions are expected to be consistent."

a. Define the simulated LOCA transient and provide a summary description of the analyses. Provide a table that documents and compares key inputs and modeling features for both studies and explain how this information relates to key inputs provided in Table 6-2 for the Westinghouse downflow plant design analysis.

b. Provide comparisons of key results from the analyses. Explain any significant discrepancies between the results from the studies and provide an assessment of the degree of conservatism reflected in each of the analyses. Discuss how differences in the prediction results relative to t_{block}, K_{max}, K_{split}, and/or m_{split} could be caused or explained by differences in the applied methodologies, plant model features (such as core nodalization), assumed key inputs, and other relevant conditions.

c. Provide references for the technical documents containing the calculation notebooks documenting the analyses in Items a and b and confirm that the analyses were quality assured.

RAI-12, Vol 4

The UPI plants were not considered as part of the analysis due to their ECCS configurations. Provide justification that plants with the UPI configurations do not require T-H analyses to demonstrate that the acceptance criteria defined in WCAP-17788 are satisfied and that the TR is applicable to their specific plant designs including applicable ECCS features.

RAI-13, Vol 4

Figure 8-13 shows the mid-core velocity in the BB channel going from negative, interpreted as downward, to about zero very rapidly before switchover time. The plotted BB inlet velocity remains stable at near zero or around a slightly negative value throughout the exhibited part of the transient while the BB exit velocity remains stable at a low negative value. In addition, the BB exit velocity is large in magnitude compared to the BB inlet velocity. Provide an explanation for this behavior.

RAI-14, Vol 4

Figures 8-16 and 8-25 show a spike in PCT occurring while the downcomer fills. Once the flow begins exiting the BB region, the core begins to cool again and PCT decreases. Were the potential range of flow rates for downcomer fill considered in the analyses? Explain how the analysis accounts for potential uncertainties or variability in the downcomer fill time. If the analysis does not account for such uncertainty/variability, explain how the behavior (PCT spike) would be affected by different downcomer fill times.

RAI-15, Vol 4

Provide the results of Figures 9-9 and 9-10 on the same graph. Normalize the integrated mass flow on an average channel basis so that a meaningful comparison can be made.

RAI-16, Vol 4

Assumption 6 in Section 4.1 states that “ECCS temperature during sump recirculation will be set at or near saturation temperature at containment pressure” and explains that “neglecting the presence of subcooling is conservative because it maximizes the steaming rate in the core and minimizes the cooldown rate of the reactor vessel (RV) and steam generators (SGs).”

Tables 6-1 through 6-4 include the parameter “ECCS temperature during recirculation phase” as a key input. The CE plant category stands apart in the sense that this input is set at a temperature of 212 °F with the “containment pressure during recirculation phase” specified as “dynamically calculated” according to Table 6-3. During the NRC audit of the AREVA T-H analyses for the CE plant category, it was clarified that S-RELAP5 was used in a coupled mode with the ICECON containment code to calculate the containment backpressure.

a. Identify contributing physical processes that are dependent on the degree of ECCS fluid temperature subcooling and explain the effects associated with these processes with regard to core cooling. In addition to core steaming, explain whether processes such as condensation, downcomer boiling, liquid entrainment, and boiling in SG tube bundles (if engaged) were considered among such processes. State whether these effects are considered conservative or non-conservative and provide justifications for the conclusions.

b. Identify the coupled S-RELAP5/ICECON methodology by providing a reference to the technical document that describes it. Explain whether the methodology was validated and assessed for applications similar to the LOCA analyses documented in Vol. 4 for the CE plant category. Clarify whether the coupled code methodology and/or application analyses obtained with this methodology have been reviewed and/or approved by NRC. Provide the key inputs and assumptions relative to the containment model. Explain which of these input parameters were modeled in a bounding manner along with the ranges considered in determining the input values for the parameters.

c. In order to assess the effect from the major assumption regarding the ECCS temperature subcooling, the NRC staff recommends performing two re-analyses for Cases 1 and 2 documented in Section 10 using S-RELAP5 in a stand-alone mode. For the purpose of these re-analyses it is suggested that an “ECCS temperature during recirculation phase” of 212 °F along with a “containment pressure during recirculation phase” of 14.7 psia consistent with the key inputs applied for the Westinghouse upflow and downflow plant categories is used. Verify that there is little impact on the K_{max} and t_{block} results compared to the results documented in Section 10.

d. Tables 6-1 through 6-4 do not provide information regarding the ECCS temperatures prior to sump switch over (SSO). Section 9.3 states that “during transfer to sump recirculation, the ECCS coolant temperature is set to 212 °F.” Explain how the ECCS temperatures prior to SSO were defined for the purposes of the analyses and provide the values used for the analyses in Sections 8, 10, and 11. Clarify whether the ECCS temperature prior to SSO should also be considered a contributing factor for the purposes of the T-H analyses in Vol. 4 and justify the response. Describe the effects that the ECCS temperature assumption prior to sump switchover can have on other processes (i.e., voiding, swelling, etc.) if it is found to have a significant impact on the results.

RAI-17, Vol 4

Section 8.2.2 presents T-H results for Case 1B. Case 1B is presented because it represents the limiting time of complete core blockage, t_{block}, for the Westinghouse upflow plant category. In discussing the quantity identified as “reactor vessel fluid mass,” shown in Figure 8-17, it is stated that “when complete core inlet blockage is applied, the RV inventory increases quickly, which can be credited to filling of the downcomer." The explanation for the inventory increase following the simulated core inlet blockage appears implausible if the result in Figure 8-17 represents the fluid mass within the entire RV volume. Since a stable ECCS liquid injection rate is expected during the period discussed in the above citation, the increase in accumulated fluid mass in the RV should be attributed to a reduction in the mass rate at which fluid exits the RV though the break, as suggested by the "break exit quality" shown in Figure 8-24, rather than by accumulation of mass in any sub-region within the entire RV control volume. The same observation applies to a similar statement in Section 8.2.3 that "when partial core inlet blockage is applied, the RV inventory increases quickly, which can be credited to filling of the downcomer." This explanation was provided with regard to the predicted "reactor vessel fluid mass" shown in Figure 8-26 for Case 2B, which was used to determine K_{max}. For Case 2B, the corresponding "break exit quality" response appears in Figure 8-34. To understand the role of entrainment and driving processes in the results:

a. Explain what causes the increase in the RV inventories shown in Figures 8-17 and 8-26. Provide updates to the explanations provided in the text of Sections 8.2.2 and 8.2.3, as appropriate.

b. Define the parameter "break exit quality" shown in Figures 8-24 and 8-34. Explain whether the same definition applies to any T-H quantity labeled as "quality" throughout Vol. 4. Otherwise, provide definitions and clarifications.

c. Provide plots showing the following sets of parameters for Cases 1B and 2B in Section 8.

    i. Mass flow rates of liquid, steam, and total (liquid and steam) fluid discharges through each opening of the double-ended guillotine (DEG) break
    ii. ECCS liquid mass flow rates injected into each cold leg and the total ECCS liquid mass flow rate injection into the reactor coolant system
    iii. Liquid mass flow rates entering the RV through each cold leg nozzle and the total liquid flow for all cold leg nozzles
    iv. Mass flow rates of liquid and steam entering the RV through each intact hot leg nozzle and the total (liquid and steam) flow rate for all intact hot leg nozzles
    v. Steam flow quality defined as a ratio of the steam mass flow rate to the total (liquid and steam) mass flow rate for the RV-side opening of the DEG break

d. Present plots that show integrals for the identified mass flow rates requested in Item c above (liquid, steam, and/or total liquid and steam, as relevant).

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The HLB T-H cases analyzed for the Westinghouse upflow plant category presented in Section 8 include Case 5, which simulated debris blockage for determination of K_{split} and m_{split} at an ECCS recirculation flow rate of 8 gallons per minute per fuel assembly (gpm/FA). As seen in Figure 8-44, following the SSO time, the downcomer and BB collapsed liquid levels decrease relatively rapidly and drop by about 8 ft and 3 ft, respectively, and reach their minimum levels at about 2,100 seconds before starting a gradual recovery. In contrast to all remaining cases presented in Section 8 (Cases 0A, 1B, 2B, 1, and 3), the result for Case 5 shows the predicted downcomer collapsed liquid level decreasing below the BB collapsed liquid level over a period of about 1,800 seconds. Explain the physical processes leading to this prediction based on the code results for this case. Specifically, explain whether liquid entrainment is among the processes. If necessary, implement modeling changes that correct any unacceptable code behavior and present updated results for Case 5.

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The HLB T-H results for the Westinghouse upflow plant category presented in Section 8 include calculations for a single case without debris simulation (Case 0A) and five additional cases that simulate debris for determining t_{block} (Case 1B), K_{max} (Case 2B), and K_{split} and m_{split} (Cases 1, 3, and 5). Regardless of whether debris was simulated or not, the results exhibit a common response as reflected in the plots of collapsed liquid levels for the downcomer, BB, hot assembly, and some plots of predicted RV fluid masses. The response takes place around and following the SSO time. It is characterized by an initial increase in the magnitude of these parameters, which reach maximum levels followed by a relatively rapid decrease. From the predicted collapsed liquid levels, this response is seen taking place around 100 seconds following SSO at 1,300 seconds for Case 0A (Figure 8-7), and within about one minute of the SSO time for Cases 1B (Figure 8-18), 2B (Figure 8-27; it is not easily seen in Figure 8-28 due to core blockage simulated coincidently with SSO), 1 (Figure 8-36, over a shorter timeframe than in the other noted figures due to the high ECCS flow), 3 (Figure 8-40), and 5 (Figure 8-44). A similar response also occurs in Figure 8-17, which illustrates the effect on a predicted RV fluid mass (note that the response is masked in Figure 8-26 due to core blockage simulated coincidently with SSO).

A similar observation applies to the results presented in Section 9 for the Westinghouse downflow plant category. Figures 9-6, 9-7, 9-17, 9-18, 9-29, 9-33, and 9-37 illustrate the response on predicted collapsed levels and Figures 9-16 and 9-22 show predicted RV fluid masses.

a. Explain the physical processes leading to this behavior based on the code results for the analyzed cases. This response reflects the system manometric balances and related contributing pressure losses experienced across the core inlet and other simulated flow passages and regions. Describe the effects of each process and explain whether the observed impact from such effects was considered acceptable. Specifically, explain whether liquid entrainment is among such processes. If liquid entrainment has an effect, analyze the degree to which it had an effect on key results from the simulated cases and justify the acceptability of the results.

b. The maximum resistance, K_{max}, results for the Westinghouse upflow and downflow plant categories are obtained from analyses in which the core blockage is applied simultaneously with SSO. The NRC staff needs assurance that K_{max} results are not affected by processes associated with the above described system response occurring around the SSO time. The NRC staff recommends performing a re-analyses for the cases presented in Sections 8 (Case 2B) and 9 (Case 2B) used to determine K_{max} with the only change being that the core inlet blockage is applied 200 seconds following the SSO time instead of coincidently with the SSO time.

RAI-20, Vol 4

The T-H analyses for the large HLB LOCA scenario are used to determine four key parameters, t_{block}, K_{max}, $K_{split,}$ and m_{split}, which are used as inputs to the overall HLB methodology described in Volume 1.

Implementing the high-level process outlined in Figure 4-2, "Overview of Hot Leg Break Methodology," Section 6.5 provides an algorithm that uses K_{split} and m_{split} for calculating in-vessel fiber loads and verifying that they comply with the applicable limits for core inlet, in-core, and total RV fiber. In particular, the core inlet fiber load is used to determine the core inlet resistance, based on the subscale head loss testing in Vol. 6, so that it can be compared against the applicable K_{max} limit as the accident progresses. This important check is performed in Step 10 of the algorithm. As stated in Step 10, "if the core inlet K factor is greater than K_{max} before the time of t_{block}, then the calculation does not meet the acceptance criteria defined by the TH analyses." The core inlet flow and fiber load after SSO are calculated using both K_{split} and m_{split}. When the core inlet resistance is less than or equal to K_{split}, the flow into the RV passes only through the core inlet where it deposits fiber. When the core inlet resistance is greater than K_{split}, the flow into the RV is split between the core inlet and the alternate flow path (AFP) based on m_{split}. The current core inlet resistance is compared against K_{split} at Step 9 of the algorithm.

The K_{split} and m_{split} critical inputs are determined in Vol. 4 from T-H analyses, which were performed using minimum BB flow resistances "for all plant categories with an upflow BB configuration." Section 4.2 states that "selecting the minimum resistance will minimize the resistance due to debris (and hence the amount of debris at the core inlet) that will begin to divert flow to the AFP." It explains that "minimizing the debris at the core inlet required to divert flow to the AFP will maximize the amount of debris predicted to bypass the core inlet and transport to the core region through the AFP." Section 4.2 further explains that a minimum UHSN resistance "will be applied for cases that are used to determine K_{split} and m_{split}" for the Westinghouse downflow plant category.

Explain if the use of maximum AFP flow resistances result in a conservative mass of debris at the core inlet for all cases. Evidently, using thus determined K_{split} and m_{split} parameters will result in the earliest time of flow diversion through the AFPs and the maximum fraction of ensuing ECCS flow through the AFPs, which will maximize the predicted amount of debris transported to the core region and minimize the amount of debris accumulated at the core inlet. Accordingly, the calculated core inlet debris amount can allow the calculation process to continue, unless stopped due to exceeding the in-core or total RV fiber limits, both of which can be significantly higher than the core inlet fiber limit, and eventually produce an acceptable overall analysis outcome without detecting possible violation of the applicable core inlet debris limit. Therefore, the generic HLB methodology, using the K_{split} and m_{split} critical inputs established in Vol. 4, could result in non-conservative results for the Westinghouse upflow, Westinghouse downflow, and CE plant categories.

It is possible that an approach based on maximized, as opposed to minimized, AFP resistances for the determination of K_{split} and m_{split} can be considered for implementation in the HLB methodology for assuring satisfaction of the core inlet fiber limit. Provide additional information to justify how the HLB methodology described in WCAP-17788 can be applied to assure satisfaction of the established core inlet fiber based on the t_{block}, K_{max}, $K_{split,}$ and m_{split} results established in Vol. 4. The justification could include sensitivity studies where AFP resistance is minimized for each plant category and plant-specific guidance on this matter.

RAI-21, Vol 4

The T-H analyses determine four key parameters, t_{block}, K_{max}, $K_{split,}$ and m_{split}, which are used as input to the overall methodology described in Vol. 1. The K_{split} results are presented in Figures 8-4, 9-3, 10-4, and 11-3 and the m_{split} results are presented in Figures 8-5, 9-4, 10-5, and 11-4 in Vol. 4. Fitting curves to the predicted K_{split} and some m_{split} results are shown in each of these plots. The same plots are reproduced in Figures 6-1 through 6-8 in Volume 1.

The T-H analyses do not provide a basis for extrapolation or interpolation of the calculated K_{split} results as a function of the ECCS recirculation flow rate. Provide the applicability of extrapolating the calculated K_{split} values outside of the analyzed range of ECCS rates for the fitting expressions in Figures 8-4, 9-3, 10-4, and 11-3. Justify the ability to interpolate the expressions to reproduce the calculated K_{split} values between the calculated points.

Similar to the case with the calculated K_{split} inputs, the m_{split} results and the supporting T-H analyses in Vol. 4 do not provide a basis for justifiable extrapolation or interpolation of the calculated m_{split} results documented as a function of the core inlet resistance reduced by K_{split} and the ECCS flow rate. Provide the basis for extrapolating the calculated m_{split} results beyond the maximum core inlet resistances analyzed for each assumed ECCS rate to produce the m_{split} results shown in Figures 8-5, 9-4, 10-5, and 11-4. For the Westinghouse upflow category, the largest core inlet resistance of about 4.0×10^4 was reached in the case of 8 gpm/FA, whereas the applicable K_{max} is 5.0×10^5; for the Westinghouse downflow category the largest core inlet resistance of about 1.2×10^5 was reached in the case of 8 gpm/FA whereas the applicable K_{max} is 6.0×10^5; for the CE category the largest core inlet resistance of about 5.4×10^5 was reached in the case of 800 gpm, whereas the applicable K_{max} is 6.5×10^6; and for the B&W category, a core inlet resistance of about 1.8×10^4 was reached for each ECCS rate, whereas the applicable K_{max} is 1.0×10^8. Figures 8-5 and 9-4 each document two fitting expressions for the cases with the lowest and highest ECCS rates for the Westinghouse upflow and downflow categories, whereas Figures 10-5 and 11-4 each show a single fitting curve presumably intended to bound the calculated m_{split} results. Describe how the m_{split} results can be justifiably interpolated to obtain a valid m_{split} input at ECCS flow rates that do not match any of the values analyzed for the Westinghouse upflow and downflow categories (8, 12, 18, 30, and 40 gpm/FA) or for the B&W category (7.5, 12.5, 17.5, 22.5, 27.5, and 43.5 gpm/FA). Also, the significant degree of scatter in the plotted m_{split} points in Figure 10-5 makes the information on the plot hard to interpret.

The NRC staff needs confidence that reliable and valid K_{split} and m_{split} inputs were obtained. If such assurance is not reached generically, additional T-H calculations to produce applicable K_{split} and m_{split} inputs, including supporting analyses, will be requested on an as-needed plant-specific basis.

RAI-22, Vol 4

The small-break LOCA analysis approach applied for the B&W plant category and the plant analysis results for a 0.5 ft^2 small HLB LOCA presented in Section 11 may not meet the requirements of 10 CFR 50.46(a)(1)(i), which states, "ECCS cooling performance must be calculated in accordance with an acceptable evaluation model and must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated." Specifically, it is questionable whether the RCS T-H conditions, predicted at the time of core inlet blockage and thereafter for a 0.5 ft^2 small HLB LOCA, remain applicable to a DEG HLB LOCA, which represents the limiting scenario as stated in the TR. The three arguments provided in Section 6.4 of Vol. 4 in support of the selected 0.5 ft^2 break size do justify extrapolation of the calculated small-break LOCA results to a full-size DEG HLB LOCA transient considered as the limiting scenario.

Provide additional LOCA calculation results for the B&W plant design category, including results for predicted safety criteria, figures of merit, and supporting analysis results, which demonstrate quantitatively that the requirements of 10 CFR 50.46(a)(1)(i) are met. T-H LOCA calculations should be performed using applicable and appropriately assessed EMs.

RAI-23, Vol 4

To assist the NRC staff evaluation of liquid discharge through the break for the large HLB LOCA scenario, provide the following information for each of the four analyzed plant categories for the limiting break size.

a. Identify key transport mechanisms of liquid discharge through each side of the break that can occur during transient phases of relevance to the T-H analyses. Explain how liquid transport mechanisms caused by liquid spillover under elevated two-phase mixture levels in the reactor upper plenum due to carry-out of dispersed liquid by entrainment under depressed mixture level conditions are accounted for and modeled in the applied codes. Describe whether the liquid transport models are reflective of and dependent on the upper plenum two-phase mixture level and explain how the performance of these models, in terms of their accuracy and sensitivity, depends on the code capabilities to predict the two-phase mixture levels in the reactor upper plenum under conditions representative of the LTCC phase of a large HLB LOCA.

b. Describe code assessments, including analyses and results, which demonstrate the capability of the codes used in the T-H analyses to adequately predict transport mechanisms that result in liquid discharge through the break during LTCC. Consideration should be given to contribution from mechanisms accounting for both entrainment and deposition (de-entrainment) of liquid that can take place in participating RV regions including the upper plenum and connected broken hot leg piping. Include information identifying test facilities, test runs, and test conditions used in the code assessments. Provide comparisons of code predictions against relevant test data, as available.

c. Explain if any special liquid entrainment models, modeling options, and related flags were available in the applied codes and if any such features were activated in the T-H analyses to account for liquid entrainment. Examples of such modeling features can be related to special upper plenum entrainment models, mixture level models, and related special interfacial drag models. State whether any break flow multipliers were applied in the analyses. Provide the multiplier values, and explain if the selected inputs were examined for impact on the predicted break liquid discharge.

d. Identify key models used and the underlying correlations related to the predicted break liquid discharges. Provide the ranges of applicability of these correlations, and compare them against the conditions predicted in the analyses documented in Sections 8 through 11. Provide the information in a table format for each of the cases analyzed to determine t_{block} and K_{max} in Section 8 (Cases 1B and 2B), Section 9 (Cases 1A and 2B), Section 10 (Cases 1 and 2), and Section 11.

e. If not provided elsewhere, include plots showing the following sets of parameters for the cases documented in Sections 8 through 11 as a function of transient time:

   i. Mass flow rates of liquid, steam, and total fluid (liquid and steam) discharges through each opening of the DEG break. Include integrals of the identified break mass flow rates.
   ii. Two-phase mixture level on the core side of the RV
   iii. Steam flow quality calculated as a ratio of the steam mass flow rate to the total (liquid and steam) mass flow rate for the RV-side opening of the DEG break
   iv. Predicted pressure difference between the upper plenum cell connected to the broken hot leg pipe and the containment backpressure.

f. Figure 1 below compares predicted exit qualities for the original analysis of Case 1 used to determine t_{block} for the CE plant category as documented in Section 10 and the revised analysis in Erratum, submitted with the February 12, 2016, letter OG-16-42 (t_{block}=20,000 seconds). It is noted that the results are significantly different following the simulated blockage time in each analysis. The results also differ during some time periods prior to 15,000 seconds, which is the earlier of both simulated t_{block} times. Describe why the results prior to 15,000 seconds are not consistent between the two cases and state which case presents the correct values. Provide similar information for the time period after blockage is simulated. Please describe why the results fluctuate significantly and justify that the code performance provides a valid representation of the system.

g. During the NRC audit of the AREVA T-H analyses for the CE plant category, entrainment predictions using S-RELAP5 were presented to the NRC staff. Explain whether any code and/or plant input model changes were found necessary to address the code performance. If they were needed, identity and describe any modeling changes that were implemented along with their supporting validation bases. Justify the break liquid carry-out predictions for each of the analyses for the CE plant category in Section 10 including any revisions to these analyses. If necessary, provide updated T-H analysis results.

h. Investigate whether the substantial scatter in the m_{split} results shown in Figure 10-5 is related to the behavior of the break liquid carry-out result. Note that if the liquid carryover is incorrect, it can render the m_{split} result unacceptable. Describe whether correction of the m_{split} results was found necessary to address the observed scatter if it was determined that effects from deficiencies in the predicted liquid entrainment were a contributing factor. Provide any updated result if applicable.

i. Provide assessments demonstrating that t_{block}, K_{max}, K_{split}, and m_{split} results, as obtained from the analyses in Sections 8 through 11 for compliance demonstration with regard to the acceptance criteria, are accurate and not influenced unduly by deficiencies in the entrainment predictions that can be attributed to various factors such as those discussed above in Items a through h. Include consideration of the effects that the ECCS temperatures, both prior and following SSO, and modeling assumptions related to this parameter can have on the prediction results for entrainment.

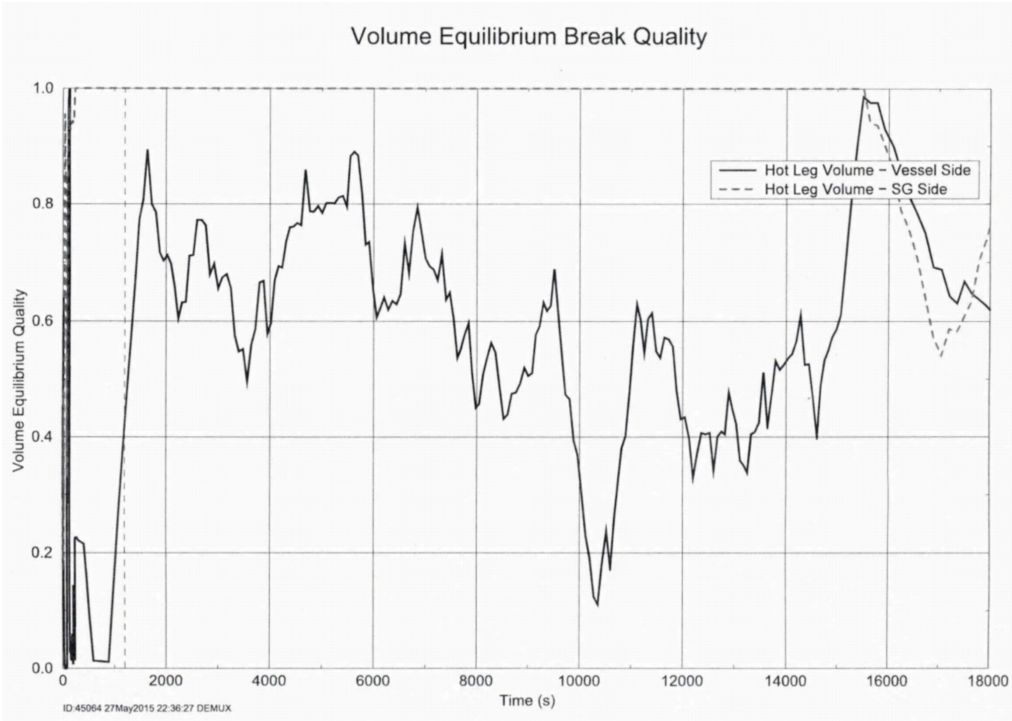

Figure 10-22 Case 1 – Break Exit Quality

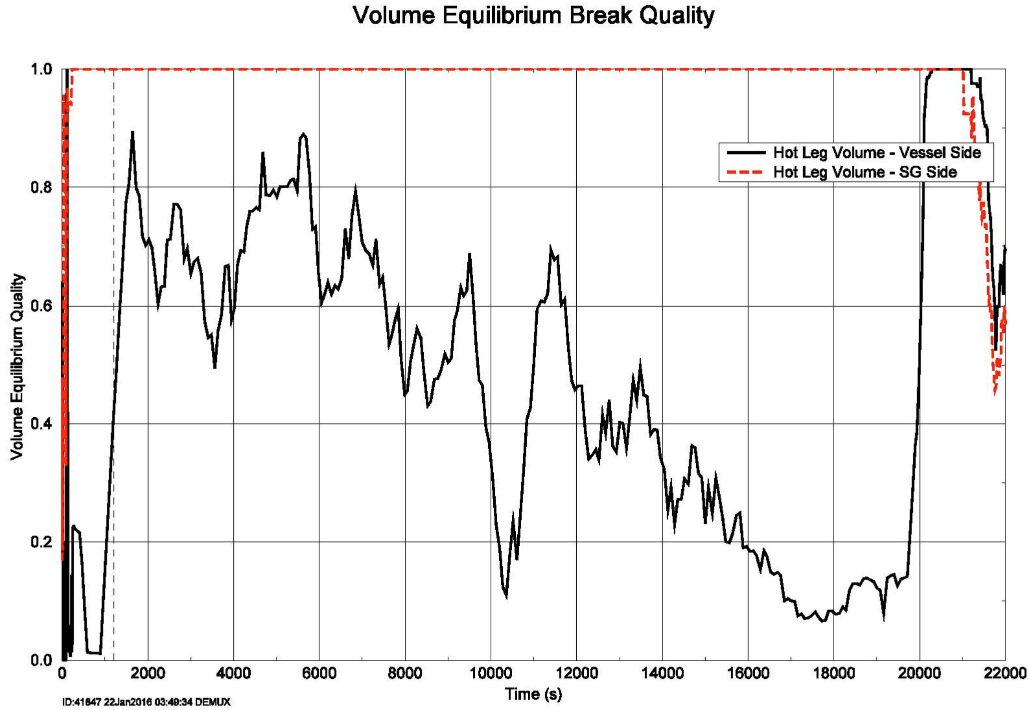

Figure 10-22 Case 1 – Break Exit Quality

Figure 1: Predicted Break Exit Qualities for Case 1 to Determine t_{block} for the CE Plant Category
(Top: original result from WCAP-17788 Rev. 0 with t_{block}=15,000 s = 250 min
Bottom: corrected result from WCAP-17788, Erratum, OG-16-42 with t_{block}=20,000 s = 333 min)

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Figures 8-9 and 9-8 indicate that the total ECCS injected masses for the Westinghouse upflow and downflow design categories increase significantly at SSO even though the injection rates appear to be constant both prior to and after the observed stepwise change at SSO.

a. Provide plots of the ECCS injection rates as a function of time for Case 0A for both Westinghouse upflow and downflow plant categories.

b. Explain the way in which the simulated ECCS pump injection rates prior to and following SSO were determined and identify the factors and assumptions that were considered when determining the flows. Include any temporary safety injection (SI) impediment, single failure assumptions, and pump performance characteristics among the considered factors and assumptions. In the above identified cases, the ECCS recirculation flow rate is much different from the ECCS injection rate prior to SSO.

c. Clarify if varying the ECCS injection mass flow rate upon SSO had an effect on the analysis results for both plant categories.

d. Table 7-1 in the revised Section 7.1.1 of Vol. 1 describes the following ECCS performance for a Westinghouse three-loop plant following a large cold leg break. From 0 to 15 min: 1 residual heat removal and 2 high head SI (HHSI) pumps are described as typical injection phase modeling with single active failure; from 15 to 45 min: 2 HHSI pumps, typical SI phase modeling for this plant; from 45 to 47 min: no flow, interruption at cold leg recirculation; from 47 min to termination: 2 HHSI pumps. This represents an ECCS performance pattern, which appears opposite to the one described above (increase vs decrease in ECCS flow rate upon SSO). Clarify if varying the ECCS injection mass flow rate upon SSO following this opposite pattern would have an effect on the analysis results for both plant categories.

e. Considering the results from Vol. 4, explain the applicable conditions and related requirements for adequately determining the values of ECCS flow. Consider injection and recirculation rates, including interruptions during switchover, on a plant-specific basis to ensure that ECCS performance is adequately represented.

f. Provide the information requested in Items a through e for the CE and B&W plant categories. It is noted that Table 6-3 lists the "low pressure safety injection (LPSI) flow rate" as a key input for the CE plant category and Table 6-4 identifies "low pressure injection (LPI) flow rate" as a key input for the B&W plant category thus linking this key input to the performance of specific ECCS components.

g. Explain the reason for including Note 2 to Table 6-4 relevant to the B&W plant category stating that "the LPI flow rate followed a pump curve in the analysis. The value shown is the flow at run-out conditions." Provide the pump curve and the flow rates used in the analysis. Justify that these parameters are applicable to all plants in this category.

h. Provide graphs of SI flow rates as a function of time for each individual reactor coolant primary loop for the entire duration of the analysis for the cases included in the case matrices in Tables 8-1, 8-2, 9-1, 9-2, 10-1, 10-2, 11-1, and 11-2. Show the contributions from both high and low pressure SI for the cold and hot legs. Describe all applicable assumptions related to the way in which these flow rates were established and simulated in the T-H analyses.

RAI-25, Vol 4

In determining the t_{block} and K_{max} inputs for the Westinghouse upflow category, Section 8.1 provides a simulation matrix of cases considering only two ECCS recirculation flow rates of 18 and 40 gpm/FA. Section 8.2 states that LTCC can be maintained if the time of complete core inlet blockage, t_{block}, occurs 143 minutes, or later, after the initiation of the LOCA event. This time is taken from Case 1B simulating the minimum ECCS recirculation flow rate of 18 gpm/FA and is stated to bound "the range of recirculation flows investigated." The K_{max} input is determined from Case 2B with the same simulated ECCS recirculation flow rate of 18 gpm/FA.

a. Provide justification that the t_{block} criterion from Case 1B at 18 gpm/FA is valid for the range of flow rates from 8-40 gpm/FA as documented in Table 6-1 for this parameter.

b. Provide justification that the K_{max} criterion from Case 2B with a simulated ECCS recirculation flow rate of 18 gpm/FA is valid for the range of flow rates from 8-40 gpm/FA as documented in Table 6-1 for this parameter.

c. Provide justification for using only 18 and 40 gpm/FA flow rates for determining the t_{block} and K_{max} inputs as stated in Note 1 to Table 6-1 and documented in the simulation matrix of cases provided in Section 8.1.

d. Define the range of ECCS recirculation flow rates for which the t_{block}, K_{max}, $K_{split,}$ and m_{split} results, as obtained in Section 8, are considered applicable to the Westinghouse upflow plant category and provide a justification for this range.

e. Provide similar responses to Items a through d for the other three plant categories to justify that the t_{block} and K_{max} inputs calculated using a single ECCS recirculation flow rate for each input are applicable to the range of flow rates defined for each plant category. For example, justify for the Westinghouse downflow category that t_{block} is determined from Case 1A simulating an ECCS recirculation flow rate of 40 gpm/FA and K_{max} is determined from Case 2B with a simulated ECCS recirculation flow rate of 18 gpm/FA.

f. Sections 8-3 and 9-3 state that "the duration and magnitude of the heatup were heavily dependent on the timing of complete core inlet blockage and the ECCS flow rate." Considering the responses to items a through e above, demonstrate that the calculated parameters are valid for the ECCS flow rates and core inlet blockage times used in the analysis.

RAI-26, Vol 4

K_{max} for the CE plant category was determined by applying a gradual ramp in the simulated core inlet resistance starting from 0 at 1,800 seconds and reaching K_{max} of 6.5×10^6 at 4,200 seconds as shown in Figure 10-2. The profile represents an increase in the resistance value by applying four different constant rates of resistance increase, which change in a stepwise manner with time.

a. Justify that the K_{max} value of 6.5×10^6, using the profile from Figure 10-2, represents a robust result and is not an outcome of tuning of the core inlet resistance profile to obtain a desired result. Results from sensitivity analyses can be used to provide the justification.

b. In the case of the profile shown in Figure 10-2, the core inlet resistance was increased from 0 to 6.5×10^6 within a time window of 2,400 seconds (40 min). As the result of 6.5×10^6 for K_{max} was tied to the specific profile from Figure 10-2, justify the K_{max} input for the CE plant category by explaining how it can be assured that the K_{max} value will not be developed within a time window shorter than 40 minutes resulting in K_{max} occurring earlier than 70 minutes into the LOCA transient, which could lead to the PCT acceptance criteria being violated.

RAI-27, Vol 4

T-H code predictions to demonstrate adequate core coolability under conditions associated with blocked core inlet flow passages require reasonable assurance of adequate code performance under the simulated conditions. The examination of code results during the NRC audit of the Westinghouse T-H analyses in Sections 8 and 9 on January 27-28, 2016, indicates that flow patterns involving parallel cross-connected channels to model the core following a simulated complete core inlet blockage can be complex. It was determined that obstruction of lateral flow passages between fuel assemblies due to the presence of spacer grids was not accounted for in the modeling of the lateral cross-connections between parallel core channels, including the hot channel. In addition, potential effects on the axial flows due to possible localized accumulation of debris at the locations of spacer grids in regions above the core inlet were not modeled to assess such effects.

Cross-flows between parallel channels can be a contributing factor affecting code prediction of local fuel conditions, including PCT, due to their impact on fluid velocities, void fraction, and two-phase flow patterns. Provide results from additional T-H analyses for a representative case analyzed in each plant category to assess the effects from the above identified factors related to lateral obstruction of cross-flow passages and impediment of axial flows on the PCT and t_{block} predictions. The analyses should be performed using core modeling changes that account for:

(1) reduced flow area of cross-flow passages due to the spacer grids present in the active core region,
(2) impact on resistances of cross-flow passages from the spacer grids present in the active core region, and
(3) increase in the simulated spacer grid resistances in the axial direction at appropriately selected spacer grid locations, including impact for both axial directions, to simulate the effect from possible local fiber accumulation.

Such modeling changes and modifications should be applied to the hot channel and all or some of the channels representing the entire core as found appropriate. If necessary to resolve the impact from the examined factors and processes on the PCT and t_{block} predictions, include sensitivity results related to specific factors and modeling assumptions as applicable. For each simulation, include sufficiently detailed results to explain effects on the predicted core T-H response, PCT, and t_{block} in comparison to the corresponding base cases. Include PCT, void fraction, fluid phase velocities, and two-phase flow patterns for appropriately selected hydraulic channels and cells, as well as integrated mass flows in both lateral and axial directions for selected critical flow passages. Include a description of the implemented modeling changes with a sufficient degree of detail to explain clearly how the physical processes and factors were accounted for in the model along with the introduced assumptions.

RAI-28, Vol 4

The Westinghouse upflow, downflow, and CE base plant models were developed for best estimate (BE) PCT and clad oxidation analysis. As discussed in Section 6.1, many of the inputs from the BE models are set to nominal values. Some changes were made to bias the model toward an Appendix K analysis. The use of Appendix K type inputs is intended to add conservatism to the model to account for uncertainties associated with the LTCC phase following a LOCA.

Section 5 notes that the EMs used to analyze debris are based on NRC-approved EMs. For example, Section 5.1 notes that WCOBRA/TRAC MOD7A is used within the Code Qualification

Document and ASTRUM EMs. However, the approach of nominal modeling with these codes has not been previously reviewed and accepted by the NRC.

Provide a table of all physical models and plant parameters that were considered in the uncertainty analysis for each computer code's most recently approved EM, and indicate how the uncertainty analysis has been adjusted to use a somewhat nominal, yet somewhat conservative analytic method. For each adjustment relative to the previously approved application, provide detail or justification that explains how the modified approach introduces an acceptable amount of conservatism. This table should expand on the information provided in, for example, Table 6-1, and should compare the current modeling approach to that previously approved for BE analysis.

RAI-29, Vol 4

State whether the base plant models were submitted to the NRC to document safety analysis. Describe how the changes made to the base models regarding core volumes, ECCS model, BB flow resistance, break pressure boundary conditions, break flow multipliers, core inlet blockage, and calculation inputs in Tables 6-1 through 6-4 maintain adequate conservatism.

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Figure 8-19 shows two time periods after complete core blockage during which the downcomer level remains steady (around 19 and 22 ft) before leveling out for the remainder of the transient. This could be explained by an accumulation of injected liquid in parts of the RCS outside of the RV. In addition, possible transport of liquid into the reactor upper plenum via the SG U-tube bundles can take place after filling the cold leg side of the RCS.

The variable m_{split} is defined as the flow split between the core inlet and AFPs. Figures 8-5, 9-4, 10-5, and 11-4 depict the calculated inputs for $m_{split.}$

a. Was passage of ECCS liquid into the upper plenum via the SGs predicted for any of the runs used to produce the results shown in Figures 8-5, 9-4, 10-5, and 11-4? For each case that predicted flow into the upper plenum via the SGs, plot (in units of lbm/s) the rate of liquid flow that enters into the core, the AFPs, the reactor upper plenum through each loop, and the total amount into the upper plenum via all loops as functions of time.

b. Define how m_{split} is calculated in Case 1B considered in Figure 8-19 and illustrate the m_{split} calculation for this case by plotting the rate (in units of lbm/s) of liquid flow into the core and into the BB AFP, the ECCS recirculation flow, the flow into the upper plenum via the SGs, if predicted, and the calculated m_{split} ratio (in dimensionless units) as functions of time.

c. Provide details of the calculation of m_{split} for any runs that resulted in liquid transport into the reactor upper plenum via the SGs.