WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)"
Request for Additional Information – (Non-Proprietary)
RAIs 83-85, 88-92, 94-95 and 113-119

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Question #83: Stratified Flow Multiplier HS_SLUG

WCOBRA/TRAC-TF2 superimposes horizontal stratified flow (including wavy-dispersed flow) onto the basic flow regime map. WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 4, "WCOBRA/TRAC-TF2 Flow Regime Maps and Interfacial Area," Subsection 4.4.5, "Horizontal Stratified Flow," analyzes test data by plotting modified Wallis numbers, as defined by Equation (4-108), versus void fraction in Figure 4-17, "Horizontal Stratified Flow Regime Transition and Relevant Data," and states that [

]^{a,c} The critical relative phase velocity for horizontal flow, $\Delta u_c = |u_g - u_l|_c$, is given in Equation (4-112) using a criterion based on the Wallis parameter. Equation (4-117) introduces a weighting factor, W_{st}. which is determined from the critical velocity using two adjustable constants, C_{hs_slug} and C_{stfru}. W_{st} is used in Equation (4-116) to modify the interfacial flow area, A_i. According to Subsection 4.4.5, the allowable input range C_{hs_slug} is from 0.1 to 9.9 with unity being the default value for C_{hs_slug} in WCOBRA/TRAC-TF2.

Referring to the data presented in Figure 4-17, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 29, "Assessment of Uncertainty Elements," Subsection 29.1.7, "Horizontal Stratified Flow Regime Transition Boundary (HS_SLUG)," states that [

]^{a,c} Subsection 29.1.7 further explains that "the horizontal stratified flow regime transition boundary multiplier, HS_SLUG, is then introduced to adjust the critical relative velocity for horizontal stratified flow." It is also stated that "For the purpose of the uncertainty analysis a random value of HS_SLUG is sampled with [

]^{a,c}

(1) Please clarify if the above cited sentence, appearing in the second paragraph of

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 29.1.7, "Horizontal Stratified Flow Regime Transition Boundary (HS_SLUG)," on page 29-34 is in error and if it should be corrected as follows: "For the purpose of the uncertainty analysis a random value of HS_SLUG is sampled with [ ]^{a,c} Please explain and correct as appropriate.

(2) WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 10, "WCOBRA/TRAC-TF2 One-Dimensional Component Models," Subsection 10.2, "Pipe Component," explains: "The HS_SLUG multiplier affects the transition between non-stratified and stratified flow regimes and is described in detail in Section 4.4.5." Subsection 4.4.5, "Horizontal Stratified Flow," does not mention the HS_SLUG quantity nor does it provide a reference to HS_SLUG. It is in Subsection 29.1.7, "Horizontal Stratified Flow Regime Transition Boundary (HS_SLUG)," where it is explained: "The horizontal stratified flow regime transition boundary multiplier, HS_SLUG, is then introduced to adjust the critical relative velocity for horizontal

stratified flow. The multiplier is represented by the symbol C_{hs_slug} in Equation 4-117." This way of identifying and describing the HS_SLUG quantity in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, is found to be confusing and inappropriate as it lacks in accuracy, clarity, and adequacy of description. This represents one example when details, essential for the description of important quantities and features of the FSLOCA™ methodology, are found scattered among various sections in Volumes 1, 2, and 3 of WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0. Please describe the process of ensuring that important aspects of the FSLOCA methodology are described in a clear, systematic, and coherent manner in the voluminous content of WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0. In particular, please provide corrections, if such were deemed necessary, to improve the description provided with regard to HS_SLUG and C_{hs_slug}.

(3) Subsection 4.4.5, "Horizontal Stratified Flow," explains that "the allowable input range of C_{hs_slug} is from 0.1 to 9.9. Subsection 10.2, "Pipe Component," states that "the default value of HS_SLUG is 1.0 and can be modified through the $NAMELIST set of the model input within allowable range of $0.1 \leq$ HS_SLUG ≤ 9.99." As both subsections refer to the same quantity, please explain why the provided allowable input ranges differ somewhat. Provide the limiting values for HS_SLUG and C_{hs_slug} as coded in WCOBRA/TRAC-TF2.

(4) Whereas HS_SLUG is sampled with [ ] a,c the $NAMELIST set of the model input can be used to modify HS_SLUG within the allowable range of $0.1 \leq$ HS_SLUG ≤ 9.99. Please explain the large disparity between the sampling range and the range of allowable values for HS_SLUG in WCOBRA/TRAC-TF2 taking into consideration that this extremely broad range of allowable values for HS_SLUG lacks a technical basis. Please explain the rationale for defining the range of allowable values and its intended application. In particular, describe how the use of inappropriate HS_SLUG values within the allowable range is controlled and prevented in plant safety analyses.

(5) WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 10.2, "Pipe Component," explains that "additional user defined multipliers have been added in WCOBRA/TRAC-TF2 that affect specific models and correlations" and describes HS_SLUG as one of them. With regard to HS_SLUG, Subsection 10.2 states that "besides the PIPE component, it also affects the horizontal flow calculation for all 1D hydraulic components, except the PUMP." Please clarify if HS_SLUG is imposed on a global basis for an entire input deck model, if it can be applied selectively to individual qualifying components in an input model, or if it can be activated for individual cells/interfaces within a specific qualifying component.

(6) Please explain if WCOBRA/TRAC-TF2 allows excluding selected qualifying one- dimensional hydraulic components in an input deck model from the effect of variation of HS_SLUG on horizontal flow modeling. In such a case, please explain the basis for exclusion and clarify how horizontal flow is modeled in such selected one- dimensional hydraulic components.

(7) Please relate the responses to Items (4) through (6) above to specific features of PWR plant models used for LOCA analyses. Identify specific components in such models that are affected by HS_SLUG. Present diagrams from a reference plant model to explain and illustrate the application of the HS_SLUG parameter in PWR LOCA analyses.

Response:

Part (1): The development of uncertainty range for the horizontal stratified flow follows Regulatory Guide 1.203 [1], Element 4 as a part of bottom up process to determine the bias and uncertainties of a closure relation. The uncertainty of transition from the horizontal stratified flow and non-stratified flow including the interpolation region was evaluated by comparing the prediction with the test data as shown in Fig. 4-17 of the topical report [2]. The range of uncertainty was determined to be [ ]^{a,c} and then it is applied to the PWR LOCA evaluation. The uncertainty range is sampled and applied globally to the components in which the horizontal stratification is allowed. The process is presented in Sections 4.4.5 and 29.1.7 of the topical report, and is consistent with Regulatory Guide 1.203.

A clarification needs to be given on the allowable input range of [ ]^{a,c} for C_{hs_slug} (HS_SLUG is the equivalent variable) in the WCOBRA/TRAC-TF2 computer code. As a part of Evaluation Model (EM) development following Regulatory Guide 1.203, the FSLOCA EM dictates that the range of C_{hs_slug} (HS_SLUG) in the LOCA evaluation is [ ]^{a,c} based on the comparison with experimental data. Practically, the computer code usually accepts a sufficiently wider range of input than what EM requires to accommodate the possible input range adjustment during the EM development process.

Part (2): We agree with the observation. The variables of C_{hs_slug} and HS_SLUG can be used interchangeably in the topical report. It is clarified in Section 29.1.7. However, it was not clear in Section 10.2.

Part (3): We agree with the observation. In section 4.4.5, sentence [

]^{a,c}

Part (4): As discussed in part (1), the input range of [ ]^{a,c} for C_{hs_slug} (HS_SLUG) is developed for the FSLOCA EM, while the WCOBRA/TRAC-TF2 computer code accepts the input range of [ ]^{a,c} that is greater than the range required by the evaluation model. The default value of C_{hs_slug} (HS_SLUG) is 1.0 and it is applied to the majority of validations in the topical report. The value of C_{hs_slug} (HS_SLUG) could be adjusted using a FORTRAN namelist in the input. The input range developed for the FSLOCA EM is documented in the EM topical report. The LOCA analysts shall use the correct input parameter range. The quality assurance (QA) program implemented in Westinghouse is able to effectively prevent an inappropriate parameter from being used by the LOCA analyst in the LOCA safety evaluation.

Part (5): The range parameter C_{hs_slug} (HS_SLUG) is applied globally to 1-D components [

]^{a,c}

Part (6): As explained in Part (5), the parameter C_{hs_slug} (HS_SLUG) and the horizontal stratification model are applied to every [

]^{a,c}

Part (7): Figure 83-1 shows the nodalization of Beaver Valley Unit 1 PWR loop model. The solid line represents each 1-D component and the dash line separates each computational node of the component. The momentum equation is solved at the cell face (dash line), where the parameters of GRAV, C_{hs_slug} (HS_SLUG), etc., are applied.

Let's take the primary loop as the example to demonstrate the application of horizontal stratified flow to PWR. [

]^{a,c}

[

]^{a,c}

References:

1. Regulatory Guide 1.203, "Transient and Accident Analysis Methods," 2005.

2. WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology)," November 2010.

3. LTR-NRC-14-12, "Submittal of Westinghouse Responses to "WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information – RAIs 77-82, 86-87, 93 and 112" (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244." March 2014.

a,c

Figure 83-1. Illustration of Nodalization of Beaver Valley Unit 1 PWR Loop Model. The solid line represents each component and the dashed line separates each computational node of the component. The momentum solution and GRAV, C_{hs_slug} (HS_SLUG),etc. are applied to the cell face (dashed line).

Question #84: Stratified Flow Multiplier HS_SLUG Application

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 4.4.5, "Horizontal Stratified Flow," states that "the stratified flow regime is superimposed on the basic flow regime map." It also explains that if the flow is not fully stratified, i.e. the weighing factor W_{st} determined from Equation (4-116) is less than unity, "the code interpolates between the interfacial area determined for stratified flow, calculated as above, and the value otherwise determined with respect to the basic flow regime map." In the case of "fully horizontal stratified flow, the interfacial area can be calculated from the cell geometry." The expression for this interfacial area term, $A_{i,strat}$, is given by Equation (4-113).

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 16, "Horizontal Stratified Flow and Wavy-Dispersed Flow," Subsection 16.5, "Assessment Results," explains that "the weighting factors W_{st} =1 indicates stratified flow, while W_{st} =0 indicates a non-stratified flow in the basic flow regime map. In the interpolation region, 0< W_{st} <1."

(1) W_{st} is used in Equation (4-116) to modify the interfacial flow area, A_i, when $0 \leq W_{st} \leq 1$. The equation appears as follows:

$$A_i = A_{i,st} = (1-W_{st})\, A_{i,map} + W_{st}\, A_{i,st}\,.$$

As provided, Equation (4-116) defines the quantity $A_{i,st,}$ which appears simultaneously on both the left hand side and the right hand side of the equation. Please define the quantity $A_{i,st}$, appearing in Equation (4-116), and explain the meaning of this equation. In addition, please explain if the interfacial area for "fully horizontal stratified flow," $A_{i,strat}$, as defined by Equation (4-113), is used for interpolation purposes when $0 \leq W_{st} \leq 1$ and provide the corresponding expressions in such a case.

(2) Besides the interpolation of the interfacial flow area, performed when $0 \leq W_{st} \leq 1$, please explain if the weighing factor W_{st} and the HS_SLUG multiplier are used for modification of other physical quantities used in WCOBRA/TRAC-TF2 for two-phase flow modeling in one-dimensional hydraulic components. In particular, please clarify if the calculation of interfacial friction and entrainment are affected due to variation of W_{st} and HS_SLUG. As applicable, please provide the corresponding relationships used for such modification purposes and describe the supporting technical basis.

Response:

Part (1): We agree with the observation. There are typographic errors in Eq. 4-113 and Eq. 4-116. These two equations will be corrected in the updated topical report [1] as follows:

$$A_i = A_{i,st} = S_i \cdot \Delta x = D_h \cdot \Delta x \sqrt{1 - \left(1 - \frac{2\,h_l}{D_h}\right)^2}\,, \qquad (4\text{-}113)$$

where $A_{i,st}$ replaced $A_{i,strat}$ to keep consistency with other equations in that section.

$$A_i = A_{i,map-st} = \left(1 - W_{st}\right) A_{i,map} + W_{st} A_{i,st}\,, \qquad (4\text{-}116)$$

where $A_{i,map-st}$ is the interfacial area used for the interpolation region. A linear interpolation is used.

Part (2): The purpose of introducing the interpolation region between the horizontal stratified flow regime and the flow regimes in the basic flow regime map is to [

]^{a,c}

There is no special physical meaning assigned to the interpolation region. A similar situation is the churn-turbulent regime in the basic flow regime map, in which a linear interpolation between bubbly slug flow and annular mist flow is used. Similarly, a simple linear interpolation between the horizontal stratified flow regime and the flow regimes in the basic flow regime map is implemented. The linear interpolation includes the flow area, Eq. 4-116 in topical report, interfacial drag coefficient, Eq. 5-250 in topical report, interfacial heat transfer factors, Eq. 6-211 in topical report, and wall drag factors, Eqs.5-294 and 5-295 in topical report.

The interpolation region as a part of 1-D component flow regime map has been validated against the JAERI Two-Phase Test Facility (TPTF) tests in Section 16, the COSI tests in Section 17, the loop seal tests in Section 18, the UPTF and CCTF tests in Section 19, the ROSA IV tests in Section 21, and the LOFT tests in Section 22 of the topical report.

Reference:

1. WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology)," November 2010.

a,c

Figure 84-1. Flow regime number of cell 17 of a horizontal PIPE flow with C_{stfru}=1.01.

a,c

Figure 84-2. Flow regime number of cell 17 of a horizontal PIPE flow with C_{stfru}=2.0 (default).

Question #85: Stratified Flow and Inclination Limitation

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 4, WCOBRA/TRAC-TF2 Flow Regime Maps and Interfacial Area," Subsection 4.4.5,

"Horizontal Stratified Flow," explains that the [ ]^{a,c} limitation for the inclination angle of a channel, β, in the described approach to stratified flow modeling is based on the assumption that the cosine value of the limiting angle [ ]^{a,c} is very close to unity. Thus, "the value can be approximated as 1.0 for simplicity, and cosβ can be removed from the stratification transition criterion."

(1) Please explain the WCOBRA/TRAC-TF2 approach to two-phase flow modeling in one-dimensional hydraulic components, including prediction of flow stratification, for channels of any inclination angle and present the applicable technical basis.

(2) Figure 21.7-2, "WCOBRA/TRAC-TF2 Nodalization of LSTF Break Unit," shows that different values of the GRAV parameter apply to branches of different orientation that are used to model the break pipe. Please explain how the inclination angle is defined for each individual cell/interface in a one-dimensional hydraulic component. Provide the range of allowable input values and the parameter used to define the inclination angle.

(3) If the horizontal flow calculation for a certain one-dimensional hydraulic component is affected by the HS_SLUG multiplier, please explain how input parameters, related to inclination, determine the application of the stratified flow model for the component. In addition, please clarify how the actual modeled flow piping inclination is accounted for.

(4) Please relate the responses to Items (1) through (3) above to specific features of PWR plant models used for LOCA analyses. Identify specific components in such models that represent inclined sections of the primary coolant piping, such as the hot leg risers to the SG inlet chambers, and bend regions. In particular, please consider the representation of the bends in the PWR loop seals as well as the bends in the SG U-tube bundle. Show diagrams from a reference plant model to explain and illustrate the modeling of such inclined and bend regions in PWR plant models developed for WCOBRA/TRAC-TF2. Please present the technical basis in support of the modeling approach and any special modeling features implemented in WCOBRA/TRAC-TF2 to simulate these regions.

Response:

Part (1): The WCOBRA/TRAC-TF2 code and the FSLOCA EM are developed for the application of LOCA evaluation of Westinghouse PWRs. The inclination angle limit of [

]^{a,c}

[

]^{a,c}

Due to the developed loop input model of the FSLOCA demonstration analyses, the significance of the inclination angle for the results of the LOCA analysis is limited. The loop input model of the FSLOCA demonstration PWR was shown in Figure 83-1. A consistent input model has been developed for the ROSA IV integral effects test as shown in Figure 21.3-8 of the topical report.

[

]^{a,c}

Part (2): In the FSLOCA EM, the inclination angle of the components in the break model is consistent with the actual break unit configuration. Example is given using the ROSA break flow model. The break unit of the ROSA facility is shown in Figure 21.7-1 of the topical report, while the WCOBRA/TRAC-TF2 input model is shown in Figure 21.7-2. The actual inclination angles of the break unit were preserved in the input model. [

]^{a,c} In the PWR model, the break orientation is consistent with the model for ROSA in Figure 21.7-2. This is discussed in Section 28.2.7 of the topical report.

Part (3): The C_{hs_slug} (HS_SLUG) uncertainty range was developed from the horizontal pipe flow data with negligible inclination angle in Section 4.4.5 of the topical report. The applicability of the C_{hs_slug} (HS_SLUG) range to a pipe flow with non-zero inclination angle may not be assumed. However, as addressed in part (1), the FSLOCA EM is developed for the particular PWR LOCA evaluation. The nodalization was given in Figure 83-1. [

]^{a,c}

[

]a,c

Part (4): Response to this part is covered by the responses to parts (1) through (3).

Reference:

1. WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology)," November 2010.

Question #88: LSTF Loop Seal Nodalization

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," Subsection 21.3, "Description of WCOBRA/TRAC-TF2 Model for ROSA/LSTF-IV," shows the one-dimensional loop noding diagram of the LSTF model in Figure 21.3-8, "WCOBRA/TRAC-TF2 Loop Noding Diagram of LSTF." Components No. 13 and 23 are used to represent the loop seal piping in both primary loops. Figure 21.3-9, "Hot Leg (Including Pressurizer), Steam Generator and Cross-Over Leg Noding," shows the one-dimensional nodalization of the loop seal region in the pressurizer loop modeled by Component No. 13 with [ ]^{a,c} cells.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 5.2.4, "Primary Coolant Loop," in "ROSA-IV Large Scale Test Facility (LSTF) System Description," Japan Atomic Energy Research Institute Report JAERI-M 89-237, January 1985 explains that LSTF had two identical loops each representing two loops of the reference four-loop PWR. Pipes with 207 mm ID and 295 mm OD were used for the hot and cold legs and the cross-over leg pipes had 168.2 mm ID and 240.2 mm OD. The pipes were made of stainless steel SDS316L-TP. Important geometric dimensions of the loop seal piping are provided in Figure 5.2.34, "Primary Loop Dimensions (Elevation View)," in Figure 5.2.38, "Geometry of Primary Loop A," and in Figure 6.11(c), "Locations of Selected Primary Loop A and B Instruments," in the JAERI-M 89-237 report.

(1) Please provide a table that documents geometric input data for each cell in Component No. 13 shown in Figure 21.3-9, "Hot Leg (Including Pressurizer), Steam Generator and Cross-Over Leg Noding," and used to model the loop seal piping. Provide length, elevation, flow area, volume, and inclination angle for each cell/interface and explain how the cross-over leg input model accounts for relevant LSTF elevation data of critical importance. Include loss coefficients, if such were input as part of the loop seal model. Describe any disparities, if present, between Component No. 13 and Component No. 23 that model the cross-over legs in both loops.

(2) Table 5.2.9, "Characteristics of Primary Loop Piping," in JAERI-M 89-237 provides the length of the cross-over leg as 9.5498 m (31.331 ft) and the cross-over leg volume, excluding the RCP volume, as 0.2122 m^3 (7.494 ft^3). The provided length and volume data correspond to the cross-over leg flow area of 0.0222 m^2 (0.2392 ft^2), which matches the 168.2 mm pipe ID. The total length of the cells of Component No. 13 in Figure 21.3-9, "Hot Leg (Including Pressurizer), Steam Generator and Cross-Over Leg Noding," amounts to 30.8608 ft. Table 26.1-4 in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 26, "WCOBRA/TRAC-TF2 Model of Pilot Plants," Subsection 26.1.2, "Modeling Consistency," lists the cross-over leg axial length, based on the LSTF noding model, as 30.86 ft. Please compare the cross-over leg integral cell length and volume based on the input data provided in response to Item (1) above against the geometric data for the LSTF cross-over leg provided in Table 5.2.9, "Characteristics of Primary Loop Piping," in JAERI-M 89-237. Please explain any differences, if present.

(3) Section 6.4.3, "Primary Loops Instruments," in JAERI 89-237 explains that Venturi flow meters were installed at each cross-over leg to measure the flow rate of primary coolant. Figure 6.11(c), "Locations of Selected Primary Loop A and B Instruments," in JAERI-M 89-237 shows the location of the flow meters in the uphill section of each loop seal. According to Table 5.7.4 in JAERI-M 89-

237, the flow meters had a contraction ratio of 0.505 corresponding to a Venturi throat diameter of 85 mm (3.34 in). As explained in Section 5.7, "Valves and Orifices," in JAERI-M 89-237, the flow meters installed in the facility acted as flow resistance for fluid in piping. Please clarify how the flow meter presence was accounted for in the LSTF loop seal models.

(4) LSTF was equipped with flow control valves, installed upstream of the RCPs, to allow for considerable variation in the primary loop coolant flow during an experimental transient. As seen from Figure 6.11(c), "Locations of Selected Primary Loop A and B Instruments," in JAERI-M 89-237, the primary coolant flow control valves were installed in the horizontal sections of the loop seal cross-over legs in both loops. According to Figure 6.11(c), the length of the horizontal cross-over leg portion associated with the primary coolant flow control valves amounted to 2 mm + 762 mm + 2 mm = 766 mm (2.513 ft). Please clarify if the primary coolant flow control valves introduced additional flow resistance and if the presence of these valves was accounted for in the LSTF WCOBRA/TRAC-TF2 loop seal models.

Response:

A detailed noding diagram of the loop seal region for the ROSA Large Scale Test Facility (LSTF) is presented in Figure 88-1. Only a single diagram is provided for the LSTF since there are no loop-to-loop differences within the model.

As noted in the Request for Additional Information (RAI), the total crossover leg length from the WCOBRA/TRAC-TF2 model is 30.861 ft compared to 31.331 ft cited in Table 5.2.9 of JAERI-M 84-237 [88-1]. The WCOBRA/TRAC-TF2 model was developed from the facility drawings provided in Sections 5 and 6 of JAERI-M 84-237. The observed difference could be the result of a small discrepancy in the calculation of the table entry, or in the definition of the crossover leg / pump interface. The drawings are considered to be an appropriate source of the facility geometry for the development of the WCOBRA/TRAC-TF2 model. Furthermore, the observed difference is small (about a 1.5% difference). It was confirmed that the elevation changes modeled are consistent with Figure 6.11(c) from JAERI-M 84-237.

The total loss through the loop for the base steady-state case was [

]^{a,c} A study is executed to illustrate the sensitivity of the key results from SB-CL-18 to additional losses in the loop seal region.

The base case is the noding sensitivity study discussed in the response to RAI 89. This case was selected because the additional cell faces in the horizontal region are required for specification of the loss associated with the control valve. The sensitivity study applies loss coefficients to approximate the drag disks, control valve, and Venturi hydraulic losses, as well as the steam generator nozzle and loop seal bends.

The pressurizer pressures, loop seal differential pressures, inner vessel delta pressures, and peak cladding temperatures are compared in Figures 88-2 through 88-6. [

]^{a,c}

Reference(s)

88-1) JAERI-M 84-237, "ROSA-IV Large Scale Test Facility (LSTF) System Description," January 1985.

a,c

Figure 88-1: Detailed Loop Seal Region Noding for ROSA LSTF

a,c

Figure 88-2a: Pressurizer Pressure without Additional Loop Seal Region Losses

a,c

Figure 88-2b: Pressurizer Pressure with Additional Loop Seal Region Losses

a,c

Figure 88-3a: Cross-Over Leg A Differential Pressures without Additional Loop Seal Region Losses

a,c

Figure 88-3b: Cross-Over Leg A Differential Pressures with Additional Loop Seal Region Losses

a,c

Figure 88-4a: Cross-Over Leg B Differential Pressures without Additional Loop Seal Region Losses

a,c

Figure 88-4b: Cross-Over Leg B Differential Pressures with Additional Loop Seal Region Losses

a,c

Figure 88-5a: Inner Vessel Differential Pressure without Additional Loop Seal Region Losses

a,c

Figure 88-5b: Inner Vessel Differential Pressure with Additional Loop Seal Region Losses

a,c

Figure 88-6a: Peak Cladding Temperature without Additional Loop Seal Region Losses

a,c

Figure 88-6b: Peak Cladding Temperature with Additional Loop Seal Region Losses

Question #89: Modeling of LSTF Loop Seal Horizontal Section and Bend Regions

[ ]a,c in Component No. 13 in Figure 21.3-9, "Hot Leg (Including Pressurizer), Steam Generator and Cross-Over Leg Noding," [

]a,c the length of the horizontal section of the cross-over leg, determined as 1.3817 m (2,383.7 mm – 2 x 501 mm = 1,381.7 mm = 1.3817 m), based on dimensions provided in Figure 5.2.34, "Primary Loop Dimensions (Elevation View)," and in Figure 5.2.38, "Geometry of Primary Loop A," in JAERI-M 89-237. The primary coolant flow control valves, as shown in Figure 6.11(c), "Locations of Selected Primary Loop A and B Instruments," in JAERI-M 89-237, occupy 2.513 ft of the 4.533-ft long horizontal sections of the LSTF loop seal cross-over legs.

(1) It is determined that the length-to-diameter ratio (L/D) for horizontal section of the LSTF loop seal cross-over leg amounts to:

$$L / D = 1{,}381.7 \text{ mm} / 168.2 \text{ mm} = 8.21.$$

Please explain the rationale for representing the entire horizontal portion of the loop seal piping [ ]a,c in the WCOBRA/TRAC-TF2 model of LSTF.

(2) As shown in Figure 21.3-9, "Hot Leg (Including Pressurizer), Steam Generator and Cross-Over Leg Noding," each of the 90° bends connecting the cross-over leg horizontal section to the downhill and uphill sides of the loop seal are modeled by [ ]a,c Please explain how the noding of bend regions in the cross-over legs was determined and describe any special considerations taken with regard to the modeling of these regions. In particular, clarify the modeling approach with regard to capturing effects of inclination on the flow behavior. As inclination angles are associated with a specific noding scheme that is applied to a bend region, please explain how the noding relates to the two-phase flow being treated as horizontal, vertical or inclined as the flow transitions from horizontal to vertical (or vice versa) when it passes through the 90° bend.

Response:

The noding of the crossover leg bends and loop seal region was based on the following: [

]a,c

Sensitivity studies which were executed with the UPTF loop seal SET determined that one of the key parameters for [

]a,c

[

]a,c Justification for this modeling approach is provided in the response to RAI 115. This approach ensures consistency between the SET and Integral Effects Test (IET) facilities relative to where flow stratification is allowed to occur in the loop seal region.

For the LSTF, the previously described noding approach resulted in a [

]a,c as shown in Table 89-1.

The pressurizer pressures are compared in Figure 89-1. It is observed that the [

]a,c

In summary, it is concluded that the noding of the loop seal region of the ROSA facility is appropriate and consistent with the UPTF loop seal separate effects test. It is also concluded that the [

]a,c

Table 89-1: Facility L/D Comparison for Horizontal Section of Loop Seal Region

Facility	Length (ft)	Diameter (ft)	Approximate L/D (-)
[			
			]a,c

a,c

Figure 89-1a: Pressurizer Pressure (Figure 21.4-1 from WCAP-16996-P)

a,c

Figure 89-1b: Pressurizer Pressure with Additional Cells in Loop Seal Region

[ ]a,c

Figure 89-2a: Cross-Over Leg A Differential Pressures (Figure 21.4-3 from WCAP-16996-P)

[ ]a,c

Figure 89-2b: Cross-Over Leg A Differential Pressures with Additional Cells in Loop Seal Region

a,c

Figure 89-3a: Cross-Over Leg B Differential Pressures (Figure 21.4-4 from WCAP-16996-P)

a,c

Figure 89-3b: Cross-Over Leg B Differential Pressures with Additional Cells in Loop Seal Region

a,c

Figure 89-4a: Inner Vessel Differential Pressure (Figure 21.4-5 from WCAP-16996-P)

a,c

Figure 89-4b: Inner Vessel Differential Pressure with Additional Cells in Loop Seal Region

a,c

Figure 89-5a: Peak Cladding Temperature (Figure 21.4-6 from WCAP-16996-P)

a,c

Figure 89-5b: Peak Cladding Temperature with Additional Cells in Loop Seal Region

Question #90: WCOBRA/TRAC-TF2 Features Applied in LSTF Loop Seal Modeling

Figure 21.3-9, "Hot Leg (Including Pressurizer), Steam Generator and Cross-Over Leg Noding," in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 21, "ROSA-IV Test Simulations," Subsection 21.3, "Description of WCOBRA/TRAC-TF2 Model for ROSA/LSTF-IV," shows one-dimensional nodalization of the loop seal region in the LSTF pressurizer loop. The overall one-dimensional loop noding diagram of the LSTF model is presented in Figure 21.3-8, "WCOBRA/TRAC-TF2 Loop Noding Diagram of LSTF." Components Nos. 13 and 23 are used to represent the loop seal piping in both primary loops. WCOBRA/TRAC-TF2 assessment results using this model are presented in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 21, "ROSA-IV Test Simulations."

(1) Please explain which instrumentation devices, installed in the ROSA-IV LSTF loop seal cross-over leg, have been considered for the assessment of WCOBRA/TRAC-TF2 using ROSA-IV LSTF test data. If certain available and relevant measurements were not used in qualifying the code capabilities to predict loop seal clearing, please explain the reasons for this.

(2) In addition to implementing an adequate noding model, meaningful assessment of code prediction results against experimental data requires that node or junction points, at which computational variables are computed by the code, relate properly to the location of experimental measuring points of interest. Please explain how this was taken into account in establishing the WCOBRA/TRAC-TF2 loop seal cross-over leg model for LSTF. In particular, please explain how the elevations were accounted for of the differential pressure tap locations, including the one in the horizontal section of the loop seal cross-over leg.

(3) For the LSTF loop seal model, please describe any specific modeling features that were applied on Component Nos. 13 and 23, a component-wide basis to or to specific cells/interfaces of these components in representing the LSTF loop seal regions. Identify individual cells/interfaces where sampling of input quantities, for example HS_SLUG, was applied and identify all sampled parameters. In addition, please identify any non-sampled user defined parameters or multipliers, e.g. C_{strfu} and STRTX, related to the modeling of participating physical processes such as flow stratification, counter-current flow limitation (CCFL), or other relevant processes, that were applied in modeling the LSTF loop seals to assess WCOBRA/TRAC-TF2. Please provide a table that lists all such applied sampled and non-sampled user defined modeling parameters or multipliers applied in the LSTF loop seal modeling. Please include a brief description, the applied range, and the input values for each parameter listed in the table.

Response:

(1) From the ROSA LSTF design information found in JAERI-M 84-237 [90-1], it appears that there are numerous measurement devices installed in the loop seal crossover legs. According to Fig.6.1 (a) and (b) and 6.2 (a) and (b) there are video probes, gamma densitometers, drag disks, conductivity probes, temperature (wall and fluid) measurements, Venturi flow meters and differential pressure measurements. Among all of these, [

]^{a,c} While the rest of the measurements could be used for validation purposes, they were either indicators of a secondary importance, had questionable reading, or were not qualified or used in the tests. Measurements that did not have sufficient design information to determine their exact location were generally not used, for example [ ]^{a,c} in the downhill (steam generator) side of the crossover legs.

(2) The specific node sizes of the loop seal region (steam generator outlet plenum and crossover leg up to the pump inlet) were driven primarily by key mechanical design features and elevations of the ROSA LSTF. In addition, to the extent possible, consistency with the UPTF SET and PWR noding was desired especially at the bottom of the crossover legs. It was therefore impossible to achieve a perfect alignment of the centers of the hydraulic nodes with the exact locations of some measurement taps. Thus, there are some deviations between the hydraulic cell centers and the differential pressure taps.

For example, for the DPE070-LSA and DPE210-LSB differential pressure tags for SB-CL-18, the elevation of their higher tap (located at the exit of the steam generator U-tubes) was determined to be at elevation 7560.9 mm, Figure A.24 of JAERI-M 89-027 [90-2]. According to the ROSA noding diagram in Figure 21.3-9 of WCAP-16996-P [90-3], the elevation of the center of the respective hydraulic cell (cell 25 of component PIPE 12) is [

]^{a,c} it is close enough for the code validation purpose given the fact that the gravity effect estimated above mostly disappears as the hydraulic cell is voided.

From Fig.6.11(c) in JAERI-M 84-237, it is seen that nozzle N-2c, used for the crossover leg differential pressure measurements DPE080-LSA and DPE070-LSA is located in the horizontal section of crossover leg A between the flow control valve and the pump-side elbow, but the exact location in terms of distance in mm from the valve outlet or orientation is not clear. The same is true for nozzle N-2h at the horizontal part of the crossover leg B; nozzle N-2h is used to measure DPE210 and DPE220. However, given that a [ ]^{a,c} (Figure 21.3-9,

WCAP-16996-P), [

]^{a,c} Early in the transient, before the loop seal clears, the gravity head is a predominant factor, hence correctly modeling the bottom elevation of the crossover leg is essential, and the elevation was indeed modeled consistent with the design. After the loop seal clears, the fluid retention in the pump-side defined by the detail in the 90-deg elbow and the vertical uphill part of the crossover leg is the defining phenomenon.

There is additional uncertainty with the lack of information for the exact elevation of the higher (pump-side) taps of DPE080-LSA and DPE220-LSB measurements. In Figure A.21 of JAERI-M 89-027, the tap elevation visually appears to be somewhere in the middle of the 702 mm spool pieces of both crossover legs. With this assumption, the elevation of the tap appears to be 702/2=351 mm (1.15-ft) below the cold leg centerline (el. 5502.8 mm); this tap elevation falls within the span of the [

]^{a,c}

(3) There is only one specific flag which is applied to the crossover leg component. [

]^{a,c} is applied at the specific cell faces labeled 'STRTX = 1' in Figure 88-1 (response to RAI 88). This flag [

]^{a,c} This flag is described in the response to RAI 86, and the basis for application of this flag is described in the response to RAI 115. Any other multipliers which would apply to the loop seal region (such as the multiplier to the [

]^{a,c} are retained at their nominal values so the as-coded models are applied in the simulation.

Reference(s)

90-1) JAERI-M 84-237, "ROSA-IV Large Scale Test Facility (LSTF) System Description," January 1985.

90-2) JAERI-M 89-027, "ROSA-IV/LSTF 5% Cold Leg Break LOCA Experiment Run SB-CL-18 Data Report," March 1989.

90-3) WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.

Question #91: V. C. Summer and Beaver Valley Unit 1 Loop Seal Models

Figure 6.2-8, "Virgil C. Summer Loop Model Noding Diagram," and Figure 26.3-14, "Beaver Valley Unit 1 Loop Model Noding Diagram," in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 26, "WCOBRA/TRAC-TF2 Model of Pilot Plants," show noding diagrams for the primary loops of the plant models across a horizontal plane. In both plant input models, Component Nos. 13, 23, and 33, represent the PWR cross-over legs in the primary coolant loops.

(1) Please provide detailed noding diagrams across a vertical plane for the cross-over leg regions in both plant models similar to the one shown for the LSTF loop seal in Figure 21.3-9, "Hot Leg (Including Pressurizer), Steam Generator and Cross-Over Leg Noding." In these diagrams, please show important elevations including the elevation of the axis of the horizontal bottom section of the loop seal. Provide the elevations data using the TAF elevation as the zero elevation point.

(2) Please provide a table that documents geometric input data for each cell in Component Nos. 13, 23, and 33, used to model the loop seal piping for both plants. Provide length, elevation, flow area, volume, and inclination angle for each cell/interface and explain how the cross-over leg input models account for relevant elevations of critical importance. Include loss coefficients, if such were input as part of the loop seal models. Describe any disparities, if present, between Component No. 13, 23, and 33 for each plant.

(3) For the loop seal models of the reference V. C. Summer and Beaver Valley Unit 1 PWR plants, please describe any specific modeling features that were applied to Component Nos. 13, 23, and 33 on a component-wide basis or to specific cells/interfaces of the loop seal components. Identify individual cells/interfaces where sampling of input quantities, e.g. HS_SLUG, was applied and identify all sampled parameters. In addition, please identify any non-sampled user defined parameters or multipliers, e.g. C_{strfu} and STRTX, related to the modeling of participating physical processes such as flow stratification, CCFL, or other relevant processes, that were applied to model the plant loop seals in the plant models. Please provide a table that lists all such applied sampled and non-sampled user defined modeling parameters or multipliers including brief descriptions, applied ranges, and input values for each listed parameter.

Response:

Detailed noding diagrams of the loop seal region for V. C. Summer and Beaver Valley Unit 1 are presented in Figures 91-1 and 91-2, respectively. Only a single diagram is provided for each PWR since there are no loop-to-loop differences within the individual models.

The noding of these components was developed based on the following concepts: [

]^{a,c}

[

]a,c

There are a few additional flags/models which are applied to the crossover leg component. The first is [ ]a,c which is applied at the specific cell faces labeled 'STRTX = 1' in Figures 91-1 and 91-2. This flag causes the code to [ ]a,c This flag is described in the response to RAI 86, and the basis for the application of this flag is discussed in the response to RAI 115. The multiplier to the [ ]a,c is also applied to all cell faces in the crossover leg where the code checks for stratification, since it is applied to the entire loop as discussed in the response to RAI 77 (transmitted in LTR-NRC-13-73, Reference 91-1). No other "special" flags or models are applied to the crossover leg. The values and ranges of all potential uncertainty contributors, including [ ]a,c, are discussed in the response to RAI 77 transmitted in LTR-NRC-13-73.

Reference(s)

91-1) LTR-NRC-13-73, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information – RAIs 46 – 58, 75 and 77' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," October 28, 2013.

a,c

Figure 91-1: Detailed Loop Seal Region Noding for V. C. Summer

a,c

Figure 91-2: Detailed Loop Seal Region Noding for Beaver Valley Unit 1

Question #92: PWR Loop Seal Horizontal Section and Bends Modeling

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 4, "WCOBRA/TRAC-TF2 Flow Regime Maps and Interfacial Area," Subsection 4.4.5, "Horizontal Stratified Flow," explains that the code allows horizontal flow when the pipe inclination angle is less than [ ][a,c] In addition, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 29, "Assessment of Uncertainty Elements," Subsection 29.5.6, "Pump Suction Piping/Loop Seal," clarifies that [

][a,c]

Figure 21.3-9, "Hot Leg (Including Pressurizer), Steam Generator and Cross-Over Leg Noding," shows the 1D nodalization of the loop seal region in the pressurizer loop, which is modeled by Component No. 13 using [ ][a,c] Figure 6.2-8, "Virgil C. Summer Loop Model Noding Diagram," and Figure 26.3-14, "Beaver Valley Unit 1 Loop Model Noding Diagram," show the noding diagrams for the primary loops across a horizontal plane. In both plant input models, Component Nos. 13, 23, and 33 represent the cross-over legs in the primary coolant loops.

(1) Please explain the noding of the horizontal section of the loop seal cross-over legs for both plant models. Provide the length-to-diameter ratio (L/D) for this horizontal section of the cross-over legs. Explain the rationale for the applied L/D ratio in the WCOBRA/TRAC-TF2 PWR models. Discuss any associated modeling guidelines along with analysis results that substantiate them, if available.

(2) Please explain the noding of the bends in the loop seals for both plant models. Show the geometry of these regions along with relevant pipe geometrical dimensions such as ID and bend radii, and provide detailed noding diagrams.

(3) In a piping bend region, inclination for individual cells/interfaces depends on and varies with the degree of refinement in the implemented nodalization scheme. Please explain the approach to nodalization of the bends in a PWR loop seal cross-over leg and clarify how the response to Item (2) above relates to this approach. Discuss any associated modeling guidelines along with analysis results used to develop them, if available. Identify any WCOBRA/TRAC-TF2 modeling features that can be used to account for effects due to channel curvature and inclination in bend regions on the flow behavior and describe them, if available.

(4) Please explain if specific sensitivity analyses related to PWR loop seal cross-over leg modeling and realistic prediction of loop seal clearing have been performed to assess WCOBRA/TRAC-TF2 in this regard. If available, please summarize the results from such sensitivity analyses that are based on data from any integral effect test facilities, such the LSTF tests described in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 21, "ROSA-IV Test Simulations," or performed using PWR plant models, e.g. the reference PWR plant models described in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 26, "WCOBRA/TRAC-TF2 Model of Pilot Plants," that demonstrate the WCOBRA/TRAC-TF2 capabilities to predict adequately PWR loop seal clearance and refill as related to modeling both SBLOCAs and LBLOCAs.

Response:

(1) Sensitivity studies which were executed with the UPTF loop seal SET determined that [

]^{a,c}

In order to achieve the desired noding consistency based on the UPTF SET simulation results and to preserve the PWR noding, it was determined that the [

]^{a,c} (shown in Table 89-1 in the response to RAI 89).

(2) The philosophy for the noding of the loop seal bends is the same as explained in the part (1) response for the horizontal region. The resulting noding guidance is to [

]^{a,c}

A detailed noding diagram of the crossover leg, including the loop seal region, was provided for each PWR in the response to RAI 91. The interior diameter of the crossover leg piping is 2.58 ft for both V. C. Summer and Beaver Valley Unit 1. The radius of curvature for the bends in the loop seal region is 4.27 ft for both V. C. Summer and Beaver Valley Unit 1.

(3) The loop seal noding is [

]^{a,c}

(4) No PWR loop seal noding sensitivity studies were executed; however, a number of sensitivity studies were conducted with SET and IET facilities to compare the effect of noding on the code predictions of the associated experimental data. Sensitivity studies with the UPTF loop seal SET model are discussed in the response to RAIs 117 and 119. Sensitivity studies with the ROSA LSTF IET facility are discussed in the response to RAIs 88 and 89. These sensitivity studies illustrate [

]^{a,c} This modeling approach was used consistently across the SET, IET, and PWR models.

Question #94: Interpolation for Stratified Flow and C_{hs_slug} Parameter

Equation (4-117) defines the weighting factor, W_{st}, as a function of the relative phase velocity, $|u_g - u_l|$, the critical relative phase velocity, Δu_c, and two adjustable constants, C_{hs_slug} and C_{stfru}, Table 1 below shows the values for the ratio of the relative velocity to the critical relative velocity, $|u_g - u_l|/\Delta u_c$, at which the W_{st} weighting factor, as calculated from Equation (4-117), becomes equal to unity or zero for three different values of the C_{hs_slug} constant: [ ]^{a,c} In computing the results provided in Table 1, the constant C_{stfru}, appearing in Equation (4-117), was set equal to its default value of [ ]^{a,c}

Table 1: Velocity Ratio Values when W_{St} Equals 0 or 1 for C_{hs_slug} Values of [ ]^{a,c} and at the Nominal Value of C_{stfru} = [ ]^{a,c}

	Relative Velocity Ratio, $|u_g - u_l|/\Delta u_c$ (-)	
Constant	Stratified Flow,	Non-stratified

( ) a,c

Figure 1 plots W_{st} as a function of the relative velocity ratio, $|u_g - u_l|/\Delta_c$, according to Equation (4-117) when the constant C_{hs_slug} is set equal to [ ]^{a,c} as well as to its limiting values of 0.1 and 9.9. For the curves shown in Figure 1, the second adjustable constant C_{stfru} was set equal to its default value of [ ]^{a,c}

a,c

Figure 1: Effect of Constant C_{hs_slug} (HS_SLUG) in Equation 4-117 on the Weighing Factor W_{st} at C_{stfru} = [ ] a,c

As seen from the results provided in Table 1 and the curves presented in Figure 1 above, the interpolation range $0 \leq W_{st} \leq 1$ for the weighting factor, W_{st}, as defined by Equation (4-117), corresponds to a relative velocity ratio, $|u_g - u_l|/\Delta u_c$, ranging from [ ] a,c when HS_SLUG varies between [ ] a,c with C_{stfru} being set at its default value of [ ] a,c

Please explain the significant disparity between the proposed HS_SLUG sampling range from [ ] a,c and the relative velocity ratio range from [ ]a,c that corresponds to W_{st} values being $0 \leq W_{st} \leq 1$ when C_{stfru} is set equal to its proposed default value of [ ] a,c When $0 \leq W_{st} \leq 1$, an interpolation technique to account for the effect of stratification is applied WCOBRA/TRAC-TF2. Please relate the response to this request for additional information to the test data points that are plotted in Figure 4-17, "Horizontal Stratified Flow Regime Transition and Relevant Data." Also, please consider the statement provided in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 4, "WCOBRA/TRAC-TF2 Flow Regime Maps and Interfacial Area," Subsection 4.4.5, "Horizontal Stratified Flow," that [ ] a,c

Response:

As explained in the response to RAI 83, the FSLOCA Evaluation Model (EM) dictates that the range of C_{hs_slug} (HS_SLUG) in the LOCA evaluation is [ ]^{a,c} based on the comparison with the experimental data, and the size of the interpolation region is established using the C_{stfru} of [ ]^{a,c}. Thus, the discussion herein will be limited to the C_{hs_slug} (HS_SLUG) range of [ ]^{a,c}

Taking Figure 4-19 in the topical report [1] as an example, it is further clarified that the horizontal stratified flow regime is limited to W_{st}=1.0 and the transition boundary varies as a function of C_{hs_slug} (HS_SLUG). The transition boundary is compared with the test data in Figure 4-17 of the topical report. [

]^{a,c}

Reference:

1. WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology)," November 2010.

Question #95: Interpolation for Stratified Flow and C_{stfru} Parameter

Equation (4-117) defines a weighting factor, W_{st}, using two adjustable constants, C_{hs_slug} and C_{stfru}. Discussing the weighting factor, W_{st}, and the corresponding interpolation range when $0 \leq W_{st} \leq 1$ in accordance with Equation (4-117), Subsection 4.4.5, "Horizontal Stratified Flow," explains that "the size of the interpolation region can be adjusted by the input variable C_{stfru}. The default value of C_{stfru} is [ ]^{a,c} The allowable input range of C_{stfru} is from [ ]^{a,c} The impact of the C_{stfru} constant on W_{st} is illustrated in Figure 1 below for three different values of C_{stfru}: its default value of [ ]^{a,c} and the lower and upper limiting values for the range of allowable input values for C_{stfru}, [ ]^{a,c} For the curves shown in Figure 1, the second adjustable constant, C_{hs_slug}, was set equal to its default value of 1.0.

a,c

Figure 1: Effect of Parameter C_{stfru} in Equation 4-117 on the Weighing Factor W_{st} at C_{hs_slug}= 1.0

Please explain the rationale for selecting [ ]^{a,c} as the default value for the C_{stfru} parameter. In addition, explain the reasons for defining a range from [ ]^{a,c} as allowable input values for C_{stfru} and describe the intended application of this proposed range. Clarify the way in which the input value for C_{stfru} is defined and describe how the use of inappropriate C_{stfru} values within the allowable range of input values is controlled and prevented in PWR plant LOCA analyses using WCOBRA/TRAC-TF2.

Response:

As discussed in RAI 84 part (2), the presence of interpolation region in the 1-D component flow regime map is to improve numerical stability of the computation. The interpolation region itself does not imply physical interpretation. [ ]^{a,c}

The allowable input range for C_{strfu} in the WCOBRA/TRAC-TF2 computer code is chosen to be [ ]^{a,c} The value of [ ]^{a,c} leads a negligible interpolation region, while the value of [ ]^{a,c} represents a very large interpolation region. [ ]^{a,c}

In addition, a sensitivity study with [ ]^{a,c}, which leads to a reduced interpolation region, was performed using the Beaver Valley Unit 1 2.6 inch SBLOCA case. The results indicate [ ]^{a,c}

Reference:

1. WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM™ LOCA Methodology)," November 2010.

a,c

Figure 95-1. Comparison of reactor vessel inventories in Beaver Valley Unit 1 [
]a,c

a,c

Figure 95-2. Comparison of fuel rod peak cladding temperatures in Beaver Valley Unit 1 [ ]a,c

Preface

Table Preface-1 provides a list of acronyms used throughout the responses to the RAIs herein.

Table Preface-1: List of Acronyms

Acronym	Definition
CCFL	Counter-Current Flow Limit
CGE	Virgil C. Summer Unit 1
DLW	Beaver Valley Unit 1
DTMAX	Maximum time step size
FSLOCA	FULL SPECTRUM LOCA
IET	Integral Effect Test
LOCA	Loss-of-Coolant Accident
PWR	Pressurized water reactor
RCP	Reactor Coolant Pump
SG	Steam Generator
TRAM	Transient and Accident Management
UPTF	Upper Plenum Test Facility

Table Preface-2 provides a list of symbols/variables used throughout the responses to the RAIs herein.

Table Preface-2: List of Symbols / Variables	
A	Area
D	Diameter (m)
g	Gravity (9.81 m/s^2)
hl/d	Residual Liquid Level
L/D	Ratio of Length over Diameter
α_v	Void / Vapor Fraction
Jg*	Modified Froude Number = $\frac{\dot{m}_v}{A\sqrt{\rho_v(\rho_l-\rho_v)gD}}$
ρ_l	Liquid Density (kg/m^3)
ρ_v	Vapor Density (kg/m^3)

The following figures are provided here, as they are referenced in multiple RAI responses.

a,b,c

Figure Preface-1: Diagram of UPTF Primary System (taken from Figure 2 of NT33/94/011, "Versuch A5, Freiblasen des Pumpenbogens, Einzeleffekt- und Integralversuche," December 1994.)

a,b,c

Figure Preface-2: Diagram of the UPTF Test Loop (taken from Figure 4 of NT33/94/011, "Versuch A5, Freiblasen des Pumpenbogens, Einzeleffekt- und Integralversuche," December 1994.)

a,c

Figure Preface-3: Noding Diagram for WCOBRA/TRAC-TF2 Input for UPTF Loop Seal Test Simulations

RAI Question #113: WCOBRA/TRAC-TF2 UPTF Loop Seal Nodalization

Full-scale separate effect experiments describing the loop seal clearing process in a PWR primary loop during a LOCA were produced as part of the TRAM experimental program, carried out at the full-scale UPTF in Mannheim, Germany. The UPTF loop seal piping had an inner diameter of 0.750 m (33.46 inch or 2.8 ft) and the length of the bottom horizontal section of the loop seal piping was equal to 1.734 m (68.3 inch or 5.7 ft), which resulted in a length-to-diameter ratio (L/D) of 2.3 for this section. Also, the facility employed pump simulators to model the RCPs in a PWR.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 18, "Loop Seal Clearance," Subsection 18.3.1, "WCOBRA/TRAC-TF2 Simulation of the UPTF 3-Bar and 15-Bar Tests," presents assessment results based on UPTF TRAM loop seal clearance tests. Figure 18.3-1, "WCOBRA/TRAC-TF2 Model of the UPTF Separate Effects Loop Seal Clearing Tests," shows the implemented UPTF loop seal nodalization.

As described, PIPE component No. 2 with [ ]^{a,c} cells was used to simulate the loop seal piping including the RCP simulator. In this model, [ ]^{a,c} was used to represent the loop seal bottom horizontal section and [ ]^{a,c} cells were used to model each of the 90° bends connecting the horizontal section of the loop seal to the downhill and uphill pipes of the cross-over leg.

(1) Please provide a table that documents the WCOBRA/TRAC-TF2 input parameters for the WCOBRA/TRAC-TF2 UPTF loop seal model shown in Figure 18.3-1, "WCOBRA/TRAC-TF2 Model of the UPTF Separate Effects Loop Seal Clearing Tests." Describe each component separately and include a full description for PIPE Component No. 2 used to represent the UPTF loop seal piping. Provide length, elevation, flow area, volume, and inclination angle for each cell/interface and explain how the loop seal input model accounts for relevant UPTF geometry and instrumentation locations.

(2) Please explain why the bend regions in the loop seal nodalization model appear as asymmetric in Figure 18.3-1. It is seen that the curvature of the uphill bend is much larger than the radius of the downhill bend. The UPTF loop seal piping had equal bend radii of 0.798 m (31.4 inch or 2.6 ft) for both bend regions.

(3) If input parameters, such as pressure loss coefficients, were used to compute pressure losses as part of the specified WCOBRA/TRAC-TF2 UPTF loop seal model, please define these input quantities and provide the formulas used for their computation. Explain any assumptions used to determine the input values for these parameters.

(4) Please explain how the UPTF RCP simulator, present in the simulated region of the UPTF primary circuit, was accounted for in the WCOBRA/TRAC-TF2 UPTF loop seal model. Provide any input parameters that were used to model the RCP simulator and explain how these parameters were computed. Provide and explain used formulas, applied assumptions, and calculated input values.

Response:

(1) The WCOBRA/TRAC-TF2 input model for the UPTF loop seal tests was developed to preserve the length and volume of the piping in the loop seal region, including proper elevation changes. The model begins at the point where the vapor was injected in the experiment (JEC02SV010, Figure Preface-2). The component cell lengths were determined such that [

]^{a,c}

Figure Preface-3 provides the cell lengths and relevant elevations for the cells in the primary PIPE component used to simulate the tests; this can be compared to the test facility described in Figure Preface-2. [

]^{a,c}

Table 113-1 provides the inclination angles for the cell faces that are neither 0.0° (horizontal) nor 90° (vertical), as depicted in Figure Preface-3.

Table 113-1: Inclination Angles for Relevant Portions of the UPTF Loop Seal Model

Cell Face Number	Description	Inclination Angle

a,c

(2) The reason for the asymmetric loop seal region is based on an interpretation of the figures provided in [113-1]. From Figure Preface-2, [

]^{a,b,c}

To demonstrate that the asymmetric noding has a minimal impact on the calculated results, the 3-bar and 15-bar cases are executed with symmetric uphill and downhill bend modeling (i.e., cells' geometry mirrored). To preserve the overall length and volume, [

]^{a,c} and the corresponding volume updated.

The residual liquid levels versus the modified Froude number (Equation 18-1 of [113-2]) are presented in Figure 113-1 for the 3-bar cases and Figure 113-2 for the 15-bar cases. The differential pressures across the loop seal versus the modified Froude number are presented in Figure 113-3 for the 3-bar cases and Figure 113-4 for the 15-bar cases.

As seen from the figures, [

]^{a,c}

(3) The only pressure loss coefficient used in the model is [

]^{a,c}

(4) The pump simulator is modeled as [

]^{a,c} Figures 113-5 to 113-7 provide a comparison of the liquid volume in the horizontal section (surrogate for residual liquid level), pressure difference across the loop seal region, and total system mass for the simulation. As seen in the figures, [

]^{a,c}

Reference(s)

113-1) NT33/94/011, "Versuch A5, Freiblasen des Pumpenbogens, Einzeleffekt- und Integralversuche," December 1994.

113-2) WCAP-16996-P/WCAP-16696-NP, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.

a,c

Figure 113-1: Symmetric Bend Study - Residual Liquid Level Comparison for the 3-bar Cases

a,c

Figure 113-2: Symmetric Bend Study - Residual Liquid Level Comparison for the 15-bar Cases

a,c

Figure 113-3: Symmetric Bend Study - Differential Pressure across the Loop Seal Region for the 3-bar Cases

a,c

Figure 113-4: Symmetric Bend Study - Differential Pressure across the Loop Seal Region for the 15-bar Cases

a,c

Figure 113-5: RCP Volume Study (15-bar, Jg*=0.178) Liquid Volume in the Loop Seal Region

a,c

Figure 113-6: RCP Volume Study (15-bar, Jg*=0.178) Pressure Drop across Loop Seal Region

a,c

Figure 113-7: RCP Volume Study (15-bar, Jg*=0.178) Total System Mass

RAI Question #114: Upper Plenum Test Facility TRAM Loop Seal Instrumentation and WCOBRA/TRAC-TF2 Upper Plenum Test Facility Model

A valid and meaningful assessment of WCOBRA/TRAC-TF2 prediction results against UPTF TRAM separate effect loop seal clearance test data imposes, as part of a code assessment study, special requirements that the model accounts adequately for the type and location of test instrumentation and measuring locations. In turn, the data channels to be used for the purposes of the code assessment study should be determined considering available test instrumentation, relevance to the phenomena being assessed and code models used for their prediction, signal behavior and data accuracy, among other factors of relevance.

(1) Please describe how the loop seal differential pressures were measured in the UPTF TRAM separate effect loop seal clearance tests. Explain how the locations of the differential pressure tap points were reflected in the WCOBRA/TRAC-TF2 UPTF loop seal models used to assess the code. Describe how the predicted loop seal differential pressure quantity was determined from the WCOBRA/TRAC-TF2 calculation results. Please identify nodes and/or cell interfaces in the WCOBRA/TRAC-TF2 UPTF loop seal model at which thermal hydraulic quantities were calculated by the code and used to determine the loop seal differential pressure predication for comparison against test data.

(2) Please describe how the loop seal residual water levels were measured in the UPTF TRAM separate effect loop seal clearance tests. Explain how the locations of the differential pressure tap points were reflected in the WCOBRA/TRAC-TF2 UPTF loop seal models used to assess the code. Describe how the computed loop seal residual water levels, used for comparison against test data, were determined from the WCOBRA/TRAC-TF2 calculation results. Identify the thermal hydraulic quantities that were used to determine these predicted residual loop seal water levels. Please identify nodes and/or cell interfaces in the WCOBRA/TRAC-TF2 UPTF loop seal model at which these thermal hydraulic quantities were calculated by the code.

Response:

(1) Per Section 6.1.3 of [114-1], the differential pressure is calculated [

]^{a,b,c}

From Figure Preface-3, the center of [

]^{a,c}

[

]^{a,c} This is demonstrated in Figure 114-2.

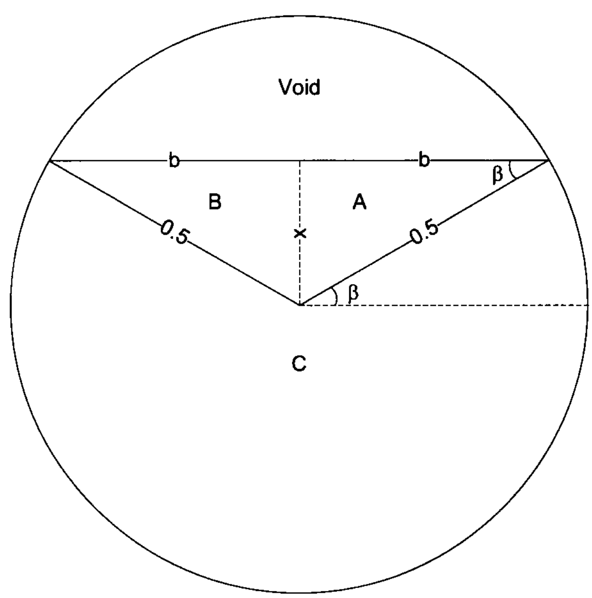
(2) The UPTF residual liquid level data was calculated by [

]^{a,b,c}

The residual liquid level from the WCOBRA/TRAC-TF2 simulation is calculated [

]^{a,c} This is demonstrated in Figure 114-3.

The residual liquid level is calculated from the void fraction based on the following geometry for a circular pipe.



$$\frac{h_l}{d} = 0.5 + x \rightarrow x = \frac{h_l}{d} - 0.5 \text{ where, } -0.5 \le x \le 0.5$$

$$b = \sqrt{0.25 - x^2} = \sqrt{0.25 - \left(\frac{h_l}{d} - 0.5\right)^2} = \sqrt{0.25 - \left(\left(\frac{h_l}{d}\right)^2 - \frac{h_l}{d} + 0.25\right)} = \sqrt{\frac{h_l}{d} - \left(\frac{h_l}{d}\right)^2} = \sqrt{\frac{h_l}{d}\left(1 - \frac{h_l}{d}\right)}$$

$$Area_A = Area_B = 0.5bx = 0.5\left(\frac{h_l}{d} - 0.5\right)\sqrt{\frac{h_l}{d}\left(1 - \frac{h_l}{d}\right)}$$

$$Area_C = \frac{\pi}{4}\left(0.5 + \frac{\beta}{\pi}\right)$$

$$\beta = \frac{\pi}{2} - acos\left(\frac{\frac{h_l}{d} - 0.5}{0.5}\right)$$

$$\alpha_v = \frac{Area_v}{Area} = 1 - \frac{Area_l}{Area} = 1 - \frac{Area_A + Area_B + Area_C}{Area}$$

$$= 1 - \frac{2\left(0.5\left(\frac{h_l}{d} - 0.5\right)\sqrt{\frac{h_l}{d}\left(1 - \frac{h_l}{d}\right)}\right) + \frac{\pi}{4}\left(0.5 + \frac{\beta}{\pi}\right)}{\frac{\pi}{4}}$$

$$= 1 - \frac{\left(\frac{h_l}{d} - 0.5\right)\sqrt{\frac{h_l}{d}\left(1 - \frac{h_l}{d}\right)}}{\frac{\pi}{4}} - \left(0.5 + \frac{\frac{\pi}{2} - acos\left(\frac{\frac{h_l}{d} - 0.5}{0.5}\right)}{\pi}\right)$$

a,c

Figure 114-1: Differential Pressure Calculation Comparison

a,c

Figure 114-2: Demonstration of Determining Code Calculated Pressure Differential

a,c

Figure 114-3: Demonstration of Determining Code Calculated Residual Liquid Level

Reference(s)

114-1) NT33/94/011, "Versuch A5, Freiblasen des Pumpenbogens, Einzeleffekt- und Integralversuche," December 1994.

114-2) WCAP-16996-P/WCAP-16696-NP, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.

RAI Question #115: WCOBRA/TRAC-TF2 Sampled Parameters and Special Options in Loop Seal Modeling

WCOBRA/TRAC-TF2 models and correlations that are relevant to predicting loop seal clearance in PWR plant LOCA analyses include such as those used for describing transition to non-stratified flow, CCFL, and liquid entrainment mechanisms. WCOBRA/TRAC-TF2 features user defined parameters and multipliers that can be applied to modify these models and criteria. Some of these user defined parameters and multipliers are sampled as part of the plant uncertainty analysis and others are not included in the sampling process.

Regarding relevant sampled parameters, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 29, "29 Assessment of Uncertainty Elements," Subsection 29.1.7, "Horizontal Stratified Flow Regime Transition Boundary (HS_SLUG)," describes that a horizontal stratified flow regime transition boundary multiplier, HS_SLUG, is employed in WCOBRA/TRAC-TF2 to adjust the critical relative velocity for horizontal stratified flow. HS_SLUG is sampled [ ]^{a,c} for the purpose of the uncertainty analysis.

Examples of WCOBRA/TRAC-TF2 parameters and multipliers that are not part of the sampling process include the parameters Cstfru and STRTX. For example, WCAP-16996-P Revision 0, Section 18, "Loop Seal Clearance," Subsection 18.3.1, "WCOBRA/TRAC-TF2 Simulation of the UPTF 3-Bar and 15-Bar Tests," states that [ ]^{a,c}

(1) Please provide a table that identifies and describes any user defined parameters, multipliers, and/or options, implemented as part of WCOBRA/TRAC-TF2 models and correlations that are used to predict loop seal clearance in PWR plant LOCA analyses, including such related to describing non-stratified flow transition, CCFL, and liquid entrainment mechanisms. Please explain if a parameter is implemented on a component-wide basis or it can be applied to specific cells/interfaces of hydraulic components used to represent the PWR loop seal region. In addition, identify if a parameter is being sampled or not as part of the plant uncertainty analysis. Include mathematical expressions that show modeling equations and quantities that can be modified through such user defined input parameters and/or special options. Present the technical rationale for the implementation of these special modeling options and provide the allowable input values. In addition, please explain how the input values for these options are determined for the purpose of performing PWR LOCA analysis using the Full Spectrum LOCA methodology.

(2) Please identify which of the parameters, multipliers, and/or options, identified in Item (1) above, were used in the WCOBRA/TRAC-TF2 loop seal assessment study presented in Subsection 18.3.1, "WCOBRA/TRAC-TF2 Simulation of the UPTF 3-Bar and 15-Bar Tests." Present the technical rationale for applying or not applying a specific parameter, multiplier, or option. Explain if a specific parameter, multiplier, or option was applied on component-wide basis and/or to specific cells/interfaces only of component PIPE 2 used to represent the UPTF loop seal in the WCOBRA/TRAC-TF2 model. Provide a table that lists each individual modeling parameter, multiplier, and option such as the one used to prescribe that [ ]^{a,c}

Response:

Identification/Description of Parameters

Table 50-1 of the response to RAI 50 [115-1] provides a list of the user defined parameters, multipliers and/or options available in WCOBRA/TRAC-TF2, including their allowable input values. For the parameters that are not sampled as part of the FSLOCA method, justification for the value used is provided in Table 50-3 of the response to RAI 50 [115-1]. In addition, the response to RAI 86 provides clarification on MSTRTX/STRTX [115-2]. Of the parameters listed in Table 50-1 of the response to RAI 50 [115-1], the following directly influence the loop seal clearing calculation:

Table 115-1: Parameters that Directly Influence the Loop Seal Clearing Calculation

a,c

Parameter	Description	Default	Application	Sampled?

Discussion Regarding Parameters Which Directly Influence Loop Seal Clearing

[

]a,c

[

]a,c

a,c

Figure 115-1: STFRU Study - Residual Liquid Level Comparison for the 3-bar Cases

a,c

Figure 115-2: STFRU Study - Residual Liquid Level Comparison for the 15-bar Cases

a,c

Figure 115-3: STFRU Study - Differential Pressure across the Loop Seal Region for the 3-bar Cases

a,c

Figure 115-4: STFRU Study - Differential Pressure across the Loop Seal Region for the 15-bar Cases

Reference(s)

115-1) LTR-NRC-13-73, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information – RAIs 46 – 58, 75 and 77' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," October 28, 2013.

115-2) LTR-NRC-14-12, "Submittal of Westinghouse Responses to 'WCAP-16996-P, 'Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)' Request for Additional Information – RAIs 77-82, 86-87, 93 and 112' (Proprietary/Non-Proprietary), Project 700, TAC No. ME5244," March 12, 2014.

115-3) Takeuchi, K., Young, M. Y., and Gagnon, A. F., "Flooding in the pressurizer surge line of AP600 plant and analyses of APEX data," *Nuclear Engineering and Design*, Volume 192, pp. 45-58, 1999.

115-4) WCAP-16996-P/WCAP-16696-NP, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.

RAI Question #116: UPTF TRAM Loop Seal Clearance Data and WCOBRA/TRAC- TF2 Assessment

The UPTF TRAM loop seal clearance experiments comprise both integral effect and separate effect tests. The separate effect tests were performed using combined steam and water or steam injection only with various flow rates and at two different pressure levels of 0.3 MPa and 1.5 MPa (43.5 psia and 217.6 psia). As described in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 18, "Loop Seal Clearance," Subsection 18.3.1, "WCOBRA/TRAC-TF2 Simulation of the UPTF 3-Bar and 15-Bar Tests," UPTF TRAM separate effect tests were used to assess the code. Regarding the test data, Subsection 18.3.1 refers to publications by J. Liebert and R. Emmerling, "UPTF Experiment: Flow Phenomena During Full-Scale Loop Seal Clearing of a PWR," Nuclear Engineering and Design, Vol. 179, No.1, pp. 51-64, 1998, and by J. Ohvo et al., "Simulation of Full-Scale UPTF Loop Seal Experiments with APROS, CATHARE and RELAP," ICONE6-6090, 6th International Conference on Nuclear Engineering, May 10-15, 1998, San Diego, California. The work by Ohvo, et al. includes a summary of the main parameters for the UPTF TRAM tests.

(1) Please provide a table identifying the UPTF TRAM separate effect test data that were used to assess WCOBRA/TRAC-TF2 as described in Subsection 18.3.1. For each data point, provide the system pressure, steam and water injection flow rates, and corresponding measured test quantities. Please explain how the test boundary conditions were simulated in UPTF WCOBRA/TRAC-TF2 model and present separate assessments for the cases with and without water injection. Explain if any UPTF TRAM test data points were excluded from the assessment results presented in Figures 18.3-2, 18.3-4, and 18.3-5 in Subsection 18.3.1. Please clarify if Figure 18.3-5 includes all data points presented in Figure 18.3-2 and in Figure 18.3-4.

(2) For each UPTF TRAM data point shown in Figures 18.3-2, 18.3-4, and 18.3-5 in Subsection 18.3.1, provide transient code prediction results for important thermal hydraulic quantities. In particular, please include plots for inlet and exit steam and liquid mass flow rates, liquid entrainment rates, phase velocities, void fractions in the horizontal section, bend regions, and downhill and uphill sections of the loop seal, as well as liquid coolant inventory residing in these simulated loop seal regions. In addition, please depict the two-phase flow regimes as identified in the loop seal nodes. Provide plots for the predicted volumetric concentrations of the interfacial friction force.

(3) Please present plots showing WCOBRA/TRAC-TF2 calculation results against measured residual loop seal water levels and loop seal pressure losses observed at various injection flow rates. Provide consideration of measurement accuracies, observed hydraulic flow oscillations, and any other factors of relevance to the presented code assessment results.

(4) For each UPTF TRAM data point shown in Figures 18.3-2, 18.3-4, and 18.3-5 in Subsection 18.3.1, provide plots comparing local transient thermal hydraulic conditions against corresponding critical conditions or criteria used in WCOBRA/TRAC-TF2 to describe phenomena of governing importance for predicting loop seal clearance including transition to non-stratified flow, CCFL, and participating liquid entrainment mechanisms. Plot the computed thermal hydraulic quantities and corresponding critical parameters as a function of transient time and at locations in the loop seal where such phenomena play a governing role.

(5) In responding to Items (1) through (4) above, please assess UPTF TRAM 0.5 MPa tests and the 1.5 MPa tests separately. Provide detailed pressure scaling considerations based on contributing

WCOBRA/TRAC-TF2 models. Derive and provide corresponding pressure scaling relationships and explain how the UPTF TRAM full-scale loop seal clearance data support them.

Response:

(1) Table 116-1 provides the experimental cases used for the code comparison of the differential pressure across the loop seal region and is taken from Table 14 of [116-1]. These cases were chosen as [

]a,c

Table 116-2 provides the experimental cases used for the code comparison of residual liquid level and is taken from Table 13 of [116-1]. Based on [

]a,b,c

Table 116-1: Differential Pressure Data from Table 14 of [116-1]			
3-bar Cases			
Run	**Jg***	**dP (kPa)**	**M_v (kg/s)**
15-bar Cases			
Run	**Jg***	**dP (kPa)**	**M_v (kg/s)**

a,b,c

a,b,c

Table 116-2: Residual Liquid Level Data from Table 13 of [116-1]

3-bar Cases

a,b,c

Run	Jg*	hl/d	M_v (kg/s)

15-bar Cases

a,b,c

Run	Jg*	hl/d	M_v (kg/s)

(2) The requested figures have been generated for the following six cases:

Pressure	Jg*	Pressure	Jg*
3-bar	0.076	15-bar	0.070
	0.176		0.178
	0.283		0.299

The figures include vapor mass injected, total mass out, entrainment rate in the horizontal and uphill bend sections, phasic velocities around the loop seal bend and horizontal regions, void fractions around the loop seal bend and horizontal regions, total system mass, flow regimes around the loop seal bend and horizontal regions, and the volumetric interfacial friction force around the loop seal bend and horizontal regions and are presented in Figures 116-1 through 116-42.

As seen Figures 116-1, 116-8, 116-15, 116-22, 116-29 and 116-36, [

]^{a,c}

On the flow regime figures, it is noted that there are three y-axis coordinates for stratified flow. This is a result of how the code reports the momentum cell being in stratified flow (i.e., stratified flow from each of the non-stratified flow regimes). This creates the appearance of the flow regime being oscillatory, when in fact

the flow remains in stratified flow. This is demonstrated by the flow regime for momentum cell 8 in Figure 116-6.

Lastly, Figures 116-7, 116-14, 116-21, 116-28, 116-35 and 116-42 provide the interfacial friction force around the loop seal region. As expected, [

]^{a,c}

a,c

Figure 116-1: 3-bar, Jg*=0.076 – Mass Flow Rate

a,c

Figure 116-2: 3-bar, Jg*=0.076 – Total System Mass

a,c

Figure 116-3: 3-bar, Jg*=0.076 – Void Fraction

a,c

Figure 116-4: 3-bar, Jg*=0.076 – Phasic Velocities

a,c

Figure 116-5: 3-bar, Jg*=0.076 – Liquid Entrainment Fraction

a,c

Figure 116-6: 3-bar, Jg*=0.076 – Flow Regime

a,c

Figure 116-7: 3-bar, Jg*=0.076 – Interfacial Friction Force

a,c

Figure 116-8: 3-bar, Jg*=0.176 – Mass Flow Rate

a,c

Figure 116-9: 3-bar, Jg*=0.176 – Total System Mass

a,c

Figure 116-10: 3-bar, Jg*=0.176 – Void Fraction

a,c

Figure 116-11: 3-bar, Jg*=0.176 – Phasic Velocities

a,c

Figure 116-12: 3-bar, Jg*=0.176 – Liquid Entrainment Fraction

a,c

Figure 116-13: 3-bar, Jg*=0.176 – Flow Regime

a,c

Figure 116-14: 3-bar, Jg*=0.176 – Interfacial Friction Force

a,c

Figure 116-15: 3-bar, Jg*=0.283 – Mass Flow Rate

a,c

Figure 116-16: 3-bar, Jg*=0.283 – Total System Mass

a,c

Figure 116-17: 3-bar, Jg*=0.283 – Void Fraction

a,c

Figure 116-18: 3-bar, Jg*=0.283 – Phasic Velocities

a,c

Figure 116-19: 3-bar, Jg*=0.283 – Liquid Entrainment Fraction

a,c

Figure 116-20: 3-bar, Jg*=0.283 – Flow Regime

a,c

Figure 116-21: 3-bar, Jg*=0.283 – Interfacial Friction Force

a,c

Figure 116-22: 15-bar, Jg*=0.070 – Mass Flow Rate

a,c

Figure 116-23: 15-bar, Jg*=0.070 – Total System Mass

a,c

Figure 116-24: 15-bar, Jg*=0.070 – Void Fraction

a,c

Figure 116-25: 15-bar, Jg*=0.070 – Phasic Velocities

a,c

Figure 116-26: 15-bar, Jg*=0.070 – Liquid Entrainment Fraction

a,c

Figure 116-27: 15-bar, Jg*=0.070 – Flow Regime

a,c

Figure 116-28: 15-bar, Jg*=0.070 – Interfacial Friction Force

a,c

Figure 116-29: 15-bar, Jg*=0.178 – Mass Flow Rate

a,c

Figure 116-30: 15-bar, Jg*=0.178 – Total System Mass

a,c

Figure 116-31: 15-bar, Jg*=0.178 – Void Fraction

a,c

Figure 116-32: 15-bar, Jg*=0.178 – Phasic Velocities

a,c

Figure 116-33: 15-bar, Jg*=0.178 – Liquid Entrainment Fraction

a,c

Figure 116-34: 15-bar, Jg*=0.178 – Flow Regime

a,c

Figure 116-35: 15-bar, Jg*=0.178 – Interfacial Friction Force

a,c

Figure 116-36: 15-bar, Jg*=0.299 – Mass Flow Rate

a,c

Figure 116-37: 15-bar, Jg*=0.299 – Total System Mass

a,c

Figure 116-38: 15-bar, Jg*=0.299 – Void Fraction

a,c

Figure 116-39: 15-bar, Jg*=0.299 – Phasic Velocities

a,c

Figure 116-40: 15-bar, Jg*=0.299 – Liquid Entrainment Fraction

a,c

Figure 116-41: 15-bar, Jg*=0.299 – Flow Regime

a,c

Figure 116-42: 15-bar, Jg*=0.299 – Interfacial Friction Force

(3) Specific uncertainties related to the residual liquid level data measurements are not readily available in the papers and reports that Westinghouse possesses. However, from the reports, the residual liquid levels are [

]a,c

a,b,c

Table 116-3: Data hl/d Uncertainties				
3-bar				
Run	Jg*	hcl010/d	hcl011/d	hf/d

Table 116-3: Data hl/d Uncertainties(cont)				
15-bar				
Run	Jg*	hcl010/d	hcl011/d	hf/d

a,b,c

Table 116-4: dP Uncertainties			
3-bar			
Jg*	**dP-LB**	**dP-Nom**	**dP-UB**
15-bar			
Jg*	**dP-LB**	**dP-Nom**	**dP-UB**

a,b,c

a,b,c

Table 116-5: Symmetric Bend Results (Ranges)

a,c

Pressure	Jg* (-)	UB hl/d	NOM hl/d	LB hl/d	LB dP	NOM dP	UB dP

a,b,c

Figure 116-43: 3-bar Residual Liquid Level Comparison, Including Uncertainties

a,b,c

Figure 116-44: 15-bar Residual Liquid Level Comparison, Including Uncertainties

a,b,c

Figure 116-45: 3-bar Pressure Differential Comparisons, Including Uncertainties

a,b,c

Figure 116-46: 15-bar Pressure Differential Comparisons, Including Uncertainties

(4) Figures 116-47 through 116-58 provide comparisons of the relative velocity vs. stratification and entrainment criteria, as well as Kutateladze values for the cells of interest. The cases represented are the same cases used for plotting results presented in part (2) of this response. See part (2) of this response for discussion related to these figures.

a,c

Figure 116-47: 3-bar, Jg*=0.076 – Horizontal Stratification and Wavy Dispersed Criteria

a,c

Figure 116-48: 3-bar, Jg*=0.076 – Kutateladze Number

a,c

Figure 116-49: 3-bar, Jg*=0.176 – Horizontal Stratification and Wavy Dispersed Criteria

a,c

Figure 116-50: 3-bar, Jg*=0.176 – Kutateladze Number

a,c

Figure 116-51: 3-bar, Jg*=0.283 – Horizontal Stratification and Wavy Dispersed Criteria

a,c

Figure 116-52: 3-bar, Jg*=0.283 – Kutateladze Number

a,c

Figure 116-53: 15-bar, Jg*=0.070 – Horizontal Stratification and Wavy Dispersed Criteria

a,c

Figure 116-54: 15-bar, Jg*=0.070 – Kutateladze Number

a,c

Figure 116-55: 15-bar, Jg*=0.178 – Horizontal Stratification and Wavy Dispersed Criteria

a,c

Figure 116-56: 15-bar, Jg*=0.178 – Kutateladze Number

a,c

Figure 116-57: 15-bar, Jg*=0.299 – Horizontal Stratification and Wavy Dispersed Criteria

a,c

Figure 116-58: 15-bar, Jg*=0.299 – Kutateladze Number

(5) Even though the UPTF loop seal tests did not perform experiments at full pressure, simulations were performed at a pressure representative of the first main steam safety valve pressure. The results are presented in Section 18.3.1 of [116-2]. As part of the response to RAI 117, the pressure differential across the loop seal for the cases executed as part of the break spectrum study (Sections 27.1.1.3 and 27.1.2.3 of [116-2]) were examined. It was shown that the vapor flows (i.e., modified Froude number) and differential pressures from the plant cases were comparable to the UPTF loop seal data.

Reference(s)

116-1) NT33/94/011, "Versuch A5, Freiblasen des Pumpenbogens, Einzeleffekt- und Integralversuche," December 1994.

116-2) WCAP-16996-P/WCAP-16696-NP, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.

RAI Question #117: WCOBRA/TRAC-TF2 Upper Plenum Test Facility Loop Seal Nodalization Sensitivity Study

Various nodalization approaches have been applied in analyzing loop seal clearance test data in assessing reactor safety codes. For example, in the work by J. Ohvo et al., "Simulation of Full-Scale UPTF Loop Seal Experiments with APROS, CATHARE and RELAP," Paper ICONE6-6090, 6th International Conference on Nuclear Engineering, May 10-15, 1998, San Diego, California, the bottom horizontal section of the UPTF the loop seal piping was represented by 2 nodes in the APROS model, by 7 nodes in the CATHARE model, and by 2 nodes in the RELAP5 model. Correspondingly, each of the 90° bend regions was represented by 3, 5, and a single node.

When describing the UPTF loop seal model, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 18, "Loop Seal Clearance," Subsection 18.3.1, "WCOBRA/TRAC-TF2 Simulation of the UPTF 3-Bar and 15-Bar Tests," states that "the noding in this model is judged sufficient for simulation of the UPTF tests, and similar modeling is expected to be used in the plant simulations." At the same time, WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 18, "Loop Seal Clearance," provides no justification for this statement.

The NRC Regulatory Guide 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance," May 1989, Subsection 2.1.1, "Numerical Methods," requires that "Sensitivity studies and evaluations of the uncertainty introduced by noding should be performed." WCAP-16996-P/ WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 18, "Loop Seal Clearance," does not examine the impact of noding on WCOBRA/TRAC-TF2 prediction results in assessing the code capabilities to predict loop seal clearance.

(1) Please perform and present results from WCOBRA/TRAC-TF2 nodalization sensitivity studies that employ 2, 3, and 4 cells of an equal length to model the UPTF loop seal bottom horizontal section, which would correspond to cell length- to-diameter ratios (L/D) of 1.16, 0.77, and 0.58. Examine any additional nodalization schemes, as deemed appropriate. Show plots comparing both the residual loop seal levels and loop seal pressure losses against measured data.

(2) Please perform and present results from WCOBRA/TRAC-TF2 nodalization sensitivity studies that employ 3, 4, and 5 cells to model each of the 90° bends connecting the bottom horizontal section of the loop seal to the downhill and uphill pipes of the UPTF cross-over leg. Show plots comparing both the residual loop seal liquid levels and loop seal pressure losses against measured data.

(3) Present and discuss the technical basis used to establish the PWR loop seal nodalization approach considered adequate for predicting loop seal clearance in WCOBRA/TRAC-TF2 plant LOCA analyses as part of the Full Spectrum™ LOCA methodology. Describe the approach to PWR loop seal modeling implemented for LOCA analyses using the Full Spectrum™ LOCA methodology. Please explain how the results from the UPTF TRAM loop seal nodalization sensitivity study support this approach.

Response:

(1) The sensitivity studies requested were executed, whereby the horizontal cell was split into two cells, three cells and four cells, respectively. The residual liquid levels versus the modified Froude number are presented in Figure 117-1 for the 3-bar cases and Figure 117-2 for the 15-bar cases. The differential pressures across the loop seal versus the modified Froude number are presented in Figure 117-3 for the 3-bar cases and Figure 117-4 for the 15-bar cases. As seen from the figures, [

]^{a,c}

a,c

Figure 117-1: Horizontal Noding Study - Residual Liquid Level Comparison for the 3-bar Cases

a,c

Figure 117-2: Horizontal Noding Study - Residual Liquid Level Comparison for the 15-bar Cases

a,c

Figure 117-3: Horizontal Noding Study - Differential Pressure across the Loop Seal Region for the 3-bar Cases

a,c

Figure 117-4: Horizontal Noding Study - Differential Pressure across the Loop Seal Region for the 15-bar Cases

(2) The sensitivity studies requested were executed, whereby the two cells representing the bend regions were split into three cells, four cells and five cells, respectively. Based on the discussion in the response to RAI 115 regarding [

]^{a,c}

The residual liquid levels versus the modified Froude number are presented in Figure 117-5 for the 3-bar cases and Figure 117-6 for the 15-bar cases. The differential pressures across the loop seal versus the modified Froude number are presented in Figure 117-7 for the 3-bar cases and Figure 117-8 for the 15-bar cases. As seen from the figures [

]^{a,c}

a,c

Figure 117-5: Bend Noding Study - Residual Liquid Level Comparison for the 3-bar Cases

a,c

Figure 117-6: Bend Noding Study - Residual Liquid Level Comparison for the 15-bar Cases

a,c

Figure 117-7: Bend Noding Study - Differential Pressure across the Loop Seal Region for the 3-bar Cases

a,c

Figure 117-8: Bend Noding Study - Differential Pressure across the Loop Seal Region for the 15-bar Cases

(3) The PWR modeling is based on the model used for UPTF loop seal simulations (see response to RAIs 91 and 92) to ensure consistency with the assessment of loop seal clearing on residual liquid retention and pressure differential. While UPTF test data is not available at full pressure, the UPTF loop seal model was executed at a pressure representative of a PWR, with scaled flow rates. The results are discussed in Section 18 of [117-1].

In addition, the pressure drop across each of the loop seals is obtained from the break spectrum studies presented in Sections 27.1.1.3 and 27.1.2.3 of [117-1]. The results for all three loop seals of each break size are presented in Figures 117-9 through 117-16 (triangles represent loop 1; squares represent loop 2; pentagons represent loop 3). As seen from the figures, the pressure drops across the loop seal region from the plant break spectrum studies are within or slightly higher than those obtained from the UPTF loop seal simulations as well as the UPTF loop seal data (see Figures 117-7 and 117-8 for UPTF data points).

a,c

Figure 117-9: Loop Seal Pressure Differential with Results from CGE Plant Break Spectrum Study 2-inch Break

a,c

Figure 117-10: Loop Seal Pressure Differential with Results from CGE Plant Break Spectrum Study 3-inch Break

a,c

Figure 117-11: Loop Seal Pressure Differential with Results from CGE Plant Break Spectrum Study 4-inch Break

a,c

Figure 117-12: Loop Seal Pressure Differential with Results from CGE Plant Break Spectrum Study 6-inch Break

a,c

Figure 117-13: Loop Seal Pressure Differential with Results from DLW Plant Break Spectrum Study 2-inch Break

a,c

Figure 117-14: Loop Seal Pressure Differential with Results from DLW Plant Break Spectrum Study 3-inch Break

a,c

Figure 117-15: Loop Seal Pressure Differential with Results from DLW Plant Break Spectrum Study 4-inch Break

a,c

Figure 117-16: Loop Seal Pressure Differential with Results from DLW Plant Break Spectrum Study 6-inch Break

Reference(s)

117-1) WCAP-16996-P/WCAP-16696-NP, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.

RAI Question #118: WCOBRA/TRAC-TF2 Upper Plenum Testing Facility Loop Seal Modeling Options Sensitivity Study

RAI Question No. 115 Item (1) requests information regarding user defined parameters, multipliers, and/or options, implemented in WCOBRA/TRAC-TF2 models and correlations relevant to predicting loop seal clearance in PWR plant LOCA analyses, including such related to describing non-stratified flow transition, CCFL, and liquid entrainment mechanisms.

Please provide results from WCOBRA/TRAC-TF2 sensitivity studies based on the UPTF TRAM full-scale separate effect loop seal clearance tests, which show the effect of varying or sampling of parameters, multipliers, and/or options relevant to the prediction of the loop clearance process. Examine each such user defined quantity and describe the bases for allowing variation or proposing sampling of input values. Provide a table, which lists all examined parameters. For the parameters, multipliers, and/or options being subject to variation or sampling, please provide the sampling range and distribution or proposed input values and allowed ranges. For the sampled parameters, such as HS_SLUG, apply the sampling approach used in PWR plant LOCA analyses. For all remaining user defined parameters, multipliers, and/or options, explain the basis for the proposed input values and ranges regardless if a specific user defined quantity is being described a subject to variation or not for the purpose of plant LOCA analyses using the Full Spectrum LOCA methodology. Analyze each parameter individually and independently from the remaining ones. In particular, demonstrate the effect of variation in Cstfru and STRTX input, if variation is allowed in plant LOCA analyses. Please present the WCOBRA/TRAC-TF2 sensitivity results and provide comparisons against UPTF TRAM full-scale separate effect loop seal clearance test data. In addition, provide comparisons among analyzed sensitivity cases, as appropriate.

Response:

See the response to RAI 115.

RAI Question #119: WCOBRA/TRAC-TF2 UPTF Loop Seal Time Step Limit Sensitivity Study

A special case of a user defined parameter of a global importance to code predictions, including loop seal clearance, is the maximum allowable time step size. WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 28, "Scoping and Sensitivity Studies," Subsection 28.2.4, "Time Step and Convergence Criteria Studies – SBLOCA," analyzes the impact of different DTMAX values on PWR plant LOCA predictions and notes that observed "differences among the cases arise from the prediction of loop seal clearance timing and extent of clearance." In the analyzed plant LOCA sensitivity studies, time step upper limits of 1 millisecond, 2 milliseconds, and 5 milliseconds were used.

Considering uncertainty in PWR plant LOCA analyses, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 29.3.3, "Uncertainty Associated with Maximum Time Step Size," explains that the maximum allowable time step size in WCOBRA/TRAC-TF2 is set by the user through the DTMAX input parameter. The subsection states that "WCOBRA/TRAC-TF2 uses DTMAX as the time step throughout significant portions of the transient." It also explains that "in the analysis, a choice of DTMAX is made and is applied in all transients." Thus, DTMAX is not sampled in PWR plant LOCA analysis using the Full Spectrum™ LOCA methodology.

The NRC Regulatory Guide 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance," May 1989, Subsection 2.1.1, "Numerical Methods," requires that "the effect of time-step size should also be investigated." WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 18, "Loop Seal Clearance," does not examine the impact of the maximum allowable time step size on WCOBRA/TRAC-TF2 prediction results in assessing the code capabilities to predict loop seal clearance.

Considering the importance WCOBRA/TRAC-TF2 capabilities to predict the loop seal clearance phenomenon, please present sensitivity results based on the UPTF TRAM full-scale separate effect loop seal clearance tests that show the effect of the maximum allowed time step size. Demonstrate if reduction of the maximum allowed time step size can lead to obtaining code predictions that remain insensitive, when considering major predicted quantities, to further restrictions of the maximum allowed time step size. Please plot the WCOBRA/TRAC-TF2 sensitivity results and provide comparisons against UPTF TRAM full-scale separate effect loop seal clearance test data. In addition, provide comparisons among examined sensitivity cases, as appropriate.

Response:

The original UPTF loop seal validation cases were performed with a maximum time step size of [ ]^{a,c}, which is greater than the typical time step used for plant analyses, which generally range between [ ]^{a,c}

A time step study was performed using the following maximum time step sizes for the symmetric bend cases used in response to RAI 113:

[ ]^{a,c}

Figure 119-1 provides a comparison of the residual liquid level versus the modified Froude number for the 3-bar cases, and Figure 119-2 provides a comparison of the residual liquid level for the 15-bar cases. Figure 119-3 provides a comparison of the differential pressure across the loop seal for the 3-bar cases, and Figure 119-4 provides a comparison of the differential pressure across the loop seal for the 15-bar cases. As seen from the figures [

]^{a,c}

a,c

Figure 119-1: Time Step Study – Residual Liquid Level Comparison for the 3-bar Cases

a,c

Figure 119-2: Time Step Study – Residual Liquid Level Comparison for the 15-bar Cases

a,c

Figure 119-3: Time Step Study – Differential Pressure across the Loop Seal Region for the 3-bar Cases

a,c

Figure 119-4: Time Step Study – Differential Pressure across the Loop Seal Region for the 15-bar Cases