# 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 96-105 and 107

**April 2014**

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**Question #96: PWR Upper Head Spray Nozzle Bypass Design Data**

Upper head cooling spray nozzles are used in PWR to adjust the coolant temperature in the upper head plenum by providing a relatively small bypass flow of coolant at the cold leg temperature from the upper downcomer region into the upper head plenum. The exact configuration and bypass flow depend on the PWR design and the production line. WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 25, "Plant Sources of Uncertainty," Subsection 25.2.2.2, " Fluid Conditions Modeling Approach," explains that "typically, plants can be separated into two categories: those with sufficient bypass flow to maintain ($T_{UH}$) near ($T_{cold}$), and those with low bypass flow, in which ($T_{UH}$) remains close to $T_{hot}$." Taking into account that the upper head-to-downcomer bypass flow affects the upper head initial temperature at steady-state, Subsection 25.2.2.2, states that "the initial temperature of the fluid in the upper head ($T_{UH}$) has been found to strongly affect the blowdown PCT in other evaluation models (for Large Break LOCA)." During small break LOCA, this bypass releases steam from the upper plenum and the resulting "venting has a high importance during the loop seal clearing period when it relieves some of the core two-phase level depression," as explained in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 29, "Assessment of Uncertainty Elements," Subsection 29.5.3, "Upper Head." Subsection 29.5.3 also explains that "the ability to vent steam through the upper head is strongly dependent on the flow area of the spray nozzles, which is the flow path connecting the upper head and the downcomer" and states that "the spray nozzle bypass itself is modeled in a best-estimate manner."

(1) Please explain if PWR upper head spray nozzle channels and relevant design features are modeled by implementing certain hydraulic components, component features, and/or activation of specific modeling options in WCOBRA/TRAC-TF2 vessel models of PWR plants and provide their corresponding description.

(2) WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 26, "WCOBRA/TRAC-TF2 Model of Pilot Plants," Subsection 26.4, "Steady State Calculation/Calibration," states that "core bypass flow (including the thimble bypass flow and the spray nozzle flow) should closely match those provided by the mechanical design data." Please explain what "mechanical design data" of the upper head spray nozzles is used to simulate these nozzles in WCOBRA/TRAC-TF2 vessel models of PWR plants.

(3) Please identify design data of upper head spray nozzles, including any relevant reactor features and conditions, such as number of spray nozzles, nozzle diameters, lengths, loss coefficients, flow areas, and other geometric dimensions and conditions, that are used for the upper head bypass simulation in WCOBRA/TRAC-TF2 vessel models. Explain the source, availability, and accuracy of data quantifying upper head bypass and explain how such bypass flow data is obtained for PWR plants of interest. Clarify how the design data is used in developing COBRA/TRAC-TF2 PWR plant models used for the purposes of LOCA analyses. Provide a table that provides the typical ranges for these parameters.

(4) Please provide the range of spray nozzle bypass capacities for PWR plants included in the scope of intended WCOBRA/TRAC-TF2 applications for LOCA analyses and estimate the uncertainties associated with provided PWR upper head spray nozzle bypass capacities.

(5) Please explain how Items (1) through (4) above relate to the statement that "the spray nozzle bypass itself is modeled in a best-estimate manner" in WCOBRA/TRAC-TF2 PWR plant LOCA analyses. Please explain how theinformation requested in Items (1) through (4) is taken into consideration in ensuring that "the spray nozzle bypass itself is modeled in a best-estimate manner." Describe any other relevant WCOBRA/TRAC-TF2 PWR plant model details and modeling features if implemented in the FSLOCA™ methodology in this regard.

Response:

(1) The Pressurized Water Reactor (PWR) upper head spray nozzle design features are [

]$^{a,c}$ Please see the responses to Items (2) and (3) below for additional information.

(2) The "mechanical design data" being referred to in Subsection 26.4 of WCAP-16996-P [96-1] is the plant-specific best-estimate upper head spray nozzle bypass flow data generated by the Westinghouse Reactor Internals Design and Analysis group, using the PWR plant- specific upper head spray nozzle design data and features as discussed in the response to Item (3) below.

(3) As noted in the response to Items (1) and (2) above, the [

]$^{a,c}$ from Idelchik, I.E. "Handbook of Hydraulic Resistance" [96-2].

The typical upper head spray nozzle flow area and loss coefficient for Westinghouse- designed plants are provided below.

| Westinghouse-Designed Plants | Upper Head Spray Nozzle Total Flow Area ($in^2$) | Upper Head Spray Nozzle Loss Coefficient (-) |
|---|---|---|
| [ | | |
| | | |
| | | |
| | | |
| | | |
| | | |

Notes:
1.) ]$^{a,c}$
2.) UHI = Upper Head Injection. Note that UHI refers to the design of the plant, but is not active

(4) The range of upper head spray nozzle bypass capacities for Westinghouse-designed plants is shown below. The associated uncertainty on the upper head spray nozzle bypass flow provided below is [

]$^{a,c}$

(5) As discussed in the responses above, the plant-specific best-estimate upper head spray nozzle bypass flow is calculated by the Westinghouse Reactor Internals Design and Analysis group using the PWR plant-specific design data and features of the upper head spray nozzles at [ ]$^{a,c}$ To ensure that the upper head spray nozzle bypass is modeled in a best-estimate manner, the [

]$^{a,c}$

References:

96-1) WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.
96-2) Idel'Chik, I. E., 1960, Handbook of Hydraulic Resistance," AEC-tv-6630.

**Question #97: PWR Upper Head Spray Nozzle Bypass Flow Tune-up**

Considering steady-state acceptance criteria for plant initial conditions, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 26, "WCOBRA/TRAC-TF2 Model of Pilot Plants," Subsection 26.4, "Steady State Calculation/Calibration," provides Table 26.4-1, "Criteria for an Acceptable Steady-State," which contains a checklist with 17 significant parameters "to verify whether these variables have reached their acceptable steady-state values." Item (12) in this table lists the "Upper Head Nozzle Flow/Vessel Flow" variable and provides a corresponding acceptance criterion, according to which the "calculated value" should be within [ ]$^{a,c}$ of the "desired value."

Considering application aspects related to the spray nozzle bypass modeling, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," Subsection 21.11.3, "Spray Nozzle Bypass Ranging Sensitivity with the SB-CL-18 Test," states that "during the steady state tune-up procedure, the bypass flow through the spray nozzle is adjusted to be within [ ]$^{a,c}$ of the desired value, established for each plant."

(1) Please explain how "the bypass flow through the spray nozzle is adjusted to be within [ ]$^{a,c}$ of the desired value, established for each plant" and describe the "steady state tune-up procedure" used to achieve this. Identify plant model input variables and related features that are subject to this "steady state tune-up" and describe how such parameters are varied. Explain if these parameters are subject to variation within certain allowable limits and, if this is the case, please describe how the corresponding limits are established.

(2) Please explain how the "desired value" for the variable "Upper Head Nozzle Flow/Vessel Flow" identified in Table 26.4-1, "Criteria for an Acceptable Steady-State," is established for each plant and clarify how it is used in PWR LOCA analyses using WCOBRA/TRAC-TF2.

(3) WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 26.4 states that "core bypass flow (including the thimble bypass flow and the spray nozzle flow) should closely match those provided by the mechanical design data, within the tolerances given in Table 26.4-1. The allowable variation is essentially equivalent to a 1 percent variation in the loop flowrate." Please explain the meaning of the statement that [ ]$^{a,c}$ Clarify how this statement relates to the criterion that the "calculated value" of the "Upper Head Nozzle Flow/Vessel Flow" parameter is within [ ]$^{a,c}$ of the "desired value."

(4) The "steady state tune-up" procedure establishes the upper head bypass flow under the reactor initial conditions at steady-rate operation. Please explain how PWR vessel model hydraulic features implemented in WCOBRA/TRAC-TF2 PWR plant models and adjustments to such model features aimed at verifying that a certain "desired value" bypass flow is achieved at the end of an initial steady-state plant simulation ensure that the bypass flow is realistically modeled during a LOCA transient calculation.

(5) Please explain how the information requested in Items (1) through (4) is taken into consideration in ensuring that "the spray nozzle bypass itself is modeled in a best-estimate manner." Describe any other relevant WCOBRA/TRAC-TF2 PWR plant

model details and modeling features if implemented in the Full Spectrum LOCA methodology in this regard.

Response:

(1) As discussed in the responses to RAI #96, the PWR plant design features of the upper head spray nozzles are [ ]$^{a,c}$ in the WCOBRA/TRAC-TF2 PWR models. To achieve the desired upper head spray nozzle bypass flow at the end of the steady run, the [ ]$^{a,c}$ of the desired value (D.V.) as shown in Table 26.4-1 of WCAP-16996-P. As noted in the responses to RAI #96, the desired value is obtained from the Westinghouse Reactor Internals Design and Analysis group, and is calculated based on the PWR plant-specific design data and features of the upper head spray nozzles at [ ]$^{a,c}$

(2) Please see the response to RAI #96.

(3) This means that the [ ]$^{a,c}$ An example is provided below to illustrate this:

From Table 26.2-1 of WCAP-16996-P, the desired loop total flowrate for V. C. Summer [ ]$^{a,c}$

The typical upper head spray nozzle bypass ranges for Westinghouse-designed plants are provided in the response to RAI #96(4). The [ ]$^{a,c}$ criterion for the "Upper Head Nozzle Flow/Vessel Flow" is [ ]$^{a,c}$ meet the tolerances provided in Table 26.4-1 of WCAP-16996-P.

(4) See the response to RAI #107(2).

(5) As discussed in the response to RAI #96, the plant-specific desired best-estimate upper head spray nozzle bypass flow is calculated by the Westinghouse Reactor Internals Design and Analysis group using the PWR plant-specific design data and features of the upper head spray nozzles at [ ]$^{a,c}$ To ensure that the upper head spray

nozzle bypass is modeled in a best-estimate manner, the calculated upper head spray nozzle bypass flow at the end of the PWR steady state run must agree with the plant-specific best-estimate value provided by the Westinghouse Reactor Internals Design and Analysis group within the tolerance shown in Table 26.4-1 of WCAP-16996-P. [

]$^{a,c}$

Reference:

97-1) WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.

**Question #98: PWR Upper Head Temperature Tune-up**

The upper head liquid temperature is dependent on the venting flow between the upper head and the reactor downcomer through the upper head spray nozzles. WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 29, "Assessment of Uncertainty Elements," Subsection 29.5.3, "Upper Head," states that "the initial upper head liquid temperature is calibrated during the steady-state calculation." WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 26, "WCOBRA/TRAC-TF2 Model of Pilot Plants," Subsection 26.4, "Steady State Calculation/Calibration," Table 26.4-1, "Criteria for an Acceptable Steady-State," includes Item (14), which lists the "Upper Head Temperature" variable and provides a corresponding acceptance criterion, according to which the "calculated value" should be within [ ]$^{a,c}$ of the "desired value."

(1) Please explain how the "desired value" for the variable "Upper Head Temperature" identified in Table 26.4-1, "Criteria for an Acceptable Steady-State," is established for each plant and describe how it is used in PWR LOCA analyses using WCOBRA/TRAC-TF2.

(2) As explained in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 29.5.3, "the initial upper head liquid temperature is calibrated during the steady-state calculation" so that it is within [ ]$^{a,c}$ of the "desired value." In addition, Subsection 29.5.3 states that "upper head liquid temperature uncertainty is considered by varying the temperature based on the ranging of vessel average temperature." As the upper head liquid temperature is influenced by the bypass flow between the upper head and the reactor downcomer through the upper head spray nozzles, please explain if the process of upper head initial temperature calibration and its uncertainty consideration have any effects on the spray bypass flow modeling.

(3) For PWR small break LOCA analyses, adequate prediction of the upper head bypass flow is of primary importance. WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 29, "Assessment of Uncertainty Elements," Subsection 29.5.3, "Upper Head," states that "the spray nozzle bypass itself is modeled in a best-estimate manner" in plant LOCA analyses using WCOBRA/TRAC-TF2. Please explain how this is done for PWR small break LOCA analyses, taking into consideration the information requested in Items (1) and (2) above, to ensure that the upper head bypass flow is not inappropriately affected due to upper head temperature adjustments.

Response:

(1) For Westinghouse-designed plants, the upper head region fluid temperature can [

]$^{a,c}$ The plant-specific best-estimate upper head temperature is calculated by the Westinghouse Reactor Internals Design and Analysis group at [

]$^{a,c}$ used to calculate the plant- specific best-estimate upper head spray nozzle bypass flow (see response to RAI #96). The

upper head spray nozzle flow passes vessel inlet temperature fluid into the upper head region. Generally speaking, however, this is [

]$^{a,c}$

The plant-specific best-estimate upper head temperature provided by the Westinghouse Reactor Internals Design and Analysis group is used as the target (i.e., desired) value for calibrating the PWR model. See the response to Item (2) below for additional information on the calibration process.

(2) The process of upper head initial temperature calibration [

]$^{a,c}$ so that the calculated upper head temperature is within the [ ]$^{a,c}$ of the desired value per Table 26.4-1 of WCAP-16996-P at the end of the steady state run. In addition, note that [

]$^{a,c}$ meet the tolerances provided in Table 26.4-1 of WCAP-16996-P.

(3) Please see the response to RAI #97(5) and the response to Item (2) above.

Reference:

98-1) WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.

**Question #99: PWR Upper Head Spray Nozzle Bypass in WCOBRA/TRAC-TF2 Pilot Plant Models**

Figures 26.2-3 through 26.2-6 in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 26, "WCOBRA/TRAC-TF2 Model of Pilot Plants," Subsection 26.2.1, "V. C. Summer WCOBRA/TRAC-TF2 Nodalization," show the RPV nodalization for the three-loop V. C. Summer plant. As seen from Figure 26.2-3, "Virgil C. Summer Vessel Model Noding Diagram," the vessel is divided into nine vertical sections with Section 1 at the bottom and Section 9 at the top. In this model, Section 7, which contains two vertical cells, represents the uppermost region and "extends vertically from the top of the hot leg to the top of the upper support plate." The downcomer region in Section 7 is modeled by nine channels occupying the peripheral ring, Channels 40, 41, 42, 82, 83, 84, 85, 86, and 87. As described, each of these channels "represent one-ninth of the downcomer annulus volume between the vessel inner wall and the core barrel outer wall." Section 8, which has one vertical cell, models the lower section of the upper head region and "extends vertically from the top of the upper support plate to the top of the upper guide tube." As seen from Figure 26.2-6, "Virgil C. Summer Vessel Sections 7 through 9," this section is divided into two radial rings with the interface boundary "formed by the cylinder which intersects the inside of the upper head sphere at the top of the upper guide tube." Channels 47, 88, and 89 occupy the outer ring and each of them include one-third of the volume in the upper head outer region. Subsection 26.2.1 states that "Channels 40 through 42 and 82 through 87, however, connect vertically to vessel Section 8 via the upper head spray nozzles."

The Beaver Valley Unit 1 three-loop PWR RPV nodalization is described in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 26.3.1, "Beaver Valley Unit 1 WCOBRA/TRAC-TF2 Nodalization." The spray nozzle bypass is modeled in a similar manner and the subsection repeats that "Channels 40 through 42 and 82 through 87, however, connect vertically to vessel Section 8 via the upper head spray nozzles."

(1) Please describe how the bypass flow path through the spray nozzles connecting the downcomer and upper head regions were represented in the WCOBRA/TRAC-TF2 pilot models for the V. C. Summer and Beaver Valley Unit 1 PWR plants described in Section 26. Provide a table that lists the input parameters associated with hydraulic components and modeling features employed to simulate the spray nozzles passages. Provide noding details that show how Channels 40 through 42 and 82 through 87 "connect vertically to vessel Section 8 via the upper head spray nozzles" for each vessel model.

(2) Please provide spray nozzles geometric data and drawings of the spray nozzles for both pilot plants and explain how plant design data was used in modeling the spray nozzle bypass flow passages in the WCOBRA/TRAC-TF2 vessel models for the V. C. Summer and Beaver Valley Unit 1 PWR plants. Please explain how spray nozzle design data was used to model the spray nozzle bypass and calculate the input parameters requested in Item (1) above.

(3) Please explain how the "steady state tune-up procedure," used to "adjust" the bypass flow through the spray nozzle "within [ ]$^{a,c}$ of the desired value, established for each plant," was performed for the V. C. Summer and Beaver Valley Unit 1 pilot PWR plants. Describe how the "desired value" for the variable "Upper Head Nozzle Flow/Vessel Flow" listed in Table 26.4-1, "Criteria for an Acceptable Steady-State,"

was established for each plant and compare the "calculated value" versus the "desired value" at the end of the steady-state runs for both plants. Also, please provide a table that lists all parameters subject to modification "during the steady state tune-up procedure." For each such parameter, provide its values at the beginning and at the end of the "steady state tune-up procedure" as well as the allowable variation range listing each parameter in a separate column.

Response:

(1) The upper head bypass flow path through the spray nozzles connecting the downcomer and upper head region is shown in Figures 26.2-3 and 26.3-3 of WCAP-16996-P [99-1] for V. C. Summer and Beaver Valley Unit 1, respectively. The top of the upper head spray nozzles is modeled at the top of downcomer Channels 40 through 42, and 82 through 87 in Vessel Section 7. Downcomer Channels 40 through 42, 82 through 84, and 85 through 87 in Vessel Section 7 are vertically connected to Upper Head Channels 47, 88 and 89 respectively in Vessel Section 8 via the upper head spray nozzles as shown in Figures 26.2-3 and 26.3-3 for V. C. Summer and Beaver Valley Unit 1, respectively. Additionally, the [ ]$^{a,c}$ so that the calculated upper head bypass flow is within the [ ]$^{a,c}$ of the desired value per Table 26.4-1 of WCAP-16996-P at the end of the steady state run.

(2) Please see the response to RAI #96.

(3) Please see the response to RAI #97(1) for the steady state tune-up procedure performed to achieve the desired upper head spray nozzle bypass flow. Please see the response to RAI #96 for the establishment of the desired upper head spray nozzle bypass flow for each plant.

A table that lists all parameters subject to modification “during the SS tune-up procedure” for Beaver Valley Unit 1 was previously provided as Table 3-1 in LTR-NRC-13-70 [99-2]. In addition, desired values and calculated values from the last iteration step output are provided in Tables 3.4, 3.6 and 3.7 of LTR-NRC-13-70. The process and relative values for V. C. Summer would be similar.

References:

99-1) WCAP-16996-P, “Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology),” November 2010.

99-2) LTR-NRC-13-70, “Summary of July 2013 NRC Code Workshop and August 2013 NRC Audit of the FULL SPECTRUM LOCA (FSLOCA) Evaluation Model (Proprietary/Non-Proprietary),” October 10, 2013.

*The series of NRC's questions that are addressed herein are related to the modeling of various core bypass flows in the ROSA LSTF tests selected to support the WCOBRA/TRAC-TF2 code validation. The requested information covers three types of bypass flows - flow through the spray nozzles, bypass leakage through the hot leg leak line and vessel internal leaks. Responses to individual parts of the various questions are provided as appropriate. Integral response is provided at the end to address topics that are common to multiple questions.*

## Question #100: Upper Head Spray Nozzle Bypass in LSTF Tests

To model the upper head spray nozzle bypass, the LSTF vessel featured 8 spray nozzle openings, each with a 3.4-mm (0.134-in) inlet ID, a 10-mm (0.394-in) exit inner diameter, and a 175-mm (6.9-in) length, where inlet and exit values correspond to normal flow direction from the downcomer into the upper head at normal operation. Based on the spray nozzle inlet diameter, the total spray nozzle bypass flow area amounts to 0.726 $cm^2$ ($7.826 \times 10^{-4}$ $ft^2$), which corresponds to an equivalent opening diameter of 0.961 cm (0.379 inch). Detailed geometrical data related to the upper head spray nozzles can be found in Figure 5.2.4, "Coolant Flow Path in Pressure Vessel," in Figure 5.2.6, "Downcomer-Upper Head Spray Nozzle Details," and in Figure 5.2.7, "Upper Head Cross Section," in "ROSA-IV Large Scale Test Facility (LSTF) System Description," Japan Atomic Energy Research Institute Report JAERI-M 84-237, January 1985.

(1) Please provide a table that documents the spray nozzle bypass capacities as measured in the LSTF tests that are analyzed in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2." Describe each individual LSTF test in a separate row including the following parameters, each in a separate column: test identifier (e.g. SB-CL-05), test date, data source documents, upper plenum-to-upper head bypass unit, and experimental upper plenum-to-upper head bypass value. Explain the source, availability, and accuracy of data quantifying the LSTF upper head bypasses in these tests and explain if the bypass data was examined and qualified as part of the WCOBRA/TRAC-TF2 assessment.

(2) Please compare LSTF upper head spray nozzle bypass data against downcomer-to- upper head bypass capacities simulated in WCOBRA/TRAC-TF2 LSTF test analyses presented in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2." In the table requested in Item (1) above, include an additional column, which documents the downcomer-to-upper head bypass values for all WCOBRA/TRAC-TF2 LSTF tests used in the simulations in consistent units. Clearly state if the downcomer-to-upper head bypass capacities in the WCOBRA/TRAC-TF2 LSTF test simulations were adjusted to account for any effects other than the downcomer-to-upper head bypass through the upper head spray nozzle openings present in the LSTF pressure vessel.

**Response:**

The requested information is provided in Table 2.3-1 of the integrated response.

**Question #101: Upper Head Spray Nozzle Bypass in LSTF WCOBRA/TRAC-TF2 Model**

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," describes the noding of the LSTF pressure vessel in Subsection 21.3, "Description of WCOBRA/TRAC-TF2 Model for ROSA/LSTF-IV." Figure 21.3-1, "WCOBRA/TRAC-TF2 Model of LSTF Pressure Vessel," Figure 21.3-5, "LSTF Pressure Vessel Sections 7 and 8," and Figure 21.3-6, "LSTF Pressure Vessel Sections 9 and 10," show nodalization details pertinent to modeling of the bypass flow path between the downcomer and the upper head.

(1) Figure 21.3-1, "WCOBRA/TRAC-TF2 Model of LSTF Pressure Vessel," illustrates that the upper head bypass nozzles were modeled as [ ]$^{a,c}$ with a certain length. Please describe how the bypass flow paths through the upper head spray nozzles in the LSTF test vessel were represented in the WCOBRA/TRAC-TF2 vessel model of LSTF. Provide noding details that show how [ ]$^{a,c}$ connect vertically to hydraulic components in vessel Section 9 to represent the upper head spray nozzles. Include a table that lists the input parameters associated with hydraulic components and modeling features employed to model these bypass flow paths in the LSTF pressure vessel and provide the input values for all LSTF tests analyzed in WCAP-16996-P Revision 0 Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2.

(2) Please explain how the spray nozzles geometric and other design data were used to model the spray nozzle bypass flow passages between the downcomer and upper head in the WCOBRA/TRAC-TF2 model of the LSTF pressure vessel and to calculate the input parameters requested in Item (1) above.

(3) Table 21.4-1, "Steady-State Parameter Checklist (Initial Conditions) for the SB-CL-18 Test," provides a downcomer-to-upper head flow rate of 0.30 percent of the core flow for both the "target (measured)" and "modeled" parameters. Table 21.5-1, "Steady- State Parameter Checklist (Initial Conditions) for the SB-CL-05 Test," lists a value of ~0.70 percent of "core flow" for the "modeled" downcomer-to-upper head flow rate and provides the "target (measured)" value as "N/A." Table 21.9-1, "Initialization of the SB-CL-02 Natural Circulation Test Simulation," gives a "target" value of 0.9% and a "calculated" value of 0.70 percent for the downcomer-to-upper head flow rate in percentage of "total core" at the end of Stage 1 of the LSTF experiment, which was run at nominal conditions. Please explain how the downcomer-to-upper head bypass flow rates, defined as "target (measured)" and "modeled" in Tables 21.4-1 and 21.5-1 and as "target" and "calculated" in Table 21.9-1, were established and explain the reported differences. Clarify why the "calculated" value, provided in Table 21.9-1, resulted in 0.70 percent.

(4) The downcomer-to-upper head flow is provided in Table 21.9-1 in units of "kg/sec" and "percent total core." It appears that the provided percentage values correspond to the ratio of the downcomer-to-upper head flow rate to the total loop flow rate, which parameter is also listed in the table. At the same time, the downcomer-to- upper head flow is provided in Tables

21.4-1 and 21.5-1 in percentage units described as "percent core flow." The listed values correspond to the ratio of the downcomer-to-upper head flow rate to the core inlet flow rate, which quantity is also listed in these tables. Please explain why different definitions for the downcomer-to- upper head flow ratio were used for the percentage values in these tables.

(5) Please explain if a "steady state tune-up procedure" was used to "adjust" the bypass flow through the spray nozzles in the WCOBRA/TRAC-TF2 model of the LSTF pressure vessel. In such a case, please describe how the "desired value" for the downcomer-to-upper head bypass flow was established for the analyzed LSTF experiments. Please provide a table that lists all parameters subject to modification "during the steady state tune-up procedure." For each listed parameter, provide the corresponding values at the beginning and at the end of the "steady state tune-up procedure" as well as the allowable variation range for the parameter. Please list each parameter in a separate column in the table.

(6) Provide a table that documents the "calculated value" for the downcomer-to-upper head bypass at the end of the steady-state runs and the corresponding "desired values" for all LSTF tests analyzed in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2."

**Response:**

For the response to Part (1), see <u>Downcomer-to-Upper Head Bypass Modeling</u> in Section 2.1 of the integrated response.

Response to Part (2): The design data of the spray nozzle [ ]$^{a,c}$; see Section 2.1 of the integrated response for further detail.

For the response to Part (3), see Section 2.1 of the integrated response and Note (4) of Table 2.3-1 therein.

Response to Part (4): The ST-NC-02 report (JAERI-M 88-215, Table 1) provides flow rate, without specifying whether this is loop or core flow rate; for the ST-NC-02 test it was assumed that Table 1 of JAERI-M 88-215 reports loop flows. Therefore the values of the DC-to-UH bypass flow provided in Table 21.9-1 are in "% of total loop flow". The usage of "% core flow" is incorrect; this statement will be corrected to read "% of total loop flow" in the updated topical report.

The difference in the definition of the downcomer-to-upper head flow ratio comes from the fact that for the 5% break test SB-CL-18 and SB-CL-05 the respective test reports (JAERI-M 89-027 and JAERI-memo 61-056) provided core inlet flows, which were then used as a basis for the downcomer-to-upper head bypass ratio.

Response to Part (5): [ ][a,c]; see *Downcomer-to-Upper Head Bypass Modeling* in Section 2.1 of the integrated response for discussion of the spray bypass tune-up.

Response to Part (6): The requested information is included in Table 3.2-1 of the integrated response.

**Question #102: LSTF Upper Head Spray Nozzle Bypass Relevance to PWR**

As reported by Y. Kukita et al., "Quasi-Static Core Liquid Level Depression and Long-Term Core Uncovery During a PWR LOCA," Nuclear Safety, Vol. 34, No. 1, 1993, pp. 33-48, the LSTF pressure vessel bypasses included upper head spray nozzles and a hot-leg nozzle leak line between each hot leg and the downcomer that simulated bypass flow rates of about 0.3 percent and 0.2 percent (for both loops) of the total core flow rate at single-phase (liquid) steady-state operation, respectively. These normal LSTF bypass flow capacities were representative of the upper vessel bypasses of Japanese-built Westinghouse-type PWR plants with a total bypass flow rate of 0.5 percent. According to the same authors, spray nozzle bypass capacities, ranging typically from 1 percent to 4 percent, were representative for most of the U.S. Westinghouse PWR configurations. A bypass of 1.8 percent of the total downcomer mass flow rate for the Westinghouse standardized four-loop single-unit plant described in the Reference Safety Analysis Report (RESAR) RESAR-3S, sometimes referenced to as a "typical" Westinghouse plant, was provided by the authors. A special 0.5-inch tubing bypass line connected the downcomer to the upper head in the LSTF pressure vessel to simulate the leakage between these two components in commercial PWRs. A somewhat broader range from 0.5 percent to 4 percent of the total core flow for the leakage between the downcomer and the upper head in a commercial PWR is provided by G. G. Loomis and J. E. Streit, "Results of Semiscale Mod-2C Small-Break (5 percent) Loss-of-Coolant Accident Experiments S-LH-1 and S-LH-2," NUREG/CR-4438, EGG-2424, November 1985.

Based on LSTF design data provided in "ROSA-IV Large Scale Test Facility (LSTF) System Description," Japan Atomic Energy Research Institute Report JAERI-M 84-237, January 1985, the total flow area of the LSTF upper head bypass nozzles amounted to 0.726 $cm^2$ (7.826x10-4 $ft^2$), which scales to a 35.03 $cm^2$ (0.0377 $ft^2$ or 5.43 $in^2$) PWR bypass flow area with an equivalent opening diameter of 6.68 cm (2.63 inch) based on the volume scaling ratio for the LSTF pressure vessel upper head region.

(1) Please provide the upper head spray nozzle bypass capacities as scaled to prototypical PWR conditions based on the LSTF upper head spray nozzle bypasses measured in each of the LSTF tests analyzed in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2." Explain how the LSTF bypass values were scaled to prototypical PWR conditions. List each LSTF test in a separate row and provide both the measured LSTF upper head spray nozzle bypass value and the scaled PWR bypass value.

(2) Please explain how the PWR upper head spray nozzle bypass values as scaled from the LSTF test data and provided in the table requested in Item (1) above, represent the range of upper head spray nozzle bypass capacities of PWR plants that will be modeled for the purpose of LOCA analyses using WCOBRA/TRAC-TF2.

(3) According to Y. Kukita et al., "Quasi-Static Core Liquid Level Depression and Long-Term Core Uncovery During a PWR LOCA," Nuclear Safety, Vol. 34, No.1, 1993, pp. 33-48,

ROSA-IV LSTF Test ST-LS-04 was conducted with a vent line connecting the upper plenum top region directly to the upper downcomer annulus to simulate a bypass flow rate of 4 percent compared to a 0.5 percent value in the standard LSTF test vessel bypass geometry. The experiment simulated conditions relevant to PWR plants with large bypass areas. The upper plenum vent line was equipped with a 44-mm (1.73-inch) inner diameter orifice and a valve. If the bypass capacity in ROSA-IV LSTF Test ST-LS-04 is within the range of spray nozzle bypass capacities of PWR plants to be analyzed with WCOBRA/TRAC-TF2, please provide WCOBRA/TRAC-TF2 prediction results for this test. Please compare the obtained results against the experimental measurements for ROSA-IV LSTF Test ST-LS-04 and assess the code performance.

**Response:**

For the response to Part (1) and (2), see the discussion in Section 2.1 of the integrated response.

For the response to Part (3), as an alternate approach to modeling ST-LS-04, Westinghouse will be presenting simulation results for the Semiscale test S-LH-1 and S-LH-2.

**Question #103: Pressure Vessel Internal Leaks in LSTF Tests**

According to Y. Kukita et al., "Data Report for ROSA-IV LSTF 5 percent Cold Leg Break LOCA Experiment Run SB-CL-08," Japan Atomic Energy Research Institute Report JAERI-M 89-220, January 1990, modifications to the LSTF design were made during the time period between March 27, 1986 and November 9, 1989 when Test SB-CL-08 was performed. As described in Subsection 2.3.1, "Sealing of Upper Pressure Vessel Internal Leaks," in the report, one modification was performed in May 1986 to seal off an unintentional small bypass leak between the upper plenum and the upper head, which was discovered at the control guide tube penetrations through the upper core support plate during facility checks.

Table 21.1-1, "Selected ROSA-IV Test Series Description and Related Technical Reports," in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," states that Test SB-CL-05 was performed on 26 June 1985 when the LSTF pressure vessel internal leak still existed. Therefore, as explained in Subsection 2.3.1, "Sealing of Upper Pressure Vessel Internal Leaks," in JAERI-M 89-220, "Run SB-CL-05 had an estimated flow rate through the upper head spray nozzles during the initial steady state of about 2.1 percent of the total core flow rate (vs. 0.3 percent for Run SB-CL-08)." K. Tasaka et al., "The Results of 5 percent Small-Break LOCA Tests and Natural Circulation Tests at the ROSA-IV LSTF," Nuclear Engineering and Design, Vol. 108, 1988, pp. 37-44, also report, in Table 2, "Test Conditions of 5 percent Break Tests," a 2.1 percent core flow downcomer-to-upper head bypass value for Test SB-CL-05.

Table 21.5-1, "Steady-State Parameter Checklist (Initial Conditions) for the SB-CL-05 Test," in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," gives a value of ~0.70 percent in "percent core flow" for the "modeled" downcomer-to-upper head flow rate and lists the "target (measured)" downcomer-to-upper head flow rate value as "N/A." With regard to the hot leg-to-downcomer "target (measured)" leakage flow rate, the table provides a value of ~0.10 kg/s (0.20 percent core flow), which agrees with the data provided in JAERI-M 89-220 (0.05 kg/s per loop) and the value identified by K. Tasaka et al., "The Results of 5 percent Small-Break LOCA Tests and Natural Circulation Tests at the ROSA-IV LSTF," Nuclear Engineering and Design, Vol. 108, 1988, pp. 37-44 (0.2 percent of core flow).

(1) Please explain why the upper head-to-downcomer bypass, existent in ROSA-IV LSTF Test SB-CL-05 and documented in the above identified sources as amounting to a relatively high value of 2.1 percent of the core flow, was not identified in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 21, "ROSA-IV Test Simulations," for the purposes of WCOBRA/TRAC-TF2 assessment analyses based on this test. Please explain the technical basis for determining the appropriateness of an upper head-to-downcomer bypass of ~0.70 percent as documented in the steady-state parameter checklist for the initial conditions obtained for Test SB-CL-05 with WCOBRA/TRAC-TF2 and listed in Table 21.5-1 in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21.

(2) Please provide a table that documents if unintentional bypasses between the LSTF upper head and the upper downcomer due to pressure vessel internal leaks existed in any of the LSTF tests analyzed in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2." Describe each individual ROSA-IV LSTF test in a separate row providing the following test parameters, each in a separate column: test identifier (e.g. SB-CL-05), test date, data source documents, bypass flow unit, unintentional bypass flow between the upper head and upper downcomer due to pressure vessel internal leaks if such were found to exist in the test. In an additional column, please provide the measured downcomer-to-upper head bypass value and state clearly if this downcomer-to-upper head bypass value includes the upper head spray nozzle bypass and any other bypass flows existing in the test. Include in a separate column the bypass value through the vent line connecting the upper plenum top region directly to the upper downcomer annulus to simulate larger spray nozzle bypass capacities or vent line between the upper plenum and the downcomer annulus or the operation of Babcock and Wilcox (B&W)-type core barrel vent valves as it was the case in ROSA-IV LSTF Test SB-CL-07. Explain the source, availability, and accuracy of the data quantifying the unintentional LSTF pressure vessel bypass in these tests. Please explain if the provided bypass data was examined and qualified as part of the WCOBRA/TRAC-TF2 assessment.

(3) Compare LSTF experimental downcomer-to-upper head bypass data against downcomer-to-upper head bypass capacities simulated in the WCOBRA/TRAC-TF2 LSTF test analyses presented in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2." In the table requested in Item (2) above, include an additional column documenting, in consistent units, the downcomer-to-upper head bypass values calculated in the WCOBRA/TRAC-TF2 ROSA-IV LSTF test simulations. Clearly state if the downcomer-to-upper head bypass capacities in the WCOBRA/TRAC-TF2 ROSA-IV LSTF test simulations were adjusted to account for downcomer-to-upper head bypass through the upper head spray nozzle openings and any pressure vessel internal leaks, if such were known to exist.

**Response:**

For the responses to Parts (1) and (3) of the question, see Section 2.1 of the integrated response.

For the response to Part (2), with the exception of the natural circulation test ST-NC-02, [

]$^{a,c}$; see discussion Uncontrolled Internal Vessel Leakages in Section 2.1 of the integrated response for more detail.

**Question #104: Hot Leg-to-Downcomer Bypass Modeling in LSTF and PWR LOCA Analyses**

A bypass leakage between the upper downcomer region and the upper plenum occurs in the PWR design via the gap opening along the periphery of the hot leg (HL) nozzles that penetrate through the downcomer. In the LSTF pressure vessel used in the ROSA-IV tests, the hot leg-to-downcomer (HL-to-DC) leakage was simulated by two dedicated hot leg leak lines. The bypass flow through these hot leg leak lines was one of the test variables in the LSTF SBLOCA tests according to Y. Kukita et al., "Data Report for ROSA-IV LSTF 5 percent Cold Leg Break LOCA Experiment Run SB-CL-08," Japan Atomic Energy Research Institute Report JAERI-M 89-220, January 1990.

Design details for the LSTF hot leg leak lines are provided in Tables 5.2.2, 5.2.4, 5.2.10, 5.7.1, 5.7.4, and A.1.1 in "ROSA-IV Large Scale Test Facility (LSTF) System Description," Japan Atomic Energy Research Institute Report JAERI-M 84-237, January 1985. According to the information provided in this report, each hot leg leak line was connected to the pressure vessel downcomer via a 21.2-mm (0.835-inch) inner diameter nozzle (Tags N-11a and N-11b) and to the hot leg via a Nominal Size 1 Schedule 160 nozzle (Tags N-1a and N-1b). The lines were equipped with a 0.687 contraction ratio orifice flow meter (Tags FE-010-HLA and FE-150-HLB) and a 0.24 kg/s normal flow capacity hand control valve (Tags HCV-010 and HCV-150) installed in each line.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," Subsection 21.11.2, "SB-CL-18 Simulation Without Hot Leg Nozzle Bypass Flow," explains that the hot leg leakage was modeled in the WCOBRA/TRAC-TF2 pressure vessel model of LSTF with Gaps 21 and 22 as shown in Figure 21.3-4, "LSTF Pressure Vessel Sections 5 and 6."

(1) According to H. Kumamaru et al., "ROSA-IV/LSTF Cold Leg Break LOCA Experiment Run SB-CL-18 Data Report," Japan Atomic Energy Research Institute Report JAERI-M 89-027, March 1989, Table 3.2, "Specified Operational Setpoints and Conditions for Run SB-CL-18," a HL-to-DC leakage of 0.049 kg/s per loop is provided as a "specified" operational setpoint for LSTF Test SB-CL-18. At the measured core inlet flow rate of 48.7 kg/s provided in Table 3.1, "Initial Conditions for Run SB-CL-18," in the same report, the resulting total HL-to-DC leakage via the gaps of both LSTF hot leg nozzles as a fraction of the core flow rate is:

HL-to-DC leakage= [(0.049 kg/s/loop) x (2 loops)] / (48.7 kg/s) = 0.0020 = 0.20%.

K. Tasaka et al., "The Results of 5 percent Small-Break LOCA Tests and Natural Circulation Tests at the ROSA-IV LSTF," Nuclear Engineering and Design, Vol. 108, 1988, pp. 37-44, report a downcomer-to-hot leg bypass of 0.2 percent of core flow for LSTF Test SB-CL-05 in Table 2, "Test Conditions of 5 percent Break Tests."

Table 21.4-1, "Steady-State Parameter Checklist (Initial Conditions) for the SB-CL-18 Test," provides a HL-to-DC leakage flow rate of 0.124 kg/s or 0.25 percent of the core flow rate for both the "target (measured)" leakage and the "modeled" leakage. Table 21.5-1, "Steady-State Parameter Checklist (Initial Conditions) for the SB-CL-05 Test," lists ~0.10 kg/s or 0.20 percent "core flow" for the "target (measured)" HL-to-DC leakage and 0.127 kg/s or 0.26 percent "core flow" rate for the "modeled" HL-to-DC leakage. Please clarify how the "target (measured)"

leakage and the "modeled" HL-to-DC leakage values provided in Tables 21.4-1 and 21.5-1 were established and explain the reported discrepancies between the measured and modeled values.

(2) Please provide a table that documents the HL-to-DC leakage observed in the ROSA- IV LSTF tests analyzed in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2." Describe each individual ROSA-IV LSTF test in a separate row including the following test parameters, each in a separate column: test identifier (e.g. SB-CL-05), test date, data source documents, HL-to-DC leakage unit, and experimental HL-to-DC leakage value. Explain the source, availability, and accuracy of data quantifying the LSTF HL-to-DC leakage bypass in these tests and explain if the bypass data was examined for qualification purposes.

(3) Please explain if a "steady state tune-up procedure" was used to "adjust" the HL-to- DC leakage in the WCOBRA/TRAC-TF2 model of the LSTF pressure vessel. In such a case, please describe how the "desired value" for the HL-to-DC leakage was established for the LSTF analyses. Please provide a table that lists all parameters subject to modification "during the steady state tune-up procedure." Describe each parameter in a separate row providing the corresponding values at the beginning and at the end of the "steady state tune-up procedure" as well as the allowable variation range.

(4) Provide a table that documents the "calculated value" for the HL-to-DC leakage at the end of the steady-state runs and the corresponding "desired values" for the ROSA-IV LSTF tests considered in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2."

(5) Compare LSTF HL-to-DC leakage test data against HL-to-DC leakage capacities simulated in WCOBRA/TRAC-TF2 ROSA-IV LSTF test analyses presented in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," and in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2." In the table requested in Item 2 above, include an additional column documenting, in consistent units, the leg-to-downcomer leakage values obtained in the WCOBRA/TRAC-TF2 ROSA-IV LSTF test simulations. Clearly state if the HL-to-DC leakage capacities in the WCOBRA/TRAC-TF2 ROSA-IV LSTF test simulations were adjusted to account for any effects other than the HL-to-DC leakage through the hot leg leak lines installed in the LSTF pressure vessel.

**Response:**

For the response, see Section 2.2 and Table 2.3-1 of the integrated response.

**Question #105: Representation of LSTF Bypasses in WCOBRA/TRAC-TF2 LSTF Test Simulations**

Analyzing WCOBRA/TRAC-TF2 prediction results for ROSA-IV LSTF Tests SB-CL-01, SB-CL-02, and SB-CL-03, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, Subsection 21.7, "Break Orientation Study: Simulation of Top/Side/Bottom 0.5 percent (SB-CL-16/12/15) and 2.5 percent (SB-CL-03/01/02) Cold Leg Breaks," presents code predictions in Figures 21.7-3 through 21.7-10. Figure 21.7-5, "Comparison of Predicted and Measured Mixture Levels in Broken Cold Leg (ROSA-IV 2.5-Percent Cold Leg Break Runs), (a) Code Calculations" shows the predicted cold leg liquid levels and Figure 21.7-5 Part (b), "Reported in Reference 5," reproduces Figure 8, "Mixture levels in cold-leg B measured for side, bottom and top break experiments," appearing in a publication by Y. Koizumi et al., "Investigation of Break Orientation Effect during Cold Leg Small-Break LOCA at ROSA-IV LSTF," Journal of Nuclear Science and Technology, Vol. 25, No. 9, September 1988.

With regard to the comparison in Figure 21.7-5, Subsection 21.7 states: [

]$^{a,c}$

Discussing WCOBRA/TRAC-TF2 calculation results for ROSA-IV LSTF Test ST-NC-02, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, Subsection 21.9, "Simulation of ST-NC-02, 2 percent Power Natural Circulation Test," shows code calculations in Figures 21.9-2 through 21.9-8. Figure 21.9-8, "Downcomer- to-Upper Plenum Differential Pressure," shows a comparison of the downcomer-to-upper plenum differential pressures for the test. With regard to the comparison in Figure 21.9-8, Subsection 21.9 states: [ "

]$^{a,c}$

The above results illustrate the sensitivity of WCOBRA/TRAC-TF2 predictions to the modeling of flows through bypass flow paths between the downcomer and the upper head or plenum that existed in the LSTF pressure vessel when the ROSA-IV tests were performed. Such bypasses are particularly important for the progression of small break LOCA transients and their inaccurate modeling test simulations can affect the validity of comparing code predictions against test data in evaluating the WCOBRA/TRAC-TF2 performance.

Please assess the adequacy of modeling LSTF pressure vessel bypasses in WCOBRA/TRAC-TF2 analyses of ROSA-IV LSTF tests presented in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 21, "ROSA-IV Test Simulations," in Section 24, "Assessment of Compensating Error in Evaluation Model Using WCOBRA/TRAC-TF2," or discussed elsewhere in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0. As part of

this assessment, please identify test simulations in which the LSTF pressure vessel bypasses were not accurately modeled. Please reanalyze these cases with accurate representation of the LSTF pressure vessel bypasses and update WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, sections in which ROSA-IV LSTF WCOBRA/TRAC-TF2 assessments are presented and/or discussed. Please provide a summary table, which lists the ROSA-IV LSTF tests that have been analyzed as part of the WCOBRA/TRAC-TF2 assessment and identify those that have been reanalyzed. Describe major results and summarize modifications in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, as applicable.

**Response:**

Westinghouse agrees that the modeling of the bypass is very important for the accurate prediction of SBLOCA scenarios. This is the reason for the dedicated bypass sensitivity presented in Section 21.11 of topical where the impact of variation in Hot Leg Nozzle Gap flow, and Spray Nozzle Bypass flow were investigated. The conclusion stated in Section 21.11 supports the decision to not model the Hot Leg Nozzle Gap flow and the modeling of the nominal Spray Nozzle bypass flow in PWRs. This decision is further supported by the response to RAI-107.

The target and the achieved bypass flows in the ROSA-IV LSTF test simulations are tabulated in Table 2.3-1 of this response. As seen in that table, the deviation between the target and actual bypass for the SBLOCA simulations is well within the range [ ]$^{a,c}$ used to study the impact of bypass uncertainty presented in Section 21.11 of the topical report where the impact was shown to be minor.

The impact of bypass on the ST-NC-02 natural circulation test simulation is as stated in note (4) of Table 2.3-1. For that test, the impact of the bypass change from [ ]$^{a,c}$ on other parameters is expected to be minor, as seen in the loop flow rate comparison of [ ]$^{a,c}$ bypass case, shown in Figure 105-1.

[a,c]

Figure 105-1 ST-NC-02 Loop Circulation Flows

# Integrated Response to NRC RAIs 100 through 105:

# Modeling of the ROSA Large Scale Test Facility Bypass Flows

## 1.0 Introduction

The design of the ROSA LSTF test facility allows for the simulation of various core bypass flow-paths that exist in a real PWR.

The upper head cooling spray nozzles provide a core bypass flow link (DC-to-UH) that allows for some amount of coolant to flow from the downcomer (DC) into the upper head (UH) and then into the upper plenum (UP) via the guide tubes (GT). The simulation of the effect of the upper head cooling spray nozzles that exist in the Westinghouse PWRs is achieved at the ROSA LSTF by using nozzles with similar design.

The effect of the HL nozzle-to-DC gap is simulated by two separate leak lines, each of which connects the downcomer and one of the hot legs; these are pipes equipped with orifice flow meters (FE010-HLA and FE150-HLB) and control valves (HCV-010 and HCV-150).

The LSTF also has the capability to simulate an UP-to-DC relief valve, which connects the top of the upper plenum to the downcomer. However, none of the tests included in the FSLOCA topical report had this valve operational and therefore this bypass flow path was not modeled in any of the ROSA LSTF tests discussed in the topical report WCAP-16996-P.

## 2.0 Vessel Core Bypass Flow Modeling in the ROSA LSTF Test Simulations

### 2.1 Downcomer-to-Upper Plenum Bypass

*Spray Nozzle Bypass Flow*

The upper head cooling spray nozzles, sometimes called downcomer (DC) spray nozzles, provide a "downcomer to upper head to upper plenum" (DC-UH-UP) core bypass flow path that allows for some amount of coolant to flow from the downcomer into the upper head and then into the bottom of the upper plenum via the guide tubes. Depending on the amount of this bypass flow, the upper head steady state temperature ranges between Thot and Tcold.

The number of spray nozzles varies among the different Westinghouse PWR designs. For example, depending on the upper plenum-to-upper head flow paths, to maintain a sufficient spray nozzle bypass to

achieve Tcold upper head, a four-loop Westinghouse PWR with "inverted hat" upper support plate configuration may have spray nozzle flow areas ranging (approximately) from [

]$^{a,c}$

A three-loop Thot upper head plant like DLW, has a total spray nozzle flow area of only about [

]$^{a,c}$

At the ROSA-IV LSTF there are eight (3.4-mm diameter) DC spray nozzles with a total flow area of 7.26E-05m$^2$ (72.6mm$^2$, or 0.097in$^2$); based on the ROSA LSTF leakage tests (Section 4.3 of JAERI-M 89-113), the effective spray nozzle loss coefficient, normalized for the total spray nozzle flow area of 72.6 mm$^2$, is estimated to be 1.72. According to Table 5.2.2 of JAERI-M 84-237, the flow area of the ROSA spray nozzle represents a PWR spray nozzle flow area of 3552 mm$^2$ (5.5in$^2$), which area tends to be on the side typical for plants with Thot upper head conditions; this is 1748 mm$^2$ (2.7in$^2$) for the Thot plant DLW, compared to the 18064-mm$^2$ to 41935-mm$^2$ (28-in$^2$ to 65-in$^2$) typical for plants with Tcold upper head. Thus, it is clear that, with respect to the spray nozzle bypass (by design and accounting for various unintended leakages), the ROSA-IV LSTF would represent a PWR with Thot upper head configuration. This conclusion is confirmed by the fact that the steady-state upper head temperatures measured at all ROSA LSTF tests, including the presumably "high DC leakage/bypass" SB-CL-05 test, tend to be slightly lower than Thot.

The measured upper head fluid temperatures at various ROSA tests (for example Fig.5.36 and 5.38 of JAERI-M 89-220 for SB-CL-08 and SB-CL-05 respectively) were only slightly lower than the hot leg (HL) temperature, which is an indication that although there might have been a net $T_{CL}$ flow from the DC through the spray nozzles into the UH, most likely there was also a significant upper plenum to upper head (UP-UH) recirculation flow through a subset of the GTs that kept the UH temperature close to the HL temperature. This behavior is consistent with PWRs with $T_{HOT}$ upper head. Note that the GT flow path between the upper head (UH) and the upper plenum (UP) is comprised by a total of 8 (parallel) guide tubes – six of them are located above the average- and high-powered assemblies, while two of them sit above low-powered (peripheral) assemblies, Figure 21.3-7 of the FSLOCA Topical. Therefore, it is quite plausible that the GT recirculation flow at the ROSA LSTF pre-transient steady states was non-uniform, due to the non-uniform fluid temperature distribution at the bottom of the UP (core exit) related to the radial power distribution in the core.

*Uncontrolled Internal Vessel Leakages:*

As noted in NRC question 103, unintended internal vessel leakages were identified at the ROSA-IV LSTF tests. Although repairs were performed to minimize them, they resulted in uncontrolled downcomer-to-

upper plenum bypass flow (capacity) in addition to the spray nozzle bypass. Since the capacity of these leakages was unquantifiable, they were not modeled explicitly. It was assumed that the desired DC-to-UH) spray bypass targets (Table 2.3-1 of the integrated response), estimated and quoted by various sources already include the effect of these uncontrolled leakages.

The unintended internal leakage around the guide tubes (repaired in May 1986) may have existed at the test preceding that repair. In the simulation of the natural circulation test ST-NC-02, conducted on 12/18/1985, this unintended leakage was explicitly modeled by opening a flow link between vessel channels 46 and 50, Figure 21.3-1 of WCAP-16996-P, with an estimated flow area of 12 $in^2$. This flow link does not have significant effect on the overall downcomer-to-upper head bypass since the most restrictive location is still modeled at the spray nozzle location at the top of the downcomer. In the ST-NC-02 simulation, it was modeled to eventually calculate better draining of the upper head.

Although it might have potentially existed, this leakage was not modeled in the simulations of the tests preceding ST-NC-02. However, the effect of this leakage on the upper head draining and on the transient as a whole is expected to be minimal due to the relatively small residual (drainable) volume at the bottom of the upper head.

*Scaling of Downcomer-to-Upper Head (Spray) Bypass:*

According to Table 5.2.2 of JAERI-M 84-237, the total spray nozzle flow area the scaling ratio (ROSA/PWR) is 1/48.91; while this number is consistent with the general ROSA/PWR ratio of 1/50, it does not represent scaling of the downcomer-to-upper plenum bypass flow. Given the uncertainty associated with the non-uniform guide tube recirculation flows and leakages it is difficult to scale the ROSA-IV downcomer-to-upper plenum bypass flows. At steady state conditions, the downcomer-to-upper head (spray) bypass flow can be defined as a net flow via the flow path "downcomer - spray nozzles – guide tubes – upper plenum". At the same time, the primary flow path through the core is "downcomer – lower plenum – core – upper plenum". At any time (steady state or transient) these two parallel flow paths would be subjected to the same pressure boundary conditions. Therefore, the ratio between their respective mass flows rates (spray bypass ratio) would be defined by their effective hydraulic resistances as:

$$\left(\dot{m}_{spray}/\dot{m}_{core}\right) = \sqrt[2]{\left(K_{core}/K_{spray}\right)}$$

, where the resistances $K$ are normalized to a flow area.

Both, a test facility or a PWR would have the similar spray bypass capacities if their $\sqrt[2]{\left(K_{core}/K_{spray}\right)}$ ratios are similar.

As discussed earlier and based on the spray bypass capacities, summarized in Table 2.3-1 hereafter, the selected ROSA-IV LSTF tests in the WCOBRA/TRAC-TF2 validation set, presented in WCAP-16996-P

[1], appear to be scaled to a typical $T_{HOT}$ upper head Westinghouse PWR. Combined with proper scaling of the various system sub-region volumes, upper plenum, upper head, core, hot leg, steam generator tubes and correct power scaling, these tests would demonstrate timing of key transient phenomena representative of the scaled PWR.

_Downcomer-to-Upper Plenum Bypass Modeling:_

Based on the ROSA design information, the most constricted location of the guide tubes is at their top – the total flow area at the top of the GTs is $8x196mm^2=1568mm^2$, which is approximately 20 times larger than the area of the DC spray nozzles ($72.6mm^2$) ; the area of the GT enclosures is even larger - $8x5166mm^2=41328mm^2$. This implies that the resistance of the flow path (DC-UH-UP) would primarily be defined by the resistance of the DC spray nozzles. This design feature is implemented in a similar way in Westinghouse PWRs.

The effect of the DC spray nozzles at the ROSA LSTF is modeled fairly straightforward. As a first approximation, their effective form loss coefficient $K_{NZL}=1.72$ (normalized for $0.097in^2$) is scaled for the modeled flow area at the top of the downcomer (151 $in^2$) and applied at the top of the downcomer channels 52, 53 and 67 through 70, Figure 21.3-1 of WCAP-16996-P. Then, iterative adjustment is made to that loss coefficient to achieve desired target DC-to-UH bypass flow (which includes the additional uncontrolled leakages). Note that this approach is similar to that implemented for the PWR spray bypass modeling, as described in the response to Part (1) of RAI-97.

[

]a,c

## 2.2 Hot Leg Leakage Bypass

At the ROSA LSTF the effects of hot leg to downcomer (HL-to-DC) leakage is simulated by two separate lines which connect the downcomer to each of the hot legs. The lines contain isolation valves and flow rates are measured by FE010-HLA and FE150-HLB. The measured steady state HL-to-DC leakage flow rates at the different tests are very similar and typically around 0.05 kg/sec; for SB-Cl-05 see Fig.5.61 and 5.64 of JAERI-memo 61-056, for SB-CL-01 see Fig.4.1 and 4.4 of JAERI-M 62-399.

The effect of the HL-to-DC leakage at the ROSA LSTF tests was modeled by using a flow links (transverse gap connections 21 and 22, in vessel Section 6), connecting the hot leg nozzle channels 25 and 35 to downcomer channels 61 and 60 respectively, see Figure 21.3-4 of WCQP-16996-P. The resistance of the two flow links is adjusted through the gap loss coefficient (WKR) to achieve the desired steady-

state HL-to-DC leakage target. The steady-state tune-up procedure for HL-to-DC leakage is iterative and, in essence, similar to the tune-up of the downcomer-to-upper head (spray) bypass. There were no additional adjustments of the HL-to-DC leakage capacity to account for any effects other than achieving the desired target.

The discrepancy in the established HL-to-DC leakage targets for the SB-CL-18 and SB-CL-05 tests, observed in Part (1) of NRC question 104 is discussed hereafter.

The HL-to-DC leakage target for the SB-CL-18 test (0.25%) was based on the measured leakage flow of 0.124 kg/sec, as measured by FE010-HLA and FE150-HLB; at the same time, Table 3.2 of JAERI-M 89-027 gives an approximate value of $2\times0.049\approx0.1$ kg/sec.

In Table 21.5-1 of WCAP-16996-P [1], the HL-to-DC leakage target for the SB-CL-05 test is reported as $\approx$0.1 kg/sec, which is based on the measured values shown in Fig.5.61 and 5.64 of JAERI-memo 61-056 and is indeed consistent with the 0.2% ratio reported in Table 2 of Tasaka's paper [11].

For the SB-CL-18 and the SB-CL-05 tests, the resistance of the HL-to-DC leakage flow path was modeled the same without any re-tuning. The resulting deviation from the established target for the SB-CL-05 test is not considered significant from a code validation perspective.

## 2.3 Summary of Desired (Target) and Modeled ROSA LSTF Bypass Flows

Table 2.3-1 provides a summary of the desired and modeled spray bypass and Hot Leg to Downcomer (HL-to-DC) leakage capacities at the ROSA LSTF test reported in WCAP-16996-P. The notes to the table provide information regarding the values presented in the table. As seen in the summary table, the calculated values are close to the desired targets.

**Table 2.3-1 Desired and Modeled ROSA LSTF Bypass Flows**

| | | | Spray Bypass, % core flow | | HL-to-DC Leakage, % core flow | |
|---|---|---|---|---|---|---|
| Test (1) | Date (1) | Test Report | Target | Modeled | Target | Modeled |
| | | | | | | |
| SB-CL-01, 2.5%, side | 5/30/85 | JAERI-memo 62-399 | [ | | | ]a,c |
| SB-CL-05, 5%, side | 6/26/85 | JAERI-memo 61-056 | [ | | | ]a,c |
| SB-CL-02, 2.5%, bottom | 7/18/85 | JAERI-memo 62-399 | [ | | | ]a,c |
| SB-CL-03, 2.5%, top | 8/8/85 | JAERI-memo 62-399 | [ | | | ]a,c |
| ST-NC-02, Nat. circ. | 12/18/85 | JAERI-M 88-215 | [ | | | ]a,c |
| SB-CL-12, 0.5%, side | 7/29/87 | JAERI-memo 63-344 | [ | | | ]a,c |
| SB-CL-14, 10%, side | 12/21/87 | JAERI-memo 63-262 | [ | | | ]a,c |
| SB-CL-15, 0.5%,bottom | 1/26/88 | JAERI-memo 63-344 | [ | | | ]a,c |
| SB-CL-16, 0.5%, top | 3/02/88 | JAERI-memo 63-344 | [ | | | ]a,c |
| SB-CL-18, 5%, side | 5/25/88 | JAERI-M 89-027 | [ | | | ]a,c |

Notes:

(1) Break type and date are taken from JAERI-M 89-113.
(2) Table 2 of Tasaka's paper [11] quotes 2.1% DC-to-UH bypass. However, this value is somewhat difficult to substantiate since such a high bypass value would result in upper head temperature close to Tcold. The measured upper head temperatures for the SB-CL-05 test appear to be only slightly below Thot, Fig.5.250 of JAERI-memo 61-056.
(3) The spray bypass of the SB-CL-05 test was adjusted [ ]a,c; thus achieving better downcomer differential pressure calculation. Thus, it

is higher than that of the SB-CL-18 test, also consistent with observations of increased leakage for the initial ROSA tests.

(4) The spray bypass values for the ST-NC-02 test are % of total loop flow. Based on bypass data in Table 2 of Tasaka's paper [11] and information in JAERI-M 89-113, the target value for the ST-NC-02 test is estimated as being close to that of the SB-CL-06 test. The lower calculated value is a result of spray nozzle loss tuneup to achieve better calculation of the downcomer-to-upper plenum differential pressure.

(5) According to JAERI-M 88-215, Section 2.1, the ST-NC-02 test was conducted with the HL-to-DC leakage line closed.

(6) Spray bypass flow for SB-CL-18 is not quoted in JAERI-M 89-027; therefore the 0.3% value for the equivalent 5% break test SB-CL-08 is taken from Table 2 of Tasaka's paper [11].

(7) The HL-to-DC leakage for SB-CL-18 is based on measured flow rates (FE010-HLA + FE150-HLB).

(8) The DC-to-UH (spray) and HL-do-DC leakage desired targets for the three 2.5% break orientation test SB-CL-01, -02 and -03 were assumed the same as those of the SB-CL-05 test; since these test were conducted around the time when SB-CL-05 it was assumed that the bypasses will be similar.

(9) The SB-CL-14 test was performed in the time period of the 0.5% break tests, and therefore it is assumed that the internal leakage and bypass flows in the ROSA vessel would have been similar to those of the three 0.5% break orientation tests.

(10) The test report for the three 0.5% break orientation test SB-CL-12, -15 and -16, JAERI-memo 62-399 [8], did not quote any values for the DC-to-UH (spray bypass) or HL-to-DC leakage targets. Since these three tests were conducted shortly before the SB-CL-18 test it was decided to use the SB-CL-18 target as well.

## 3.0 References


1) WCAP-16996-P,"Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.
2) JAERI-M 84-237, "ROSA-IV Large Scale Test Facility (LSTF) System Description," January 1985.
3) JAERI-M 89-113, "Supplemental Description of ROSA-IV/LSTF with No.1 Simulated Fuel-Rod Assembly," September 1989.
4) JAERI-M 89-220, "Data Report for ROSA-IV LSTF 5% Cold Leg Break LOCA Experiment Run SB-CL-08," January 1990.
5) JAERI-memo 61-056, "ROSA-IV/LSTF 5% Cold Leg Break LOCA Experiment Data Report, Run SB-CL-05," March 1986.
6) JAERI-memo 62-399, "ROSA-IV/LSTF 2.5% Cold Leg Break LOCA Experiment Data Report for Runs SB-CL-01, 02 and 03," November 1987.
7) JAERI-M 88-215, "Post-Test Analysis with RELAP5/MOD2 of ROSA-IV/LSTF Natural Circulation Test ST-NC-02," October 1988.
8) JAERI-memo 63-344, "Quick Look Report for ROSA-IV/LSTF 0.5% Cold Leg Break LOCA Tests, SB-CL-15 and SB-CL-16," September 1988.
9) JAERI-memo 63-262, "Quick Look Report for ROSA-IV/LSTF 10% Cold Leg Break LOCA Test, SB-CL-14," July 1988.
10) JAERI-M 89-027, "ROSA-IV/LSTF 5% Cold Leg Break LOCA Experiment, Run SB-CL-18 Data Report," March 1989.
11) Tasaka, K., et al., 1988, "The Results of 5% Small Break LOCA Tests and Natural Recirculation Tests at the ROSA-IV LSTF," Nuclear Engineering and Design, Vol.108, 1988, pp 37-44.

**RAI Question #107: Pressurized Water Reactor Hot Leg Bypass in WCOBRA/TRAC-TF2 Plant Simulations**

Addressing the modeling of bypass via gaps that exist at the interface of the core barrel and the hot leg nozzles, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 29, "Assessment of Uncertainty Elements," Subsection 29.5.3, "Upper Head," states that "because the spray nozzle bypass itself is modeled in a best-estimate manner, neglecting the hot leg to downcomer gap, less bypass is modeled than is physically expected, so there is no need to range this parameter." As further explained in Subsection 29.5.4, "Upper Plenum," the gaps at the interface of the core barrel and the hot leg nozzles provide for leakage paths between the upper plenum and the upper downcomer region during all operating modes. It is explained that "for small breaks, these leakage paths are expected to have high importance during the loop seal clearing period when they provide alternative paths from the upper plenum to the cold leg break location to vent steam and relieve some two-phase level depression." Subsection 29.5.4, "Upper Plenum," concludes that "the ROSA sensitivity study in Section 21.11 shows that neglecting this gap is conservative." Accordingly, Section 21, "ROSA-IV Test Simulations," Subsection 21.11.2, "SB-CL-18 Simulation Without Hot Leg Nozzle Bypass Flow," states that "the results provided in this section clearly show that not modeling HL-to-DC bypass is a conservative modeling approach for the ROSA 5 percent small break transient."

The hot leg gaps in the LSTF pressure vessel were simulated by two dedicated hot leg leak lines. Based on the leak line 21.2-mm (0.835-inch) pressure vessel nozzle ID and the 0.687 contraction ratio of the orifice installed in each line, the LSTF hot leg gap bypass area for both loops amounted to 3.33 cm2 (36.05x10-4 ft2) with an equivalent diameter of a 2.060 cm (0.811 inch). Based on the LSTF upper head volume scaling ratio, the LSTF hot leg gap bypass area corresponds to a PWR hot leg gap bypass area of 160.7 cm2 (0.173 ft2 or 24.9 in2) with an equivalent diameter of 14.3 cm (5.63 inch). For the reference Tsuruga Westinghouse-type four-loop Unit 2 PWR, the LSTF bypass area corresponds to a 0.068-inch gap width of the opening between the barrel and the vessel exit nozzle based on the hot leg ID of 29.0 inch specified in Table 5.2.9, "Characteristics of Primary Loop Piping," in "ROSA-IV Large Scale Test Facility (LSTF) System Description," JAERI-M 84-237, January 1985.

(1) Please state clearly if no hot leg gap bypass is credited for the purposes of LOCA analyses of any PWR plant designs using the FSLOCA methodology. Also, clarify if no other features of WCOBRA/TRAC-TF2 PWR vessel models are somehow modified or adjusted because of not modeling hot leg bypass in PWR LOCA analyses.

(2) WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 29, "Assessment of Uncertainty Elements," Subsection 29.5.3, "Upper Head," states that "the spray nozzle bypass itself is modeled in a best-estimate manner" and explains that "there is no need to range this parameter" as "less bypass is modeled than is physically expected" due to "neglecting the hot leg to downcomer gap." The staff finds this justification insufficient. Please provide the range of upper head spray nozzle bypass capacities of PWR plants considered for intended WCOBRA/TRAC-TF2 LOCA analysis applications. Provide the uncertainties associated with this parameter and describe the plant conditions considered in assessing them. Then, provide the range of hot leg bypass

capacities along with their uncertainties for the considered PWR plants taking into account the variation of the hot leg gap during a LOCA transient. Explain which upper head spray nozzle bypass values are used in WCOBRA/TRAC-TF2 PWR models so that "the spray nozzle bypass itself is modeled in a best-estimate manner" and demonstrate that these values are conservative considering the provided hot leg bypass capacities and the uncertainties for the upper head spray nozzle bypass and the hot leg gap bypass.

Response:

(1) The Hot Leg Nozzle gap is [

]$^{a,c}$ in the WCOBRA/TRAC-TF2 vessel models of the Virgil C. Summer and Beaver Valley Unit 1 PWRs [107-1]. The typical magnitude of the Hot Leg Nozzle gap flow is [

]$^{a,c}$

(2) The typical range of Upper Head (UH) Spray Nozzle bypass flow for Westinghouse 2, 3, and 4 Loop PWRs is given below;

[

]$^{a,c}$

It is clear that [

]$^{a,c}$

Figure 107-1 below shows the typical Spray Nozzle geometry. As seen in the figure, most of [

]$^{a,c}$ Using a

typical nozzle design as shown in Figure 107-2 and Sections 3 and 11 of Idelchik [107-2], the [

]a,c the Hot Leg Nozzle Gap flow in the WCOBRATRAC-TF2 PWR models.

a,c

Figure 107-1: Typical Head Cooling Spray Nozzle

a,c

Figure 107-2: Typical Nozzle Design

References:

107-1) WCAP-16996-P, "Realistic LOCA Evaluation Methodology Applied to the Full Spectrum of Break Sizes (FULL SPECTRUM LOCA Methodology)," November 2010.
107-2) Idel'Chik, I. E., 1960, Handbook of Hydraulic Resistance," AEC-tv-6630.