WCAP-16996-P/ WCAP-16996-NP Volumes I, II, and III, Revision 0, "Realistic LOCA [Loss-of-Coolant Accident] Evaluation Methodology Applied to the Full Spectrum of Break sizes (FULL SPECTRUM™ LOCA [(FSLOCA)] Methodology)"

REQUEST FOR ADDITIONAL INFORMATION (RAI)

THIRD SET OF RAI QUESTIONS

RAI Questions 30 through 35

ENCLOSURE 1

Table 1: Summary of RAI Questions

Question No.	Subject	Date Issued	Date Responded	Disposition (O/C)(†)	Note
Set 1	**Questions 1 through 19**				
1	WCOBRA/TRAC MOD7A Revision 7				
2	TRAC-PF1/MOD2 Code				
3	Large-break LOCA (LBLOCA) and small-break LOCA (SBLOCA) phenomena identification and ranking tables (PIRTs)				
4	End of blowdown				
5	Gap conductance				
6	Pressurizer response				
7	Long-term cooling and PIRT				
8	SBLOCA boundary and Region-I to Region-II boundary				
9	Worst SBLOCA				
10	Loss-of-offsite power (LOOP) versus reactor coolant pumps (RCPs) operating				
11	LOOP seal behavior				
12	Worst break sampling				
13	Decay heat multiplier/sampling				
14	Number of SBLOCA cases sampled: 93 versus 124				
15	SBLOCA upper limit break size				
16	Long-term cooling restriction				
17	Swelled or two-phase mixture level versus collapsed level				
18	High pressure safety injection (HPSI) curve basis and uncertainty				
19	SBLOCA axial power shape				
Set 2	**Questions 20 - 29**				
20	^{235}U, ^{238}U, and ^{239}Pu decay heat uncertainty fits to ANS 5.1-1979				
21	^{235}U, ^{238}U, and ^{239}Pu decay heat and uncertainty comparison to ANS 5.1-1979				
22	^{235}U, ^{238}U, and ^{239}Pu decay heat uncertainty comparison to American Nuclear Society (ANS) 5.1-1979				
23	Burnup limit in assessing kinetics parameters				
24	Editorial				
25	Utilized codes				
26	Actinides decay heat power				
27	Decay heat in demonstration plant analyses				
28	Decay heat uncertainty distribution				
29	Decay heat sampling approach				

(†) O=Open; C=Closed.

Table 1: Summary of RAI Questions (Continued)

Question No.	Subject	Date Issued	Date Responded	Disposition (O/C)$^{(\dagger)}$	Note
Set 3	**Questions 30 - 35**				
30	Scaling of the Westinghouse vertical Condensation on Safety Injection (COSI) test facility and tests				
31	Westinghouse vertical COSI downcomer condensation				
32	Westinghouse vertical COSI heat loss				
33	Westinghouse vertical COSI data and condensation outside the jet region				
34	Westinghouse vertical COSI data qualification				
35	Scale impact on cold leg condensation				

(†) O=Open; C=Closed.

RAI #30: Scaling of the Westinghouse Vertical COSI Test Facility and Tests

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, “Realistic LOCA [Loss-of-Coolant Accident] Evaluation Methodology Applied to the Full Spectrum of Break sizes (FULL SPECTRUM™ LOCA [(FSLOCA)] Methodology),” Subsection 6.3.6, “Special Model: Cold Leg Condensation Model,” describes the model for predicting direct contact condensation on the Safety Injection (SI) water for both small-break LOCA (SBLOCA) and large-break LOCA (LBLOCA) applications. The model employs an **[ ]** that was derived from a best fit to a set of data points derived from tests at the Westinghouse Condensation on Safety Injection (COSI) test facility. The facility is referred to as the Westinghouse vertical COSI test facility and the tests as the Westinghouse vertical COSI tests. **[**

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WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 6.3.6 states that the Westinghouse vertical COSI test facility “geometrically is a 1:100 scale of a pressurized water reactor (PWR) cold leg.” Additional information on scaling of a similar test facility is provided by P. Coste et al., “Status of a Two-Phase computational fluid dynamics (CFD) Approach to the PTS Issue,” Proc. OECD/NEA & IAEA Workshop “Experiments and CFD Code Applications to Nuclear Reactor Safety,” 10-12 September 2008, Grenoble, France. This reference explains that “COSI represents a PWR cold leg with the safety injection at the scale of 1/100 for volume and power, and conservation of Froude number” from a PWR under SBLOCA conditions.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 17.2.1, “Test Facilities and Tests Description,” explains that a large matrix of tests was conducted over the course of the COSI program by both Westinghouse and Framatome and that “some reconfigurations of the facility test section were performed with regard to the length of the main pipe in the test assembly and the angle and size of the injection piping.” Please clarify and address, as appropriate, the following items related to the scaling of the Westinghouse vertical COSI test facility and test matrix conditions used to produce the data set for fitting the FSLOCA methodology cold condensation correlation.

(1) Please describe the scaling of the Westinghouse vertical COSI test facility geometry and test matrix conditions used to produce the cold leg condensation rates. For this purpose, provide specific scaling relationships and criteria that are considered appropriate for investigation of SI cold leg condensation. Include specific consideration of cold leg diameter and cold leg length. Explain how the defined relationships and criteria apply to the Westinghouse vertical COSI test facility geometry and test matrix conditions. Explain which parameters and criteria support the scalability of the Westinghouse vertical COSI test data to prototypical conditions and which limit their applicability to such conditions.

(2) Based on the applied experimental procedures and conditions, data analysis, and scaling, describe the impact of involved major experimental distortions, test limitations, contributing processes, and uncertainties, related to the COSI test geometry and test conditions, on the applicability of the derived condensation data set to prototypical PWR conditions. In particular, please address such impacts related to the cold leg diameter scale.

RAI #31: Westinghouse Vertical COSI Downcomer Condensation

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 17.2.1, "Test Facilities and Tests Description," describes the approach in deriving the Westinghouse vertical COSI cold leg condensation data used to develop the correlation for SI jet condensation in the FSLOCA methodology. It explains that "the COSI experimental data report only gives boiler power and heat loss for the entire test loop." The boiler power was measured and the integral heat loss from the test section, boiler, and pipelines to the environment was estimated. The net total condensation heat transfer rates in the tests were obtained as difference between the boiler power and the heat loss as "steam from the inlet was completely condensed in the Westinghouse COSI tests." To obtain the cold leg condensation test data, the net total condensation rate was split into two parts: (1) condensation rate due to condensation in the cold leg and (2) condensation rate due to condensation in the downcomer. The first part included direct contact condensation on the SI jet in the cold leg and the second part accounted for condensation due to a possible "water fall" in the test section downcomer.

The downcomer condensation heat transfer rate was estimated from two test series, **[ ]** which were performed with the same test facility configuration and at the same test conditions (weir height, SI flow rate, SI diameter, system pressure) except for the downcomer water level. **[ ]** only with adjusting downcomer water level from -1.6 m to -0.3 m. Subsection 17.2.1 Equation (17-2) provides the expressions for the downcomer condensation rate Q_{DC} (in kW) as function of the SI rate m_{SI} (in kg/s):

[ ]

Assuming that the identified downcomer water levels were based on the lengths of the corresponding downcomer water falls, the water fall length ratio is assessed as:

[ ]

SI rates were equal in the tests and Equation (17-2) gives the downcomer condensation rate ratio:

[ ]

The downcomer condensation rate ratio is practically equal to the water fall length ratio for the Westinghouse vertical COSI tests used to establish the downcomer condensation rate.

Please provide additional information and clarification with regard to the following items.

(1) Please define the reference elevation used to determine the downcomer levels in **[ ]** test series. Explain how the downcomer water level was measured and how well was it controlled and maintained in testing.

(2) Please explain if Equation (17-2) was based on the assumption that the condensation rate in the downcomer region was proportional to the length of a free water fall in the steam-filled upper downcomer region. This would allow attributing the difference in the boiler power between the corresponding **[ ]** and establishing Equation (17-2).

(3) Please explain if all **[ ]** runs in each test series were used in establishing Equation (17-2) and present the corresponding test data used.

(4) The expressions in Equation (17-2) were based on information from two Westinghouse **[ ]** tests that differed only with regard to the downcomer water level. Equation (17-2) correlates the downcomer condensation rate only with the SI rate and does not take into consideration other important parameters such as SI temperature, pressure, and variations in cold leg and downcomer conditions. If Equation (17-2) was used for all tests listed in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Table 17-2, “Westinghouse Vertical COSI Tests Data,” please explain the basis for applying Equation (17-2) under different test conditions and possible implications with regard to the validity of the derived cold leg condensation rates.

RAI #32: Westinghouse Vertical Condensation on Safety Injection Heat Loss

The Westinghouse COSI test data average heat loss and associated uncertainty used to derive the cold leg condensation rates are shown in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Table 17-1, 'Westinghouse COSI Test Data Average Heat Loss and Uncertainty." **[**

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Please provide additional information and clarification with regard to the following items.

(1) Please explain how the values for the heat loss uncertainty in Table 17-1 were determined. As the heat loss matched the boiler power, please clarify if the heat loss uncertainties corresponded to the uncertainties in the boiler power. **[**

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(2) **[**

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(3) Please explain how the boiler power was measured and provide the measurement accuracy.

(4) As seen from Table 17-2 in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 17.2.1, "Test Facilities and Tests Description," the cold leg condensation rates range between **[ ]**

Considering uncertainties related to heat loss estimates, downcomer condensation rate estimates, and boiler power, please provide estimates for the overall uncertainty of the cold leg condensation data and explain why the data included in Table 17-2 were considered representative and acceptable for the purpose of defining the cold leg condensation correlation.

RAI #33: Westinghouse Vertical Condensation on Safety Injection Data and Condensation outside the Jet Region

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Subsection 6.3.6, "Special Model: Cold Leg Condensation Model," clarifies that "the cold leg condensation model assumes that the majority of condensation occurs in a small region near the SI injection port and the condensation outside the mixing zone is negligible." Accordingly, the cold leg SI condensation rates, described in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Subsection 17.2.1, "Test Facilities and Tests Description," and presented in Table 17-2, "Westinghouse Vertical COSI Tests Data," were derived as integral condensation rates accounting for the condensation processes in the entire cold leg test section. The characteristic of the Westinghouse Vertical COSI condensation rates is further exacerbated by the fact that the Westinghouse Vertical COSI cold leg test section was significantly oversized in length in comparison to a typical PWR **[ ]**

In WCOBRA/TRAC-TF2 calculations, the cold leg condensation model is applied to the **[ ]** Please explain if this can lead to over-prediction of the condensation rate for the entire cold leg region in WCOBRA/TRAC-TF2 PWR LOCA analyses due to condensation in the remaining cold leg cells.

RAI #34: Westinghouse Vertical Condensation on Safety Injection Data Qualification

With regard to the Westinghouse COSI facility, WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 17.2.1, "Test Facilities and Tests Description," states that "a core series of 15 tests, with 75 individual data, from Westinghouse configuration was conducted." The Westinghouse vertical COSI cold leg condensation rates used to define the empirical correlation for prediction of direct contact condensation on SI water in the cold legs are presented in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Table 17-2, "Westinghouse Vertical COSI Tests Data." The table contains 60 data points. In addition, Figure 6-15 in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, presents a comparison between the calculated Nusselt number and the measured Nusselt number for the fitted data points.

Please clarify and address, as needed, the following items related to the set of Westinghouse vertical COSI data, which was utilized to define the SI condensation correlation.

(1) Please explain if all available Westinghouse vertical COSI test runs were assessed and reported as “points” in the second column of WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Table 17-2. Clarify if any estimated condensation rates were disregarded and not included as “points” in Table 17-2 and if so please explain the reasons. In addition, please clarify if all data points in Table 17-2 were plotted in Figure 6-15.

(2) Table 17-2 provides only the derived condensation rates and does not include the measured boiler power, estimated downcomer condensation rate, and downcomer level. Please provide an expanded table that includes also these test parameters.

RAI #35: Scale Impact on Cold Leg Condensation

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 6.3.6, “Special Model: Cold Leg Condensation Model,” and Subsection 17.2.1, “Test Facilities and Tests Description,” explain that the Westinghouse horizontal injection COSI dataset, Framatome COSI dataset and ROSA-IV large scale test facility (LSTF) Test SB-CL-05 SI condensation separate effects test dataset were used “to independently perform the validation” of the cold leg condensation model.

The cold leg diameter of the Westinghouse and Framatome test sections was **[ ]** The length of the Framatome cold leg test section was only **[ ]** from the inlet to the downcomer compared with **[ ]** in the Westinghouse test section. The Westinghouse horizontal COSI test section had an SI line attached at **[ ]** longitudinal angles with an increased diameter of **[ ]** The Framatome COSI test section had an SI line with a diameter of **[ ]** and was oriented at **[ ]** azimuthal angle and **[ ]** longitudinal angles. The downcomer water level in the Framatome COSI tests was at **[ ]** and the downcomer condensation rate was evaluated using Equation (17-2). A subset of qualified Framatome COSI test runs that had zero break flow vented out of the test facility exiting the cold leg test section were used in the validation process are shown in the Table 17-5.

The LSTF was a 1/48 volumetrically scaled model of a Westinghouse-type 3423 MWt four-loop PWR. The cold legs were sized to preserve the volumetric ratio and the pipe length-to-square root of diameter, $L/(D)^{0.5}$, ratio for the reference PWR. The table below summarizes major geometric parameters for the test facility.

Table: Major Geometry Parameters for LSTF ROSA-IV

Parameter	LSTF	Prototype	Length Ratio
Cold leg diameter (in)	8.15	27.5	3.4
SI line diameter (in)	3.44	5.20	1.5
Cold leg pipe length (ft)	12.1	22.9	1.9
Azimuthal angle (deg)	90°	90°/45°	-
Longitudinal angle (deg)	45°	90°	-

For the purposes of validating the cold leg condensation model in the FSLOCA methodology, a simple modeling approach using a TEE component as shown in Figure 17-9, was applied to both the Westinghouse horizontal COSI and Framatome COSI test facilities. The noding diagram for the ROSA-IV SB-CL-05 safety injection tests was similar to that of the

Westinghouse vertical COSI facility. A separate noding diagram, shown in Figure 17-10, was used for Framatome counter-current COSI tests.

Please clarify the following items related to the validation of the cold leg condensation model in the FSLOCA methodology that was derived from Westinghouse vertical COSI test data.

(1) Both the Westinghouse and Framatome COSI experiments were performed with the same cold leg diameter of 4.65 in and with the same downcomer geometry. Key geometry differences involved only the orientation and diameter of the SI injection line. The calculation for the heat loss, downcomer condensation, and upper and lower bound of the cold leg condensation rates for the Framatome tests followed the same procedure that used for the Westinghouse COSI data reduction. Please explain how the Westinghouse horizontal injection COSI dataset and the Framatome COSI dataset contribute to the validation of the FSLOCA methodology cold leg condensation model. Provide the resolution of identified open items pertaining to the Westinghouse vertical COSI tests that are also applicable to the Westinghouse horizontal injection COSI dataset and the Framatome COSI dataset.

(2) ROSA-IV LSTF Test SB-CL-05 was used as a separate effects test for cold leg SI condensation by modeling only the cold leg and SI injection portion in ROSA-IV and using test measurements of instantaneous flow conditions in the cold leg at four selected instances **[ ]** Please explain which of the flow parameters in Table 17-7, "ROSA SB-CL-05 SI Condensation Test Data for separate effects tests (SETs)," were measured and how the provided experimental values were established and qualified. For example, test measurements can exhibit noticeable oscillations in time. For all remaining parameters in Table 17-7, if any, please provide the expressions used for their calculation.

(3) WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Subsection 17.2.2, "Description of WCOBRA/TRAC-TF2 Models," explains that in the cold leg condensation model validation studies based on the Westinghouse horizontal COSI test facility, Framatome COSI test facility, and ROSA-IV LSTF, a simple modeling approach with a TEE component was applied to simulate only "the scaled part of the cold leg" with the side TEE junction representing the injection port. Please explain how "the scaled part of the cold leg" was determined in the assessment studies and show that the applied scaling has no impact on the assessment results.

(4) The comparison between the calculated condensation rates and the experimentally derived rates for LSTF ROSA-IV SB-CL-05 cold leg condensation test, shown in Figure 17-13, indicates that WCOBRA/TRAC-TF2 under-predicted all four rates. WCAP-16996-P/ WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 17, "Cold Leg Condensation: COSI Experiments, ROSA-IV SB-CL-05 Experiment, and UPTF-8A Experiment," does not provide direct comparison of WCOBRA/TRAC-TF2 predictions for the SI condensation rate against test data from test facilities other than COSI and LSTF. Please demonstrate that the WCOBRA/TRAC-TF2 cold leg condensation model will not inherently and systematically over-predict the cold leg condensation rate in PWR LOCA analyses if such a model is based on indirect measurements in a single scaled test facility with regard to PWR cold leg geometry.