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

REQUEST FOR ADDITIONAL INFORMATION (RAI)

SEVENTH SET OF RAI QUESTIONS

RAI Questions 107 through 121

ENCLOSURE 3

The most current Table 1 is contained in the proprietary attachment to the transmittal package.

Table 2: List of Abbreviations

Abbreviation	Meaning	Note
1D	One Dimensional	
ADAMS	Agencywide Documents Access and Management System	
ASTRUM	Automated Statistical Treatment of Uncertainty Method	
BAF	Bottom of Active Fuel	
BNWL	Battelle Northwest Laboratories	
CCFL	Counter-Current Flow Limitation	
CFD	Computational Fluid Dynamics	
CHF	Critical Heat Flux	
COBRA	Coolant Boiling in Rod Arrays	
COCO	Containment Pressure Analysis Code	
COSI	Condensation on Safety Injection	
CQD	Code Qualification Document	
CSAU	Code Scaling, Applicability, and Uncertainty	
CSE	Containment Systems Experiment	
CT	Churn-Turbulent	
DC	Downcomer	
DEG	Double Ended Guillotine	
EM	Evaluation Model	
ECCS	Emergency Core Cooling System	
EOP	Emergency Operating Procedures	
EPRI	Electric Power Research Institute	
FD	Film/Drop	
FLECHT	Full Length Emergency Cooling Heat Transfer	
FSLOCA	Full Spectrum Loss-of-Coolant Accident	
GE	General Electric	
HL	Hot Leg	
HPTF	High Pressure Test Facility	
HTSTR	Heat Structure	
IAEA	International Atomic Energy Agency	
ID	Inner Diameter	
ISP	International Standard Problem	
JAERI	Japan Atomic Energy Research Institute	
LB	Large Bubble	
IBLOCA	Intermediate Break Loss-of-Coolant Accident	
IET	Integral Effects Test	
LBLOCA	Large Break Loss-of-Coolant Accident	
LHGR	Linear Heat Generation Rate	
LOCA	Loss-of-Coolant Accident	
LSTF	Large Scale Test Facility	

Table 2: List of Abbreviations (Continued)

Abbreviation	Meaning	Note
MLO	Maximum Local Oxidation	
NRC	U. S. Nuclear Regulatory Commission	
OD	Outer Diameter	
ORNL	Oak Ridge National Laboratory	
PCT	Peak Cladding Temperature	
PDF	Probability Density Function	
PIRT	Phenomena Identification and Ranking Table	
PKL	Primärkreislauf (German for Primary Coolant Circuit)	
PWR	Pressurized Water Reactor	
PIRT	Phenomena Identification and Ranking Table	
RBHT	Rod Bundle Heat Transfer Test	
RCP	Reactor Coolant Pump	
RCS	Reactor Coolant System	
RELAP	Reactor Excursion Leak Analysis Program	
RG	Regulatory Guide	
ROSA	Rig-of-Safety Assessment	
RPV	Reactor Pressure Vessel	
SB	Small Bubble	
SBLOCA	Small Break Loss-of-Coolant Accident	
SEASET	Separate Effects and System Effects Test	
SG	Steam Generator	
SI	Safety Injection	
SLB	Small-to-Large Bubble	
TAF	Top of Active Fuel	
TC	Thermocouple	
TEE	T-Junction	
TF	Three-Field	
TF	Two-Fluid	
TF2	Three-Field and Two-Fluid	
THTF	Thermal Hydraulic Test Facility	
TPTF	Two-Phase Flow Test Facility	
TRAC	Transient Reactor Analysis Code	
TRAC-M	Transient Reactor Analysis Code - Modernized	
TRAM	Transient and Accident Management	
UPTF	Upper Plenum Test Facility	

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 (36.05×10-4 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.

RAI Question #108: WCOBRA/TRAC-TF2 Assessment Using Counter-Current Flow Data by Costigan et al.

A simple experimental study of counter-current flow limitation was carried out at Harwell by Costigan et al., “Counter-current two-phase flow in horizontal channels of circular cross-section,” 2nd international Conference on Multiphase Flow, Paper F3, London, 1985. The apparatus operated at close to atmospheric pressure and consisted of a H-shaped test section. Water was injected into the left-hand limb, simulating the SG, and air into the right-hand limb representing the reactor upper plenum.

(1) Please compare WCOBRA/TRAC-TF2 predictions of the observed flooding phenomena against the experimental data of Costigan et al. Present sensitivity studies showing the impact of the H_SLUG parameter variation. Plot the comparison results using the phase Wallis parameters or any other appropriately defined dimensionless number.

(2) Please present sensitivity results illustrating the effect of nodalization refinement in representing the horizontal limb of the H-shaped test facility. For this purpose, please present code predictions using fine noding with cell length-to-hydraulic diameter ratio less than or equal to one and coarse noding with cell length-to-hydraulic diameter ratio greater two.

RAI Question #109: Semiscale Test S-LH-1 Assessment of WCOBRA/TRAC-TF2

Semiscale test facility was based on the full-height full-pressure scaling concept. Semiscale Mod-2C was a scaled model representation of a Westinghouse four-loop PWR plant with a fluid volume scaling ratio of about 1/1,705. The pressure vessel featured an external downcomer, the intact primary loop simulated three combined unaffected loops and the broken primary loop simulated one loop with a break. Accordingly, the intact loop steam generator (SG) consisted of six inverted U-tubes and the broken loop SG had two inverted U-tubes. As documented in Table 1, “Comparison of Semiscale Systems,” by G. G. Loomis, “Summary of the Semiscale Program (1965-1986),” NUREG/CR-4945, EGG-2509, July 1987, the Semiscale Mod-2C primary system piping was all stainless steel with the broken loop being 1.5-inch Schedule 160 pipe and most of the intact loop being 2.5-inch Schedule 160 pipe.

A special 0.5-inch tubing bypass line connected the downcomer to the upper head to simulate the leakage between these two components in commercial PWRs. According to 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, this PWR leakage flow varies between 0.5 percent and 4 percent of the total core flow.

Test S-LH-1, which simulated a 5 percent cold leg, centerline, communicative break in the loop piping between the pump and the vessel downcomer, exhibited important small break LOCA phenomena including liquid holdup in SG U-tubes, consequent core uncovery, and sequential loop seal clearance in the intact and broken loops. The upper head to downcomer bypass flow was calibrated at 0.9 percent of the recirculation flow by installing 0.125-inch thick flat plate orifice with 0.116-inch diameter hole in the bypass line to reduce steam venting through the spray nozzles during the transient. The experiment is described 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.

An early core uncovery prior to loop seals clearance caused a first heater-rod heatup. The observed loop seal clearing in the intact loop at 171.4 s and in the broken loop at 262.3 s allowed the core to refill and cool after the first core uncovery. During the period of the first core uncovery, the uphill side of the SGs had liquid holdup, which was dependant on the heat transfer and CCFL phenomenon in the U-tubes. A second core uncovery was caused by reduced system inventory later in the transient.

(1) Please describe the WCOBRA/TRAC-TF2 model used to simulate Semiscale Mod-2C Test S-LH-1. Explain which special modeling features were activated in the analysis and describe any modeling parameter adjustments if such were employed in the analysis.

(2) Please present WCOBRA/TRAC-TF2 assessment results using Semiscale

(3) Mod-2C Test S-LH-1 experimental data. Show comparison plots for important parameters such as core collapsed and two-phase mixture levels, differential pressures reflecting manometric fluid head balance in both tests loops, and heater rod temperatures. In particular, please compare differential pressures and collapsed liquid levels in the uphill and downhill sides of the SGs, loop seal uphill and downhill differential pressures for both loops, rod surface temperature at the 208-cm elevation, break mass flow rate, and integrated break mass flow.

RAI Question #110: Semiscale Test S-LH-2 Assessment of WCOBRA/TRAC-TF2

Semiscale Tests S-LH-1 and S-LH-2 were performed using the Semiscale Mod-2C facility configuration. Both tests simulated a 5 percent centerline communicative break in the cold leg piping between the pump exit and the vessel downcomer. For this purpose, the break was simulated by an orifice of a 0.20-ft2 scaled area and an equivalent break diameter of 6.1 inch corresponding to a 4.92 percent break size based on a 27.5-inch PWR cold leg diameter.

In Test S-LH-1, a flat plate orifice with a 0.25 contraction ratio hole was installed in the special 0.5-inch tubing bypass line between the downcomer and the upper head. In Test S-LH-2, this orifice was removed. This resulted in initial condition core bypass flows of 0.9 percent and 3 percent in Test S-LH-1 and Test S-LH-2, respectively. Although these bypass flows differed by a ratio of 3.3, both values were thought to be within the range of possible PWR bypass flow. The bypass line hydraulic resistances for both tests are provided by G. G. Loomis and J. E. Streit, "Results of Semiscale Mod-2C Small-Break (5 percent) LOCA Experiments S-LH-1 and S-LH-2," NUREG/CR-4438, EGG-2424, November 1985.

As performed, Tests S-LH-1 and S-LH-2 examine the effect of the core bypass flow on the small break LOCA transient response. With regard to loop seal clearance in particular, Test S-LH-1, which had 0.9 percent bypass flow, exhibited loop seal clearance in both loops, first in the intact loop at 171.4 s followed by the broken loop at 262.3 s. In contrast, Test S-LH-2, which simulated 3 percent bypass flow, exhibited loop seal clearance only in the intact loop at 205.4 s with no clearance in the broken loop.

(1) Please describe the representation of the special 0.5-inch tubing bypass line between the downcomer and the upper head in the WCOBRA/TRAC-TF2 model used to simulate Semiscale Mod-2C Test S-LH-1 and Test S-LH-2.

(2) Please present WCOBRA/TRAC-TF2 assessment results using Semiscale Mod-2C Test S-LH-2 experimental data. Show comparison plots for important parameters such as core collapsed and two-phase mixture levels, differential pressures reflecting manometric fluid head balance in both tests loops, and heater rod temperatures. In particular, please compare differential pressures and collapsed liquid levels in the uphill and downhill sides of the SGs, loop seal uphill and downhill differential pressures for both loops, rod surface temperature at the 208-cm elevation, break mass flow rate, and integrated break mass flow.

(3) Please present comparison results between WCOBRA/TRAC-TF2 predictions for Semiscale Mod-2C Test S-LH-1 and Test S-LH-2. Show comparison plots for important parameters such as core collapsed and two-phase mixture levels, differential pressures reflecting manometric fluid head balance in both tests loops, and heater rod temperatures. In particular, please compare differential pressures and collapsed liquid levels in the uphill and downhill sides of the SGs, loop seal uphill and downhill differential pressures for both loops, rod surface temperature at the 208-cm elevation, break mass flow rate, and integrated break mass flow. As part of the comparative analysis, use experimental data from both tests when assessing the WCOBRA/TRAC-TF2 capabilities in modeling effects associated with core bypass flow, particularly with regard to impact on loop seal behavior.

RAI Question #111: Sensitivity of WCOBRA/TRAC-TF2 Semiscale Predictions to SG Nodalization

The 5 percent SBLOCA Semiscale Test S-UT-8, performed with the Semiscale Mod-2A test facility system configuration, revealed the possibility for primary liquid holdup in the PWR SGs during a small break LOCA. In this test, condensation-induced filling of the SG tubes in the intact loop caused an extreme core liquid level suppression prior to the clearance of the liquid seal formed in the pump suction crossover piping. Test S-UT-8 data is reported by W. W. Tinle, "Test data Report on Westinghouse Reactor Vessel Level Indicating System Performance during Semiscale Test S-UT-8," EGG-SEMI-5827, March 1982. The same effect was observed in Semiscale Mod-2C Tests S-LH-1 and S-LH-2 as reported 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.

The Semiscale Mod-2C intact loop was equipped with a Type II SG, which was a lumped representation of the three SGs in the intact loops of the reference Westinghouse four-loop plant. The affected Semiscale Mod-2C loop was equipped with a Type III SG featuring an external downcomer for γ-densitometer measurements. Accordingly, the intact loop Type II SG model had 6 inverted U-tubes: 2 short, 2 medium, and 2 long tubes representative of the range of bend elevations in a typical PWR SG, as described by Y. S. Bang et al., “Assessment of RELAP5/MOD3.2 With the Semiscale Natural Circulation Experiment, S-NC-8B,” NUREG/IA-0144, August 1998. The affected loop Type III SG model had two inverted U-tubes with a 22.2-mm (0.87-inch) OD.

A simple sensitivity study on the nodalization of the SGs using an earlier version of RELAP5 was performed by C. Lee, T. Ito, and P. B. Abramson, “Sensitivity of SBLOCA Analysis to Model Nodalization,” Paper CONF-830901-2, Anticipated and Abnormal Plant Transients in Light Water Reactors Conference, 26 September 1983, Jackson, Wyoming. The analysis examined a 4-inch cold leg break in a Westinghouse four-loop plant using a coarse SG nodalization with 4 vertically stacked secondary side nodes in the U-tube region and the corresponding 8 nodes in the U-tubes, 4 in the uphill side and 4 in downhill side. The U-tube bend sections were modeled with 2 nodes, one on each side. In the fine noding scheme, the number of nodes in the SGs was doubled while keeping the rest of the plant model identical. In this case, the U-tube bends were represented by 4 nodes, 2 on each side.

The study revealed that the predicted transient behavior was quite sensitive to the implemented SG nodalization schemes. While global system parameters, such as integrated break mass discharge, primary liquid inventory, and primary system pressure were relatively insensitive to the nodalization, the predicted distribution of coolant inventory in the primary loops was significantly affected by change in nodalization. In particular, more detailed nodalization led to prediction of higher liquid holdup in the SG U-tubes thus resulting in less coolant inventory in the reactor vessel and therefore causing earlier and more severe core uncovery.

(1) Please present sensitivity results for Semiscale Mod-2C Tests S-LH-1 and S-LH-2, which examine the effect of SG nodalization on small break LOCA predication results. For this purpose, please present test prediction results obtained with a SG nodalization scheme corresponding to the standard noding approach adopted in WCOBRA/TRAC-TF2 for modeling of SGs with inverted U-tube bundles. In addition, please present test prediction results obtained with a refined noding using a doubled number of nodes (cells) to represent the SG U-tube bundle. Also, please present sensitivity results examining the impact of refined nodalization of the 180º-bend region of the U-tube bundle by increasing further the number of cells representing this region. Compare the code test predictions against key measured quantities in each test.

(2) Please present sensitivity results, as requested in Item (1) above, using SG models with split representation of the U-tube bundles. For this purpose, please model when the intact loop Type II SG U-tubes using three PIPE hydraulic components each representing two U-tubes. Please split the U-tubes in the SG bundle based on the U-tube apex elevations so that tubes with a different length are represented by individual hydraulic components. Please use two PIPE hydraulic components to model the broken loop Type III SG U-tubes individually.

(3) When providing the information requested in Items (1) and (2) above, please include, among other important parameters, WCOBRA/TRAC-TF2 predictions for the SG U-tube bundle upside and downside collapsed liquid levels in the broken and in the intact loops, the uphill and downhill loop seal collapsed liquid levels in both loops, and the vessel core-side and downcomer-side collapsed liquid levels. Please compare obtained code predictions against test measurements as appropriate.

RAI Question #112: Sensitivity of WCOBRA/TRAC-TF2 Small Break LOCA Predictions to Steam Generator Nodalization

Please present sensitivity results for a reference four-loop Westinghouse plant using WCOBRA/TRAC-TF2, which examine the effect of SG nodalization on small break LOCA predication results. Show the sensitivity impact for the limiting small break size, which yields the most severe core level suppression for the selected PWR plant model and applying nominal input parameters.

(1) Please present code results using a standard SG nodalization scheme, adopted for WCOBRA/TRAC-TF2 modeling of SGs with inverted U-tubes, and a refined noding in which the number of nodes representing the SG U-tube bundle is doubled. In particular, explain and present sensitivities to refined nodalization of the 180º-bend region of the U-tube bundle.

(2) Please present sensitivity results as requested in Item (1) above when the SG U-tube bundle in each PWR primary loop is modeled using two and tree pipe hydraulic components. In modeling the U-tubes in each SG bundle by multiple pipe components, please split the U-tubes into individual groups based on the U-tube apex elevations so that the tallest, middle, and shortest tubes are represented by individual hydraulic components.

(3) In responding to Items (1) and (2) above, please include, among others, comparison plots for the SG U-tube upside and downside collapsed liquid levels in the broken and intact loops, uphill and downhill loop seal collapsed liquid levels in the broken and intact loops, vessel core-side and downcomer-side collapsed liquid levels, core void fractions, and peak clad temperatures.

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

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

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

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

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

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

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

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

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

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

(1) Please describe how the loop seal differential pressures were measured in the UPTF TRAM separate effect loop seal clearance tests. Explain how the locations of the differential pressure tap points were reflected in the WCOBRA/TRAC-TF2 UPTF loop seal models used to assess the code. Describe how the predicted loop seal differential pressure quantity was determined from the WCOBRA/TRAC-TF2 calculation results. Please identify nodes and/or cell interfaces in the WCOBRA/TRAC-TF2 UPTF loop seal model

at which thermal hydraulic quantities were calculated by the code and used to determine the loop seal differential pressure predication for comparison against test data.

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

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

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

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

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

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

for the implementation of these special modeling options and provide the allowable input values. In addition, please explain how the input values for these options are determined for the purpose of performing PWR LOCA analysis using the Full Spectrum LOCA methodology.

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

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

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

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

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

loop seal regions. In addition, please depict the two-phase flow regimes as identified in the loop seal nodes. Provide plots for the predicted volumetric concentrations of the interfacial friction force.

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

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

(5) In responding to Items (1) through (4) above, please assess UPTF TRAM 0.5 MPa tests and the 1.5 MPa tests separately. Provide detailed pressure scaling considerations based on contributing WCOBRA/TRAC-TF2 models. Derive and provide corresponding pressure scaling relationships and explain how the UPTF TRAM full-scale loop seal clearance data support them.

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

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

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

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

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

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

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

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

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

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

UPTF TRAM full-scale separate effect loop seal clearance test data. In addition, provide comparisons among analyzed sensitivity cases, as appropriate.

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

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

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

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

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

RAI Question #120: IVO Loop Seal Clearance Data and WCOBRA/TRAC-TF2 Assessment

A full-scale separate effect test facility, constricted by Imatran Voima Oy (IVO) in Finland, was used to study two-phase flow phenomena in a PWR loop seal region following a cold leg break LOCA. The full-scale loop seal test facility used a piping with an ID of 0.850 m (33.46 inch or 2.8 ft) and a length of the horizontal section of the seal of

4.3 m (169.3 inch or 14.1 ft), which resulted in a L/D of 5.1 for this section. The tests were conducted at atmospheric pressure and room temperature using air and water. As part of this experimental effort, two reduced-scale loop seal models were constructed using transparent pipes with an ID of 0.080 m (3.15 inch) to examine effects of scaling and geometry on the loop seal processes and flow regime transitions. Test data from these facilities were used for comparison against the full-scale loop seal geometry tests. The IVO tests are described by H. Tuomisto, "Large-Scale Air/Water Flow Tests for Separate Effects During LOCAs in PWRs," Nuclear Engineering and Design, Vol. 102, No. 2, pp. 171-176, 1987 and by H. Tuomisto and P. Kajanto, "Two-Phase Flow in a Full-Scale Loop Seal Facility," Nuclear Engineering and Design, Vol. 107, No. 3, pp. 295-305, 1988.

IVO separate effect loop seal clearance test data has have been used for assessing various reactor safety thermal hydraulic codes. Results from a RELAP5 assessment study are documented by O. Kymäläinen, "The Assessment of RELAP5/MOD2 against IVO Loop Seal Tests," NUREG/IA-0082, April 1992. In this work, RELAP5/MOD2 analyses for both the full-scale and the 1/10-scale atmospheric air-water loop seal facilities were performed. The calculated residual water levels differed from the measured data and the code yielded lower values. Also, the predicted gas superficial velocities, needed for loop seal clearing, was lower than the experimentally values. Even with interfacial drag modifications, agreement with the experimental data was not found. Results from a more recent TRACE assessment study are presented by S. Hillberg, "Full Scale Loop Seal Experiments with TRACE V5 Patch 1," NUREG/IA-0403, December 2011. The assessment was focused on the code capability to predict the residual water level in the horizontal pipe section of the loop seal and examined the pressure behavior during the clearance of the loop seal. Effects related to loop seal nodalization, maximum time step size, and initial liquid levels were studied. The simulations revealed sensitivities to loop seal nodalization particularly with regard to representing the 90º bends of the seal piping.

IVO full-scale loop seal experiments are discussed in WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 18, "Loop Seal Clearance," Subsection 18.2.2.4, "Effect of Scale," and void fraction data points are compared against three different limiting lines in Figure 18.2.2-12, "IVO Full-Scale Final Void Fraction and Limit Lines." However, no assessment of WCOBRA/TRAC-TF2 prediction results against IVO separate effect loop seal experiments was reported.

(1) Please perform an additional assessment study for WCOBRA/TRAC-TF2 using IVO separate effect atmospheric air-water test data obtained from both the full-scale and the 1/10-scale loop seal test facilities. Please describe the applied WCOBRA/TRAC-TF2 models for the IVO test facilities as requested in RAI Question No. 112 Items (1) through (4) with regard to the WCOBRA/TRAC-TF2 UPTF loop seal model. Also, describe the IVO loop seal tests instrumentation, test data, and assessed code predication results as requested in RAI Question No. 113, Items (1) and (2), with regard to the WCOBRA/TRAC-TF2 UPTF TRAM loop seal clearance test data. Document user defined parameters, multipliers, and/or options used in the WCOBRA/TRAC-TF2 IVO loop seal models as requested in RAI Question No. 114, Items (1) and (2), with regard to the WCOBRA/TRAC-TF2 UPTF TRAM loop seal model.

(2) Please present detailed results from the WCOBRA/TRAC-TF2 assessment using IVO separate effect atmospheric air-water test data from the full-scale and the 1/10-scale loop seal test facilities as requested in RAI question #115 items (1) through (4) with regard to the WCOBRA/TRAC-TF2 UPTF TRAM loop seal tests assessment study.

(3) Please perform and present results from sensitivity calculations assessing effects related to IVO the full-scale and 1/10-scale loop seal test facilities nodalization in the applied WCOBRA/TRAC-TF2 IVO loop seal models as requested in RAI question #116 items (1) through (3) with regard to the WCOBRA/TRAC-TF2 assessment using the UPTF TRAM loop seal tests. The length of the bottom horizontal section of the full-scale IVO loop seal piping had an L/D ratio of 5.1, which was significantly larger than the corresponding ratio in the full-scale UPTF loop seal facility characterized by an L/D ratio of 2.3. Therefore, please adjust the number of cells in the WCOBRA/TRAC-TF2 IVO full-scale loop seal model so that the cell length-to-diameter ratios in the IVO full-scale loop seal model are close to the ratios examined in the UPTF full-scale loop seal model (L/D of 1.16, 0.77, and 0.58). Examine any additional nodalization schemes, as deemed appropriate.

(4) Please provide results from WCOBRA/TRAC-TF2 sensitivity studies based on the IVO separate effect full-scale and 1/10-scale loop seal clearance tests, which show the effect of varying or sampling of parameters, multipliers, and/or options relevant to the prediction of the loop clearance process. Perform and document the code assessment results as requested in RAI question #118 with regard to the WCOBRA/TRAC-TF2 UPTF loop seal model.

(5) Please provide results from WCOBRA/TRAC-TF2 sensitivity calculations based on the IVO separate effect full-scale and 1/10-scale loop seal clearance tests that show the effects related to the applied maximum allowed time step size (DTMAX). Perform and document the code assessment results as requested in RAI question #119 with regard to the WCOBRA/TRAC-TF2 UPTF TRAM loop seal assessment study.

RAI Question #121: ECTHOR Loop Seal Clearance Data and WCOBRA/TRAC-TF2 Assessment

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 18, “Loop Seal Clearance,” Subsection 18.2.2, “PWS 2.3 Loop Seal Tests,” discusses scaled air-water experiments examining the hydraulic behavior of a U-tube under conditions similar to those encountered in a PWR loop seal during a small break LOCA. The tests were performed as part of the ECTHOR (an acronym from French “Ecoulements dans des Tuyauteries Horizontales en Eau-Air,” which stands for Water-Air Flow in Horizontal Pipes) Program carried out under an agreement between Framatome, Électricité de France, Commissariat à l'Energie Atomique, and Westinghouse. Description of the ECTHOR tests is provided by J. P. Bourteele, “Investigation of Stratified and Countercurrent Flows in Horizontal Piping during a Loss-of-Coolant Accident,” European Two-Phase Flow Group Meeting, Glasgow, June 3-6, 1980, and by R. J. Skwarek, “Experimental Evaluation of PWR Loop Seal Behavior during Small LOCAs,” Proceedings of the ANS Specialists Meeting on Small Break Loss-of-Coolant Accident Analyses in LWRs: Conference Papers, August 25-27, 1981, Monterey, California, pp. 5.1-5.12.

The ECTHOR separate effect air-water scaled loop seal tests were performed at atmospheric pressure in a U-tube pipe with an inner diameter of 0.25 m (9.84 inch or 0.82 ft) representing the geometry of a PWR loop seal at a scaling ratio of 0.32 (approximately 1/3). ECTHOR loop seal tests have been used in the past for interfacial drag model development and assessment of various reactor safety thermal hydraulic codes such as CATHARE (acronym from Code for Analysis of Thermalhydraulics during an Accident of Reactor and safety Evaluation) and RELAP5.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II, and III, Revision 0, Section 18, “Loop Seal Clearance,” Subsection 18.2.2, “PWS 2.3 Loop Seal Tests,” Figures 18.2.2-3 shows residual liquid level data, Figures 18.2.2-4 and 18.2.2-5 depict average void fraction data, and Figure 18.2.2-9 plots U-tube differential pressure data from the ECTHOR tests. The test data are compared against limiting lines for governing participating processes in Figures 18.2.2-7 and 18.2.2-8. However, no assessment of WCOBRA/TRAC-TF2 prediction results against ECTHOR separate effect air-water scaled loop seal data was reported.

Please perform an additional assessment study for WCOBRA/TRAC-TF2 using ECTHOR separate effect air-water scaled loop seal test data. Perform this study and document the code assessment results as requested in RAI question #120 items (1) through (5) with regard to the WCOBRA/TRAC-TF2 IVO separate effect atmospheric air-water tests.