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WCOBRA/TRAC Validation with Revised Downcomer Noding for D.C. Cook Units 1 and 2
(Non-Proprietary)

WCOBRA/TRAC Validation with Revised Downcomer Noding for D.C. Cook Units 1 and 2

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ACRONYMS and NOMENCLATURE

ASTRUM	Automated Statistical Treatment of Uncertainty Method
BE	Best Estimate
BELOCA	Best-Estimate Loss-of-Coolant Accident
CQD	Code Qualification Document
CCFL	Counter-current flow limiting
CCTF	Cylindrical Core Test Facility
CSAU	Code Scaling, Applicability, and Uncertainty
ECC	Emergency Core Cooling
ECCS	Emergency Core Cooling System
EM	Evaluation Model
KWU	Kraftwerk Union AG
LBLOCA	Large-Break Loss-of-coolant Accident
LOCA	Loss-of-coolant Accident
LPCI	Low Pressure Coolant Injection
PCT	Peak Cladding Temperature
PLHR	Peak Linear Heat Rate
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
UPTF	Upper Plenum Test Facility

1.0 Executive Summary

The large break Loss-of-Coolant Accident (LOCA) analysis of D. C. Cook Unit 1 has been performed using a plant-specific adaptation of the 2004 NRC-Approved Westinghouse Realistic Large Break LOCA Evaluation Model Using ASTRUM (Reference 1). This same plant-specific adaptation will be employed for the D.C. Cook Unit 2 large break LOCA analysis. The only deviation from the approved methodology in this D.C. Cook-specific adaptation is the use of an increased number of circumferential noding stacks in the downcomer. The D. C. Cook -specific application uses twelve stacks, as compared to the use of four stacks for four loop plants in the Reference 1 methodology.

The use of a finer nodalization in the downcomer than that used in the as-approved model requires that certain code assessments against experimental data be performed with similar noding, in order to ensure that the basis for acceptability of the overall uncertainty methodology is not adversely impacted. More specifically, the Upper Plenum Test Facility (UPTF) Test 6 series (ECCS bypass tests), UPTF Test 25A (downcomer entrainment test) and Cylindrical Core Test Facility (CCTF) Test C2-4 Run 62 (reference transient for the Core-II configuration, Reference 2) have been re-performed with twelve downcomer stacks. These are the tests cited in Reference 1 for Code, Scaling, Applicability, and Uncertainty (CSAU) Step 13, Determination of the Combined Bias and Uncertainties, for the phenomena related to the downcomer. The details of the code assessments performed to validate the plant-specific adaptation of the Reference 1 methodology for application to D. C. Cook Unit 1 and Unit 2 are presented in the following sections. The results of these assessments confirm the continuing applicability of the Reference 1 uncertainty methodology for the D. C. Cook plant-specific adaptation.

2.0 Selection of Test Simulations for Validation of Revised Noding

The Automated Statistical Treatment of Uncertainty Method (ASTRUM) represents the second generation of best-estimate large-break LOCA evaluation models developed by Westinghouse. The first generation approved best-estimate LBLOCA methodology is described in WCAP-12945-P-A (Reference 3) for Westinghouse designed 3- and 4-loop plants with emergency core cooling system (ECCS) injection into the cold legs. This is referred to herein as the Code Qualification Document (CQD). Like the CQD methodology, ASTRUM is patterned after the CSAU methodology. The only significant difference from the CQD methodology is in the application of the uncertainty analysis to the pressurized water reactor (PWR) LBLOCA scenario.

The downcomer noding in the CQD (Reference 3) was validated by the simulation of the UPTF Emergency Core Cooling bypass tests (UPTF Test 6 series), UPTF downcomer entrainment test (UPTF Test 25A), and a series of CCTF tests which simulated a 4-loop PWR during refill and reflood conditions. In the CQD simulations, the ECC bypass phenomenon was shown to be conservatively calculated by WCOBRA/TRAC, therefore, this phenomenon was not ranged in the uncertainty analysis. The downcomer entrainment during reflood was shown to be accurately predicted by WCOBRA/TRAC, therefore, this phenomenon was also not ranged in the uncertainty analysis. The ranging of the downcomer condensation was determined by comparing the results of the UPTF Test 6 simulations with the experimental data. CCTF played an important role in validating the ability of the code to simulate the interaction of different phenomena during the refill/reflood period of a PWR LOCA as described in Appendix A of the CQD (Reference 3).

The same tests selected for the validation of the downcomer noding in the CQD were used for the D.C. Cook model validation, with the exception of the CCTF series of simulations. CCTF Test C2-4 Run 62 was selected for this validation effort for the following reasons: Run 62 is the reference case, it is representative of the CCTF test series presented in the CQD, and it is the case which is cited for CSAU Step 13 for ASTRUM (Reference 1).

In the sections which follow, a brief description of the test facility and the validation test is provided followed by the WCOBRA/TRAC transient results which support the revised downcomer noding. With the number of circumferential noding stacks in the downcomer increased to twelve, the WCOBRA/TRAC transient results demonstrate that the conclusions from the CQD remain valid and continue to support the uncertainty treatment described in the CQD, and therefore the ASTRUM topical as well.

3.0 Upper Plenum Test Facility (UPTF) Simulations Using WCOBRA/TRAC

3.1 Introduction

The Upper Plenum Test Facility was designed to obtain experimental data relative to the multi-dimensional flows expected in a PWR during a Loss-of-Coolant Accident (LOCA). The UPTF was the German contribution to the 2D/3D program established by the United States (NRC), Japan (JAERI) and the Federal Republic of Germany (BMFT). Tests conducted in the UPTF gave special consideration to:

1. Entrainment and de-entrainment in the upper plenum,
2. Co-current and countercurrent two-phase flow in the upper core and tie plate region,
3. Co-current and countercurrent flow and bypass in the downcomer, and
4. Condensation and steam/water mixing processes caused by ECC injection in the loops.

This section first describes the test facility, consistent with the description provided in the CQD, and provided herein for the completeness of the discussion. Second, descriptions of the modeling of the UPTF experiments using the WCOBRA/TRAC twelve downcomer channel model are provided. Tests 6 and 25 were modeled to examine the ability of the code to predict ECC bypass and the steam-water interaction in the downcomer.

3.2 UPTF Facility Description

The UPTF simulated a full-scale 3900 MWt German PWR. The facility had four loops, each with a steam/water separator to simulate a steam generator and a variable resistance to simulate a reactor coolant pump. The upper plenum contained full size internals in an arrangement typical of a KWU PWR. Figures 3-1 and 3-2 show an overall diagram of the UPTF. The upper plenum test facility was designed to investigate:

1. Water entrainment and separation processes in the upper plenum,
2. Co-current and countercurrent steam/water flow phenomena in the upper core tie plate region including water break-through into the core,
3. Co-current and countercurrent steam/water flow in the downcomer and possible bypass of the ECC water injected into the cold legs of the loops to the break nozzle,
4. Condensation and mixing processes in the hot and cold legs of the loops, in the upper plenum and in the downcomer as a result of the injection of cold ECC water and,
5. Loop behavior with regard to possible water plug formation and oscillations in the hot and cold legs of the loops with ECC injection.

This range of investigation was achieved by varying the configuration of the facility. Full details of the facility and its instrumentation are given in Reference 5.

There were three intact loops and one loop with a break in the cold leg. The loop break was represented by gate valves and orifice plates to control the flow and a containment simulator gave the desired back pressure. The broken loop cold leg contained a water separator to prevent water from entering the containment simulator. The steam generators were simulated by four steam/water separators and adjustable passive resistances were used to simulate the four reactor coolant pumps. The facility did not contain a heated core, but the internals at the top of the core and in the upper plenum were full-scale replicas. The core itself was simulated by a steam/water injection system to set up the appropriate flow conditions in the vessel. The tubes that deliver the fluid to the core came up through the lower plenum.

The reactor vessel is shown in Figure 3-3. The upper plenum contained sixty-one guide tubes, eight support columns above the simulated fuel assemblies, and eight support columns outside the periphery of the core (Figure 3-4). The downcomer gap width was 0.25 meters (9.8 inches) and the vessel internal diameter was 4.87 meters (191.7 inches).

The UPTF facility simulated the upflow of steam and droplets through the core during reflood by injection of steam and water into dummy fuel rods. The dummy fuel rods represented the upper quarter of a core with 193 assemblies of 16x16 array of fuel rods. Sixty-one of the assemblies were below guide tubes and had control rod spider simulators (Figure 3-5). The remaining assemblies were below flow restrictors in the upper core plate. The water and steam injection nozzles are shown in Figure 3-6. There were seventeen independently controlled injectors which divided to provide a separate nozzle for each dummy fuel rod assembly.

The dummy control rods terminated at the bottom of the guide tubes which were sealed to prevent flow from the upper plenum to the upper head. The upper head was thereby isolated from the rest of the vessel and had no effect on the facility.

The UPTF cold legs had an inner diameter of 750 millimeters (2.46 feet). The ECC injection was at an angle of 60° to the cold leg centerline in UPTF and was 5822 millimeters (19.1 feet) from the inside wall of the vessel.

The steam generator simulators for the intact and broken loops and the broken cold leg water separator are shown in Figure 3-7. Flow entered an inlet plenum, which had the same volume as a PWR steam generator, and rose through cyclone tubes. The cyclones separated the water from the steam and the water was removed from the loop. The steam flowed through the steam generator upper plenum and returned to the cold leg.

The water drainage system removed the large quantities of water that accumulated during a test. Generally these quantities were found in the test vessel, the steam generator simulators, the broken cold leg water separator, and in the drainage vessels of the broken loops.

The raw data produced from the instrumentation was continuously recorded throughout a test, some of which was post-processed to give computed parameters. An example of a computed parameter derived from raw data is liquid level, which is derived from the measurement of differential pressure.

The downcomer was instrumented with fluid distribution grids, turbine meters, differential and absolute pressure transducers, and fluid and wall thermocouples. The lower plenum and core regions were instrumented with optical liquid level detectors, differential pressure transducers, and fluid and wall thermocouples. The instrumentation in the upper plenum included:

(i) Wall and fluid thermocouples,
(ii) Fluid thermocouples in end boxes and below tie plate,
(iii) Differential pressure transducers across the tie plate,
(iv) Differential pressure transducers and capacity liquid level detectors in upper plenum,
(v) Optical liquid level detectors and fluid distribution grids,
(vi) Video probes in upper plenum,
(vii) Break-through detectors below tie plate,
(viii) Tie plate drag bodies in end boxes and,
(ix) Turbine meters in end boxes and in upper plenum.

3.3 ECC Bypass and Entrainment Test Description

Two UPTF tests were evaluated using the twelve channel WCOBRA/TRAC model to determine the ability of the code to calculate bypass and downcomer entrainment phenomena. Test 6 (Reference 6) approximated conditions in the Reactor Coolant System (RCS) during blowdown and Test 25 (Reference 7) investigated the steam-water interaction (entrainment) during reflood.

Test 6 consisted of five steady-state runs with steam flows to establish points on a flooding curve for the downcomer. In Test 6, the pump simulators were closed and only the cold leg break valve was opened in order to force all steam injected in the core simulator to flow down through the lower plenum, up the downcomer, and then out of the system through the broken cold leg. Steam was injected to both the core and the steam generator simulators, except during the one sub-phase in which all flow was injected to the core. Water was injected at equal rates to each of the three intact loops. Table 3-1 summarizes the conditions for each phase of Test 6.

Test 25 was a steady-state simulation to investigate Emergency Core Cooling (ECC) entrainment out the break during the reflood portion of a PWR LOCA. The test was conducted in two phases, Phase A (consisting of sub-phases Ia, Ib, II, III, and IV) and Phase B, and four sub-phases (not considered for this evaluation). [

]^{b} Table 3-2 lists the conditions for each Phase A sub-phase of Test 25.

3.4 WCOBRA/TRAC Model for UPTF Test 6

The UPTF system configuration for Test 6 is shown in Figure 3-8. Steam was injected into the core through the core simulators and through the steam generator simulators. Flow through the intact loops was blocked at the intact loop pump simulators and the broken hot leg valve was closed, forcing all flow through the broken cold leg to the containment simulator tank.

The WCOBRA/TRAC model VESSEL component for the calculations to compare with the UPTF Test 6 simulations is shown in Figures 3-9 through 3-13. [

]^{a,c}

The WCOBRA/TRAC loop model used for the UPTF Test 6 transient calculations is shown in Figure 3-14. In the test facility, the broken loop is a piping system leading from the vessel to a steam water separator and then to the containment simulator (Figure 3-1) [

]^{a,c}

The intact cold legs were represented by PIPE components, and the ECC was modeled as a boundary condition applied through the FILL components. The broken loop was represented by one PIPE component. The pressure at the broken loop flowmeter was specified by a BREAK component.

3.4.1 Simulation of UPTF Test 6

Figures 3-15 through 3-19 contain plots of the WCOBRA/TRAC calculated vessel inventory versus the experimental data for the five UPTF Test 6 cases. It can be seen in Figure 3-15 that WCOBRA/TRAC calculates the start of vessel refill about 10 seconds earlier than the test data for Run 131. However, the calculated filling rate of the vessel is less than in the experimental data. By about 35 seconds into the simulation, the calculated vessel inventory is the same as the experimental data, after which time the calculated inventory remains lower than the data. The behavior for Run 132 as plotted in Figure 3-16 is quite similar to Run 131. Again, WCOBRA/TRAC calculates the start of vessel refill earlier than the test data; however, the rate of filling is lower than in the test data. The WCOBRA/TRAC calculated vessel inventory is the same as the data 35 seconds into the simulation, after which time the calculated vessel inventory is significantly less than the experimental data. The Run 135 behavior is also similar to the previous two cases discussed, as presented in Figure 3-18. WCOBRA/TRAC calculates filling of the vessel about 10 seconds earlier than in the data, but the rate of filling is less than in the experimental data. The vessel inventory in the WCOBRA/TRAC calculation is roughly the same as the experiment at 35 seconds, after which time the vessel inventory is greater in the experimental data.

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3.5 WCOBRA/TRAC Model for UPTF Test 25

UPTF Test 25 simulated conditions expected during the reflood phase of a large break LOCA. ECC was injected to the cold legs, while steam flow through the UPTF was established by injecting steam in the steam generator simulators. UPTF Test 25 consisted of two phases: Phase A which was preheated so that the downcomer walls were above saturation temperature, and Phase B in which the downcomer walls were preheated to approximately the saturation temperature.

WCOBRA/TRAC was used to simulate Phase A of UPTF Test 25 in order to validate the ability of the code to predict the steam-water interaction (entrainment) in the downcomer during reflood when downcomer boiling had occurred. Figure 3-26 shows the UPTF system configuration for UPTF Test 25.

The vessel model used in the simulation of UPTF Test 25 was nearly identical to that used in the Test 6 simulations. The vessel component noding for Test 6 is shown in Figures 3-9 through 3-13. For the UPTF Test 25 simulation, the upper plenum in Section 7, which was represented by channel 27 in Figure 3-9, was divided into [

]^{a,c} (as depicted in Figure 3-27). The vessel model included heat slabs to represent the core barrel and test vessel walls. These heat slabs were initialized at the measured temperatures recorded at the start of Phase A.

The UPTF loops for UPTF Test 25 were modeled as shown in Figure 3-27. The intact cold legs were represented by the TEE components 5, 6, and 7. The ECC injection to the intact cold legs was modeled by FILL components 2, 3, and 4. Steam, which in UPTF Test 25 was injected through the steam generator simulators, was modeled to be injected via FILL components 16, 17, and 18. These FILL components were connected to TEE components 13, 14, and 15, which modeled the path from the steam generator simulators to the intact cold legs and the intact hot legs. (These TEE components were coarsely noded, since their only purpose was to provide a conduit for steam injection boundary condition to the cold legs and a vent path to relieve pressure in the upper plenum during the pause in injection between sub-phases.)

The broken cold leg was represented by PIPE component 8, which connected to TEE component 9 that represented the broken loop steam generator simulator. The path to the break downstream of the steam generator simulator was modeled by PIPE component 11. A constant pressure BREAK (component 12) represented the UPTF containment simulator tank.

3.5.1 Simulation of UPTF Test 25 – Phase A

The WCOBRA/TRAC calculated transient corresponding to the UPTF Test 25 simulation was run for nearly the entire 900 seconds of the test. Figures 3-28 and 3-29 compare the measured and predicted absolute pressures in the upper plenum and downcomer. During the active injection phases, the pressure increased, and then decreased to the containment pressure as injection diminished.

The downcomer fluid temperatures are compared in Figures 3-30 through 3-33. High in the downcomer the fluid temperature measurement fluctuated considerably, between superheated vapor and saturation. Lower in the downcomer there are much fewer fluctuations. [

]^{a,c}

The differential pressures between the upper plenum and the downcomer are shown in Figures 3-34 and 3-35, and the axial differential pressure measurements in the downcomer are compared in Figures 3-36 through 3-39. The WCOBRA/TRAC prediction of the upper plenum to downcomer differential pressure is in good agreement with the data. The WCOBRA/TRAC prediction of the axial differential pressures in the downcomer were also in adequate agreement with the data.

The azimuthal pressure differentials in the downcomer are compared at two levels. Figures 3-40 and 3-41 show the measured and predicted azimuthal pressure differentials at a level near the middle of the downcomer, where little cross-flow occurs. Figure 3-42 shows the measured pressure differential higher in the downcomer, near the loop connections. At this elevation, the measurements showed fluctuations indicating cross-flows which were also found in the WCOBRA/TRAC prediction (Figure 3-43).

The predicted and estimated water levels in the downcomer are compared in Figures 3-44 and 3-45. The trends for the predicted collapsed liquid levels are seen to be in very good agreement with the trends observed in the measurements. Decreases occur when the steam flows decrease, and vessel drainage was initiated. The predicted and estimated levels are in very good agreement during sub-phases I and III of the simulation for the intact loop quadrants. There is also relatively good agreement for sub-phases II and IV, with the predicted level tending to be slightly higher than the experimental data for the intact loops. There is good agreement between the predicted and estimated broken loop level for all four sub-phases. As such, it is concluded that WCOBRA/TRAC does a good job of predicting the downcomer levels.

In Figure 3-44, two curves are shown. One curve represents the level in the broken loop quadrant of the downcomer, and the other represents the level in the intact loop quadrants of the downcomer. In Figure 3-45, four curves are shown. Each curve represents the level in a different quadrant of the downcomer each of which being adjacent to a loop connection. In the measured levels, the level was highest in the downcomer quadrant below the broken cold leg. Similarly, the prediction of downcomer levels (Figure 3-45) also shows this multi-dimensional effect.

Vapor flow to the broken loop is shown in Figures 3-46 and 3-47. The estimated and predicted values compare very well. Figures 3-46 and 3-47 demonstrate that the vapor flow rate changes during each sub-phase with the increase in steam injection rate. The predicted total flow rate to the broken loop is shown in Figure 3-48. During sub-phase I, which had the highest steam injection rate, the liquid flow is fairly constant. In sub-phases II, III, and IV, the liquid flow rate decreases to nearly zero early in the transient time as the liquid level in the downcomer drops. Later in transient time for sub-phases II, III, and IV, the liquid flow to the break increases as the downcomer level rises.

One specific parameter of interest is the void height in the downcomer as a function of the steam flow rate. The void height is the downcomer level measured downward from the bottom of the cold leg (at the inside diameter of the pipe). The WCOBRA/TRAC calculated downcomer void height was determined for each of the four sub-phases, and then plotted against test data and estimates provided by MPR Associates (Reference 9) in Figure 3-49.

Compared to the MPR estimates (Reference 9), the WCOBRA/TRAC prediction for the intact quadrants in Figure 3-49 is very good. For all four sub-phases, WCOBRA/TRAC predicts a slightly lower void height that the MPR estimate. Overall, the MPR estimate and the WCOBRA/TRAC prediction compare very well.

The WCOBRA/TRAC predictions in Figure 3-49 also match very well against the UPTF Test 6 experimental data. The calculated intact quandrant void heights are very close to the data for sub-phases I and II. The WCOBRA/TRAC predicted intact quandrant void height for sub-phase III is slightly lower than the data, and the prediction is slightly higher for sub-phase IV. The WCOBRA/TRAC predicted void heights for the broken loop quadrants fall between the high and low data values from UPTF Test 6 for all four sub-phases.

It is concluded that there is no significant difference in the WCOBRA/TRAC calculation of the UPTF Test 25A between the original simulation for the CQD and the simulation with revised downcomer noding.

Table 3-1 UPTF Test 6 Conditions					
	Run Number				
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					]b

Table 3-2 UPTF Test 25 Conditions					
	Phase A: Sub-Phase Parameters				
[					
					]b

*A conversion from kg/sec (actual test data) to lb_m/sec for the Steam Injection Flow/Loop is provided for ease of comparison for Figures 3-46 through 3-48.

Table 3-3 Condensation Efficiency Range

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					][a,b,c]

WC/T = Average condensation efficiency calculated by WCOBRA/TRAC.

MAX(MPR) = Condensation efficiency calculated by MPR (1990) using method 1 described in Section 25-9 of the CQD (Reference 3)

MIN(MPR) = Condensation efficiency calculated by MPR (1990) using method 2 described in Section 25-9 of the CQD (Reference 3)

XMAX = MAX(MPR) / WC/T

XMIN = MIN(MPR) / WC/T

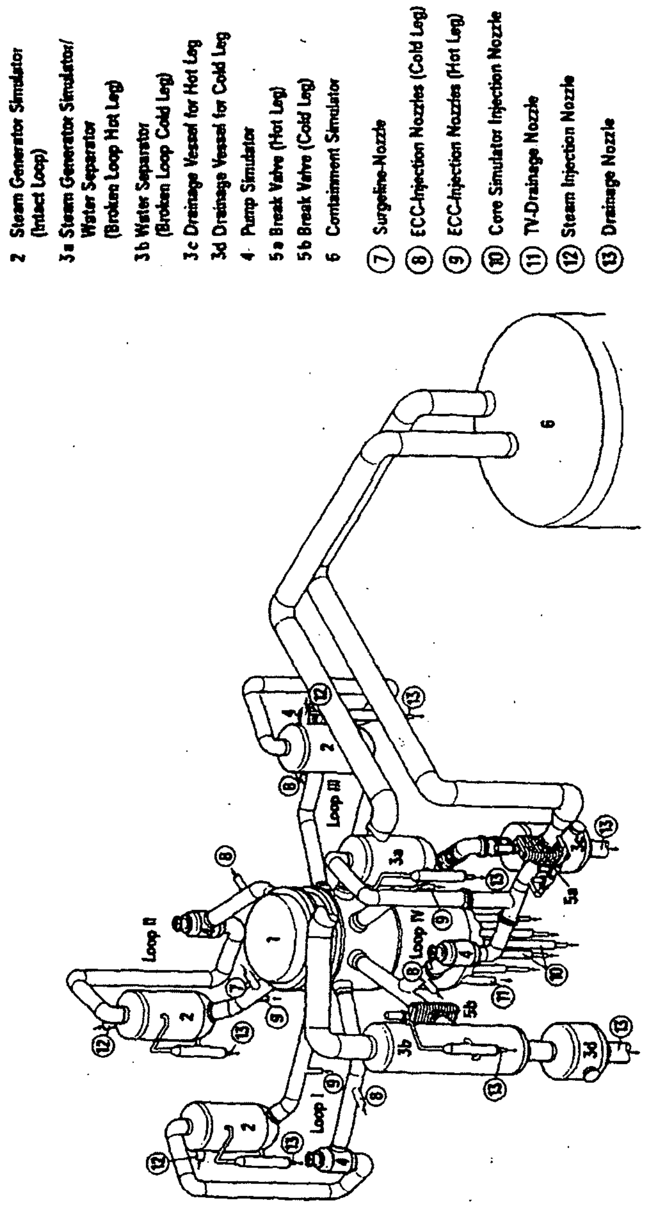

FIGURE 3-1 UPTF PLAN VIEW

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Figure 3-2 UPTF Test Vessel and Primary Loop

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Figure 3-3 UPTF Reactor Vessel

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Figure 3-4 UPTF Upper Plenum Structures

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Figure 3-5 Dummy Fuel Assembly and End Box with Flow Restrictor (A) or Spider (B)

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Figure 3-6 UPTF Core Simulator Injection Assembly

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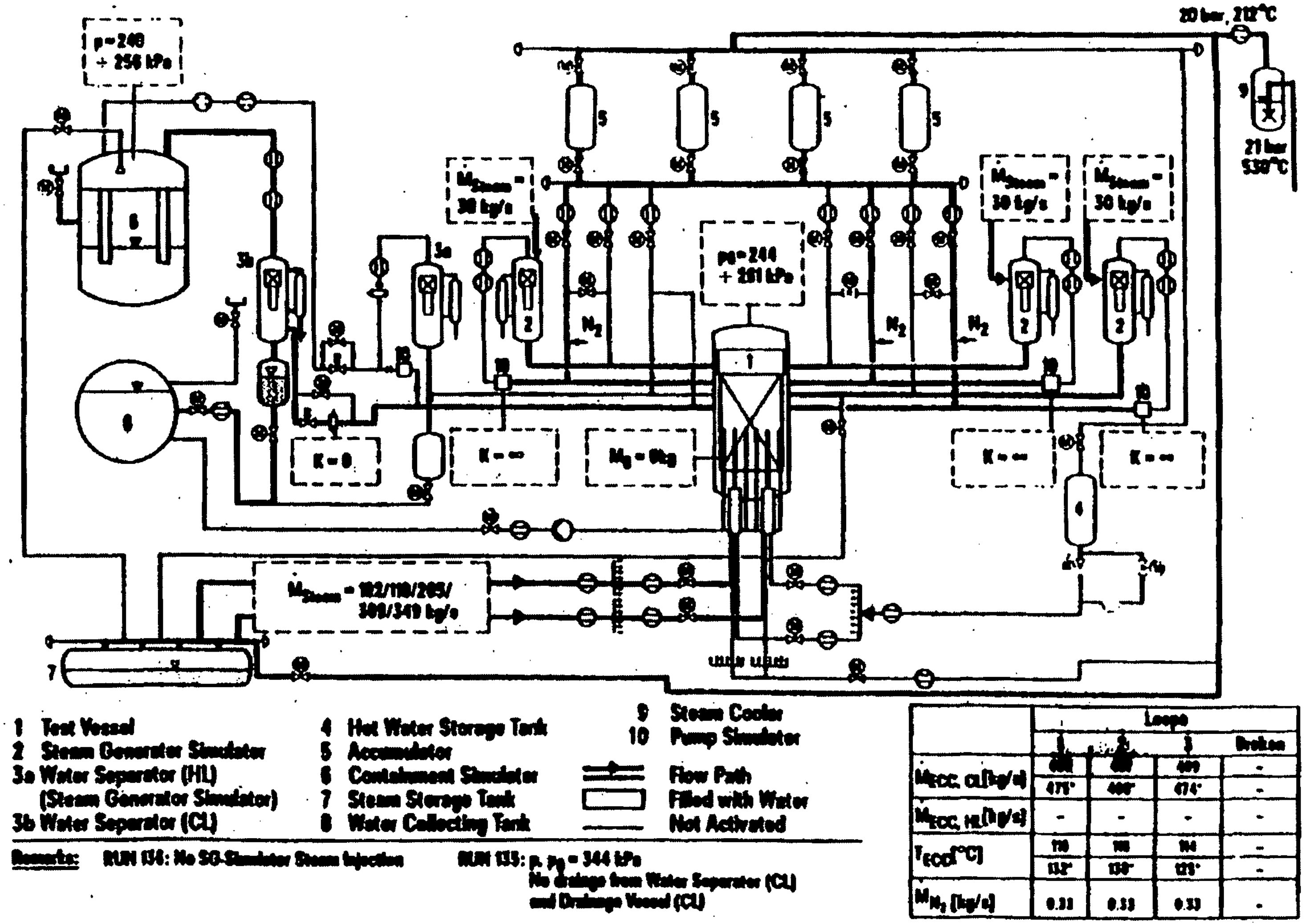
Figure 3-7 UPTF Steam Generator Simulators and Water Separators



	Loops			
	1	2	3	Broken
$M_{ECC,CL}$ [kg/s]	[illegible]	[illegible]	409	-
	475*	400*	474*	-
$M_{ECC,HL}$ [kg/s]	-	-	-	-
T_{ECC} [°C]	110	108	114	-
	132*	130*	129*	-
M_{N_2} [kg/s]	0.33	0.33	0.33	-

* RUN 135

Figure 3-8 UPTF System Configuration for Test 6

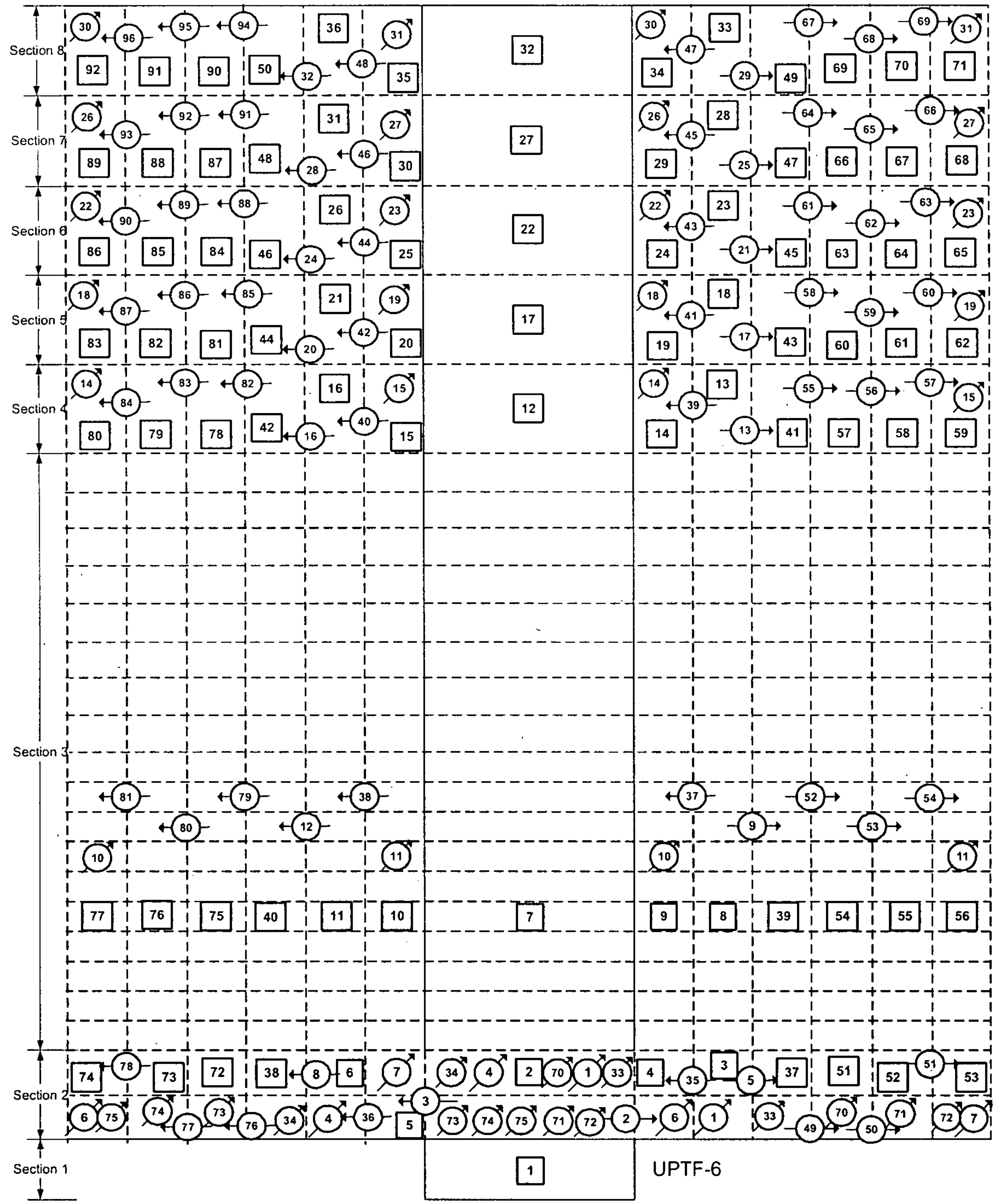
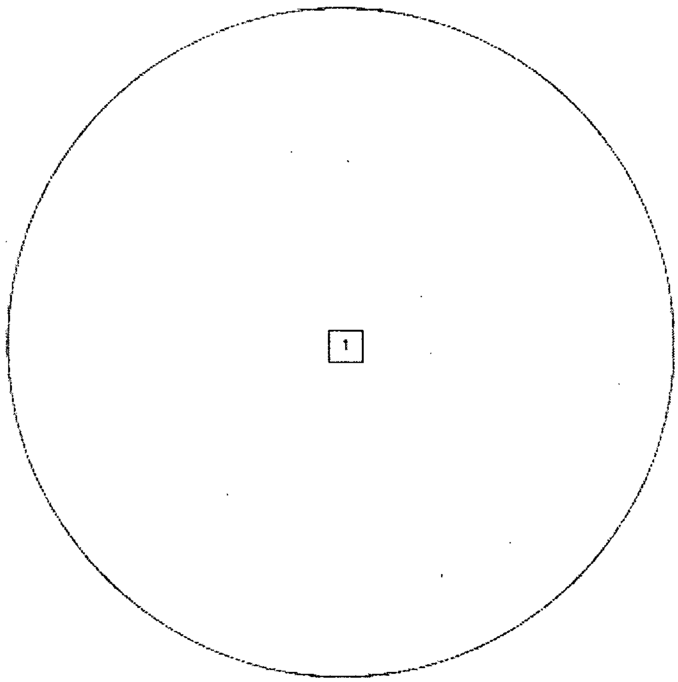
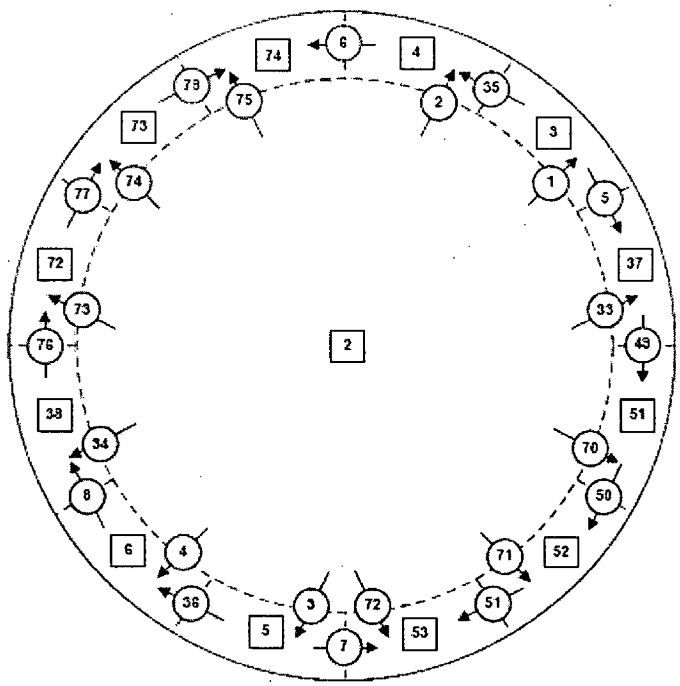


Figure 3-9 WCOBRA/TRAC VESSEL Component Axial View for UPTF Test 6

Channel □
Gap ○



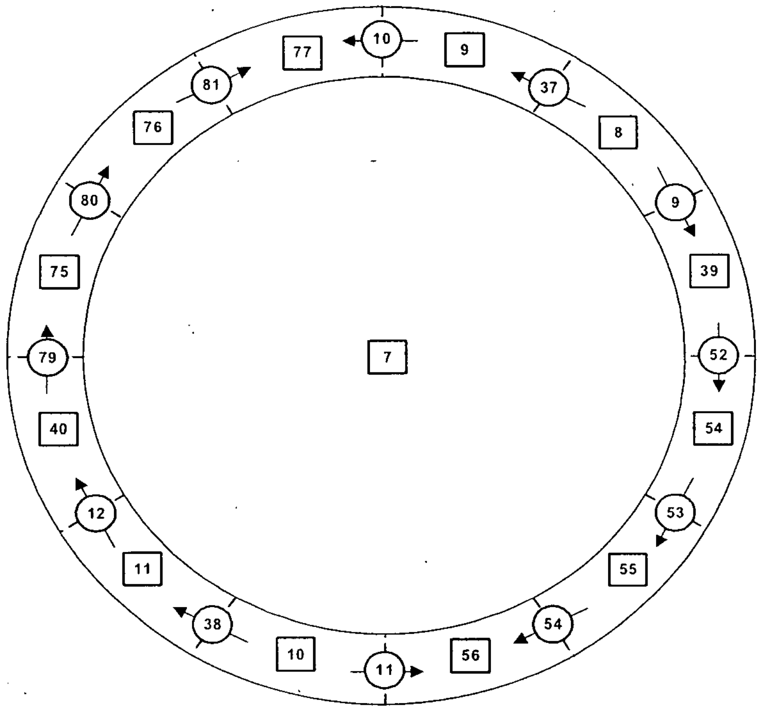
Section 1



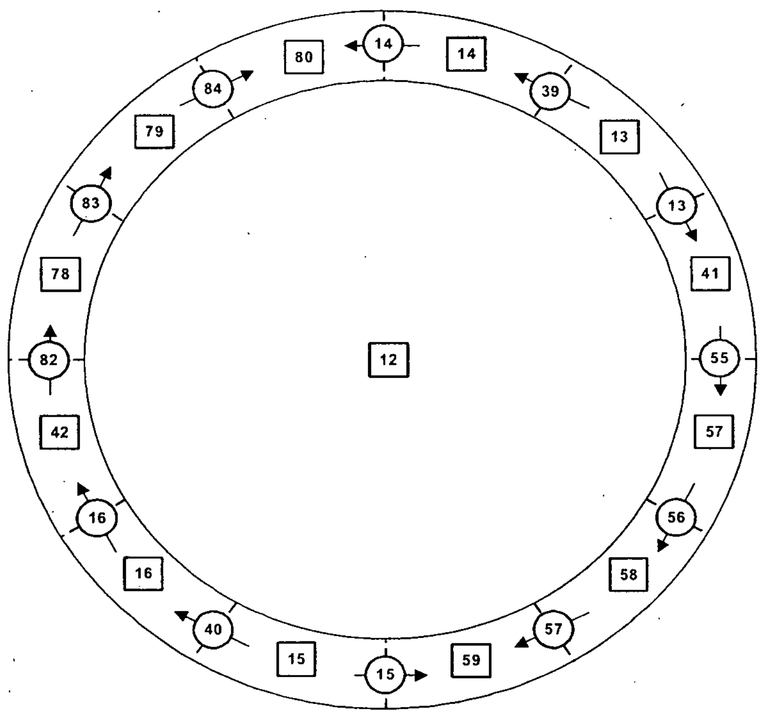
Section 2

Figure 3-10 WCOBRA/TRAC VESSEL Component Sections 1 and 2 for UPTF Test 6

Channel □
Gap ○



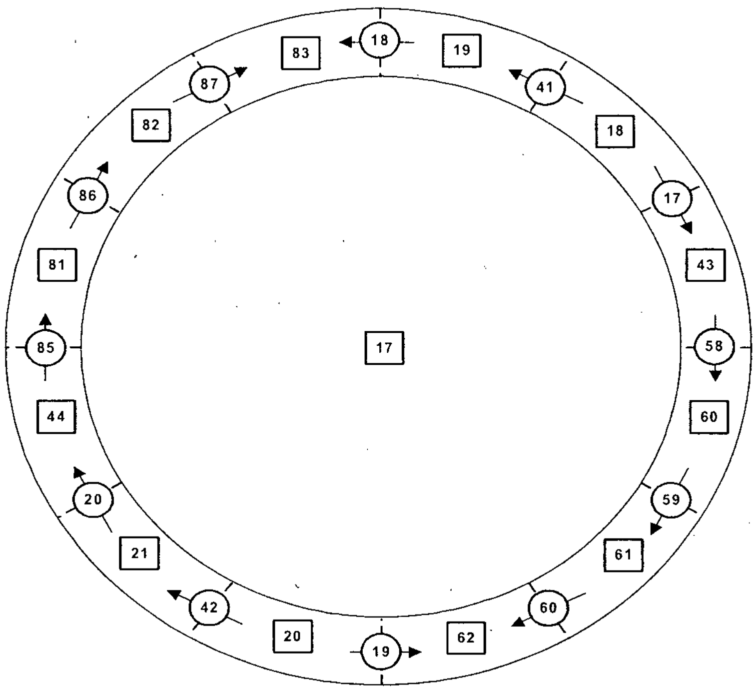
Section 3



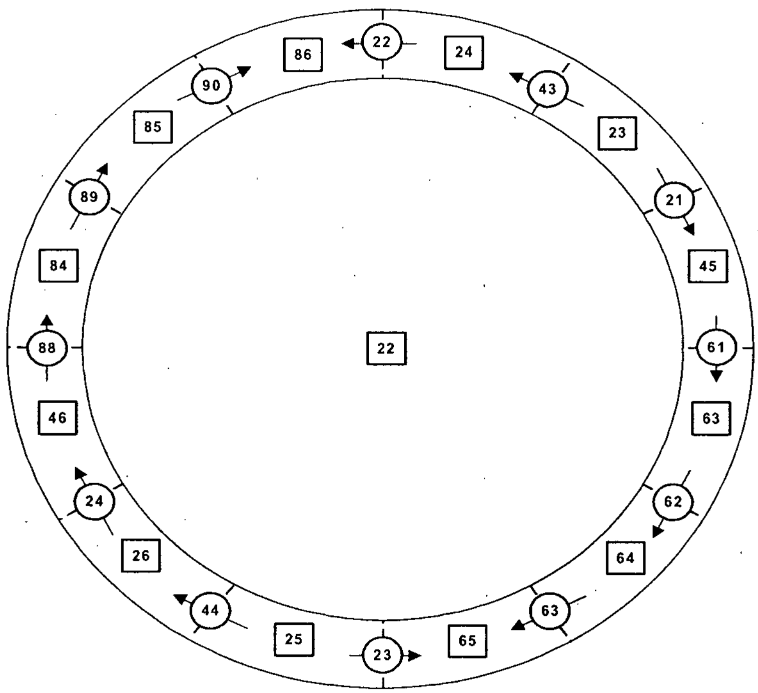
Section 4

Figure 3-11 <u>W</u>COBRA/TRAC VESSEL Component Sections 3 and 4 for UPTF Test 6

Channel □
Gap ○



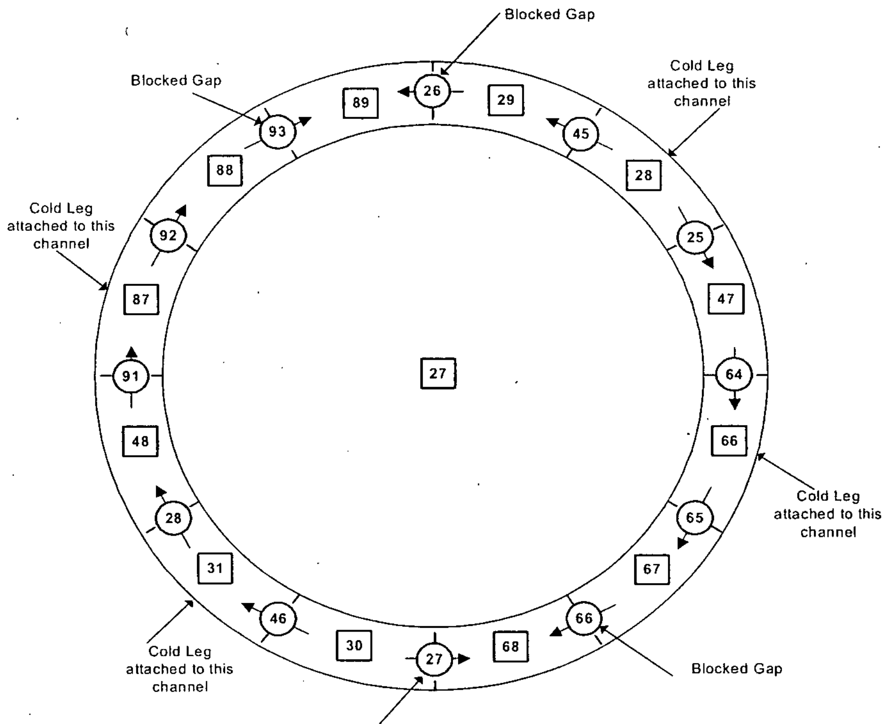
Section 5



Section 6

Figure 3-12 WCOBRA/TRAC VESSEL Component Sections 5 and 6 for UPTF Test 6

Channel □
Gap ○



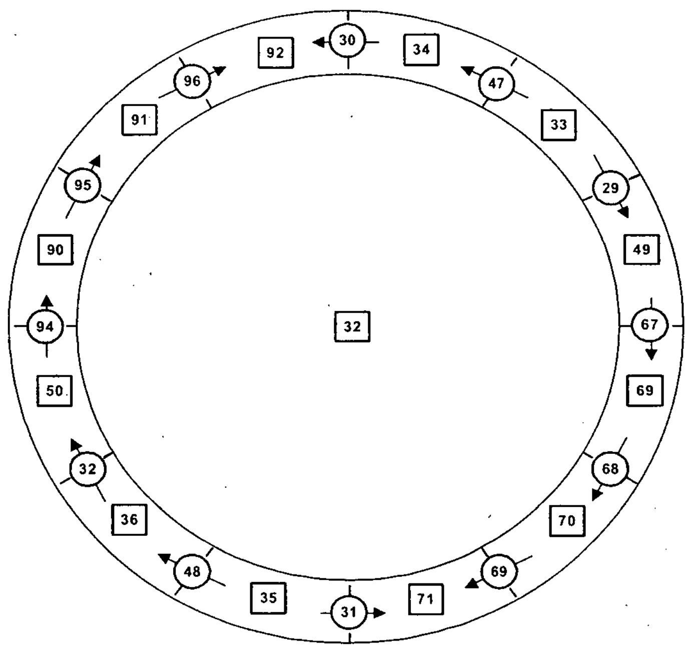


Figure 3-13 WCOBRA/TRAC VESSEL Component Sections 7 and 8 for UPTF Test 6

Channel □
Gap ○

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Component □
Junction ○

Figure 3-14 WCOBRA/TRAC One-Dimensional Component Model for UPTF Test 6

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Figure 3-15 Vessel Fluid Inventory, UPTF Test 6 – Run 131

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Figure 3-16 Vessel Fluid Inventory, UPTF Test 6 - Run 132

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Figure 3-17 Vessel Fluid Inventory, UPTF Test 6 – Run 133

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Figure 3-18 Vessel Fluid Inventory, UPTF Test 6 – Run 135

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Figure 3-19 Vessel Fluid Inventory, UPTF Test 6 – Run 136

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Figure 3-21 Vessel Condensation Efficiency, UPTF Test 6 - Run 131

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Figure 3-21 Vessel Condensation Efficiency, UPTF Test 6 – Run 131

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Figure 3-22 Vessel Condensation Efficiency, UPTF Test 6 – Run 132

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Figure 3-23 Vessel Condensation Efficiency, UPTF Test 6 – Run 133

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Figure 3-24 Vessel Condensation Efficiency, UPTF Test 6 – Run 135

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Figure 3-25 Vessel Condensation Efficiency, UPTF Test 6 - Run 136

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Figure 3-26 System Configuration for UPTF Test 25, Phase A (Run 242) and Phase B (Run 241)

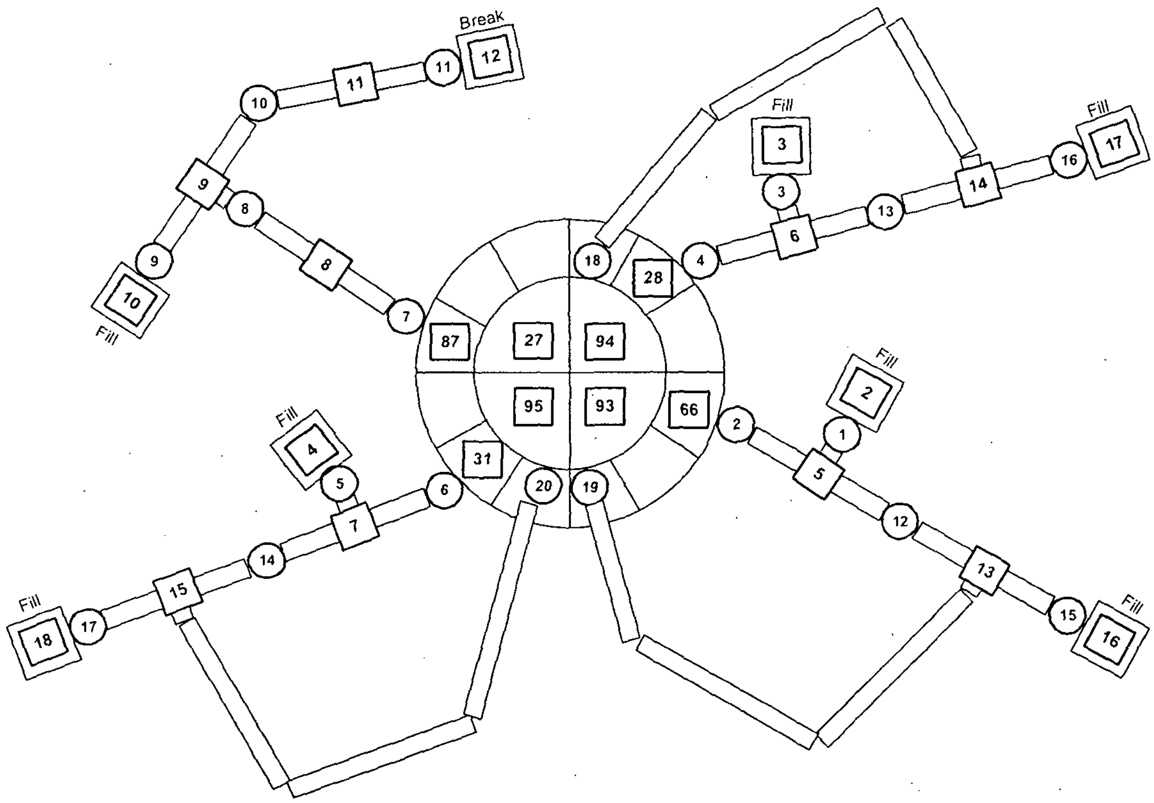

Figure 3-27 WCOBRA/TRAC Loop Model for UPTF Test 25

Figure 3-28 Measured Absolute Pressure in the Upper Plenum and Downcomer for UPTF Test 25

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Figure 3-29 Predicted Absolute Pressure in the Upper Plenum and Downcomer for UPTF Test 25

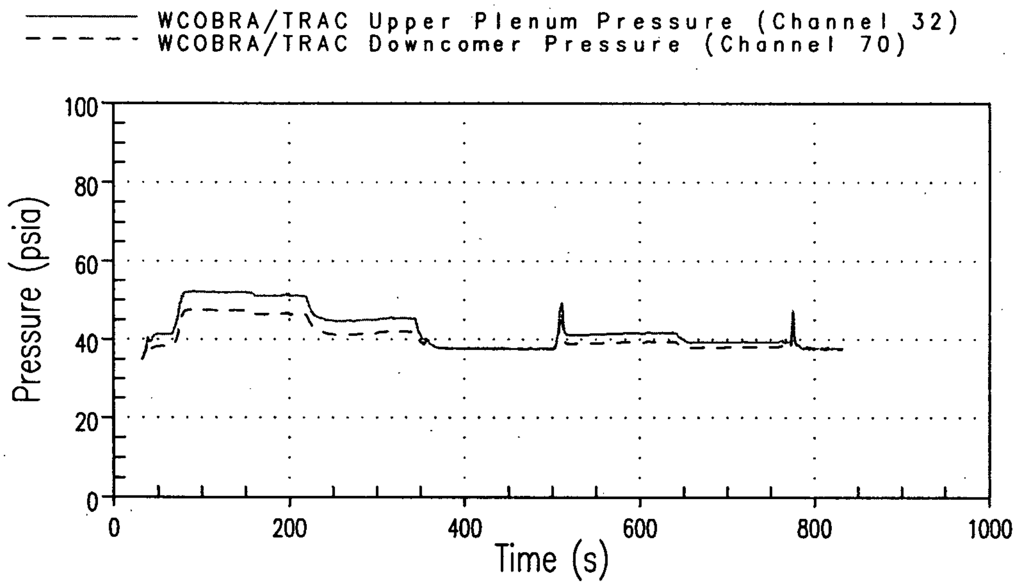

Figure 3-30 Measured Downcomer Fluid Temperature at Level 28 for UPTF Test 25

[

][b]

Figure 3-31 Predicted Downcomer Fluid (Vapor) Temperature at Level 28 for UPTF Test 25

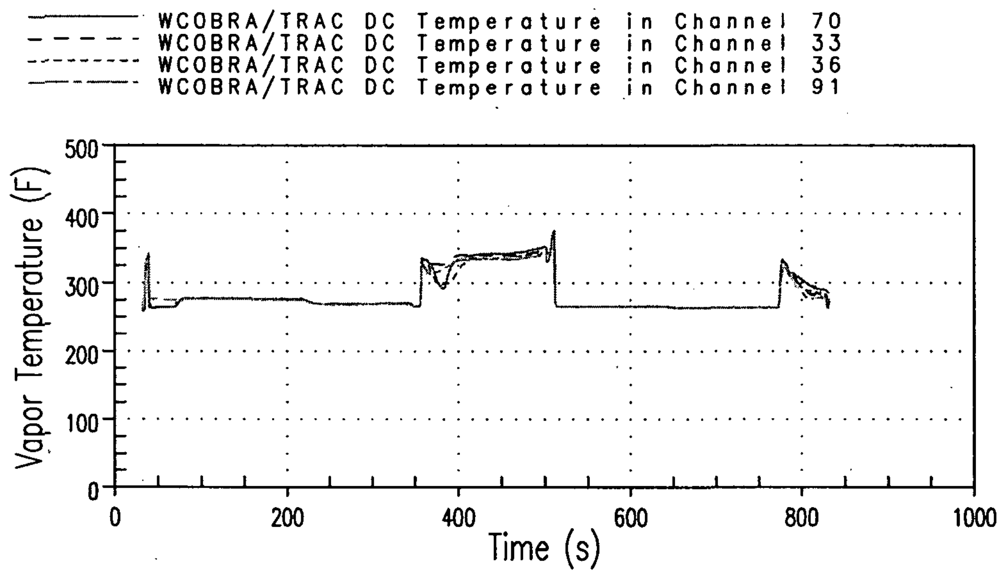

Figure 3-32 Measured Downcomer Fluid Temperature at Level 24 for UPTF Test 25

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Figure 3-33 Predicted Downcomer Fluid (Vapor) Temperature at Level 24 for UPTF Test 25

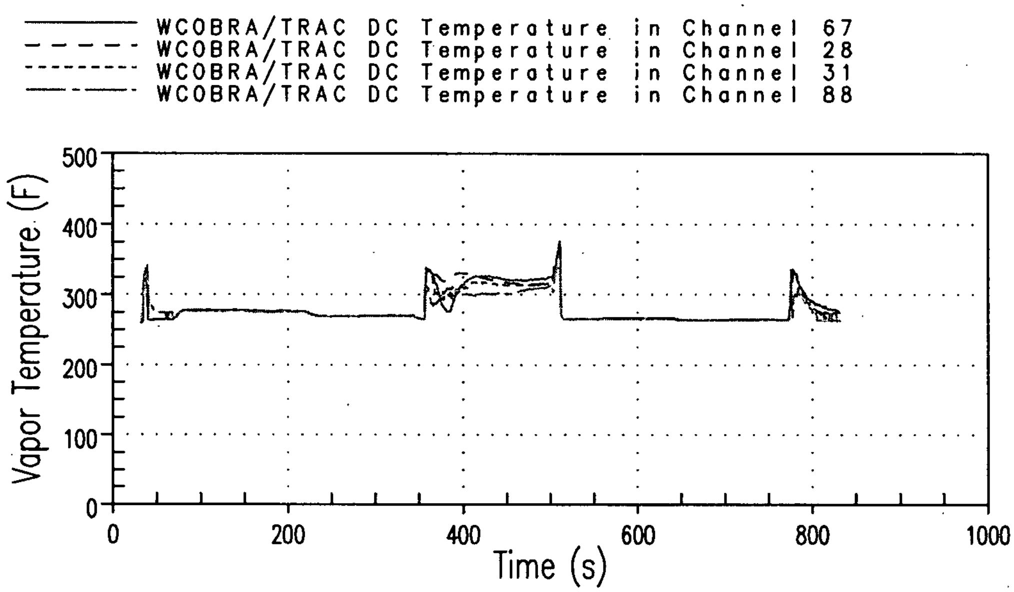

Figure 3-34 Measured Differential Pressure between Upper Plenum and Downcomer for UPTF Test 25

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Figure 3-35 Predicted Differential Pressure between Upper Plenum and Downcomer for UPTF Test 25

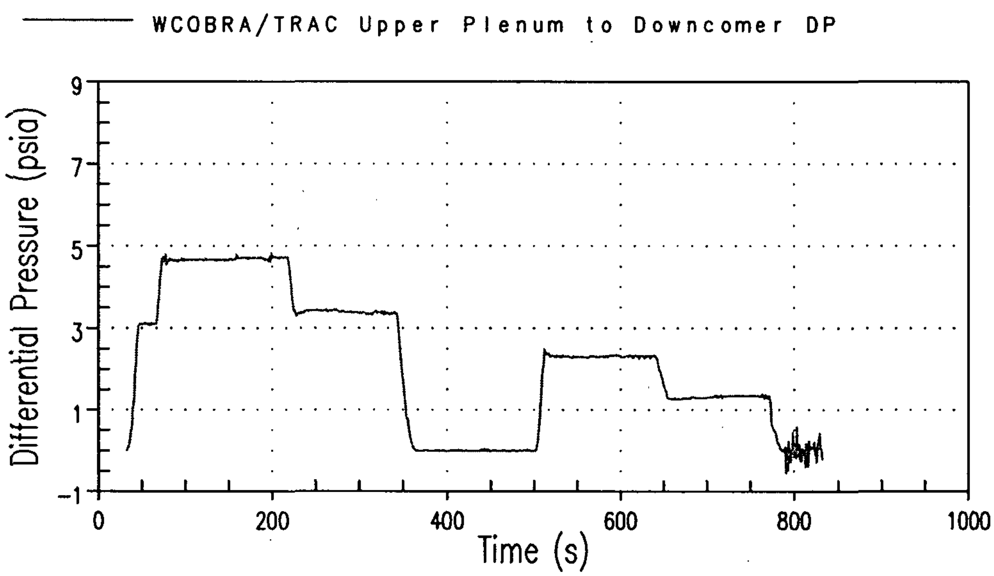

Figure 3-36 Measured Axial Differential Pressure in Downcomer for UPTF Test 25

[

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Figure 3-37 Predicted Axial Differential Pressure in Downcomer for UPTF Test 25

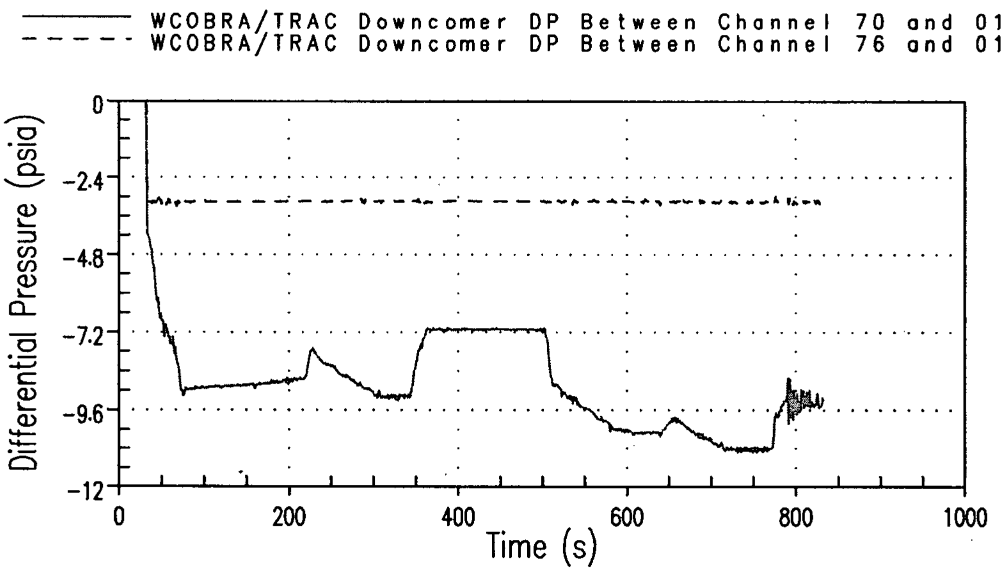

Figure 3-38 Measured Axial Differential Pressures in Downcomer for UPTF Test 25

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Figure 3-39 Predicted Axial Differential Pressures in Downcomer for UPTF Test 25

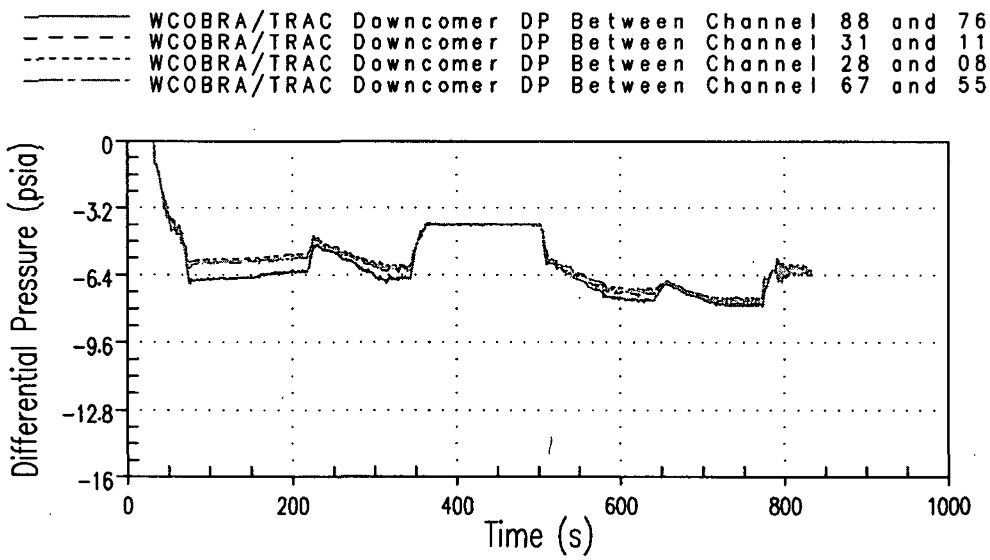

Figure 3-40 Measured Azimuthal Differential Pressure in Downcomer at Level 06 for UPTF Test 25

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Figure 3-41 Transverse Differential Pressures in Downcomer at Level 06 for UPTF Test 25

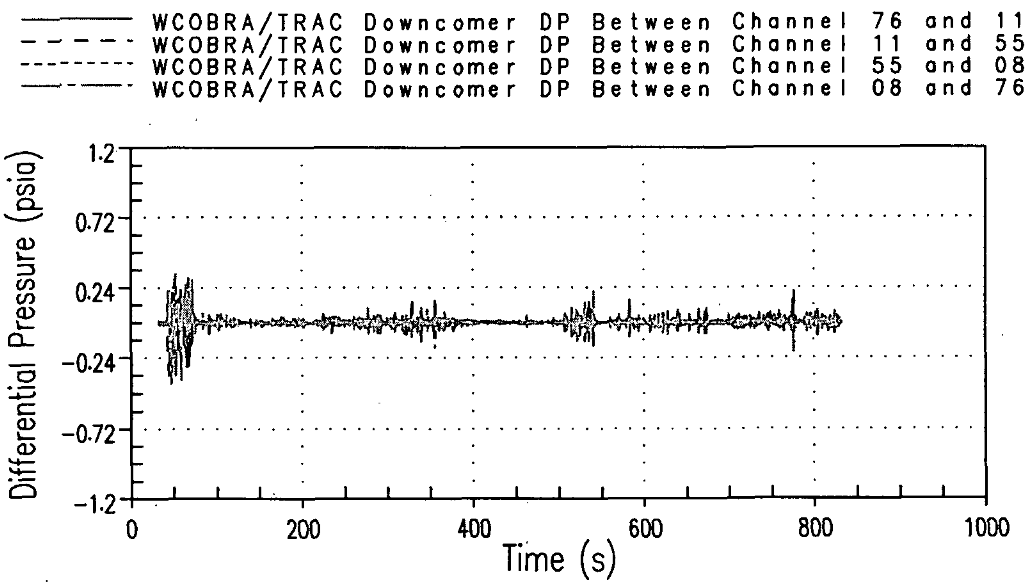

Figure 3-42 Measured Azimuthal Differential Pressure in Downcomer at Level 22 for UPTF Test 25

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Figure 3-43 Transverse Differential Pressures in Downcomer at Level 22 for UPTF Test 25

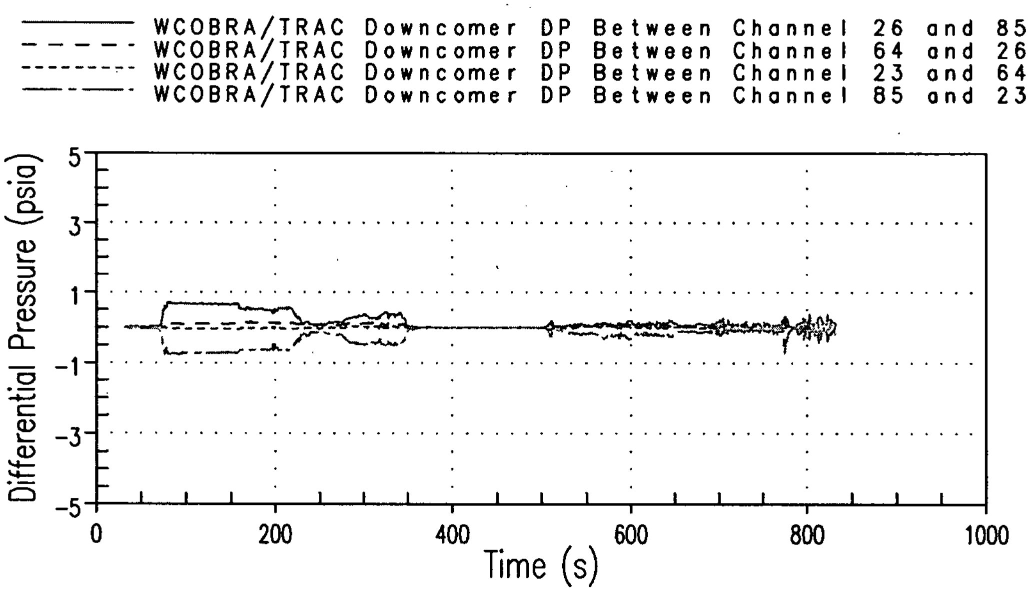

Figure 3-44 Estimated Downcomer Water Levels for UPTF Test 25

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Figure 3-45 Calculated Downcomer Water Levels for UPTF Test 25

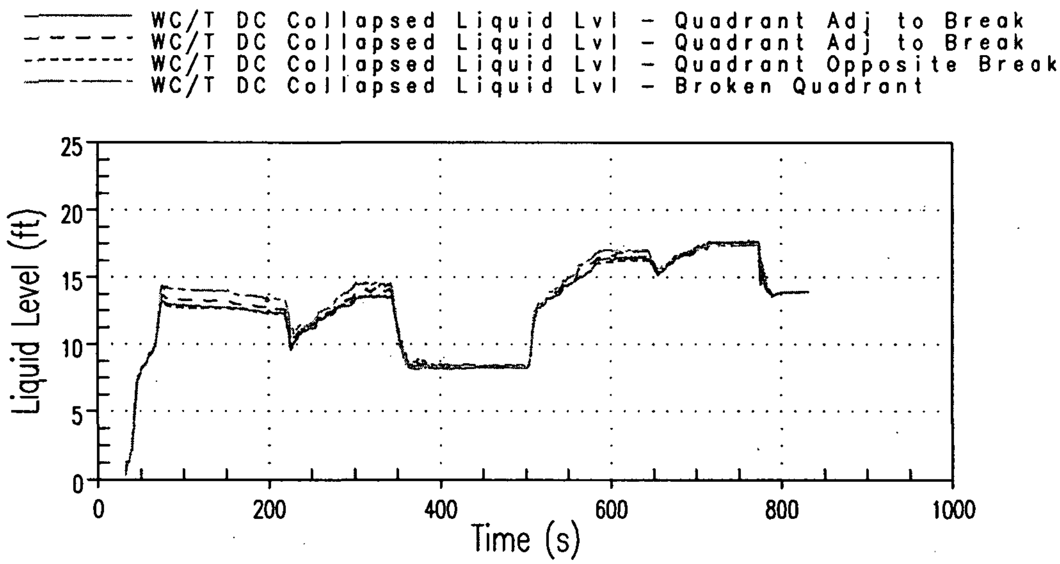

Figure 3-46 Estimated Broken Loop Steam Flow Rate for UPTF Test 25

[

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Figure 3-47 Calculated Broken Loop Steam Flow Rate for UPTF Test 25

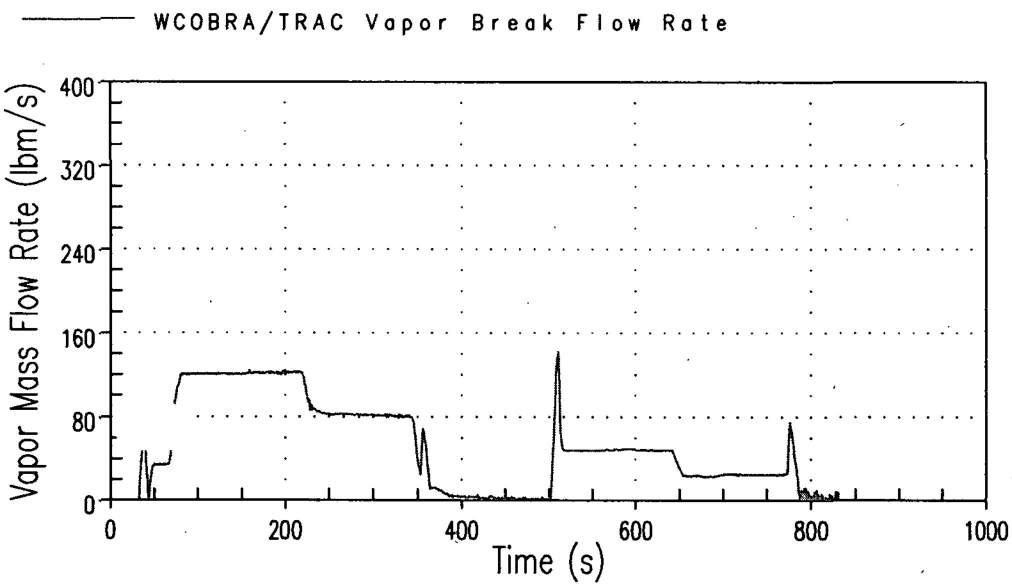

Figure 3-48 Calculated Broken Loop Total Flow Rate for UPTF Test 25

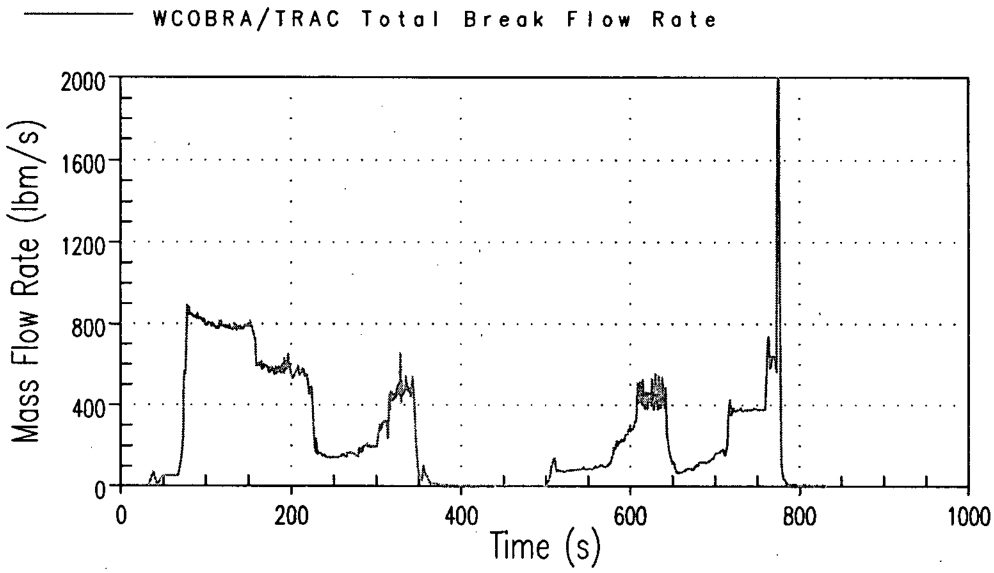

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Figure 3-49 Void Height versus Steam Flow Rate for UPTF Test 25A

4.0 Cylindrical Core Test Facility (CCTF) Simulation Using WCOBRA/TRAC

4.1 Introduction

To assess the capability of the WCOBRA/TRAC computer code to predict the thermal-hydraulic core behavior in PWRs, specific code validation was performed using data from the Cylindrical Core Test Facility (CCTF Core-II, Reference 2). The CCTF test program was conducted by the Japan Atomic Energy Research Institute (JAERI) and was used to investigate the thermal-hydraulic response of the plant during the refill and reflood phases associated with a postulated Loss of Coolant Accident (LOCA). The objective of this section is to assess the ability of WCOBRA/TRAC to predict the cladding temperature response, mass flows, and liquid distribution in CCTF. The facility and test used for the prediction are summarized, the WCOBRA/TRAC modeling is described in detail, and the predicted results are compared with data.

4.2 CCTF Test C2-4 Run 62

The CCTF tests are the largest scale integral tests available to investigate the phenomena important during the reflood phase. CCTF has a flow area scaling of 1/21.4 to a four-loop PWR. Their large scale makes them particularly suited as verification of the ability of the code to predict three-dimensional effects in the core. In addition, the full-height scaling makes these tests important indicators on the extent to which core/downcomer oscillations affect the reflood transient.

The test chosen for simulation by WCOBRA/TRAC is C2-4 (Run 62). Run 62 (Reference 2) was taken as the reference test in the Code Qualification Document (Reference 3) CCTF simulations. The initial and boundary conditions for this test are given in Table 4-1. They are compared, where appropriate, with the range of conditions expected in a typical four-loop PWR at the beginning of reflood (scaled to CCTF).

4.3 CCTF Facility Description

The CCTF Core-II is a large scale experimental facility designed to study the system response of a typical four-loop PWR for loss-of-coolant transients (Figure 4-1). The facility is used to provide data on the thermal-hydraulic behavior in the primary system during the refill and reflood phases of a hypothetical LOCA in a PWR. Table 4-1 compares the scaled dimensions of the system components with those of a PWR.

The CCTF includes a full-height (3657.6 mm (12 foot) heated length) core section with three intact loops, and a fourth loop simulating a full double-ended guillotine break. The test vessel includes a downcomer, lower plenum, core region, and upper plenum with associated internals (support columns and guide tubes). The dimensions for the vessel are shown in Figure 4-2. The configuration of the rods in the core and the upper plenum structure are shown in Figure 4-3. The core has 32 8x8 rod bundles each containing 57 electrically heated rods (10.7 mm (0.421 in) OD) and 7 unheated/instrumented rods (13.8 mm (0.543 in) OD). The rods have a pitch spacing of 14.3 mm (0.563 in). The geometry of these rods is equivalent to a typical PWR 15x15 fuel assembly. Each heated rod has a nichrome heating element and is packed with magnesium oxide and boron nitride. The sheath is made of Inconel-600. The rods are held together by six grids spaced at 665 mm (26.18 in) intervals up the bundle.

The core is divided into the three main power zones: low, intermediate, and high. The lower power zone consists of 16 assemblies on the periphery of the core, as shown in Figure 4-3. The intermediate power zone consists of 12 assemblies, while the high power zone consists of the 4 central assemblies. Under guide tubes, there are 4 low power assemblies and 6 medium power assemblies. Under support columns, there are 8 low power assemblies and 2 high power assemblies. Under open holes, there are 4 low power assemblies, 6 medium power assemblies, and 2 high power assemblies. The axial power profile, along with the locations at the grid spacers, is shown in Figure 4-4.

The three intact loops and the broken loop each contain a steam generator and pump simulator. Flow from the broken loop enters two interconnected containment tanks via two blowdown valves, connected to each break. ECC water can be injected either from two accumulator tanks or by an LPCI pump and its associated water storage tank. Water can be injected directly to injection ports positioned in the lower plenum or to the cold legs.

4.4 CCTF Test Procedure

The following is a general outline of the experimental test procedure. Figure 4-5 shows the sequence of events for the test and Table 4-2 contains a summary of the initial test conditions for CCTF Test C2-4 Run 62.

The primary system was heated with pre-heaters to its specified temperatures and pressurized to a specified pressure using steam. The water in the LPCI tanks and accumulator tanks was heated to its specified temperature. LPCI water was circulated to ensure that the injection lines were at the same temperature. The accumulator tanks were pressurized with nitrogen to give sufficient head for the required injection flow. The steam generator secondary fluid was then heated and pressurized. The heaters were then turned off and the lower plenum was filled to the specified level with saturated water. When the initial conditions had been established power was applied to the heater rods and data recording started (referred to as time zero). The heater rods heated up under near adiabatic conditions until the cladding temperature reached a pre-specified value.

At this point accumulator injection to the lower plenum began. The containment tank pressure was maintained throughout the tests by controlling the outlet valve on the containment tanks. The heater rod power decay was initiated when the water reached the bottom of the heated length of the core (referred to as the BOCREC time). The water injection was changed from the lower plenum to the cold legs after a specified time. When the accumulator flow was coming to an end, LPCI flow was introduced to the cold legs and was maintained until the end of the test.

The generated steam and the entrained water flowed via broken and intact loops to the containment tanks. The steam was then vented to the atmosphere to maintain a constant pressure in the containment tanks. After all thermocouples on the surface of the heater rods indicated quench, the power supply to the heater rods and the ECC water injection were turned off. The recording system was then stopped, terminating the test.

4.5 WCOBRA/TRAC CCTF Model

The WCOBRA/TRAC model used for the CCTF simulations uses one-dimensional components for the three intact loops and for the broken loop, and employs a sub-channel formulated three-dimensional mesh for the vessel. First, the vessel component model is described. This is followed by a description of the loop model.

4.5.1 Vessel Component Model

The approach used in choosing the noding for a PWR application is described in Section 1.3.4.2 of Volume 1 of the CQD (Reference 3). In summary, cell boundaries are placed at all significant area changes, pressure loss locations, or changes in flow direction in the RCS. In addition, lateral sub-regions are defined in sections where the flow could be multi-dimensional. Multi-dimensional flows are considered likely when the flows into the lateral sub-region are unequal, or where there is a large variation in the heat transfer to the sub-region. In nearly all sub-regions, the combination of these requirements results in a larger number of axial and lateral cells in each sub-region than the minimum required.

In order to apply the code uncertainty estimated from experiments, there must be a specific relationship between the noding used for the PWR model application (as presented in the CQD and the noding utilized in the D.C. Cook specific application), and that used for the experiments. One can choose to either preserve the number of cells or to preserve the axial and lateral dimension of the cells, but not both. This occurs because it is necessary to comply with other rules for model development (e.g., cell boundaries at important pressure change locations) must also be met. For example, for small scale experiments, application of the equal cell number rule will result in smaller cells, while application of the equal dimension rule may result in fewer cells.

The approach taken in this application is consistent with the CQD (Reference 3) with respect to the axial dimensions of the cells in the vessel model. The only change from the CQD model was the addition of lateral cells in the downcomer of the CCTF vessel model. A comparison between the CCTF and the PWR noding as presented in the CQD application (in Reference 3) with the increase in lateral cells from four to twelve is summarized in Table 4-3.

A noding diagram of the vessel model used in the CCTF analysis is shown in Figure 4-6 which shows the channel and inter-channel connections (gaps). Transverse cross sections of each of the seven sections are shown in Figures 4-7 through 4-13. Shown in each figure are the channels used to model each section of the mesh.

The noding for the lower plenum (Section 1) consists of thirteen channels arranged such that the twelve annular channels (1, 2, and 47 through 56) lie below the corresponding channels of the downcomer in the core region and the thirteenth channel (channel 3) lies beneath the core and connects to the four core channels above.

The arrangement of four channels in the core region (Section 2) was chosen to model the different power regions within the core and also to combine regions of the core which share a similar type of flow behavior due to their position in relation to guide tubes, support columns and open flow holes in the upper core support plate. This type of modeling is equivalent to that used for the CQD PWR application. Grouped together are low powered bundles below support columns (channel 6); low powered and medium powered bundles below the open hole regions of the upper core support plate (channel 7); medium and low powered bundles below guide tubes (channel 8) and the final group which contains all the high powered rods (channel 9).

Six WCOBRA/TRAC rods are used to model the 1824 fuel rod simulators. Table 4-4 shows which rods/assemblies they each represent and to which core channels they are connected.

The downcomer region is modeled with a two-dimensional mesh arranged in an annular ring of twelve channels (channels 4, 5, and 57 through 66). Each of these channels represents one twelfth of the downcomer.

The mesh for the upper plenum consists of five sections. The first, Section 3, represents the volume between the tie plate at the top of the heated length and the upper core support plate and also includes the corresponding part of the downcomer. This section, called the tie plate or counter-current flow limiting (CCFL) region, is modeled by seventeen channels. Twelve channels (10, 11, and 67 through 76) extend the downcomer and sit directly above the twelve downcomer channels level with the core region. The four core channels of Section 2 connect to four channels in the tie plate region (channels 12, 13, 14 and 15). A further channel (16) represents the volume of the tie plate region located above the solid portion of the tie plate. Channel 16 is a "global" channel and is not axially connected to channels in Sections 2 and 4.

The upper plenum modeling is similar to the PWR modeling in its use of "jet" channels (for example, channels 12, 13, 14, and 15) surrounded by "global" channels such as channel 16. The goal of this model is to accurately reflect the expected liquid distribution in the upper plenum, which is conceptually illustrated in Figure 4-14. Above the open holes in the core plate, steam and entrained drops generated in the core are expected to form jets (represented by the "jet" channels) which penetrate through a layer of water which has de-entrained onto the structures in the upper plenum, then drained onto the core plate solid surface (represented by the "global" channels).

Sections 4 and 5 (Figures 4-10 and 4-11) represent elevations extending from the top of the upper core support plate to the bottom of the hot legs. The two sections are modeled in the same way, so only section 4 is described. The section has twelve channels (17, 18, and 77 through 86) which correspond to the downcomer channels of the lower sections. Three of the upper plenum channels represent the flow areas projected by the open hole region, support column region, and high power channel region through the upper core support plate (channels 20, 19 and 21 respectively). The fourth represents the flow areas and wetted perimeters of the guide tubes through the section (channel 21) while the fifth channel (channel 23), the global channel, makes up the remainder of the volume of the section.

Section 6 contains the hot and cold leg connections and extends from the bottom to the top of the hot legs. The section is similar to the previous two having twelve downcomer channels and five plenum channels which correspond to those described for Sections 4 and 5. Additionally, this section has four extra channels on either side which represent the hot leg penetrations – three for the intact hot legs (channels 33, 34, and 117) and one for the broken loop hot leg (channel 118). Gaps 90, 91, 96, and 112 are blocked to represent the hot leg nozzle penetrations in the downcomer.

Section 7 represents elevations running from the top of the hot legs to the upper core plate. It has five plenum channels and twelve downcomer channels arranged in the same way as for Sections 4 and 5.

The fuel rod simulators and the solid structures within the vessel component are modeled using the rod and unheated conductor models.

4.5.2 Loop Component Model

A diagram of the loop components used to model the CCTF system is shown in Figure 4-15. The three intact loops each consists of a hot leg pipe, steam generator (with associated fills), pump suction pipe, pump pipe, cold leg tee, and ECCS fill components. The fill components for the steam generator each have a constant zero velocity specified, corresponding to the way the CCTF steam generator operated during the test. The ECC fill component, which is connected to the branch of the cold leg tee, models the correct volumetric flow of ECC water into the cold leg due to accumulator flow and LPCI.

Each of the cold leg and hot leg pipes are broken into mesh cell lengths such that no one cell produced an overly restrictive limit on the timestep to be less than or equal to the Courant number. The length and elevation changes of the piping are conserved. Heat transfer to and from the pipe wall is included by representing the pipe wall by two radial heat transfer nodes.

The pump simulators are modeled using a pipe component that has the same volume as the pump simulator but with the flow area of the cold leg so that the code would not calculate any spatial acceleration pressure losses through the pump. A loss coefficient is specified at a node boundary near the pump location to simulate the loss caused by the pump simulator. The tee branch for the ECC fill line in the cold leg is attached to the node corresponding to the physical location of the line in the facility.

The steam generator components are modeled with the secondary side divided into four vertical nodes that are filled with water (void fraction equal to zero). The primary side is divided into eight nodes, six in the tube region, one for the inlet plenum, and one for the outlet plenum. The total length of the tube nodes is equal to the average tube length. The flow area of these nodes is equal to the flow area of a single tube times the number of tubes in the tube bundle. The volume of the inlet plenum modeled corresponds to the physical volume of the plenum. The height of the plenum is set equal to the vertical distance from the top of the tube sheet to the outside bottom surface of the shell to conserve elevation. The distance between the shell bottom and the cold leg centerline was then modeled as part of the cold and hot leg pipes. The area of the junction connecting the plenum to the piping is set equal to the area of the connecting pipes in the facility. The top area of the plenum is set equal to the tube bundle area.

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4.6 CCTF Test C2-4 Run 62 Transient Calculation

In this section, the WCOBRA/TRAC predictions are examined. Predicted cladding temperatures are compared with data averages of all instrumented rods within the channel, excluding obviously bad data channels. Predicted vapor fractions are compared with vapor fractions estimated from differential pressure (delta-p) measurements. In the core, the delta-p between several one-foot spans is available. Collapsed water levels and masses in various components are also estimated from delta-p measurements.

In CCTF, liquid and vapor mass flows in the loops were measured at instrument spool pieces containing turbine meters and drag discs. The locations of these measurement spool pieces are shown in Figure 4-1.

In general, the peak cladding temperature (PCT) values and quench times calculated by WCOBRA/TRAC for the CCTF tests were over-predicted (Figures 4-16 to 4-18). WCOBRA/TRAC also predicts a period of cool down at about 100 seconds, followed by a second heatup. This is caused by excess entrainment into the loops as will be shown later. The predicted vapor temperatures (Figure 4-19) are substantially higher than the data, although the measurements are probably affected by rewetting of the thermocouples (T/Cs). At elevations other than 6 feet, the data showed almost immediate rewetting. Prior to rewet the vapor temperature measurement at 6 feet (Figure 4-19) agrees well with the predicted value.

The core collapsed liquid level is shown in Figure 4-20. WCOBRA/TRAC under-predicts the mass in the bundle during most of the transient. For a short time period around 150 seconds there is a great deal of oscillation in the calculated results; comparison of the mean values to the data appears to be at or slightly below the core collapsed liquid level. Figure 4-21 shows the collapsed level in the upper plenum. Evidence of liquid appears soon after reflood begins in the WCOBRA/TRAC calculation. This is caused by excess entrainment from the core. There is no measured evidence of liquid until 240 seconds into the test, indicating that entrainment from the core was low prior to this time. The predicted level reaches an equilibrium value, indicating that for any liquid entrained into the upper plenum an equal amount is entrained into the hot legs.

In a gravity reflood transient, the magnitude of the inlet flow is influenced by two competing effects: the driving force of the column of water in the downcomer, and the resistance to steam flow in the loops. Figures 4-22 and 4-23 show the pressure drop from the lower plenum to the upper plenum and from the lower plenum to the top of the downcomer. The predicted values are in good agreement with the measured values. Figures 4-24 and 4-25 compare the pressure difference across the intact loop and broken loops. The agreement is seen to be good between the predicted values and the data.

Figures 4-26 and 4-27 compare predicted and measured total flow rates in the intact and broken hot legs. Both figures indicate that WCOBRA/TRAC over-predicts the total flow. The reason for this is the higher predicted entrainment from the bundle. This higher entrainment also leads to the cooling and subsequent heat up of the cladding as noted earlier.

CCTF played an important role in validating the ability of the WCOBRA/TRAC code to accurately calculate the interaction of different phenomena during the refill/reflood period of a PWR LOCA as described in Appendix A of the CQD (Reference 3). The collapsed liquid levels in the downcomer, core, and upper plenum as well as the pressure drop and flow rate comparisons confirm that the WCOBRA/TRAC code predicts the thermal-hydraulics during gravity reflood in an adequately accurate manner and is essentially unchanged from the results documented in CQD.

Specifically, in comparisons of CCTF data in the CQD, the calculated cladding temperature with the WCOBRA/TRAC model (with 4 downcomer channels) is on average 69.4°C (125°F) greater than the experimental data considering the 6, 8, and 10 ft elevations. For the CCTF Test C2-4 Run 62 simulation with twelve downcomer channels, the WCOBRA/TRAC calculated clad temperature is on average also 67.4°C (121°F) greater than the experimental data considering the same elevations. There are small elevation to elevation differences, however, the overall prediction matches very well. It can be seen that the PCT results from the cases with revised downcomer noding are quite similar to the results documented in the CQD, and the average PCT difference between the WCOBRA/TRAC calculation and the experimental data is similar between these cases. See Table 4-5 for additional information.

As such, it is concluded that WCOBRA/TRAC continues to adequately predict the thermal-hydraulic behavior of CCTF Test C2-4 Run 62. It is also concluded that there is no significant difference in the WCOBRA/TRAC calculation of the CCTF Test C2-4 Run 62 between the original simulation and the simulation with revised downcomer noding.

Table 4-1 Component Dimensions of CCTF Compared to PWR				
[				
				][b]

Table 4-2 CCTF Test C2-4 Run 62 Conditions

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							]a,b,c

Table 4-3 CCTF/PWR Axial Noding Comparison			
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			]a,c

Table 4-4 CCTF Rod to Channel Connections

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			]a,c

Table 4-5 WCOBRA/TRAC Calculated PCT Comparison

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						][a,b,c]

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Figure 4-1 Top View of Primary Loop Piping

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Figure 4-2 Diagram of CCTF Pressure Vessel

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Figure 4-3 CCTF Cross Sections (a) Pressure Vessel (b) Upper Plenum Internals

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Figure 4-4 Axial Power Profile of Heated Rods in CCTF

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]b

Figure 4-5 CCTF Test Sequence for Run 62

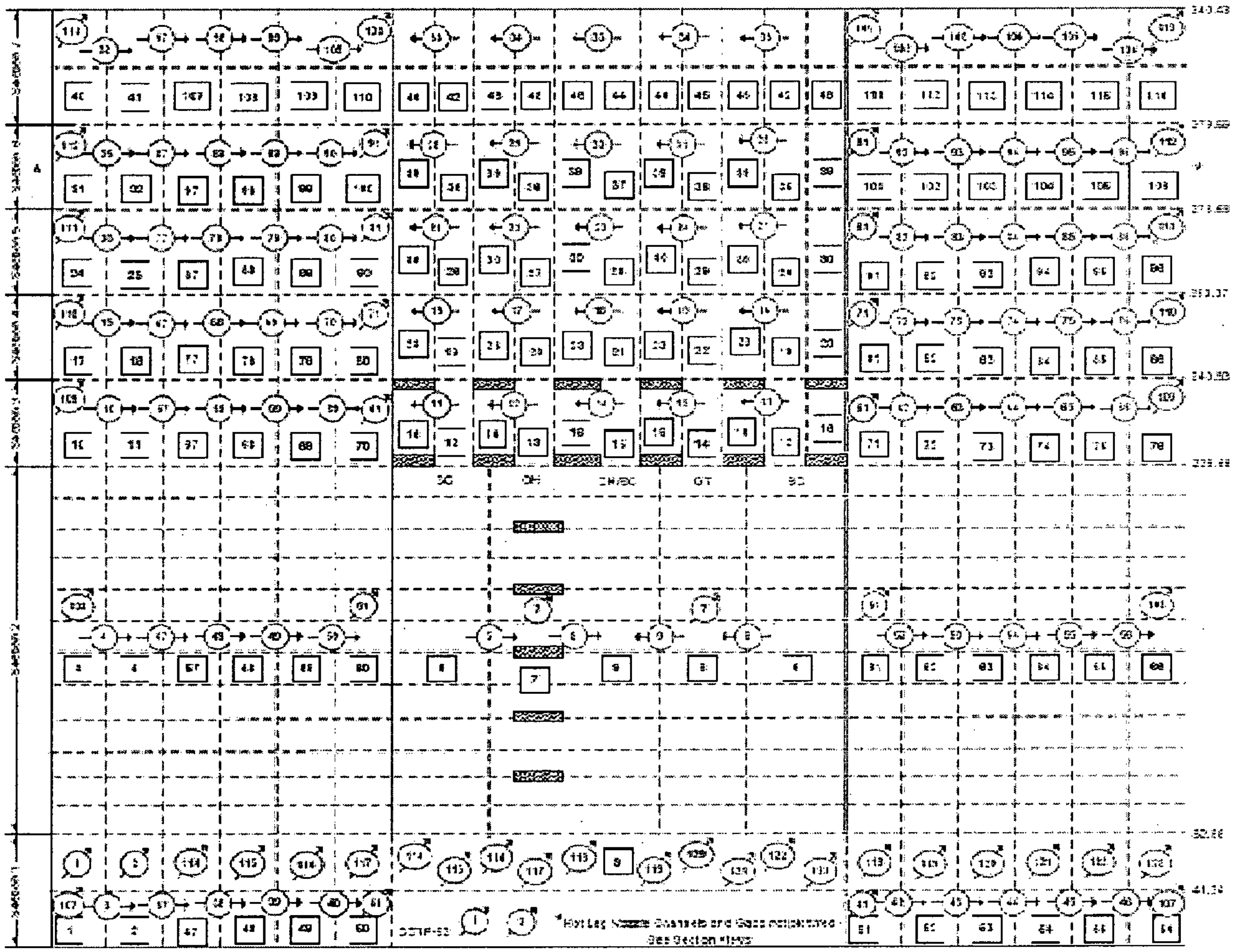

Figure 4-6 CCTF Vessel Noding Diagram

Channel □
Gap ○

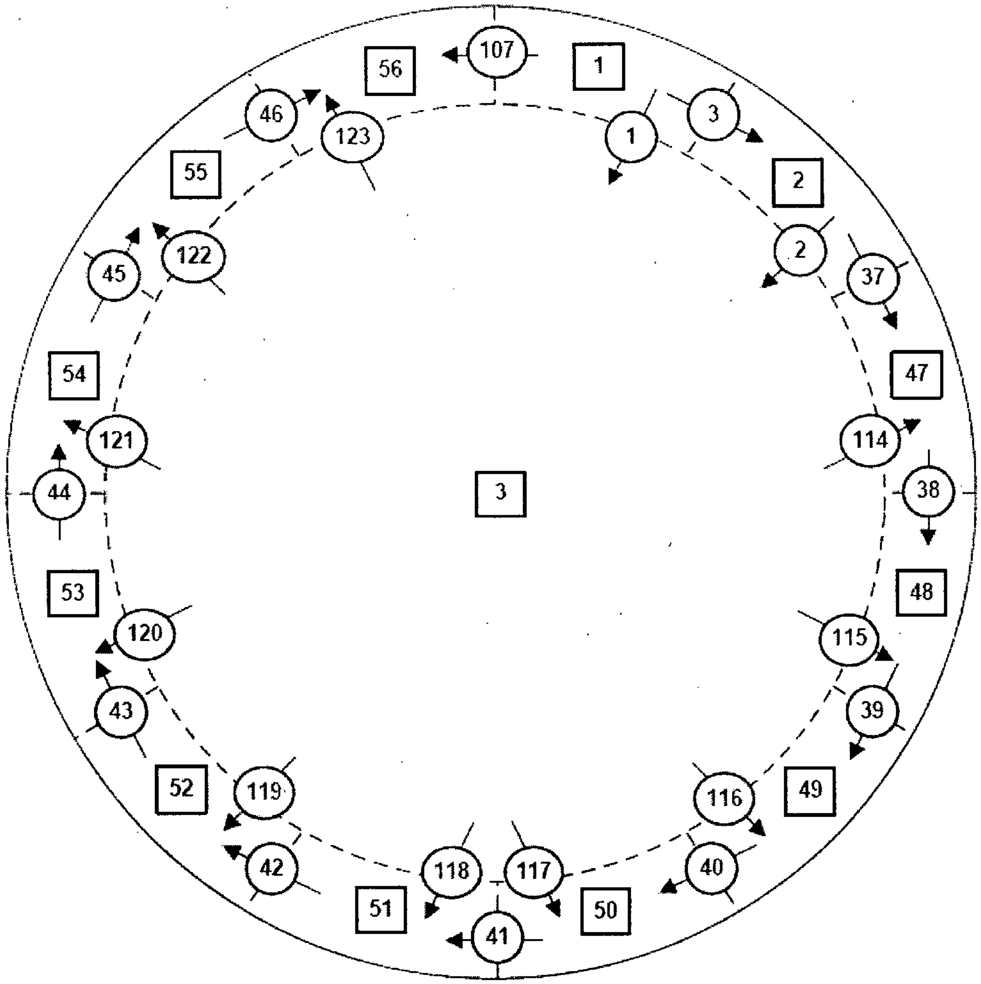

Figure 4-7 CCTF Section 1 Noding

Channel □
Gap ○

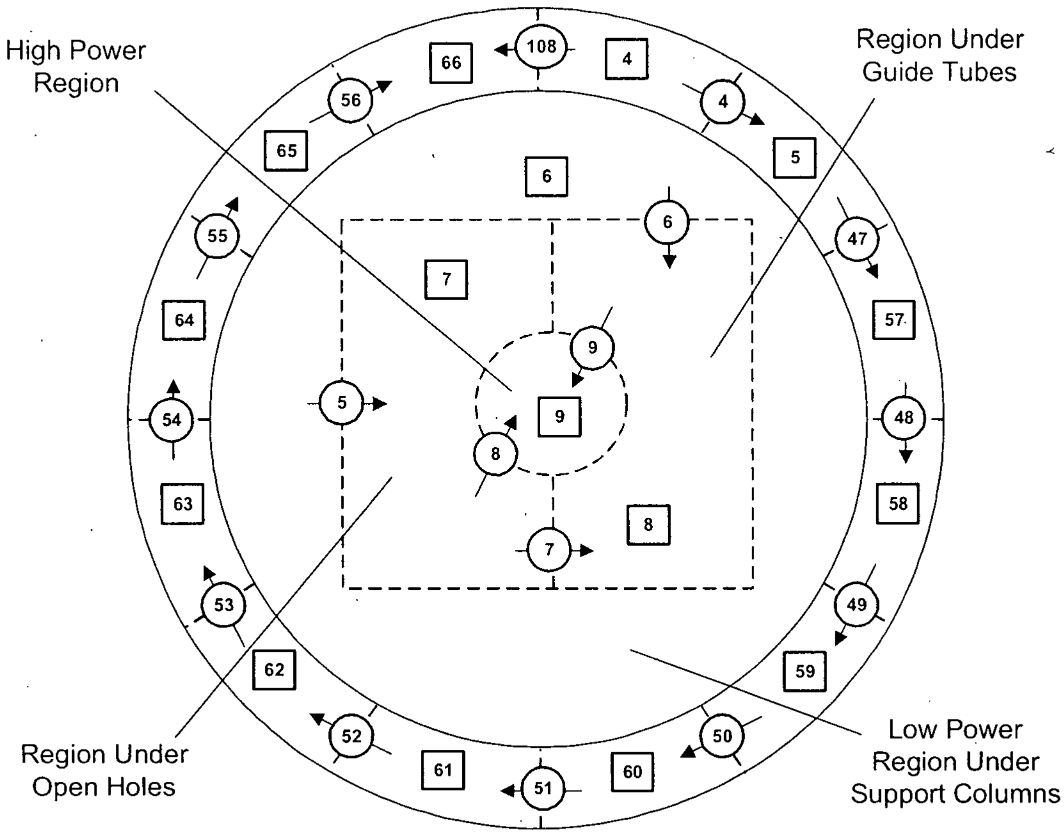

Figure 4-8 CCTF Section 2 Noding

Channel □
Gap ○

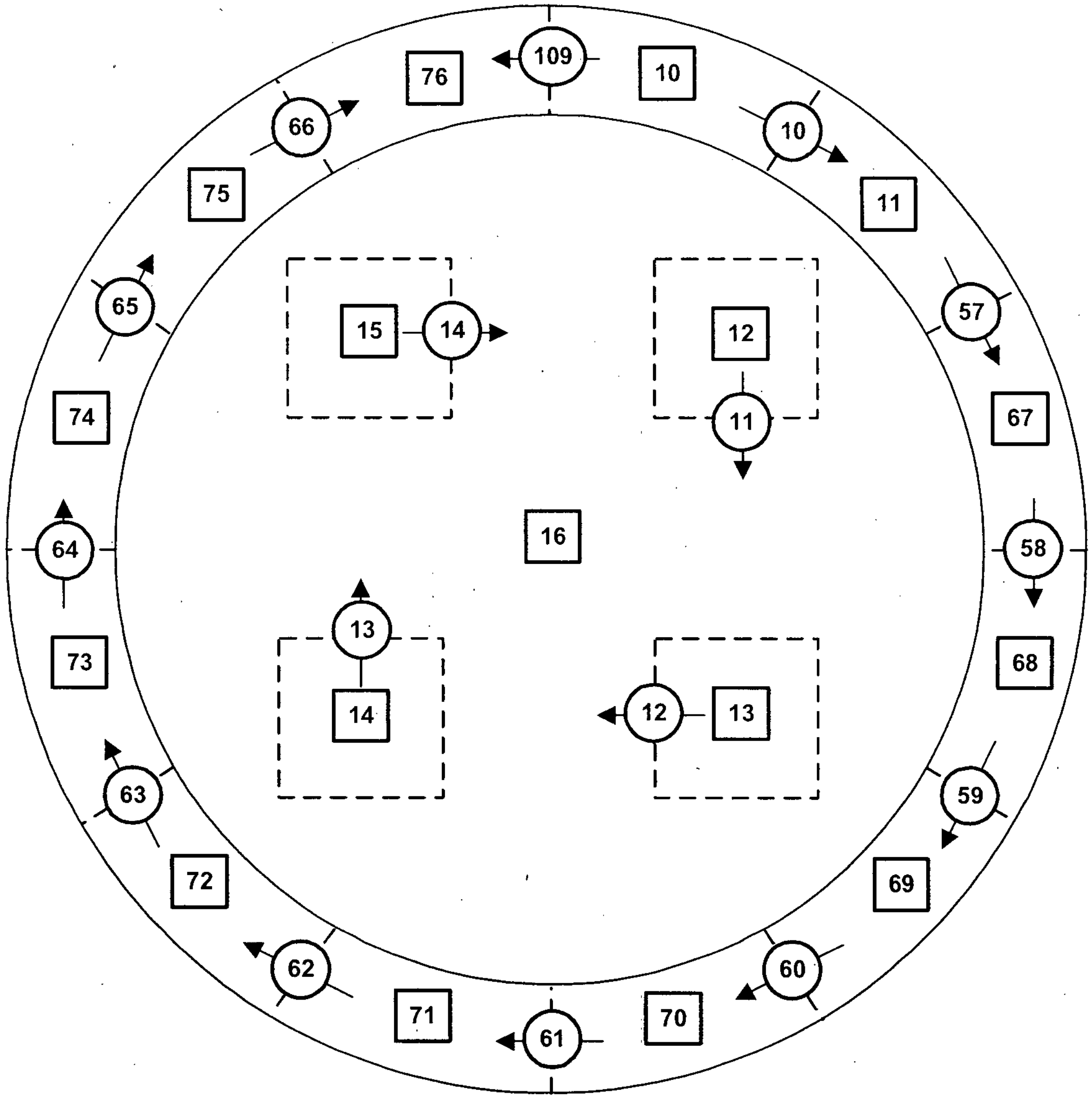

Figure 4-9 CCTF Section 3 Noding

Channel □
Gap ○

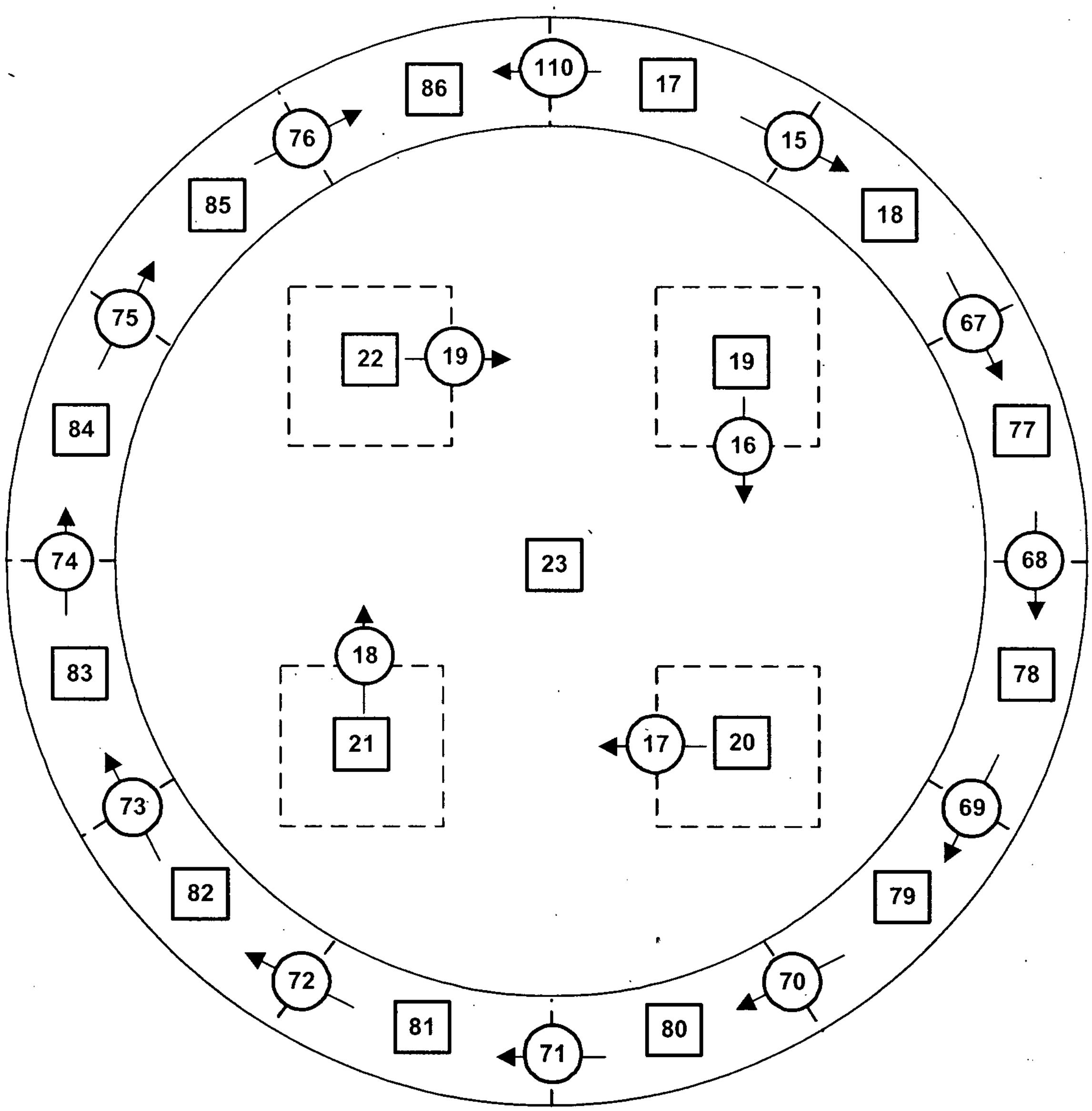

Figure 4-10 CCTF Section 4 Noding

Channel □
Gap ○

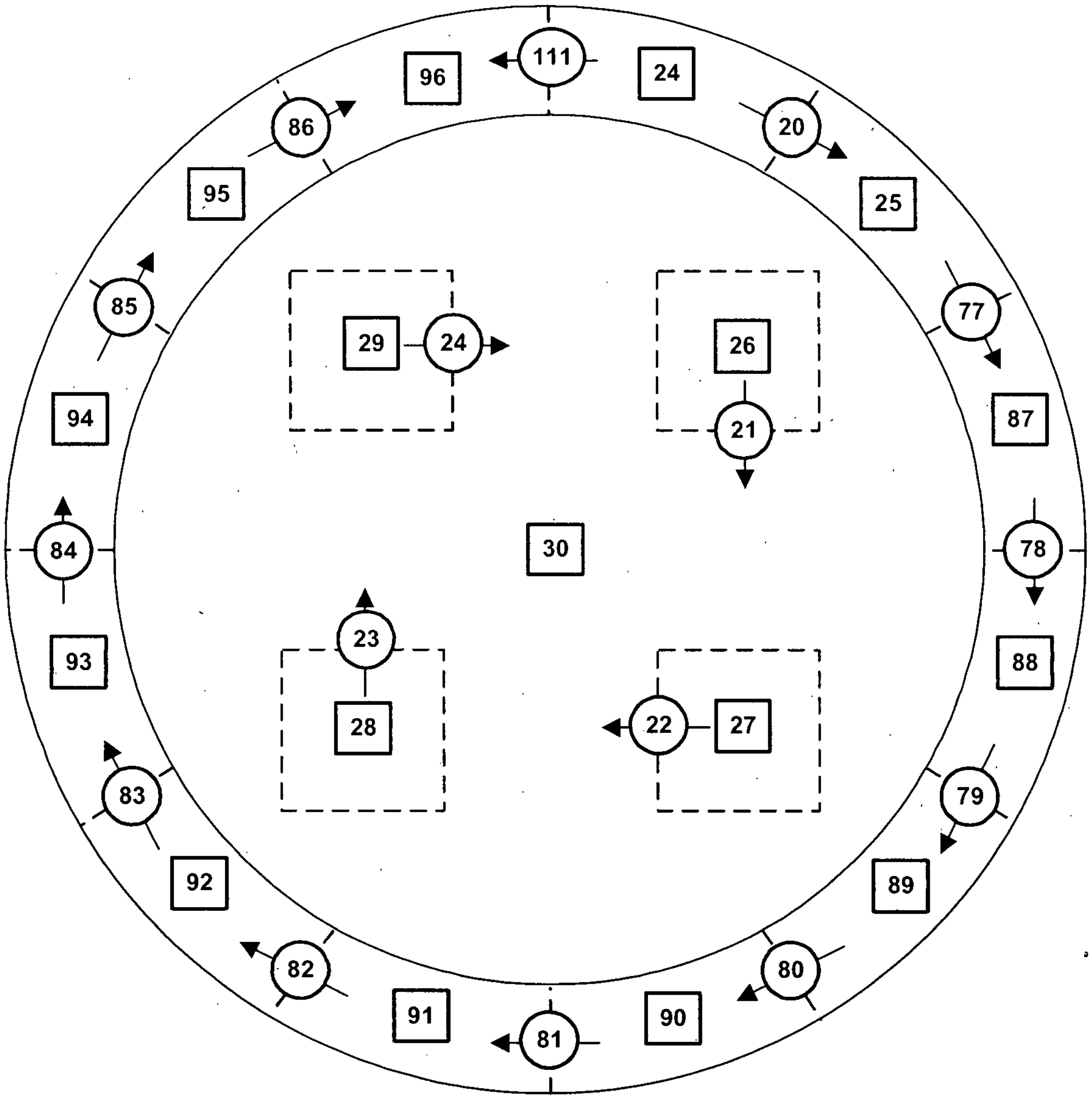

Figure 4-11 CCTF Section 5 Noding

Channel □
Gap ○

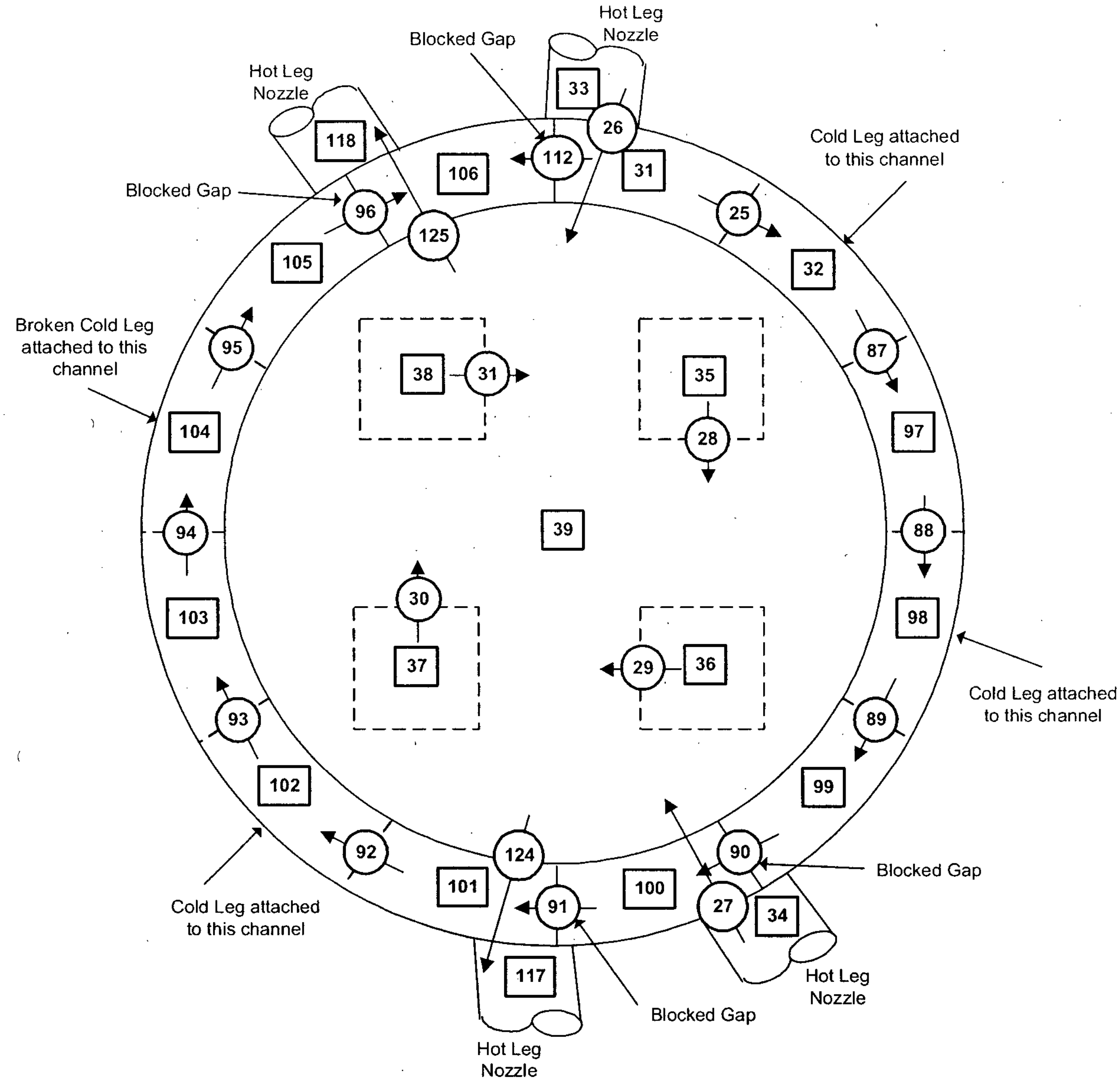

Figure 4-12 CCTF Section 6 Noding

Channel □
Gap ○

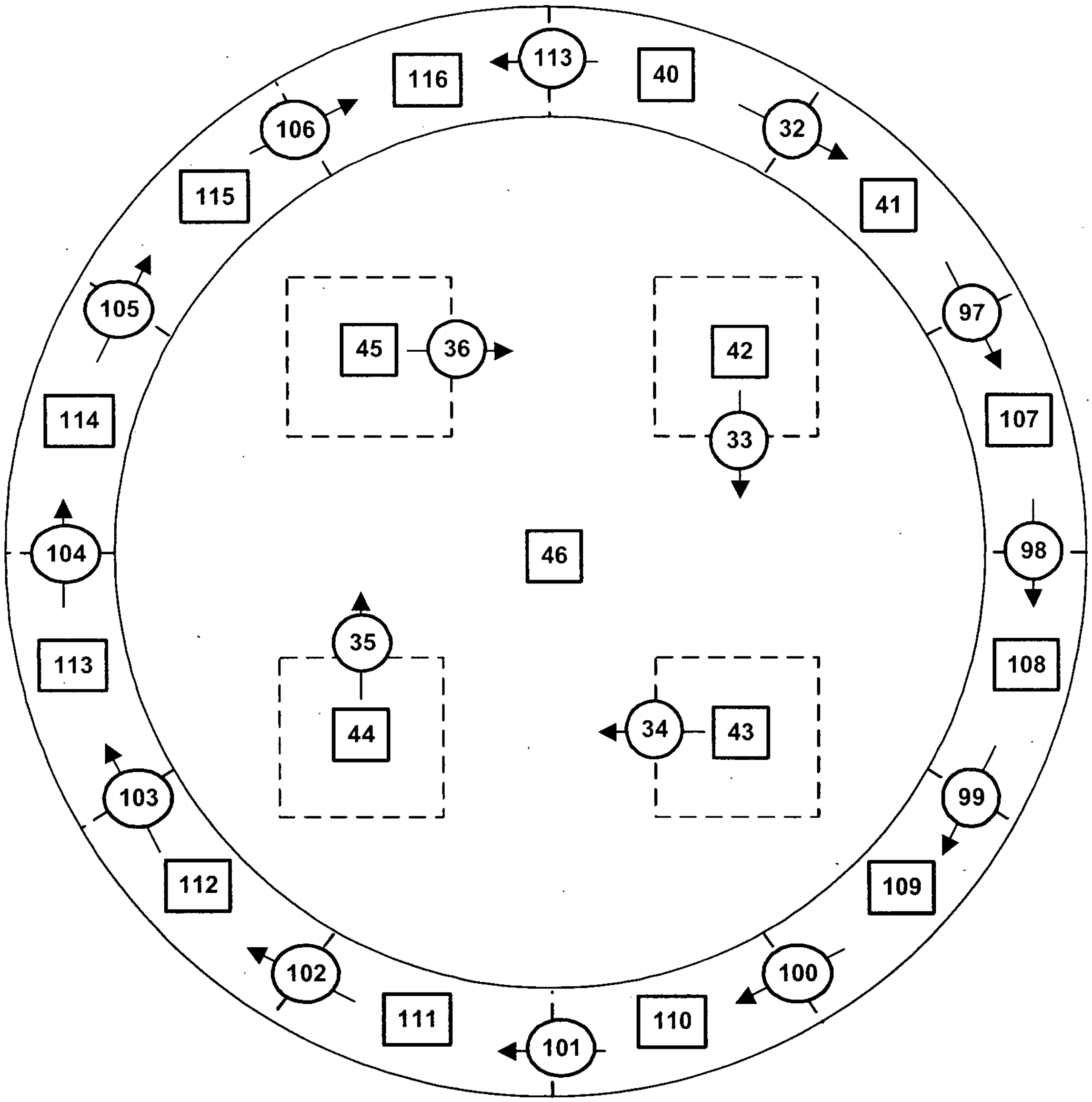

Figure 4-13 CCTF Section 7 Noding

Channel □
Gap ○

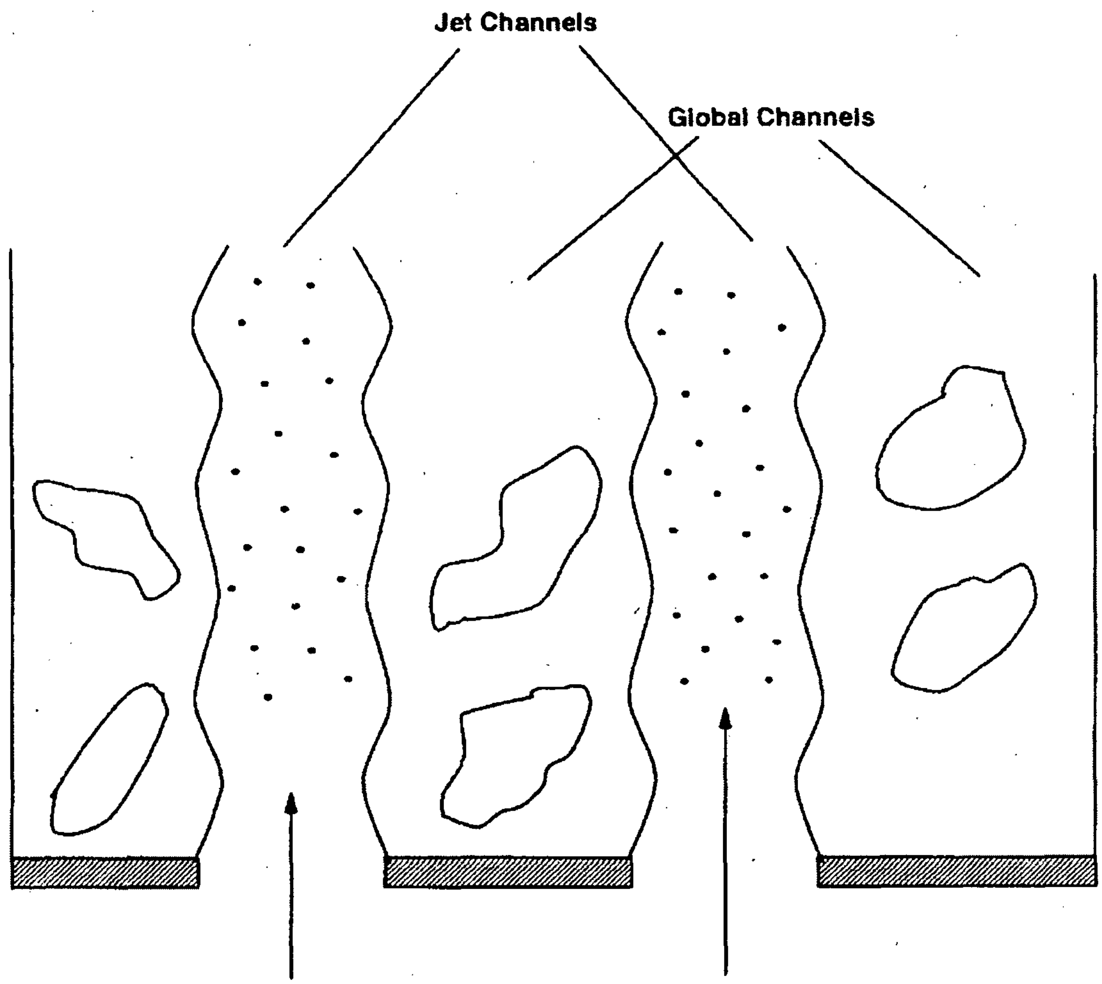

Figure 4-14 Illustration of Predicted Liquid Distribution

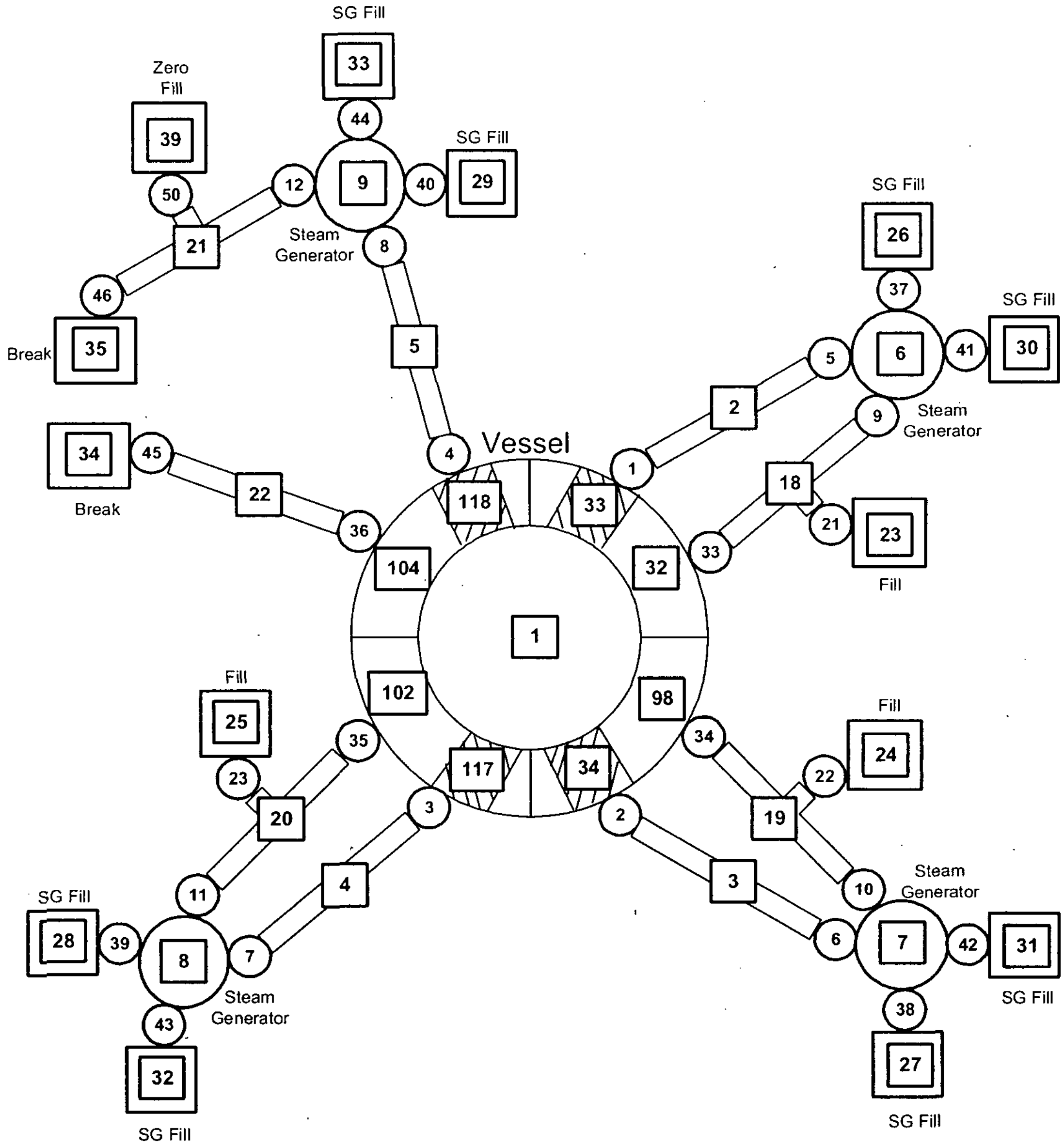

Figure 4-15 CCTF Loop Component Diagram

Junction □
Component ○

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Figure 4-16 CCTF Run 62 Cladding Temperature at 6.0 ft for Channel 9 (Rod 6)

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Figure 4-17 CCTF Run 62 Cladding Temperature at 8.0 ft for Channel 9 (Rod 6)

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Figure 4-18 CCTF Run 62 Cladding Temperature at 10.0 ft for Channel 9 (Rod 6)

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Figure 4-19 CCTF Run 62 Vapor Temperature at 6.0 ft for Channel 9

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Figure 4-20 CCTF Run 62 Liquid Level in Core

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Figure 4-21 CCTF Run 62 Liquid Level in Upper Plenum

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Figure 4-22 CCTF Run 62 Pressure Difference from Lower Plenum to Upper Plenum

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Figure 4-23 CCTF Run 62 Pressure Difference from Lower Plenum to Top of Downcomer

[

]b

Figure 4-24 CCTF Run 62 Pressure Difference Across Intact Loop

[

]b

Figure 4-25 CCTF Run 62 Pressure Difference Across Broken Loop

[

]b

Figure 4-26 CCTF Run 62 Total Mass Flowrate in Intact Loop Hot Leg

[

]b

Figure 4-27 CCTF Run 62 Total Mass Flowrate in Broken Loop Hot Leg

5.0 Conclusions

Three test simulations were executed in order to validate the D.C. Cook-specific adaptation of the Reference 1 evaluation model, namely: UPTF Test 6, UPTF Test 25A and CCTF Test C2-4 Run 62. WCOBRA/TRAC was able to predict the overall thermal-hydraulic behavior of the reflood phase with adequate agreement to the test data and consistent with the CQD results with respect to the simulation of CCTF Test C2-4 Run 62 with the revised twelve downcomer channel model. The cladding temperature calculation for the high power rods at the 6, 8, and 10 foot elevations in the core was conservative compared to the experimental data. The average difference between the experimental data PCT and the WCOBRA/TRAC calculated PCT at these elevations was similar between the WCOBRA/TRAC simulation with twelve downcomer channels and the CQD WCOBRA/TRAC simulation of CCTF Test C2-4 Run 62. The collapsed liquid levels in the downcomer, core, and upper plenum as well as the pressure drop and flow rate comparisons confirm that the code's ability to predict the thermal-hydraulics during gravity reflood is adequately accurate and essentially unchanged from the results documented in CQD.

WCOBRA/TRAC also sufficiently predicts the bypass phenomenon in the UPTF Test 6 experiments. [

]a,c

The UPTF Test 25A was simulated with WCOBRA/TRAC to validate the models and correlations used in the code to evaluate the steam water interaction in the downcomer, as well as entrainment in the downcomer at conditions typical of a reflood phase in a postulated LBLOCA. Comparisons between the WCOBRA/TRAC predictions and the measurements showed good overall agreement with the experimental data.

Based on the results of the WCOBRA/TRAC validation with revised downcomer noding, it is concluded that the D.C. Cook-specific adaptation of the vessel model with revised downcomer noding is acceptable for application of the ASTRUM methodology, and that no changes in the uncertainty treatment described in Reference 1 are necessary.

6.0 References

1. Nissley, M. E., et. al., 2005, "Realistic Large-Break LOCA Evaluation Methodology Using the Automated Statistical Treatment of Uncertainty Method (ASTRUM)," WCAP-16009-P-A.

2. Okubo, T., et al., 1984, "Data Report on Large Scale Reflood Test -- 82 --- CCTF CORE-II TEST C2-4 (RUN 062) ---," Department of Nuclear Safety Research, Tokai Research Establishment, JAERI-memo - 59-450.

3. Bajorek, S. M., et. al., 1998, "Code Qualification Document for Best Estimate LOCA Analysis," WCAP-12945-P-A, Volume 1, Revision 2 and Volumes 2 through 5, Revision 1, and WCAP-14747 (Non-Proprietary).

4. Akimoto, H., et al., 1984c, "Pressure Drop through Broken Cold Leg During Reflood Phase of Loss-of-Coolant Accident of PWR," Journal of Nuclear Science and Technology, 21.

5. Emmerling, R., et al., 1988, "Research Program Reactor Safety Upper Plenum Test Facility Program and System Description," U9 414/88/023.

6. 2D/3D Program Upper Plenum Test Facility Experimental Data Report, 1988, "Test No. 6, Downcomer Countercurrent Flow Test," U9 316/88/18.

7. 2D/3D Program Upper Plenum Test Facility Experimental Data Report, 1990, "Test No. 25, Downcomer /Cold Leg Steam/Water Interaction Test," E314/90/11, KWU.

8. MPR, 1990, "Summary of Results from the UPTF Downcomer Separate Effects Tests, Comparison to Previous Scaled Tests, and Application to U.S. Pressurized Water Reactors," MPR Associates, MPR-1163.

9. MPR, 1993, "Reactor Safety Issues Resolved by the 2D/3D Program," MPR Associates, MPR-1346.

10. Glaeser, H., 1992, "Downcomer and Tie Plate Countercurrent Flow in the Upper Plenum Test Facility (UPTF)," Nuclear Engineering and Design 133.

Attachment 1 to AEP:NRC:7565-01

DONALD C. COOK NUCLEAR PLANT UNIT 1 TECHNICAL SPECIFICATION PAGES
MARKED TO SHOW CHANGES

3.4.1-1

3.4.1-2

5.6-3

3.4 REACTOR COOLANT SYSTEM (RCS)

3.4.1 RCS Pressure, Temperature, and Flow Departure from Nucleate Boiling (DNB) Limits

LCO 3.4.1 RCS DNB parameters for pressurizer pressure, RCS average temperature, and RCS total flow rate shall be within the limits specified below:

a. Pressurizer pressure is greater than or equal to the limit specified in the COLR;

b. RCS average temperature is less than or equal to the limit specified in the COLR; and

c. RCS total flow rate is greater than or equal to the limit specified in the COLR. The minimum RCS total flow rate shall be ≥ ~~341,100~~354,000 gpm.

APPLICABILITY: MODE 1.

--NOTE--

Pressurizer pressure limit does not apply during:

a. THERMAL POWER ramp > 5% RTP per minute; or

b. THERMAL POWER step > 10% RTP.

ACTIONS

CONDITION	REQUIRED ACTION		COMPLETION TIME
A. One or more RCS DNB parameters not within limits.	A.1	Restore RCS DNB parameter(s) to within limit.	2 hours
B. Required Action and associated Completion Time not met.	B.1	Be in MODE 2.	6 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.4.1.1	Verify pressurizer pressure is greater than or equal to the limit specified in the COLR.	12 hours
SR 3.4.1.2	Verify RCS average temperature is less than or equal to the limit specified in the COLR.	12 hours
SR 3.4.1.3	Verify RCS total flow rate is ≥ ~~341,100~~ $\boxed{354,000}$ gpm and greater than or equal to the limit specified in the COLR.	12 hours
SR 3.4.1.4	------------------------------NOTE------------------------------ Not required to be performed until 24 hours after ≥ 90% RTP. -- Verify by precision heat balance that RCS total flow rate is ≥ ~~341,100~~ $\boxed{354,000}$ gpm and greater than or equal to the limit specified in the COLR.	24 months

5.6 Reporting Requirements

5.6.5 CORE OPERATING LIMITS REPORT (COLR) (continued)

5. LCO 3.1.6, "Control Bank Insertion Limits";

6. LCO 3.2.1, "Heat Flux Hot Channel Factor ($F_Q(Z)$)";

7. LCO 3.2.2, "Nuclear Enthalpy Rise Hot Channel Factor ($F^N_{\Delta H}$)";

8. LCO 3.2.3, "AXIAL FLUX DIFFERENCE (AFD)";

9. LCO 3.3.1, "Reactor Trip System (RTS) Instrumentation," Functions 6 and 7 (Overtemperature ΔT and Overpower ΔT, respectively) Allowable Value parameter values;

10. LCO 3.4.1, "RCS Pressure, Temperature, and Flow Departure from Nucleate Boiling (DNB) Limits"; and

11. LCO 3.9.1, "Boron Concentration."

b. The analytical methods used to determine the core operating limits shall be those previously reviewed and approved by the NRC, specifically those described in the following documents:

1. WCAP-9272-P-A, "Westinghouse Reload Safety Evaluation Methodology," (Westinghouse Proprietary);

2. WCAP-8385, "Power Distribution Control and Load Following Procedures - Topical Report," (Westinghouse Proprietary);

3. WCAP-10216-P-A, "Relaxation of Constant Axial Offset Control/F_Q Surveillance Technical Specification," (Westinghouse Proprietary);

4. ~~WCAP-10266-P-A, "The 1981 Version of Westinghouse Evaluation Mode Using BASH Code,"~~Plant-specific adaptation of WCAP-16009-P-A, "Realistic Large-Break LOCA Evaluation Methodology Using the Automated Statistical Treatment of Uncertainty Method (ASTRUM)," (Westinghouse Proprietary);

5. WCAP-12610-P-A, "VANTAGE+ Fuel Assembly Reference Core Report," (Westinghouse Proprietary);

6. WCAP-8745-P-A, "Design Bases for the Thermal Overpower ΔT and Thermal Overtemperature ΔT Trip Functions," (Westinghouse Proprietary); and

7. WCAP-13749-P-A, "Safety Evaluation Supporting the Conditional Exemption of the Most Negative EOL Moderator Temperature Coefficient Measurement," (Westinghouse Proprietary).

Attachment 2 to AEP:NRC:7565-01

DONALD C. COOK NUCLEAR PLANT UNIT 1 TECHNICAL SPECIFICATION PAGES WITH THE PROPOSED CHANGES INCORPORATED

3.4.1-1

3.4.1-2

5.6-3

3.4 REACTOR COOLANT SYSTEM (RCS)

3.4.1 RCS Pressure, Temperature, and Flow Departure from Nucleate Boiling (DNB) Limits

LCO 3.4.1 RCS DNB parameters for pressurizer pressure, RCS average temperature, and RCS total flow rate shall be within the limits specified below:

a. Pressurizer pressure is greater than or equal to the limit specified in the COLR;

b. RCS average temperature is less than or equal to the limit specified in the COLR; and

c. RCS total flow rate is greater than or equal to the limit specified in the COLR. The minimum RCS total flow rate shall be ≥ 354,000 gpm.

APPLICABILITY: MODE 1.

---NOTE---

Pressurizer pressure limit does not apply during:

a. THERMAL POWER ramp > 5% RTP per minute; or

b. THERMAL POWER step > 10% RTP.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. One or more RCS DNB parameters not within limits.	A.1 Restore RCS DNB parameter(s) to within limit.	2 hours
B. Required Action and associated Completion Time not met.	B.1 Be in MODE 2.	6 hours

SURVEILLANCE REQUIREMENTS

	SURVEILLANCE	FREQUENCY
SR 3.4.1.1	Verify pressurizer pressure is greater than or equal to the limit specified in the COLR.	12 hours
SR 3.4.1.2	Verify RCS average temperature is less than or equal to the limit specified in the COLR.	12 hours
SR 3.4.1.3	Verify RCS total flow rate is ≥ 354,000 gpm and greater than or equal to the limit specified in the COLR.	12 hours
SR 3.4.1.4	-----NOTE----- Not required to be performed until 24 hours after ≥ 90% RTP. -----	
	Verify by precision heat balance that RCS total flow rate is ≥ 354,000 gpm and greater than or equal to the limit specified in the COLR.	24 months

5.6 Reporting Requirements

5.6.5 CORE OPERATING LIMITS REPORT (COLR) (continued)

5. LCO 3.1.6, "Control Bank Insertion Limits";
6. LCO 3.2.1, "Heat Flux Hot Channel Factor ($F_Q(Z)$)";
7. LCO 3.2.2, "Nuclear Enthalpy Rise Hot Channel Factor ($F^N_{\Delta H}$)";
8. LCO 3.2.3, "AXIAL FLUX DIFFERENCE (AFD)";
9. LCO 3.3.1, "Reactor Trip System (RTS) Instrumentation," Functions 6 and 7 (Overtemperature ΔT and Overpower ΔT, respectively) Allowable Value parameter values;
10. LCO 3.4.1, "RCS Pressure, Temperature, and Flow Departure from Nucleate Boiling (DNB) Limits"; and
11. LCO 3.9.1, "Boron Concentration."

b. The analytical methods used to determine the core operating limits shall be those previously reviewed and approved by the NRC, specifically those described in the following documents:

1. WCAP-9272-P-A, "Westinghouse Reload Safety Evaluation Methodology," (Westinghouse Proprietary);
2. WCAP-8385, "Power Distribution Control and Load Following Procedures - Topical Report," (Westinghouse Proprietary);
3. WCAP-10216-P-A, "Relaxation of Constant Axial Offset Control/F_Q Surveillance Technical Specification," (Westinghouse Proprietary);
4. Plant-specific adaptation of WCAP-16009-P-A, "Realistic Large-Break LOCA Evaluation Methodology Using the Automated Statistical Treatment of Uncertainty Method (ASTRUM)," (Westinghouse Proprietary);
5. WCAP-12610-P-A, "VANTAGE+ Fuel Assembly Reference Core Report," (Westinghouse Proprietary);
6. WCAP-8745-P-A, "Design Bases for the Thermal Overpower ΔT and Thermal Overtemperature ΔT Trip Functions," (Westinghouse Proprietary); and
7. WCAP-13749-P-A, "Safety Evaluation Supporting the Conditional Exemption of the Most Negative EOL Moderator Temperature Coefficient Measurement," (Westinghouse Proprietary).

Attachment 3 to AEP:NRC:7565-01

REGULATORY COMMITMENTS

The following table identifies those actions committed to by Indiana Michigan Power Company (I&M) in this document. Any other actions discussed in this submittal represent intended or planned actions by I&M. They are described to the Nuclear Regulatory Commission (NRC) for the NRC's information and are not regulatory commitments.

Commitment	Date
I&M will complete the residual heat removal (RHR) cross-tie valve modification, allowing Donald C. Cook Nuclear Plant Unit 1 to operate with RHR cross-tie valves open and four-loop injection during a postulated large break loss-of-coolant accident.	Prior to entering Mode 3 following the Unit 1 Cycle 22 Outage.

Attachment 4 to AEP:NRC:7565-01

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

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Ref: LTR-LIS-07-827, Attachment 1

Our ref: CAW-07-2344

November 19, 2007

APPLICATION FOR WITHHOLDING PROPRIETARY INFORMATION FROM PUBLIC DISCLOSURE

Subject: "WCOBRA/TRAC Validation with Revised Downcomer Noding for D. C. Cook Units 1 and 2," dated November 2007 (Proprietary)

The proprietary information for which withholding is being requested in the above-referenced document is further identified in Affidavit CAW-07-2344 signed by the owner of the proprietary information, Westinghouse Electric Company LLC. The affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.390 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying affidavit by American Electric Power (AEP) Company.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-07-2344, and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: Jon Thompson (NRC O-7E1A)

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared J. A. Gresham, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse), and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

J A Gresham

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed before me
this 19th day of November, 2007

Sharon L. Markle

Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Sharon L. Markle, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Jan. 29, 2011
Member, Pennsylvania Association of Notaries

(1) I am Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse), and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of

Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information that is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in "WCOBRA/TRAC Validation with Revised Downcomer Noding for D. C. Cook Units 1 and 2" (Proprietary), dated November 2007 for submittal to the Commission, being transmitted by the American Electric Power (AEP) Company letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by AEP for D. C. Cook Units 1 and 2 is that associated with the request for NRC approval of "WCOBRA/TRAC Validation with Revised Downcomer Noding for D. C. Cook Units 1 and 2."

This information is part of that which will enable Westinghouse to:

(a) Obtain NRC approval of "WCOBRA/TRAC Validation with Revised Downcomer Noding for D. C. Cook Units 1 and 2.

(b) Provide documentation of the specific adaptation of the ASTRUM analysis method for D. C Cook Units 1 and 2.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to potentially sell the use of this information to its customers for purposes of BELOCA analysis.

(b) The information requested to be withheld reveals the distinguishing aspects of a methodology which was developed by Westinghouse.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar calculations and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

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