NUREG/IA-0230

International Agreement Report

An Assessment of TRACE V5 RC1 Code Against UPTF Counter Current Flow Tests

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Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

August 2010

Prepared as part of
The Agreement on Research Participation and Technical Exchange
Under the International Code Assessment and Maintenance Program (CAMP)

Published by
U.S. Nuclear Regulatory Commission

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ABSTRACT

In a loss of coolant situation ECC lines from cold and hot leg sides try to discharge cooling water into reactor core. Simultaneously core generates great amounts of steam which in return is directed towards the break. On the cold leg side cooling water and steam meet in the downcomer where steam flows up and cooling water is heading into lower plenum. If the steam flow is high enough the result is that a portion, if not all, of the ECC water ends up in the break with the steam flow. Similar situation is present at the upper tie plate where ECC water should break through upper tie plate into the core but steam flow may prevent this from happening.

TRACE V5 RC1 was used in this report to build a partial UPTF model and simulations were run comparing them to the data from 2 counter current flow tests. The simulations for downcomer test were run without counter current flow limitation (CCFL) and with Bankoff restriction using Kutateladze scaling. The upper tie plate simulations were run with also using Wallis scaling.

The one dimensional TRACE UPTF model produced reasonable results in roughly half of the downcomer counter current flow simulations. In upper tie plate CCF simulations ECC water countered too much drag in the upper tie plate and core area for the ECC water to reach lower plenum. It is possible that the built nodalization for upper tie plate was not detailed enough to simulate the inconsistent void fraction distribution.

CONTENTS

Figures

ABBREVIATIONS

CAMP	Code Assesment and Maintenance Program
CCF	Counter Current Flow
CCFL	Counter Current Flow Limitation
ECC	Emergency Core Cooling
KWU	Kraftwerk Union
TRACE	TRAC/RELAP Advanced Computational Engine
UPTF	Upper Plenum Test Facility
USNRC	United States Nuclear Regulatory Commission

1 INTRODUCTION

In a loss of coolant situation ECC lines from cold and hot leg sides try to discharge cooling water into reactor core. Simultaneously core generates great amounts of steam which in return is directed towards the break. On the cold leg side cooling water and steam meet in the downcomer where steam flows up and cooling water is heading into lower plenum. If the steam flow is high enough the result is that a portion, if not all, of the ECC water ends up in the break with the steam flow. Similar situation is present at the upper tie plate where ECC water should break through upper tie plate into the core but steam flow may prevent this from happening.

Upper Plenum Test Facility (UPTF) is a full scale geometrical simulation of a four loop 1300 MW Siemens/KWU pressurized water reactor. Wide variety of counter current flow situations have been tested with this facility and some of the data can be found from report *Downcomer and tie plate countercurrent flow in the Upper Plenum Test Facility* (Ref. 1).

TRACE V5 RC1 was used in this report to build a partial UPTF model and simulations were run comparing them to the data from 2 counter current flow tests. The simulations for downcomer test were run without counter current flow limitation (CCFL) and with Bankoff restriction using Kutateladze scaling. Upper tie plate simulations were run with also using Wallis scaling.

The description for the UPTF facility can be found from chapter 2 and the built TRACE model description is presented in chapter 3. The counter current flow situation generally and in these simulations is presented in chapter 4. Results of the simulations have been presented in chapter 5.

2 UPPER PLENUM TEST FACILITY DESCRIPTION

Upper Plenum Test Facility is a simulation of a 1300 MW KWU reactor's primary circuit. The facility includes four loops with pump and steam generator simulators and a pressure vessel with downcomer, upper and lower plenum and a core area. Core steam generation is simulated with 193 steam/water injection nozzles which are placed directly below the 193 dummy fuel assemblies. Core, upper plenum, downcomer and loops are built in 1:1 scale. The facility is presented in Figure 1 and major dimensions can be found from Figure 2.

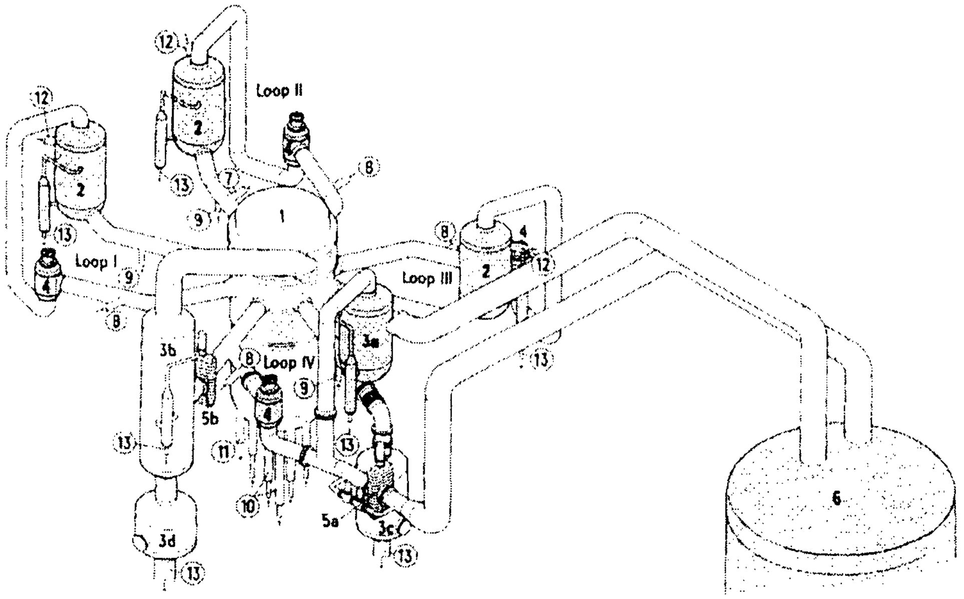

Figure 1. Upper Plenum Test Facility primary circuit (Ref. 1)

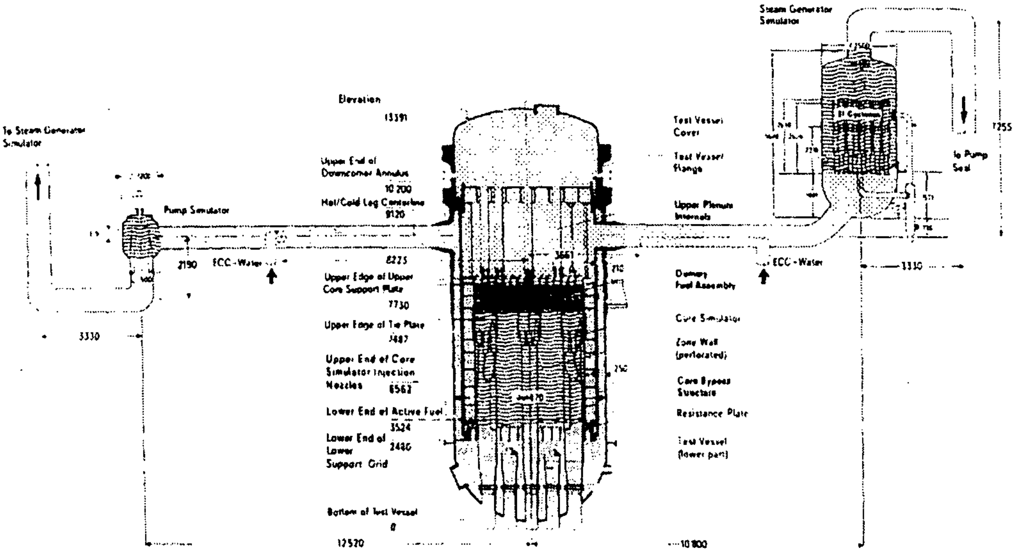

Figure 2. Upper Plenum test facility pressure vessel (Ref. 1)

3 MODEL DESCRIPTION

TRACE version 5, release candidate 1 was used to simulate relevant parts of the Upper Plenum Test Facility. Steam generator or pump simulators were not modelled because the simulated tests had no mass flow though these components. The ECC water was injected as a mass flow boundary to hot and cold legs 1-3 while the break was located either in fourth cold or hot leg. Simulated steam from core was injected as mass flow boundary to the lower one of the two core nodes.

Downcomer region was divided into 8 five-cell pipes representing 8 sectors of the downcomer. When CCF limitation was used it was set to all of the cell edges of this area. Cells were connected with single junctions to their neighbour pipe cells to allow horizontal flow in downcomer area.

Since the simulations were run in steady state, a large water storage node was placed on the bottom of the lower plenum. This node was not physical but it enabled steady state simulations as water no longer packed in the lower plenum hindering the passage of steam. It was tested on multiple occasions that this node did not interfere with the relevant results. In some occasions its large steam volume even dampened pressure oscillations in the system which increased the readability of the results. Figure 3 shows the model editor view of the UPTF model.

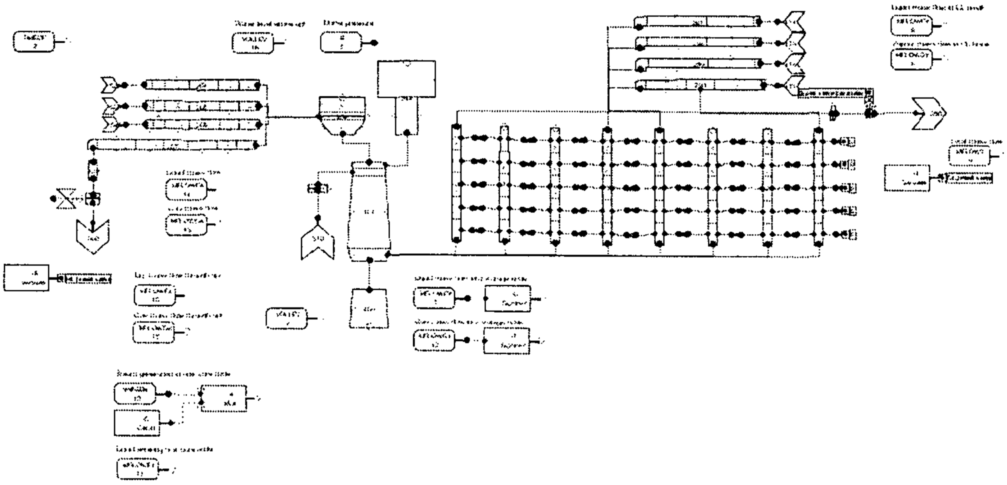

Figure 3. Model Editor view of the UPTF model

Animation model was built for closer inspection of simulation results. It also allowed real time adjusting of break valve flow which speeds up the manual iteration process of achieving the desired pressure level. The animation model is shown in Figure 4.

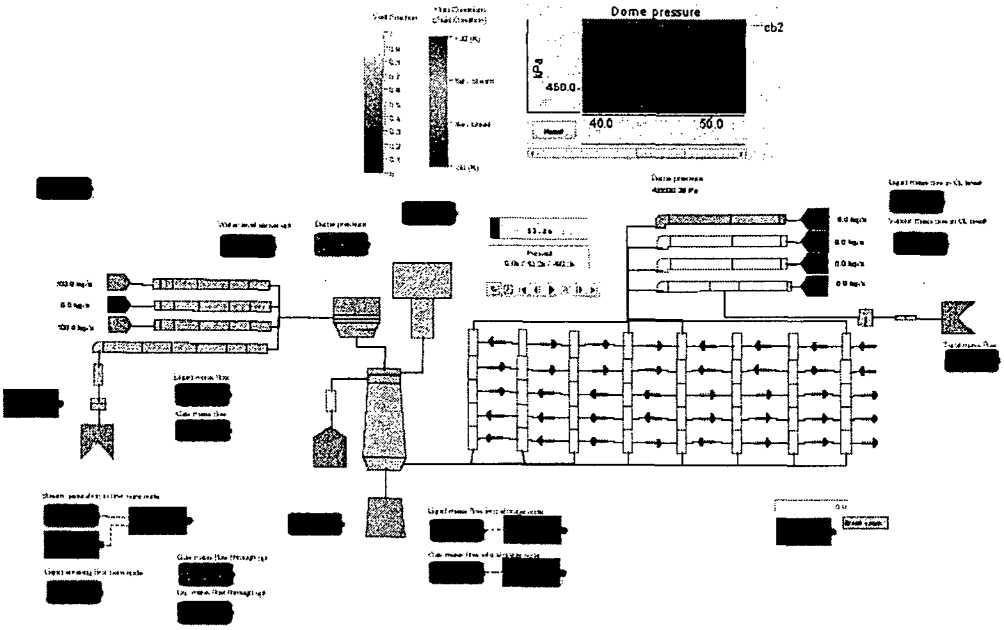

Figure 4. UPTF Animation Model

4 COUNTER CURRENT FLOW SIMULATIONS

The simulations were divided into downcomer and upper tie plate simulations. In the downcomer simulations hot leg was blocked while emergency core cooling water was discharged into cold leg side. Respectively in the upper tie plate simulations cold leg was blocked while ECC water was discharged into hot leg side.

Downcomer simulations were run with no CCFL and with Bankoff restriction using Kutateladze scaling and it was set in all downcomer cell edges. Required parameters *slope* (M_B) and *correlation constant* (C_B) were set as 1 which is their default value. Tie plate simulations were run with no CCF limitation and with Bankoff using Kutateladze and Wallis scalings set in upper tie plate. Also in this simulation parameters were set to their default value 1. Bankoff flooding correlation is presented in equation (1).

Bankoff correlation can be written (Ref. 2):

$$H_g^{1/2} + M_B H_l^{1/2} = C_B \tag{1}$$

where H_g is the dimensionless gas flux, H_l is the dimensionless liquid delivery, C_B is the abscissa intercept, and M_B is the slope.

For Wallis (diameter dependence) scaling H_g and H_l are

$$H_k = j_k \left(\frac{\rho_k}{gD\Delta\rho} \right)^{1/2} \tag{2}$$

where *k* refers to phase, *j* is the superficial velocity, *D* is the diameter of the holes, *g* is gravitational constant, σ is the surface tension, ρ is the density and $\Delta\rho$ is the difference between phase densities.

Respectively for Kutateladze (surface tension dependence) scaling

$$H_k = j_k \left(\frac{\rho_k}{gL\Delta\rho} \right)^{1/2} \tag{3}$$

where

$$L = \left(\frac{\sigma}{g\Delta\rho} \right)^{1/2} \tag{4}$$

Downcomer counter current flow simulations were imitating the situation in Glaeser report (Ref. 1) test 7 where hot leg was blocked, no non-condensible gas flow was present and break was opened to the fourth cold leg. In the same time steam nozzles were injecting saturated steam into core and variable amount of ECC water was pushed into cold legs 1-3. The situation where the 2 flows meet in downcomer area is presented in Figure 5.

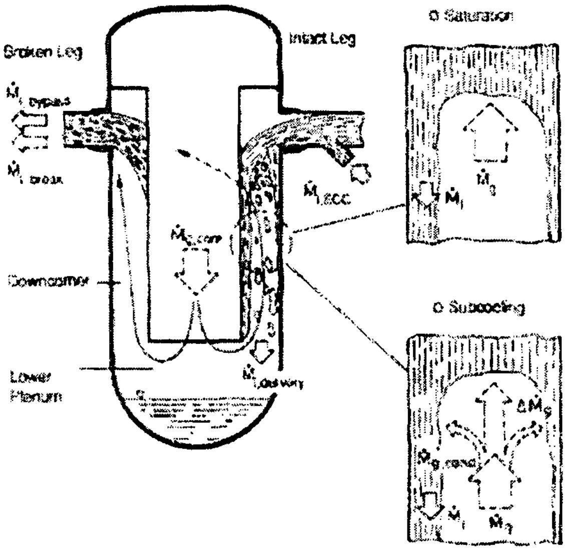

Figure 5. Downcomer CCF situation (Ref. 1)

Upper tie plate simulations were imitating the situation in Glaeser report (Ref. 1) test 10a where the injection gas mass flow decreased during simulation. For this report each one of the reported states (5 for part 1 and 6 for part 2) was ran as steady state. Test 10a included two parts where one was with 2x 100 kg/s ECC water injection and another was with 400 kg/s injection. When CCFL was present it was set to the cell edge representing upper tie plate. Upper tier plate had approximately the same hydraulic diameter as the core area but its flow area was only half of the one in the core. Because of this difference in flow area the upper tier plate should have bigger effect on the flow. Upper tie plate counter current flow situation is shown in Figure 6.

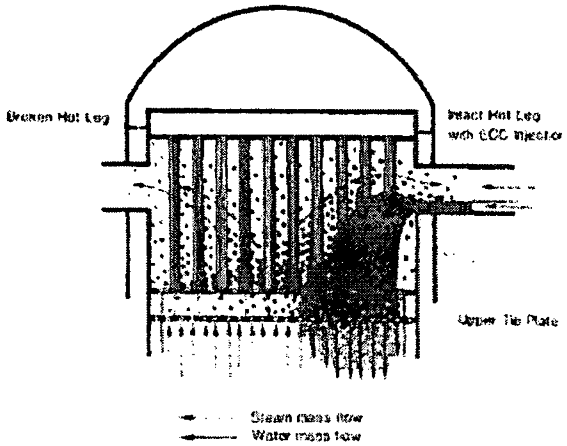

Figure 6. Upper tie plate CCF situation (Ref. 1)

5 SIMULATION RESULTS

The simulations were intended to run interactively, manually iterating break valve flow area until desired pressure level was achieved. It was, however, discovered that the model was very sensitive to the states which lead to the wanted pressure level. For example in some of the downcomer cases if the simulation started with small break valve opening it lead to high pressure, smaller steam volumetric flow and less resistance to the ECC water. As a result the ECC water had good access to the lower plenum and it condensated steam efficiently. This simulation stabilized to different ECC water penetration level than the case where the simulation started with fully open valve. In this latter case the steam flow was large from the beginning and ECC water never reached lower plenum area but was directed straight to the break without having change to properly condensate the steam flow. Because of this sensitivity all of the cases were run multiple times from the same initial conditions and with constant break valve opening until the valve setting that lead to correct pressure level was found.

5.1 Downcomer Counter Current Flow

Without using any counter current flow limitation the built model produced reasonably good ECC water penetration results in 6 of the 10 simulations. In run 200/I simulation predicted correctly virtually no passing ECC water flow. In cases 200/II, 202/III and 203/II-IV simulated mass flows were reasonably close to those measured in tests. Simulations of cases 200/III and 203/I indicated too much ECC water ending up in the lower plenum area. In cases 201/I and 202/II no water reached lower plenum area which didn't correlate with the relatively big mass flows measured in the test. It is also notable that in multiple simulations the model was unable to achieve as low as targeted pressure levels even when the break valve was set fully open. In most of the cases this was due to not enough water penetrating downcomer region which resulted in less than predicted condensation.

When Bankoff restriction was used with Kutateladze scaling it was observed that the default settings were not suitable for the simulated cases. No water passed into lower plenum area in any of the situations. The initial conditions for the test and simulation can be found from Table 1 and the results are presented in Table 2.

Table 1. Initial conditions of test 7 (Ref. 1) and simulation

	Pressure [kPa]	Injection steam massflow [kg/s]	ECC water massflow [kg/s]	Injection steam temp.(sat) [°K]	ECC water subcooled [°K]	ECC water temperature [K]
200/I	451	104	CL1: 494	421	22	399
200/II	330	54	CL1: 736	410	9	401
200/III	498	102	CL1: 735	429	23	406
201/I	330	102	CL2: 487	410	10	400
			CL3: 490		11	399
201/III	414	102	CL1: 493	418	14	404
			CL2: 487		14	404
			CL3: 489		15	403
202/II	416	128	CL2: 486	418	13	405
			CL3: 491		14	404
203/I	401	69	CL1: 735	417	13	404
203/II	286	30	CL1: 737	405	0	405
203/III	398	71	CL1: 737	417	10	407
			CL3: 733		13	404
203/IV	337	51	CL1: 493	411	3	408
			CL2: 485		3	408
			CL3: 487		6	405

Table 2. Results of test 7 (Ref. 1) and simulation

	TEST		SIMULATION		
	Pressure [kPa]	LP liquid massflow [kg/s]		Pressure [kPa]	LP liquid massflow [kg/s]
200/I	451	5	no CCFL	500	0
			Kutateladze	493	0
200/II	330	351	no CCFL	344	410
			Kutateladze	352	0
200/III	498	6	no CCFL	480	303
			Kutateladze	496	0
201/I	330	861	no CCFL	506	0
			Kutateladze	499	0
202/III	414	942	no CCFL	405	980
			Kutateladze	585	0
202/II	416	714	no CCFL	557	0
			Kutateladze	552	0
203/I	401	95	no CCFL	403	380
			Kutateladze	405	0
203/II	286	519	no CCFL	285	500
			Kutateladze	311	0
203/III	398	823	no CCFL	366	810
			Kutateladze	510	0
203/IV	337	1031	no CCFL	334	1080
			Kutateladze	480	0

5.2 Upper Plenum Counter Current Flow

In the upper tie plate simulations water failed to penetrate core area but was flushed to the break with the steam flow. Only in one simulation some of the ECC water reached lower plenum area but even in that case the flow was only 35 kg/s when test data indicated liquid mass flow of 390 kg/s. It is notable that having counter current flow limitation set to the upper tie plate did not affect the amount of penetrated water. During the simulations water level above the upper tie plate varied between 0,25 and 0,41 meters (highest water level being in the simulation case where ECC water penetration was observed). In two of the simulation cases correct pressure level was not reached even when the break valve was set fully open. However, higher pressure reduced steam volumetric flow in upper tie plate should have allowed ECC water to penetrate through the plate more easily. Results of the simulations can be found from Table 3.

Using the simulation case where 35 kg/s ECC water penetrated upper tier plate CCFL attributes were varied in order to test if more suitable values could be found. It was also tested how setting counter current flow limitation to all of the core edges would affect the ECC penetration. Trace Theory Manual (Ref. 2) suggest that C_B values are usually in range of 1-2. Values between 0,5-3 were tested but they didn't bring any improvement to the results. With Kutateladze scaling adding CCF limitation to the whole core area rised the penetration by about 16 kg/s but caused the flow to oscillate. The resulting flow of 51 kg/s is still very low compared to the 390 kg/s measured in the test. Varying C_B for Wallis scaling and using CCFL for the whole core area didn't seem to have any effect on the results.

One thing to keep in mind is that the UPTF model for this report was created using one-dimensional components. However, the counter current flow situations are three-dimensional. This affects especially the upper tie plate simulations where, in this model, each of the hot legs is connected to a single upper plenum node. The reality, however, is that hot legs surround the upper plenum area and the void fraction is not homogenous in a situation where ECC water is injected from some of the legs.

TRACE contains also a three-dimensional pressure vessel component. The usage of this component might produce better results for an upper tier plate CCF situation. Another option might be to create more detailed noding with 1D components for this area. It must also be kept in mind that Bankoff restriction was created for a single vertically rising pipe. Using it for different geometries should be done with caution.

Table 3. Results of test 10a (Ref. 1) and simulation

	Injection gas mass flow [kg/s]	TEST		SIMULATION		
		Pressure [kPa]	LP liquid massflow [kg/s]		Pressure [kPa]	LP liquid massflow [kg/s]
PART 1 HL1: 100 kg/s HL3: 100 kg/s	172,98	600	75,51	no CCFL	603	0
				Kutateladze	603	0
				Wallis	603	0
	151,48	588	87,21	no CCFL	583	0
				Kutateladze	583	0
				Wallis	583	0
	127,46	539	135,06	no CCFL	540	0
				Kutateladze	540	0
				Wallis	540	0
	103,15	496	142,82	no CCFL	496	0
				Kutateladze	496	0
				Wallis	496	0
	76,54	463	182,83	no CCFL	485	0
				Kutateladze	486	0
				Wallis	486	0
PART 2 HL2: 400 kg/s	215	620	109	no CCFL	721	0
				Kutateladze	721	0
				Wallis	721	0
	198,33	704	243	no CCFL	705	0
				Kutateladze	706	0
				Wallis	706	0
	163,54	673	219	no CCFL	666	0
				Kutateladze	667	0
				Wallis	667	0
	130,83	652	254	no CCFL	648	0
				Kutateladze	648	0
				Wallis	648	0
	98,48	588	324	no CCFL	586	0
				Kutateladze	586	0
				Wallis	586	0
	68,25	527	390	no CCFL	524	35,2
				Kutateladze	524	35,1
				Wallis	524	35,2

6 CONCLUSIONS

The one dimensional TRACE UPTF model produced reasonable results in roughly half of the downcomer counter current flow simulations. In upper tie plate CCF simulations ECC water countered too much drag in the upper tie plate and core area for the ECC water to reach lower plenum. Instead the water was flushed straigh to the hot leg break with the ongoing steam flow.

The UPTF model for this report was created using one-dimensional components. The situation in upper tier plate and downcomer, however, is three dimensional. This affects especially the upper tie plate simulations where, in this model, each of the hot legs is connected to one single upper plenum node. The reality, however, is that hot legs surround the upper plenum area and the void fraction is not homogenous in a situation where ECC water is injected from some of the legs. The current 1D downcomer noding is fairly detailed; allowing water circulation around the downcomer ring which may have something to do with the better results of the simulations.

TRACE contains also a three-dimensional pressure vessel component. The usage of this component might produce better results for an upper tier plate CCF situation. Another option might be to create more detailed noding with 1D components for this area.

7 REFERENCES

1. Glaeser H. Downcomer and tie plate countercurrent flow in the Upper Plenum Test Facility (UPTF). Nuclear Engineering and Design 133. 1992.

2. TRACE V5.0 Theory Manual - Field Equations, Solution Methods and Physical Models. USA, USNRC

NRC FORM 335
(9-2004)
NRCMD 3.7

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BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)
NUREG/IA-0230

2. TITLE AND SUBTITLE
An Assessment of TRACE V5 RC1 Code Against UPTF Counter Current Flow Tests

3. DATE REPORT PUBLISHED

MONTH	YEAR
August	2010

4. FIN OR GRANT NUMBER

5. AUTHOR(S)
Seppo Hillberg

6. TYPE OF REPORT
Technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*
VTT - Technical Research Centre of Finland
Nuclear Power Plant Modelling
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9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*
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Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES
A. Calvo, NRC Project Manager

11. ABSTRACT *(200 words or less)*

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12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*
Upper Plenum Test Facility (UPTF)
Code Application Maintenance Program (CAMP)
VTT - Technical Research Centre of Finland
TRACE V5 RC1
Loss of coolant situation
Four loop 1300 MW Siemens/KWU pressurized water reactor
Counter Current Flow Limitation (CCFL)
Bankoff restriction
Kutateladze scaling
Wallis scaling

13. AVAILABILITY STATEMENT
unlimited

14. SECURITY CLASSIFICATION
(This Page)
unclassified
(This Report)
unclassified

15. NUMBER OF PAGES

16. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
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