NUREG/IA-0116
KWU E412/91/E100

International Agreement Report

Assessment of RELAP5/MOD3/V5m5 Against the UPTF Test No. 11 (Countercurrent Flow in PWR Hot Leg)

Prepared by
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U.S. Nuclear Regulatory Commission
Washington, DC 20555

May 1993

Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Thermal-Hydraulic Code Assessment
and Application Program (ICAP)

Published by
U.S. Nuclear Regulatory Commission

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ABSTRACT

Analysis of the UPTF Test No. 11 using the "best-estimate" computer code RELAP5/MOD3/Version 5M5 is presented.

Test No. 11 was a quasi-steady state, separate effect test designed to investigate the conditions for countercurrent flow of steam and saturated water in the hot leg of a PWR.

Without using the code's new countercurrent flow limitation (CCFL) model, RELAP5/MOD3/V5M5 overestimated the mass flow rate of back down flowing water up to 35 % (1.5 MPa runs) and 43 % (0.3 MPa runs). This is the most obvious difference to RELAP5/MOD2, which did not allow enough countercurrent flow. From the point of view of performing plant calculations this is certainly an improvement, because the new junction-based CCFL option could be used to restrict the flows to a flooding curve defined by a user-supplied correlation.

Very good agreement with the experimental data for 1.5 MPa - which are relevant for SBLOCA reflux condensation conditions - could be obtained using the code's new CCFL option in the middle of the inclined part (riser) of the hot leg. Using the same CCFL correlation for the simulation of 0.3 MPa test series - typical for reflood conditions -, the code underestimated by 44 % the steam mass flow rate at which complete liquid carry over occurs.

An unphysical result was received using a CCFL correlation of the Wallis type with the intercept C = 0.644 and the slope m = 0.8. The unphysical prediction is an indication of possible programming errors in the CCFL model of the RELAP5/MOD3/V5M5 computer code.

EXECUTIVE SUMMARY

During the boil-down phase of a small-break LOCA, an important source of cooling water to the core may come from the steam which, having previously boiled off in the core, condenses in the steam generator tubes and drains back down into the reactor vessel via the hot leg. The condensate and the steam flow through the hot legs in coutercurrent; therefore, the possibility that steam flow could inhibit the water back down flow is a potential concern regarding the reflux condensation cooling mode.

Test No. 11 conducted in the Upper Plenum Test Facility (UPTF) was a quasi-steady state, separate effect test, designed to investigate the conditions for countercurrent flow of steam and saturated water in the hot leg of a PWR. Analysis of the UPTF Test No. 11 using the "best-estimate" computer code RELAP5/MOD3/Version 5M5 is presented in this report.

Without using the code's new countercurrent flow limitation (CCFL) model, RELAP5/MOD3/V5M5 overestimated the mass flow rate of back down flowing water up to 35 % (1.5 MPa runs) and 43 % (0.3 MPa runs). This is the most obvious difference to RELAP5/MOD2, which did not allow enough countercurrent flow. From the point of view of performing plant calculations this is certainly an improvement, because the new junction-based CCFL option could be used to restrict the flows to a flooding curve defined by a user-supplied correlation.

Very good agreement with the experimental data for 1.5 MPa - which are relevant for SBLOCA reflux condensation conditions - could be obtained using the code's new CCFL option at the junction situated in the middle of the inclined part (riser) of the hot leg. The flooding correlation used was of the Wallis type: $(J^*_S)^{1/2} + m \cdot (J^*_W)^{1/2} = C$, where J^*_S and J^*_W represents the Wallis parameters for steam and water respectively. The parameter C (determining the steam mass flow rate at which complete liquid carry over occurs) was set at 0.664; it was calculated using UPTF data for 1.5 MPa and riser's hydraulic diameter (D_H = 0.750 m). The slope m of the flooding curve was determined through parameter studies. The data were matched best when using m=1. Using the same CCFL correlation for the simulation of 0.3 MPa test series - typical for reflood conditions -, the code underestimated by 44 % the steam mass flow rate at which complete liquid carry over occurs.

An unphysical result was received using a CCFL correlation of the Wallis type with the intercept C = 0.644 and the slope m = 0.8. This is an indication of possible programming errors in the CCFL model.

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1 INTRODUCTION

During the boil-down phase of a small-break loss-of-coolant accident (SBLOCA), an important source of cooling water to the core may come from the steam which, having previously boiled off in the core, condenses in the steam generator tubes and drains back down into the reactor vessel via the hot leg (reflux condensation cooling mode). The condensate and the steam flow through the hot legs in coutercurrent; therefore, the possibility that steam flow could patialy or totaly inhibit the water back down flow - partial delivery or countercurrent flow limitation (CCFL) respectively - is a potential concern regarding the reflux condensation cooling mode.

Test No. 11 conducted in the Upper Plenum Test Facility (UPTF) in Germany was a quasi-steady state, separate effect test involving the UPTF system with blocked pump simulators and broken hot leg open to the containment simulator. The test was designed to investigate the conditions for countercurrent flow of the steam coming from the core and saturated water in the hot leg of a pressurized water reactor. Saturated water was fed into the inlet plenum of the UPTF water separator simulating the steam generator in the broken loop hot leg and saturated steam at various flow-rates was introduced via the core simulator system.

A steady flow test case that simulates specific PWR conditions was run to verify that there is no countercurrent flow limitation in the hot leg for expected PWR conditions. A second main objective was to study CCFL phenomena in a large pipe under hydraulic conditions related to SBLOCA (high pressure) and reflood (low pressure). Tests that map out CCFL were run to determine the countercurrent flow boundary. It was found that stable countercurrent flow existed at conditions expected during the reflux condensation phase of a SBLOCA and that there was no countercurrent flow limitation until the steam flow-rate was well above that seen during the reflux phase of typical SBLOCA calculations.

The test provides valuable data for assessing the ability of advanced thermal-hydraulics codes to model countercurrent flow limitation in much bigger pipes than those in which experiments had previously been carried out. A number of codes have already been used to model the test, including TRAC-PF1/MOD1 and MOD2 /1/, ATHLET /2/, RELAP5/MOD2 /3,4/, the developmental version of RELAP5/MOD3 (RELAP5/MOD2.5/V4B1) /5/ as well as the final "frozen" version of RELAP5/MOD3,

which differs from the earlier developmental version in the way in which the flow-regime and interphase friction are determined in inclined pipes /6/.

The present study describes post-test calculations of the UPTF Test No. 11 performed with the RELAP5/MOD3/Version 5M5 computer code.

This report is organized as follows: Section 2 describes the experimental facility and section 3 describes the RELAP5 model used to simulate the experiments. In section 4 results from the simulation are presented and discussed. Conclusions are presented in section 5.

2 FACILITY AND TEST DESCRIPTION

This section is largely taken from reference /7/. It is included here for completeness.

Primary concern of the UPTF test program is the overall 1:1 scale investigation of the three-dimensional thermalhydraulic behavior of fluid in the reactor pressure vessel and primary system during the last part of blowdown, the refill and the reflood phases of a postulated loss-of-coolant accident (LOCA) in a pressurized water reactor (PWR).

The UPTF test program is one of the research activities being performed within the framework of the Arrangement on Research Participation and Technical Exchange among the United States Nuclear Regulatory Commission (USNRC), Japan Atomic Energy Research Institute (JAERI) and the Federal Minister for Research and Technology (BMFT) of the Federal Republic of Germany (FRG) in a Coordinated Analytical and Experimental Study on the Thermalhydraulic Behavior of Emergency Core Coolant (ECC) during the Refill and Reflood Phases of a LOCA in a PWR (the 2D/3D Agreement).

2.1 UPTF SYSTEM DESCRIPTION

UPTF is a full-scale model of a four-loop 1300 MWe pressurized water reactor including the reactor vessel, downcomer, lower plenum, core simulation, upper plenum, loop simulation with steam generator simulation. The thermalhydraulic feedback of the containment is simulated using a containment simulator. The flow diagram of the system and an isometrical view of the test facility are shown in Figures 2.1 and 2.2. The major dimensions of the test facility are given in Figure 2.3.

The test vessel, core barrel and internals are a full-size simulation of a PWR, with four full-scale hot and cold legs simulating three intact loops and one broken loop.

In UPTF both cold and hot leg breaks can be investigated including emergency core coolant injection into the intact and broken cold legs and/or hot legs and into the downcomer. The steam produced in the real core and the water entrained by this steam flow are simulated by steam and water injection through the core simulator.

The steam production on the primary side of the real intact loop steam generator is simulated by direct steam injection into the steam generator simulators.

2.2 TEST OBJECTIVES FOR TEST No. 11

This test investigates steam/water flow phenomena in the hot leg during reflux condensation, which is a cooling mode that may occur during a small-break loss-of-coolant accident (SBLOCA). Reflux condensation refers to the cooling mode in which steam is the continuous phase above the reactor core and in the primary loops. Heat is transferred from the core by partial evaporation of the water in the core and subsequent condensation of that steam in the steam generators. The condensate flows in countercurrent to the steam through the hot legs back into the reactor vessel in so-called reflux condenser mode. The possibility that steam flow could inhibit the water back flow because of countercurrent flow limitation is a potential concern regarding this cooling mode (see Fig. 2.7).

A steady flow test case that simulates specific PWR conditions was run to verify that there is no countercurrent flow limitation in the hot leg for expected PWR conditions. A second main objective was to study CCFL phenomena in a large pipe under hydraulic conditions related to SBLOCA (high pressure) and reflood (low pressure). Tests that map out CCFL were run to determine the countercurrent flow boundary.

The UPTF can only be operated in a pressure range up to 1.8 MPa (261 psia), whereas PWR reflux condensation would be expected to occur at pressures as high as 8 MPa (1160 psia). Since the actual phenomena at high pressure cannot be tested directly, posttest analyzes will be required to apply the test results to the higher pressures typical of PWR's. The test conditions were selected to produce the "best simulation" of PWR conditions, considering the lower pressure of UPTF.

2.3 UPTF SYSTEM CONFIGURATION FOR TEST No. 11

The UPTF configuration for Test No. 11 is shown on Fig. 2.4. In this diagram the steam and water flow paths used in this test are indicated by thick lines.

- All vent valves were locked closed.
- All pump simulators were closed.
- All drainage systems were not activated.
- The valves (JEA 01-03 AA02) connecting the steam generator simulator secondary side to the primary were open.
- The sparger (spray nozzle) was installed in the water separator JEA 04 BB01 (see Fig. 2.5).
- All valves of the ECC system were closed. The pressure in the ECC system was the same as the pressure in the primary system to assure no leakage between primary system and ECC system.
- The core simulator water injection system was not activated.
- During the runs 030 to 034 the break valve JEC 05 AA001 was fully open and system and containment simulator pressure were constant at 0.3 MPa.
- During the runs 036 to 045 the break valve JEC 05 AA001 was partially open and the bypass valve JEC 05 AA02 was used to control the primary system pressure to 1.5 MPa.

2.4 DESCRIPTION OF THE TEST

Countercurrent flow in the hot leg was simulated by venting steam from the primary system through the UPTF broken loop hot leg to the containment simulator downstream from the water separator. Simultaneously, a stream of saturated water was injected into the water separator inlet chamber (Figure 2.8).

The test consisted of a series of flow conditions to map out the countercurrent flow curves at 0.3 and 1.5 MPa. The steam and water mass flow rates injected during this test are listed in Table 1.

In UPTF-RUN 037 (see Table 1) typical PWR reflux condensation mode fluid momentum fluxes were applied. These fluid momentum fluxes were based on typical PWR reflux condensation mode mass flow rates assuming three active steam generators. A pressure-scaling method that maintains PWR fluid momentum fluxes was used to determine the UPTF mass flow rates for RUN 037. For details the reader is referred to /8/.

Table 1: Series of Flow Conditions in Test No. 11

UPTF RUN No.	Pressure	Injected Mass Flow Rates		Water Downflow
		Steam	Water	Rate
	bar	kg/s	kg/s	kg/s
37	15.3 ± 0.18	8.3 ± 0.6	9.8 ± 0.6	9.8 ± 0.6
36	15.2 ± 0.18	9.2 ± 0.6	29.6 ± 0.6	29.6 ± 0.6
38	15.25 ± 0.18	18.1 ± 0.6	29.4 ± 0.6	29.4 ± 0.6
39	15.0 ± 0.18	24.0 ± 0.6	29.6 ± 0.6	25.2 $^{+5.0}_{-1.0}$
45	15.0 ± 0.18	28.0 ± 0.6	29.5 ± 0.6	14.2 $^{+2.8}_{-1.0}$
40	14.97 - 15.46	31.0 ± 0.6	29.4 ± 0.6	5.4 $^{+1.1}_{-0.5}$
44	15.0 ± 0.18	32.6 ± 0.6	29.4 ± 0.6	2.7 $^{+0.6}_{-0.5}$
43	15.0 ± 0.18	33.5 ± 0.6	29.5 ± 0.6	2.0 ± 0.5
42	14.82 - 15.78	36.0 ± 0.6	29.4 ± 0.6	0.6 ± 0.2
41	15.0 ± 0.18	40.2 ± 0.6	29.5 ± 0.6	0
30	3.06 ± 0.08	4.6 ± 0.2	30.5 ± 0.6	30.5 ± 0.6
31	3.1 ± 0.08	11.0 ± 0.6	30.6 ± 0.6	30.6 ± 0.6
33	3.16 ± 0.08	12.4 ± 0.6	30.5 ± 0.6	17.7 $^{+8.8}_{-0.5}$
32	3.18 ± 0.08	12.9 ± 0.6	30.5 ± 0.6	11.7 $^{+5.8}_{-0.5}$
35	3.2 ± 0.08	15.3 ± 0.6	30.5 ± 0.6	2.4 $^{+1.2}_{-0.5}$
34	3.1 ± 0.08	20.5 ± 0.6	30.5 ± 0.6	0

The measured water level increase in the lower plenum of the test vessel was used to calculate the mean downflowing water rate by means of the volume versus elevation calibration curve.

The upflowing water mass flow rate was separated by the cyclones and measured using the water level outside the cyclones in the water separator. At higher injected steam mass flow rates a small part of the upflowing water was carried out by the steam to the containment simulator. To check the water mass balance the water level in the water separator was measured and no water was drained from the water separator or from the lower plenum of the test vessel during the test.

The water mass collected outside the cyclones was determined using the volume versus elevation calibration curve for the water separator.

The injection of saturated water into the inlet chamber of the broken hot leg water separator started before the injection of steam into the core simulator (water first mode).

The water flow on the bottom of the hot leg before start of steam injection is clearly indicated by the pipe flow meter data (see Fig. 2.6).

After starting the steam injection the water mass stored in the broken loop hot leg and in the inlet chamber of the water separator increases when relatively high steam mass flow rates are injected. This water accumulation is typical for the onset of flooding or complete liquid carry-over.

The water and steam injection lasted at least 200 s when water downflow was observed. In case of no water downflow the steam and water injection was stopped when the water level outside the cyclones reached the upper end of the cyclones.

The mean water downflow rate was determined for time periods when the injection rates were constant and the accumulated water mass in the broken loop hot leg and water separator inlet chamber reached a quasi-stationary maximum value (indicated by the DP-measurements JEC 04 CP009 and JEC 04 CL001 and the pipe flow meter data).

For test runs at 1.5 MPa test vessel pressure in the test vessel was controlled by opening and closing the hot side break valve (as the maximum allowed pressure in the containment simulator was

0.6 MPa). This pressure control led to slow oscillations of the test vessel pressure in these test runs.

In test runs with a test vessel pressure of 0.3 MPa the hot leg break valve was open and the pressure in the containment simulator controlled the test vessel pressure.

For each of the 16 test points the pipe flow meter fluid density and differential pressure measurements in the broken loop hot leg are plotted versus time in reference /7/. These measurements indicate that beyond the complete carry-over limit liquid was still present in the horizontal section, but it did not flow out into the upper plenum.

2.5 TEST RESULTS AND FINDINGS

The injected mass flow rates and the measured mean water downflow rate $\dot{m}_{w,d}$ for quasi-stationary conditions are listed in Table 1 for each test point. Using these data the following correlations between the injected steam mass flow rate $\dot{m}_s$ and $\dot{m}_{w,d}$ were plotted:

$\dot{m}_s$	$= f(\dot{m}_{w,d})$	see Fig. 2.9
j_s	$= f(j_{w,d})$	see Fig. 2.10
J^*_s	$= f(J^*_{w,d})$	see Fig. 2.11

with

j = superficial velocity

J^*_k = Wallis parameter (modified Froude number)

$$J^*_k = j_k \cdot \sqrt{\frac{\rho_k}{g \cdot D_H \cdot (\rho_f - \rho_g)}} \qquad (2.1)$$

ρ = Fluid density

g = Gravitational acceleration

D_H = Hydraulic diameter

Subscripts:

w	= Water
s	= Steam
w,d	= Water downflow

The hydraulic diameter was set at be 4 times the minimum flow area divided by the circumference of this flow area in the deflector nozzle region (see Fig. 2.11).

A mass balance method based on the water level measurement in the lower plenum of the test vessel and in the water separator secondary side was used to determine the error bands for the calculated mass flow rate $m_{w,d}$.

Relatively high uncertainties (e. g. for the 0.3 MPa data) were determined because a small part of the injected water was flowing via the steam injection holes into the inactive core simulator steam pipes near the broken loop hot leg. This water was automatically drained during the test for safety reasons. That is why, for total water downflow, the water mass increase measured in the lower plenum was about 15% smaller than the water injection rate. That is why for zero water upflow the water downflow rate in Table 1 could be set equal to the water injection rate.

Figure 2.11 shows that the Wallis parameter seems to be the right method for pressure scaling of countercurrent flow data in a PWR hot leg.

2.6 COMPARISON TO CCFL DATA OF SMALL-SCALE PWR MODEL HOT LEGS

Countercurrent flow tests in scaled PWR hot legs have been performed by Richter et al. /9/ (inner diameter of hot leg D = 0.203 m) and Ohnuki /10/ (D = 0.026 m/0.051 m/0.076 m) for air-water flow /9, 10/ and steam flow /10/.

Richter et al. and Ohnuki used the Wallis correlation

$$(J^*_s)^{1/2} + m \cdot (J^*_w)^{1/2} = C \qquad (2.2)$$

to represent their experimental data.

Richter et al. used the constants m = 1 and C = 0.7, which were drawn from countercurrent flow data in vertical pipes.

Ohnuki /10/ investigated the dependence of the parameters m and C on the geometry of the hot leg using 19 different model hot legs in his tests. Ohnuki's correlation for the parameter C is valid only for inclination angles of the riser part of the hot leg up to 45°, while the UPTF hot leg has an inclination angle of 50°. Therefore only an approximate value for parameter C can be calculated using Ohnuki's correlation and the geometrical data of the UPTF hot leg (horizontal part: 7.146 m, riser part: 1.391 m, diameter 0.75 m, C = 0.753). For Ohnuki's investigations the parameter m is 0.75.

As shown in Figure 2.11, the Wallis correlation with the parameters m and C according to Richter et al. agrees fairly well with the UPTF data although there was no ECC injection pipe in the model hot leg of Richter et al. and the inclination angle of the riser part was 45°.

Deviations between the UPTF experimental data and the Ohnuki's correlation shown in Figure 2.11 are probably caused by the higher geometrical scaling factor.

Flooding in an elbow between a vertical and a horizontal pipe was investigated by Krolewski /11/ and Siddiqui et al. /12/ using air-water flow.

Krolewski used a tube with 50.8 mm inner diameter. The onset of flooding was taken as the point at which the pressure drop across the test section increased sharply as the gas flow rate was gradually increased. The data of Krolewski indicate a minimum Wallis parameter of about J^*_S = 0.25 for complete liquid carry-over which is well below the Wallis parameter drawn for UPTF experiment.

The experiments of Siddiqui et al. were performed with an elbow shape consisting of tubes of inner diameters 36.5 to 47 mm. It was observed that flooding is caused by unstable wave formation at the hydraulic jump which forms in the lower pipe limb close to the bend. A minimum Wallis parameter of J^*_S = 0.2 for complete liquid carry-over was measured which was largely independent of tube diameter, bend radius and liquid supply rate. Beyond the complete carry-over limit liquid was still present in the horizontal section, but it did not flow out of the gas inlet. This phenomenon could also be

observed in the UPTF-tests.

The comparison of data shown in Figure 2.11 indicates a strong effect of the inclination of the riser part on the CCFL-characteristics. That is why, care should be taken in extrapolating CCF-data for PWR hot legs to higher inclination angles of the riser part.

3 CODE AND MODEL DESCRIPTION

3.1 CODE DESCRIPTION

The present study was performed with the RELAP5/MOD3/Version 5M5 computer code. This is the last official "frozen" version released within ICAP for code assessment calculations. The code is implemented on a SIEMENS WS30-1000 computer operating under AEGIS and UNIX. The computer is a 32-bit workstation with a PRISM risc processor; it is quite similar to Apollo Domain DN 10000 workstations.

With the exception of a correction for fixing an error concerning the restart capability the code has not been modified. The MLIST in the installation procedure for 32-bit machines was completed by variables FLOMPJ and STRGEO. For code compilation the "-save" option was invoked to force the compiler to allocate static storage to all variables.

3.2 RELAP5 NODALISATION

Four RELAP5 nodalisations have been developed for the simulation of UPTF Test No. 11. They are depicted in Figures 3.1-3.4. Nodalisation no. 1 is similar to the one used in reference /3/ for the assessment of RELAP5/MOD2 (see Fig. 3.1). In nodalisations 2, 3 and 4 single volume components (SNGLVOL) have been introduced between source terms (e.g. steam-supply - TMDPVOL 100 + TMDPJUN 105 - and water supply - TMDPVOL 450 + TMDPJUN 445) and connecting branches in order to avoid possible RELAP5-errors evaluating the volume average velocity at the branch. Nodalisations 2, 3 and 4 differ only in the number of control volumes modeling the hot leg. The hot leg of nodalisation no. 2 consists of 6 control volumes (Fig. 3.2), whereas the hot leg in nodalisation no. 3 and 4 consist of 12 volumes and 9 volumes, respectively (Fig. 3.3 and 3.4). Nodalisation no. 4 seems to be best suited for the simulation of the test .

Correspondingly, Nodalisation No. 4 is considered the basic nodalisation within the present study. It is described in detail in this section.

The hot leg piping is modeled with two branch and two pipe components. Components 400 (branch)

and 401 (branch) simulate the pipe from the reactor pressure vessel (RPV) to the Hutze, while the region at the Hutze itself is modeled by the pipe component 410 having 4 volumes of the same length (4•0.9645 m). The first junction of the branch 401 (junction 401-01) connects the adjacent components 401 and 410. The region between Hutze and steam generator inlet is modeled with the pipe component 420 consisting of 3 volumes. The first volume of this component simulates the horizontal part (length 1.251 m), the second and third volumes simulate the 50° inclined part - riser (length 2•0.834 m). The single junction (SNGLJUN) component 415 connects the pipe component 410 to the pipe component 420.

The flow area of the pipe 410 simulating the Hutze region has 0.3974 m^2, the corresponding hydraulic diameter is 0.639 m. Junctions 401-01 and 415 have the same flow areas and hydraulic diameters as the pipe 410.

The steam generator inlet plenum is modeled as one volume using the branch component 430. The first junction of the branch 430 connects the pipe component 420 to the steam generator inlet plenum. Above the steam generator inlet plenum two volumes are modeled: single volume component 600 and branch component 610. These two volumes do not reflect the UPTF geometry. Nodalization studies have shown, that connecting volume 430 directly to the time dependent volume 440 leads to unrealistic carry-over of injected water into volume 440 (see reference /3/).

The steam injection is simulated by components 100, 105 and 200. The injection steam mass flow rate is controled by the TMDPJUN 105. The steam coming from TMDPVOL 100 is injected through SNGLVOL 200 into the hot leg (volume 400). Passing the hot leg and the steam generator inlet the steam escapes via the volumes 600 and 610 into the time dependent volume 440. This volume controls the system pressure.

The injection of saturated water into the inlet chamber of the broken hot leg water separator is simulated by components 450, 445 and 500. The water coming from TMDPVOL 450 is injected into volume 430 through the SNGLVOL 500. The time dependent junction 445 controls the injected water mass flow rate. The water flowing through the piping system can finally escape into the pipe component 120 via the second junction of the branch 400.

The pipe component 120 represents the core simulator. Since the core simulator does not play an

important role for the objectives of the UPTF Test No. 11 it is modeled in a simplified manner. The water accumulated in component 120 is drained through the TMDPJUN 125 into the TMDPVOL 130 using a control system depending on the collapsed water level in the core simulator.

The RELAP5 input deck described above is enclosed in Appendix A.

Several calculations have been performed using a CCFL model. The CCFL correlation was applied in the middle of the riser, i.e. for nodalisation no. 4 at the junction 420-02.

3.3 SIMULATION PROCEDURE AND BOUNDARY CONDITIONS

Both the 0.3 MPa and the 1.5 MPa UPTF 11 test series have been simulated with RELAP5/MOD3/ Version 5M5. Every series was simulated in a "through" run. The calculations followed the experimental procedure of allowing the liquid flow to settle down into a steady state before starting or increasing the steam injection.

Boundary conditions for the 1.5 MPa series: The simulated test rig was initially filled with pure steam. There are no water or steam injections during the first 12 seconds of the simulation. At 12 s water injection started and reached 9.8 kg/s within 0.5 s. At 45 s after simulation beginning, the steam supply to the reactor vessel was ramped up from zero to 8.3 kg/s over a period of 5 seconds, and then held steady for 200 seconds. These boundary conditions corespond to the UPTF11 run 37 (see Table 1). At 150 s the water supply was increased to 29.4 kg/s over 50 s and kept then constant for the rest of the calculation time. The steam injection flow rate was gradually increased, in steps of 50 seconds length and then held steady for 200 seconds. In this way, all UPTF 11 runs of the 1.5 MPa series (runs 36 - 45) have been simulated within a "through" RELAP5 calculation. The simulation was not limited to the steam injection flow rates measured in the test. It was continued also for higher steam flow rates in order to reach complete liquid carry over. The sequence of the simulation's boundary conditions for the 1.5 MPa series is depicted in Figure 3.5.

Boundary conditions for the 0.3 MPa series: The simulated test rig was initially filled with pure steam. There are no water or steam injections during the first 10 seconds of the simulation. At 10 s water injection started and reached 30.5 kg/s within 2.5 s. It was then kept constant for the rest of the

calculation time. At 45 s after simulation beginning the steam supply to the reactor vessel was ramped up from zero to 4.6 kg/s over a period of 5 seconds, and then held steady for 200 seconds. During the simulation the steam injection flow rate was gradually increased, in steps of 50 seconds length and then held steady for 200 seconds. In this way, all UPTF 11 runs of the 0.3 MPa series (runs 30 - 35) have been simulated within a "through" RELAP5 calculation. The sequence of the simulation's boundary conditions for the 0.3 MPa series is depicted in Figure 3.6.

4 RESULTS AND DISCUSSION

As already stated, several nodalisations were used for the post-test calculation of the UPTF Test No. 11. The calculations presented and discussed in section 4.1 and 4.2 were performed with the basic nodalisation (nodalisation no. 4 with 9 volumes hot leg model). The simulations were done in two steps: the first one without using the flooding model (see section 4.1) and the second one by testing various flooding correlations in the inclined part (riser) of the hot leg (see section 4.2). Results of nodalisation studies are presented in section 4.3.

4.1 POST-TEST CALCULATIONS WITHOUT CCFL MODEL

Figures 4.2 and 4.1 show the flooding curves calculated by RELAP5/MOD3 with and without using a CCFL model, respectively. In this section, only calculations without a CCFL model are discussed. The evolution in time of various parameters and variables is included in Appendix B (simulation of the 1.5 MPa tests) and C (simulation of the 0.3 MPa tests).

The most obvious difference between RELAP5/MOD3 predictions and former calculations with RELAP5/MOD2 (e.g. ref. /3/) is that RELAP5/MOD3 allowed too much countercurrent flow where MOD2 did not allow enough. It means that new junction-based CCFL option could be used to restrict the flows to a flooding curve defined by a user-supplied correlation. This is undoubtedly an improvement from the point of view of performing plant calculations.

Another interesting point is that the code predicts qualitatively well the inclination of the water-steam interface over the hot leg when stratified flow occurs. Fig. 17 in Appendix B shows the liquid fractions VOIDF in volumes 400-01 (outlet of the core simulator), 410-01 (first volume of the hutze region), 410-04 (last volume of the hutze region) and 420-01 (last horizontal part of the hot leg). It can be seen that the water level is increasing from core outlet to the riser, especially during the partial delivery phase (beginning at approx. 1950 s), when the water back-flow begins to be limited by the steam flow.

<u>Simulation of the 1.5 MPa tests:</u> The code calculates qualitatively well the countercurrent flow limitation when the water down-flow is restricted by the steam flow. This is an improvement compared to RELAP5/MOD2 calculations in which the transition from full liquid flow (total delivery) to complete

liquid carry over happened suddenly caused by a very small increase in steam flow. Quantitatively seen, RELAP5/MOD3 overestimates the water back-flow by 15 to 35 %.

Complete liquid carry over is predicted in the RELAP5/MOD3 calculation at a steam mass flow rate of 46 kg/s, i.e. an overestimation of 15 % compared to experimental data (complete liquid carry over was measured in UPTF Test No. 11, run 41 at a steam mass flow rate of 40.2 kg/s). The Wallis parameter for steam at the carry over point (related to the Hutze hydraulic diameter D_H = 0.639 m) was J^*_S = 0.50 in the test, whereas in the RELAP5/MOD3 calculation J^*_S = 0.57.

The code predicts over the whole range of steam mass flow rates - up to the complete liquid carry over point - stratified flow in the horizontal part of the hot leg. For the inclined part (riser) the flow regime is annular mist through out the simulation since the void fraction exceeds the value of 0.75 in this region (see Fig. 18 - 20 in Appendix B). The transition from slug to annular flow in vertical pipes happens at a void fraction of 0.75 regardless of the gas velocity.

<u>Simulation of the 0.3 MPa tests:</u> At this pressure level RELAP5/MOD3 again overestimates the water down-flow (code uncertainty up to 43 %). Compared with the calculations for 1.5 MPa, the predictions for 0.3 MPa are - qualitatively seen - less accurate. The same behavior as in the former RELAP5/MOD2 calculations can be observed: the transition from total water delivery to complete liquid carry over happens suddenly, caused once again by a very small increase in steam flow. However complete liquid carry over was well predicted at a steam mass flow rate of 21.3 kg/s (20.5 kg/s in the test). The corresponding Wallis parameter for steam related to the hydraulic diameter of the Hutze was J^*_S = 0.53 in the test whereas in the RELAP5/MOD3 calculation J^*_S = 0.54.

4.2 POST-TEST CALCULATIONS USING THE CCFL MODEL

Post-test calculations of the UPTF Test No. 11 were also done using the code's new CCFL option at junction 420-02 (in the middle of the riser). Four Wallis type correlations have been used which differ only by the slope m:

$$(J^*_S)^{1/2} + 0.9 \cdot (J^*_W)^{1/2} = 0.644 \qquad (4.1)$$

$$(J^*_S)^{1/2} + 1.0 \cdot (J^*_W)^{1/2} = 0.644 \qquad (4.2)$$

$$(J^*_S)^{1/2} + 1.1 \cdot (J^*_W)^{1/2} = 0.644 \quad (4.3)$$

$$(J^*_S)^{1/2} + 0.8 \cdot (J^*_W)^{1/2} = 0.644 \quad (4.4)$$

The parameter C = 0.644 - which is determining the steam mass flow rate at the complete liquid carry over point - was calculated using the UPTF data for 1.5 MPa (complete liquid carry over at $\dot{m}_S$ = 40.2 kg/s) and riser's hydraulic diameter (D_H = 0.750 m). The slope m of the flooding curve was varied between 0.8 and 1.1 in order to analyze the sensitivity of the code.

Experimental and predicted flooding curves using the flooding correlation (4.1) are compared in Fig. 4.1. The good agreement with 1.5 MPa data is obvious. Complete liquid carry over is predicted in the RELAP5/MOD3 calculation at the same steam mass flow rate as in the experiment: 40.2 kg/s. The Wallis parameter for steam (related to the Hutze hydraulic diameter D_H = 0.639 m) at the carry over point was J^*_S = 0.50 in the test as well as in the RELAP5/MOD3 calculation.

However, the RELAP5/MOD3 prediction failed when using the same correlation for 0.3 MPa. In this case, the code underpredicts the water down-flow and calculates complete liquid carry over at a steam mass flow rate of 11.2 kg/s, which is 44 % lower than measured data. The predicted Wallis parameter related to the Hutze hydraulic diameter is J^*_S = 0.29 (J^*_S = 0.53 in the experiment).

Predictions using the flooding correlations (4.1), (4.2) and (4.3) are compared against experimental data in Fig. 4.3. When changing the parameter m from 0.9 to 1.1, the slope of the predicted flooding curve was slightly modified. The slope can be further optimized through parameter studies until the best fit with data is reached.

<u>Code failure using the CCFL model:</u> An unphysical result was received when simulating the 1.5 MPa test series (runs 36 - 45 of the UPTF Test No. 11) using the CCFL model (4.4) with the slope of the flooding curve m = 0.8. Following the procedure described in Section 3.3 a quasi steady state phase was reached between simulation time 2200 s and 2250 s; within 50 s the water and steam were injected at constant mass flow rates of 29.4 kg/s and 36 kg/s, respectively (see Fig. 4.5). The mass flow rate of the water flowing back through the hot leg was in this period of time approximately 2 kg/s, i.e. the water back flow was limited and the code calculated the water velocity using the given flooding curve (4.4). At 2250 s the mass flow rate of the injected steam started to increase and the water back flow was more and more limited down to 0.3 kg/s at 2280 s. Then happened a sudden and unphysical

jump in the mass flow rate of the back down flowing water though the steam injection mass flow rate was continuing to increase. At 2300 s the injected steam mass flow rate was 40.2 kg/s and the mass flow rate of the countercurrent water 6.8 kg/s. Nevertheless, at this steam mass flow rate the countercurrent flow should be limited to 0.0 as requested by the flooding correlation (4.4). Figure 4.6 compares experimental data against the predicted flooding curve in terms of water and steam mass flow rates. The flooding curve that the code should approximately predict if it worked correctly is also indicated. A representation of the same calculation in terms of the Wallis parameters for steam and water at the Hutze is given in Fig. 4.7. Appendix D includes supplementary curves which give more information about this case.

The unphysical prediction discussed above is an indication of possible programming errors in the CCFL model of the RELAP5/MOD3/V5M5 computer code.

4.3 NODALISATION STUDIES

Simulations of UPTF Test No. 11 were performed using various nodalisations in order to quantify the influence of the spatial discretisation on calculational results. The results are compared against experimental data in Fig. 4.4. The sensitivity of results to the use of the abrupt area change model at the Hutze was also analyzed.

Spatial Discretisation

As noted above, four RELAP5 nodalisations have been developed for the simulation of UPTF Test No. 11. Nodalisation no. 1 is similar to the one used in reference /3/ for the assessment of RELAP5/MOD2 (see Fig. 3.1). In nodalisations 2, 3 and 4 single volume components have been introduced between source terms (e.g. steam-supply - TMDPVOL 100 + TMDPJUN 105 - and water supply - TMDPVOL 450 + TMDPJUN 445) and the connecting branches in order to avoid possible RELAP5-errors when evaluating the volume average velocity at the branch. Nodalisations 2,3 and 4 differ only in the number of control volumes modeling the hot leg. The hot leg of nodalisation no. 2 consists of 6 control volumes (Fig. 3.2), whereas the hot leg in nodalisation no. 3 and 4 consists of 12 volumes and 9 volumes, respectively (Fig. 3.3 and 3.4).

Predictions with nodalisations no. 1 and 2 (both with 6 volumes hot legs) overestimate the water down-flow through the hot leg more than the other two nodalisations (Fig. 4.4); too much countercurrent flow is allowed. In both calculations a sudden transition from full liquid flow to very low flow occured, when the steam flow was increased slightly over 40 - 41 kg/s. This behavior was not seen in the experiment.

Calculations with nodalisations no. 3 and 4 (with 12 and 9 volumes hot legs, respectively) have shown a better agreement with the experiment from the qualitative point of view. The sudden transition seen before does not occur any more and the slope of predicted flooding curves is closer to the one of the experimental curve. The water down-flow is still overestimated but not so much as when using only 6 volumes for the hot leg nodalisation.

When using 12 volumes for the hot leg (nodalisation no. 3) the predicted flooding curve ist the closest to the experimental one. This nodalisation is, however, not recommendable since several volumes have the ratio length to diameter L/D < 1.

Predictions for the 0.3 MPa tests were not very sensitive to the nodalisation used at least qualitatively. In all calculations the same unrealstic jump from full liquid flow to complete liquid carry over was observed.

Conclusion: A nodalisation with 9 volumes for the hot leg seems to be best suited for the simulation of steam/water countercurrent flow in the hot leg of a PWR. This is the reason why nodalisation no. 4 was defined as the basic nodalisation for the present study.

Abrupt Area Change Model

A calculation was done using the abrupt area change option in the junction 401-01, which connects the Hutze region (flow area 0.397 m^2) with a normal pipe part (flow area 0.442 m^2). None impact on the calculation results has been observed with except of unsignificant differences in the amplitude of pressure drop oscillations over the entire hot leg during the partial water delivery phase.

5 CONCLUSIONS

Without using the code's new countercurrent flow limitation model, RELAP5/MOD3/V5M5 overestimated the mass flow rate of back down flowing water up to 35 % (1.5 MPa runs) and 43 % (0.3 MPa runs). This is the most obvious difference to RELAP5/MOD2, which did not allow enough countercurrent water flow. From the point of view of performing plant calculations this is certainly an improvement because it means that the new junction-based CCFL option could be used to restrict the flows to a flooding curve defined by a user-supplied correlation.

Without using the new CCFL model, RELAP5/MOD3 predicts complete liquid carry over at a steam mass flow rate of 46 kg/s within the 1.5 MPa simulation (40.2 kg/s in the experiment) and at 21.3 kg/s for the 0.3 MPa simulation (20.5 kg/s in the experiment), respectively. The corresponding Wallis parameters (related to the hydraulic diameter of the Hutze) for steam as predicted by RELAP5/MOD3 are J^*_S = 0.57 for 1.5 MPa and J^*_S = 0.54 for 0.3 MPa. The Wallis parameters for steam calculated from UPTF experimental data were J^*_S = 0.50 and J^*_S = 0.53 for 1.5 MPa and 0.3 MPa test series, respectively.

Very good agreement with the 1.5 MPa experimental data (which are relevant for SBLOCA-conditions) could be obtained using the code's new CCFL option at a junction situated in the middle of the inclined part (riser) of the hot leg. The flooding correlation used was of the Wallis type: $(J^*_S)^{1/2} + m \cdot (J^*_W)^{1/2} = C$, where J^*_S and J^*_W represents the Wallis parameters for steam and water, respectively. The parameter C (determining the steam mass flow rate at which complete liquid carry over occurs) was set at 0.664; it was calculated using UPTF data for 1.5 MPa and riser's hydraulic diameter (D_H = 0.750 m). The slope m of the flooding curve was determined through parameter studies. The data were matched best by using m=1.

Applying the flooding curve presented above complete liquid carry over is predicted by RELAP5/MOD3 at the same steam mass flow rate as in the experiment: 40.2 kg/s. The Wallis parameter for steam at the carry over point was J^*_S = 0.50 in the test as well as in the RELAP5/MOD3 calculation (related to the Hutze hydraulic diameter D_H = 0.639 m).

Using the same CCFL correlation for the simulation of 0.3 MPa test series - typical for reflood conditions -, RELAP5/MOD3 underestimated by 44 % the steam mass flow rate at which complete

liquid carry over occurs.

Nodalisation studies have shown that a hot leg model with 9 control volumes between reactor vessel and steam generator inlet chamber is quite adequate for simulating steam/water countercurrent flow in the hot leg during typical reflux condensation conditions.

Code failure using the CCFL model: An unphysical result was received when simulating the 1.5 MPa test series (runs 36 - 45 of the UPTF Test No. 11) using a CCFL correlation of the Wallis type with the intercept C = 0.644 and the slope m = 0.8. The unphysical prediction is an indication of possible programming errors in the CCFL model of the RELAP5/MOD3/V5M5 computer code.

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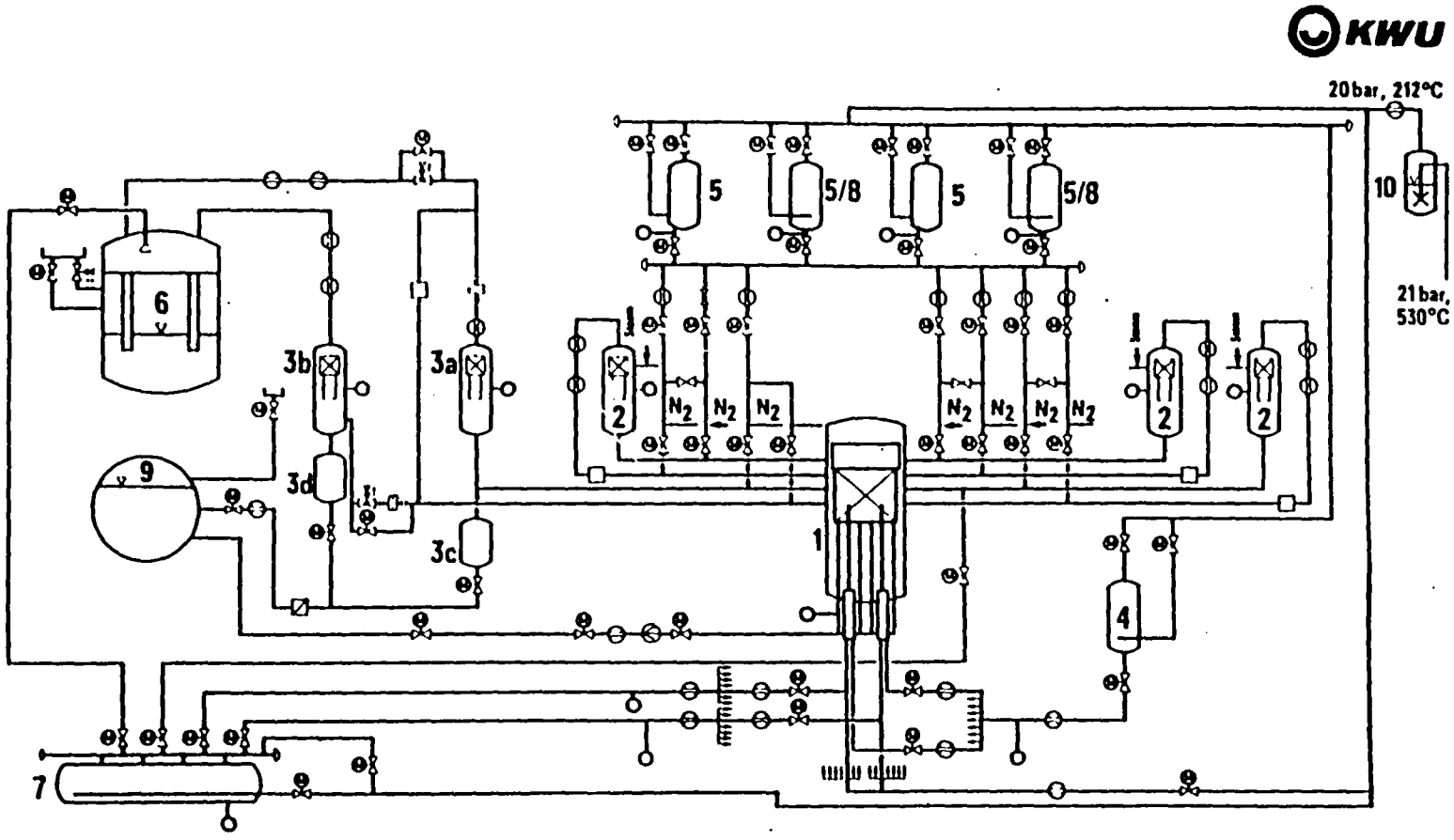
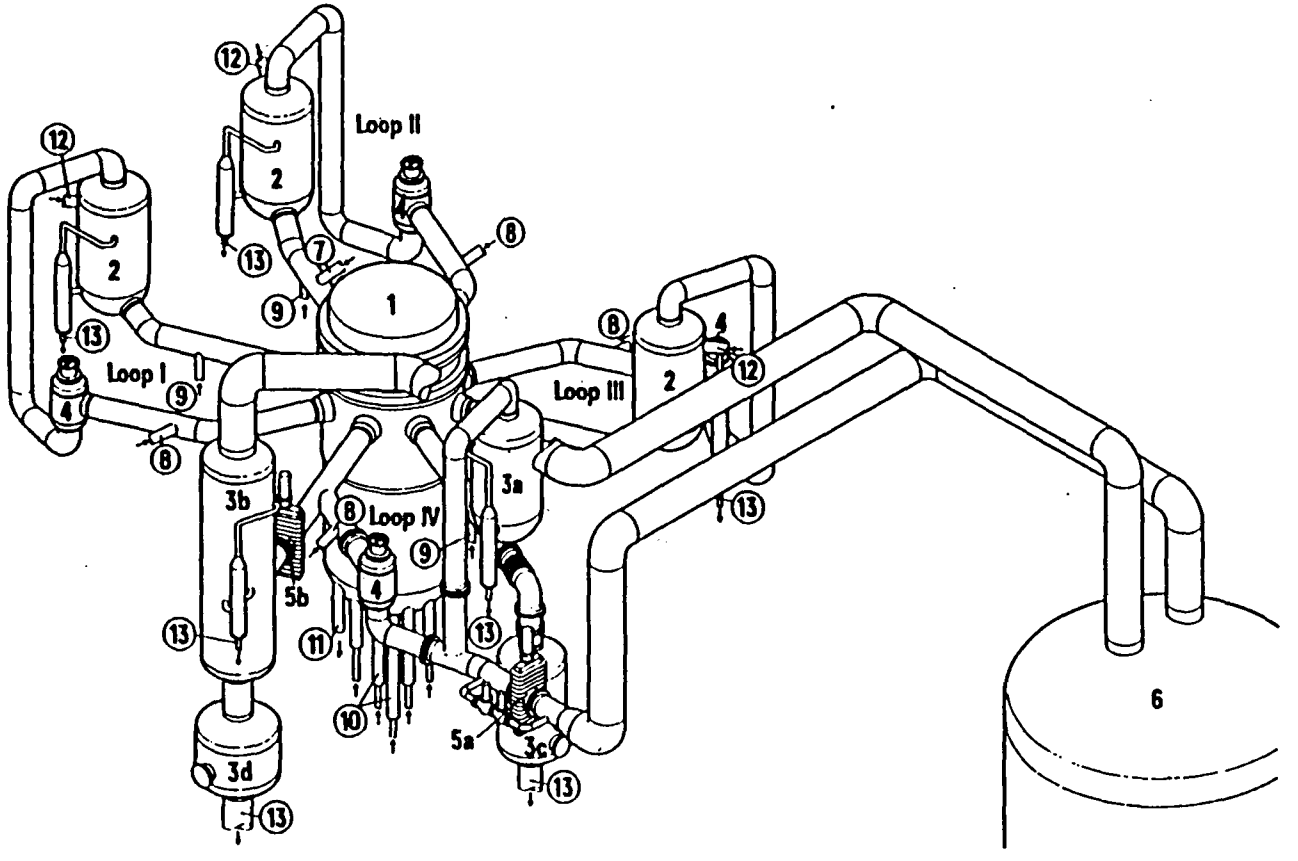
FIGURES



1 Test Vessel
2 Steam Generator Simulator (Intact Loop)
3a Steam Generator Simulator/ Water Separator (Broken Loop Hot Leg)
3b Water Separator (Broken Loop Cold Leg)
3c Drainage Vessel for Hot Leg
3d Drainage Vessel for Cold Leg
4 Hot Water Storage Tank
5 Accumulator
6 Containment Simulator
7 Steam Storage Tank
8 N_2 - Tank
9 Water Collecting Tank
10 Steam Cooler
11 Pump Simulator

O Sample

Fig. 2.1: UPTF Flow Diagram



1 Test Vessel
2 Steam Generator Simulator (Intact Loop)
3a Steam Generator Simulator/ Water Separator (Broken Loop Hot Leg)
3b Water Separator (Broken Loop Cold Leg)
3c Drainage Vessel for Hot Leg
3d Drainage Vessel for Cold Leg
4 Pump Simulator
5a Break Valve (Hot Leg)
5b Break Valve (Cold Leg)
6 Containment Simulator
7 Surgeline-Nozzle
8 ECC-Injection Nozzles (Cold Leg)
9 ECC-Injection Nozzles (Hot Leg)
10 Core Simulator Injection Nozzle
11 TV-Drainage Nozzle
12 Steam Injection Nozzle
13 Drainage Nozzle

Fig. 2.2: Upper Plenum Test Facility - Primary System

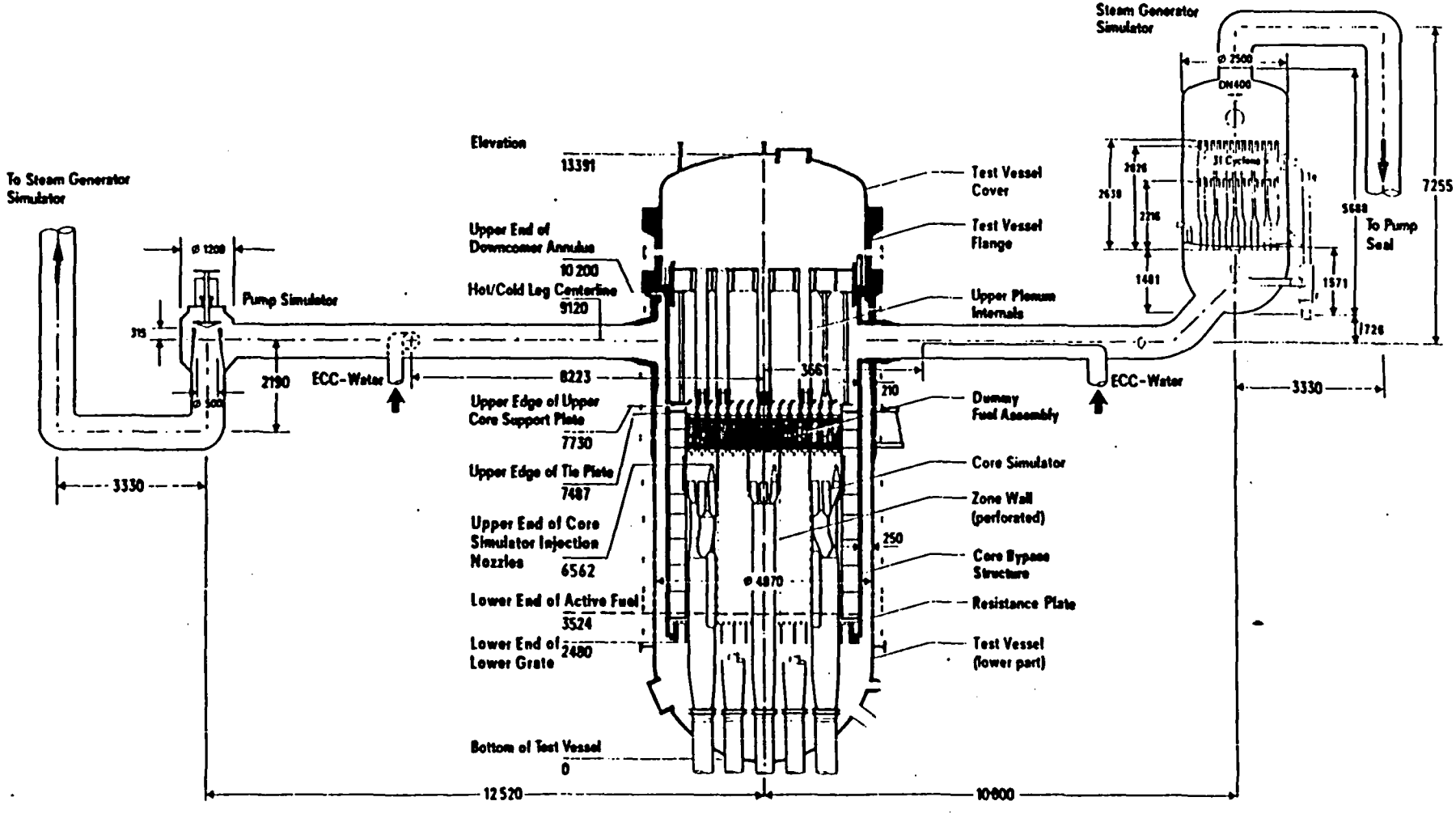
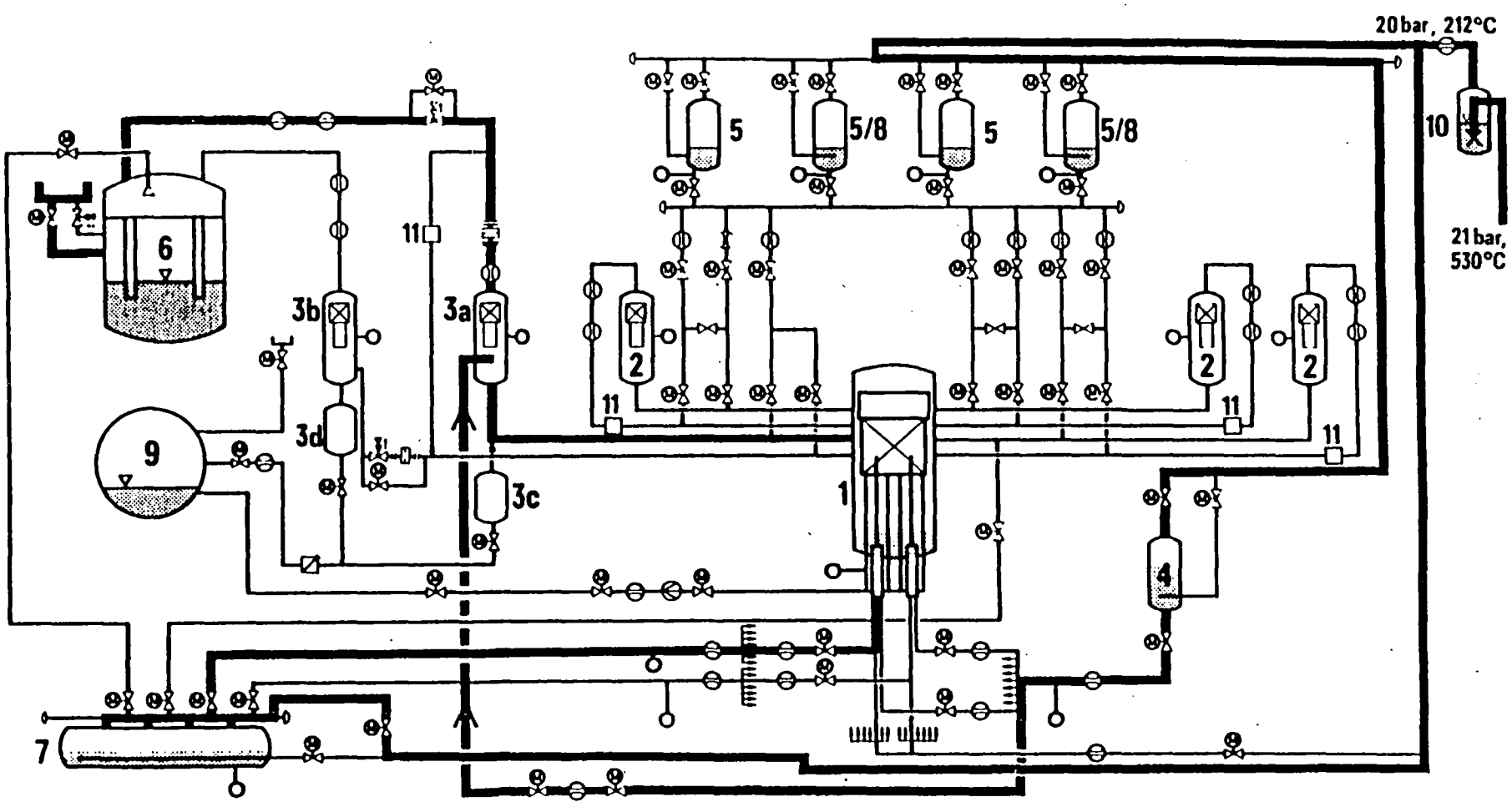


Fig. 2.3: Major Dimensions of UPTF-Primary System



1 Test Vessel
2 Steam Generator Simulator (Intact Loop)
3a Water Separator (Broken Loop Hot Leg)
3b Water Separator (Broken Loop Cold Leg)
3c Drainage Vessel for Hot Leg
3d Drainage Vessel for Cold Leg
4 Hot Water Storage Tank
5 Accumulatur
6 Containment Simulator
7 Steam Storage Tank
8 N_2-Tank
9 Water Collecting Tank
10 Steam Cooler
11 Pump Simulator
O Sample

Flow Path
Filled with Water
Not Activated

Fig. 2.4: System Configuration

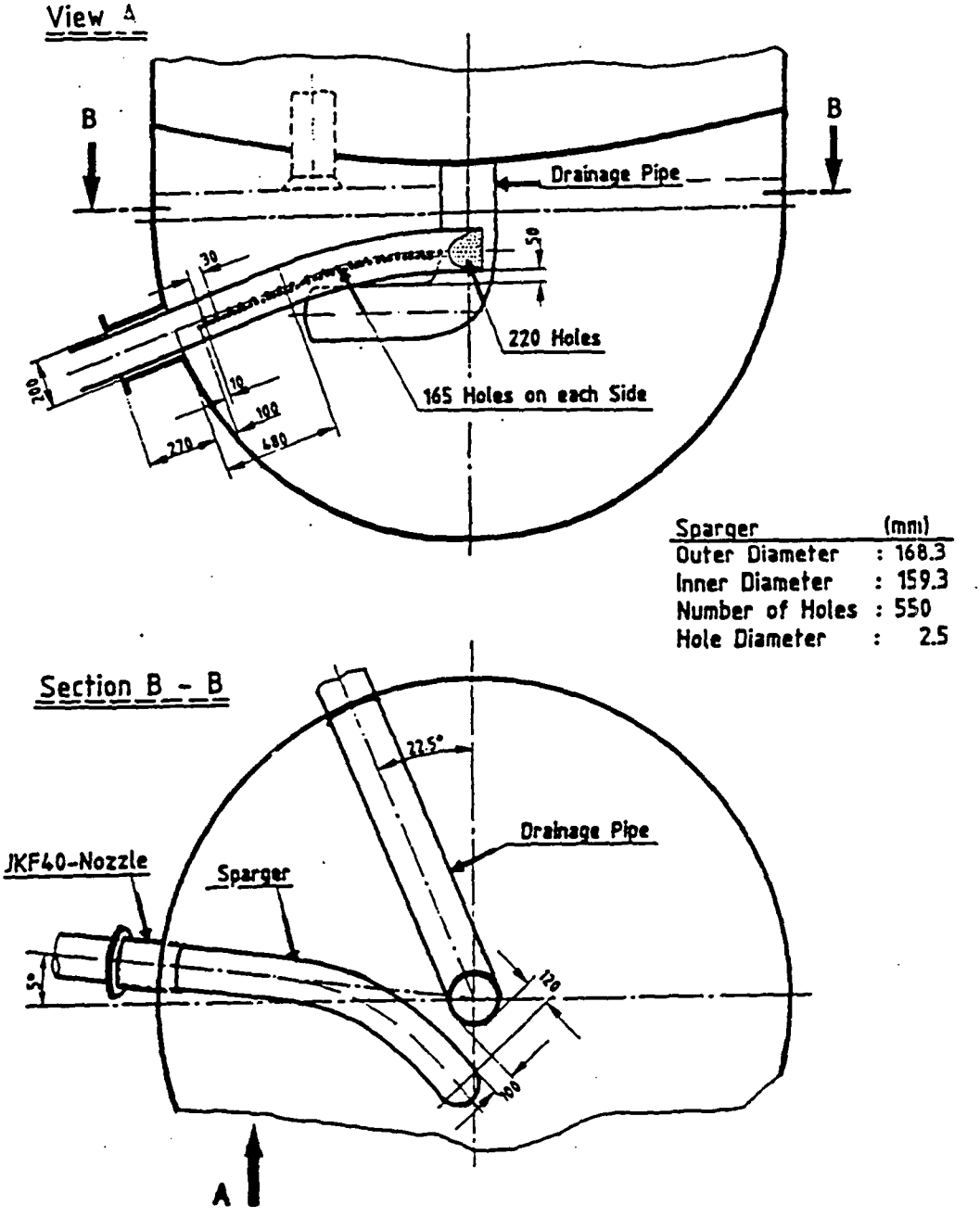


Fig. 2.5: Design of Water Separator JEA04BB01 Inlet Chamber

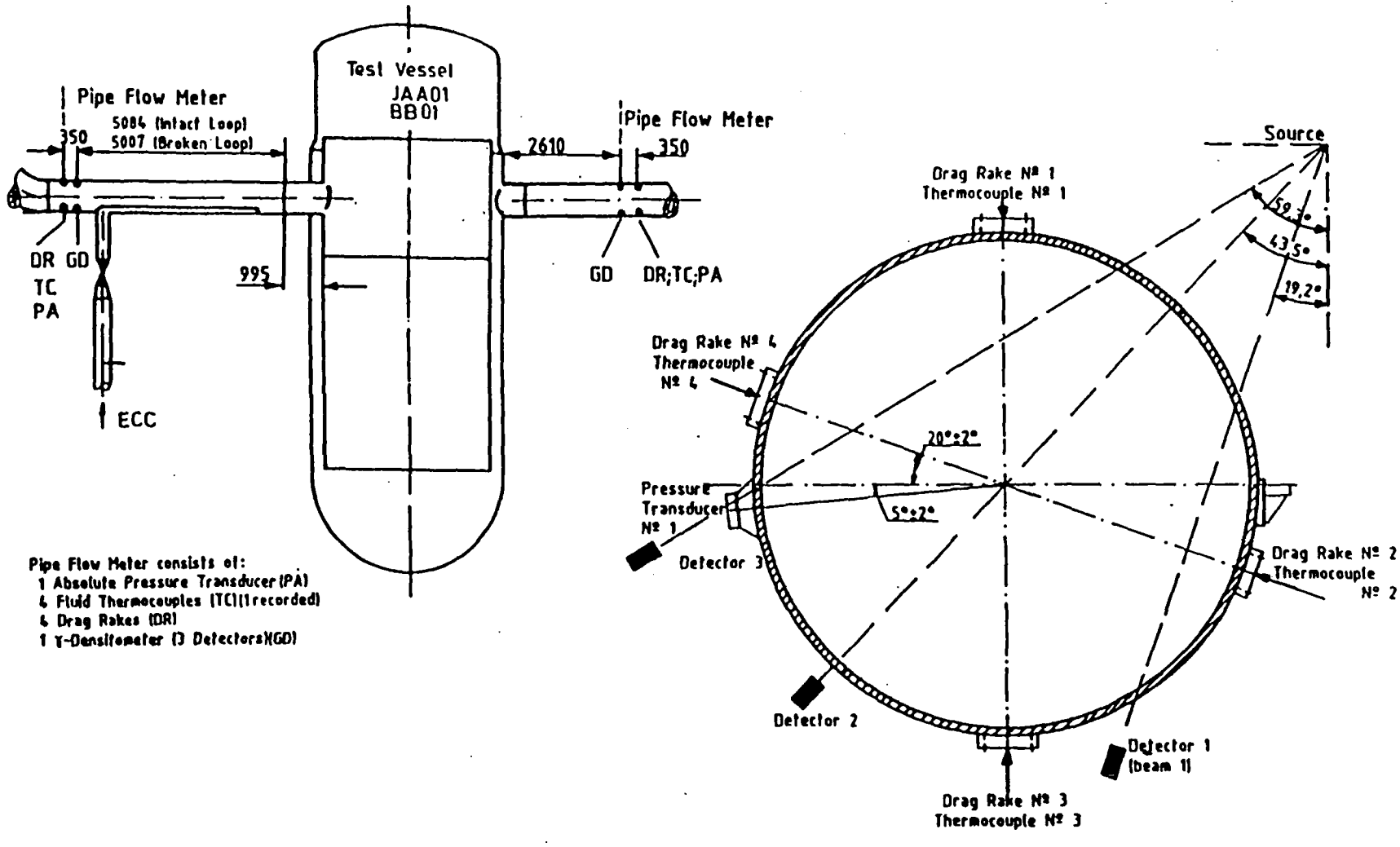


Fig. 2.6: Arrangement of Pipe Flow Meter Measurement System in Broken Hot Leg

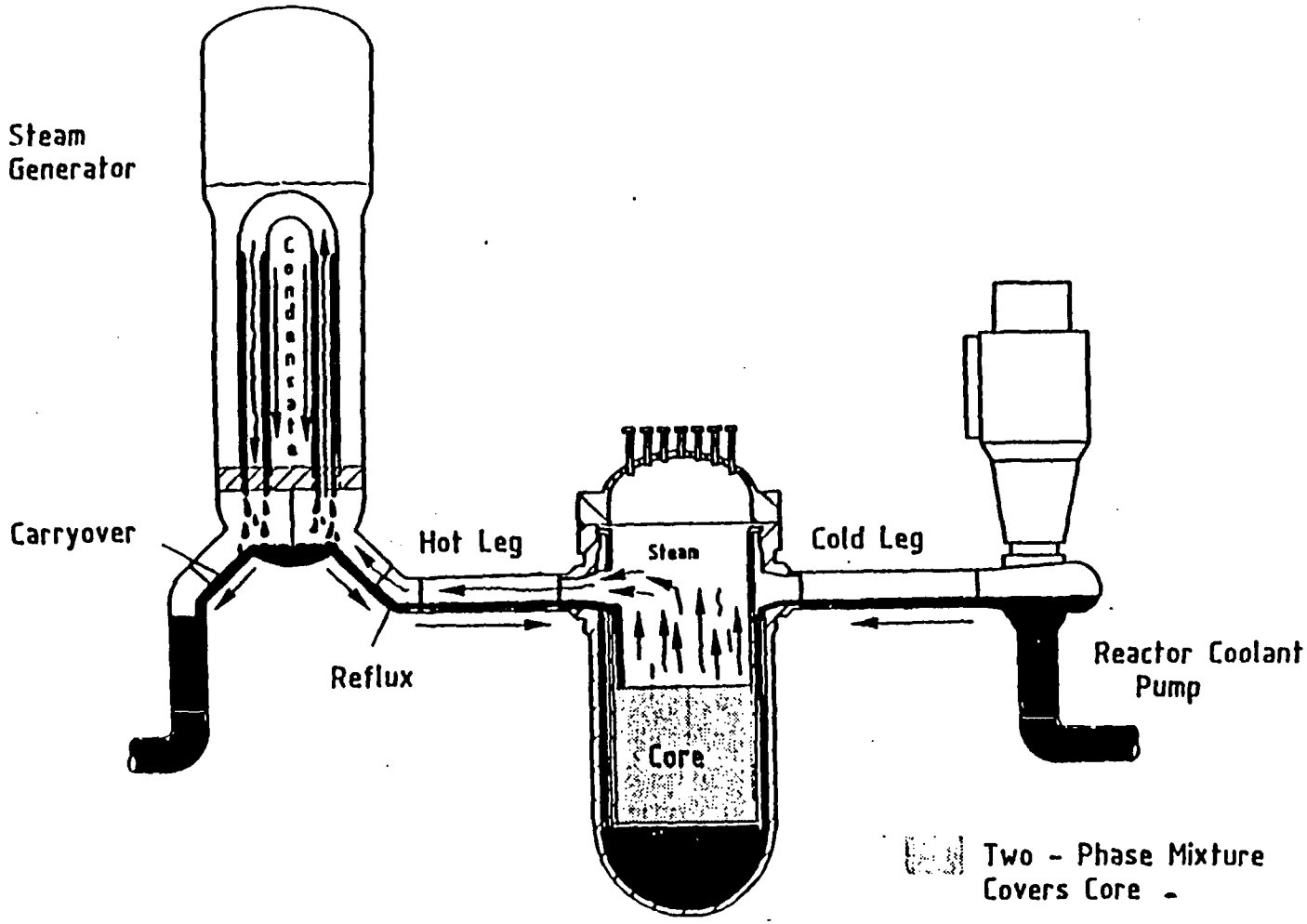


Fig. 2.7: Reflux Condensation Flow Path

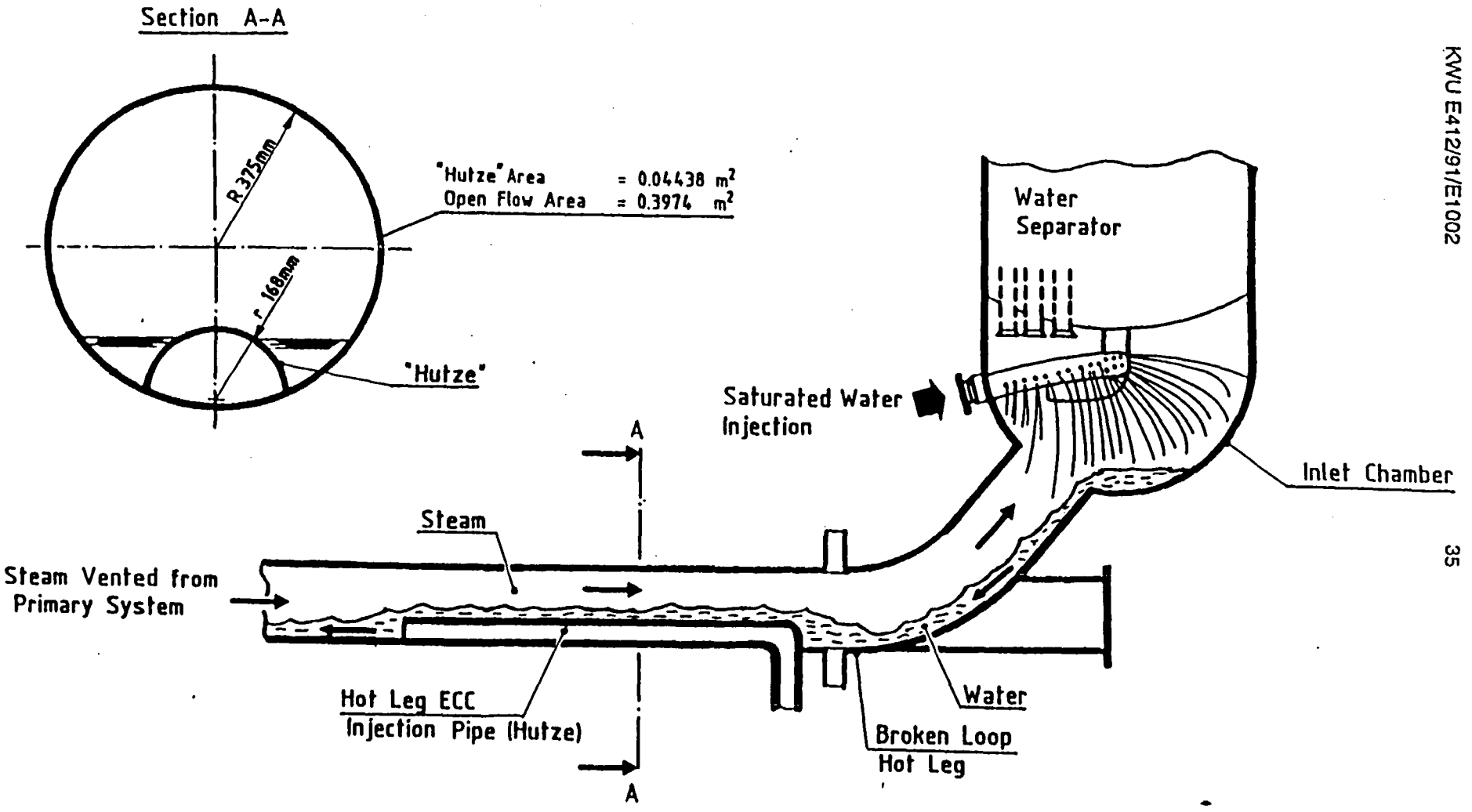


Fig. 2.8: UPTF Hot Leg Countercurrent Flow

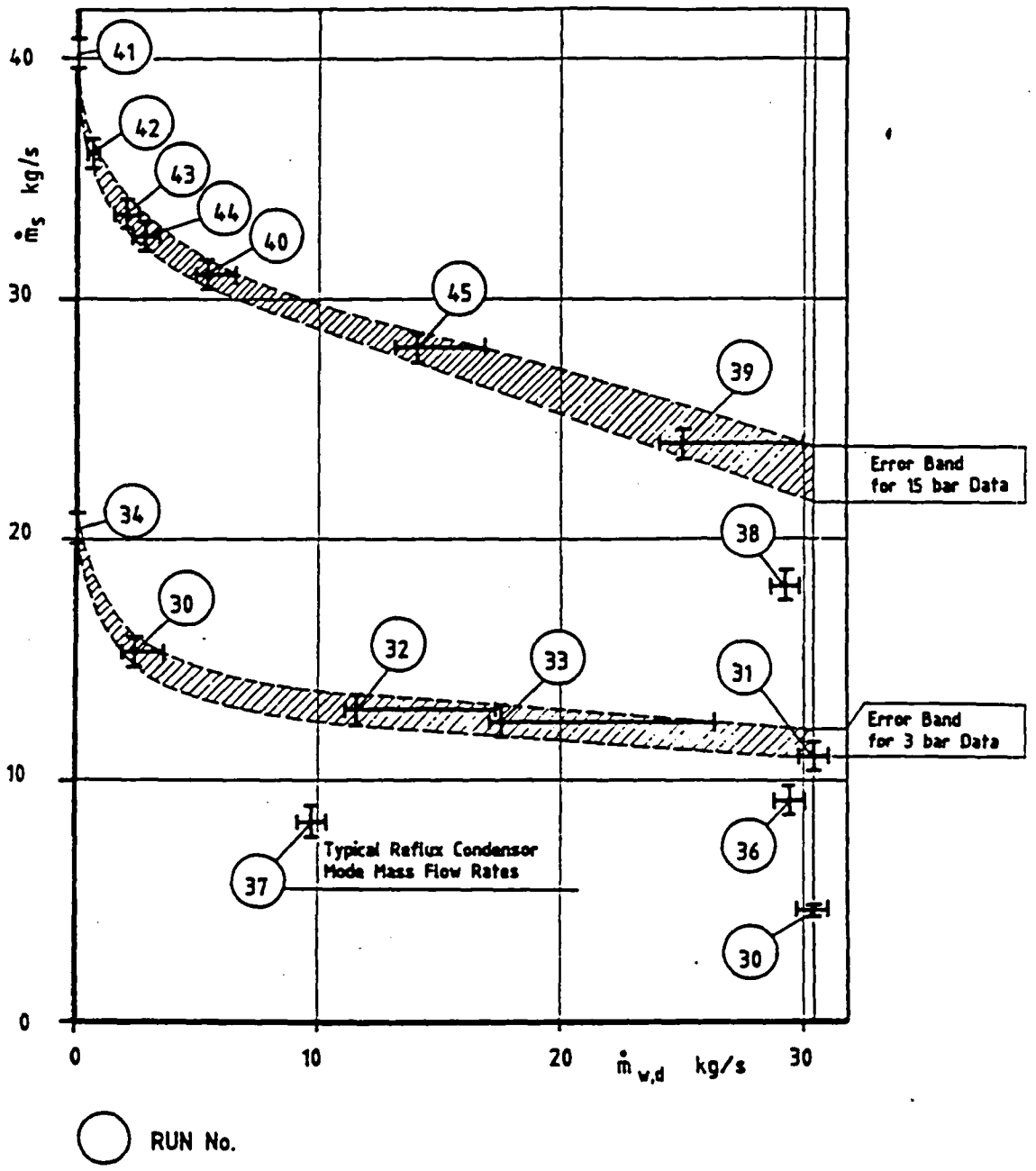


Fig. 2.9: CCF of Steam and Saturated Water in Hot Leg

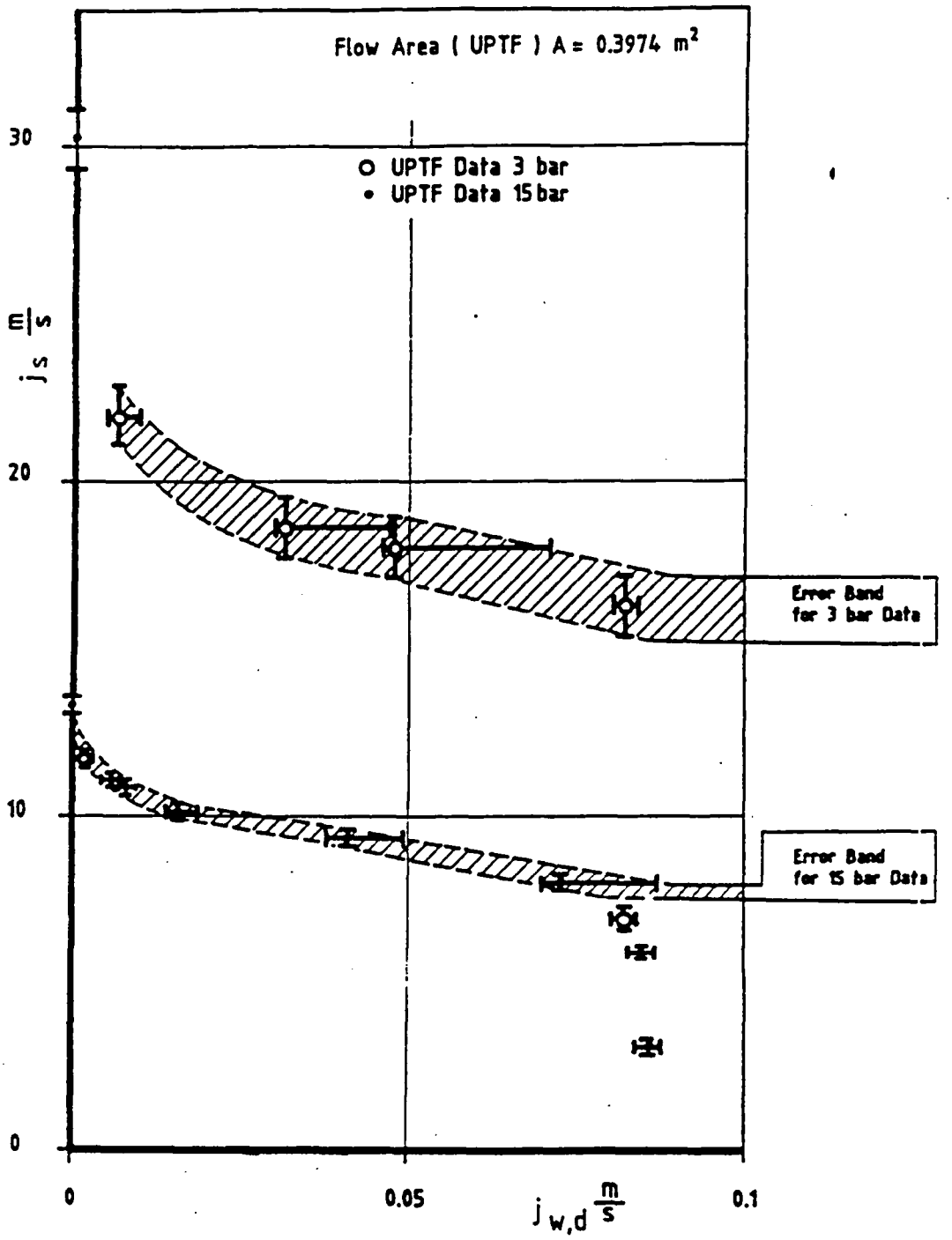


Fig. 2.10: Superficial Velocities of Steam and Water in Hot Leg

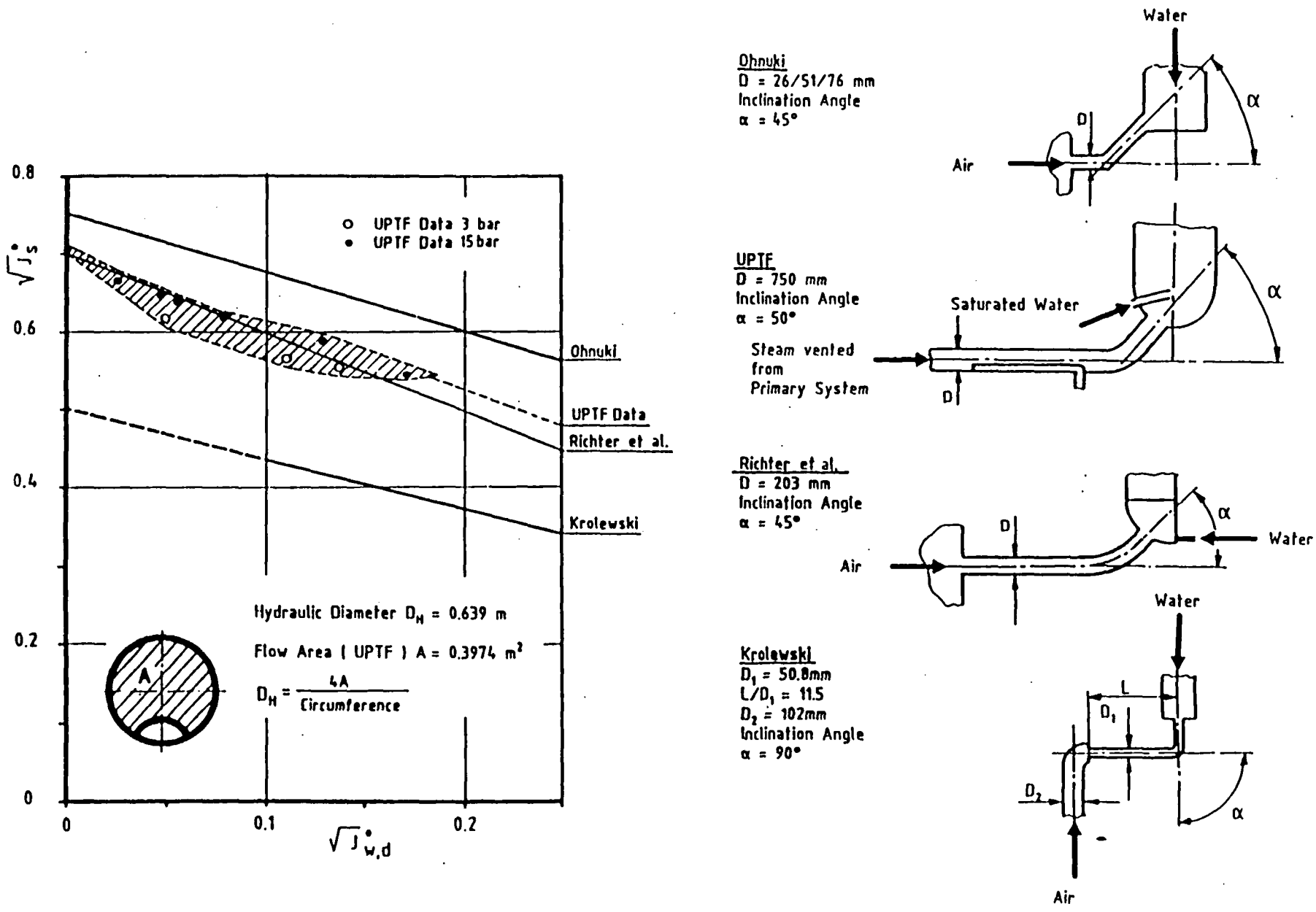


Fig. 2.11: Comparison of UPTF Data with Correlations of Richter et al., Ohnuki and Krolewski

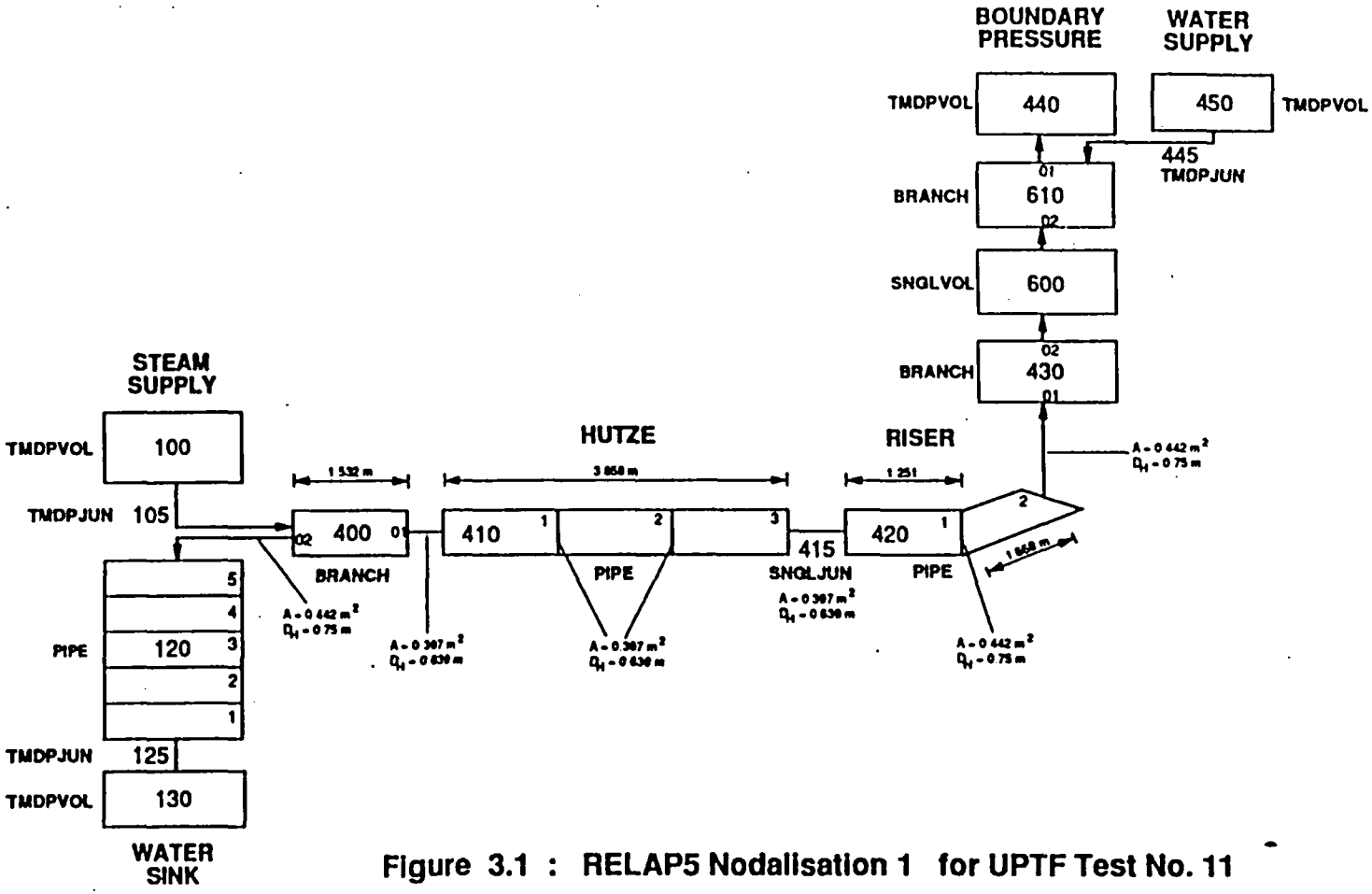


Figure 3.1 : RELAP5 Nodalisation 1 for UPTF Test No. 11

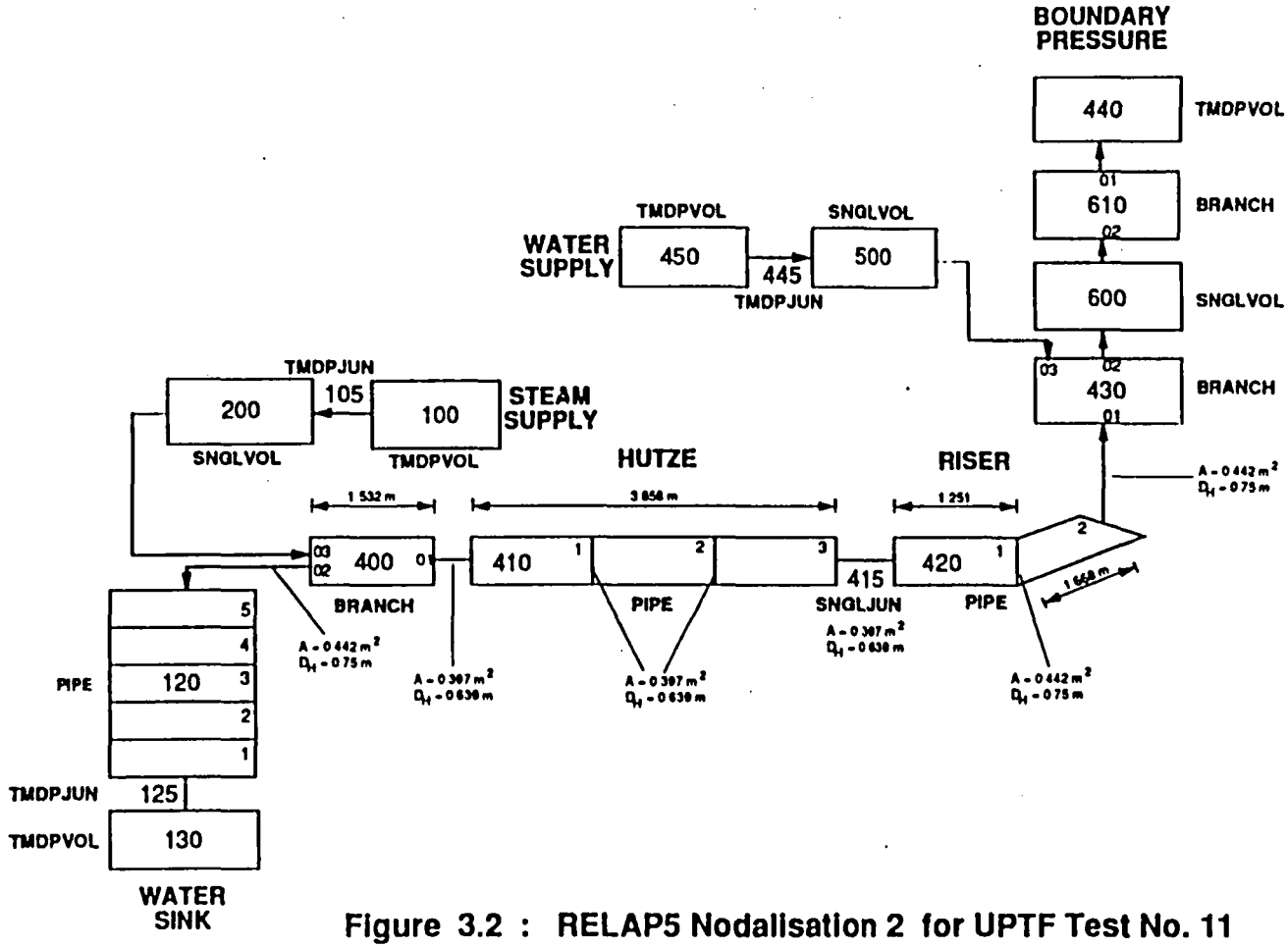


Figure 3.2 : RELAP5 Nodalisation 2 for UPTF Test No. 11

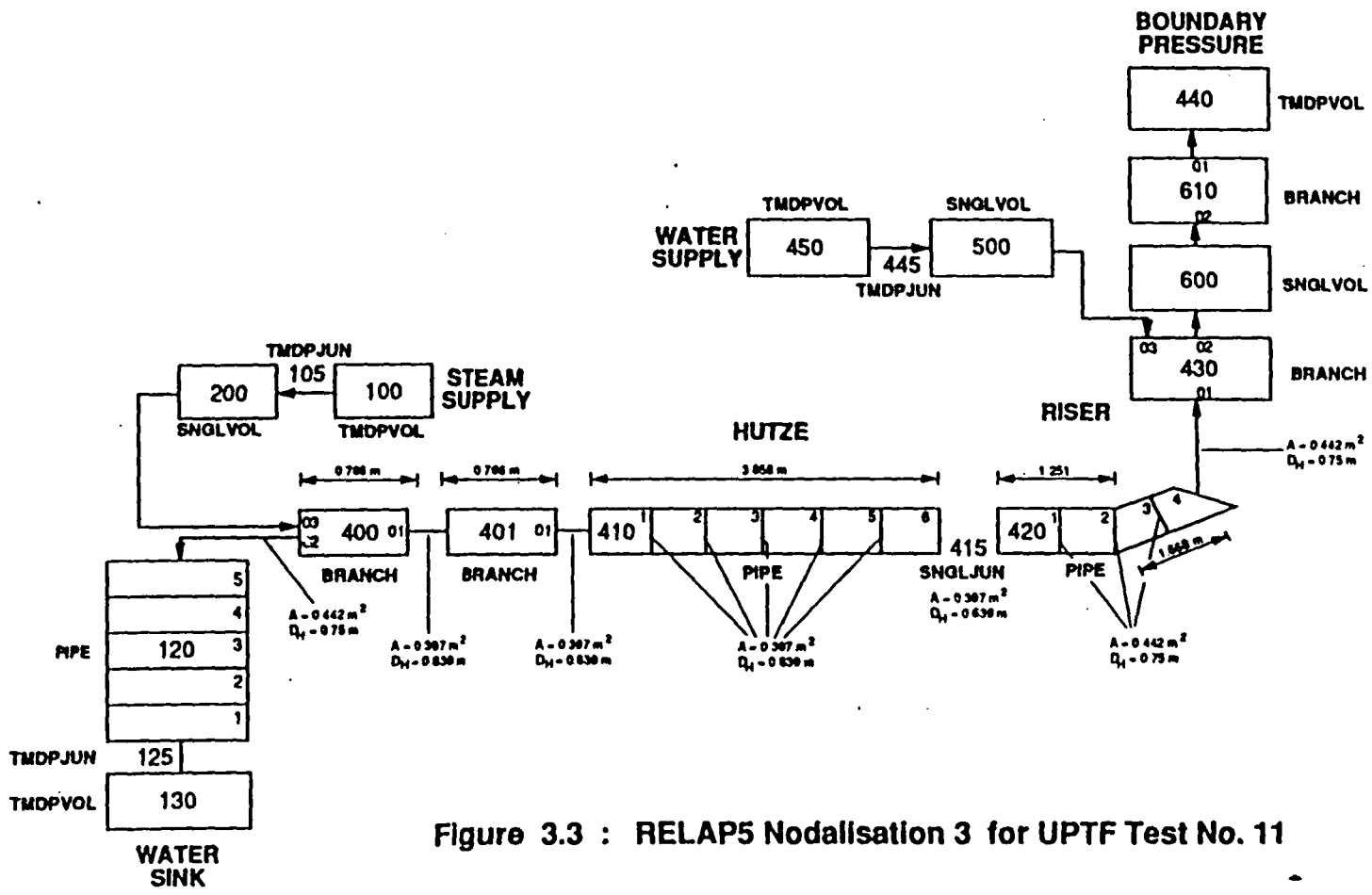


Figure 3.3 : RELAP5 Nodalisation 3 for UPTF Test No. 11

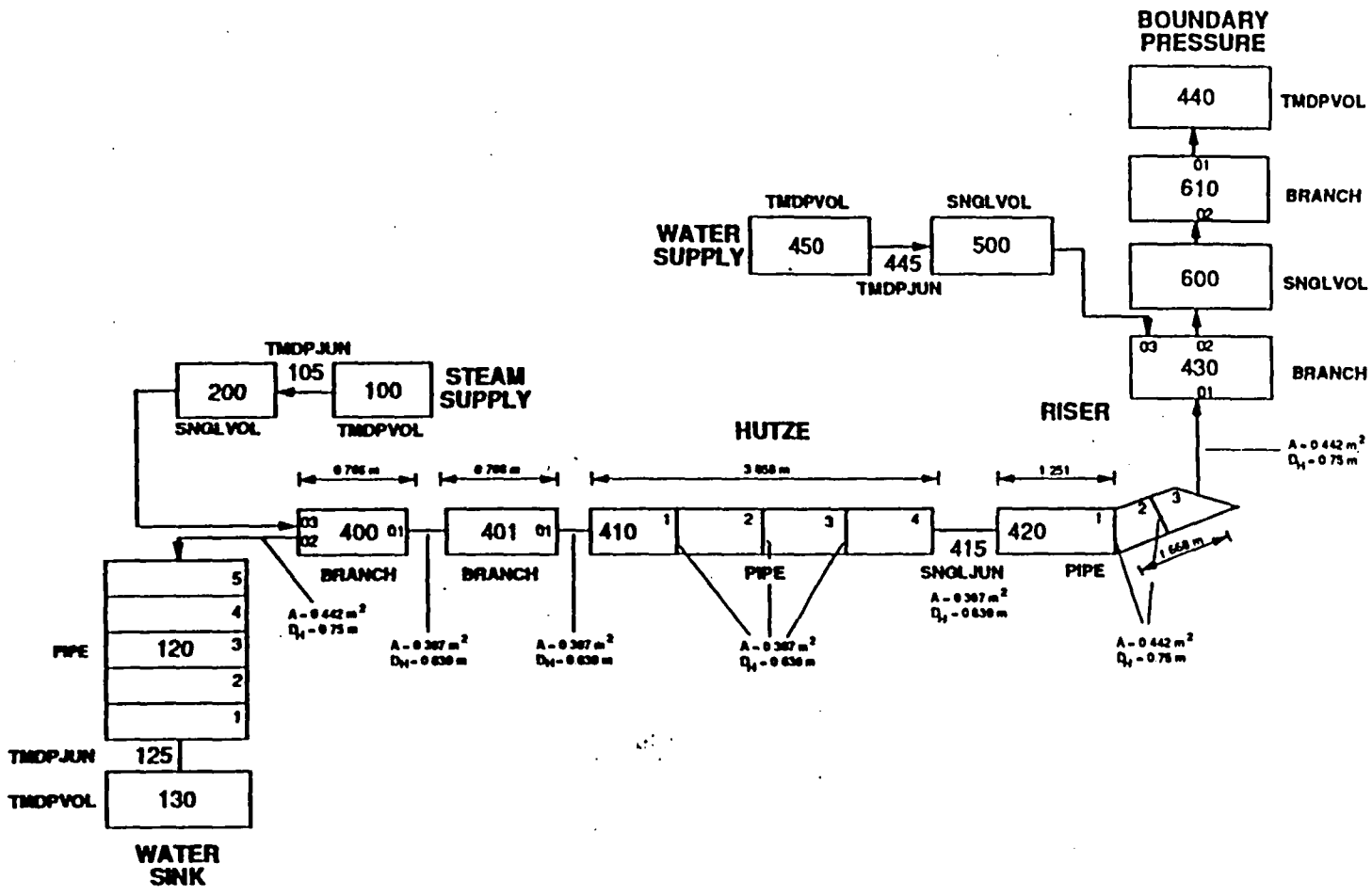


Figure 3.4 : RELAP5 Nodalisation 4 (Basic Nodalisation) for UPTF Test No. 11

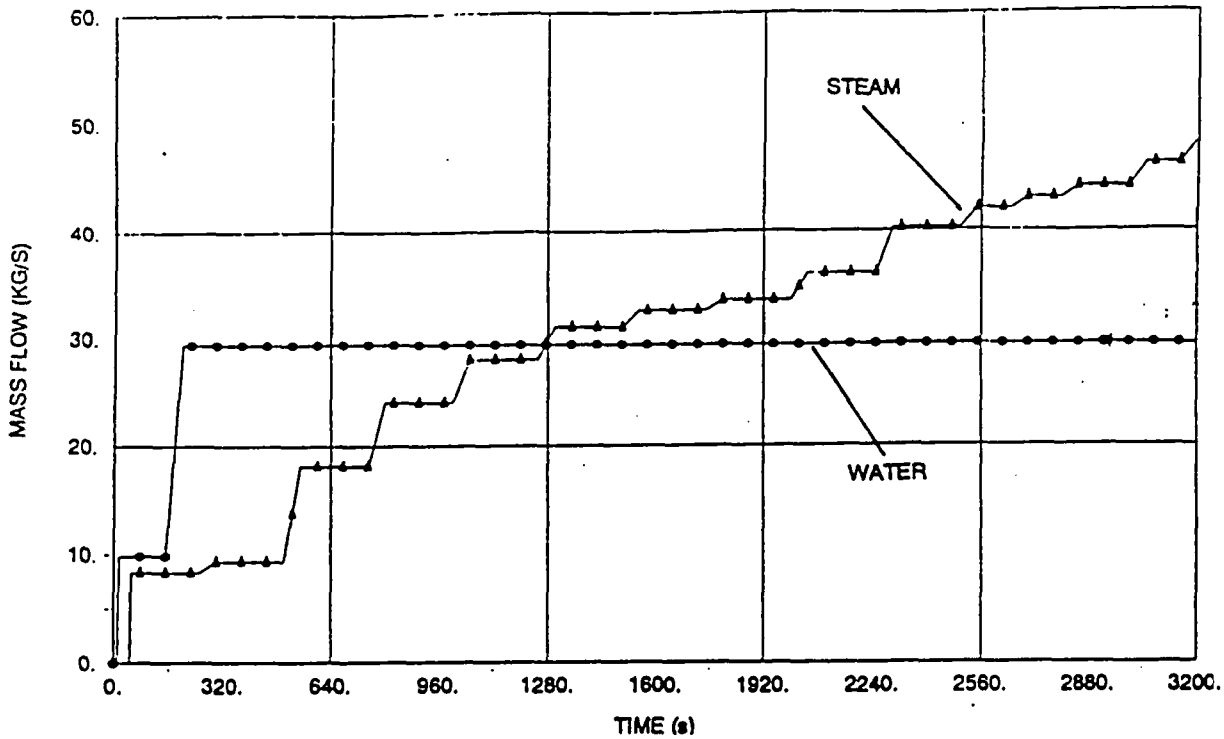


Fig. 3.5: Boundary Conditions for RELAP5 Simulation of UPTF 11 Runs 36 - 45. Injected Steam and Water Mass Flow Rates.

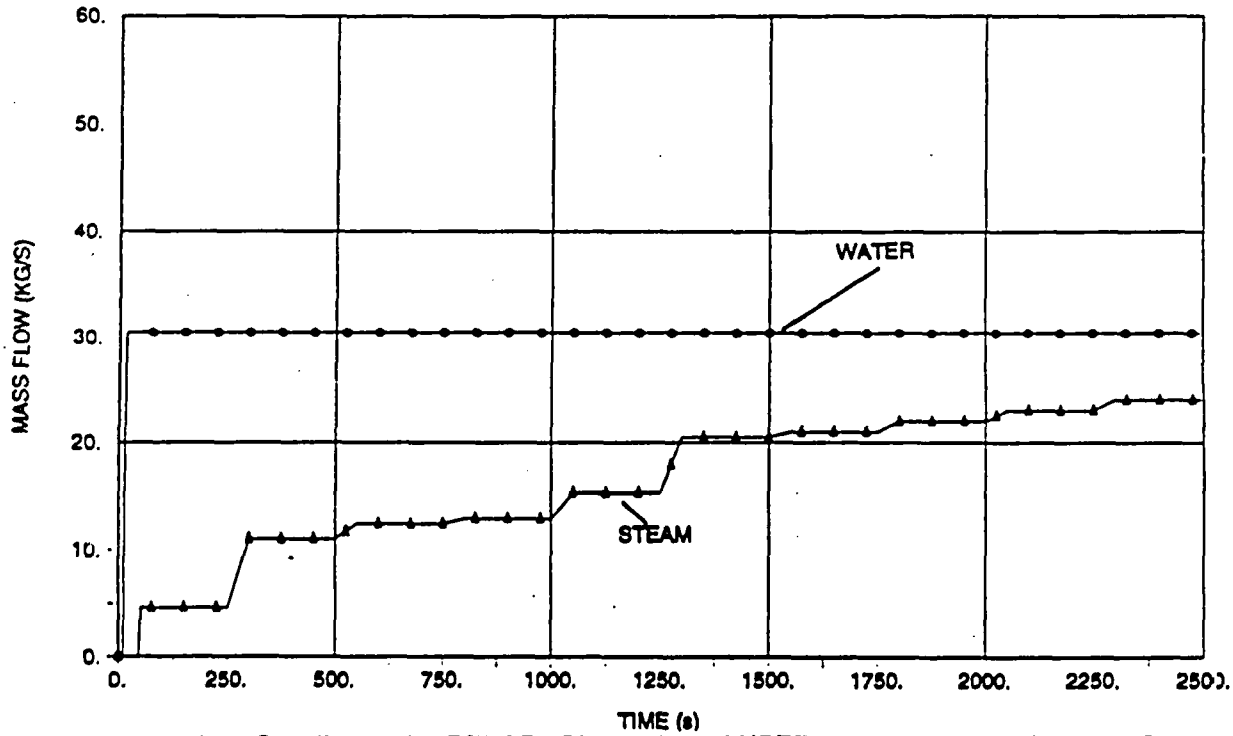


Fig. 3.6: Boundary Conditions for RELAP5 Simulation of UPTF 11 Runs 30 - 35. Injected Steam and Water Mass Flow Rates.

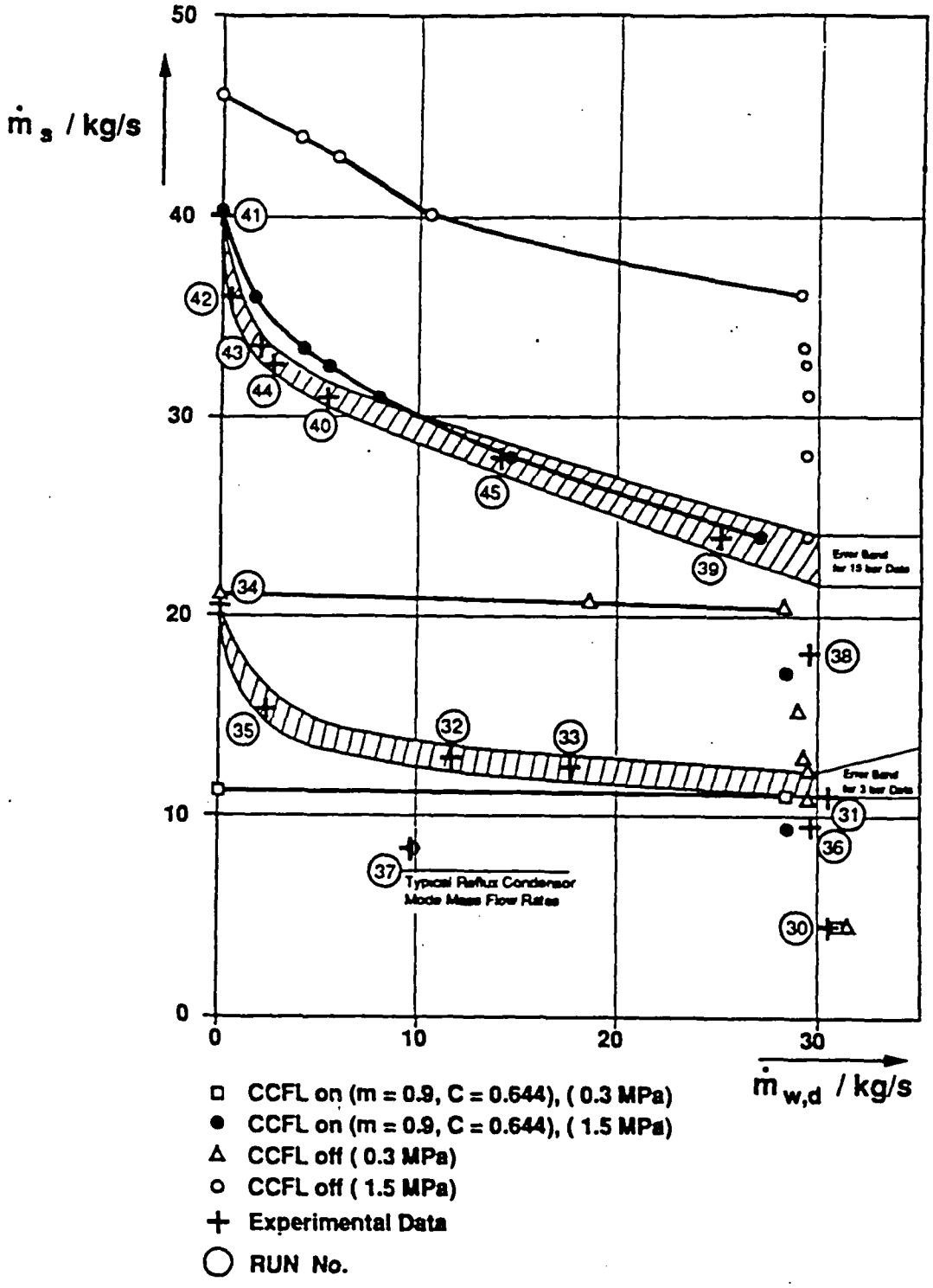


Fig. 4.1 : Experimental and Predicted Flooding Curves (Nodalisation No. 4)

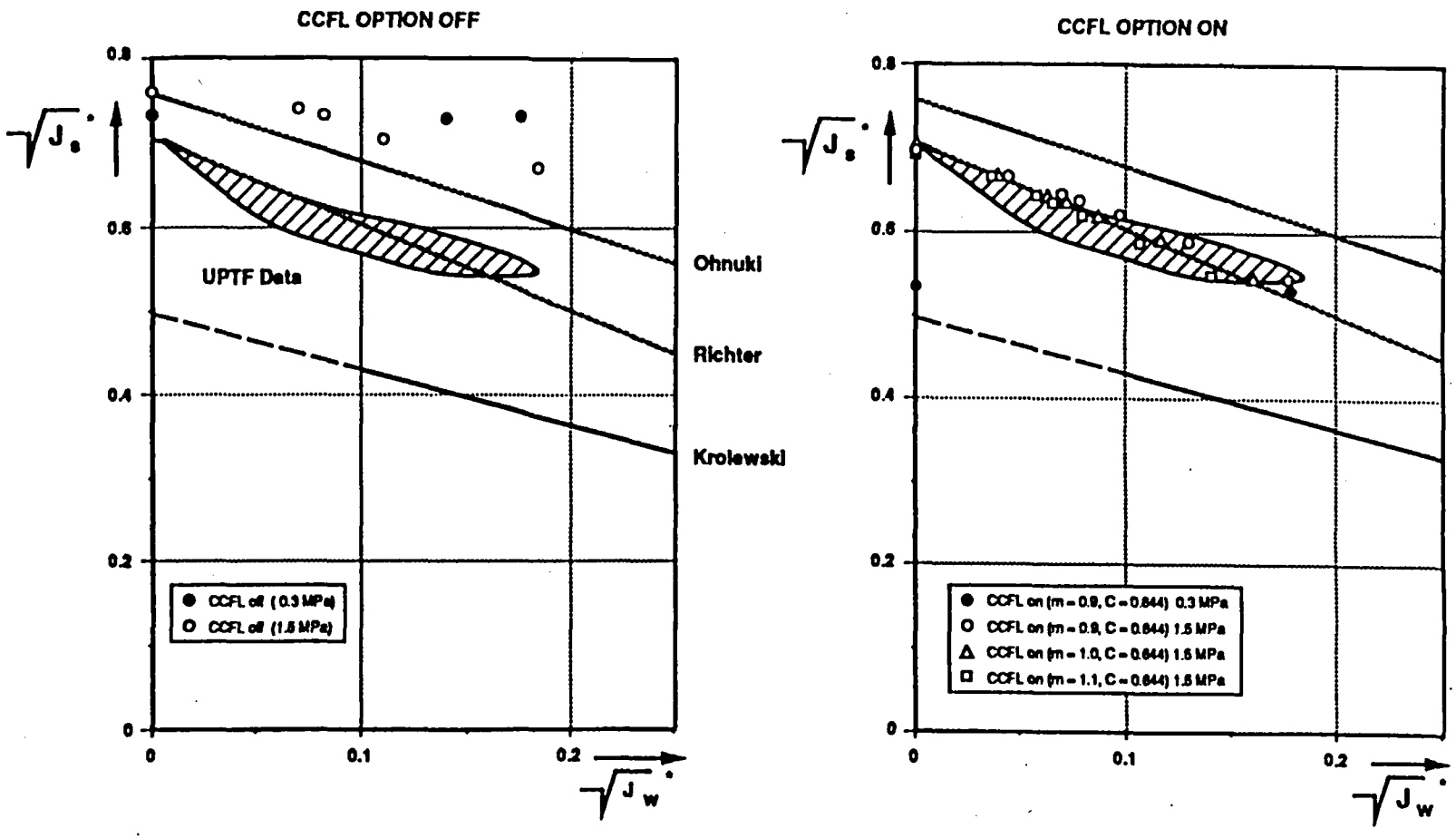


Fig. 4.2 : Comparison of RELAP5/MOD3/V5M5 Results with UPTF- Data and Flooding Correlations

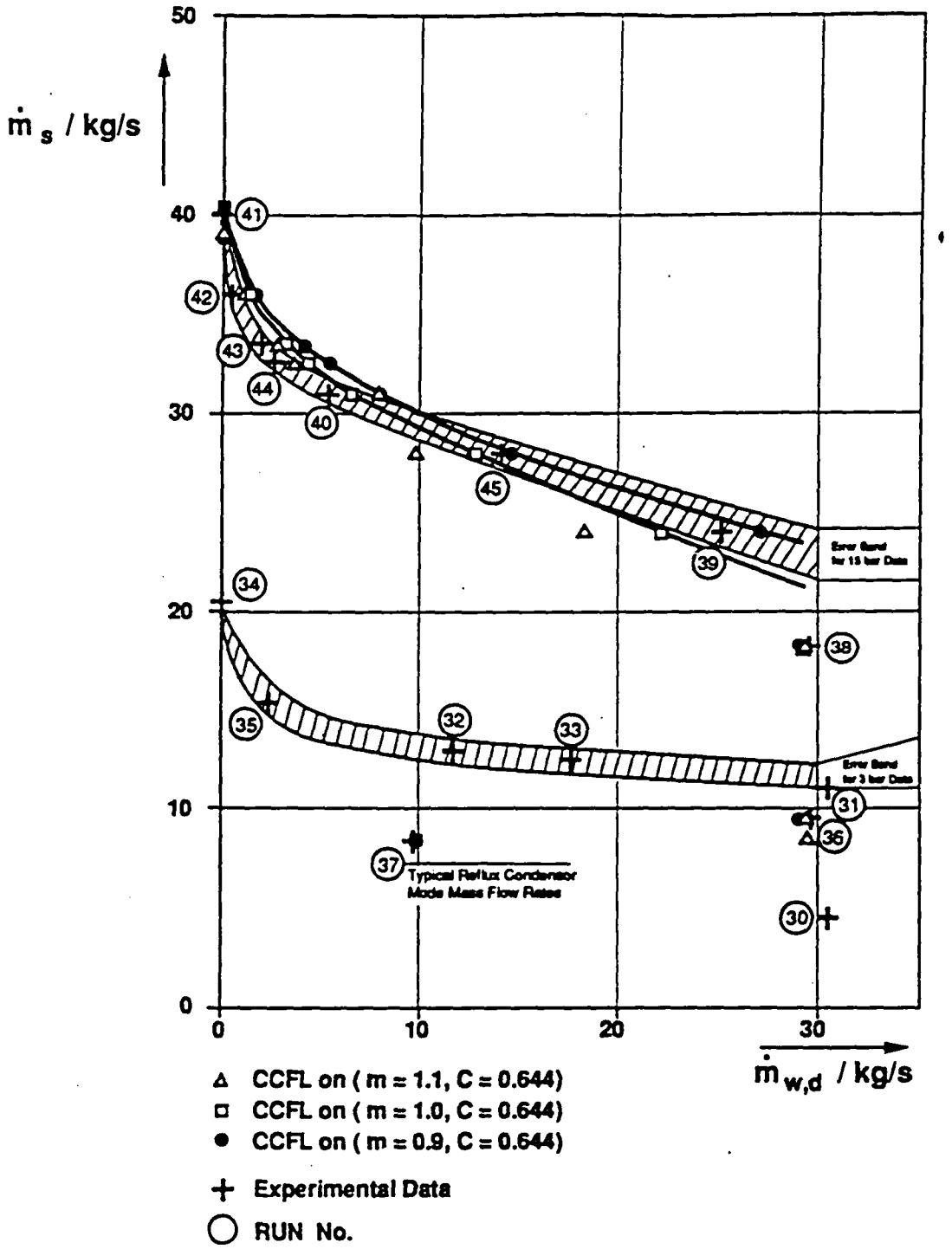


Fig. 4.3 : Experimental and Predicted Flooding Curves for 1.5 MPa
(Nodalisation No. 4)
Study on code Sensitivity to the Slope m of the CCFL Correlation

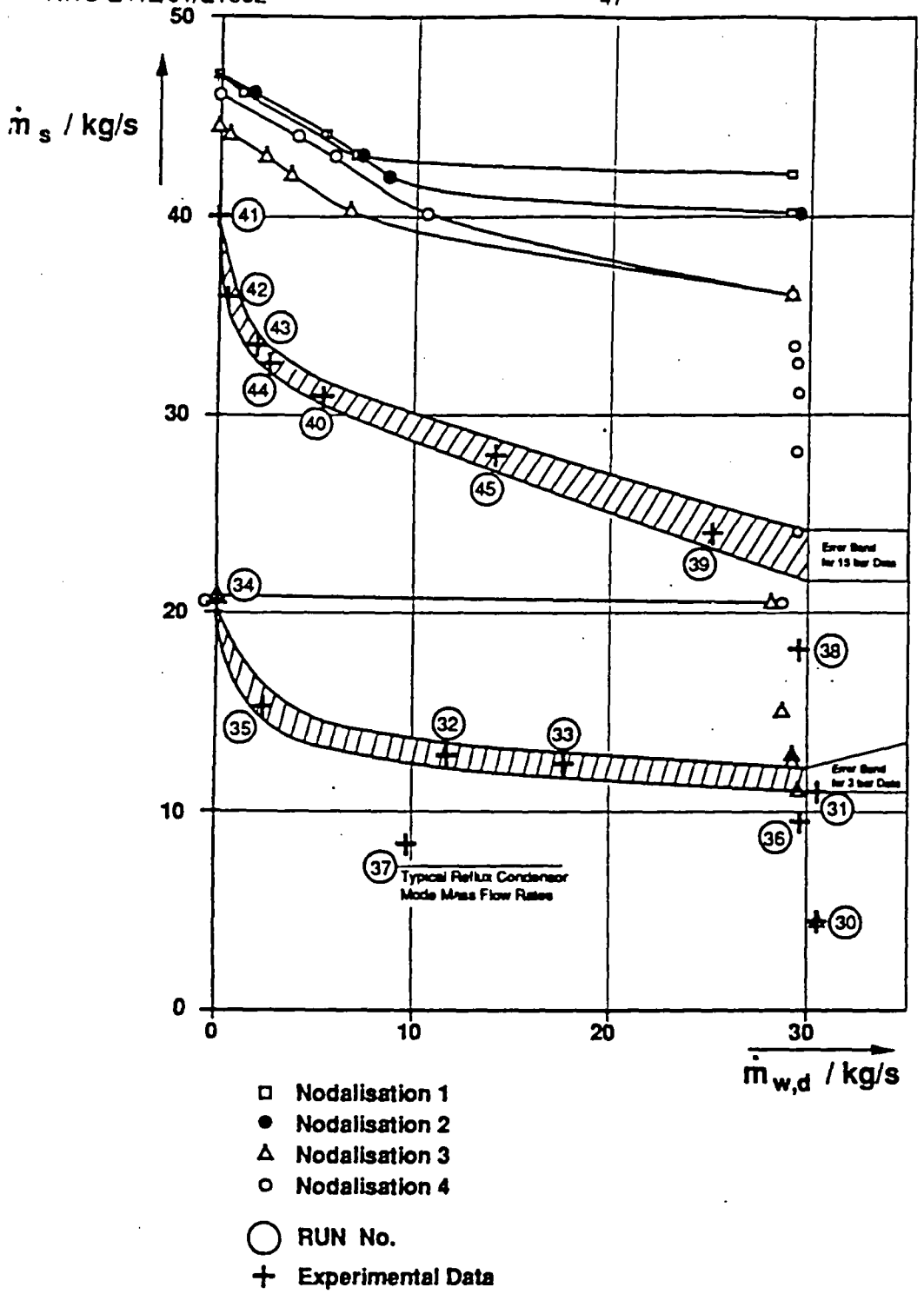


Fig. 4.4 : Nodalisation Studies.
Experimental and Predicted Flooding Curves

UPTF TEST No. 11, RUNS 36 - 45 (PRESSURE 1.5 MPa)

POST-TEST CALC.WITH RELAP5/MOD3/V5M5, NOD. No.4 (9 VOL. HOT LEG)

CCFL MODEL (m=0.8, C=0.644) USED AT JUNCTION 420-02 (RISER)

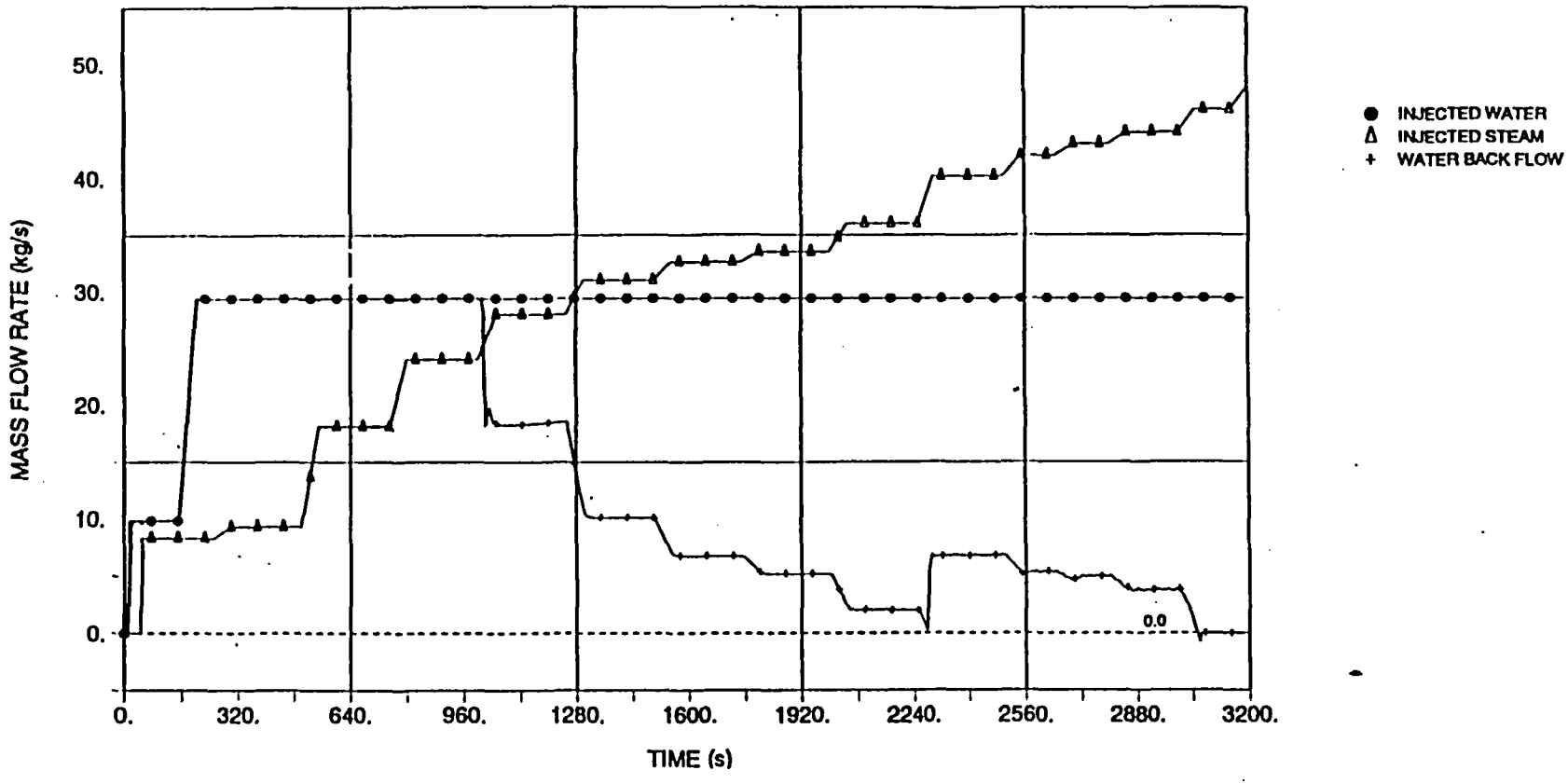


Fig. 4.5: Injected Steam, Injected Water and Water Back Flow at the Hutze

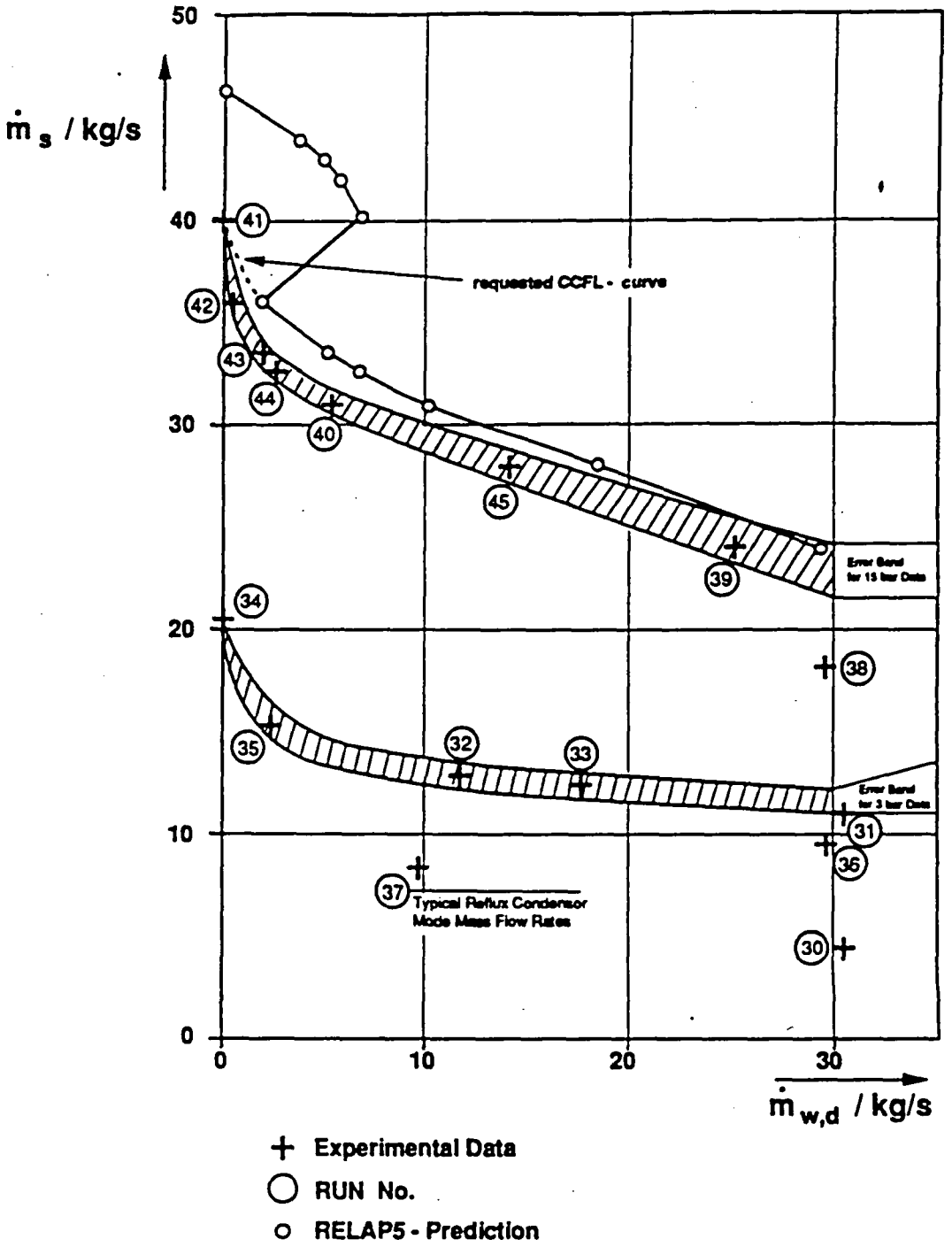


Fig. 4.6 : Comparison of UPTF Data with RELAP5/MOD3/V5M5 - Predictions Using a Wallis Type CCFL Correlation with m = 0.8 and C = 0.644 at the Junction 420-02 (Basic Nodalisation). Steam and Water Mass Flow Rates through the Hot Leg

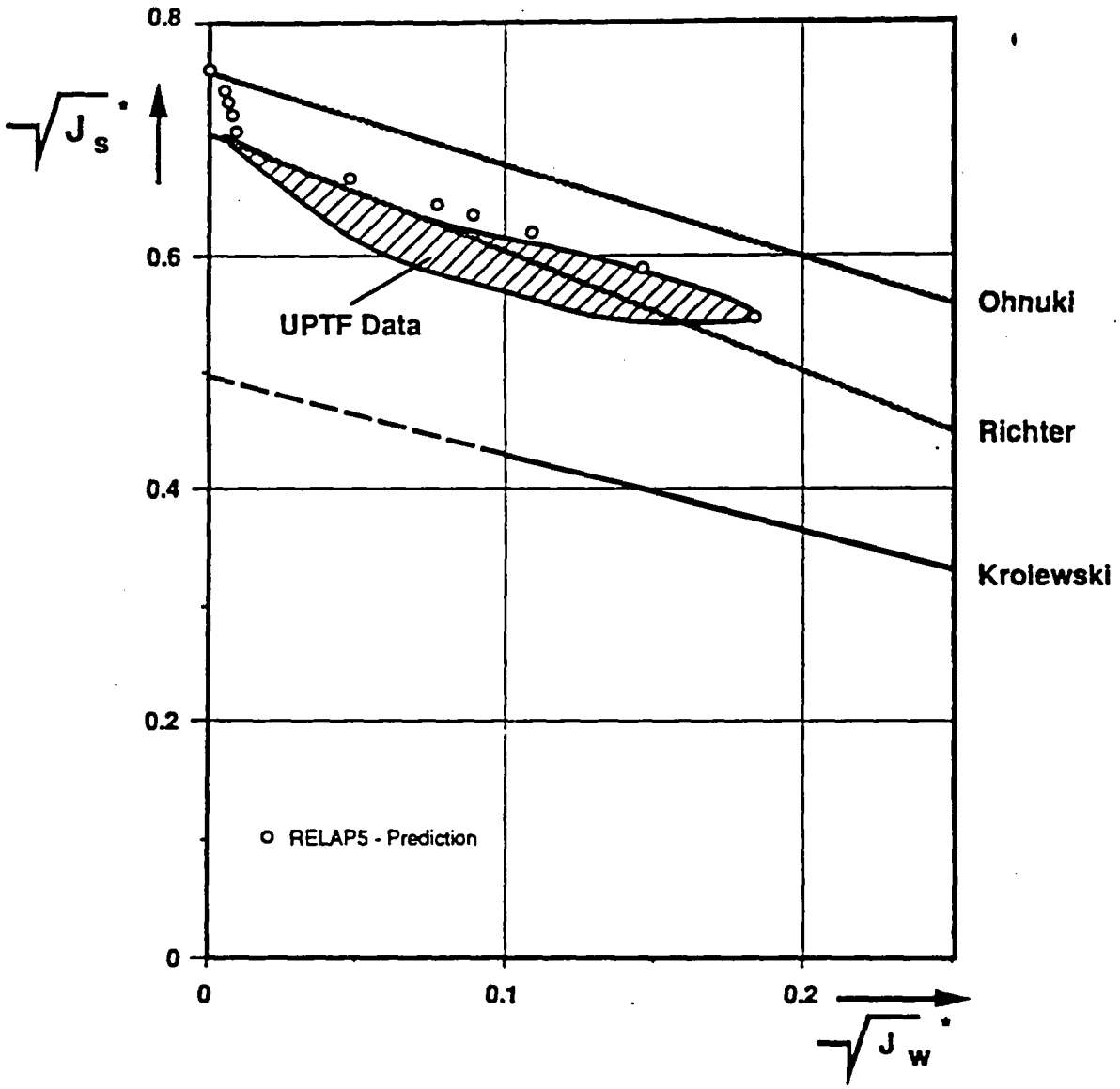


Fig. 4.7 : Comparison of UPTF Data with RELAP5/MOD3/V5M5 - Predictions Using a Wallis Type CCFL Correlation with m = 0.8 and C = 0.644 at the Junction 420-02 (Basic Nodalisation). Wallis Parameter for Steam and Water at the Hutze

APPENDIX A

RELAP5/MOD3 Input Deck for the Simulation of UPTF Test No. 11

```
=UPTF TEST NO 11, RUNS 36-45, DT=0.025, CCFL OPTION OFF, BASIC NODALISATION
*
*  HOT LEG WITH  9 VOLUMES
*
*  INTRODUCE SNGLVOL BETWEEN TMDPVOL+TMDPJUN (SOURCE/SINK) AND
*  CONNECTION COMPONENT (AS SUGGESTED BY STUBBE).
*
*
*     PRESSURE              1.5 MPa
*     STEAM INJECTION  - UP TO 2500 LIKE IN UPTF RUNS NR. 36 - 45
*                      - 2500 - 3200 INCREASED STEPWISE UP TO 52 KG/S
*                      - STEAM MASS FLOWS CHANGED WITHIN 50 S
*                      - STEAM MASS FLOWS KEPT THAN CONSTANT 200 S
*
*       WATER INJECTION    9.8  KG/S  AT 12.5 S
*       WATER INJECTION   29.4  KG/S  AT 200 S
*
*
*
*
100     NEW     TRANSNT
101     RUN
102     SI      SI
105     1.0     2.0   200000.
201    3200.   1.E-9   0.025     3   200  20000  100000
*
*
501     TIME   0    GT    NULL     0      13. L
*
*
*MINOR EDIT
*
*
*
301  P       430010000
302  MFLOWJ    445000000
303  MFLOWJ    105000000
*
304  CNTRLVAR  103    * WATER MASS FLOW AT J 41001
305  CNTRLVAR  104    * STEAM MASS FLOW AT J 41001
306  CNTRLVAR  109    * WATER MASS FLOW AT J 42001
307  CNTRLVAR  110    * STEAM MASS FLOW AT J 42001
308  CNTRLVAR  111    * WATER MASS FLOW AT J 43001
309  CNTRLVAR  112    * STEAM MASS FLOW AT J 43001
*
310  CNTRLVAR 254    * SQRT(WALLIS PARAM.) FOR WATER AT J 42001
311  CNTRLVAR 258    * SQRT(WALLIS PARAM.) FOR STEAM AT J 42001
312  CNTRLVAR 284    * SQRT(WALLIS PARAM.) FOR WATER AT J 41001
313  CNTRLVAR 288    * SQRT(WALLIS PARAM.) FOR STEAM AT J 41001
314  CNTRLVAR 234    * SQRT(WALLIS PARAM.) FOR WATER AT J 43001
```

```
315  CNTRLVAR 238    * SQRT(WALLIS PARAM.) FOR STEAM AT J 43001
*
320  VELFJ  410010000
321  VELGJ  410010000
322  VELFJ  420010000
323  VELGJ  420010000
324  VELFJ  430010000
325  VELGJ  430010000
*
330  MFLOWJ 410010000
331  MFLOWJ 430010000
*
371  VOIDF   400010000
372  VOIDF   410010000
373  VOIDF   410020000
374  VOIDF   410030000
375  VOIDF   420010000
376  VOIDF   420020000
377  VOIDF   430010000
*
381  FLOREG  400010000
382  FLOREG  410010000
383  FLOREG  410020000
384  FLOREG  410030000
385  FLOREG  420010000
386  FLOREG  420020000
387  FLOREG  430010000
*
390  DT      0
391  DTCRNT  0
*
*-------- STEAM SUPPLY SIMULATION--------------------------------
*
*
*         NAME     TIME DEPENDENT VOLUME
1000000   OBPL1    TMDPVOL
*         AREA LENGTH VOL X  ANGLE ELEV  ROUGH DHYDR FLAG
1000101   2.   0.     5.  0.  0.   0.  0.00015  0.   00
*         CTRL
1000200   2
*         VAR  PRESSURE
1000201   0.0  15.E+5    1.
*
*
*        TIME DEPENDENT JUNCTION FOR STEAM SUPPLY
*
*         NAME          TIME DEPENDENT JUNCTION
1050000   OP-HKL1       TMDPJUN
*         FROM       TO         AREA
1050101   100000000  200000000  0.5
```

```
*         CTRL
1050200   1
*         VAR  WFLOW SFLOW X
*
1050201   0.   0.    0.    0.
1050202   45.  0.    0.0   0.
1050203   50.  0.    8.3   0.
1050204   250. 0.    8.3   0.
1050205   300. 0.    9.3   0.
1050206   500. 0.    9.3   0.
1050207   550. 0.   18.1   0.
1050208   750. 0.   18.1   0.
1050209   800. 0.   24.0   0.
1050210  1000. 0.   24.0   0.
1050211  1050. 0.   28.0   0.
1050212  1250. 0.   28.0   0.
1050213  1300. 0.   31.0   0.
1050214  1500. 0.   31.0   0.
1050215  1550. 0.   32.6   0.
1050216  1750. 0.   32.6   0.
1050217  1800. 0.   33.5   0.
1050218  2000. 0.   33.5   0.
1050219  2050. 0.   36.0   0.
1050220  2250. 0.   36.0   0.
1050221  2300. 0.   40.2   0.
1050222  2500. 0.   40.2   0.
1050223  2550. 0.   42.0   0.
1050224  2650. 0.   42.0   0.
1050225  2700. 0.   43.0   0.
1050226  2800. 0.   43.0   0.
1050227  2850. 0.   44.0   0.
1050228  3000. 0.   44.0   0.
1050229  3050. 0.   46.0   0.
1050230  3150. 0.   46.0   0.
1050231  3200. 0.   48.0   0.
1050232  3300. 0.   48.0   0.
1050233  3350. 0.   50.0   0.
1050234  3450. 0.   50.0   0.
1050235  3500. 0.   52.0   0.
*
*
*
*         NAME      SNGLVOL
2000000   CONNECT1  SNGLVOL
*
*         AREA  LENGTH  VOL  X ANGLE ELEV  ROUGH    DH   VFLAG
2000101   0.5     1.     0.  0.   0. 0.    0.0      0.0   10000
*         CNTRL  PRESSURE   QUANTITIES
2000200   002    15.E+5     1.
*
```

```
*
*-------- CORE  SIMULATOR ------------------------------------
*
*
1200000   CORE1   PIPE
1200001   5
1200101   7.0     5
1200201   0.0     4
1200301   0.5     5
1200401   0.0  5
1200501   0.0  5
1200601   90.0  5
1200801   0.00015  0.35  5
1200901   0.0  0.0  4
1201001   00000   5
1201101   000000  4
1201201   002  15.0E5  0.0  0.  0.  0.  1
1201202   002  15.0E5  0.5  0.  0.  0.  2
1201203   002  15.0E5  1.0  0.  0.  0.  5
1201300   1
1201301   0.0  0.0  0.0  4
*
*
*-------- SYSTEM FOR CONTROLLED WATER DRAIN ---------------------
*
1250000   RDB1   TMDPJUN
1250101   120000000 130000000 0.04
1250200   1  501 CNTRLVAR 200
1250201   0.0   0.  0. 0.
1250202   100. 100. 0. 0.
*
1300000   UP1     TMDPVOL
*         AREA LENGTH VOL X  ANGLE ELEV  ROUGH DHYDR FLAG
1300101   2.   0.     2.  0.  90.  1.   .00015  0.   00000
1300200   002
1300201   0.0 15.E+5 0.
*
*-------------------------------------------------------------
*        MAIN COOLANT SYSTEM
*-------------------------------------------------------------
*
*-------- HOT LEG BETWEEN HUTZE AND CORE SIMULATOR
*
*         NAME      BRANCH
4000000   HKL1      BRANCH
4000001   3         1
*
*         AREA  LENGTH  VOL  X ANGLE ELEV  ROUGH    DH   VFLAG
4000101   0.4418   0.766  0.  0.   0. 0.    0.00015  0.75  10000
*         CNTRL  PRESSURE   QUANTITIES
```

```
4000200   002    15.E+5     1.
*
*         FROM       TO          AREA   KFOR  KBACK FVCAHS (JFLAG)
4001101   400010000  401000000   0.4418  0.0    0.0  000000
4002101   400000000  120010000   0.4418  0.0    0.0  000000
4003101   200010000  400000000   0.04    0.0    0.0  000000
*
*       JUNCTION DIAMETER AND CCFL DATA
*         DH       FORM      C       M
4001110   0.639     0.       0.7    1.0
*
*         CTRL WFLOW SFLOW  X
4001201   0.0   0.0  0.0
4002201   0.0   0.0  0.0
4003201   0.0   0.0  0.0
*
*
*
*         NAME      BRANCH
4010000   HKL2      BRANCH
4010001   1         1
*         AREA   LENGTH  VOL  X ANGLE ELEV  ROUGH    DH   VFLAG
4010101   0.4418   0.766  0.  0.   0. 0.    0.00015  0.75  10000
*         CNTRL  PRESSURE   X
4010200   002    15.E+5     1.
*         FROM       TO          AREA    KFOR  KBACK FVCAHS (JFLAG)
4011101   401010000  410000000   0.3974  0.121  0.0  000000
*       JUNCTION DIAMETER AND CCFL DATA
*         DH       FORM      C       M
4011110   0.639     0.       0.7    1.0
*         CTRL WFLOW SFLOW  X
4011201   0.0   0.0  0.0
*
*
*
*-------- HOT LEG WITH HUTZE ---------------------------------
*
*         NAME      PIPE
4100000   HKL3      PIPE
*         NUM OF VOL
4100001   4
*         J-AREA    VOL.NO
4100101   0.3974    4
*         LENGTH    VOL.NO
4100301   0.9645    4
*         ANGLE     VOL.NO
4100601    0.       4
*         ELEV      VOL.NO
4100701   0.0       4
*         ROUGH     DHYDR VOL.NO
```

```
4100801   0.00015   0.639    4
*         KFOR   KBACK JUN.NO
4100901   0.0156 0.0156   3
*         PVBFE (VOL.FLAG)   VOL.NO
4101001   10000                4
*         FVCAHS (J-FLAG)    JUN.NO
4101101   000000               3
*         CTRL PRESSURE
4101201   2    15.E+5    1.  0. 0. 0.  4
*         CTRL
4101300   0
*         WFLOW SFLOW  X   JUN.NO
4101301   0.    0.     0.    3
*       JUNCTION DIAMETER AND CCFL DATA
*          DH       FORM      C       M
4101401   0.639      0.       0.7     1.0    1
4101402   0.639      0.       0.7     1.0    3
*
*
*
*         NAME      SINGLE JUNCTION
4150000   HKL4      SNGLJUN
*         FROM       TO         AREA KFOR KBACK JFLAG
4150101   410010000  420000000 0.3974  0.   0.    000000
*       JUNCTION DIAMETER AND CCFL DATA
*         DH       FORM      C       M
4150110   0.639     0.       0.7    1.0
*         CTRL  WFLOW SFLOW X
4150201   0     0.    0.    0.
*
*-------------- RISER --------------------------------
*
*         NAME      PIPE
4200000   HKL5      PIPE
*         VOL.NO
4200001   3
*         AREA      VOL.NO
4200101   0.4418    3
*         LENGTH    VOL.NO LENGTH VOL.NO
4200301   1.251     1         0.834  3
*         VOL       VOL.NO
4200401   0.        3
*         ANGLE     VOL.NO  ANGLE  VOL.NO
4200601    0.       1          50.   3
*         ELEV      VOL.NO  ELEV     VOL.NO
4200701   0.        1         0.63885   3
*         ROUGH     DHYDR   VOL.NO
4200801   0.00015   0.75     3
*         KFOR    KBACK JUN.NO
4200901   0.0157  0.0157     2
```

```
*         V-FLAG  VOL.NO
4201001   10000      3
*         J-FLAG  JUN.NO
4201101   000000   1
4201102   000000   2     * OR 100000 FOR CCFL
*         CTRL PRESSURE
4201201   2    15.E+5  1.  0. 0. 0.  3
*         CTRL
4201300   0
*         WFLOW SFLOW  X  JUN.NO
4201301   0.    0.     0.  2
*       JUNCTION DIAMETER AND CCFL DATA
*          DH       FORM        C       M
4201401   0.75       0.       0.644     1.0    2
*
*
*
*--------- WATER SEPARATOR INLET CHAMBER -----------------------
*
*         NAME      BRANCH
4300000   EIN-DE    BRANCH
*
4300001   3         1
*         AREA    LENGTH  VOL  X ANGLE ELEV  ROUGH   DH   VFLAG
4300101   0.0     1.3   4.22  0.  90.  1.076 0.00015  0.  10000
*         CNTRL  PRESSURE   QUANTITIES
4300200   002    15.E+5     1.
*         FROM       TO          AREA    KFOR  KBACK  JFLAG
4301101   420010000  430000000   0.4418  0.59  0.125  000000
4302101   430010000  600000000   1.C     1.0   1.0    000000
4303101   500010000  430010000   0.04    0.0   0.0    001000
*       JUNCTION DIAMETER AND CCFL DATA
*         DH       FORM      C       M
4301110   0.75      0.       0.7    1.0
*         CTRL WFLOW SFLOW  X
4301201   0.0   0.0  0.0
4302201   0.0   0.0  0.0
4303201   0.0   0.0  0.0
*
*
*
*-------- WATER SEPARATOR ---------------------------------------
*
*         NAME      SNGLVOL
6000000   STDOM     SNGLVOL
*
*         AREA  LENGTH  VOL  X ANGLE ELEV  ROUGH   DH  VFLAG
6000101   1.0     2.0   0.0  0.  90. 2.0   0.00015  0. 10000
*         CNTRL  PRESSURE   QUANTITIES
6000200   002    15.E+5     1.
```

```
*
*       ARTIFICIAL SEPARATOR
*
*        NAME      BRANCH
6100000  SEP       BRANCH
*
6100001  2         1
*
*        AREA  LENGTH  VOL  X ANGLE ELEV  ROUGH    DH    VFLAG
6100101  1.0     2.0    0.  0.  90. 2.0   0.00015  0.44  10000
*        CNTRL  PRESSURE   QUANTITIES
6100200  002    15.E+5     1.
*
*        FROM       TO          AREA  KFOR KBACK JFLAG
6101101  610010000  440000000   2.0   3.5  3.5   011000
6102101  600010000  610000000   2.0   3.5  3.5   011000
*        CTRL WFLOW SFLOW  X
6101201  0.0   0.0  0.0
6102201  0.0   0.0  0.0
*
*        NAME       TIME DEPENDENT VOLUME
4400000  DE2        TMDPVOL
*        AREA LENGTH VOL X  ANGLE  ELEV ROUGH DHYDR V-FLAG
4400101  4.   0.     5.  0.  0.    0.  0.00015  0.  00000
*        CTRTL
4400200  2
*        VAR  PRESSURE
4400201  0.0  15.E+5     1.
*
*
*-------- WATER SUPPLY SYSTEM -------------------
*
*        NAME            TIME DEPENDENT JUNCTION
4450000  DE-HKL1         TMDPJUN
*        FROM       TO         AREA
4450101  450000000  500000000  0.04
*        CTRL
4450200  1
*        VAR   WFLOW SFLOW X
4450201  0.    0.    0.    0.
4450202  12.   0.    0.    0.
4450203  12.5  9.8   0.    0.
4450204  150.  9.8   0.    0.
4450205  200. 29.4   0.    0.
*
*
*        NAME      TIME DEPENDENT VOLUME
4500000  DE1       TMDPVOL
*        AREA LENGTH VOL X  ANGLE  ELEV ROUGH DHYDR VFLAG
4500101  2.   0.     5.  0. 0.     0.  0.00015  0.   00
```

```
*        CTRL
4500200  2
*        VAR PRESSURE
4500201  0.0 15.E+5     0.
*
*
*        NAME      SNGLVOL
5000000  CONNECT1  SNGLVOL
*
*        AREA  LENGTH  VOL  X ANGLE ELEV  ROUGH    DH   VFLAG
5000101  0.04    0.5     0.  0.   0. 0.    0.0      0.0   10000
*        CNTRL  PRESSURE   QUANTITIES
5000200  002    15.E+5     1.
*
*
*
*-----------------------------------------------------------------
*         CONTROL COMPONENTS
*-----------------------------------------------------------------
*
*
* CONTROL VARIABLES SIGNIFICANCE
*
*   CNTRLVAR   1    * WATER SUP.VEL. AT J 40001
*   CNTRLVAR   2    * STEAM SUP.VEL. AT J 40001
*   CNTRLVAR   3    * WATER SUP.VEL. AT J 41001
*   CNTRLVAR   4    * STEAM SUP.VEL. AT J 41001
*   CNTRLVAR   5    * WATER SUP.VEL. AT J 41002
*   CNTRLVAR   6    * STEAM SUP.VEL. AT J 41002
*   CNTRLVAR   7    * WATER SUP.VEL. AT J 41500
*   CNTRLVAR   8    * STEAM SUP.VEL. AT J 41500
*   CNTRLVAR   9    * WATER SUP.VEL. AT J 42001
*   CNTRLVAR  10    * STEAM SUP.VEL. AT J 42001
*   CNTRLVAR  11    * WATER SUP.VEL. AT J 43001
*   CNTRLVAR  12    * STEAM SUP.VEL. AT J 43001
*
*
*   CNTRLVAR  14    * COLLAPSED WATER LEVEL IN COMP. 120 (CORE)
*   CNTRLVAR  16    * COLLAPSED WATER LEVEL IN COMP. 430 (SG INLET)
*
*   CNTRLVAR  17    * WATERVOLUME IN SYSTEM (FROM 400 TO 610)
*   CNTRLVAR  18    * INTEGRAL OF INJECTED WATER
*
*   CNTRLVAR  19    * WATER MASS FLOW THROUGH J 40002 (DRAINED WATER)
*   CNTRLVAR  20    * WATER MASS FLOW THROUGH J 61001 (ENTRAINED WATER TO SG)
*
*   CNTRLVAR  21    * INTEGRAL DRAINED WATER THROUGH J 40002
*   CNTRLVAR  22    * INTEGRAL ENTRAINED WATER THROUGH J 61001
*
*   CNTRLVAR  34    * WALLIS PARAMETER FOR WATER AT J 43001
```

```
*   CNTRLVAR  38    * WALLIS PARAMETER FOR STEAM AT J 43001
*   CNTRLVAR  54    * WALLIS PARAMETER FOR WATER AT J 42001
*   CNTRLVAR  58    * WALLIS PARAMETER FOR STEAM AT J 42001
*   CNTRLVAR  64    * WALLIS PARAMETER FOR WATER AT J 41500
*   CNTRLVAR  68    * WALLIS PARAMETER FOR STEAM AT J 41500
*   CNTRLVAR  74    * WALLIS PARAMETER FOR WATER AT J 40001
*   CNTRLVAR  78    * WALLIS PARAMETER FOR STEAM AT J 40001
*   CNTRLVAR  84    * WALLIS PARAMETER FOR WATER AT J 41001
*   CNTRLVAR  88    * WALLIS PARAMETER FOR STEAM AT J 41001
*
*   CNTRLVAR  100    * WATER MASS FLOW AT J 40002
*   CNTRLVAR  101    * WATER MASS FLOW AT J 40001
*   CNTRLVAR  102    * STEAM MASS FLOW AT J 40001
*   CNTRLVAR  103    * WATER MASS FLOW AT J 41001
*   CNTRLVAR  104    * STEAM MASS FLOW AT J 41001
*   CNTRLVAR  105    * WATER MASS FLOW AT J 41002
*   CNTRLVAR  106    * STEAM MASS FLOW AT J 41002
*   CNTRLVAR  107    * WATER MASS FLOW AT J 41500
*   CNTRLVAR  108    * STEAM MASS FLOW AT J 41500
*   CNTRLVAR  109    * WATER MASS FLOW AT J 42001
*   CNTRLVAR  110    * STEAM MASS FLOW AT J 42001
*   CNTRLVAR  111    * WATER MASS FLOW AT J 43001
*   CNTRLVAR  112    * STEAM MASS FLOW AT J 43001
*
*   CNTRLVAR  170    * WATER INVENTORY IN SYSTEM (FROM 400 TO 610)
*
*   CNTRLVAR 234    * SQRT(WALLIS PARAM.) FOR WATER AT J 43001
*   CNTRLVAR 238    * SQRT(WALLIS PARAM.) FOR STEAM AT J 43001
*   CNTRLVAR 254    * SQRT(WALLIS PARAM.) FOR WATER AT J 42001
*   CNTRLVAR 258    * SQRT(WALLIS PARAM.) FOR STEAM AT J 42001
*   CNTRLVAR 264    * SQRT(WALLIS PARAM.) FOR WATER AT J 41500
*   CNTRLVAR 268    * SQRT(WALLIS PARAM.) FOR STEAM AT J 41500
*   CNTRLVAR 274    * SQRT(WALLIS PARAM.) FOR WATER AT J 40001
*   CNTRLVAR 278    * SQRT(WALLIS PARAM.) FOR STEAM AT J 40001
*   CNTRLVAR 284    * SQRT(WALLIS PARAM.) FOR WATER AT J 41001
*   CNTRLVAR 288    * SQRT(WALLIS PARAM.) FOR STEAM AT J 41001
*
*
*------ SUPERFICIAL VELOCITIES (M/S)---------------
*
20500100   JF40001 MULT    1.0     0.  1
20500101   VOIDFJ  400010000
20500102   VELFJ   400010000
*
20500200   JG40001 MULT    1.0     0.  1
20500201   VOIDGJ  400010000
20500202   VELGJ   400010000
*
20500300   JF41001 MULT    1.0     0.  1
20500301   VOIDFJ  410010000
```

```
20500302   VELFJ   410010000
*
20500400   JG41001 MULT    1.0     0.  1
20500401   VOIDGJ  410010000
20500402   VELGJ   410010000
*
20500500   JF41002 MULT    1.0     0.  1
20500501   VOIDFJ  410020000
20500502   VELFJ   410020000
*
20500600   JG41002 MULT    1.0     0.  1
20500601   VOIDGJ  410020000
20500602   VELGJ   410020000
*
20500700   JF415   MULT    1.0     0.  1
20500701   VOIDFJ  415000000
20500702   VELFJ   415000000
*
20500800   JG415   MULT    1.0     0.  1
20500801   VOIDGJ  415000000
20500802   VELGJ   415000000
*
20500900   JF42001 MULT    1.0     0.  1
20500901   VOIDFJ  420010000
20500902   VELFJ   420010000
*
20501000   JG42001 MULT    1.0     0.  1
20501001   VOIDGJ  420010000
20501002   VELGJ   420010000
*
20501100   JF43001 MULT    1.0     0.  1
20501101   VOIDFJ  430010000
20501102   VELFJ   430010000
*
20501200   JG43001 MULT    1.0     0.  1
20501201   VOIDGJ  430010000
20501202   VELGJ   430010000
*
*
*--PHASE MASS FLOWS CALCULATED WITH JUNCTION PROPERTIES (KG/S)---
*
20501900  W40002   MULT      0.442 0.0  0
20501901           VELFJ     400020000
20501902           VOIDFJ    400020000
20501903           RHOFJ     400020000
*
20502000  W435     MULT      2.0   0.0  0
20502001           RHOFJ     610010000
20502002           VELFJ     610010000
20502003           VOIDFJ    610010000
```

```
*
20510100   WF40001 MULT    0.3974   0.  1
20510101   VOIDFJ  400010000
20510102   VELFJ   400010000
20510103   RHOFJ   400010000
*
20510200   WG40001 MULT    0.3974   0.  1
20510201   VOIDGJ  400010000
20510202   VELGJ   400010000
20510203   RHOGJ   400010000
*
20510300   WF41001 MULT    0.3974   0.  1
20510301   VOIDFJ  410010000
20510302   VELFJ   410010000
20510303   RHOFJ   410010000
*
20510400   WG41001 MULT    0.3974   0.  1
20510401   VOIDGJ  410010000
20510402   VELGJ   410010000
20510403   RHOGJ   410010000
*
20510500   WF41002 MULT    0.3974   0.  1
20510501   VOIDFJ  410020000
20510502   VELFJ   410020000
20510503   RHOFJ   410020000
*
20510600   WG41002 MULT    0.3974   0.  1
20510601   VOIDGJ  410020000
20510602   VELGJ   410020000
20510603   RHOGJ   410020000
*
20510700   WF415   MULT    0.3974   0.  1
20510701   VOIDFJ  415000000
20510702   VELFJ   415000000
20510703   RHOFJ   415000000
*
20510800   WG415   MULT    0.3974   0.  1
20510801   VOIDGJ  415000000
20510802   VELGJ   415000000
20510803   RHOGJ   415000000
*
20510900   WF42001 MULT    0.4418  0.  1
20510901   VOIDFJ  420010000
20510902   VELFJ   420010000
20510903   RHOFJ   420010000
*
20511000   WG42001 MULT    0.4418  0.  1
20511001   VOIDGJ  420010000
20511002   VELGJ   420010000
20511003   RHOGJ   420010000
```

```
*
20511100   WF43001 MULT    0.4418  0.  1
20511101   VOIDFJ  430010000
20511102   VELFJ   430010000
20511103   RHOFJ   430010000
*
20511200   WG43001 MULT    0.4418  0.  1
20511201   VOIDGJ  430010000
20511202   VELGJ   430010000
20511203   RHOGJ   430010000
*
*
*---- WALLIS PARAMETERS FOR STEAM AND WATER -------------
*
20503000  DRHO     SUM       9.81  0.0  0
20503001  0.0  0.75 RHOFJ     430010000
20503002      -0.75 RHOGJ     430010000
*
20503100  NENN     DIV       1.0   0.0  0
20503101           CNTRLVAR  30
20503102           RHOFJ     430010000
*
20503200  ABS      STDFNCTN  1.0   0.0  0
20503201  ABS      CNTRLVAR  31
*
20503300  SQRT     STDFNCTN  1.0   0.0  0
20503301  SQRT     CNTRLVAR  32
*
20503400  JF430    MULT      1.0   0.0  0
20503401           CNTRLVAR  33
20503402           CNTRLVAR  11
*
20503500  NENN     DIV       1.0   0.0  0
20503501           CNTRLVAR  30
20503502           RHOGJ     430010000
*
20503600  ABS      STDFNCTN  1.0   0.0  0
20503601  ABS      CNTRLVAR  35
*
20503700  SQRT     STDFNCTN  1.0   0.0  0
20503701  SQRT     CNTRLVAR  36
*
20503800  JD430    MULT      1.0   0.0  0
20503801           CNTRLVAR  37
20503802           CNTRLVAR  12
*
**************************************************
*
20505000  DRHO     SUM       9.81  0.0  0
20505001  0.0  0.75 RHOFJ     420010000
```

```
20505002      -0.75 RHOGJ     420010000
*
20505100  NENN     DIV       1.0   0.0  0
20505101           CNTRLVAR  50
20505102           RHOFJ     420010000
*
20505300  SQRT     STDFNCTN  1.0   0.0  0
20505301  SQRT     CNTRLVAR  51
*
20505400  JF420    MULT      1.0   0.0  0
20505401           CNTRLVAR  53
20505402           CNTRLVAR   9
*
20505500  NENN     DIV       1.0   0.0  0
20505501           CNTRLVAR  50
20505502           RHOGJ     420010000
*
20505700  SQRT     STDFNCTN  1.0   0.0  0
20505701  SQRT     CNTRLVAR  55
*
20505800  JD420    MULT      1.0   0.0  0
20505801           CNTRLVAR  57
20505802           CNTRLVAR  10
*
*******************************************************
*
20506000  DRHO     SUM       9.81  0.0  0
20506001  0.0  0.639 RHOFJ     415000000
20506002      -0.639 RHOGJ     415000000
*
20506100  NENN     DIV       1.0   0.0  0
20506101           CNTRLVAR  60
20506102           RHOFJ     415000000
*
20506300  SQRT     STDFNCTN  1.0   0.0  0
20506301  SQRT     CNTRLVAR  61
*
20506400  JF415    MULT      1.0   0.0  0
20506401           CNTRLVAR  63
20506402           CNTRLVAR   7
*
20506500  NENN     DIV       1.0   0.0  0
20506501           CNTRLVAR  60
20506502           RHOGJ     415000000
*
20506700  SQRT     STDFNCTN  1.0   0.0  0
20506701  SQRT     CNTRLVAR  65
*
20506800  JD415    MULT      1.0   0.0  0
20506801           CNTRLVAR  67
```

```
20506802          CNTRLVAR   8
**************************************************
*
20507000  DRHO     SUM       9.81  0.0  0
20507001  0.0  0.639 RHOFJ     400010000
20507002      -0.639 RHOGJ     400010000
*
20507100  NENN     DIV       1.0   0.0  0
20507101          CNTRLVAR  70
20507102          RHOFJ     400010000
*
20507300  SQRT     STDFNCTN  1.0   0.0  0
20507301  SQRT     CNTRLVAR  71
*
20507400  JF400    MULT      1.0   0.0  0
20507401          CNTRLVAR  73
20507402          CNTRLVAR   1
*
20507500  NENN     DIV       1.0   0.0  0
20507501          CNTRLVAR  70
20507502          RHOGJ     400010000
*
20507700  SQRT     STDFNCTN  1.0   0.0  0
20507701  SQRT     CNTRLVAR  75
*
20507800  JD400    MULT      1.0   0.0  0
20507801          CNTRLVAR  77
20507802          CNTRLVAR  2
*
**************************************************
*
20508000  DRHO     SUM       9.81  0.0  0
20508001  0.0  0.639  RHOFJ     410010000
20508002      -0.639  RHOGJ     410010000
*
20508100  NENN     DIV       1.0   0.0  0
20508101          CNTRLVAR  80
20508102          RHOFJ     410010000
*
20508300  SQRT     STDFNCTN  1.0   0.0  0
20508301  SQRT     CNTRLVAR  81
*
20508400  JF41001  MULT      1.0   0.0  0
20508401          CNTRLVAR  83
20508402          CNTRLVAR   3
*
20508500  NENN     DIV       1.0   0.0  0
20508501          CNTRLVAR  80
20508502          RHOGJ     410010000
*
```

```
20508700  SQRT     STDFNCTN  1.0   0.0  0
20508701  SQRT     CNTRLVAR  85
*
20508800  JD41001  MULT      1.0   0.0  0
20508801           CNTRLVAR  87
20508802           CNTRLVAR  4
*
*
*-------- SQUARE ROOTS FROM WALLIS PARAMETERS -------------
*
20513400  ABS      STDFNCTN  1.0   0.0  0
20513401  ABS      CNTRLVAR  34
*
20513800  ABS      STDFNCTN  1.0   0.0  0
20513801  ABS      CNTRLVAR  38
*
20515400  ABS      STDFNCTN  1.0   0.0  0
20515401  ABS      CNTRLVAR  54
*
20515800  ABS      STDFNCTN  1.0   0.0  0
20515801  ABS      CNTRLVAR  58
*
20516400  ABS      STDFNCTN  1.0   0.0  0
20516401  ABS      CNTRLVAR  64
*
20516800  ABS      STDFNCTN  1.0   0.0  0
20516801  ABS      CNTRLVAR  68
*
20517400  ABS      STDFNCTN  1.0   0.0  0
20517401  ABS      CNTRLVAR  74
*
20517800  ABS      STDFNCTN  1.0   0.0  0
20517801  ABS      CNTRLVAR  78
*
20518400  ABS      STDFNCTN  1.0   0.0  0
20518401  ABS      CNTRLVAR  84
*
20518800  ABS      STDFNCTN  1.0   0.0  0
20518801  ABS      CNTRLVAR  88
*
20523400  SQ_JF430  STDFNCTN  1.0   0.0  0
20523401  SQRT      CNTRLVAR  134
*
20523800  SQ_JG430  STDFNCTN  1.0   0.0  0
20523801  SQRT      CNTRLVAR  138
*
20525400  SQ_JF420  STDFNCTN  1.0   0.0  0
20525401  SQRT      CNTRLVAR  154
*
20525800  SQ_JG420  STDFNCTN  1.0   0.0  0
```

```
20525801  SQRT      CNTRLVAR  158
*
20526400  SQ_JF415  STDFNCTN  1.0   0.0  0
20526401  SQRT      CNTRLVAR  164
*
20526800  SQ_JG415  STDFNCTN  1.0   0.0  0
20526801  SQRT      CNTRLVAR  168
*
20527400  SQ_JF400  STDFNCTN  1.0   0.0  0
20527401  SQRT      CNTRLVAR  174
*
20527800  SQ_JG400  STDFNCTN  1.0   0.0  0
20527801  SQRT      CNTRLVAR  178
*
20528400  SQ_JF410  STDFNCTN  1.0   0.0  0
20528401  SQRT      CNTRLVAR  184
*
20528800  SQ_JG410  STDFNCTN  1.0   0.0  0
20528801  SQRT      CNTRLVAR  188
*
*
*-------- COLLAPSED WATER LEVELS ---------------
*
20501400   CL120   SUM     1.0  0.0  1
20501401   0.0     0.5     VOIDF  120010000
20501402           0.5     VOIDF  120020000
20501403           0.5     VOIDF  120030000
20501404           0.5     VOIDF  120040000
20501405           0.5     VOIDF  120050000
*
20501600   CL430   SUM     1.0  0.0  1
20501601   0.0     1.0764  VOIDF  430010000
*
*------- MASS INVENTORIES --------------------
*
20501700   WATERAC SUM       1.0  0.0  0
20501701   0.0     0.338441  VOIDF   400010000
20501702           0.338441  VOIDF   401010000
20501703           0.38295   VOIDF   410010000
20501704           0.38295   VOIDF   410020000
20501705           0.38295   VOIDF   410030000
20501706           0.38295   VOIDF   410040000
20501709           0.552692  VOIDF   420010000
20501711           0.3685    VOIDF   420020000
20501712           0.3685    VOIDF   420030000
20501713           4.22      VOIDF   430010000
20501714           2.0       VOIDF   600010000
20501715           2.0       VOIDF   610010000
*
20517000   WATERAC MULT      1.0  0.0  0
```

```
20517001   CNTRLVAR    17
20517002   RHOF        410010000
*
20501800  WINJ     INTEGRAL  1.0   0.0  0
20501801           MFLOWJ    445000000
*
20502100  WDRAIN   INTEGRAL  1.0   0.0  0
20502101           CNTRLVAR  19
*
20502200  WOUT     INTEGRAL  1.0   0.0  0
20502201           CNTRLVAR  20
*
*-------- SYSTEM FOR CONTROLLED WATER DRAIN ----------
*
20520000   LEVLAG  LAG    -1.0  0.0  1
20520001   1.   CNTRLVAR  101
*
*--------------- END CONTROL VARIABLES ---------------
*
*
* EXPANDED EDIT/PLOT VARIABLES
*
20800001   DT      0
20800002   DTCRNT  0
*
*
*
.** END OF INPUT
```

APPENDIX B

Analysis of UPTF Test No. 11, Runs 36 - 45 (Pressure 1.5 MPa) with RELAP5/MOD3/V5M5 (Basic Nodalisation) Results of Calculation without CCFL Model

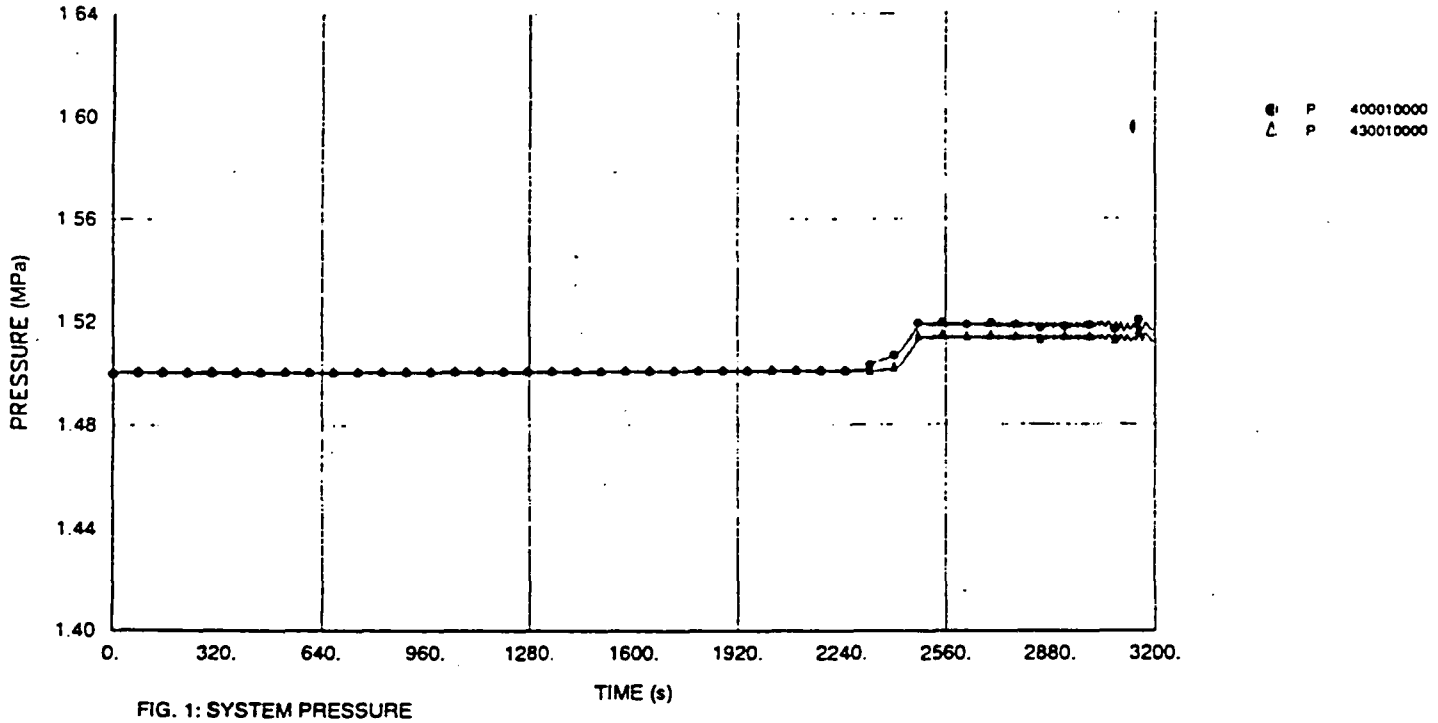


FIG. 1: SYSTEM PRESSURE

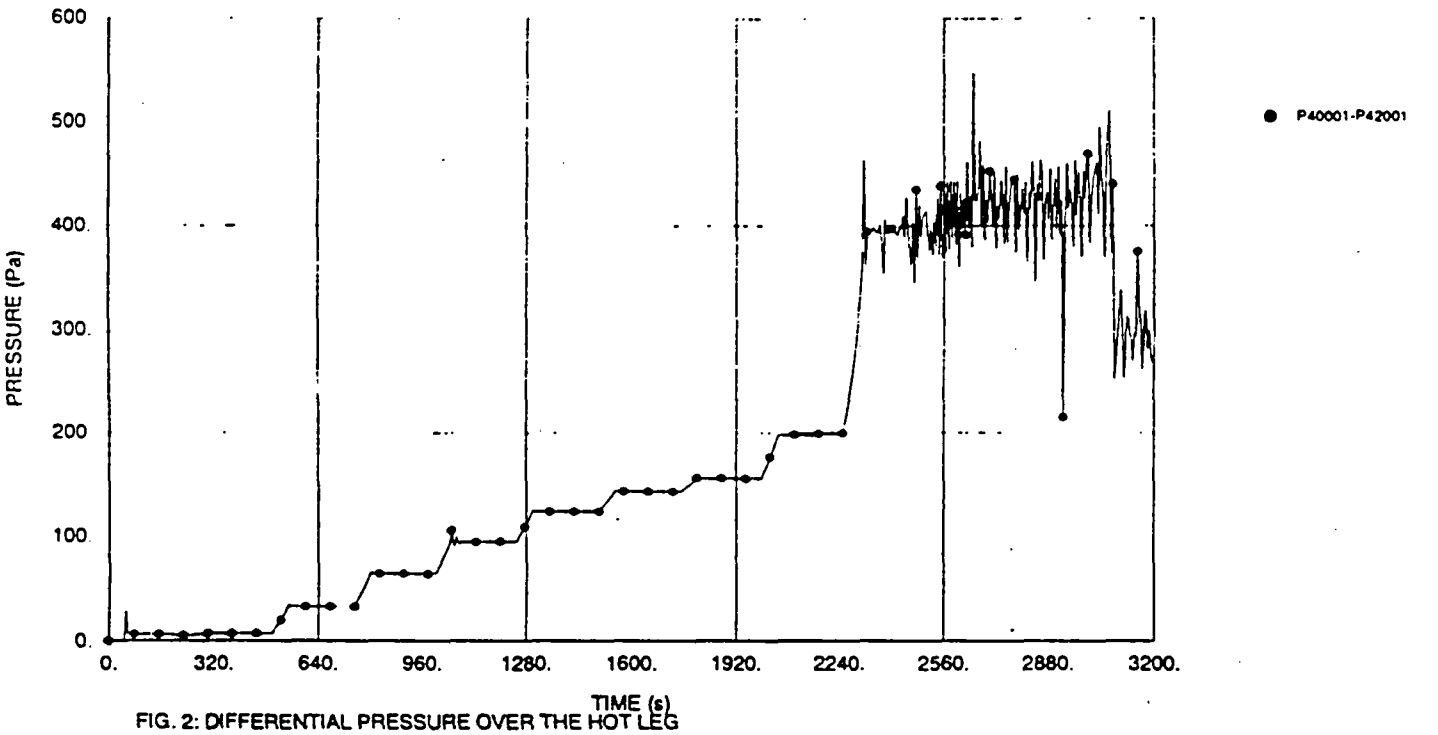


FIG. 2: DIFFERENTIAL PRESSURE OVER THE HOT LEG
(TO BE COMPARED WITH JEC04CP006)

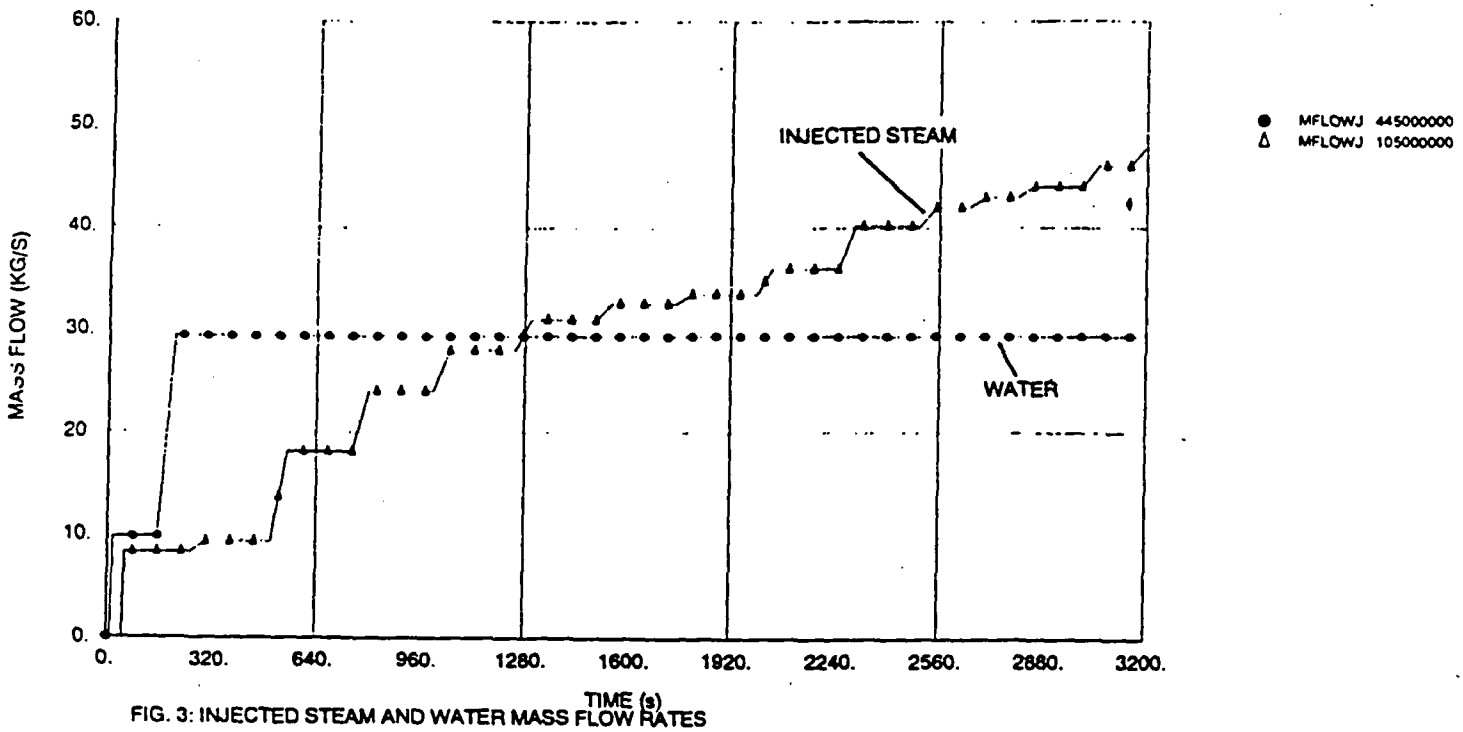


FIG. 3: INJECTED STEAM AND WATER MASS FLOW RATES

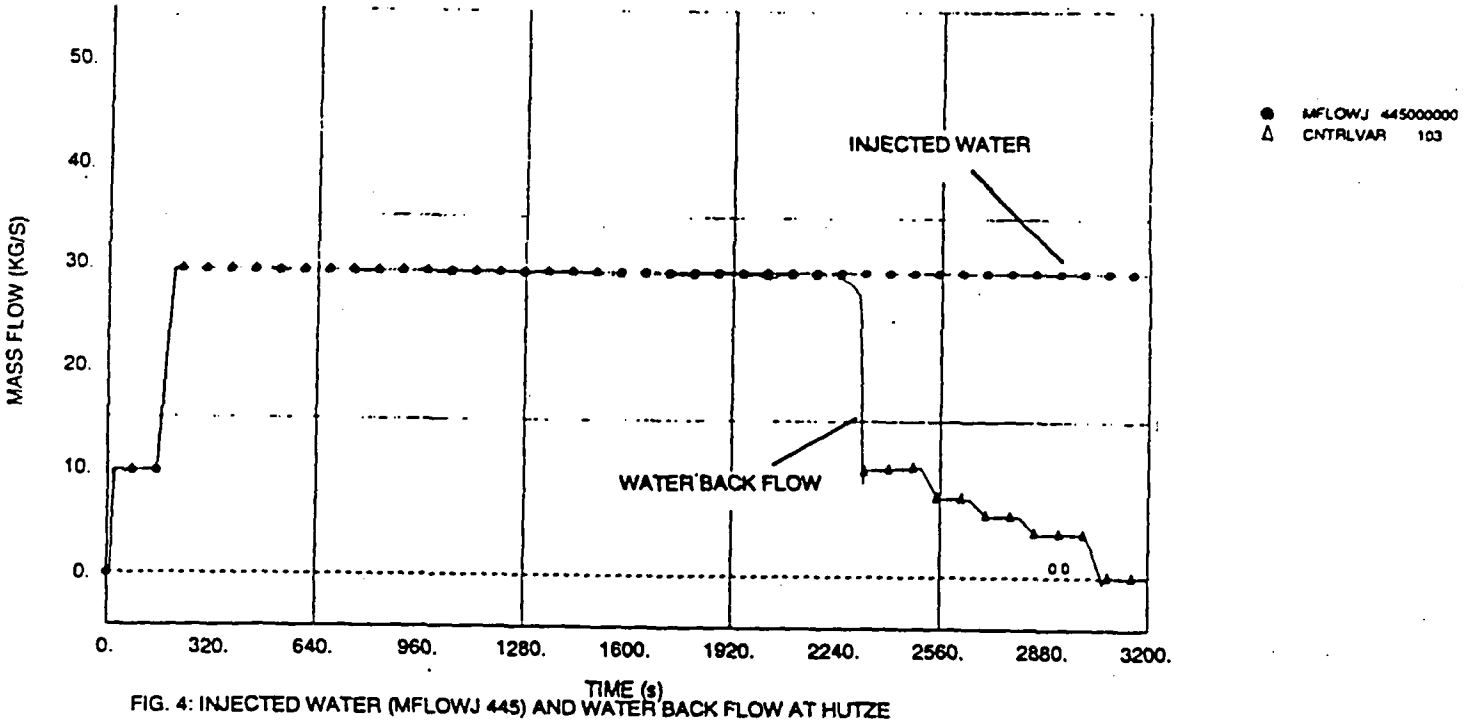


FIG. 4: INJECTED WATER (MFLOWJ 445) AND WATER BACK FLOW AT HUTZE

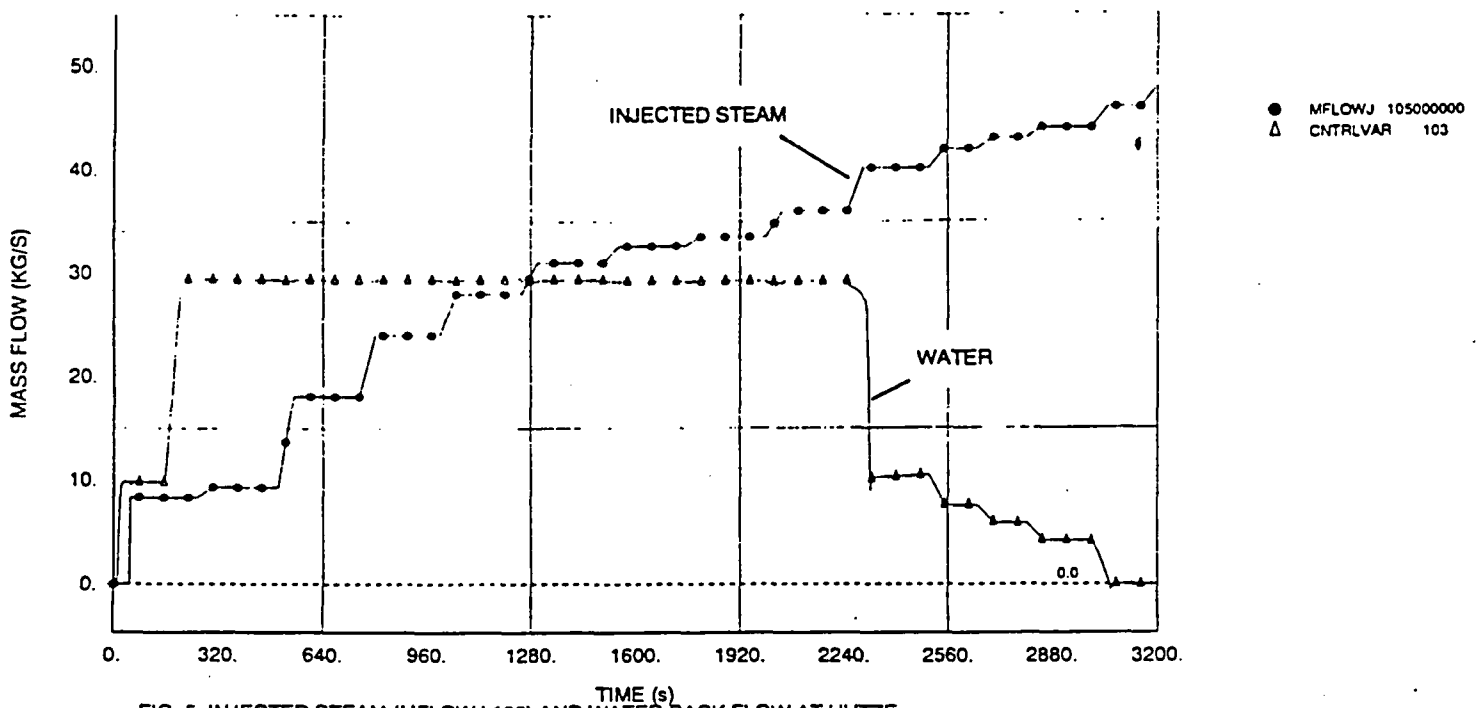


FIG. 5: INJECTED STEAM (MFLOWJ 105) AND WATER BACK FLOW AT HUTZE

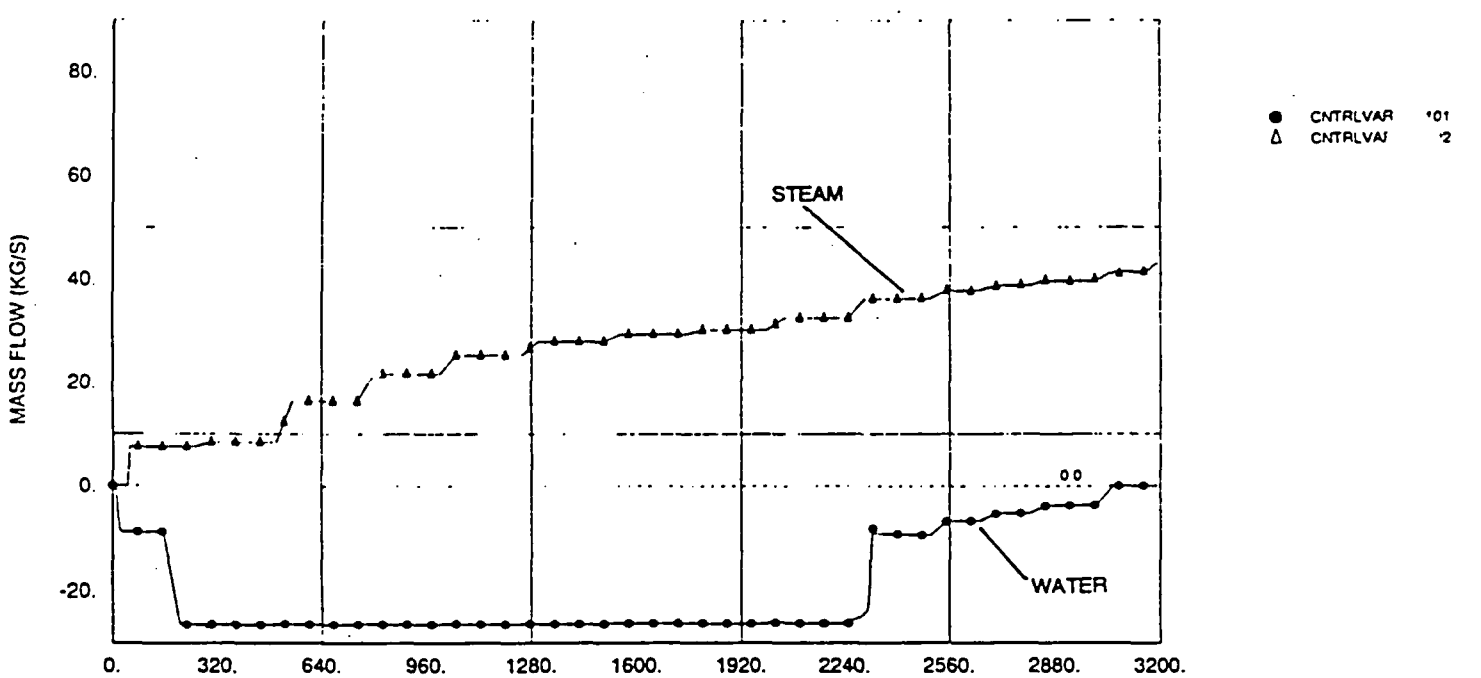


FIG. 6: STEAM AND WATER MASS FLOWS THROUGH J 400-01
(CALCULATED WITH JUNCTION PROPERTIES)

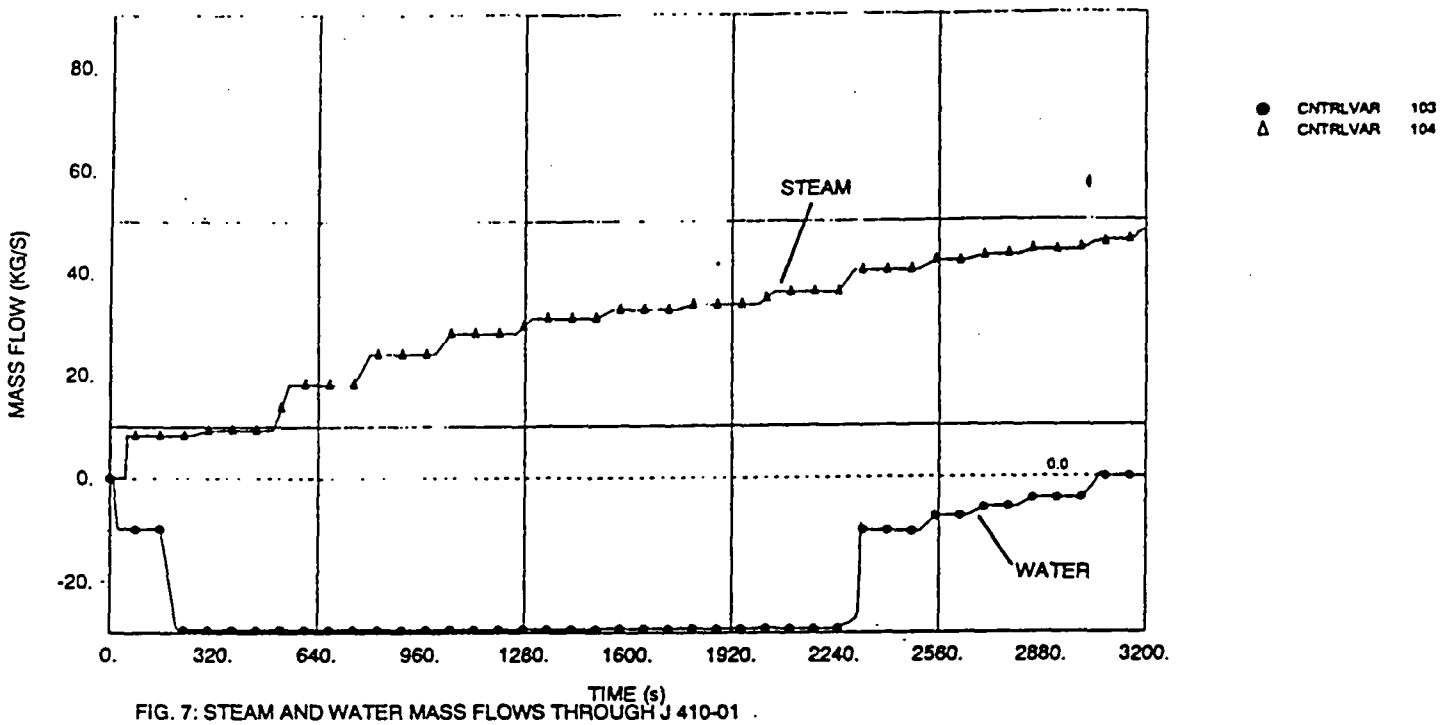


FIG. 7: STEAM AND WATER MASS FLOWS THROUGH J 410-01
(CALCULATED WITH JUNCTION PROPERTIES)

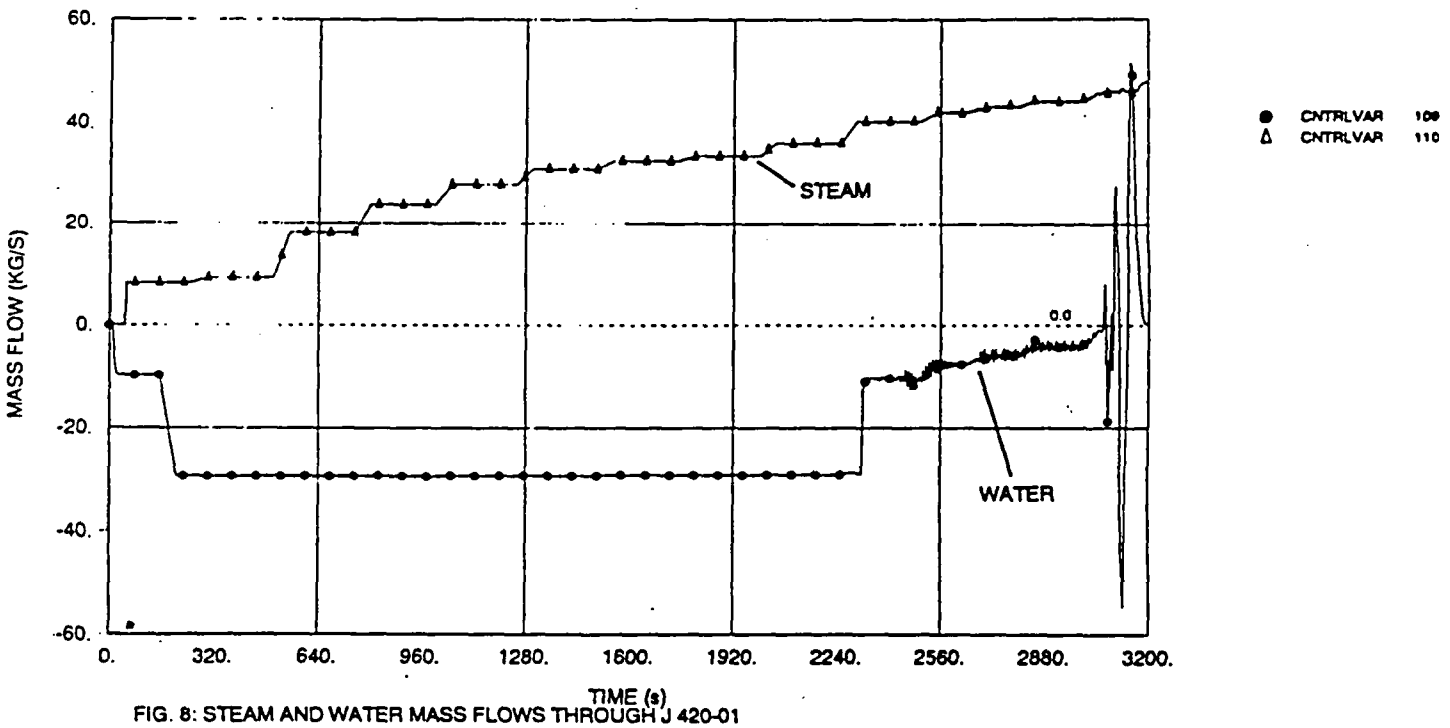


FIG. 8: STEAM AND WATER MASS FLOWS THROUGH J 420-01
(CALCULATED WITH JUNCTION PROPERTIES)

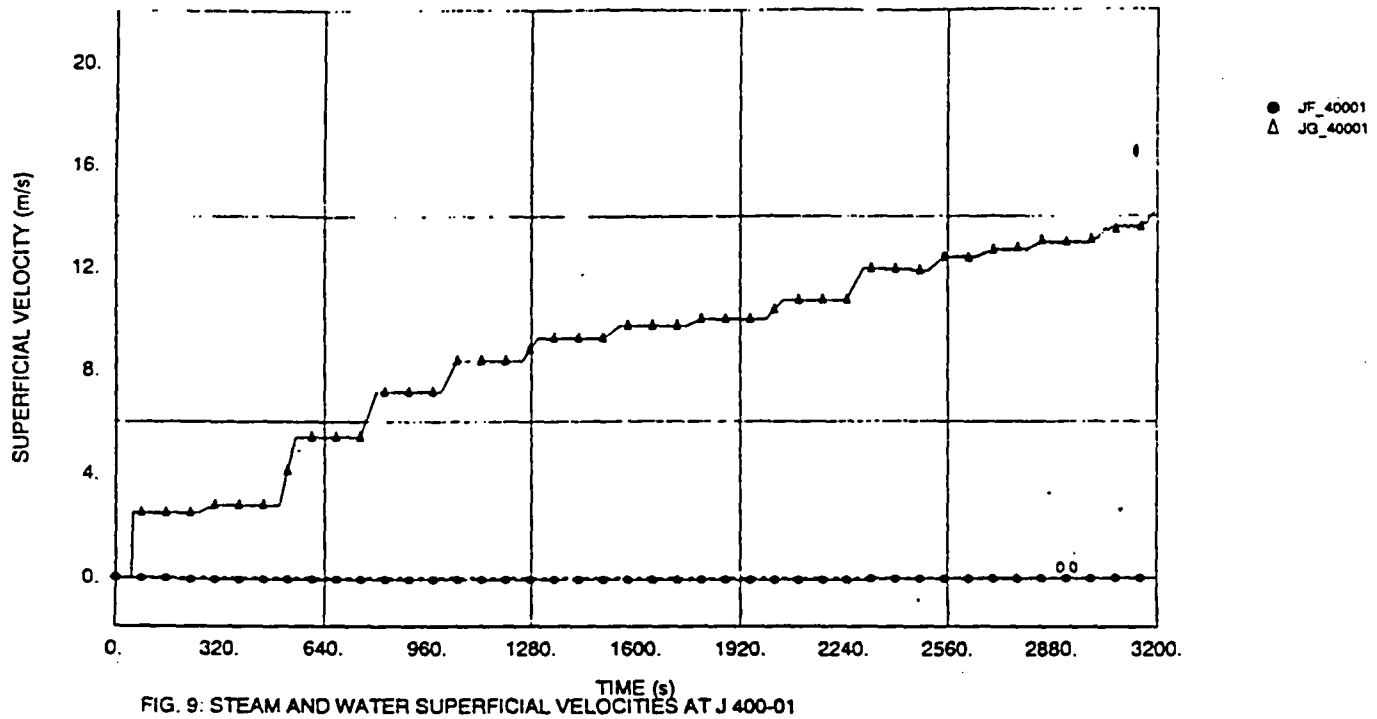


FIG. 9: STEAM AND WATER SUPERFICIAL VELOCITIES AT J 400-01

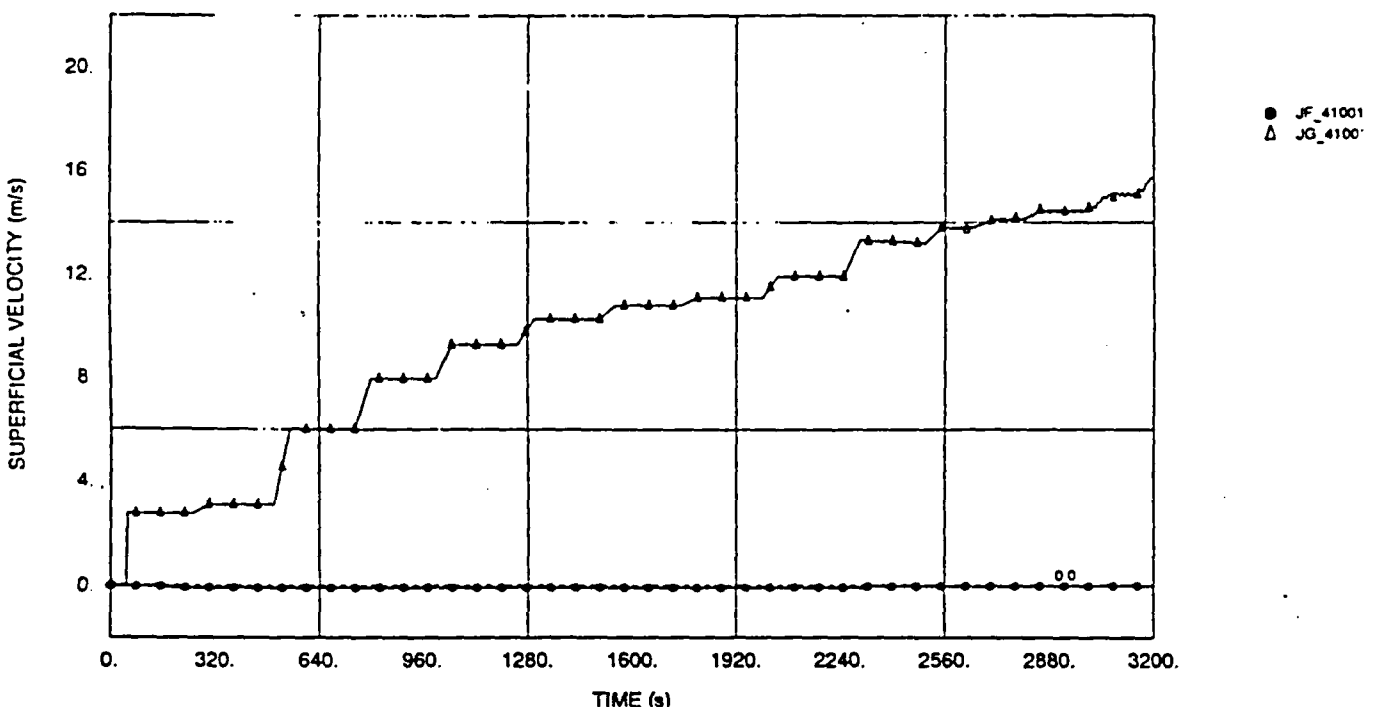


FIG. 10: STEAM AND WATER SUPERFICIAL VELOCITIES AT J 410-01

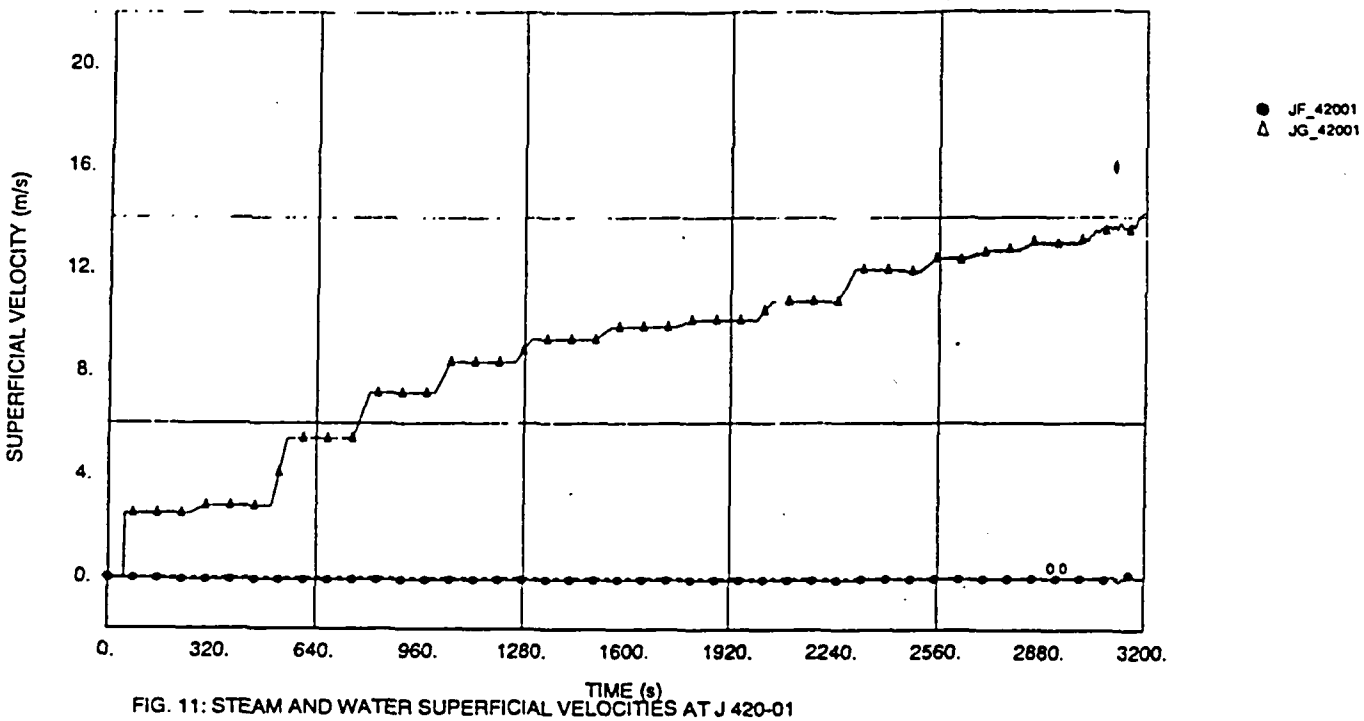


FIG. 11: STEAM AND WATER SUPERFICIAL VELOCITIES AT J 420-01

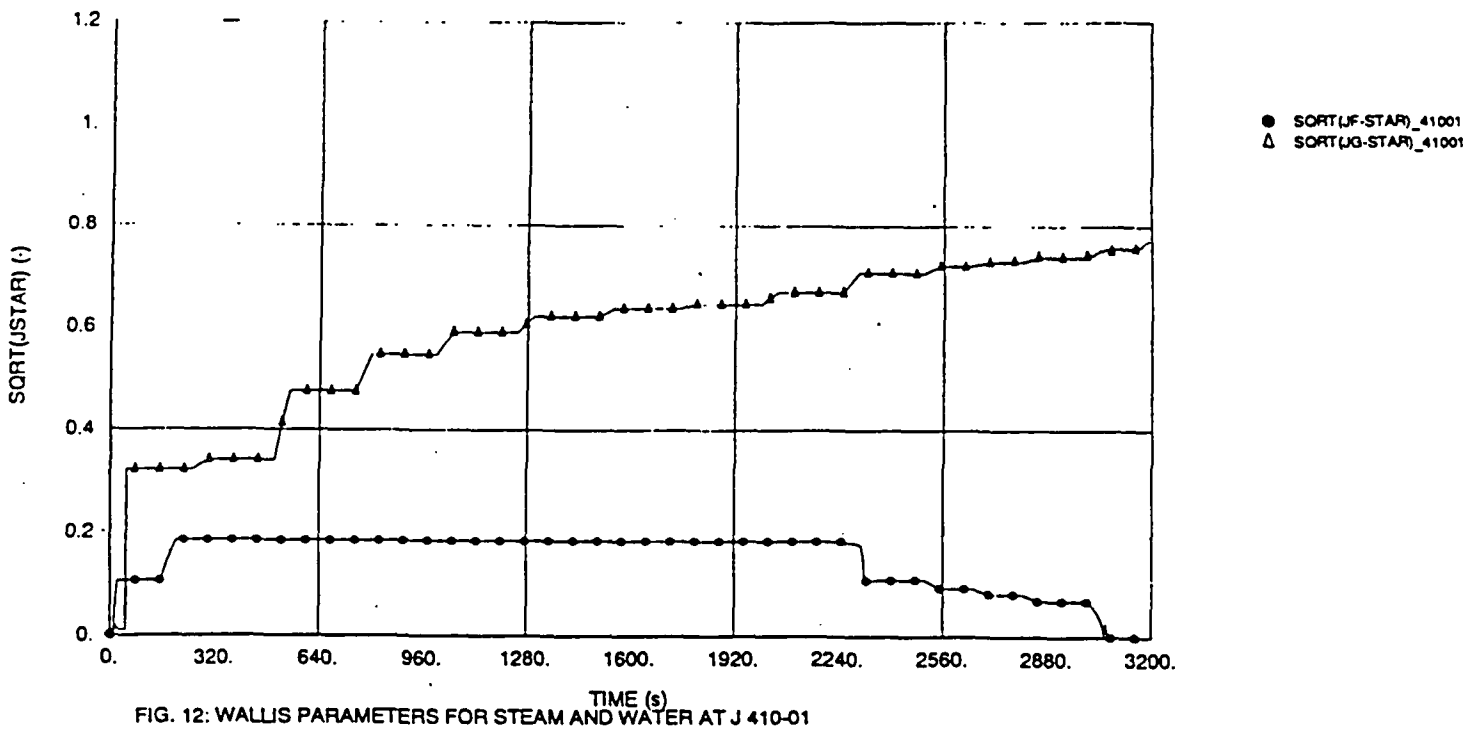


FIG. 12: WALLIS PARAMETERS FOR STEAM AND WATER AT J 410-01

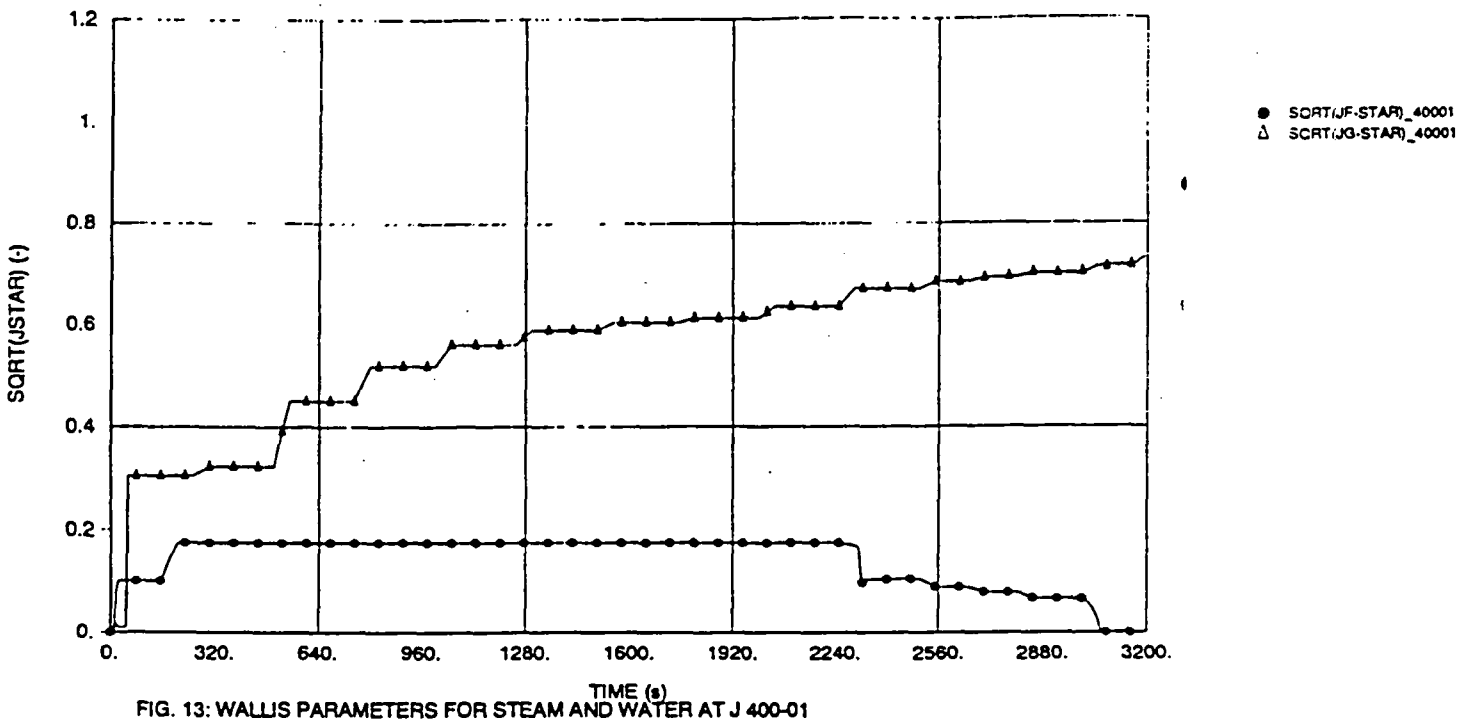


FIG. 13: WALLIS PARAMETERS FOR STEAM AND WATER AT J 400-01

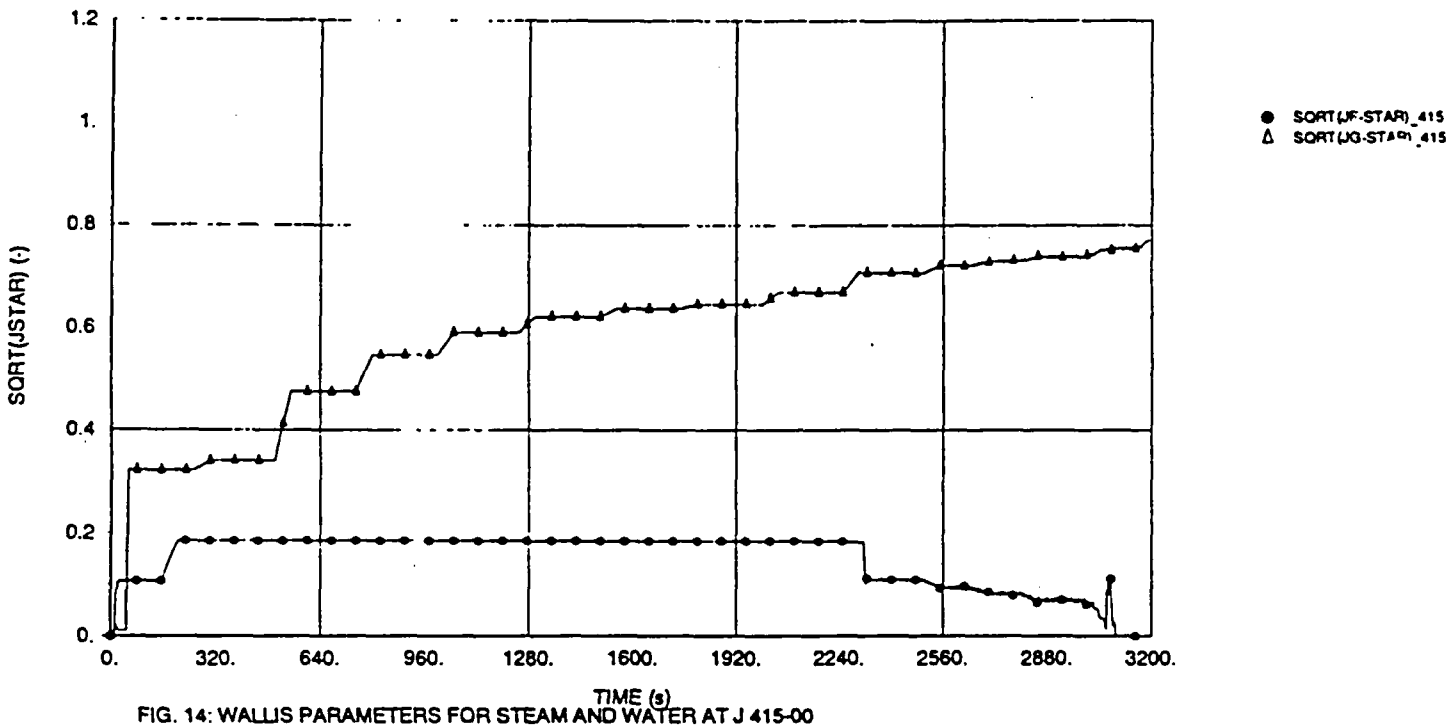


FIG. 14: WALLIS PARAMETERS FOR STEAM AND WATER AT J 415-00

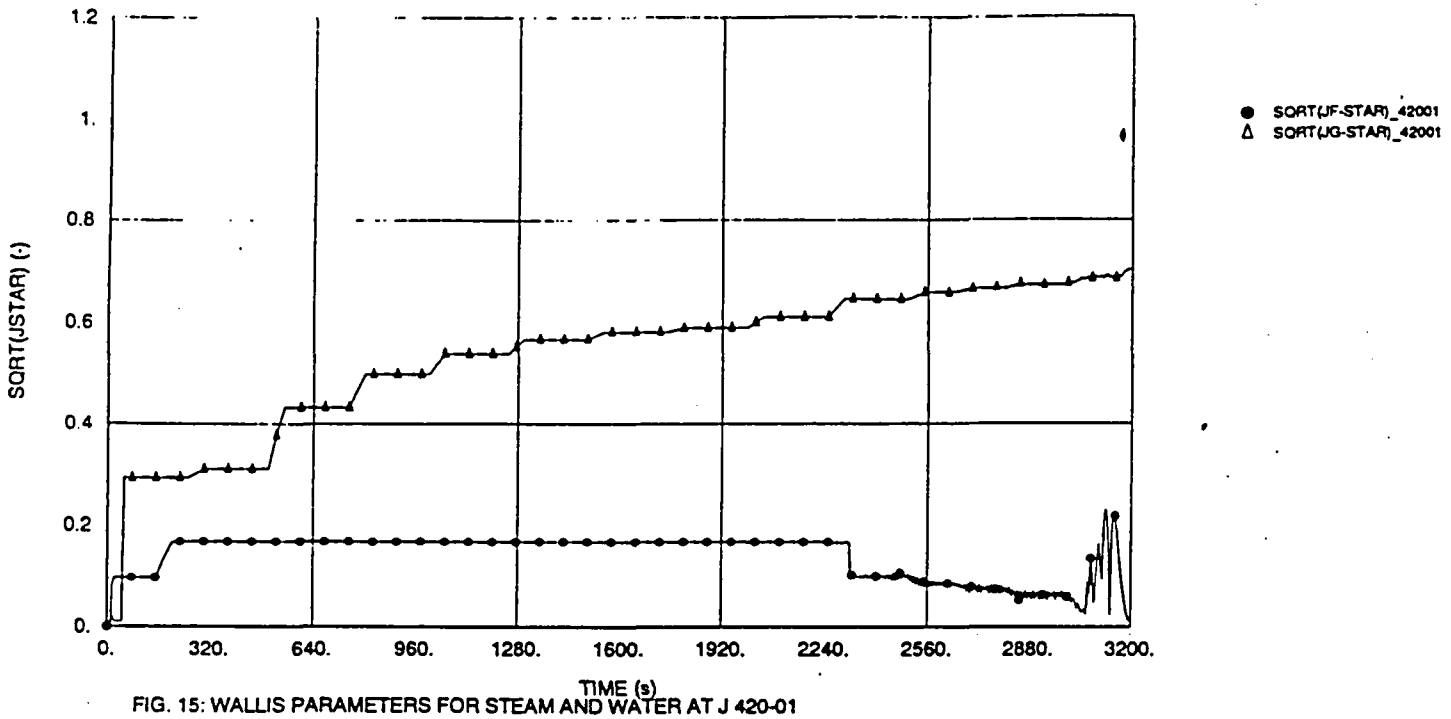


FIG. 15: WALLIS PARAMETERS FOR STEAM AND WATER AT J 420-01

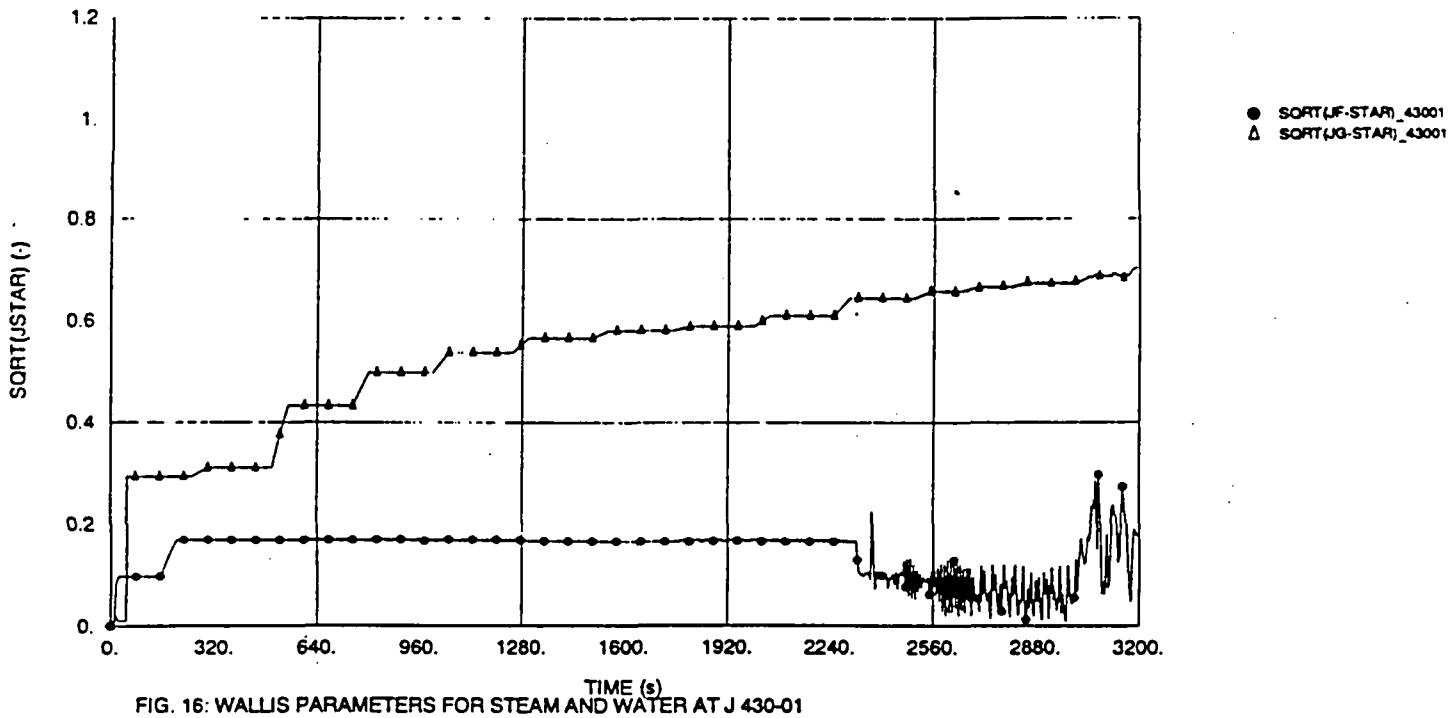


FIG. 16: WALLIS PARAMETERS FOR STEAM AND WATER AT J 430-01

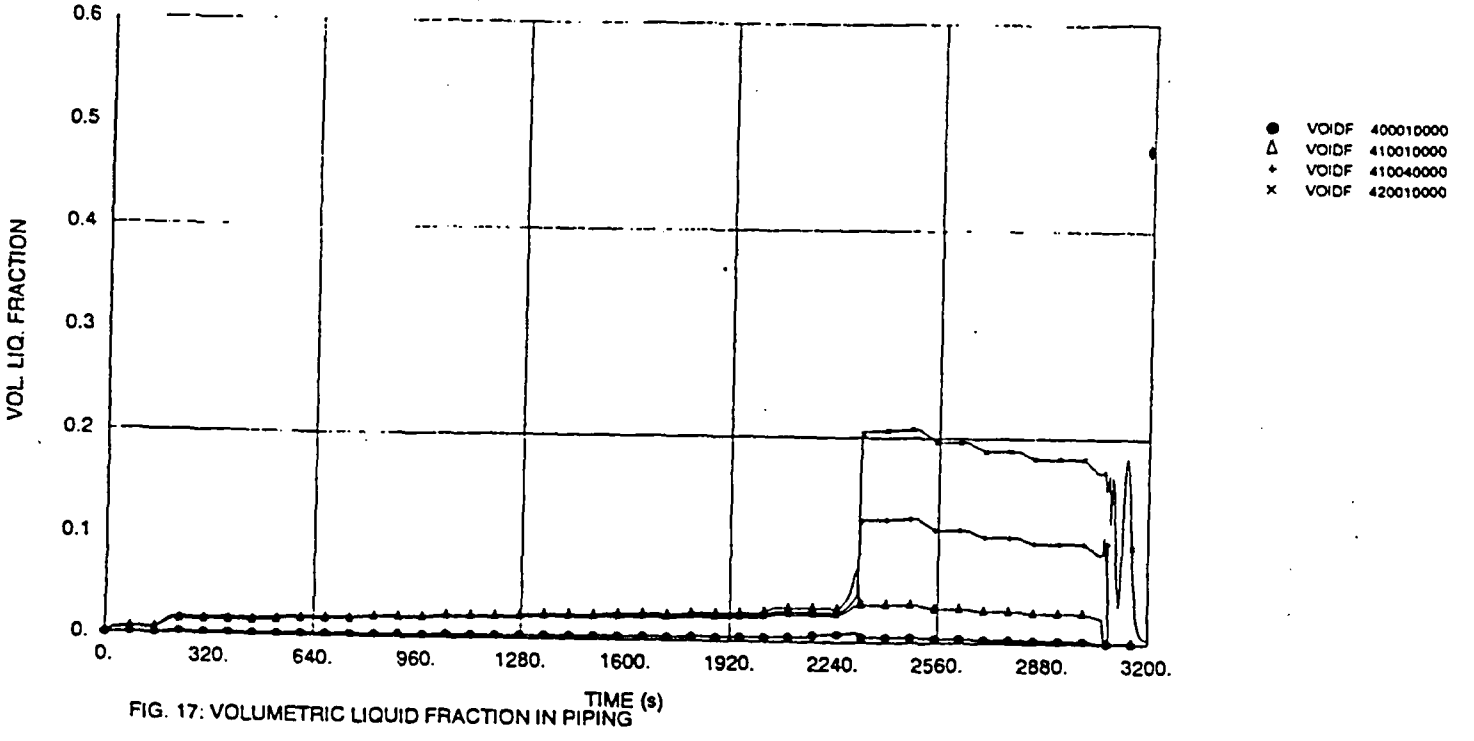


FIG. 17: VOLUMETRIC LIQUID FRACTION IN PIPING

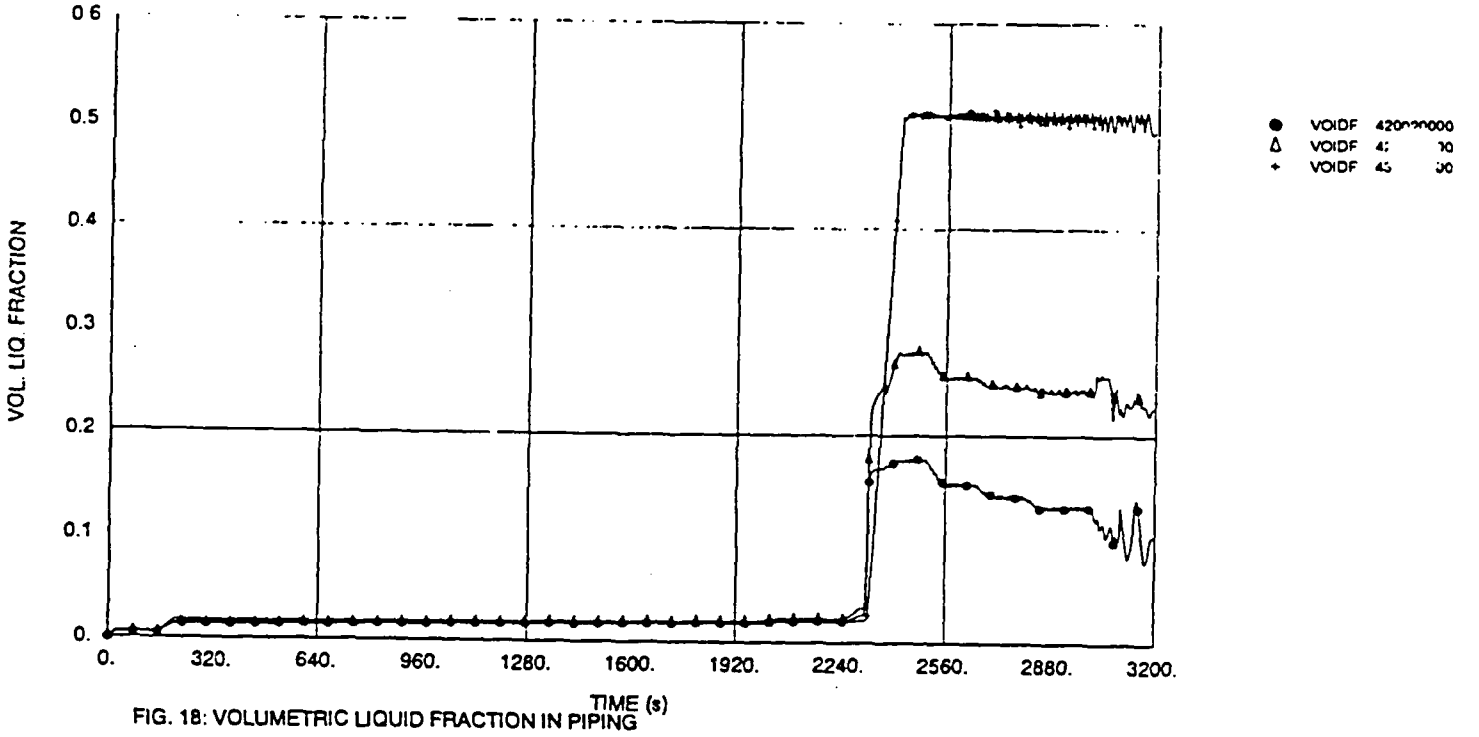


FIG. 18: VOLUMETRIC LIQUID FRACTION IN PIPING

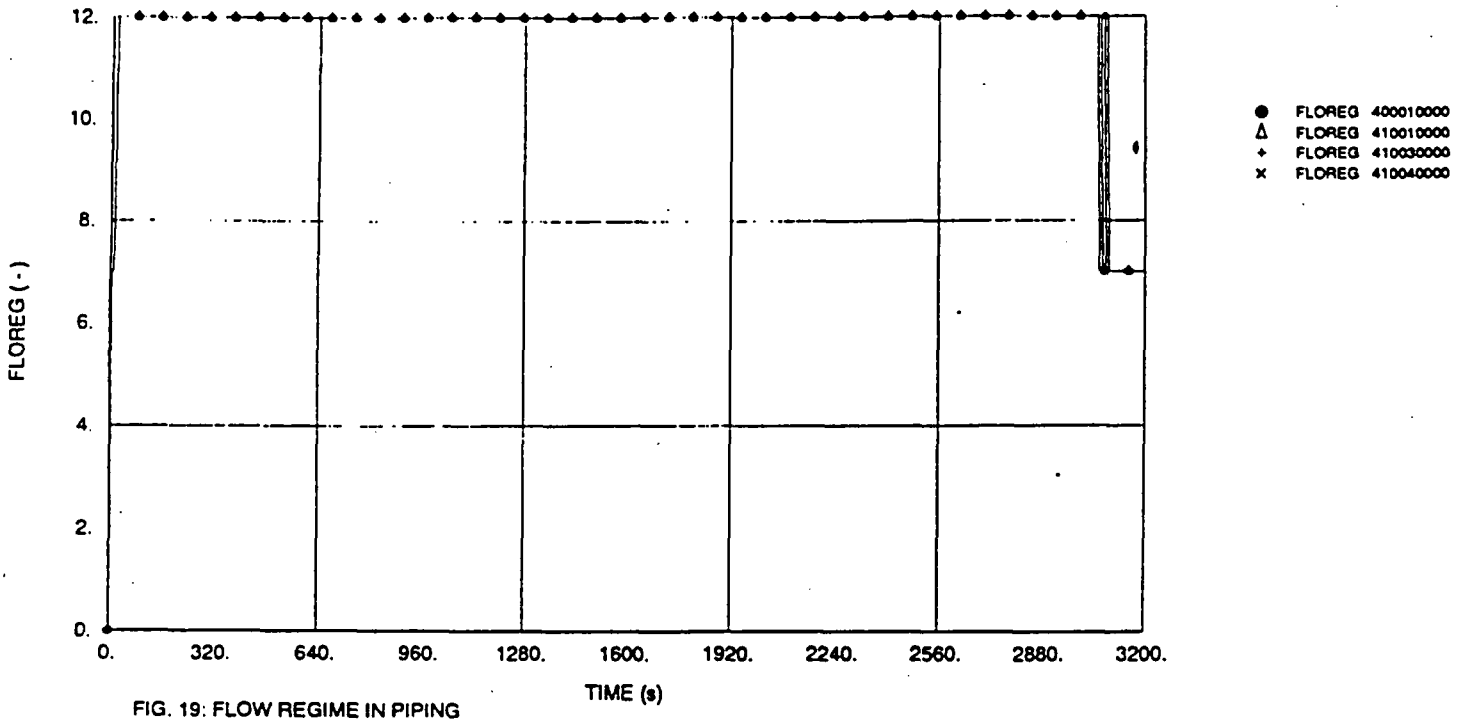


FIG. 19: FLOW REGIME IN PIPING

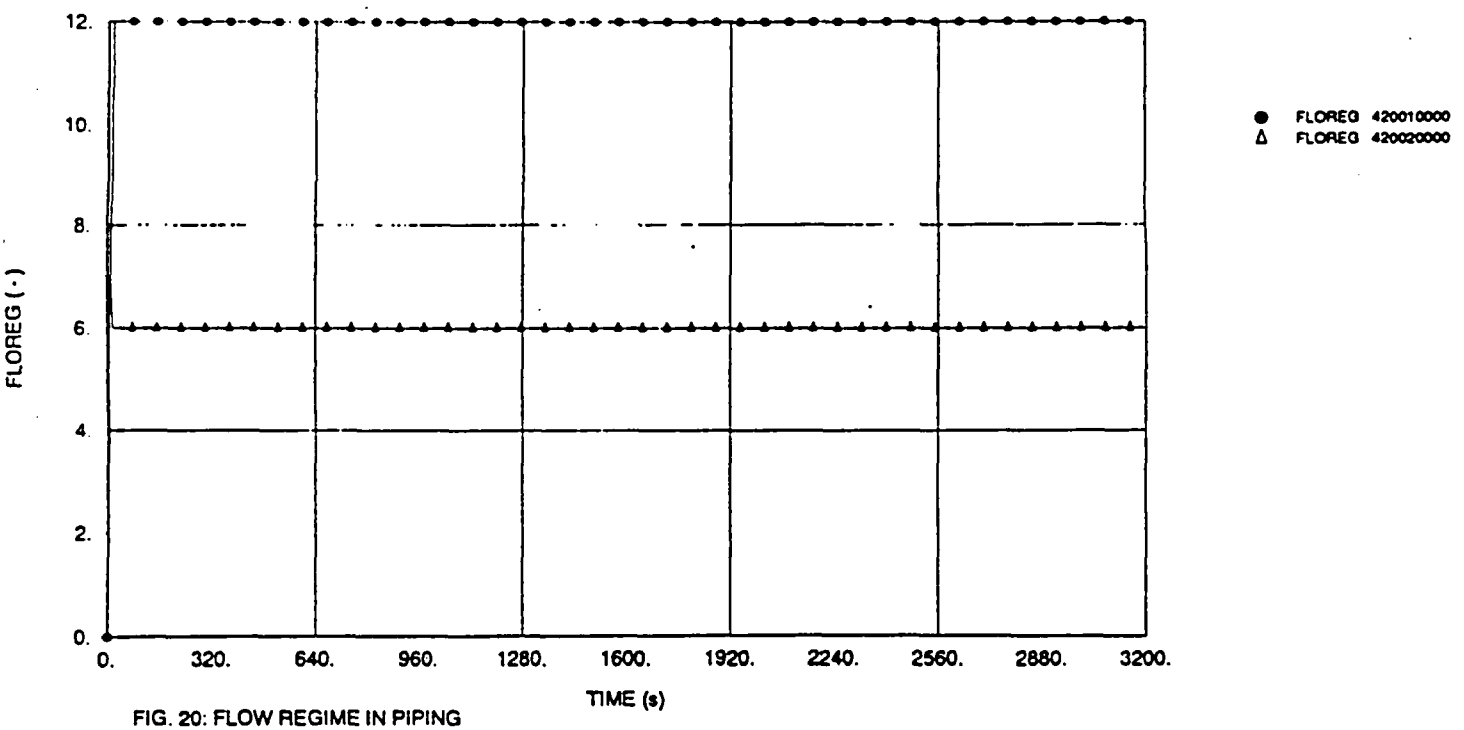


FIG. 20: FLOW REGIME IN PIPING

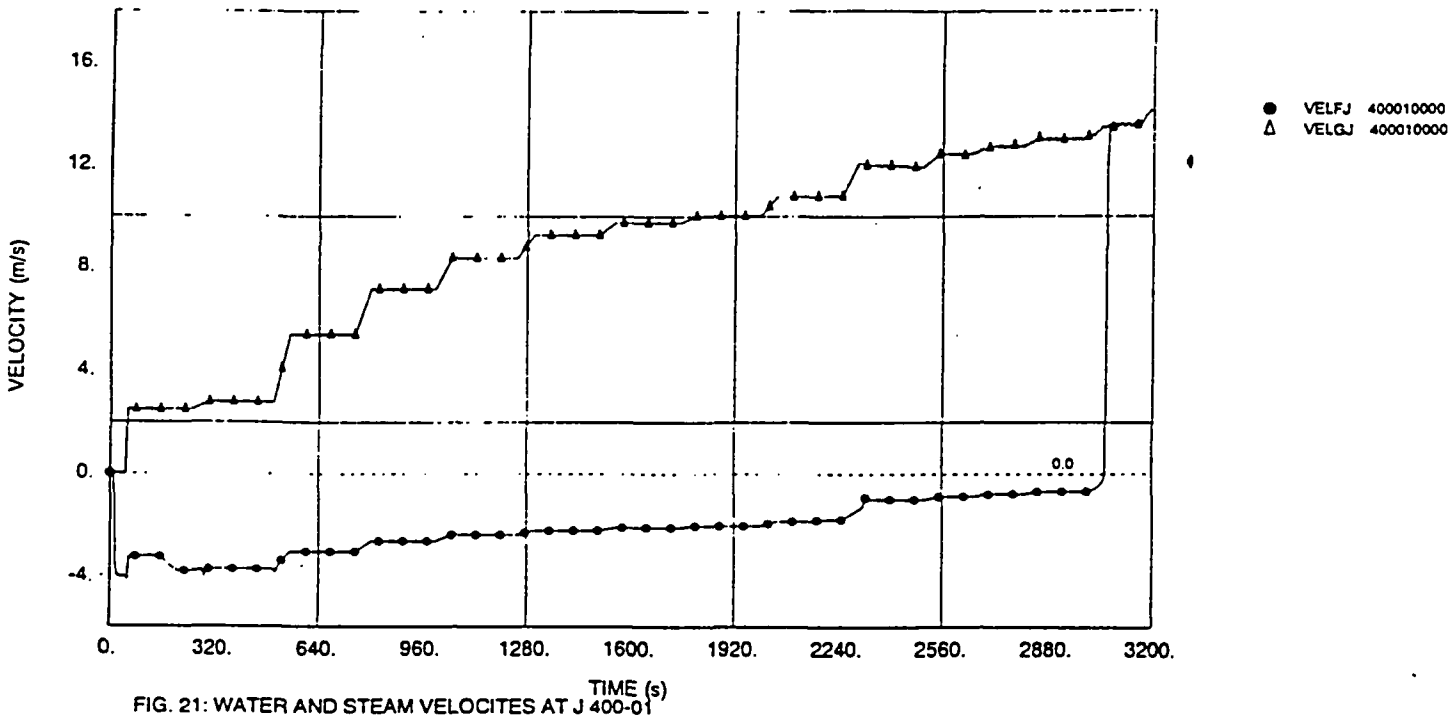


FIG. 21: WATER AND STEAM VELOCITES AT J 400-01

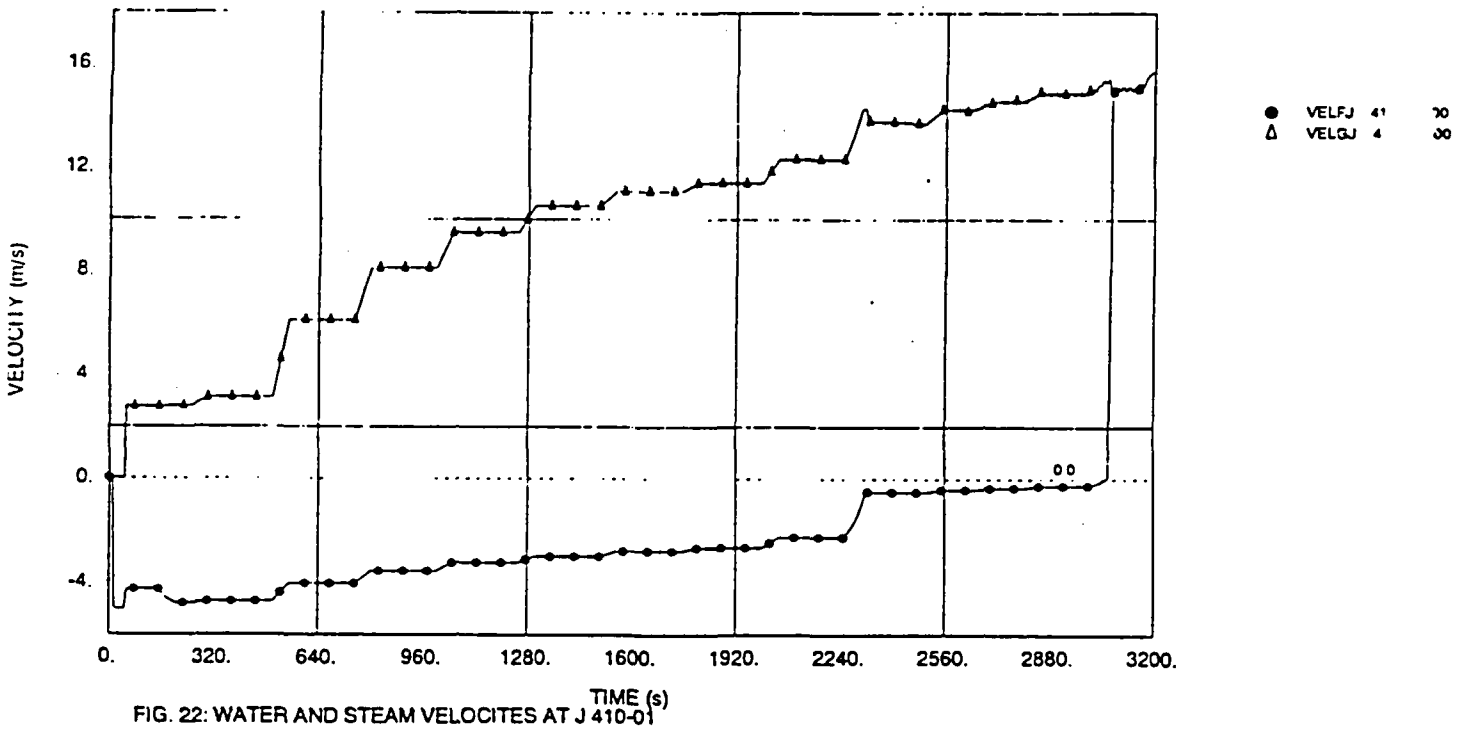


FIG. 22: WATER AND STEAM VELOCITES AT J 410-01

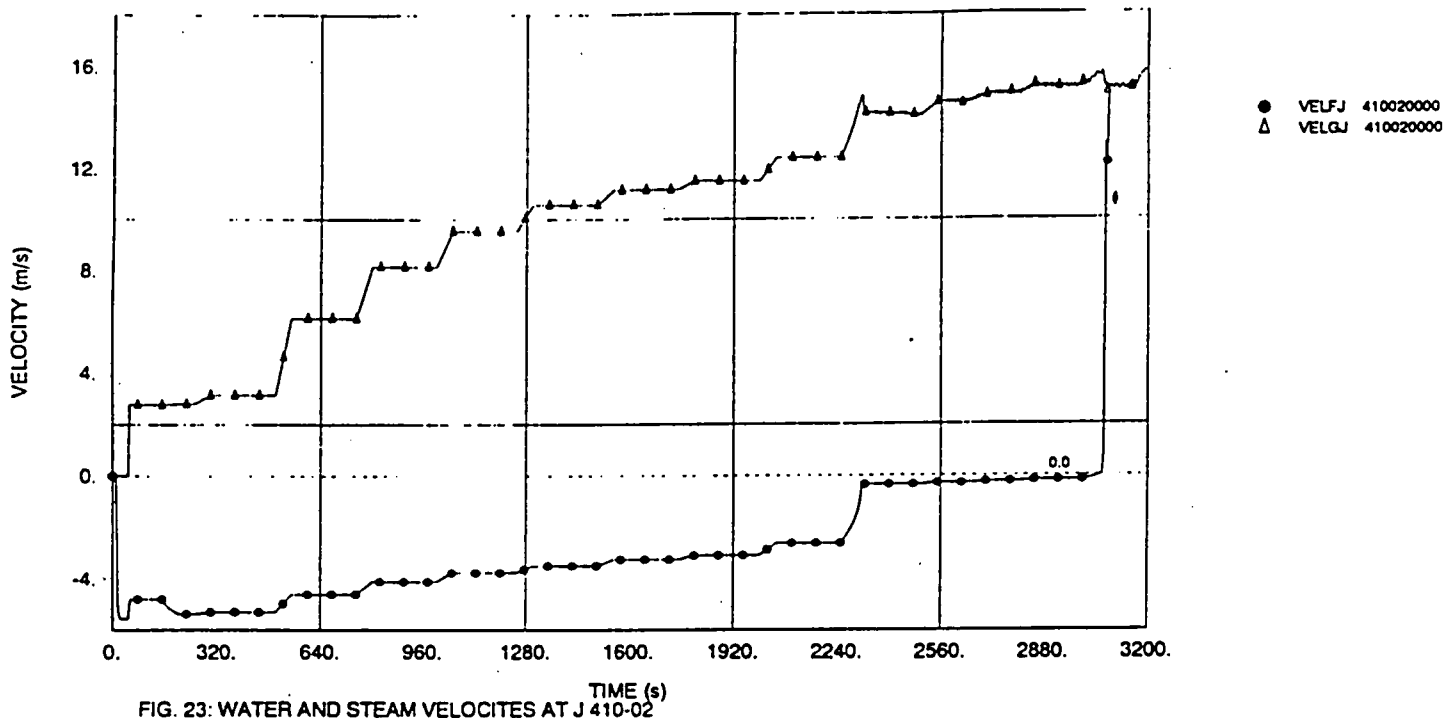


FIG. 23: WATER AND STEAM VELOCITES AT J 410-02

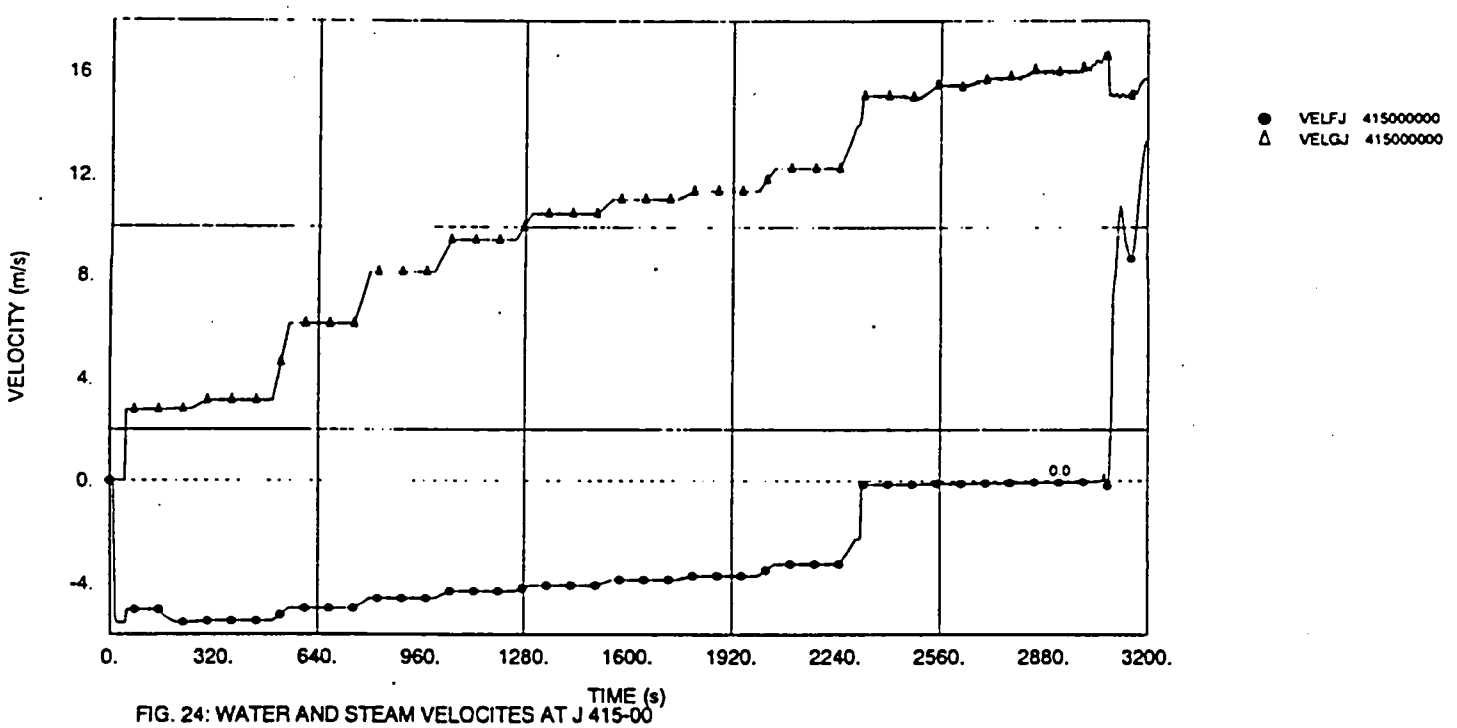


FIG. 24: WATER AND STEAM VELOCITES AT J 415-00

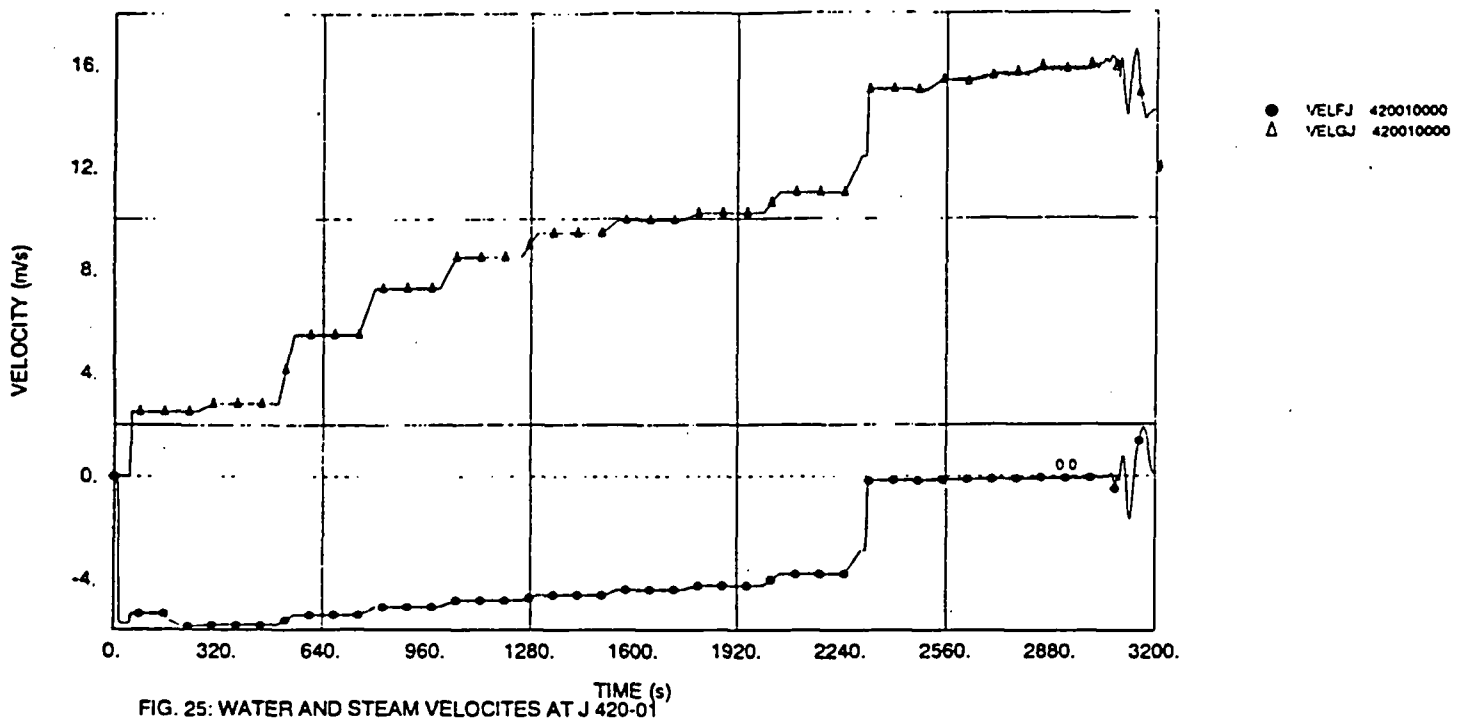


FIG. 25: WATER AND STEAM VELOCITES AT J 420-01

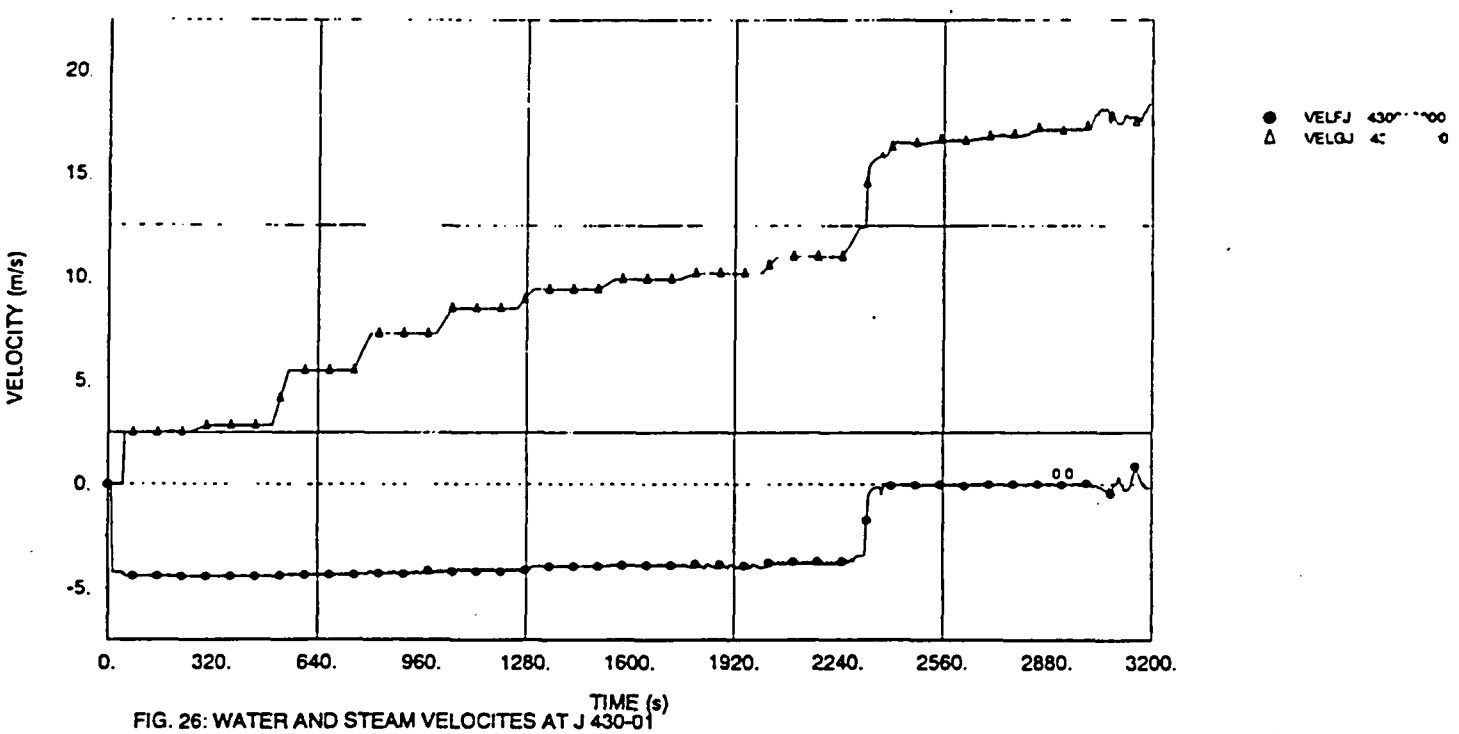


FIG. 26: WATER AND STEAM VELOCITES AT J 430-01

APPENDIX C

Analysis of UPTF Test No. 11, Runs 30 - 35 (Pressure 0.3 MPa) with RELAP5/MOD3/V5M5 (Basic Nodalisation) Results of Calculation without CCFL Model

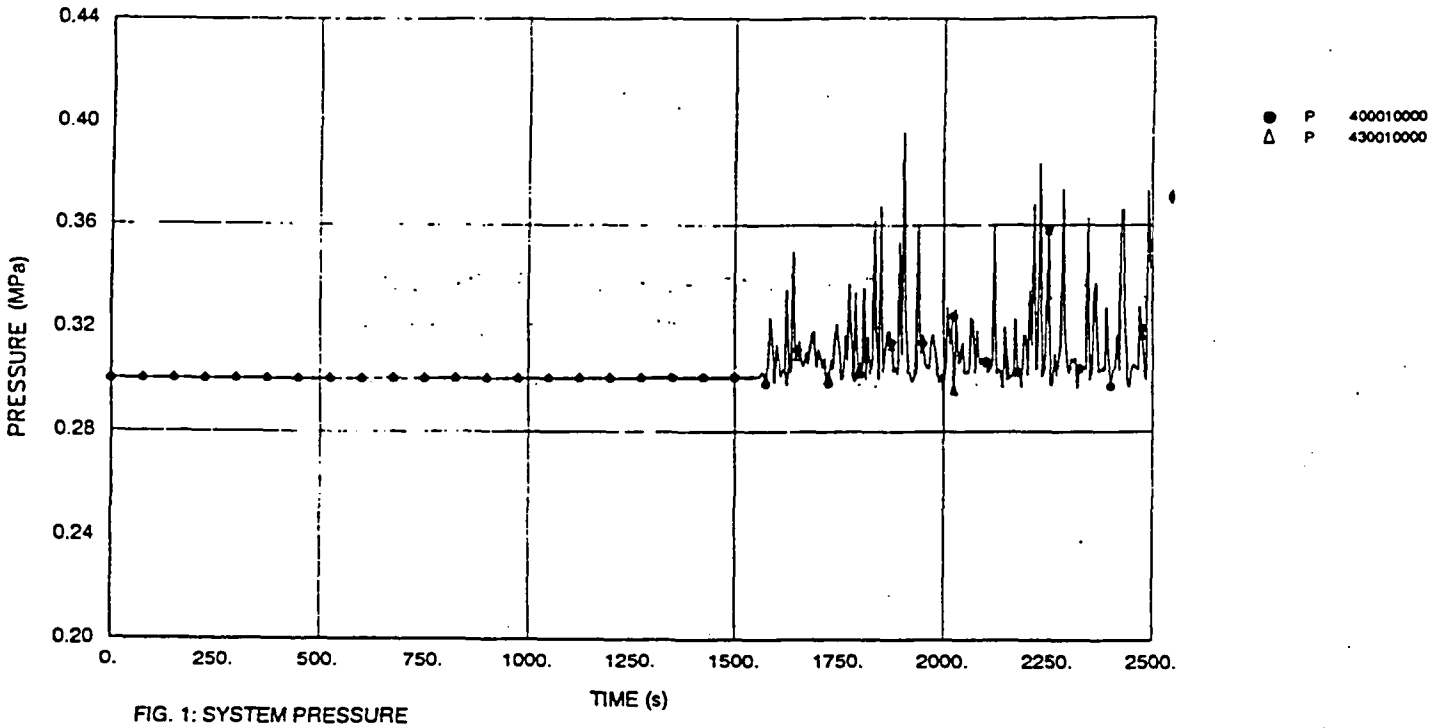


FIG. 1: SYSTEM PRESSURE

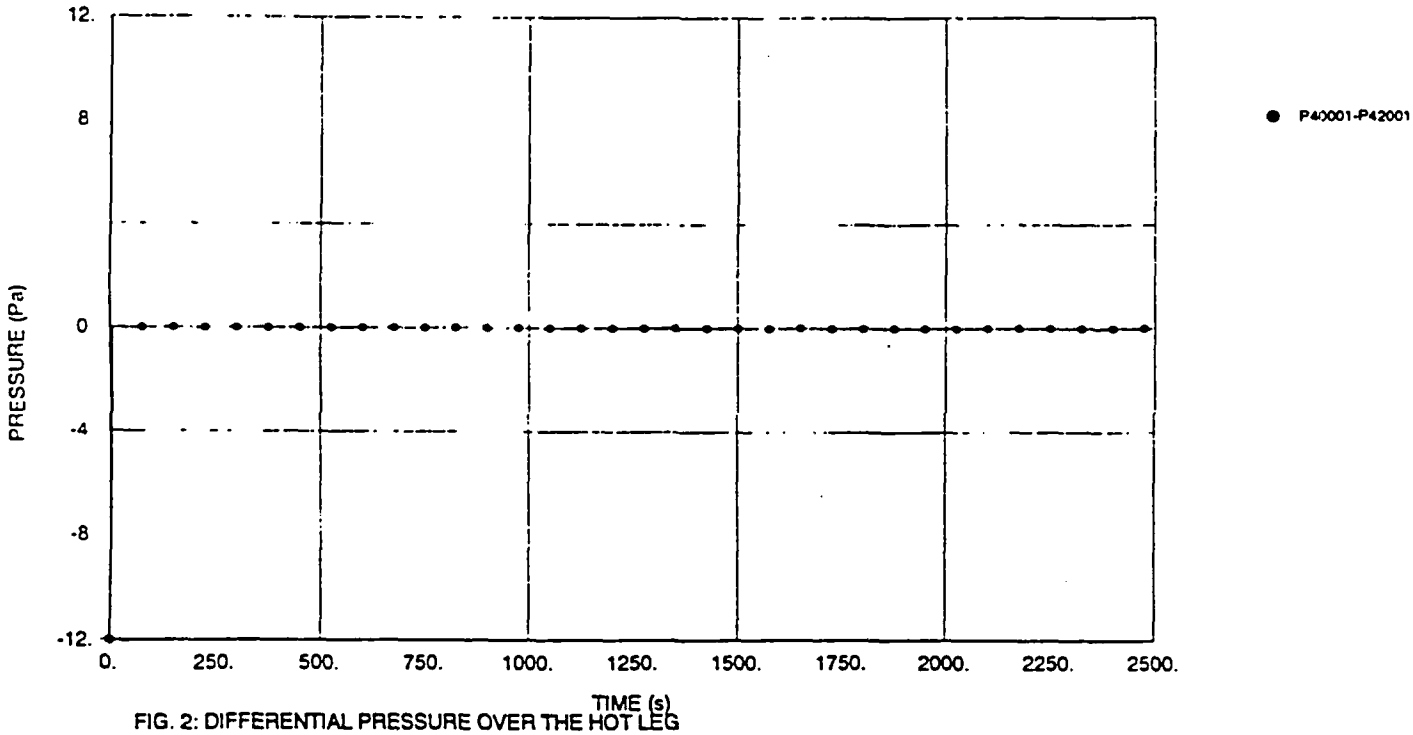


FIG. 2: DIFFERENTIAL PRESSURE OVER THE HOT LEG
(TO BE COMPARED WITH JEC04CP006)

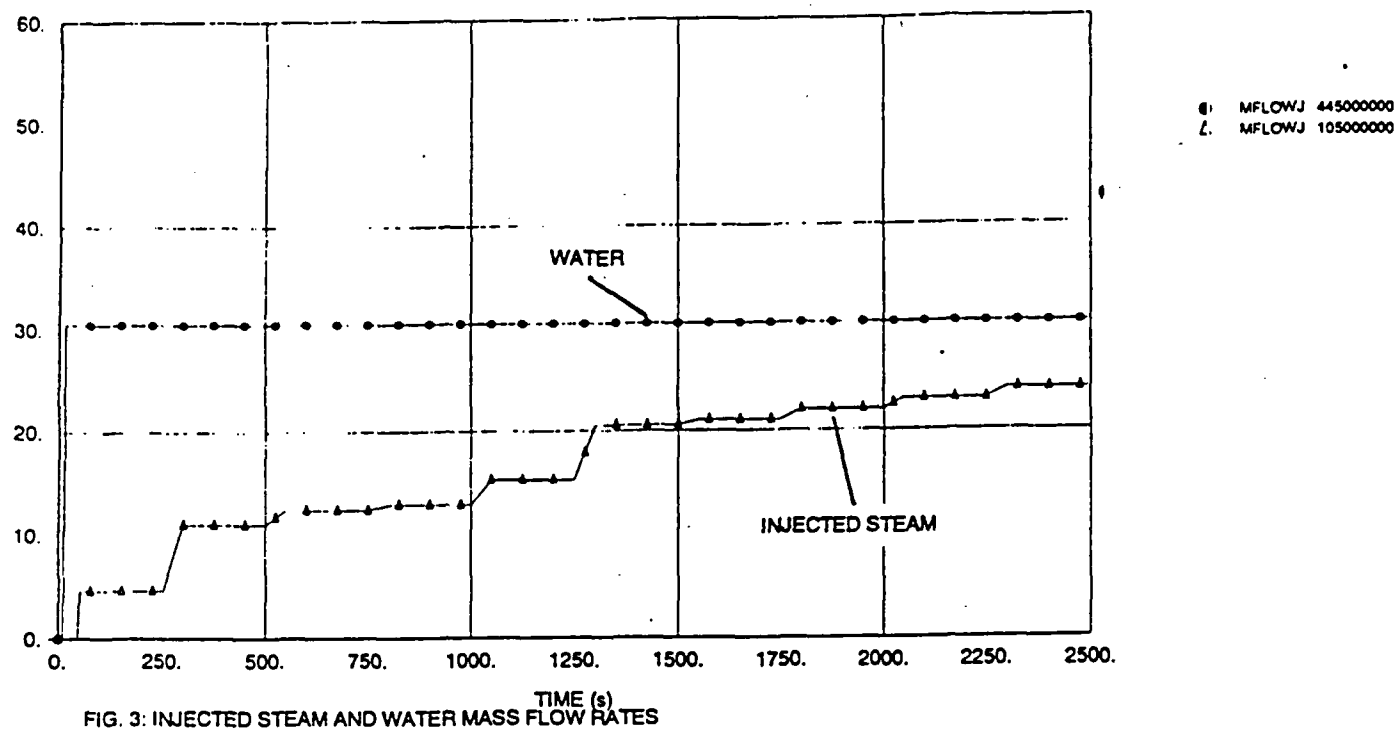


FIG. 3: INJECTED STEAM AND WATER MASS FLOW RATES

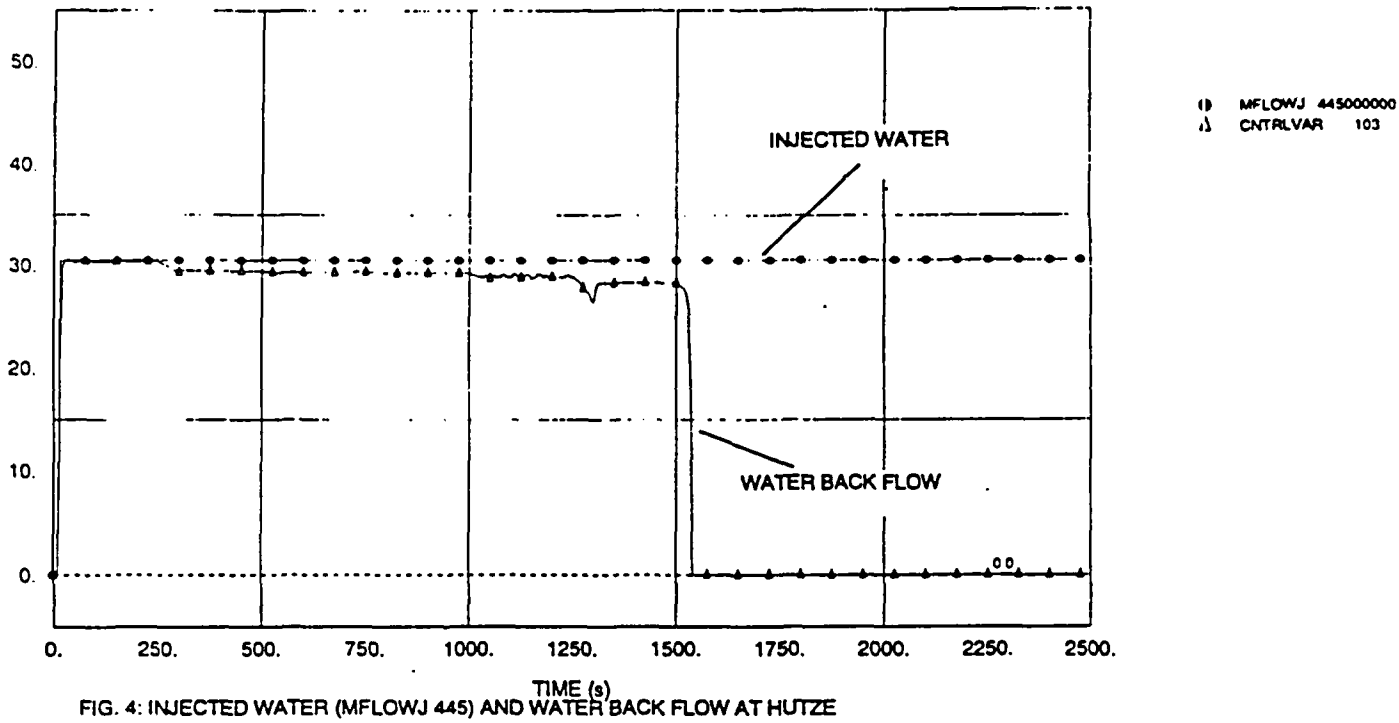


FIG. 4: INJECTED WATER (MFLOWJ 445) AND WATER BACK FLOW AT HUTZE

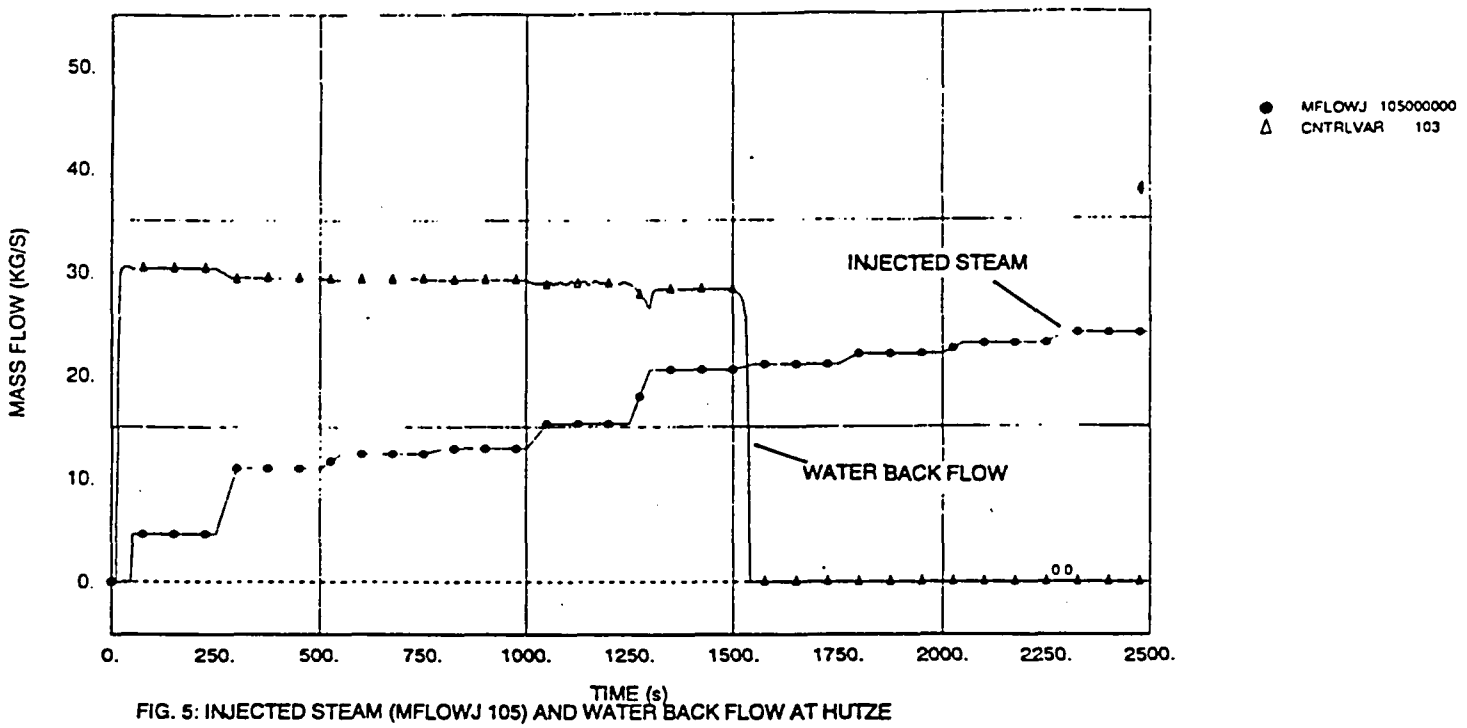


FIG. 5: INJECTED STEAM (MFLOWJ 105) AND WATER BACK FLOW AT HUTZE

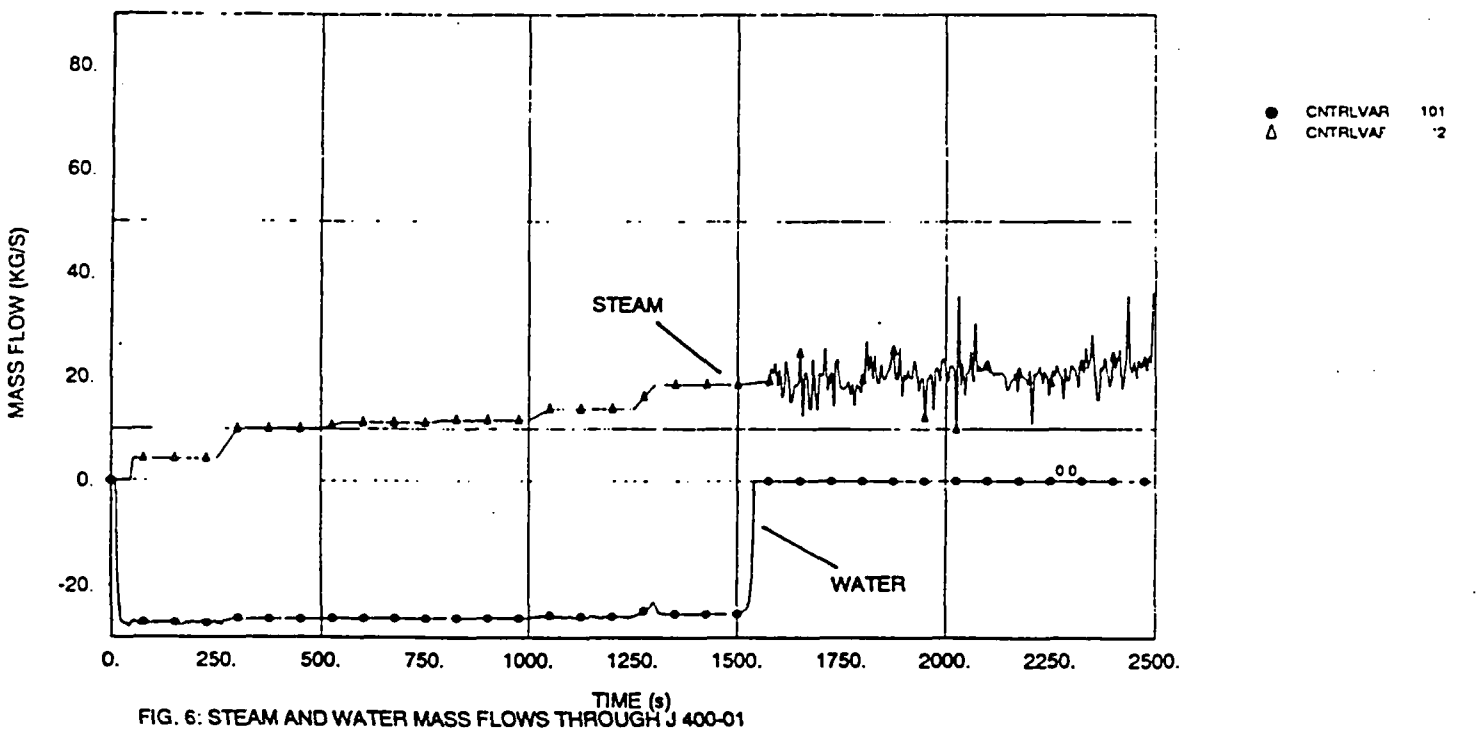


FIG. 6: STEAM AND WATER MASS FLOWS THROUGH J 400-01
(CALCULATED WITH JUNCTION PROPERTIES)

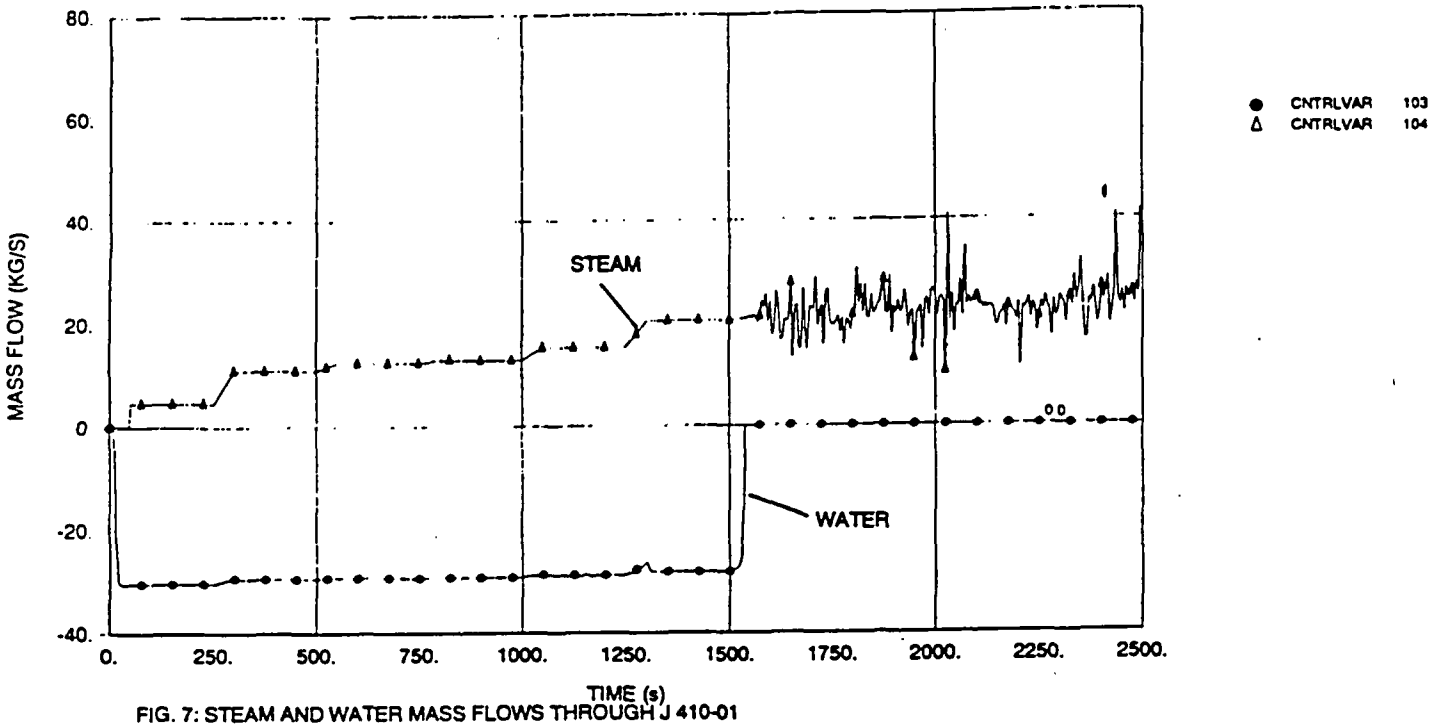


FIG. 7: STEAM AND WATER MASS FLOWS THROUGH J 410-01
(CALCULATED WITH JUNCTION PROPERTIES)

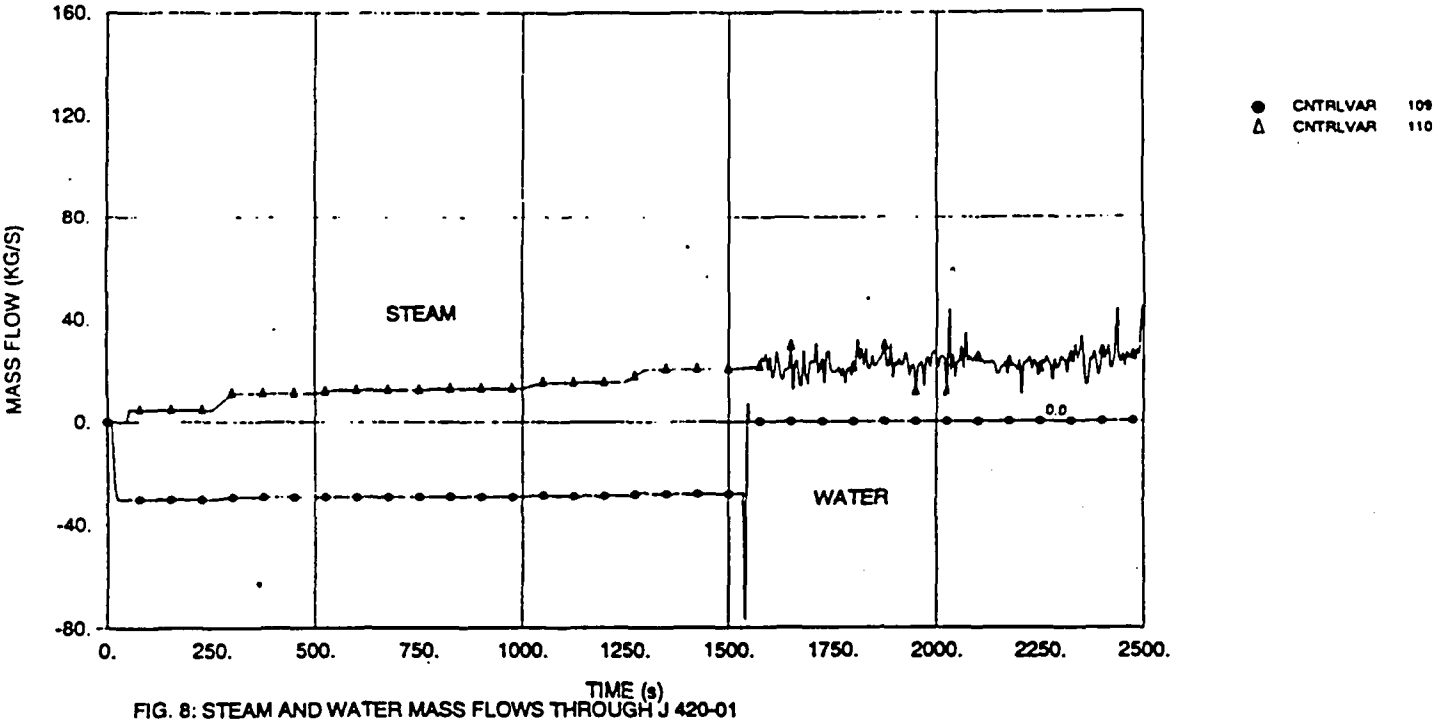


FIG. 8: STEAM AND WATER MASS FLOWS THROUGH J 420-01
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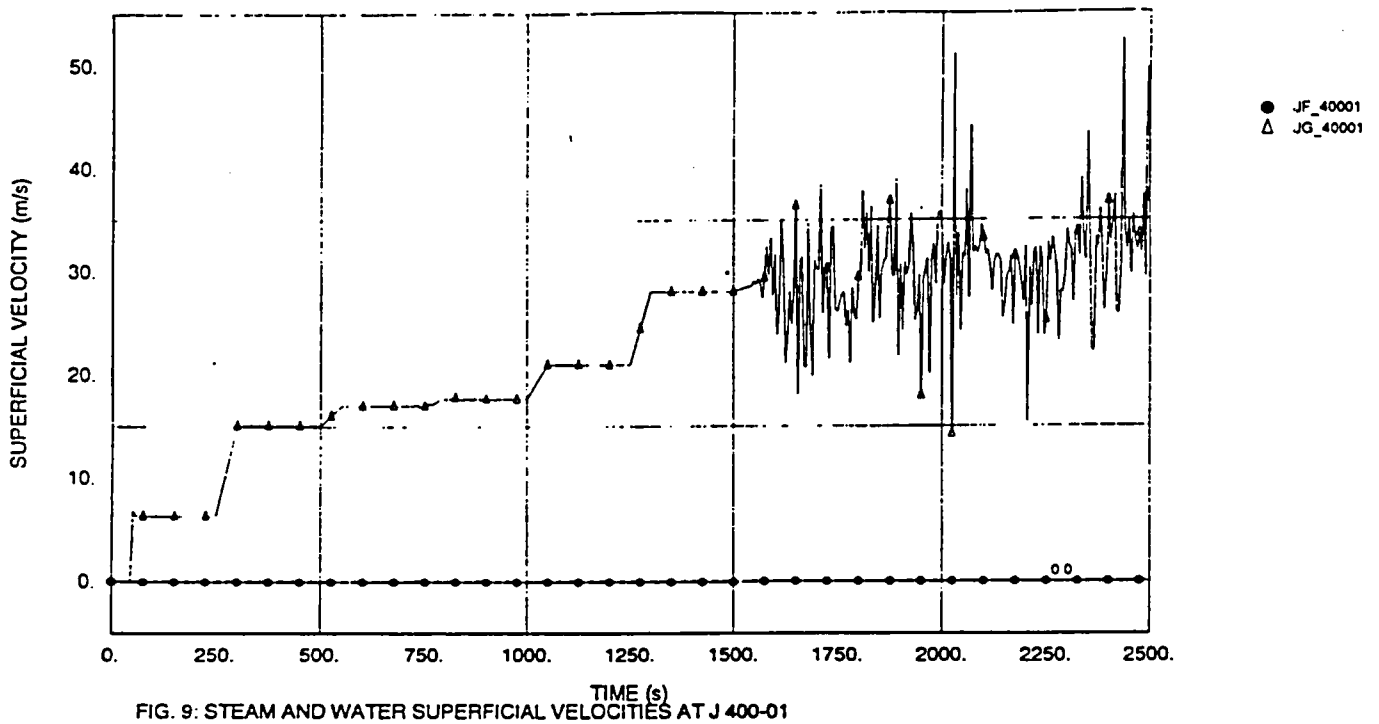

FIG. 9: STEAM AND WATER SUPERFICIAL VELOCITIES AT J 400-01

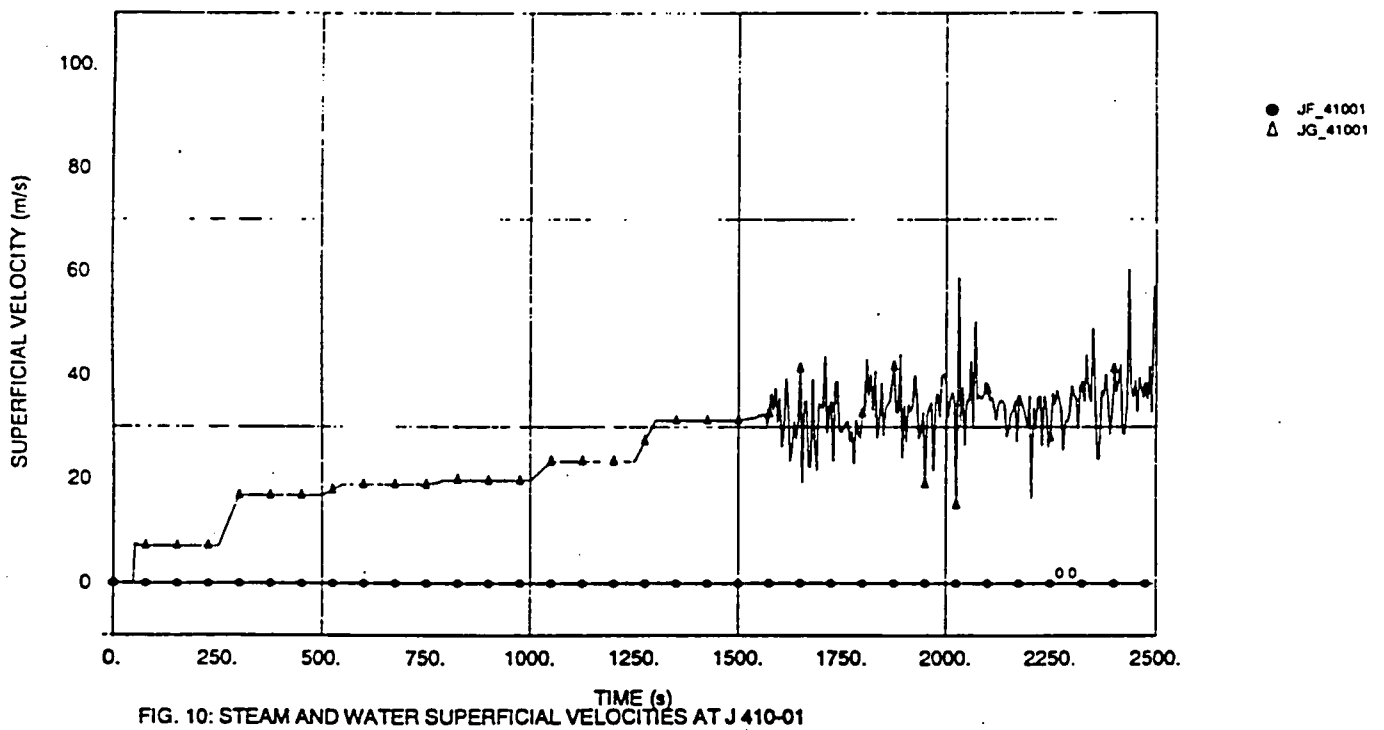

FIG. 10: STEAM AND WATER SUPERFICIAL VELOCITIES AT J 410-01

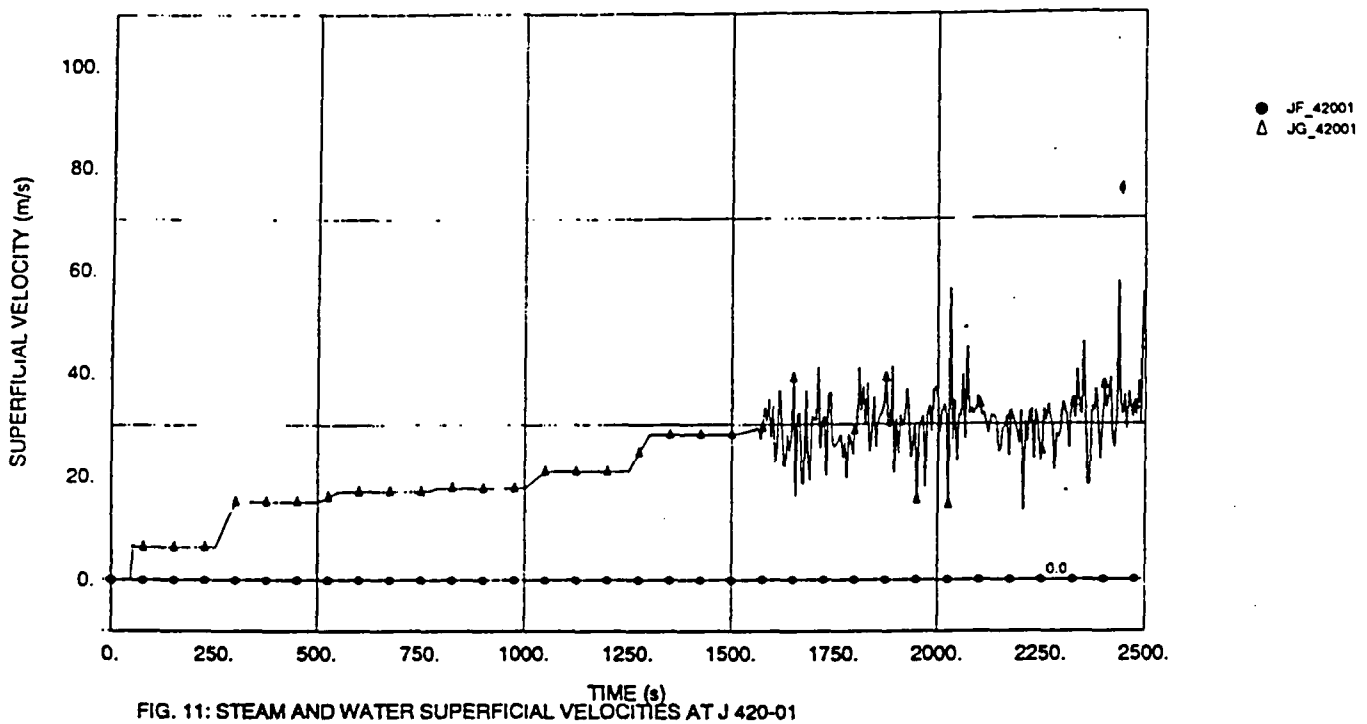

FIG. 11: STEAM AND WATER SUPERFICIAL VELOCITIES AT J 420-01

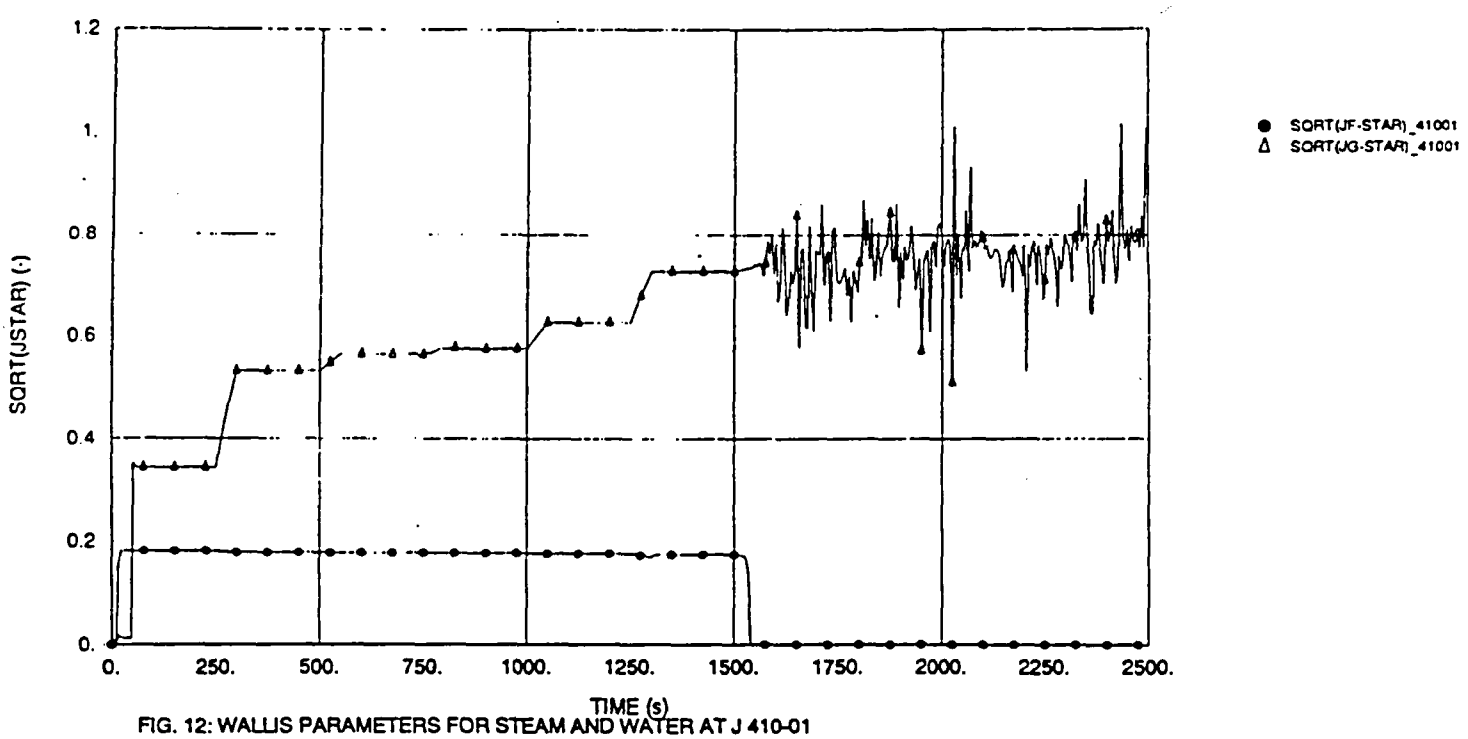

FIG. 12: WALLIS PARAMETERS FOR STEAM AND WATER AT J 410-01

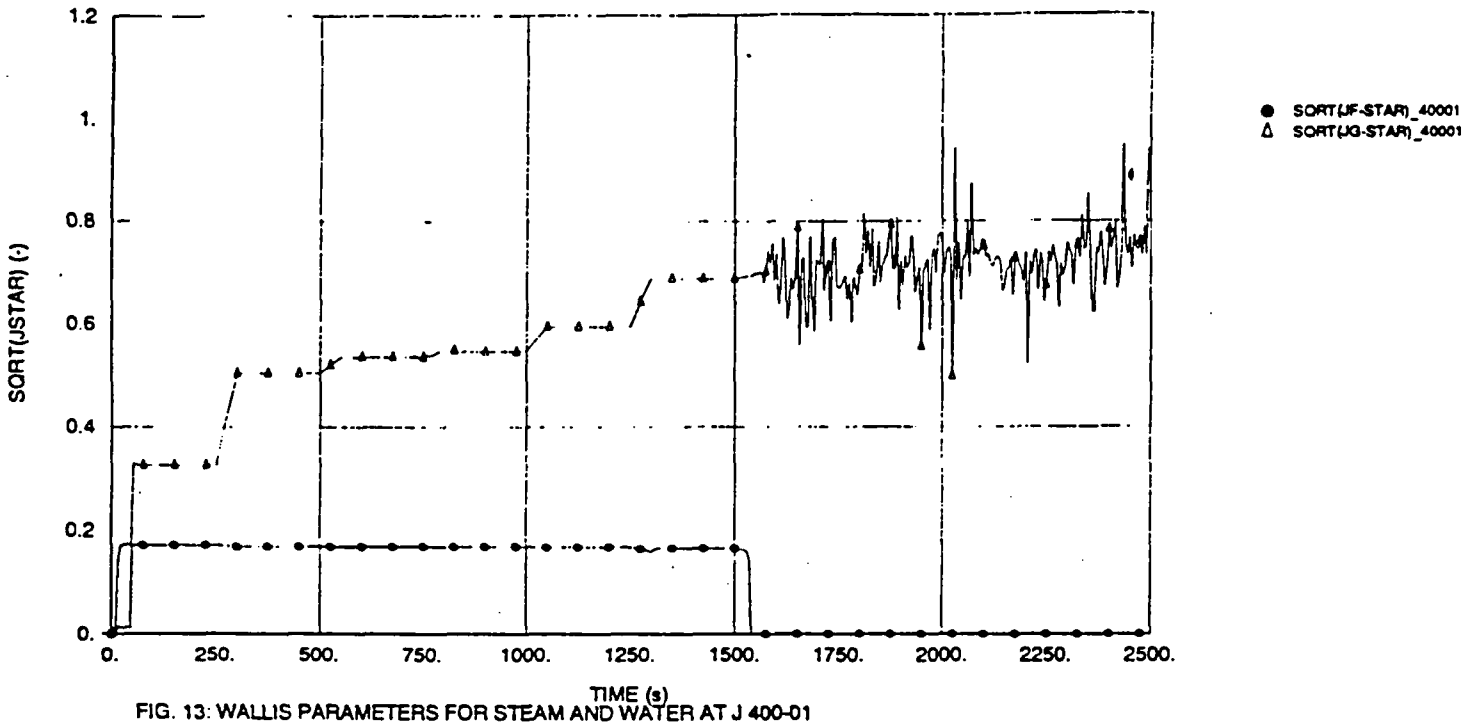

FIG. 13: WALLIS PARAMETERS FOR STEAM AND WATER AT J 400-01

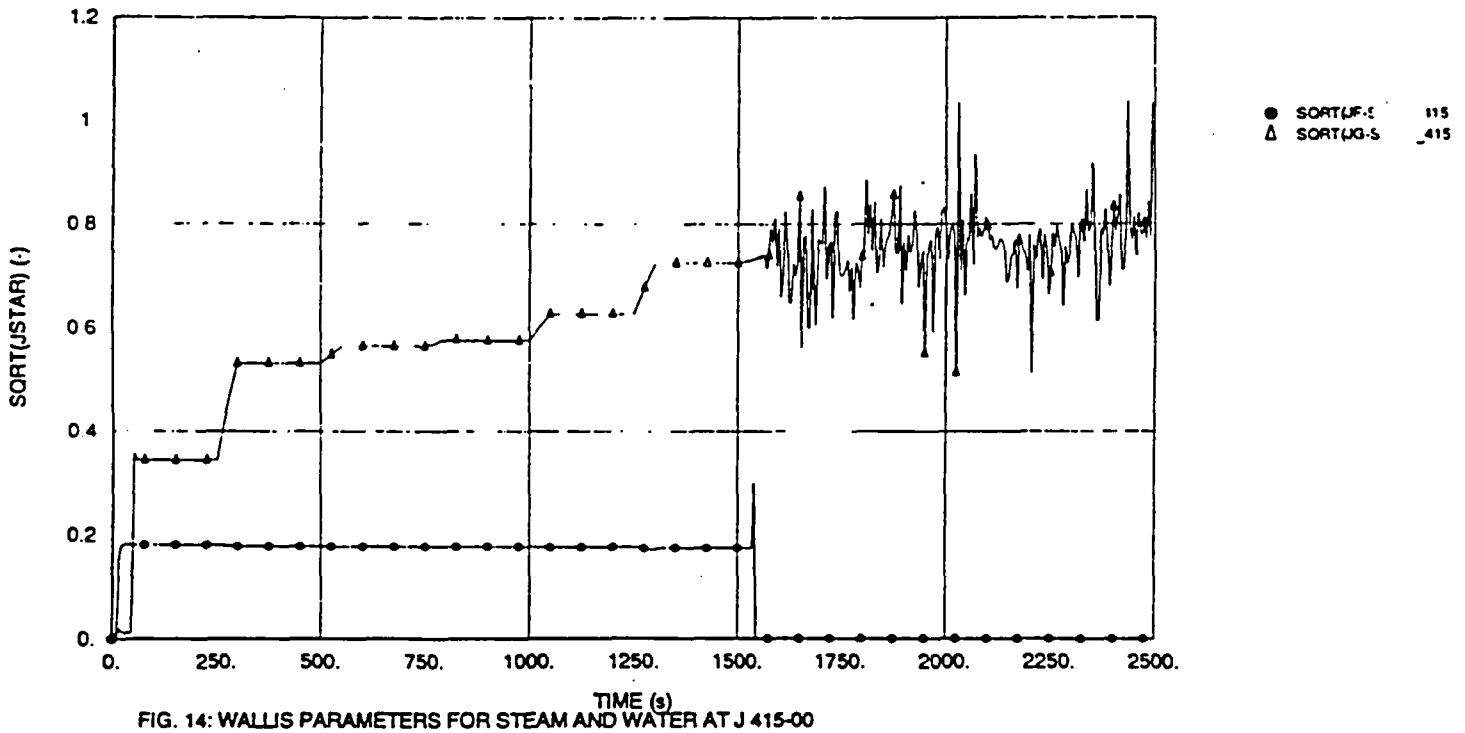

FIG. 14: WALLIS PARAMETERS FOR STEAM AND WATER AT J 415-00

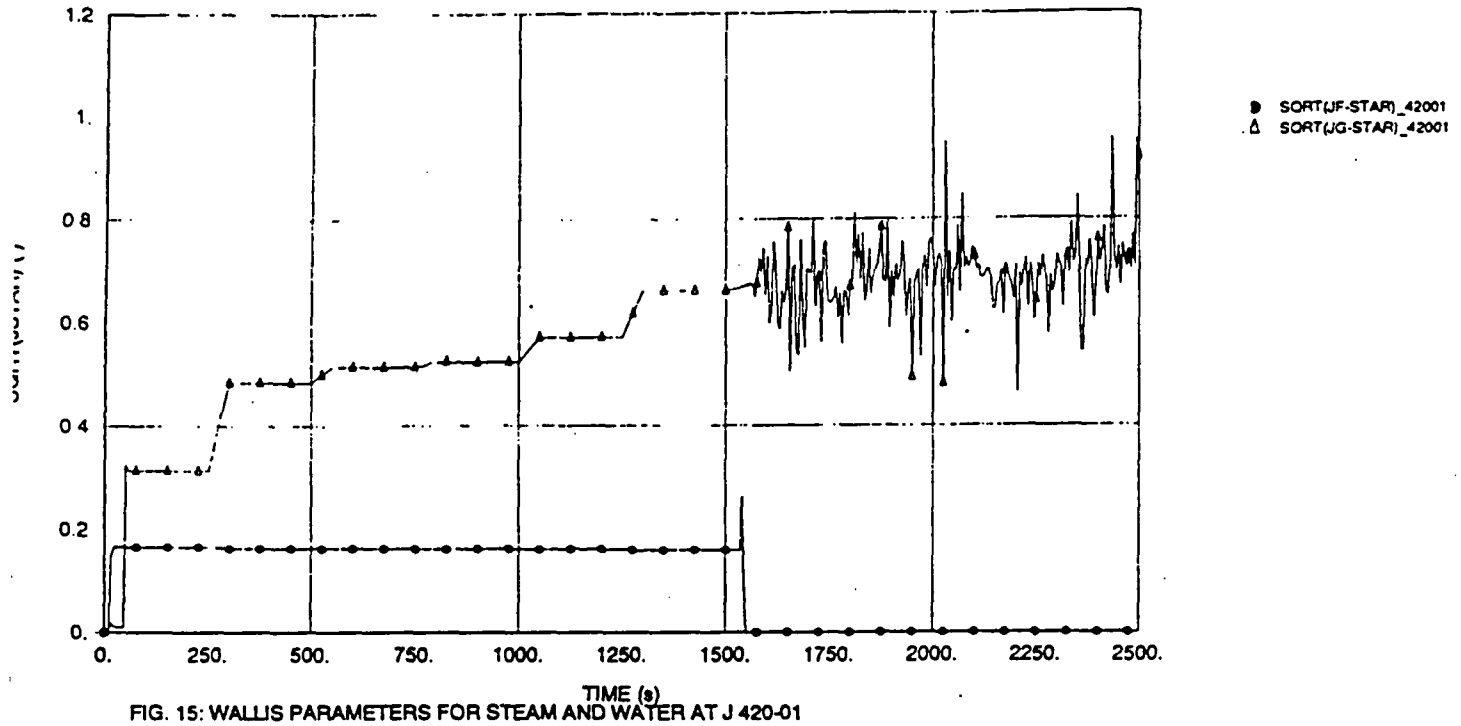

FIG. 15: WALLIS PARAMETERS FOR STEAM AND WATER AT J 420-01

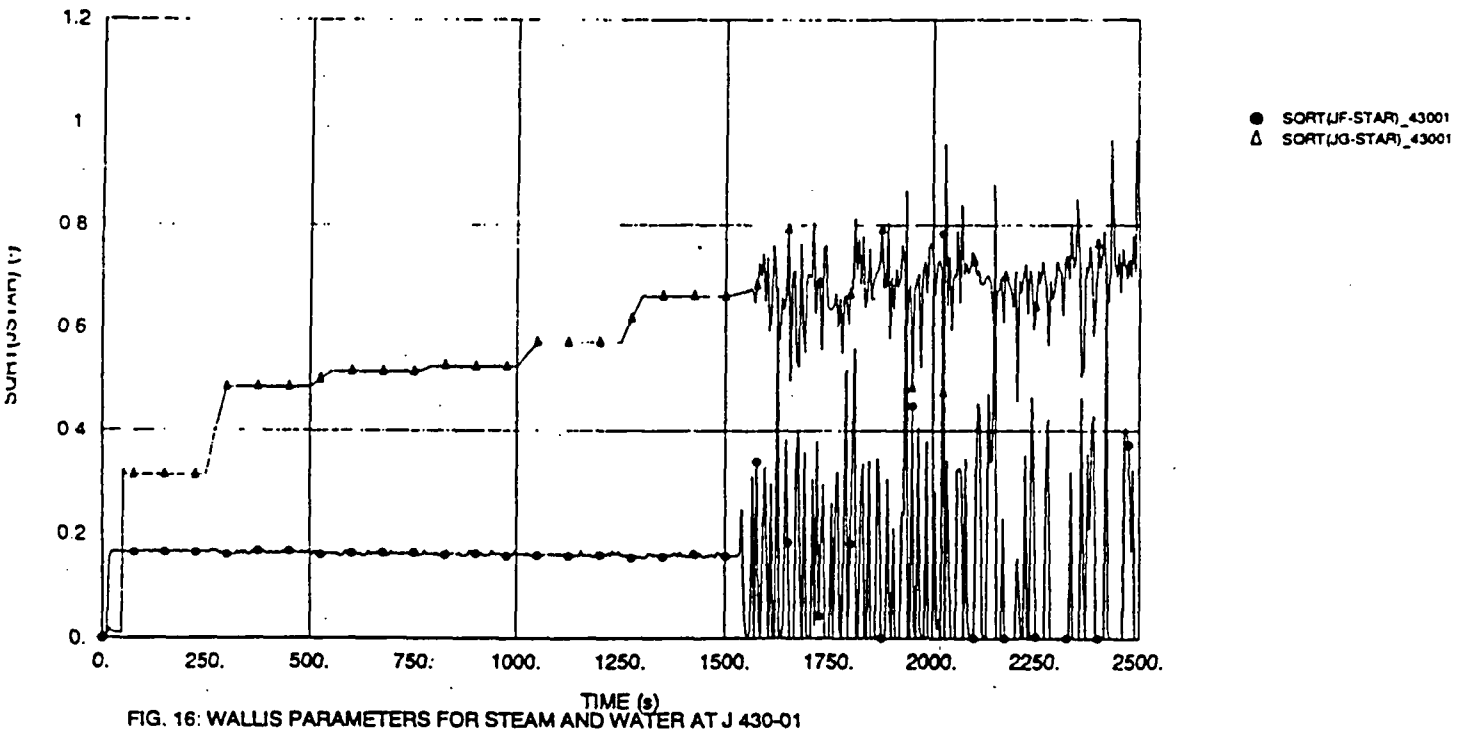

FIG. 16: WALLIS PARAMETERS FOR STEAM AND WATER AT J 430-01

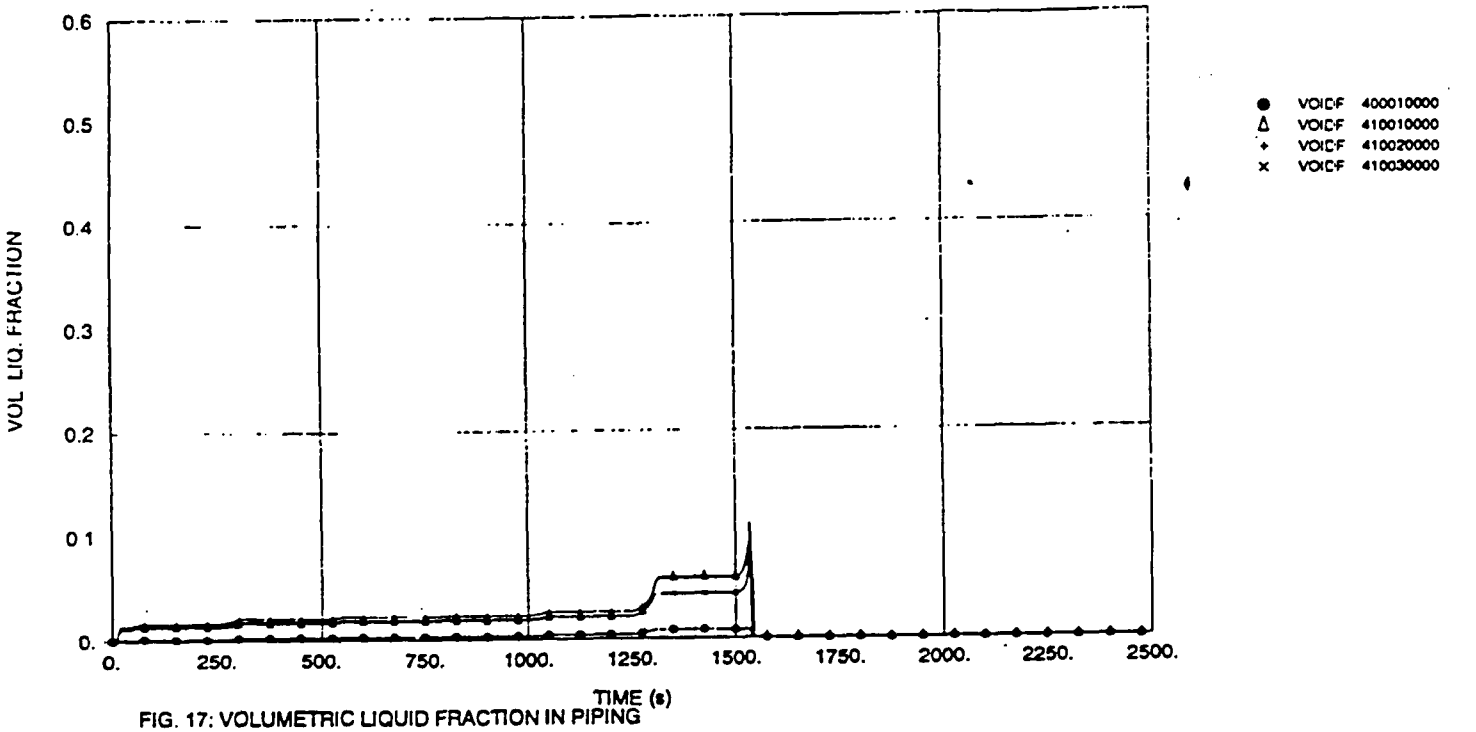

FIG. 17: VOLUMETRIC LIQUID FRACTION IN PIPING

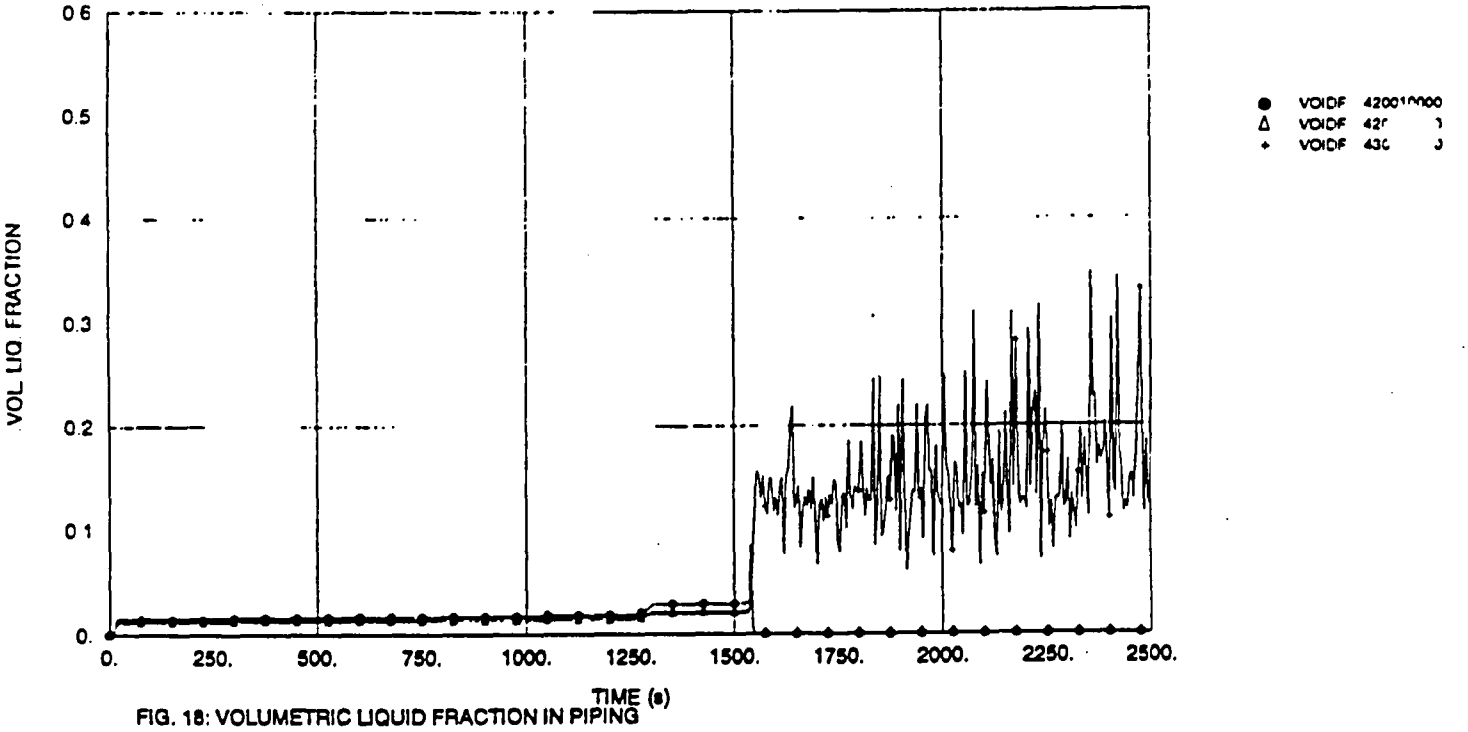

FIG. 18: VOLUMETRIC LIQUID FRACTION IN PIPING

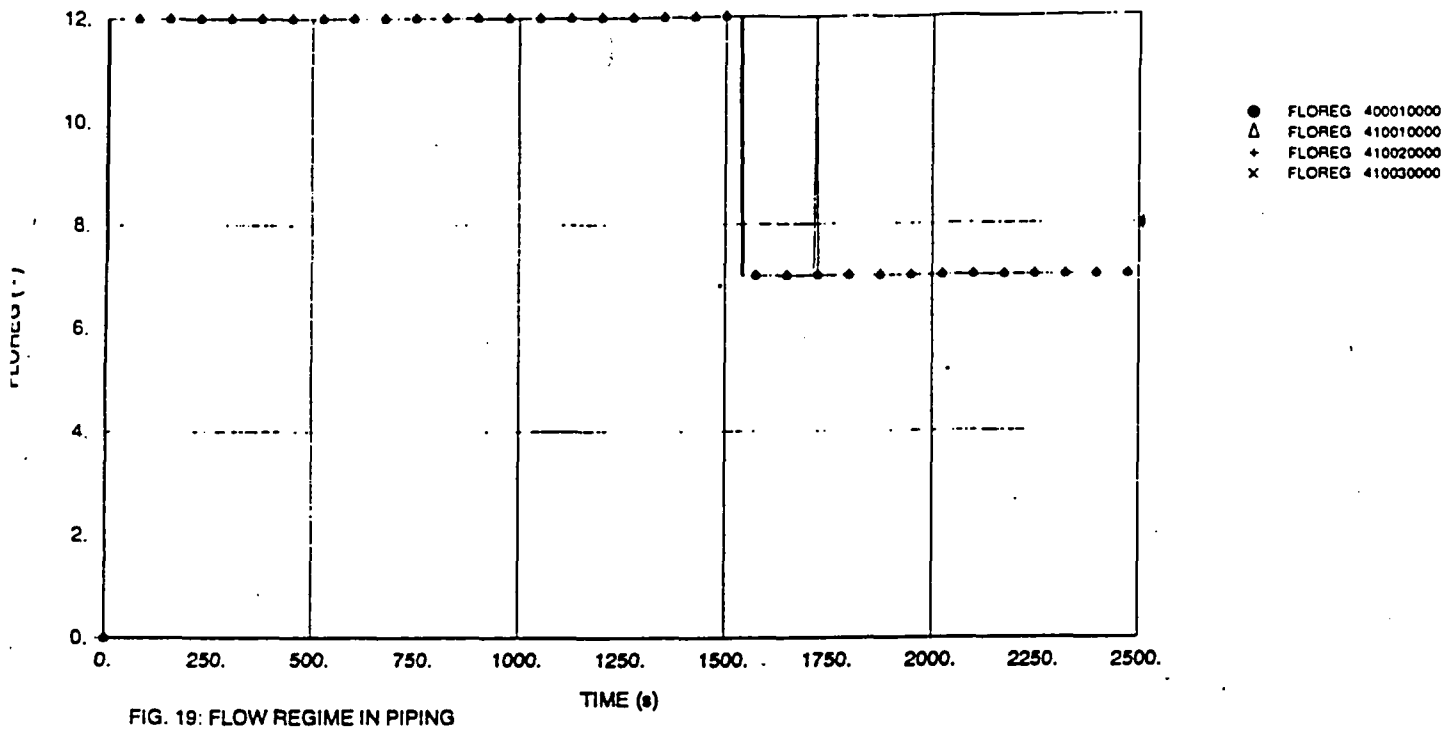

FIG. 19: FLOW REGIME IN PIPING

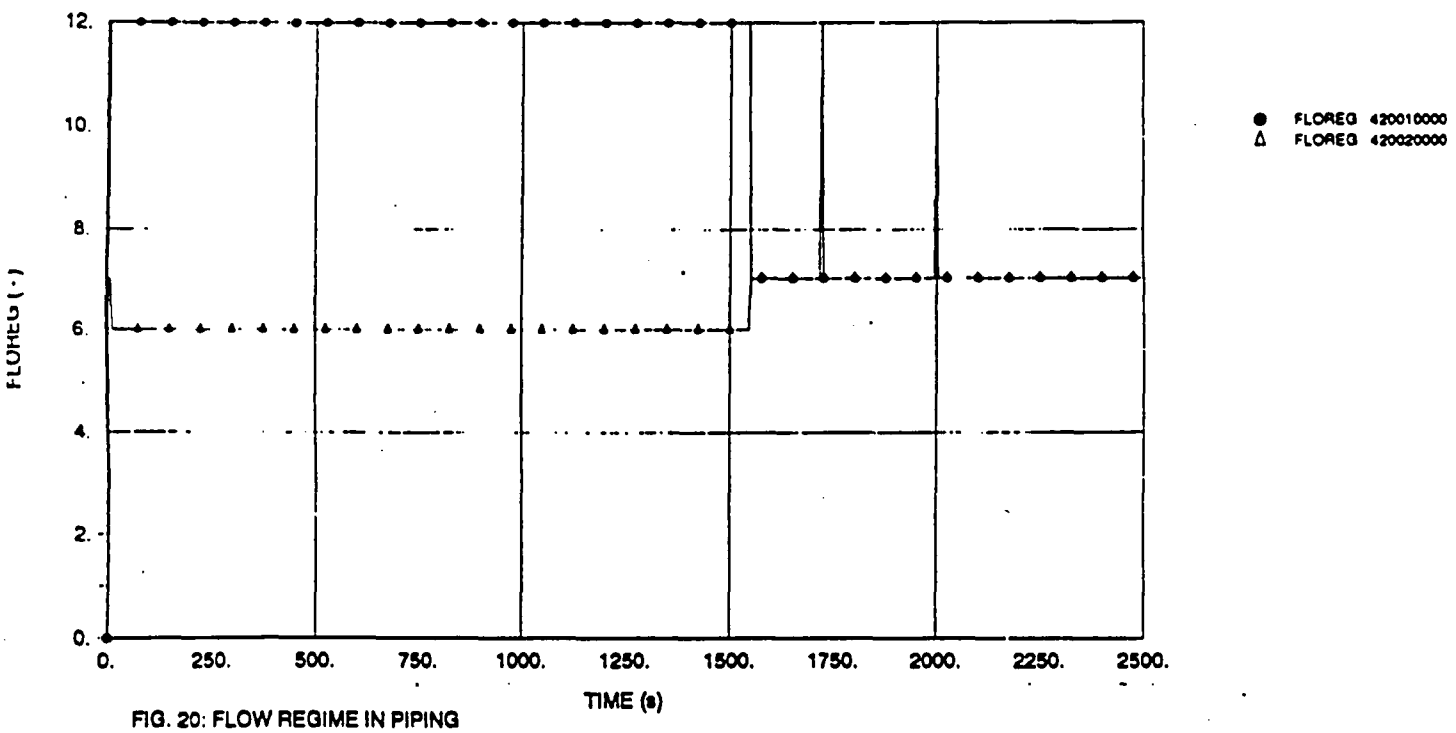

FIG. 20: FLOW REGIME IN PIPING

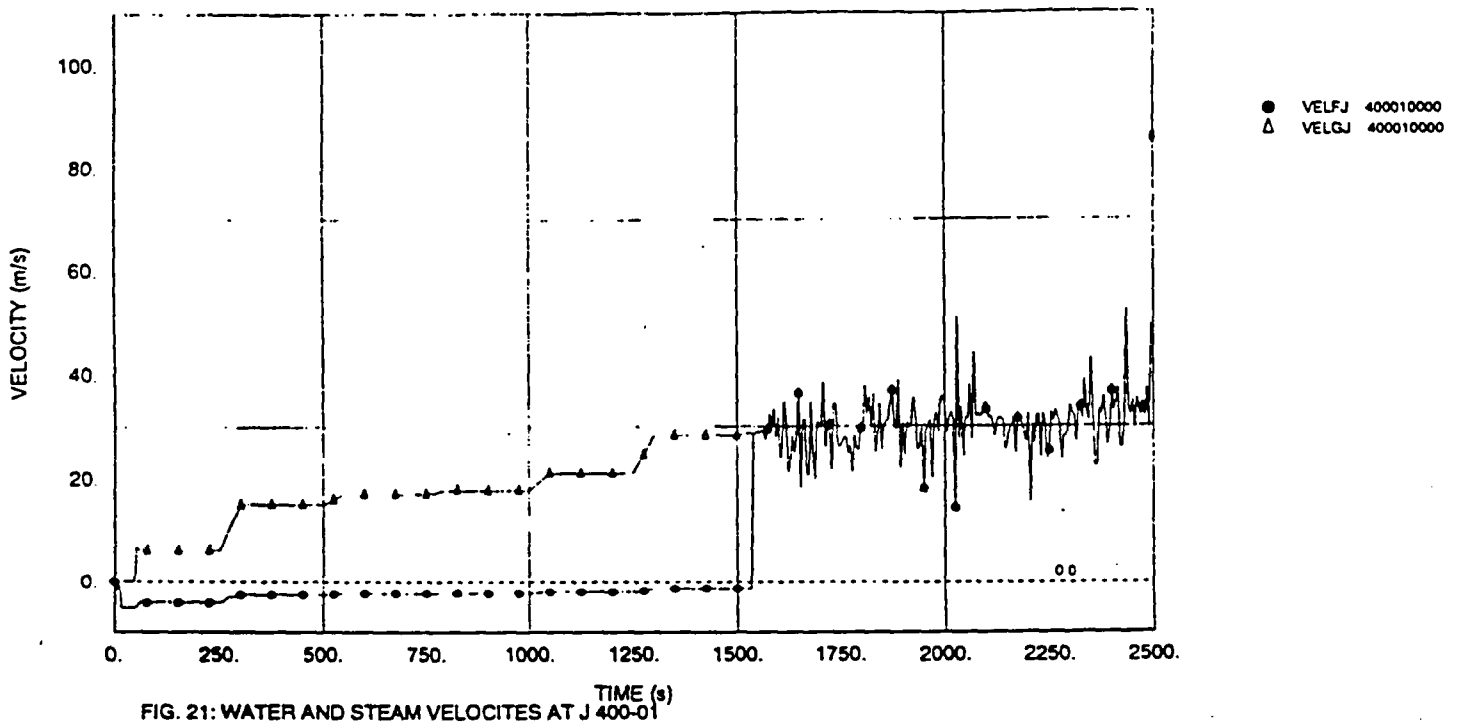

FIG. 21: WATER AND STEAM VELOCITES AT J 400-01

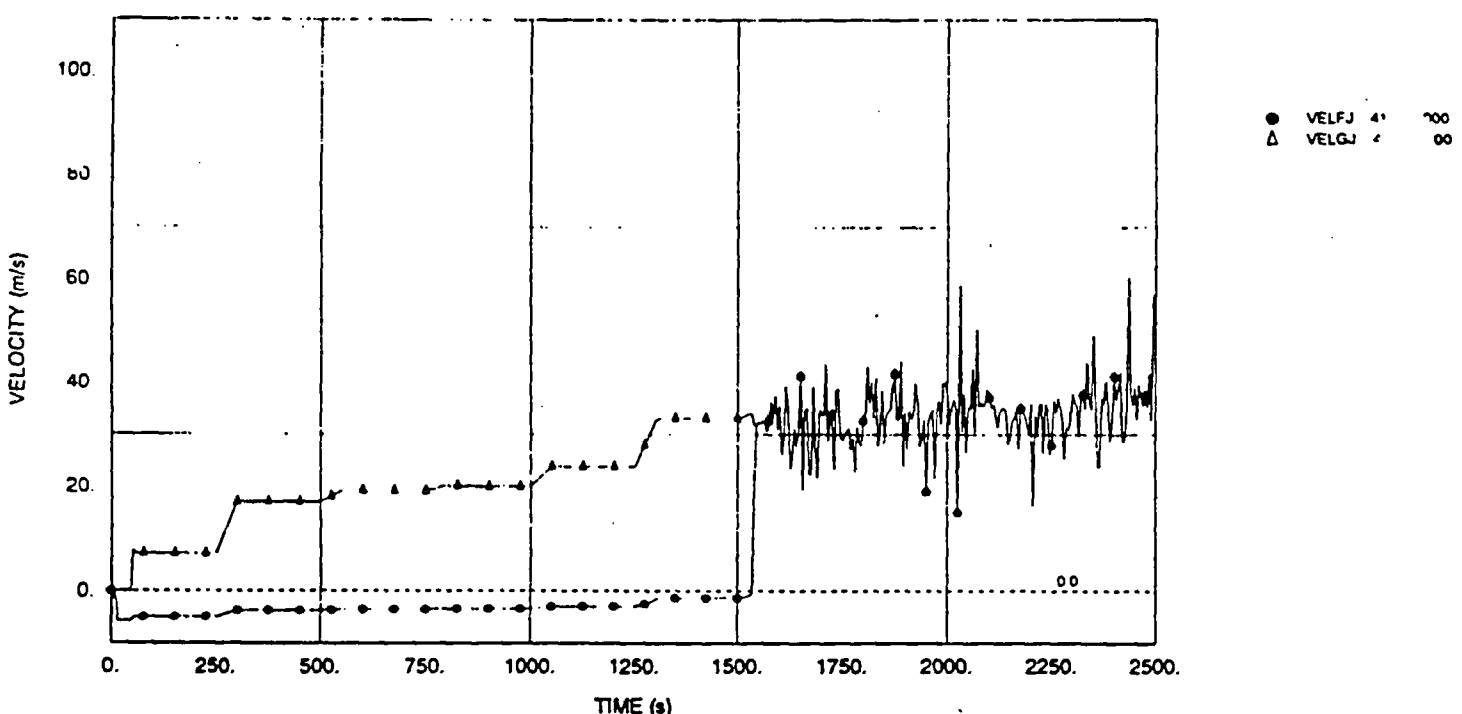

FIG. 22: WATER AND STEAM VELOCITES AT J 410-01

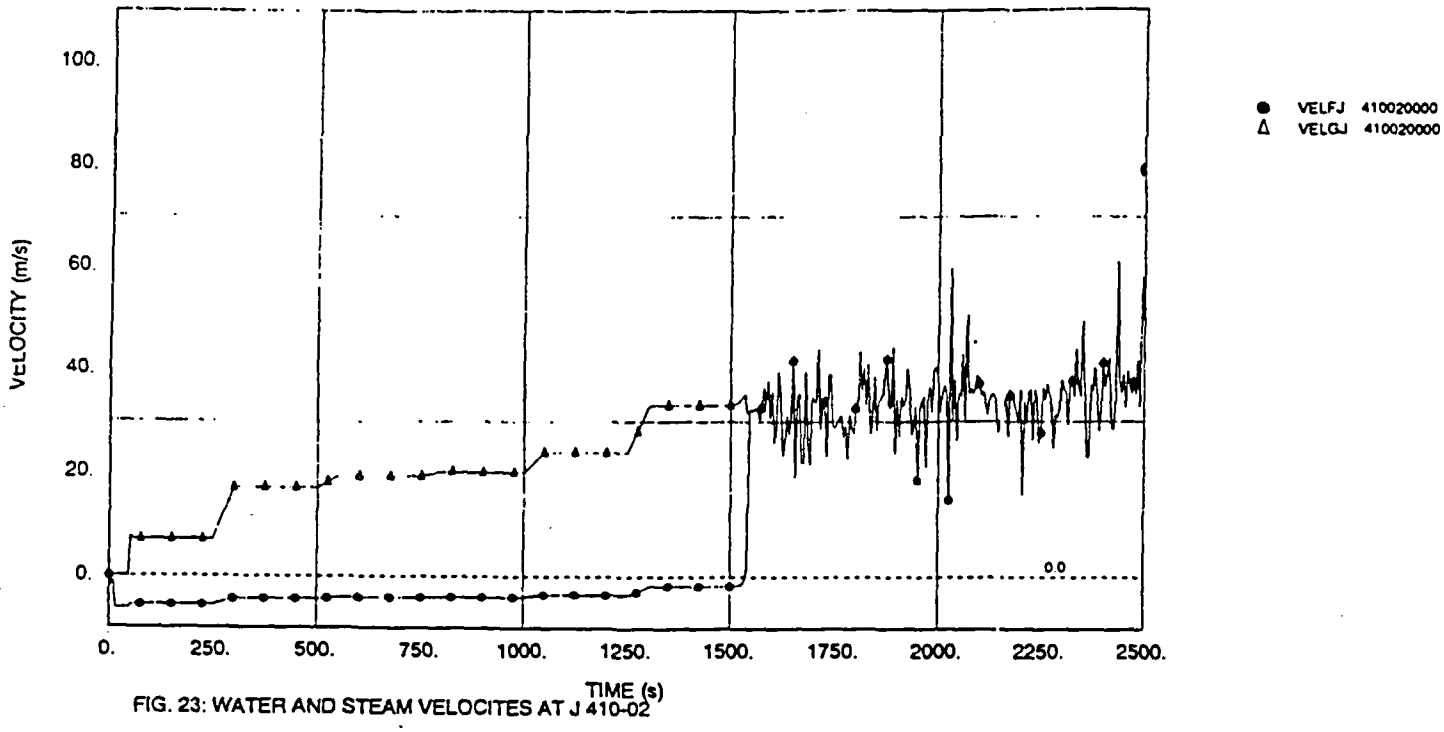

FIG. 23: WATER AND STEAM VELOCITES AT J 410-02

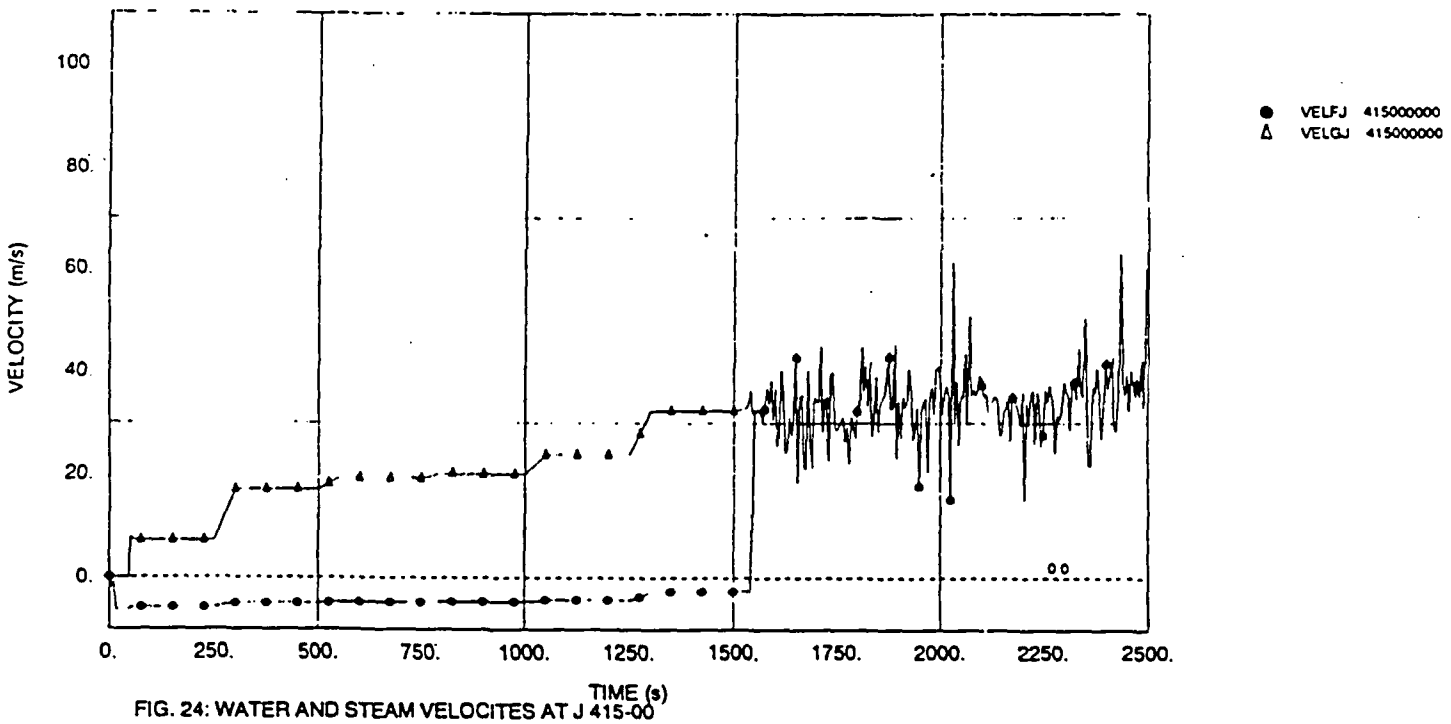

FIG. 24: WATER AND STEAM VELOCITES AT J 415-00

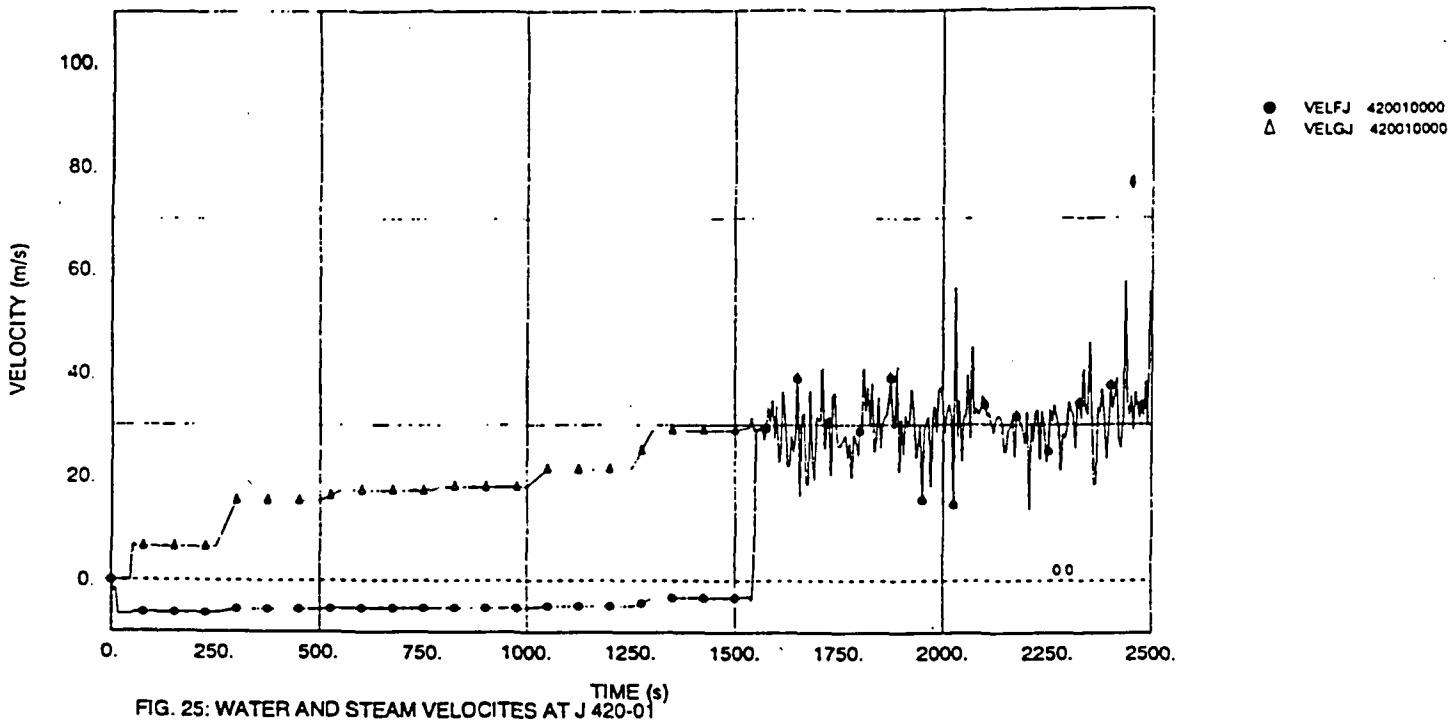

FIG. 25: WATER AND STEAM VELOCITES AT J 420-01

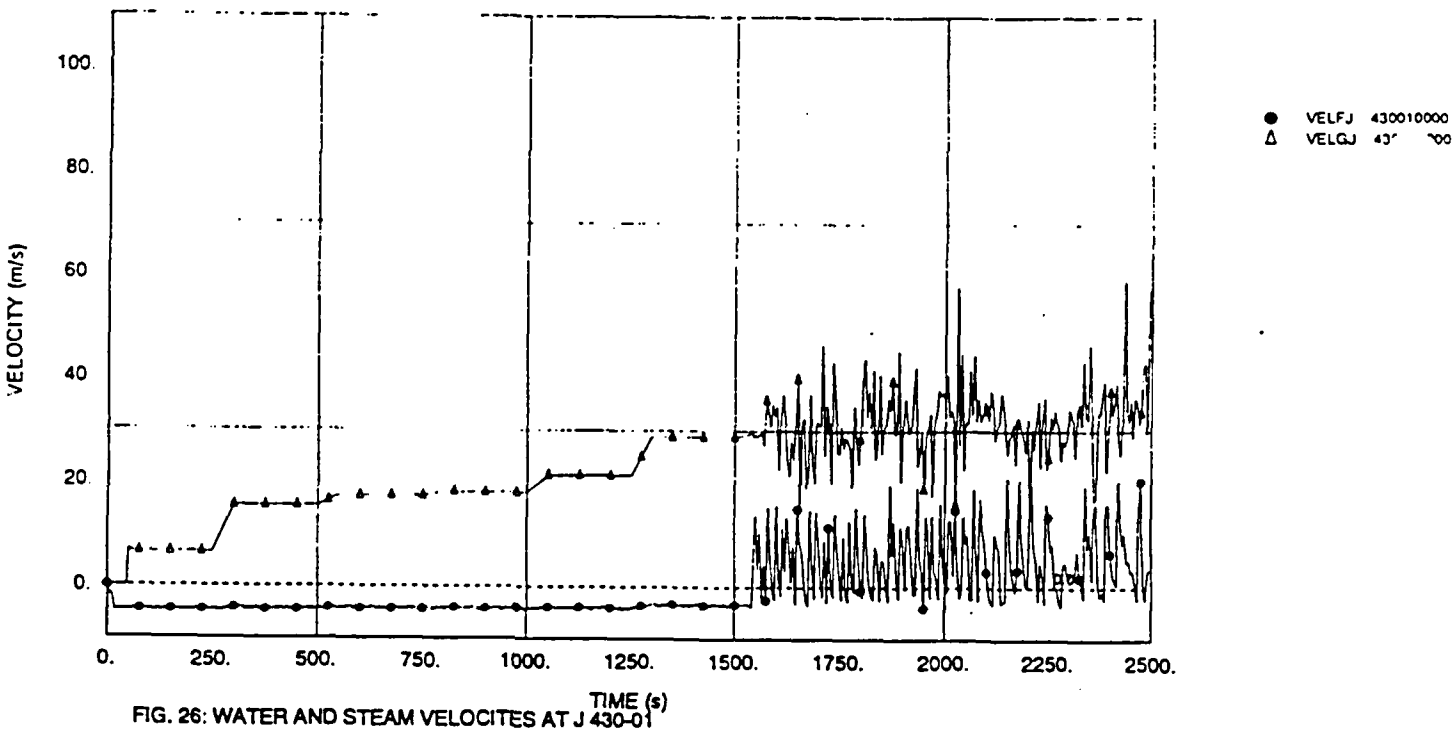

FIG. 26: WATER AND STEAM VELOCITES AT J 430-01

APPENDIX D

Analysis of UPTF Test No. 11, Runs 36 - 45 (Pressure 1.5 MPa) with RELAP5/MOD3/V5M5 (Basic Nodalisation). Results of Calculation Using a CCFL Model of the Wallis Type with m = 0.8 and C = 0.644

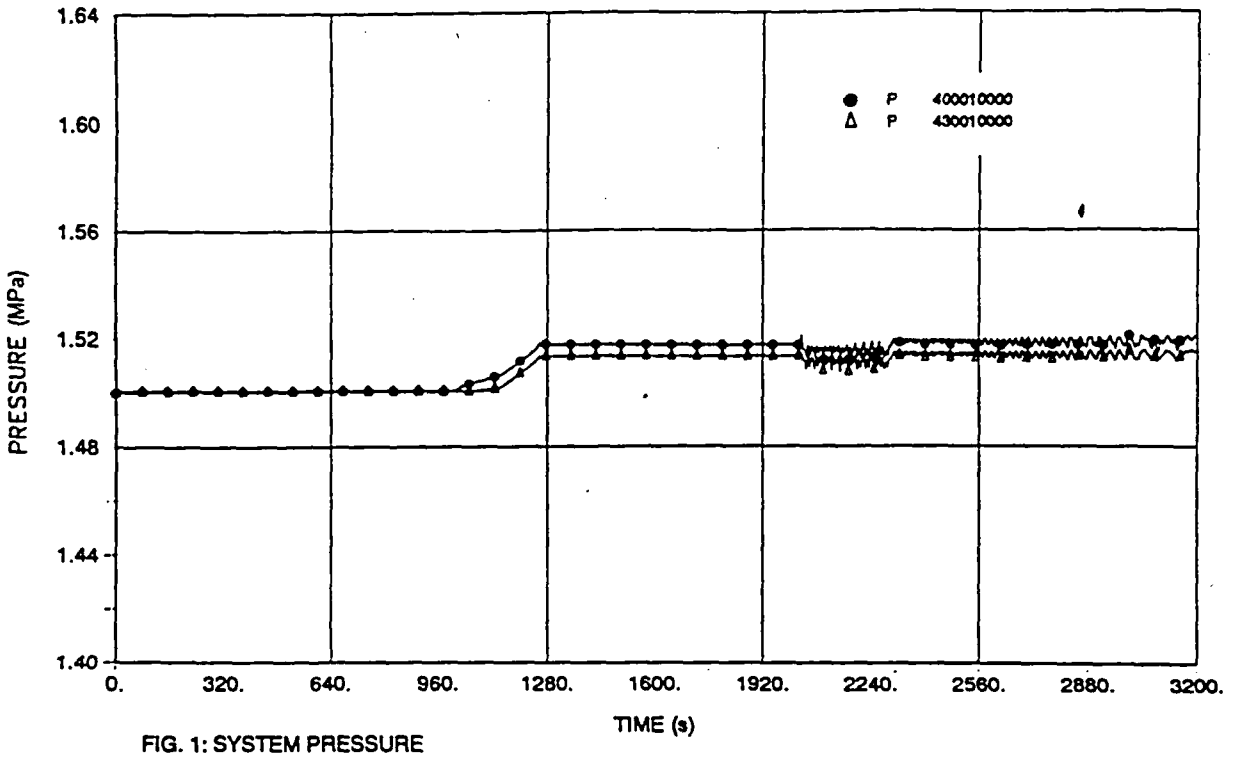

FIG. 1: SYSTEM PRESSURE

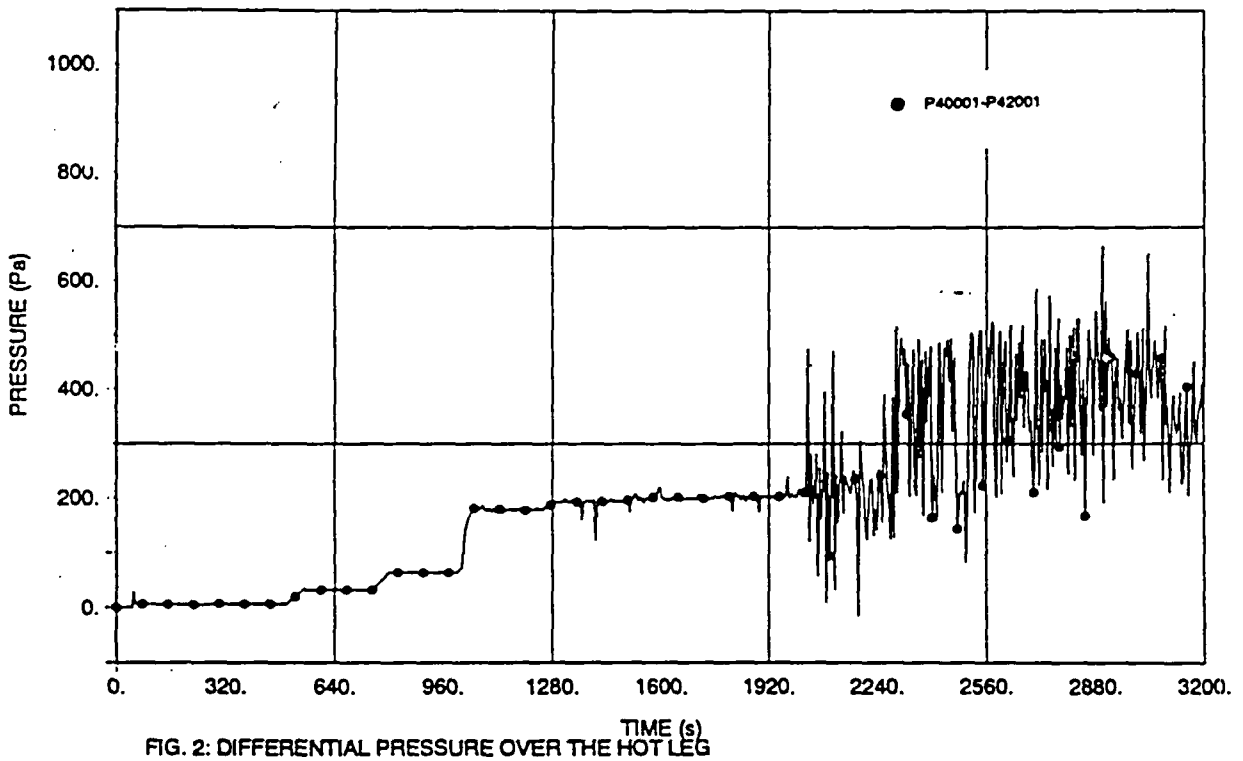

FIG. 2: DIFFERENTIAL PRESSURE OVER THE HOT LEG

(TO BE COMPARED WITH JEC04CP006)

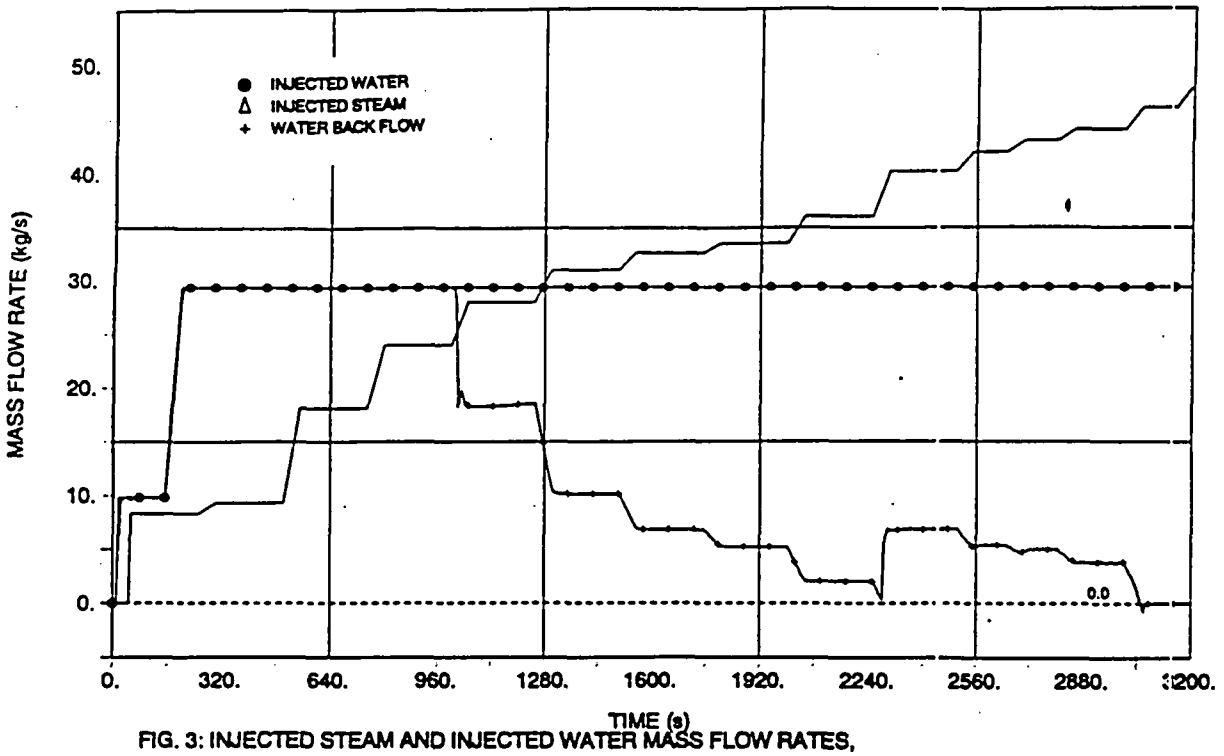

FIG. 3: INJECTED STEAM AND INJECTED WATER MASS FLOW RATES, WATER BACK FLOW AT THE HUTZE

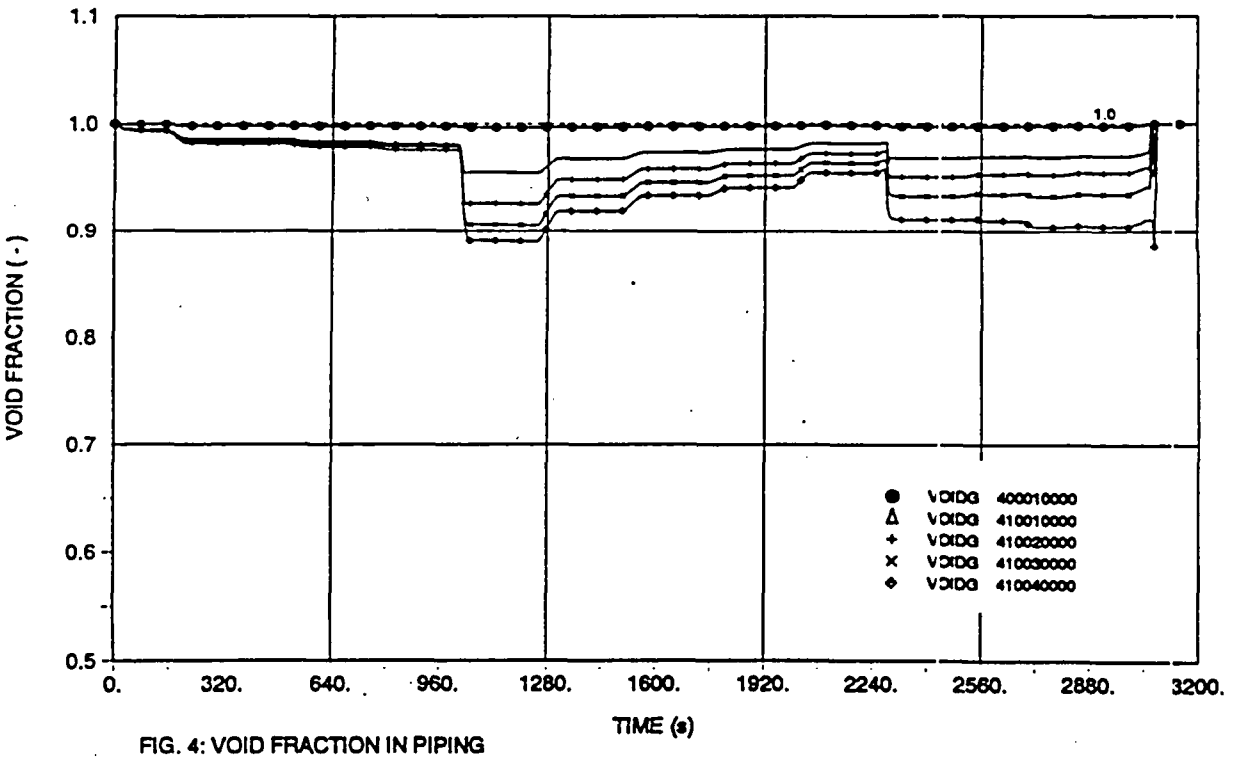

FIG. 4: VOID FRACTION IN PIPING

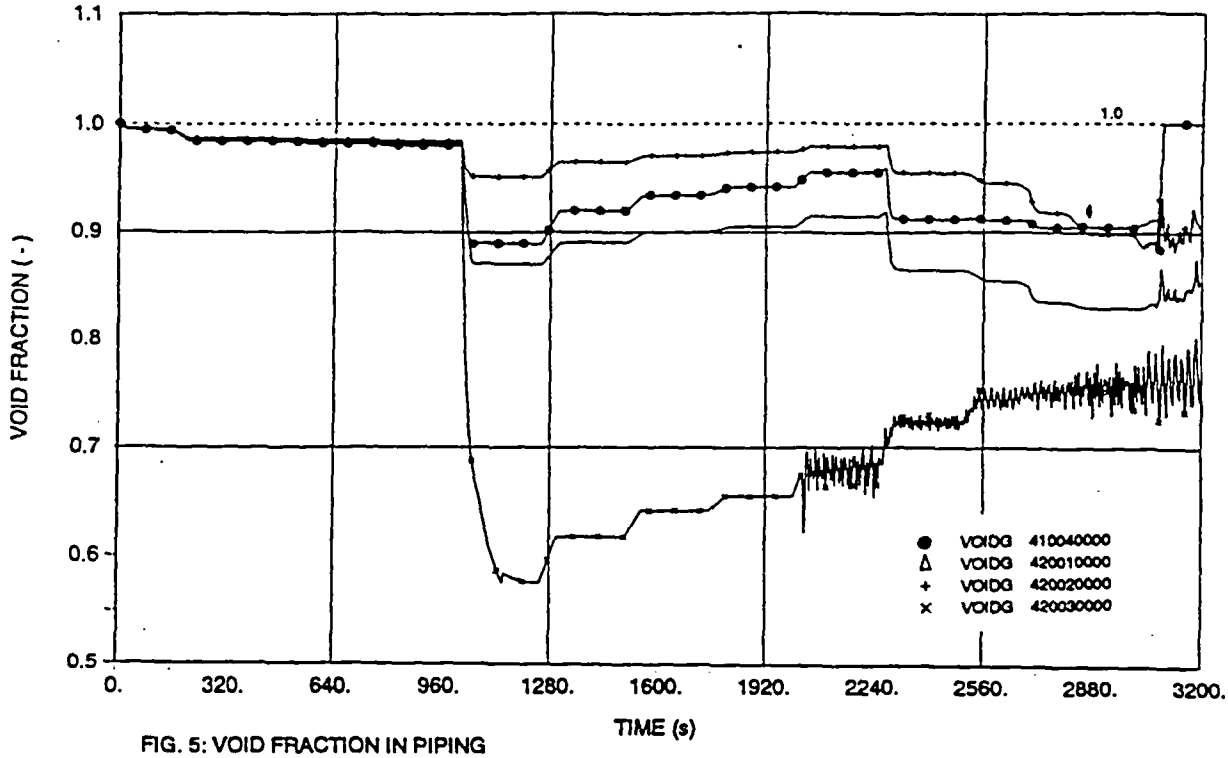

FIG. 5: VOID FRACTION IN PIPING

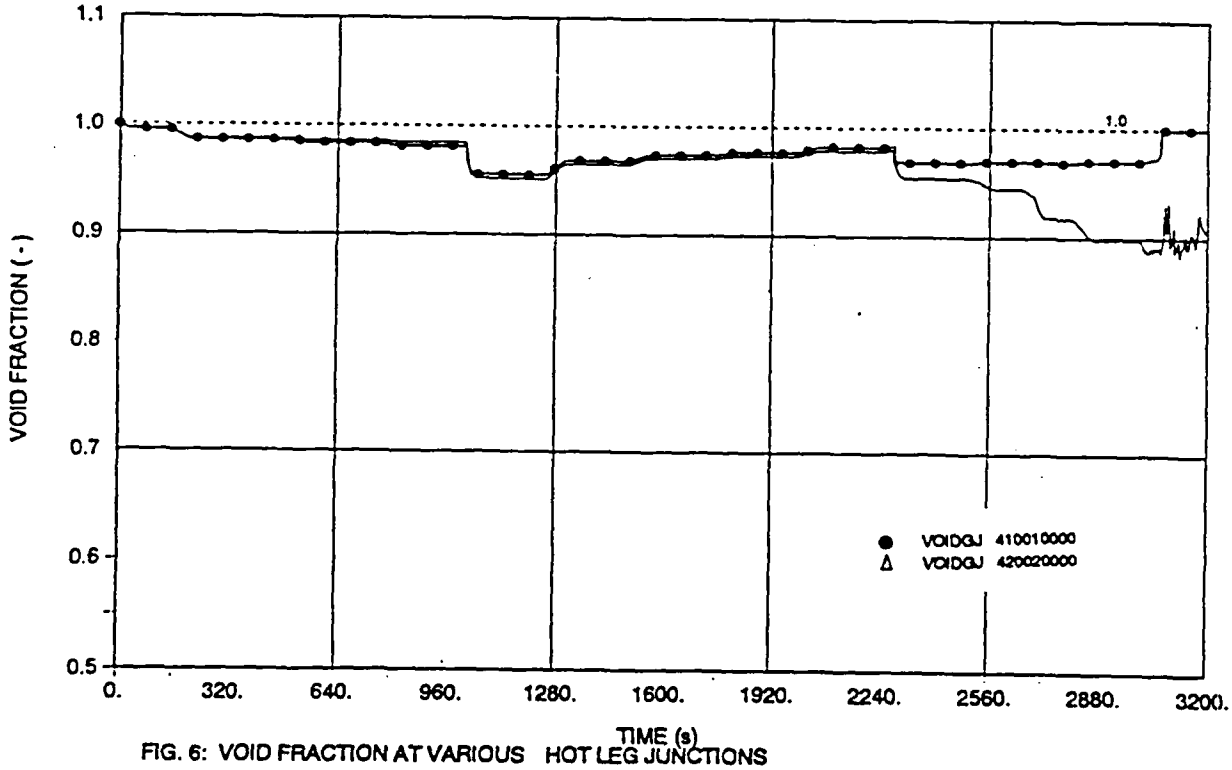

FIG. 6: VOID FRACTION AT VARIOUS HOT LEG JUNCTIONS

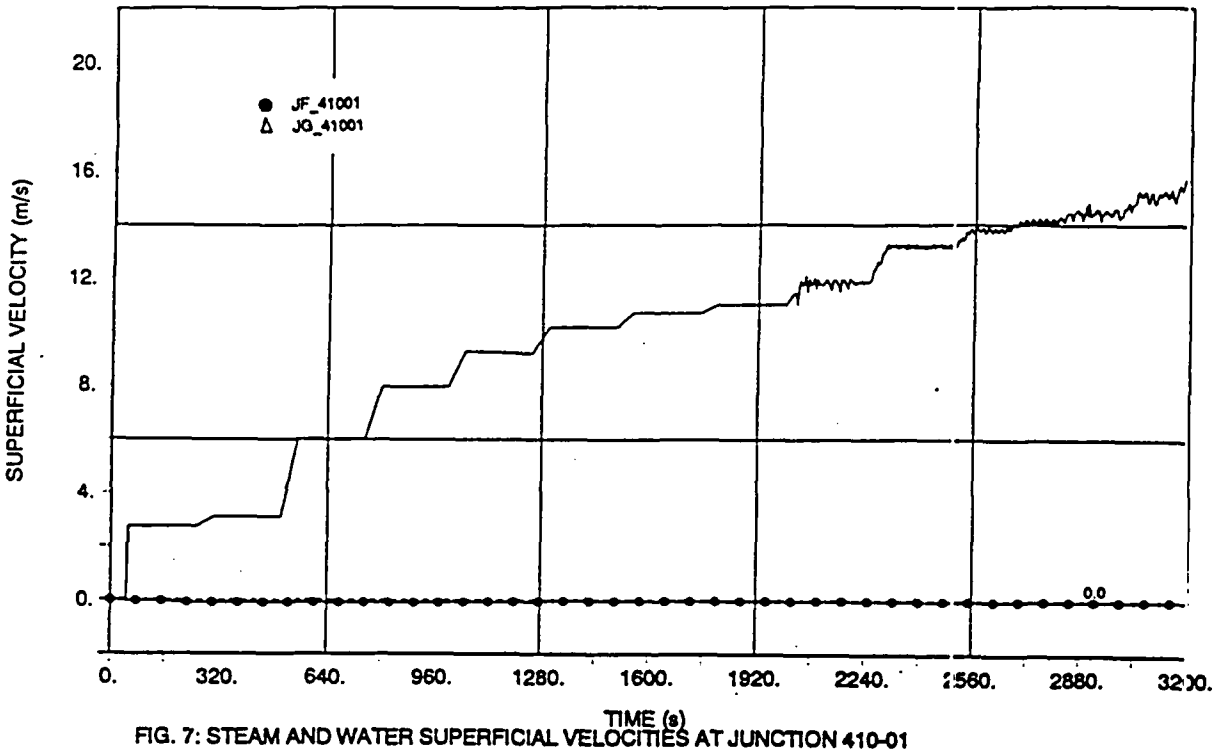

FIG. 7: STEAM AND WATER SUPERFICIAL VELOCITIES AT JUNCTION 410-01

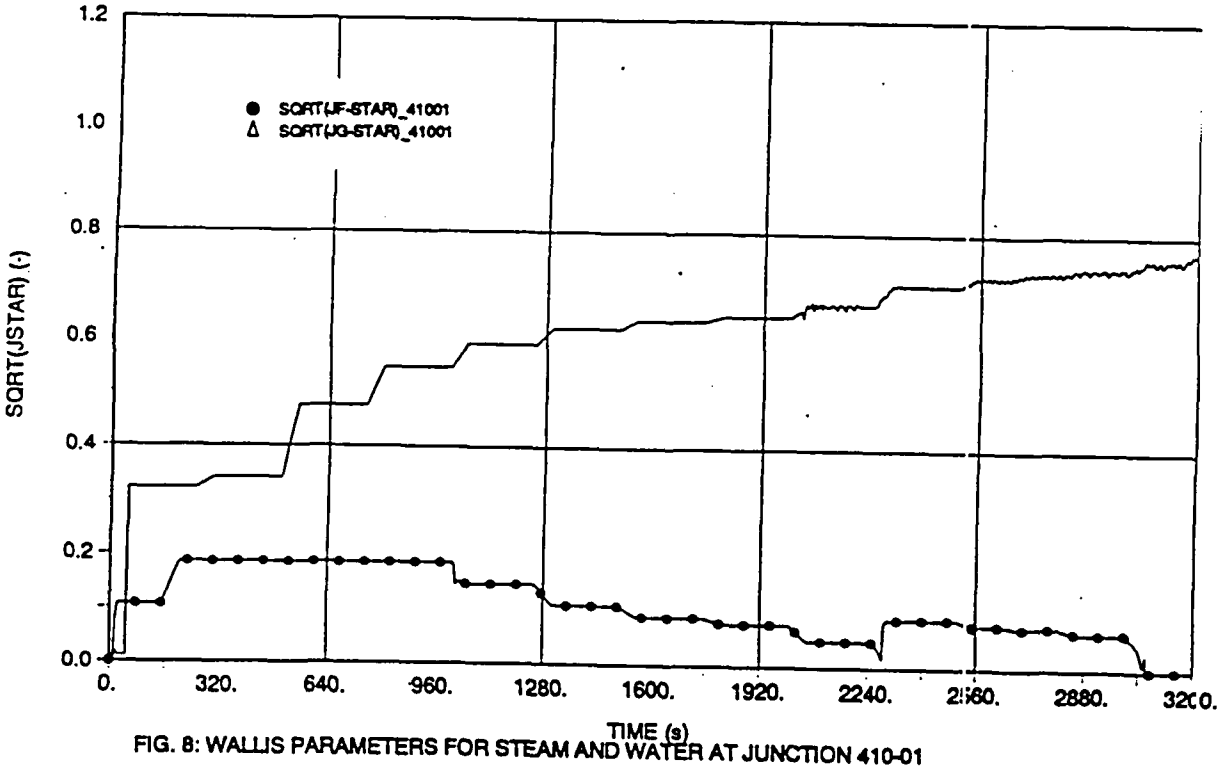

FIG. 8: WALLIS PARAMETERS FOR STEAM AND WATER AT JUNCTION 410-01

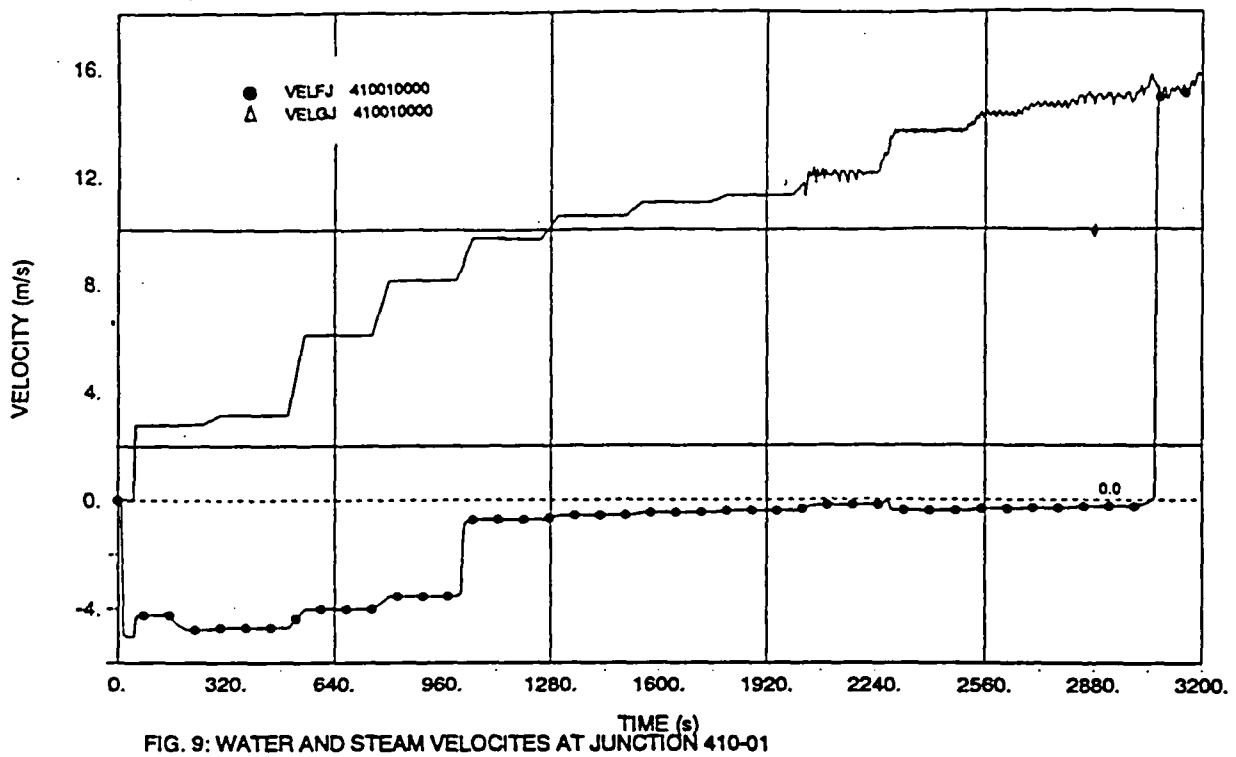

FIG. 9: WATER AND STEAM VELOCITES AT JUNCTION 410-01

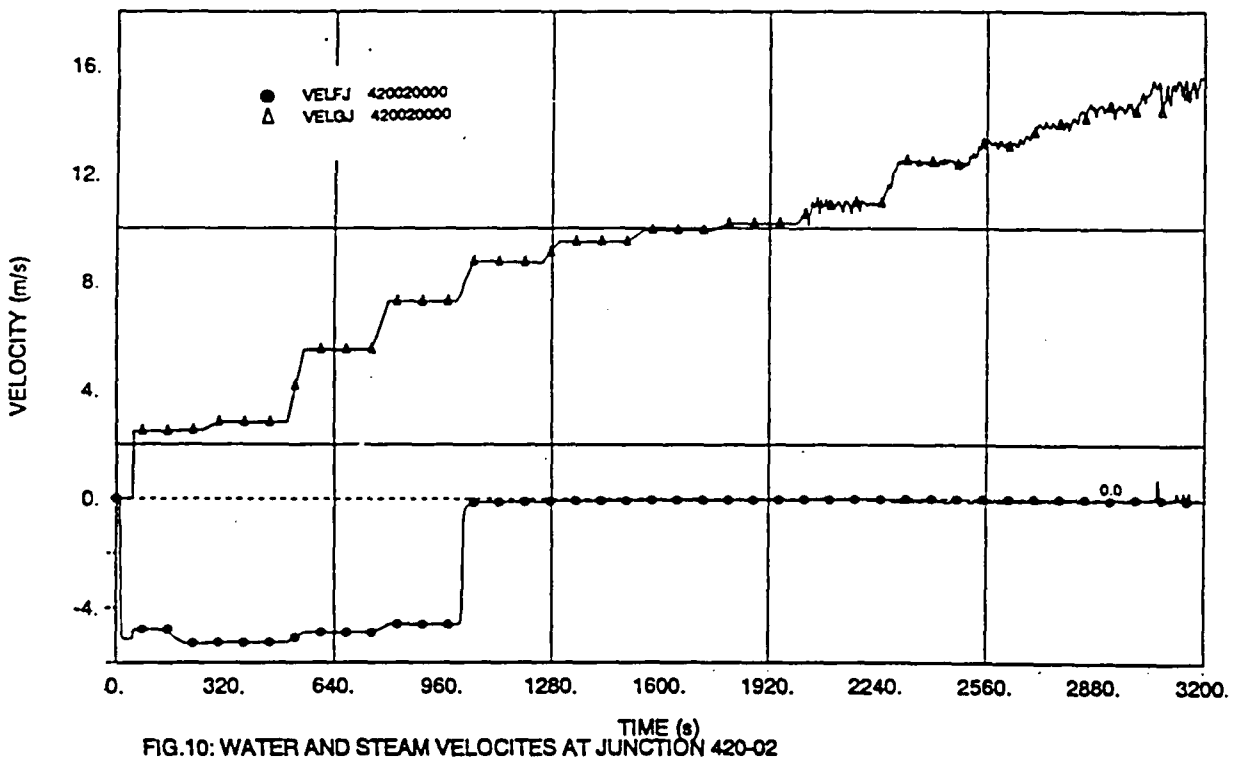

FIG.10: WATER AND STEAM VELOCITES AT JUNCTION 420-02

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Number, if any.)

NUREG/IA-0116
KWU E412/91/E1002

2. TITLE AND SUBTITLE

Assessment of RELAP5/MOD3/V5m5 Against the UPTF Test No. 11 (Countercurrent Flow in PWR Hot Leg)

3. DATE REPORT PUBLISHED

MONTH	YEAR
May	1993

4. FIN OR GRANT NUMBER

L2245

5. AUTHOR(S)

F. Curca-Tivig

6. TYPE OF REPORT

Technical Report

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.)

Siemens AG-KWU Group
D 8520 Erlangen
Federal Republic of Germany

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.)

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

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

Analysis of the UPTF Test No. 11 using the "best-estimate" computer code RELAP5/MOD3/Version 5m5 is presented.

Test No.11 was a quasi-steady state, separate effect test designed to investigate the conditions for countercurrent flow of steam and saturated water in the hot leg of a PWR.

An unphysical result was received using a CCFL correlation of the Wallis type with the intercept C = 0.644 and the slope m = 0.8. The unphysical prediction is an indication of possible programming errors in the CCFL model of the RELAP5/MOD3/V5m5 computer code.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

ICAP Report
RELAP5/MOD3/V5m5
UPTF Test 11

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page)
Unclassified

(This Report)
Unclassified

15. NUMBER OF PAGES

16. PRICE

NRC FORM 335 (2-89)

Printed on recycled paper

Federal Recycling Program