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International Agreement Report

Analysis of LOBI Test BLO2 (Three Percent Cold Leg Break) With RELAP5 Code

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

March 1992

Prepared as part of
The Agreement on Research Participation and Technical Exchange
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ANALYSIS OF LOBI TEST BLO2 (THREE PERCENT COLD LEG BREAK) WITH THE RELAP5 CODE

by

A.H. Scriven

SUMMARY

The test BLO2 was a UK specified test conducted on the electrically heated 2 loop test system at Ispra, North Italy as part of the LOBI 'B' series of tests sponsored by the Joint European Research Commission.

The pretest calculations for this test were performed with the RELAP5 MOD1 code, and the post-test analysis was carried out using RELAP5 MOD2. Comparisons between the codes predictions and the test data are given, and for the case of the post-test MOD2 calculation, detailed studies of the codes performance in a number of areas are included.

Of particular note in this test is the stratified break offtake condition for part of the test, the sensitivity to accurate bypass modelling and the clearance of both loop seals early in the transient. The correct modelling of these inter-related effects is a good test for the code.

This test also benefits from a reliable and accurate break mass flow measurement system, installed since the International Standard Problem (ISP18) test, which enables better determination of the boundary conditions of the test.

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Approved: M.W.E. Coney
Acting Section Head
Fluid Dynamics Section

Contents .....

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1.0 TEST SPECIFICATION

This section gives details of the exact specification of the test and is in most part identical to the pre-test specification report, (Scriven 1986), which was issued on limited circulation and is therefore not available to many people wishing to understand the test.

Where the initial conditions in the test departed markedly from those specified, the actual conditions are given alongside. However this Report is not concerned with reporting the exact details of test execution which will be fully documented in the LOBI Experimental Data Report when this is published.

Experiment BL02 was a 3% cold leg break intended to extend and supplement the study of break size effects which were begun with the previously performed tests ISP18 and BL00.

There was only one execution phase for the test but conceptually the test can be thought of as comprising three stages typical of small break transients.

1. Rapid depressurization of the primary side via mass loss though the break with reverse heat transfer from the secondary side and extensive voiding in the core region.

2. A slow depressurization as the break flow subsides to a point at which it can be approximately balanced by the HPIS system. The length and nature of this balance are vital to the understanding of small break core uncoveries.

3. A progressive refilling of the system as the accumulator setpoint is reached together with an increasing HPIS flowrate.

The balance achieved in stage 2 is highly dependent on the interacting effects of break flow, HPIS flow, core vapour generation rate and liquid inventory in different parts of the loop. This test is seen as being one of a series designed to examine the effects of varying these parameters in a systematic manner, and because of this the specification was intended to be as similar as possible to the previously performed tests ISP18 and BL00.

Those readers familiar with tests BL00 (0.4% CL break) and ISP18 (1.0% CL break) may be satisfied with knowing that this test is identical to BL00 except for:-

- Break size is 3%.
- HPIS flowrate is as specified for ISP18.

1.1 General Aims and Objectives - Particular Physical Phenomena

1. Study of a range of break sizes. (comparison with ISP18 and BL00)

2. Study of the depth and time of core uncovery.

3. Study of heat transfer from heater rods to high void fraction.

4. Study of fluid drainage from the steam generators and loop piping.

5. Characterization of break behaviour by study of pressure response in a test which is not tied to secondary side cooldown rates.

6. Effect of reverse heat transfer from secondary side to primary.

7. Behaviour of loop seals and effect of bypass flows.

8. Effect of condensation and non-equilibrium during HPIS and Accumulator injection.

1.2 System Configuration

The following sections describe the detailed setup of the LOBI facility with respect to geometrical arrangement, instrumentation connections and data logging and recording systems.

The loop and its components have been described in great detail by the LOBI project in three reports Addabbo, Piplies and Riebold, 1983; Ohlmer, Sanders and Eder, 1983 and Ohlmer, Sanders, Doeringand Floegel, 1983. Reference will be made to these descriptions in the following sections, and the reports, together with detailed drawings released by the LOBI team will be referred to as the 'LOBI base set'. A schematic diagram showing the main components of the loop is given as fig. 1

1.2.1 Loop components

The loop was configured according to Table 1 on page 3 which is the same as for BL00 except for break size.

Break position	Cold leg break between main coolant pump and pressure vessel.
Break assembly	Standard configuration for small breaks. (see LOBI documents)
Break size	1 * 0.03 the area of a main coolant pipe, 3% (break orifice 5.2mm dia)
Upper head	Connected in normal way to upper plenum and upper downcomer. (see LOBI documents)
Pressurizer	Connected in normal way to intact loop hot leg.
HPIS	Injection into intact loop, characteristics given in Table 5 on page 8
Accumulators	Injection into intact loop cold leg.
Containment	Connected to atmosphere.
Pump seal water drainage	Continuous drainage from upper plenum in steady state, then from lower plenum draining during transient.
Locked rotor simulators	Intact loop fully open. Broken loop to be valved into 'resistance' position after pump reaches zero speed.
Auxiliary feedwater	Operational in both loops. See relevant section for details.

Table. 1 System configuration for LOCA test BL02.

1.3 Controlled Trips and Events

Set point	Trip or Event
Before -200 sec	Pressurizer cooling and additional heating off, loop now in steady state condition
-240 sec	Start closure of shutoff valve in tube to top of upper head. Valve has closure time of 8 seconds.
-5 sec	Start closure of drain valve in upper plenum. Valve has closure time of 8 seconds.
0 sec	Open valve in break assembly.
0 sec	Turn off normal pressurizer heaters.
131 Bar	Shut off valve in steam line. Valve has closure time of 1.5 seconds.
131 Bar	Main coolant pumps begin coastdown.
131 Bar + delay 2 sec	Scram. Heating power begins to decay.
131 Bar + delay 5 sec	Shut off valves in feed water lines. Closure time 5 seconds.
131 Bar + delay 60 sec	Auxiliary feedwater on (3% of nominal feedwater.)
131 Bar + delay 201 sec	Main pumps at zero speed. 4 seconds later locked rotor simulator operated in broken loop.
117 Bar + delay 35 sec	HPIS starts.
117 Bar + delay 600 sec	Activate cooldown control for secondary side.
41 Bar	Accumulators begin injection.
10 Bar	End of test. Isolate break. Measure liquid refill to restore initial levels.

Table. 2 List of most important trips and events

1.4 Initial Conditions and Setpoints

1.4.1 Initial conditions

1.4.1.1 Primary side

	Specified	Actual (if different)
Mass flows		
Intact loop	21.0 Kg/sec	
Broken loop	7.0 Kg/sec	
Pressure		
Upper plenum	15.8 MPa	15.6
Fluid Temperatures		
Intact loop vessel inlet	294.0 C	290.5
Broken loop vessel inlet	294.0 C	290.5
Pressurizer	346.0 C	
Heater Power		
Core	5.28 MW	5.09 (and falling)
Water Level		
Pressurizer	4.8 m	

1.4.1.2 Secondary side

Feedwater mass flows		
Intact loop	2.0 Kg/sec	
Broken loop	0.68 Kg/sec	
Pressure		
Steam dome intact and broken loop	6.45 MPa	6.25 (and falling)
Main feedwater Temperatures		
Intact loop	210.0 C	
Broken loop	210.0 C	
Recirculation ratio		
Intact loop	6.5 (approx)	
Broken loop	4.5 (approx)	
Collapsed Water Level		
Intact loop downcomer	8.33 m	
Broken loop downcomer	8.23 m	

1.4.2 Relief valve setpoints

The relief valves on both steam generator secondary sides were set to open at 79 bar and close at 78 bar. These valves function during the time after the main steam valve is closed and up to the time of activation of the secondary side cooldown.

1.5 Boundary Conditions

1.5.1 Heating power

Power remains at 100% until trip on low primary pressure (131 bar in upper plenum with delay of 2 seconds.) Power then decays according to Table 3 on page 6 throughout the transient.

Time from power trip (seconds)	Heating Power (fraction of full power)
0.0	1.00
1.0	0.90
2.0	0.73
3.0	0.65
5.0	0.51
7.0	0.40
9.0	0.32
13.0	0.20
15.0	0.161
16.0	0.15
17.0	0.14
18.0	0.13
20.0	0.12
24.0	0.10
30.0	0.08
40.0	0.065
68.0	0.048
110.0	0.04
170.0	0.035
270.0	0.028
470.0	0.023
870.0	0.02
1000.0	0.019
2000.0	0.016
4000.0	0.013
6000.0	0.011
10000.0	0.010

Table. 3 Heating power as a function of time after trip

1.5.2 Pump speeds - intact and broken loops

After the break opens, pump speed is fixed at constant 100% value until tripped on low primary pressure of 131 bar in upper plenum. After this both pumps coast down according to Table 4 on page 7 until they reach zero speed.

Two seconds after pump speed reaches zero speed, the mechanical brakes are applied, and two seconds after this the locked rotor resistance simulator in the broken loop is valved into position. This is the 'standard' multi-hole orifice plate used in both ISP18 and BL00, whose characteristics and dimensions are part of the LOBI base geometry set.

Time from pump trip (seconds)	Normalised Speed (%)
0	100
5	88
10	71
15	59
27	41
40	32
50	26
120	11.5
200	11.5
201	0

Table. 4 Pump speed coastdown curve after trip

1.5.3 HPIS operation

The HPIS was set up to be the standard LOBI simulation of two out of four pumps as used in ISP18. The injection is into the cold leg only with injection characteristics of pressure versus flow as given in Table 5 on page 8 with the initiating trip being primary pressure reaching 117 bar with a delay of 35 seconds.

Pressure (Pascals)	Mass flowrate (Kg/sec)
1.0E5	0.201
11.0E5	0.192
21.0E5	0.183
31.0E5	0.172
41.0E5	0.160
50.0E5	0.147
61.0E5	0.132
71.0E5	0.1162
81.0E5	0.098
91.0E5	0.077
101.0E5	0.052
111.0E5	0.0218
117.0E5	0.0

Table. 5 Characteristics of HPIS pumps.

1.5.4 Auxiliary feedwater operation

The auxiliary feedwater system is used in this test.

- The temperature of the feed should be 150 C.
- The flowrate should be 3% of the nominal initial flow.
- The feed water control is to maintain level in the downcomer of each steam generator at that level which exists at the initiation of the auxiliary feedwater. (132 bar pressure + delay of 60 seconds.)

1.5.5 Pressurizer and surge line, spray/cooling system

The pressurizer has the extra heating and/or cooling systems switched off before transient commences, and rig should be in steady state without these.

At break opening the normal heating systems in the pressurizer are switched off.

1.5.6 Pressurizer relief valve

Not required for this test.

1.5.7 Accumulator injection system

The simulation is as for BL00 modelling a plant with three out of eight accumulators functioning. The injection is into the intact loop only.

The set point is 41 bar.

The volume of water in the accumulator was modelled on a plant system with water volume of 28 cubic meters and accumulator volume of 47 cubic meters. In LOBI this translates to a liquid volume of 140 l in an accumulator of 280 l.

1.5.8 Cooldown of secondary side

- The cooldown is activated by pressure in upper plenum falling below 117 bar + a delay of 600 seconds.
- The rate of cooldown is 56 K/h, determined from the pressure on the secondary side, and achieved by venting steam from the Steam Generator discharge valves.
- The intact and broken loop steam generators remain connected throughout, and thus cooldown together.

1.5.9 Upper head - upper plenum connections and bypass flow paths

The arrangement for the upper head and bypass connections is the same as in BL00 and ISP18 and has been described in detail in the LOBI base geometry set. The resistances in the bypass lines are not changed from normal operation.

The pump seal water drain line which is connected to the upper plenum was closed before the transient began and the lower drainpoint from the vessel lower plenum was used throughout the transient to compensate the measured seal water injection flows. Around -240 seconds the line connected to the top of the upper head used for warmup was isolated.

1.5.10 Main coolant pump seal water injection

The seal water injection was continous thoughout the transient, and was measured. The characteristics of this flow have been given as part of the LOBI base set.

Compensation for pump seal water via draining from the lower plenum was used in this test commencing from time upper plenum takeoff was terminated.

1.5.11 End of test

Primary pressure falls below 10 bar.

2.0 RELAP5 MODELS

2.1 Model Used For RELAP5/MOD1 Pre-Test Prediction

The model used for the pre-test prediction was very similar to the LOBI base input deck as described in LOBI report LPC 86-20. The author had spent some seven months working on the production of this deck at ISPRA some three years ago, so the similarities are not surprising. Full details of this input deck have been provided by LOBI, and a copy could be provided on request by the author should this be desired. Significant changes had been made in the detail of the steam generator modelling, and in the control systems, but these have little impact on this test.

One aspect of the deck which is important was that the bypass flow paths, discussed later and shown diagramatically in fig. 3 were modelled rather crudely, being lumped into a single flow path with an area which appears in the light of more recent data to have been somewhat small.

2.2 Model Used For RELAP5/MOD2 Post-Test Prediction

The model used for the post-test calculations was based on the same input deck, but with modifications appropriate for the MOD2 version of RELAP5. In addition small volumes were introduced at the downcomer entry and upper plenum exit elevations, connected to the loop pipework by cross-flow junctions. The bypass paths were modelled as three distinct paths of the correct sizes, and the heat losses from the pressurizer were increased to account for the latest thermal coastdown experiments performed by LOBI. Furthermore, a very detailed model of the secondary side control system was incorporated to account for the observed behaviour. This system comprised large and small valves, each with rate of stem travel limits, stem versus area characteristics, and precise modelling of the electronic control system for these valves. A simplified schematic of the primary side noding is given as fig. 2 and Appendix A gives the test specific input data for this test. Previous Reports have listed the full input deck which is not reproduced here to reduce bulk.

3.0 TEST ANALYSIS

The test was performed in March 86. At the time of writing no reports of this test have been received, and the data reported here is derived from a preliminary datatape only.

3.1 Boundary Conditions

3.1.1 Initial conditions

Understanding the data from the datatape was not straightforward. Initial examination shows some disturbing facts.

1. The loop was not at steady state at test initiation. Core power was dropping rapidly and was well below specified value, secondary side pressure was dropping and system was out of balance.

2. The initial pressure on the primary side, specified as 158 bar, was also falling. If taken from the pressure transducer in the pressurizer vapour space it was 152 bar at test start. This value agrees with the value measured in intact loop hot leg, but not with that measured in the vessel upper plenum, which should be almost exactly the same. The difference is some +5 bar (3% error). A note had been given with the datatape suggesting only the pressurizer pressure measurement could be relied on due to interference, however if the temperatures in the pressurizer are examined, they clearly support a saturation pressure of 157 bar as given by the upper plenum pressure.

3. Because of dropping core power, the secondary side pressure was falling up to the time of test initiation, and was some 2 bar low. As a result wall temperatures will not be at steady state.

In conclusion the specified conditions were significantly different from those specified (4 degrees on temperature, 4 bar on pressure and core power 4% low.) This makes direct comparison with the pre-test calculation difficult for the early part of the test, although does not affect the overall system behaviour or the phenomena seen.

3.1.2 Transient conditions

Most of the specified transient boundary conditions were well met in the test. The exception being the secondary side control.

In the test, as becomes evident from a study of the datatape, the auxiliary feedflows to the steam generators were incorrectly tripped. This occurred in conjunction with a small steam leak, probably through the main steam valve not closing completely, which depressurized the secondary side far too rapidly. These effects cannot be expected in the pre-test calculation, and are in the post-test calculation on the basis of reasonable guesses for these effects.

With these points in mind we can assess the calculations.

3.2 Brief Synopsis of Experimental Phenomena

The loop depressurized to saturation conditions, holding around 80 bar until the break uncovered at around 400 seconds allowing steam to exit the break and producing a more rapid pressure fall. At this time **both** loop seals cleared, which was the cause of the break uncovery as steam flow round the steam generators then reached the break.

Depression of the core level was rather mild, amounting to around 1 m before the loop seals cleared, recovering then dropping some 0.5 m later. As a result rod heatup was only seen in the unheated length at or above the nozzle elevations.

HPIS flow quenched the rods at nozzle elevation and restored core inventory before accumulator injection around 800 seconds.

3.3 Overview of RELAP5 Predictions

The pre-test calculation ran well till accumulator injection, at which point it crashed. Several short post-test calculations were performed as will be discussed latter, the final calculation which is presented here ran successfully, with a CPU to problem time ratio of around two. The illustrations fig. 4 to fig. 14 show the major system parameters for this test. Looking quickly through these we can see primary system depressurization well calculated in both pre- and post- test calculations (fig. 4). Accumulator injection occurs at exactly the right time in the post-test calculation, (fig. 7) due to the good prediction of system pressure. For the pre-test calculation, the code failed at the time of injection. Based on the predicted pressure at this time, agreement would have been reasonable.

Integrated break mass loss (fig. 8) shows correct mass depletion, while (fig. 10) gives the cladding temperature rise at the nozzle elevation and shows approximately correct behaviour for both calculations However in the pre-test calculation the elevation below this level also showed temperature rises not seen in LOBI, and the level depression in the vessel was too great. This was primarily caused, as mentioned above, by an incorrect bypass modelling, coupled with a failure to predict the loop density distribution. The generated vapour had to depress the core level rather than escape via the hot legs and core to downcomer bypasses. This effect causes the pre-test calculation to be significantly in error in all the test details.

In the pre-test calculation the loop seal did not clear, in the post-test calculation the broken loop seal cleared at the right time but in the test both loop seals cleared.

Finally fig. 11 to fig. 14 shows clearly that RELAP is failing to calculate the loop density distribution. The broken loop cold leg density is well predicted, but the failure to clear the intact loop seal is evident in the high RELAP5 density in the intact loop cold leg after 400 seconds. Both hot legs show incorrect draining around 400 seconds and these density plots, more than most other system parameters, suggest that major details of the calculation are in error.

In the following the post-test calculation will be presented, together with an analysis of the LOBI data, and code deficiencies identified.

3.4 Noding and Sensitivity Studies

Experience with modelling the International Standard Problem 18 (ISP18) LOBI test has shown the importance of the bypassed steam flow in the vessel. Referring to fig. 3 when steam is being produced in the vessel and a level is established several routes exist for steam escape. Flow via the hot legs towards the steam generators, bypass via the upper head, bypass via the two small holes at the top of the vessel and bypass at the nozzle elevation. This last bypass is rather large, and the total LOBI bypass amounts to some 5%, far greater than typical plant values. It is the exact flow though these bypasses, governed by liquid level in the vessel, which controls the pressure buildup in the vessel and hence the core level depression.

In many small cold leg break transients, the level in the downcomer is fixed at about the cold leg elevation for quite some time. Under these conditions quite stable stratification can exist in the cold leg with steam from the core passing through the bypasses and flowing over the liquid in the downcomer and along the cold leg.

This steam flow is not condensed by the liquid, despite the often high subcooling of the liquid as much HPIS has reached the broken loop cold leg passing round the downcomer.

The quality at the break and hence the break flow are strongly affected by this process.

Furthermore the cold HPIS, penetrates the downcomer via bouyancy effects and reaches the lower plenum, producing subcooling here.

The input deck used to calculated ISP18 did not manage to produce either of these phenomena correctly. The volume at the juncture of downcomer and cold leg mixed the bypasses steam with the subcooled HPIS, producing incorrect break enthalpy, and wrong lower plenum subcooling.

In an attempt to improve this modelling, the downcomer was split into two volumes connected by a cross-flow junction. The idea was to allow HPIS to enter from the intact loop side and steam from the volumes above into the broken loop side and suppress the condensation caused by the mixing. This scheme is shown in fig. 15 where the volumes 301 and 302 represent the annular region at nozzle elevation. These volumes were tried both as normal vertical volumes, and as shown, as horizontal volumes in which the horizontal stratification model could be applied. This latter was an attempt to allow the liquid and vapour to flow together towards the broken loop cold leg (239), and to make use of the junction orientation model for stratified volumes which accounts for entrainment and pullthrough, by applying this model at entry and exit from these horizontal volumes. It was also thought this may circumvent the problem with connecting a horizontal stratified volume, the cold leg, to a vertical volume, the downcomer, were the vertical stratification model, switching on discontinuously in the vertical volume can drain out the horizontal volume unphysically.

This approach showed some promise but could not be used because it repeatedly caused code failure, often around the time of accumulator injection, but occasionally before. It also resulted in a reduced running speed. The problem seemed to be the extremely small size of these volumes, coupled with the X-flow junction option. Recent changes made at Winfrith on behalf of the Board to the junction entrainment model may have helped this modelling approach, but the failure would probably still occur. It remains as a possible nodalization for portions of a test, via a restart renodalization, especially if the mechanism of failure is better understood. A small separate effects test of the code could shed some light on this topic, and is being considered as a future project.

The calculation was therefore performed with a single X-flow volume at the nozzle elevation, and this volume was given a height equal to the diameter of the intact loop pipework, as recommended by the code developers for tracking liquid levels.

A second area where modelling changes were tried was the exact location of the bypasses. Clearly the upper plenum bypass position is fixed, and the bypass via the 5mm holes is defined, but at nozzle elevation the position of the bypass is unknown. This is in fact significant. Steam generation depresses the core level which reaches first the elevation of the two holes. Enhanced steam flow though these holes relieves the pressure somewhat and slows the level fall.

The fall in level then reaches the top of the nozzle connection on the intact loop side, as this is higher than the broken loop side. If significant steam bypass occurs at this elevation, the level can remain here for a considerable time. Under these conditions the broken loop hot leg would remain full.

Conversely if the major portion of the bypass occurs at the bottom of this connection, the level will fall to this point before stabilizing. Here the broken loop hot leg would be fully uncovered and could drain completely. Thus the position of this bypass can result in a vastly different observed density behaviour in the hot legs.

To assess this effect calculations were performed with the bypass in both the extreme positions. Although different behaviour was seen, it was not possible to conclude which was closest to the LOBI behavior due to other modelling problems which led to an incorrect mixture level in the vessel. This problem is explained in detail in a later section. For the calculation reported here the bypass position was set to be the centre of the nozzle elevation.

The last sensitivity is the size of the bypasses, especially the one at the nozzle elevation. Measurements by LOBI under cold conditions have provided an estimate of the combined bypass, from which this bypass can be inferred, but this gives rise to considerable error, maybe around 2%. For completeness a short run was performed with a reduced bypass.

It would be expected that this could force more vapour round the loops, thus having an effect on liquid holdup in the hot legs and steam generators, and indeed this was a prime reason for trying this calculation, but the increased pressure buildup in the vessel caused the loop seal to clear far too early, and gave very much worse agreement with the LOBI test than the 'best estimate' bypass value.

These results were not conclusive so far as defining the actual bypass, as a known deficiency in RELAP5 MOD2 is the tendency to overpredict the interphase drag in bubble/slug regimes. This effect could prevent the vapour passing round the loop and thus force a loop seal clearance, even if the steam flow had been correctly calculated. However it was felt that for the final calculation the larger bypass value must be used.

From the above we see three distinct areas where uncertainties exist in the best model of LOBI. Some rather delicate balances exit in the BL-02 test which make it difficult to vary these parameters so as to reach firm conclusions as to their overall effects, and as will be seen later other effects come to dominate many of the features where these uncertainties would otherwise manifest themselves. There is definite scope for further investigation of the areas, although it is believed that for BL02 the current model is adequate.

3.5 Primary Side Pressure Response

The primary side response seen in fig. 6 reflects the system mass and energy depletion rates. For a 3% break the dominant mechanism is the break flow. The pre-test calculation was untuned, and used a break multiplier of 1.0 for the subcooled discharge and 0.85 for the two-phase region. The choice of 0.85 was based on prior experience with the MOD1 choked flow model, but was not based on any data from 3% LOBI tests.

The post-test MOD2 calculation used a multiplier of 0.85 for both subcooled and twophase. An initial short calculation with the default values of 1.0 showed significant overprediction of break flow in both regimes. The break flow multiplier was therefore modified, and it is this 'tuned' value that gives rise to the rather good pressure history seen.

A discussion of this point is given in the section on break flow.

With this fit of the pressure drop, it is unsurprising but gratifying that the accumulator injection and HPIS injection are well predicted, as both are tripped on a pressure signal.

3.6 Secondary Side Response

The calculated response from the post-test prediction can be seen in fig. 5. The pre-test value is not shown as previously mentioned the test boundary conditions were too far from those specified to admit comparison.

To achieve this response several factors had to be included in the post-test calculation which were not in the pre-test.

3.6.1 Relief valve modelling

The valves used on the secondary side as pressure relief valves have uncertain discharge behaviour. The valve manufacturers provide data on the discharges they measure through these valves, both in normal and choked conditions, together with the variations with stem position. A short study was performed, using RELAP5, to see how best to model these valves. A valve sizing input deck was set up which was designed to vary the area of a valve to achieve a given flow rate. This was used to see what area RELAP5 required to match the manufacturers data.

In the event, the areas required for normal and choked flow were quite different. It was decided to use the area appropriate for choked flow in the BL02 input deck. This was rather larger than the area derived from the manufactures discharge coefficients.

Later information suggests that the manufacturers data may have a large scatter, maybe some + or - 30% for a given valve.

The matter is further complicated by the sharp knee in the relation between stem lift and area. When the valve is initially opening, controlled by the electronic differential/integral controller but limited by its maximum stem travel time (which was 45 seconds), then for a very significant time at the start of a pressure transient the valve is only very sightly open. Very small errors here can result in the effective valve area being in error by factors of Two or three, thus making initially pressure responses completely incorrect. The exact nature of these curves is unknown and can only be deduced from their observed response.

The input deck used for BL02 included the deduced valve responses used in the ST02 transient analysis (Scriven, 1987), which were found to best fit the rather tortuous secondary side response of that test.

3.6.2 Steam leak and auxiliary feed flow actuation

The cooldown of the secondary side in the time before the controlled cooldown becomes active is very much faster than would be expected even assuming a high limit for the heat losses of around 25kW.

This is due to two effects. As was seen in the BL00 test, and also indicated in the ST02 transient, there appears to be a small steam leak during the whole transient. The most likely site for this leak is the large steam control valve, which is shut at the start of the transient. A 1mm diameter hole would be appropriate to explain the observed pressure histories. This size of leak was included in the BL02 deck as being the valve area when the stem was at zero position.

The second effect is the faulty activation of the auxiliary feedwater. In the specification this was tripped on by pressure reaching 131 bar with a delay of 60 seconds, and was set at 3% of normal feed, controlled by liquid level in SG downcomer. In the test the auxiliary feed came on at 65 seconds in the intact loop and at 90 seconds in the broken loop. These then remained on till tripped off at 380 and 350 seconds respectively. These timed valves were used in the post-test calculation instead of the specified behaviour. The effect of tripping off the auxiliary feed can be seen in the kink in the secondary side pressure response at around 380 seconds in fig. 5

With all the above included, the secondary side response in predicted reasonably well.

3.7 *Break Flow*

As mentioned above, the break flow was tuned for this calculation.

Referring to fig. 14 we see that RELAP5 is predicting the density near the break rather well. This is probably the best density prediction for the loop. Despite this in an initial short test run the break flow was found to be too high.

The LOBI condensing weightank system provides a total measure of break mass loss. A small program was written to process this measurement and to derive the instantaneous break mass flow via numerical differentiation. While this process produces rather a lot of noise, it still gives a quite accurate overall value for the break flow.

This derived data was compared with the initial RELAP5 break mass flow, and it was seen that RELAP5 overpredicted the flow both in the single phase and two-phase region. Based on this comparison break flow multipliers of 0.85 were used for both the subcooled and two-phase discharge coefficient and the result can be seen in fig. 16 where the agreement is now seen to be good. The success of this approach is seen in fig. 8 where the overall integrated break flow is given.

The question now arises as to the source of the overprediction in RELAP5. fig. 17 and fig. 18 show the LOBI measured densities on either side of the break offtake volume. The density in the volume between break and vessel is most representive of the conditions in the break volume itself.

Firstly we can see stable stratified conditions exiting from around 100 seconds up to the point of loop seal clearance. This was the time of greatest break flow error as it covers the subcooled and two-phase discharge. Following 400 seconds the flow is mostly single phase vapour.

As mentioned above RELAP5 predicts this density very well, and furthermore is also predicting stratified flow in the time region and using the horizontal stratified flow regime map. Thus the upstream conditions are in good accord.

The break offtake in LOBI is directly in the side of the pipe on the centreline. This configuration would require some allowance to be made for conditions at the break junction being different from those in the donor upstream volume. Clearly with a liquid level above the break the junction void fraction would be mostly liquid despite a volume voidage which could be close to 50%. RELAP5 has a special model for this condition.

In the two-phase discharge region there is a possibility that the liquid entrainment / vapour pullthrough model employed in RELAP5 is not giving the correct junction voidage at the break. Recent literature studies by Ardron have highlighted likely problems with the model as currently coded, and Ardron in conjunction with Bryce has implemented an updated version of the model in a test version of RELAP5 which has given improved results in LOFT test analysis. (Ardron and Bryce private communication). This work is presently being assessed and will be communicated to the RELAP5 developers in due course. It is presently uncertain if the model as implemented will cause stability problems and consequent code failures.

This could definitely contribute to the break mass flow error, but another effect predicted by Bryce (Bryce, 1986) in a recent theoretical study of the RELAP5 critical flow model is thought to be a larger influence in this case.

Bryce's study suggests that if the upstream condition are equilibrium subcooled, that is if the volume given time to reach equilibrium would contain no vapour, then RELAP5 will overpredict the break mass flow. The reason is that in calculating the break junction conditions, the liquid and vapour components derived from the upstream volume will not be kept sufficiently in non-equilibrium, and the vapour will 'condense out'. Thus the break junction density will be too high, and hence the mass flow will be too high.

In the present calculation the liquid in the cold leg pipe is around 20 degrees subcooled due to cold ECCS reaching the broken loop cold leg via the downcomer. These are exactly the conditions in which overprediction of break density can occur, and it is believed this is the primary source of error in the break flow.

In the early subcooled flow region, neither of the above sources of error can be invoked. There is no stratification, and no vapour present, yet a multiplier of 0.85 was still required. It is uncertain what the source of this error is. The vena- contracta calculated by the code for abrupt area change may be inappropriate for the LOBI side offtake geometry, particularly when there are high loop flows past the break, or the subcooled break discharge model itself may be calculating the wrong sonic velocity limit.

The RELAP5 critical flow model appears still to require refinement, and while not being so important for plant scoping studies, the need for accurate 'untuned' break predictions for experiment analysis is paramount.

3.8 Loop Seal Clearance

The experiment exhibited one phenomena totally unseen in the calculation, that of both loop seals clearing at around 400 seconds. At first thought this appears an unlikely event. Consider the mechanism to blow a loop seal.

Generation of steam in the core creates a pressure difference between the top of core and the top of the downcomer. The magnitude of this pressure difference depends on the rate of generation of steam and the rate of escape of steam via the bypasses and round the loops.

This pressure difference depresses the core liquid level and ultimately controls the degree of rod heatup seen in the early stages of these small break tests.

The flow of steam round the loops, which would remove this pressure rise, is inhibited by the liquid remaining in the 'U' tube at the pump inlet. As the pressure rises so the level in the loop seal is depressed on the steam generator side giving rise to a head of liquid on the pump side. The maximum value for this head is the depth of the loop seal. Once the pressure difference reaches this magnitude, then the liquid is expelled from the loop seal in a rapid surge. Any vapour passing round the bottom bend will enter the up side reducing the density there and hence the head. The reduced head will allow more vapour to follow amplifying the process and clearing the loop seal.

With a loop seal cleared, steam can pass freely round the loop thus equalizing the pressure difference and restoring the core level. It would therefore be expected that once one of the loop seals blows, the resulting fall in pressure difference will prevent the other loop seal from being cleared in the same way. It is therefore immediately surprising that in BL-02 both seals were blown.

Furthermore, the construction of LOBI is such that the intact loop seal is some 0.5m deeper than the broken loop seal. This implies that to clear this loop seal would need a pressure difference of some 3500 Pa more than that needed to clear the broken loop, and this ignores the fact that with the break being in the broken loop cold leg there will be an even greater tendency for this loop to clear first.

In the test the intact loop seal blew ***before*** the broken loop seal.

RELAP5 in fact predicts a clearance of the broken loop, with consequent reduction in forcing pressure, and no clearance of the intact loop.

3.8.1 Study of mechanism of both loops clearing

To understand the behaviour of LOBI it is necessary to look in detail at the distribution of liquid in the loop.

3.8.1.1 Draining of steam generators

There is another part of the loop which has the ability to prevent vapour flow from the core, and that is the up side of the steam generator 'U' tubes. Any liquid blocking these tubes will exert a pressure head countering the driving pressure difference in the core, and this head will be combined with the head produced in the loop seal.

The LOBI datatape contains differential pressure readings at different elevations within the 'U' tubes. A small program was written to process these values to produce collapsed and mixture levels, assuming negligible pressure difference due to flow. (This will be valid after about 50 seconds in the transient as the flows decay rapidly). The results can be seen in fig. 19 for both the broken and intact loops. The levels shown are referenced to the loop piping centrelines

as shown in the scaled picture which gives some idea of the position corresponding to the marked level.

As can be seen the intact loop steam generator drains more rapidly than the broken loop steam generator. At the time when the intact loop steam generator is empty the broken loop still has almost 1m of head still in it. The loop pressure difference at this time is great enough to blow the intact loop seal being equivalent to around 2.5 m head, but the total head needed to blow both the broken loop SG and the loop seal would be 3 m. So the intact loop blows first.

As seen in this figure, the level in the intact loop steam generator then recovers! It rises to around 2 m. By this time the broken loop SG has finished draining, and because the head in the intact loop SG has causes a revival of the loop pressure difference back up to 2 m, the broken loop seal can then blow.

The timing and exact nature of these events are critical.

The recovery of the level in the intact loop can be understood by looking at the mixture level in the core riser region. This parameter was calculated in a similar way to the derived collapsed steam generator levels, via a specially written program, except this time the mixture level is the most important value. This value is calculated by processing a chain of delta-P signals to find the level at which a step change occurs. Between these two pressure tappings will be the mixture level. By calculating the voidage between the pressure tappings directly below this level and using this to calculate a mixture level with respect to the bottom tapping of the two containing the step change an accurate value for this parameter can be derived.

fig. 20 plots this derived value together with the previously plotted steam generator collapsed level with the zero line being the loop centreline as indicated. As soon as the intact loop seal blows, the steam in the upper core region begins to flow round the intact loop, thus relieving the pressure difference. This allows the core mixture level, which had until then been depressed to some 1m below the nozzle elevation, to rise. Because of the greater diameter of the intact loop pipework compared to the broken loop pipework, and because of the flow into the intact loop hot leg, liquid is first carried from the riser back into the intact loop hot leg. This happens at around 375 seconds as can clearly be seen as the rising core level results in a rising level in the intact loop steam generator. This is the mechanism of the recovery of the liquid level seen earlier, and which is responsible for the subsequent blowing of the broken loop seal.

It can be seen that to calculate the loop seal behaviour requires a very accurate prediction of the steam generator draining behaviour, together with an exact core mixture level calculation. We look first at the draining of the steam generators, bearing in mind that the density plots already given as fig. 11 to fig. 14 have shown a problem in following the hot leg densities.

An indication of the conditions in the hot legs can be gained by looking at the temperatures measured at the bottom of the hot leg tube, and the output from the flow direction indicators. These latter devices, consisting of two thermocouples mounted either side of a small heating coil, can be used to deduce both flow direction and some idea of flow magnitude. At low flows the temperature rise above ambient measured will be quite large, reducing at larger flows. However at very small flows the heated fluid will not be convected to the thermocouple, and thus will produce a close to zero reading too. Fortunately it is normally clear which of the two cases it is.

These values are shown in fig. 21 for the broken loop. The positive value for the flow direction indicator represents flow from the vessel towards the steam generator, and the temperature has been scaled to show clearly on the same plot.

As expected the flow is positive and decreasing as the pumps coast down, and by around 150 seconds the flow has become stagnant. This is seen both in the irregular output from the flow indicator, and interestingly in the subcooling of the fluid temperature at the bottom of the tube. In this case this is not due to cold liquid from the steam generators falling back into the hot leg as may be thought, but rather is due to the rather high local heat losses from the instrumented spool piece which contains the thermocouple. This spool piece contains cooling adaptors, mounted in the lower third of the tube, which can remove some few Kw of power in

a very local region. When the flow is truly stagnate this will cause local subcooling as seen here. This is a prime example of a LOBI specific effect which can easily be misinterpreted.

At around 250 seconds there is a clear indication of flow reversal, and now we would expect countercurrent flow with steam flowing towards the steam generator and liquid draining back. Finally at loop seal clearance the flow again becomes positive.

Looking at the draining of the steam generator 'U' tubes themselves, in fig. 22 and fig. 23 the differential pressures over the 'U' tubes are shown for both RELAP5 and LOBI. The overall agreement is not too bad, and the time at which the 'U' tubes empty are quite close, with the RELAP calculation draining the intact loop steam generator some 20 seconds too early and the broken loop a few seconds late. The exact nature of the draining is however wrong. In LOBI there is a very rapid pressure fall at 100 seconds followed by a plateau region from 150 to 200 seconds. This is at the time of flow stagnation before flow reversal in the hot leg. RELAP shows no trace of this effect.

However it can be concluded that the 'U' tube draining is predicted well enough to give the correct conditions leading up to loop seal clearance. Any deficiencies are to be found elsewhere.

Referring back to fig. 19 it is seen that after the 'U' tubes empty there is still a head of some 3.5 m between the loop pipework centreline and the top of the steam generator inlet plena. Differences in the draining behaviour between RELAP5 and LOBI must occur in this region.

It has already been seen from fig. 11 and fig. 14 that the hot legs drain completely in the RELAP5 calculation, well before the loop seal clears. Therefore from about 300 seconds when the 'U' tubes empty to around 350 seconds when the calculation drains the hot legs, RELAP5 must be incorrectly predicting the draining from steam generator inlet plena, down into the vertical entry section and along the hot leg itself.

The boundary condition for this draining are the clearance of the steam generator 'U' tubes already discussed, the exit condition from the hot legs into the vessel and the steam flow passing along the hot legs. Taking the matter of the exit conditions into the vessel, consider fig. 24 which shows the hot leg densities and riser mixture levels for both LOBI and RELAP5. (They have been scaled, but only trends are important here). In LOBI the core mixture level drops below the nozzle elevation at some 200 seconds, and remains below until loop seal clearance. Thus the boundary condition in LOBI is discharge into a steam filled upper plenum.

In RELAP5 the mixture level does not fall below the nozzle elevations until 320 seconds, and immediately it does so, the hot legs drain completely. There is no indication in the RELAP5 calculation that the hot leg can remain nearly full when the upper plenum is voided, as happens in LOBI.

This immediately raises two questions.

1. Why is the RELAP5 calculated mixture level wrong?

2. Why does RELAP5 drain the hots legs so much faster than LOBI?

3.8.1.2 Bypass effects

Both of these questions could be resolved by supposing that the modelled bypass flows are too large. This would have the effect of reducing the pressure difference available to depress the core level, and reducing the steam flow round the loops which would otherwise limit the drainback in the hot legs.

This possibility is considered unlikely for a number of reasons. The previous sensitivity of bypass effects showed that the effect of increasing the loop steam flow by reducing the bypass flows was to blow the loop seal far too early, and gave much worse agreement with the steam generator draining behaviour discussed before. The error in core mixture level can be understood without recourse to a smaller bypass as will be shown later. The loop differential pressure calculated by RELAP5 is not consistent with this theory, although it is possible that the position of the bypass may be a contributory factor.

For these reasons bypass alone is discarded as the source of these errors.

3.8.1.3 Counter-current flow limiting

An approach to this problem which gives a more satisfactory explanation is to examine the counter-current flows occuring in the hot legs, and entry to the steam generators. Appraisal of the velocities and areas shows that the critical points would be the vessel entry point and the steam generator inlet.

Although there is no data from LOBI on these flows, much can be deduced from the RELAP5 calculated results. Firstly in a specially written program the liquid and gas velocities at these locations were combined with the predicted voidage and pipe areas to produce the superficial velocities. These are shown in fig. 25 and fig. 26 with the positions diagramatically indicated. The counter current flow is clearly visible from 130 seconds up to the draining of the hot leg. There is a possibility that during this period excessive liquid drainback occurs, and to investigate this the Wallis flooding criteria was calculated, being SQRT(Jg *) + SQRT(Jf *). This is shown plotted in fig. 27 and fig. 28 for both locations mentioned above, and in the steam generator 'U' tubes for completeness. Also on this graph is included the typical limit of .7 given for this parameter.

Two thing are clear. Firstly the SG 'U' tubes show a lower value and hence would not be expected to control the flooding. Secondly the flooding limit of .7 would not cause a change in the RELAP5 calculated draining rate.

However the .7 limit is really applicable to vertical tubes, and does not account for end effects or bends. Also the liquid holdup in LOBI keeps fluid in the horizontal hot leg section implying that the limit is being imposed in the horizontal section, not the vertical section. Finally recent preliminary experimental work at CERL with an air-water rig modelling exactly this geometry has shown that very significant amount of water can be held in the hot leg with zero liquid flow and a gas flow corresponding to a flooding limit of 0.4. This value is also suggested for horizontal pipework from some theoretical works.

Imposing such a limit on the graphs would completely change the calculated draining behaviour for RELAP5, prevent the hot legs emptying and better predicting the liquid head in the loop.

It is believed that the current version of RELAP has no explicit flooding model. The interphase drag which is calculated based on flow-regime and voidage considerations is the mechanism for limiting liquid draining. Further study of the behaviour of this model under simple conditions may be required to understand its detailed behaviour.

It is felt that test BL02 is a clear indication of the need to better model counter-current flow flooding in the RELAP5 code. Further work is needed to assess exactly what flooding limit is appropriate, and following this such a limit should be included in RELAP5 in an appropriate form.

3.9 Rod Heatup

The exact nature of the rod heatup seen in fig. 10 can now be explained. For clarity fig. 29 shows this excursion as a temperature difference from saturation plotted together with a scaled version of the mixture level in the riser. Clearly to correctly predict rod temperatures requires correct prediction of riser mixture level.

3.9.1 Core mixture level

As mentioned previously the RELAP5 calculation produces an incorrect riser mixture level. This is shown in more detail in fig. 30 with a diagramatic representation of the part of the level displayed. Although the magnitude of the maximum depression of around 1m is the same, the timing and detail of the level behaviour are quite different.

Now the mixture level depends critically on the voidage in the core region. The system has to be balanced with the downcomer full of liquid to the nozzle elevation equaling the loop pressure difference plus the head of liquid in the core. For instance for zero loop pressure difference and 10% voidage, the core mixture level would be 10% higher than the downcomer level (roughly).

This means that the greater the core voidage, the higher the core mixture level would have to be to balance the downcomer head. For a given loop pressure difference a greater core voidage would result in a higher mixture level in the core.

The loop pressure difference is shown in fig. 31 for both RELAP5 and LOBI. It can be seen that for RELAP5 this value reaches its maximum of around 18kPa earlier than in LOBI. This would imply an earlier depression of the mixture level when in fact the reverse is seen. These facts point to an error in the calculated core voidage.

To examine this the LOBI vessel differential pressure data was processed to obtain the voidage at various elevations. This is shown in fig. 32 and fig. 33 for both LOBI and RELAP5. The voidage just below the nozzles records the fall of the mixture level, while that in the upper plenum is fairly representative of the value throughout the core. It is immediately clear that RELAP5 in overpredicting the voidage, calculating a mean value around 30 to 40% against the LOBI derived value of 20%.

This fact alone explains the incorrect mixture level behaviour to a large degree.

The reason for this overprediction is to be found in the interphase drag calculated by RELAP5. For low voidages in bubbly and slug type flow, and especially in rod bundle geometries, RELAP overpredicts the interphase drag. This is partly due to the reduced drag on bubble swarms, partly due to profile slip effects and may be influenced by the rod bundle geometry itself.

This effect has been implicated before, particularly in respect to voidage profiles in the riser of the steam generator secondary side. If the downcomer level is set correctly to the measured value, the total mass inventory is often found to be low. If the downcomer level is raised to compensate, the riser level can enter the separators, and wreck the steady state conditions. In a recent analysis of the ST02 transient test in which initial mass inventory on the secondary side proves to be critical, this was a major problem, although due to the void profile being present only during flowing conditions it was not possible to prove conclusively that it was wrong.

Recent work by Ardron and Clare (1987) on an assessment of the interphase drag in RELAP5 has compared code values to correlations by Wilson for low flows and Rooney for high flow. The conclusion of this work was that density errors of around -20% to -40% could exist for small diameters, and these would reduce for large diameters and higher pressures. (The density errors were calculated as

$$\frac{\text{Rho(R5)} - \text{Rho(Wilson)}}{\text{Rho(Wilson)}}$$

For the LOBI case the density error is around -25%, suggesting that this corresponds to a 'small' diameter, and reinforcing Ardrons calculations. However Ardron tended to suggest that the models in RELAP5 were not in excessive error, and perhaps could be acceptable. As the work was a study compared to other correlations this conclusion is reasonable, but test BL02 has provided definite evidence of the incorrect voidage distribution and has given firm values to the errors.

The present work has shown the problems which errors of this kind can produce, and the far-reaching effects they have on both the primary, the secondary side and on rod heatup. These errors are therefore considered by this author to be unacceptable, and work should continue to correct them.

3.10 Loop Differential Pressure

The above factors of incorrect core voidage and liquid holdup in the steam generators combine to expain the rather odd behaviour of the loop differential pressure. This parameter highlights the degree of mismatch between experiment and calculation, and will be discussed in detail.

Referring to fig. 34 and fig. 35 we see the totally different behaviour of the systems. In LOBI the loop differential pressure increases as steam is produced. The riser level falls to the nozzle elevation at which point it pauses as extra steam is bypassed. Continued steam production overcomes this and the level falls to around -1m, corresponding to a pressure difference of 18Kpa or so. At this point the system is balanced until the emptying of the steam generators reduces the loop pressure head to this value, and the intact loop seal blows. The riser mixture level recovers as the loop pressure difference falls.

Expulsion of liquid into the hot legs and steam generator inlets recreates a pressure head in the loop, and the loop pressure difference can again increase. Superimposed on this is the gradual fall off in steam production.

This is the sequence in LOBI up to around 450 seconds. Now consider the RELAP prediction. Here the pressure difference rises, but the mixture level cannot reach the nozzle elevation to allow steam to bypass due to the excess core voidage requiring a greater pressure head to depress the mixture level. Thus the mixture level tend to remain around the nozzle elevation for too long. This is accentuated by the need for the upper plenum X-flow junction to be completely empty before pure vapour flow is allowed through the bypass at this elevation. Before this the junction void fraction will be the volume mixed value. In reality as soon as part of the bypass in uncovered, vapour will have free passage and so the pressure rise can be slowed.

Eventually the level does fall as the hot legs drain completely, and shortly after the broken loop seal blows, relieving the pressure and allowing steam to reach the break. The events following this in both RELAP and LOBI are a second depression of the core level despite a lower pressure difference. In RELAP this depression proceeds too far and reaches, coincidentally, the level of the first depression in LOBI.

The reason for this is seen in fig. 36 and fig. 37 where the downcomer voidage is superimposed. At the time of break uncovery the sharp drop in pressure causes flashing of the liquid in the downcomer. This is increased by the considerable input of stored heat in the vessel walls. In LOBI we see this beginning at 400 seconds, and rising to around 20%. It is this reduction in the density of the downcomer fluid which allows the core level to be depressed again with a lower head needed to do so.

For RELAP the same factor allows the deep core depression, but this time the voidage rises to some 30 to 40% thus explaining the overprediction of the level of depression. As mentioned earlier, experience with ISP18 had shown that significant amounts of cold HPIS penetrate the downcomer in LOBI, and the split downcomer noding, abandoned due to code running problems, had been tried to model this better. The RELAP calculation is predicting insufficient downcomer subcooling because of this and hence is producing an excessive vapour generation and resulting voidage error.

3.10.1 Pertaining to bypass effects

It is seen from the above discussions that the effects of hot leg draining, ECCS penetration and core void profile all inter-relate to control the transient. The other effects of bypass size and position while of definite significance, cannot be extricated from the other effects in this test, and therefore firm conclusions regarding the correctness of these factors cannot be drawn from this calculation.

Possibly if the other errors could be corrected in the RELAP5 model then sensitivities on bypass could yield meaningful results.

4.0 CONCLUSIONS

The BL02 test was performed satifactorily so far as the major boundary conditions were concerned, despite problems with the secondary side control, which is of small effect in this transient, and some problems with the initial drift of the 'steady state' conditions.

All of the main objectives were met, with the exception of a deep core uncovery and rod heatup. Future tests especially BL21 and BL12 will cover this area. Many interesting phenomena were seen and analysis of these together with the differences between the experiment and the prediction have resulted in an understanding of most of the major effects and have led directly to the discovery of modelling problem areas.

These areas can be split into two groups, those which results from poor definition of parts of the LOBI loop and can be addressed by the LOBI team, and those which result from deficiencies in the RELAP5 MOD2 code.

There remain uncertainties over the correct modelling of parts of the LOBI facility. The bypass sizes and positions have been seen to be significant and poorly defined. It is recommended that these are reassessed, possibly in conjuction with code sensitivities in experiments which allow better interpretation of their effects than did BL02.

The attempt to better model the bypass steam/ECCS mixing in the upper downcomer region indicated possible benefits from this kind of split downcomer nodalization. An effort should be made to determine the source of the code running problems encountered, and to pursue this form of pseudo-3D noding. It is expected the effects of ECCS penetration of the downcomer and steam/ECCS cocurrent flows will be encountered many times in small break analyses, indeed the over prediction of the downcomer voidage and subsequent excessive core level fall are direct consequences of this modelling problem in the BL02 test.

The calculation has highlighted some of the problems with the RELAP5 break flow model. Although not thought to be so significant for this test, the model implemented by Ardron in a test version of RELAP5 to improve the offtake from stratified conditions should be further developed to assure stability, and could then be used to assess the magnitude of its effect on this calculation.

The problems with the two-phase break model forseen by Bryce have been found to be real, and encouragement should be given to the code developers to rectify these problems.

It is felt the draining of the hot legs in test BL02 is a clear indication of the need to better model counter-current flow flooding in the RELAP5 code. Further work is needed to assess exactly what flooding limit is appropriate, and following this such a limit should be included in RELAP5.

Test BL02 has provided definite evidence of the incorrect voidage distribution in bubbly and slug flow in vertical bundle type geometries. The cause of this error, the overprediction of interphase drag, gives rise to several problems in initializing secondary side models correctly, and has now been seen to strongly influence vessel behaviour and rod heatup in small break tests. It is considered important to correct this failing in the code.

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Appendix A, Drg. No. RL3.5.2580-2598 attached-

Appendix A. RELAP5 MOD2 INPUT DECK. TEST SPECIFIC INPUT

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=BL-02 SMALL BREAK 3.0% TEST
*
*      ==== FLAGS MAJOR INPUT SEGMENTS
*     $$$$ FLAGS SUBSECTIONS WITHIN MAJOR INPUT SEGMENTS
*************************************************************
*
*
*      ====== SYSTEM CONTROL BLOCK  ======
*
*
*************************************************************
*  PROBLEM SPECIFICATION                                    *
*************************************************************
0000100 NEW  TRANSNT
0000101  RUN
0000102  SI
*0000104  NONE
0000110 NITROGEN
*************************************************************
*  TIME STEP CONTROL CARDS                                  *
*************************************************************
*   START OFF BY FORCING SMALL TIME STEP AND LET CODE INCREASE IT
*   OTHERWISE MAX VALUE IS USED FOR FIRST STEP, AND PROBLEMS RESULT
0000201    0.001 1.0D-6   0.01   00003    1     10   1000
0000202   200.0  1.0D-3   0.5    00003   20    400   400
0000203  1400.0  1.0D-7   0.25   00003    8    800   800
*0000204  1000.0  1.0D-7   0.5    00003    4    400   400
*
*************************************************************
*  MINOR EDIT VARIABLES                                     *
*************************************************************
*
301     P        350010000        * UPPER PLENUM
302     MFLOWJ   584000000          * RELIEF VALVE FLOW
303     MFLOWJ   510010000          * DOWNCOMER
304     CNTRLVAR 501               * ILSG LEV
305     TEMPF    139010000         * TEMP IN COLD LEG
306     TEMPF    100010000         * TEMP IN HOT  LEG
307     MFLOWJ   950000000          * BREAK MASS FLOW
308     CNTRLVAR 43                * PRESSURIZER LEVEL
309     P        560010000        * STEAM DOME PRESSURE
310     CNTRLVAR 598               * RELIEF VALVE CONT
311     MFLOWJ   594000000          * RELIEF VALVE FLOW
312     MFLOWJ   610010000          * DOWNCOMER
313     CNTRLVAR 601               * BLSG LEVEL
314     TEMPF    239010000         * TEMP IN COLD LEG
315     TEMPF    200010000         * TEMP IN HOT  LEG
316     MFLOWJ   950000000          * BREAK MASS FLOW
317     MFLOWJ   390000000          * SEAL DRAIN FLOW
318     P        660010000        * STEAM DOME PRESSURE
319     CNTRLVAR 599               * STEAM CONTROL
320     CNTRLVAR 81                * TOTAL CORE POWER
```

```
321     CNTRLVAR  911            * TOTAL PRIMARY MASS
322     CNTRLVAR  920            * NET FLOW OUT OF PRIMARY
323     CNTRLVAR  921            * TOTAL MASS LOSS
324     MFLOWJ    300020000
325     MFLOWJ    301030000
326     MFLOWJ    363020000
*
*
*****************************************************
*
*       ====== CONTROL SYSTEM  ========
*
*
* THIS BLOCK CONTAINS ALL THE INFORMATION WHICH SETS UP THE
* SYSTEM SETPOINTS, AND RESPONSES. BY CHANGING THIS ALL
* NON-HARDWARE CHANGES TO LOBI CAN BE MIMICED.
*
*****************************************************
*  VARIABLE TRIPS                                   *
*****************************************************
*  501 = START OF TRANSIENT (PRESSURIZER TMDPVOL VALVED OUT)
*    (switch seal drain to lower plenum)
*
*  502  START + DELAY ON BREAK OPEN
*  503  CLOSURE OF UPPER PLENUM BYPASS VALVE
*
*
*  510 = PRESSURE SETPOINT ONE < 131 BAR IN UPPER PLENUM
*
*  511  POWER TRIPS OFF
*  512  START OF INTACT LOOP SECONDARY COOLDOWN
*  513  START OF BROKEN LOOP SECONDARY COOLDOWN
*  514  CLOSURE OF INT LOOP STEAM ISOLATION VALVE
*  515  CLOSURE OF BRK LOOP STEAM ISOLATION VALVE
*  516  CLOSURE OF TERTIARY SIDE ISOLATION VALVE
*  517  CLOSURE OF MAIN FEED WATER LINES
*  518  INTACT LOOP AUX FEED COMES ON
*  519  BROKEN LOOP AUX FEED COMES ON
*
*  520 = PRESSURE SETPOINT TWO < 117 BAR IN UPPER PLENUM
*  521 = HPIS FLOW
*
*  530 = PRESSURE SETPOINT THREE < 110 BAR IN UPPER PLENUM
*
*  531  INTACT LOOP PUMP TRIP
*  532  PUMP REACHES ZERO SPEED
*  533  PUMP LOCKED ROTOR RESISTANCE VALVED INTO PLACE
*
*  536  BROKEN LOOP PUMP TRIP
*  537  PUMP SPEED REACHES ZERO
*  538  PUMP LOCKED ROTOR RESISTANCE VALVED INTO PLACE
*
*  549 = CLOSURE TIME FOR VALVES
* PRESSURIZER VALVE SETPOINTS
*
*  560 = PRESSURIZER PRV RE-SEAT PRESSURE
*  561 = PRESSURIZER PRV LIFT PRESSURE
*****************************************************
*
*   TRANSIENT TRIPS AND CONTROLS
*
501     CNTRLVAR  99     GE  NULL    0    0.5  N   * START
501     TIME      0      GE  NULL    0  200.0  L   * START
502     TIME      0      GE  TIMEOF  501   0.0  L   * BREAK OPEN
503     TIME      0      LE  NULL    0   20.0  N  0.0
*
```

```
510    P       350010000 LE   NULL     0  131.0E5 L   * SET 1
511    TIME     0        GE   TIMEOF  510   2.0   L   * POWER
512    TIME     0        GE   TIMEOF  520  600.0   L   * I.L. COOL
513    TIME     0        GE   TIMEOF  520   1.0E6 L   * B.L. COOL
514    TIME     0        GE   TIMEOF  510   1.0E6 L   * I.L. ISOL
515    TIME     0        GE   TIMEOF  510   1.0E6 L   * B.L. ISOL
516    TIME     0        GE   TIMEOF  510   0.0   L   * STEAM LINE
517    TIME     0        GE   TIMEOF  510   1.5   L   * MAIN FEED
518    TIME     0        GE   TIMEOF  501  65.0   L   * AF on il
519    TIME     0        GE   TIMEOF  501  90.0   L   * Af on bl
*
*
520    P       350010000 LE   NULL     0  117.0E5 L   * SET 2
*
521    TIME     0        GE   TIMEOF  520  35.0   L   * HPIS
*
*
530    P       350010000 LE   NULL     0  110.0E5 L   * SET 3
*
531    TIME     0        GE   TIMEOF  510   0.0   L   * PUMP TRIP
532    PMPVEL   125        LE   NULL     0   0.0   L   * ZERO SPEED
533    TIME     0        GE   TIMEOF  532  1.0E6  L   * RESISTANCE
*
536    TIME     0        GE   TIMEOF  510   0.0   L   * PUMP TRIP
537    PMPVEL   125        LE   NULL     0   0.0   L   * ZERO SPEED
538    TIME     0        GE   TIMEOF  537   4.0   L   * RESISTANCE
*
*  SYSTEM SET POINTS DURING STEADY STATE RUNNING
*
549    TIME     0        GT   NULL     0  1.0E6  L
*
560    P       410010000 GT   NULL     0  170.0E5  N  * PRESSURIZER
561    P       410010000 GT   NULL     0  165.0E5  N  * RELIEF VALVE
* special trips experiment specific
578    TIME     0        GE   TIMEOF  501  380.0  L   * AF off il
579    TIME     0        GE   TIMEOF  501  350.0  L   * Af off bl
*
*          $$$$  INTERACTIVE CONTROL BLOCK $$$$
*
*    CONTROL VARIABLE              FUNCTION
*
*       70                   SET TEMP FOR PRIMARY COLD LEGS
*       71                   CORE POWER
*       72                   SET SPEED FOR INTACT LOOP PUMP
*       73                   SET SPEED FOR BROKEN LOOP PUMP
*       74                   SG1 DOWNCOMER THROTTLE VALVE
*       75                   SG2 DOWNCOMER THROTTLE VALVE
*       76                   SG2 DOWNCOMER SET LEVEL
*       77                   SG2 DOWNCOMER SET LEVEL
*       78                   PRESSURIZER SET LEVEL
*       79                   PRESSURIZER SET PRESSURE
*       80                   HPIS FLOW
*       81                   CORE POWER MODIFICATION OPTION
*       82                   HPIS FLOW  MODIFICATION OPTION
*       83                   PRESSURIZER HEATER CONTROL
*       84                   SG1 RELIEF VALVE SET POINT
*       85                   SG2 RELIEF VALVE SET POINT
*       99                   BREAK OPEN   (0 CLOSED, 1 OPEN)
*      100                   PROBLEM STOP (0 RUN,    1 STOP)
*
*          END PROBLEM TRIP VIA INTERACTIVE CONTROL
*               (OR VIA PRESSURE TRIP)
*
*  TRIP 597 IS END OF PROBLEM ON LOW PRESSURE (< 10 BAR)
*  SET UP TRIP 598 TO BE PERMANENTLY ON
*  TRIP 599 TO BE CONTROLED BY CONTROL VAR 100
```

```
*************************************************************
597     P        350010000 LT   NULL     0  10.0D5  L
598     TIME     0        GT   NULL     0  -1.0    L  0.0
599     CNTRLVAR 100      GT   NULL     0  0.5    N
699     597              OR          599      N
*     SET END OF PROBLEM TRIP TO BE 699
600     699
*************************************************************
*
*   PRIMARY TEMP
20507000 PRIMTEMP  TRIPUNIT  563.60   0.0      1
20507001 598
*************************************************************
*   CORE POWER
20507100 COREPOWR  FUNCTION  5.090D6  0.0      1
20507101 TIME     0        100
*************************************************************
*   INTACT LOOP PUMP SPEED
20507200 SETFLOW1  TRIPUNIT    21.0      0.0      1
20507201 598
*************************************************************
*   BROKEN LOOP PUMP SPEED
20507300 SETFLOW2  TRIPUNIT     7.0      0.0      1
20507301 598
*************************************************************
*   SG1 THROTTLE VALVE FOR RECIRC RATIO
20507400 RECIRC1   TRIPUNIT     0.35     0.0      1
20507401 598
*************************************************************
*   SG2 THROTTLE VALVE FOR RECIRC RATIO
20507500 RECIRC2   TRIPUNIT     0.22     0.0      1
20507501 598
*
*************************************************************
*   SG1 DOWNCOMER SET LEVEL
20507600 SG1LEVEL  TRIPUNIT     8.33     0.0      1
20507601 598
*
*************************************************************
*   SG2 DOWNCOMER SET LEVEL
20507700 SG2LEVEL  TRIPUNIT     8.23     0.0      1
20507701 598
*
*
*************************************************************
*   PRESSURIZER SET LEVEL
20507800 PRESLEVL  TRIPUNIT     4.80     0.0      1
20507801 598
*
*************************************************************
*   PRESSURIZER SET PRESSURE
20507900 PRIMPRES  TRIPUNIT    155.0     0.0      1
20507901 598
*
*************************************************************
*   HPIS FLOW RATE
20508000  HPISFLOW . FUNCTION    1.0  0.0  1
20508001  P        139010000    10
*
*
*************************************************************
*   CORE POWER WITH HEATLOSS COMPENSATION SWITCH IF NEEDED
20508100  POWER     SUM         1.0  0.0  1
20508101  0.0       1.0     CNTRLVAR  71  * DECAY POWER FROM TABLE
*20508102          -??      CNTRLVAR  ??  * MODIFICATION
*
```

```
*****************************************************
*   HPIS REDUCED IF WANTED
20508200 HPIS      SUM        1.0  0.0  1
20508201 0.0       1.0  CNTRLVAR  80  * HPIS FROM TABLE
*20508202          1.0  CNTRLVAR  ??  * MODIFICATION
*
*****************************************************
*   PRESSURIZER HEATER CONTROL
20508300 PRESHEAT  TRIPUNIT    1.0E-12   0.0      1
20508301 598
*
*****************************************************
*   SG1 RELIEF VALVE SETPOINT
20508400 SG1RVLV   TRIPUNIT    79.0E+5    0.0      1
20508401 598
*
*****************************************************
*   SG2 RELIEF VALVE SETPOINT
*                    TURNED OFF!
20508500 SG2RVLV   TRIPUNIT    80.0E+6    0.0      1
20508501 598
*
*****************************************************
*****************************************************
*   SATURATION TEMPERATURE IN INTACT LOOP HOT LEG
20509000  SAT-T     FUNCTION    1.0  0.0  1
20509001  P         100010000   3
*
*   SET UP CONTROL VARIABLES 99 AND 100 FOR BREAK OPEN AND PROBLEM
*   STOP VIA INTERACTIVE CONTROL
20509900 BREAKOPN  TRIPUNIT  0.01     0.0      1
20509901 598
*****************************************************
20510000 PROBEND   TRIPUNIT  0.01     0.0      1
20510001 598
*
*****************************************************
20510100 TIMESTEP  SUM      1.0      0.001 0   1   1.0E-6
20510101 0.0       1.0      TIME     0
20510102          -1.0      CNTRLVAR  102
*****************************************************
20510200 LASTTIME  MULT     1.0      0.0  0
20510201 TIME      0
*****************************************************
*****************************************************
*  LOGICAL TRIPS                                    *
*****************************************************
*
* PRESSURIZER RELIEF VALVE HYSTERYSIS
605     606      AND      561      N
606     605      OR       560      N
*  PRESSURIZER RELIEF VALVE OPENS BY SOME SIGNAL (OPTION)
607    -598      AND     -598      L * SWITCHED OFF
*
608     607      OR       606      N *
609    -608      AND     -608      N *
*
*****************************************************
610     518      AND     -578      N  * TRIPS AUX FEED ON/OFF
611     519      AND     -579      N  * TRIPS AUX FEED ON/OFF
*
*
*  $$$$  INVERSE TRIPS  $$$$$
*
*     620   TRUE   THROUGH STEADY STATE UP TO START OF TRANSIENT
*
```

```
620    -501      AND      -501      N  0.0  * STEADY STATE
*
*      621  TRUE   THROUGH STEADY STATE AND UP TO MOMENT OF SCRAM
*
621    -510      AND      -510      N  0.0  * UP TO SCRAM
*
*      622  TRUE   THROUGH STEADY STATE AND UP TO IL COOLDOWN
*
622    -512      AND      -512      N   0.0 * UP TO IL COOLDOWN
*
*      623  TRUE   THROUGH STEADY STATE AND UP TO BL COOLDOWN
*
623    -513      AND      -513      N   0.0 * UP TO BL COOLDOWN
*
*      624  TRUE   THROUGH STEADY STATE AND UP TO MAIN FEED OFF
*
624    -517      AND      -517      N   0.0 * MAIN FEED ON
*
*
*      625  TRUE   THROUGH STEADY STATE AND UP TO AUX FEED ON
*
625    -518      AND      -518      N   0.0 * AUX FEED OFF
*
*
*      626  TRUE   THROUGH STEADY STATE AND UP TO AUX FEED ON
*
626    -519      AND      -519      N   0.0 * AUX FEED OFF
628     521      AND       521      N   * HPIS
*
*  UNIT TRIP CONTROL VARIABLES FOR STATE SWITCHING
*
*     STATE 1    UP TO START (STEADY STATE)
20505000 STEADY    TRIPUNIT  1.0      1.0      1
20505001 620     * THIS IS JUST .NOT.501
*****************************************************
*     STATE 2   AFTER START
20505100 BREAKOPN  TRIPUNIT  1.0      0.0      1
20505101 501
*
*     STATE 3    UP TO MOMENT OF SCRAM
20505200 FULLPOWR  TRIPUNIT  1.0      1.0      1
20505201 621     * THIS IS JUST .NOT.502
*****************************************************
*     STATE 4   AFTER SCRAM
20505300 SCRAM     TRIPUNIT  1.0      0.0      1
20505301 510
*****************************************************
*     STATE 5   UP TO START OF IL COOLDOWN
20505400 STEAM     TRIPUNIT  1.0      0.0      1
20505401 622
*****************************************************
*     STATE 6   AFTER START OF IL COOLDOWN
20505500 COOLDOWN  TRIPUNIT  1.0      0.0      1
20505501 512
*****************************************************
*     STATE 7   UP TO START OF BL COOLDOWN
20505600 STEAM     TRIPUNIT  1.0      0.0      1
20505601 623
*****************************************************
*     STATE 8   AFTER START OF BL COOLDOWN
20505700 COOLDOWN  TRIPUNIT  1.0      0.0      1
20505701 513
*
*****************************************************
*     STATE 9   UP TO START OF INTACT LOOP AUX FEED
20505800 AUXFEED   TRIPUNIT  1.0      0.0      1
```

```
20505801 625
*
*************************************************************
*     STATE 10  AFTER START OF INTACT LOOP AUX FEED
20505900 AUXFEED   TRIPUNIT  1.0      0.0      1
20505901 518
*
*************************************************************
*     STATE 11  UP TO START OF BROKEN LOOP AUX FEED
20506000 AUXFEED   TRIPUNIT  1.0      0.0      1
20506001 626
*
*************************************************************
*     STATE 12  AFTER START OF BROKEN LOOP AUX FEED
20506100 AUXFEED   TRIPUNIT  1.0      0.0      1
20506101 519
*
*
*      $$$$$  CHANGABLE DATA FOR EXPERIMENT SELECTION $$$$$$
*
* $$$$$ TABLES, FLOW VALUES AND CURVES SET BY CONTROL LOGIC $$$$
*
*
*  ====== PRESSURIZER SURGE LINE CONNECTION
*****************************************
*
*
4000303  2.800     3    * FOR INTACT LOOP CONNECTION
*4000303  5.33      3    * FOR BROKEN LOOP CONNECTION
4050101  400010000 103000000 1.3685D-4 0.0       0.0   00100 * INTACT
*4050101  400010000 203000000 1.3685D-4 1.0       0.5   20001  * BROKEN
*
*   =====  BREAK SIZE  AND MULTIPLIER =======
*  ***************************
*
*  THIS IS THE BREAK FLOW MULTIPIER FOR JUNCTION 950
*
9500102  0.85      0.85
*
*  ACCUMULATOR ENABLE/DISABLE SWITCH
685    598     AND    598    L  * ACCU ON FOR THIS TEST
*
*
*************************************************************
*   THIS TABLE CONTROLS THE BREAK ISOLATION VALVE          *
*   ARGUS BALL VALVE OPENING CHARACTERISTICS               *
*   NORMALISED STEM POSITION AGAINST NORMALISED FREE AREA  *
*************************************************************
*
*   IN HERE WE PUT THE FRACTION OF THE 100% FLOW AREA WHICH THE BREAK
*   REPRESENTS
*
*                          3% BREAK
20215000 NORMAREA    0     1.0     0.03
20215001 0.0000    0.00
20215002 0.2556    0.00
20215003 0.3889    0.11
20215004 0.4444    0.19
20215005 0.5000    0.27
20215006 0.5556    0.35
20215007 0.6111    0.44
20215008 0.6667    0.52
20215009 0.7222    0.60
20215010 0.7778    0.69
20215011 0.8333    0.77
20215012 0.8889    0.85
```

```
20215013 0.9444    0.93
20215014 1.0000    1.00
*
*
*************************************************************
*  THIS TABLE contains the stem position versus area        *
*  function for all the control valves on the               *
*  pressurizer and steam generators
*************************************************************
*
*
20215100 NORMAREA    0     1.0     1.0
20215101 0.0000    0.00
20215102 0.04      0.00
20215103 0.05      0.045
20215104 0.10      0.050
20215105 0.2       0.076
20215106 0.3       0.105
20215107 0.4       0.145
20215108 0.5       0.200
20215109 0.55      0.235
20215110 0.6       0.276
20215111 0.65      0.324
20215112 0.7       0.381
20215113 0.75      0.447
20215114 0.8       0.525
20215115 0.85      0.617
20215116 0.9       0.725
20215117 0.95      0.851
20215118 1.0       1.00
*
*************************************************************
*  THIS TABLE contains the stem position versus area        *
*  for the relief valve of the pressurizer. Because the valve
*  is much larger than the orifice junction area this
*  compensates for the odd turn on/off behaviour.
*************************************************************
*
*
20215200 NORMAREA    0     1.0     1.0
20215201 0.0000    0.00
20215202 0.026     1.0   * full orifice area when partially open
20215203 1.0       1.0
*
*************************************************************
*  THIS TABLE contains the stem position versus area        *
*  for the steam closure valve to mimic small leak.
*  The valve closes over 1.5 seconds.
*  When stem is fully closed, small leak remains
*  Valve area is 44.0d-4
*************************************************************
*
*
20215300 NORMAREA    0     1.0     1.0
20215301 0.0000    2.00D-4   * small leak area about 1mm dia hole
20215302 0.01      0.01
20215303 1.0       1.00
*************************************************************
*  THIS TABLE contains the stem position versus area        *
*  function for the large relief valve on the intact loop   *
*  SG WHICH MAY BE DIFFERENT FROM OTHERS
*************************************************************
*
*
20215400 NORMAREA    0     1.0     1.0
20215401 0.0000    0.00
```

```
20215402 0.04      0.00
20215403 0.05      0.045
20215404 0.10      0.050
20215405 0.2       0.076
20215406 0.3       0.105
20215407 0.4       0.145
20215408 0.5       0.200
20215409 0.55      0.235
20215410 0.6       0.276
20215411 0.65      0.324
20215412 0.7       0.381
20215413 0.75      0.447
20215414 0.8       0.525
20215415 0.85      0.617
20215416 0.9       0.725
20215417 0.95      0.851
20215418 1.0       1.00
*
*
*  ===== POWER DECAY ====
*
*****************************************************
*  ELECTRICAL POWER CONTROL CURVE - ANS 100% CORRECTED FOR LOBI (ISP18)
*****************************************************
*  THIS CURVE IS MULTIPLIED BY CNTRLVAR 71 TO GIVE POWER
*   THE CNTRLVAR CAN BE ALTERED DURING STEADY STATE RUNNING TO
*  MIMIC RIG CONTROL, AND THEN GO INTO THE DECAY TRANSIENT
*
20210000 POWER    511      1.0      1.0
20210001 0.0       1.00
20210002 1.0       0.90
20210003 2.0       0.73
20210004 3.0       0.65
20210005 5.0       0.51
20210006 7.0       0.40
20210007 9.0       0.32
20210008 13.0      0.20
20210009 15.0      0.161
20210010 16.0      0.15
20210011 17.0      0.14
20210012 18.0      0.13
20210013 20.0      0.12
20210014 24.0      0.10
20210015 30.0      0.08
20210016 40.0      0.065
20210017 68.0      0.048
20210018 110.0     0.04
20210019 170.0     0.035
20210020 270.0     0.028
20210021 470.0     0.023
20210022 870.0     0.02
20210023 1000.0    0.019
20210024 2000.0    0.016
20210025 4000.0    0.013
20210026 6000.0    0.011
20210027 10000.0   0.010
*
*  ======= HPIS  =====
*
*  TABLE OF HPIS FLOW AS A FUNCTION OF SYSTEM PRESSURE
*  THESE VALUES ARE MULTIPLIED BY CNTRLVAR 80 TO GET
*  HPIS FLOWS, AND CAN BE ADJUSTED BY OPERATOR DURING TRANSIENT
*  TO MIMIC CONTROL OF HPIS PUMPS.
*
*       HPIS SYSTEM CURRENTLY MODELLING
*    2/4 PUMPS INJECTING INTO THE INTACT LOOP COLD LEG
```

```
*          (SAME AS ISP 18)
*
20201000 POWER    0        1.0      1.0
20201001   1.0E5    0.201
20201002  11.0E5    0.192
20201003  21.0E5    0.183
20201004  31.0E5    0.172
20201005  41.0E5    0.160
20201006  51.0E5    0.147
20201007  61.0E5    0.132
20201008  71.0E5    0.1162
20201009  81.0E5    0.098
20201010  91.0E5    0.077
20201011 101.0E5    0.052
20201012 111.0E5    0.0218
20201013 117.0E5    0.0
20201014 170.0E5    0.0
*************************************************************
*         PUMP SPEED-TIME CURVES - TEST BL-00              *
*************************************************************
*  INTACT LOOP PUMP SPEED-TIME CURVE FROM TRIP ON PRESSURE AT 131 BAR
*            TRIP
20212500  POWER    531   1.0    1.0
*
*     (TIME-TRIP TIME)   NORMALIZED SPEED
20212501      0.0          1.000
20212502      5.0          0.88
20212503      10.0         0.71
20212504      15.0         0.59
20212505      27.0         0.41
20212506      40.0         0.32
20212507      50.0         0.26
20212508     120.0         0.115
20212509     200.0         0.115
20212510     201.0         0.00
*
*  BROKEN LOOP PUMP SPEED-TIME CURVE FROM TRIP ON PRESSURE AT 131 BAR
*
*            TRIP
20222500  POWER    536   1.0    1.0
*
*     (TIME-TRIP TIME)   NORMALIZED SPEED
20222501      0.0          1.000
20222502      5.0          0.88
20222503      10.0         0.71
20222504      15.0         0.59
20222505      27.0         0.41
20222506      40.0         0.32
20222507      50.0         0.26
20222508     120.0         0.115
20222509     200.0         0.115
20222510     201.0         0.00
*
*************************************************************
*         INTACT LOOP PROGRAMMED COOLDOWN CURVE            *
*************************************************************
*  INTACT LOOP COOLDOWN-TIME CURVE FROM TRIP 512
*            TRIP       CONVERT TO PA
20250500  POWER    512   1.0    1.0E5
*
*  (TIME-TRIP TIME)  PRESSURE DIFFERENCE (BAR)
20250501  0.00        0.0
20250502  360.0       6.16   * 56 DEGREES PER HOUR
20250503  720.0       11.95
20250504 1800.0       27.00
*
```

```
*****************************************************
*        BROKEN LOOP PROGRAMMED COOLDOWN CURVE      *
*****************************************************
*  BROKEN LOOP COOLDOWN-TIME CURVE FROM TRIP 513
*              TRIP       CONVERT TO PA
20260500  POWER    513  1.0   1.0E5
*
*  (TIME-TRIP TIME)  PRESSURE DIFFERENCE (BAR)
*****************************************************
20260501  0.00        0.0
20260502  360.0      6.16   * 56 DEGREES PER HOUR
20260503  720.0      11.95
20260504 1800.0      27.00
*****************************************************
*
* GENERAL DEADBAND FUNCTION... USED BY FEW DELTA T CONTRLVARS
*
20250600 REAC-T
20250601 -100.0    -100.0
20250602 -0.0001    -0.0001
20250603 -0.0001     0.0
20250604  0.0001     0.0
20250605  0.0001     0.0001
20250606  100.0     100.0
***
*****************************************************
*                                                   *
*  PUMP SPEED CONTROLLER - INTACT LOOP              *
*                                                   *
*****************************************************
*
*   THIS IS THE MASS FLOW CONTROLLED ERROR SEEKING PUMP SPEED
*
*   WORK OUT MASS FLOW ERROR SIGNAL
20511400 FLOWER1   SUM       1.0      0.0      1
20511401  0.0       1.0      CNTRLVAR  72        * SET FLOW
20511402           -1.0      MFLOWJ    125010000  * MINUS REAL FLOW
*****************************************************
20511500 INTER1    INTEGRAL  1.0      0.0      1
20511501 CNTRLVAR  114
*****************************************************
20511600 PSPEED1   SUM       1.0      505.00   0
20511601 0.0       1.0      PMPVEL    125
20511602           10.0     CNTRLVAR  114
20511603           0.8      CNTRLVAR  115
*****************************************************
*
*    CONTROL VAR 116 IS NOW PUMP SPEED TO BE USED FOR STEADY STATE
*      (SET FLOW CAN BE CHANGED FOR INTERACTIVE PUMP CONTROL)
*
*  PUMP SPEED TABLE - INTACT LOOP PUMP -SET FOR INTERPOLATION ONLY
*****************************************************
1256100  598       CNTRLVAR  122    * TRIP IS SET PERM ON
1256101  0.0       0.0             * SO THIS 1 TO 1 MAPPING
1256102  1000.0    1000.0          * IS ALWAYS USED
*****************************************************
*****************************************************
*****************************************************
*
*       SET UP CNTRLVAR 120 TO BE DESIRED COSTDOWN CURVE
*
20512000 SPEEDT1   FUNCTION  1.0      0.0      1
20512001 TIME      0         125
*****************************************************
20511700 STORE     MULT      1.0      0.0      0
20511701 CNTRLVAR  51    * 0 UP TO BREAK, 1 AFTER
```

```
20511702 CNTRLVAR  119
*************************************************************
20511800 SPEED     MULT      1.0     505.0      0
20511801 CNTRLVAR   50    * 1 UP TO BREAK, 0 AFTER
20511802 CNTRLVAR  116    * CONTROLLED SPEED
*************************************************************
20511900 OLDSPEED  SUM       1.0      505.0     0
20511901 0.0       1.0       CNTRLVAR  117
20511902           1.0       CNTRLVAR  118
*************************************************************
20512100 DECAY     MULT      1.0      0.0       1
20512101 CNTRLVAR  117
20512102 CNTRLVAR  120
*************************************************************
20512200 PUMPVEL   SUM       1.0     505.0      1
20512201 0.0       1.0       CNTRLVAR  118
20512202           1.0       CNTRLVAR  121
*************************************************************
*                                                           *
*  PUMP SPEED CONTROLLER - BROKEN LOOP PUMP                 *
*                                                           *
*************************************************************
20521400 FLOWER2   SUM       1.0      0.0       1
20521401 0.0       1.0       CNTRLVAR  73
20521402          -1.0       MFLOWJ    225010000
*************************************************************
20521500 INTER2    INTEGRAL  1.0      0.0       1
20521501 CNTRLVAR  214
*************************************************************
20521600 PSPEED2   SUM       1.0      396.00    0
20521601 0.0       1.0       PMPVEL    225
20521602          15.0       CNTRLVAR  214
20521603           1.5       CNTRLVAR  215
*************************************************************
*  PUMP SPEED TABLE - BROKEN LOOP PUMP                      *
*************************************************************
2256100  598      CNTRLVAR  222        * TRIP IS SET PERM ON
2256101  0.0      0.0
2256102  1000.0   1000.0
*************************************************************
20522000 SPEEDT2   FUNCTION  1.0      0.0       1
20522001 TIME      0         225
*
*
20521700 STORE     MULT      1.0      0.0       0
20521701 CNTRLVAR   51
20521702 CNTRLVAR  219
*************************************************************
20521800 SPEED     MULT      1.0     396.0      0
20521801 CNTRLVAR   50
20521802 CNTRLVAR  216
*************************************************************
20521900 OLDSPEED  SUM       1.0     396.0      0
20521901 0.0       1.0       CNTRLVAR  217
20521902           1.0       CNTRLVAR  218
*************************************************************
20522100 DECAY     MULT      1.0      0.0       0
20522101 CNTRLVAR  217
20522102 CNTRLVAR  220
*************************************************************
20522200 PUMPVEL   SUM       1.0     396.0      0
20522201 0.0       1.0       CNTRLVAR  218
20522202           1.0       CNTRLVAR  221
*
*************************************************************
*
```

```
*  PRESSURE RELIEF VALVE AND PROGRAMMED CONTROL FOR SECONDARY SIDE
*
* INTACT LOOP
*
*
*
*       SET UP CNTRLVAR 561 TO BE PROGRAMMED RESPONSE
*   PRESSURE DIFF STARTING FROM TRIP 512
20556100 PROGRAM   FUNCTION  1.0      0.0      1
20556101 TIME      0        505
*****************************************************
* 562 IS THE SETPOINT FOR THE INTEGRAL CONTROLLER, BEING
* THE RELIEF VALVE UPPER LIMIT MINUS PROGRAMMED COOLDOWN
*
20556200 SETPOINT  SUM      1.0      0.0      1
20556201 0.0       1.0      CNTRLVAR  84     * RELIEF SET POINT
20556202          -1.0      CNTRLVAR 561     * MINUS COOLDOWN IF ACTIVE
*
* control system for relief valve based on LOBI data
* stem = Va( (X-X0)/DX0  + 1/Ti( Int(X-X0)/DX0
* with   Va  = 0.25   DX0 = 10.0 MPa  Ti = 1.0
*
20556300 PROGDIF1  SUM      1.0E-7   0.0      1 * scale factor
20556301   0.0     1.0      P        560010000 * CURRENT VALUE
20556302          -1.0      CNTRLVAR  562      * MINUS SETPOINT
***
20556400 DEADBN1   FUNCTION  1.0      0.0      1
20556401 CNTRLVAR  563      506 * USE DEADBAND TO REDUCE CHATTER
***
* NOTE LIMIT TO +VE VALUES ONLY IN INTEGRAL
20556500 INTTSEC1  INTEGRAL  1.0      0.0      0  3  0.0   10.0
20556501 CNTRLVAR  564
***
20556600 CONTROL1  SUM      0.25     0.0      0  3   0.0   1.0
20556601 0.0       1.0      CNTRLVAR  564
20556602           1.0      CNTRLVAR  565
*
20556700 SWITCH    MULT     1.0      0.0      1
20556701 CNTRLVAR  566   *  SWITCH OUT THIS TERM WHEN steady state
20556702 CNTRLVAR   51   *  PROGRAM LIMITS
***
20556900 SWITCH    MULT     1.0      0.0      1
20556901 CNTRLVAR  567   *  SWITCH OUT THIS TERM WHEN SMALL VALVE IS OFF
20556902 CNTRLVAR   50   * OFF
*
*         BASIC CONTROL FOR SMALL VALVE ON SG
* THE FOLLOWING SYSTEM ENSURES THE VALVE CAN ONLY MOVE AT SOME LIMITED
* SPEED AS GIVEN BY THE LOBI TEAM DATA.
*
20557000 AREACHNG  SUM      1.0      0.0      0  3  -1.0   1.0
20557001 0.0       1.0      CNTRLVAR  569   *  DESIRED VALVE POSITION
20557002          -1.0      CNTRLVAR  599   * - CURRENT VALVE POSITION
*
*                                   LIMITED TO < 2% IE 50SEC
20557100 DA/DT     DIV      1.0      0.0      1  3  -0.02  0.02
20557101 CNTRLVAR   101     CNTRLVAR  570   *  AREA RATE OF CHANGE
*
20557200 AREALLOW  MULT     1.0      0.0      1
20557201 CNTRLVAR   101     CNTRLVAR  571   *  AREA CHANGE FOR THIS DT
*
* LARGE VALVE CONTROL
*
20557900 SWITCH    MULT     1.0      0.0      1
20557901 CNTRLVAR  567   *  SWITCH OUT THIS TERM WHEN LARGE VALVE IS OFF
20557902 CNTRLVAR   51   *ON
*
```

```
*        BASIC CONTROL FOR LARGE VALVE ON SG
* THE FOLLOWING SYSTEM ENSURES THE VALVE CAN ONLY MOVE AT SOME LIMITED
* SPEED AS GIVEN BY THE LOBI TEAM DATA.
*
20558000 AREACHNG  SUM      1.0      0.0      0 3 -1.0  1.0
20558001 0.0       1.0      CNTRLVAR  579  * DESIRED VALVE POSITION
20558002          -1.0      CNTRLVAR  598  * - CURRENT VALVE POSITION
*
*                                LIMITED TO 1.0 SEC
20558100 DA/DT     DIV      1.0      0.0      1 3 -1.0  1.0
20558101 CNTRLVAR  101      CNTRLVAR  580  * AREA RATE OF CHANGE
*
20558200 AREALLOW  MULT     1.0      0.0      1
20558201 CNTRLVAR  101      CNTRLVAR  581  * AREA CHANGE FOR THIS DT
*
* CNTRLVAR 598 CONTROLS THE LARGE VALVE ON THE STEAM GENERATOR
*
20559800 CONTROL   SUM      1.0      0.0      0 3  0.0  1.0
20559801 0.0       1.0      CNTRLVAR  598    * ITS OWN OLD VALUE
20559802           1.0      CNTRLVAR  582    * + AREA CHANGE
*
* CNTRLVAR 599 CONTROLS THE SMALL VALVE ON THE STEAM GENERATOR
*
20559900 CONTROL   SUM      1.0      0.0      0 3  0.0  1.0
20559901 0.0       1.0      CNTRLVAR  599    * ITS OWN OLD VALUE
20559902           1.0      CNTRLVAR  572    * + AREA CHANGE
*
*
*  BROKEN LOOP
*
*
*      SET UP CNTRLVAR 661 TO BE PROGRAMMED RESPONSE
*
20566100 PROGRAM   FUNCTION 1.0      0.0      1
20566101 TIME      0        605
*****************************************************
***
20566200 SETPOINT  SUM      1.0      0.0      1
20566201 0.0       1.0      CNTRLVAR  85     * RELIEF SET POINT
20566202          -1.0      CNTRLVAR 661     * MINUS COOLDOWN
*
20566300 PROGDIF2  SUM      1.0E-7   0.0      1 * int control
20566301  0.0      1.0      P        660010000 * CURRENT VALUE
20566302          -1.0      CNTRLVAR  662     * MINUS SETPOINT
***
20566400 DEADBN2   FUNCTION 1.0      0.0      1
20566401 CNTRLVAR  663      506 * USE DEADBAND TO REDUCE CHATTER
***
20566500 INTTSEC1  INTEGRAL 1.0      0.0      0 3  0.0   10.0
20566501 CNTRLVAR  664
***
20566600 CONTROL2  SUM      1.0      0.0      0 3  0.0  1.0
20566601 0.0       1.0      CNTRLVAR  664
20566602           0.1      CNTRLVAR  665
***
20566700 SWITCH    MULT     1.0      0.0      1
20566701 CNTRLVAR  666   * SWITCH OUT WHEN OUTSIDE PROG LIMITS
20566702 CNTRLVAR  51
*
*
*    THIS IS THE BASIC VALVE RATE LIMITING CONTROL SYSTEM (SMALL VALVE)
20567000 AREACHNG  SUM      1.0      0.0      0 3 -1.0  1.0
20567001 0.0       1.0      CNTRLVAR  667   * DESIRED VALVE POSITION
20567002          -1.0      CNTRLVAR  699   * - CURRENT VALVE POSITION
*
*                                LIMITED TO < 2% IE 50SEC
```

```
20567100 DA/DT     DIV      1.0      0.0      1 3  -0.02  0.02
20567101 CNTRLVAR  101      CNTRLVAR  670  * AREA RATE OF CHANGE
*
20567200 AREALLOW  MULT     1.0      0.0      1
20567201 CNTRLVAR  101      CNTRLVAR  671  * AREA CHANGE FOR THIS DT
*
*
*   SG2  RELIEF VALVE OPERATION
20567900 SG1PRV2   TRIPUNIT     1.0      0.0      1
20567901 549 * OFF
*
*****************************************************
*
*   THIS IS THE BASIC VALVE RATE LIMITING CONTROL SYSTEM (LARGE VALVE)
20568000 AREACHNG  SUM      1.0      0.0      0 3  -1.0   1.0
20568001 0.0       1.0      CNTRLVAR  679  * DESIRED VALVE POSITION
20568002          -1.0      CNTRLVAR  698  * - CURRENT VALVE POSITION
*
*                                  LIMITED TO 2.5 SECONDS
20568100 DA/DT     DIV      1.0      0.0      1 3  -0.4   0.4
20568101 CNTRLVAR  101      CNTRLVAR  680  * AREA RATE OF CHANGE
*
20568200 AREALLOW  MULT     1.0      0.0      1
20568201 CNTRLVAR  101      CNTRLVAR  681  * AREA CHANGE FOR THIS DT
*
*  CONTRLVAR 698 IS LARGE VALVE STEM POSITION
*
20569800 CONTROL   SUM      1.0      0.0      0 3   0.0   1.0
20569801 0.0       1.0      CNTRLVAR  698    * ITS OWN OLD VALUE
20569802           1.0      CNTRLVAR  682    * + AREA CHANGE
*
*  CONTRLVAR 699 IS SMALL VALVE STEM POSITION
*
20569900 CONTROL   SUM      1.0      0.0      0 3   0.0   1.0
20569901 0.0       1.0      CNTRLVAR  699    * ITS OWN OLD VALUE
20569902           1.0      CNTRLVAR  672    * + AREA CHANGE
*****************************************************
*****************************************************
*  SG1 MAIN FEED LEVEL CONTROLLER, INTACT LOOP
*****************************************************
20550100 ILSGLVL   SUM      1.0      0.0      1
20550101 0.0       1.105    VOIDF    555010000
20550102           1.402    VOIDF    500010000
20550103           2.000    VOIDF    510010000
20550104           2.000    VOIDF    510020000
20550105           2.000    VOIDF    510030000
20550106           0.750    VOIDF    551010000
20550200 SG1LVERR  SUM      1.0      0.0      1
20550201 0.0       1.0      CNTRLVAR  76
20550202          -1.0      CNTRLVAR  501
20550300 FEEDFLO1  SUM      1.0      2.1      0
20550301 0.0       1.0      MFLOWJ   580000000
20550302           2.0      CNTRLVAR  502
*
*****************************************************
*  SG2 MAIN FEED LEVEL CONTROLLER, BROKEN LOOP
*****************************************************
20560100 BLSGLVL   SUM      1.0      0.0      1
20560101 0.0       1.128    VOIDF    655010000
20560102           1.304    VOIDF    600010000
20560103           2.000    VOIDF    610010000
20560104           2.000    VOIDF    610020000
20560105           2.000    VOIDF    610030000
20560106           0.750    VOIDF    651010000
20560200 SG2LVERR  SUM      1.0      0.0      1
20560201 0.0       1.0      CNTRLVAR  77
```

```
20560202          -1.0     CNTRLVAR  601
20560300 FEEDFLO2  SUM      1.0      0.7      0
20560301 0.0       1.0      MFLOWJ   680000000
20560302          0.667     CNTRLVAR  602
*
*
* SG1 AUX FEED LEVEL CONTROL, SET TO MAINTAIN LEVEL IN DOWNCOMER
* WHICH EXISTS WHEN AUX FEED COMES ON
*   FIRST ARRANGE TO STORE LAST LEVEL BEFORE AUX FEED TRIPS IN
20551000 STORE     MULT     1.0      0.0      0
20551001 CNTRLVAR  59
20551002 CNTRLVAR  512
*************************************************************
20551100 LEVEL     MULT     1.0      0.0      1
20551101 CNTRLVAR  58
20551102 CNTRLVAR  501
*************************************************************
20551200 OLDLEVEL  SUM      1.0      0.0      1
20551201 0.0       1.0      CNTRLVAR  510
20551202          1.0      CNTRLVAR  511
*
* CALCULATE LEVEL ERROR AND SET AUX FEED ACCORDINGLY
* (FULL AUX FEED FOR A LEVEL 5CMS LOW, OFF IF HIGH)
*
*                                          MAX AUX FEED
20551300 AUXFEED1  SUM      2.0      0.0      0 3 0.0  0.06
20551301 0.0       1.0      CNTRLVAR  510
* note level diff not used, feed on fully when tripped
*20551302          -1.0     CNTRLVAR  501
*
*
*
* SG2 AUX FEED LEVEL CONTROL, SET TO MAINTAIN LEVEL IN DOWNCOMER
* WHICH EXISTS WHEN AUX FEED COMES ON
*   FIRST ARRANGE TO STORE LAST LEVEL BEFORE AUX FEED TRIPS IN
20561000 STORE     MULT     1.0      0.0      0
20561001 CNTRLVAR  61
20561002 CNTRLVAR  612
*************************************************************
20561100 LEVEL     MULT     1.0      0.0      1
20561101 CNTRLVAR  60
20561102 CNTRLVAR  601
*************************************************************
20561200 OLDLEVEL  SUM      1.0      0.0      1
20561201 0.0       1.0      CNTRLVAR  610
20561202          1.0      CNTRLVAR  611
*
* CALCULATE LEVEL ERROR AND SET AUX FEED ACCORDINGLY
* (FULL AUX FEED FOR A LEVEL 5CMS LOW, OFF IF HIGH)
*
*                                          MAX AUX FEED
20561300 AUXFEED1  SUM      1.0      0.0      0 3 0.0  0.021
20561301 0.0       1.0      CNTRLVAR  610
* note level diff not used, feed on fully when tripped
*20561302          -1.0     CNTRLVAR  601
*
*****************************************************
* PRESSURIZER LEVEL CONTROL VIA PUMP SEAL FLOW BLEED
*****************************************************
20539000 PRELVERR  SUM      1.0      0.0      1
20539001 0.0       1.0      CNTRLVAR  43 * REAL LEVEL
20539002          -1.0     CNTRLVAR  78 * - SET POINT
*************************************************************
*
* SUM SEAL FLOWS FOR INTACT AND BROKEN LOOPS TO ALLOW COMPENSATION
* DURING TRANSIENT IF SPECIFIED
```

```
*
*       SET SCALE FACTOR TO ZERO TO TURN OFF THIS OPTION
*                    ]
*                    \/
20539100   DRAINFLO  SUM   1.0   0.0   1
20539101   0.0  1.0  MFLOWJ  124000000
20539102       1.0  MFLOWJ  224000000
*
*************************************************************
*  PRESSURIZER CONTROL VALVE LOGIC
*************************************************************
*************************************************************
*
*
*
*
20549900 PORVOPEN  SUM      1.0      0.0      0  3   0.0   1.0
20549901 0.0       1.0      CNTRLVAR  83
*
```

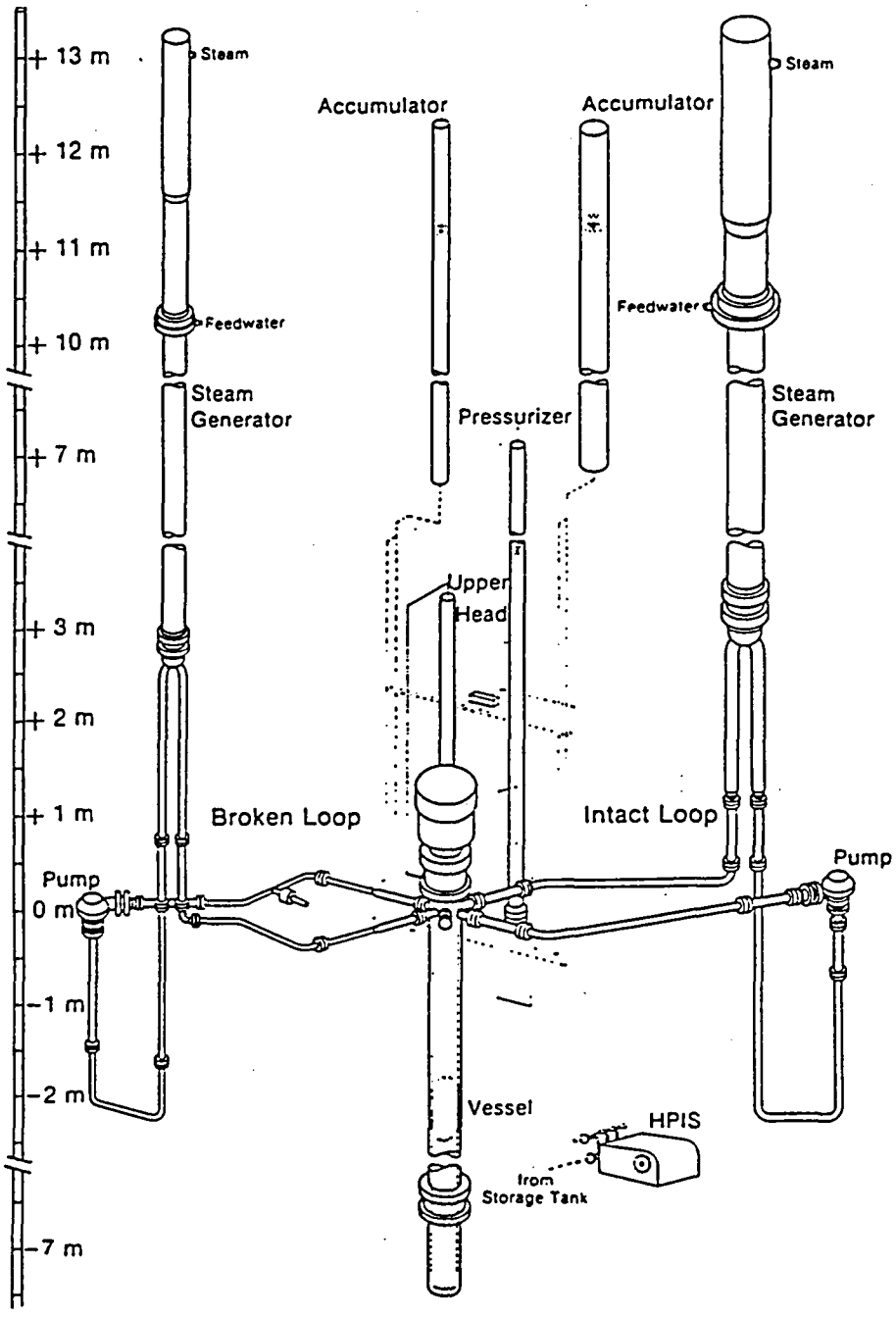

FIG. 1 LOBI-MOD2 FACILITY, PRIMARY CIRCUIT

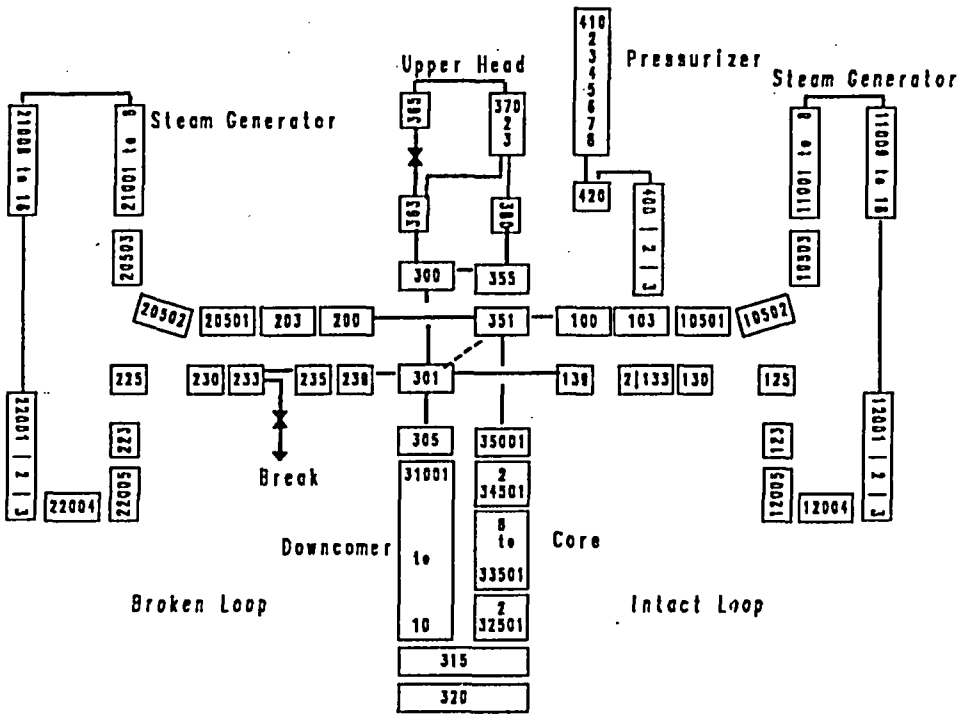

FIG. 2 SIMPLIFIED NODING DIAGRAM FOR LOBI PRIMARY SIDE

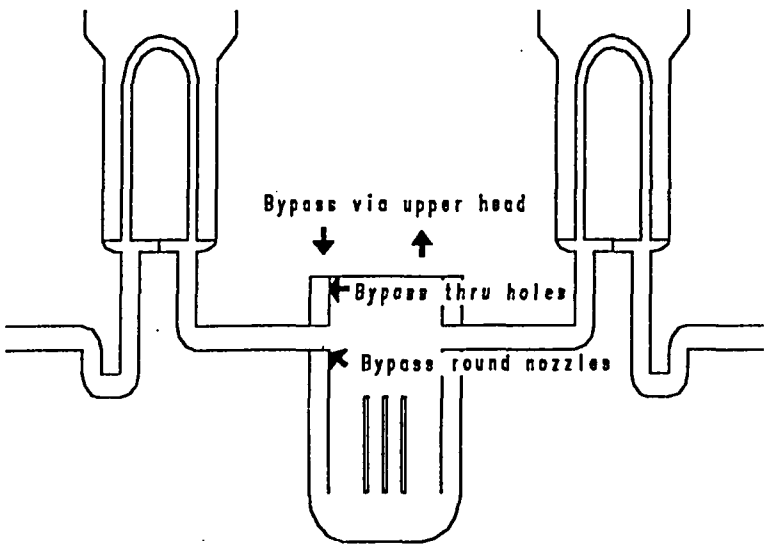

FIG. 3 ILLUSTRATION OF BYPASS PATHS IN LOBI VESSEL

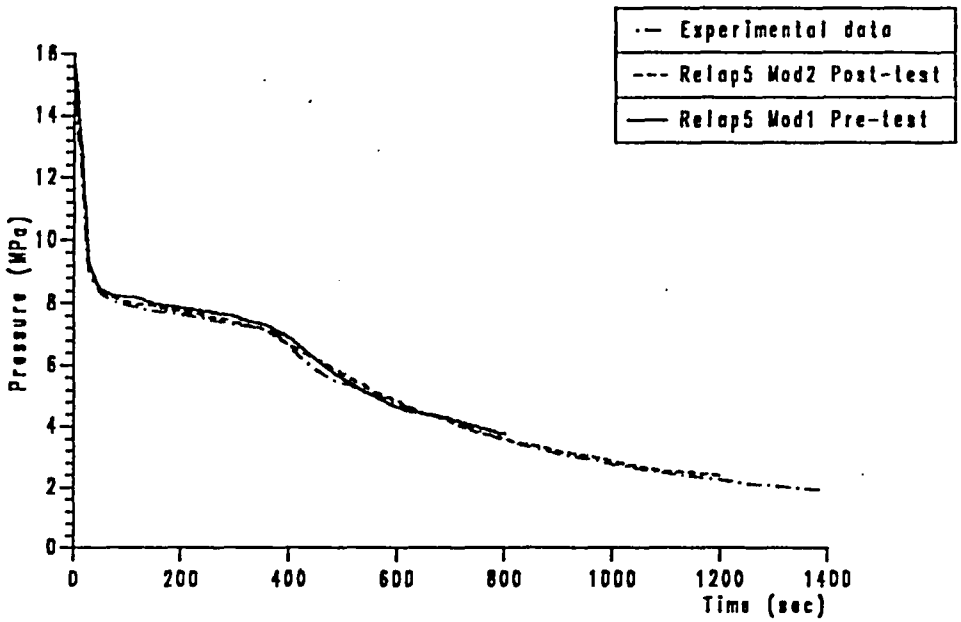

FIG. 4 COMPARISON OF PRIMARY PRESSURES: RELAP5 MODI AND MOD2 WITH LOBI DATA

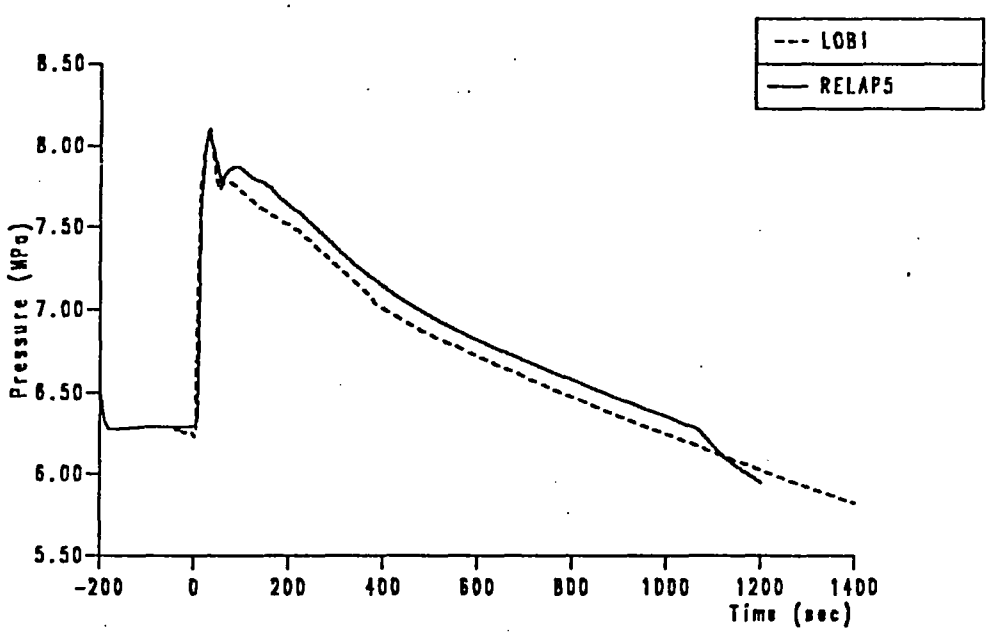

FIG. 5 SECONDARY SIDE PRESSURES: POST TEST WITH DATA

(C)

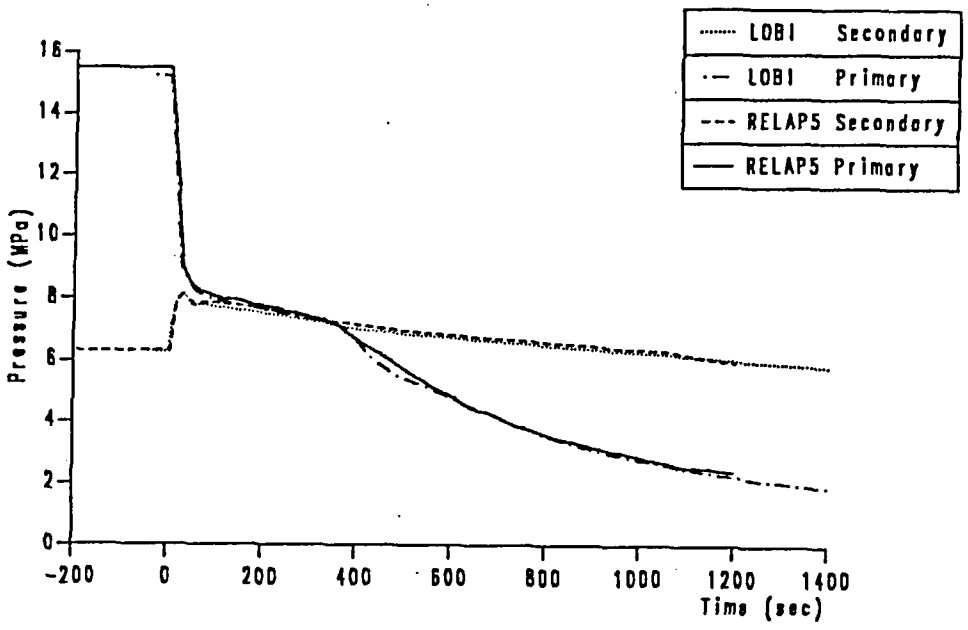

FIG. 6 PRIMARY AND SECONDARY PRESSURES TOGETHER: POST TEST WITH DATA

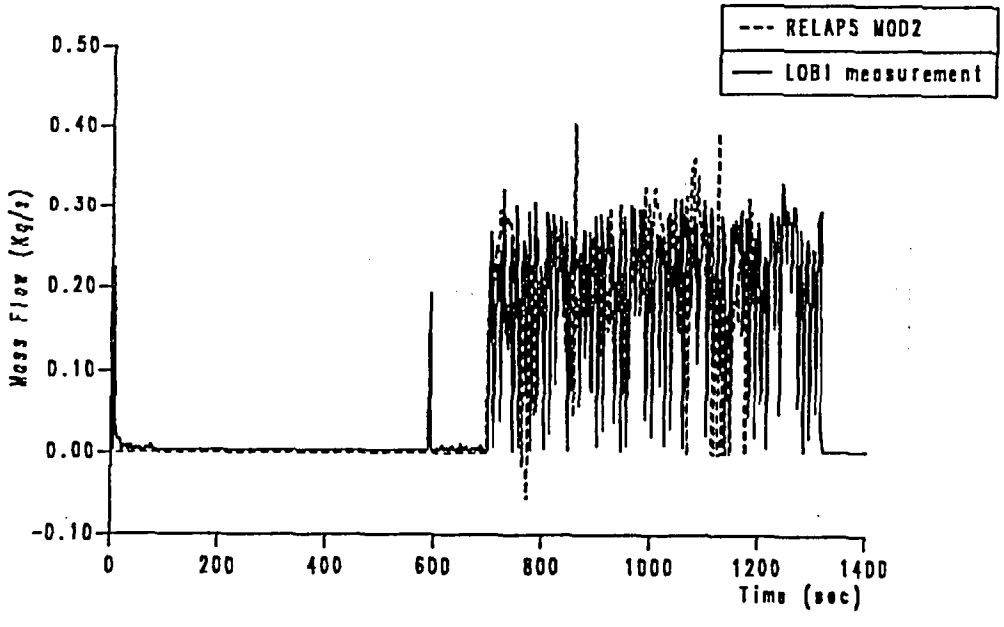

FIG. 7 ACCUMULATOR INJECTION COMPARISON

(C)

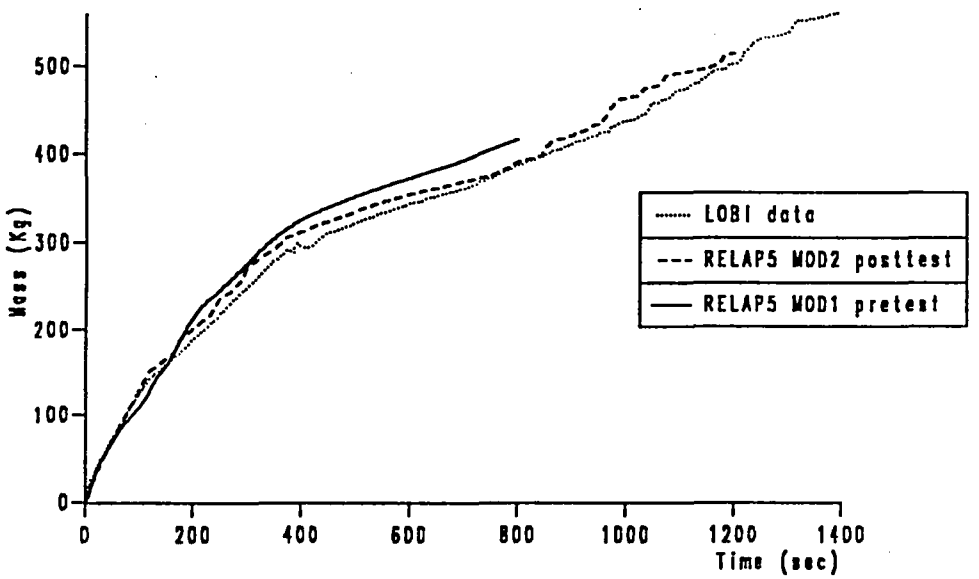

FIG. 8 COMPARISON OF INTEGRATED BREAK FLOWS

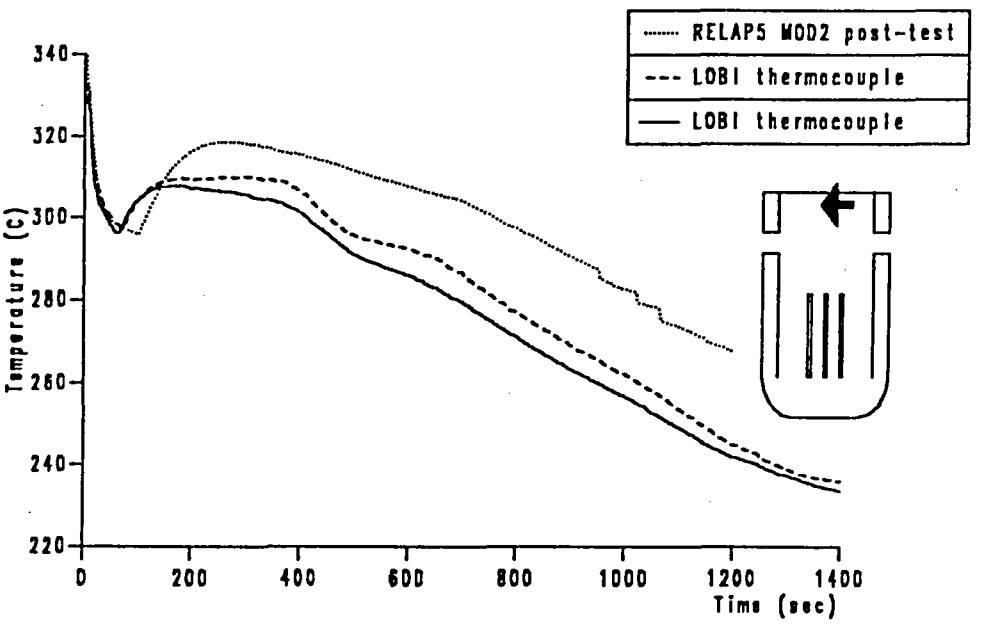

FIG. 9 CLAD TEMPERATURES AT TOP OF UNHEATED LENGTH

(C)

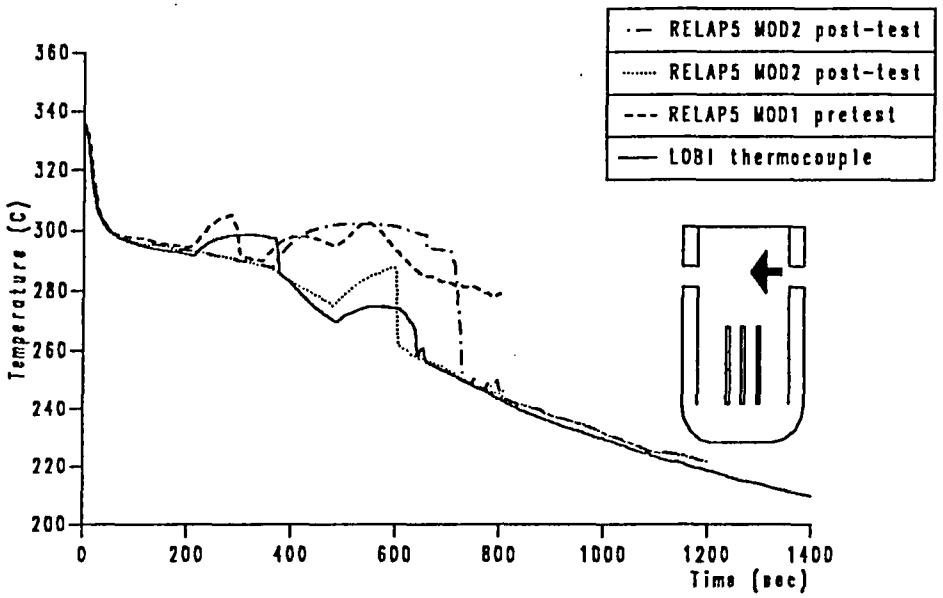

FIG. 10 CLAD TEMPERATURES NEAR NOZZLE ELEVATION

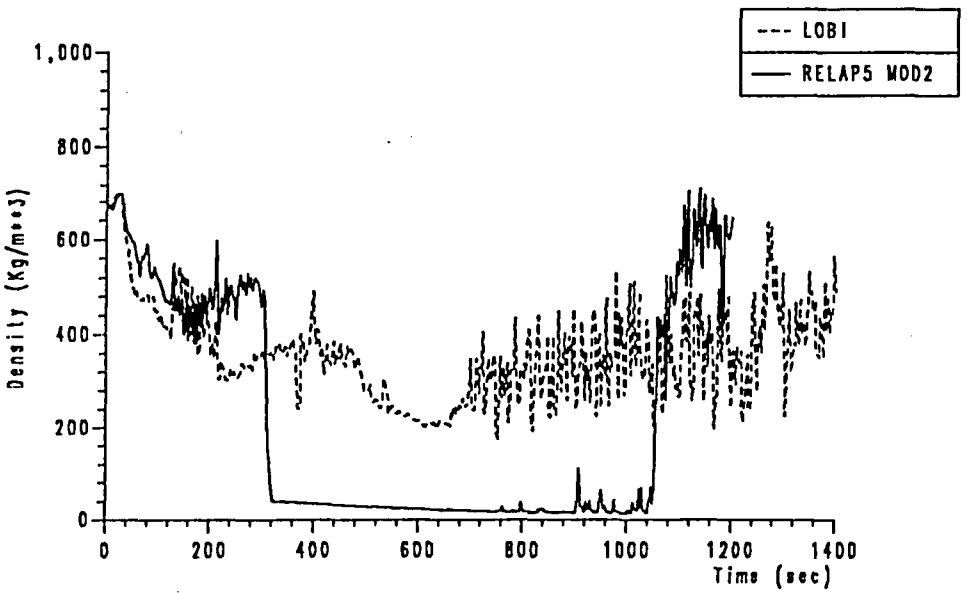

FIG. 11 DENSITIES ROUND LOOP: INTACT HOT LEG

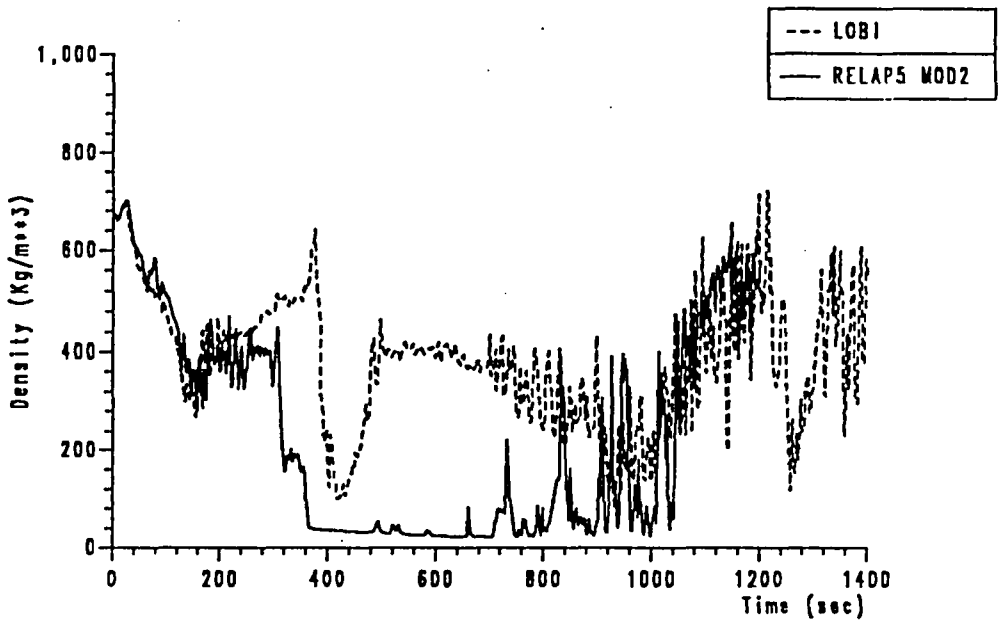

FIG. 12 DENSITIES ROUND LOOP: BROKEN HOT LEG

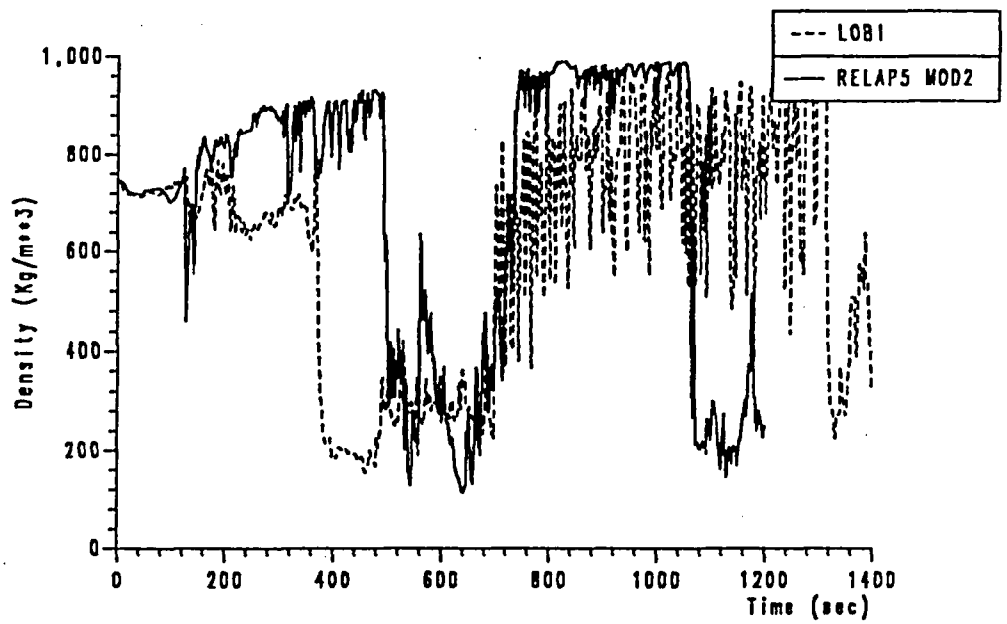

FIG. 13 DENSITIES ROUND LOOP: INTACT COLD LEG

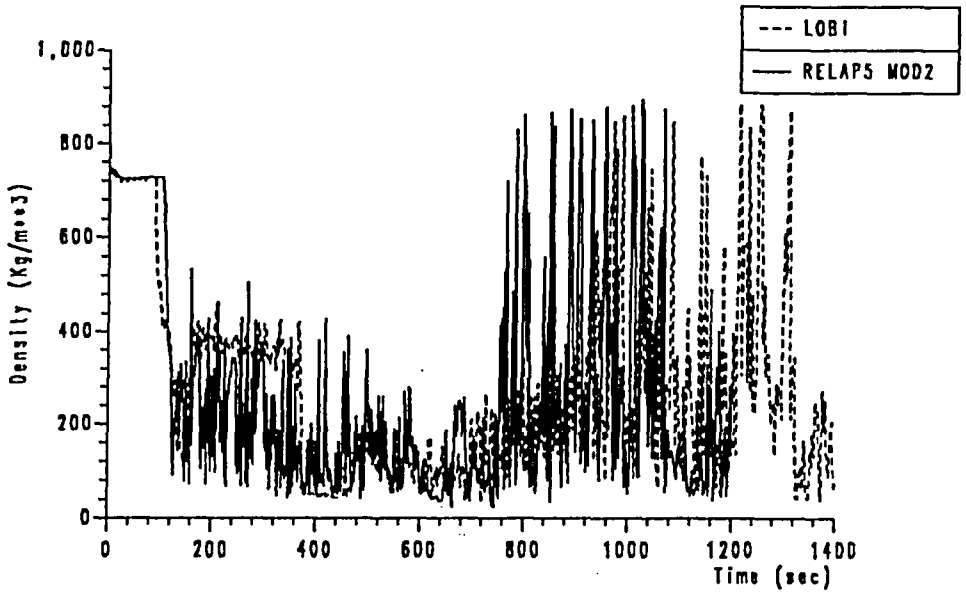

FIG. 14 DENSITIES ROUND LOOP: BROKEN COLD LEG

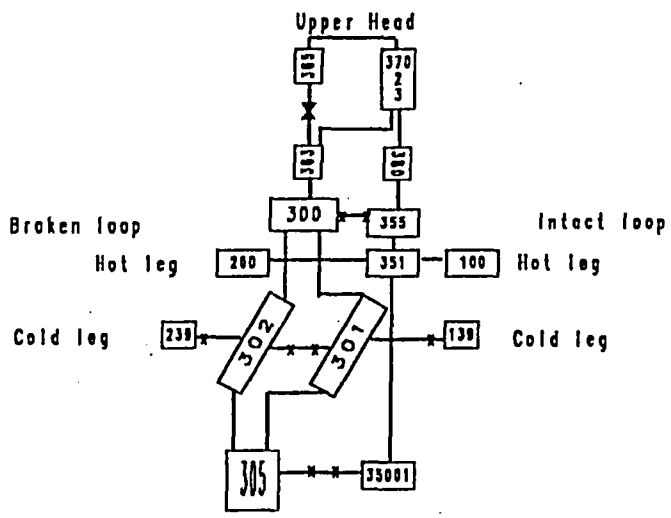

FIG. 15 NODING WITH SPLIT DOWNCOMER

(C)

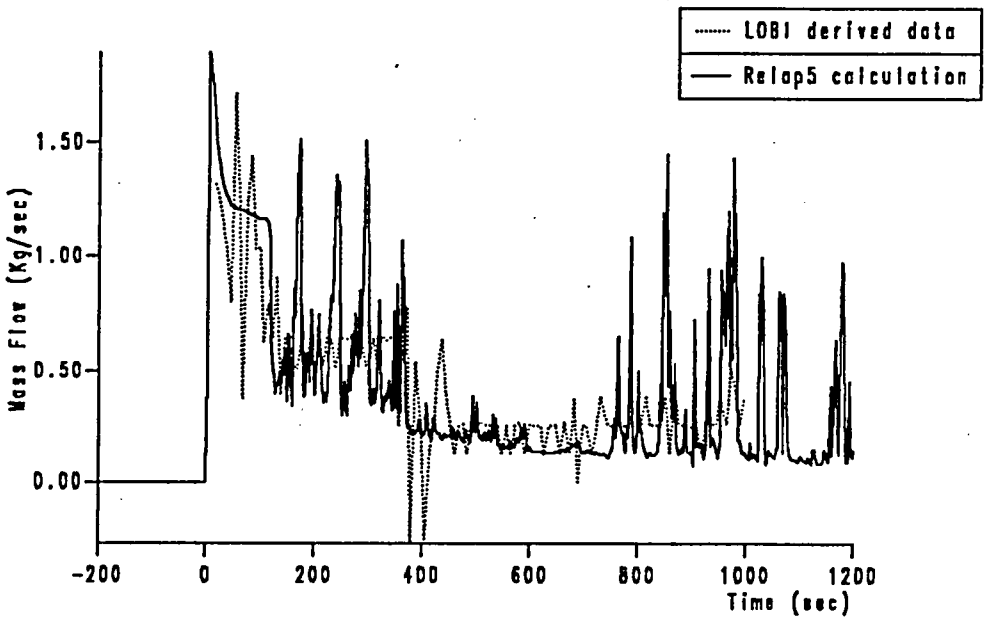

FIG. 16 BREAK FLOW COMPARISON

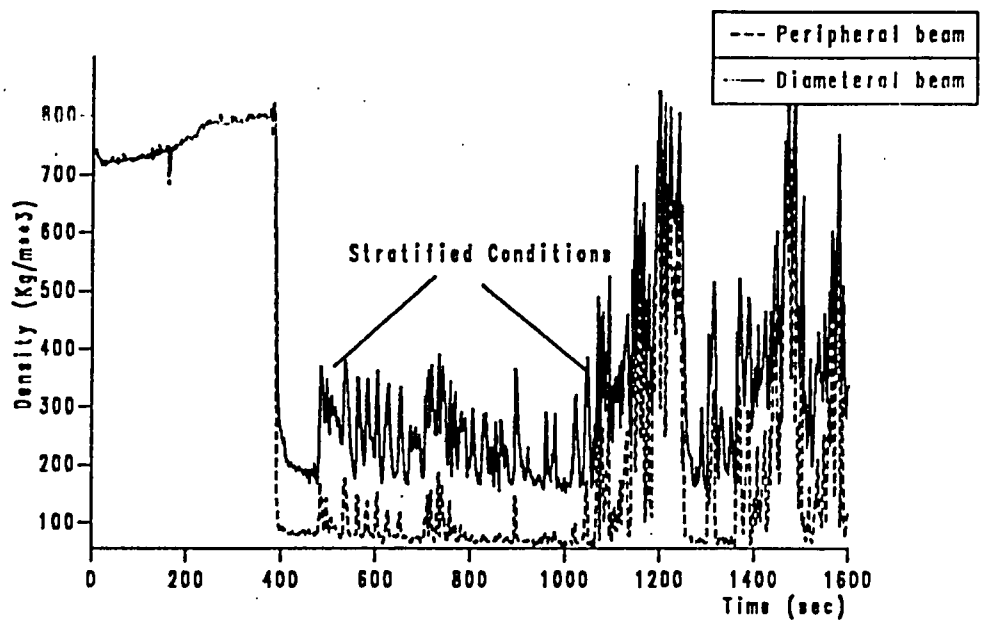

FIG. 17 DENSITIES DOWNSTREAM BL PUMP: LOBI DATA

(C)

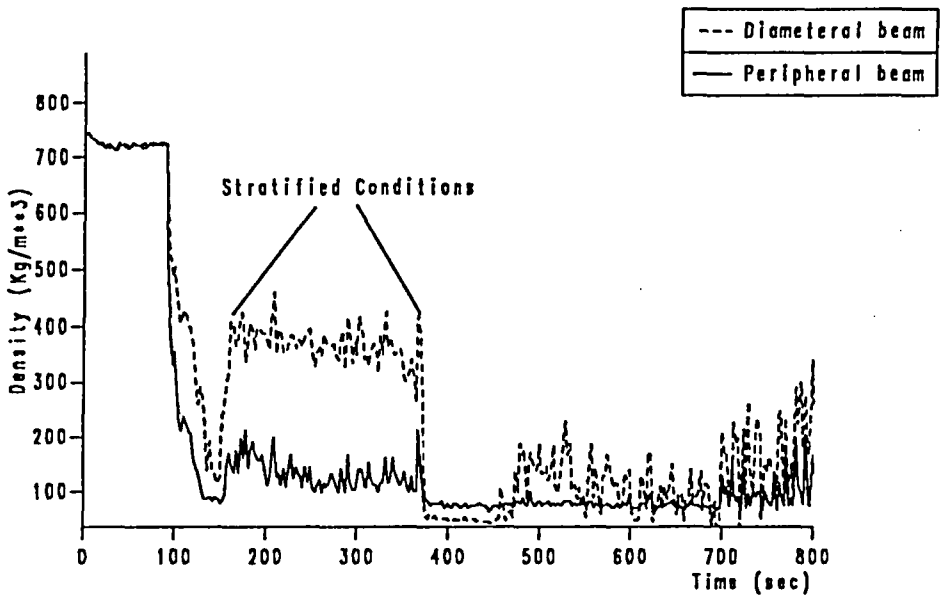

FIG. 18 DENSITIES BETWEEN BREAK AND VESSEL: LOBI DATA

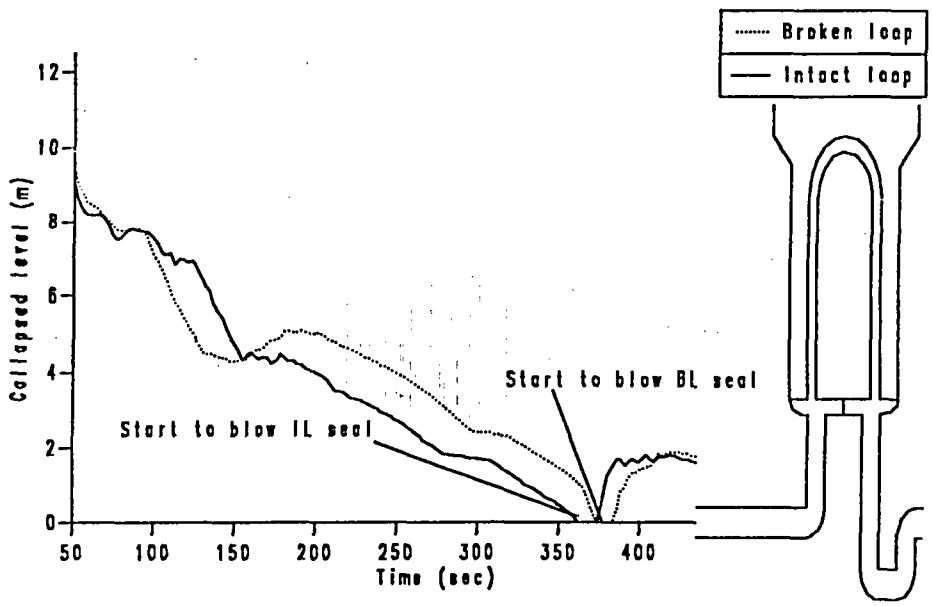

FIG. 19 COLLAPSED LEVELS IN SG UP SIDES: LOBI DERIVED DATA

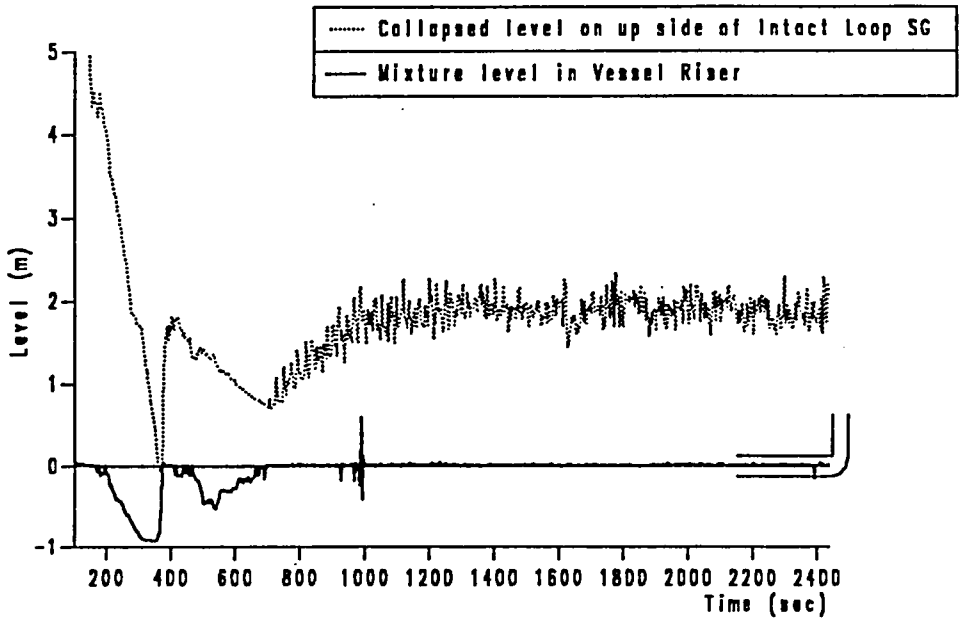

FIG. 20 DISPOSITION OF LIQUID IN LOOP: LOBI DERIVED DATA

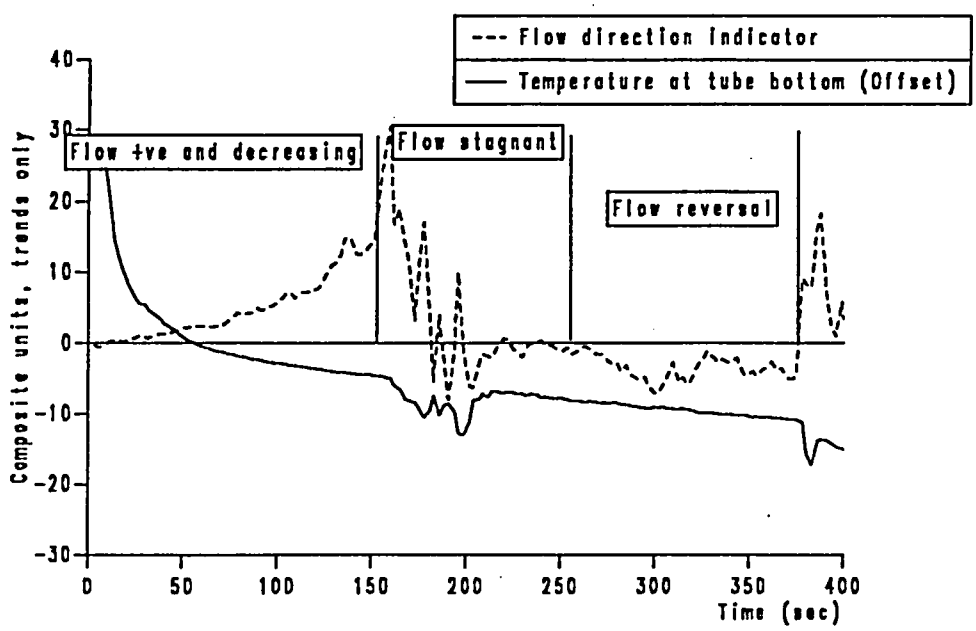

FIG. 21 CONDITION IN BROKEN LOOP HOT LEG: LOBI DATA

(C)

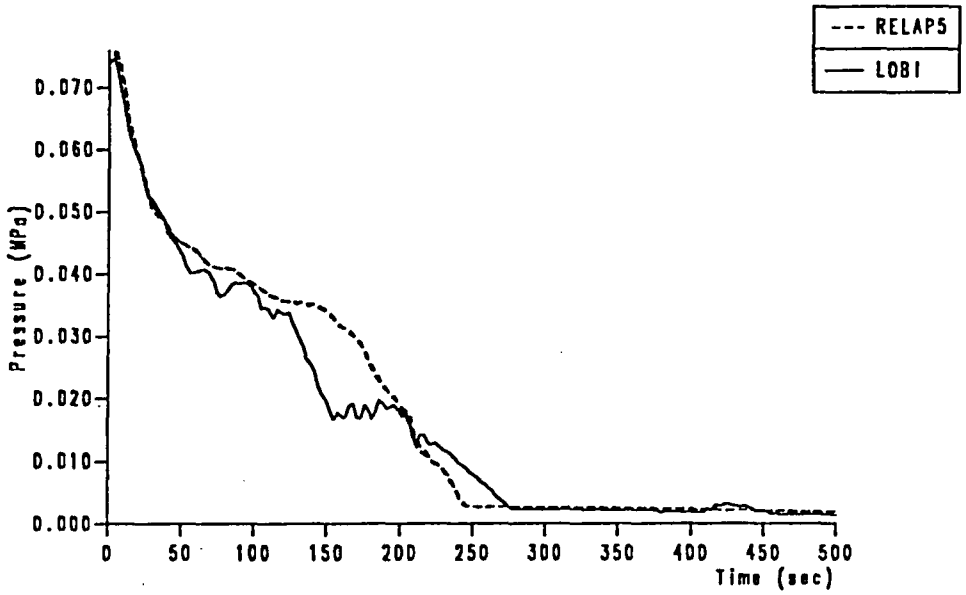

FIG. 22 DIFFERENTIAL PRESSURE UP SIDE IL SG

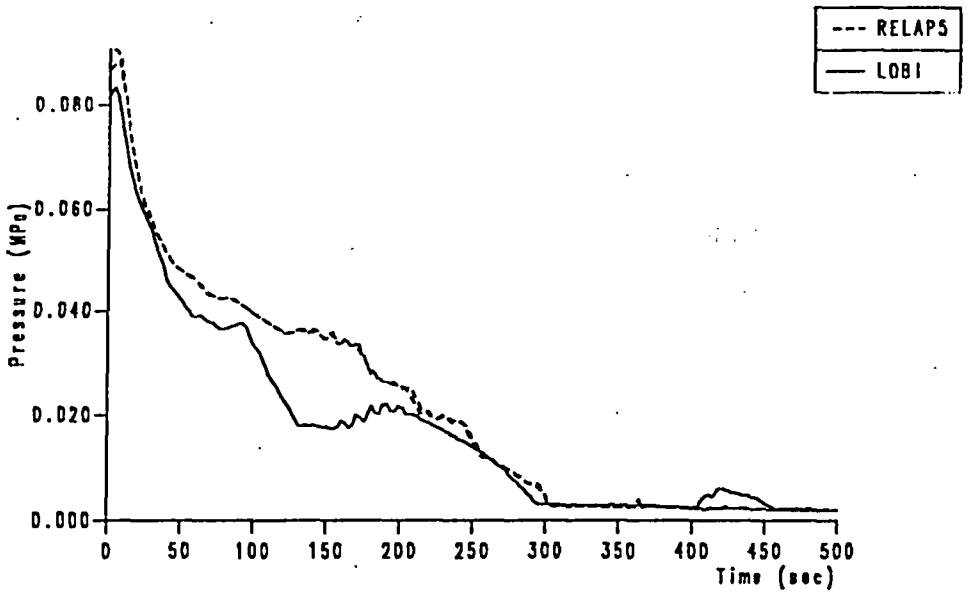

FIG. 23 DIFFERENTIAL PRESSURE UP SIDE BL SG

(C)

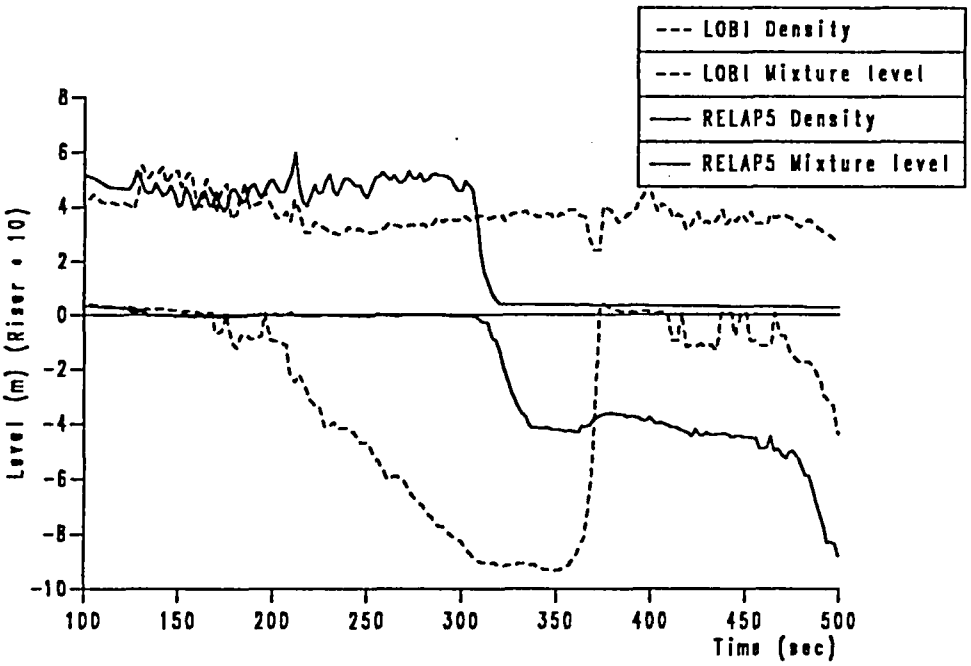

FIG. 24 RISER MIXTURE LEVEL AND HOT LEG DENSITY

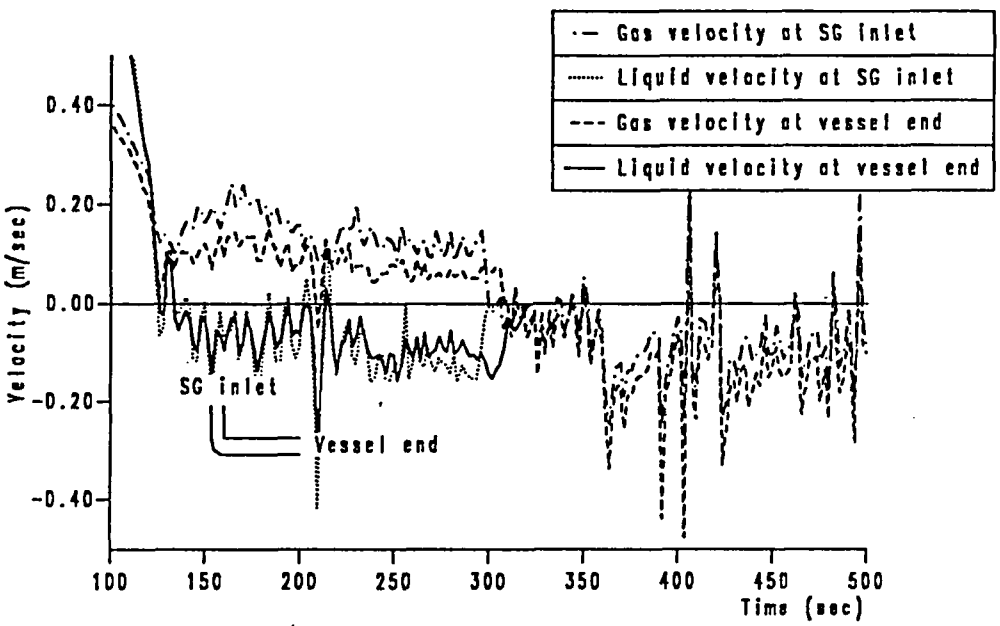

FIG. 25 SUPERFICIAL VELOCITIES IN INTACT LOOP HOT LEG: RELAP5 PROCESSED RESULTS

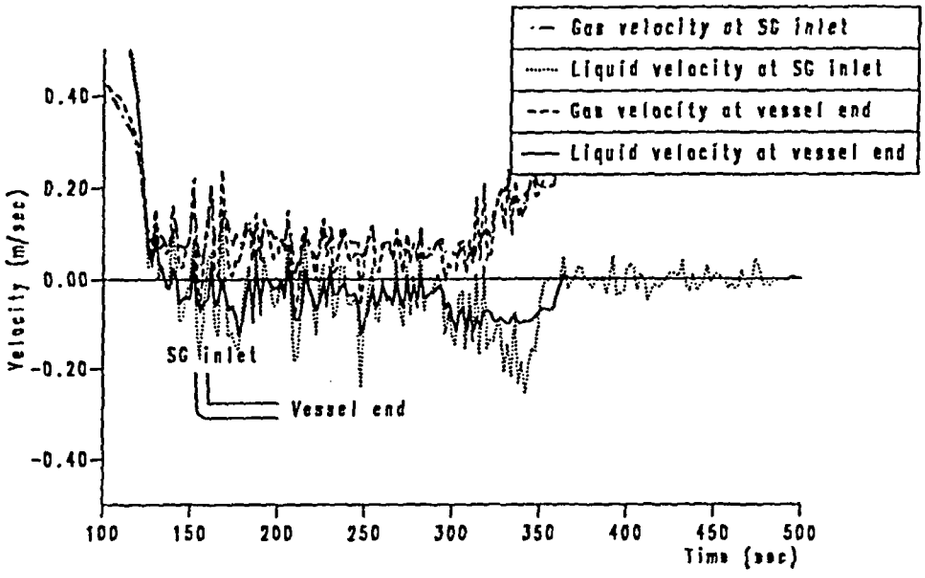

FIG. 26 SUPERFICIAL VELOCITIES IN BROKEN LOOP HOT LEG: RELAP5 PROCESSED RESULTS

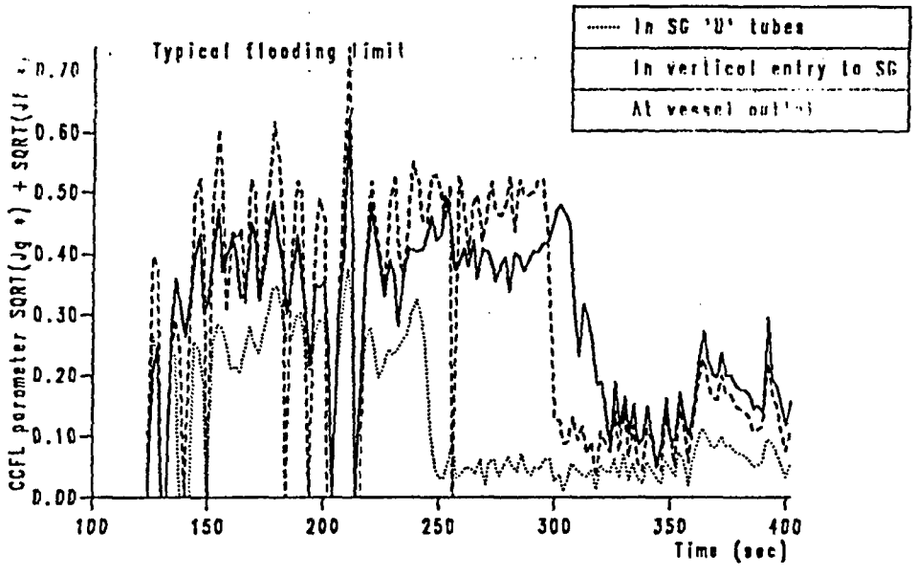

FIG. 27 COUNTER CURRENT FLOODING LIMIT FOR INTACT LOOP: RELAP5 PROCESSED RESULTS

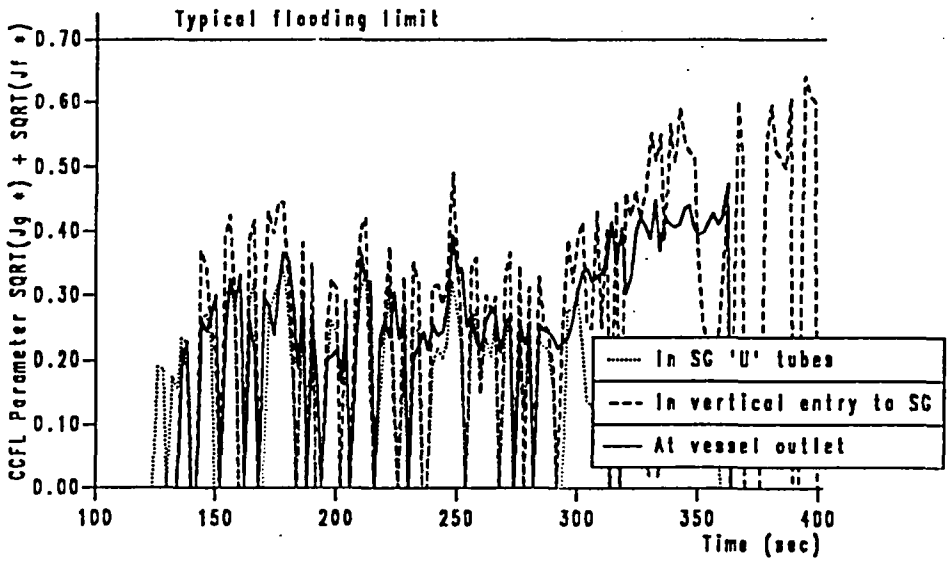

FIG. 28 COUNTER CURRENT FLOODING IN BROKEN LOOP HOT LEG: RELAP5PROCESSED RESULTS

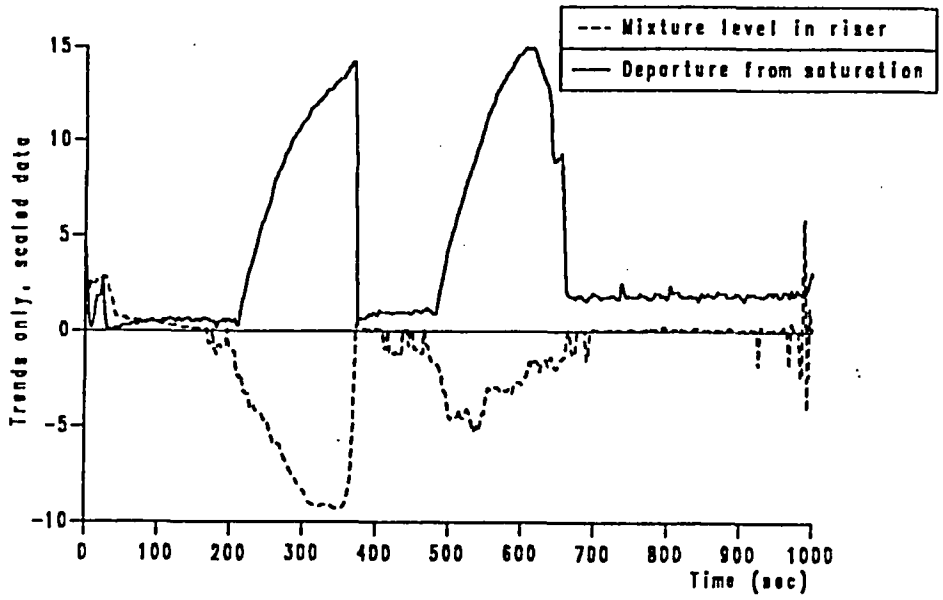

FIG. 29 RELATION BETWEEN TEMPERATURE EXCURSION AND LEVEL: LOBI DATA

(C)

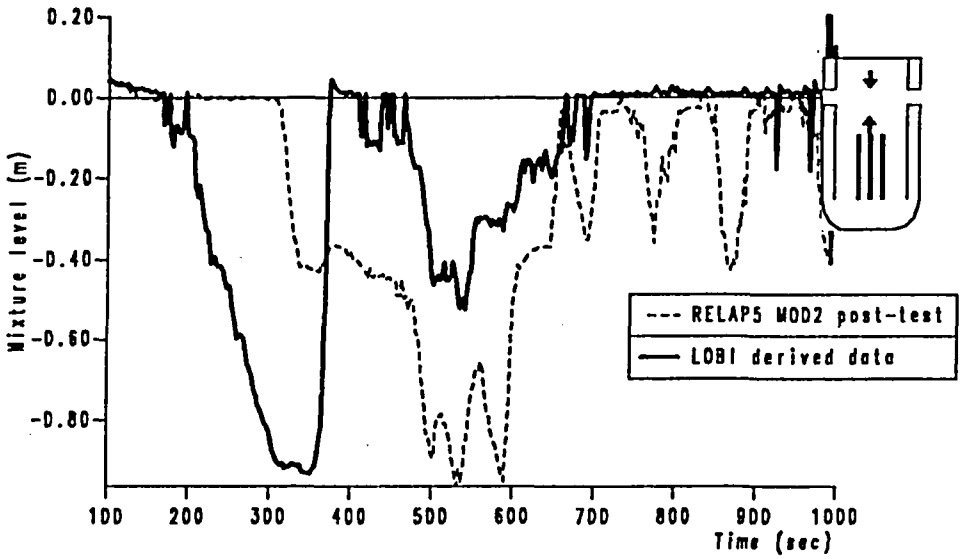

FIG. 30 COMPARISON OF MIXTURE LEVELS IN VESSEL RISER

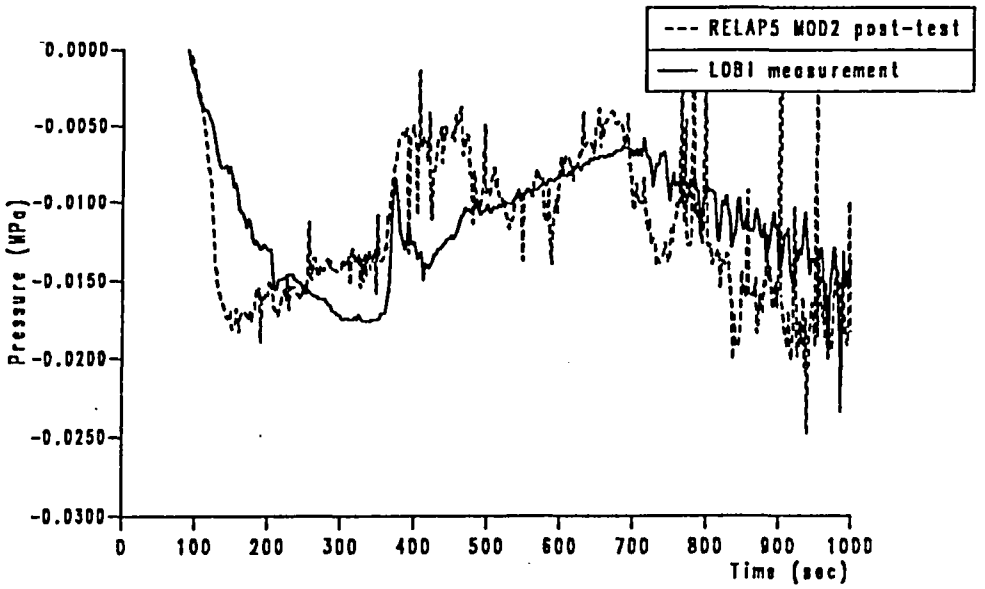

FIG. 31 DIFFERENTIAL PRESSURE OVER INTACT LOOP

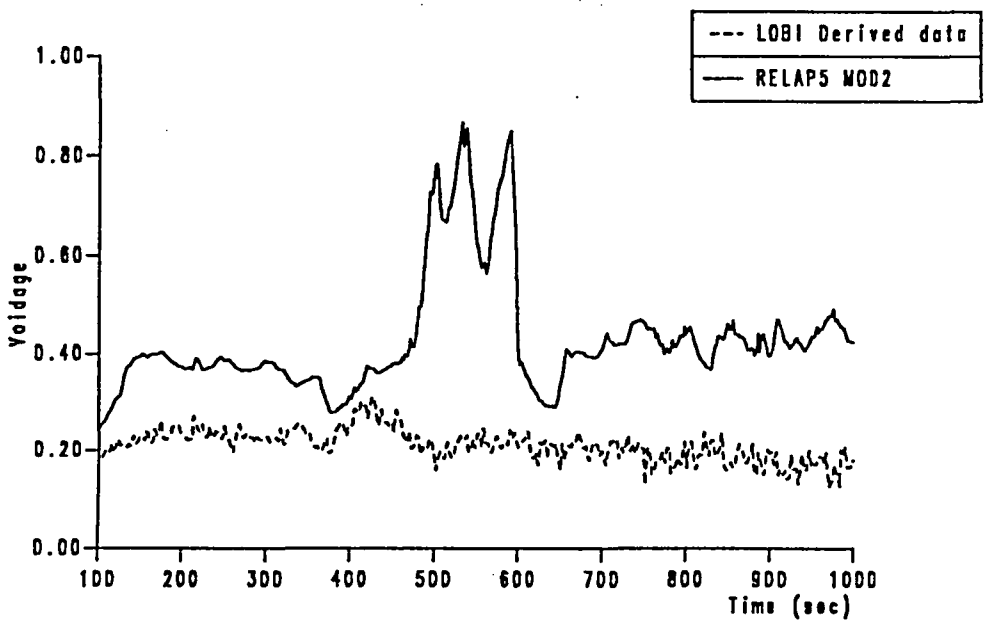

FIG. 32 VOIDAGE IN UPPER PLENUM REGION

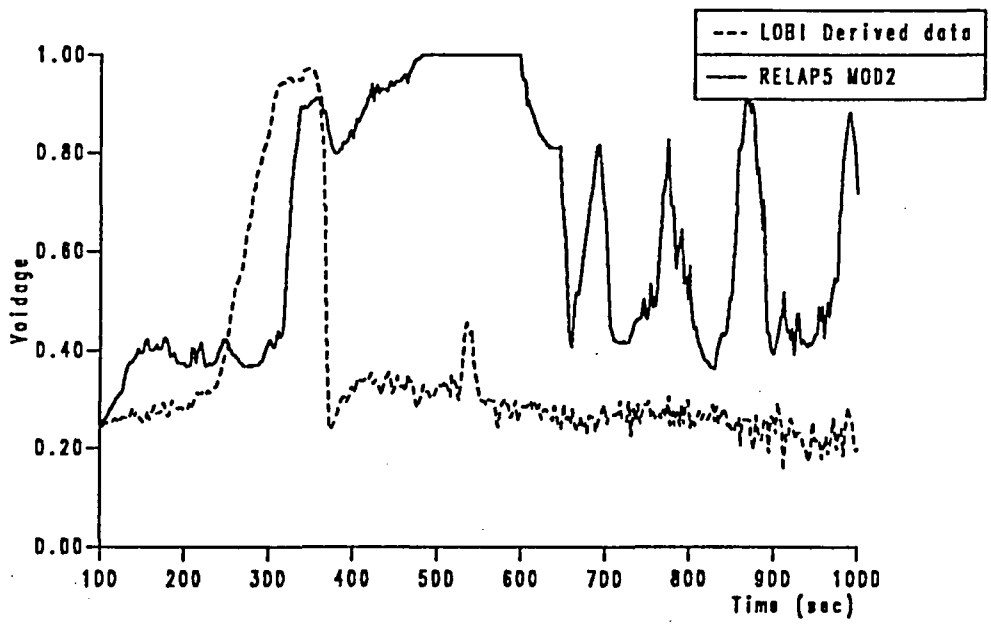

FIG. 33 VOIDAGE IN RISER JUST BELOW NOZZLE ELEVATIONS

(C)

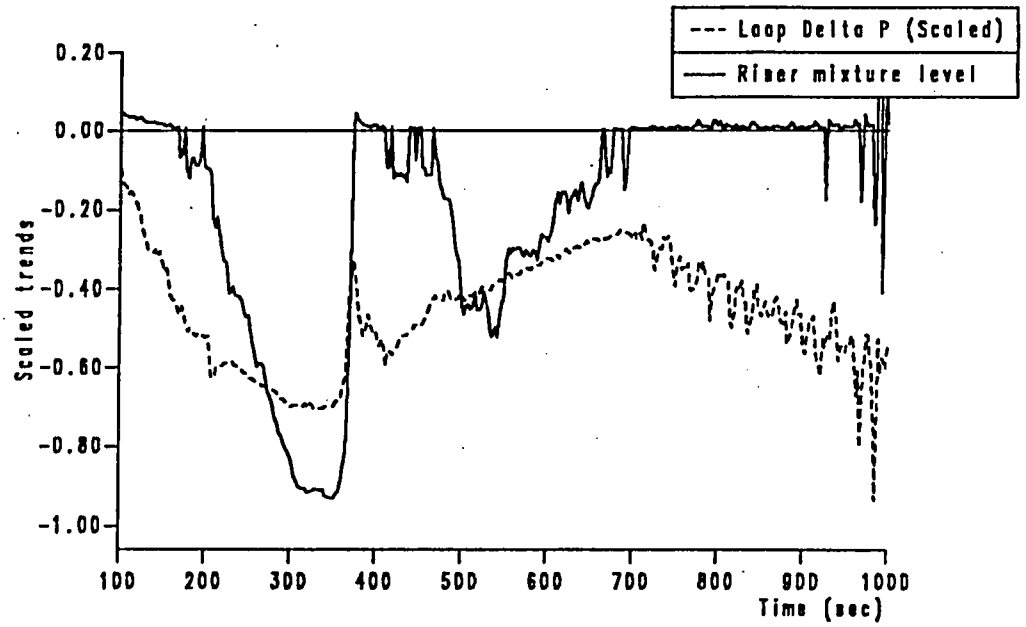

FIG. 34 RELATION BETWEEN MIXTURE LEVEL AND LOOP DP: LOBI DATA

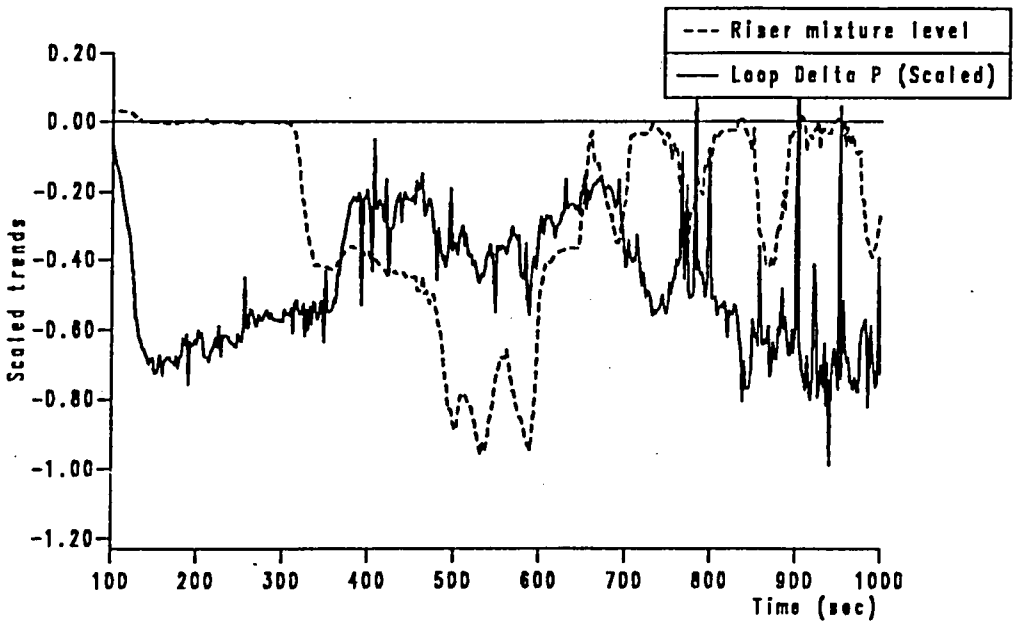

FIG. 35 RELATION BETWEEN MIXTURE LEVEL AND LOOP DP: RELAP5 RESULTS

(C)

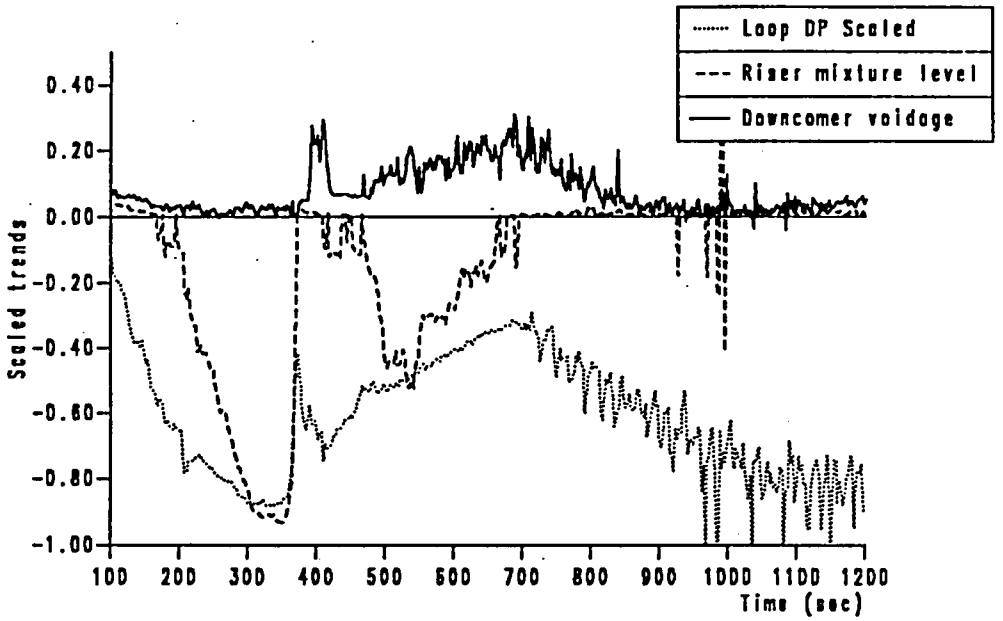

FIG. 36 LOBI DOWNCOMER VOIDAGE, RISER LEVEL AND LOOP DP

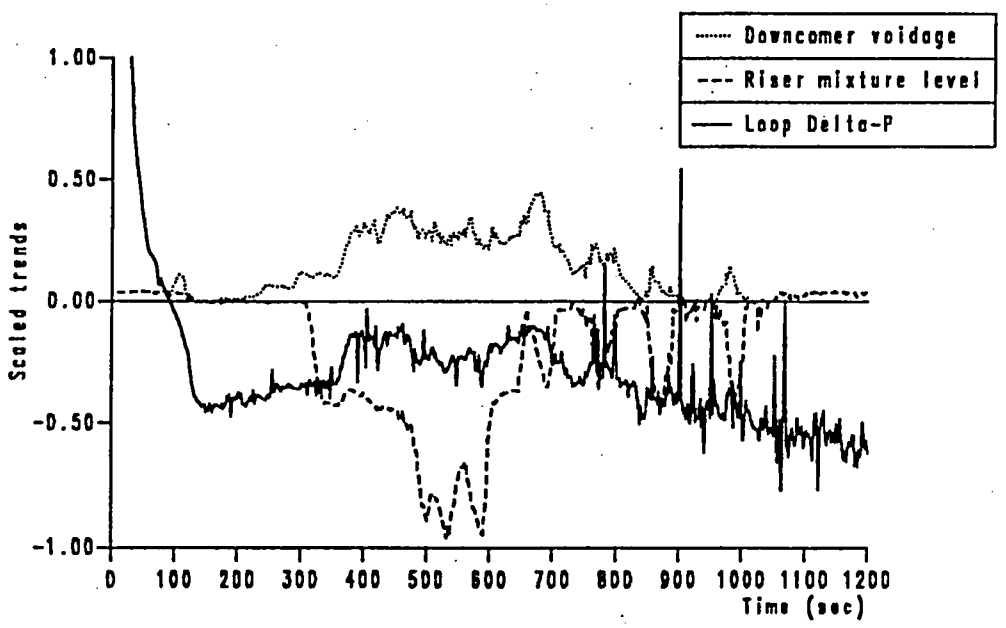

FIG. 37 DOWNCOMER VOIDAGE, RISER LEVEL AND LOOP DP: RELAP5 RESULTS

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

The test BL02 was a United Kingdom specified test conducted on the electrically heated 2-loop test system at Ispra, North Italy, as part of the LOBI 'B' series of tests sponsored by the Joint European Research Commission.

The pretest calculations for this test were performed with the RELAP5/MOD1 code and the post-test analysis was carried out using RELAP5/MOD2. Comparisons between the code predictions and the test data are given, and for the case of the post-test MOD2 calculation, detailed studies of the codes performance in a number of areas are included.

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RELAP5/MOD1 Code
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MARCH 1992