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International Agreement Report

Application of the RELAP5/MOD2 Code to the LOFT Tests L3-5 and L3-6

Prepared by
A. H. Scriven

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Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
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April 1992

Prepared as part of
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NOTICE

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APPLICATION OF THE RELAP5/MOD2 CODE TO THE LOFT TESTS L3-5 AND L3-6

A. H. Scriven

Addressee: Mr. K. Ardron, NPN-TD Barnwood

SUMMARY

RELAP5/MOD2 is being used by National Power Nuclear, Technology Division for calculation of certain small break loss-of-coolant accidents and pressurized transients in the Sizewell 'B' PWR.

The code version being used is RELAP5/MOD2 cycle 36.05 Winfrith version E03. As part of the programme of assessment of this code a number of comparisons of calculations with integral test facility experiments are being carried out.

At the request of NPN-TD the LOFT 2.5% small cold leg break tests L3-5 (pumps off) and L3-6 (pumps on) have been calculated. These previously performed tests involved a number of features, including stratification, pump performance and offtake effects which suggested they would be useful measures of code performance

Conclusions

1. For both tests the RELAP5 MOD2 code performed the numerical calculation with no difficulties.

2. The time step selection logic in the code needs to be improved. In one test it would, if not overridden, have required twice as much computer time to complete the calculation as was actually needed.

3. For both tests the code performed well. Most differences from the experimental results were either minor or related to uncertainties in the input data to the code. (Two major uncertainties were the upper plenum bypass flow and the pump moment of inertia. The upper plenum bypass has a large effect on the whole transient, while the pump inertia only affects the early part of the transient.)

4. The code coped well with the high voidage pumping regime found in L3-6, although the pump model in RELAP has been 'tuned' to this test by the code developers.

5. A recurring code problem was the excessive interphase drag sometimes calculated by the code. In one case this probably prevented the draining of the steam generator 'U' tubes, and in another led to an incorrect secondary side mass inventory.

6. The value of the L3-5 experiment for code assessment was greatly reduced because of uncertainty in the critical input parameter of upper plenum bypass. Two calculations performed with and without such bypass produced widely different results which bracketed the experimental values.

7. The analysis suggests that the upper plenum bypass in LOFT is located at least as low as the hot leg nozzle elevations, rather than in the upper part of the vessel, and may be smaller than has been reported by EG&G.

8. Although flow conditions in the pipe containing the break offtake were stratified for long periods, these tests did ***not*** provide a sensitive test of the modified offtake entrainment model in the code. This was because the fluid level in the pipe was only very briefly at the elevation of the break offtake, so the overall effect of the offtake model was small.

9. In the pumps on test, L3-6, the high loop mass flows prevented RELAP from predicting stratified conditions in the loop at a time when the experimental data clearly indicated stratification.

10. Correct modelling of the LOFT pump moment of inertia has been highlighted as being of significance even for small break tests. This is frequently ignored in LOFT analyses. The LOFT data giving the speed dependent moment of inertia has been seen to be in error, and a simpler model has been suggested.

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Approved: I. Milne

Contents ....✓....

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Date ....17 Jan. 90....

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1 INTRODUCTION

1.1 Background to This Work

The RELAP5/MOD2 code has been chosen by National Power Nuclear, Technology Division (NPN-TD) as the tool for performing small break calculations in support of the Sizewell 'B' Pre Operation Safety Report (POSR).

The version of the code to be used is MOD2 cycle 36.05 together with a number of optional model improvements implemented by the Atomic Energy Establishment (Winfrith).

Before undertaking the formal plant calculations, the code is being tested against a wide range of experiments. This exercise is necessary to help to identify and quantify any code shortcomings. In particular, because of the model improvements included in the NPN-TD version of RELAP, it is important to confirm that the code continues to perform at least as well as the internationally released code for which a great deal of validation has been carried out.

The LOFT test facility at Idaho in the USA, although now decommisioned, remains unique in its nuclear core and scaling. During the LOFT test programme a large number of tests were performed and the results recorded. Calculations of LOFT tests form a major part of any code assessment.

In 1980 two tests were performed in the LOFT facility. These tests, designated L3-5 and L3-6 were 'twin' tests. Both represented a four inch equivalent (2.5%) break in the cold leg, and they were started from nominally the same initial conditions and with the same arrangement of the emergency injection system. The difference was simply that in L3-5 the primary coolant pumps were turned off shortly after the break was opened, while in L3-6 the pumps were left running until late in the transient. The idea was to see which operation resulted in the worst core uncovery and subsequent fuel rod heatup.

Calculations were performed for each test, both before and after the test was run. These calculations were carried out by the LOFT analysis team at EG&G using the RELAP5/MOD1 code which they were then developing. (Condie, Kee, Modro and Chen 1981, Condie and Modro 1980 and Chen, Condie and Modro 1980).

Shortly after, test L3-6 was specified as an International Standard Problem, (Number 11), for calculation by many countries. In fact this author submitted a calculation for this exercise using the RELAP4/MOD6 code. (Scriven 1982). The results of the submissions from many different organizations were summarized in a comparison report. (Peterson and Cook 1982). Overall these tests have been quite extensively calculated. Even so there remain several areas of every calculation which show discrepancies with the data.

At the request of NPN-TD, both tests were calculated again, using the RELAP5/MOD2 code currently employed by NPN-TD. RELAP5/MOD2 contains significantly different models to those in MOD1, and in particular the model to calculate the offtake of fluid from a horizontally stratified pipe has been rewritten in the NPN-TD version. In test L3-5, with the pumps inactive, the flow in the cold leg containing the break is known to stratify, thus providing a useful benchmark.

These calculations are to form part of an assessment matrix for the NPN-TD code version. This matrix seeks to cover the range of conditions likely to be found when calculating full scale plant transients and these two test in particular contain many features typical of small break accidents.

1.2 Philosophy of This Calculation

When performing post-test calculations, it is possible to 'tune' the results obtained, both by changes to the input data specified and to the models in the code. This tuning is aimed at better matching the experimental data.

If performed in a methodical way this can be a useful way of testing the sensitivity of the calculation to small changes in some parameters. In some cases the uncertainties on input data may even justify such 'adjustment'. In others it is worthwhile knowing the effect of some change to allow a 'fingerprint' of a code shortcoming to be built up.

The purpose of recalculating L3-5 and L3-6 with RELAP5/MOD2 is to validate the use of the code for full scale plant calculations, for which there is no 'correct' data for comparison. Therefore a fair test of the code is to employ it as if the experimental data were not known in advance.

In essence this means that the optional model improvements which can be selected should be chosen to be those currently recommended for plant use, and the noding detail should be comparable with that used in full scale plant calculations. The initial conditions for the test are then recreated in the input data, together with any 'events' such as pump trips and valve opening, which are needed to define the course of the transient. With this done the code is run, and the result taken to be the 'best-estimate' for that test. No further refinement or 'tuning' of the calculation is then permitted.

These are the guiding principles which were adopted, as far as possible, for the L3-5 and L3-6 calculations.

2 THE EXPERIMENT

2.1 The LOFT Facility Configuration for L3-5 and L3-6

The LOFT facility has been described in numerous reports, the most detailed being the facility description document produced by EG&G (Reeder 1978). For this Report it suffices to recall that LOFT is a 1/70th scale representation (by volume) of a Pressurized Water Reactor with a 50 MW nuclear core. It has a single active loop, comprising 14 inch diameter piping, a steam generator and two parallel pumps. Two dead-end pipes simulate what was a broken loop when the facility was being used to model large break blowdowns. These pipes have no use other than fluid storage reservoirs during small breaks tests.

The break location for small break tests is an offtake pipe, containing an orifice, connected to the cold leg of the pumped loop. This small pipe, roughly 1.3 inches in diameter, is attached at the centreline of the 14 inch cold leg piping, and this arrangement produces a strong interaction between the fluid level in the cold leg and the discharge quality. The system is depicted in Fig. 1 on page 3 below.

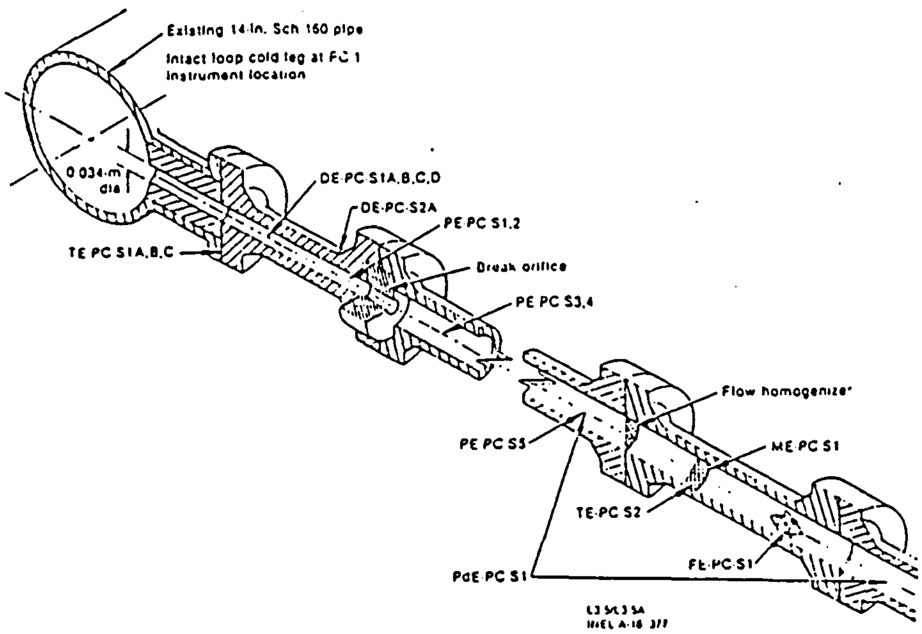

Fig. 1. Schematic of the LOFT small break offtake configuration

In both tests the high pressure injection lines were connected directly into the top of the downcomer, rather than the more usual attachment to the cold leg midway between the pumps and the vessel.

Full details of the tests are given in the EG&G Experimental data reports, Dao and Carpenter 1980 and Peterson and Cook 1982.

2.2 Highlights of the Twin Tests

The purpose behind these two tests was to investigate the effects of a late pump trip.

2.2.1 L3-5

In L3-5 the pump was tripped very soon after reactor scram, which is the currently recommended practice. The loop flow reduced and single phase natural circulation commenced. As fluid is discharged from the break so the pressure falls and vapour formation begins. This causes a transition to two-phase natural circulation, which continues until the primary side pressure drops below secondary side pressure, at which point it ceases as the steam generator is no longer a heat sink. In L3-5 this occured at 750 seconds.

During two-phase natural circulation it is possible for the vapour which is condensing on the cold steam generator 'U' tubes to run back into the vessel upper plenum via the hot leg. This situation of counter current stratified flow in the hot leg and heat removal from the core with zero net loop flow is termed 'reflux condensation'. In Condie, Kee, Modro and Chen 1981 the EG&G authors argue that this mode probably did not take place in L3-5, based on their analysis of the relative flow areas available for liquid and vapour flows in the hot leg.

However conditions in the loop were characterized by low flows and distinct stratification.

With the steam generator not acting as a heat sink, energy removal is via the break. The High Pressure Safety Injection (HPIS) provides makeup fluid which boils in the core and discharges as steam and hot water from the break. This is a stable condition unless the water level in the core is depressed below the level of the loop piping.

Depression can occur if vapour is unable to reach the break from the upper plenum. Pressure buildup in the upper plenum forces the water level down and can uncover the fuel rods. Normally it is the presence of a few meters of water in the 'U' shaped loop seals directly upstream of the primary coolant pumps which creates a blockage in the loops, preventing vapour from passing round the loop to the break in the cold leg. In LOFT however there are other substantial flow paths, or bypasses, which connect the upper plenum to the top of the downcomer and hence allow direct passage of the steam to the break.

Because of these flow paths there was no significant level depression in L3-5 and the fuel rods were always covered. Therefore the fuel rod temperatures remained at the saturation temperature throughout the test.

L3-5 was therefore a 'benign' test with no threat to the plant.

2.2.2 L3-6

In L3-6 the pumps were left running after the reactor was tripped. This meant that the loop
the loops was highly mixed, suppressing stratification. Because of this the quality of fluid exiting the break was substantially lower than in L3-5, leading to a greater depletion of primary fluid mass. While the pumps remained on the core was well cooled, with fuel rod temperatures remaining at saturation.

The pumps were turned off at the predetermined event of primary pressure reaching 2.27 MPa (2371 seconds). Immediately the fluid around the system collapsed, settling out and stratifying. The level in the core was below the top of the fuel rods which began rapidly heating up. Also at this time the HPIS was turned off as part of the preparation for a follow on experiment termed L8-1. The heatup was rather severe and was terminated by all available emergency water, that is both HPIS pumps 'unscaled' and the Accumulator 'B'.

This test showed the potentially damaging effects of continued pump operation, followed by a late trip.

3 THE CALCULATION

3.1 Code Version and Options

Both calculations were performed using RELAP5/MOD2 cycle 36.05 version E03 on the Harwell Cray computer. This version includes some 17 optional correction/model improvements. These options have been fully described by W. Bryce at a meeting of the RELAP User Group, (Bryce 1988), at which he listed those options he felt would give the current 'best' prediction.

For the LOFT calculations here all these 'recommended' options were used. They are options 1,3,4,5,7,8,10,13,15 and 16.

3.2 Input Deck Development

3.2.1 Noding Scheme

In common with nearly all RELAP calculations of LOFT experiments, the noding scheme used is derived from an original input deck used by EG&G for their own RELAP5 MOD1 analysis and subsequently released for public use.

This deck was used by NPN-TD for a RELAP5 MOD1 analysis of the LOFT LP-SB-03 small break test,(Harwood 1985) and then modified for use with the RELAP5 MOD2 code, (Harwood and Brown 1986), to include cross flow junctions. The current deck is based on that used by NPN-TD for the analysis of LOFT test LP-FW-01 in 1988 (Croxford, Harwood and Hall 1985), in which some simplifications were made to the inactive dead-end 'broken' loop pipes.

A diagram of the noding scheme used is included as Fig. 2 on page 6.

The deck has 120 volumes, with 8 in the pressurizer, 6 in the active core, 6 in the downcomer, 8 for the steam generator 'U' tubes, 5 for the hot leg and 8 for the cold leg. This detail of noding corresponds closely with that used in the NPN-TD Sizewell reference input deck used for full scale plant studies, (Harwood 1985). This is in line with the philosophy for these calculations, so few changes were made to the overall noding.

For the present calculation the secondary steam valve control system was completely rewritten, the HPIS was modified to inject directly into the reactor vessel downcomer, the transition from steady state to transient was automated, the break modelling changed and the pump speed control and inertia were modified.

3.2.2 Pump Inertia

When the pumps are tripped in L3-5, they coast down as the stored rotational energy is dissipated. The rate of coast down is determined by the combined moment of inertia of the pump system and the initial speed.

In LOFT the pumps are driven in a rather unique way. Each of the two parallel pumps is driven and controlled by a motor-generator set comprising an induction motor, manually adjusted clutch (fluid coupling) and an alternating current generator-flywheel combination. This generator-flywheel is connected to the pump drive motor.

When coasting down the pump can either be left connected to the flywheel system, or decoupled. The standard practice is to have the pump connected to the flywheel system until the speed drops to around 70 rads/sec and then to decouple the flywheel. This procedure leads to a coastdown of around 25 seconds, and the experimentally measured coastdown curve is given on page 160 of Reeder 1978.

In some of the LOFT large break tests, L2-5 for instance, a fast pump coastdown was required in order to investigate the the situation in which an early rewet did not occur. In these cases the procedure was to decouple the pump from the flywheel at the beginning of the test. This leads to a coastdown of the order of 5 seconds. This coastdown was seen in the L2-5 test which was used for International Standard Problem 13 (ISP13) (Burtt 1984).

The LOFT system description manual gives two values for the pump moment of inertia, one of 1.43 kgm^2 for the pump and motor, and a second of 316.04 kgm^2 for the generator and flywheel combined.

When this author calculated the L2-5 test as a submission for ISP13, the small value of 1.43 was used to represent the pump decoupled from the flywheel at the start of

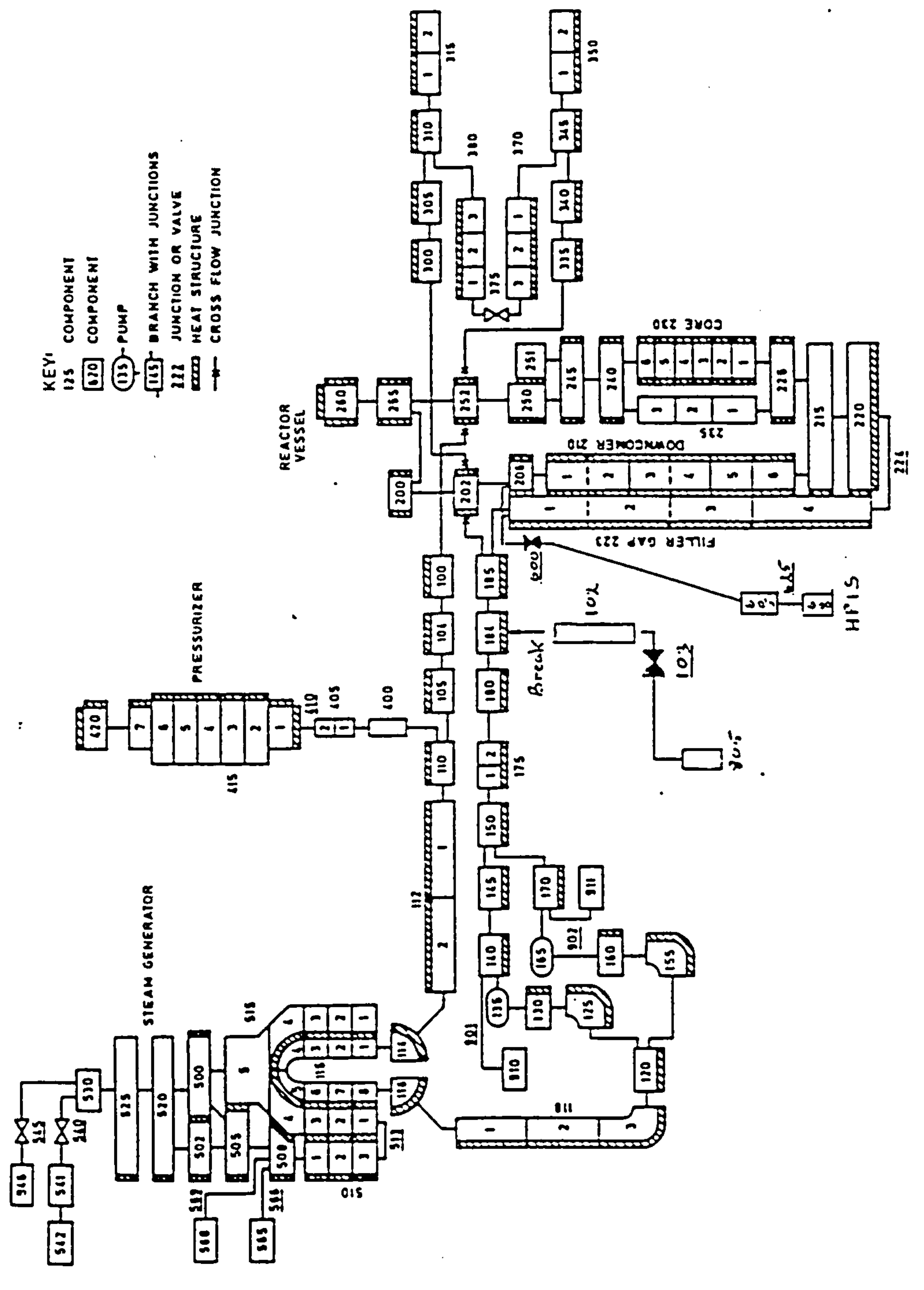

Fig. 2. Noding scheme for both L3-5 and L3-6 calculations

the transient (Scriven 1982). This produced a rapid pump coastdown which well matched the experimental data. In the case of the present tests however there is some considerable confusion.

In both tests, L3-5 and L3-6, the experimental operating documents state that the pumps coasted down ***under the influence of the flywheel system.*** This is born out by the measured pump rotational speeds published by EG&G showing a coastdown over some 25 seconds, matching the curves given in the LOFT system description manual.

Despite this fact, in both of the pre-test calculations performed by EG&G and in both of the subsequent post-test calculations the pump inertia used was 1.43, being that for the pump ***without*** the flywheel (Condie, Kee, Modro and Chen 1981). NPN-TD have also left the inertia set at this value in all of their LOFT calculations, irrespective of the presence or absence of the flywheel.

A further puzzle is that the value quoted for generator and flywheel combined (316.04) is far too large. If this value were to be used the pump would coast down over a few hundred seconds! The coupling between the flywheel system and the pump is clearly not a straightforward one.

EG&G themselves recognize this fact. In fact it was because of this very problem that they introduced a special model into the RELAP5 code. This model, called the variable inertia model, allows the moment of inertia to change with pump speed. The model uses a cubic function of the form.

$$I = I_3S^3 + I_2S^2 + I_1S + I_0 \qquad S \ \mathrm{GT} \ W_1$$

In which the inertia at any moment, I, is given in terms of the relative pump speed, S, and four user specified coefficients. This model is applied for pump relative velocities greater than the W_1 set point. The idea is that the user inputs suitable values for I_3 to I_0 to define the moment of inertia as the pump coasts down, and at the moment when the LOFT pump is decoupled from the flywheel, the W_1 setpoint, the inertia switches to the fixed 1.43 value.

The model is invoked simply by entering the coefficients on the CCC0308 input card for the pump. If this card is not entered, the inertia remains at the fixed value.

As stated above it is rather odd that EG&G refrained from invoking this model in their own analyses.

For the LP-02-6 large break test, in which the flywheel system was used, there have been a number of analyses, both with TRAC and RELAP. EG&G made a pre-test prediction with TRAC (Condie, Demmie and Coryell 1983), Los Alamos made post test calculations with both TRAC PD2/MOD1 and TRAC-PF1/MOD1 (Knight 1985), EG&G Services made a post test RELAP5 MOD2 calculation (Pena 1985) and most recently AERE (Winfrith) made a post test calculation with TRAC-PF1/MOD1 (Birchley, Coddington and Gill 1988).

EG&G ***did*** use a cubic speed dependent inertia for their TRAC calculation, although they set the cubic coefficient to zero. Los Alamos appear to have used similar data, although it is not specified in the report. AERE Winfrith, in the most recent calculation also used the same data, and the EG&G services RELAP5/MOD2 calculation began by also using this data.

The coefficients used were

$$I_3 = 0$$

$$I_2 = -22.86511$$

$$I_1 = 27.016042$$

$$I_0 = 5.745888$$

Taking the relative pump speed as one, for full speed operation, would therefore lead to a moment of inertia for coupled operation of about 9.9 kgm² which is quite different from the 316.04 quoted in the LOFT system description manual.

All these calculations failed to predict the correct pump coastdown, giving a coastdown which was too slow.

Los Alamos and Winfrith both discuss this and suggest that the cubic inertia equation is incorrect. EG&G services tried modifying the coefficients, but were only able to improve some parts of the coastdown curve, and finally resorted to using a table of pump speed versus time.

The relation between inertia and pump speed is given in Fig. 3. It can be seen that it varies between 5 and 15 during the coastdown.

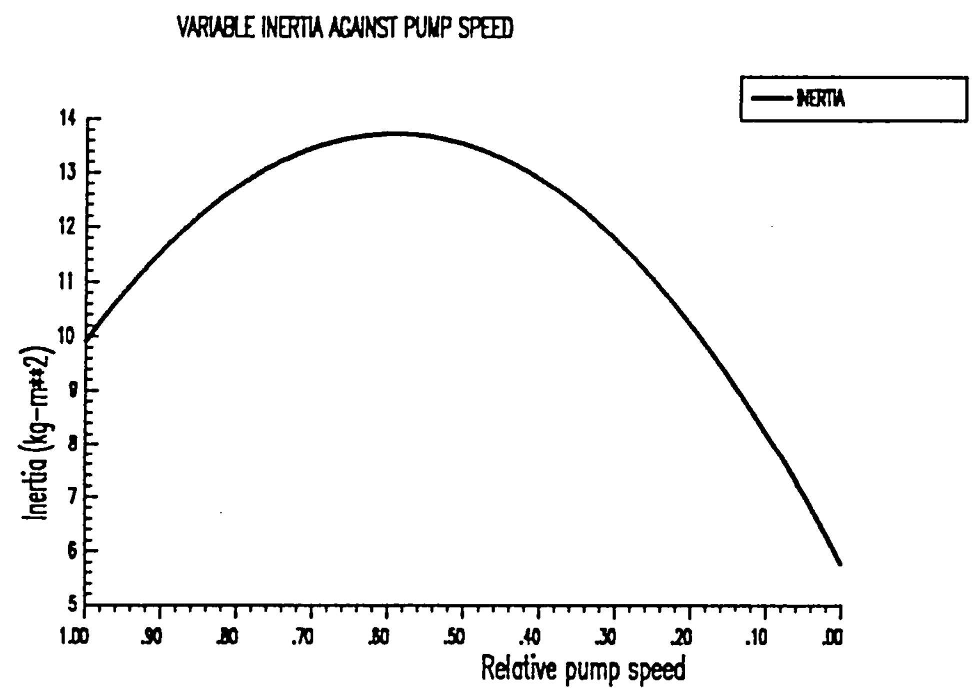

Fig. 3. Variation of inertia with pump speed from cubic equation

Often the effect of the pump coastdown on major system parameters such as pressure is very small. It is only apparent when the pumps are tripped early in the transient when the core power is still comparatively high. This is the case in L3-5, while in L3-6 the run down of the pump is of no significance.

In L3-5 the pumps are tripped at 0.8 seconds. At this time considerable heat is still being transferred from the core to the steam generators by the forced loop flow. The exact manner in which the loop flow decays will affect the energy removed from the system and hence will change the primary pressure response. Because of this it is important to account for the pump coastdown accurately.

Because of the uncertainty over what value to use for pump inertia, it was decided that for L3-5 some brief investigation of the consequences was needed. The L3-5 calculation was run through the initial steady state period up to transient initiation. Following this, three short calculations were made, restarting from the end of steady state and running for some 50 or so seconds.

1. In the first the pump inertia was set to that connected, (1.43).
2. In the second this value was increased arbitrarily to 4.
3. In the third this value was further increased to 22.

These values represent the uncoupled behaviour, and the bounds of the inertia given by the variable inertia equation.

For each of these this value was maintained, with no attempt to model the decoupling of the flywheel which occurs in LOFT when the speed drops below 70 rads/sec. Furthermore the variable inertia equation was not used as this will tend to obscure the results as it changes the inertia during coastdown The results are shown in Fig. 4 on page 10 and Fig. 5 on page 10 below.

The first thing to note is that none of the calculated coastdowns match the experimental data. However as the decoupling of the flywheel was not modelled, this is to be expected. For the purposes of this calculation it is most important that the time of the end of coastdown is best fitted. This is the time forced flow ceases and natural circulation takes over. From the curves presented it was thought that the coastdown with moment of inertia 4 gave the best approximation to this. Therefore the remaining part of the L3-5 transient was restarted from the calculation using this value.

The experimental coastdown curve ***after*** the flywheel decouples looks very similar to the predicted coastdown with the 1.43 moment of inertia. This indicates the correctness of the uncoupled moment of inertia, and the correct operation of the RELAP model.

From these results we can deduce that a reasonable model would be to set the inertia to 10, reducing to 1.43 when the flywheel decouples at 70 rads/sec. This would be achieved using the RELAP variable inertia model, but setting I_3 to I_1 equal to zero, putting I_0 to 10 and W_1 to trip the inertia back to 1.43 at 73.54 rad/sec. This will prevent the pump coastdown being to dependent on minor changes in pump speed which lead to large fluctuations in the moment of inertia.

Looking at the primary pressure responses produced by these varying coastdowns demonstrates the significance of this effect. The fast pump coastdown reduces the heat transferred to the secondary side and therefore leads to a higher primary pressure during the coastdown period. Although the final pressure reached will be the equilibrium saturation temperature, it can be important to correctly model the early heat transfer to the steam generator. For instance, at the start of this transient the main steam valve is tripped and begins to close. This closure takes some 13 seconds, which means it is open during most of the pump coastdown period.

Heat transfer to the secondary side during this time will produce steam which will both raise the pressure and exit through the main steam valve. Putting extra heat in during this time can lead to extra mass loss through the steam valve and consequently change the liquid inventory of the steam generators. For some transients where the steam generators subsequently boil dry a small change in inventory at the start of a transient can lead to very large differences later on in the time of dryout.

In summary then, there exists an uncertainty in how to model the pump inertia. This has not been fully resolved. The value of 4 kgm^2 was used for these calculations, but a better model may be to use the variable inertia model with the speed dependent terms set to zero giving a two values for the inertia of 10 kgm^2 before decoupling and 1.43 kgm^2 after decoupling.

3.2.3 Break Modelling

How the break is modelled can have a very great effect on any calculation. The physical system being represented is the 14 inch cold leg pipe, a length of 1.3 inch piping connected at right angles to the main pipe which leads to a break sizing orifice, an instrumentation pipe leading to a valve and further piping from the valve to the LOFT blowdown suppression tank. This is detailed in Fig. 1 on page 3.

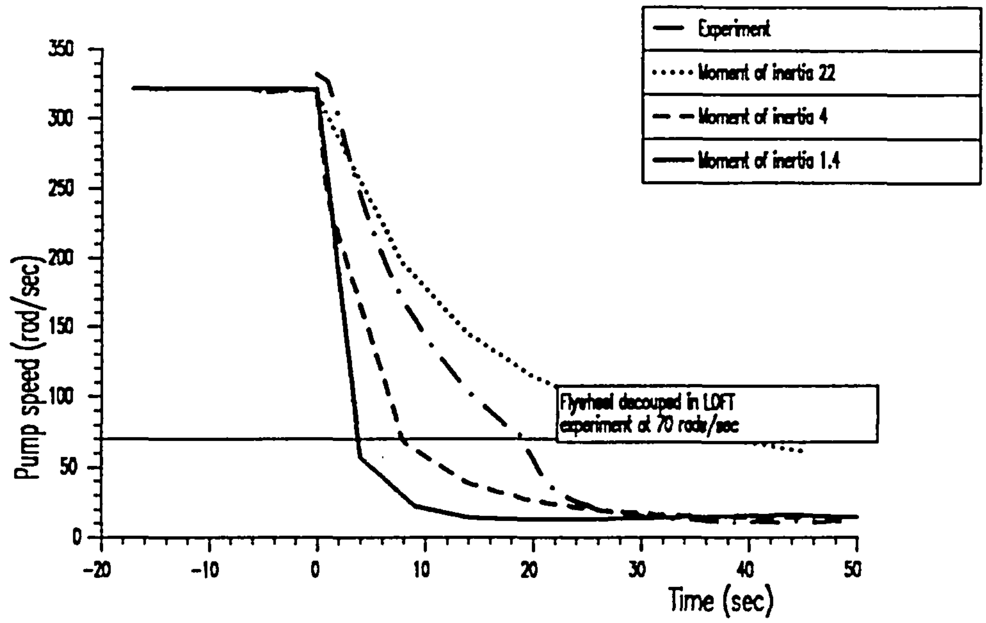

Fig. 4. Effect on pump coastdown of varying the moment of inertia

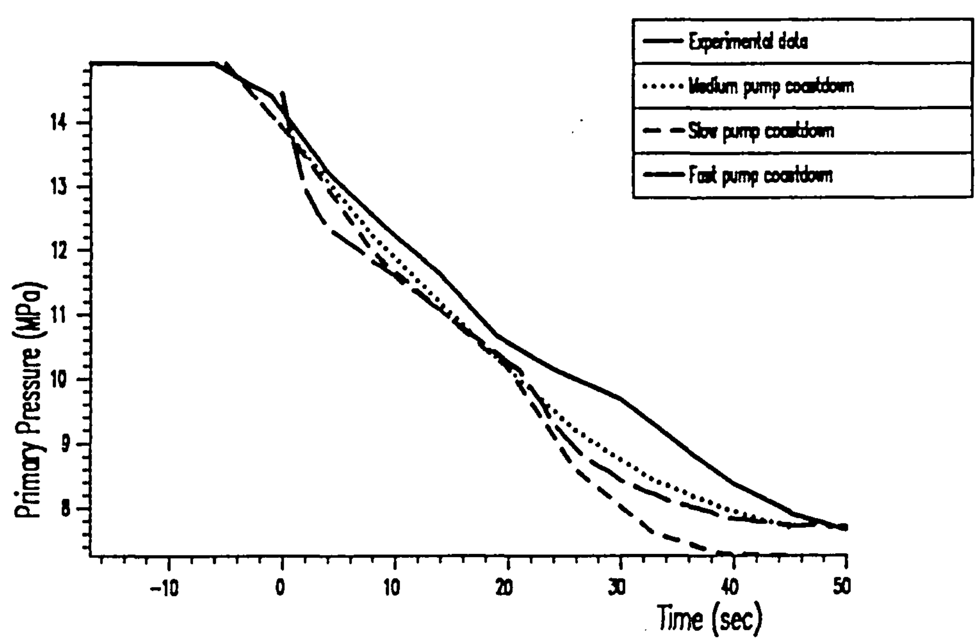

Fig. 5. Effect on primary pressure of different pump coastdowns

In operation the valve is opened to initiate the simulated break. The fluid in the main pipe flows into the offtake pipe, and under two-phase conditions will be at a different quality (and often a different flow regime) to that in the main pipe. The flow out of the offtake pipe through the break orifice is choked. Downstream of the orifice, measuring devices homogenise the flow allowing mass flux to be measured. Because this occurs downstream of a choking plane, this will have no effect on the flow upstream of the break.

There is some choice as to how this geometry is modelled in RELAP. In MOD1 of RELAP ***all*** *junctions had to connect to either the inlet or outlet of the essentially 1* dimensional volumes. Both the pre and post test analysis performed by EG&G used MOD1 and modelled the offtake junction in this way. This is actually incorrect as there is no account of the change in flow direction at the junction, giving spurious momentum effects, and the results can vary depending on which volume the junction attaches to.

RELAP5 MOD2 has an extra model, the cross-flow junction, especially designed to overcome this limitation. It can be thought of as attaching to the middle of a volume, rather than the ends, and it neglects the momentum terms present in the main pipe flow when calculating the cross flow.

NPN-TD used this model in their calculation of both LP-SB-01 and LP-SB-03 (Harwood and Brown 1986 and Hall and Brown 1986). These transient also had a similar break offtake arrangement.

However in a report detailing several calculations of a range of small break sizes in the Sizewell plant, (Harwood 1988), NPN-TD did not use this model, choosing instead a normal end junction. Furthermore in the RELAP5 Developmental Assessment manual, (Bryce 1988), when EG&G calculated the small break L3-7 test, despite using MOD2, they also chose a normal junction for the break.

In the case of the NPN-TD calculation it is known that the choice was made based on the *efficiency of code running. Using a cross-flow junction would have introduced a* very small volume just upstream of the break, and probably resulted in slower code execution. However the reason EG&G made a similar choice for L3-7 is not known.

Overall it was decided that the cross-flow junction should be used together with the modified Ardron-Bryce entrainment model for offtake from a horizontally stratified volume. This choice was later confirmed by NPN-TD as their current best modelling practice, and is consistent with the philosophy for these calculations stated earlier.

Therefore the break offtake was modelled with a cross-flow junction from the main loop piping feeding into a horizontal volume. The junction was specified as in the middle of the pipe. At the end of the horizontal volume a valve was included discharging directly into a time dependent volume. This valve, when fully open, had the same area as the break orifice used in the experiment.

This slight simplification of the break geometry effectively combines the break orifice and break opening valve. Therefore conditions ***downstream*** of the break will not be directly comparable to those seen in LOFT. However the effects of cross flow from the loop piping into a small bore pipe, and the possible stratification in this pipe directly upstream of the break will be correctly represented.

A two-phase choking multiplier of 0.84 was used at the break. This value is given on page 44 of the Post-test analysis report, (Condie, Kee, Modro and Chen 1981), and agrees with that derived from modelling the break nozzle response as measured in the LOFT Test Support Facility (LTSF). This is the figure most commonly used in small break analyses with RELAP5.

3.2.4 Bypass Effects

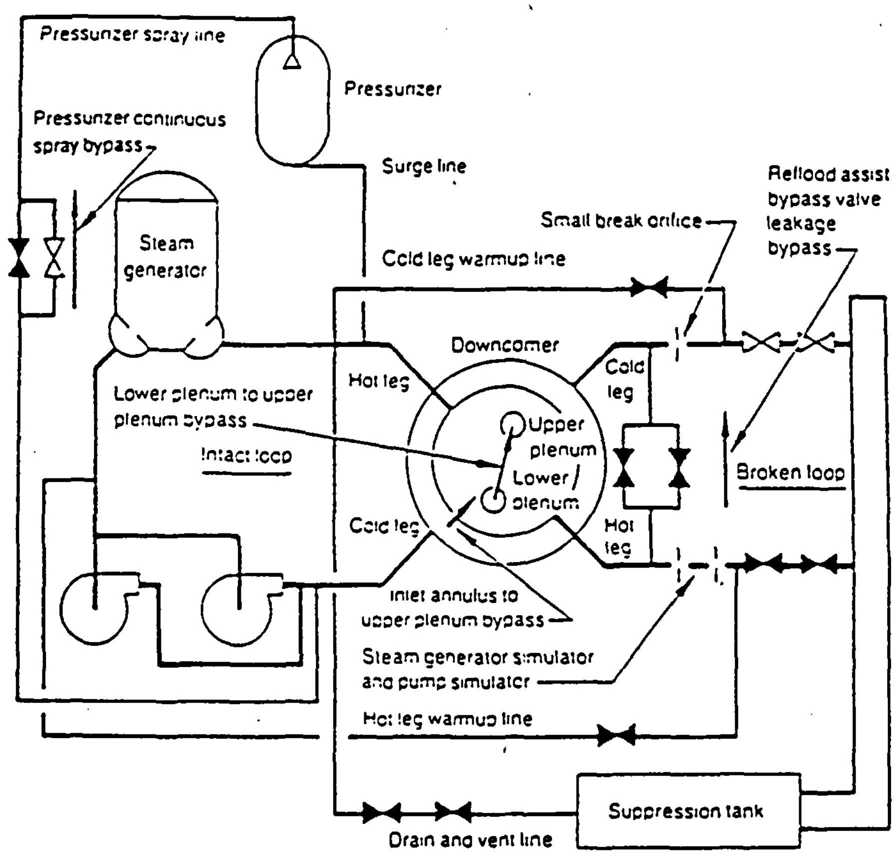

Fig. 6. Bypass paths in the LOFT facility.

In the same way that data on the correct pump inertia, discussed above, appears somewhat uncertain, there are also problems with knowing what sizes and locations of bypass to use for the LOFT facility.

Loft has three major bypass paths, and these are shown in Fig. 6. They are

1. Lower plenum to upper plenum. (3.6%)
2. Inlet annulus to upper plenum. (6.6%)
3. Reflood assist bypass valve leakage. (1.3% but varies with pressure)

The figures in brackets are the percentage of the total primary loop flow which pass through each route in normal operation. These figures are those given on page 26 of Condie, Kee, Modro and Chen 1981.

Of these three, the lower plenum to upper plenum can be neglected as any errors in this value will have only a minor effect on the calculation. The remaining two bypasses however are crucial.

In L3-6 with the pumps on, these bypasses are of marginal importance. However in L3-5 the pump trip leads to stratification around the system. A liquid level develops in the reactor vessel, both in the downcomer and in the upper plenum. Steam produced in the core must find some way to exit through the break, or be condensed. This is where the bypasses become important. If steam can exit easily from the upper plenum to the top of the reactor downcomer, and hence to the break, there will be no pressure buildup and the downcomer and upper plenum levels will be approximately level, except for the reduced density in the core due to vapour.

If there is considerable resistance in the bypasses, the downcomer and upper plenum levels will be affected, which in turn affects the densities in both hot and cold legs and impacts on the break flow. In this case knowledge of the correct bypass flows can be absolutely vital to a good prediction of major experimental effects.

The bypass sizes in the LOFT deck obtained as the basis for the present calculations gave flows of 2.6% and 1.5% respectively for the upper plenum and valve leakage flows. It is unclear why the value for the upper plenum bypass is so different from that quoted by EG&G themselves in Condie, Kee, Modro and Chen 1981. However the upper plenum bypass flow was left at 2.6%.

A potentially greater uncertainty involves the exact postion of the upper plenum bypass. In the standard LOFT deck the bypass is modelled between the top of the downcomer and the top of the upper plenum. This effective ensures that any steam produced in the core can exit via this route to the top of the downcomer.

In Appendix A of Croxford, Harwood and Hall 1985 it is argued that there could be bypass at the level of the hot leg nozzle penetrations. If all the bypass occurred at this elevation the effects produced would be quite different, a fact which was demonstrated in the aforementioned report by changing the bypass location.

With a bypass at a much lower elevation, steam is effectively prevented from reaching the downcomer. Consider the situation shown in Fig. 7 on page 14.

Here the bypass is assumed to be at nozzle elevation, and the mixture level in the core is above this point. Vapour collecting at the top of the upper plenum cannot exit via this bypass. In effect when the liquid level in the downcomer or upper plenum is at or above the nozzles, there is ***no*** vapour bypass at all.

This presents a problem for the L3-5 analysis. This effect is likely to influence the whole nature of the transient, and yet cannot be accurately modelled.

To overcome this is was decided to perform ***two*** calculations of the L3-5 transient. The first would use the bypass size and position in the basic LOFT deck, while the second, restarted some 100 seconds into the transient, would have ***no upper plenum bypass at all.*** This was accomplished by deleting the bypass junction 208 on restart.

Analysis of both these calculations will highlight the role of this bypass flow and allow some bounding estimates to be made.

3.3 Modelling Test Specific Effects

3.3.1 Steam Control Valve

The Main Steam Control valve dominates the early secondary side behaviour. This valve opens and closes at 5% per second. At Scram the valve begins to close, reaching the shut position about 13 seconds later. However when shut the valve still passes a small amount of steam. This leak rate varies from experiment to experiment. For L3-6 it was probably equivalent to about 0.5% of the total flow area (quite a lot), and for L3-5 it was about half this.

This valve is also used to relieve the pressure buildup on the secondary side. It is set to open as the pressure rises above 71.2 bar and to close when the pressure drops below 64 bar. In L3-6 the pressure never quite reaches this set point, partly because of the continual leak, but noise in the measurement system did cause the valve to open around 88 seconds into the transient. This dropped the pressure and when the lower limit was reached, the valve closed. For L3-5 the valve opened also,

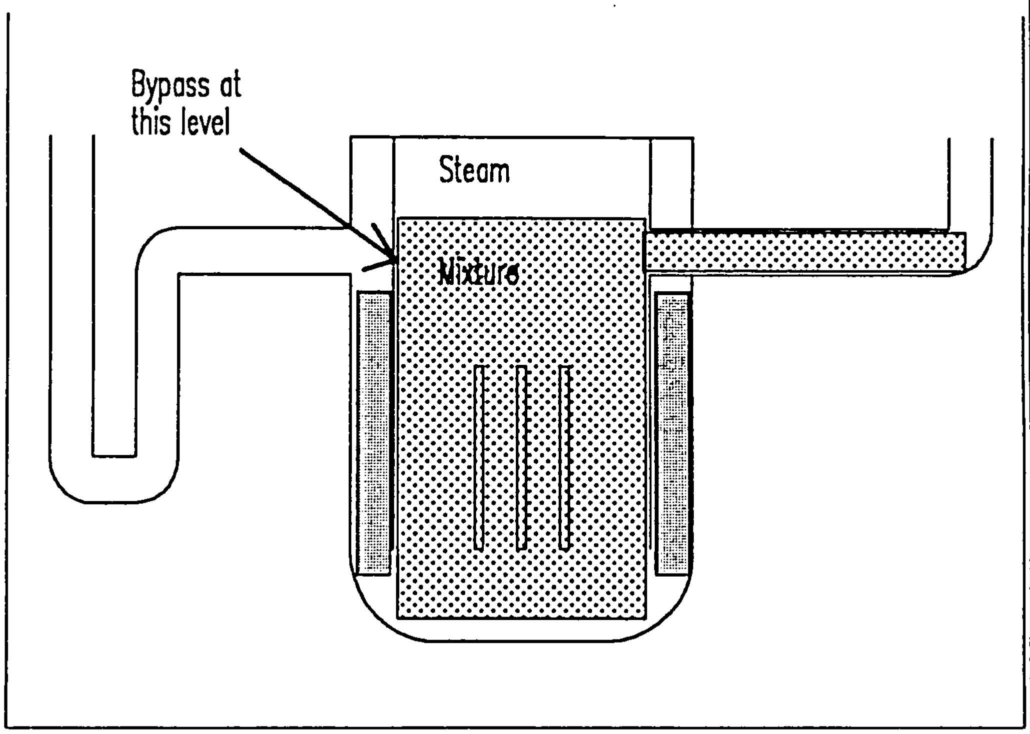

Fig. 7. Effect of bypass location on steam flows

around 80 seconds, but it is not clear if this was again instrument noise, or if in fact the pressure actually did rise above the set point.

During the early stage of the transient, just after scram, the behaviour of the secondary side is quite important. The primary side begins with a cold leg temperature defined by the secondary side sink temperature. The temperature of the hot leg is simply the cold leg temperature plus the rise generated by the heat transferred from the core. At scram the core power decays rapidly, and the temperature difference between hot and cold legs. decreases. The primary side temperature tends towards a single temperature, and this temperature then controls the saturation pressure at which the primary side pressure will hold up.

During this temperature equilibration the primary side is losing heat to the secondary side. This heat is divided between heating up the secondary side and making up the energy loss via steam exiting through the main steam valve. (There is a small environmental heat loss term, but at this stage of the transient it is negligible.) The more steam which leaves the secondary side through the main steam control valve, the lower will be the rise in secondary side pressure and temperature, and in turn the lower will be the final primary side pressure which is reached as fluid in the hot legs begins to flash and halt the initial depressurization.

The core heat input is greatest immediately after scram. This is also the time that the energy transport *from* the secondary side is largest due to the steam flow through the main steam valve.

Any small errors in the prediction of the steam flows during this period will therefore introduce quite large discrepancies in the observed system behaviour.

In practice this means that the main steam valve initial position and closure rate must be accurately represented.

To model this the RELAP deck was configured to match the valve response time of 5% per second maximum travel. The valve area was carefully chosen so as to give the correct measured initial steam mass flow ***with the valve at the same position of 60% open as measured.*** If the valve position had been incorrect, then despite a correct initial flow rate, the closure time of the valve would have been incorrect and the integrated steam flow would have been in error. This need to simultanously match the valve position and steam mass flow rate is often not appreciated in post-test analyses.

There is one further complication. Valve flow area is related to valve stem position in an imprecise manner (i.e. the data is not normally available). Normally this is taken as a linear relation, but especially when the valve is almost fully closed, there can be very large differences, both in linearity and offset. The exact relation for the LOFT steam valve is not known. Because of the sensitive dependence between the decaying core power and the steam exiting the secondary side, small errors in valve area can be significant in terms of secondary side pressure reached.

To assess the magnitude of this effect it canbe assumed that the valve behaves like a ball valve. A simple calculation to give the overlapping area between two circles a given distance apart produces:-

$$\text{Area} = 2\left[R^2\theta - \frac{xR\sin(\theta)}{2} \right]$$

Where x is the distance between the circle centres, R is the circle radius and θ is given by $\theta = \cos^{-1}(\frac{x}{2R})$. This is shown in Fig. 8 and Fig. 9 on page 16.

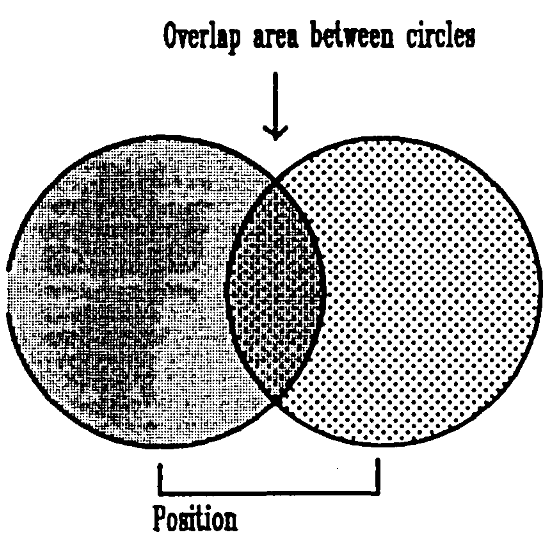

Fig. 8. Overlapping area between two circles

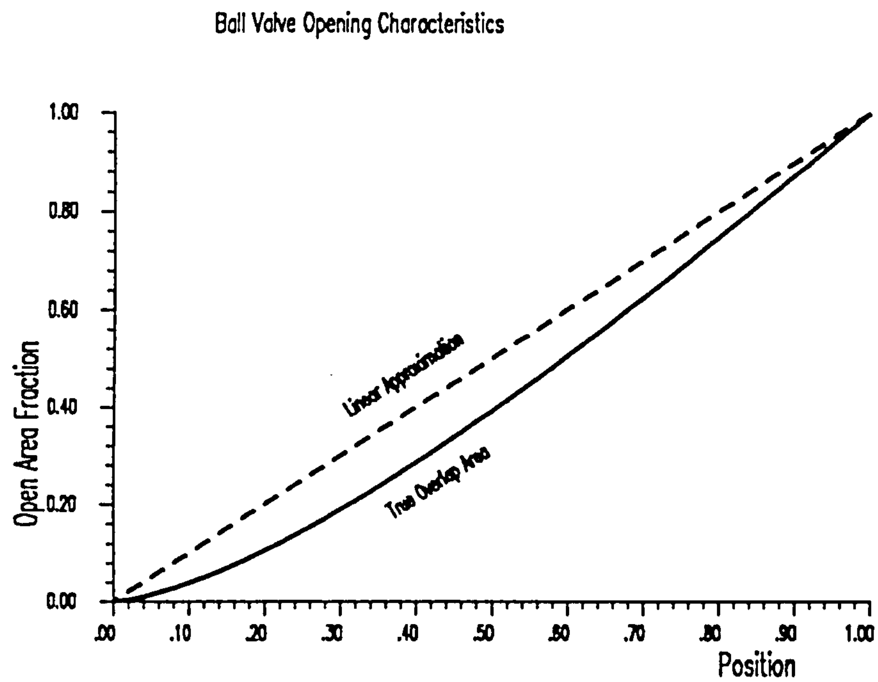

Fig. 9. Typical ball valve characteristics

Taking as an example the unspecified opening of the steam valve at 88 seconds in the L3-6 transient, the LOFT data shows that the valve opens to 15% position before closing. For a linear response this would correspond to 15% open area, but with the assumption of ball valve like opening it becomes only 8% open. This in turn affects the secondary side pressure dip seen in the transient.

These effects are significant, but are related to unknown valve characteristics. Therefore there remains an uncertainty in the input data which will affect the predicted secondary side response. It is possible to adjust the valve position versus area table to give a 'best fit' to the observed secondary side response, but it must be remembered that this may tend to mask other effects which are perhaps not correctly modelled.

In the RELAP calculation the valve position versus area table was left as a linear relation, and the resulting slight over-prediction of the secondary side pressure rise can be interpreted as a consequence of this.

A leak of 0.5% for L3-6 and 0.25% for L3-5 was included when the valve was shut, but the experimentally spurious opening at 88 seconds was specified as a given timed setpoint. This was necessary because in the experiment the valve control logic incorrectly triggered on noise, an event which can not be expected to be predicted by the correctly modelled control logic. By explicitly specifying the time of triggering of the valve setpoint the effect of the rapid secondary side depressurization on the primary side can be seen clearly. However the valve response ***after*** this setpoint trips is modelled using the correct valve response times and characteristics.

3.4 Initial Conditions

Both calculations were begun with a null transient. This serves to check the stability of the initial conditions, and to allow direct comparison with the experimentally measured values.

The initial conditions reached after 200 seconds of the null transient were steady for all the major parameters. For all except the steam mass flow the agreement with the experimental values was very close, being within the experimental uncertainty. Reproducing these here would convey little, the conditions are fully tabulated in Bayless and Carpenter 1981 and Dao and Carpenter 1980, and the agreement can be seen in the comparison plots presented in section 4. It is more constructive to concentrate on the ill matched parameter, the steam flow.

The control system in the RELAP deck was designed to automatically converge several of the major but independent parameters. The primary pressure was fixed with a time dependent volume on the pressurizer. The pump speed was adjusted to give the measured loop mass flow. The core power was fixed. On the secondary side the pressure was controlled via the opening of the main steam control valve and the auxiliary feed maintained the water level. A correct match for these parameters is therefore 'built-in'.

This means the dependent parameters are the hot and cold leg temperatures and the steam mass flow. The cold leg temperature is fixed by the secondary side pressure plus the heat transfer. The hot leg temperature is fixed by the core power input and the mass flow and the steam flow is fixed by the heat input of the core transfered from the primary side via the 'U' tubes.

With this arrangement the RELAP calculation produced good hot and cold leg temperatures but too much steam flow, about 3 kg/sec more than the measured 28 kg/sec by the end of the null transient. This is 10% of the total energy removal, or around 5 MW. Environmental losses of 0.2 MW and pump energy input of some 0.4 MW maximum cannot significantly affect this size of imbalance.

By performing an energy balance we find that with 50 MW of input power (assuming no environmental heat losses for the moment) and a pressure of 55.7 bar this steam flow corresponds to an initial liquid temperature very close to saturation.

What this appears to mean is that in the calculation the main feed, entering the system at around 224 centigrade, has not yet brought the steam generator secondary side to its equilibrium proportions of saturated and subcooled liquid. While this could be corrected by running the null transient longer, or by better initialization of the subcooling when starting the calculation, it was considered of little significance for these tests.

Overall then the primary and secondary pressures, flows, temperatures and levels were adequately matched.

3.5 Experience with Running the Code During the Transient

Generally there were no problems in running the code for both transients, in as much as the calculation proceeded without encountering numerical failures.

The code calculated at about real time speed for the L3-5 transient but ran much slower with the pumps on in the L3-6 transient, giving about three times slower running overall. This leads to a generally applicable comment on the time step control in the code.

3.5.1 Time step control

The L3-6 transient highlights one of the problems with the RELAP5 timestep control algorithm. This problem has been mentioned before in Relap User Group meetings, and was a suggestion by this authcr for an area of work in the RELAP5/MOD3 ICAP improvement plan, but has never been seen as clearly manifest as in this calculation.

Because the pumps are running throughout most of the transient, flow velocities are high. The timestep control scheme limits the timestep based on the Courant limit in the junction node just downstream of the two parallel pumps. In this node fluid velocities are just larger than 10 m/s and the node length is .5 m giving a Courant limit just slightly over .05 seconds. With a user input maximum time step of .2 seconds, the code halves the timestep giving .1 and then .05 seconds. Both of these are ***greater*** than the calculated Courant limit, so the code halves again and fixes the timestep at 0.025 seconds. This value would then be maintained until the pumps trip at 2300 seconds. ***With this small timestep the code runs around 5 times slower than real time.***

Changing the user maximum timestep to .16 seconds means that the code will reduce it though .08 to .04 which then satisfies the Courant limit. With a 0.04 timestep the code is running nearly twice as fast as with a .025 timestep. Over 2000 seconds the savings in CPU time and money are considerable.

Although the careful user can identify this kind of problem, it is basically due to the rigid timestep halving/doubling scheme which RELAP uses. A more flexible scheme which could increase and decrease timesteps more smoothly and faster would be a major advance. An additional bonus would be the smaller number of repeated timesteps taken as the code tries to rapidly reduce timestep size when conditions change rapidly.

4 THE ANALYSIS

The analysis of the calculated results will be presented in two sections, the L3-6 test will be discussed first followed by the L3-5 test.

Comparisons between the nature of the phenomena seen in the two tests have been made in several previous documents, and will not be repeated here.

4.1 L3-6 (Pumps on)

As described in Section 2.2.2, the continued pump operation ensured a well wetted core despite a large mass depletion. It is interesting to see how RELAP copes with the high quality/high velocity flows round the loops, and with the break flow under these conditions.

To gain an overall impression of the transient calculation, some of the commonly compared 'major' parameters will be presented, followed by more detailed discussion of the discrepencies. To begin with Fig. 10 to Fig. 13 show four frames from an animated system mimic which is showing mixture level. (In the first picture, the stratification shown in the horizontal pipes is only an attempt to indicate the void fraction without recourse to colour; the flow regime is actually slug flow. The remaining pictures really do have stratified conditions. Also note that the steam generator is shown to be discharging steam in all four frames. This is the small leak which was modelled.)

In the first frame, after 500 seconds of break flow, the upper plenum has voided, and a level has appeared at the outlet nozzle elevation. The downcomer is full up to the cold leg nozzle elevation, but the loop piping is full of a frothy mixture

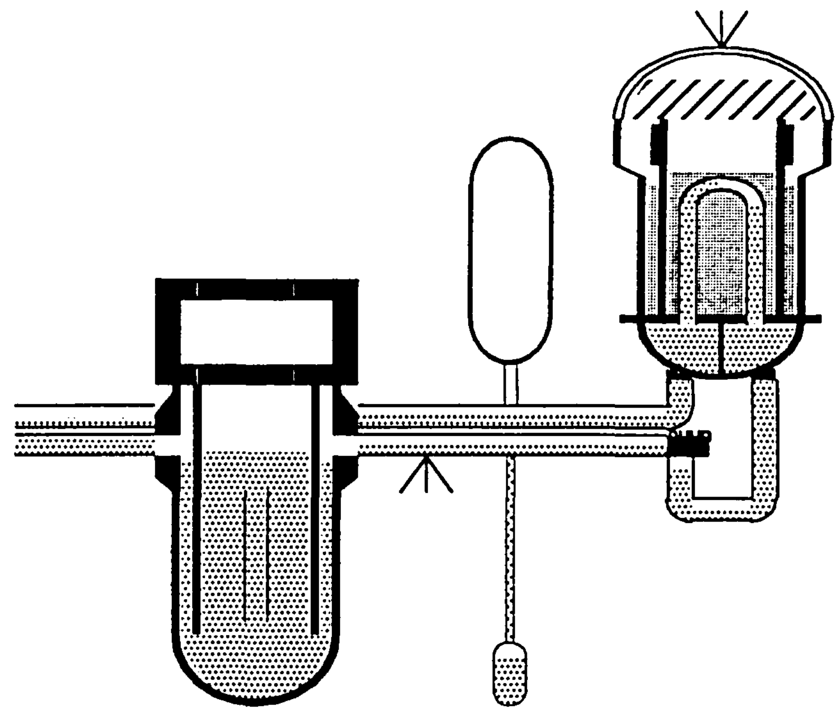

Fig. 10. Mixture levels at 500 seconds

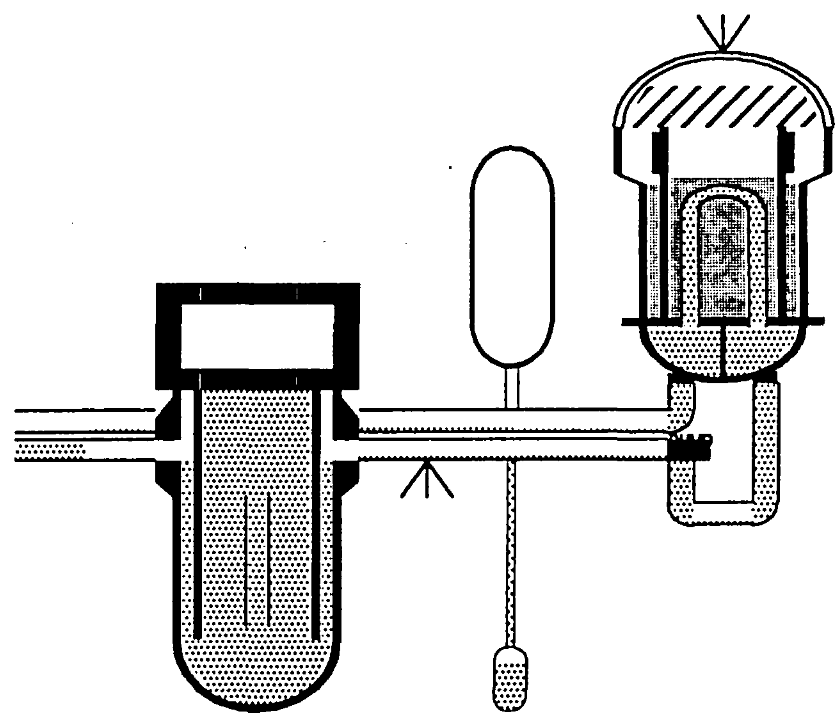

Fig. 11. Mixture levels at 1162 seconds

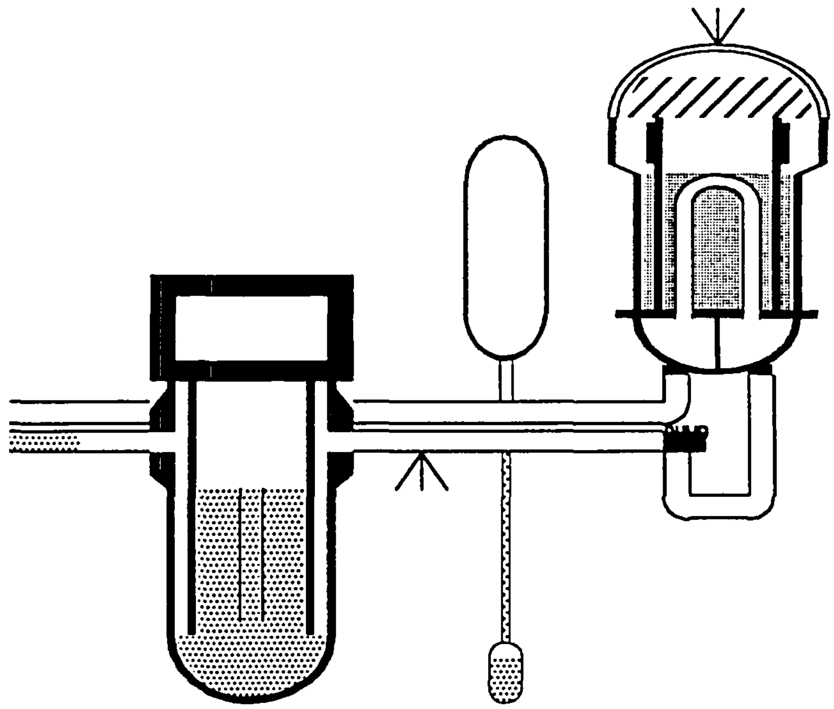

Fig. 12. Mixture levels at 2273 seconds: Just before pumps are tripped

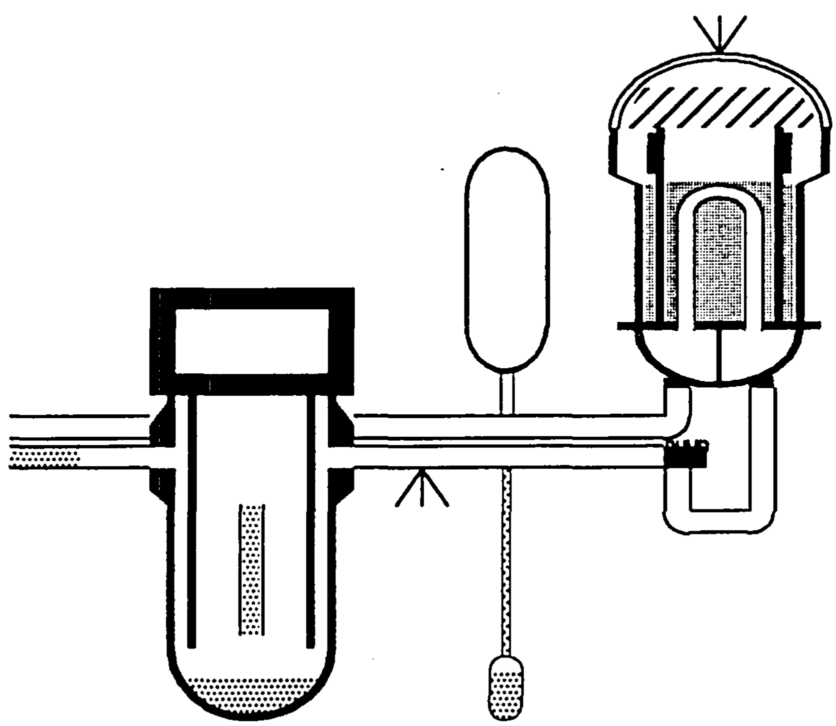

Fig. 13. Mixture levels at 2396 seconds: Just after pumps have been tripped

By 1163 seconds a rather interesting effect is shown. The voidage in the loop pipework has increased, and both hot and cold legs are stratified, with rather low liquid levels, but the vertical sections of the steam generator are still full of a frothy mixture. Further more the upper plenum now shows no distinct level. (The mixture level is based on a clear separation of the liquid from the vapour above, if the voidage gradient is smooth there will be no calculated mixture level even if the voidage in the upper volumes approaches unity). The level in the downcomer is still at the nozzle elevation. The pump is able to maintain a flow even with such a high voidage, and the high steam flow passing through the low quality mixture in the core prevents a clear mixture level from forming.

Just before the pumps trip on pressure of 2.15 MPa, the situation is as shown in the third frame. The entire active loop appears empty of liquid, the level in the downcomer has fallen to near the bottom, but the core is still just covered. The mass flow around the loop is some 5 kg/s of steam and this seems just enough to hold the frothy mixture up in the vessel.

In the last frame the pumps have tripped, the loop flow has dropped to zero and the liquid has collapsed into the lower plenum. At this time, hardly surprisingly, the core fuel rod temperatures begin to climb very rapidly.

This sequence demonstrates, rather graphically, the overall nature of the transient.

The next 9 illustrations beginning with Fig. 14 on page 22 give a good indication of the general agreement with the experimental data.

Generally the agreement is satisfactory. Especially pleasing are the densities in the hot and cold legs, the break flow, total system mass inventory and the pressurizer level.

The combination of reasonable primary pressure and correct break flow also leads to a good calculation of the time and nature of the fuel rod heatup. The primary pressure reaches the 2.15 MPa setpoint at 2267 seconds, within 100 seconds of the experimental value. The pumps trip and with the core completely uncovered the whole core heats up, in accord with the experimental measurements.

We look now at the discrepancies.

4.1.1 Densities

Although giving excellent overall agreement[1] , the density plots do show one error. The LOFT data for the top and bottom density measuring beams, shown in Fig. 16 on page 23 clearly indicates that the flow is significantly stratified by 600 seconds. This is despite the pumps running and strong mixing taking place.

The RELAP density at this time is in perfect agreement, a rather rare event, but the predicted flow regime is slug flow. The RELAP code does not switch to stratified conditions until after 1000 seconds.

However the code's predicted flow regime is not the only part of the RELAP model which is relevant. Even though the RELAP code does not predict stratified flow, the modified Ardron/Bryce entrainment model would still be used if the mass velocity is less than 2500 $kgm^{-2}s^{-1}$. Therefore if there were an offtake from the hot leg, which in this test there is not, then the offtake quality would reflect to some extent the startification in the main pipe. At 600 seconds, when the experiment is cleary

[1] In LOFT there are three gamma beams used for density measurement at any location. The beams are produced by a single source, and pass through the pipes entering at the 11 O'clock position and exiting to the three detectors at 6 O'clock (Bottom beam), 4 O'clock (Middle beam) and 3 O'clock (Top beam) positions. For stratified conditions therefore the ***bottom*** beam gives the average density. This is the measurement to be compared with the RELAP calculation. The top beam indicates when the level drops below the pipe centreline.

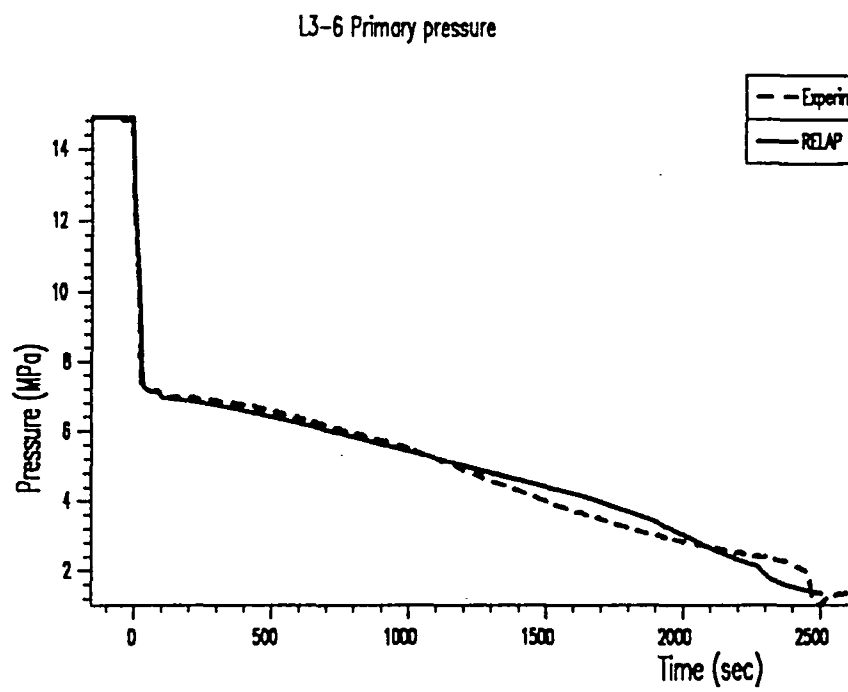

Fig. 14. Primary pressure

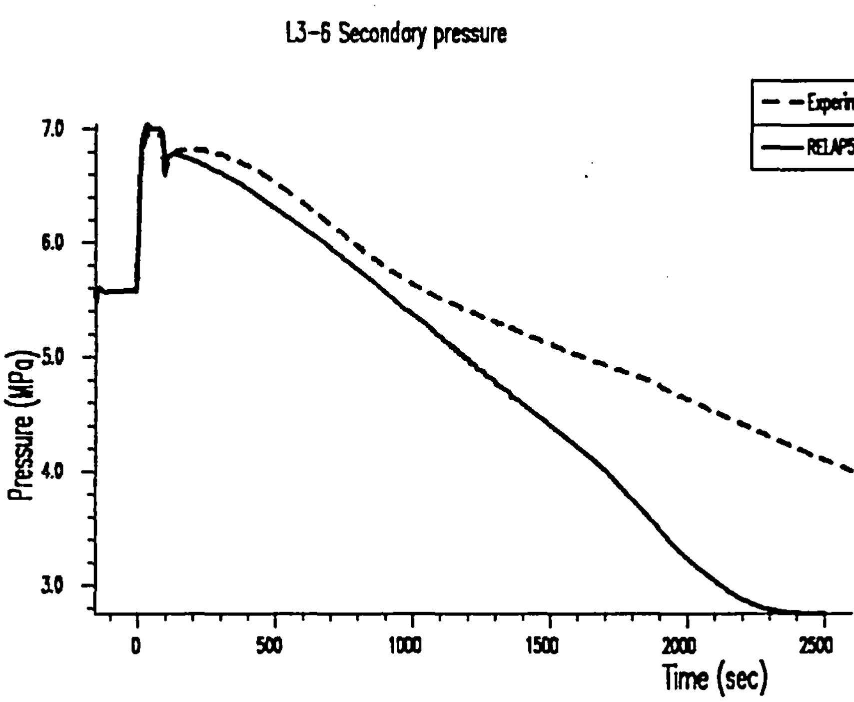

Fig. 15. Secondary pressure

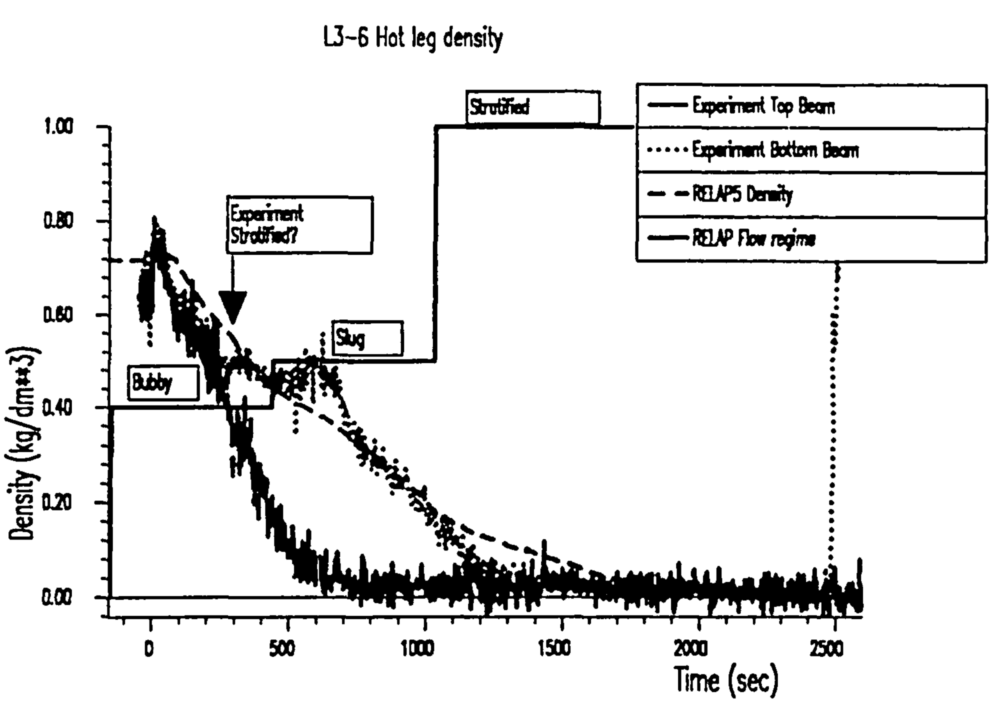

Fig. 16. Hot leg densities

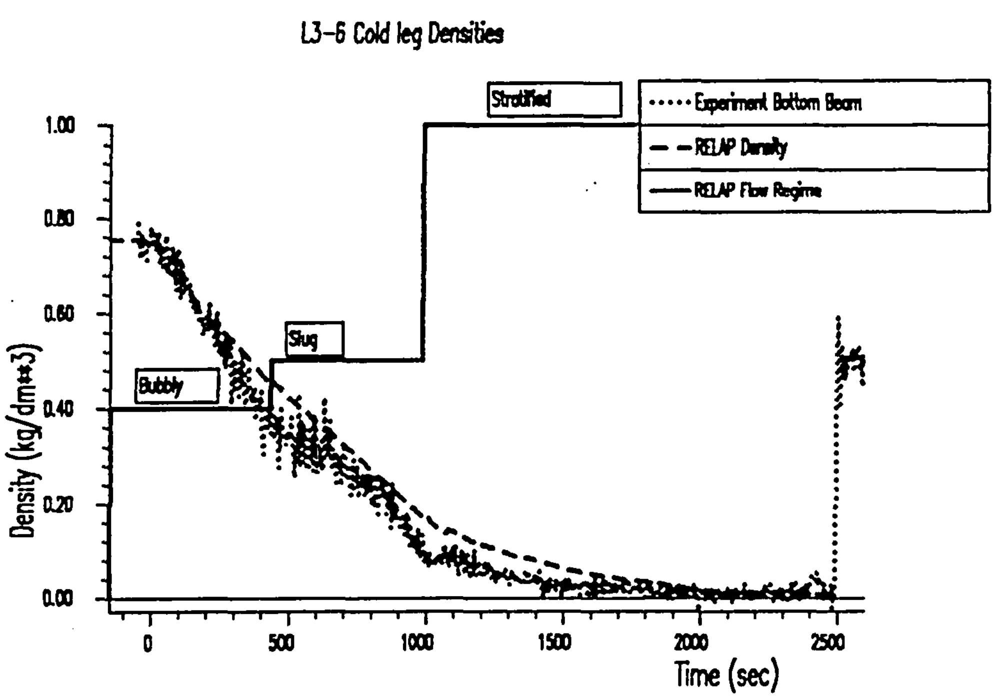

Fig. 17. Cold leg densities

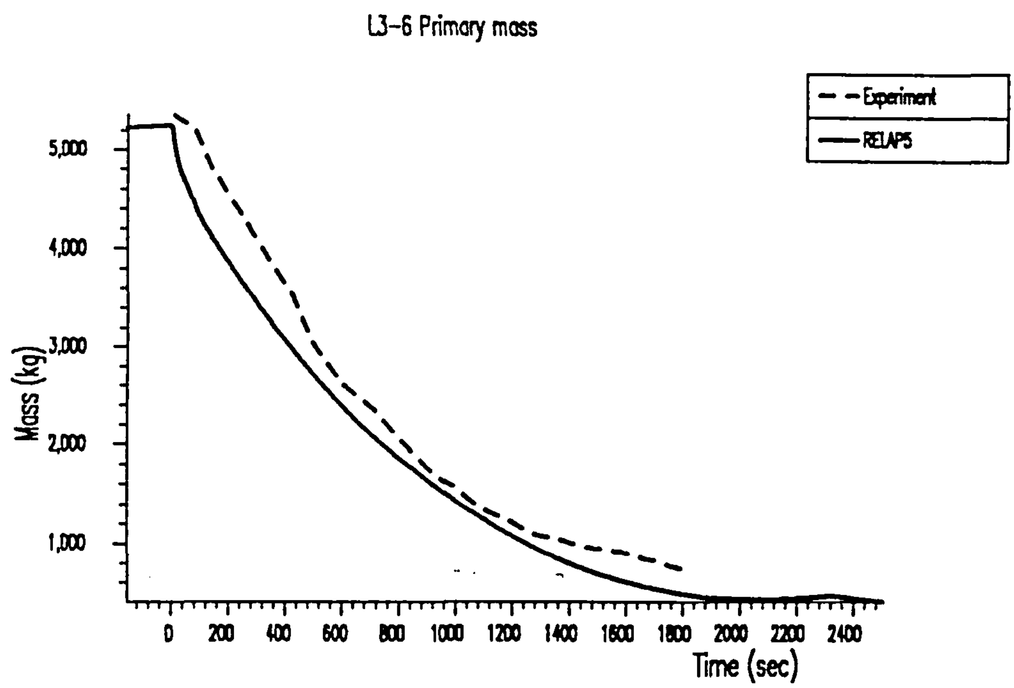

Fig. 18. Primary mass inventory

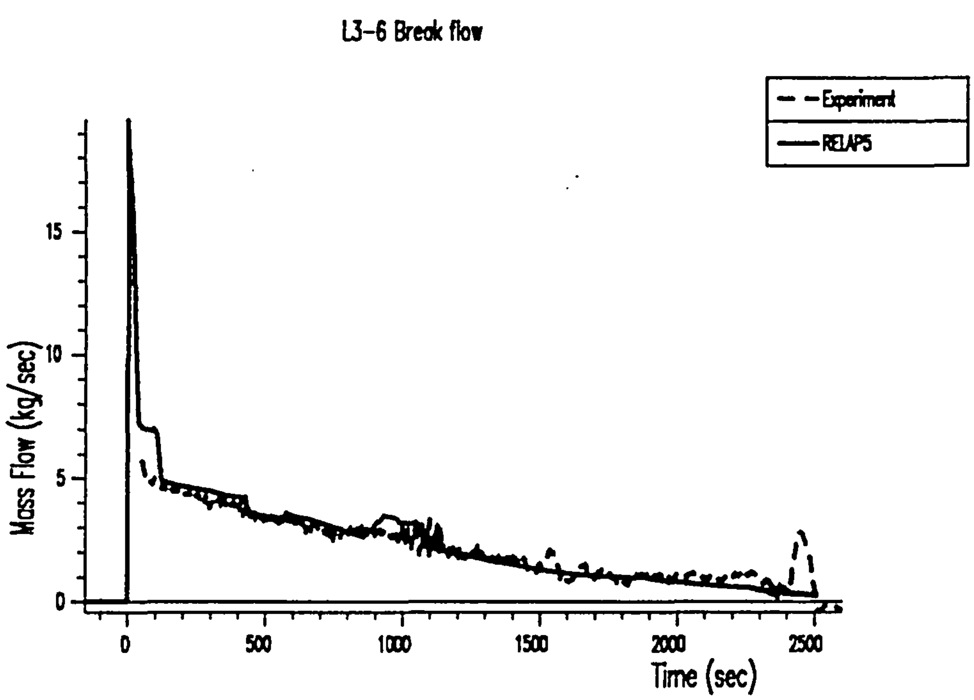

Fig. 19. Break mass flow

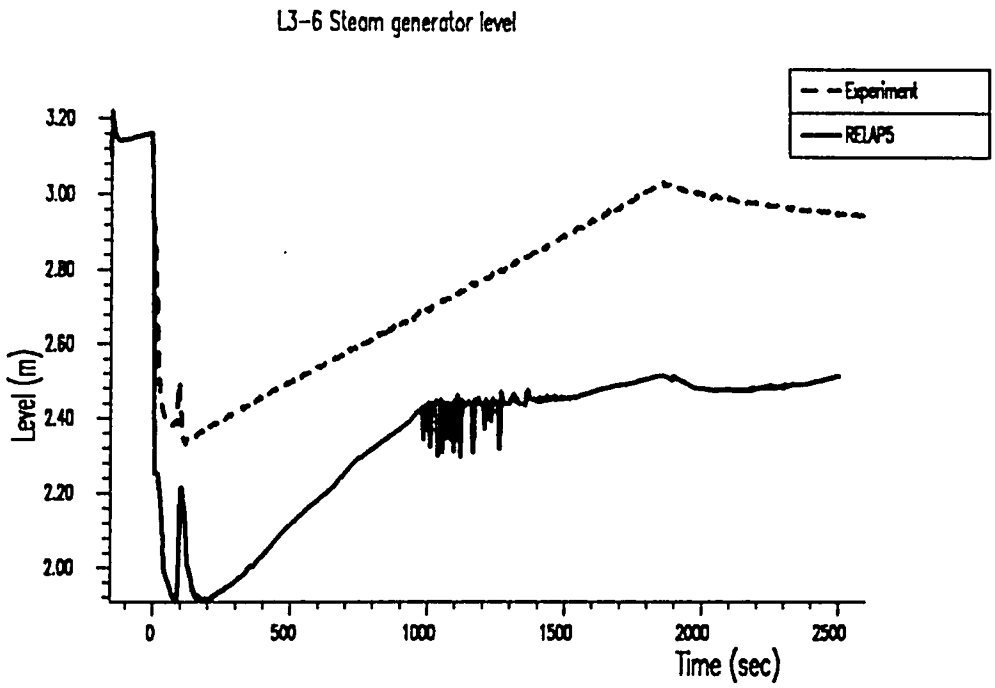

Fig. 20. Steam generator collapsed level

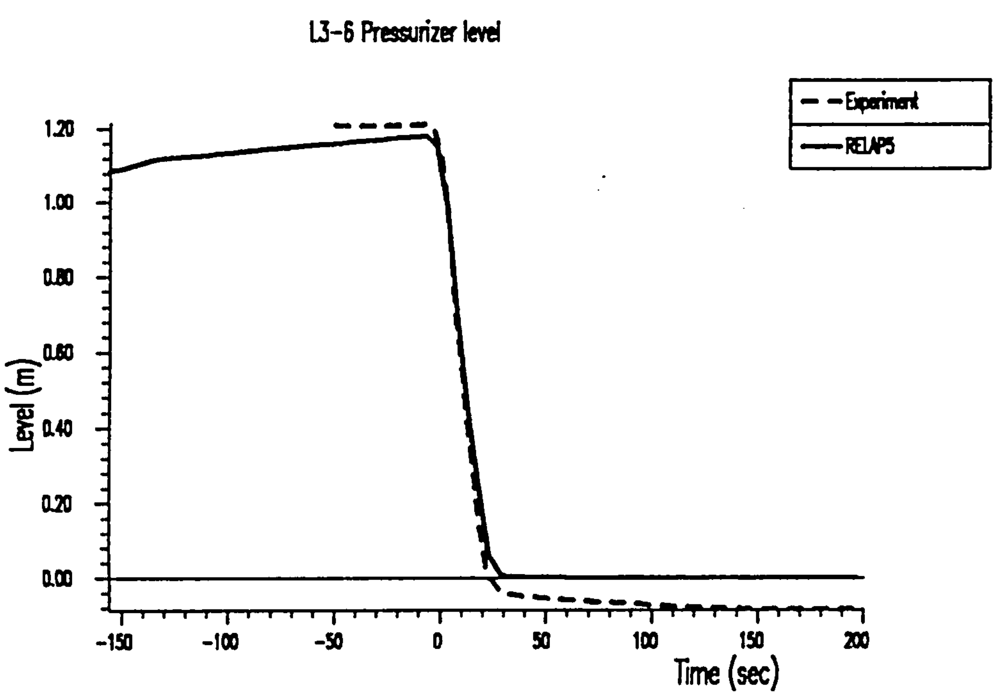

Fig. 21. Pressurizer collapsed level

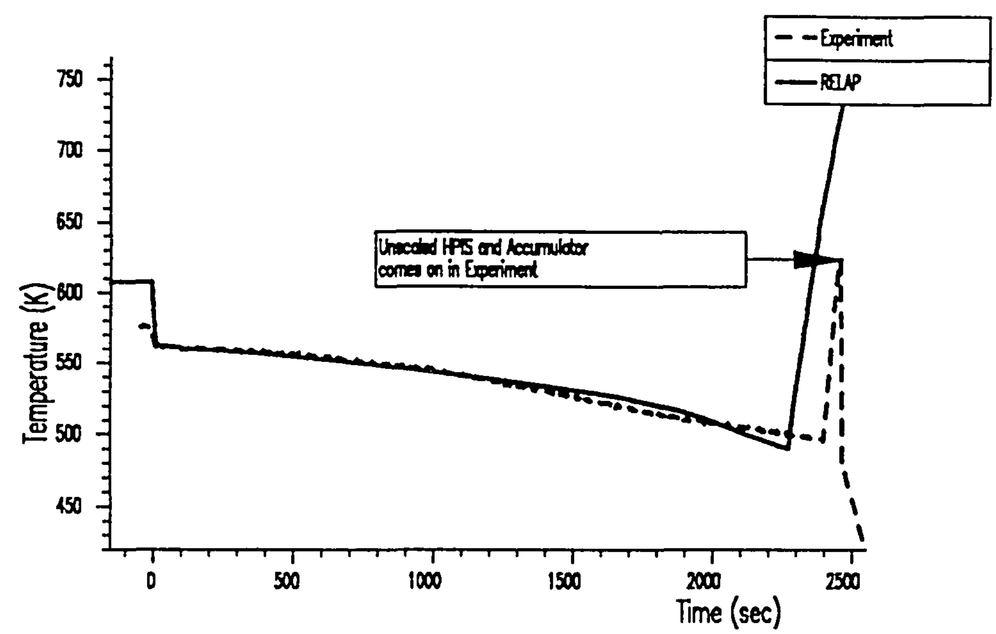

Fig. 22. Fuel rod temperatures

stratified, the RELAP calculates a mass velocity of 1200 $kgm^{-2}s^{-1}$, thus allowing the modified offtake model to operate.

Ironically, in the cold leg where there *is* an offtake the LOFT top measurement beam failed in this test, so the situation there is not so clear. The middle beam suggests that there is little, if any, stratification as would be expected just downstream of the operating pumps.

The need to improve the criteria for stratified conditions in RELAP has been encountered before. Even if the modified offtake model allows preferential liquid or vapour entrainment before stratified flow is entered, the RELAP code will base it's flow calculations for the main pipe on the flow regime present. Vapour and liquid flows are quite different in slug and stratified conditions, and this will lead to errors in the calculation.

4.1.2 Secondary side liquid level

The initial liquid level in the steam generator was correctly set. This is really the collapsed level in the annular downcomer. When the reactor is scrammed, the recirculation ceases and the vapour generation rate falls off, essentially leading to a settling of the fluid in the system.

In Fig. 20 on page 25 it is seen that the RELAP calculation and the LOFT data settle out at different values. This can be due to a number of factors; liquid held up in the separator, the voidage in the riser region or differences in details of the variation in cross sectional area with height. Previous calculations of tests in the LOBI facility in Italy, for which the steam generator details are better known, suggests that all these effects can be important.

Achieving the correct initial head of fluid is not sufficient to ensure that the total mass in the steam generator is right. For instance a liquid column with 30% vapour in would be 30% higher than a water only column to give the same head. If there are changes in cross sectional area with height, which there are in steam generators, then the mass of fluid in each case will be different.

The RELAP code is also known to overpredict the interphase drag in bubbly flow in vessels, and this would lead to a larger quantity of vapour being present in the riser region. This in turn would push more fluid into the separator and will reduce the calculated mass of liquid in the steam generator.

The response of the level after settling is correct, showing the switching on and off of the auxiliary feed. For the L3-6 calculation, because the level never falls below 2.0 meters, it seems unlikely that this error will be important.

4.1.3 Pressure responses

The initial rapid pressure fluctuation on both primary and secondary sides are very well followed. On a longer timescale the primary pressure begins to drift higher than the experimental value after about 1000 seconds, while the secondary pressure is consistently lower.

The reason for this is the coupling of the two systems. In Fig. 23 on page 28 and Fig. 24 on page 28 the differences between the RELAP calculation and the LOFT data is shown.

In the RELAP calculation the primary and secondary pressures stay linked together until nearly 2000 seconds, while in LOFT they decouple around 1000 seconds.

In order to 'drag' the secondary side pressure down, there has to be a substantial transfer of heat from secondary to primary. This is what make the RELAP primary pressure stay above the LOFT pressure after 1000 seconds.

Since the steam generator is essentially liquid full in both calculation and experiment, it must be differences on the primary side which give the enhanced RELAP heat transfer.

In fact the RELAP calculation shows the steam generator 'U' tubes to contain a frothy mixture, like that shown in Fig. 11 on page 19 up until 1700 seconds. Only then does it drain out leaving the tubes vapour filled. This mixture ensures good heat transfer and prevents the primary decoupling from the secondary.

The LOFT instrumentation does not permit confirmation that earier draining of the steam generator tubes has taken place, but it seems the only realistic explanation.

Either the pump characteristics are incorrect, giving too high a vapour flow or the RELAP code, by using an incorrect interphase drag, is keeping liquid in the 'U' tubes. The loop flows are supported by the fact that the core does not dry out before pump trip, thus implying that the interphase drag is the most likely source of error. It is, unfortunately, not possible to be more precise.

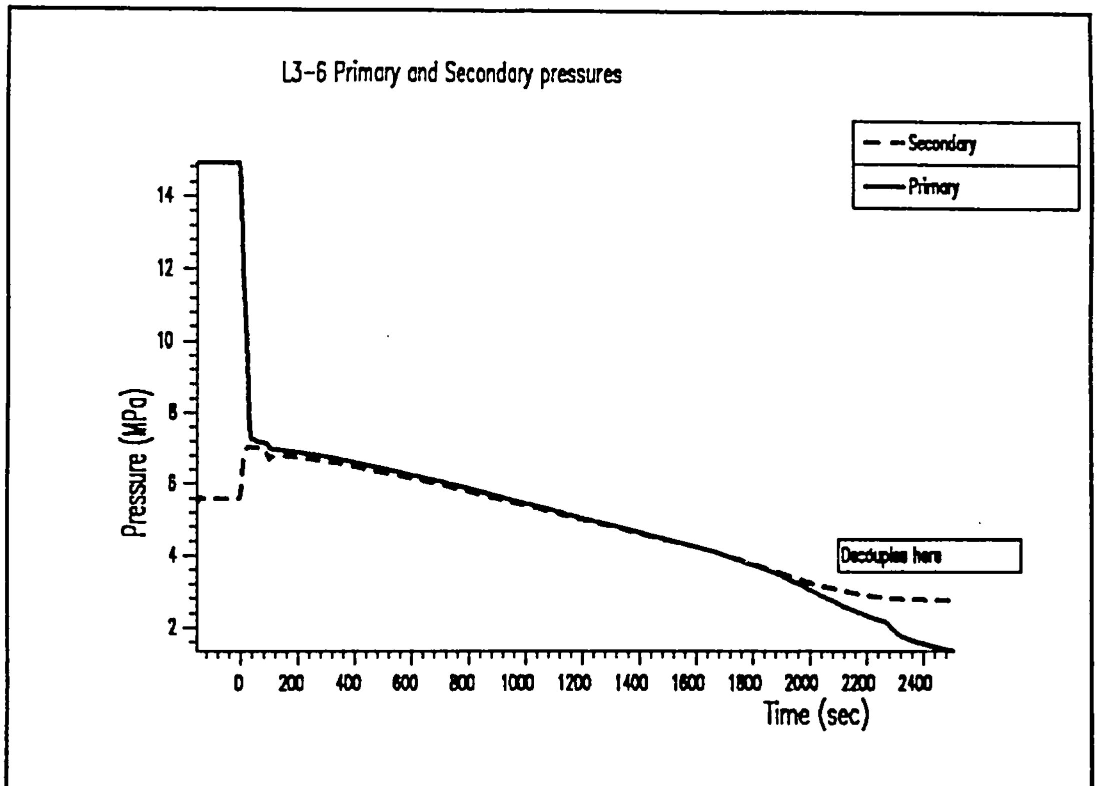

Fig. 23. Relap pressures

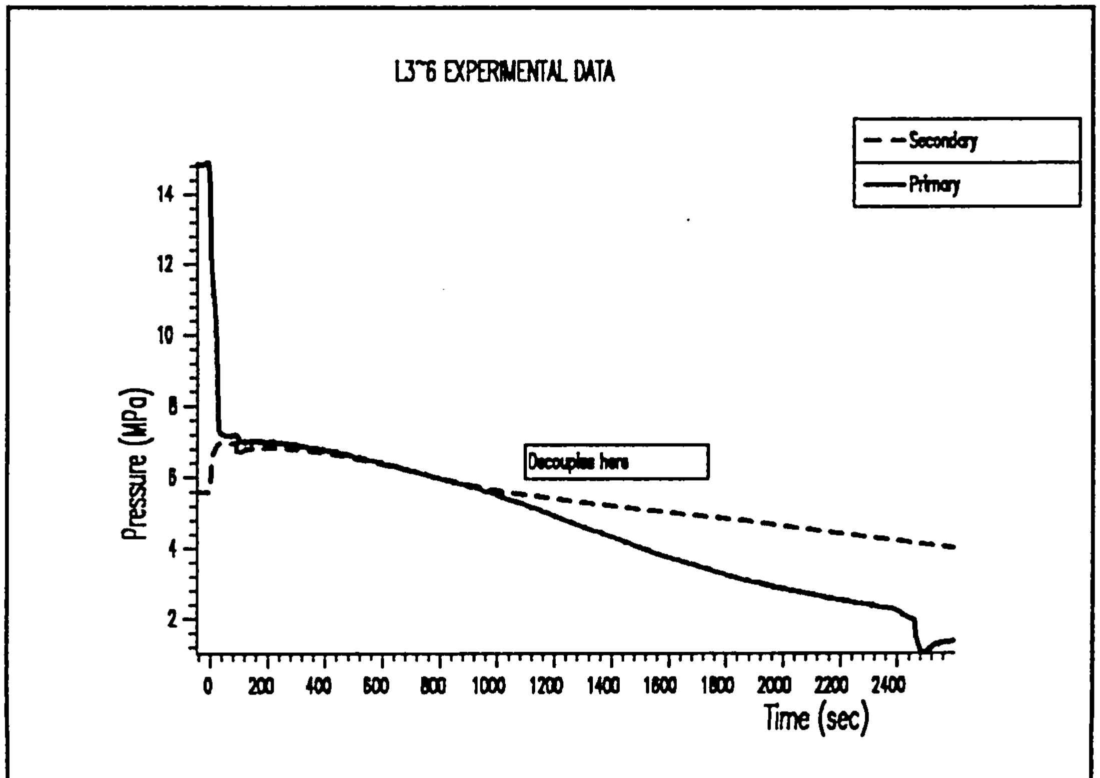

Fig. 24. LOFT pressures

4.2 L3-5 (Pumps off)

This transient was calculated twice, once without the upper plenum bypass. Following on from the presentation adopted for L3-6, the transient will be generally discussed before taking up specific points.

To begin with Fig. 25 to Fig. 28 show four more animation frames.[2]

Of immediate note is the different character from the L3-6 test. With the pumps tripped the loop flows reduce, maintained only by natural circulation, and the fluid begins to settle out giving stratified conditions early in the transient.

By 500 seconds the liquid has already drained substantially from the steam generator 'U' tubes, and both hot and cold legs are stratified.

By 618 seconds the steam generator 'U' tubes are empty, thus decoupling the primary and secondary sides. The loop seal is fluid filled with equal heads on either side.

The 800 and 2050 second pictures show the system changing little, with the fuel remaining covered throughout, and no substantial core level depression.

Looking in detail at the two calculation and referring to Fig. 29 on page 32 to Fig. 38 on page 36, we find the following points.

4.2.1 Bypass

In all figures the calculation with no upper plenum bypass gives better agreement than the calculation with bypass. (Remember that there is still a 1.5% bypass via the Reflood Assist valve leakage even in the calculation with the upper plenum bypass turned off. As the upper plenum bypass was 2.6% this equates to a reduction in the total bypass by about 2/3rds, and a change in its location.)

The primary pressure is much improved by removing the bypass while the secondary side measured response is bracketed by the two calculations, indicating the sensitivity of even this parameter to the bypass flows.

The figures for densities, break flows and inventory show the most direct influence. With a large upper plenum bypass the vapour generated in the core can easily escape to the top of the downcomer, and hence to the break. There is no core level depression which means that the level in the downcomer will be level with the bottom of the cold leg nozzle penetrations, while the level in the core, being greater due to the lower density fluid in the core, will be higher than the downcomer level and in fact covers the hot leg takeoff nozzles.

Under these conditions fluid cannot drain from the hot leg, but can from the cold, leading to the density predictions shown in Fig. 33 on page 34 and Fig. 35 on page 35. These are quite different from the experimentally measured values.

Because of the predicted draining of the cold leg, the break flow is taken from the very low density volume, leading to a low break mass flow. This in turn gives the primary mass inventory seen in Fig. 32 on page 33 which is completely incorrect.

It is clear that the calculation with 'standard' bypass is unacceptable.

In the calculation with no upper plenum bypass the event are different. Pressure buildup in the upper plenum in relieved only when the level is depressed to the hot leg nozzle elevations. This leads to draining of the hot legs as seen in Fig. 34 on page 34 in much better agreement with the data, although a little fast.

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[2] Actually these frames are for the case of no upper plenum bypass, but they are only used to discuss general points.

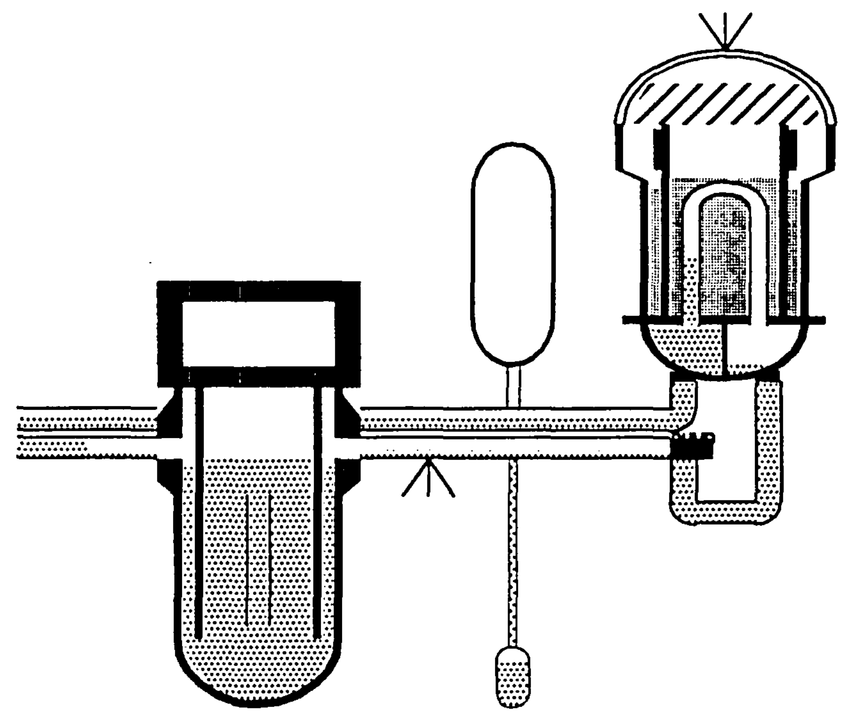

Fig. 25. Mixture levels at 500 seconds

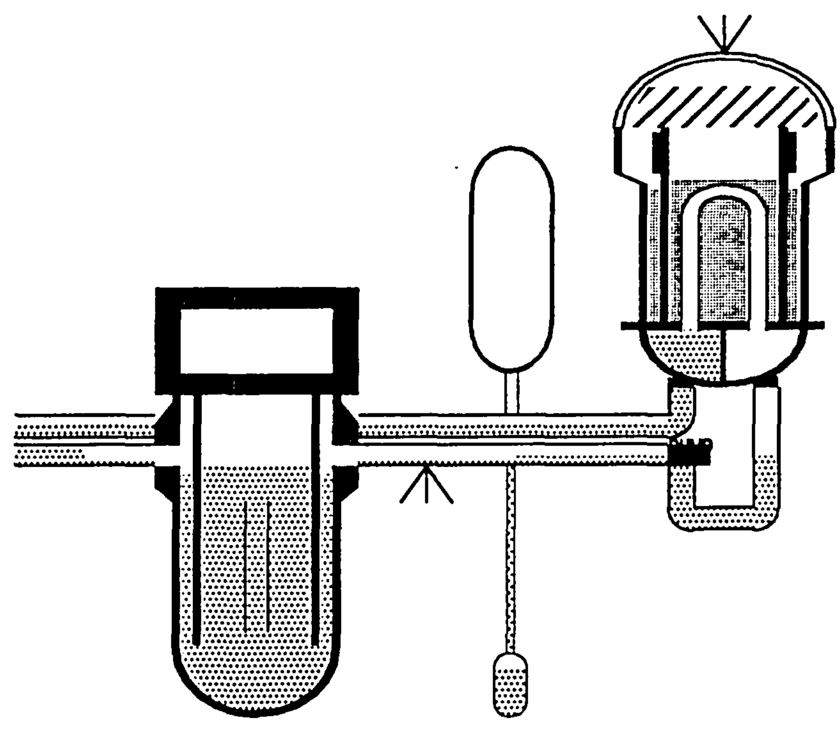

Fig. 26. Mixture levels at 618 seconds

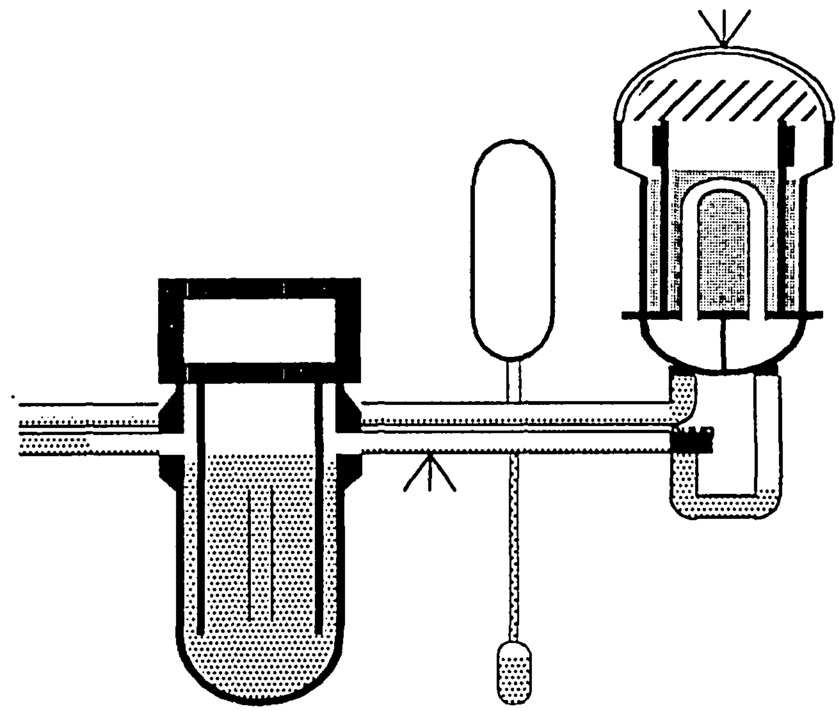

Fig. 27. Mixture levels at 800 seconds

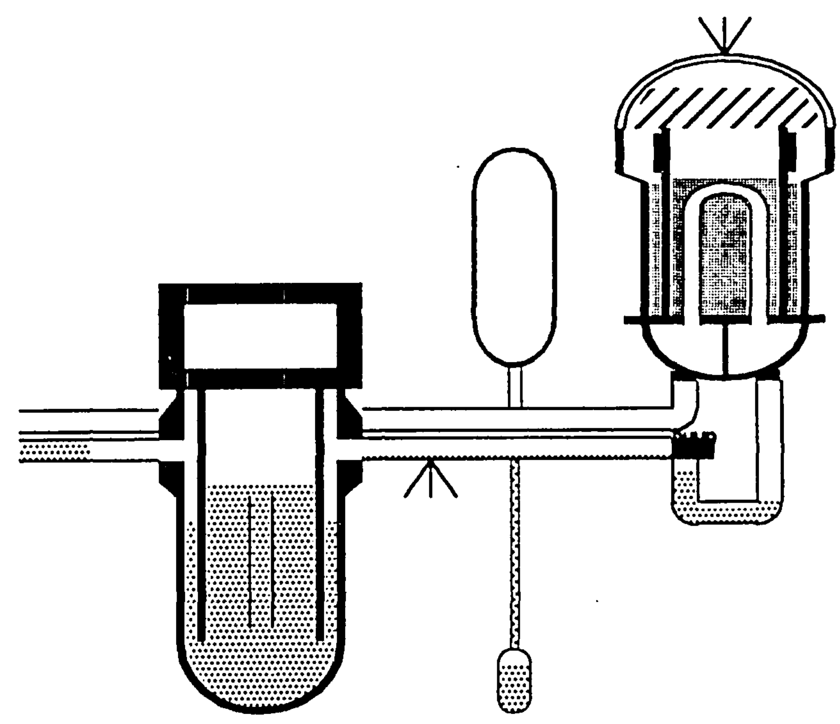

Fig. 28. Mixture levels at 2050 seconds

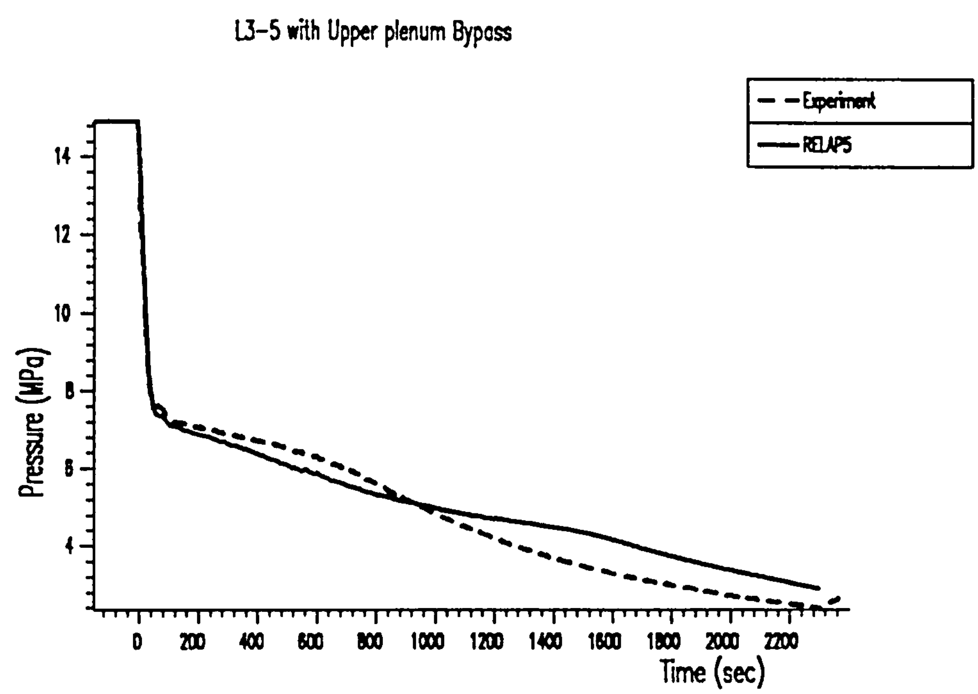

Fig. 29. Primary pressure (Bypass in calculation)

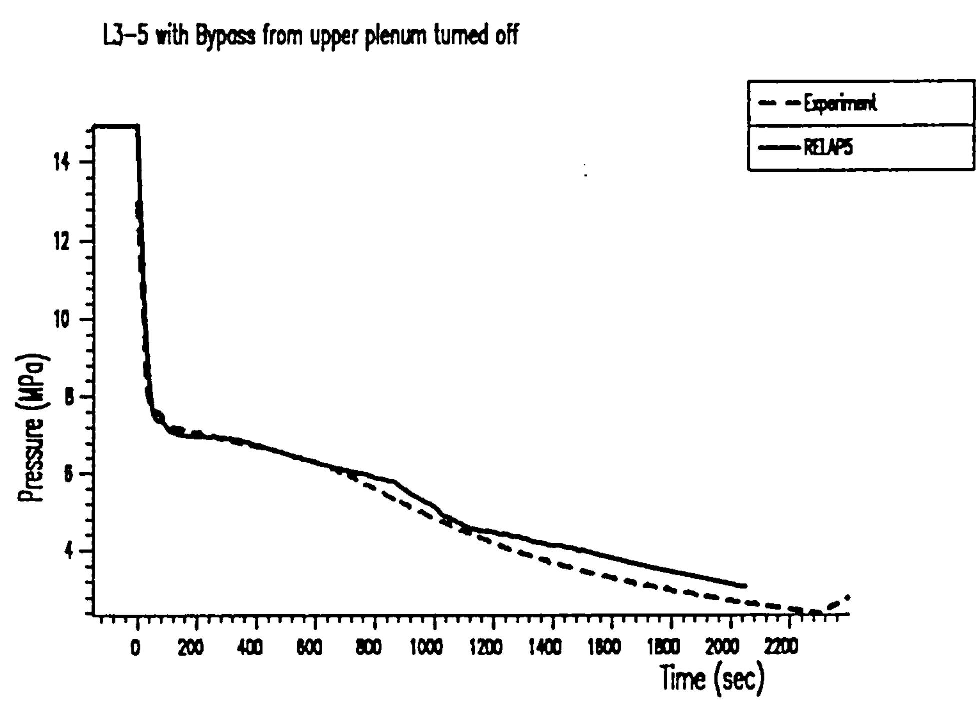

Fig. 30. Primary pressure (No bypass)

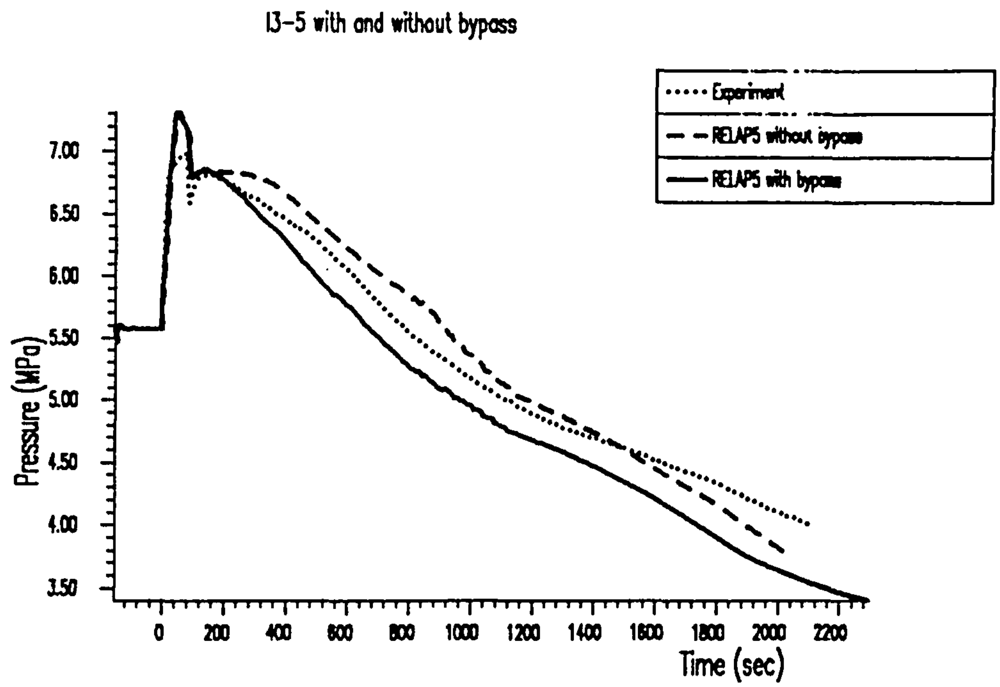

Fig. 31. Secondary side pressure for both calculations

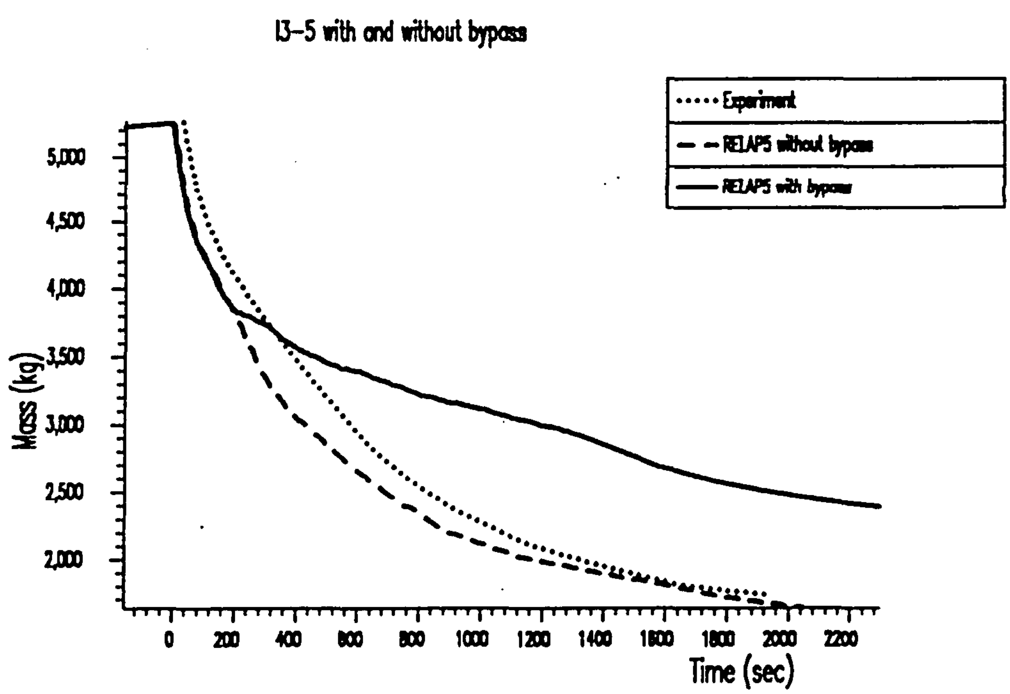

Fig. 32. Primary mass inventory for both calculations

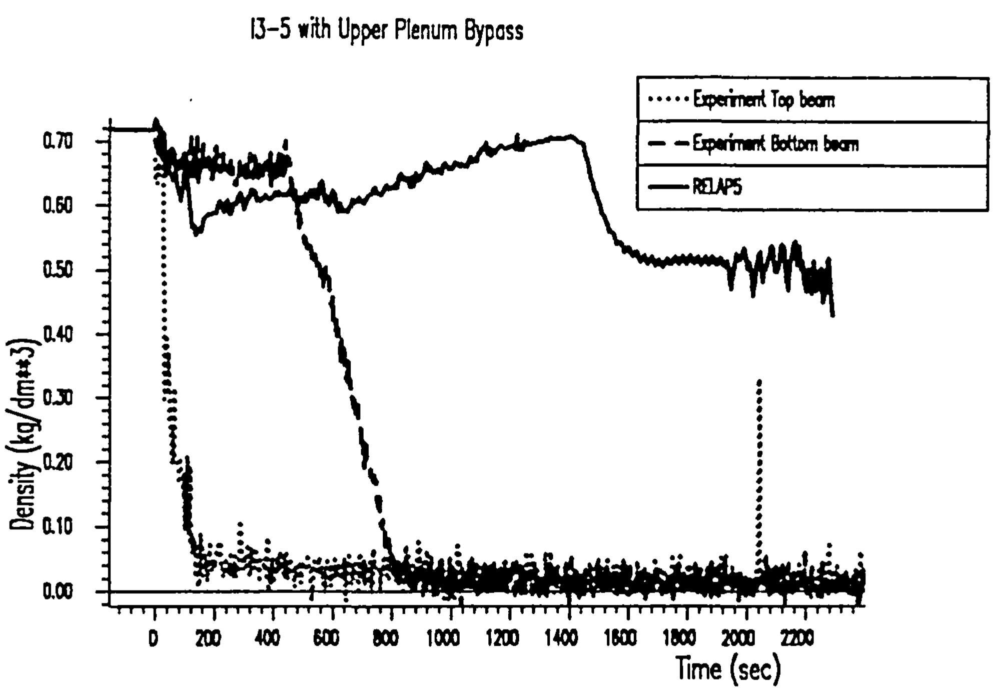

Fig. 33. **Hot leg density (Bypass)**

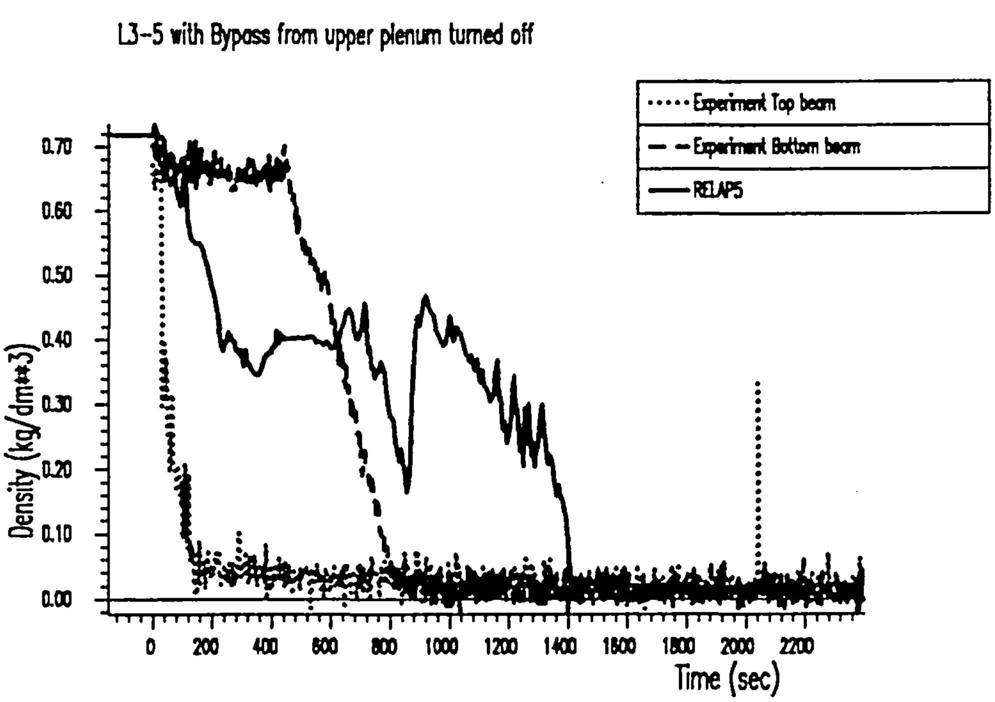

Fig. 34. **Hot leg density (No Bypass)**

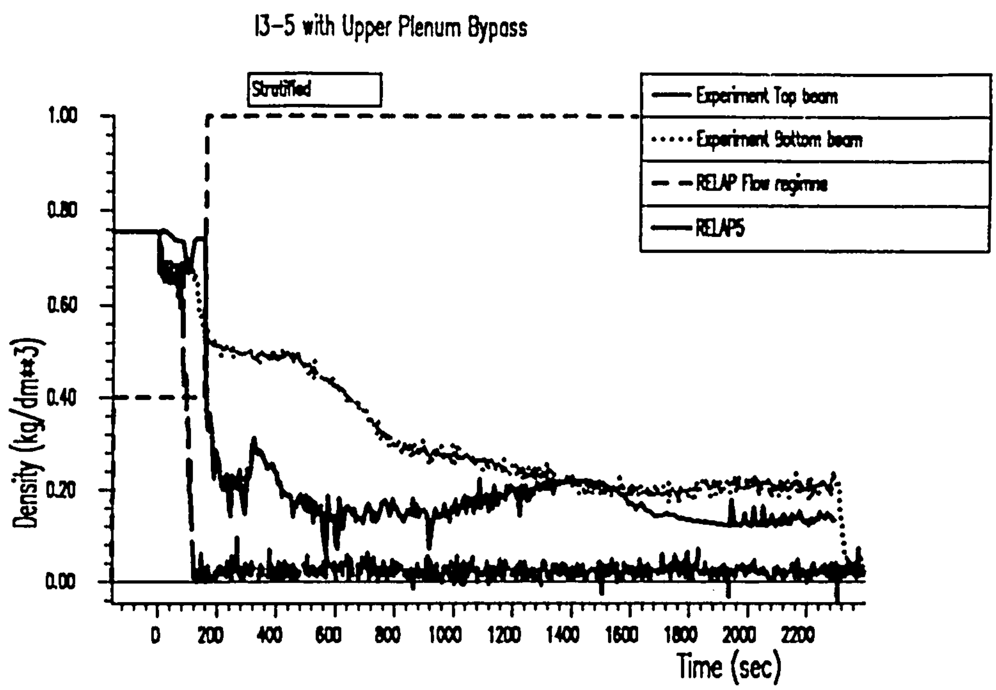

Fig. 35. Cold leg density (Bypass)

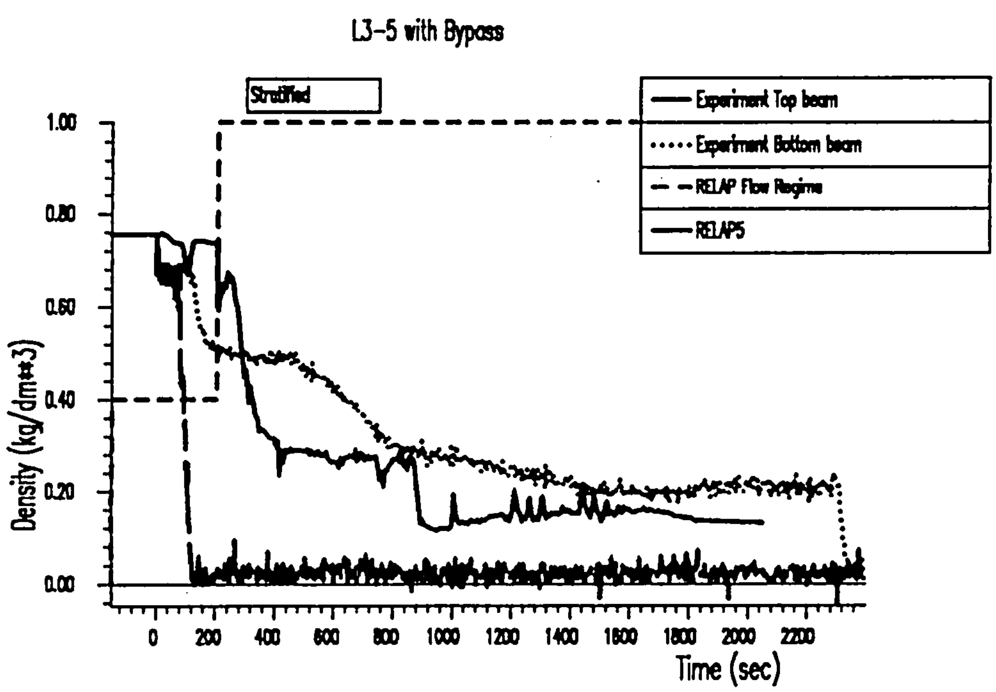

Fig. 36. Cold leg density (No Bypass)

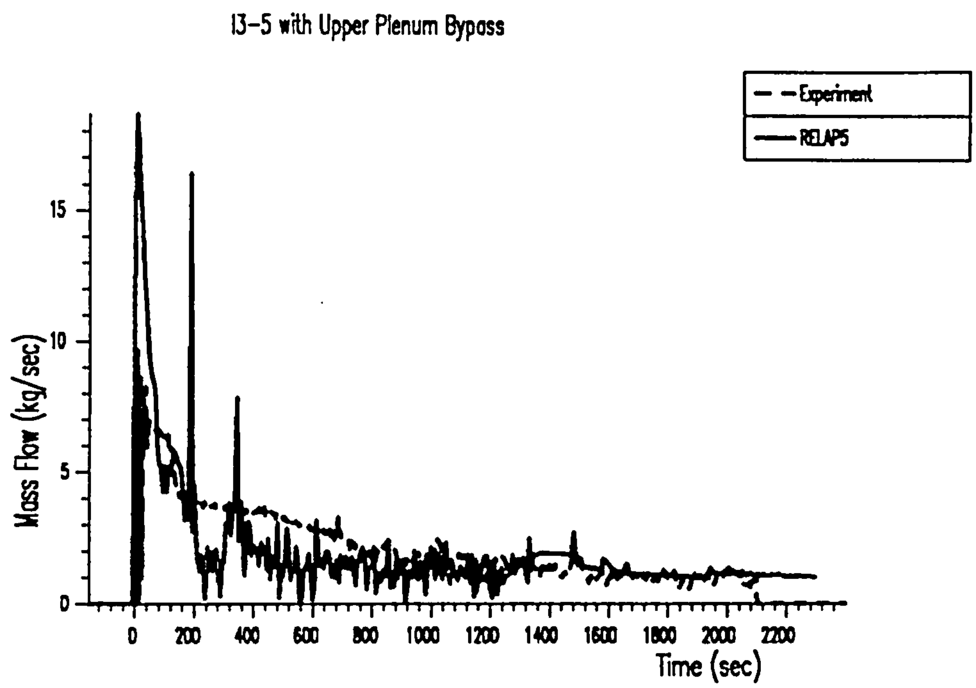

Fig. 37. Break flow (Bypass)

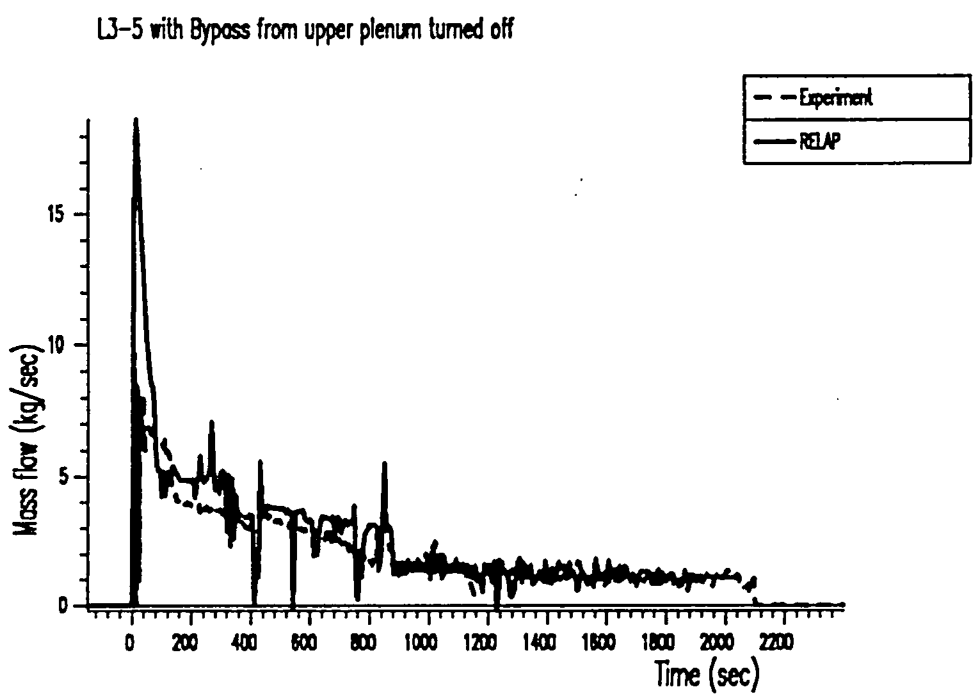

Fig. 38. Break flow (No Bypass)

The corresponding effect on the downcomer level acts to slow the cold leg draining, again is better keeping with the data, and to give higher density at the break.

Although both calculations predict stratification in the volume upstream of the break offtake T-junction at about the same time, the calculation with no bypass has a much higher calculated level in this volume, giving a higher break mass flow.

The consequences of this are the excellent break flow agreement shown in Fig. 37 on page 36 and the quite acceptable primary mass inventory plot. The effect on primary pressure is as seen earlier.

The conclusion is that the upper plenum bypass effectively controls the important events in L3-5. Of the two calculations performed, the 'best' prediction is assuming no upper plenum bypass at all. However there are strong indications, especially the hot leg density plots, that a correct model would have some small upper plenum bypass left, but its location is uncertain.

In the following sections only the calculation with no bypass will be considered, the other being too far from the experimental conditions to admit relevant comparisons.

4.2.2 Break flow

One of the reasons for calculating the L3-5 test was to help assess the modified break offtake model in the E03 version of the RELAP code. In this test the upstream conditions are stratified from before 200 seconds to the end of the test, thus suggesting a good test for the model. This however is not quite the case.

The LOFT loop pipework is 14" diameter, and the offtake pipe is around 1" diameter located on the centreline. With liquid levels in the loop pipework above or below the offtake the flows will be predominantly liquid or vapour, the effect of the modified offtake model being slight. It is only when the level is close to the centreline, within an inch or so, that the model can be thought of as 'active'.

Even when active, the model depends on the calculated upstream volume conditions. Looking at Fig. 36 on page 35 we see that the density is substantially too low from 400 seconds to 800 seconds, exactly the time when in LOFT the liquid level is passing over the offtake pipe. After 800 seconds the flow at the break is almost all vapour and the model will have little effect.

This can be seen from the break flow calculated with the bypass present. In this case the upstream density falls very rapidly. The liquid level is below the offtake pipe from some 200 seconds onwards, and the calculated flow during this time, being predominantly vapour, is the same as that measured in LOFT after 1000 seconds when the LOFT break is fully uncovered.

The indication is that if the level does not remain near the offtake for an appreciable time, then a good break flow calculation does not amount to a confirmation of the modified break offtake model. This test therefore appears not to be a sensitive test of this model.

4.2.3 Natural circulation

The EG&G analysis of L3-5 suggested that reflux mode natural circulation did not occur in the test, despite being predicted by the RELAP5 MOD1 code. The analysis is based on the proportions of the liquid and vapour cross sections in the hot leg pipe, and on the feasible flow rates. EG&G state that RELAP5 MOD1 predicted equal velocities for both the liquid and vapour, while their calculations suggested that to match the flow areas the vapour should be travelling 20 times as fast as the liquid.

In the present calculation it has been seen that the hot leg density, and hence the liquid and vapour flow areas, depend critically on the upper plenum bypass. However RELAP5 MOD2 does predict reflux natural circulation, and in fact calculated a vapour flowrate some 15 times that of the liquid. If these flow rates had been used by EG&G they would have concluded that reflux mode natural circulation did indeed take place in L3-5!

We are left in the unsatisfactory state of not possessing sufficient experimental data to resolve this, except to say that the RELAP calculation is self consistent, and that the EG&G argument against natural circulation is dubious.

5 ACKNOWLEDGEMENTS

The author is deeply indepted to Mr. M. G. Croxford for preparing the initial 'base' input deck for these calculations, and for his work in beginning the calculations themselves, at a time when changing computer systems made any work extremely difficult.

6 CONCLUSIONS

1. For both tests the RELAP5 MOD2 code performed the numerical calculation with no difficulties.

2. The time step selection logic in the code needs to be improved. In one test it would, if not overridden, have required twice as much computer time to complete the calculation as was actually needed.

3. For both tests the code performed well. Most differences from the experimental results were either minor or related to uncertainties in the input data to the code. (Two major uncertainties were the upper plenum bypass flow and the pump moment of inertia. The upper plenum bypass has a large effect on the whole transient, while the pump inertia only affects the early part of the transient.)

4. The code coped well with the high voidage pumping regime found in L3-6, although the pump model in RELAP has been 'tuned' to this test by the code developers.

5. A recurring code problem was the excessive interphase drag sometimes calculated by the code. In one case this probably prevented the draining of the steam generator 'U' tubes, and in another led to an incorrect secondary side mass inventory.

6. The value of the L3-5 experiment for code assessment was greatly reduced because of uncertainty in the critical input parameter of upper plenum bypass. Two calculations performed with and without such bypass produced widely different results which bracketed the experimental values.

7. The analysis suggests that the upper plenum bypass in LOFT is located at least as low as the hot leg nozzle elevations, rather than in the upper part of the vessel, and may be smaller than has been reported by EG&G.

8. Although flow conditions in the pipe containing the break offtake were stratified for long periods, these tests did ***not*** provide a sensitive test of the modified offtake entrainment model in the code. This was because the fluid level in the pipe was only very briefly at the elevation of the break offtake, so the overall effect of the offtake model was small.

9. In the pumps on test, L3-6, the high loop mass flows prevented RELAP from predicting stratified conditions in the loop at a time when the experimental data clearly indicated stratification.

10. Correct modelling of the LOFT pump moment of inertia has been highlighted as being of significance even for small break tests. This is frequently ignored in LOFT analyses. The LOFT data giving the speed dependent moment of inertia has been seen to be in error, and a simpler model has been suggested.

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11. ABSTRACT *(200 words or less)*

RELAP5/MOD2 is being used by National Power Nuclear, Technology Division for calculation of certain small break loss-of-coolant accidents and pressurized transients in the Sizewell 'B' PWR.

The code version being used is RELAP5/MOD2 cycle 36.05 Winfrith version E03. As part of the programme of assessment of this code a number of comparisons of calculations with integral test facility experiments are being carried out.

At the request of NPN-TD the LOFT 2.5% small cold leg break tests L3-5 (pumps off) and L3-6 (pumps on) have been calculated. These previously performed tests involved a number of features, including stratification, pump performance and offtake effects which suggested they would be useful measures of code performance

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