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International Agreement Report

Analysis of the THETIS Boildown Experiments Using RELAP5/MOD2

Prepared by
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GL4 7RS
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Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

July 1989

Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Thermal-Hydraulic Code Assessment
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NOTICE

Abstract: To test the ability of RELAP5/MOD2 to model two phase mixture level and fuel rod heat transfer when the core has become partially uncovered, post test calculations have been carried out of a series of boildown tests in the AEEW THETIS out-of-pile test facility. This report describes the comparison between the code calculations and the test data.

Excellent agreement is obtained with mixture level boildown rates in tests at pressures of 40 bar and 20 bar. However at pressures below 10 bars the boildown rate is considerably overpredicted. A general tendency for RELAP5/MOD2 to overpredict void fraction below the two-phase mixture level is observed, which is traced to defects in the interphase drag models within the code. The heat up of exposed rods above the two-phase mixture level is satisfactorily calculated by the code.

The results support the use of RELAP5/MOD2 for analysis of high pressure core boildown events in PWRs.

Executive Summary:

In the analysis of small break LOCAs in PWRs it is sometimes necessary to calculate the two-phase mixture level in the core, and heat transfer from exposed fuel rods, for conditions where the core has become partially uncovered. To test the ability of RELAP5/MOD2 to model such conditions, post-test calculations have been carried out of a series of boildown tests in the THETIS out-of-pile test facility at UKAEA Winfrith. In these experiments the two-phase mixture level boildown rate was measured in a full length electrically heated rod bundle at decay power levels, at pressures between 2 and 40 bars.

The present report describes comparison between RELAP5 calculations and measurements of the mixture level, void fraction distribution and exposed-rod heat-up rates, in the boildown transients. Comparisons are also described between the present calculations and the analyses of the THETIS tests reported previously with RELAP5/MOD1 and TRAC-PF1/MOD1.

The prime conclusion is that the report supports use of RELAP5/MOD2 for analysis of high pressure core boildown events in PWRs. Detailed conclusions are as follows:

(a) When a fine node (24 axial volumes) representation was used to model the THETIS rod bundle, excellent agreement was obtained with mixture level boildown rates in tests at pressures of 40 bar and 20 bar. However at pressures below 10 bars the boildown rate was considerably overpredicted.

(b) It was found that there was a tendency for RELAP5/MOD2 to overpredict void fraction below the two-phase mixture level, with errors increasing with decreasing pressure. The errors have been traced to defects in the interphase drag models within the code.

(c) Calculations with a coarse node representation (six axial volumes) of the rod bundle, typical of that used in reactor transient analysis, again showed good agreement at pressures above 20 bars. However, oscillations were encountered in the simulation of the steady state condition prior to boildown. These oscillations were found to be due to the periodic triggering of the RELAP5/MOD2 vertical stratification model.

(d) RELAP5/MOD2 gave a satisfactory representation of the heat-up of exposed rods above the two-phase mixture level.

(e) RELAP5/MOD2 performed much better than RELAP5/MOD1 in previous simulations of the THETIS experiments. In particular, accuracy, stability, running speed and mass conservation errors were much improved in the RELAP5/MOD2 simulation.

CONTENTS

1. INTRODUCTION

In the analysis of small break LOCAs in PWRs it is sometimes necessary to calculate the two-phase mixture level in the core, and heat transfer from exposed fuel rods, for conditions where the core has become partially uncovered. To test the ability of RELAP5/MOD2 to model such conditions, post-test calculations have been carried out of a series of boildown tests in the THETIS out-of-pile test facility at UKAEA Winfrith [1]. In these experiments the two phase mixture level boildown rate was measured in a full length electrically heated rod bundle at decay power levels, at pressures between 2 and 40 bars.

The present report describes comparison between RELAP5 calculations and measurements of the mixture level, void fraction distribution and exposed-rod heat-up rates, in the boildown transients. Comparisons are also described between the present calculations and the analyses of the THETIS tests reported previously with RELAP5/MOD1[3] and TRAC-PF1/MOD1[4].

2. EXPERIMENT

2.1 Facility description and instrumentation

The THETIS test facility is described in ref. [2]. It consisted of a vertical bundle of electrically heated rods enclosed in a 130.6mm i.d. circular shroud tube placed inside a vertical cylindrical pressure vessel (see Fig. 1). The shroud tube was closed at the bottom but open at the top. Systems were provided to supply a constant measured flow rate of make-up water to the bottom of the test section, and to maintain the rig pressure at a pre-selected value.

The pin bundle, which is shown in Fig. 2, consisted of 61 pins of 12.2mm outside diameter. 57 of the pins were electrically heated fuel pin simulators with a heated length of 3.6m.

The design of the fuel pin simulators is shown in Fig. 3. Each pin consisted of a central helically wound nichrome heating element surrounded by magnesium oxide insulation and enclosed inside two concentric stainless steel sheaths. A "chopped cosine" axial power distribution was achieved by varying the pitch of the helical heating element. Twelve 1mm diameter thermocouples were located between the inner and outer sheaths in each heater rod, allowing temperature measurements to be made at a large number of axial stations within the cluster.

Four pins in the cluster were tubes containing water filled instrumentation lines connected to pressure tappings at different locations along the tube length. Measurement of the differential pressure between the pressure tappings allowed average void fractions to be estimated in different axial zones within the bundle. The elevation of the pressure tappings on the instrument tubes are shown in Fig. 4. Also shown are the axial locations of thermocouple junction elevations and spacer grid locations within the cluster.

2.2 Test procedure and initial conditions

The test procedure was described by Jowitt [2] and is briefly summarised here.

In each experiment the test section power was set to 100kW and an equilibrium condition was established in which the system pressure was constant and the pipework had reached a steady temperature. In the equilibrium state, sufficient make-up flow was provided to compensate for the liquid boil-off rate so that the entire heated length of the rod bundle was wetted. The data logger was then started and after a short delay period the transient was initiated by cutting off the make-up flow, so that the liquid level in the bundle boiled down. Tests were carried out at pressures of 40, 20, 10, 5 and 2 Bar. Table 1 summarises the experimental conditions for the particular tests analysed in this report.

3. RELAP5/MOD2 CALCULATION

3.1 Description of model

The version of the code used for the analysis described in this report was the latest available released version (cycle 36.04) with minor error corrections as implemented by W. Bryce at UKAEA, Winfrith.

The test facility was represented using 26 hydrodynamic volumes (nodes) as shown in Fig. 5; the noding arrangement is similar to that used in the calculations described in ref. [4]. The test section, (ie. the pin bundle and enclosing shroud tube) was modelled as a RELAP5/MOD2 "pipe" component. The heated part of the test section was represented by the nodes numbered 2-25 each of height 0.15m. Nodes numbered 1 and 26 represented the unheated part of the bundle. Heat structures, representing the heater pins, were connected to nodes 4-25 of the heated length. In ref. [4] it was deduced that a layer of sub-cooled water, ~30cm deep, had formed in the annular space between the shroud tube and pressure vessel during the boildown tests, causing high heat losses at the base of the cluster. To simulate these heat losses, heat input into the lowest two volumes of the heated length (corresponding to volumes 2 and 3 in the present simulation) was neglected in the ref. [4] calculation; the same procedure was used in the present calculations to compensate for the heat losses.

The steady make-up flow supplied prior to the boildown phase of the experiment was simulated using a TIME DEPENDENT VOLUME and JUNCTION connected to the bottom of the cluster. The top of the test section was connected to a TIME DEPENDENT VOLUME at the required fixed pressure.

In order to model radial thermal conduction, the pins were represented as cylindrical heat structures with nine radial mesh points. The locations of the radial mesh points are denoted by the crosses in Fig. 3.

A sample input data deck for the test at a pressure of 40 bar is included in Appendix 1.

3.2 Steady state calculation

Before commencing the boildown calculation it was first necessary to simulate the steady state condition that existed prior to the transient. This was done by performing a calculation in which the initial make-up flow, temperature and system pressure were set to the values in table 1, at an initial power of zero. The power was then ramped up to the experimental value over a 200s period. Typically a problem time of 600-1200s was required before an acceptable steady condition was achieved. Fig. 6 shows a typical result of a steady state calculation, and demonstrates that thermodynamic parameters are well converged.

3.3 Transient calculation - comparison of experimental results and calculation

Comparisons between predictions and test data derived from ref. [1] are described below. Code predictions are compared with the following measured quantities;

(1) Dry-out level trajectory. This is defined as the trajectory of the lowest point in the bundle at which the rods were dry. [2]

(2) Void fraction axial distribution at different times during the transient.

(3) Pin temperature axial distribution at different times during the transient. (Note that thermocouple data is available only for the tests at 5 and 20 bars).

Note that in the plots of experimental and calculated results, time zero refers to the time at which the make-up flow was reduced to zero.

(a) 40 bar case

The measured and calculated dry out level trajectory for the 40 bar case is shown in fig. 7. In the RELAP5/MOD2 calculation the dry out level at a particular time is taken as the elevation of the bottom of the lowest hydrodynamic volume in which dry out is calculated at that time. It is seen that the calculated and measured trajectories are in excellent agreement, the maximum error in calculated mixture level being 0.2m.

The measured and calculated profiles of void fraction versus elevation in the bundle at three different times are shown in fig. 8. The measured void profile shows a gradual increase in void fraction up to the two-phase mixture level* followed by a sharp transition to steam only conditions. The characteristic shape of the curves is seen to be reproduced quite well in the code simulation. However, there is a tendency to overestimate void fraction below the two phase mixture level at higher

* The location of the two-phase mixture level can be identified with the elevation at which the void fraction suddenly increases to unity in Fig. 8.

elevations in the bundle with maximum errors in the two phase mixture density* reaching -20%.

It is clear by comparing Figs. 7 and 8 that whereas the code tends to under-predict the mixture level elevation by up to 30cm, the dry-out level is predicted accurately (to better than 3cm). Although the discrepancies between these two calculated levels are not large, there is evidently some cancellation of errors in the RELAP5 calculation of the dry-out level, due perhaps to the choice of void fraction at which RELAP5 calculates dry-out to occur.

(b) <u>20 bar case</u>

The measured and calculated mixture level trajectories for this test are shown in Fig. 9. Again, agreement is excellent.

Axial void fraction distributions are shown in Fig. 10. Similar trends are observed to those noted in the 40 bar case. However errors in void fraction are now somewhat higher, with maximum errors in the fluid density below the two phase mixture level reaching -40%.

Measured and calculated rod temperatures during boildown are compared at three elevations in Fig. 11. The experimental curves are the median value of measurements from several different thermocouples at a given elevation. Typical scatter in the experimental pin temperatures was in the range $\pm 7K$ to $\pm 20K$. It is seen that RELAP5 predicts the rod temperatures to within this uncertainty range, though there appears to be a slight tendency to overpredict rod surface heat transfer.

(c) <u>10 bar case</u>

Results for the 10 bar case are shown in Figs. 12 and 13. The error in calculated boildown trajectory is larger than in the tests at higher pressure, with error in the mixture level elevation falling from over 0.5m at early times, to about 0.25m at the end of the test. Unfortunately, the measured void fraction data are incomplete, in that data for the top half of the bundle in this test are not available. However the general trends observed in the 40 bar and 20 bar cases are still evident.

The maximum two-phase mixture density error at 10 bars is -45%, for those locations where the data are available.

(d) <u>5 bar and 2 bar cases</u>

Results for these cases are shown in Figures 14 to 17. Agreement between measured and calculated boildown trajectories is significantly worse than observed at the higher pressures. At 2 bars, for example, dry-out is calculated to occur first at intermediate elevations rather than at the top of the bundle as

---

* This density error is defined as:

$$\frac{\text{(calculated mixture density - measured mixture density)}}{\text{measured mixture density}}$$

observed in the tests. This implies the calculation of premature ejection of large quantities of water from this elevation in the bundle. Similarly, the predictions of void fraction are significantly worse, than those observed at higher pressures. In particular, the void fractions in the upper parts of the bundle are increasingly overpredicted as pressure is reduced.

Measured and calculated rod temperatures during boildown are compared at three elevations for the 5 bar case in Fig. 18. As observed in the 20 bar case, the code gives reasonably accurate predictions of the rod temperatures.

3.4 Computing time

The calculations were executed on a CRAY-XMP computer. CPU time was 60s for the 40 bar case rising to 600s for the 2 bar case. The average time step was 0.3s at 40 bars but decreased to 0.03s at 2 bars, and the CPU time used per hydrodynamic volume per time step was in all cases in the range of 6.46×10^{-4}s to 6.67×10^{-4}s.

4. CALCULATIONS WITH COARSE NODE REPRESENTATION OF ROD BUNDLE

In reactor transient calculations using RELAP5/MOD2 it is common to use six vertically stacked nodes to represent the core, in order to limit computational costs [5,6]. In order to assess the adequacy of this level of noding the calculations described above were repeated using a six-node representation of the test bundle shown in Fig. 19. In this case the lowest hydrodynamic volume was left unheated to give an approximate representation of the heat losses discussed above. Other features of the model were left unchanged. Results of the transient calculation with the coarse node model are described below.

4.1 Steady state calculation

The procedure for calculating the steady state condition with the 6 node model was similar to that employed in the 24 node calculations described above. Results for the 40 and 5 bar cases are shown in Figs. 20 and 21. A noticeable feature of these is the large amplitude void fraction oscillations evident in the 5 bar case. After some investigation, the origin of the oscillations was traced to the periodic triggering of the RELAP5/MOD2 vertical stratification model, which has the effect of sharply reducing interphase drag in a volume when the void fraction in the vertically adjacent volumes differs by more than 0.5.

To test the hypothesis that the oscillations were due to triggering of the vertical stratification model, the logic in subroutine PHAINT was modified to prevent the vertical stratification model from being invoked. The steady state calculations were then re-run with this modified version of the code. The results for the 5 bar case is shown in Fig. 22. The oscillations are seen to have disappeared, though the new steady state condition does not correspond to the mean value of the previous oscillatory state.

To investigate the implications of the change to the steady state obtained with the modified code, it was decided to carry out the analysis of some of the boildown transients using the modified code version. The calculations are described later in the report.

4.2 Transient calculation

The measured dry out level trajectory in the 40 bar case and that calculated with the standard code are shown in Fig. 23. Agreement is still good, despite the coarser noding, with a typical error in mixture level elevation of 0.2m. The measured and calculated profiles of void fraction versus elevation at three different times are shown in Fig. 24. The general trends observed in the 24 volume calculations are still observed; the characteristic shape of the experimental curves is seen to be reproduced quite well by the code, but with a tendency to overestimate void fraction below the two phase mixture level at higher elevations in the bundle.

The measured level trajectories for the cases at 20, 10, 5 and 2 bars are compared with calculations of the standard code in Figs. 25, 27, 29 and 31. Accuracy decreases as pressure reduces, with typical errors in mixture level elevation of 2m at the lowest pressures. The measured and calculated void fraction profiles for the same cases are shown in Figs. 26, 28, 30 and 32. The general trends described in the 40 bar case are still observed, with the void fraction overprediction becoming more severe as the pressure falls.

As in the fine node calculation, RELAP5 predicts the rod temperatures to within the experimental pin temperature uncertainty range, though with a slight tendancy to overpredict rod surface heat transfer.

As noted above, some transient calculations were repeated with a modified version of RELAP5/MOD2, in which the vertical stratification model had been disabled. Figures 33 and 34 show the dry out level trajectories for the 40 bar and 5 bar cases obtained with the modified code. These can be compared to the results obtained using the standard code in Figures 23 and 29. It is seen that there is little effect on boildown simulation, despite the major improvement on steady state calculation at the lower pressure.

4.3 Computing time

The coarse node calculations were also executed on a CRAY-XMP computer. The CPU time was 12s for the 40 bar case increasing to 34s for the 2 bar case. The average timestep was 0.5s at 40 bars falling to 0.2s at 2 bars. CPU time per volume per timestep was in the range 5.9×10^{-4}s to 6.1×10^{-4}s in all calculations, similar to the values found in the fine node case.

5. DISCUSSION

5.1 Review of current calculation

With the fine node representation of the THETIS test section RELAP5/MOD2/ Cycle 36.04 gives an excellent simulation of the dry out level trajectory measured in the tests at 40 bar and 20 bar and an acceptable representation of the test at 10 bar. The code also gives a good representation of dry surface heat transfer above the mixture level for these conditions. Inspection of the measured and calculated void fraction profiles shows a tendency for the code to over-predict void fraction below the two phase mixture level, with errors increasing with decreasing pressure. At 40 bars the maximum error in calculated two phase mixture density is ~ -33%, rising to ~ -46% at 10 bars; these errors occur at an experimental void fraction of about 0.4 (see Figs. 8 and 13).

Ardron and Clare [7] have assessed the performance of the interphase drag models used in RELAP5/MOD2 in vertical flow in the bubbly and slug flow regime ($\alpha < 0.75$). They concluded that for conditions pertinent to boil-off in a pin bundle geometry (liquid superficial velocities ~ 0, hydraulic diameter ~ 1.0cm) the models tend to over-predict void fraction, with errors increasing as pressure decreases. According to Fig. 3a in ref. [7], the error in two-phase mixture density at a void fraction of 0.4 is ~ -30% at 40 bars increasing to ~ -50% at 10 bars. These values are quantitatively consistent with our present findings, and indicate that the errors in void fraction are traceable to defects in the interphase drag models used in the code. Despite the errors, it appears that the performance of the models is acceptable at pressures above 40 bars, which is consistent with the conclusions in ref. [7].

At pressures below 10 bars void fraction errors become unacceptably large, leading to a large over-prediction of the liquid level boildown rate. It appears therefore that at present RELAP5/MOD2 is unsuitable for calculating boildown behaviour at these low pressures.

With the coarse node model some loss of accuracy was seen in comparison with the fine node case. However the dry out level trajectories and the axial void distributions in the 40 bar and 20 bar cases are calculated with acceptable accuracy. The coarse node calculation displayed oscillations in the steady state, which are evidently due to cyclic triggering of the vertical stratification model used in the code. When this model was disabled the oscillations were found to disappear. However, simulation of the boildown phase was unchanged.

It is worth noting that in the analysis of small break LOCAs and pressurised transients in PWRs, uncovered core conditions are normally encountered only at pressures above 40 bars, since at lower pressures the reactor vessel is normally refilling due to injection of ECC water from the accumulator system. The present study indicates that the use of RELAP5/MOD2 with a conventional coarse node core representation will probably provide acceptable accuracy for describing core boildown under these conditions.

5.2 Comparison with previous calculations

The THETIS boildown experiments were previously analysed using the codes RELAP5/MOD1[3] and TRAC-PF1/MOD1[4]. In the RELAP5/MOD1 analysis [3] considerable difficulty was encountered in establishing a satisfactory initial steady state; consequently an initial condition was selected corresponding to the experimental condition at about 40s into the experimental transient. Careful selection of the time steps was also found necessary to produce acceptable mass conservation errors. Even with these adjustments the accuracy of the transient predictions was very poor both in terms of the trajectory of the dry out elevation and of the heater rod temperatures. In contrast, the agreement with experimental data at high pressures produced by RELAP5/MOD2 is very good. Mass conservation errors in the present calculations were typically less than 1% of the final mass inventory, though errors rose sharply below 5 bars, reaching 10% at 2 bars.

In the TRAC-PF1/MOD1 analysis of THETIS boildown tests [4] difficulty was also found in matching initial conditions; again the time origin for the transient calculation had to be artificially adjusted. After adjustment to the released version of TRAC-PF1/MOD1, reasonable agreement with volumetrically averaged void fraction in the test section was achieved. Typical void fraction errors were -10% at high pressure, rising to -35% at low pressure, though maximum errors were higher than this. The trend of increasing void fraction errors with reducing system pressure is qualitively similar to that observed using RELAP5/MOD2 and the errors also appear to be quantitively similar.

6. CONCLUSIONS

1. To assess the ability of RELAP5/MOD2/Cycle 36.04 to model core uncovery in a PWR, post-test calculations have been carried out of core boildown experiments in the UKAEA Winfrith THETIS test facility.

2. When a fine node representation was used to model the THETIS rod bundle, excellent agreement was obtained with mixture level boildown rates in tests at pressures of 40 bar and 20 bar. However at pressures below 10 bars the boildown rate was considerably over-predicted.

3. It was found that there was a tendency for RELAP5/MOD2 to over-predict void fraction below the two-phase mixture level, with errors increasing with decreasing pressure. The errors have been traced to defects in the interphase drag models within the code.

4. Calculations with a coarse node representation of the rod bundle, typical of that used in reactor transient analysis, again showed good agreement at pressures above 20 bars. However, oscillations were encountered in the simulation of the steady state condition prior to boildown. These oscillations were found to be due to the periodic triggering of the RELAP5/MOD2 vertical stratification model.

5. RELAP5/MOD2 gave a satisfactory representation of the heat-up of exposed rods above the two-phase mixture level.

6. RELAP5/MOD2 performed much better than RELAP5/MOD1 in previous simulations of the THETIS experiments. In particular, accuracy, stability, running speed and mass conservation errors were much improved in the RELAP5/MOD2 simulation.

7. The calculations support the use of RELAP5/MOD2 for analysis of high pressure core boildown events in PWRs.

7. ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance of W.M. Bryce of UKAEA, Winfrith, in creating the modified experimental version of RELAP5 referred to in section 4.1 of this report.

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APPENDIX

SAMPLE INPUT DATA DECK FOR 40 BAR, 24 VOLUME CALCULATION

```
= THETIS BOILDOWN:40 bar, 24 volume
*
*
0000100 NEW      TRANSNT
0000101 RUN
0000102 SI       SI
0000105 1.0      2.0
*
* Time step control;
*       End time Min dt   Max dt   Optn     Mn       Mj       Rst freq
0000201 1700.0   1.0E-7   0.5      1003     4        100      1700
*
* -------------------------------------------------------------------
* MINOR EDIT VARIABLES
* -------------------------------------------------------------------
0000301 TMASS        0          * Total mass in system
0000302 EMASS        0          * Estimate of mass error
0000303 VOIDG        001020000  * Vapour void fraction
0000304 VOIDG        001030000
0000305 VOIDG        001040000
0000306 VOIDG        001050000
0000307 VOIDG        001060000
0000308 VOIDG        001070000
0000309 VOIDG        001080000
0000310 VOIDG        001090000
0000311 VOIDG        001100000
0000312 VOIDG        001110000
0000313 VOIDG        001120000
0000314 VOIDG        001130000
0000315 VOIDG        001140000
0000316 VOIDG        001150000
0000317 VOIDG        001160000
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0000320 VOIDG        001190000
0000321 VOIDG        001200000
0000322 VOIDG        001210000
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0000324 VOIDG        001230000
0000325 VOIDG        001240000
0000326 VOIDG        001250000
0000327 VOIDG        001260000
0000328 TEMPG        001030000
0000329 TEMPG        001040000
0000330 TEMPG        001050000
0000331 TEMPG        001060000
0000332 TEMPG        001070000
```

```
0000333 TEMPG          001080000
0000334 TEMPG          001090000
0000335 TEMPG          001100000
0000336 TEMPG          001110000
0000337 TEMPG          001120000
0000338 TEMPG          001130000
0000339 TEMPG          001140000
0000340 TEMPG          001150000
0000341 TEMPG          001160000
0000342 TEMPG          001170000
0000343 TEMPG          001180000
0000344 TEMPG          001190000
0000345 TEMPG          001200000
0000346 TEMPG          001210000
0000347 TEMPG          001220000
0000348 TEMPG          001230000
0000349 TEMPG          001240000
0000350 TEMPG          001250000
0000351 TEMPG          001260000
0000352 VOIDGJ         002000000  * Single Junction void fraction
0000353 MFLOWJ         002000000  * Single Junction mass flow
0000354 HTTEMP         001100109  * Mesh point temperatures
0000355 HTTEMP         001100209
0000356 HTTEMP         001100309
0000357 HTTEMP         001100409
0000358 HTTEMP         001100509
0000359 HTTEMP         001100609
0000360 HTTEMP         001100709
0000361 HTTEMP         001100809
0000362 HTTEMP         001100909
0000363 HTTEMP         001101009
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0000368 HTTEMP         001101509
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0000370 HTTEMP         001101709
0000371 HTTEMP         001101309
0000372 HTTEMP         001101909
0000373 HTTEMP         001102009
0000374 HTTEMP         001102109
0000375 HTTEMP         001102209
0000376 TEMPF          001030000   * Volume liquid temperatures
0000377 TEMPF          001040000
0000378 TEMPF          001050000
0000379 TEMPF          001060000
0000380 TEMPF          001070000
0000381 TEMPF          001080000
0000382 TEMPF          001090000
0000383 TEMPF          001100000
0000384 TEMPF          001110000
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0000386 TEMPF          001130000
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0000387 TEMPF         001140000
0000388 TEMPF         001150000
0000389 TEMPF         001160000
0000390 TEMPF         001170000
0000391 TEMPF         001180000
0000392 TEMPF         001190000
0000393 TEMPF         001200000
0000394 TEMPF         001210000
0000395 TEMPF         001220000
0000396 TEMPF         001230000
0000397 TEMPF         001240000
0000398 TEMPF         001250000
0000399 TEMPF         001260000
*
0000501 TIME  0  GT NULL 0 1200.0 L       * Make up flow trip
*
* ----------------------------------------------------------------------
* COMPONENT 1 ; PIPE
* ----------------------------------------------------------------------
00010000 'CLUSTER' PIPE
0010001 26                 * Number of volumes
0010101 6.265E-3 26        * Volume flow area, volume number
0010301 0.1      1         * Volume length
0010302 0.15     25
0010303 0.3      26
0010601 90.0     26        * Vertical angle
*
* Pipe volume friction data;
*       Rough    Hyd-dia  Vol no.
0010801 2.5E-7   0.0122   26
*
* Pipe volume control flag;
0011001 00       26        * Wall friction component, nonequilibrium
*
* Pipe junction control flag;
0011101 01000    25        * No choking, no area change,
*                          * centally located, non homogeneous.
*
* Pipe volume IC's;
*       Flags    Pressure Temp     Dummy                          NV
0011201 003      4.026E6  310.0    0.0      0.0      0.0      1
0011202 003      4.026E6  440.0    0.0      0.0      0.0      25
0011203 003      4.026E6  475.0    0.0      0.0      0.0      26
*
* Pipe junction IC's;
*       ILiqVel  IVapVel  IntVel   Jn no
0011301 0.0      0.0      0.0      25
```

```
* ----------------------------------------------------------------------
* COMPONENT 2 ; SNGLJUN
* ----------------------------------------------------------------------
0020000 'OUTLET' SNGLJUN
* Single junction geometry;
*       From      To        Area     Loss-F   Loss-B   Flags
0020101 001010000 003000000 4.7E-3   1.0      0.5      0000
*
* Single junction IC's;
*       Control  ILiqVel  IVapVel  IntVel
0020201 0        0.0      0.0      0.0
* ----------------------------------------------------------------------
* COMPONENT 3 ; TMDPVOL
* ----------------------------------------------------------------------
0030000 'STMDRM' TMDPVOL
* TMDPVOL geometry;
*       Area     VolLen   VolVol   A-ang    I-ang    ElChange
0030101 1.0E6    100.0    0.0      0.0      90.0     100.0
*       Rough    Hyd-dia  Fg
0030102 2.5E-7   9.12E-3  00
*
* TMDPVOL data;
*       Flag
0030200 002
*       Time     Pressure Quality
0030201 0.0      4.026E6  1.0
* ----------------------------------------------------------------------
* COMPONENT 4 ; TMDPJUN
* ----------------------------------------------------------------------
0040000 'INLET' TMDPJUN
* TMDPJUN geometry;
*       From      To        Area
0040101 005000000 001000000 4.7E-3
0040200 1        501        * Control word
*
* TMDPJUN data;
*       Time     LiqFlow  VapFlow  IntFlow
0040201 -1.0     36.0E-3  0.0      0.0
0040202  0.0     0.0      0.0      0.0
* ----------------------------------------------------------------------
* COMPONENT 5 ; TMDPVOL
* ----------------------------------------------------------------------
0050000 'FEED' TMDPVOL
* TMDPVOL geometry;
*       Area     VolLen   VolVol   A-ang    I-ang    El-Change
0050101 1.0E6    100.0    0.0      0.0      90.0     100.0
*       Rough    Hyd-dia  Flags
0050102 2.5E-7   9.12E-3  00
*
* TMDPVOL data;
*       Flag
0050200 003
*       Time     Pressure Temperature
0050201 0.0      4.026E6  310.0
```

```
* ----------------------------------------------------------------
* HEAT SLAB DATA
* ----------------------------------------------------------------
* General heat structure data;
*        NH       MeshPts  Geometry Flag     L-bound
10011000 22       9        2        0        0.0
*
* Heat structure mesh flags;
*        Locn     Format
10011100 0        1
*
* Mesh interval data;
10011101 3        4.0132E-3
10011102 2        4.3942E-3
10011103 1        5.6642E-3
10011104 2        6.3820E-3
*
* Heat structure composition data;
10011201 002      3
10011202 003      5
10011203 002      6
10011204 001      8
*
* Heat source distribution;
10011301 0.0      3
10011302 1.0      5
10011303 0.0      8
*
* Initial temp data;
*        Temp     MeshPt
10011401 550.0    4
10011402 540.0    5
10011403 520.0    6
10011404 470.0    7
10011405 460.0    8
10011406 450.0    9
*
* Boundary conditions;
*        BVol      Inc      BCType   SurArCd  Height   NH
10011501 0         0        0        1        9.15     22      * Left
10011601 001040000 10000    1        1        9.15     22      * Right
*
* Source data;
*        Type     Multplyr DH-left  DH-rght  HSno
10011701 001      0.03463  0.0      0.0      1
10011702 001      0.03750  0.0      0.0      2
10011703 001      0.04011  0.0      0.0      3
10011704 001      0.04243  0.0      0.0      4
10011705 001      0.04446  0.0      0.0      5
10011706 001      0.04615  0.0      0.0      6
10011707 001      0.04753  0.0      0.0      7
10011708 001      0.04858  0.0      0.0      8
10011709 001      0.04928  0.0      0.0      9
10011710 001      0.04963  0.0      0.0      10
```

```
10011711 001      0.04963  0.0      0.0      11
10011712 001      0.04928  0.0      0.0      12
10011713 001      0.04858  0.0      0.0      13
10011714 001      0.04753  0.0      0.0      14
10011715 001      0.04615  0.0      0.0      15
10011716 001      0.04446  0.0      0.0      16
10011717 001      0.04243  0.0      0.0      17
10011718 001      0.04011  0.0      0.0      18
10011719 001      0.03750  0.0      0.0      19
10011720 001      0.03463  0.0      0.0      20
10011721 001      0.03152  0.0      0.0      21
10011722 001      0.02818  0.0      0.0      22
*
* Additional right boundary card;
*        Flag     Hyd-dia  HtEq-dia ChanLen  HS
10011901 0        0.0      0.0      3.66     22
* ------------------------------------------------------------
* THERMAL PROPERTY DATA
* ------------------------------------------------------------
*                  ThCond  VolHtCap
20100100 TBL/FCTN 1        1         * Stainless steel
20100200 TBL/FCTN 1        1         * Magnesium oxide
20100300 TBL/FCTN 1        1         * Nichrome
*
* Stainless steel
*        Temp     ThCond
20100101 300.0    12.61
20100102 366.5    13.85
20100103 477.6    15.92
20100104 588.7    18.17
20100105 700.0    20.42
20100106 810.9    22.50
20100107 922.0    24.92
20100108 1033.2   26.83
20100109 1144.3   29.42
20100110 1477.6   36.06
*
*        Temp     VolHtCap
20100151 300.0    3.803E6
20100152 366.5    3.908E6
20100153 477.6    4.084E6
20100154 588.7    4.260E6
20100155 700.0    4.436E6
20100156 810.9    4.665E6
20100157 922.0    4.929E6
20100158 1033.2   5.105E6
20100159 1477.6   5.727E6
```

```
*
* Magnesium oxide;
*          Temp      ThCond
20100201 300.0     0.2520
20100202 373.15    0.2451
20100203 422.04    0.2405
20100204 477.59    0.2352
20100205 533.15    0.2300
20100206 588.71    0.2249
20100207 644.26    0.2196
20100208 699.82    0.2143
20100209 755.37    0.2091
20100210 810.93    0.2039
20100211 866.48    0.1987
20100212 922.04    0.1934
20100213 977.59    0.1882
20100214 1033.15   0.1830
20100215 1088.71   0.1777
20100216 1144.26   0.1725
20100217 1199.82   0.1673
20100218 1255.37   0.1621
20100219 1310.93   0.1568
20100220 1366.48   0.1516
20100221 1422.04   0.1464
20100222 1477.59   0.1412
20100223 1533.15   0.1359
20100224 1588.71   0.1307
20100225 1644.26   0.1255
20100226 1699.82   0.1203
20100227 1755.37   0.1150
20100228 1810.93   0.1098
20100229 1866.48   0.1046
20100230 1922.04   0.0993
20100231 5000.00   0.0993
*
*          Temp      VolHtCap
20100251 300.0     2076.81
20100252 373.15    2033.52
20100253 422.04    2004.59
20100254 477.59    1971.74
20100255 533.15    1938.87
20100256 588.71    1906.01
20100257 644.26    1873.15
20100258 699.82    1840.29
20100259 755.37    1807.43
20100260 810.93    1774.56
20100261 866.48    1741.70
20100262 922.04    1708.84
20100263 977.59    1675.96
20100264 1033.15   1643.11
20100265 1088.71   1610.25
20100266 1144.26   1577.39
20100267 1199.82   1544.53
20100268 1255.37   1511.67
```

```
20100269 1310.93  1478.80
20100270 1366.48  1445.94
20100271 1422.04  1413.08
20100272 1477.59  1380.22
20100273 1533.15  1347.35
20100274 1588.71  1314.49
20100275 1644.26  1281.63
20100276 1699.82  1248.77
20100277 1755.37  1215.90
20100278 1810.93  1183.04
20100279 1866.48  1150.18
20100280 1922.04  1117.32
20100281 5000.00  1117.32
*
* Nichrome;
*         Temp     ThCond
20100301 300.0    1.1163
20100302 373.15   1.1163
20100303 1922.04  1.1163
20100304 5000.00  1.1163
*
*         Temp     VolHtCp
20100351 300.0    2180.80
20100352 373.15   2180.80
20100353 1922.04  2180.80
20100354 5000.00  2180.80
*
* General data table for power;
20200100 POWER
*         Time    Power
20200101 0.0     0.0
20200102 200.0   1.0E5
*
 * END OF DATA DECK
```

TABLE 1

TEST NUMBER	PRESSURE /Bars	MAKE-UP FLOW RATE/KgSec-1	MAKE-UP FLOW TEMPERATURE/K	TEST SECTION POWER/KW
561-2	2.00	$120.0 \times 10^{-}$	352	100
551-2	5.25	$97.4 \times 10^{-}$	342	100
553-4	10.21	$47.4 \times 10^{-}$	310	100
555-6	20.15	$53.0 \times 10^{-}$	356	100
557-8	40.26	$36.0 \times 10^{-}$	310	100

LIST OF FIGURES

Transient calculation with standard code

Transient calculation with modified code.

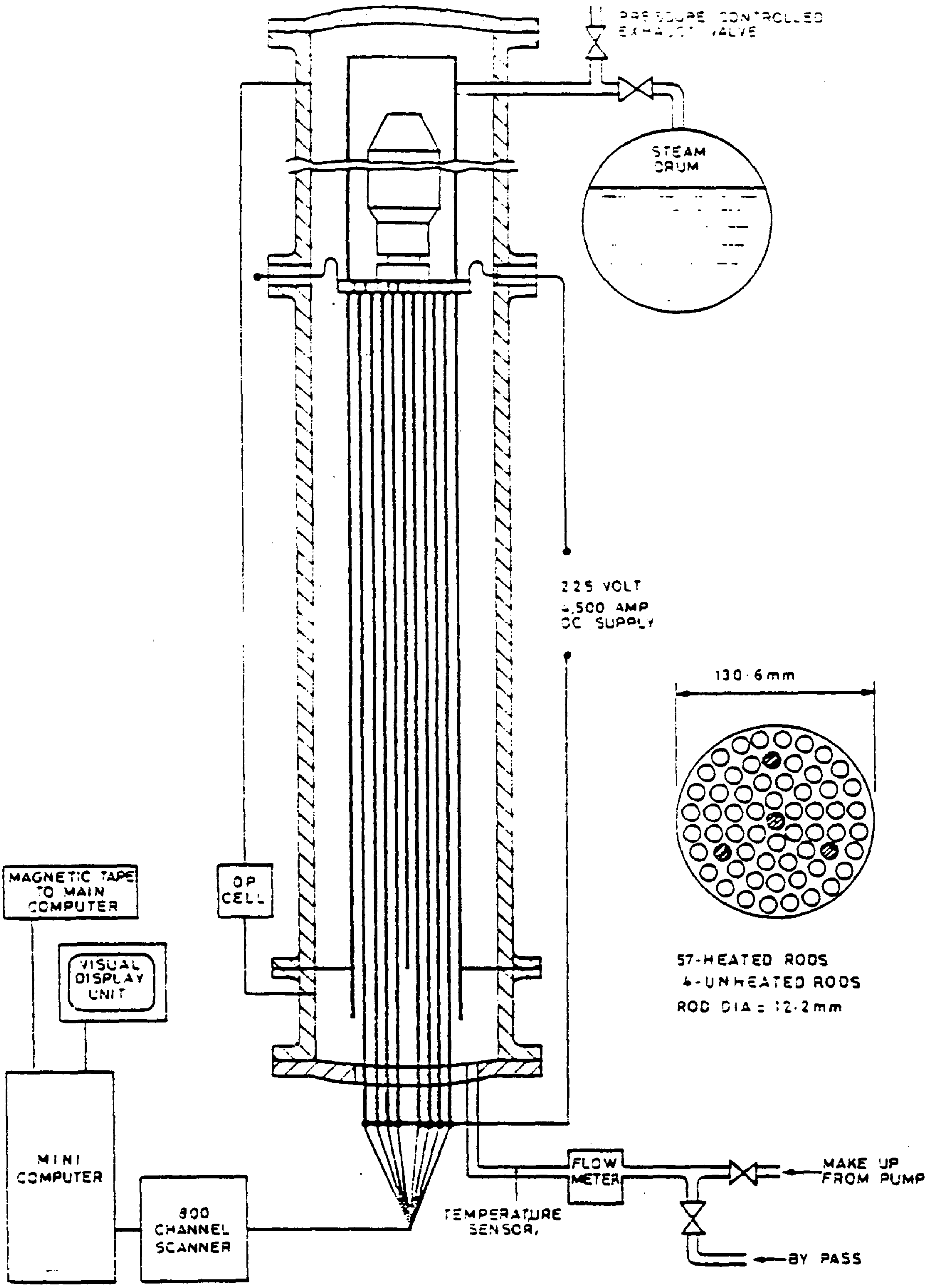

Figure 1: THE THERMAL HYDRAULIC EMERGENCY COOLING TEST INSTALLATION (THETIS)

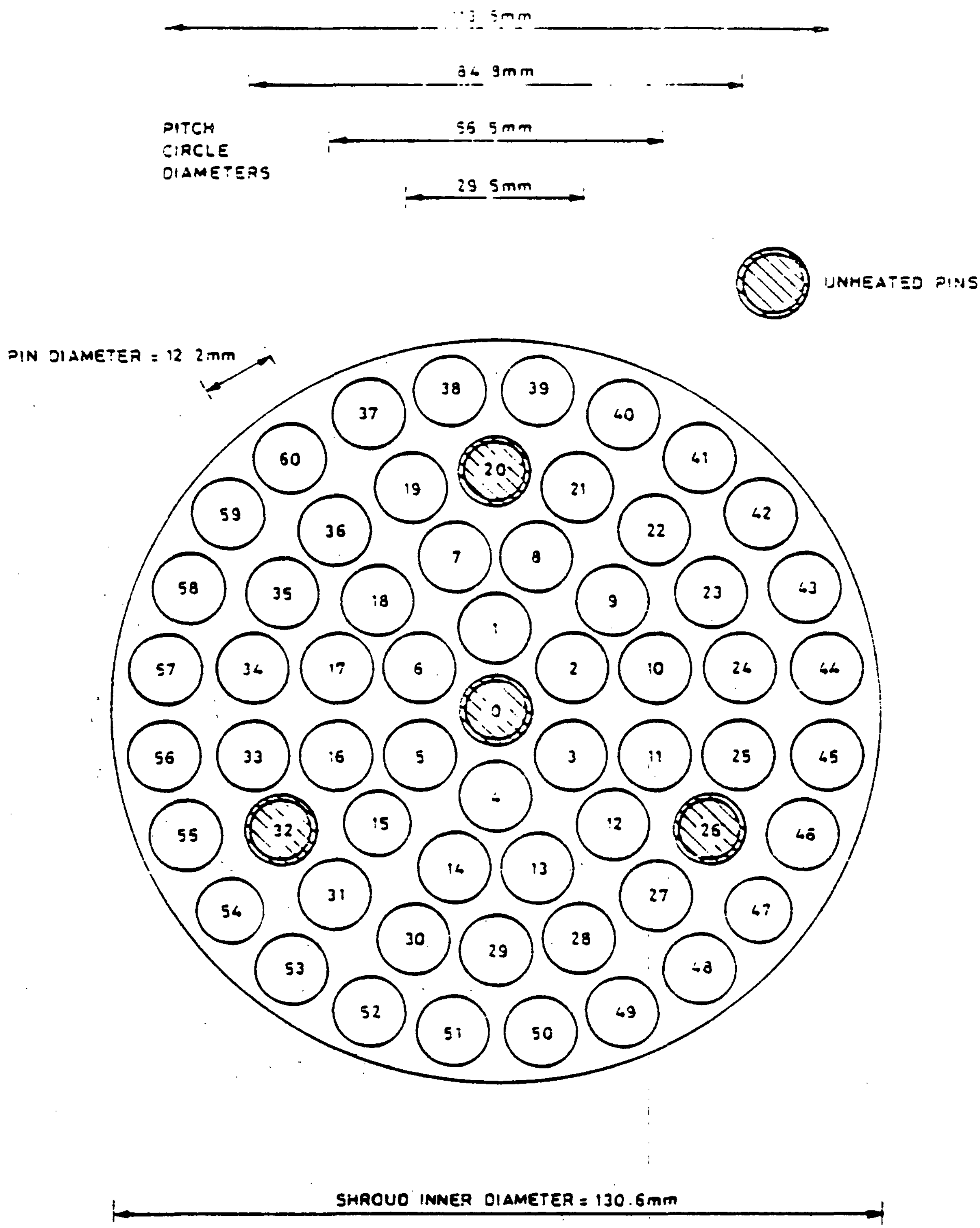

Figure 2: 61 PIN CLUSTER CROSS SECTION AND PIN NUMBERING SYSTEM

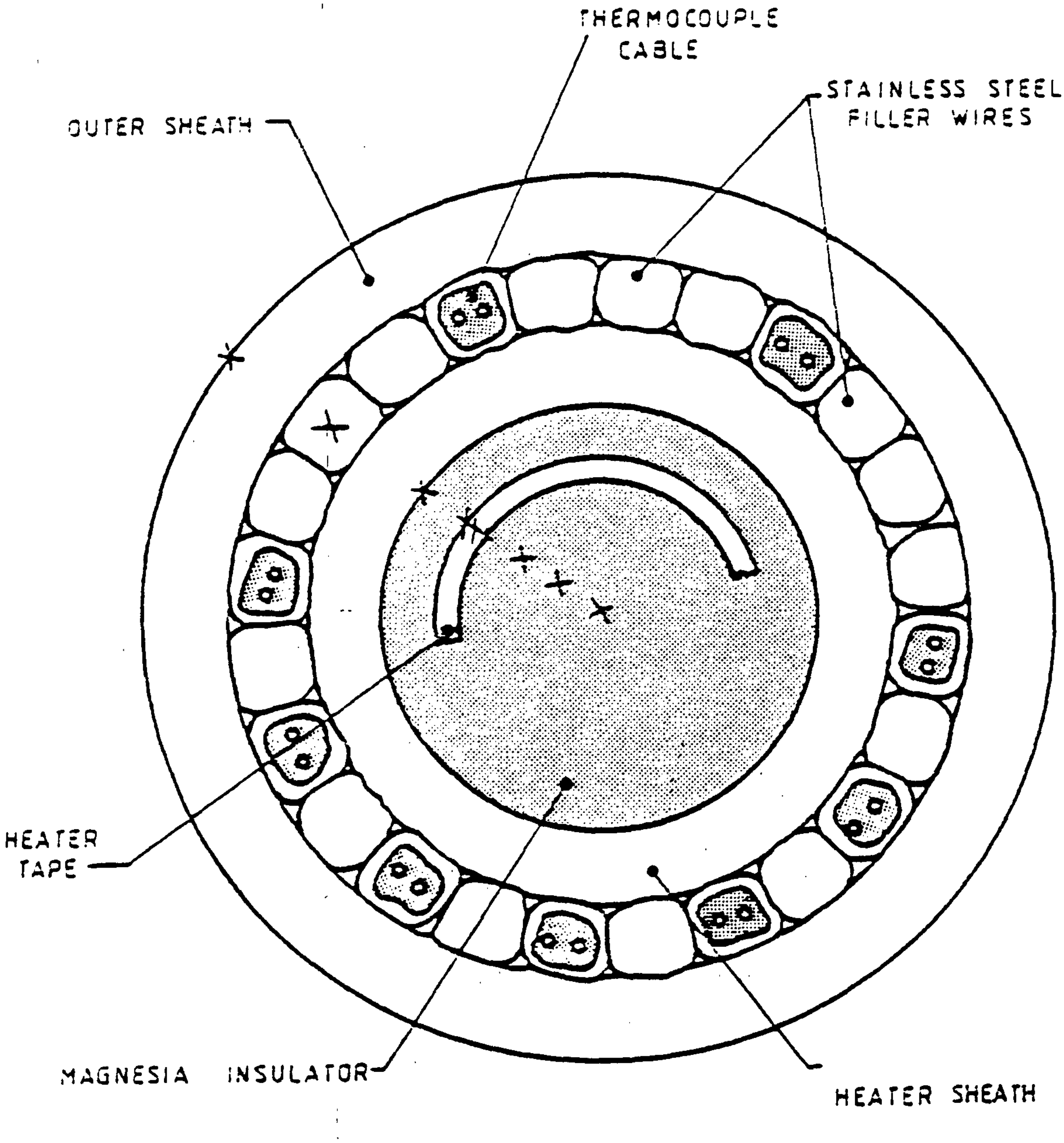

Figure 3: THERMOCOUPLE IN UPPER HALF ARRANGED FOR 610 mm AXIAL SPACING, IN LOWER HALF FOR 105 mm AXIAL SPACING

CROSS-SECTION OF MODEL FUEL PIN

PINS	1	2	3	4	5	6	POSITION OF	
TYPE	2	3	5	1	6	4	PRESSURE TAPS	SPACER GRIDS
POSITIONS	8, 9	10, 11	14, 15	7, 18	16, 17	12, 13		
	21, 22	23,24,25	29,30,31	19,35,36	33, 34	27, 28		
	39,40,41,42	43,44,45,46	51,52,53,54	37,38,59,60	55,56,57,58	47,48,49,50		

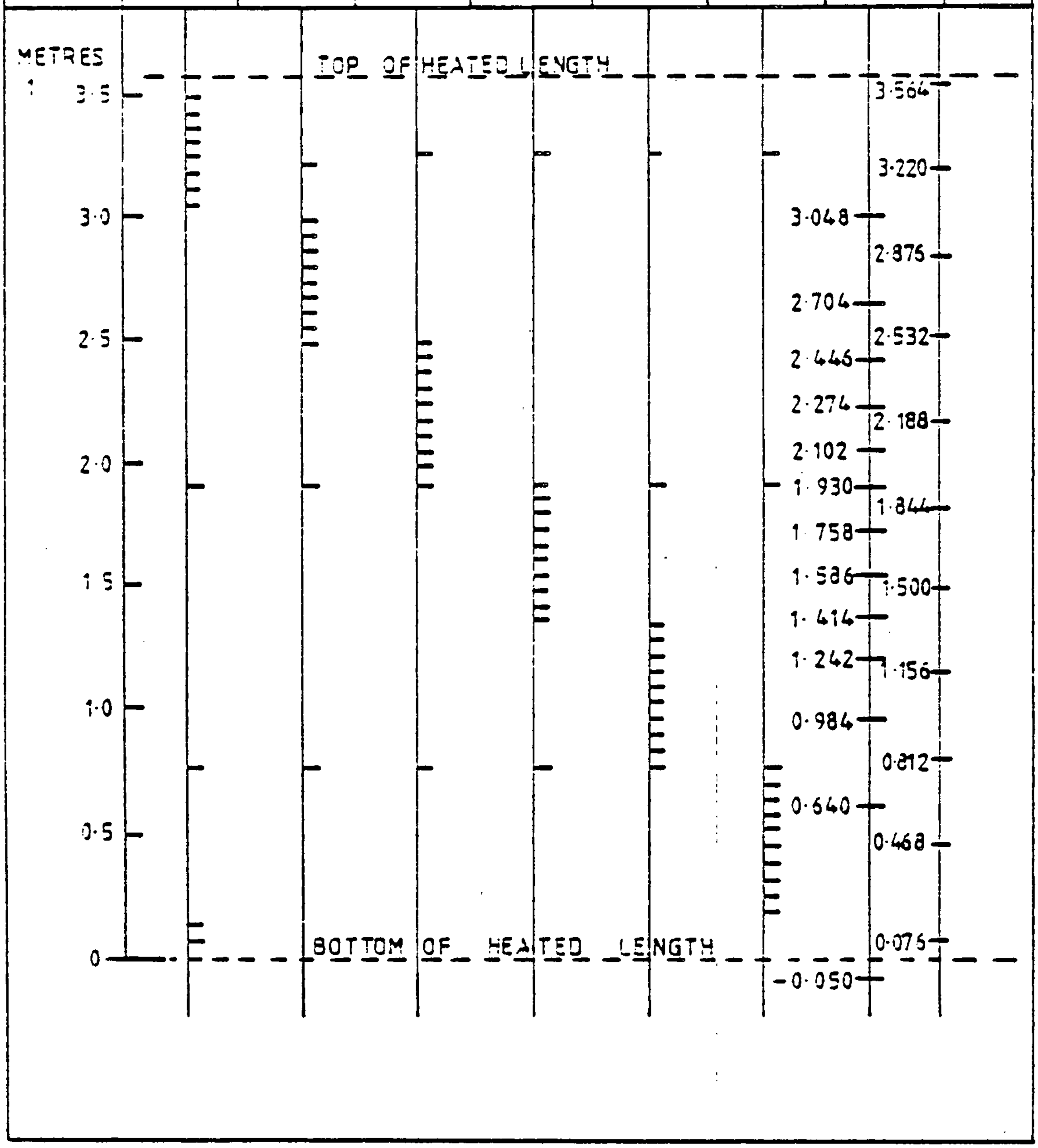

FIG.4 THERMOCOUPLE, PRESSURE TAP AND SPACER GRID POSITIONS

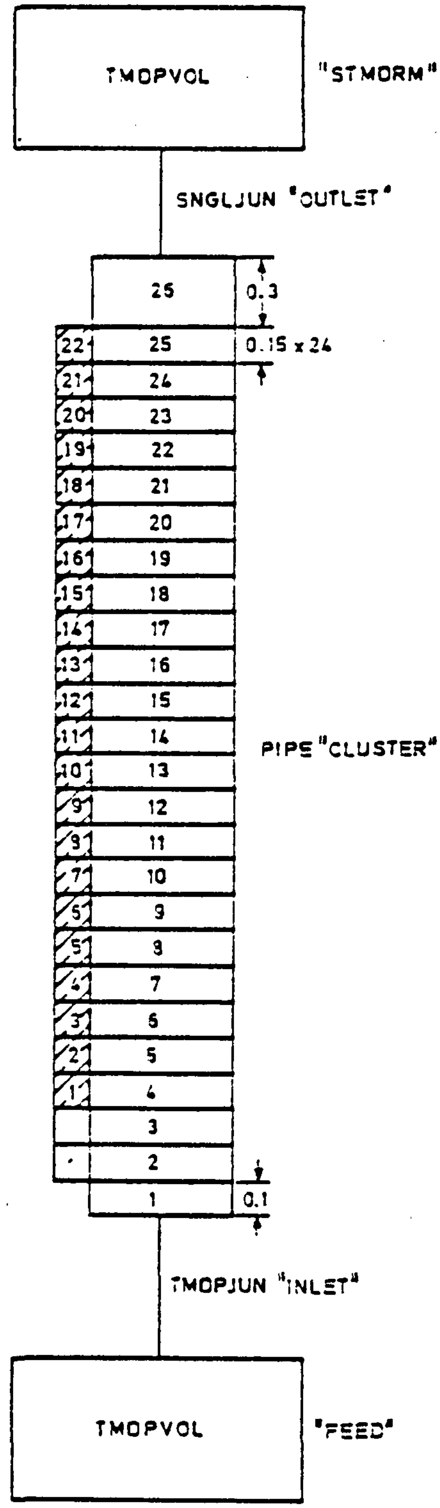

FIG. 5. NODING DIAGRAM FOR 24 VOLUME CALCULATION

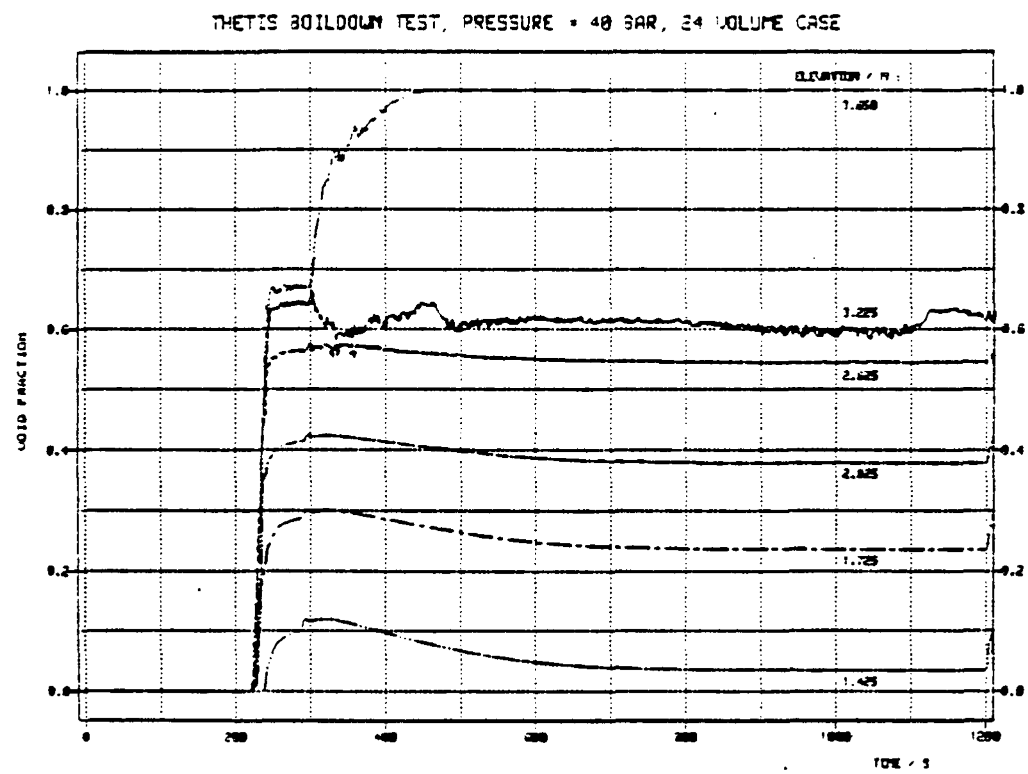

Figure 6: CALCULATED VOID FRACTION HISTORIES DURING STEADY STATE

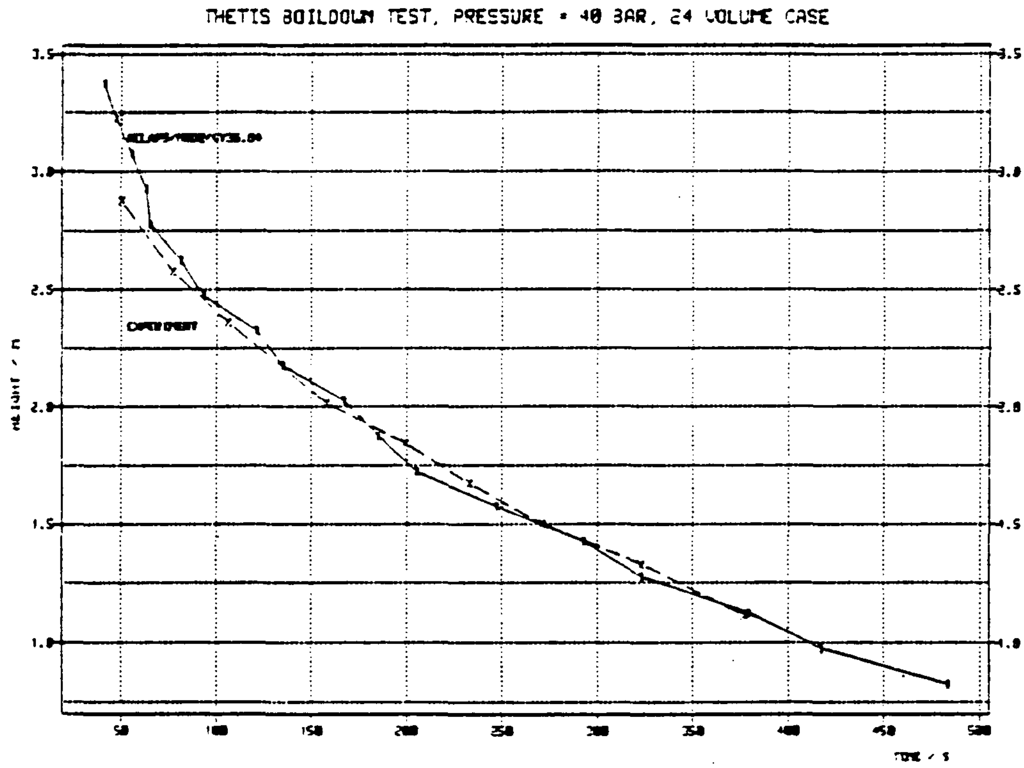

Figure 7: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

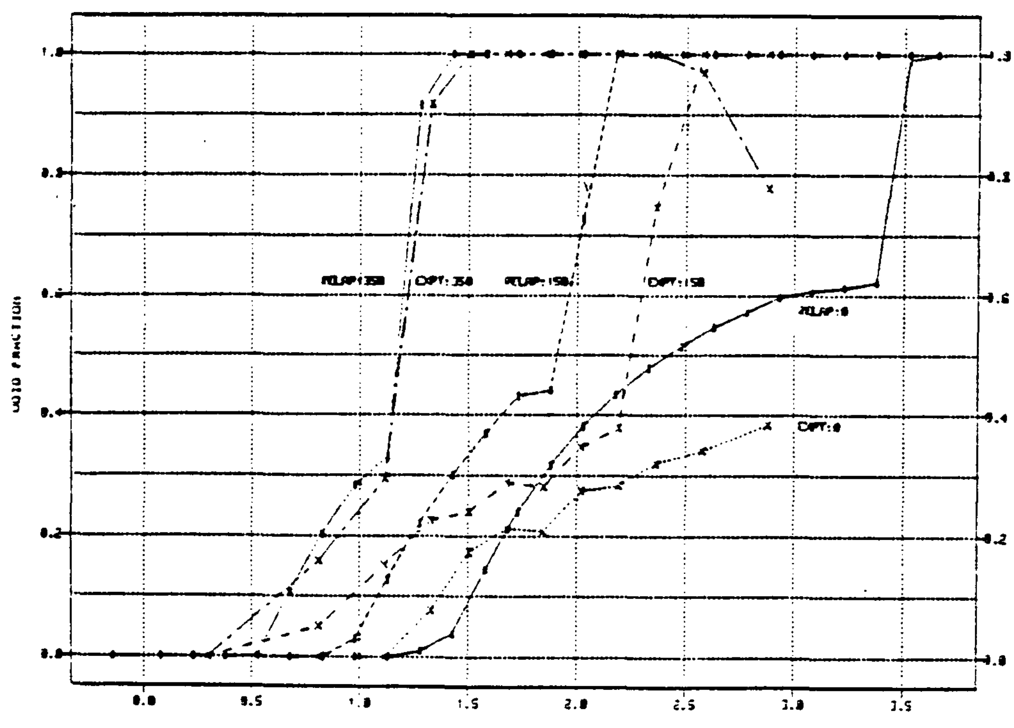

Figure 8: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

THETIS BOILDOWN TEST, PRESSURE = 20 BAR, 24 VOLUME CASE

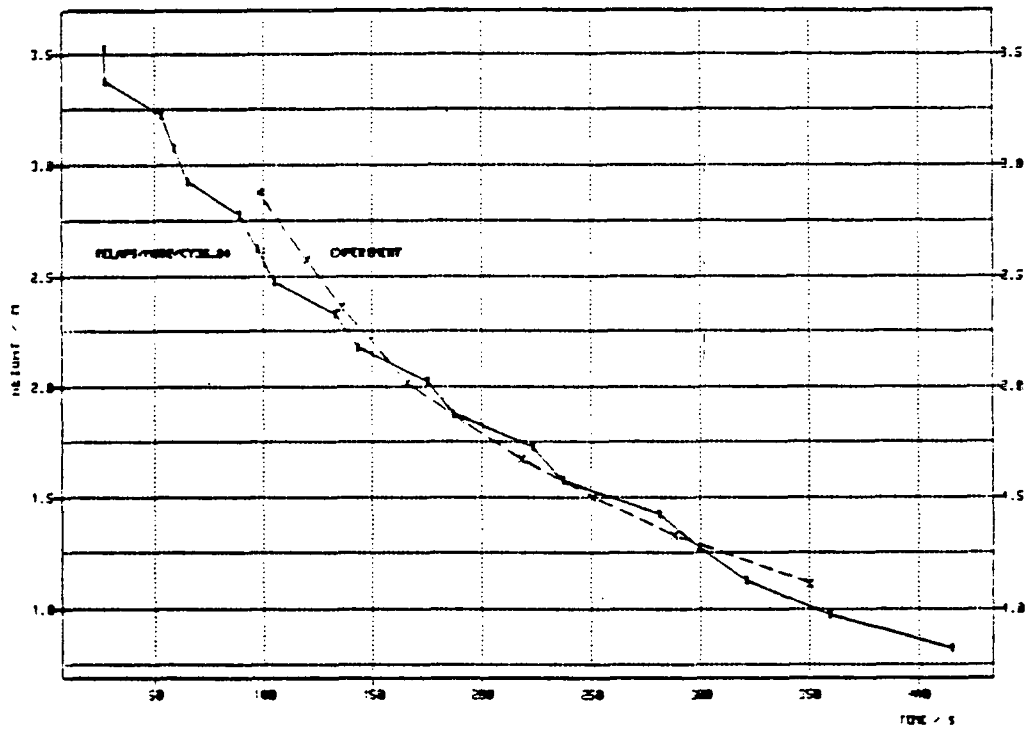

Figure 9: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

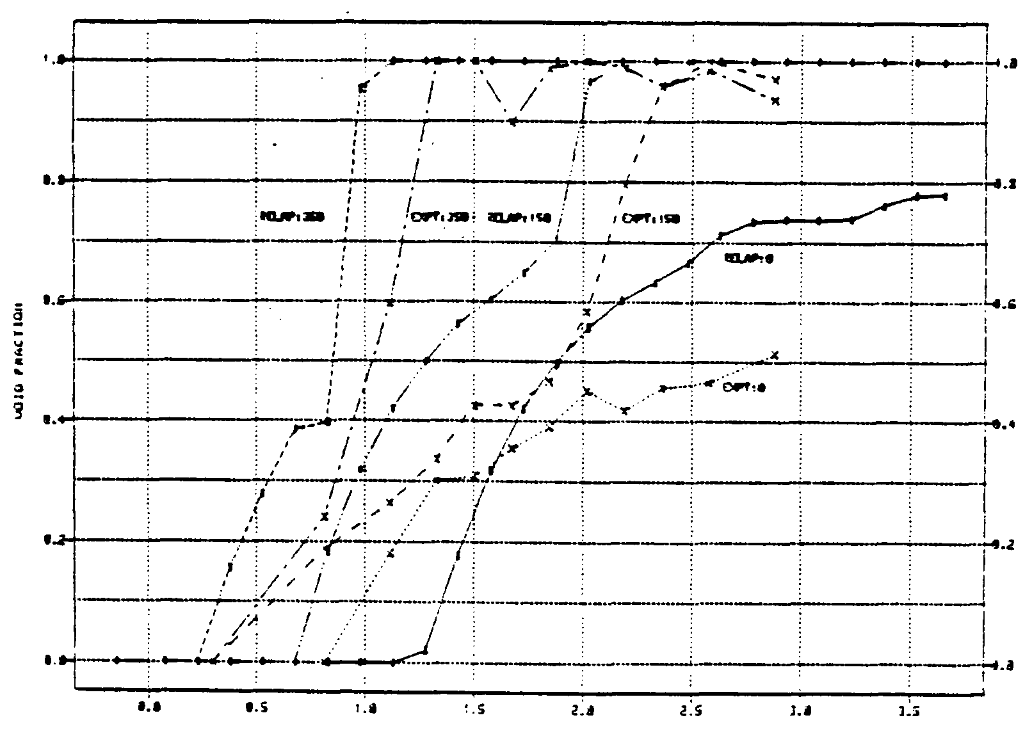

Figure 10: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

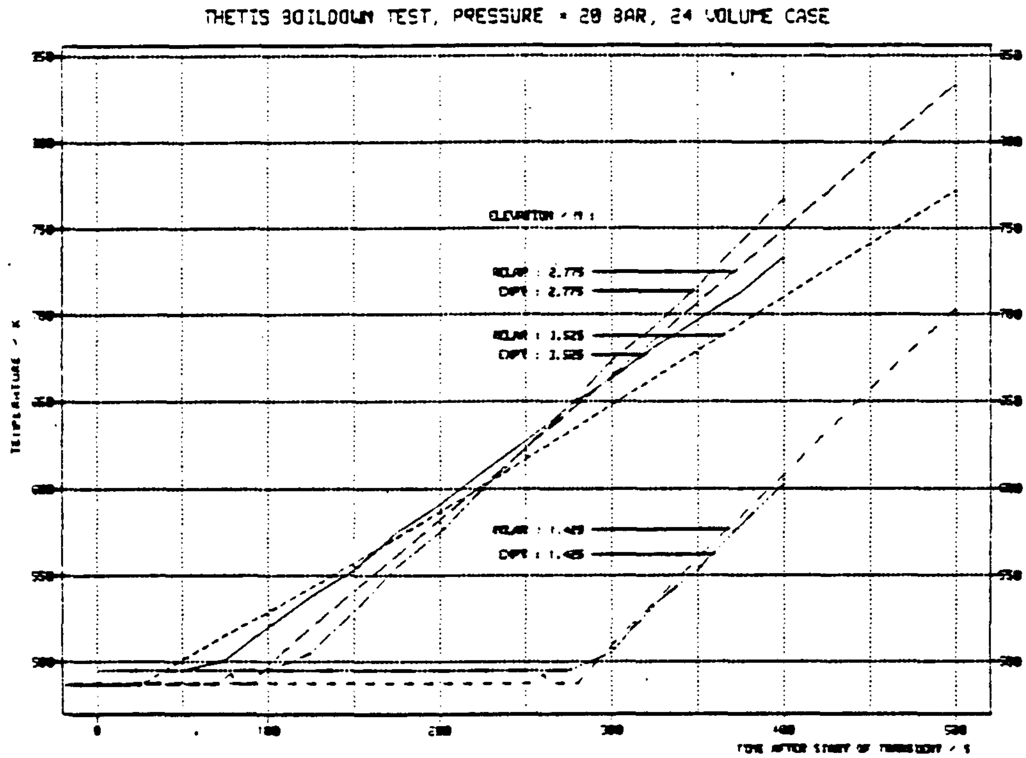

Figure 11: COMPARISON OF EXPERIMENTAL AND RELAP HEATER ROD SURFACE TEMPERATURES

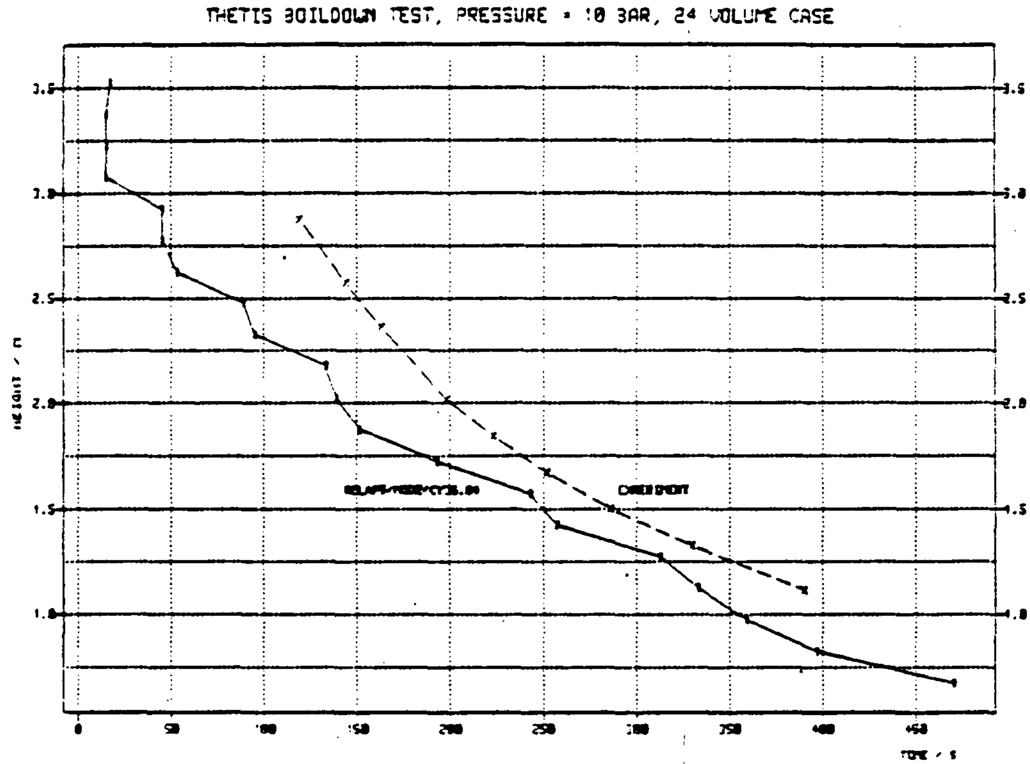

Figure 12: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

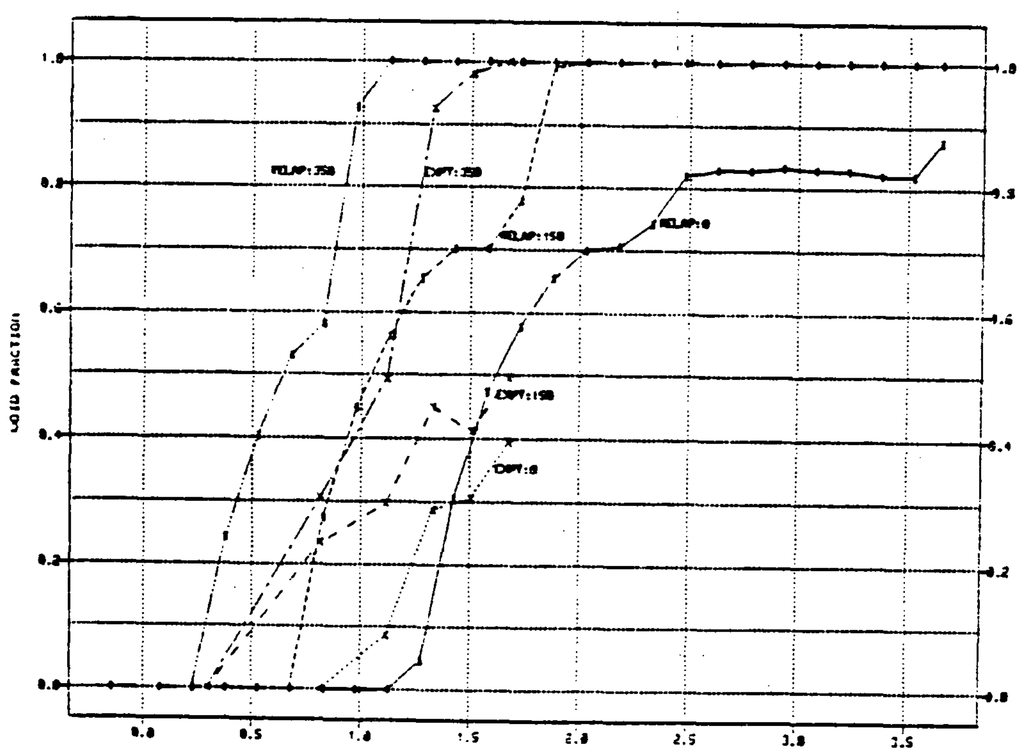

Figure 13: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

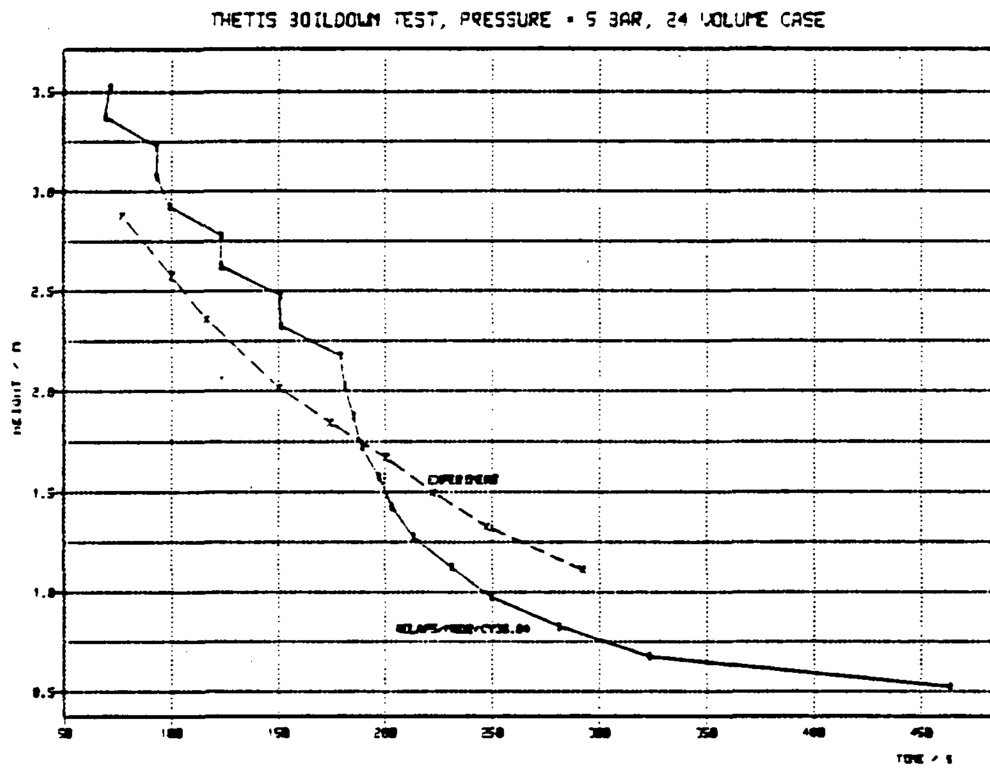

Figure 14: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

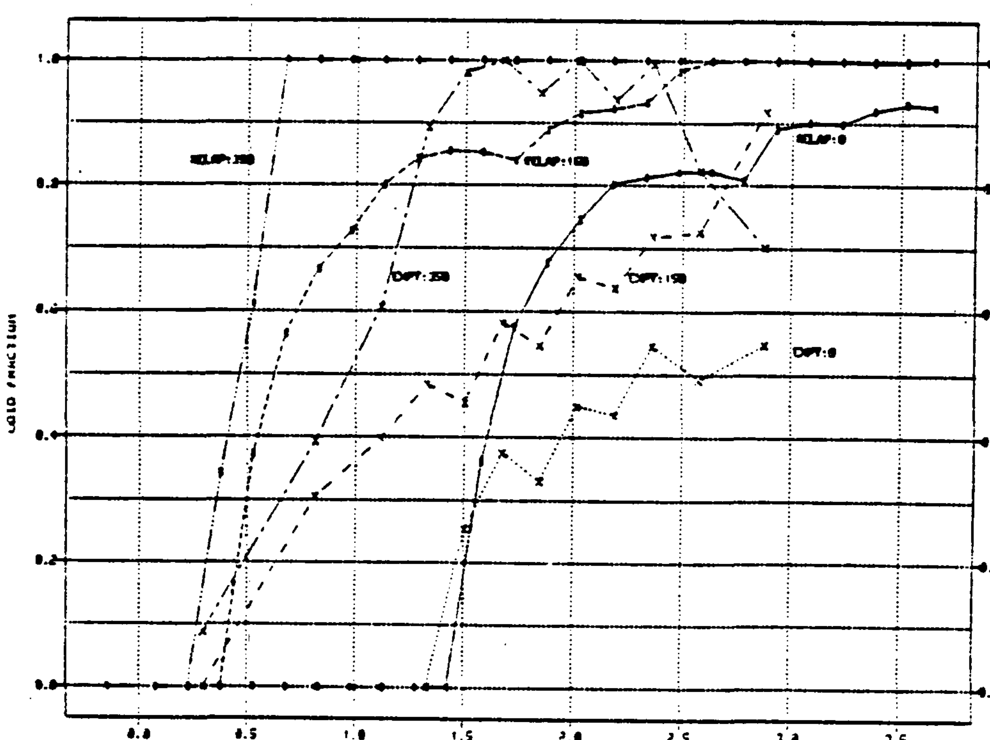

Figure 15: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

THETIS BOILDOWN TEST, PRESSURE = 2 BAR, 24 VOLUME CASE

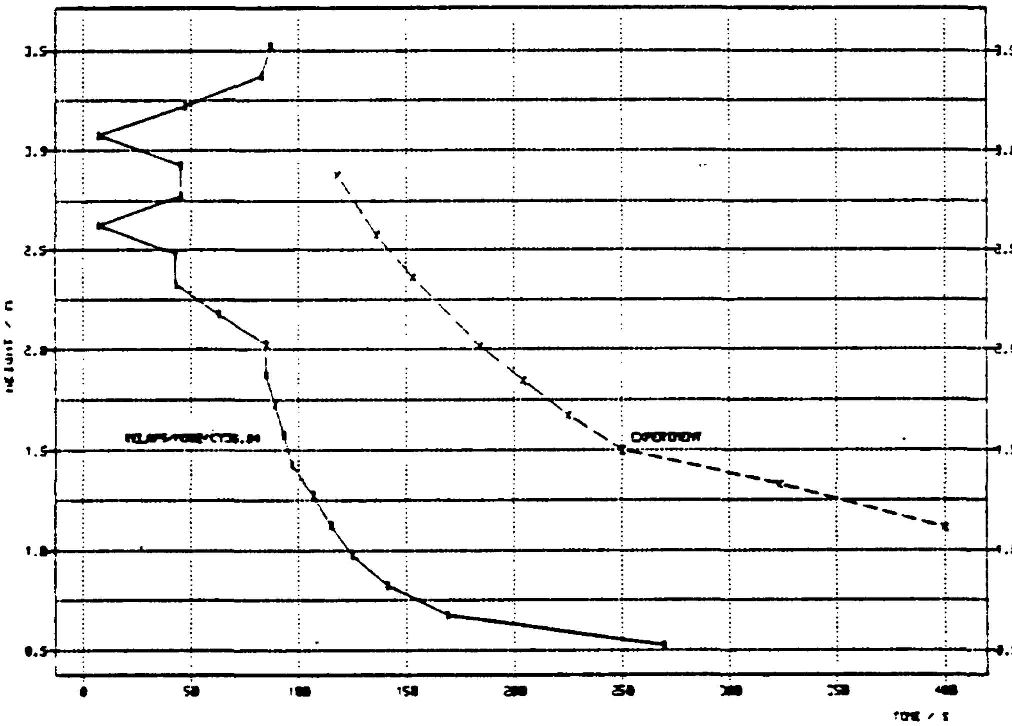

Figure 16: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

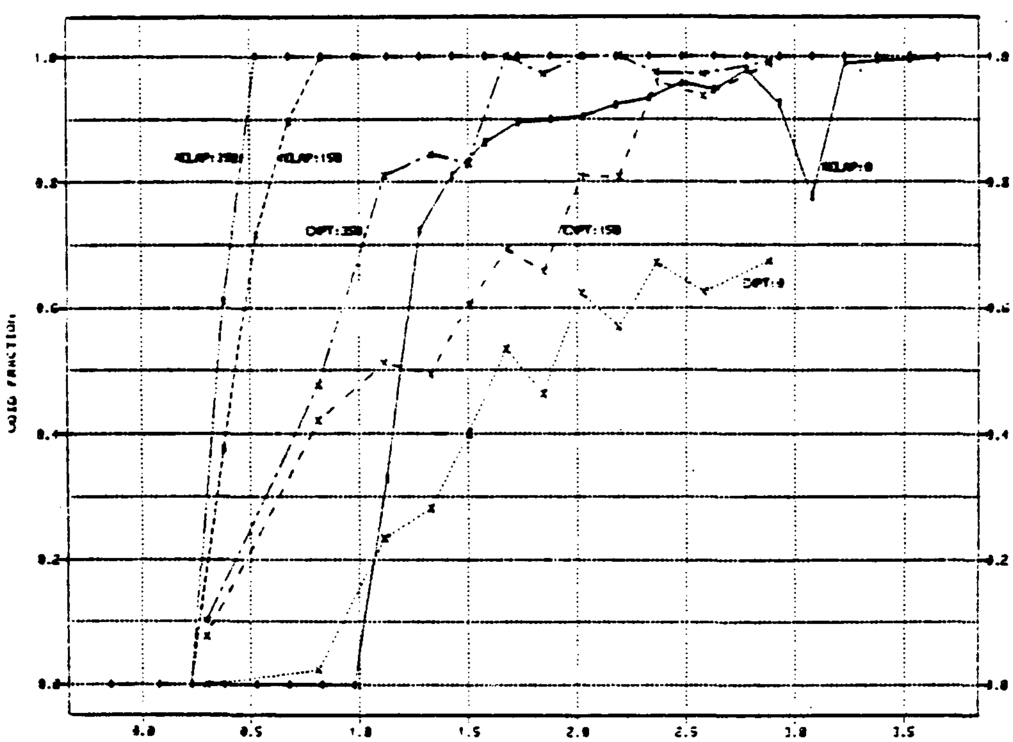

Figure 17: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

THETIS BOILDOWN TEST, PRESSURE = 5 BAR, 24 VOLUME CASE

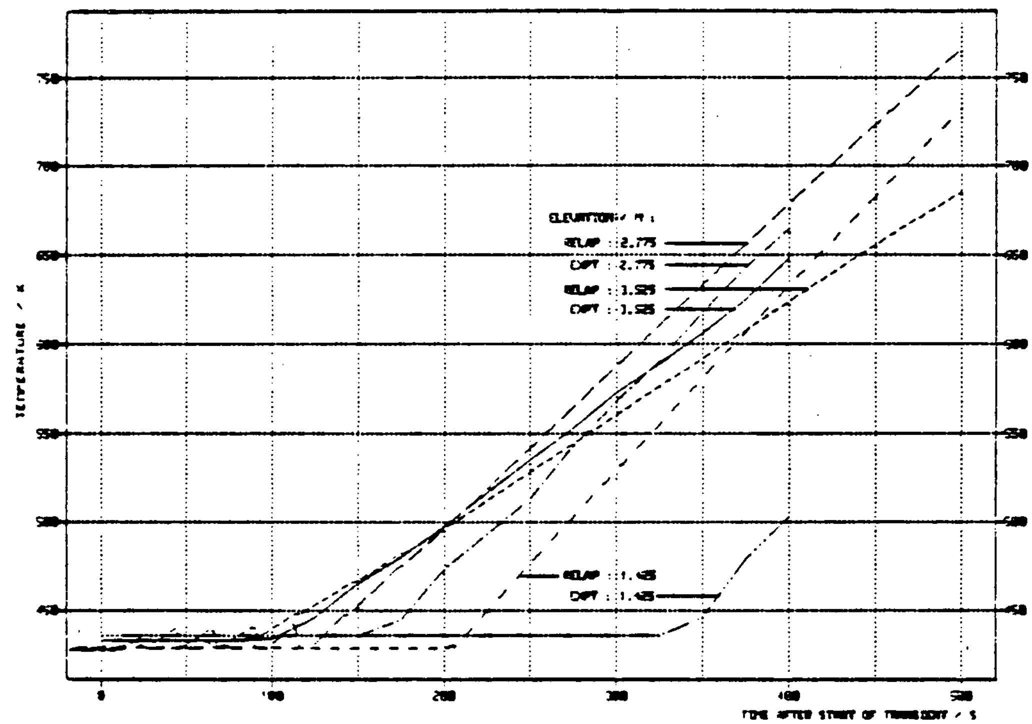

Figure 18: COMPARISON OF EXPERIMENTAL AND RELAP HEATER ROD SURFACE TEMPERATURES

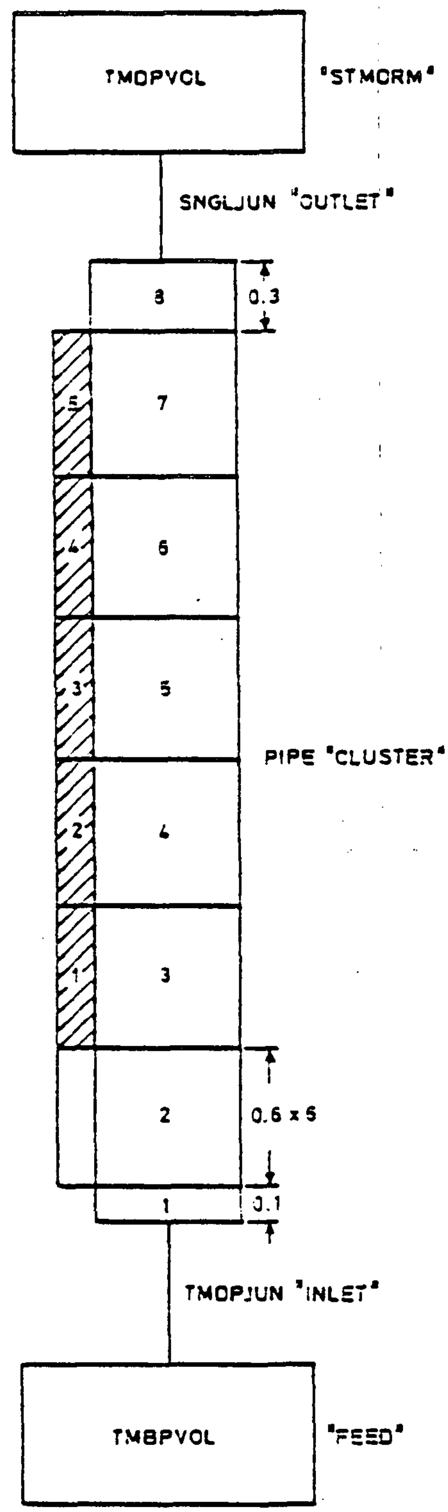

FIG. 19. NODING DIAGRAM FOR 6 VOLUME CALCULATION

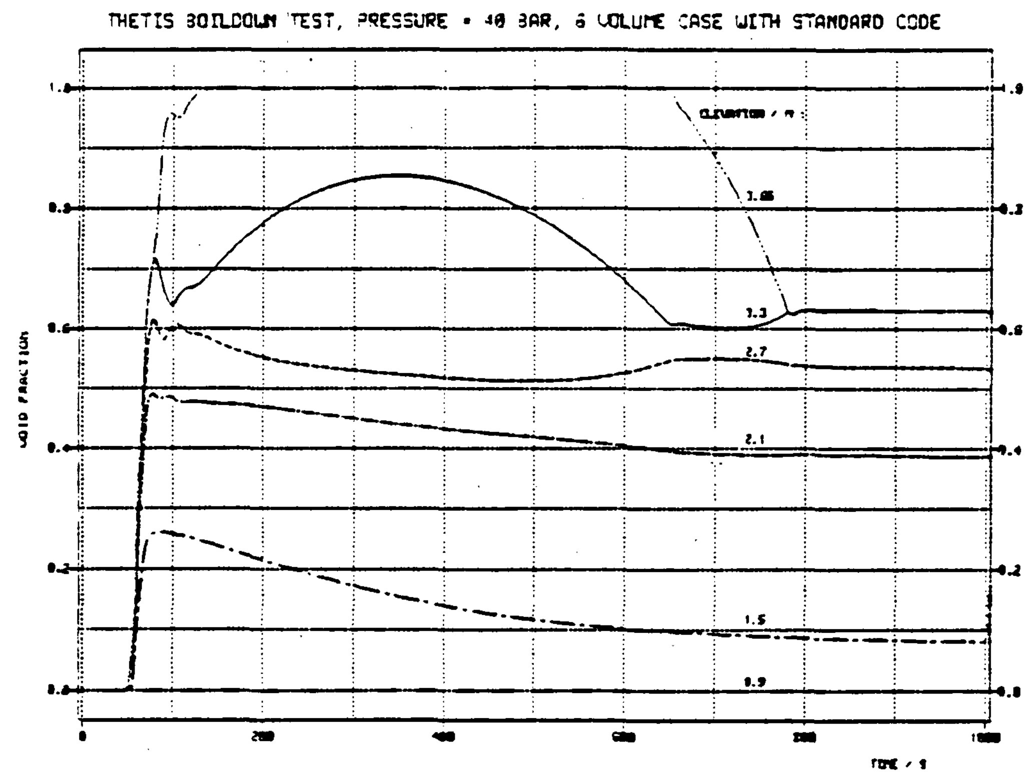

Figure 20: CALCULATED VOID FRACTION HISTORIES DURING STEADY STATE

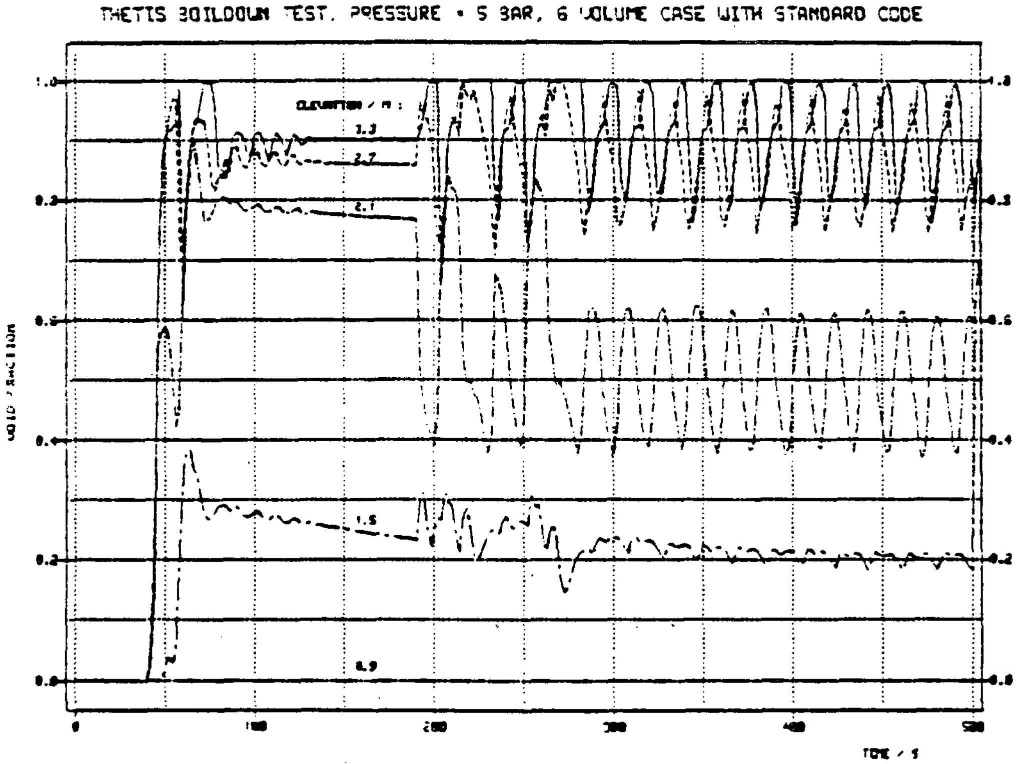

Figure 21: CALCULATED VOID FRACTION HISTORIES DURING STEADY STATE

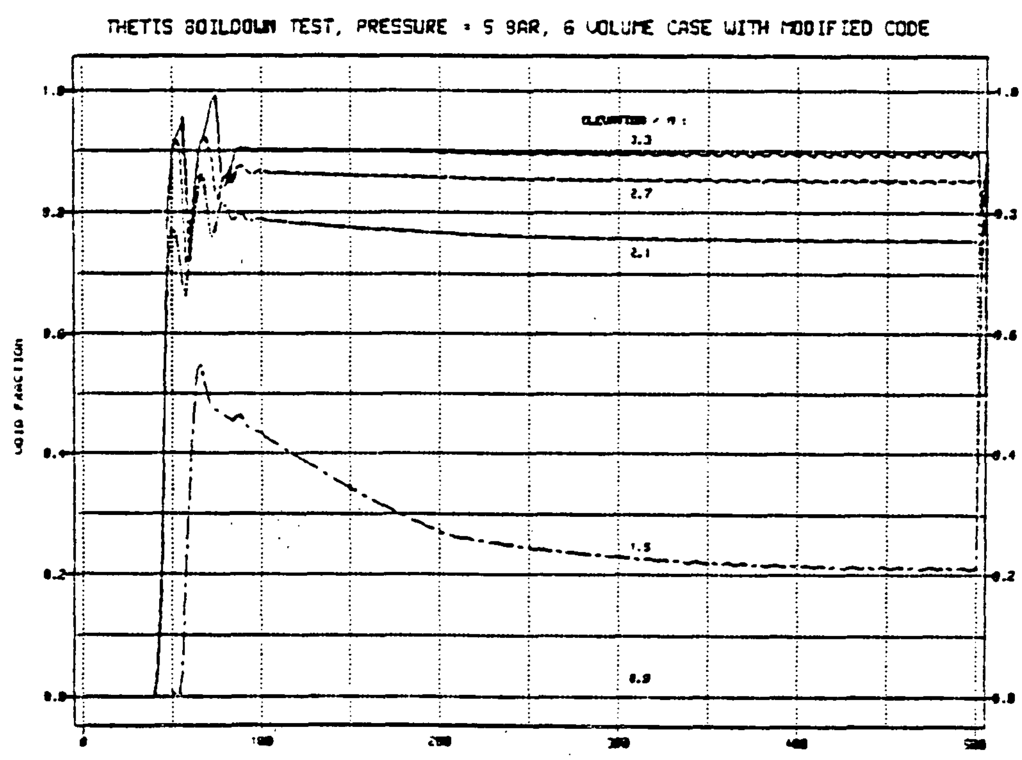

Figure 22: CALCULATED VOID FRACTION HISTORIES DURING STEADY STATE

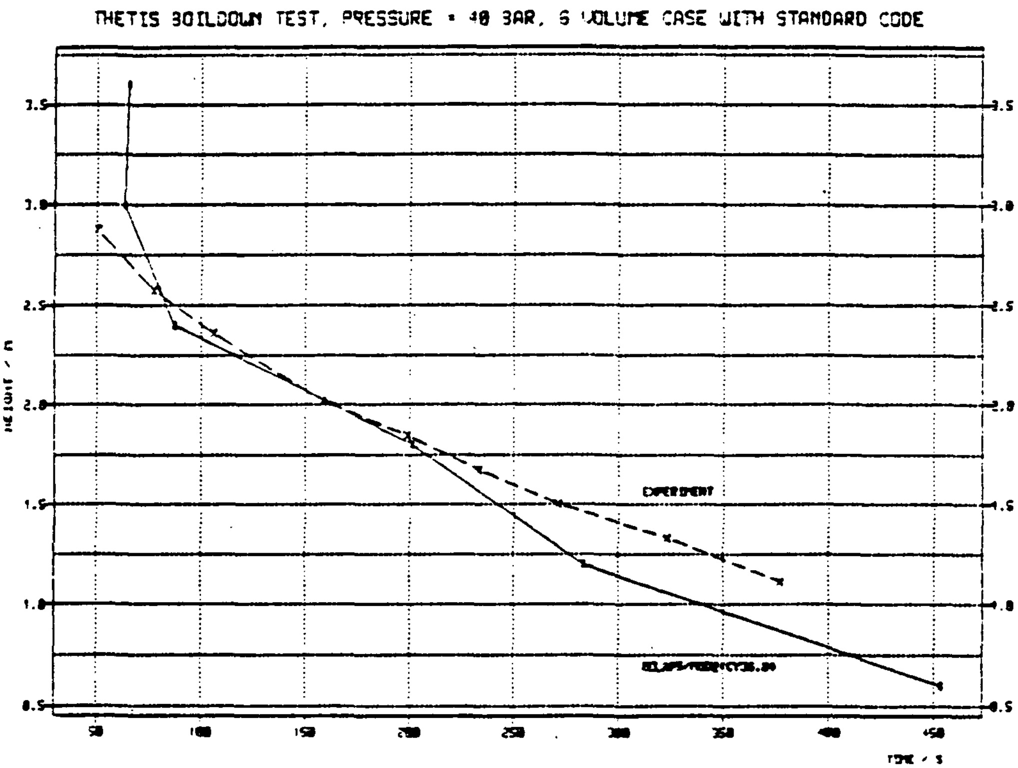

Figure 23: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

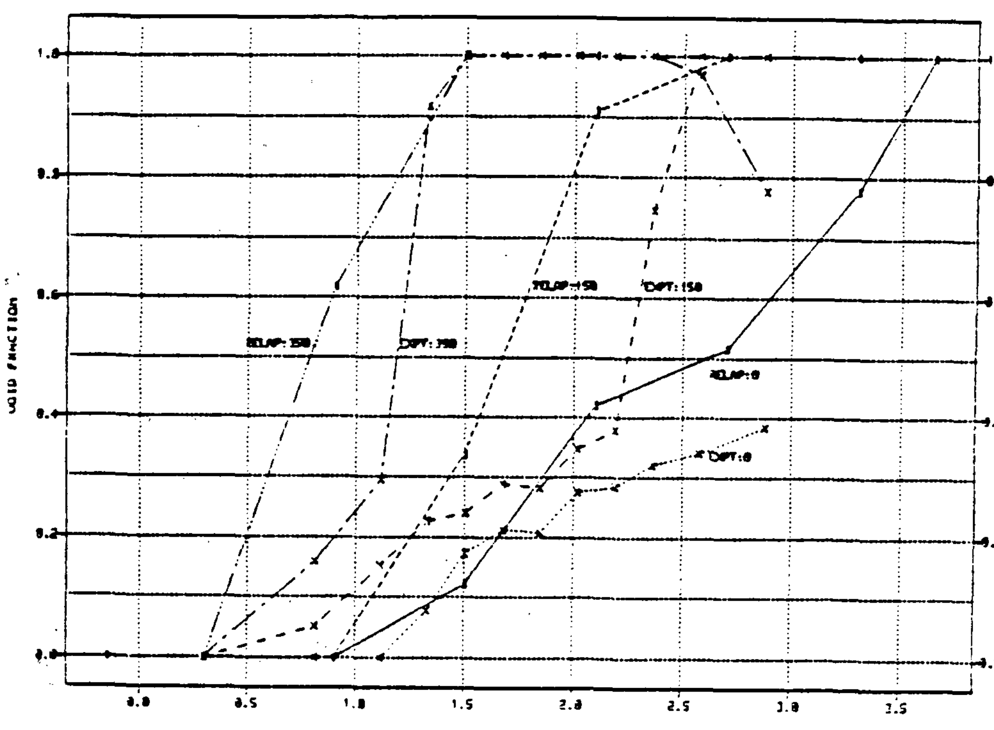

Figure 24: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

THETIS BOILDOWN TEST, PRESSURE = 20 BAR, 6 VOLUME CASE WITH STANDARD CODE

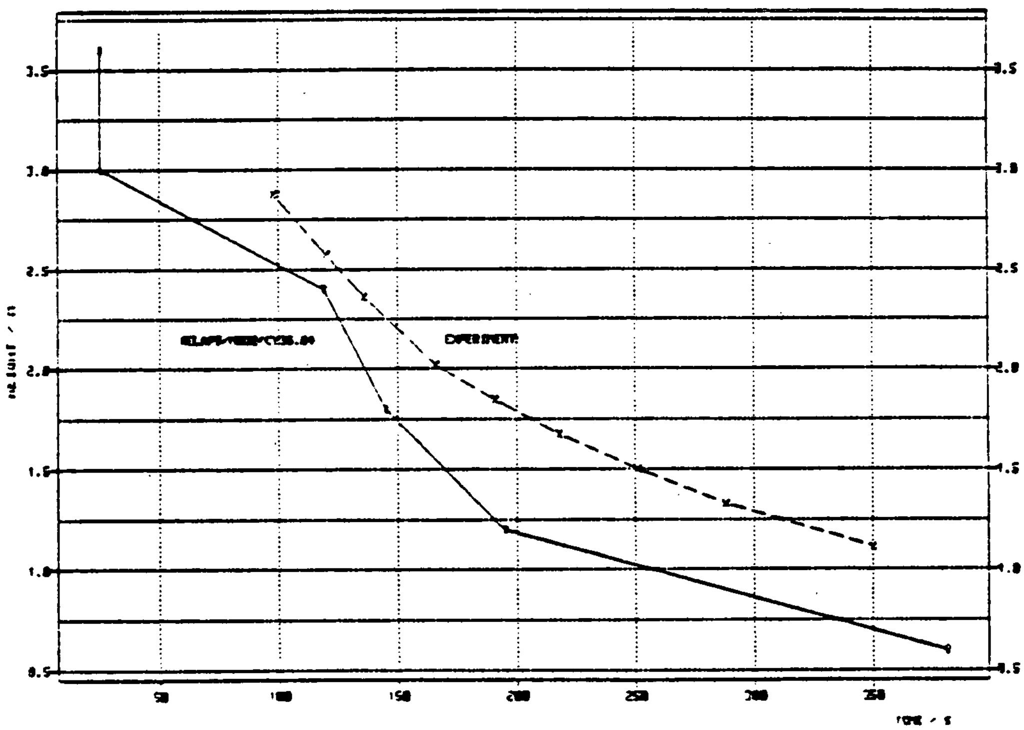

Figure 25: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

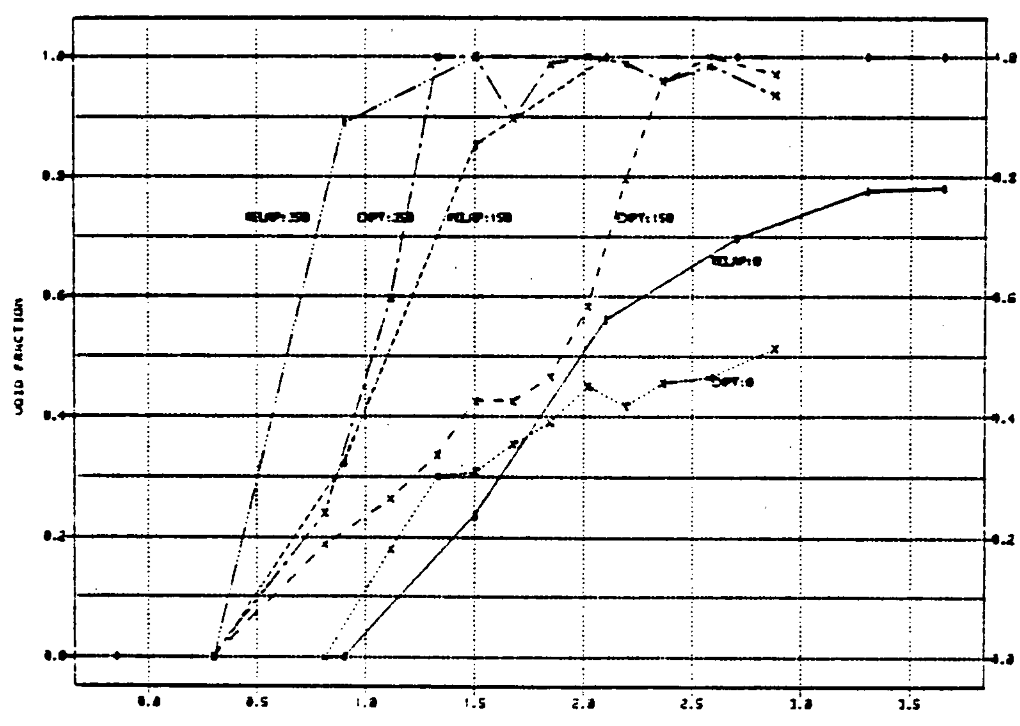

Figure 26: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

THETIS BOILDOWN TEST, PRESSURE = 10 BAR, 6 VOLUME CASE WITH STANDARD CODE

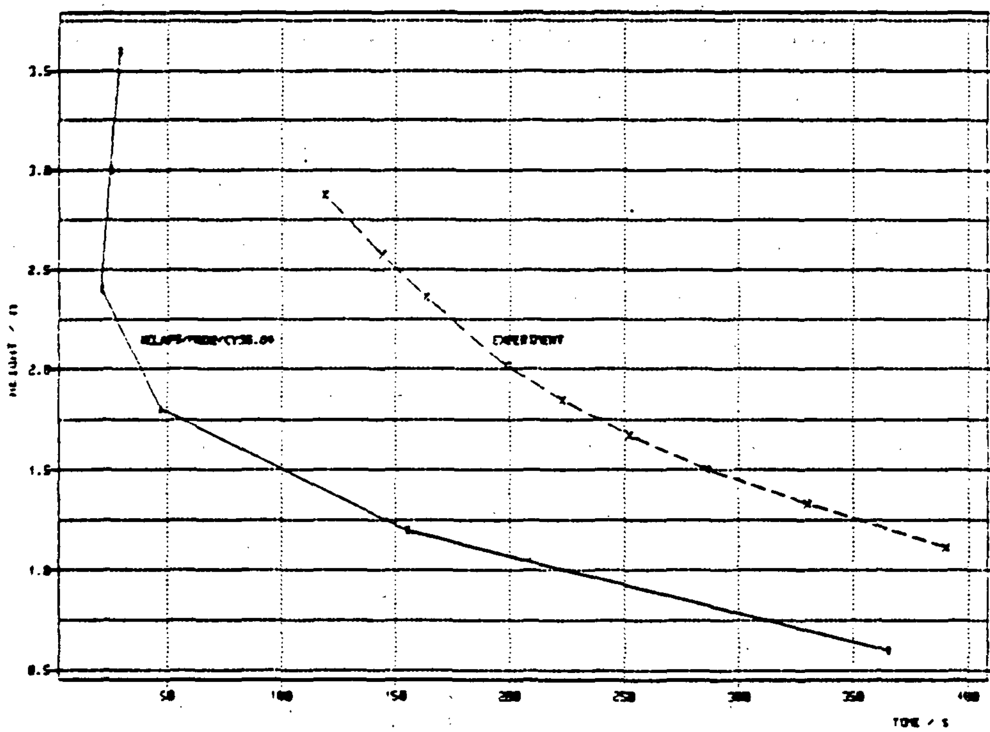

Figure 27: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

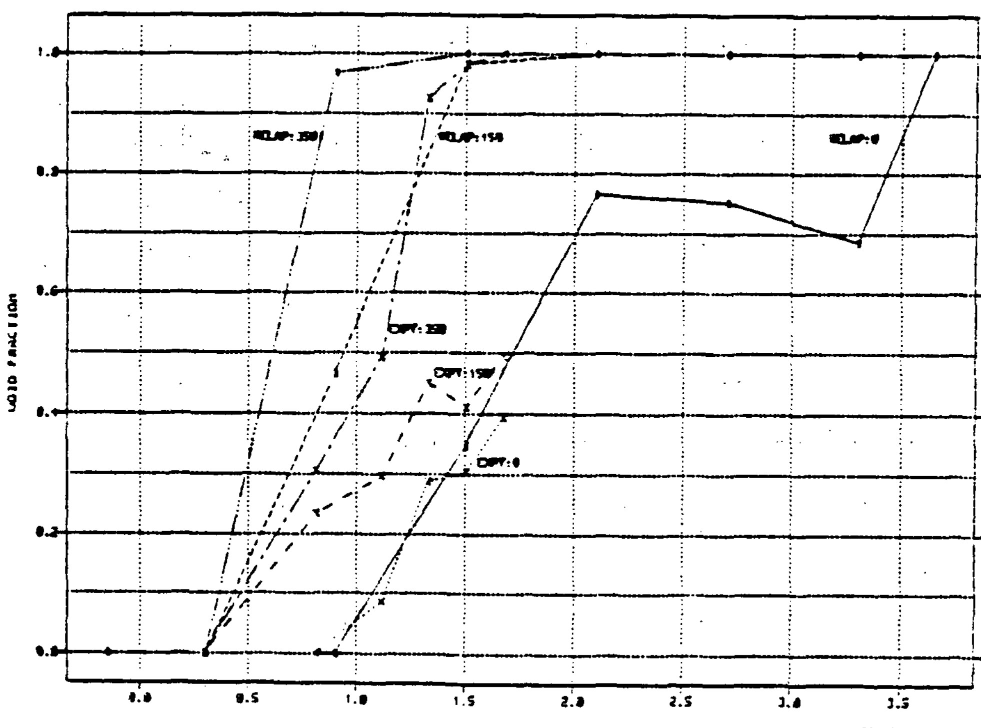

Figure 28: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

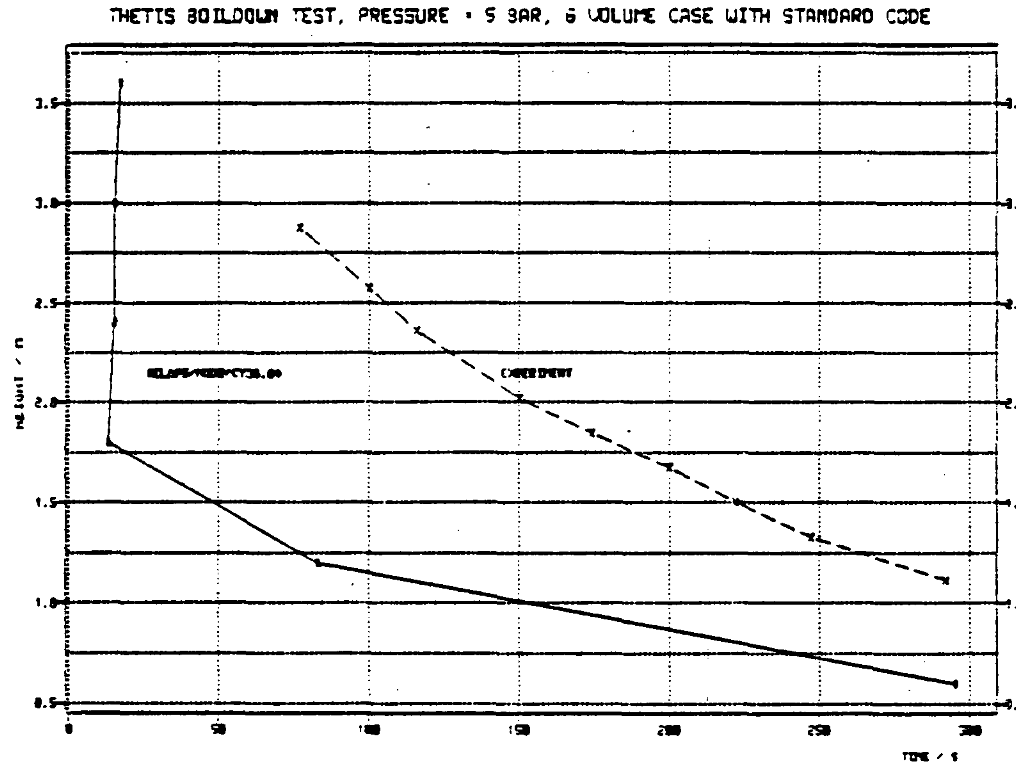

Figure 29: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

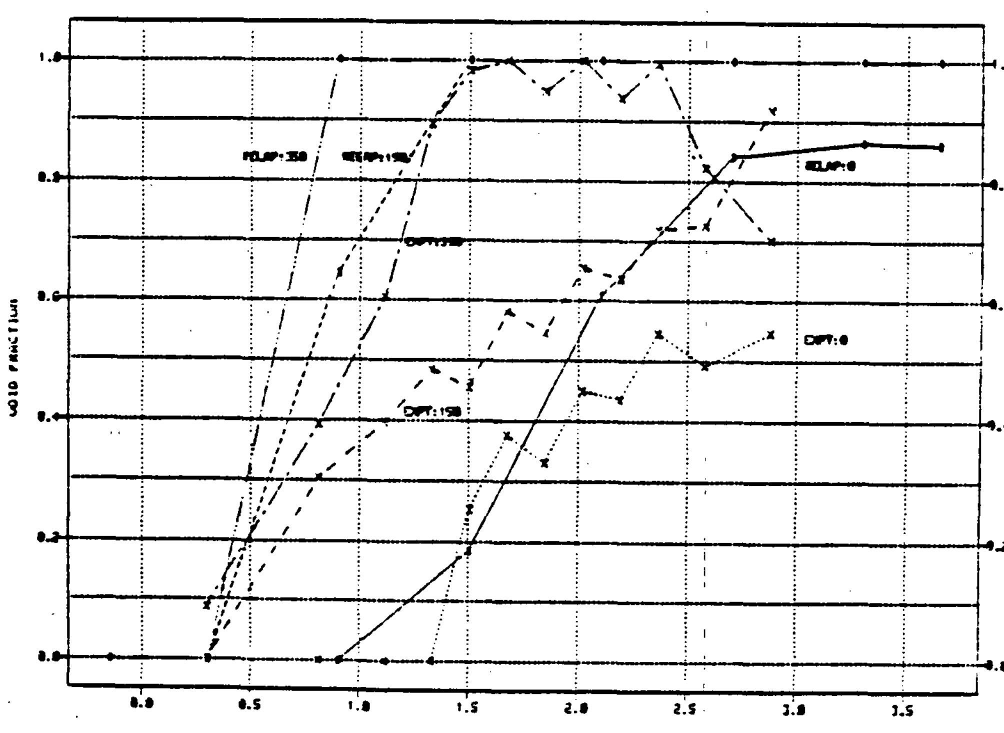

Figure 30: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

THETIS BOILDOWN TEST, PRESSURE = 2 BAR, 6 VOLUME CASE WITH STANDARD CODE

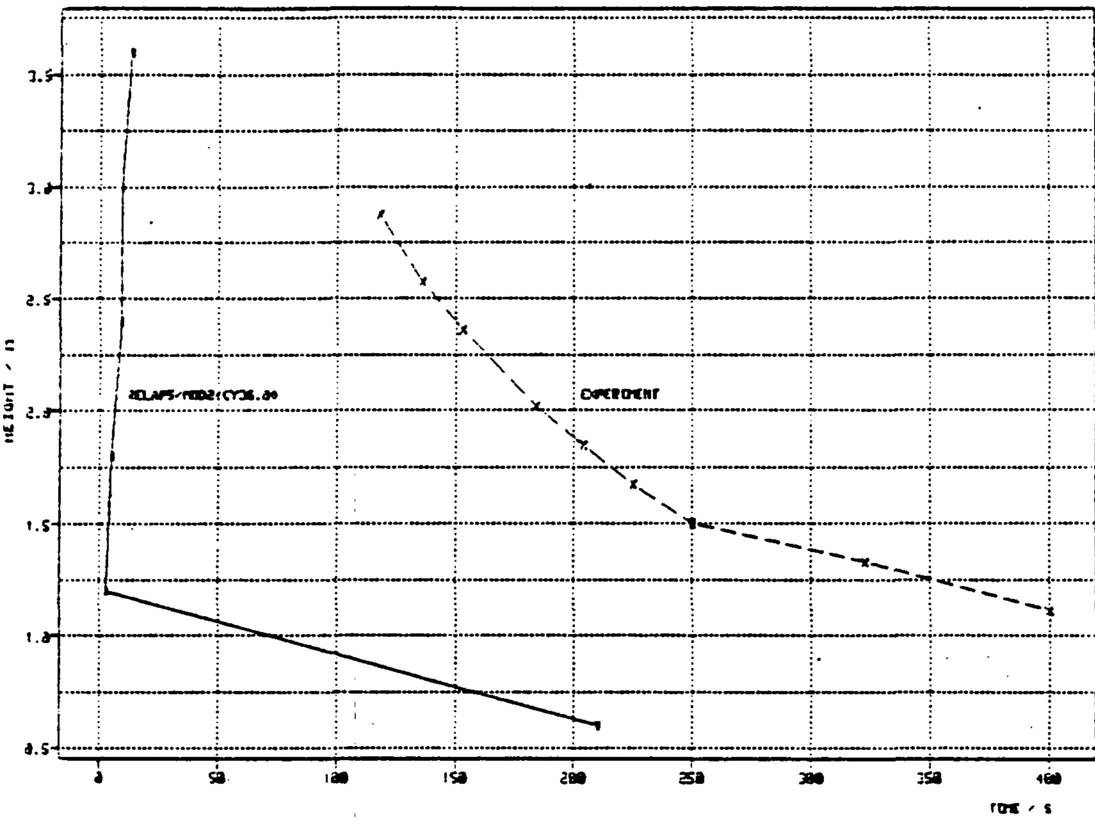

Figure 31: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

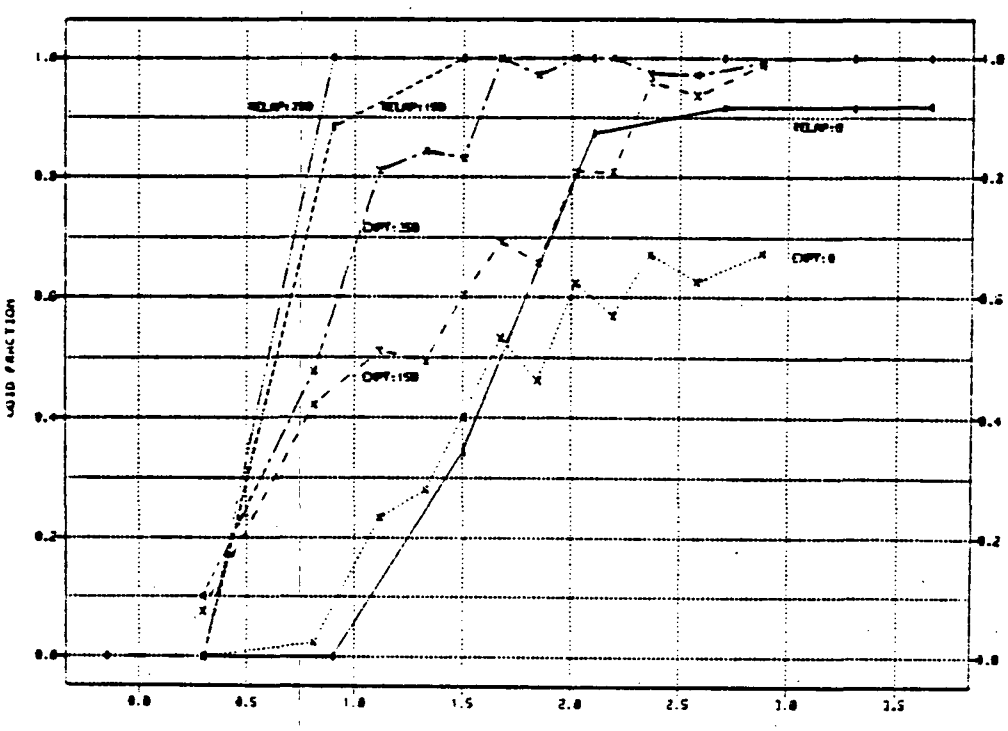

Figure 32: VOID FRACTION PROFILES AT 0,150,350 SECONDS INTO TRANSIENT

THETIS BOILDOWN TEST, PRESSURE = 40 BAR, 6 VOLUME CASE WITH MODIFIED CODE

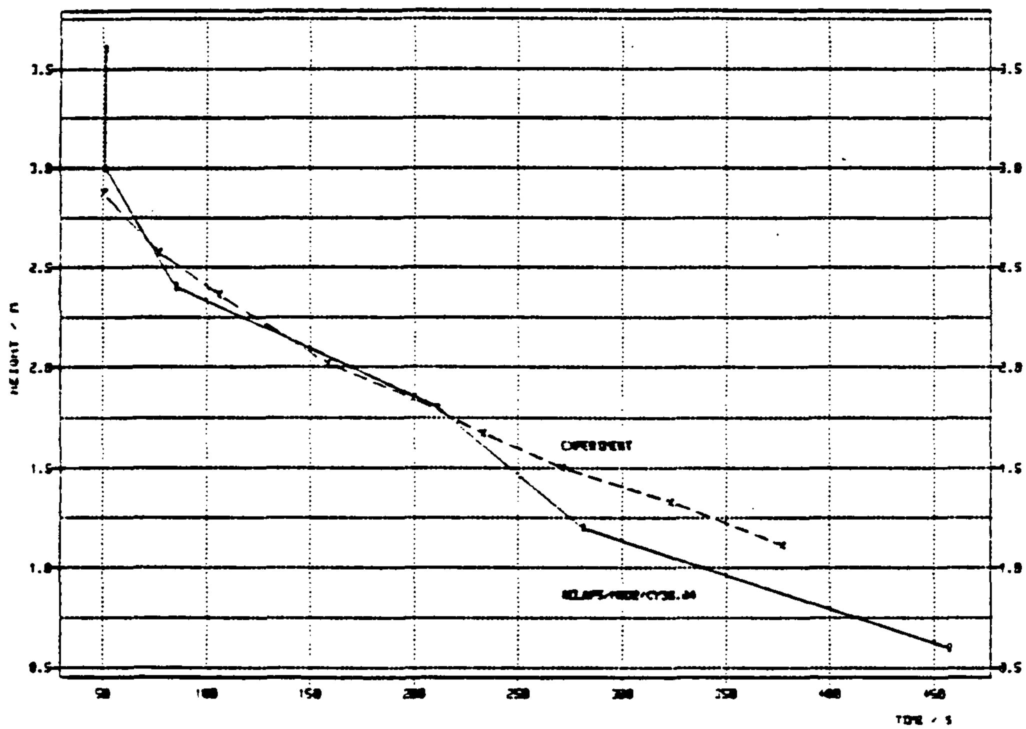

Figure 33: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

THETIS BOILDOWN TEST, PRESSURE = 5 BAR, 6 VOLUME CASE WITH MODIFIED CODE

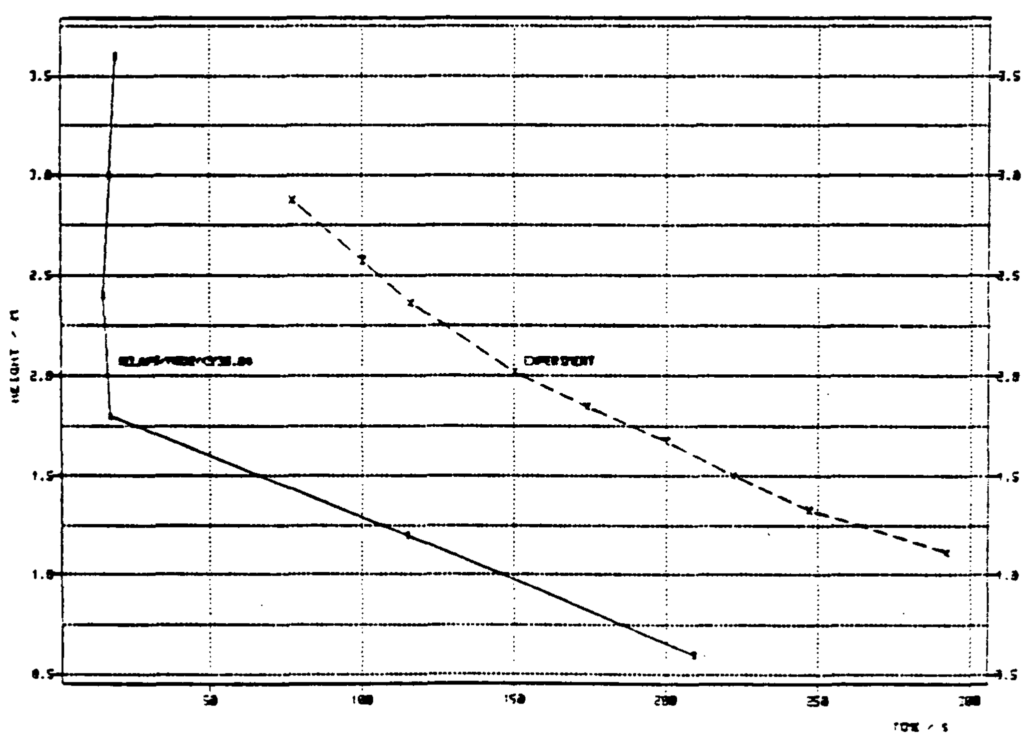

Figure 34: HEAT STRUCTURE DRY OUT HISTORIES FROM START OF TRANSIENT

CENTRAL ELECTRICITY GENERATING BOARD

Generation Development and Construction Division

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U.S. Nuclear Regulatory Commission
Washington D.C. 20555
U.S.A.

Our ref | Your ref | Date
29 May 1987

Dear Dr. Lauben,

UKAEA/USNRC Administrative Agreement WH36047

As you are aware, one of the features of the above Agreement was that the UKAEA obtained access to the RELAP5/MOD2 code on behalf of the Central Electricity Generating Board. In partial fulfillment of UK commitments under the above Agreement, and following discussions with Mr J. Fell of UKAEA, I enclose copies of three reports produced recently by CEGB.

- GD/PE-N/544. RELAP5/MOD2 Analysis of OECD LOFT Test LP-SB-01. Please note that the LP-SB-02 data is proprietary to LOFT consortium members, and distribution of this report should be limited accordingly.

- GD/PE-N/557. Assessment of Interphase Drag Correlations in the RELAP5/Mod2 and TRAC-PF1/Mod1 Thermal Hydraulic Codes

  This report describes comparisons of the void fraction calculated by the code with values derived using recognised correlations for void fraction in fully developed vertical two-phase flows. The study is restricted to void fractions below about 0.75.

- GD/PE-N/576 Analysis of the THETIS Boildown Experiments using RELAP5/Mod2

  This report examines the performance of the code in predicting void fraction in a vertical heated rod bundle. Results are consistent with the findings of GD/PE-N/557, indicating acceptable performance above 2 MPa, but increasing errors at lower pressures.

I believe that these reports broadly conform to the guidelines for ICAP reports, and I have no objection to your issuing them as NUREG reports. If you elect to do so please ensure that proper reference is made to CEGB.

I note that we have not prepared data packages since I consider that they are unlikely to be necessary for these reports. However if there is any additional information which you or your contractors require I shall be happy to provide it.

For the record, I also enclose a copy of CEGB Report GD/PE-N/535, describing RELAP5/MOD2 analysis of LOFT test LP-SB-03. This report was handed out at the Meeting in Erlangen, Germany in June 1986, and subsequently copied to Mr G.W.Johnsen and Dr. F. Odar (letter, 9th September 1986). I was somewhat surprised to find no record of this report in Tables 4 or 7 of Ref(1). Please let me know if you have any difficulty with this report.

Finally, I should like to give you an update on our current work with RELAP5/MOD2. As you are aware, we have also been analysing LOFT tests LP-SB-02 and LP-FW-01 with RELAP5. To obtain good agreement in these cases, we have found it necessary to develop (in collaboration with Wallace Bryce at Winfrith) an alternative formulation for the flow quality delivered to the breakline Tee (horizontal stratification entrainment model). We are also making good progress on our analysis of Semiscale tests S-LH-1 and 2 with RELAP5/Mod2. We hope to send you the reports on these analyses within a few months.

Yours sincerely

Peter Hall

Peter Hall
Safety Technology Section

Reference (1). ICAP Annual Report. NUREG-1270 March 1987.
Ting, P., Hanson, R. and Jenks, R.

cc:
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SEE INSTRUCTIONS ON THE REVERSE

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12 SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)
To test the abiltiy of RELAP5/MOD2 to model two phase mixture level and fuel rod heat transfer when the core has become partially uncovered, post test calculations have been carried out of a series of boildown tests in the AEEW THETIS out-of-pile test facility. This report describes the comparison between the code calculations and the test data.

Excellent agreement is obtained with mixture level boildown rates in tests at pressures of 40 bar and 20 bar. However at pressures below 10 bars the boildown rate is considerably overpredicted. A general tendency for RELAP5/MOD2 to overpredict void fraction below the two-phase mixture level is observed, which is traced to defects in the interphase drag models within the code. The heat up of exposed rods above the two-phase mixture level is satisfactorily calculated by the code.

The results support the use of RELAP5/MOD2 for analysis of high pressure core boildown events in PWRs.

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