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POST-TEST ANALYSIS WITH RELAP5/MOD2 OF ROSA-IV/LSTF NATURAL CIRCULATION TEST ST-NC-02

October 1988

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Results of post-test analysis for the ROSA-IV/LSTF natural circulation experiment ST-NC-02 are presented. The experiment consisted of many steady-state stages registered for different primary inventories.

The calculation was done with RELAP5/MOD2 CYCLE 36.00. Discrepancies between the calculation and the experiment are observed: the core flow rate is overestimated at inventories between 80% and 95%; the inventory at which dryout occurs in the core is also much overestimated.

The causes of these discrepancies are studies through sensitivity calculations and the following key parameters are pointed out: the interfacial friction and the form loss coefficients in the vessel riser, the SG U-tube multidimensional behaviour, the interfacial friction in the SG inlet plenum and in the pipe located underneath.

Keywords: PWR, LOCA, Small Break, Natural Circulation, ROSA-IV, LSTF, RELAP5, Safety

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ROSA－Ⅳ／ＬＳＴＦ自然循環実験ＳＴ－ＮＣ－02のRELAP 5／MOD 2コードによる実験後解析

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（1988年9月28日受理）

ROSA－Ⅳ計画の大型非定常試験装置（ＬＳＴＦ）による自然循環実験ＳＴ－ＮＣ－02を計算コードRELAP 5／MOD 2（Cycle 36.00）により解析した結果を報告する。実験は1次系質量インベントリを100％から23％まで段階的に減らし，それぞれの段階において定常状態を達成することにより行った。

計算結果は，質量インベントリ80～95％において循環流量を過大評価し，また炉心ドライアウトが開始する質量インベントリの値を過大評価した。

これらの相違の原因を感度解析によって調べた結果，以下の3点に関して問題があることが明らかとなった。

⑴ 圧力容器炉心部の相間摩擦及び圧力損失の予測

⑵ ＳＧ細管の並列チャンネル挙動のモデル化

⑶ ＳＧ入口プレナム及びホットレグとの接続部における相間摩擦の予測

本研究は，主著者（C. chauliac）が，原研のROSA－Ⅳ計画とフランス原子力庁（CEA）のBETHSY－CATHARE計画に関する相互参加ならびに技術協力に関する原研とCEAとの間の協定に基づく駐在員として原研に在任中（昭和60年7月～61年7月）になされたものである。

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Contents

目　　次

List of Tables

List of Figures

1. Introduction

In December 1985, the ROSA-IV/LSTF Program conducted two natural circulation tests: ST-NC-01 (with 5% core power) and ST-NC-02 (with 2% core power). During these tests many steady-state stages were obtained at different primary inventories, which was decreased stepwise.

The same qualitative results as on PKL [5], Semiscale [6] and LOBI [7] were obtained: when the primary inventory decreases from the initial value of 100% the loop flow pattern shifts from single-phase natural circulation to two-phase natural circulation. The core flow rate increases due to the increase in the static head difference between the downcomer and the riser in the vessel and between the upflow and downflow sides of the steam generator U-tubes. When the primary inventory drops further, the core flow rate decreases due to the increase of the void fraction at the top and in the downflow side of the steam generator U-tubes. Some additional decrease in the primary inventory leads to the interuption of the natural circulation at the top of the SG U-tubes and the flow regime shifts to the reflux condensation mode. Finally, as the primary inventory goes on decreasing, core dryout occurs.

The knowledge of the facility response gained through the first natural circulation experiment (ST-NC-01) permitted to better conduct the second experiment (ST-NC-02). For this reason, this latter experiment was chosen to perform the post-test analysis.

This report presents the results of the calculation which was done with RELAP5/MOD2 Cycle 36.00. First the conditions of the calculation are presented. Then the results of the basic calculation are discussed. Finally the presentation focuses on sensitivity tests which aim at finding some key parameters to improve the calculation results.

2. General conditions of the calculation

The calculation was performed with RELAP5/MOD2 Cycle 36.00[8].

2.1 Nodalization

The nodalization is shown in Fig. 1. It uses 152 volumes and 158 junctions.

This nodalization was originally built up at INEL (Idaho National Engineering Laboratory). For the calculation presented here, the main modifications are:

- The bypass flow between the downcomer and the upper head is set to 2% of the core flow during steady state at nominal conditions.
- The rated pump head is modified: 10.7 m for pump B and 11.2 m for pump A (as measured during calibration tests) instead of 10 m in INEL data.
- The overall heat loss for the primary and secondary sides is set to 110 kW during steady state at nominal conditions. The heat losses are uniformly distributed throughout the loops.
- The friction factors and the nodalization of the vessel riser are modified to match the results of differential pressure (DP) calibration tests.
- All the components which are not used during ST-NC-02 are deleted: the ECCS system, the auxiliary feedwater system, the bypass line between the hot legs and downcomer.
- A valve line is implemented at the bottom of the vessel as in the experiment.
- A horizontal node is added at the top of the SG U-tubes

to better study the strarification and the end of the two-phase natural circulation.

Two limitations of this nodalization must be pointed out:

- It uses only one mean SG U-tube although a large multidimensional behaviour of the SG U-tunes was observed in the experiment.
- It uses only one mean core channel although the radial peaking factor for the core power (ratio of the high power rods to the low power rods) is 2.3 and large radial temperature differences are observed at the top of the core during single phase flow with pumps on.

A small leakage was observed in the experiment between the upper head and the upper plenum and between the downcomer and the upper plenum. However, as the amount of the leakage is not known and is considered to be very small, it is not modeled in the calculation.

The effect of the leakage between the downcomer and the upper plenum is studied through a sensitivity test in Appendix 2.4. In this test, the leakage value is unrealistically large to see the influence of the leakage for extreme conditions.

The effect of the leakage between the upper head and the upper plenum is quite obvious for primary inventories lower than 85%: in the experiment the upper head completely empties (according to the conduction probes data). However, in the calculation, the liquid located in the upper head under the level of the spray nozzles (the spray nozzles are the flow path between the downcomer and the upper head) remains there until the last stage of the calculation (27% inventory). As a consequence, for the same total mass inventory in the calculation and in the experiment, a larger mass of fluid can flow through the loops for the experiment (the difference is 2.4% of the primary circuit initial inventory). This discrepancy is taken into account in the presentation of the calculation results: instead of presenting the actual inventory, this inventory is decreased in an amount of 2.4 % (for inventories lower than 85%).

2.2 Boundary conditions

A detailed description of the experiment can be found in [1]. The first stage of the experiment is a steady state at the nominal conditions of LSTF: full power (10 MW), pumps on, the same temperature increase across the core as in the actual plant.

The second stage of the experiment studies natural circulation for 100% mass inventory in the primary side. The core power is lessened down to 1.42 MW (2% power for the reference reactor) and this value is kept for the remainder of the experiment. The pumps are turned off. The secondary pressure is lessened to 6.6 MPa and this value is kept for the remainder of the experiment.

During the later stages of the experiment the pressurizer surge line valve is closed and remains in this position. The primary side inventory is decreased gradually by means of bleeding through the drain line located at the bottom of the vessel. In the experiment, the drain valve is closed every time a 5% decrease in the primary inventory is reached and then the boundary conditions are kept constant until steady state is achieved. The same procedure was followed in the calculation except that 10% steps instead of 5% were chosen.

For every stage of the calculation, the feedwater temperature is adjusted to the experimental value. A slow 30 K fluctuation of this temperature occured all through the experiment.

In general, the boundary conditions for the calculation are the same as for the experiment except the following ones:

- The secondary side mass is kept constant (instead of keeping constant the secondary level in the experiment). This procedure allows the calculation to reach steady state faster and should make no difference in the primary side behaviour.
- The pump speed is set to zero after the pumps are switched off (although the rotor is not locked in the experiment). Some comments about the effect of this choice are given in Appendix 2. 5.

2.3 RELAP5/MOD2 options

The cross-flow option is used at the junctions between the cold legs and the downcomer and at the junctions between the hot legs and the upper plenum.

The abrupt area change junction junction model is used at the SG plena and at the spray nozzle located between the downcomer and the upper head. Elsewhere, the form loss coefficients as measured on the facility during the calibration tests are used.

All the volumes are calculated with the two-fluid non-equilibrium option.

All the junctions use the phase separation model when stratified flow occurs.

In order to reach the steady state faster, the "steady-state" option of RELAP5/MOD2 is used throughout the calculation. One specific feature of this option is that it decreases artificially the heat capacity of the walls so that the thermal relaxation of the walls speeds up.

This procedure allows the calculation of the whole experiment in 2200 s equivalent experimental time instead of about 2800 s in the experiment from the time when the pumps are switched off up to the time when 30% inventory is reached (however the number of inventories studied in the experiment is twice the number studied in the calculation. See subsection 2.2)

Another specific feature of the "steady-state" option is that the calculation automatically stops when the convergence criteria are fulfilled [8]. However, it was observed that sometimes convegence was reached although the primary bleed was still on. In those conditions the calculation was prolonged with the "transient" option. Another problem is that convegence might be reached for an incorrect solution: this was foud for the 94% inventory where the loop flow rate was 8.5 kg/s at the end of the "steady-state" stage but became 7.8 kg/s when the calculation was prolonged with the "transient" option.

The 70% inventory calculation illustrates another problem: convergence is reached with the "steady-state" option although loop oscillations develop if the calculation is prolonged with the "transient" option (see Subsection 3.4).

Related to these remarks the consistency between the "steady-state" results and the "transient" results was systematically checked for every inventory. No other problems than those stated above was found.

3. Comparison of the basic calculation with the experimental results

3.1 Steady state, pumps on

The comparison between the experiment and the calculation is shown on Table 1.

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3. Comparison of the basic calculation with the experimental results

3.1 Steady state, pumps on

The comparison between the experiment and the calculation is shown on Table 1.

Table 1 Summary of initial conditions

	Experiment		Calculation	
Pressurizer Pressure (MPa)	15.47 ± 0.06		15.49	
Pressurizer level (m)	2.65 ± 0.13		2.62	
Loop	A	B	A	B
Hot leg temperature (K)	598±5	598±5	598.9	598.9
Cold leg temperature (K)	565±5	565±5	565.0	565.0
Pump speed (rd/s)	85.8	86.1	92.6	93.4
Flow rate (kg/s)	25.5±0.6	25.5±0.6	25.5	25.5
Secondary pressure (MPa)	7.38±0.03	7.42±0.03	7.40	7.40
Steam flow rate (kg/s)	2.6±0.1	2.7±0.1	2.7	2.7

The calculation results are in good agreement with the experimental ones except for the pump speed. However, the point of importance is that the pump head (11.1 kPa) is close to the experimental value (10.7 +0.2 kPa as deduced from the DP cells located between the inlet and the outlet of the pumps). So it is concluded that the discrepancy observed about the pump speed is due either to some uncertainty in the pump characteristics or to some error in the pump speed measurement.

Adjusting the calculated steady-state is a difficult process which has to cope with the experimental uncertainty. For instance, Fig. 10 shows a discrepancy between the experimental and calculated differential pressure through the vessel. This discrepancy might be due partly to some overestimation of the friction in the core (the data reduction from the calibration tests tend to slightly overestimate this friction). However, adjusting the calculated DP through the vessel on the experimental value would worsen the results for the pump head.

Finally, the calculated steady state presented here corresponds to a choice which seems to be a good compromise.

Another difference between the calculation and the experiment lies in the upper head temperature which is equal to the cold leg temperature in the calculation and close to the hot leg temperature in the experiment. This strange experimental behaviour does not seem to be related to the undesirable leakage flow paths (discussed in Subsection 2.1) because it was still observed after those leakages were sealed off. It is considered that this behaviour has not a large effect on the overall primary circuit results during this test.

3.2 Natural circulation at full inventory

The loop flow rate is about 7% overestimated by the calculation (Fig. 3). However, for such a flow rate the measurement uncertainty is about 3% (if a 1% full-scale uncertainty is assumed for the DP measurement at the venturi). So, the calculation is rather close to the experimental value.

The pressurizer pressure (Fig. 2) is overestimated by the calculation (13.4 MPa instead of 12.2 MPa). Two factors can be quoted to account for this discrepancy :

- the pressurizer spray was used in the experiment and not used in the calculation.
- the initial discrepancy between the experiment and the calculation about the upper hesad temperature (Subsection 3.1) results in a higher pressurizer liquid level in the calculation than in hte experiment because between those two stages the upper head temperature volves from about 590 K to about 572 K in the experiment and from 565 K to about 571 K in the calculation.

3.3 90% and 80% primary inventories

The loop flow rate is highly overestimated (up to 50%) as shown in Fig. 3.

This discrepancy is discussed in datail through the basic sensitivity study (Subsection 4.1) and several other sensitivity tests (see Appendix 2).

The primary pressure is underestimated (Fig. 2) and this discrepancy is related to the overestimation of the loop flow rate. This observation can be linked with the results of SB-CL-05 post-test analysis both for the loop flow rate and the primary pressure [2].

The calculated differential pressures at different locations in the primary side are compared to the experiment in Fig. 4 through 7 and do not exhibit large discrepancies.

The calculation for the 80% inventory by using the "transient" option of RELAP5 shows that the results are very stable (no significant fluctuations) and consistent with the results of the "steady state" option.

3.4 70% primary inventory

As in the experiment, the calculation shows a large drop in the loop flow rate (Fig. 3). This is mainly due to a large increase of the void fraction at the top and in the downflow side of the SG U-tubes. The "steady-state" option of RELAP5 does not shown any interruption of the two-phase natural circulation at the top of the SGs and there is no counter-current flow in the SGs.

The primary pressure is in good agreement with the experiment (Fig. 2).

The prolongation of the calculation with the "transient" option of RELAP5 shows that, after a while, large oscillations occur as in the experiment. However the nature of the oscillations is different between the experiment and the calculation.

In the calculation the oscillations can be roughly divided into two phases(Figs. 11 through 14) : during the first phase, the void fraction is high at the top of the SG so that the flow in the loop is limited. Due to condensation and CCFL the liquid holdup progressively increases in the upflow side of the SG (and consequently the liquid holdup also increases in the downflow side due to a feedback effect through the vessel on the outlet plenum pressure). During the second phase, the liquid reaches the top of the SG, the flow increases sharply and the SG U-tubes drain until a new cycle is ready to start again.

The amplitude of the oscillations in the SGs is about 5 to 6 kPa with a period of about 105 s. The associated oscillations of the loop flow rate have an amplitude of about 60% of the mean value. However the flow rate oscillations in the two loops are out of phase so that the core flow rate is not much affected (Fig. 13).

The heat transfer rate at the SGs oscillates with the same period as the flow rate (Fig. 14).

In the experiment, the oscillations proceed in a very different way. Their period and amplitude seem to depend on the tube length (Figs. 17 through 21) with a larger period for the longest tubes and the larger amplitude for the mean tubes. Those different oscillaitons in the different tubes of one SG combine themselves in such a way that they have little effect on the loop flow rate. Finally the loop flow rate fluctuations are small (Figs. 15 and 16).

The main reason for the difference between the experiment and the calculation is due to the calculation geometry which uses only one mean SG U-tube instead the 141 U-tubes in the experiment. With such a geometry the oscillations qualitatively look like the oscillations observed on LOBI [3] which has a much smaller number of SG U-tubes than LSTF (8 tubes for the "broken" loop, 24 tubes for the "intact" loop).

3.5 primary inventories less than 50%

During this stage of the experiment, reflux condensation occurs in the calculation as well as in the experiment.

The calculation showed that dryout takes place in the core for the largest inventory studied here (48.7%). However in the experiment dryout occured only for an about 24% inventory.

The reason for this discrepancy is a too large liquid holdup in the SG U-tubes and their plena (Fig 4). Consequently the liquid levels in the vessel are underestimated (Figs. 5 through 7). In particular it is noted that the experiment exhibits a plateau for the downcomer and core liquid levels at inventories less than 60% (Figs. 5 and 7) due to the draining of the SG U-tubes. This plateau is not found in the calculation.

Some shortcoming in the RELAP5 interfacial friction model is suspected and this topic is studied through the finel calculation (Subsection 4.2) and other sensitivity tests (Subsection 4.3.2).

An interesting feature of LSTF can be noticed here: in LSTF, as in most of the "integral facilities" the same scaling ratio cannot be kept in every component. For istance, although each loop of LSTF is scaled about 1/24 in volume of the PWR ones, the SG plena are 1/12 scaled. However this distortion presents two advantages: it makes the geometry closer to the PWR one. Also it gives a good opportunity to test the analytical models dealing with the flooding phenomona in the system "hot leg + SG plenum + SG U-tube upflow side" (a small error in these models has a larger influence on the core liquid level for LSTF than the PWR).

The use of the "steady-state" option of RELAP5 permits the continuation of the calculation for inventories lower than 50% because, due to the fast convergence of the calculation, the rod heat-up remains small enough. However the use of the "transient" option leads to rod burn-up.

4. Basic sensitivity test and final calculation

The results of the basic calculation presented in Section 3 show mainly two large shortcomings: the loop flow rate is about 50% overestimated when the primary inventory is close to 80% and core dryout occurs for a 50% inventory instead of about 24% inventory in the experiment.

The basic sensitivity test presented here focuses first on the loop flow rate (Subsection 4.1) and is then extended to all the stages of the experiment (Subsection 4.2).

4.1 Basic sensitivity test

The way which is used here is to adjust the calculated flow rate to the experimental one, then to study the differencial pressure (DP) distribution throughout the primary circuit and compare it to the experimental data and finally look for some modifications in order to improve the DP distribution.

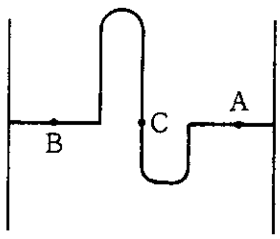
4.1.1 Step 1

This strategy is applied to the case where the largest discrepancy between the calculated and the experimental flow rates was observed: the 81% inventory. A valve is implemented in the cross-over leg of each loop. It is closed gradually until the experimental flow rate is reached. Then the valve remains in the same position and the calculation goes on until steady-state conditions are obtained.

In those conditions it is observed that the pressure loss through the valve is 13 kPa. It means that somewhere in the primary circuit there is a force which acts like a pump and provides a 13 kPa head which does not exist in the experiment.

In order to locate this undesirable driving head, the DP distribution throughout the primary circuit is shown in the following table. Point A is located in the cold leg, Point B in the hot leg and Point C is located in the cross-over leg below the SG outlet at the altitude of the horizontal legs.

	Basic calculation	This Test	Experiment
$P_A - P_B$	-6.0	-8.5	-2.8
$P_B - P_C$	-4.0	-8.9	not measured
Pump head	-9.0	-3.9	-3.8



Unit : kPa

In the above Table the experimental values are interpolated from the 83.2% and 78.7% inventory data. The pump head is calculated from the differential pressure between the pump inlet and outlet (DPE090 and LPE230). $(P_A - P_B)$ is the measurement performed by DPE140.

If we trust the measurements, the comparison presented above show that, in order to eliminate the 13 kPa driving head which is in excess, it is necessary to increase $(P_A - P_B)$ in an amount of about 6 kPa and $(P_B - P_C)$ in an amount of about 7 kPa.

The following table shows the DP distribution inside the vessel.

	This Test	Experiment
core DP (DPE300)	25.0	27.3
upper plenum DP (DPE320)	8.4	9.7
downcomer DP (DPE360)	55.0	52.2

Unit : kPa

In the above Table the downcomer DP measurement is corrected to take into account the discrepancy observed between the experiment and the calculation during steady state with pumps on (Fig. 7). A constant shift in the measurement is assumed.

The above Table shows that the error in the calculation is not located in one component but rather distributed in the different parts of the vessel.

The discrepancy on the downcomer DP is related to a difference of liquid level between the experiment and the calculation. In the experiment, the mixture level is located in front of the cold legs allowing some vapour to flow into the cold legs (Fig. 9) (this fact is confirmed by the signals of the conductivity probes located at the top of the downcomer). However, in the calculation the liquid level is above the cold legs (the void fraction in the volume facing the cold legs is 0.11 and the top of this volume is 20 cm higher than the top of the cold legs) and there is no vapour in the cold legs.

A reason for this discrepancy might be a bypass effect. A sensitivity test performed to investigate this question and presented in Appendix 2.4 does not show the correct trends. However, the bypass effect might be studied in several other ways and the issue is still open.

Another reason for this discrepancy could be some shortcoming in the calculation of the vapour condensation at the top of the downcomer (this vapour is coming from the upper head in the calculation). A sensitivity test dealing with this topic is presented in Subsection 4.3.3 and shows a small effect of the condensation.

Inside the vessel riser (core and upper plenum) the discrepancy observed on DP might be due to some shortcomings either in the interfacial friction model or in the wall friction model. Modification of the interfacial friction is studied in Subsection 4.3.1.

The other way is to assume some shortcoming in the RELAP5/MOD2 form loss model for two-phase flow.

Inside the vessel riser, the LSTF model for the basic calculation uses the form loss coefficients derived from the calibration tests performed under single phase liquid flow. These coefficients are used together with the smooth area change model. However the accuracy of these coefficients under two-phase flow is not well known. Also no report about the qualification of the RELAP5 form loss model for two-phase flow does exist to our knowledge.

The sensitivity test presented here assumes that the form loss coefficients are underestimated when two-phase flow occurs. Also, the adjustment of (P_A - P_B) to the experimental value is serched by modifying the form loss coefficients only in the vessel riser (the shortcoming in the downcomer DP, discussed above and not well understood, is not directly treated. So, the solution presented here is only partial).

4.1.2 Step 2

The method which is used here is the following one :

- All the form loss coefficients in the vessel riser are multiplied by a constant N.
- The position of the valve located in the cross-over leg is adjusted in order to obtain the experimental flow rate.
- If the experimental flow rate is obtained concurrently with $P_B - P_A$ close to 2.8 kPa (experimental value), the value for N is considered as the correct solution.

The following table shows the value of $P_A - P_B$ for different values of B when the calculated flow rate agrees with the experimental one :

N	2	5	7	10
P_A-P_B (kPa)	-7.0	-4.3	-2.4	+0.6

Consequently N=7 is the correct order of magnitude and is chosen.

4.1.3 Step 3

The next step of this sensitivity test consists of removing the valves located in the cross-over legs and running the calculation with the form loss coefficients multiplied by 7 in the vessel riser. In those conditions, the loop flow rate is still overestimated (11.0 kg/s instead of about 9.2 kg/s in the experiment) because the motor head through the SG has not been corrected ($P_B - P_C$ = -7.6 kPa).

Coming back to the experimental results, it is found that during this stage of the experiment several SG U-tubes are in "abnormal" conditions (see Appendix 1). If the pressure increases from the SG inlet plenum to the SG outlet plenum (as in the calculation discussed here) the flow in those abnormal tubes reverses.

If the flow in those abnormal tubes is large, it will carry some "cold" fluid from the SG outlet plenum to the inlet plenum (the temperature difference is about 2 K) in an amount sufficient to condense part of the vapour present in the inlet plenum. This behaviour will decrease the gravity head effect through the SG, decrease the pressure difference between the SG plena and finally moderate the opposite flow in the abnormal tubes. In short, SG outlet plenum will generate a feedback effect which will moderate the increase of pressure.

Therefore it is concluded that the velocity of the fluid in the SG abnormal U-tubes is probably small. A simple hand calculation (see Appendix 1) shows that 0.1 m/s fluid velocity in the abnormal tubes requires an about 0.1 kPa differential pressure between the tops of the SG inlet plenum (point D) and outlet plenum (point E).

However, the calculation presented in this Step shows that $P_E - P_D =$ 4.1 kPa. So this value seems highly unlikely and must be corrected by taking into account the abnormal SG U-tubes.

4.1.4 Step 4

This test focuses on the driving head through the SG and, as a result of the discussion presented in Step 3, tries to decrease it down to a reasonable value by calculating the behaviour of the SG abnormal U-tubes.

As in step No.3, the present test multiplies the form loss coefficients in the vessel riser by 7.

Then, the SG U-tubes are divided into two sets of N_1 highest tubes and N_2 lowest tubes (with $N_1 + N_2 = 141$ tubes as in the experiment). A valve is implemented at the inlet of the highest tubes.

At the beginning of the calculation, the valve is closed, resulting in two effects :

- the void fraction collapses in the highest tubes due to the condensation of the vapour.
- the differential pressure between the tops of the SG inlet and outlet plena ($P_E - P_D$) decreases due to the friction increase through the lowest tubes.

Coping with the remarks presented in Step 3, the values of N_1 result and N_2 are searched in order to minimize ($P_E - P_D$). A rather good result is found with :

$$N_1 = 40\% \qquad N_2 = 60\% \qquad P_E - P_D = 0.8 \text{ kPa}$$

The calculation then goes on with the opening of the valve located at the inlet of the highest tubes. The conditions in those tubes (liquid single phase of a temperature close to the secondary side temperature, pressure at the outlet greater than at the inlet) are well adapted to calculate reverse flow. However, immediately after the opening of the valve some bubbles rise at the inlet of the tubes, decreasing the static head in the upflow side, and finally the flow in the highest tubes establishes in the same direction as in the other tubes.

Another sensitivity test was performed by increasing sharply the heat transfer coefficient in the condensation correction for the highest tubes (it was multiplied by 1000) in order to condense the rising steam bubbles (this configuration provides a larger pressure increase from the tube inlet to the tube outlet and should ease reverse flow). However, after 20 seconds of reverse flow, the flow reestablished in the normal direction for the same reason as above.

Nevertheless, predicting the reverse flow in the abnormal U-tubes is not fundamental for this test. The fundamental result is that the existence of the abnormal tubes can be taken into account by closing them off. In such conditions 40% stalled tubes gives a reasonable DP through the SG. It is also noted that this number is probably close to the experimental value because, for the same inventory, several longest and mean SG U-tubes are under abnormal conditions according to the measurements.

However, even for 40% stalled tubes, the loop flow rate is still somehow overestimated (10.1 kg/s instead of about 9.2 kg/s in the experiment).

4.1.5 Step 5

The remaining discrepancy on the loop flow rate is considered as coming from the gravity head difference between the SG inlet and outlet plena.

In the region which includes the inclined pipe located under the SG inlet plenum and the inlet plenum itself, some shortcomings in the conventional constituteve models are suspected because the flow in the inclined pipe is not fully developed and the entrance effects are important. In particular it is considered (according to the pictures of the experiment taken by the video probes) that the flow of liquid and vapour in the inclined pipe tends to separate instead of being "bubbly" as in the basic calculaiton and as in Step 4.

In order to cope with this observation, the interfacial friction in the inclined pipe and in the SG inlet plenum is divided by 100. The other conditions are the same as in the previous test: form loss coefficients multiplied by 7 in the vessel riser; 40% highest tubes blocked.

The resulting loop flow rate is 9.65 kg/s (instead of 9.2 kg/s in the experiment) with a differential pressure between the tops of the SG inlet and outlet plena $P_E - P_D = 0.4$ kPa.

A summary of the different steps of this sensitivity test is presented in Table 2.

Table 2 Summary of the the basic sensitivity study for the 81% inventry

	Loop Flow rate (kg/s)
Basic calculation	13.8
Step 3 = form loss 7 in the vessel riser	11.0
Step 4 = Step 3 + 40% highest SG U-tubes blocked	10.1
Step 5 = Step 4 + T_i/100 (inclined pipe and SG inlet plenum)	9.65
Experiment	9.2

4.2 Generalization : final calculation

The same method is then applied to other stages of the experiment, resulting in the final calculation.

The conditions of this calculation are:

- The form loss coefficients in the vessel riser are multiplied by 7 as soon as two-phase flow occurs in the riser.
- The intefacial friction is divided by 100 in the SG inlet plenum and in the inclined pipe located underneath.
- The SG U-tubes are divided into N_1 highest tubes and N_2 lowest tubes ($N_2 = N_1 - 141$) for the inventories larger than 80% (at lower inventories, no abnormal tubes were observed in the experiment). The value of N_1 is looked for in order to obtain a reasonable DP through the SG and a reasonable loop flow rate.

The results are presented in Figs. 2 through 10.

4.2.1 100% inventory

Dividing the SG U-tubes into 10% highest tubes and 90% lowest tubes and using the same technique as in Subsection 4.1.4 (closing and opening the valve at the inlet of the highest tubes) is here successful and the flow in the highest tubes reverses (it is considered that the failure to calculate this flow regime for the 81% inventory is due to the effect of the steam bubbles rising in the upflow side of the tubes).

The effect of the abnormal tubes on the loop flow rate is small: the flow rate drops to 6.25 kg/s from 6.40 kg/s in the basic calculation, as compared to about 6.9 kg/s in the experiment. The liquid velocity in the abnormal tubes is 12 cm/s and the temperature in the SG inlet plenum is

1.2 K lower than in the hot legs.

However, in the experiment, the SG inlet plenum temperature is about 3 to 4 K lower than in the hot leg. So, it is concluded that the number of abnormal SG U-tubes is larger than 10% (some hand calculation shows that if the velocity in the abnormal tubes is 10 cm/s, their number should be about 30% in order to match the SG inlet plenum temperature). Increasing the number of abnormal tubes would also improve the calculated loop flow rate.

However, it was considered sufficient here to handle the key parameter and further improvement for the 100% inventory was not looked for.

4.2.2 94% inventory

10% blocked tubes were assumed (as for the 81% inventory, reverse flow cannot be calculated for the highest tubes, see remarks in Subsections 4.1.4 and 4.2.1) resulting in a much improved calculated loop flow rate (Fig. 3).

However, still some errors remain because the upper plenum liquid level is too low (Fig. 6) and cousequently too much vapour is entrained in the hot legs.

This discrepancy is related to the fact that, as pointed out in Subsection 4.1.1, the solution proposed in order to improve the calculation of the vessel differential pressure is only partial.

4.2.3 Inventories less than 90%

For the 81% inventory, the results are the same as those of the basic sensitivity study (Subsection 4.1).

For inventories lower than 70%, the modifications implemented in this final calculation are very efficient: the draining of the SG U-tubes is eased and no more dryout occurs for the inventories studied here (as in the experiment).

As discussed in Subsection 4.3.2, the key parameter here is the interfacial friction in the SG inlet plenum and in the inclined pipe located underneath.

The results presented on Figures 2 through 10 show a good agreement with the experiment except for the differential pressure between the downcomer and the upper plenum (Fig. 10). This discrepancy is due to an insufficient draining of the downflow side of the SG which results in a too low downcomer liquid level (Fig. 7).

Another good result of this test is that the two-phase natural circulations interrupted at the top of the SG U-tube for a 60% inventory in the calculation as compared to an experimental valve ranging from 58% to 69% (according to the tube, the measurement being made by the conduction probes) and a 49% inventory in the basic calculation.

With the two-phase circulation interrupted, reflux condensation takes place. For the 60% inventory, this calculation shows that the reflux liquid velocity in the hot legs is about 1 cm/s and the vapour velocity about 70 cm/s.

4.3 Other tests

Other sensitivity tests related to the previous one are briefly reported here. The remaining sensitivity tests which were performed for other purposes are presented in Appendix 2.

4.3.1 Interfacial friction in the vessel riser

In the step No.1 described in Subsection 4.1.1, another way to improve the calculatin of the differential pressure between the downcomer and the upper plenum is to decrease the interfacial friction in the vessel riser. The idea subjacent to this test is to take into account a suspected phase separation effect because, during steady state with pumps on (100% inventory), large temperature differences (up to 30 K) are observed at the top of the core between thermocouples located at different redial positions (the radial power factor between the low heat flux rods and the high heat flux rods is 2.3).

Also this test tries to cope with the fact that RELAP5/MOD2 has no interfacial friction model specific to the rod bundle geometry although the flow pattern in such a geometry is known to be different from the flow pattern in tubes. Some papers have reported some shortcomings of RELAP5/MOD2 in this field. An example is found in [9], but the measurements which are quoted do not allow to discriminate between the effect of wall friction and the effect of interfacial friction.

Following the same process as in step No.1 it is found that the adjustment with the DP through the vessel requires to divide the interfacial friction in the vessel riser by an amout of 1000. This order of magnitude seems very high and leads to rather unrealistic results such as very low void fraction in the core (no more than 5%).

Part of this result can be explained by the fact that, as discussed in Subsection 4.11, the discrepancy found for the vessel DP is solved through modification of the physical models in the vessel riser only (althouth some discrepancy also exists in the downcomer).

So it is concluded that some shortcomings in the interfacial friction model cannot be excluded. However, an improvement of this model based on this natural circulation test seems rather difficult to obtain because the measurements are not designed for this purpose and because the modification of the present model is probably dependent on the flow rate.

4.3.2 Interfacial friction in the SG inlet plenum region

For the inventories lower than 60% two other sensitivity tests were performed.

In the first one, the only difference with the basic calculation is that the interfacial friction is reduced by a factor of 100 in the inclined pipe located under the SG inlet plenum and in the plenum itself. Roughly the same kind of results as in the final calculation was obtained.

In the second one, instead of reducing the interfacial friciton by a factor of 100, slug flow is assumed in the same region. Here again, roughly the same kind of results as in the final calculation was obtained.

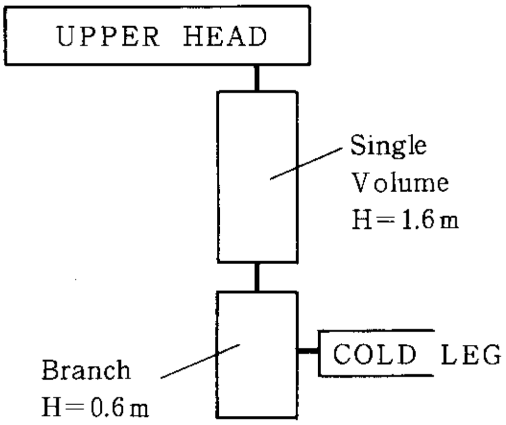
These tests show that, at low primary inventories, the friction in the vessel riser has no effect on the results (low velocities). They also show that the interfacial friction in the region of the SG inlet plenum is clearly a key parameter.

4.3.3 Nodalization of the top of the downcomer and condensation in the downcomer

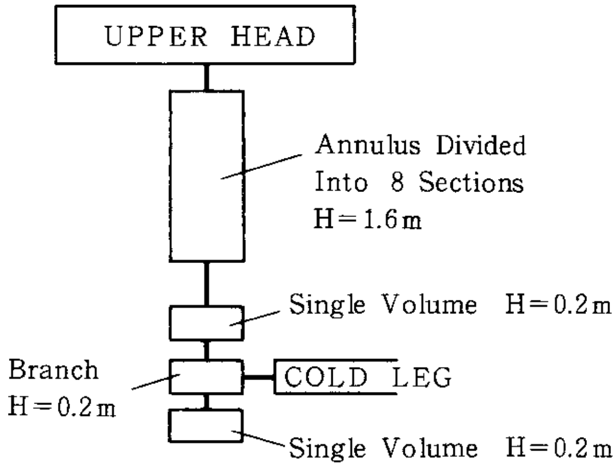
In the Step 1 of the basic sensitivity test (Subsection 4.1.1) it is found that the liquid level in the downcomer is overestimated: this level is located above the top of the cold legs in the calculation instead of being in front of the cold legs as in the experiment.

Some explanation of this discrepancy might be the existence of a temperature stratification in the liquid with a low condensation of the vapour (this vapour is coming from the upper head) at the interface.

This effect was studied by modifying the nodalization of the upper part of the downcomer and running the calculation in the same way as step No.1.



Basic Calculation



This Test

For the 94% inventory (with the liquid lerel located in a single volume for the basic calculation) the difference between the two calculations is negligible. This result is due to the fact that in the basic calculation the liquid present in the single volume is at the saturation temperature. In particular, it is noted that the upper plenum liquid level remains underestimated.

For the 21% inventory, the liquid level in the downcomer is pushed downward along a 12 cm height (in this test) and reaches the top of the cold legs. This result can be explained by the fact that in the basic calculation the liquid present in the branch is divided into 3 components as in this test, the upper component becomes saturated so that condensation decreases and the liquid level drops until it reaches the top of the cold legs.

For the 21% inventory it was also checked that it is possible to lower further the downcomer liquid level by decreasing the interfacial condensation coefficient in the branch facing the cold leg (reducing this coefficient by a factor of 10 results in a 2 cm drop of the liquid level). Such a modification has obviously no effect for the 94% inventory, because, as noted above, the vapour located at the top of the downcomer is in contact with saturated liquid.

Finally this test shows that there is a small effect of the nodalization and of the condensation model on the liquid level in the downcomer. However, this effect does not explain the overall discrepancy between the experiment and the calculation about the liquid distribution in the vessel for inventories larger than 80%.

5. Conclusions

This analysis shows that RELAP5/MOD2 cycle 36.00 is able to qualitatively simulate the loop flow patterns which were observed during the ST-NC-02 natural circulation test on LSTF: single phase natural circulation, two-phase natural circulation, reflux condensation as well as the oscillations related to the transition between the two latter flow patterns.

Two topics of interest have been pointed out in this report: the primary flow rate and the energy removal from the primary circuit (until core dryout occurs). In those two fields, the basic calculation exhibits large discrepancies from the experiment: during two-phase natural circulation, the loop flow rate is sometimes more than 50% overestimated; during reflux condensation, dryout in the core occurs for a too large inventory (larger than 49% instead of about 24% in the experiment).

The reasons for those discrepancies have been identified as:

- The liquid distribution in the vessel is not correctly condensation coefficient in the branch facing the cold leg (reducing this coefficient by a factor of 10 results in a 2 cm drop of the liquid level). Such a modification has obviously no effect for the 94% inventory, because, as noted above, the vapour located at the top of the downcomer is in contact with saturated liquid.

Finally this test shows that there is a small effect of the nodalization and of the condensation model on the liquid level in the downcomer. However, this effect does not explain the overall discrepancy between the experiment and the calculation about the liquid distribution in the vessel for inventories larger than 80%.

5. Conclusions

This analysis shows that RELAP5/MOD2 cycle 36.00 is able to qualitatively simulate the loop flow patterns which were observed during the ST-NC-02 natural circulation test on LSTF: single phase natural circulation, two-phase natural circulation, reflux condensation as well as the oscillations related to the transition between the two latter flow patterns.

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The reasons for those discrepancies have been identified as:

- The liquid distribution in the vessel is not correctly calculated. To a little extent, this is due to the nodalization of the downcomer.

- The differential pressure in the vessel riser is underestimeted. This is due to some shortcoming either in the interfacial friction or in the wall friction. The experimental results do not allow to discriminate between these two parameter effects.
- In the experiment, some SG U-tubes are in abnormal conditions (reverse flow) and provide a limitation to the loop flow rate. The nodalization must take them into accout.
- The interfacial friction in the SG inlet plenum and in the inclined pipe located underneath is overestimated. In the experiment, the phases in this region tend to separate and the interfacial friction is low.

Most of these discrepancies have been corrected in the final calculatin which uses a very simple set of corrections. However the applicability of these corrections to other test conditions has not been confirmed.

This final calculation must be regarded mainly as a way of quantification of parameter effects. In particular, it shows that the interfacial friction in the SG inlet plenum and in the inclined pipe located underneath is about 100 times overestimated. Assuming slug flow (rather than bubbly) in this region gives fairly good results. Also, this calculation shows that up to 40% of the SG U-tubes were probably in abnormal conditions during the experiment. Nevertheless their effect on the loop flow rate was no more than 10%.

If a very general correction of the shortcomings of the code observed in the basic calculation is looked for, it should be done through the study of separate effect tests. This is the case especially for:

- the interfacial friction and/or the form loss coefficients in a rod bundle geometry.
- the interfacial friction in the SG inlet plenum and the inclined pipe located underneath.

Finally, two issues remain to be clarified :

- the discrepancy about the liquid distribution in the vessel (especially the liquid level in the downcomer). In particular, some possible bypass effect should be further investigated.
- the reason for which RELAP5/MOD2 does not allow reverse flow in the abnormal SG U-tubes for the 94% and 81% inventories. Some shortcoming in the package of "wall friction + interfacial friction + condensation" is suspected here.

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[8] V. H. Ransom et al., RELAP5/MOD2 Code Manual, NUREG/CR-4321, August 1985.

[9] C. P. Fineman, RELAP5/MOD2 Code Assessument for the Semiscale Mod-2C Test S-LH-1, ANS/ENS Meeting, San Diego, February 1986.

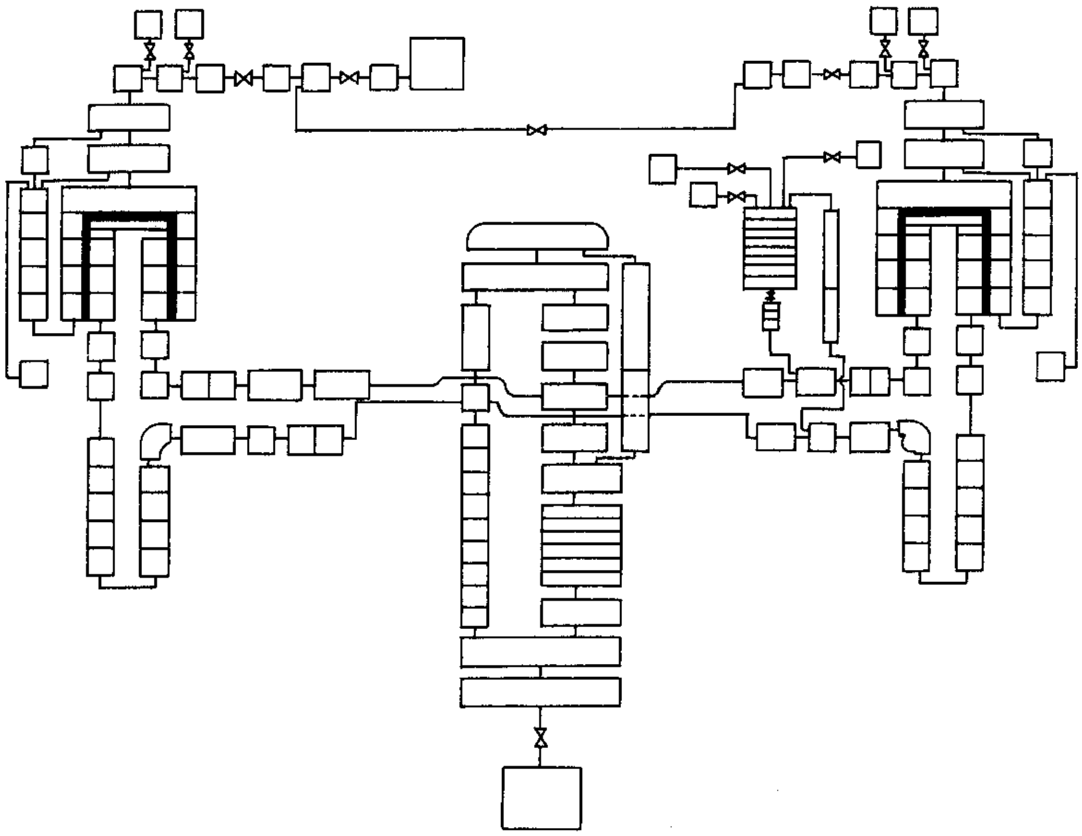


Fig. 1 RELAP5 Model for LSTF Natural Circulation Calculation

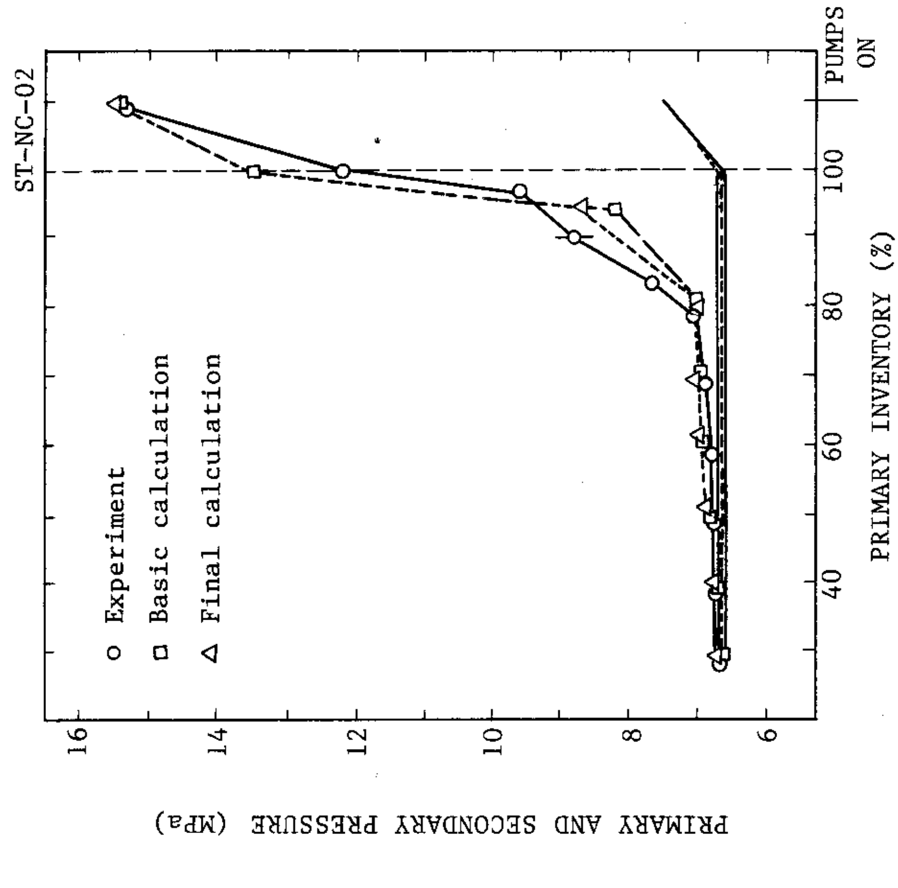


Fig. 2 Primary and Secondary System Pressures

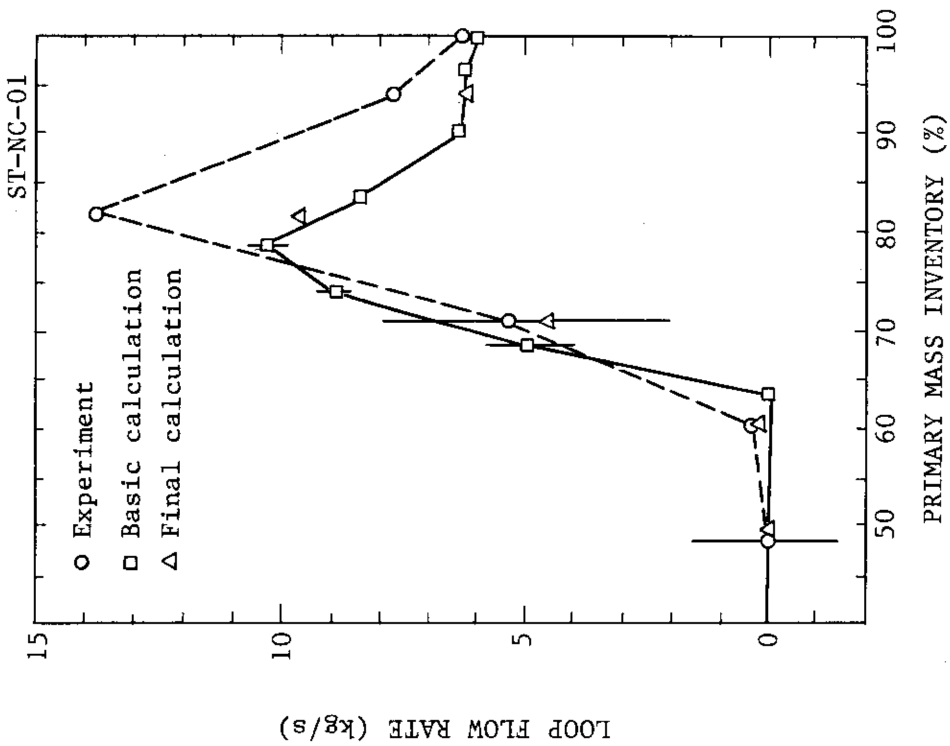


Fig. 3 Primary Loop Flow Rate

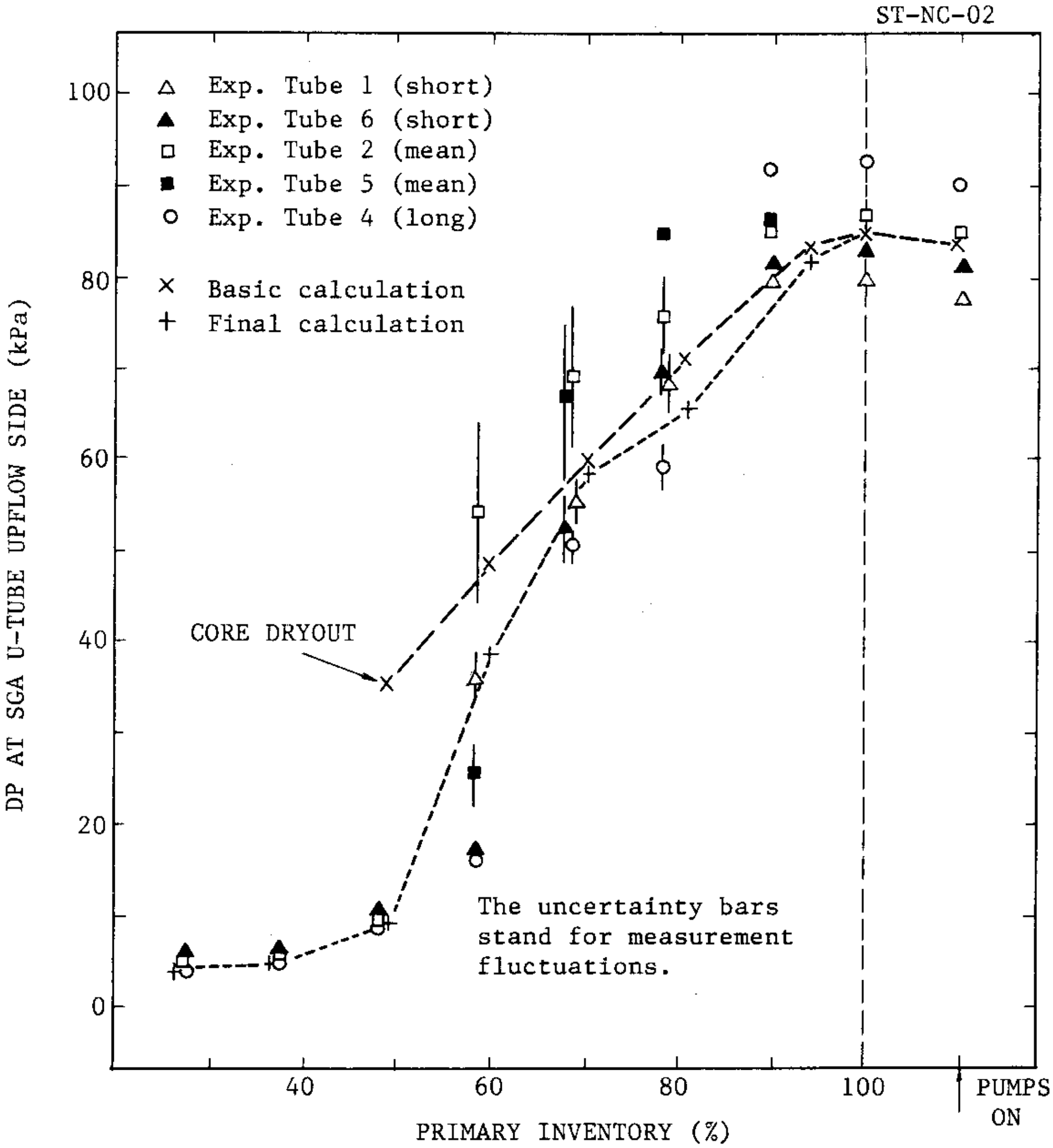


Fig. 4 Differential Pressure at SG-A U-Tube Upflow Side

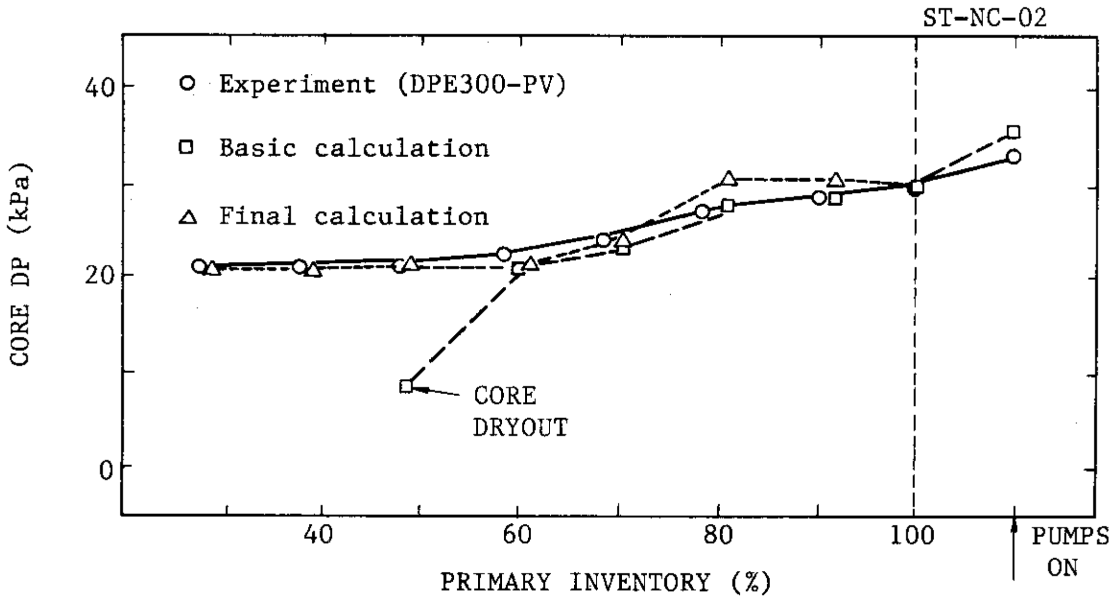


Fig. 5 Core Differential Pressure

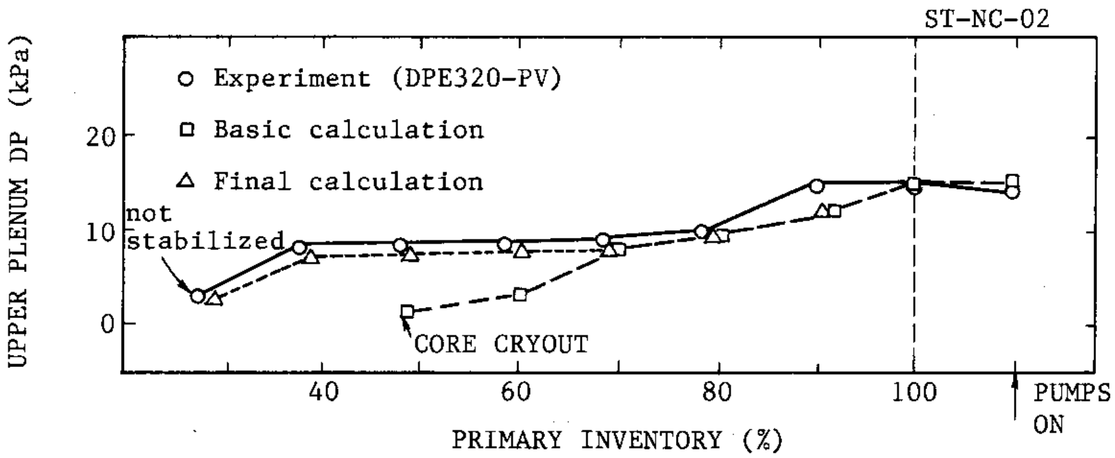


Fig. 6 Upper Plenum Differential Pressure

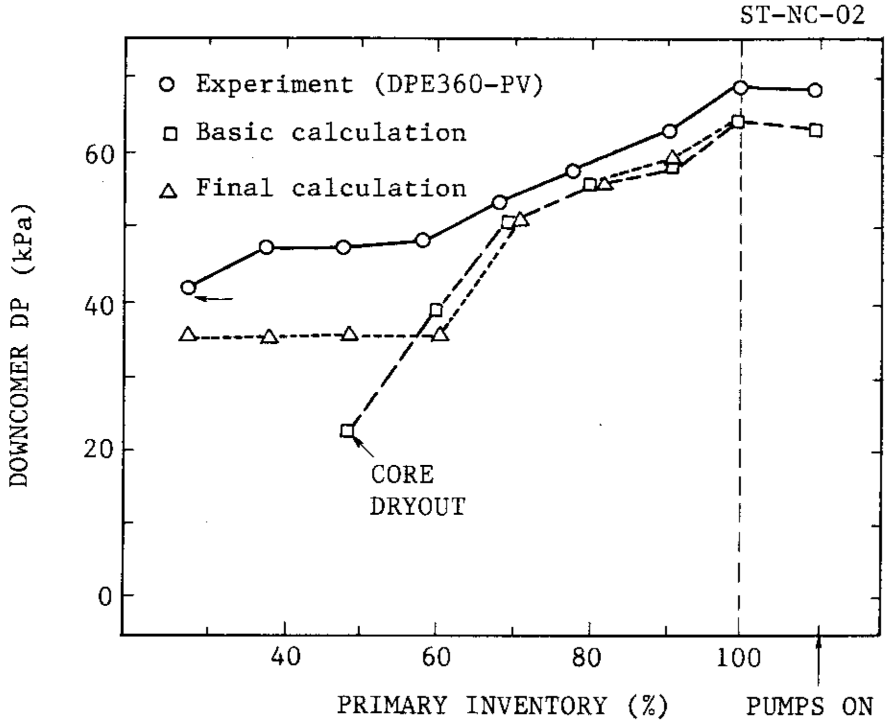


Fig. 7 Downcomer Differential Pressure

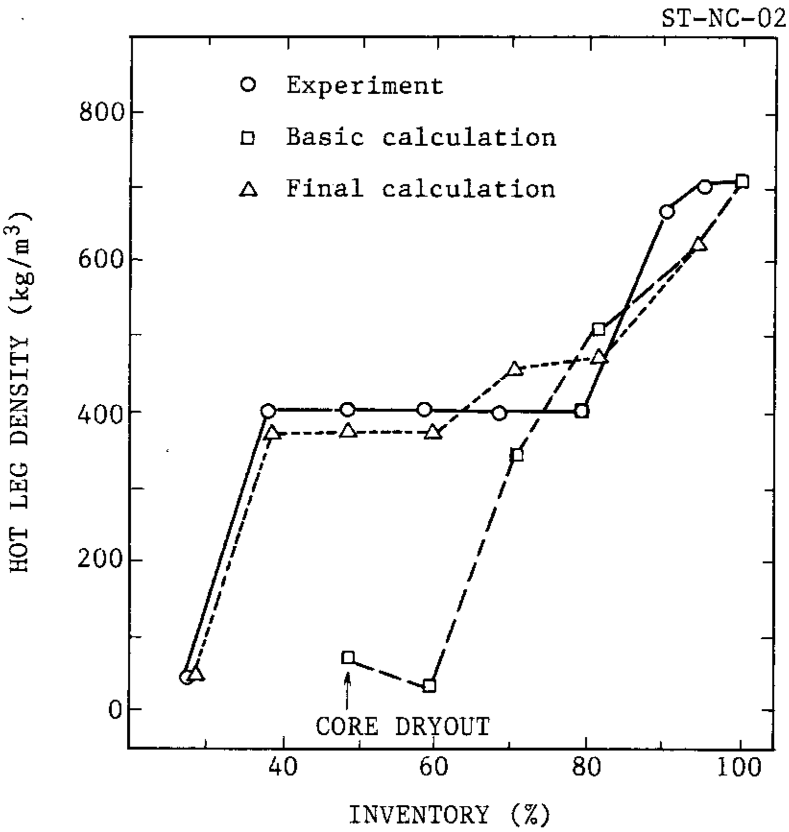


Fig. 8 Hot Leg Density

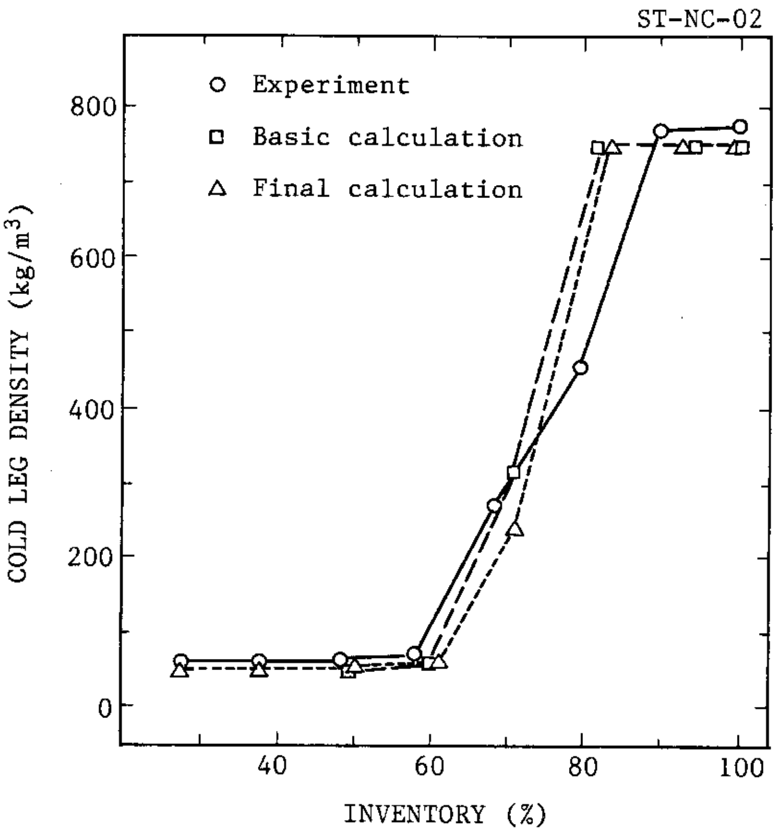


Fig. 9 Cold Leg Density

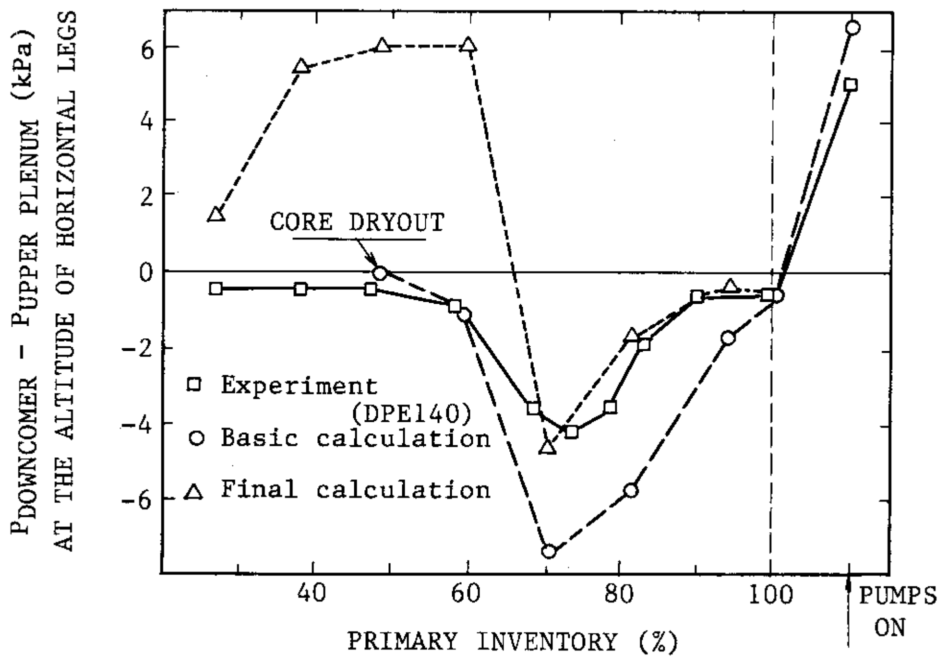


Fig. 10 Differential Pressure Between Downcomer and Upper Plenum

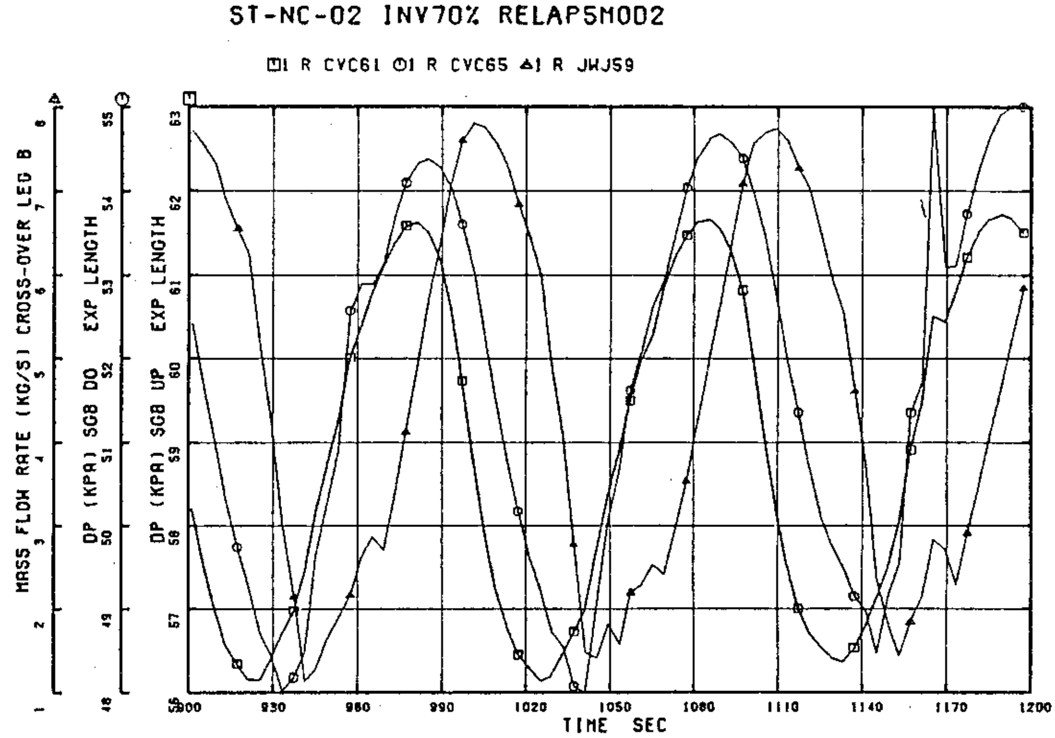


Fig. 11 Primary Loop Flow Rate and SG Differential Pressure Oscillations (RELAP5/MOD2)

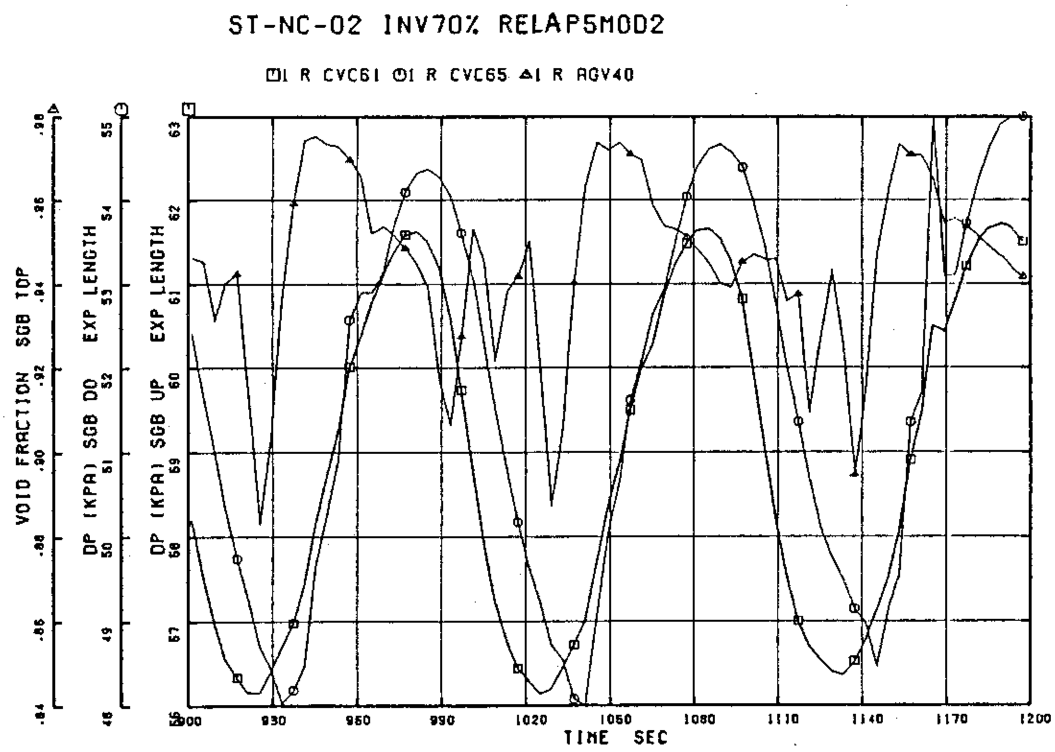


Fig. 12 U-Tube Top Void Fraction and SG Differential Pressure Oscillations (RELAP5/MOD2)

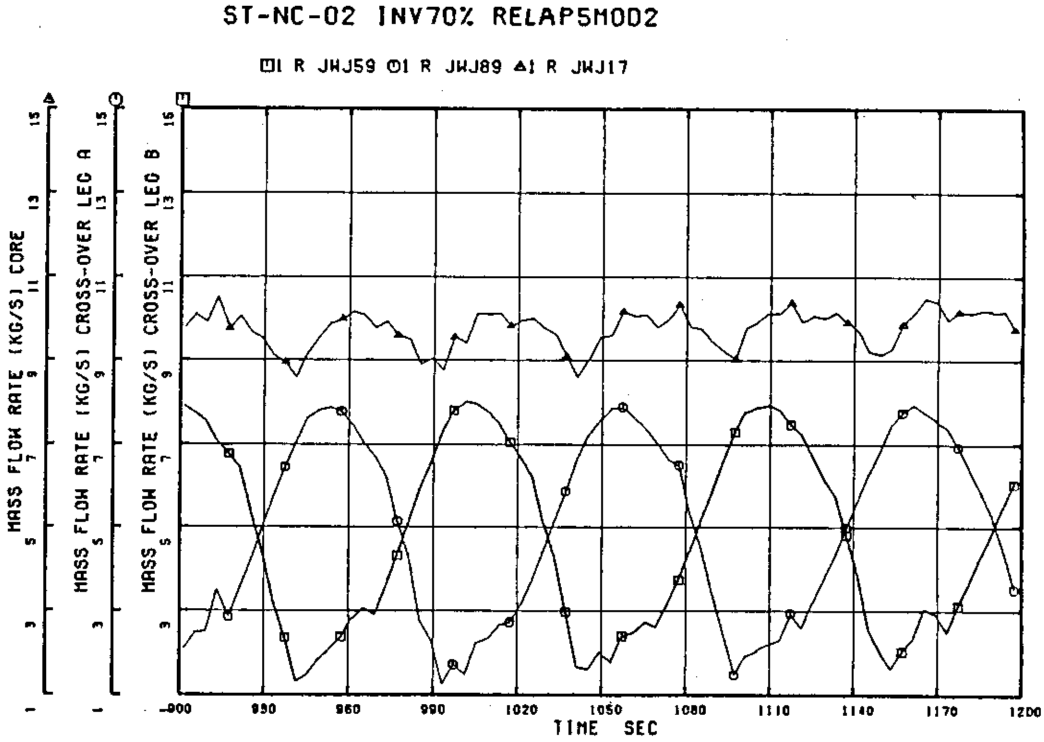


Fig. 13 Core and Primary Loop Flow Oscillations (RELAP5/MOD2)

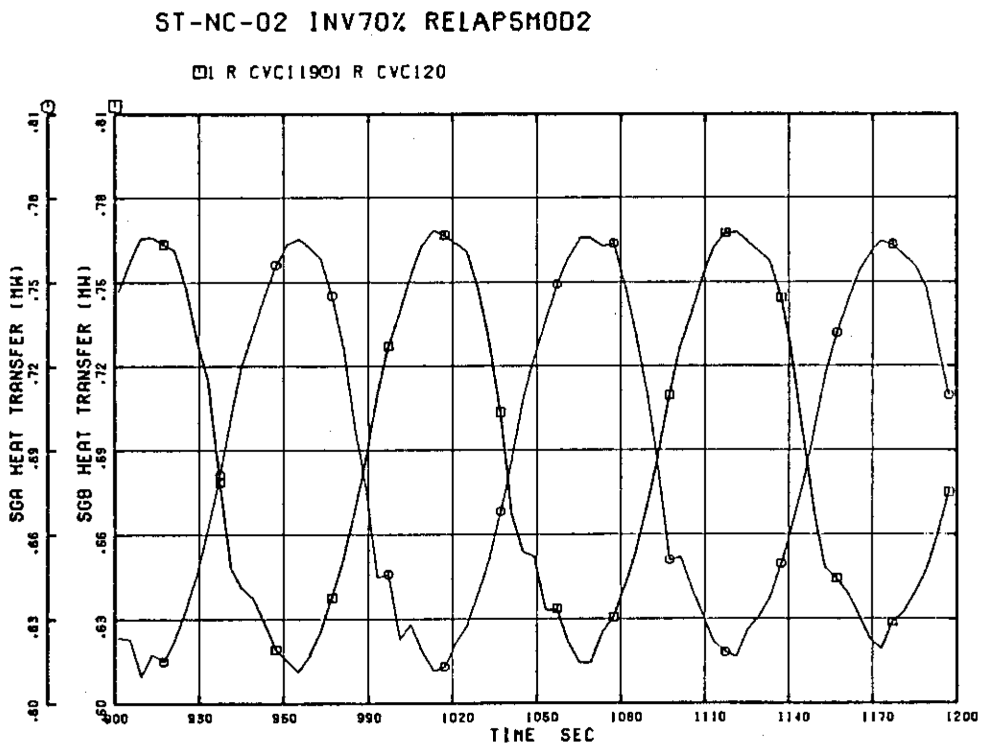


Fig. 14 SG Heat Transfer Rate Oscillations (RELAP5/MOD2)

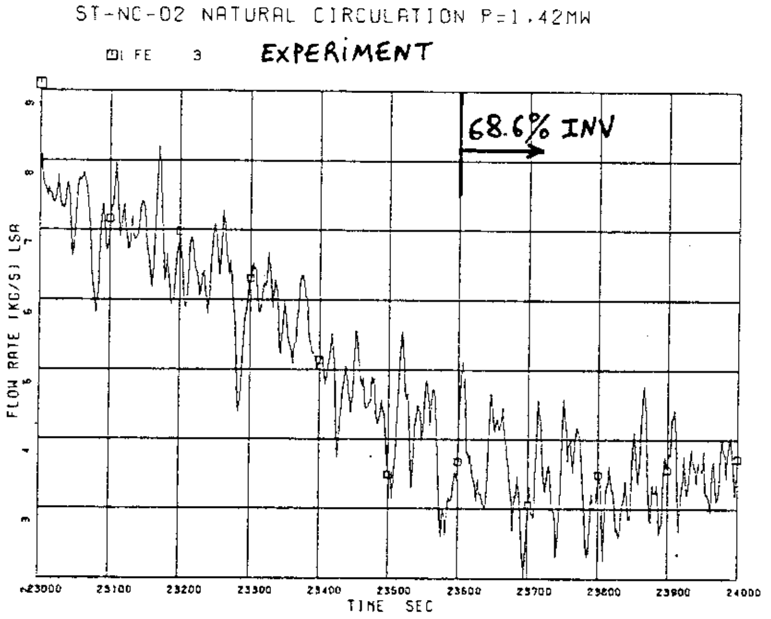


Fig. 15 Primary Loop Flow Oscillations, Loop A (Experiment)

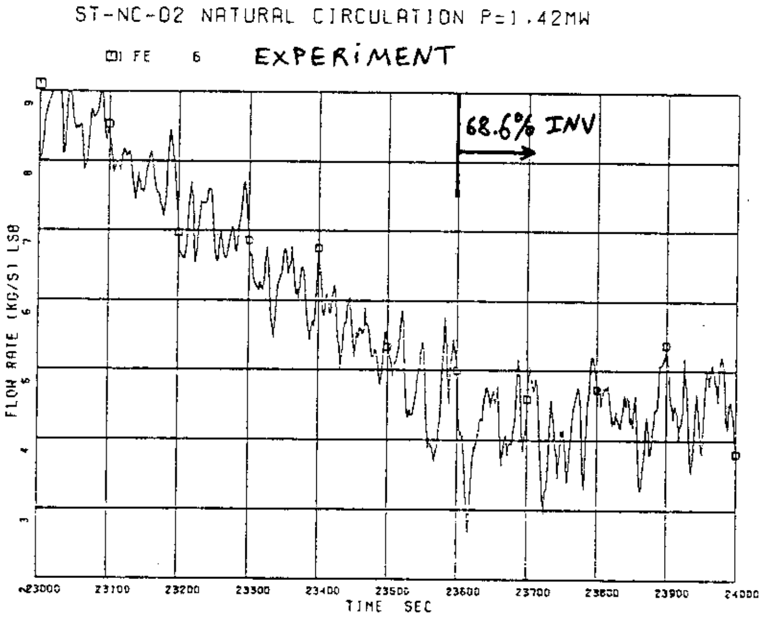


Fig. 16 Primary Loop Flow Oscillations, Loop B (Experiment)

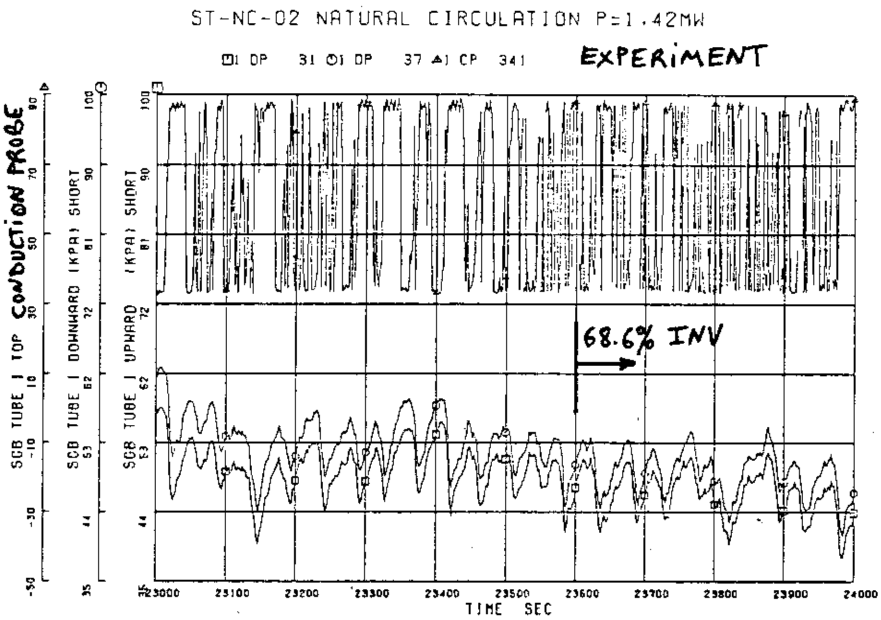


Fig. 17 U-Tube Level Oscillations (Experiment, Tube 1)

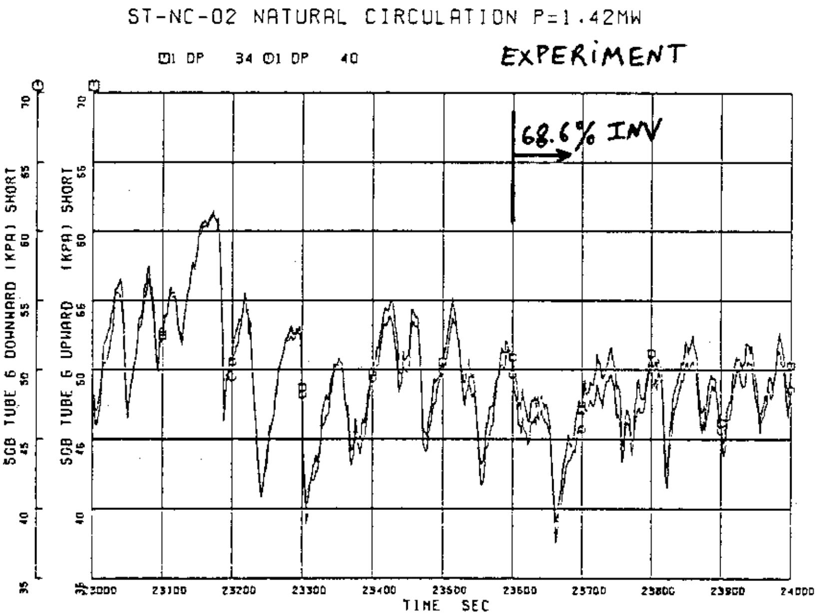


Fig. 18 U-Tube Level Oscillations (Experiment, Tube 6)

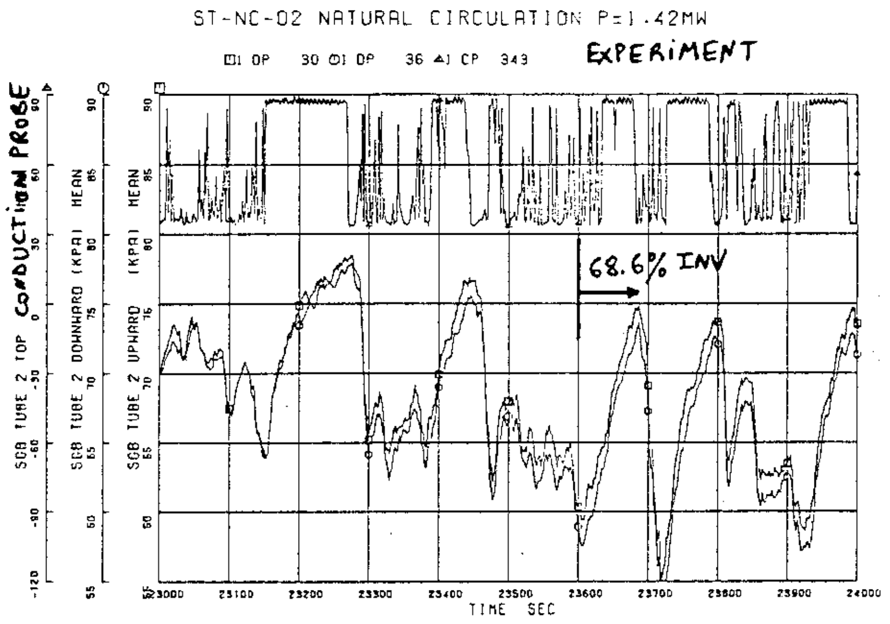


Fig. 19 U-Tube Level Oscillations (Experiment, Tube 2)

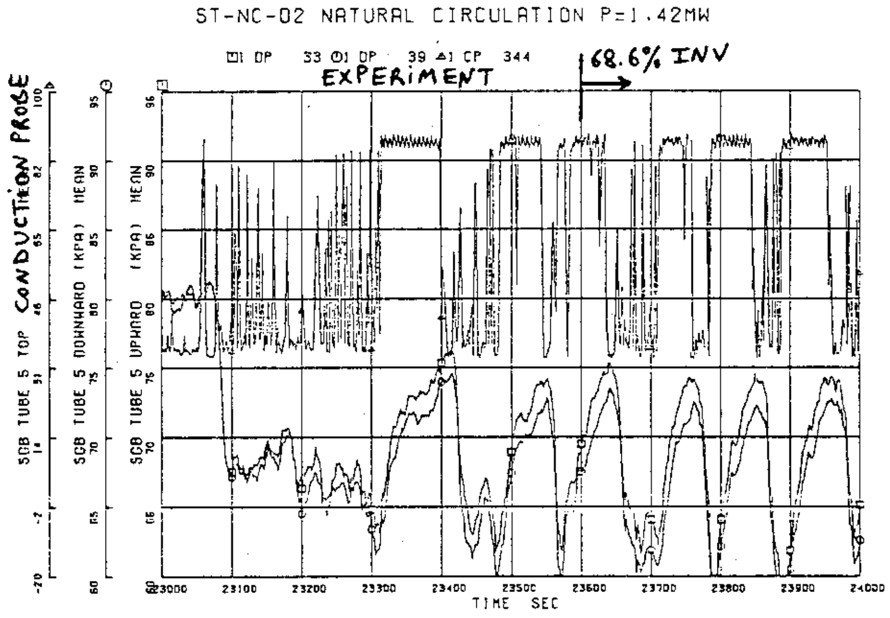


Fig. 20 U-Tube Level Oscillations (Experiment, Tube 5)

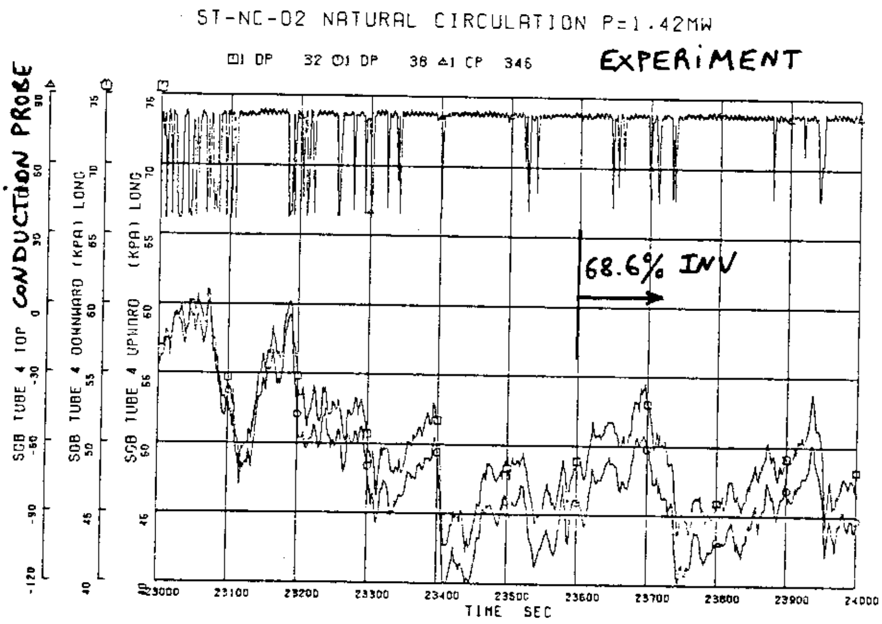


Fig. 21 U-Tube Level Oscillations (Experiment, Tube 4)

Appendix 1 Experimentally measured multidimensional behaviour of the SG U-tubes

The experimental results show that for inventories larger than 80% the flow in some SG U-tubes stops or possibly goes in the opposite direction to the mean flow.

In those tubes, the fluid temperature is equal to the secondary side temperature all along the tubes. As the conduction probes located at the top of these isothermal tubes are wet, it means that the liquid continuum is not interrupted and that the flow goes in the reverse direction because some increase of pressure is measured from the tube inlet to outlet (the differential pressure is imposed by the other tubes in which the friction effect is small as compared to the static head effect). This behaviour is evidenced by the fact that, for the 100% inventory for instance, the SG inlet plenum temperature is about 4 K lower than the hot leg temperature.

Six tubes per SG are instrumented (and each SG has 141 tubes).

At 100% inventory, all the longest measured SG tubes (2 per SG) are in these abnormal conditions and all of them remain in such conditions until the 85% inventory is reached.

At 85% inventory, some of the mean measured SG tubes (2 per SG) also behave in the same abnormal way and it goes on together with some of the longest measured tubes until the 80% inventory is reached.

For inventories lower than 80% this behaviour does no more occur.

The trigger for the behaviour of those abnormal U-tubes is not well understood. So the final calculation presented in this study does not try to calculate the onset of the phenomenon but tries to quantify its effect and to calculate reverse flow once the temperature becomes uniform in some tubes.

The fluid velocity in the abnormal tubes can be simply evaluated by negleting the form loss at the tubes inlet and outlet and assuming that the differential pressure between the inlet and outlet of those tubes is due to friction only. The orders of magnitude are the following ones :

V = 0.01 m/s	DP = 1.5 Pa
V = 0.1 m/s	DP = 0.1 kPa
V = 1 m/s	DP = 6 kPa

Appendix 2 Other sensitivity tests

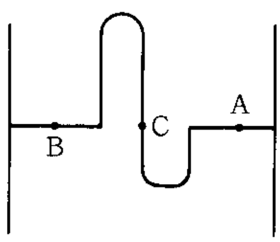
The following sensitivity tests are performed by changing only one parameter of the calculation. However the final calculation (presented in section 4) shows that more than one parameter must be modified in order to calculate correctly this natural circulation test.

Nevertheless those tests are presented here as a piece of additional information which provides a better knowledge both of the test and of the behaviour of RELAP5/MOD2.

A2.1 Effect of the abnormal SG U-tubes without any correction of the vessel differential pressure

The overall DP distribution throughout the primary circuit for the basic calculation is shown in the Table below. A is located in the cold leg, B in the hot leg and C is located in the cross-over leg below the SG outlet at the altitude of the horizontal legs. DP_{SG} is the difference between the pressure at the top of the SG inlet plenum and at the top of the SG outlet plenum

Inventory	$P_A - P_B$	$P_B - P_C$	$P_C - P_A$	DP_{SG}
100%	-0.9	-1.8	2.7	-0.36
94%	-1.8	-1.9	3.7	-0.15
81%	-6.0	-4.0	10.0	-0.60



Unit : kPa

This table shows that, for the RELAP5 basic calculation, the increase of pressure through the SG is small, both in alsolute value and as compared to the other DP in the circuit.

In those conditions the effect of the abnormal SG U-tubes (see Appendix 1) on the loop flow rate can be only very small. This was verified through some sensitivity tests performed in the same way as in Subsection 4.1.4.

A2.2 Modification of the primary pressure

For the 94% inventory, the primary pressure is understimated (Fig 2). In order to study the effect of this understimation, the pressurizer was connected to a "time dependent volume" imposing the experimental pressure. In those conditions a 60 kg (about 1%) increase in the primary inventory is observed and the loop flow rate decreases from 7.8 kg/s to 7.2 kg/s (instead of about 6.3 kg/s in the experiment for 94% to 95% inventories). So the discrepancy with the experiment is reduced to 14%.

For the 81% inventory, the discrepancy on the primary pressure is small (Fig 2). Using the same method results in a very small effect on the loop flow rate (a 4% increase in the loop flow rate is observed, probably related to the increase of the primary inventory).

A2.3 Nodalization

When the primary inventory decreases from the initial full inventory, the increase in the loop flow rate is much related to the time when the decreasing froth level in the upper plenum reaches the level of the hot legs: from that time, a larger amount of vapour can flow towards the SGs, increasing the void fraction in the upflow side of the SGs and therefore increasing the loop flow rate.

So, the calculation of the level in front of the hot legs is an important parameter. However the definition of level does not exist in RELAP5 for the vertical volumes such as the ones which are used for the nodalization of the upper plenum. In those volumes RELAP5 deals only with the mean void fraction in each node.

Consequently some effect of the height of the volume located in front of the hot legs is suspected. In the basic calculation, the volume height is 0.6 meter and the hot legs are connected at mid-height by cross-flow junctions. In the sensitivity test presented here, this height was chosen equal to the hot leg diameter (0.207 m) and the volumes located above and underneath were lengthened accordingly.

The calculated loop flow rate is compared to the basic calculation and the experimental value on the following Table

Inventory	Experiment	Basic	Present
94%	6.3	7.8	7.6

Unit : kg/s

So, a small effect of the nodalization is found. However this effect disappears for the 81% inventory.

A2.4 Bypass paths

The basic calculation assumes a 2% bypass between the upper head and the downcomer. However some calibration tests (with nitrogen) showed that a small bypass did exist during the natural circulation experiments between the top of the upper plenum and the downcomer. The flowrate through the bypass was not measured.

The sensitivity test presented here aims at handling what would be the qualitative effect of this bypass.

The choice of the bypass value was made in order to match the measured DP between the downcomer and the upper plenum (DPE140) during steady state with pumps on. This leads to a rather unrealistic 6.9% value for the bypass and introduces a discrepancy between the measured and calculated pump head (see table below). So, some inconsistency in the experimental data (related to the measurement uncertainty) is found.

	Experiment	Basic	Present
Pump speed (rd/s)	86	93	90
DPE 140 (kPa)	5.0	6.5	5.0
Pump head (kPa)	10.7	11.1	9.5

Nevertheless the test was run in order to look at some qualitative trends.

The main result is that this additional bypass opens a new path for the natural circulation inside the vessel itself, so that the circulation of fluid inside the vessel is greatly accelerated and becomes significantly different from the sum of the flow rates in the two loops. Without entering into more details the results for the loop flow rate (in kg/s) are summarized in the following table:

Inventory	Experiment	Basic	Present
100%	6.0	6.4	6.0
94%	6.3	7.8	11.0
81%	9.2	13.8	12.4

Unit : kg/s

Finally it is observed that the qualitative trend is not consistent with the experimental results (large overstimation of the loop flow rate for the 94% inventory). Therefore, assuming that RELAP5 deals correctly with the effect of the bypass, it is considered that the bypass between the upper plenum and the downcomer is probably small and it was justified to neglect it.

A2.5 Pump conditions

The table presented in Subsection 4.1.1 shows that the pumps are the main contribution to the flow resistance in the primary circuit. Consequently it is important to check the pump conditions and their effect.

As pointed out in Subsection 2.2, the basic calculation was run by setting the pump speed to zero. However in the experiment the pump was free to rotate.

The measured pump speed was zero for every inventory. The measurement dead band is 1 rd/s. The consistency of the experimental data is checked in the following table where the measure pump speed (zero) is compared to the calculated one. The calculated pump speed is obtained by using the pump characteristic curve, the measured loop flow rate and the measured differential pressure between the pump inlet and outlet. Single phase liquid is assumed at the pump. The effect of the measurement uncertainty (1% full range uncertainty is assumed for the DP measurement) is shown.

Inventory	Measured Pump head (kPa)	Measured Flow rate (kg/s)	Calculated Pump speed (rd/s)	
100%	-1.2	6.0	5.5	
	-1.7	6.0	0	Uncertainty effect
79%	-4.5	10.3	2.7	
	-5.0	10.3	0	Uncertainty effect

This table shows that the experimental data are consistent.

In the calculation loss through the pump decreases and the flow rate increases. For the 81% inventory (maximum flow rate in the calculation) the resulting loop flow rate is 15 kg/s with the unlocked pump (instead of 13.8 kg/s in the basic calculation and about 9.2 kg/s in the experiment) and the pump speed is 15 rd/s.

Finally, as expected, the use of the "unlocked" conditions worsens the calculation results. However it remains possible that the pump was really not rotating in the experiment due to the high frictional torque value at low pump speed (the frictional torque of the pump is not known for speed smaller than 10 rad/s and is extrapolated in a questionable way in the pump model used for the calculation). In particular if the pump stopped early in the experiment it might have been unable to rotate again thereafter.

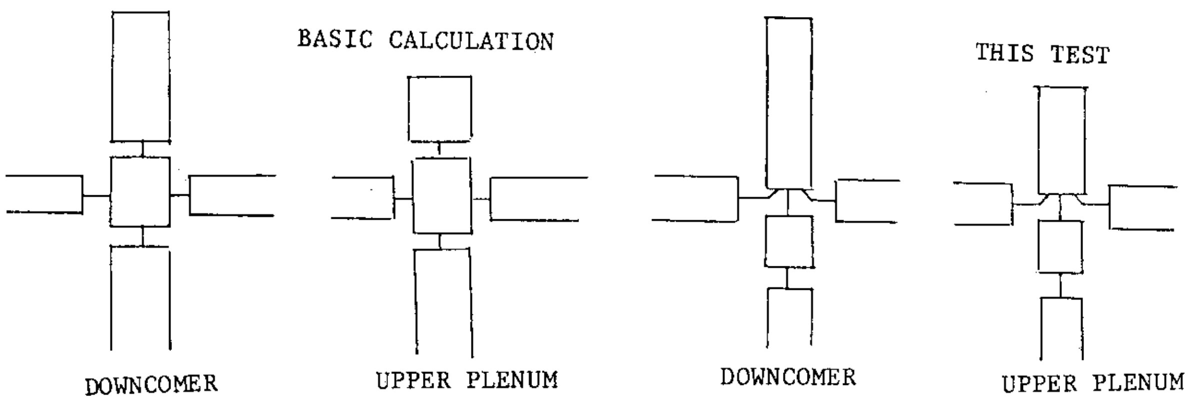
The fluid density in the pump is another topic of interest. For all the inventories the basic calculation shows that the pump is under single phase liquid flow. However it is probable that some vapour goes into the pump when there is vapour in the cold leg. This effect might increase the friction through the pump. Nevertheless the above table shows that for the 79% inventory, although the cold leg void fraction is large in the experiment (Fig. 9), the pump data are consistent with the assumption of single phase liquid.

A2.6 Modification of the branching of the horizontal legs with the vessel

As explained in Subsection 2.3 the basic calculation uses the cross-flow option at the junctions between the horizontal legs and the vessel.

The cross-flow option is generally recommended as a large improvement of RELAP5/MOD2 over RELAP5/MOD1. It makes some simplifications of the momentum equation in order to take into account in particular the change in the fluid velocity direction across the junction.

The test presented here uses an ordinary junction between the horizontal legs and the vessel according to the following figure:



This test was performed only for the 81% inventory and shows a very large effect on the loop flow rate which becomes equal to 11.0 kg/s (instead of 13.8 kg/s in the basic calculation and about 9.2 kg/s in the experiment).

However this improvement in the calculation of the loop flow rate is obtained by means of a worse distribution of the liquid in the primary circuit: in particular, a large amount of liquid is found in the downcomer above the level of the cold legs (contrary to the experiment).

Finally it is concluded that the mode of branching chosen in this test does not account better for the experimental results. Connecting the horizontal legs "above" the adjacent volume in the vessel (instead of "under" in the test presented here) does no more improve the results.