NUREG/IA-0090

International Agreement Report

Assessment of RELAP5/MOD2 Using the Test Data of REWET-II Reflooding Experiment SGI/R

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

May 1993

Prepared as part of
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NOTICE

Abstract

An analyses of a reflooding experiment with RELAP5/MOD2 cycle 36.04 is presented. The experiment had been carried out in the REWET-II facility simulating the reactor core with a bundle of 19 electrically heated rods. On the basis of the results of two calculations recommendations for the core nodalization are presented, and a modification to the code is proposed.

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ASSESSMENT OF RELAP5/MOD2 USING THE TEST DATA OF REWET-II REFLOODING EXPERIMENT SGI/R

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Executive Summary

An experiment carried out in the framework of the REWET-project in 1983 has been used as an experimental database in the RELAP5/MOD2 assessment as a part of the International Code Assessment and Application Program (ICAP).

The REWET-II facility is a scaled-down model of the Loviisa 1 and 2, VVER-440 type reactors. The core in the facility consists of 19 electrically heated fuel rod simulators. The facility has been used in reflooding experiments with downcomer and/or upper plenum ECC injection.

Two calculations have been done. The number of the subdivisions of the reactor core heat structures describing the rod simulators has been the varied parameter. In both calculations the nodes in the core were quite short. The maximum possible number of subdivisions was used in the first calculation, and 1/8 of it in the second.

The code's ability to represent the phenomena during this reflooding test was good. The small differences in cladding temperatures and quenching times between the analysis and the measurements show the

code to be slightly conservative. The oscillating nature of many parameters, seen in the experiments, is also present in the calculations, and even more strongly.

The calculations have mainly been performed using a maximum time step of 0.01 second. The total number of time steps was 97767. The total CPU-time consumption per volume (node) and per time step was 0.013 seconds.

1. Introduction

The REWET-project, started in 1976, is carried out in cooperation between the Technical Research Centre of Finland and the Lappeenranta University of Technology. The project has contributed to the experimental database of reflooding and natural circulation phenomena for code assessment. Reflooding has been studied in two test series, first to study the reflooding in general, reported in reference /1/, and secondly to study the effect of the spacer grids on the reflooding process (SGI), reported in reference /2/. The analyses of the tests have been performed with several codes but the main tool has been the NORCOOL-I code, developed in Nordic cooperation. The knowledge from the earlier analyses has given the basis of the modeling of the facility for the RELAP5/MOD2 code. In comparison of the capabilities of different codes to describe reflooding phenomena, the SGI/R test has been used as the reference test.

Special features of the VVER-reactor as well as, a) the use of atmospheric pressure, b) the short heated length of the core, c) the stepwise varying linear power in the REWET-II facility with rather cold rod ends and d) the small injection flow rates in the SGI/R test, have been the reasons why the modeling of the core has not followed all the recommendations given in the RELAP5/ MOD2 manuals. The modeling of the core has been the main point of interest in the two assessment calculations performed.

2. Facility description

The REWET-II test facility was originally designed to investigate the phenomena during the reflood phase of a LWR LOCA. The scaling factor between the facility and the reference reactor, the VVER-440 type reactor is 1:2333. The main design principle is accurate simulation of the specific features of the rod bundle geometry and the primary system elevations (Fig.1). The steam generators and the primary pumps are simulated as flow resistances. Fig.2 shows schematically the REWET-II test facility, and the facility characteristics are given in Table 1. A more detailed description of the facility is in the reference /4/.

The test section of the facility consists of 19 electrically heated full length fuel rod simulators in a triangular grid (Fig.3), an upper plenum, a lower plenum and a downcomer. One intact primary loop and a broken loop in the test facility simulate the five intact loops and the broken loop of the reference PWR, respectively. The heating coil of a fuel rod simulator is packed in magnesium oxide inside a stainless steel cladding. The test section is thermally isolated. The spacer grid elevations and the rod simulator power distribution are shown in Fig.4.

The primary measurements in the experiment are rod surface temperatures, pressures, pressure differences, coolant flow rates and the heating power.

The data acquisition system consists of a measurement and control processor and a desk-top computer. During an experiment 96 data channels are scanned once in a second.

Fuel rod simulators:	
Heated length	242 cm
Outer diameter	0.91 cm
Power distribution	chopped cosine
Axial peaking factor	1.5
Number of rods in bundle	19
Wall thickness of housing	2 mm
Bundle arrangement	triangular
Lattice pitch	1.22 cm
ECC injection location	upper plenum and/or downcomer
Fuel rod simulator bundle power	0-90 kW
Average fuel rod simulator power	0-4.7 kW
Average linear heat rating	0-20 W/cm
Flooding rate	0-15 cm/s
System pressure	0.1-1.0 MPa
Maximum cladding temperature	1000 °C
Coolant temperature	15-120 °C

Table 1. REWET-II facility characteristics

3. Test description

In preparation for a test, the system is heated up by steam. The lower plenum is filled up with water to the bottom level of the core heated section. The fuel rod simulators are heated up until the initial cladding temperature is reached in the middle of the core. The pressure difference measurements are set to show zero in the beginning of the test. In the reference test SGI/R the test parameters were:

Initial rod temperature	600 °C	± 3 °C (<400 °C), ± 0.75 % (>400 °C)
Average power/bundle	30 kW	
Coolant temperature	30 - 34 °C	± 3 °C (<400 °C), ± 0.75 % (>400 °C)
Flooding rate	0.069 kg/s	± 1.0 %
ECC injection location	downcomer	
Pressure	0.1 MPa	± 1.0 %

4. Code input model description

4.1 Loop and vessel model

The REWET-II facility was modeled with 60 volumes and 60 junctions. The nodalization scheme is shown in Fig.5 and the main geometrical data of the volumes are listed in Table 2. The lengths of the nodes were chosen taking into account the measurement locations. The injection pipe lines are not considered, nor is the downcomer overflow tank. The containment simulator tank is modeled with two time dependent volumes. Part of the containment tank volume was included in the entrainment over flow tank.

The pipe walls were modeled as cylindrical heat slabs, one in each node, except none in the upper head volume. The thickness of the pipe walls is 1.0-2.0 mm described with three radial mesh points.

In the first short calculation it was noticed that the cold water injection into the downcomer, full of steam in the beginning, resulted in very short time steps and water property errors. From the measured data it could be seen that no water was flowing to the downcomer overflow tank until the downcomer was full of water up to the loop connection point. Hence, in the further calculations the injection point was moved to a lower part of the downcomer.

	Node	Area (m2)	Length (m)	Elevation change (m)	Hydraulic diameter (m)
PIPE	10001	.0019813	0.205	0.205	0.01165
	10002	.0019813	0.205	0.205	0.01165
	10003	.0013182	0.15	0.15	0.00715
	10004	.0013182	0.15	0.15	0.00715
	10005	.0013182	0.127	0.127	0.00715
	10006	.0013182	0.127	0.127	0.00715
	10007	.0013182	0.1255	0.1255	0.00715
	10008	.0013182	0.1255	0.1255	0.00715
	10009	.0013182	0.131	0.131	0.00715
	10010	.0013182	0.131	0.131	0.00715
	10011	.0013182	0.131	0.131	0.00715
	10012	.0013182	0.131	0.131	0.00715
	10013	.0013182	0.1295	0.1295	0.00715
	10014	.0013182	0.1295	0.1295	0.00715
	10015	.0013182	0.129	0.129	0.00715
	10016	.0013182	0.129	0.129	0.00715
	10017	.0013182	0.1305	0.1305	0.00715
	10018	.0013182	0.1305	0.1305	0.00715
	10019	.0013182	0.1375	0.1375	0.00715
	10020	.0013182	0.1375	0.1375	0.00715
	10021	.0013182	0.168	0.168	0.00715
PIPE	10501	.00312	0.60	0.60	0.063
	10502	.00312	0.60	0.60	0.063
	10503	.00312	0.60	0.60	0.063
	10504	.00312	0.60	0.60	0.063
BRANCH	11000	.00312	0.432	0.432	0.063
PIPE	11501	.00312	0.56	0.56	0.063
	11502	.0553	0.10	0.10	0.265
PIPE	32001	.000412	0.40	0.0	0.0229
	32002	.000412	0.70	0.70	0.0229
	32003	.000412	0.70	0.70	0.0229
	32004	.000412	0.67	0.0	0.0229
PIPE	12001	.000412	0.40	0.0	0.0229
	12002	.000412	0.70	0.70	0.0229
	12003	.000412	0.70	0.70	0.0229
	12004	.000412	1.40	0.0	0.0229
BRANCH	12500	.005891	0.15	0.0	0.0866
SNGLVOL	13000	.04983	0.602	0.602	0.252
PIPE	14001	.000412	0.525	0.0	0.0229
	14002	.000412	0.525	0.0	0.0229
TMDPVOL	15001	.500	1.768	1.768	0.7979
TMDPVOL	19001	.500	1.768	1.768	0.7979
PIPE	19501	.000412	0.60	0.0	0.0229
	19502	.000412	0.60	0.0	0.0229
SNGLVOL	20501	.00080425	0.61	0.61	0.032
BRANCH	21001	.00080425	0.935	0.935	0.032
TMDPVOL	21101	100.00	10.0	0.0	11.28
PIPE	22001	.00080425	1.27	1.27	0.032
	22002	.00080425	1.27	1.27	0.032
	22003	.00080425	1.090	1.090	0.032
	22004	.00080425	0.775	0.775	0.032
	22005	.001237	1.3465	1.3465	0.0395
	22006	.001237	1.3465	1.3465	0.0395
SNGLVOL	23001	.00183225	0.675	0.0	0.0483
PIPE	24001	.00183225	0.608	0.608	0.0483
	24002	.00183225	0.608	0.608	0.0483
	24003	.00183225	0.608	0.608	0.0483
	24004	.00183225	0.608	0.608	0.0483
	24005	.0040838	0.620	0.620	0.0721
	24006	.0026609	0.592	0.592	0.0582

Table 2. Geometric data of the volumes

4.2 Core model

The number of the heat slabs and nodes in the core was chosen with the help of a hand calculation of the axial heat transfer in the quench front. In this calculation an average quenching temperature of 400 °C and a minimum quench front velocity of 2.4 mm/s were used. The calculation gave mesh division lengths of about 1.5 - 1.6 mm. Based on this the core was modeled with 21 nodes and heat slabs, two per each axial power step. The number of subdivisions (number of mesh points) in each heat slab was 128 in the first calculation. In the second calculation the number of subdivisions was only 16.

In the core two heat slabs per volume were used, one for the fuel rod simulators and one for the housing. Fine mesh reflood calculation was performed only in the heat slabs describing the rod simulators.

The radial description of the rod simulator consists of three materials: cladding, magnesium oxide and combined magnesium oxide and heating coil. The total number of radial mesh points in the rod was seven.

4.3 Steady state

In the beginning of the calculation the radial temperature profile in the core was determined during the heating period with a model consisting of only the core and one time dependent volume. The temperature profile was included in the final steady-state calculation, which took only a few seconds. In the first calculation this calculation of the heating period resulted in too low shroud temperatures. In the second calculation the shroud temperatures were raised to the measured values.

5. Results

The plots from the first calculation are shown in Figs 6-36 and from the second calculation in Figs 37-40. Because of the oscillating nature of many parameters both in the experiment and in the calculations, comparisons with the experimental data have been done by drawing the average values from the experiments on the plots from the calculations. The measured cladding temperatures in the plots are collected from different levels in different rods. The original plots of the experiment are from reference /3/.

The water temperatures in Fig.6 show that the U-tube oscillations are not large enough to mix the cold water in the lower plenum. In spite of this, the cladding temperatures in the lower part of the core are well predicted but the calculated quenching times are somewhat longer than in the experiment (Fig.8). The maximum temperatures and the turn over times are well predicted.

In the calculations the upper part of the core quenches more slowly (Fig.9) than in the experiment, the reasons of which are discussed later. In Fig.11 the calculated quench front elevations are actually the CHF-points in the core (taken from the listings because the code did not accept the parameters of the plot variables descriped in the code manual). In Fig.10 the temperatures measured below and above a spacer grid are compared with the calculated ones.

The shroud temperatures in case 1 (Fig.12) and case 2 (Fig.38) show how important it is for the exact prediction to have quenching models for all of the heat slabs. This is not possible in the RELAP5 model, so dividing the core flow channel into two channels describing the inner and outer regions, may have given better results.

The measured pressure differences give information of the actual water inventory in each part of the facility. The pressure differences DP1, DP2, DP3 and DP6 (Fig.17,18,19 and 22) give an indication of having the correct water inventory in the lower part of the core, but too much water in the upper part. In spite of having more water in the calculation than in the experiment the cladding temperatures are higher and the quenching times longer. In the experiments the water forms liquid films on surfaces and quenches the rods from top down. The upper plenum is more voided (DP5, Fig.21) in the calculation.

In the calculation the injection to the bottom end of pipe 220 instead of the upper part of the downcomer as in the experiment caused a faste rising water level in the downcomer and larger pressure differences DP7 (Fig.22) and DP8 (Fig.23). From the pressure difference DP4 (Fig. 19) it can be seen that the actual water inventory in the downcomer was well predicted.

The calculation of the liquid mass collected in the entrainment water tank descriping the entrainment water going from the core through the upper plenum to the loops was not succesfull in the first calculation. This water inventory in the second calculation is shown in Fig 39. A small amount of water is collected into the tank before the level gauge gives any signal. So the start of water collection in the tank may actually happen at the same time, but the water mass flow to the tank is too small in the calculations, even if the steam flow in the broken loop is overestimated (Fig.35). The steam mass flow in the intact loop is well predicted as shown in Fig.34. When the water starts to flow into the loops the measurements are no longer reliable as can be clearly seen in Figs 34 and 35.

In the second calculation with 16 subdivisions in the heat slabs of the core, the main difference compared to first calculation is a delayed quenching esspecially in the middle of the core (Fig.37). The pressure differences, flow rates and fluid temperatures are nearly equal in both calculations.

6. Run statistics

The first calculation was made by using the maximum time step of 0.01 second, which was slightly below the listed Courant-limit. In some restarts smaller time step limits were needed (0.004 sec) in order to overcome errors that stopped the calculation. The total number of time steps was 97767. The consumed CPU time versus real time is shown in Fig.36. The average CPU-time consumption per volume and per time step was 0.013 seconds.

In the second calculation the same maximum time step of 0.01 s was used, but the CPU-time consumption was reduced over 40 % (Fig.40) due to the smaller number of the subdivisions in the quench front calculation.

7. Conclusions

The capability of RELAP5/MOD2 to calculate this REWET-II test with the downcomer injection seems to be good. The maximum cladding temperatures, temperature turn over times, quenching temperatures and quenching times in the middle of the rod bundle are well predicted. U-tube oscillations are stronger than in the experiments. Water inventories are quite well predicted, only the separation of water and steam phases in the upper part of the core with the phenomena of the falling films was less well predicted.

One of the main practical problems in the calculations was the need of using short nodes in the core and a large number of subdivisions in the heat structures as well. CPU time saving could be obtained by changing the number of subdivisions at different levels of the core or by making the number of subdivisions dependent of the linear power variations. CPU time saving could also be obtained by a user defined subdivision number in each heat slab and a larger maximum number of subdivisions. The heat slabs and nodes could then be longer.

8. References

1. Kervinen T., Hämäläinen A., Miettinen J., Reflood Experiments in the REWET-II Rod Bundle Facility Including Comparisons with Computer Calculations, Proc. Second International Topical Meeting on Nuclear Reactor Thermal-hydraulics at Santa Barbara, California, January 11-14, 1983.

2. Kervinen T., Purhonen H., Kalli H., REWET-II Experiments to Determine the Effects of Spacer Grids on the Reflooding Process. Fifth International Meeting on Thermal Nuclear Reactor Safety, Karlsruhe, FRG, September 9-13, 1984.

3. Kervinen T., Purhonen H., Kouvo J., Experimental Data Report for REWET-II Reflooding Test SGI/R, Technical Research Center of Finland/Nuclear Engineering Laboratory, Technical Report, 1983.

4. Kervinen T., Purhonen H., Description of Rewet-II an Rewet-III facilities, to be published.

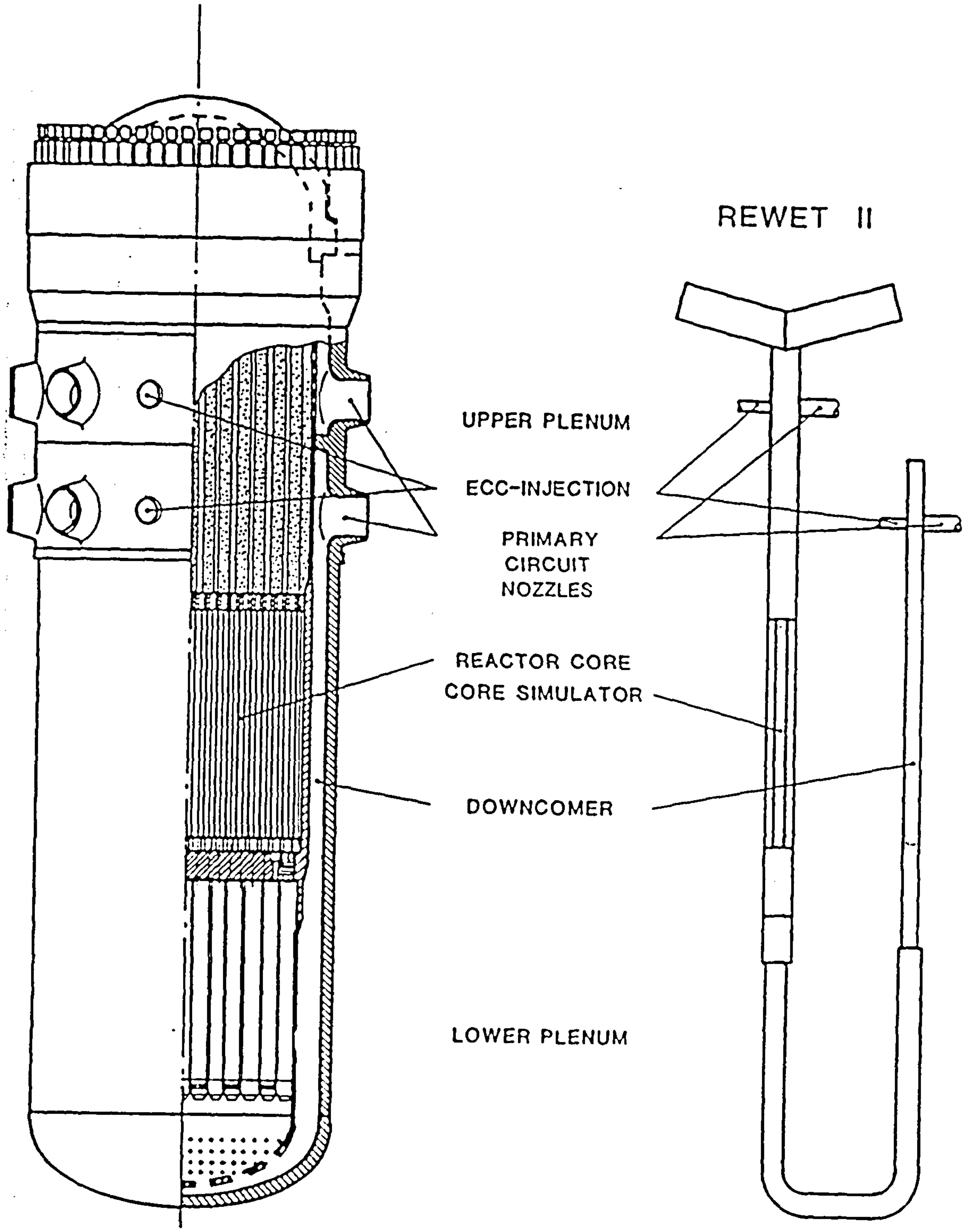

Fig.1 Simulation of the VVER-440 reactor vessel with the REWET-II facility

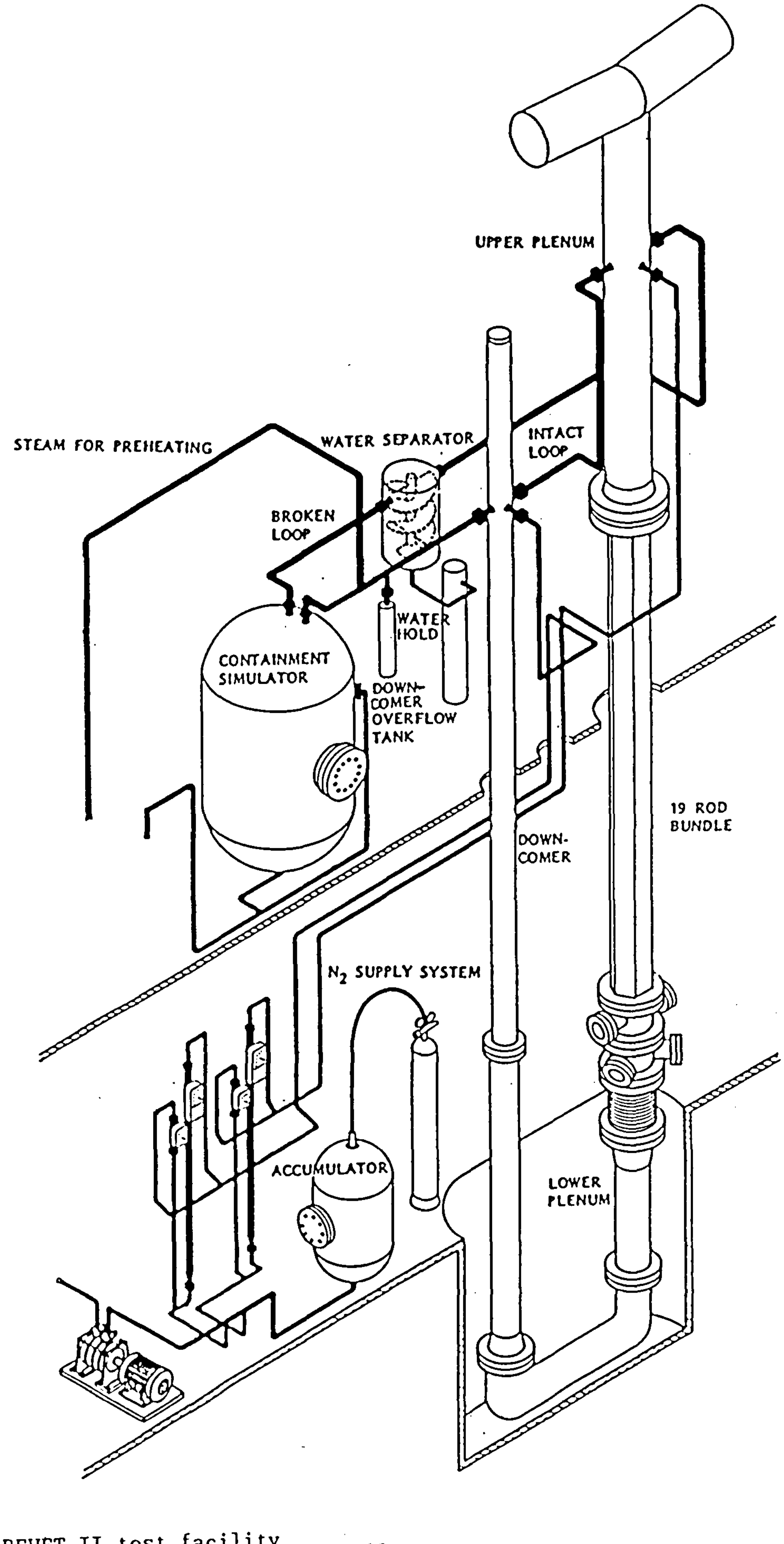

Fig.2 REWET-II test facility

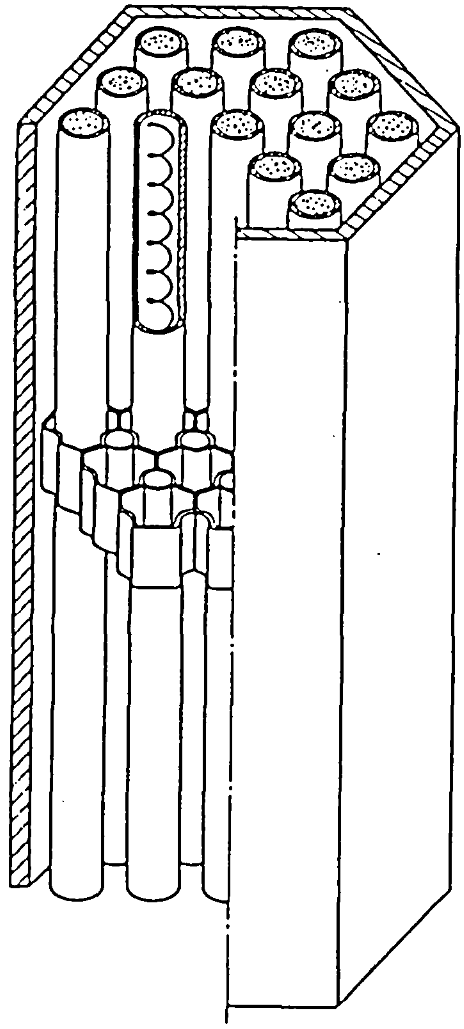

Fig.3 Test rod arrangement in the core of the REWET-II facility

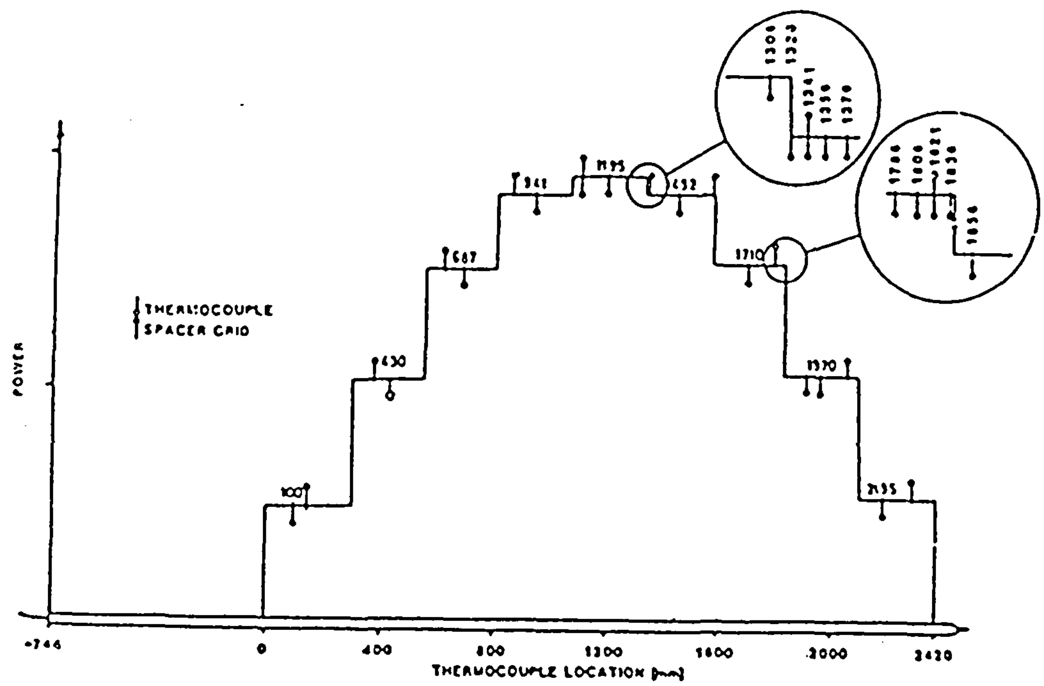

Fig.4 The axial power distribution and the spacer grid elevations in the core

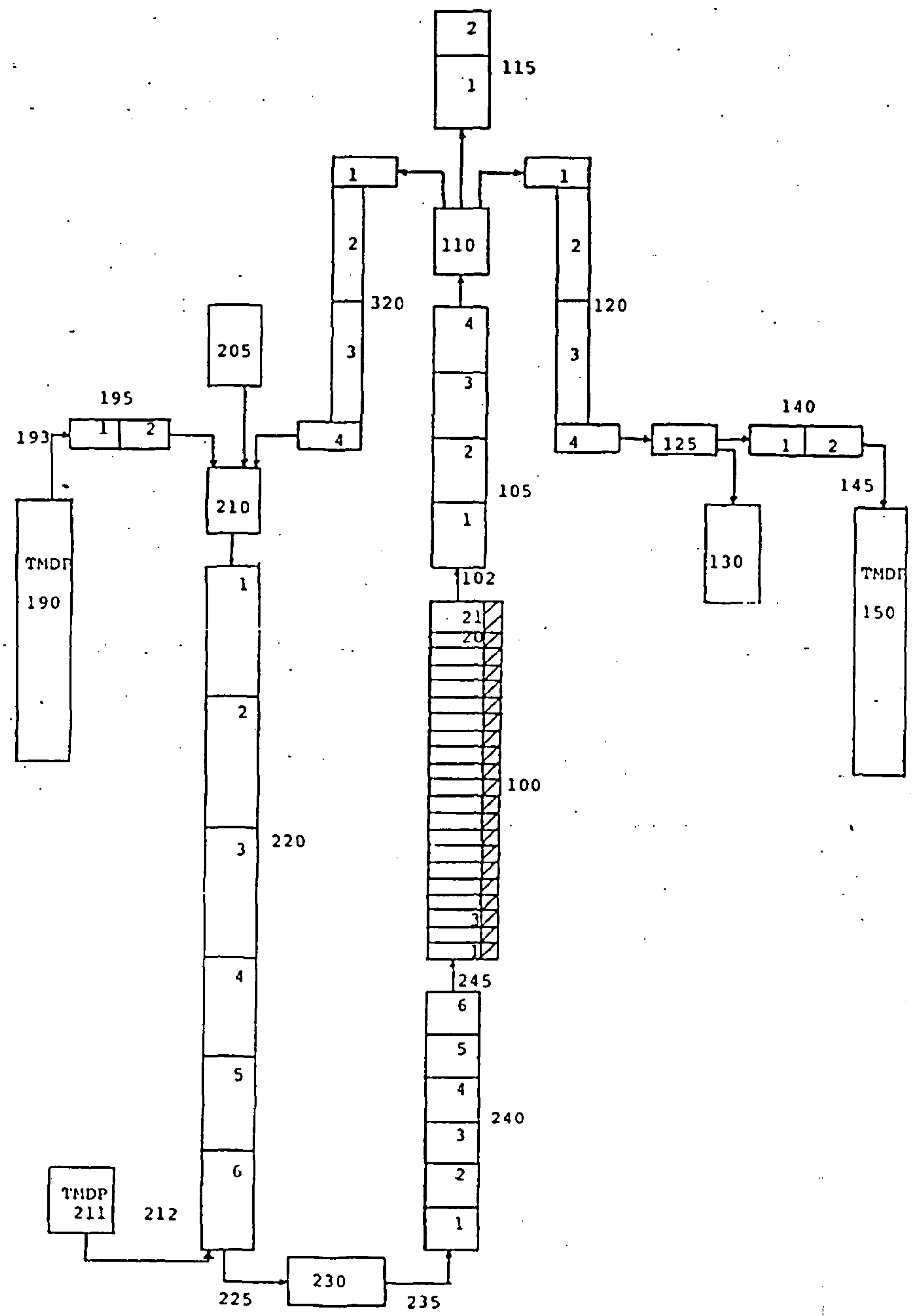

Fig.5 Nodalization scheme of the REWET-II facility

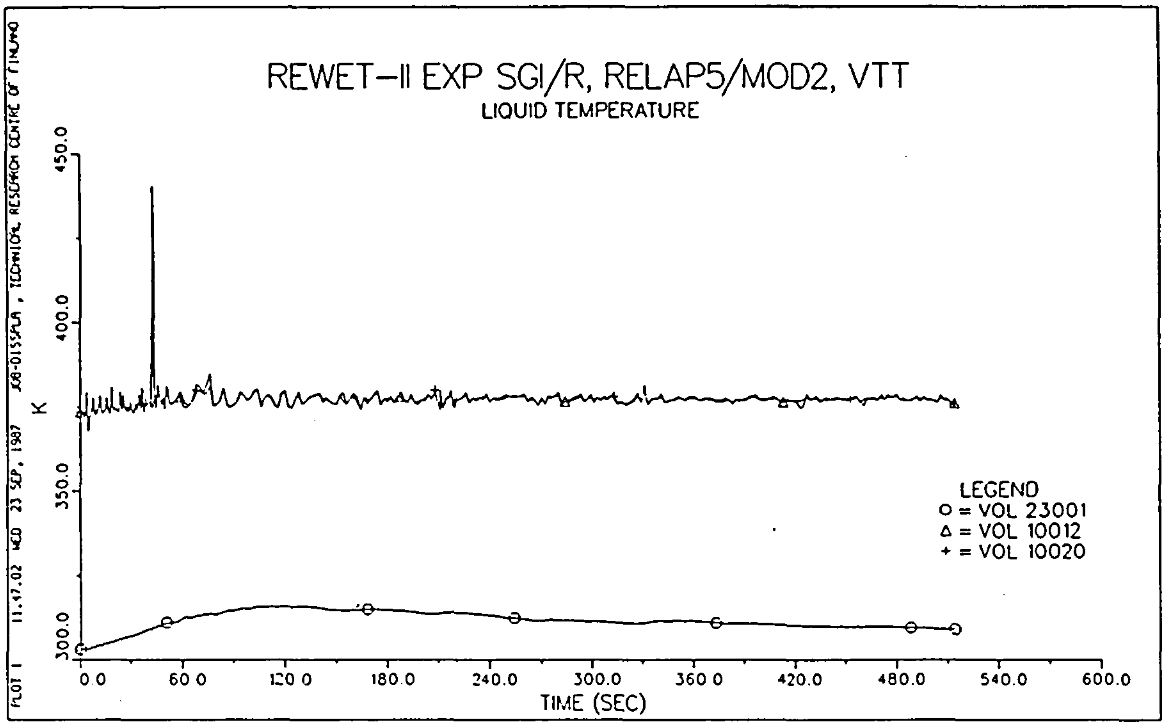

Fig.6 Liquid temperature in the lower plenum and in the middle and upper part of the core

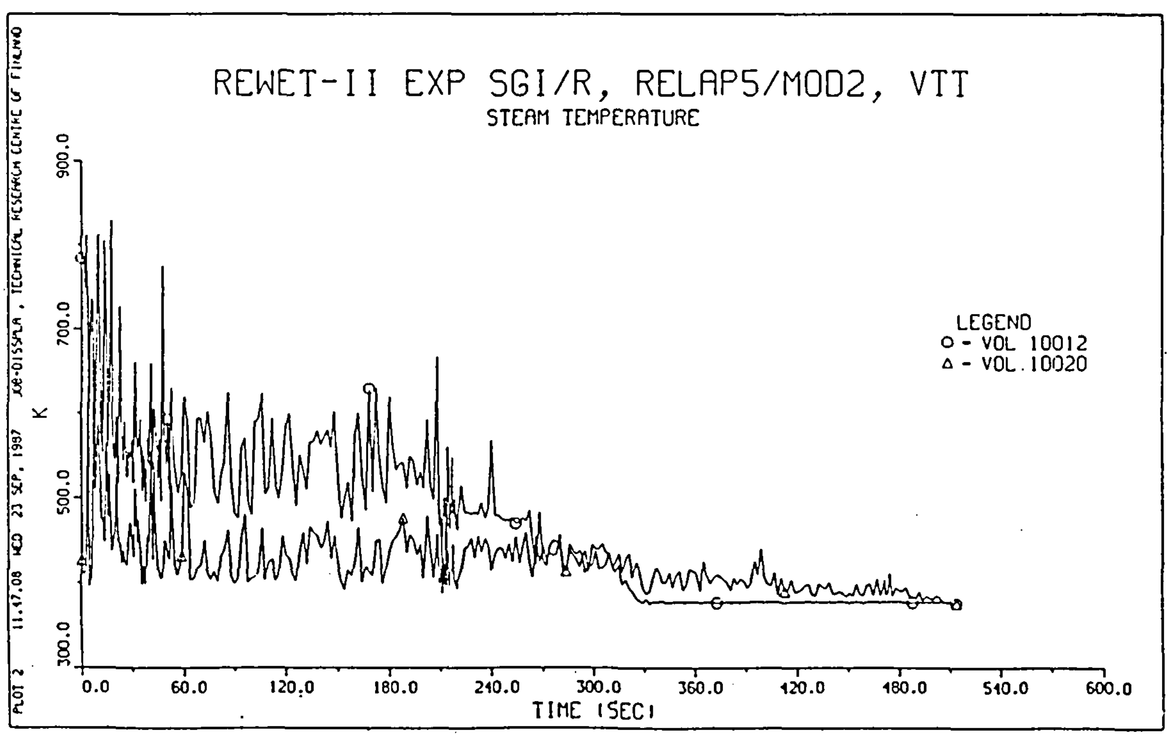

Fig.7 Steam temperature in the middle and upper part of the core

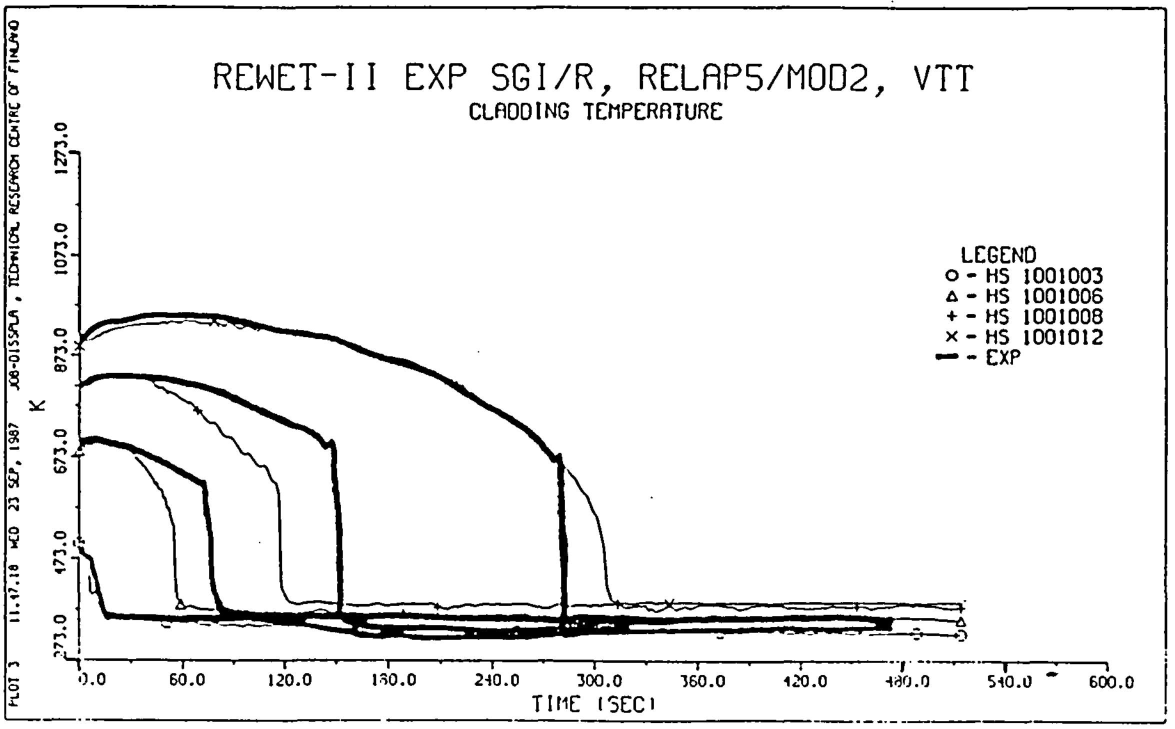

Fig.8 Cladding temperature in the lower and middle part of the core

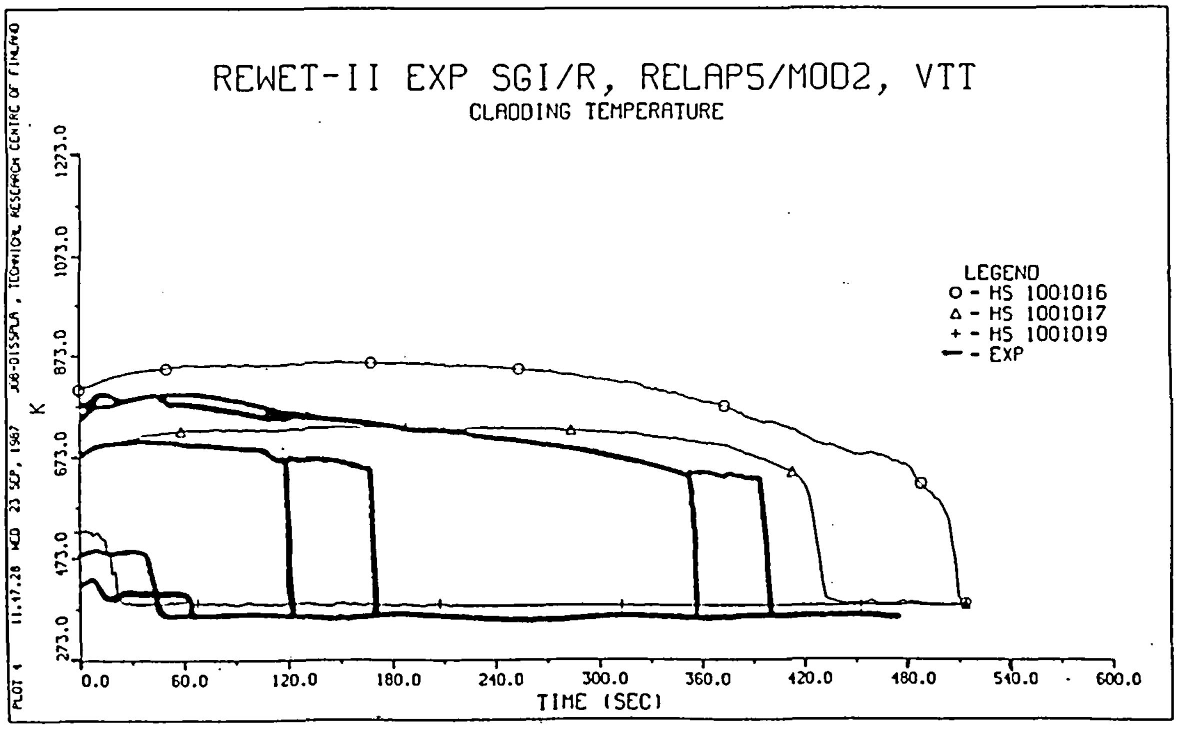

Fig.9 Cladding temperature in the upper part of the core

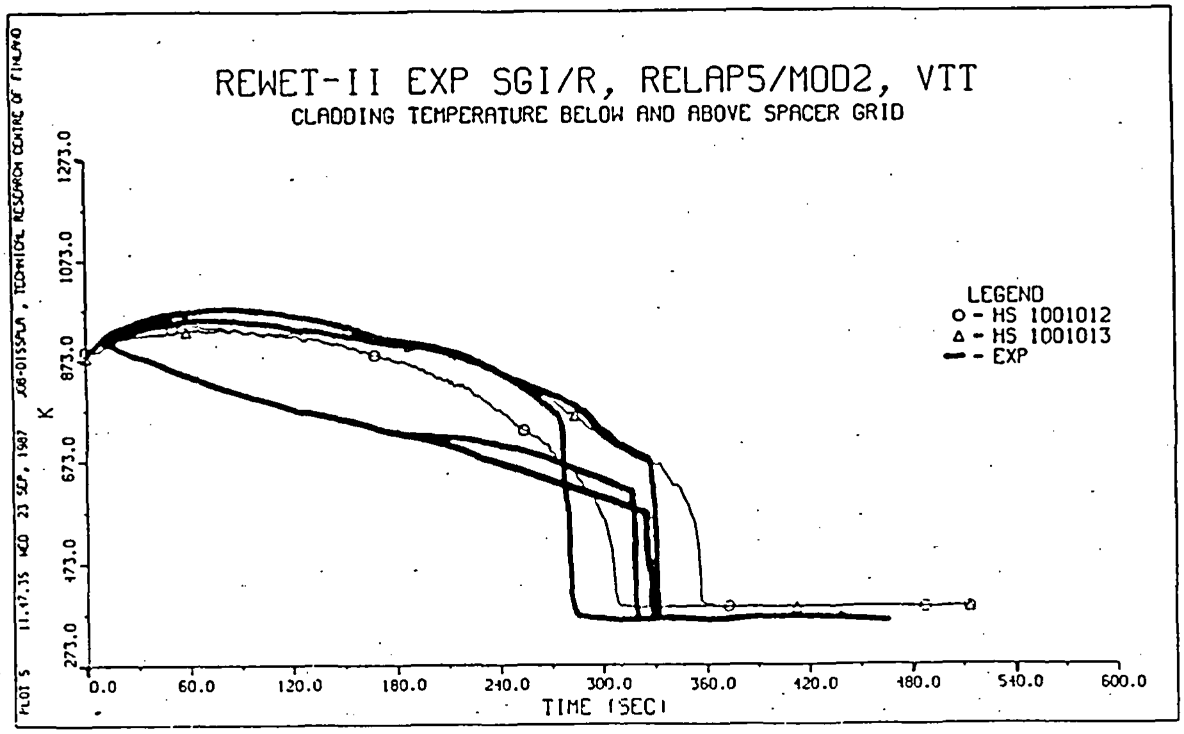

Fig.10 Cladding temperature below and above the spacer grid elevation

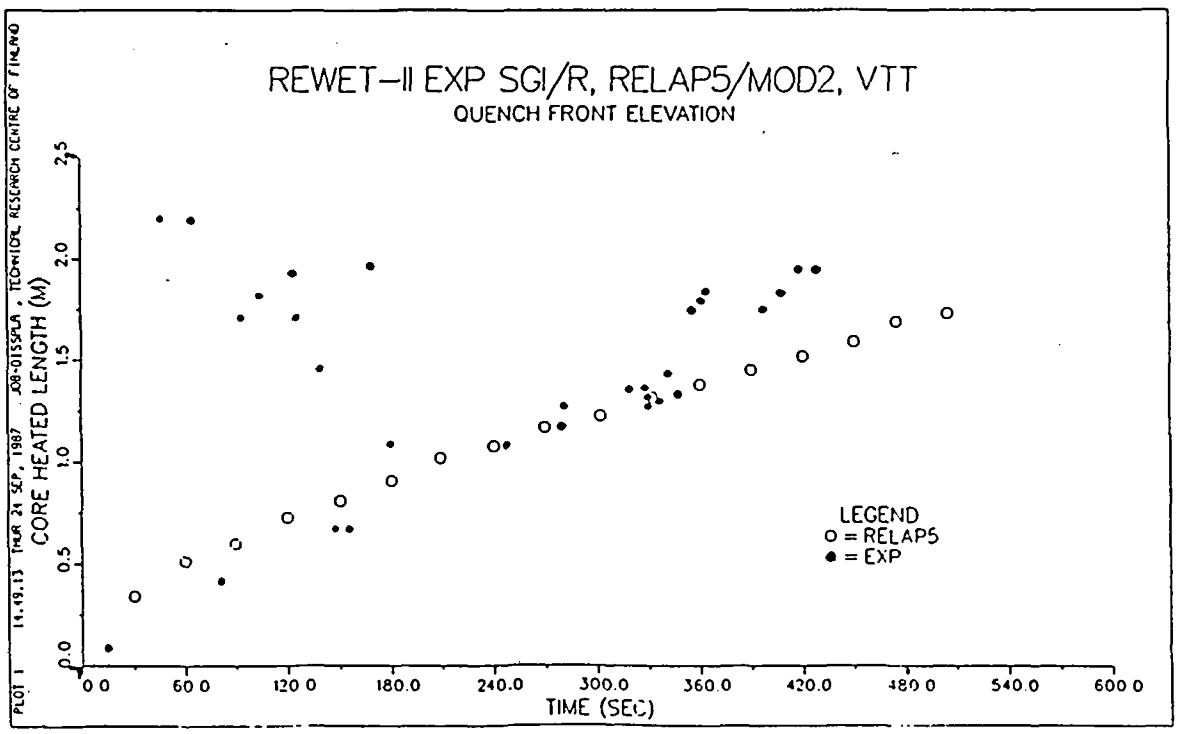

Fig.11 Quench front elevation/position of the CHF point, collected from the printouts

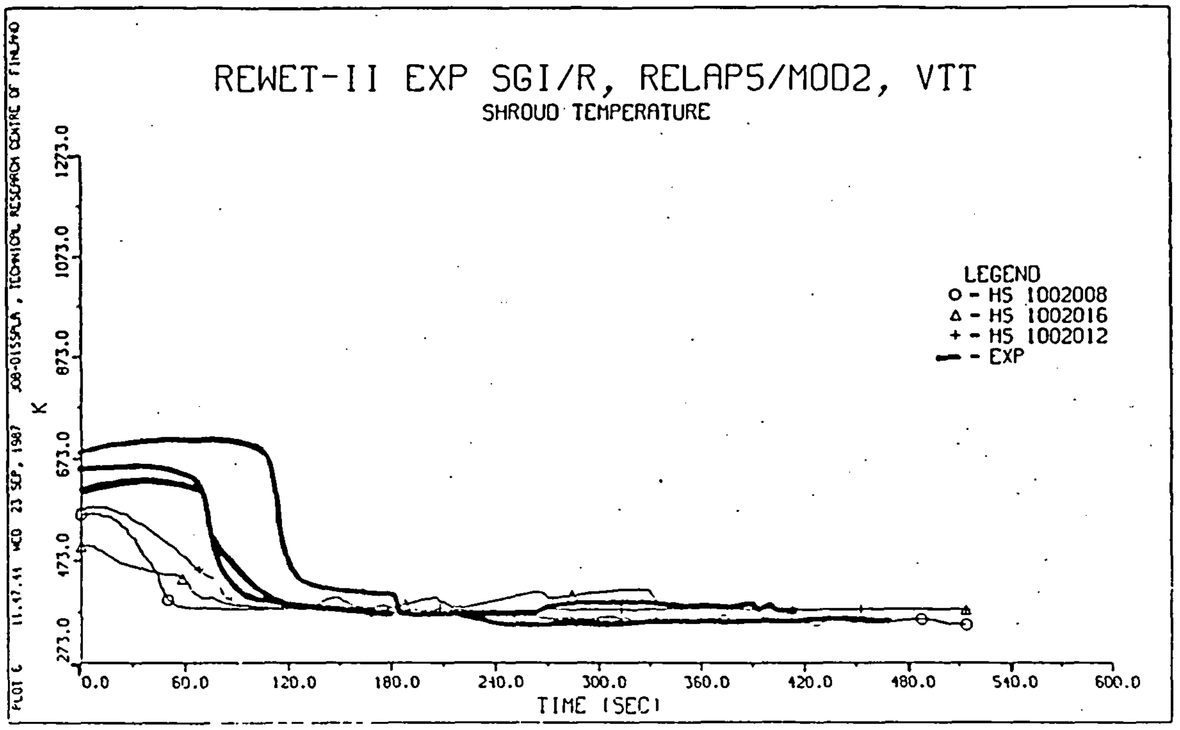

Fig.12 Shroud temperature

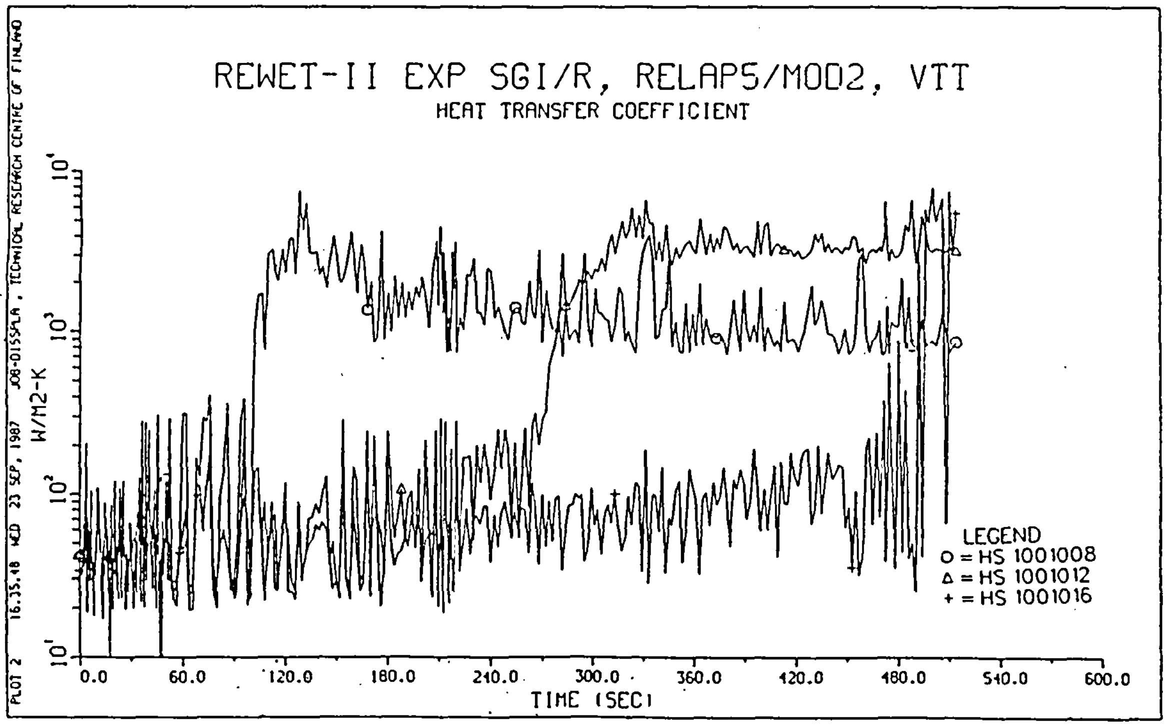

Fig.13 Heat transfer coefficient in the core

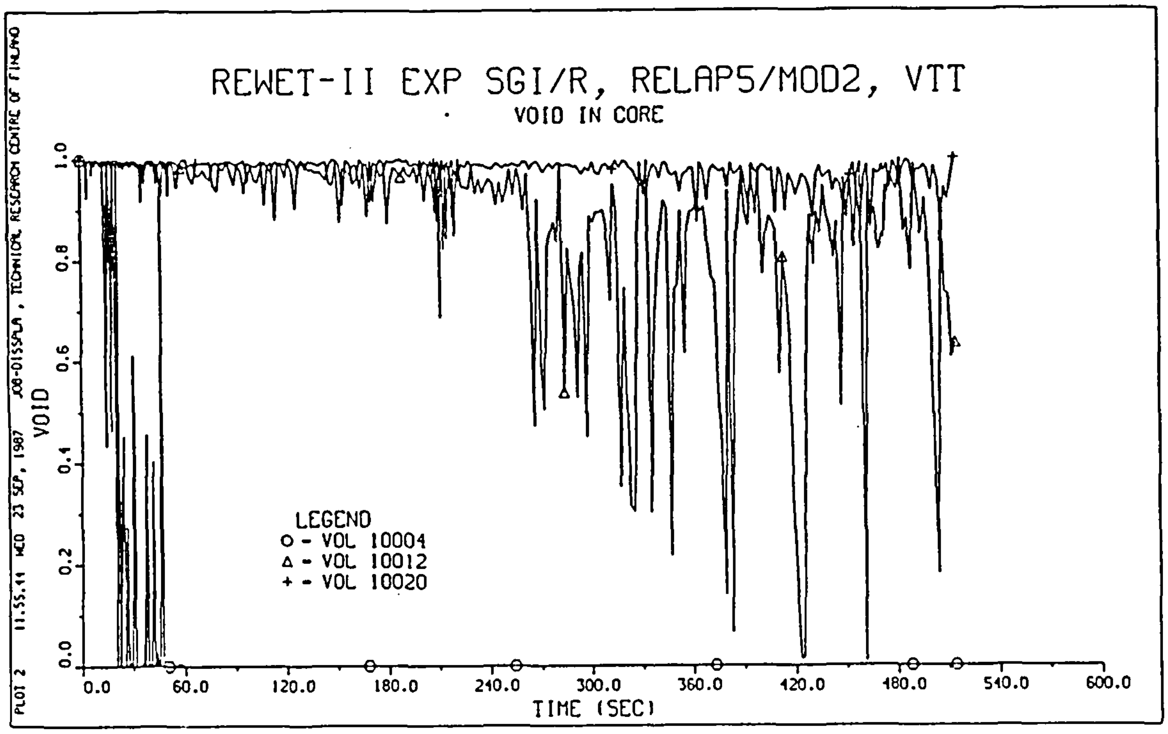

Fig.14 Void in the core

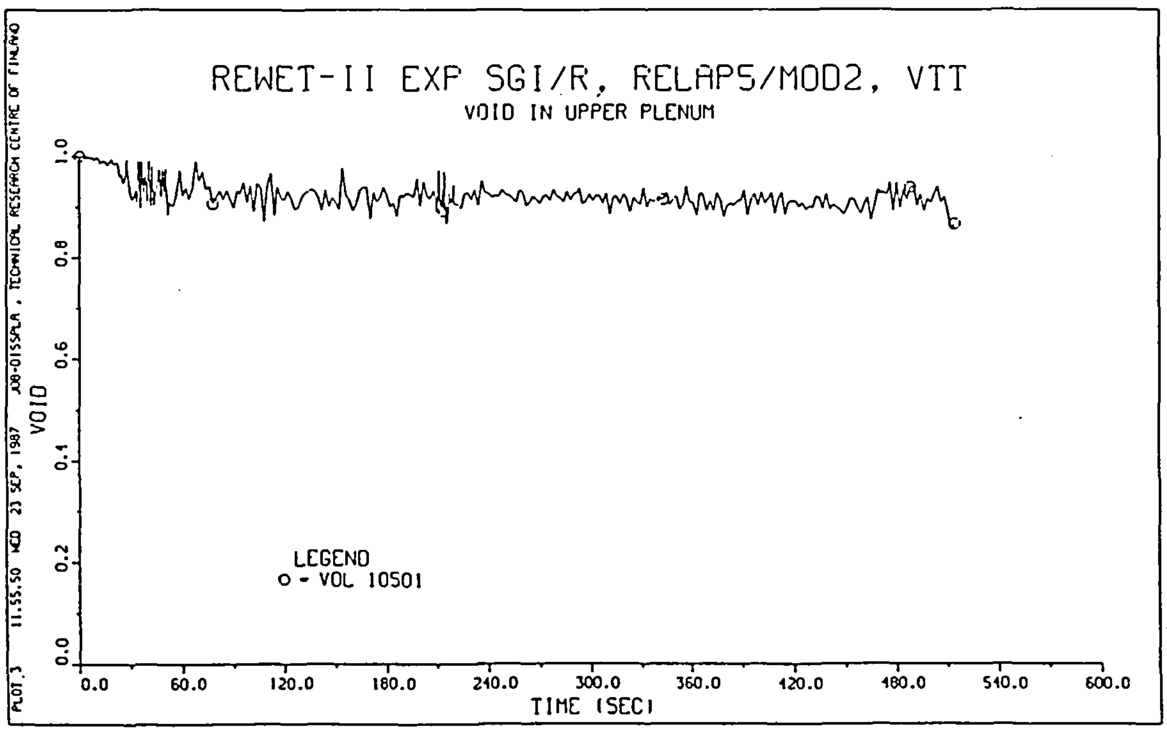

Fig.15 Void in the upper plenum

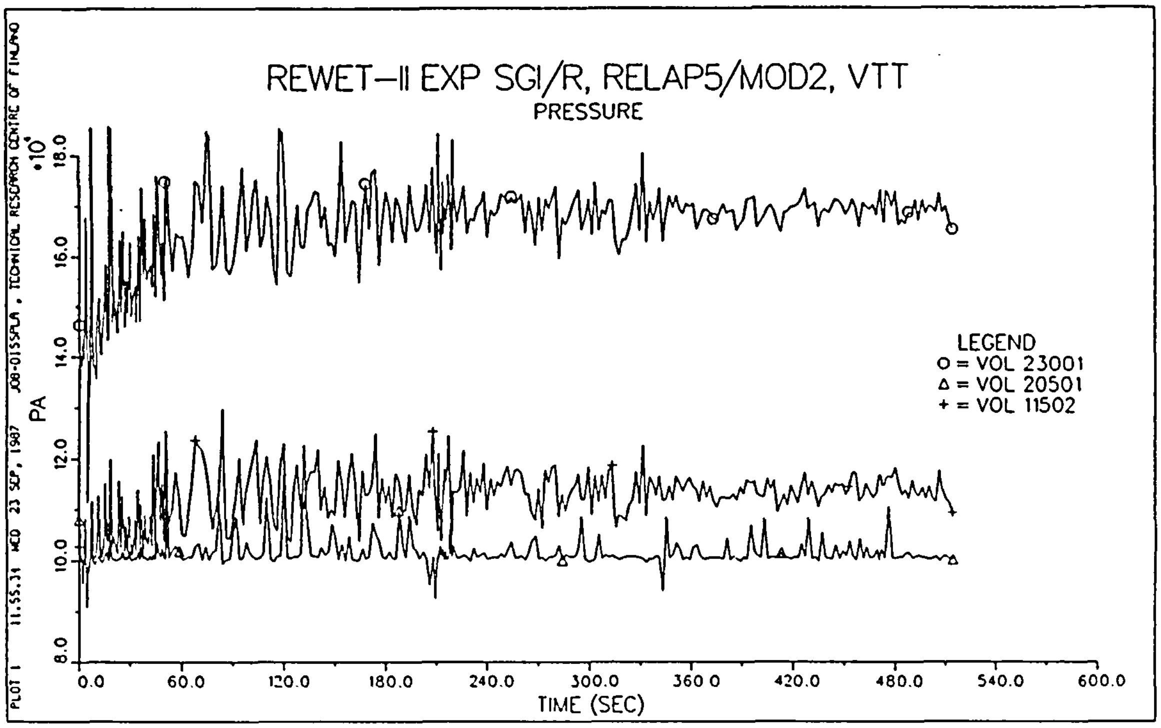

Fig.16 Pressures in the lower plenum, downcomer head and upper plenum head

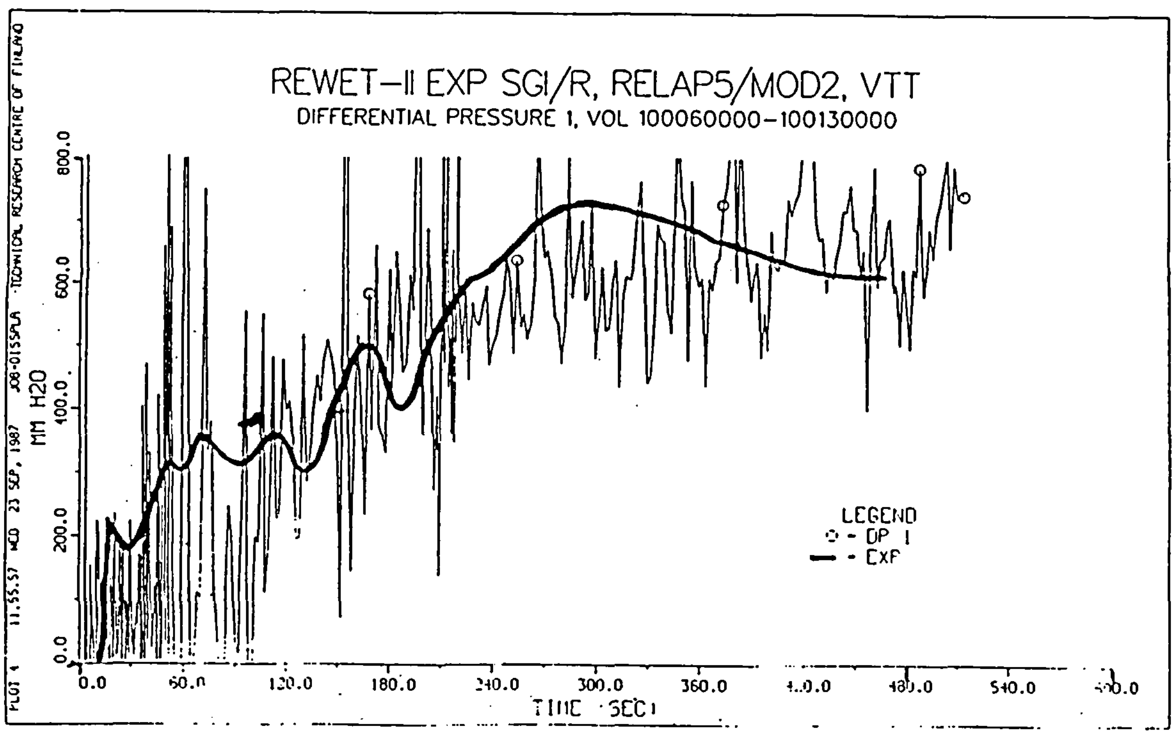

Fig.17 Differential pressure 1, between vols 100060000-100130000

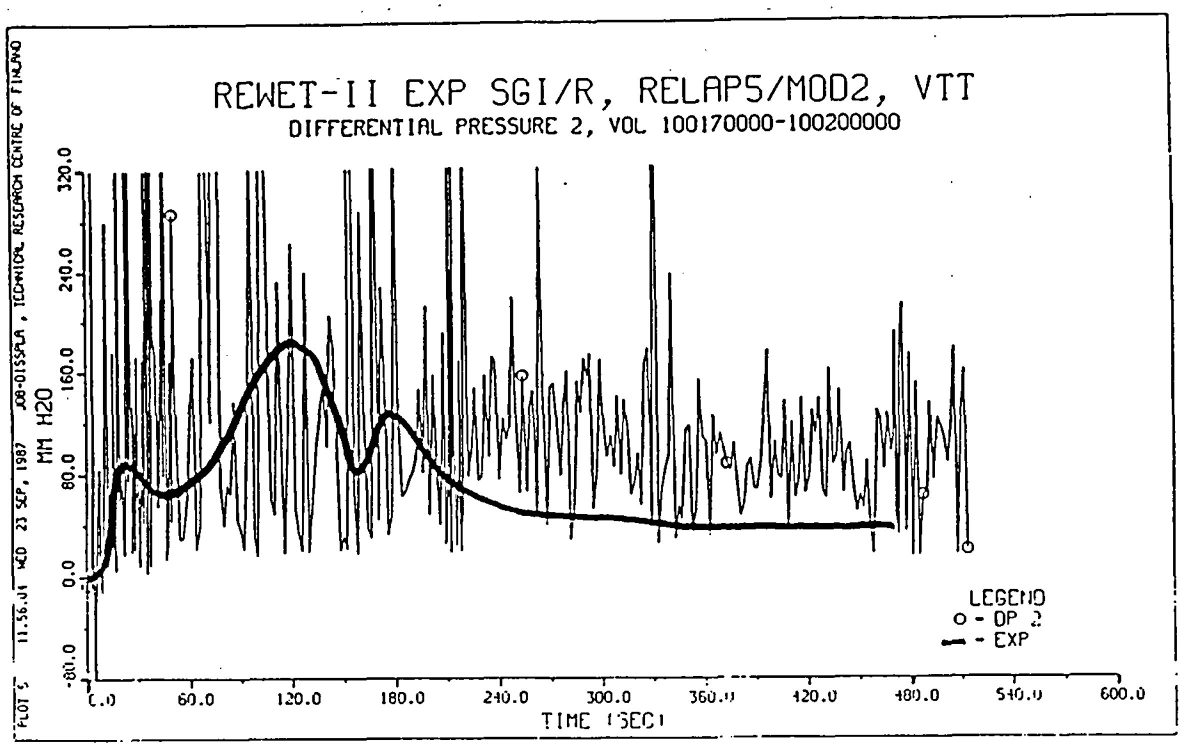

Fig.18 Differential pressure 2, between vols 100170000-100200000

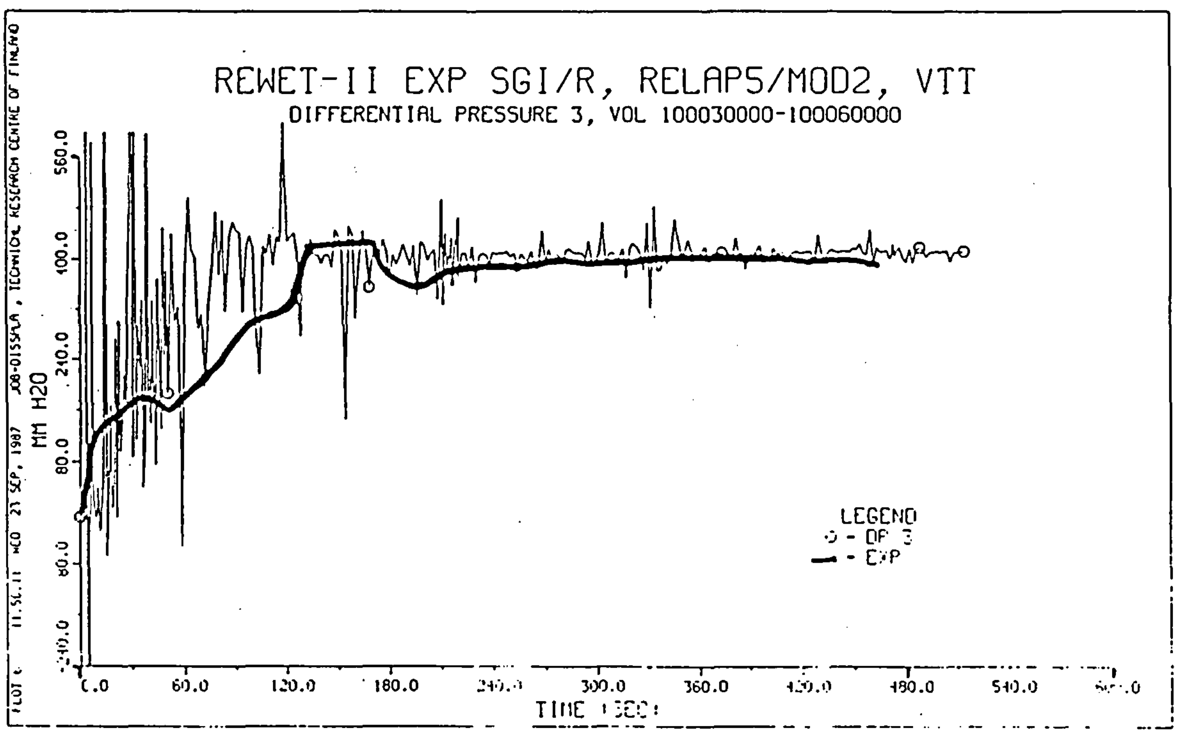

Fig.19 Differential pressure 3, between vols 100030000-100060000

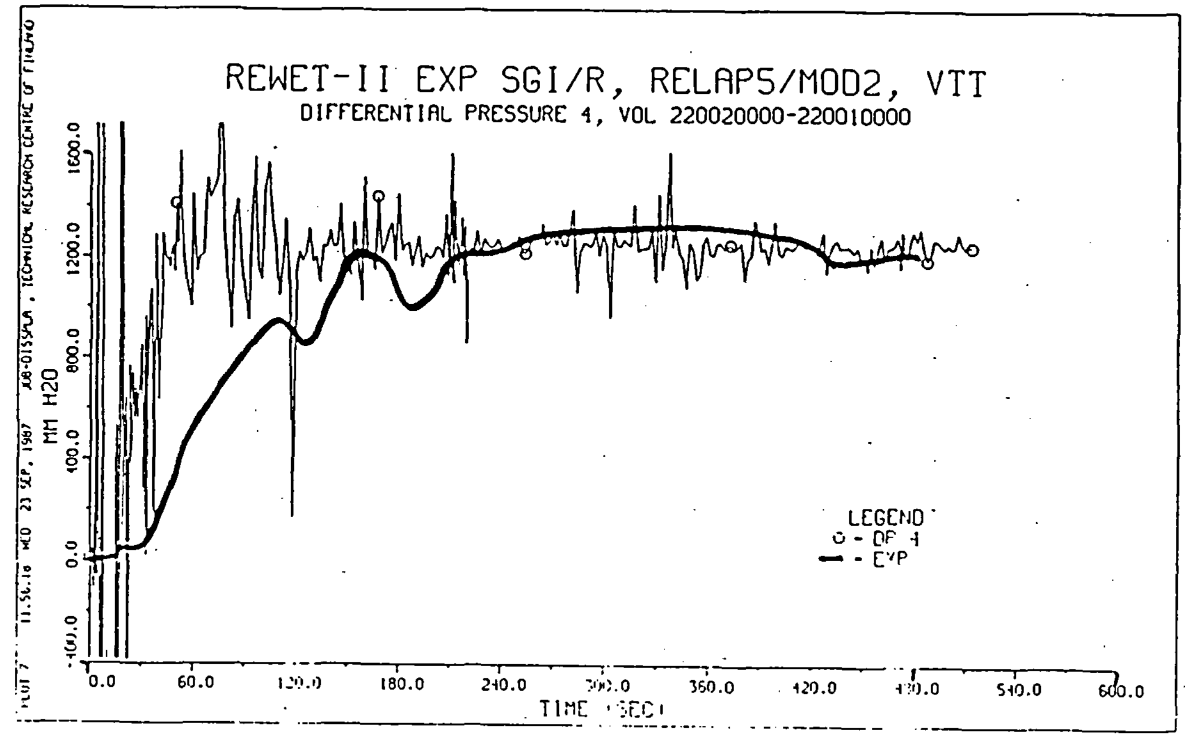

Fig.20 Differential pressure 4, between vols 220020000-220010000

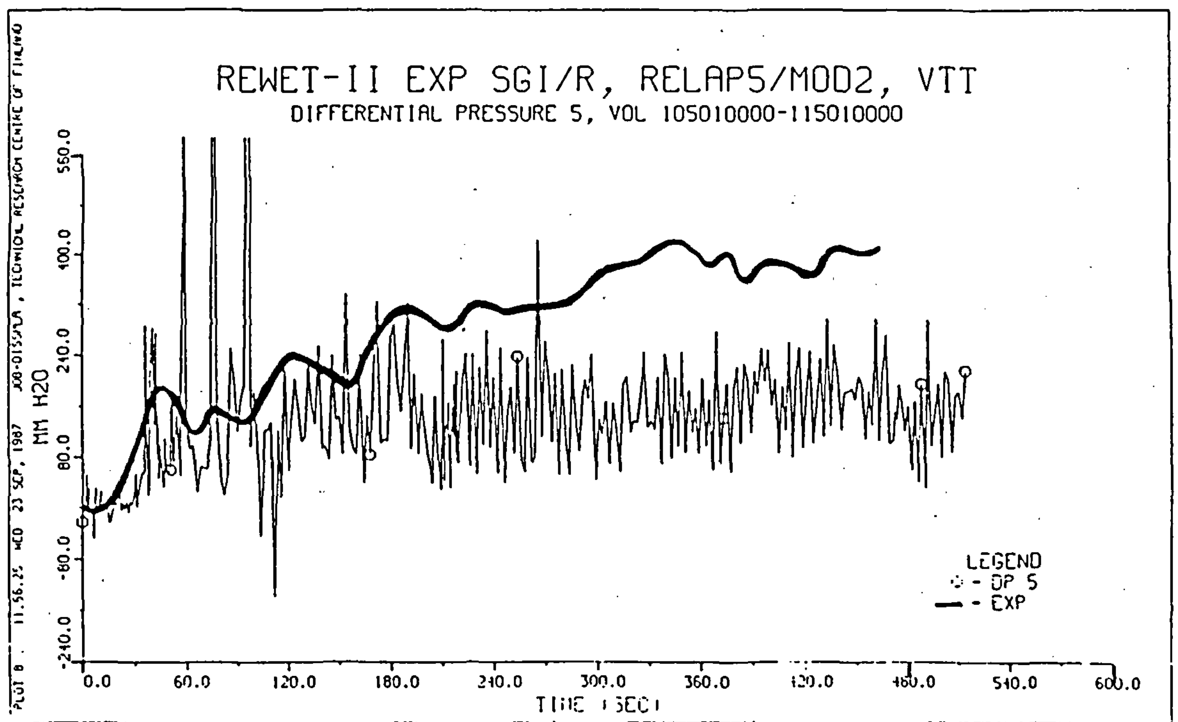

Fig.21 Differential pressure 5, between vols 105010000-115010000

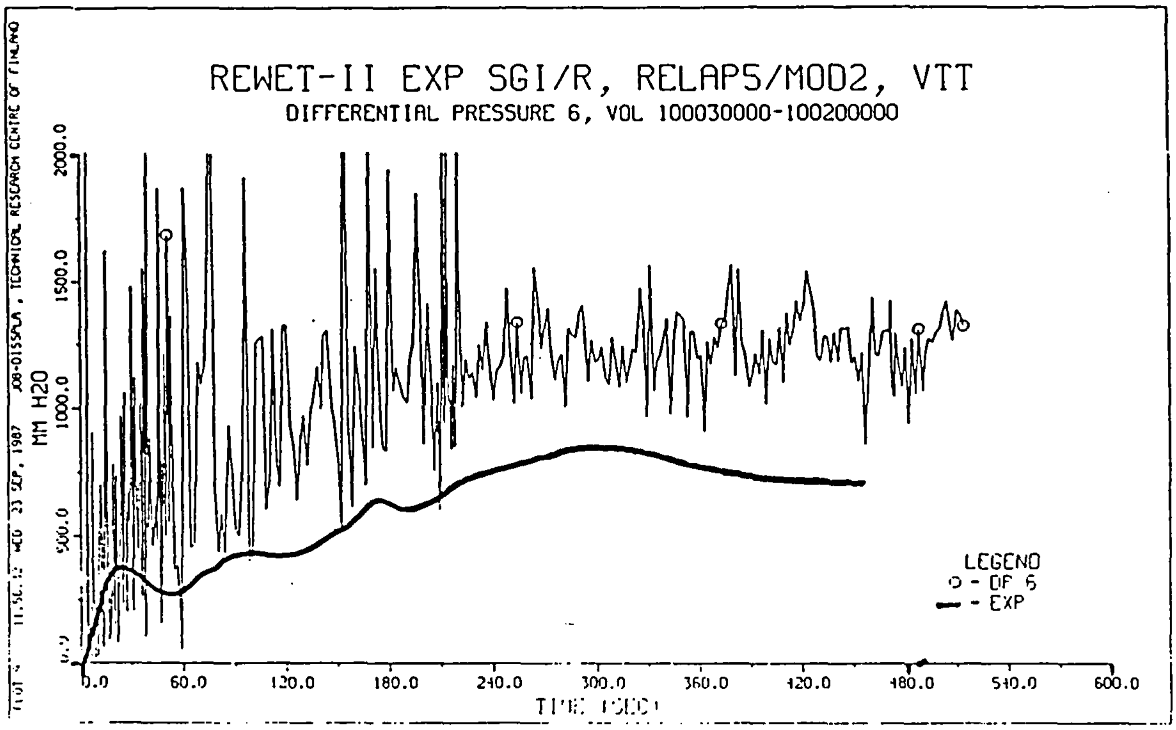

Fig.22 Differential pressure 6, between vols 100030000-100200000

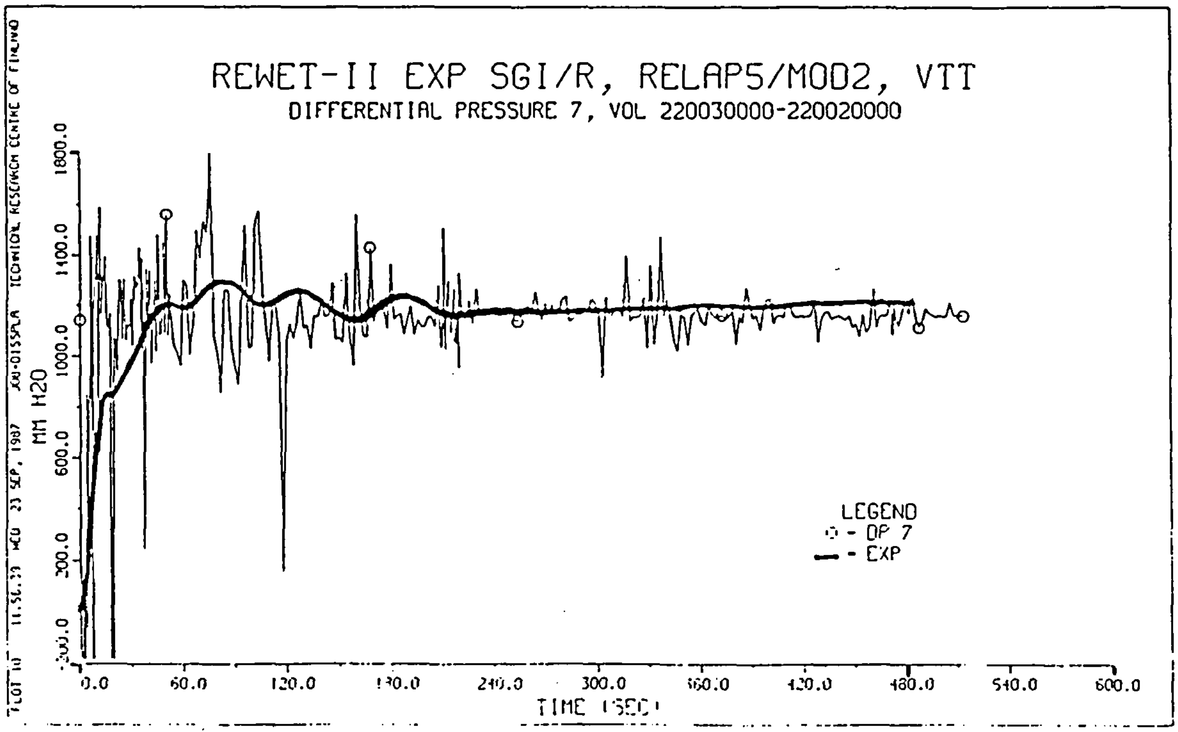

Fig.23 Differential pressure 7, between vols 220030000-220020000

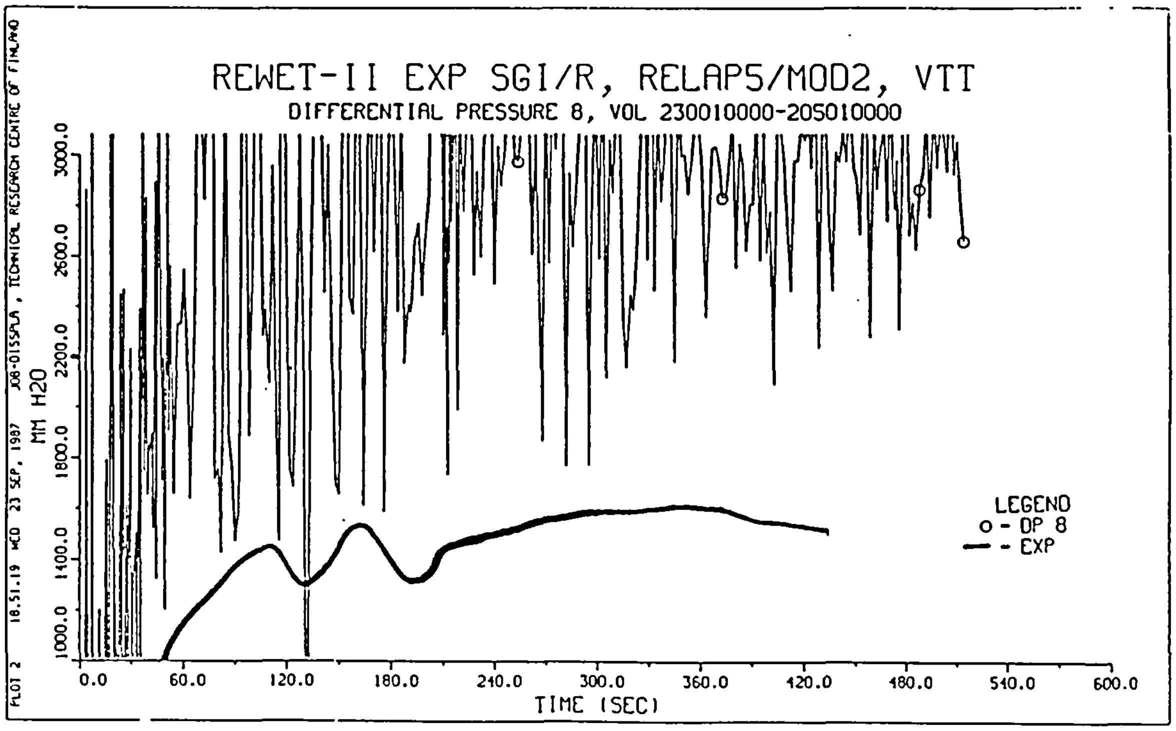

Fig.24 Differential pressure 8, between vols 230010000-205010000

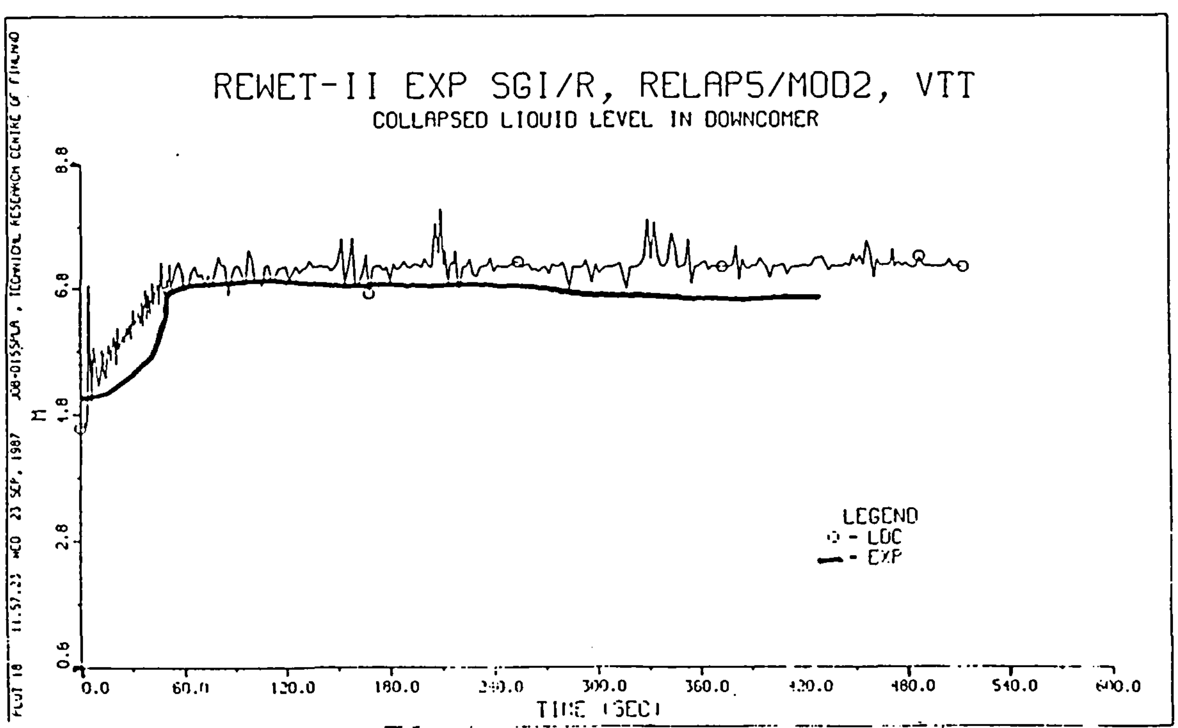

Fig.25 Collapsed liquid level in the downcomer

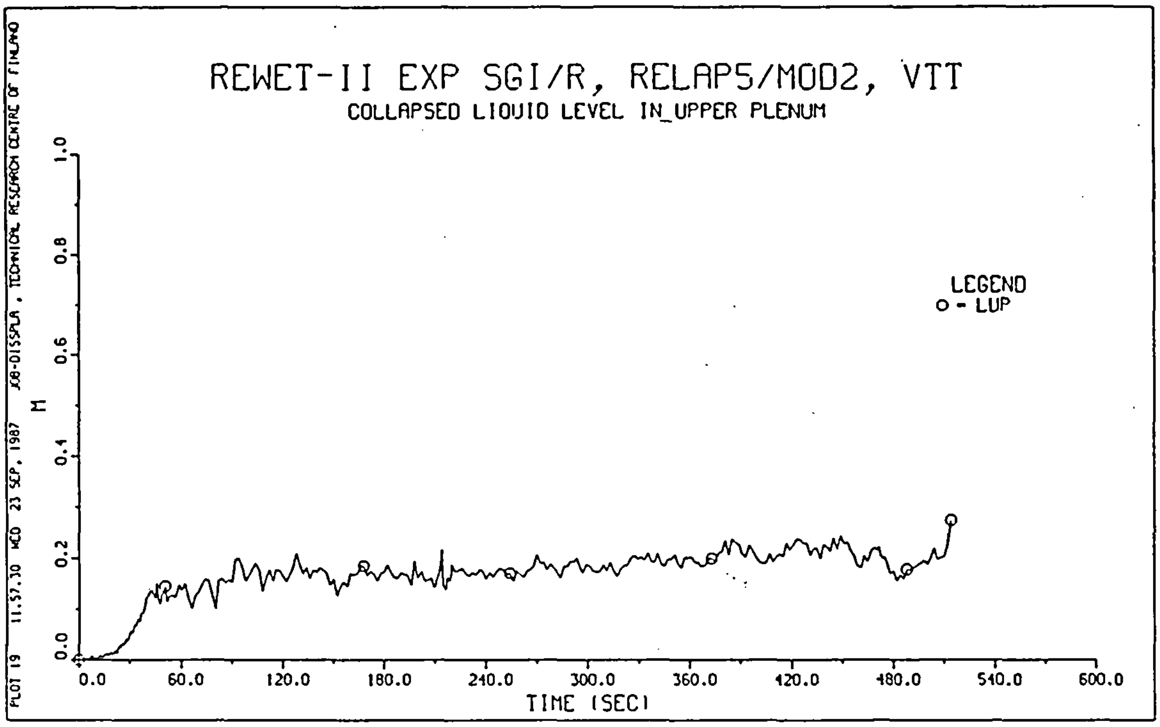

Fig.26 Collapsed liquid level in the upper plenum

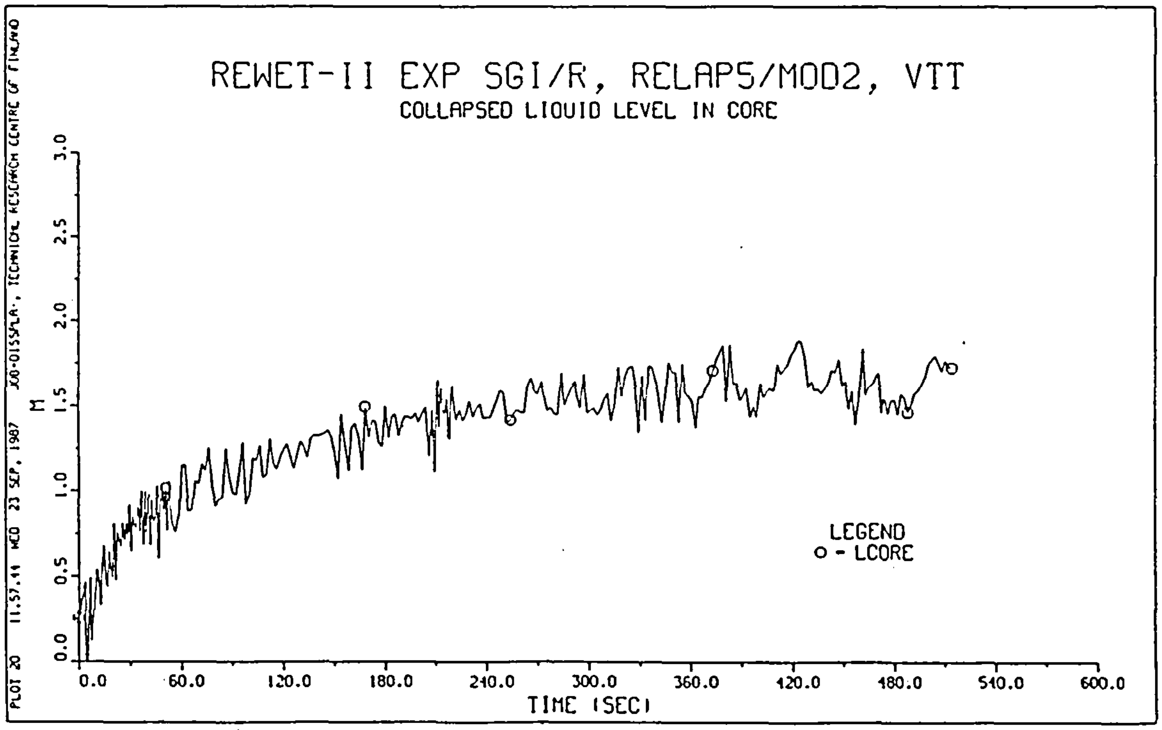

Fig.27 Collapsed liquid level in the core

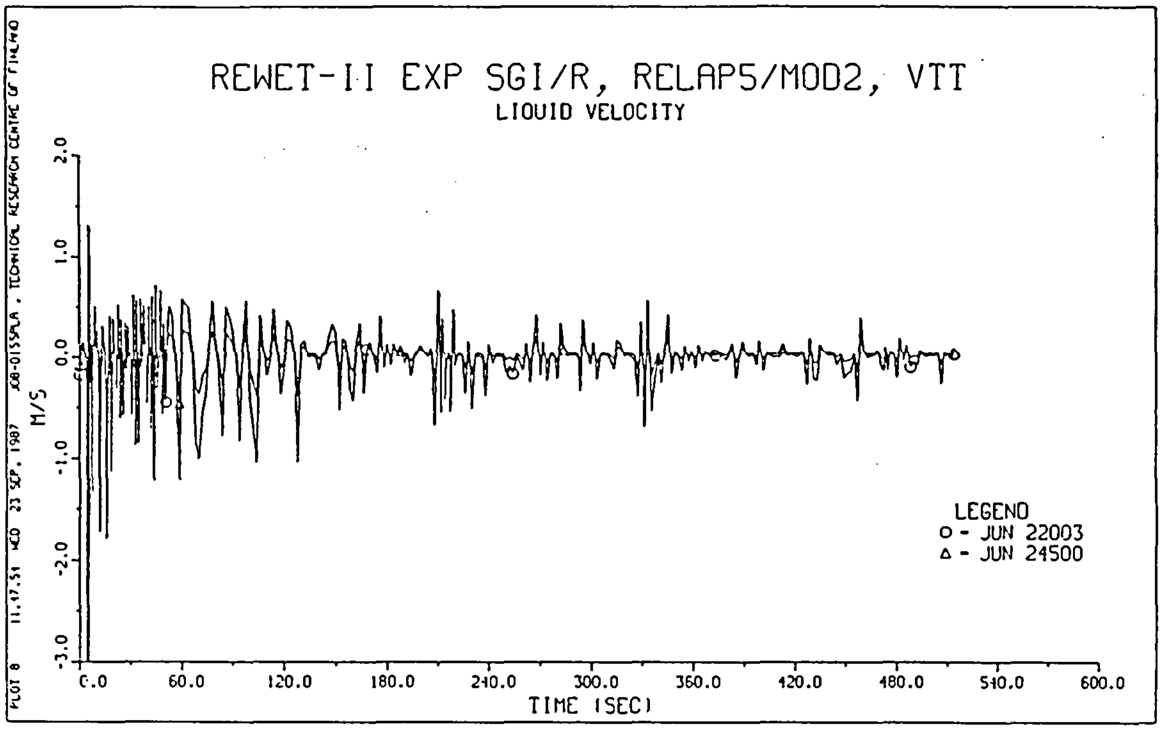

Fig.28 Liquid velocity in the downcomer and core inlet

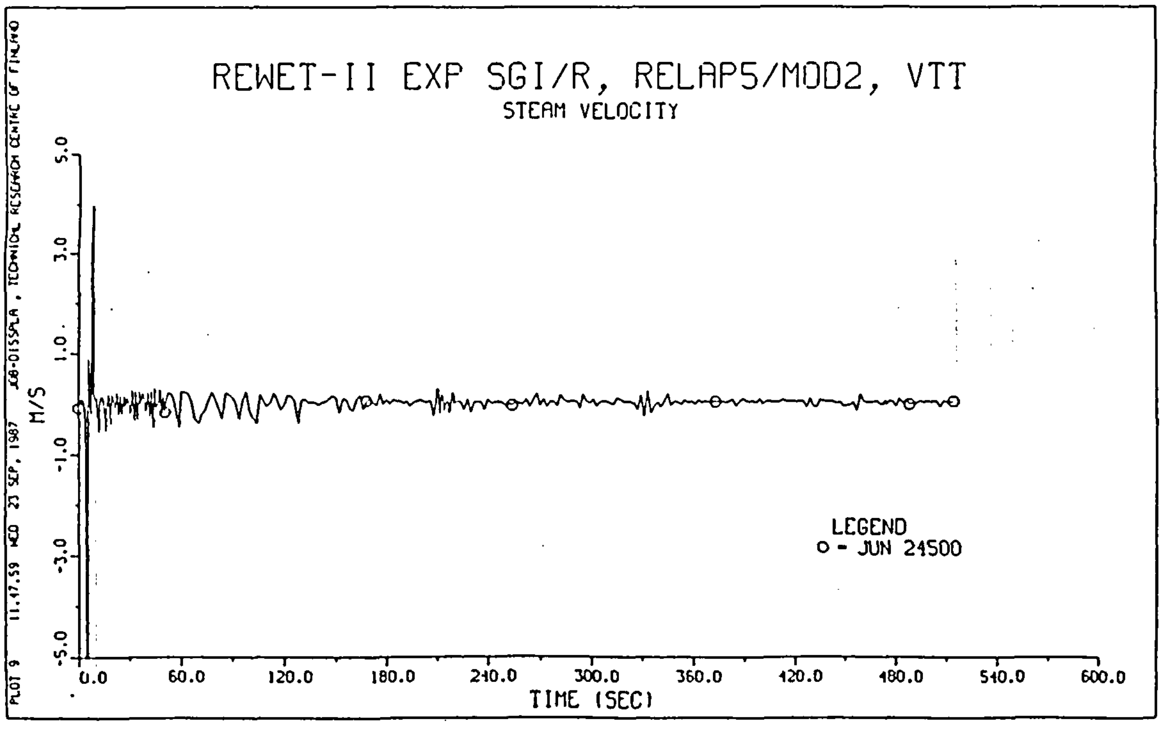

Fig.29 Steam velocity in the core inlet

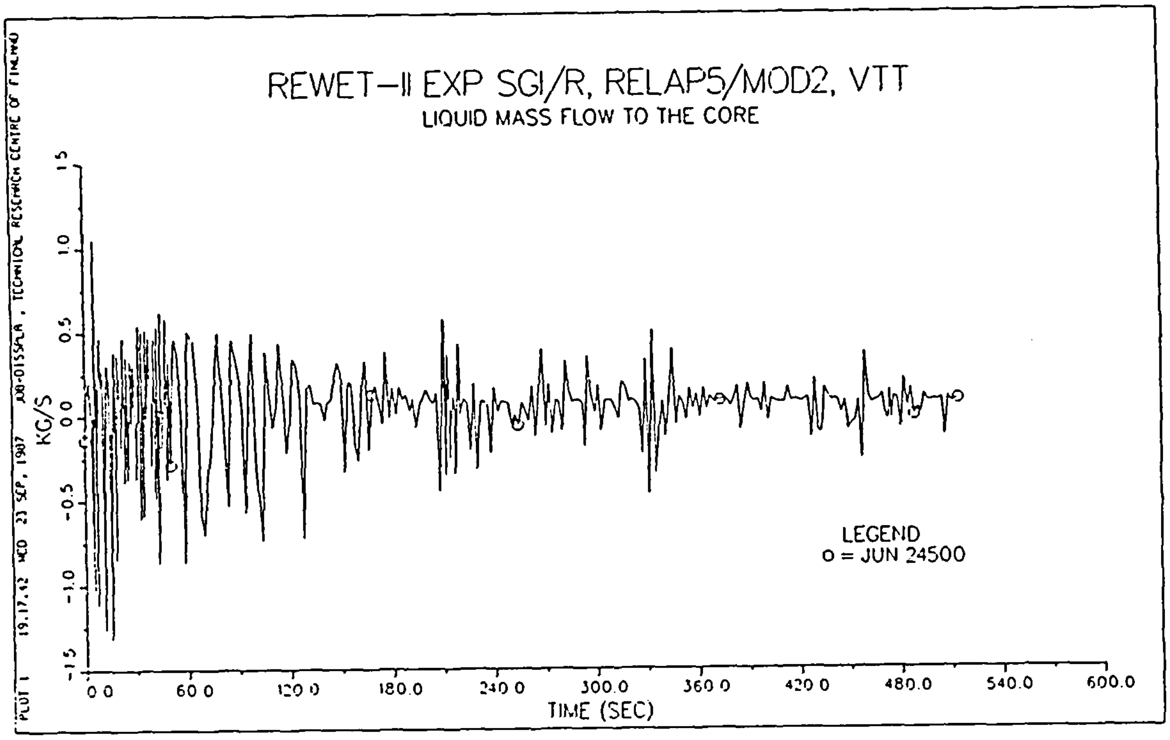

Fig.30 Liquid mass flow to the core

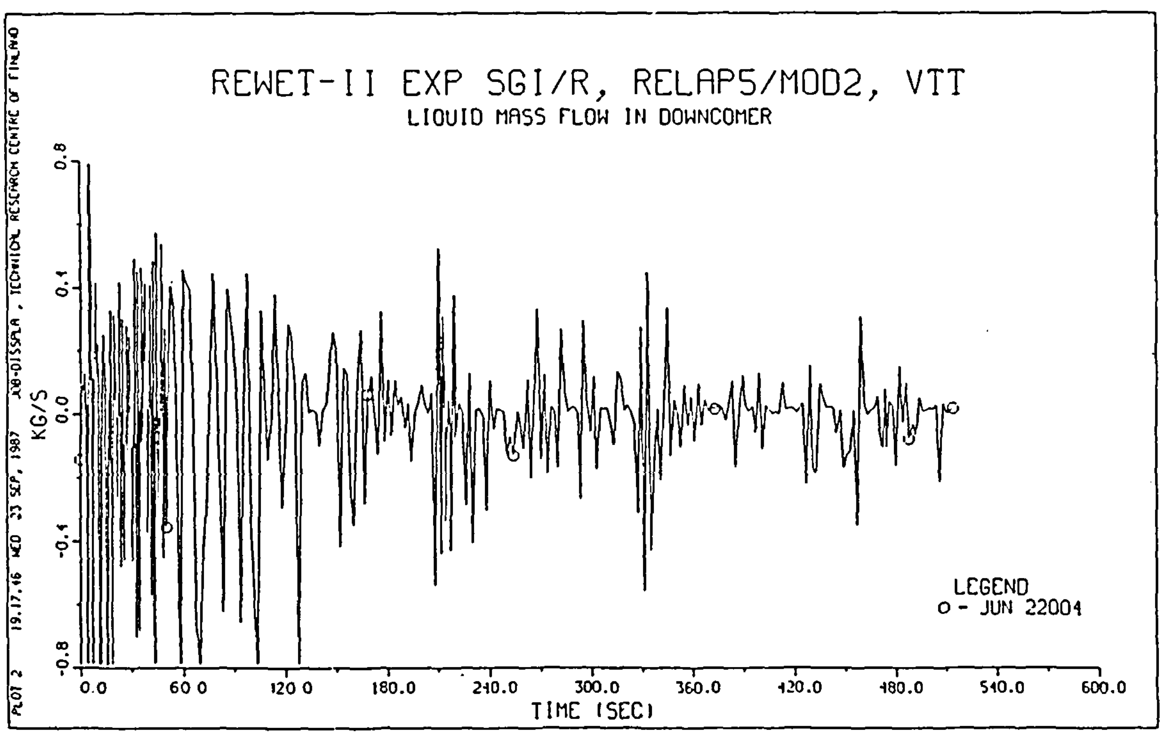

Fig.31 Liquid mass flow in the downcomer

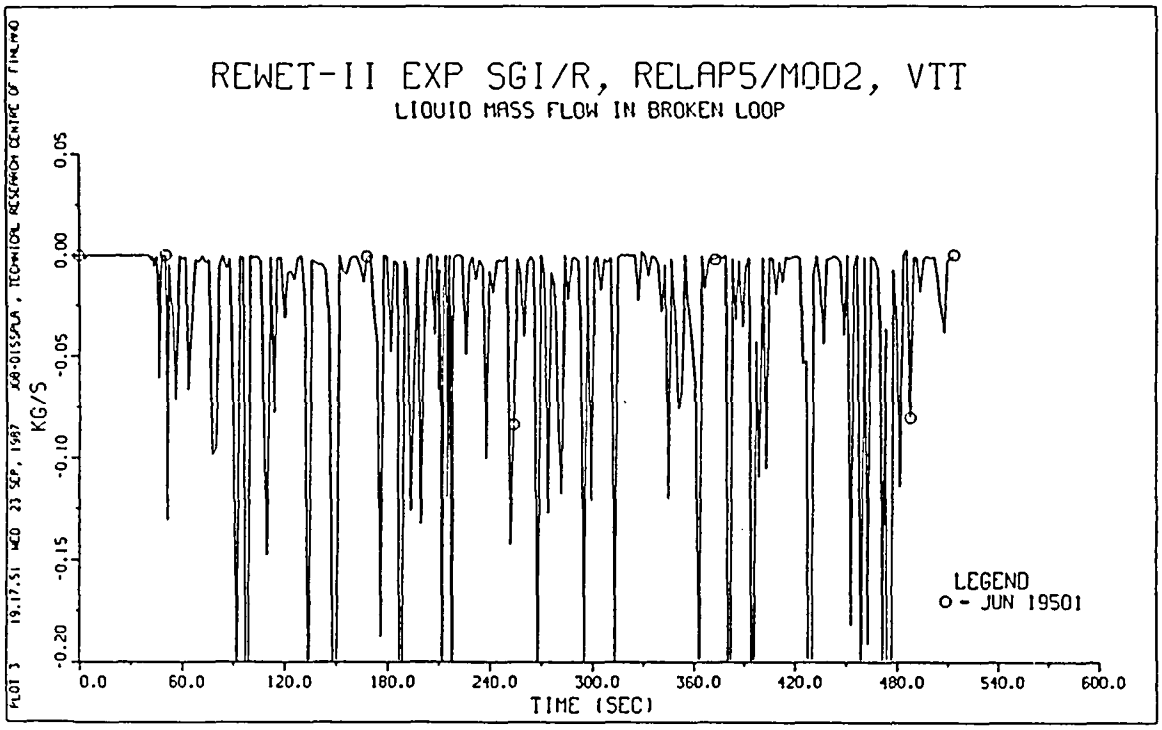

Fig.32 Liquid mass flow in the broken loop

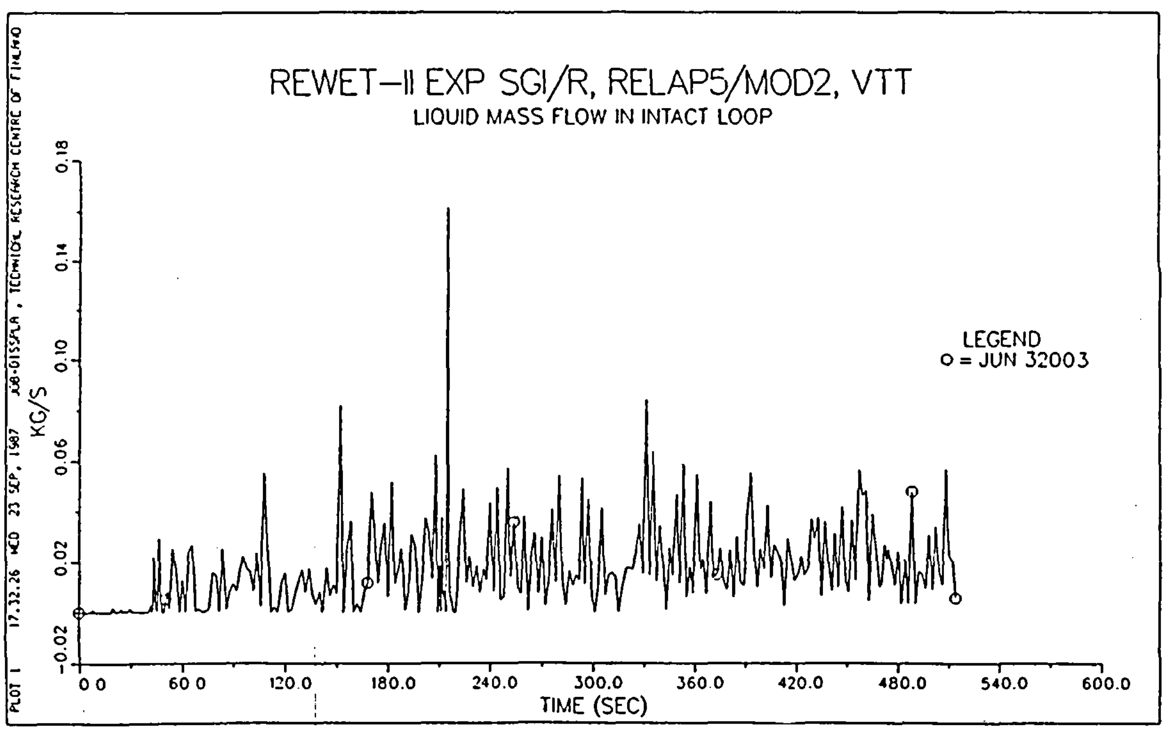

Fig.33 Liquid mass flow in the intact loop

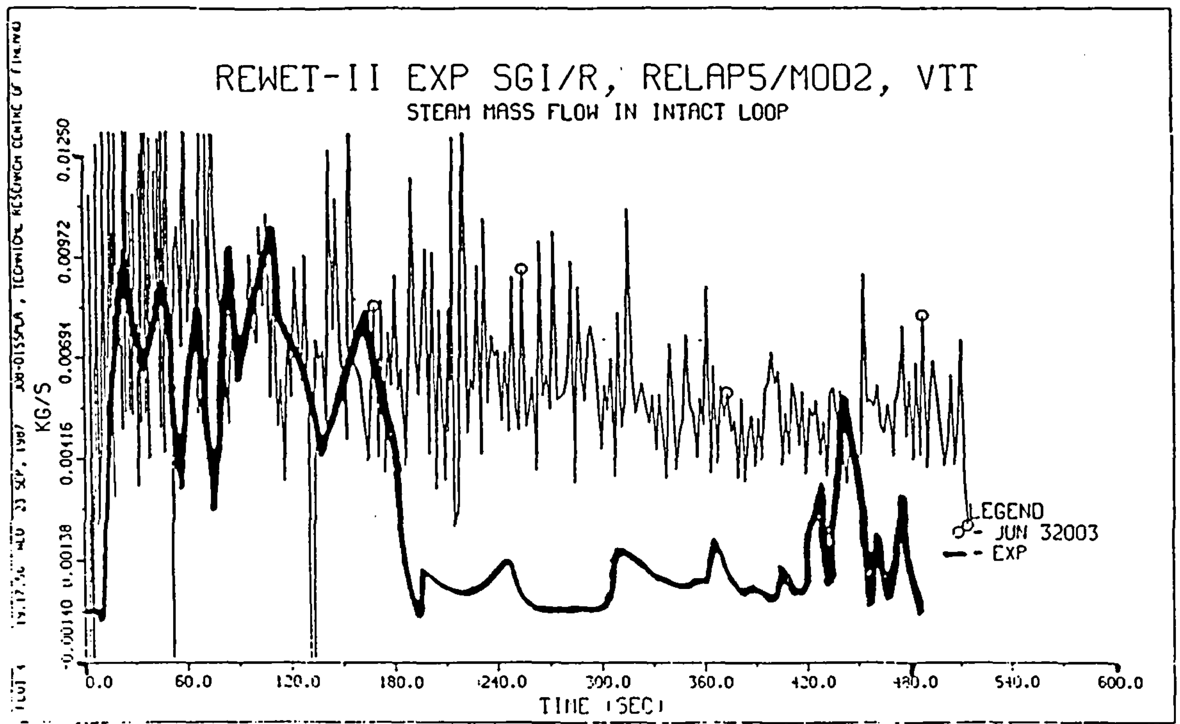

Fig.34 Steam mass flow in the intact loop

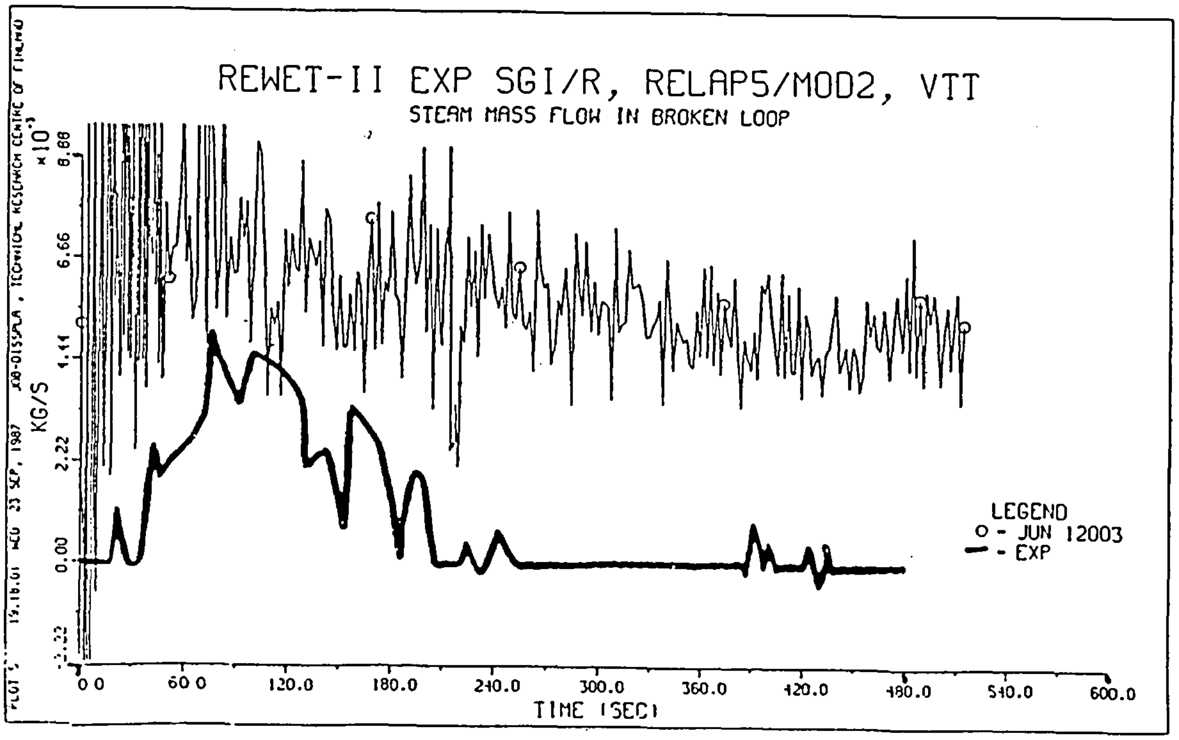

Fig.35 Steam mass flow in the broken loop

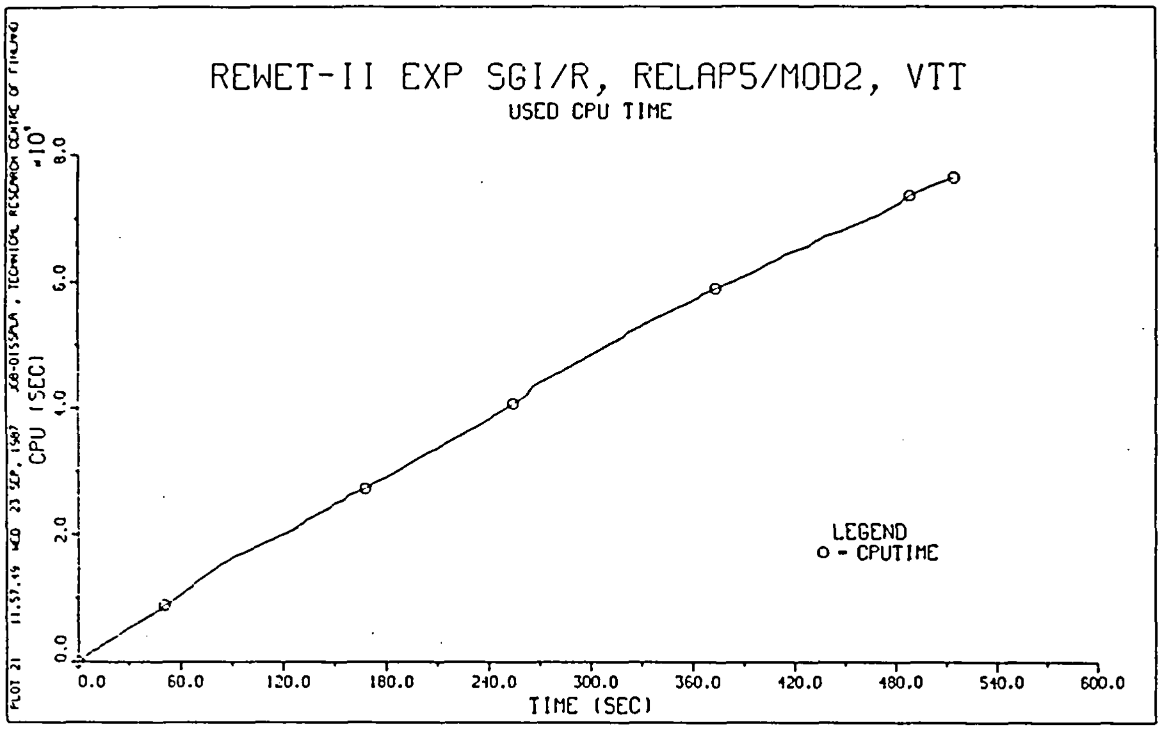

Fig.36 Consumed CPU time versus real time

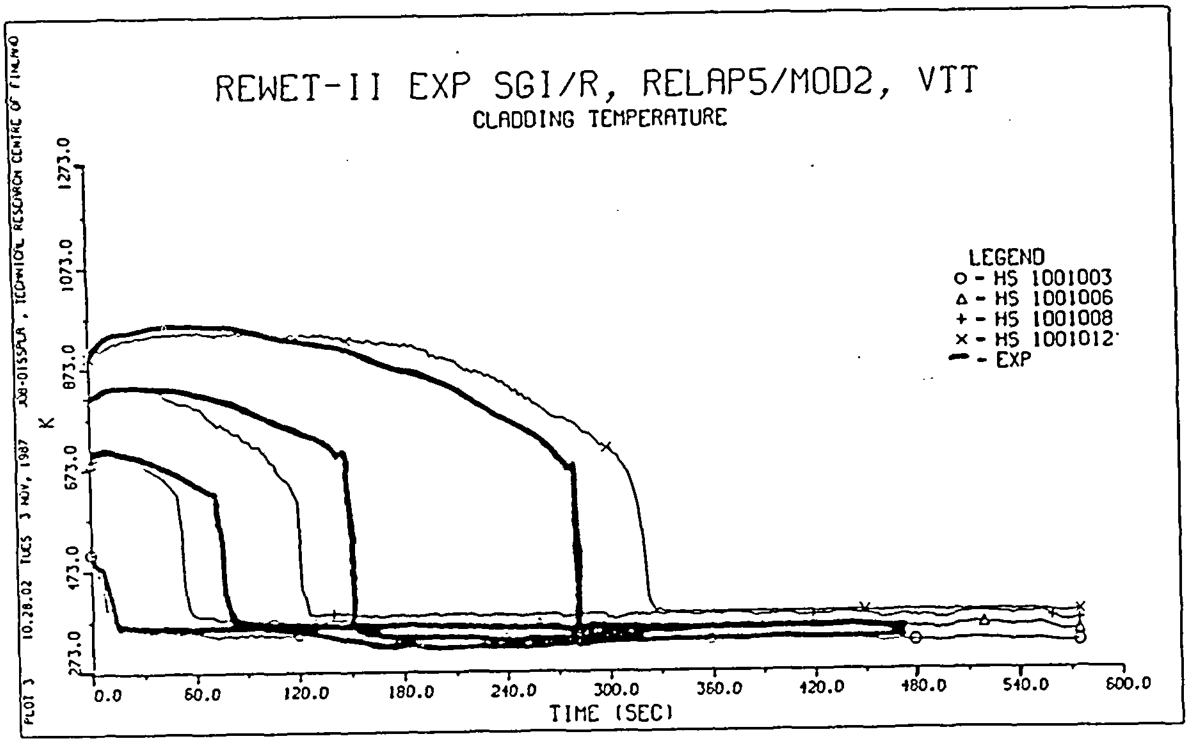

Fig.37 Cladding temperatures in the lower and middle part of the core, case 2

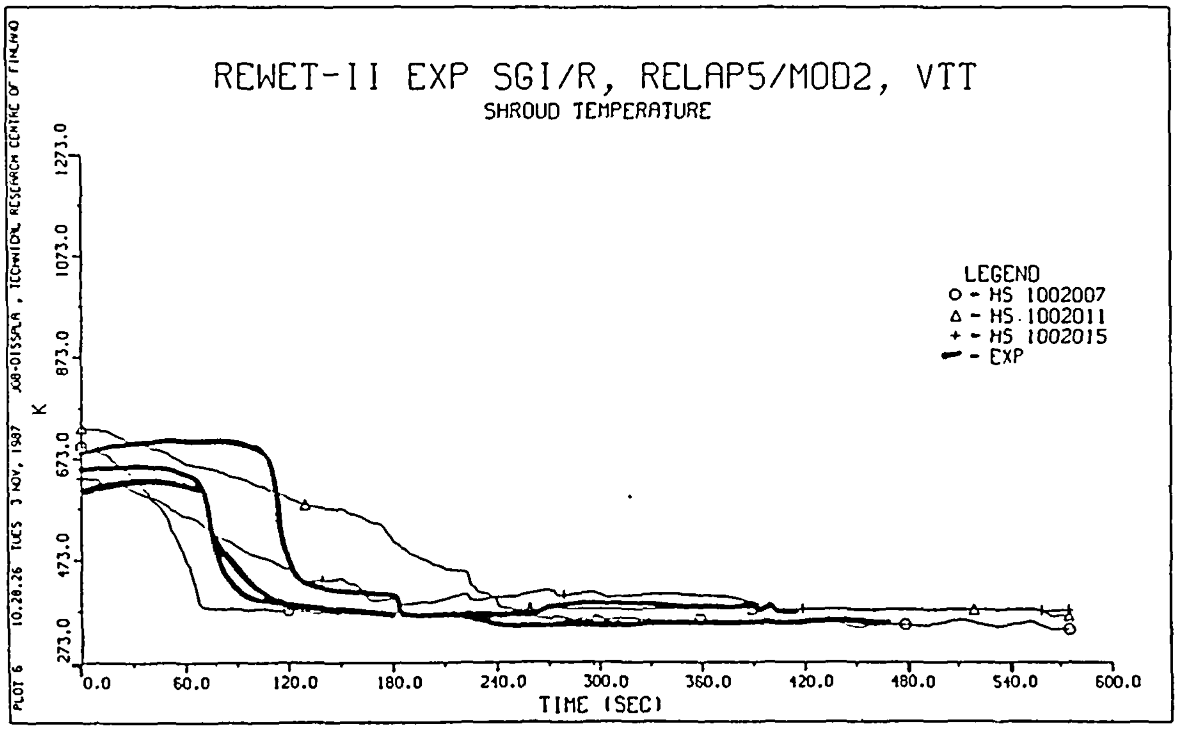

Fig.38 Shroud temperature, case 2

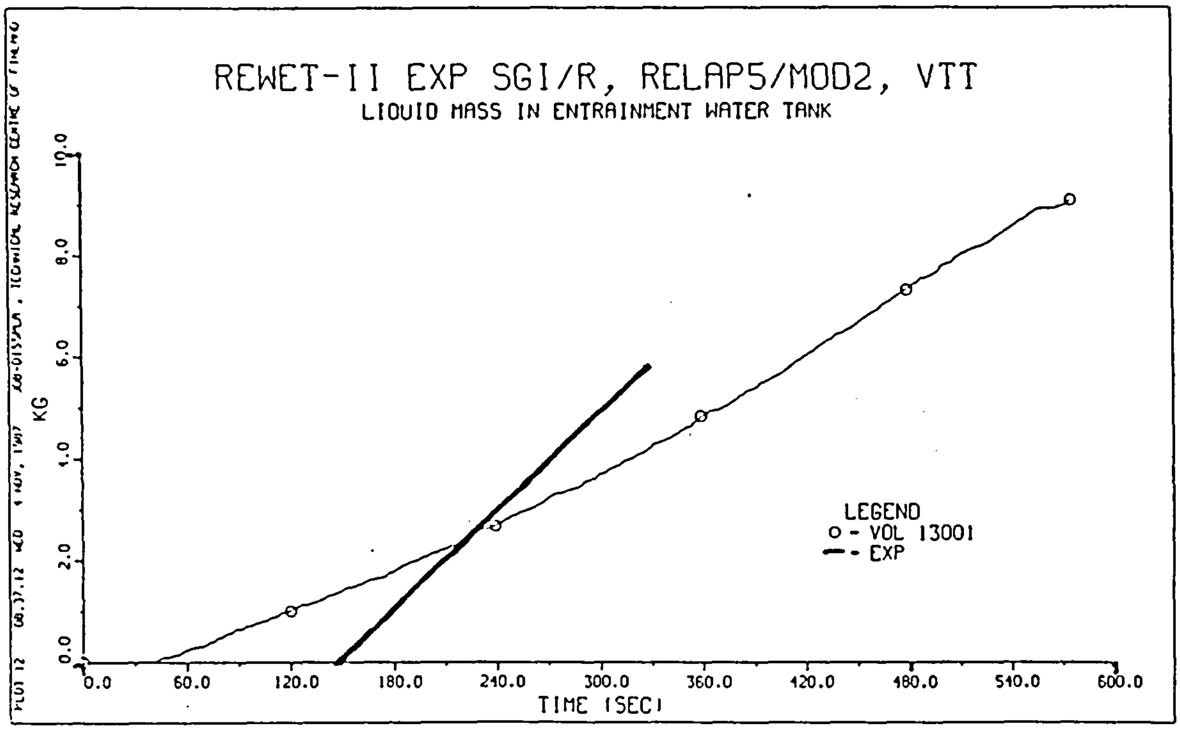

Fig.39 Liquid mass in the entrainment water tank, case 2

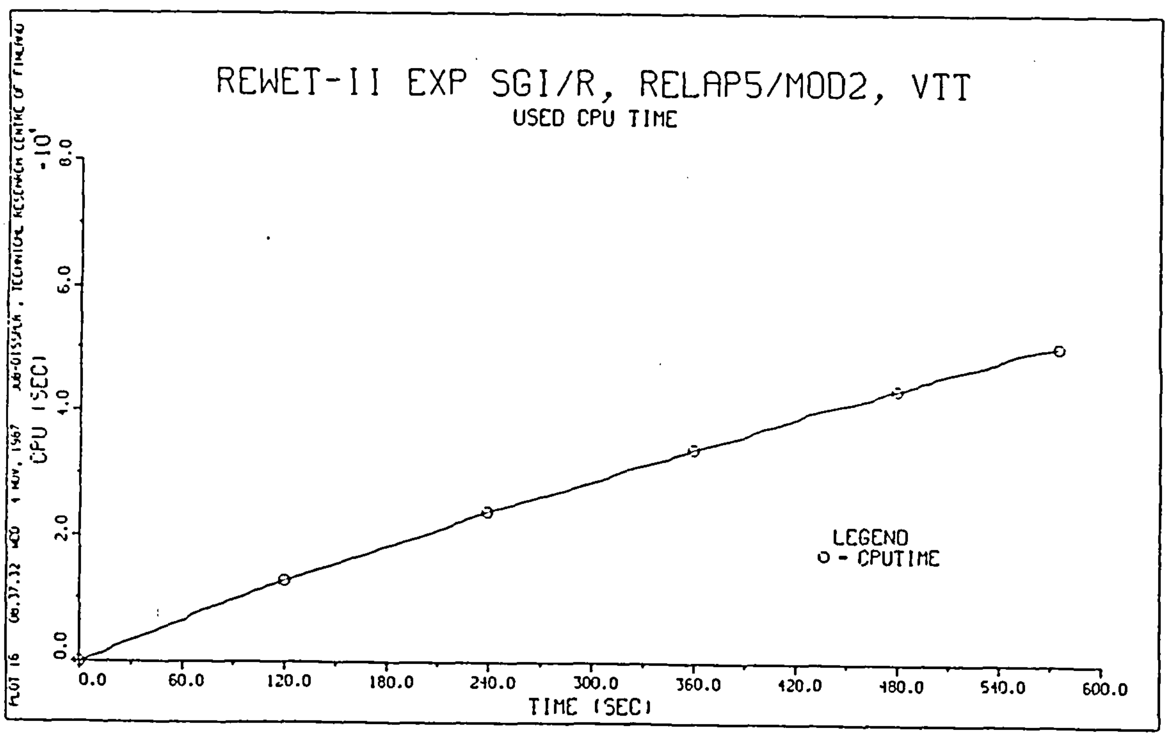

Fig.40 Consumed CPU time versus real time, case 2

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11. ABSTRACT *(200 words or less)*

An analyses of a reflooding experiment with RELAP5/MOD2 cycle 36.04 is presented. The experiment had been carried out in the REWET-II facility simulating the reactor core with a bundle of 19 electrically heated rods. On the basis of the results of two calculations recommendations for the core nodalization are presented, and a modification to the code is proposed.

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