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Abstract

MORI, Takamasa, CIGARINI, Marco and DALLE DONNE, Mario :
Pre-test Calculation of Reflooding Experiments with Wider Lattice in APWR-Geometry (FLORESTAN 2) using the Advanced Computer Code FLUT-FDWR

After the reflooding tests in an extremely tight bundle (p/d = 1.06, FLORESTAN 1) have been completed, new experiments for a wider lattice (p/d = 1.242, FLORESTAN 2) ,which is employed in the recent APWR design of KfK, are planned at KfK to obtain the benchmark data for validation and improvement of calculation methods. This report presents the results of pre-test calculations for the FLORESTAN 2 experiment using FLUT-FDWR, a modified version of the GRS computer code FLUT for analysis of the most important behaviour during the reflooding phase after a LOCA in the APWR design.

Zusammenfassung

MORI, Takamasa, CIGARINI, Marco und DALLE DONNE, Mario :
Vorabberechnungen mit dem Rechenprogramm FLUT-FDWR für Flutexperimente in FDWR-Geometrie mit weitem Gitter (FLORESTAN 2)

Nachdem Flutexperimente für ein extrem enges Stabbündel (p/d = 1.06, FLORESTAN 1) durchgeführt worden sind, werden neue Experimente mit einem weiteren Gitter (p/d = 1.242, FLORESTAN 2) zur Zeit bei KfK vorbereitet. Sie dienen dazu, die Berechnungsmethoden zu validieren und zu verbessern. Die Geometrie mit dem weiteren Gitter entspricht dem neuen FDWR Konzept von KfK. Der Bericht stellt die Ergebnisse von Vorabberechnungen für das FLORESTAN 2 Experiment vor. Diese Rechnungen sind mit FLUT-FDWR durchgeführt worden. FLUT-FDWR ist eine modifizierte Version des GRS Rechenprogramms FLUT für die Analyse der wichtigsten Ereignisse während der Flutphase nach einem LOCA in einem FDWR.

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Nomenclature

d_1	average diameter of the water droplets in the zone of length L immediately downstream of the quench front (m)
d_2	average diameter of the water droplets in the remaining part, beyond the zone of length L, of the dispersed flow region (m)
L	axial length of the zone of dispersed flow film boiling immediately downstream of the quench front where the average droplet diameter d_1 is used (m)
R_l ,R_v	geometrical parameters for the calculation of the interfacial drag coefficient between vapor and liquid water (m)
φ_{ax}	axial power form factor

1. Introduction

In the concept of the Advanced Pressurized Water Reactor (APWR) with improved uranium utilisation, the main new feature is the introduction of a tight lattice core in order to achieve an higher conversion ratio than in the conventional PWR. For the determination of the optimum design in consideration of the safety requirements, it is necessary to establish flexibly-applicable and highly-accurate predictive methods for core thermal-hydraulic behaviour under accident conditions.

For the past few years, much work is being made in this field at the Institut für Neutronenphysik und Reaktortechnik des Kernforschungszentrums Karlsruhe (INR/KfK). The computer codes RELAP5/MOD1-EUR /1/and FLUT (GRS-Garching) /2/have been implemented and further improved in this center. New correlations and physical models based on both theoretical and experimental work on thermohydraulic in hexagonal rod bundels with tight lattice have been introduced in the codes and the new developed versions RELAP5-APWR /3/ and FLUT-FDWR[1] /4/ have been used to analyse the behaviour of three main reference designs of APWR during an Anticipated Transient Without SCRAM (ATWS) and during a Loss of Coolant Accident (LOCA).

The Code FLUT-FDWR, used for the analysis of the reflooding phase of the LOCA, was verified by means of many post-test calculations of forced flooding experiments in PWR geometry as well as in APWR-geometry with an extremely tight lattice (p/d = 1.06, FLORESTAN experiment /6/) and a wider lattice (p/d = 1.13, NEPTUN-III experiment /7/) /4/ /8//9/.

In a recent design of APWR in KfK, an even wider lattice (p/d = 1.242) is employed with a core height of 3.5 m /10/ . Following the design stage, a new series of reflooding experiments with the same p/d configuration is planned in KfK for validation and improvement of calculation methods. The new experiments will be carried out by using the same test loop as used in the previous FLORESTAN experiment with an extremely tight lattice. This report shows the results of pre-test calculations for the new experiment using the FLUT-FDWR code /5/. For comparison, calculations are also carried out for a few imaginary experiments. In this

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[1] FDWR = Fortgeschrittener Druckwasserreaktor = Advanced Pressurized Water Reactor.

report, the new experiment is called as FLORESTAN 2; the previous one FLORESTAN 1.

2. Test Section of FLORESTAN 2 Reflooding Experiment

The test bundle of FLORESTAN 2 experiment consists of 61 electrically heated fuel rod simulators with a pitch to diameter (p/d) ratio 1.242 in a hexagonal housing. Each rod is 5600 mm in total length, of which 2024 mm is heated with a cosine-shaped power distribution. Cross sectional views of the heated rod and the axial power distribution are shown in Figure 1 on page 8. The main data of the test section is given in Table 1. The outer diameter and pitch of the rod are 9.5 mm and 11.8 mm, respectively. The thickness of zircaloy cladding is 0.57 mm, which leads to an inner diameter of 8.36 mm. Taking into account a gap of 0.05 mm, we obtain an outer diameter of 8.26 mm for the Al_2O_3 annular pellets. The part inside the Al_2O_3 pellet (the heater) is the same as used in the FLORESTAN 1 experiment /6/ . The heated part of the rod is supported by appropriate spacer grids. The same test loop as in the FLORESTAN 1 experiment is used in the FLORESTAN 2, and is schematically shown in Figure 2 on page 8.

	FLORESTAN 2	FLORESTAN 1
Rod diameter (mm)	9.5	10.1
Rod pitch (mm)	11.8	10.7
Coolant flow area (mm^2)	3328.4	1452.0
Hydraulic diamter (mm)	6.20	2.60
Number of rods	61	61
Heated length (mm)	2024	2024
Power axial form factor	1.3	1.3
Power radial form factor	1.0	1.0

Table 1. Main Data of Test Section: Comparison between FLORESTAN 1 & 2.

3. FLUT-FDWR Calculations

For our calculations, we considered four different cases, of which the specifications are listed in Table 2 on page 4. The cases named FLORESTAN 2 (the same peak linear heat rating, but lower rod power compared with the reference reactor) and FLORESTAN 2Q (the same total rod power, but higher peak power compared with the reference reactor) are realisable only with minor changes of the original FLORESTAN facility and by using the same type of electric heater as used in the FLORESTAN 1 experiment(axial power form factor $\varphi_{ax}=1.30$). The case FLORESTAN 2P differs from 2Q because of its axial power form factor $\varphi_{ax}=1.45$, which is a calculated value for an actual APWR core /11/ . The realisation of this experiment would require the development of new electric heater to obtain the new power profile. Finally, the FLORESTAN 3 corresponds to a bundle of rods having the same power (considered 40 sec after shut-dowm), axial length and axial power form factor as the reference reactor design. For each case, we carried out a FLUT-FDWR calculation of forced reflooding with the physical beginning and boundary conditions listed in Table 3 on page 4 .

The nodalisations for FLUT-FDWR calculations are shown in Figure 3 on page 9 and Figure 4 on page 9. The important input parameters for the calculation were determined based on the experiences /4//5/ /8/as follows;

$R_l = R_v = 0.5$ m.

L $= 0.2$ m.

$d_1 = 0.127$ mm.

$d_2 = 0.2$ mm.

These parameters have been introduced into the FLUT-FDWR code, and the meaning of them is described in Reference /5/ .

	Name in figures	Rod power (kW)	Heated rod length (m)	Axial power factor	Number of grids	Linear heat rating (kW/m)	
						Average	Peak
FLORESTAN 2	PRE2C	2.310	2.024	1.30	7	1.14	1.48
FLORESTAN 2Q	PRE2QC	3.581	2.024	1.30	7	1.77	2.30
FLORESTAN 2P	PRE2PC	3.581	2.024	1.45	7	1.77	2.57
FLORESTAN 3 (Reactor)	PRE3C	3.581	3.500	1.45	11	1.02	1.48

Table 2. Specification of FLUT-FDWR Calculations

Flooding rate	4.5 cm/s
Upper Plenum pressure	4.2 bar
Initial cladding temperature at the midplane	500 °C
Flooding water temperature	130 °C

Table 3. Reflooding Condition for FLUT-FDWR Calculations

4. Results

Quench-front: The quench-front position versus time is compared among four cases in Figure 5 on page 10 . The quench-front propagation velocity is similar between PRE2C and PRE3C which have the same peak linear heat rating. On the other hand, PRE2QC and PRE2PC with higher peak linear heat rating show quite lower velocity.

Cladding Temperature: The cladding temperature versus time in four cases are shown in Figure 6 on page 10 to Figure 9 on page 12. Those at the middle level and the maximum temperature obtained are compared among four cases in Figure 10 on page 12 and Table 4 on page 5, respectively. The three cases with the same rod power show similar results for the maximum temperature (PRE2QC, PRE2PC and PRE3C).

	PRE2C	PRE2QC	PRE2PC	PRE3C
Maximum temperature (°C)	536.2	598.7	627.5	603.6
Time (s)	17.1	47.7	55.1	68.7
Height (m)	1.01 ~ 1.06	1.27 ~ 1.32	1.27 ~ 1.32	2.25 ~ 2.30
Midplane level (m)	1.012	1.012	1.012	1.750

Table 4. Maximum Cladding Temperature

Water Carry Over and Discharged Vapour: The accumulations of water carry over and discharged vapour are shown in Figure 11 on page 13 and Figure 12 on page 13, respectively.

Pressure Difference and Collapsed Water Level: The collapsed water levels in four cases are compared in Figure 13 on page 14. The pressure difference between lower and upper plena is given for each case in Figure 14 on page 14 to Figure 17 on page 16 .

5. Conclusion

The experiments in the FLORESTAN facility with a shorter heated length (2.024 m) compared with the actual reactor (3.5 m) will give useful information to check the computer codes and also to get an idea of the real phenomena in the reactor:

- FLORESTAN 2 and FLORESTAN 3 give about the same quench velocity.

- FLORESTAN 2Q and FLORESTAN 3 give about the same maximum cladding temperature.

If a code is able to calculate these two cases (FLORESTAN 2 and FLORESTAN 2Q) correctly, it will probably evaluate FLORESTAN 3 well.

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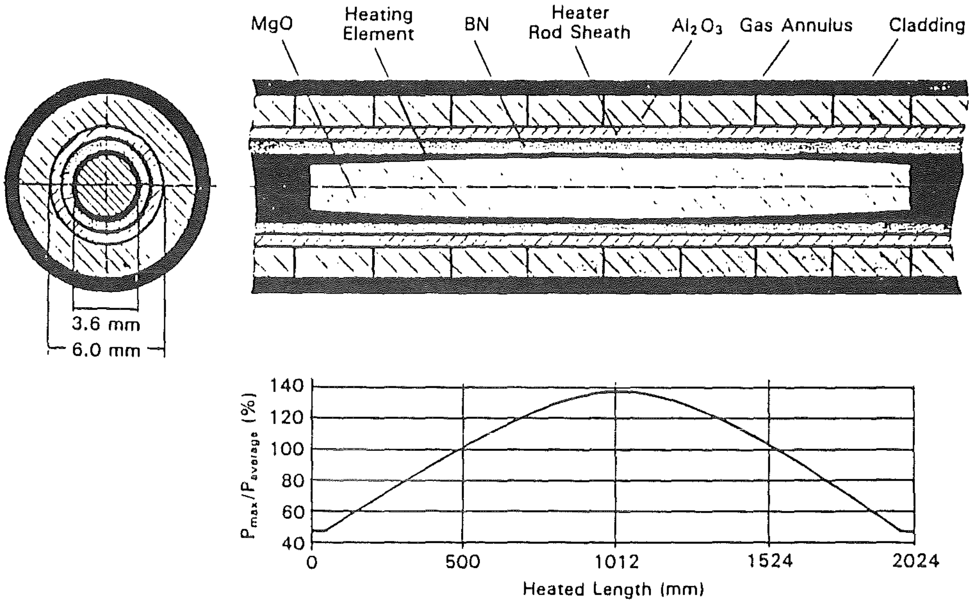


Figure 1. FLORESTAN 2 Fuel Rod Simulator.

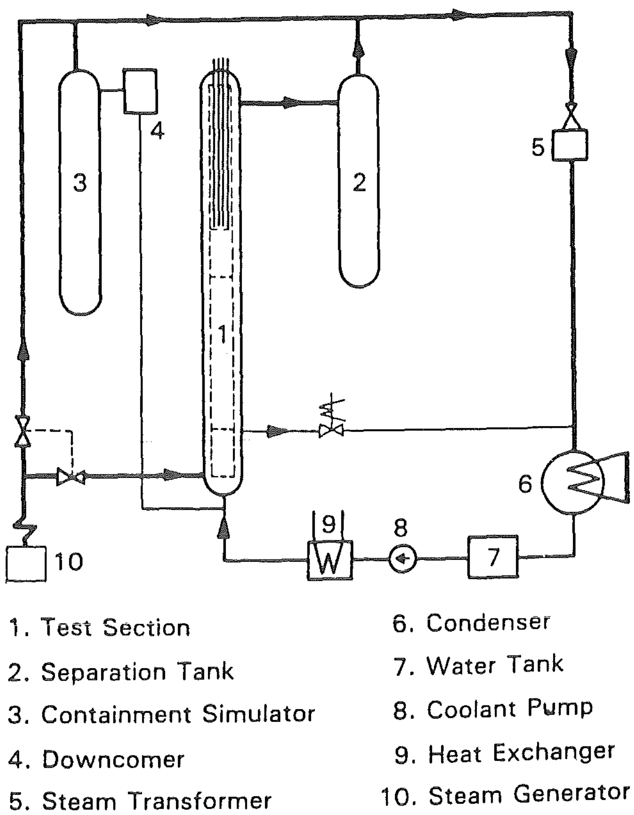
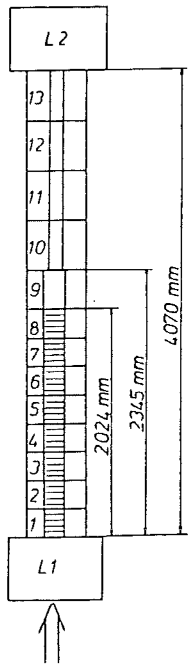
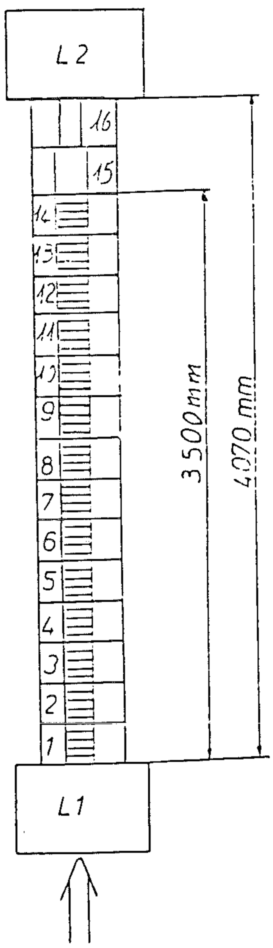


Figure 2. FLORESTAN Test Loop for Reflooding Experiment.



1 Pipe (13 cells)
2 Lumps
40 Heated conductors
5 Unheated conductors

Figure 3. FLUT-Nodalisation of the FLORESTAN 2-Test Section.



1 Pipe (16 cells)
2 Lumps
70 Heated conductors
2 Unheated conductors

Figure 4. FLUT-Nodalisation of the FLORESTAN 3-Test Section.

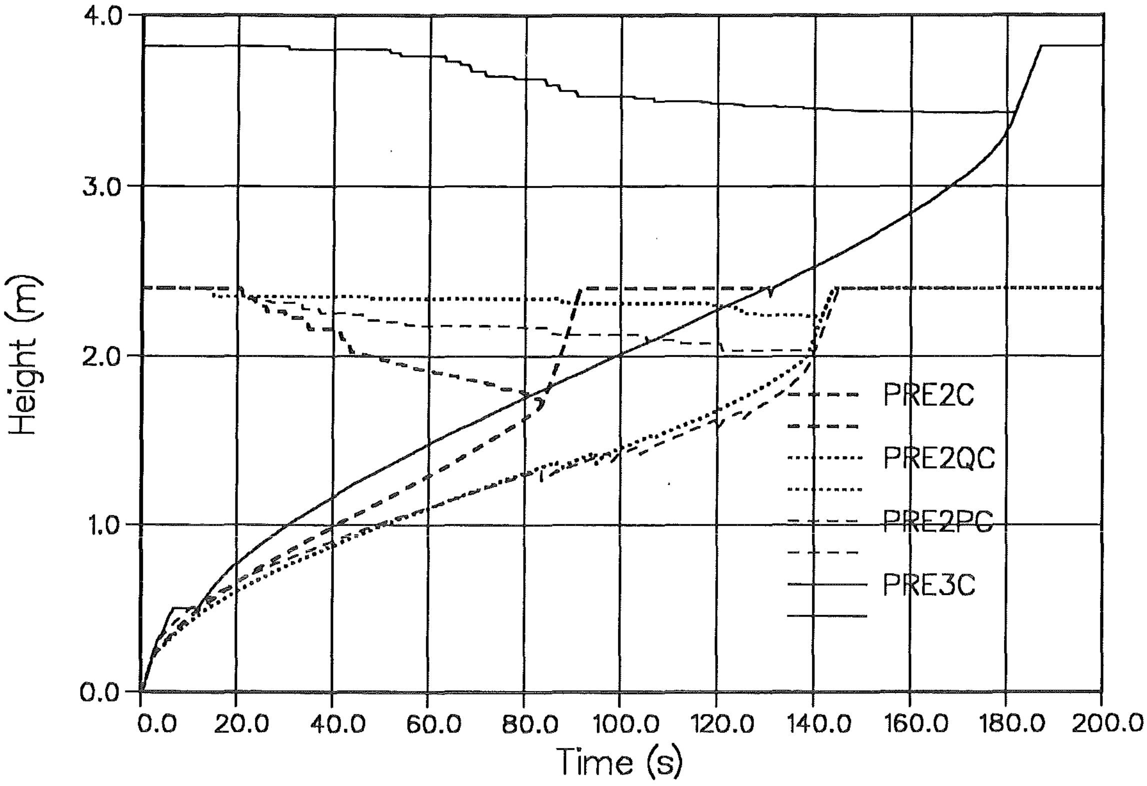


Figure 5. Quench-front.

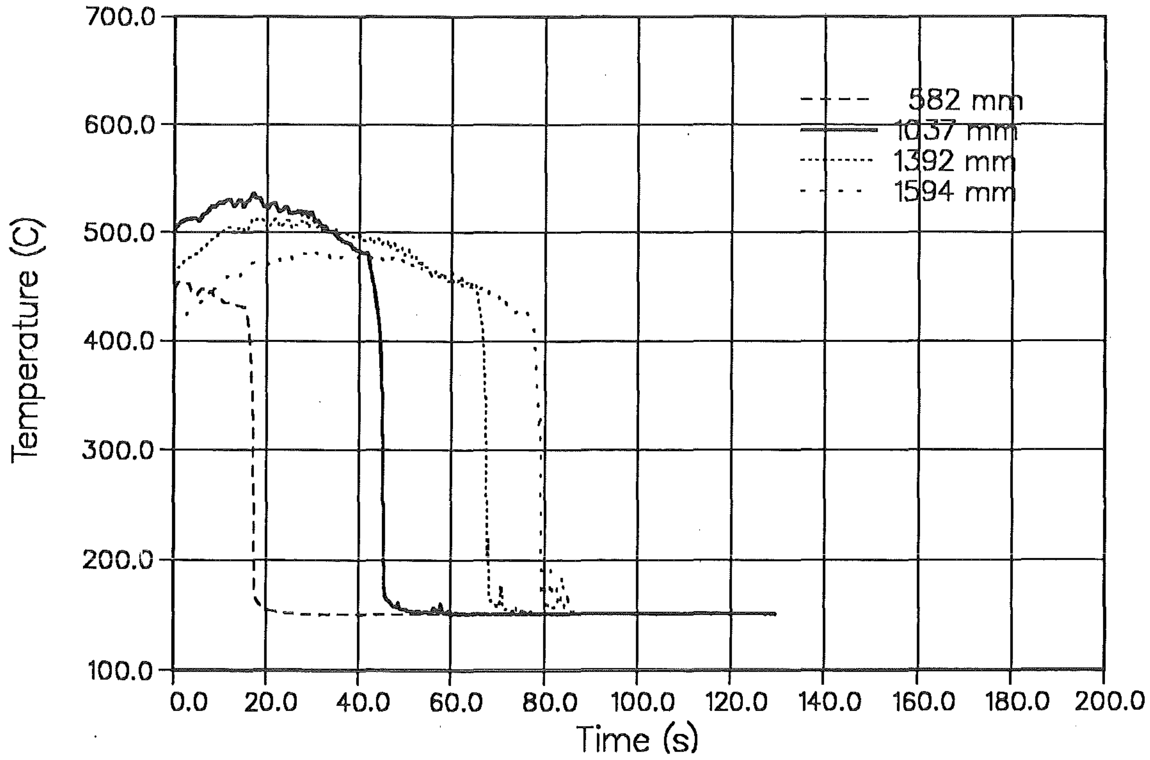


Figure 6. Cladding Temperature versus Time (PRE2C).

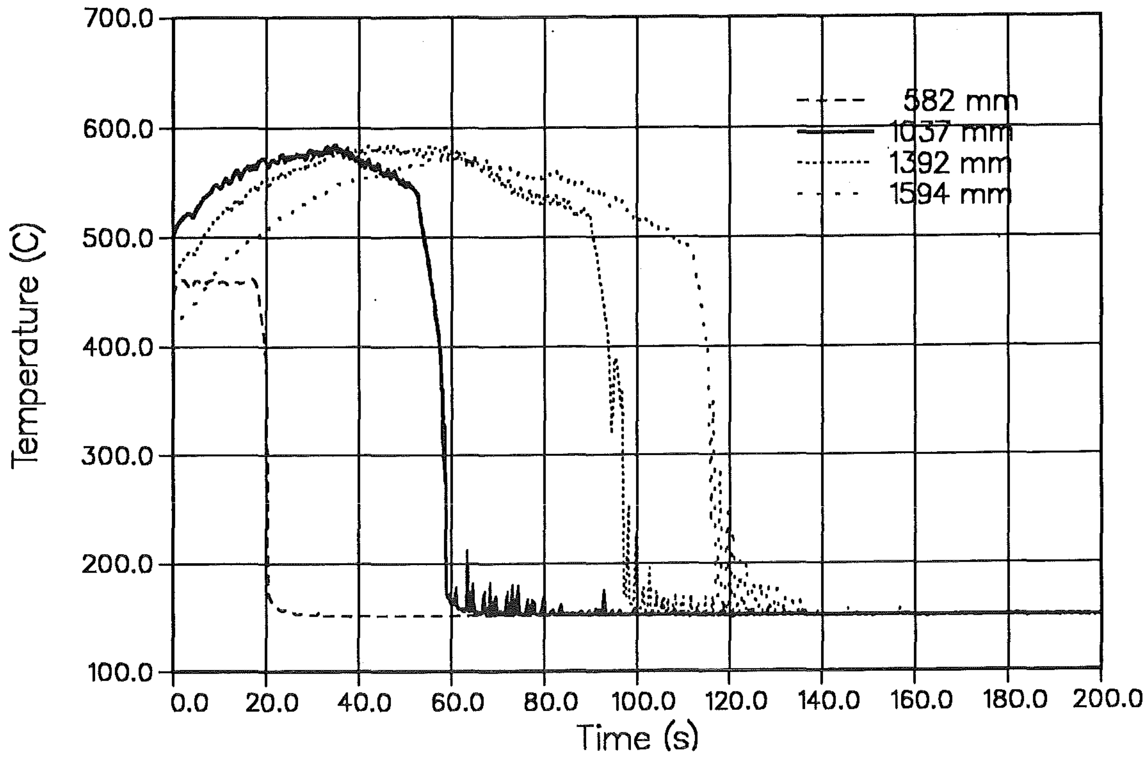


Figure 7. Cladding Temperature versus Time (PRE2QC).

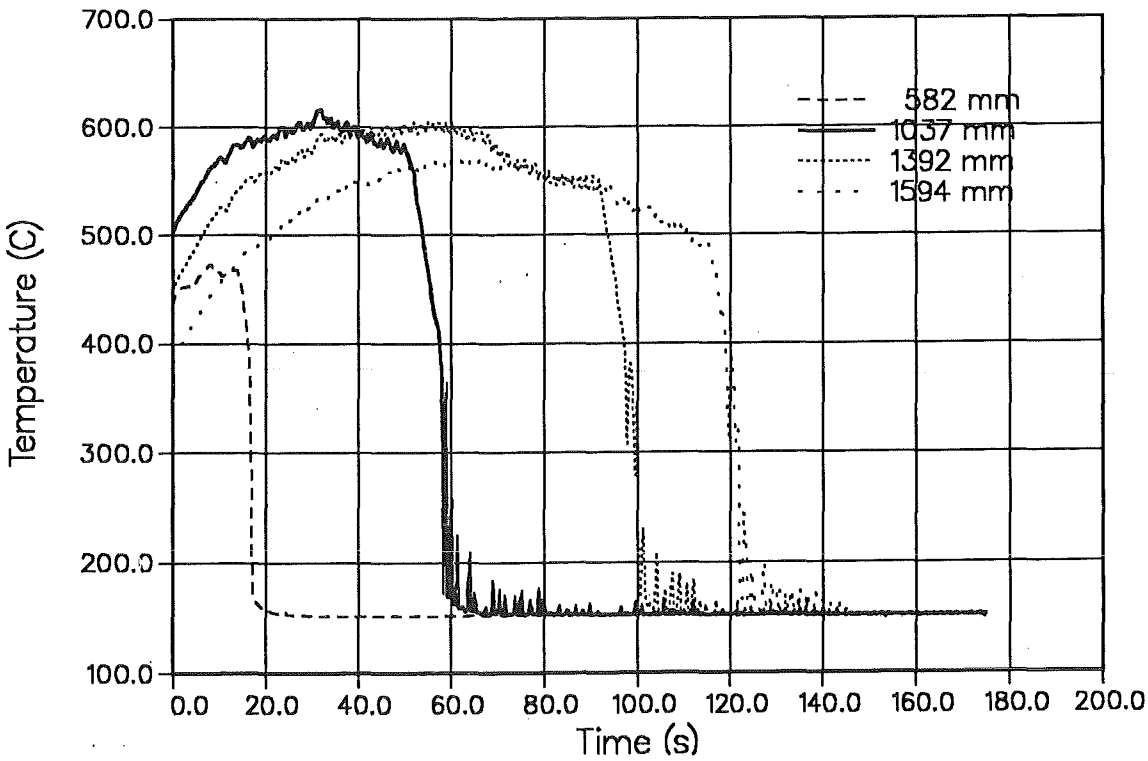


Figure 8. Cladding Temperature versus Time (PRE2PC).

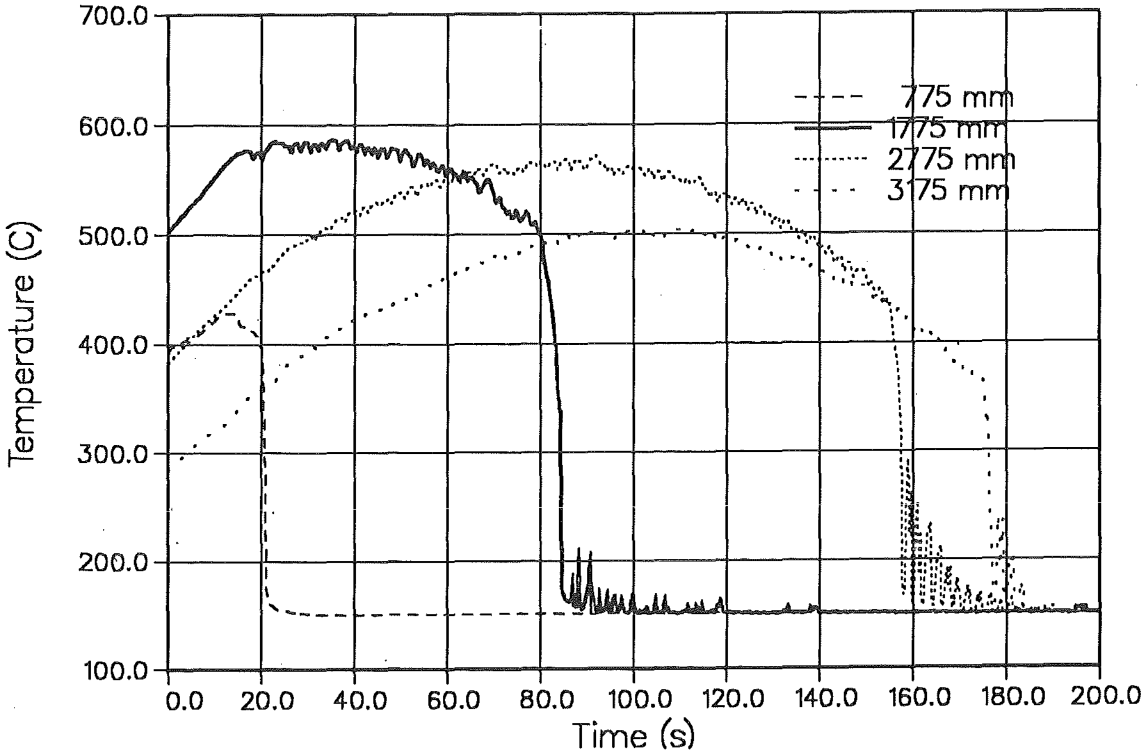


Figure 9. Cladding Temperature versus Time (PRE3C).

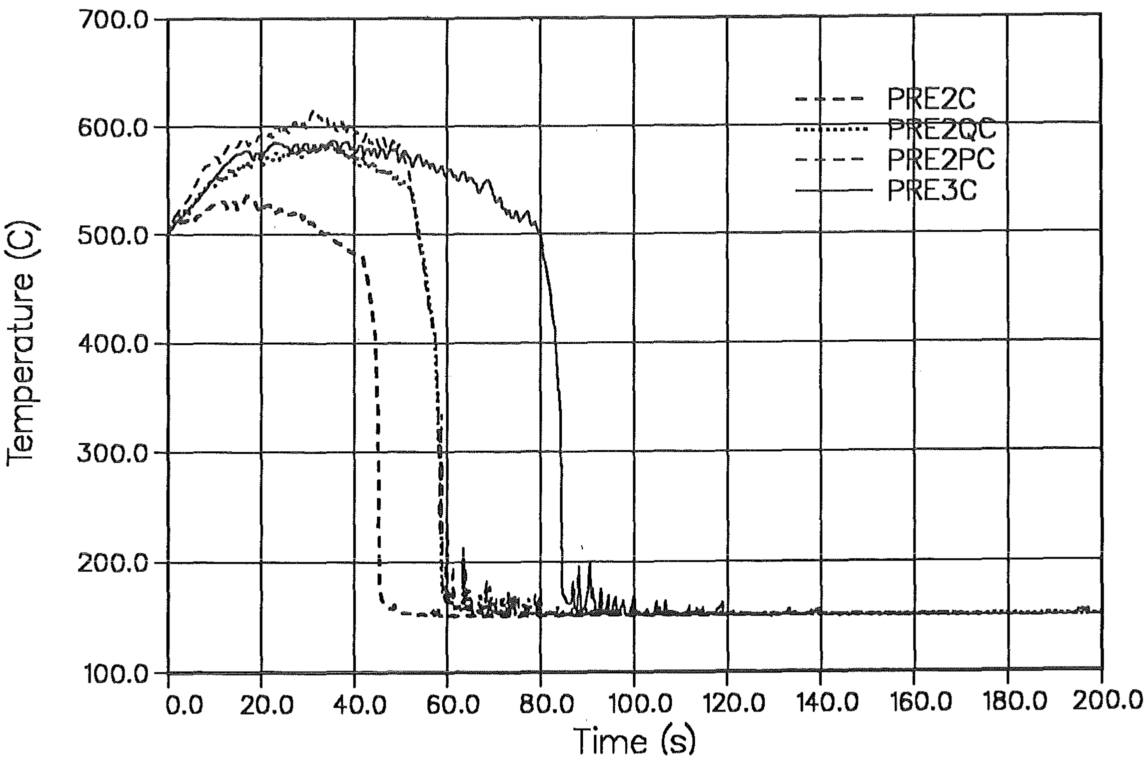


Figure 10. Comparison of Cladding Temperature at the Middle Level versus Time.

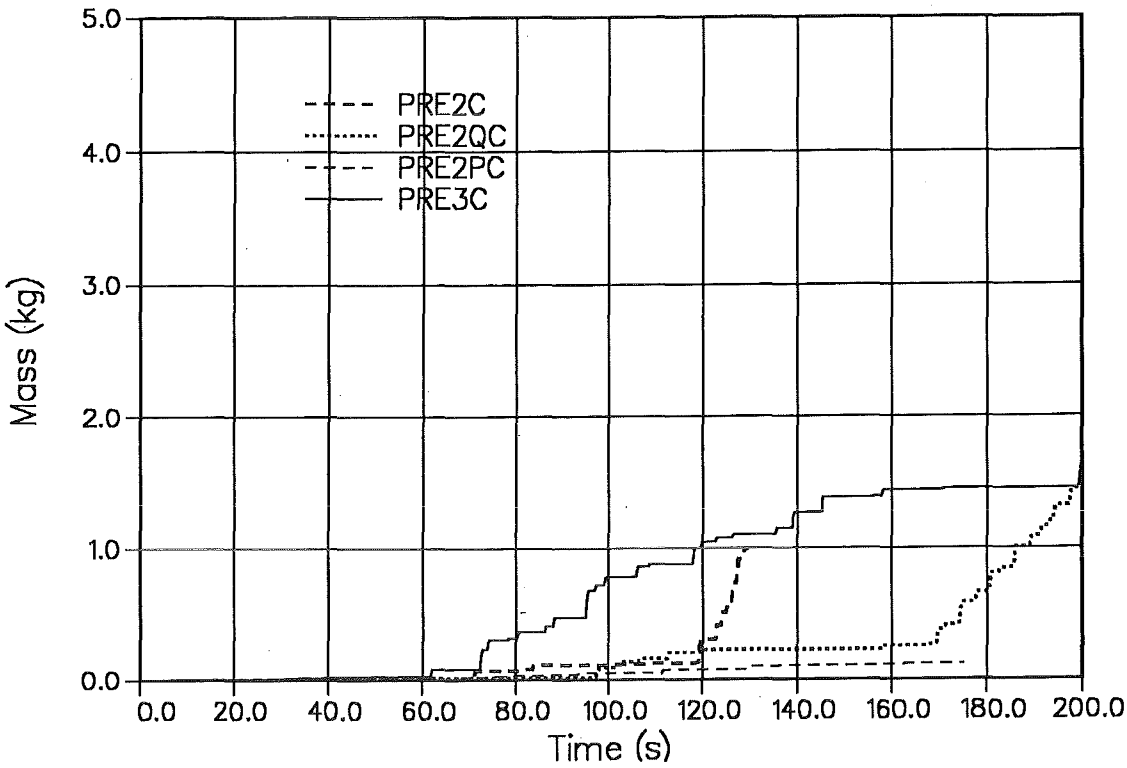


Figure 11. Comparison of Accumulated Water Carry Over.

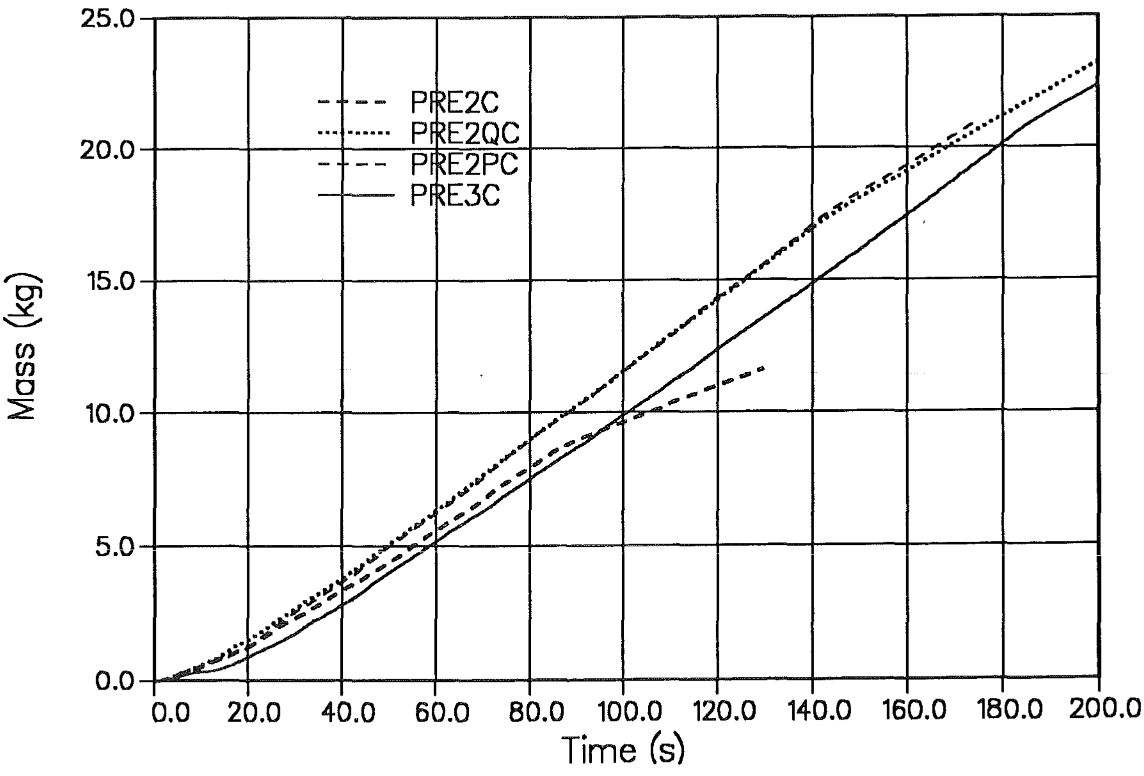


Figure 12. Comparison of Accumulated Discharged Vapour.

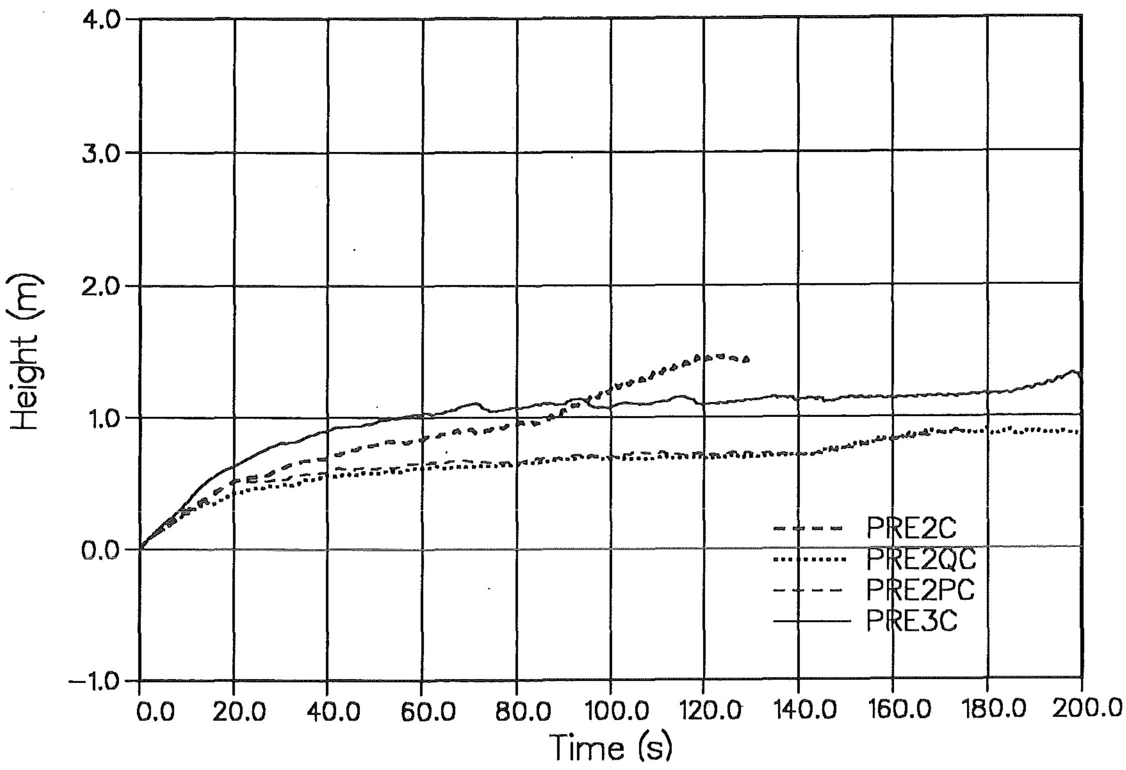


Figure 13. Comparison of Collapsed Water Level.

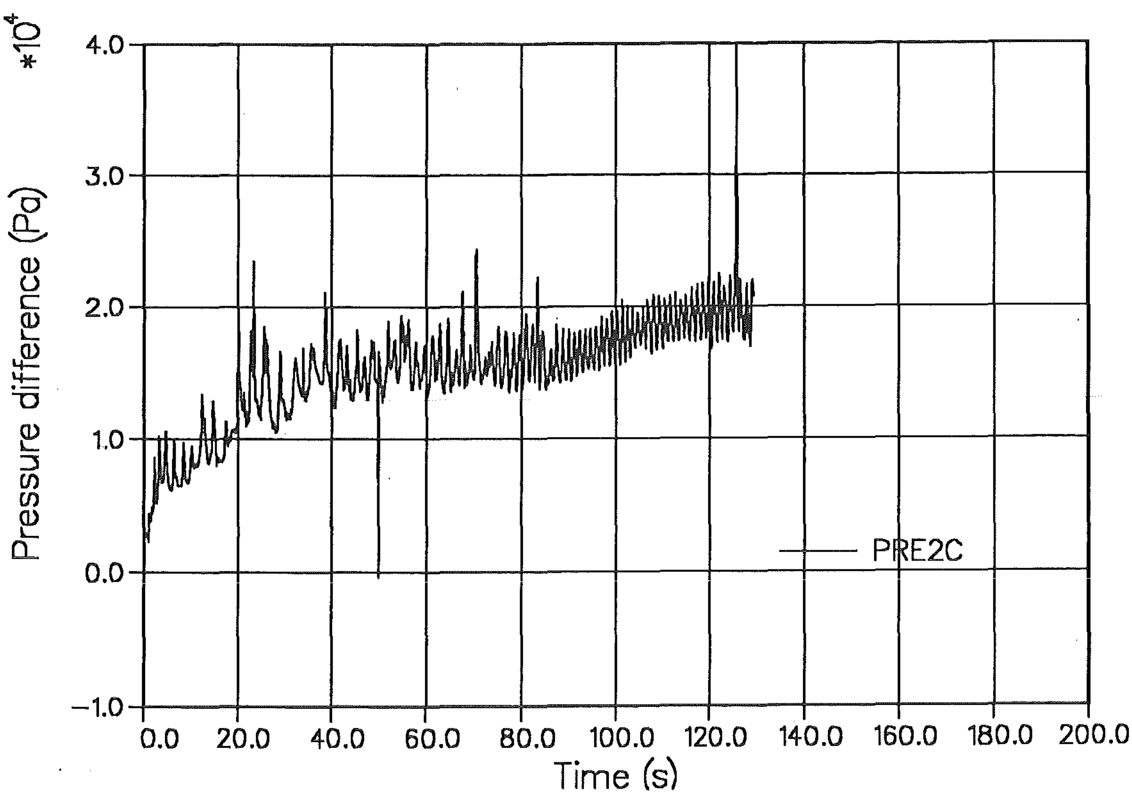


Figure 14. Pressure Difference between Lower and Upper Plena (PRE2C).

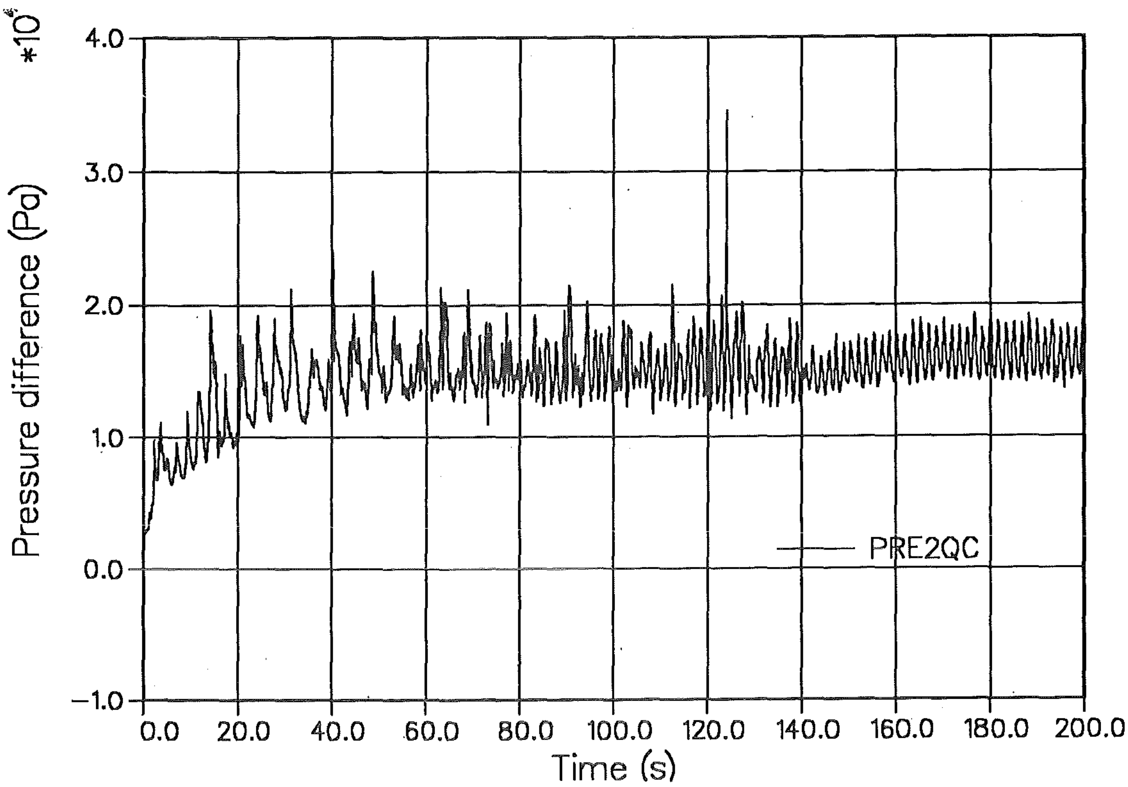


Figure 15. Pressure Difference between Lower and Upper Plena (PRE2QC).

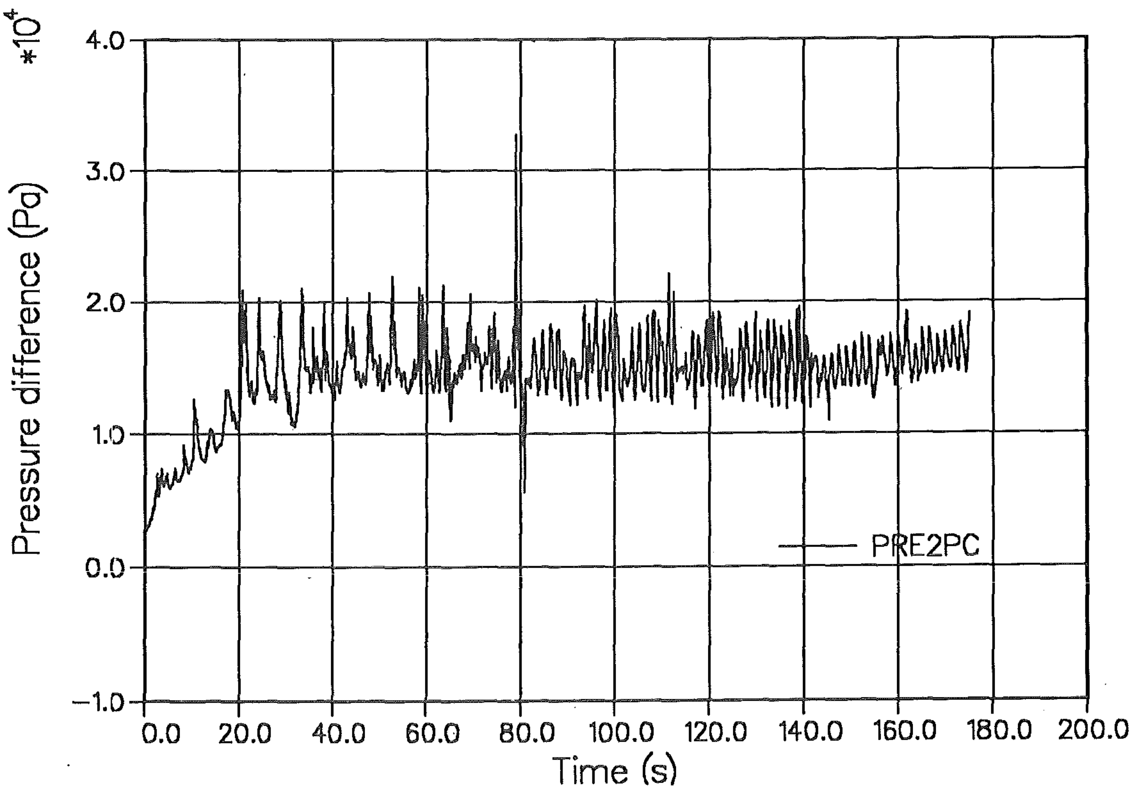


Figure 16. Pressure Difference between Lower and Upper Plena (PRE2PC).

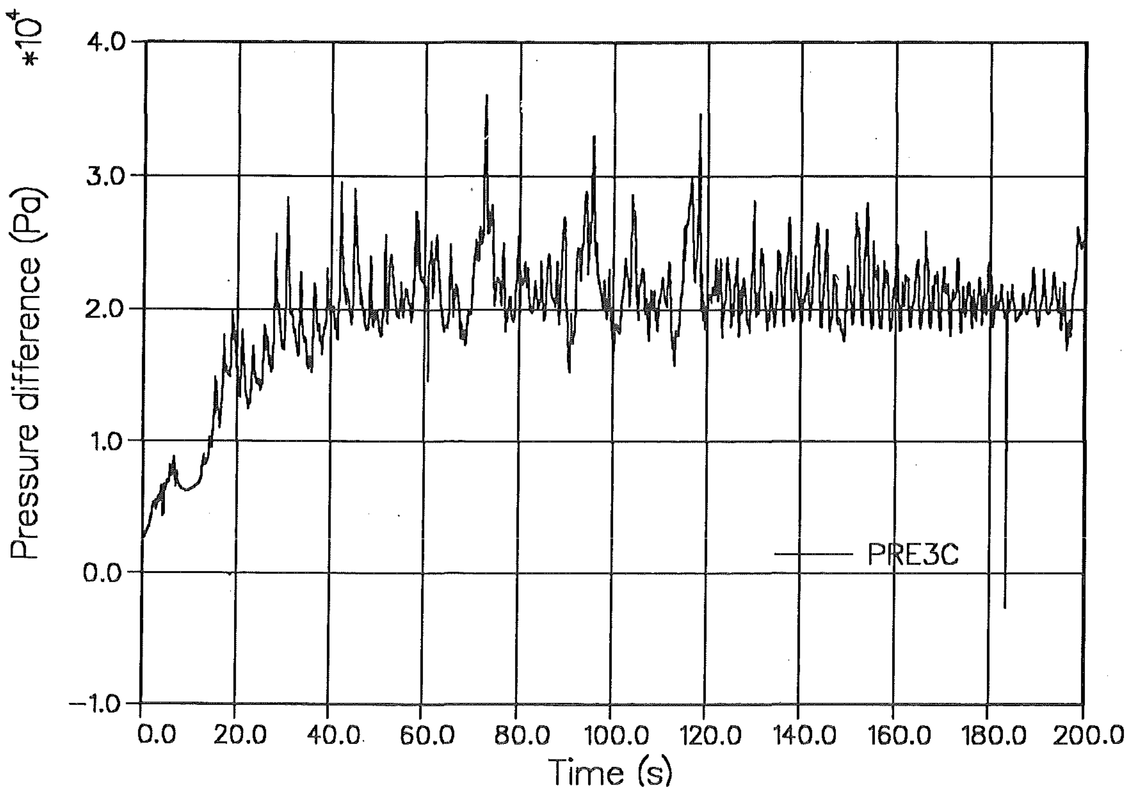


Figure 17. Pressure Difference between Lower and Upper Plena (PRE3C).