NUREG/IA-0112
ECN-C--92-008

International Agreement Report

Assessment of RELAP5/MOD2 Against ECN-Reflood Experiments

Prepared by
A. Woudstra, J. P. A. Van De Bogaard, P. M. Stoop

Netherlands Energy Research Foundation ECN
Service Unit General Services
P. O. Box 1, NL-1755 ZG Petten
The Netherlands

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

July 1993

Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Thermal-Hydraulic Code Assessment
and Application Program (ICAP)

Published by
U.S. Nuclear Regulatory Commission

Available from

Superintendent of Documents
U.S. Government Printing Office
P.O. Box 37082
Washington, D.C. 20013-7082

and

National Technical Information Service
Springfield, VA 22161

NUREG/IA-0112
ECN-C—92-008

International Agreement Report

Assessment of RELAP5/MOD2 Against ECN-Reflood Experiments

Prepared by
A. Woudstra, J. P. A. Van De Bogaard, P. M. Stoop

Netherlands Energy Research Foundation ECN
Service Unit General Services
P. O. Box 1, NL-1755 ZG Petten
The Netherlands

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

July 1993

Prepared as part of
The Agreement on Research Participation and Technical Exchange
under the International Thermal-Hydraulic Code Assessment
and Application Program (ICAP)

Published by
U.S. Nuclear Regulatory Commission

NOTICE

ABSTRACT

As part of the ICAP (International Code Assessment and Applications Program) agreement between ECN (Netherlands Energy Research Foundation) and USNRC, ECN has performed a number of assessment calculations with the computer program RELAP5.
This report describes the results as obtained by ECN from the assessment of the thermohydraulic computer program RELAP5/MOD2/CY 36.05 versus a series of reflood experiments in a bundle geometry. A total number of seven selected experiments have been analyzed, from the reflood experimental program as previously conducted by ECN under contract of the Commission of the European Communities (CEC). In this document, the results of the analyses are presented and a comparison with the experimental data is provided.

EXECUTIVE SUMMARY

For both Pressurized and Boiling Water Reactors (PWR's and BWR's) the bottom reflooding process following a large break LOCA is one of the phenomena of great interest to be examined. To test the ability of RELAP5/MOD2 to model such conditions a great number of experimental programs has been conducted to study the reflood heat transfer process and quench front propagation for bottom flooding conditions. The assessment calculations as reported in this document concern reflood experiments as conducted by the Netherlands Energy Research Foundation (ECN). The experimental facility represents a 36-rod bundle segment of a standard 15 x 15 PWR fuel design with an axially uniform power profile.

This report describes comparisons between RELAP5/MOD2 calculations and measurements of wall temperatures at different levels, quench front position, collapsed liquid level, mass inventory in the bundle and integrated boundary mass flows.

The prime conclusions are as follows:

- The RELAP5/MOD2 reflood heat transfer model is only valid for high reflood rates.
- Liquid carry-over is strongly overpredicted.
- Refinement of axial nodalization above the recommended value did not improve the calculational results.

CONTENTS | PAGE

1. INTRODUCTION

As part of the International Code Assessment and Applications Program (ICAP) agreement between the Netherlands Energy Research Foundation (ECN) and the United States Nuclear Regulatory Commission (US-NRC), ECN has conducted a number of assessment calculations using the thermohydraulic system code RELAP5/MOD2/CY 36.05. ref. [1]. The assessment calculations as reported in this document concern a selection of seven reflood experiments as conducted by ECN under contract of the Commission of the European Communities (CEC). The results of this ECN-reflood experimental program have been documented in ref. [2].

As described in NUREG-1271, ref. [5], quantification of code uncertainty for Large Break Loss-of-Coolant Accidents (LB-LOCA), Small Break Loss-of-Coolant Accidents (SB-LOCA) and operational transients requires a large number of assessment calculations to be performed for a variety of integral as well as separate effect experiments. For each of these three classes of accidents, phenomenologically based code assessment matrices have been composed for both the Pressurized and Boiling Water Reactors environment (PWR's and BWR's). One of the phenomena to be examined concerns the reflooding process following LB-LOCA in both PWR's and BWR's. A number of separate effect experimental programs have been conducted to study the reflood heat transfer process and quench front propagation for bottom flooding conditions. Table 1.1 lists some of these experimental programs including their main characteristics. As can be observed from this table, the ECN-reflood experimental facility represents a 36-rod bundle segment of a standard 15 x 15 PWR fuel design. The ECN-reflood experimental program differs from other reflood experimental programs by the axially uniform power profile being used.

RELAP5/MOD2 reflood assessment results already available indicate that discrepancies exist between code predictions and experimental results, ref. [3]. Liquid carry-over is grossly overpredicted and therewith underprediction of the collapsed liquid level occurs. Most of this RELAP5/MOD2 assessment work indicates the cause of overprediction of carry-over is an overestimation of the interphase drag in rod bundle geometries, particularly in the slug flow regime. As stated in ref. [3], most of the RELAP5/MOD2 interphase drag model assessment during the development stage has been based mainly on tube and open vessel data, and only to a minor extent on rod bundle data.

The ECN-reflood data base comprises a total of 48 experiments. Out of this data base, a total of seven experiments have been selected for code assessment, based on the different physical phenomena observed during the experiments and the parameter variations used.

The structure and contents of this assessment document is as much as possible in conformity with the guidelines described in NUREG-1271, ref. [5]. Chapter 2 presents a description of the ECN-reflood experimental facility, the operating procedures and the test matrix. In chapter 3 the RELAP5/MOD2 input model is being described, as well as the initial and operating conditions of the selected experiments. The results of the RELAP5/MOD2 analyses are presented in chapter 4 and compared against the experimental data. Sensitivity analyses with respect to e.g. nodalization are also given in chapter [4]. Information with respect to run statistics can be found in chapter 5, followed by the conclusions in chapter 6. Finally, the RELAP5/MOD2 input deck being used for one of the experiments is being shown in Appendix A.

Table 1.1. Comparison of some reflood experimental facilities.

	No. of rods	Height (%)	Axial power profile	Remark
Flecht	7 x 7 & 10 x 10	100	Cosine, Skewed	15 x 15
Flecht seaset	21, 161, 163	100	Cosine, Skewed	17 x 17
Neptun	6 x 6	50	Cosine	BWR geometry
THTF	8 x 8	100	Flat	PWR 17 x 17 rod geometry
ECN-reflood	6 x 6	100	Uniform	PWR 15 x 15 rod geometry

2. FACILITY AND TEST DESCRIPTION

An extensive description of the ECN 36-rod reflood experimental program can be found in ref. [2]. Here, only a brief description of the facility and the experimental program will be given.

2.1. Geometrical layout

A schematic picture of the ECN 36-rod reflood test facility is shown in Fig. 2.1. Apart from the test section, the facility consists of the following components:

- A pressurized water supply accumulator and injection line;
- Two carry-over tanks connected to the test section upper plenum;
- A blowdown tank for steam condensation.

Heat tracing of piping and vessels has been utilized to prevent steam condensation effects.

The test section itself comprises a 36-rod bundle, located inside a rectangular low mass housing. The bundle consists of 32 electrically heated rods and 4 unheated corner rods, which are used to bear instrumentation, instrumentation leads and the grids. The indirectly heated rods (heated length 3.00 m, outer diameter 10.7 mm) are divided into three concentric rows. Axially a uniform power profile is applied, while radially the 4 centre rods, the inner row and the outer row heater rods can be set at different power levels to establish a radially non-uniform power or initial wall temperature profile. The upper plenum of the test section contains a mechanical steam water separator, see Fig. 2.2.

2.2. Instrumentation

The ECN 36-rod reflood test facility has been instrumented using:

- thermocouples for temperature measurements;
- flowmeters for steam and water flow measurements;
- pressure transducers for absolute pressures, pressure differences and water level measurements;
- resistors for heater current measurements.

The overall test facility instrumentation is shown in Fig. 2.1. Instrumentation directly coupled to the test section is shown in Figs. 2.3 and 2.4. As indicated, housing differential pressure cells are located every 0.25 m to obtain void fraction measurements along the heated length of the bundle. Channel thermocouples are mounted to measure the coolant temperature radially and axially across the bundle. Apart from this, wall thermocouples are positioned at 8 levels per rod at different azimuthal positions, as shown in Fig. 2.4.

2.3. Operational procedures

In order to meet the initial conditions for each experiment, first the accumulator is filled with water and heated to the desired coolant temperature. Next, the test section, the carry-over vessels and steam/water separator vessel are pressurized by nitrogen at the desired pressure. The accumulator is pressurized with nitrogen up to a pressure level which is necessary for the required flow rate control.
In case of radially uniform initial temperature profiles, the bundle was initially low powered. For radially non-uniform high temperature profiles, a radially non-uniform power profile was initially supplied to the bundle.

Once the initial pressure and temperature conditions are met, the desired coolant flow is established. At the time when the coolant reached the bottom side of the test section heated length the power is (stepwise) increased to the desired level. This moment is determined by a fast temperature increase of the heater rod thermocouple at level 1, see Fig. 2.3. This time, which could also be determined by a pressure increase of the lowest differential pressure cell in the heated part of the test section is defined as the "start of the experiment".

After all heater rods are quenched, as could be observed from the rod wall thermocouple measurements, the heater power is switched off, and the experiment is terminated.

2.4. Test matrix

The test matrix of the experimental program was designed to provide an experimental data base in order to determine the reflood phenomena as a function of the next parameters:

- flooding rate;
- system pressure;
- subcooling;
- initial cladding temperature and radial temperature distribution;
- rod power level and radial power distribution.

The range of test conditions and parameters studied during the experimental program is shown in Table 2.1. The complete test matrix comprises 48 experiments and is shown in Table 2.2.

2.5. Selected experiments

Out of the test matrix as shown in Table 2.2, 7 experiments have been selected for purpose of code assessment. Those selected experiments are presented in Table 2.3. Selection of the experiments is based on both the parameter variations being used for the various experiments, and the different physical phenomena being observed.

The data present in Tables 2.2 and 2.3 originates from ref. [2]. However, in order to perform the code assessment work as accurate as possible, more precise initial conditions have been obtained from the available data tapes. These latter initial conditions have been summarized in Table 2.4.

Table 2.1. Range of initial test conditions for the analyzed reflood experiments

Initial heater rod wall temperature	200°C - 850°C
Power	1.7 - 5 W/cm²
Bundle outlet pressure (upper plenum pressure)	.2 - .6 MPa
Flooding rates:	
Constant	1.4 - 8.0 cm/sec
Variable in steps	3.0 - 0.9 cm/sec
Coolant subcooling	20°C - 80°C

Table 2.2. Test matrix for the ECN-reflood program

Exp. No.	(MPA)	T_{wall} initial, lev.4 (°C)			Power (W/cm^2)			V_{in} (cm/sec)	T_{in} (°C)
		c.r.	i.r.	o.r.	c.r.	i.r.	o.r.		
3215	.6	200	200	200	3.3	3.6	3.6	1.5	80
3216	.2	-	-	-	3.4	3.7	3.6	-	40
3218	.6	-	-	-	3.3	3.6	3.6	-	140
3220	.2	-	-	-	1.7	1.8	1.8	.7	100
3221	-	-	-	-	4.0	2.2	1.8	1.3	-
3224	-	-	-	-	3.4	3.7	3.6	1.5	-
3229	-	-	-	-	4.1	2.9	2.2	1.4	-
3230	.2	200	200	200	3.4	3.7	3.6	1.1-0.9	100
3231	-	-	-	-	3.4	3.7	3.6	1.7-0.9	40
4100	.2	600	600	600	3.3	3.6	3.5	8.0	100
4102	-	-	-	-	3.3	3.6	3.5	5.0	-
4106	-	-	-	-	3.6	3.6	3.5	2.4	-
4113	-	-	-	-	3.8	3.6	3.5	-	40
4114	-	-	-	-	3.8	3.0	2.2	-	-
4115	-	-	-	-	3.8	2.2	1.4	-	-
4116	-	-	-	-	3.8	3.0	2.1	-	100
4117	-	-	-	-	3.7	2.2	1.4	-	-
4118	-	400	400	400	3.6	3.6	3.5	-	-
4119	-	600	600	600	3.6	3.6	3.5	5.0	40
4120	-	-	-	-	3.6	3.6	3.6	8.0	-
4121	-	400	400	400	3.6	3.6	3.5	2.4	-
4122	-	600	600	600	1.9	1.7	1.7	-	-
4124	-	600	<	<<	3.6	2.2	1.4	-	-
4125	-	<<	600	600	0	3.6	3.5	-	-
4126	-	600	<	<<	3.6	2.2	1.4	8	-
4127	-	<<	600	600	0	3.6	3.5	-	-
4128	-	600	600	600	5.2	5.0	4.8	2.4	-
4129	-	-	-	-	4.8	5.0	4.8	8	-
4130	-	-	-	-	3.6	2.1	1.3	-	-
4131	-	600	<	<<	3.6	2.2	1.4	2.4	100
4132	-	<<	600	600	0	3.6	3.5	-	-
4133	-	-	-	-	0	3.6	3.5	8	100
4134	-	600	<	<<	3.6	2.2	1.4	-	-
4135	-	600	600	600	3.6	2.1	1.3	-	-
4136	-	-	-	-	5	5	5	2.4	100
4137	-	-	-	-	5	5	5	8	-
4138	-	800	800	800	3.6	3.6	3.6	2.4	-
4139	-	<<	800	800	0	3.6	3.6	-	-
4140	-	800	800	800	3.6	3.6	3.6	8	-
4141	-	<<	800	800	0	3.6	3.6	-	-
4142	-	800	800	800	3.6	3.6	3.6	2.4	40
4143	-	<<	800	800	0	3.6	3.6	-	-
4144	-	800	800	800	3.6	3.6	3.6	8	-
4145	-	<<	800	800	0	3.6	3.6	-	-
4146	.4	800	800	800	3.6	3.6	3.6	2.4	60
4147	-	-	-	-	3.6	3.6	3.6	8	-
4149	-	-	-	-	3.6	3.6	3.6	2.4	120
4150	-	-	-	-	3.6	3.6	3.6	8	-

c.r. = central rods
i.r. = inner ring rods
o.r. = outer ring rods

Table 2.3. Selected experiments

Experi-ment	Pressure (MPa)	Wall temp. (K)	Power (W/cm²)			Inlet velocity (cm/s)	Inlet temp. (K)	Sub cooling (K)
			c.r.	i.r.	o.r.			
3216	0.2	473	3.4	3.7	3.6	1.5	313	80
3224	0.2	473	3.4	3.7	3.6	1.5	373	20
4100	0.2	873	3.3	3.6	3.5	8.0	373	20
4106	0.2	873	3.6	3.6	3.5	2.4	373	20
4120	0.2	873	3.6	3.6	3.6	8.0	313	80
4138	0.2	1073	3.6	3.6	3.6	2.4	373	20
4149	0.4	1073	3.6	3.6	3.6	2.4	393	23

c.r. = central rods

i.r. = inner ring rods

o.r. = outer ring rods

Table 2.4. Initial and operating conditions

EXP	P (MPa)	T_{in} (K)	t (s)	v_{in} (m/s)	Wall temperature (K), level 2	3	4	5	6	7	8	t (s)	Power (W)	Power (W/cm^2)
3216	0.2	313	0 4.9 5.0 805.0	0 0 .15486 .014356	450	459	463	473	473	449	449	0 14.5 17.5 587.5	426.0 426.0 114805.3 115736.9	 3.56 3.59
3224	0.2	373	0 4.9 5.0 1192.5	0 0 .014371 .014193	475	469	467	473	473	467	452	0 13.5 17.5 965.0	475 475.0 113668.6 115347.2	 3.52 3.57
4100	0.2	373	0 7.4 7.5 1000.0	0 0 .080549 .080549	899	893	893	873	865	863	846	0 17.0 20.5 398.0	8962.0 8962.0 114336.6 115819.2	 3.54 3.59
4106	0.2	373	0 7.4 7.5 1000.0	0 0 .023222 .023222	860	863	867	868	870	870	850	0 6.0 11.0 781.0	6505.0 6505.0 112308.7 114510.7	 3.48 3.55
4120	0.2	313	0 5.9 6.0 1000.0	0 0 .081754 .081754	849	851	859	857	860	859	841	0 13.0 16.0 131.5	6558.0 6558.0 113832.5 115350.4	 3.53 3.57
4138	0.2	373	0 7.9 8.0 1000.0	0 0 .02349 .02349	1105	1105	1114	1118	1122	1121	1095	0 14.0 19.0 409.0 799.0	18806.0 18806.0 112584.2 114032.4 114973.0	 3.49 3.53 3.56
4149	0.4	393	0 5.9 6.0 200.0 380.0 766.0	0 0 .023123 .023267 .023275 .023273	1082	1085	1104	1116	1115	1115	1083	0 10.0 14.0 574.0	10390.0 10390.0 112502.3 114565.7	 3.49 3.55

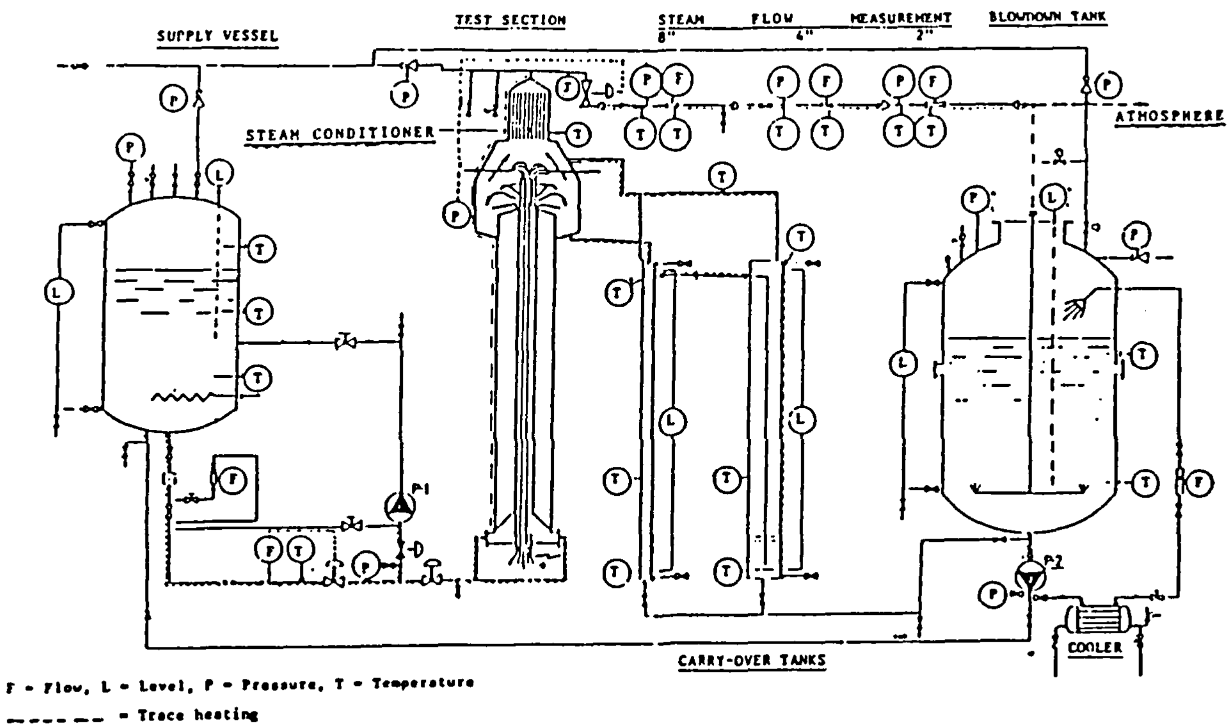


Figure 2.1. ECN-Reflood test facility schematics.

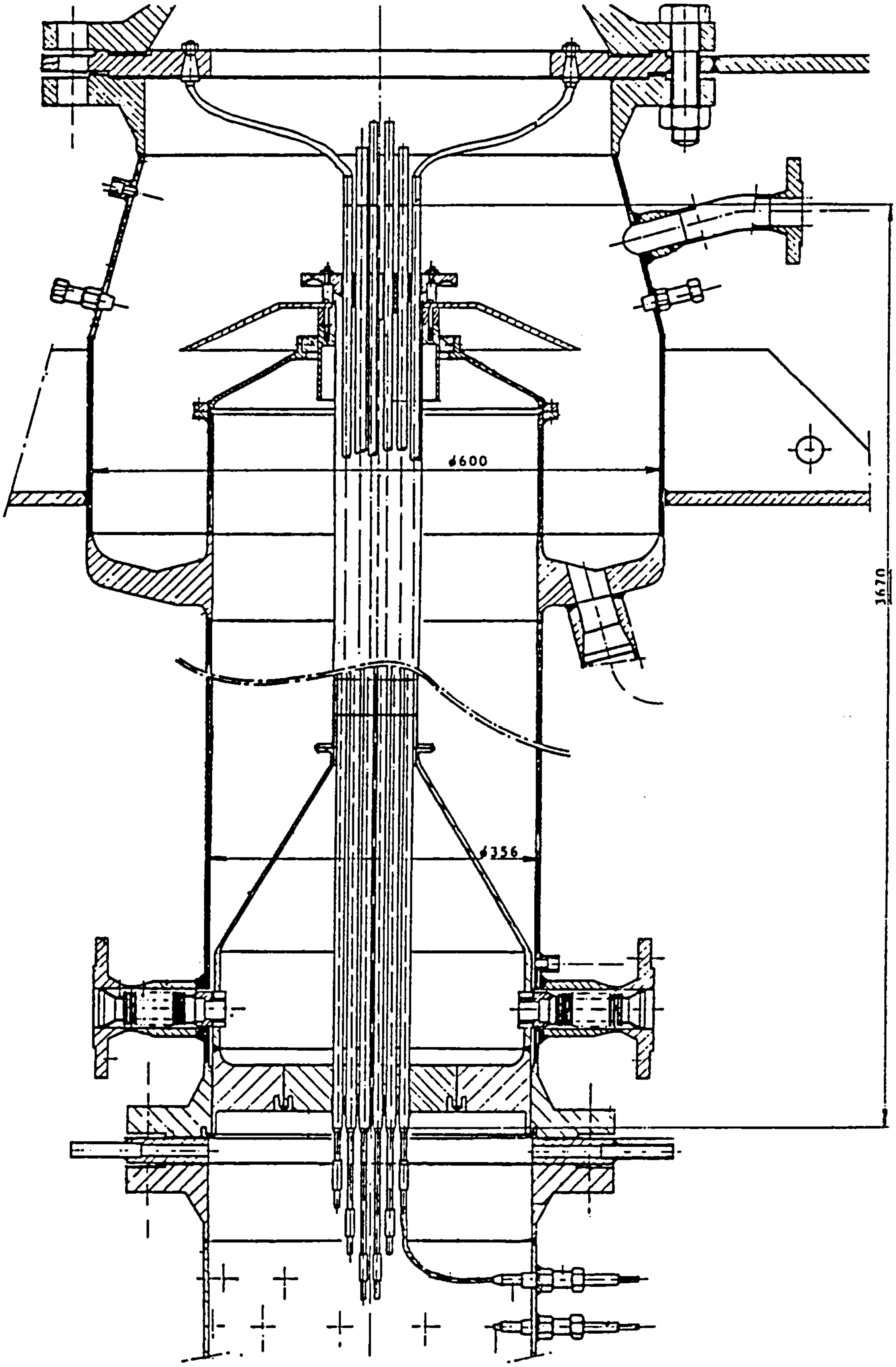


Figure 2.2. Test section and steam/water separator.

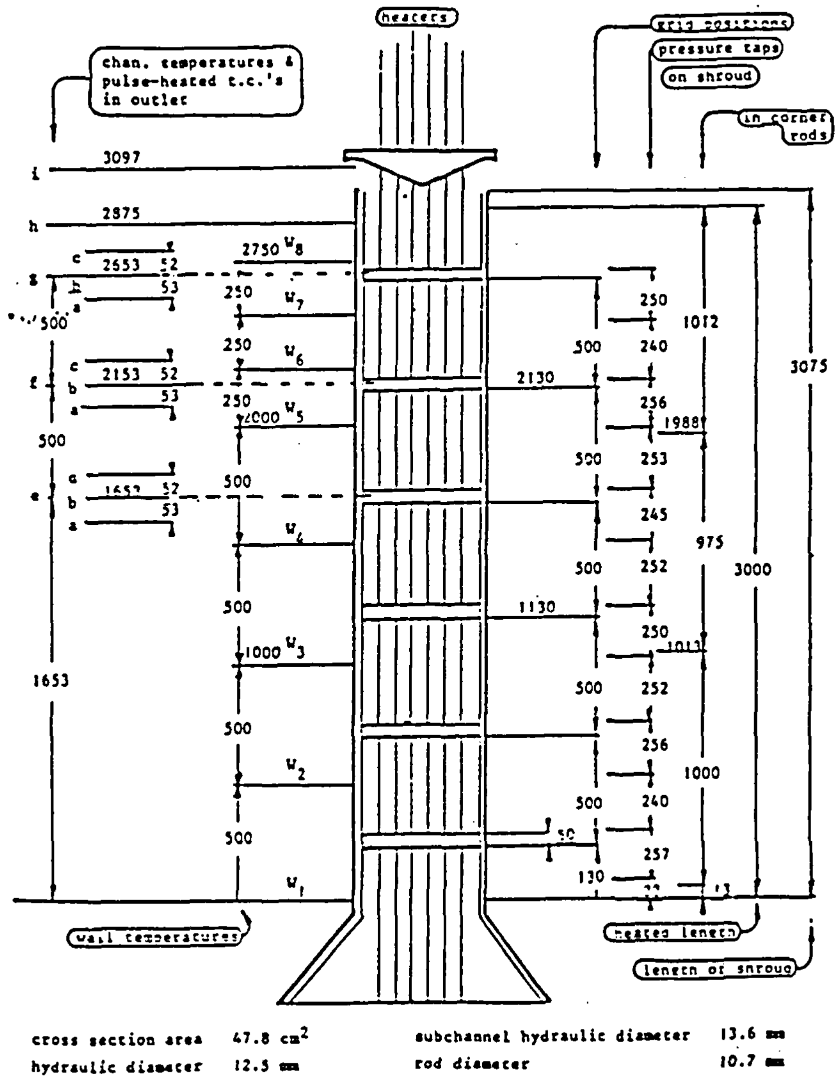
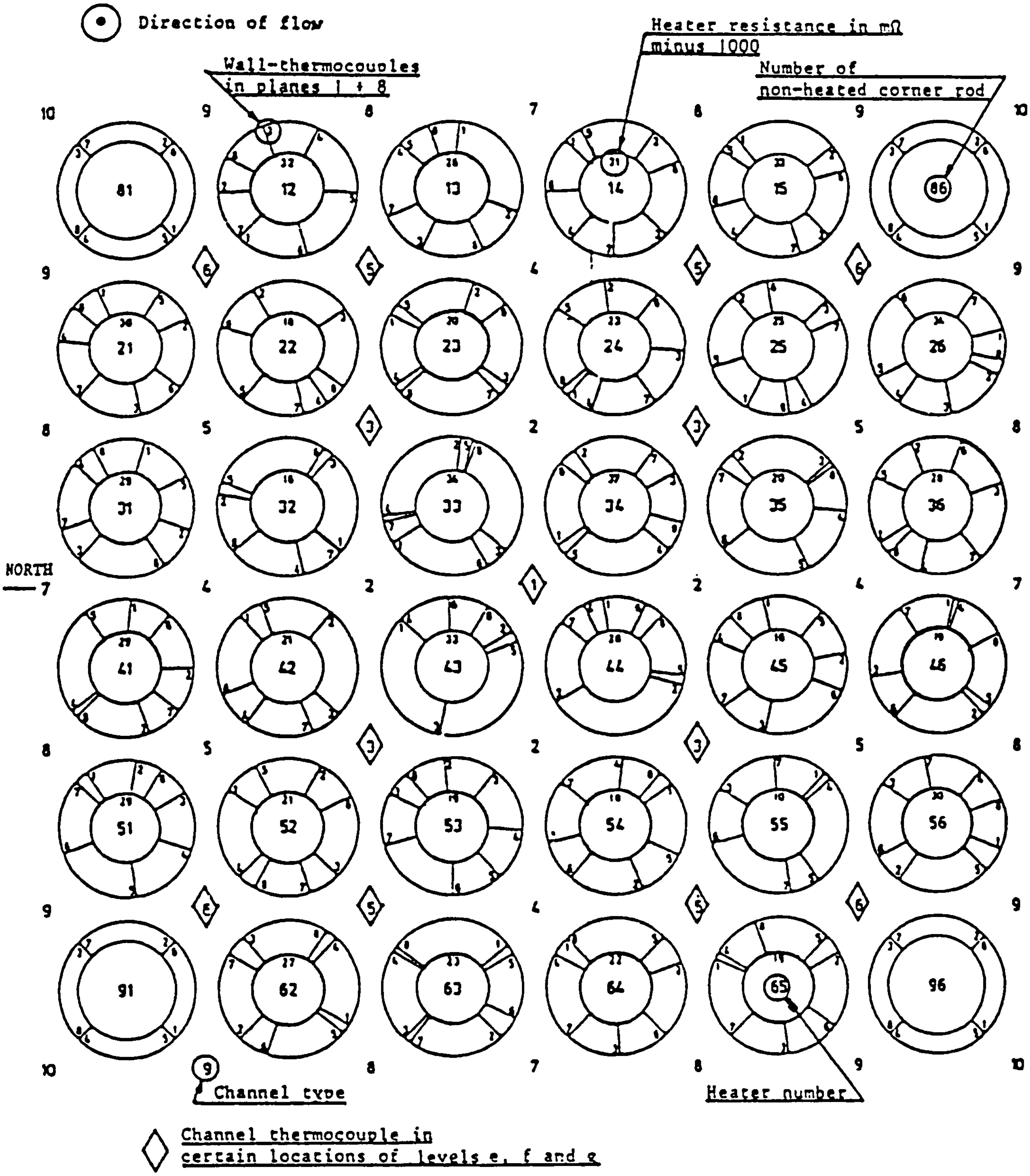


Figure 2.3. Reflood instrumentation in 36-rod bundle.



cross section area 47.8 cm^2 subchannel hydraulic diameter 13.6 mm

hydraulic diameter 12.5 mm rod diameter 10.7 mm

Figure 2.4. Cross-section of the bundle with thermocouple positions.

3. CODE INPUT MODEL DESCRIPTION

The nodalization of the ECN 36-rod reflood test facility is quite simple. As indicated in Fig. 3.1 the electrically heated rod bundle is modelled as a pipe which is connected to a heat slab representing the heater rods. Mass flow, pressure and temperature of water entering the lower plenum of the test section are controlled by the time dependent junction 115 and the time dependent volume 110. Downstream of the test section, the steam water separator has been modelled with the RELAP5 separator component. The separator component is connected to the time dependent volumes 950 and 955.

3.1. Input model sensitivity analyses

Parameters for which a sensitivity analysis may be performed are the length of the hydrodynamic nodes and the maximum number of fine mesh intervals as applied by RELAP5/MOD2 to calculate the axial heat conduction in the rods when using the reflood model. User recommendations suggest a length of the hydrodynamic nodes between 0.15 and 0.61 m, and a maximum number of axial fine mesh intervals equal to 16 or 32. The maximum time step size should range between 0.01 and 0.05 seconds.

Four sensitivity analyses have been performed for experiment number 4100. The parameter variations studied are listed in Table 3.1. while the corresponding nodalization schemes are presented in Fig. 3.1. The resulting rod wall temperature time histories for levels 2 and 3 as identified in Fig. 2.3. are shown in respectively Figs. 3.2 and 3.3. As can be observed from these figures, run 1, 2, and 3 give approximately the same temperature behaviour. Run 4, in which volume lengths of 0.5 m have been used, deviates significantly from the previous three runs, but nevertheless comes closest to the experimentally determined temperature time histories. However, for purpose of determination of code uncertainty the nodalization of run 3 has been selected as the base case input model for code assessment. The temperature time histories as obtained for this run only differ to a minor extend from the ones resulting from run 1 and 2.

Furthermore, a hydrodynamic node length equal to 0.25 m as used in run 3 seems to be the lower bound with respect to core modelling for an actual nuclear power plant. RELAP5/MOD2 plant transient analyses using shorter length of the core hydrodynamic nodes will end-up in unacceptably high computer running times. The number of axial fine mesh intervals does not appear to influence the calculated temperature time histories significantly. Since a two times greater number of mesh intervals results in a small increase in computer running time, as will be shown in chapter 5, the finest mesh intervals will be used in the base case input model.

3.2. Base case input model

Based on the considerations as outlined in the previous section, the base case RELAP5/MOD2 input model nodalization is shown in Fig. 3.4. The hydraulic volumes have a length of 0.25 m and the number of axial fine mesh intervals equal to 32. The maximum time step size is fixed at 0.01 s.

3.3. Initial and operating conditions

The initial and operating conditions are presented in Table 2.4. The data have been fixed at these values by a careful examination of the available data tapes. In Appendix A the input decks for experiment 3216 are given for both the steady state calculation as well as the transient calculation (restart of the steady state calculation). The input decks for the other experiments can be obtained from Appendix A by replacing some data according to Table 2.4.

Table 3.1. Sensitivity analyses performed for experiment no. 4100

Run no.	Volume length (m)	Number of mesh intervals (-)	Maximum time step size (s)
1	.125	16	0.01
2	.125	32	0.01
3	.25	32	0.01
4	.50	32	0.01

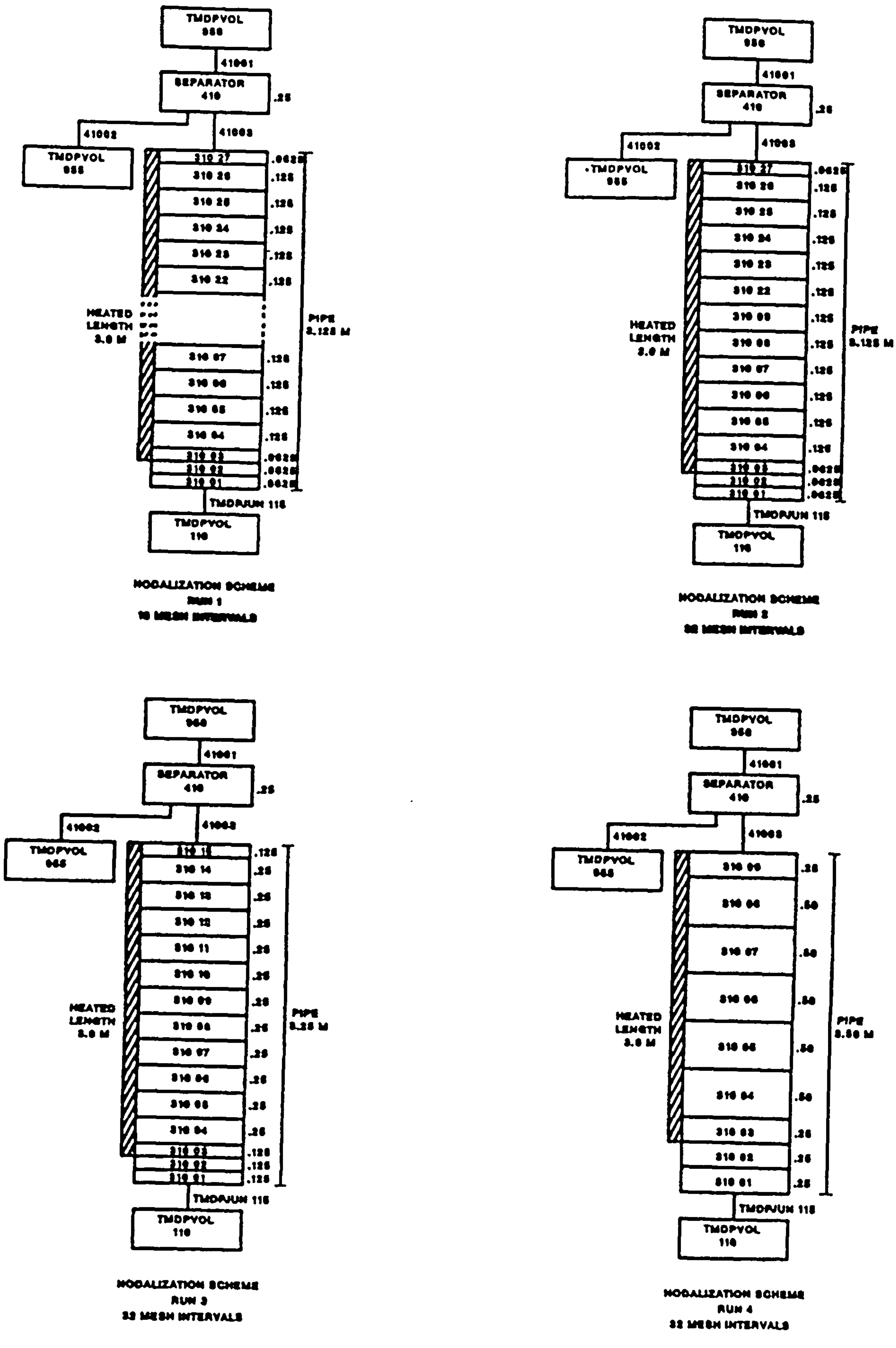


Figure 3.1. Nodalization schemes for sensitivity study.

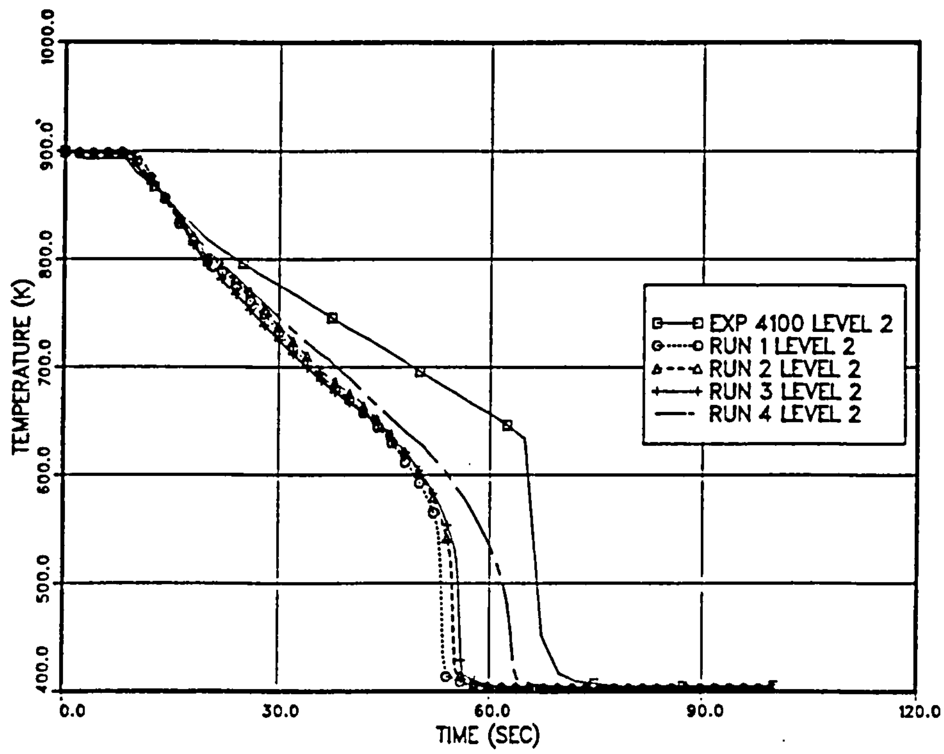


Figure 3.2. EXP 4100; Wall temperatures at level 2.

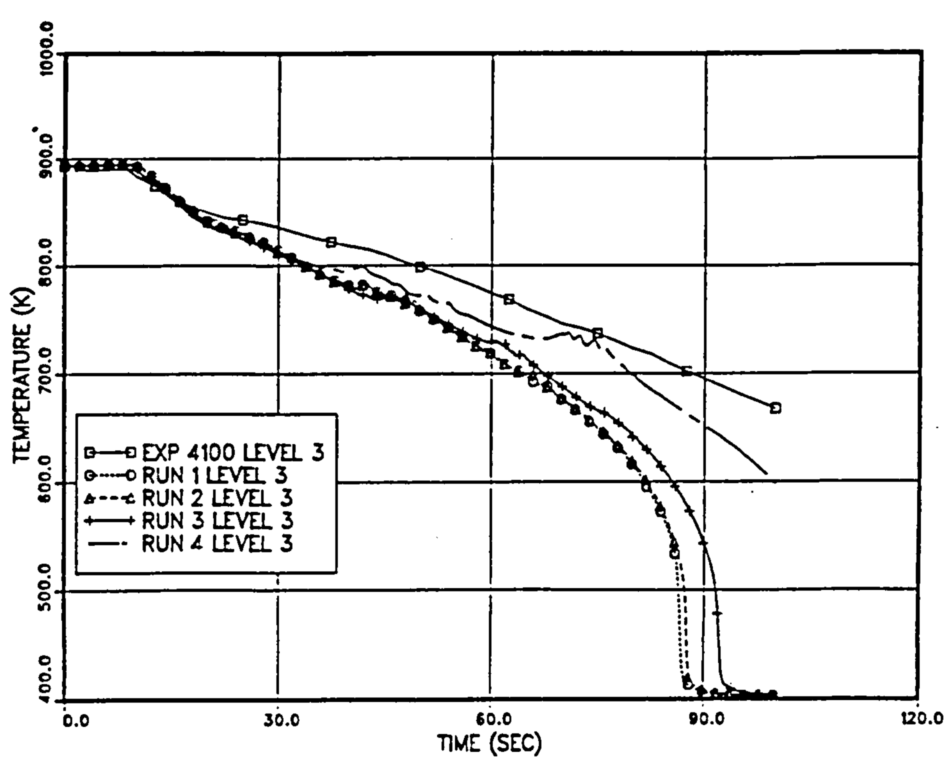


Figure 3.3. EXP 4100; Wall temperatures at level 3.

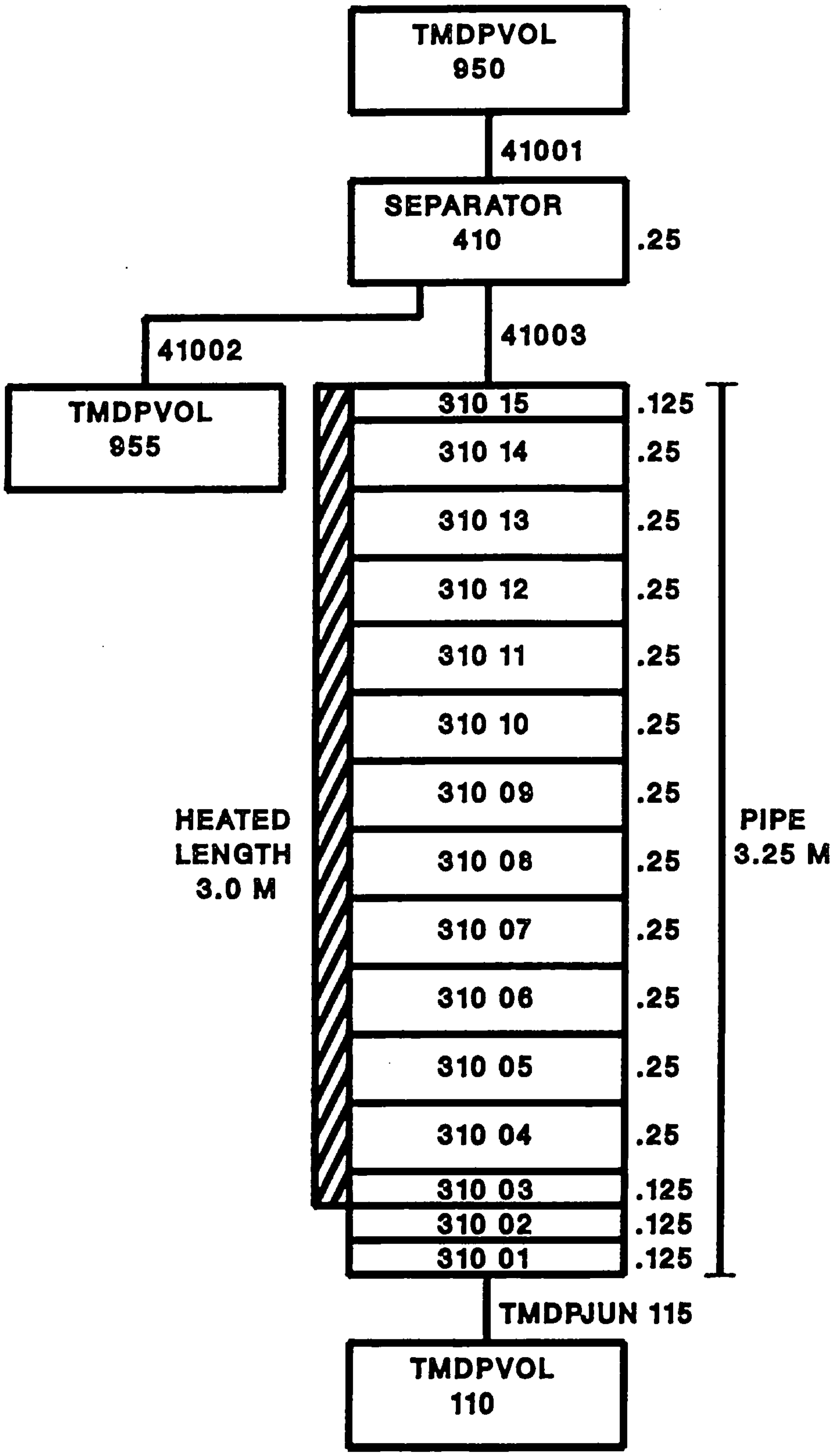


Figure 3.4. **NODALIZATION SCHEME**

4. RESULTS

Comparisons between predictions with the code RELAP5/MOD2 and selected test data from the ECN-reflood experiments [2] are described below.

4.1. Sensitivity analyses

The results of the sensitivity analyses as described in chapter 3.1 can be summarized as follows:

- The results of the coarse node model calculations (0.50 m) deviate significantly from the results obtained with the fine node model (0.125 and 0.25 m).
- The number of axial fine mesh intervals (16 or 32) does not influence the calculated temperature time histories significantly as can be seen in Fig. 3.2 and 3.3.

Based on these conclusions the nodalization as presented in Fig. 3.4. is applied for the analyses.

4.2. RELAP5/MOD2 results vs experimental data

Code predictions are compared with the following measured quantities:

- Integrated boundary mass flows.
- Liquid mass inventory in the bundle.
- Collapsed liquid level.
- Quench front position.
- Wall temperatures at different levels.

Comparisons between code predictions and test data for the seven selected reflood experiments are presented as follows:

Experiment 3216: figures 4.1 - 4.8.
Experiment 3224; figures 4.9 - 4.16.
Experiment 4100; figures 4.17 - 4.24.
Experiment 4106; figures 4.25 - 4.32.
Experiment 4120; figures 4.33 - 4.40.
Experiment 4138; figures 4.41 - 4.48.
Experiment 4149: figures 4.49 - 4.56.

4.3. Analysis of results

The calculations have been performed with the code RELAP5/MOD2 using the available reflood model. As already mentioned in the previous section the number of axial mesh intervals during reflood is set to 16 and the nodalization presented in Fig. 3.4 is applied. The reflood model has to be activated at the start of each calculation. The reflood heat transfer package in the code RELAP5/MOD2, however, is only valid for flow patterns occurring at high reflood velocities (inverted annular flow). As for low reflood velocities a different flow pattern occurs (annular flow) a herewith corresponding heat transfer package should have been applied. For this reason agreement between calculated and experimental data can be expected for high reflood velocities. Only at these high reflood velocity conditions a flow pattern with the quench front below the collapsed liquid level will occur.

In Figs. 4.57 through 4.70 the RELAP5/MOD2 calculated and the experimental results concerning quench front position and collapsed liquid level are presented for the different selected cases.

Only for experiment 4120 the condition of a quench front below the collapsed liquid level is met as can be seen in Figs. 4.65 and 4.66. For this experiment the calculated values compare in general well with the experimental results as presented in Figs. 4.33 through 4.40.

Figs. 4.71 through 4.78 show the calculated and measured heat flux at axial level 5, 6, 7, and 8 for experiment 4120. These figures show that near the quench front the calculated heat flux is overpredicted and that well above the quench front the heat flux is underpredicted. This explains the overprediction of the wall temperatures below the quench front and the underprediction of the wall temperatures above the quench front as presented in Figs. 4.39 and 4.40. The approach of the quench front causes a faster wall temperature decrease in the calculation due to an overestimation of the heat transfer and so the heat flux. Except for level 8 the calculated wall temperatures for experiment 4100 show the same good agreement as described above for experiment 4120 (Figs. 4.23 and 4.24). This agrees well with the above stated simplification in the RELAP5/MOD2 reflood model concerning heat transfer and flow regime. Experiment 4120 as well as experiment 4100 have a high reflood velocity leading to the inverted annular flow regime identical to the model in RELAP5/MOD2.

The calculated wall temperatures for experiments 3216 and 3224 show a large deviation from the experimental data (Figs. 4.7 and 4.8 and Figs. 4.15 and 4.16). These experiments have a low reflood velocity and for that reason do not experience the inverted annular flow regime. For this reason the heat transfer is widely underpredicted. Poor comparison results are also obtained for experiment 4106, 4138, and 4149 where the quenching of the higher levels starts far too late or not at all. The calculated quenching of level 2 and 3 in these experiments is reasonably predicted. cFigs. 4.31 and 4.32, Figs. 4.47 and 4.48, and Figs. 4.55 and 4.56). For almost all calculations the liquid carry-over is grosly overpredicted and this results in an underprediction of the collapsed liquid level. The overprediction of the carry-over of the water at the bundle outlet is that an overprediction of the interphase drag in rod bundle geometries.

4.4. Suggestions for model improvements

As the reflood heat transfer package in the code RELAP5/MOD2 is only valid for flow patterns occurring at high reflood velocities (inverted annular flow) implementation of heat transfer correlations for other flow patterns (annular flow) during reflood is recommended. Most of the RELAP5/MOD2 assessment work indicates an overprediction of the carry-over due to an overprediction of the interfacial drag. This deficiency of the code is also demonstrated in these analyses. For this reason the introduction of a better correlation for the interfacial friction in the bubbly and slug flow regimes is suggested.

4.5. User guidelines

User recommendations in the RELAP5/MOD2 manual suggest a length of the hydrodynamic nodes between 0.15 and 0.61 m, and a maximum number of axial fine mesh intervals equal to 16 or 32. The recommended maximum time step size should range between 0.01 and 0.05 seconds. In the base case RELAP5/MOD2 input model for the presented reflood analyses the length of the hydrodynamic nodes is 0.25 m with a maximum number of 32 axial fine mesh intervals at the quench level. The maximum time step equals to 0.01 second.

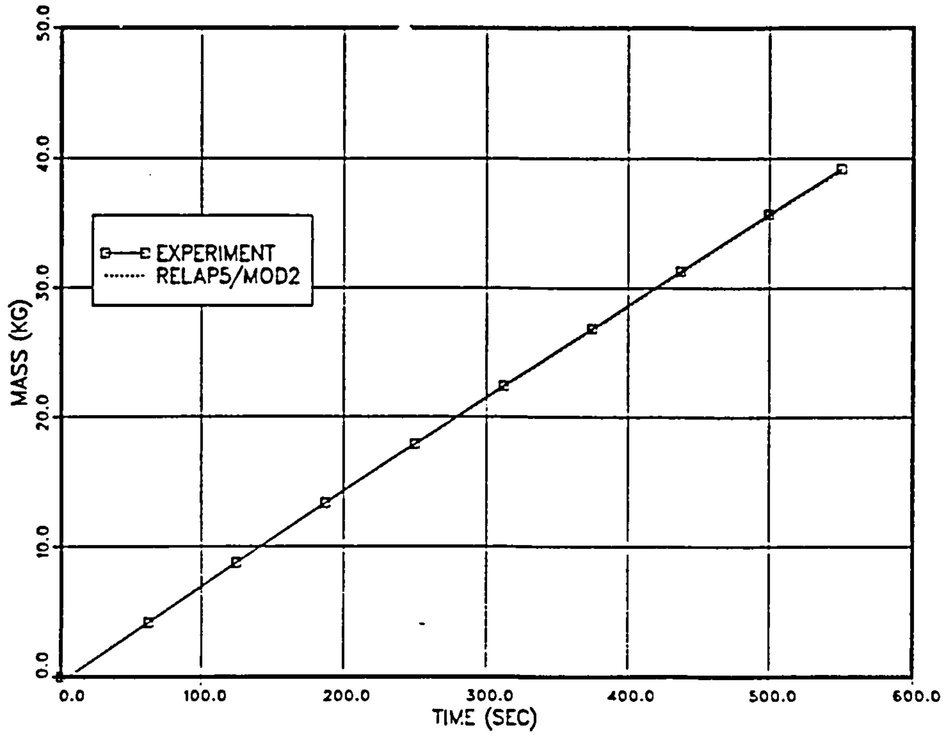


Figure 4.1. EXP 3216; Mass injected.

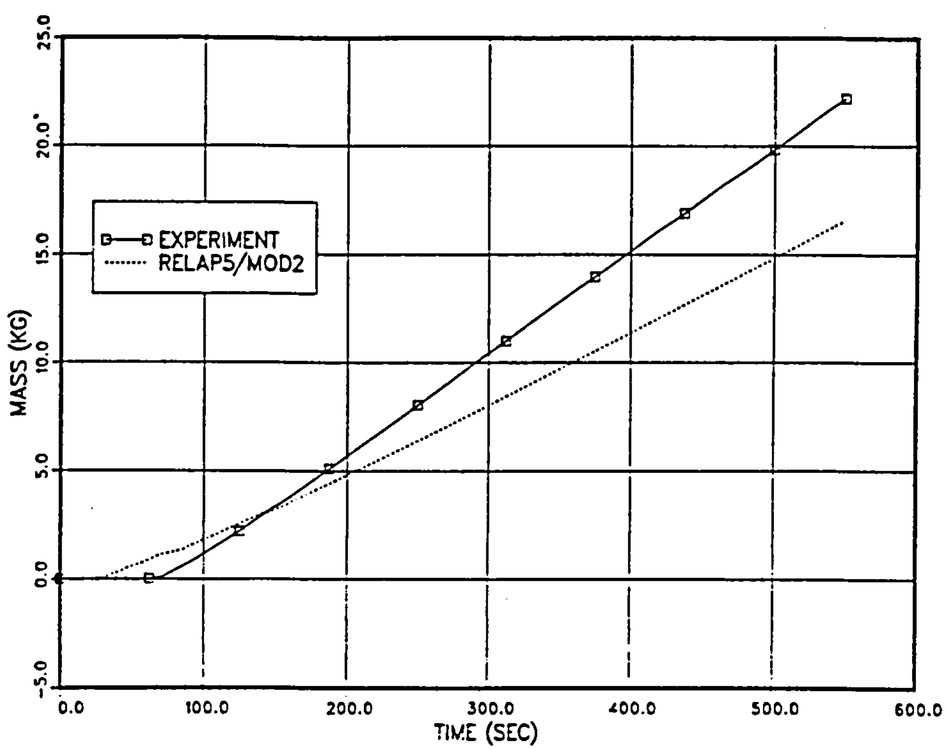


Figure 4.2. EXP 3216; Mass steam out.

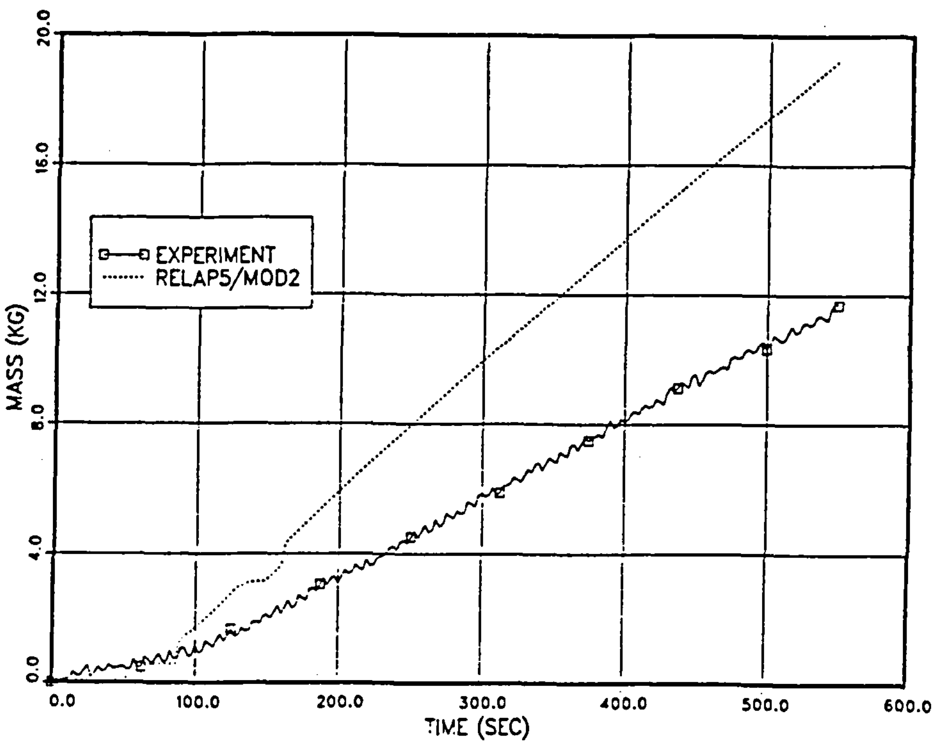


Figure 4.3. EXP 3216; Total mass carry-over.

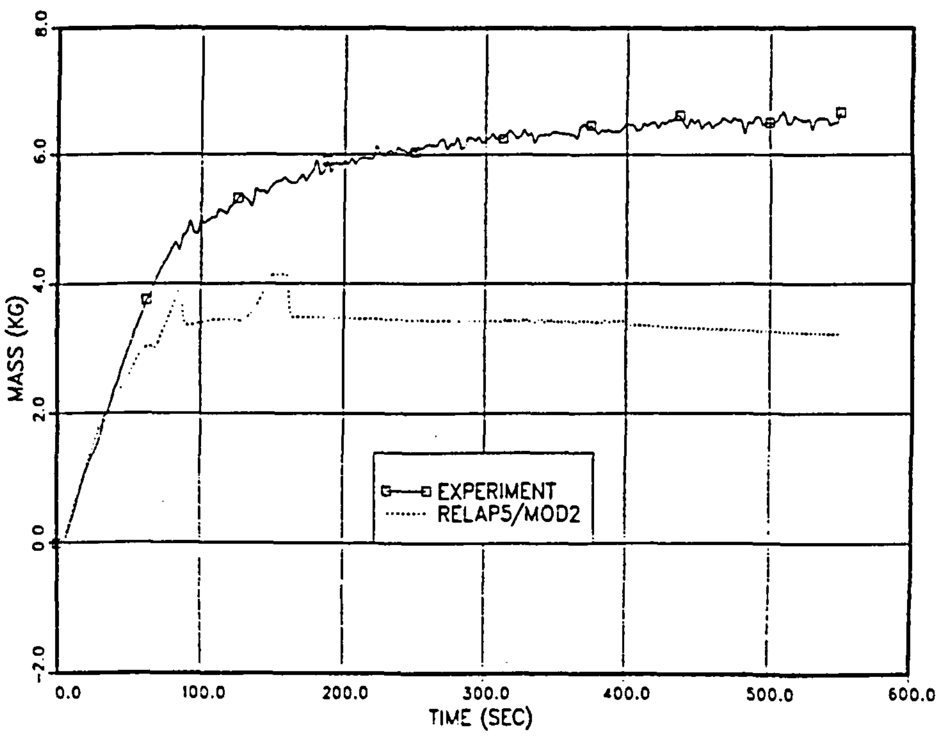


Figure 4.4. EXP 3216; Mass in the bundle.

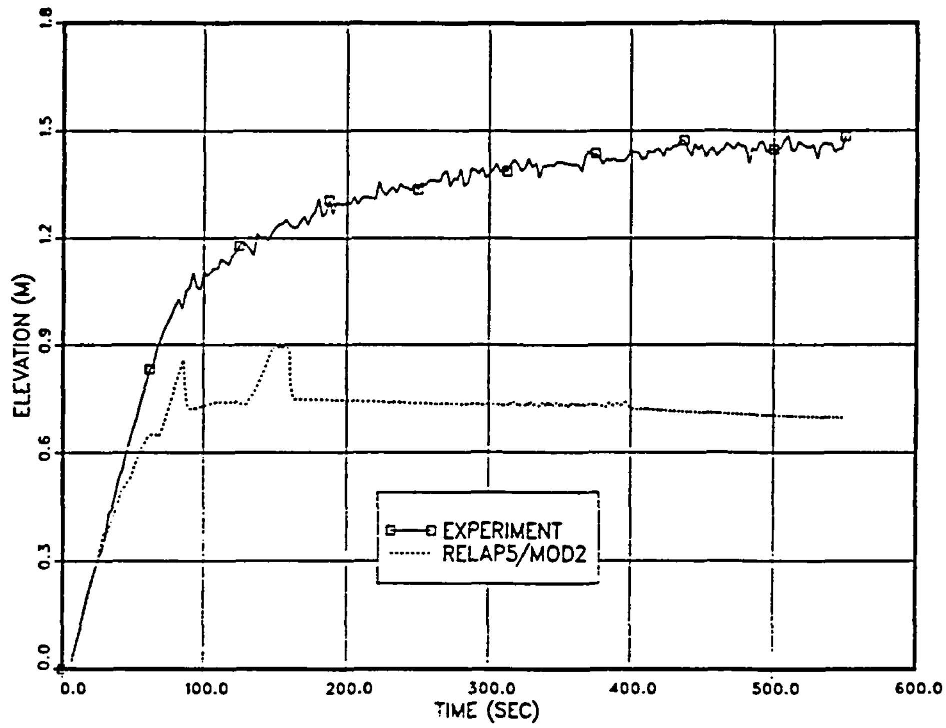


Figure 4.5. EXP 3216; Collapsed liquid level.

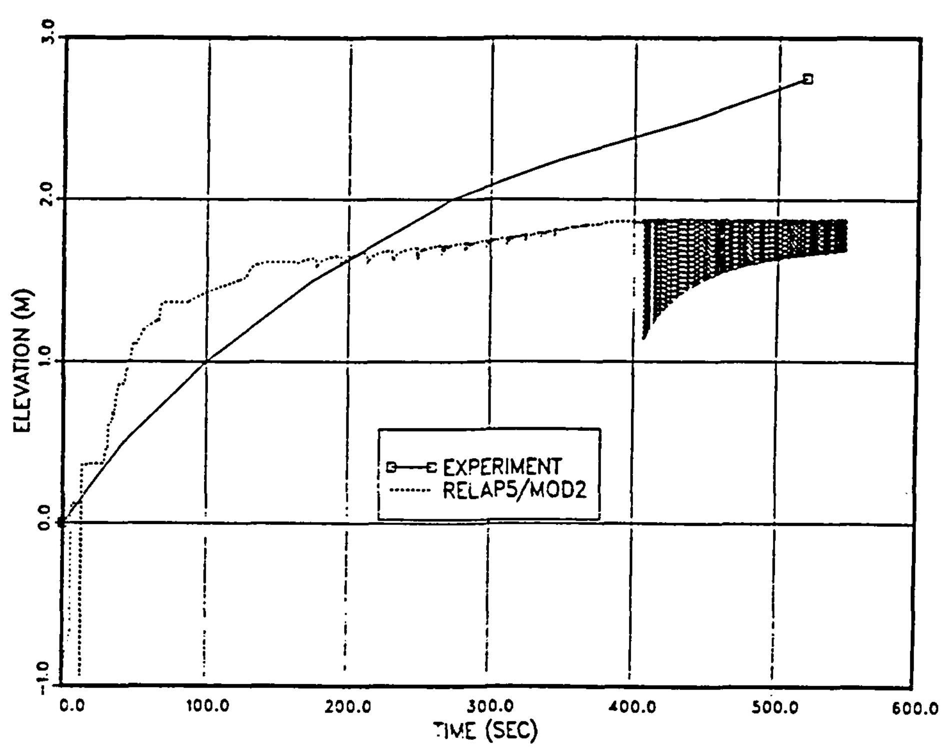


Figure 4.6. EXP 3216; Quench front position.

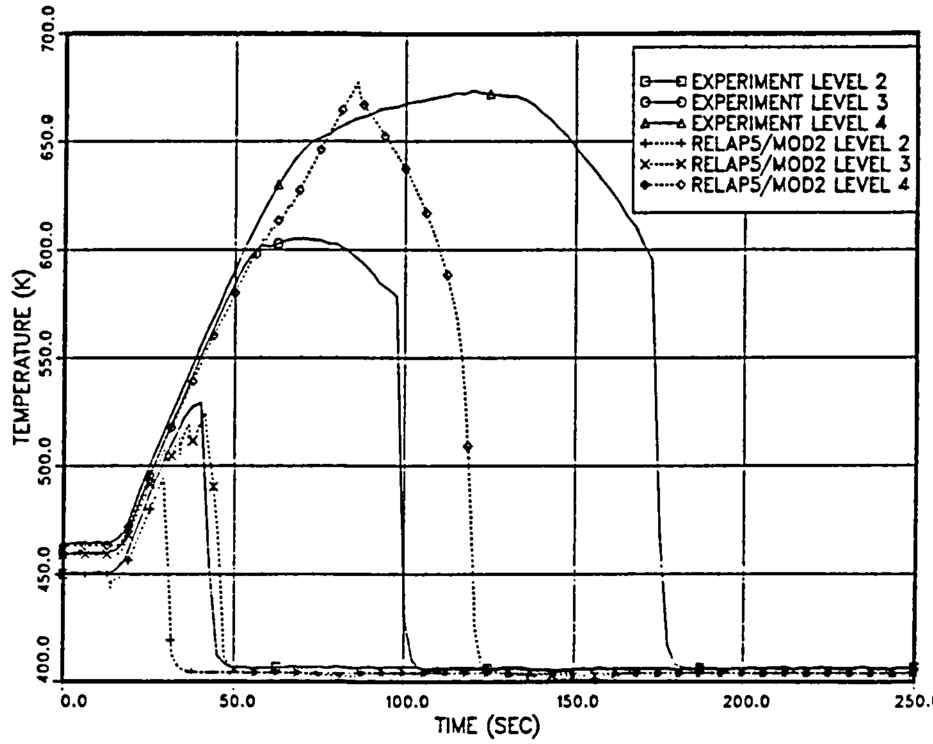


Figure 4.7. EXP 3216; Wall temperatures at level 2, 3, 4.

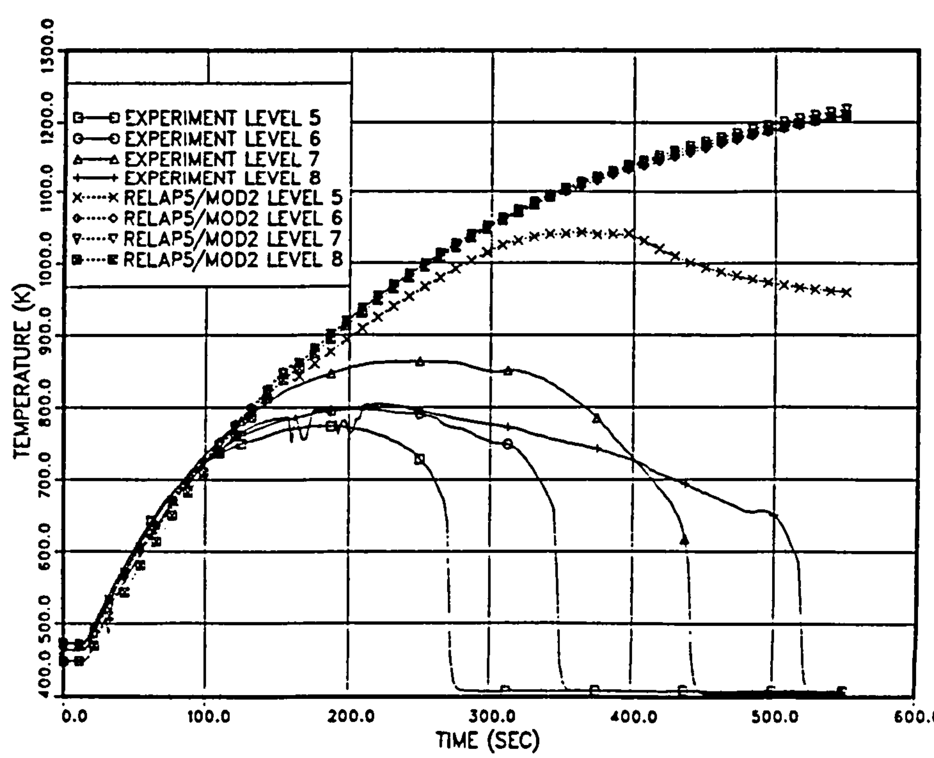


Figure 4.8. EXP 3216; Wall temperatures at level 5, 6, 7, 8.

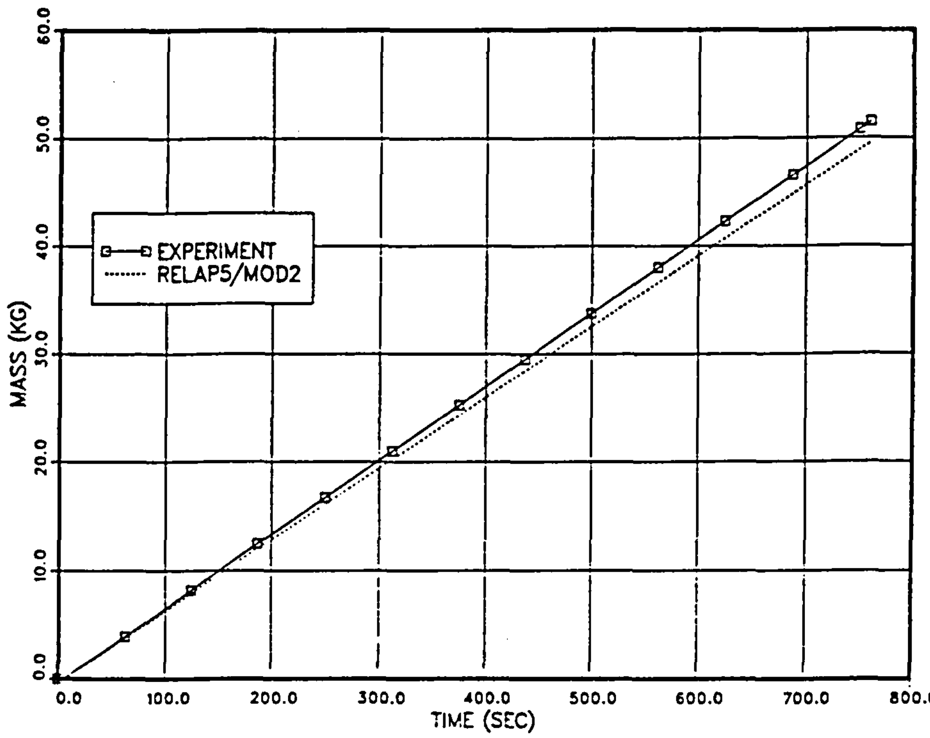


Figure 4.9. EXP 3224; Mass injected.

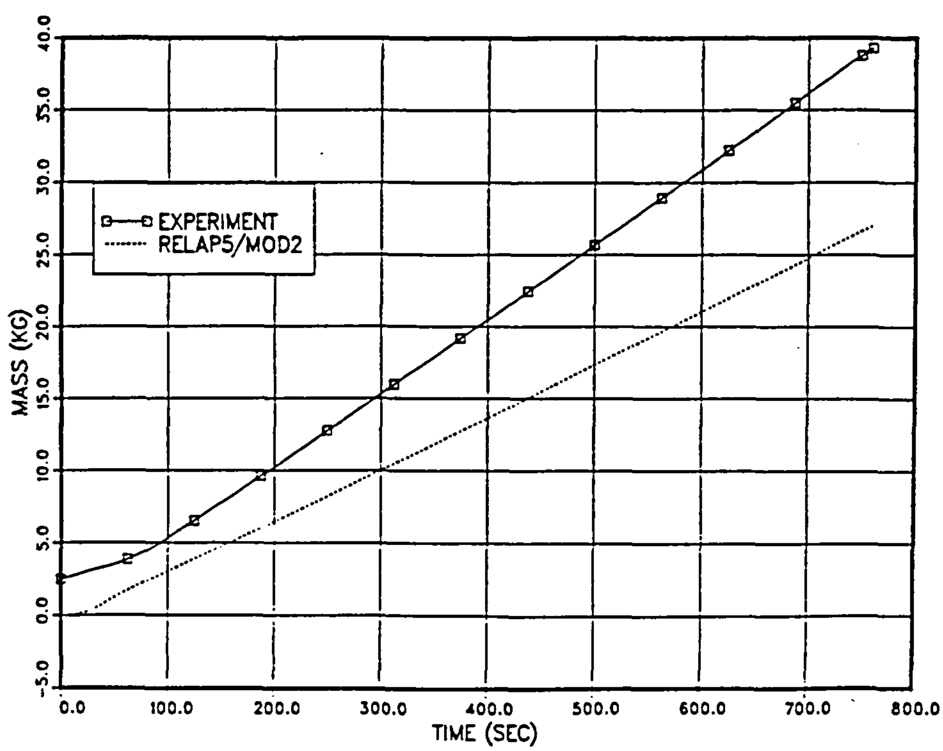


Figure 4.10. EXP 3224; Mass steam out.

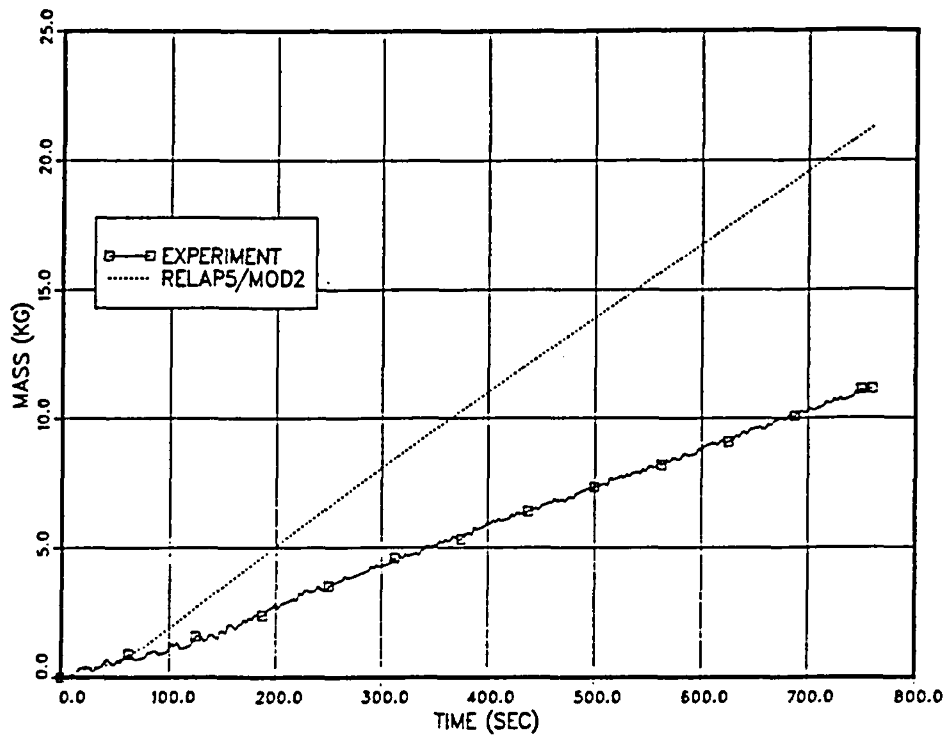


Figure 4.11. EXP 3224; Total mass carry-over.

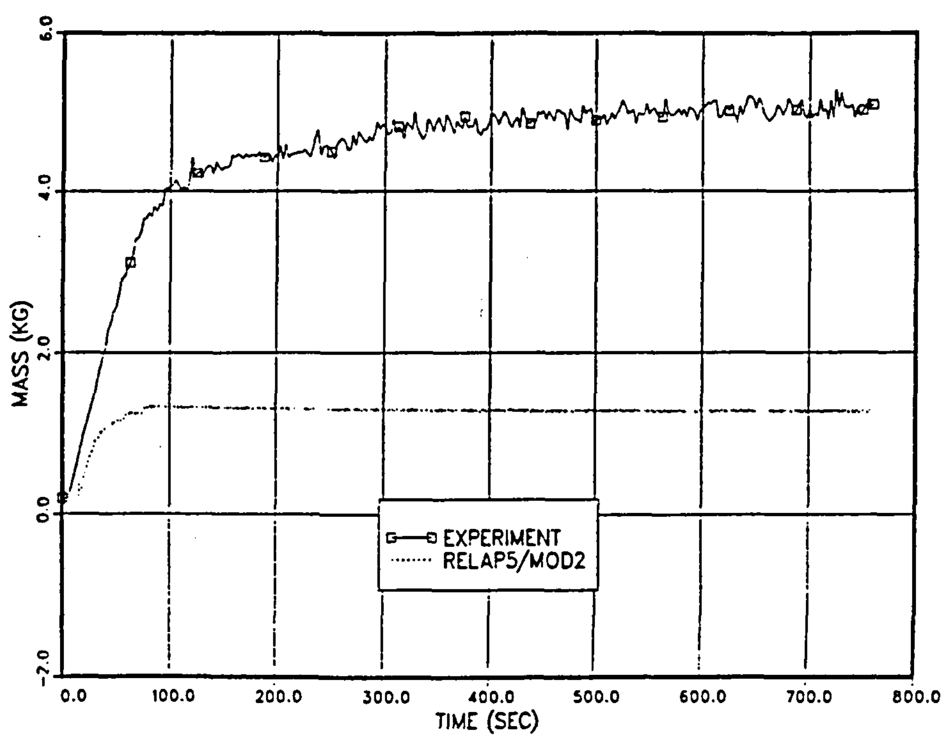


Figure 4.12. EXP 3224; Mass in the bundle.

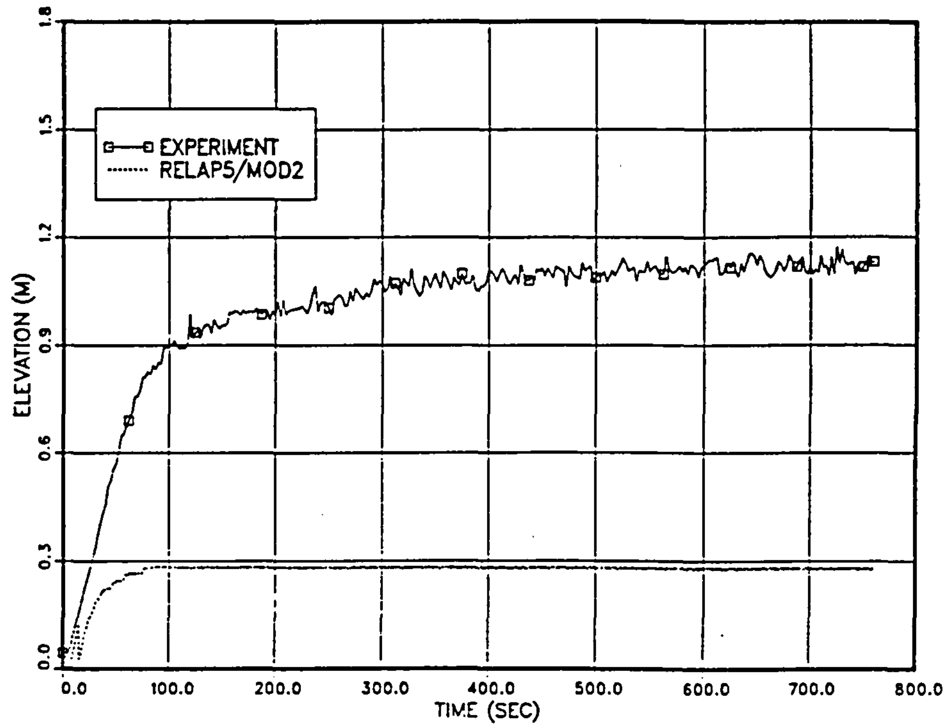


Figure 4.13. EXP 3224; Collapsed liquid level.

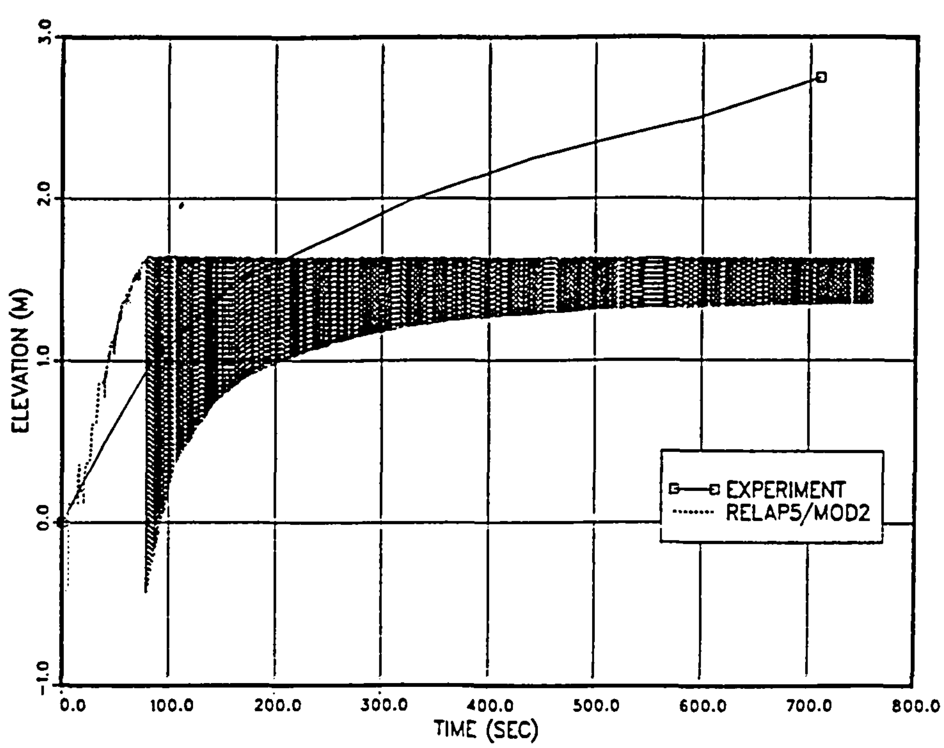


Figure 4.14. EXP 3224; Quench front position.

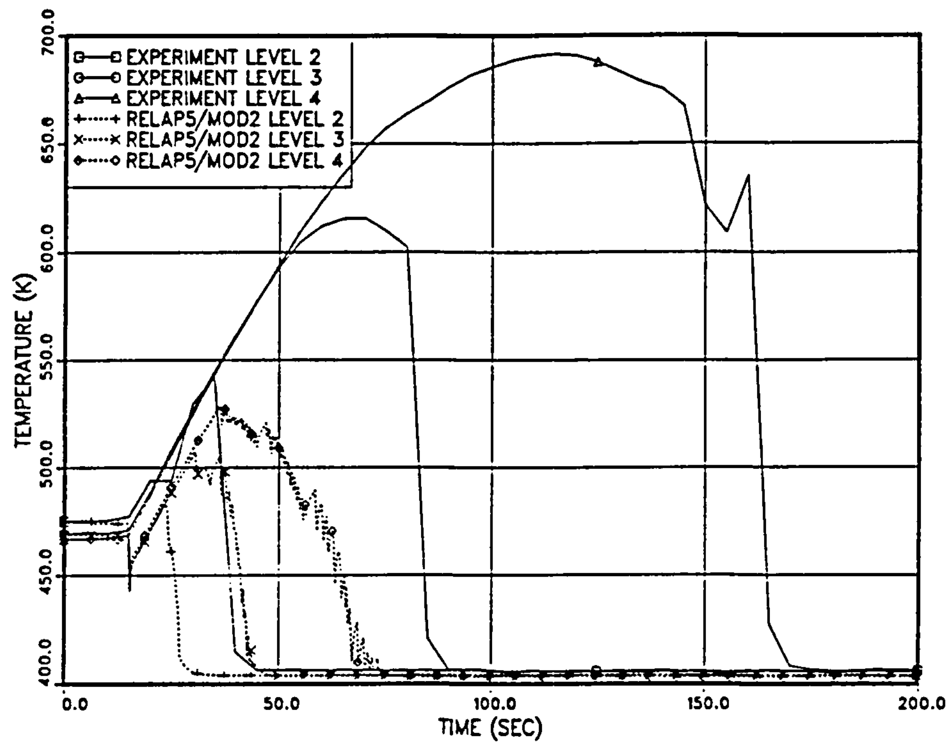


Figure 4.15. EXP 3224; Wall temperatures at level 2, 3, 4.

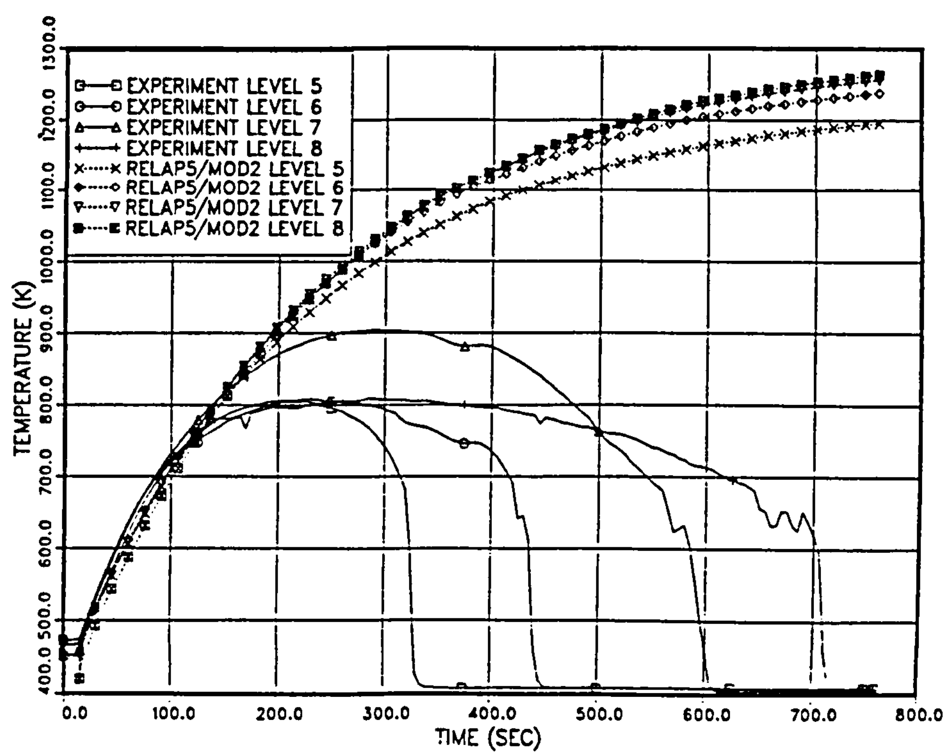


Figure 4.16. EXP 3224; Wall temperatures at level 5, 6, 7, 8.

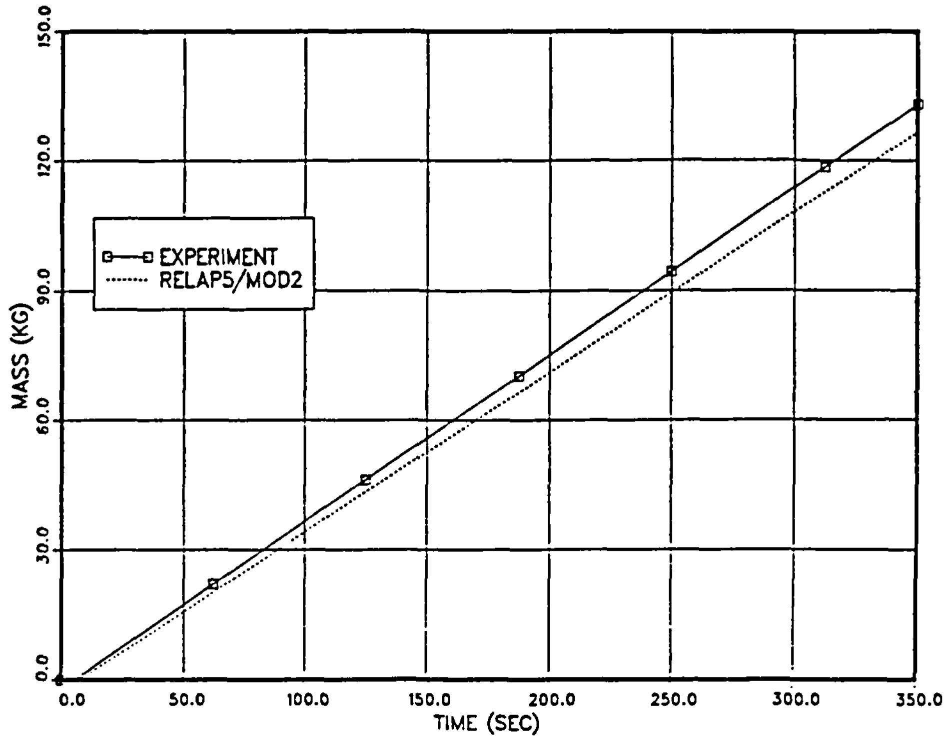


Figure 4.17. EXP 4100; Mass injected.

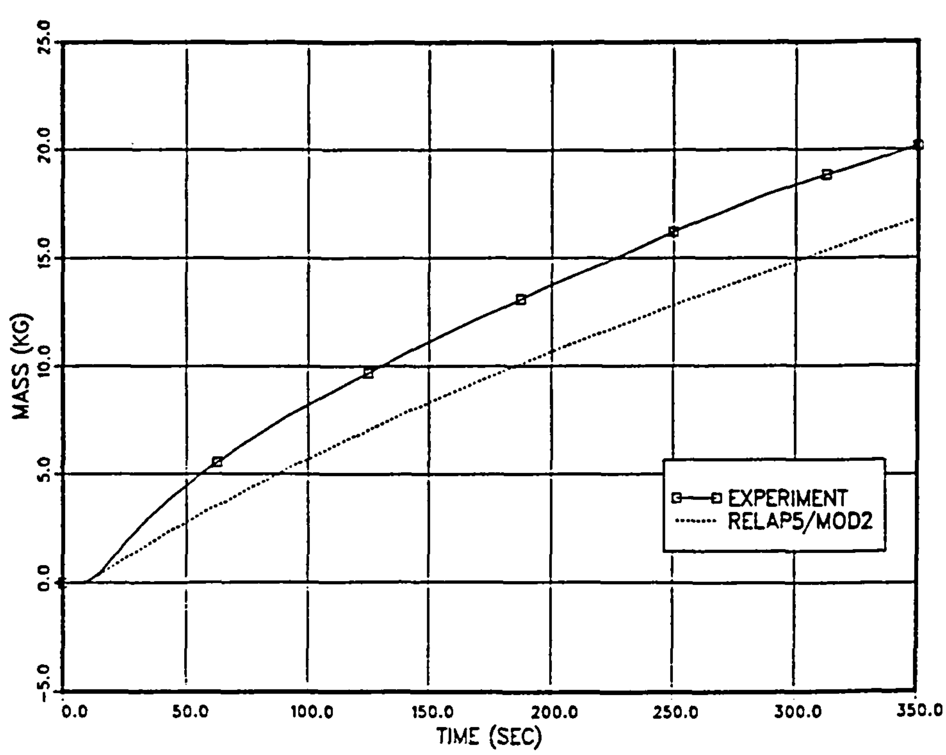


Figure 4.18. EXP 4100; Mass steam out.

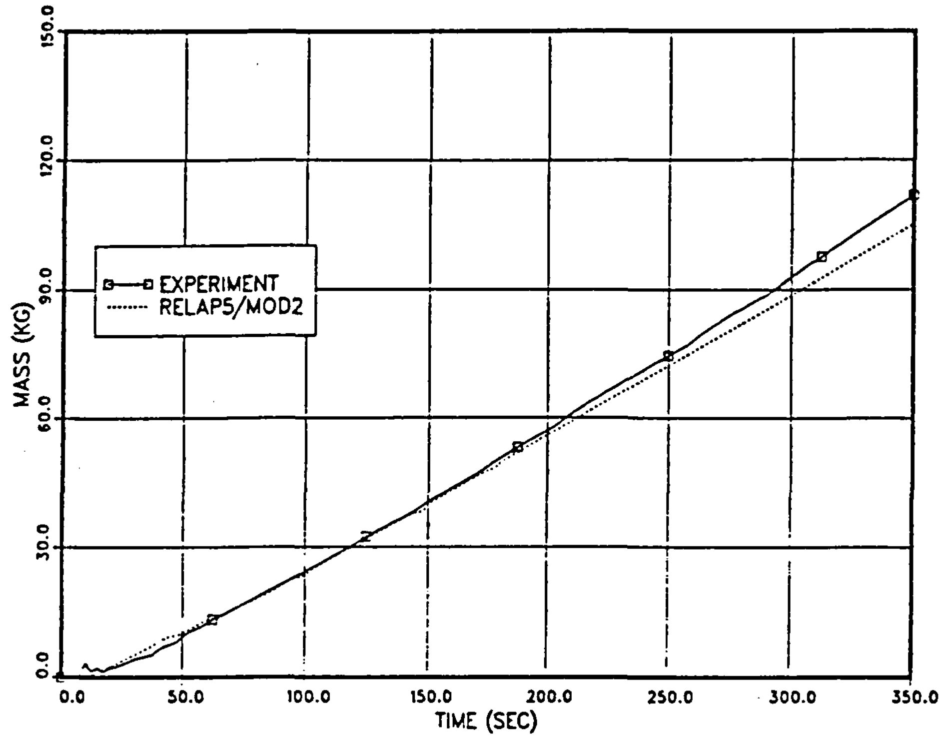


Figure 4.19. EXP 4100; Total mass carry-over.

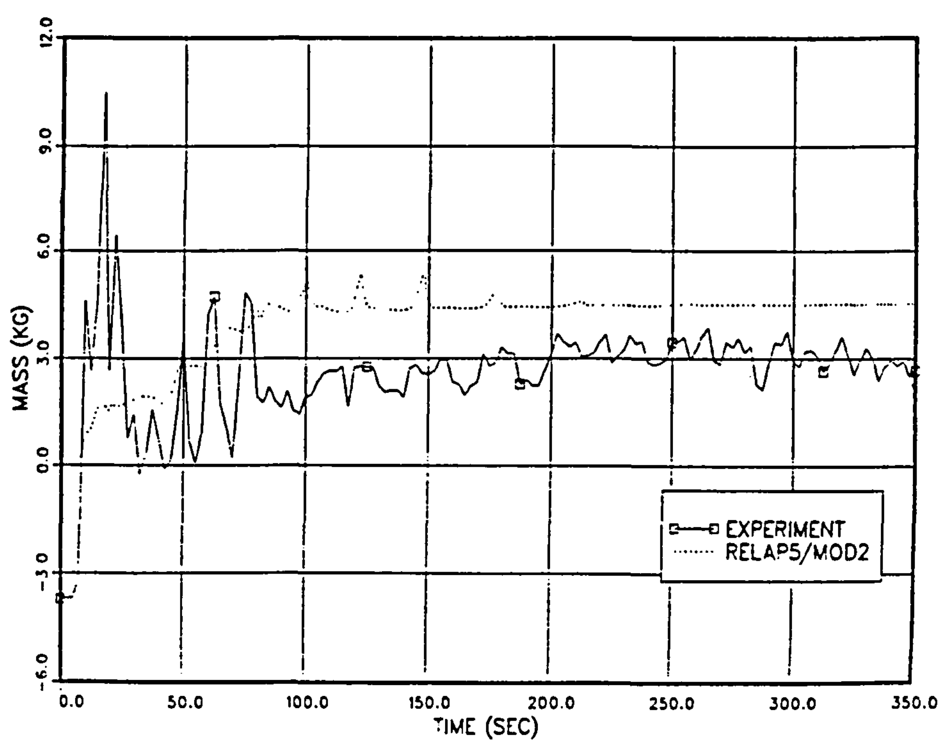


Figure 4.20. EXP 4100; Mass in the bundle.

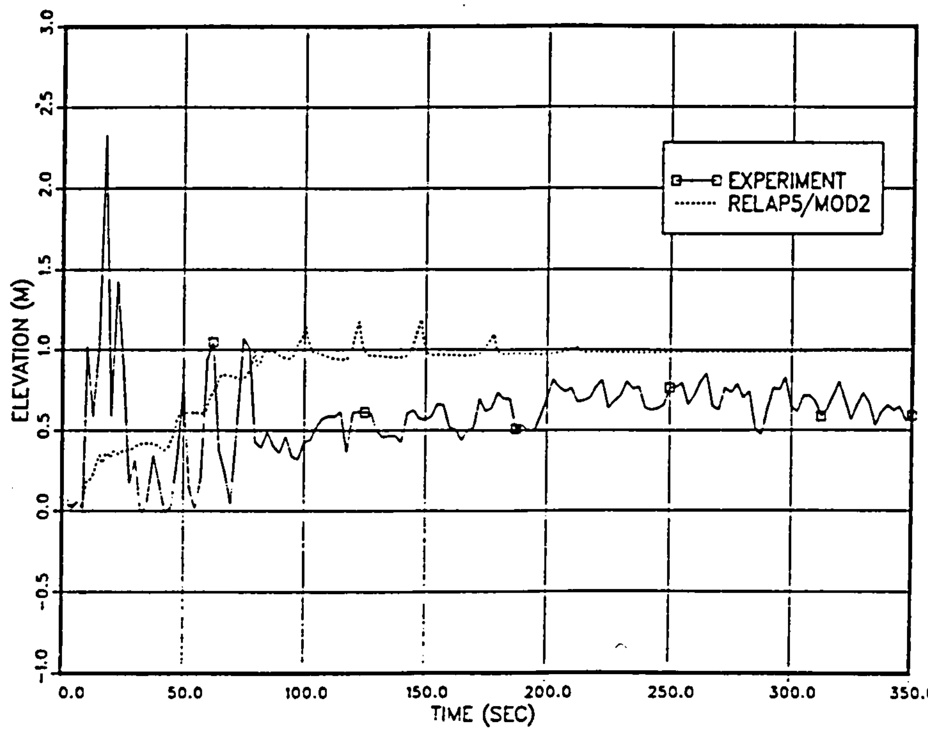


Figure 4.21. EXP 4100; Collapsed liquid level.

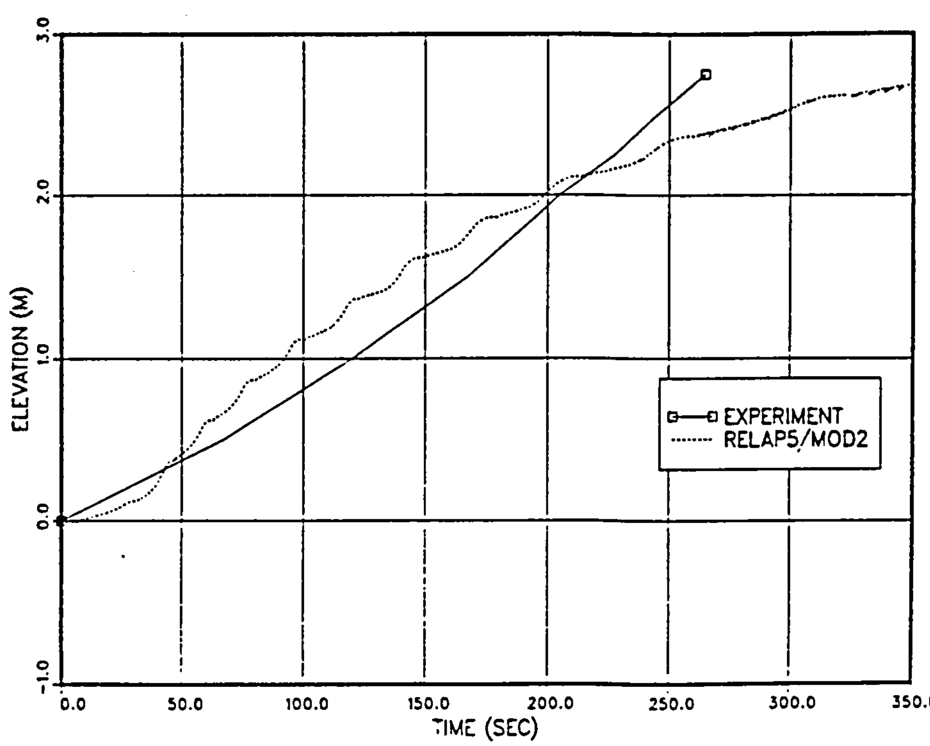


Figure 4.22. EXP 4100; Quench front position.

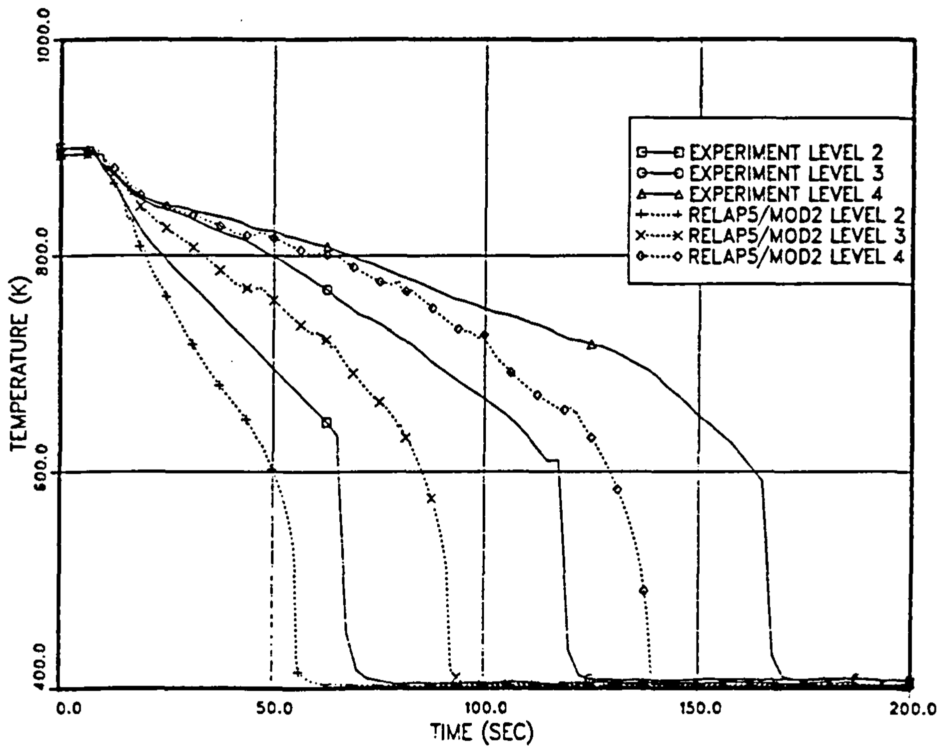


Figure 4.23. EXP 4100; Wall temperatures at level 2, 3, 4.

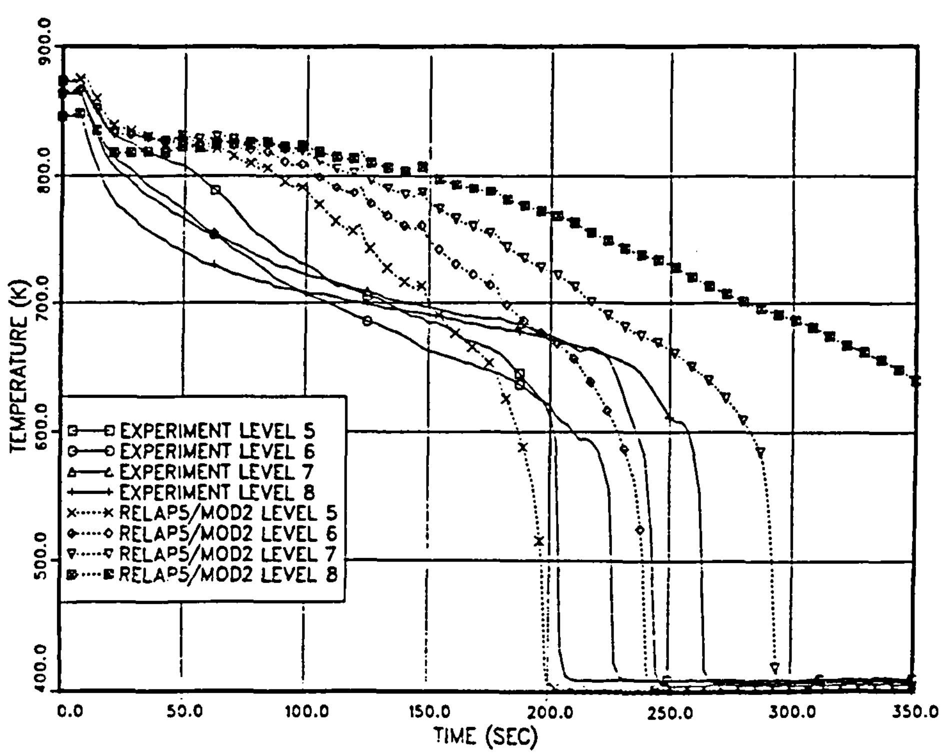


Figure 4.24. EXP 4100; Wall temperatures at level 5, 6, 7, 8.

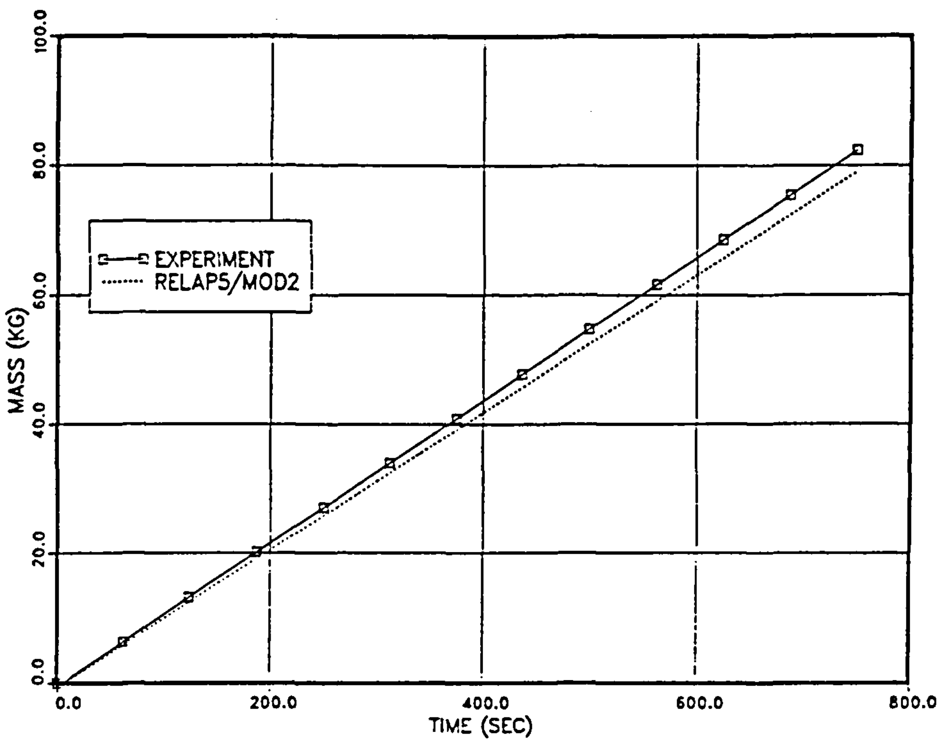


Figure 4.25. EXP 4106; Mass injected.

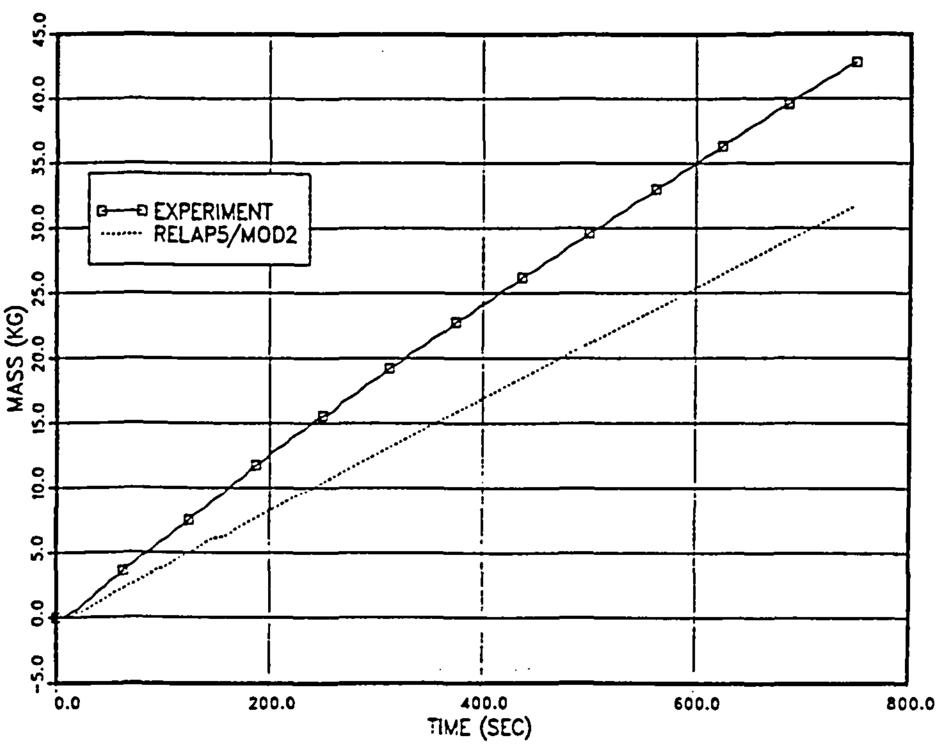


Figure 4.26. EXP 4106; Mass steam out.

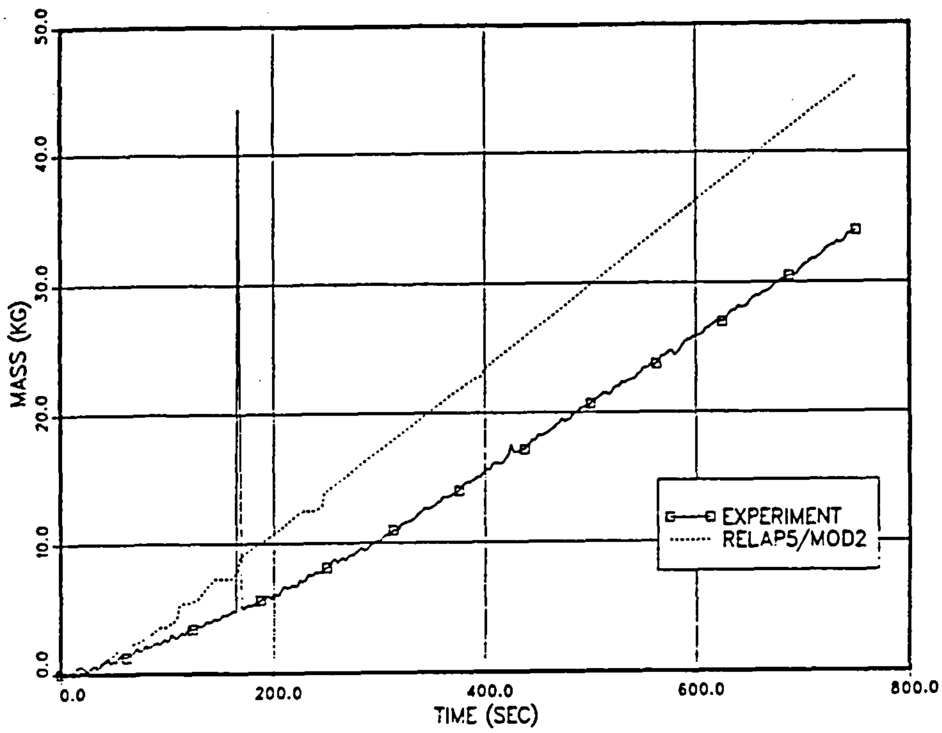


Figure 4.27. EXP 4106; Total mass carry-over.

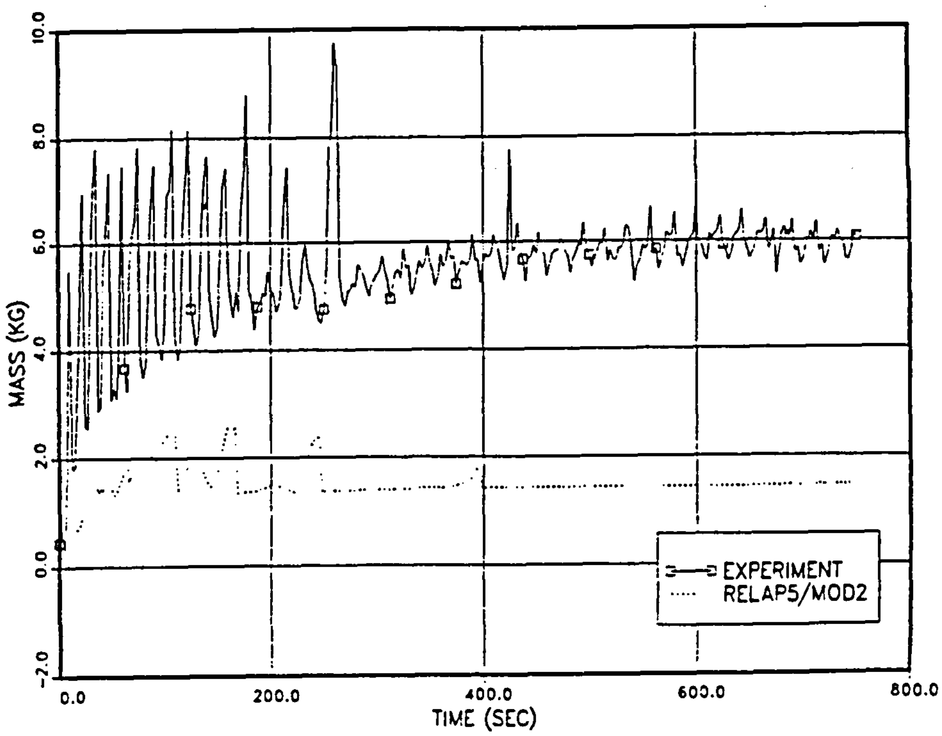


Figure 4.28. EXP 4106; Mass in the bundle.

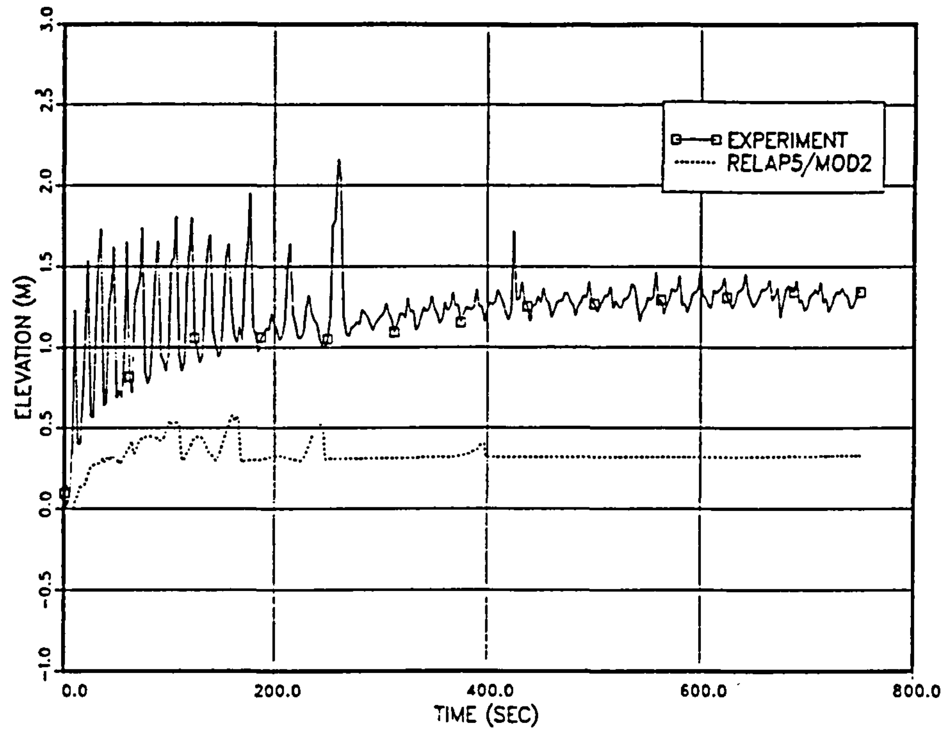


Figure 4.29. EXP 4106; Collapsed liquid level.

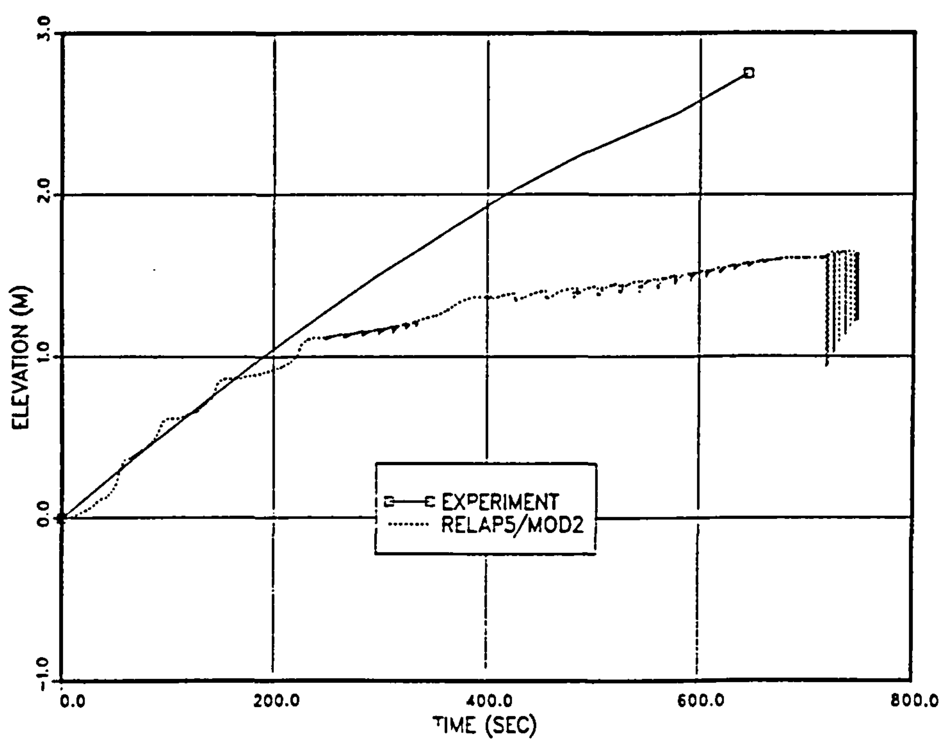


Figure 4.30. EXP 4106; Quench front position.

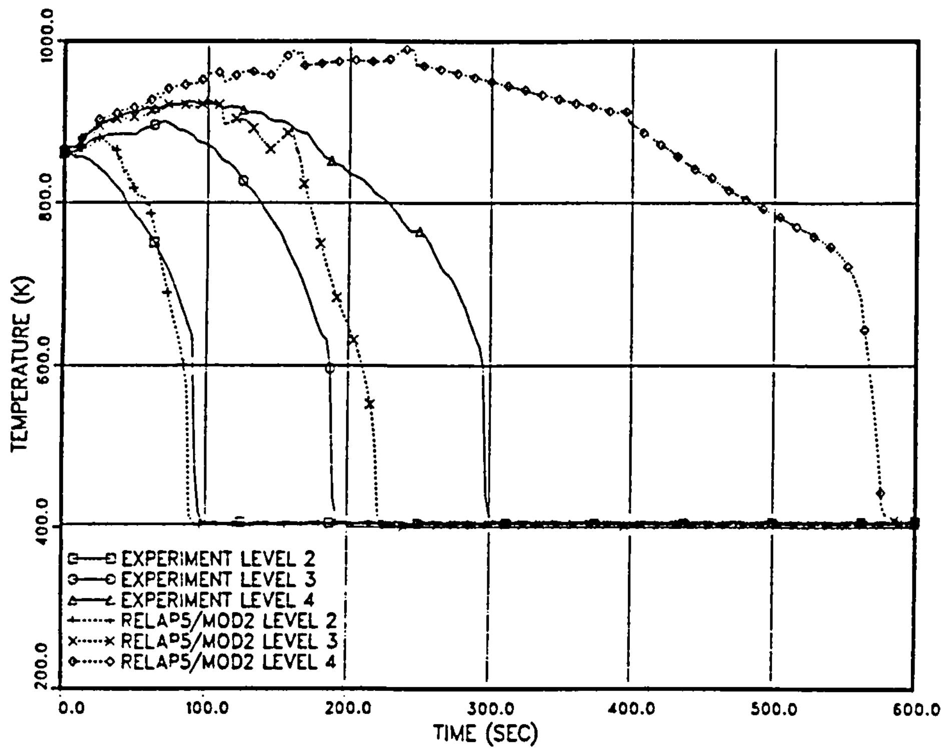


Figure 4.31. EXP 4106; Wall temperatures at level 2, 3, 4.

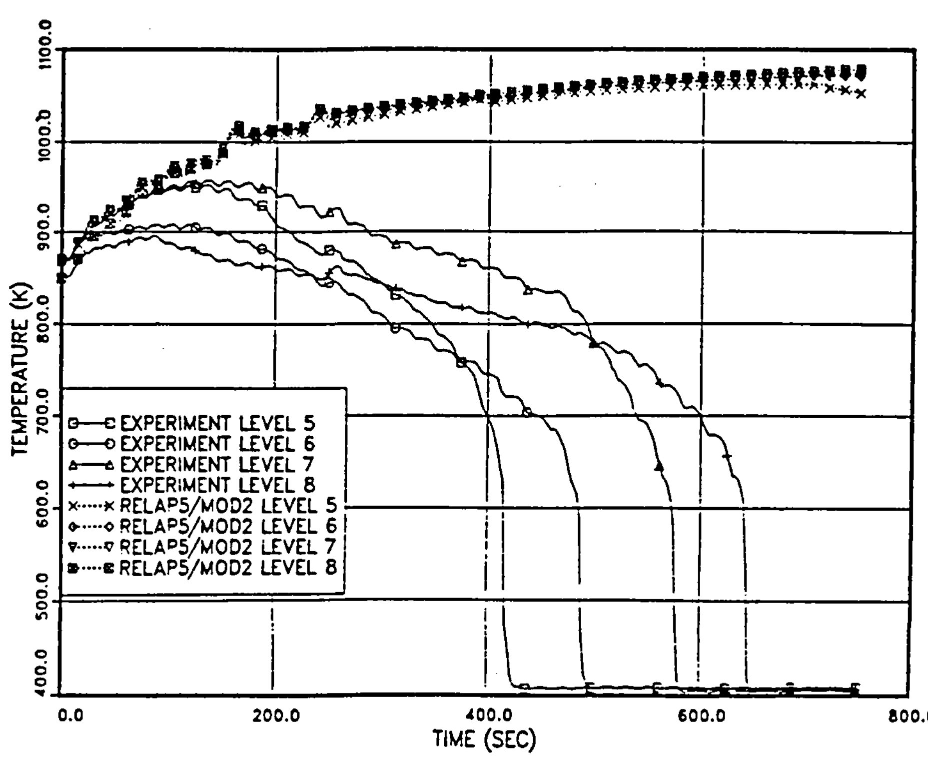


Figure 4.32. EXP 4106; Wall temperatures at level 5, 6, 7, 8.

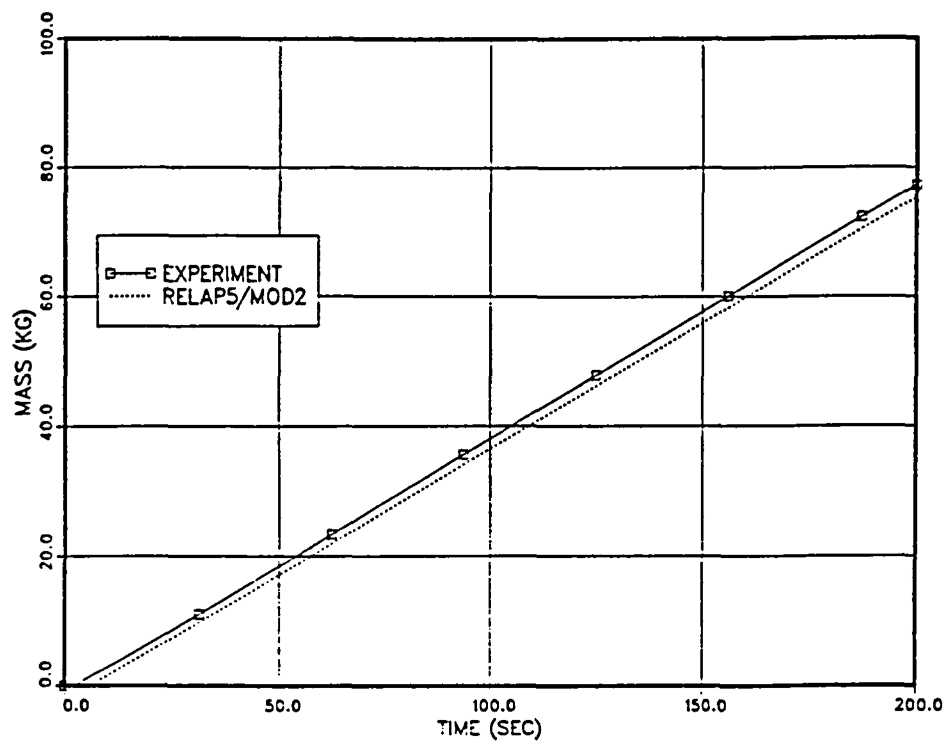


Figure 4.33. EXP 4120; Mass injected.

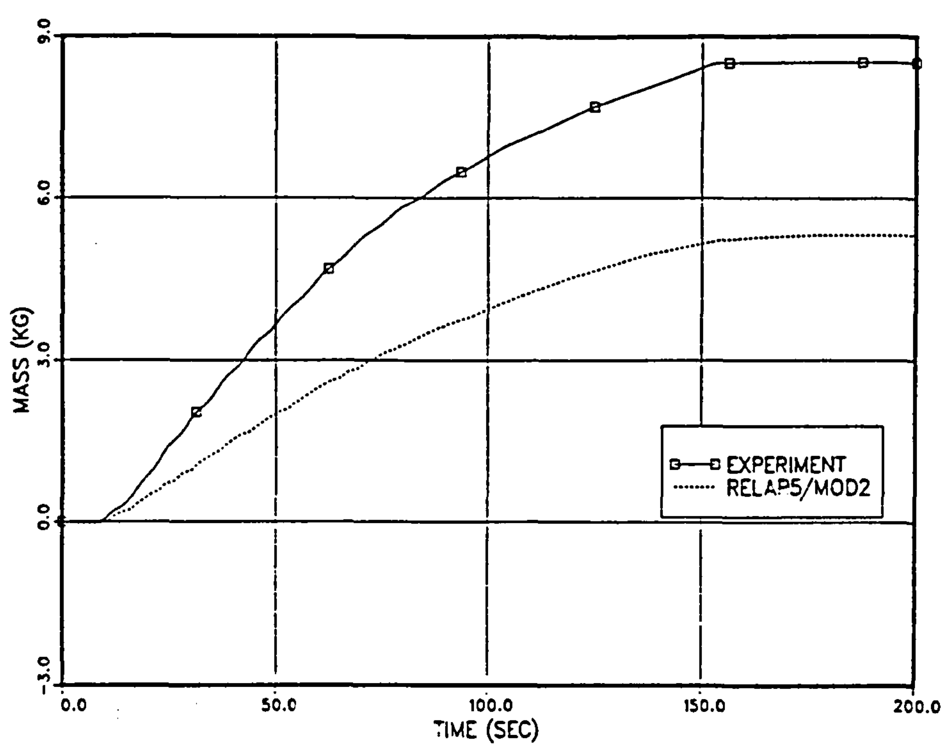


Figure 4.34. EXP 4120; Mass steam out.

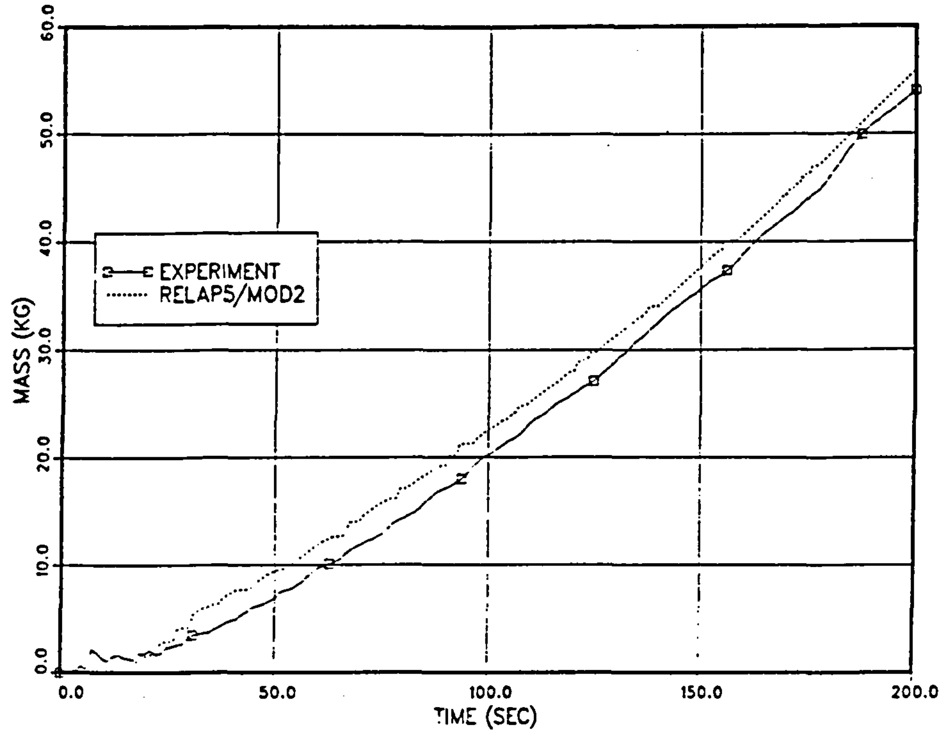


Figure 4.35. EXP 4120; Total mass carry-over.

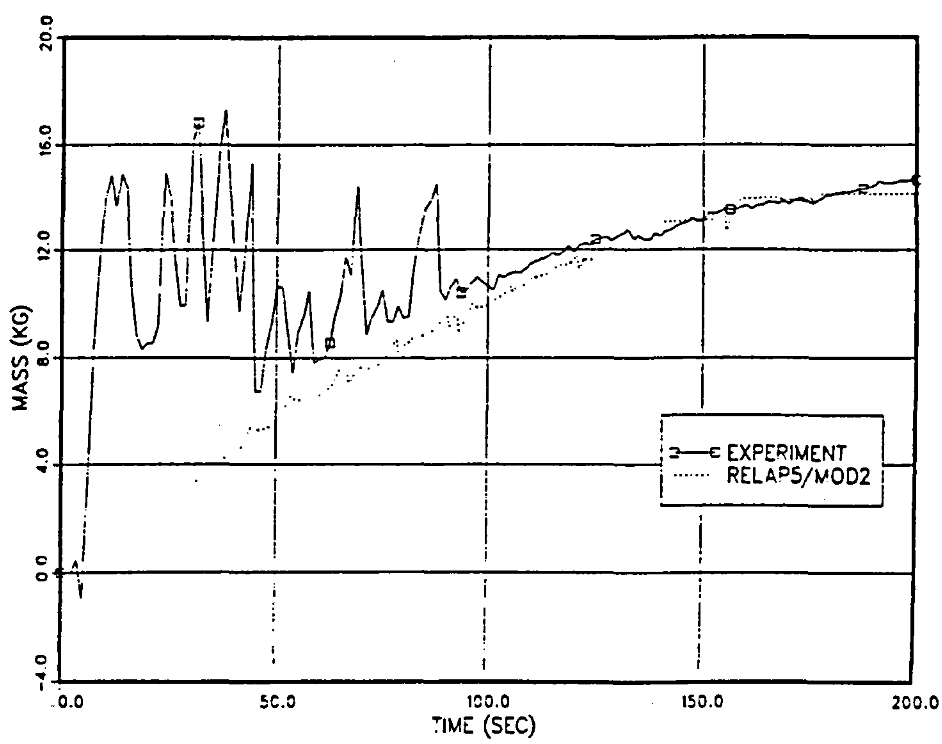


Figure 4.36. EXP 4120; Mass in the bundle.

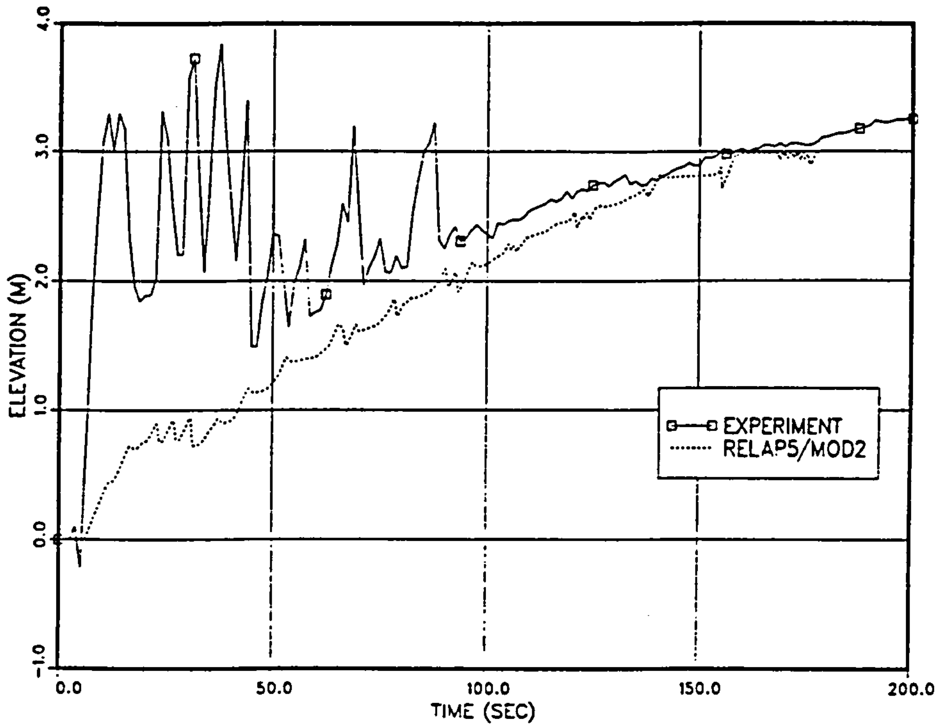


Figure 4.37. EXP 4120; Collapsed liquid level.

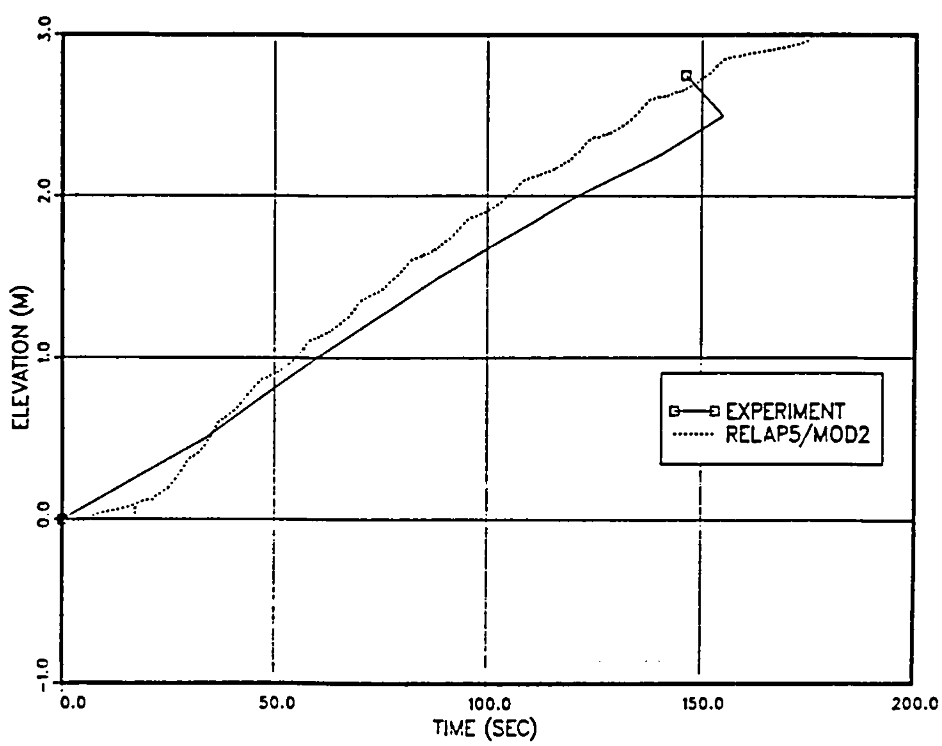


Figure 4.38. EXP 4120; Quench front position.

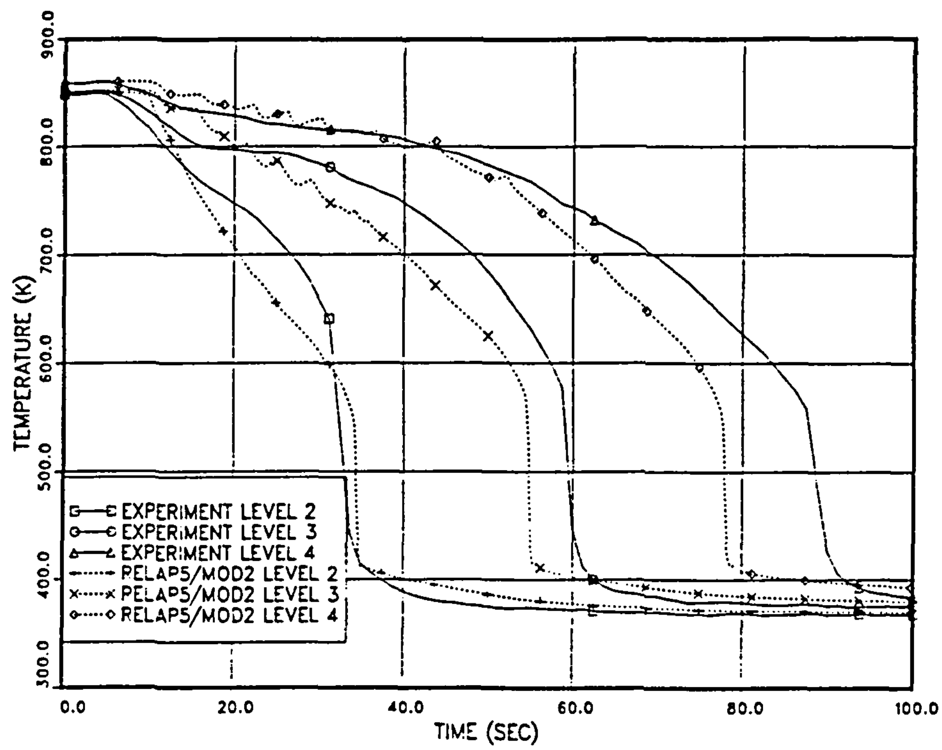


Figure 4.39. EXP 4120; Wall temperatures at level 2, 3, 4.

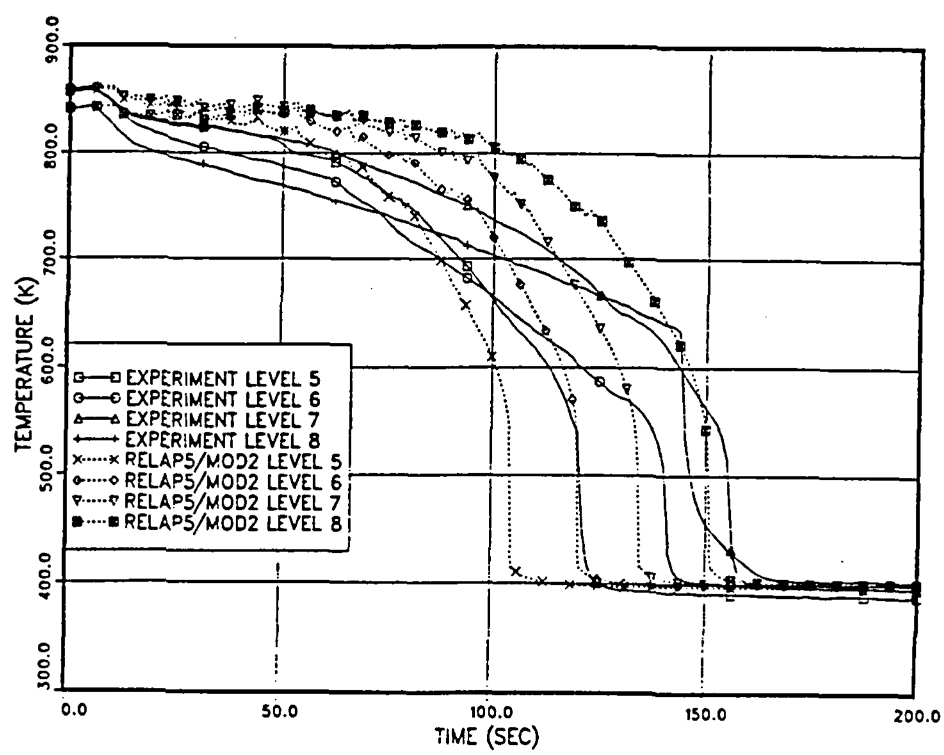


Figure 4.40. EXP 4120; Wall temperatures at level 5, 6, 7, 8.

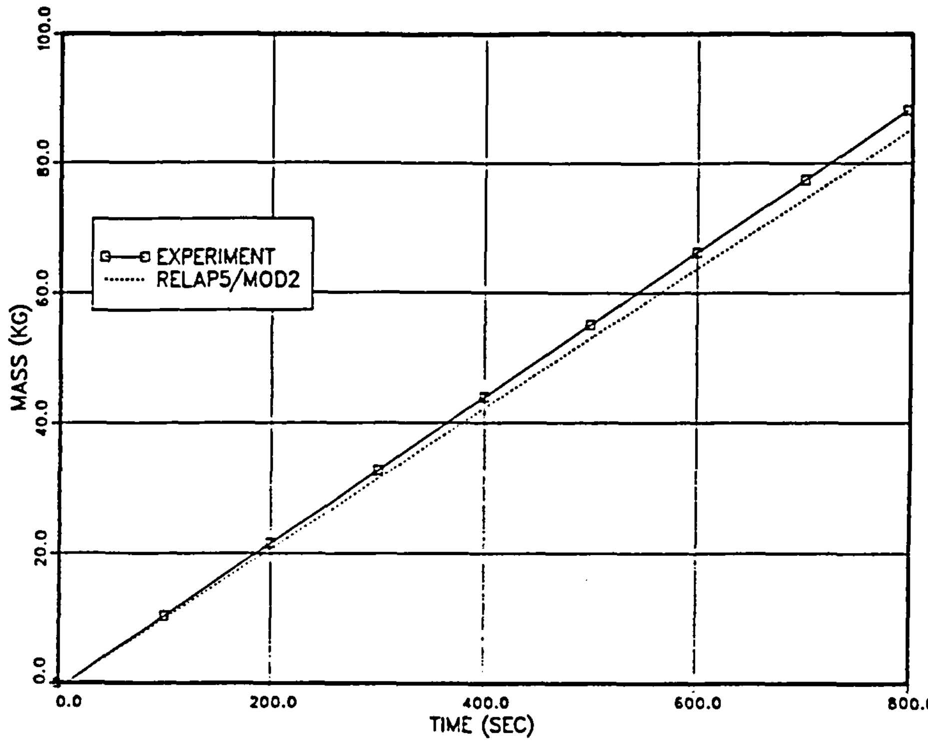


Figure 4.41. EXP 4138; Mass injected.

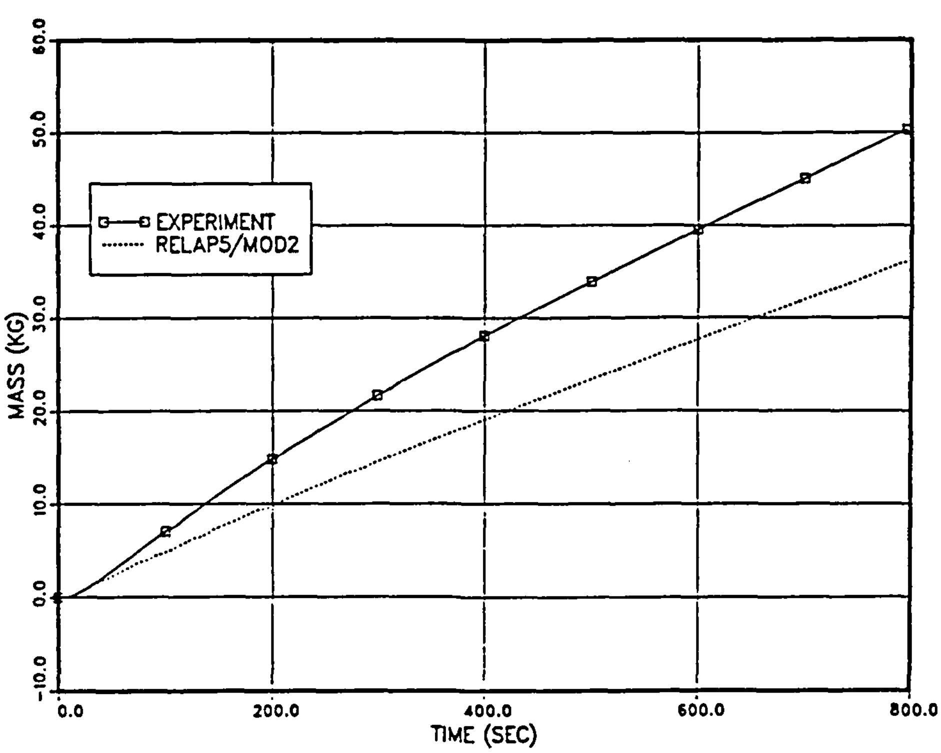


Figure 4.42. EXP 4138; Mass steam out.

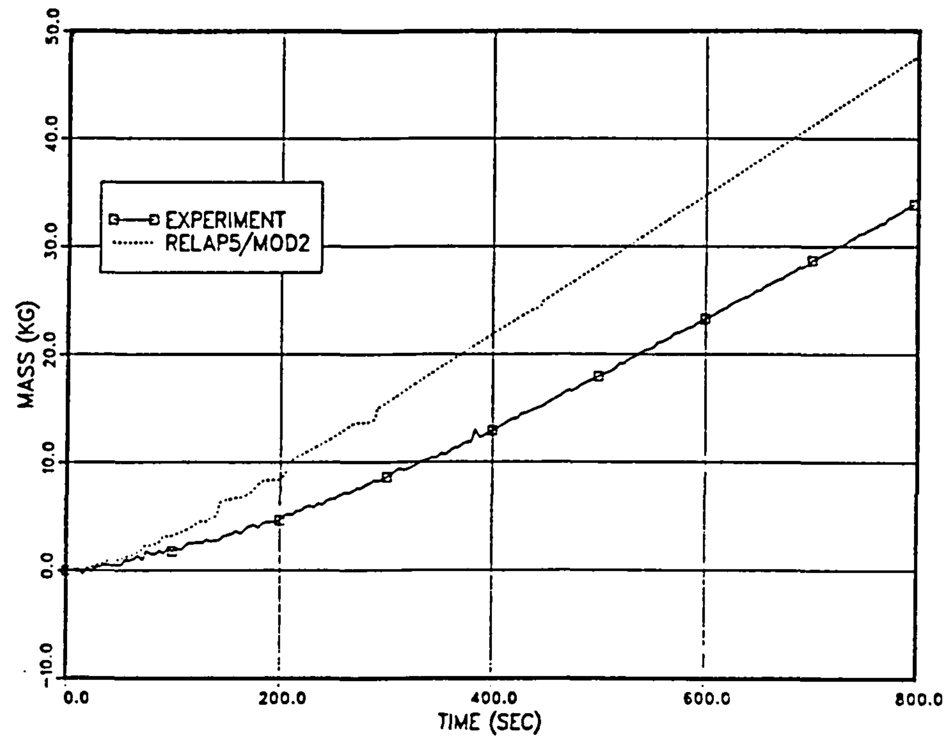


Figure 4.43. EXP 4138; Total mass carry-over.

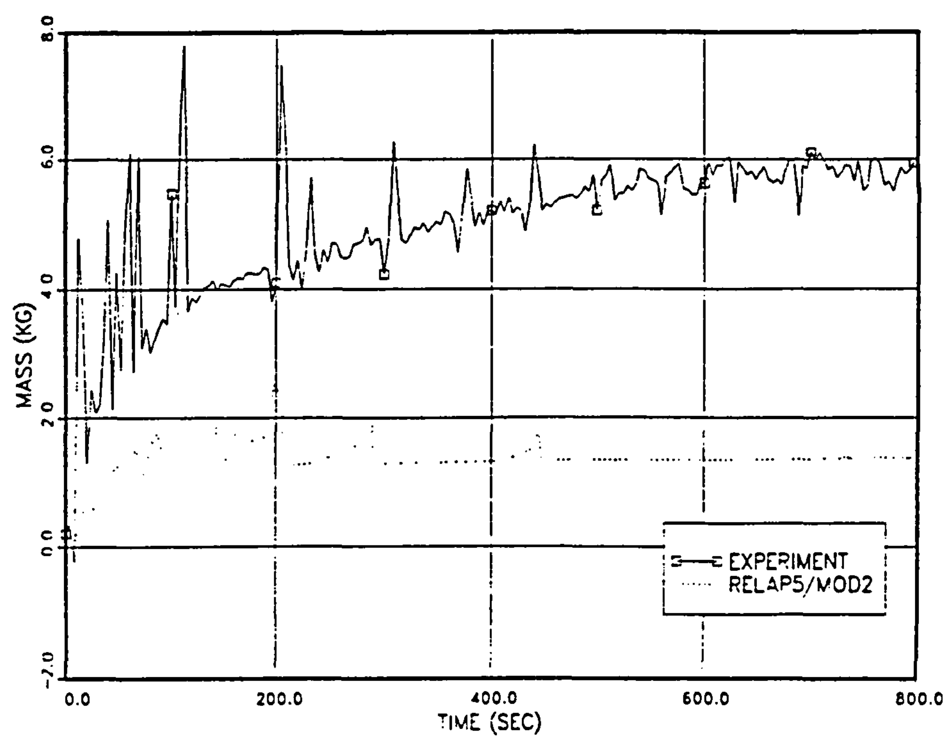


Figure 4.44. EXP 4138; Mass in the bundle.

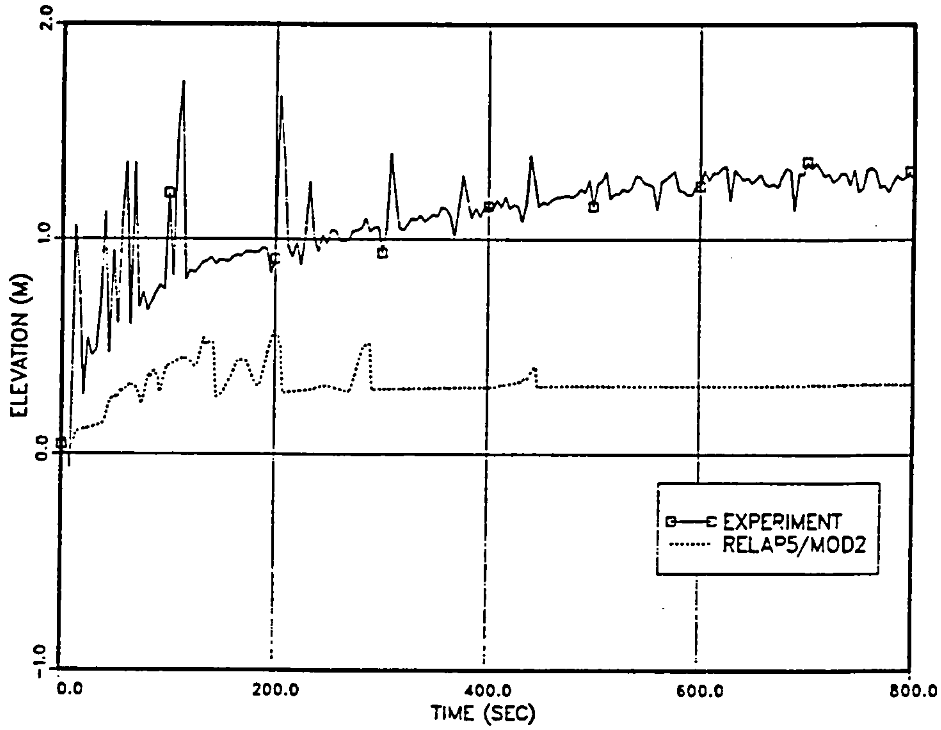


Figure 4.45. EXP 4138; Collapsed liquid level.

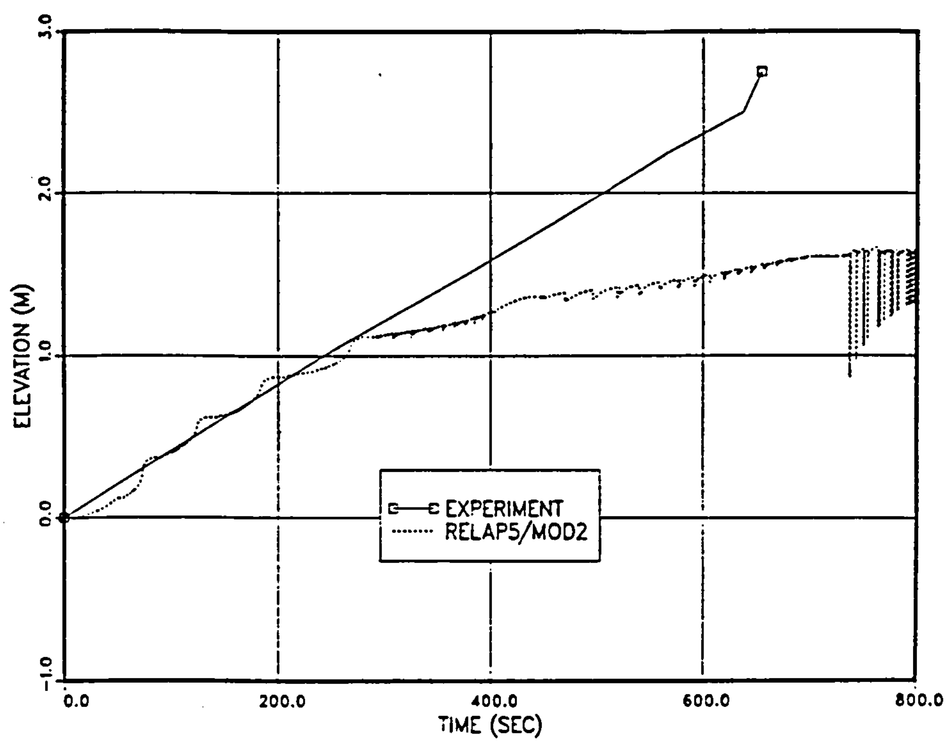


Figure 4.46. EXP 4138; Quench front position.

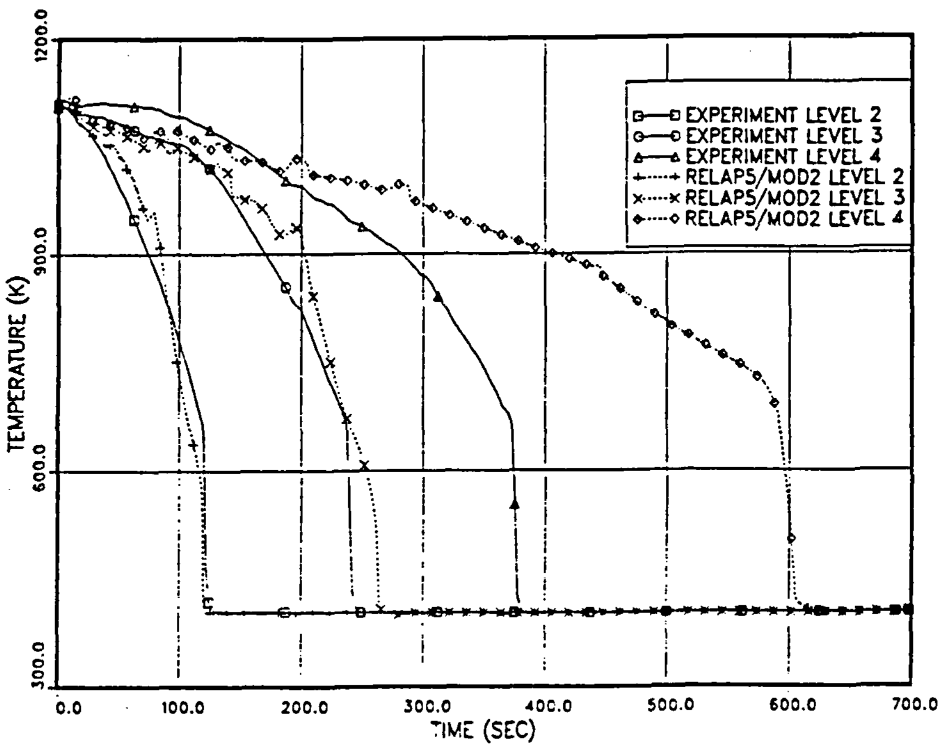


Figure 4.47. EXP 4138; Wall temperatures at level 2, 3, 4.

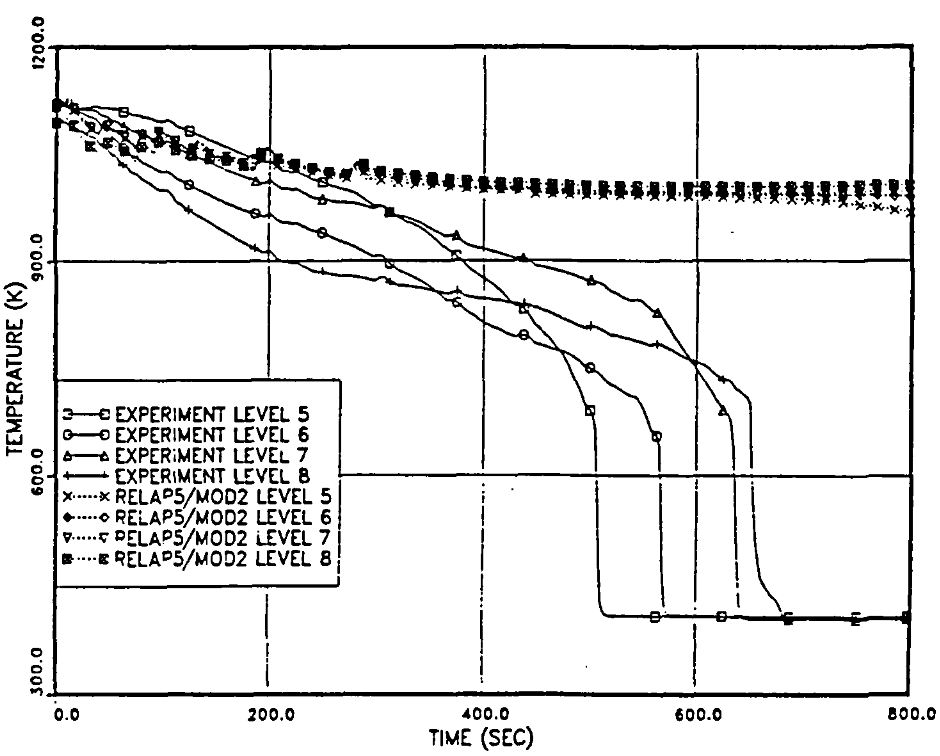


Figure 4.48. EXP 4138; Wall temperatures at level 5, 6, 7, 8.

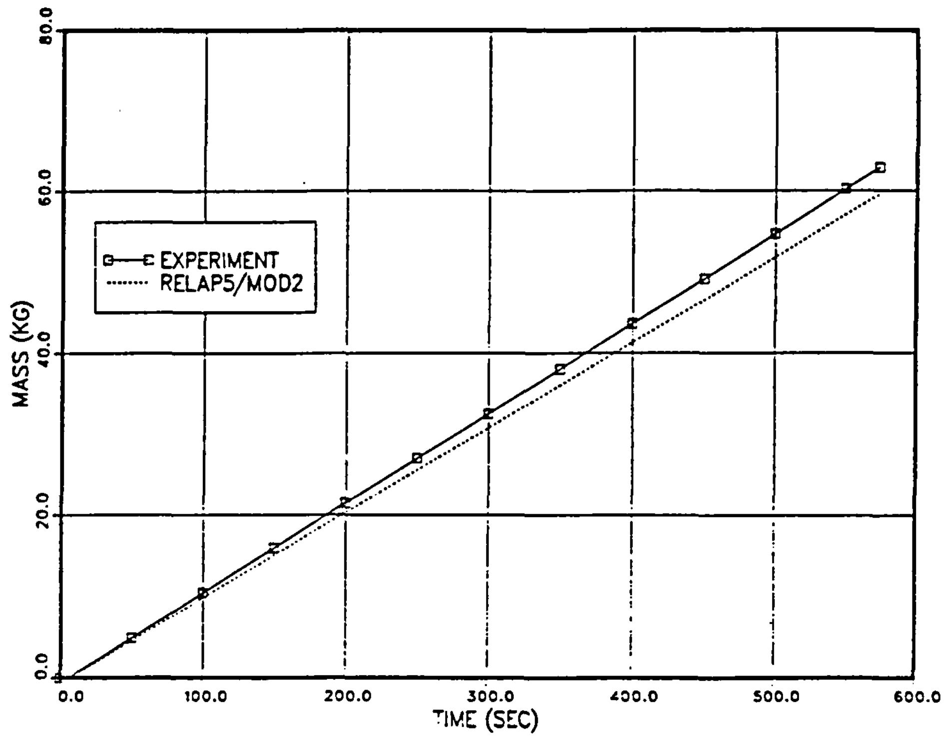


Figure 4.49. EXP 4149; Mass injected.

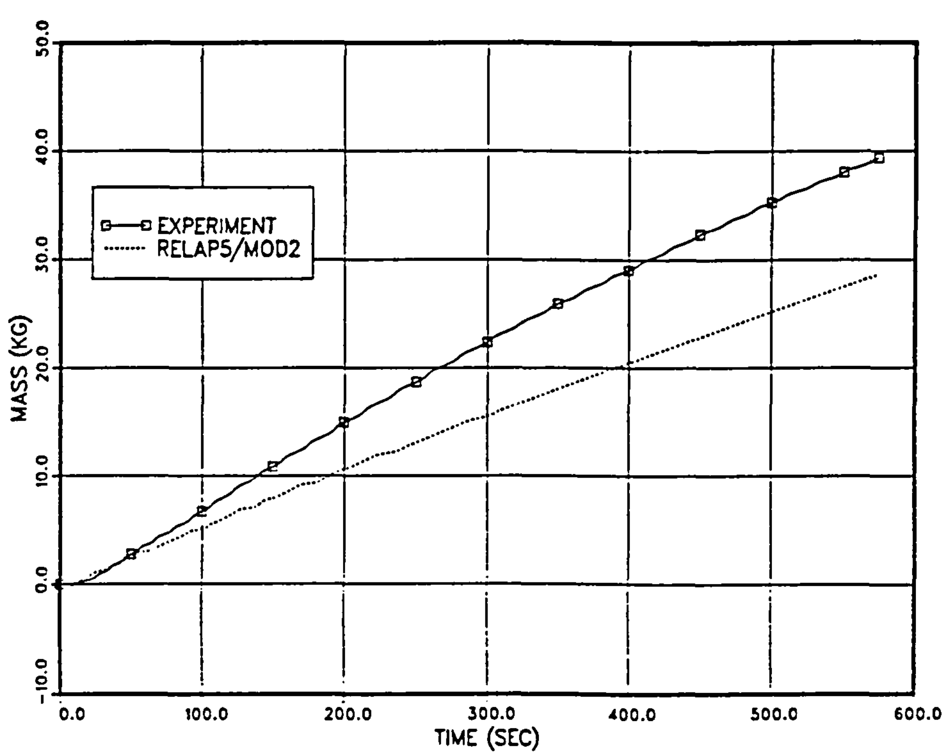


Figure 4.50. EXP 4149; Mass steam out.

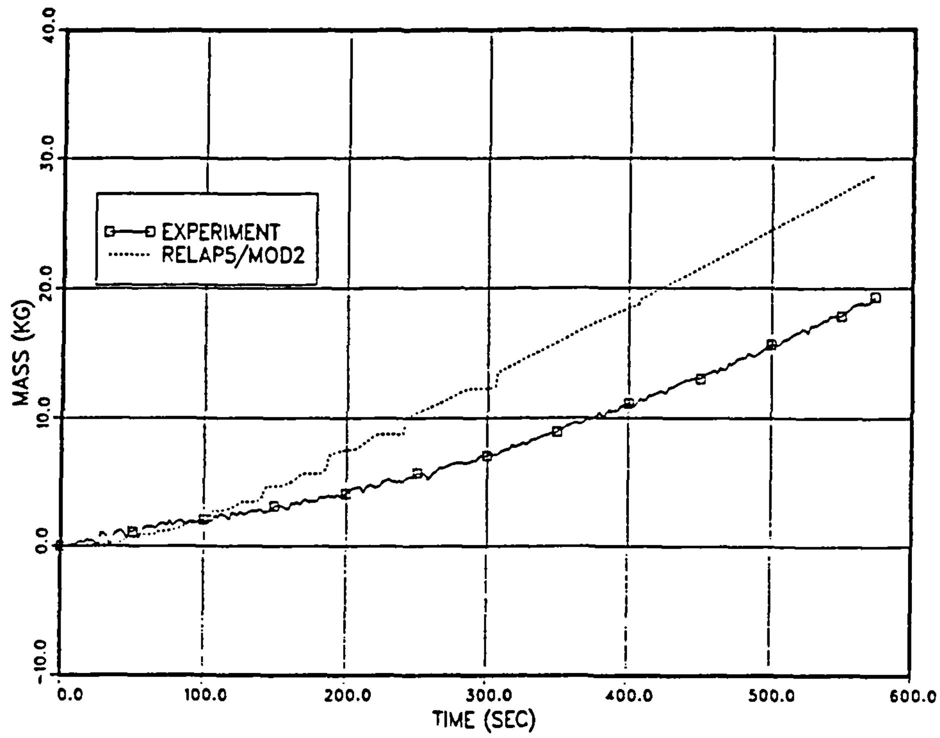


Figure 4.51. EXP 4149; Total mass carry-over.

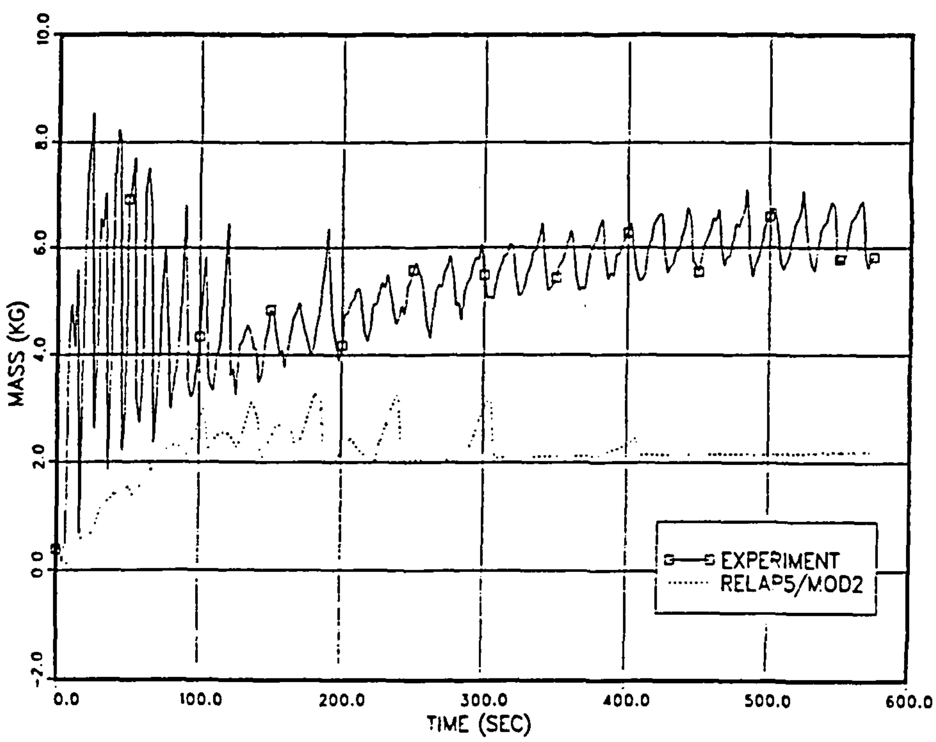


Figure 4.52. EXP 4149; Mass in the bundle.

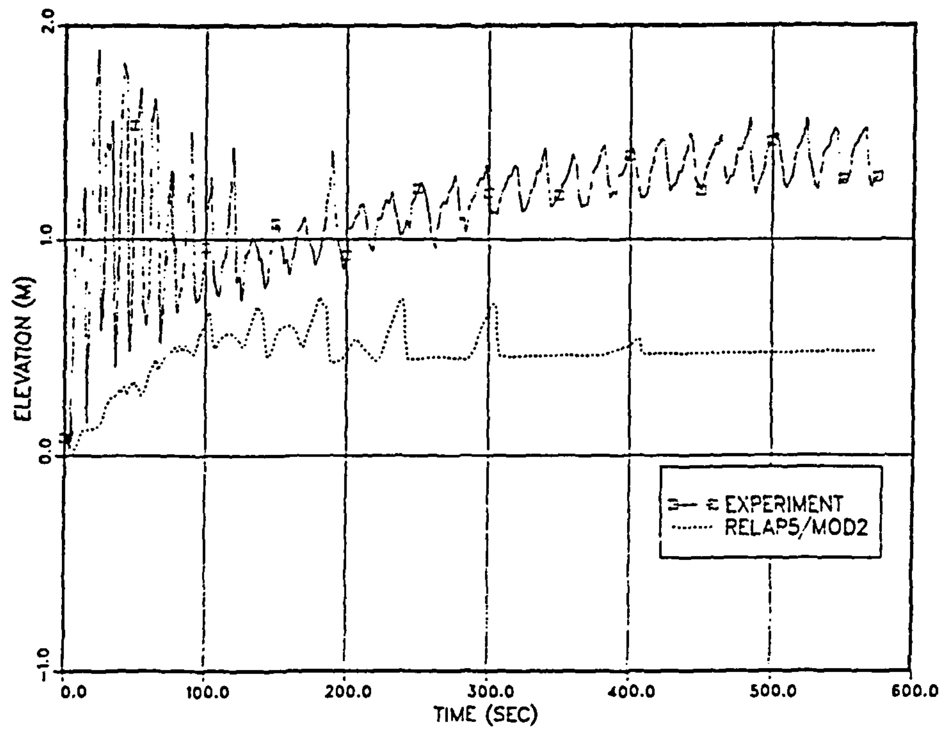


Figure 4.53. EXP 4149; Collapsed liquid level.

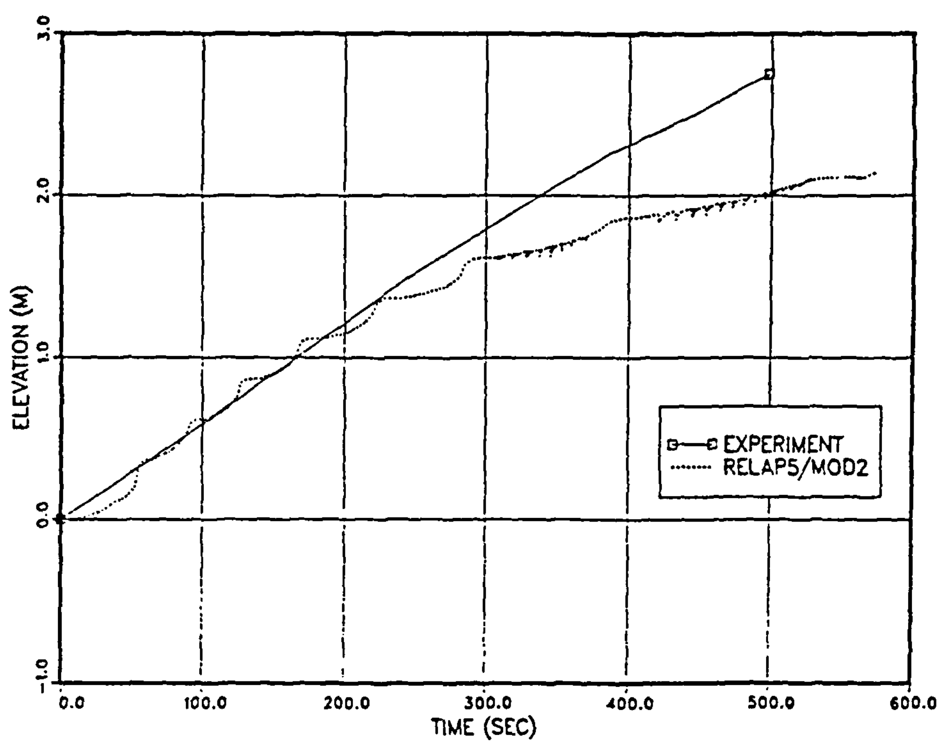


Figure 4.54. EXP 4149; Quench front position.

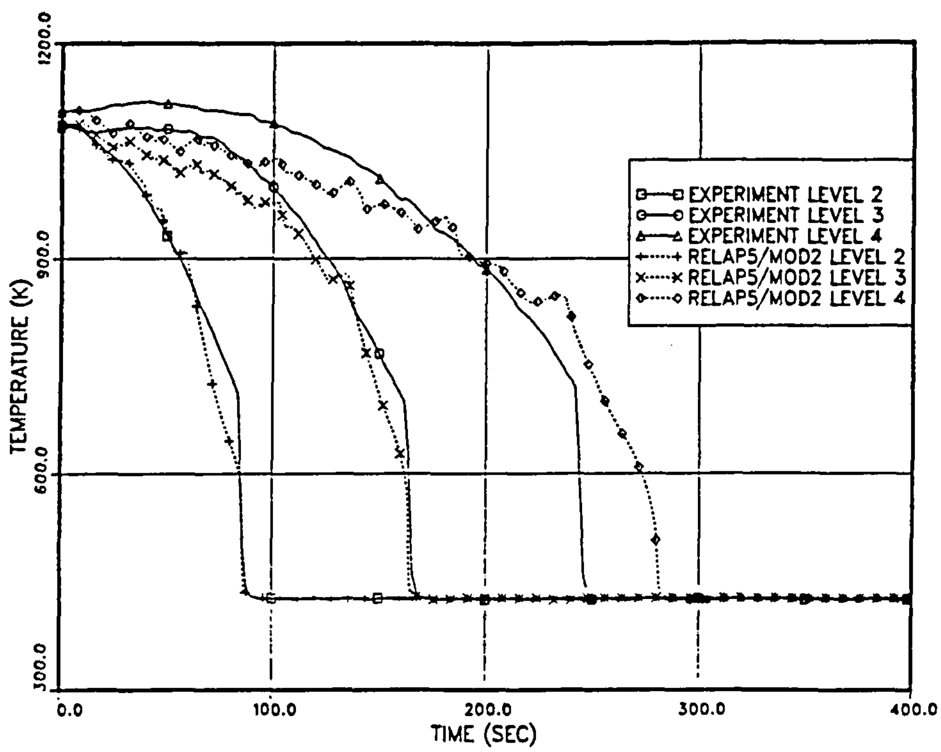


Figure 4.55. EXP 4149; Wall temperatures at level 2, 3, 4.

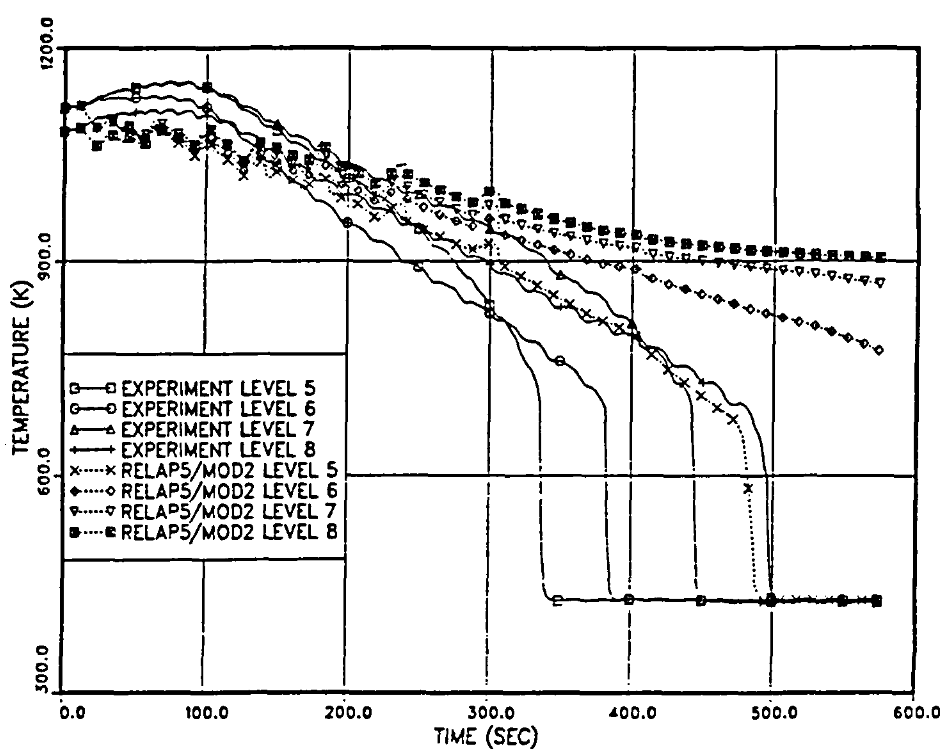


Figure 4.56. EXP 4149; Wall temperatures at level 5, 6, 7, 8.

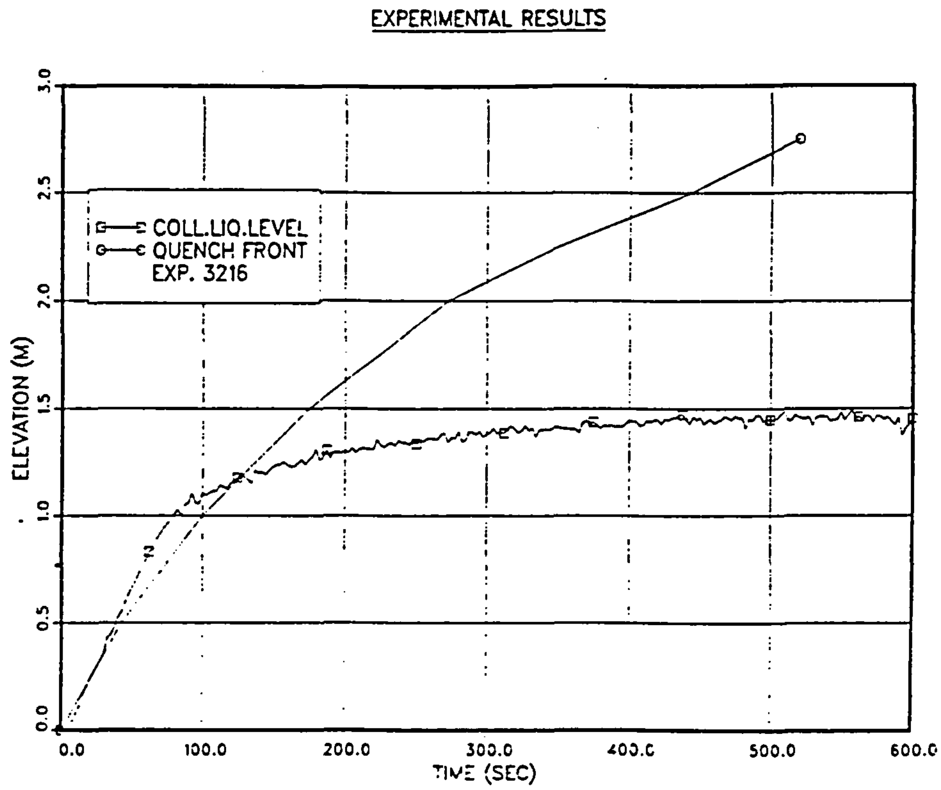


Figure 4.57. EXP 3216; Experimental quench front and collapsed liquid level.

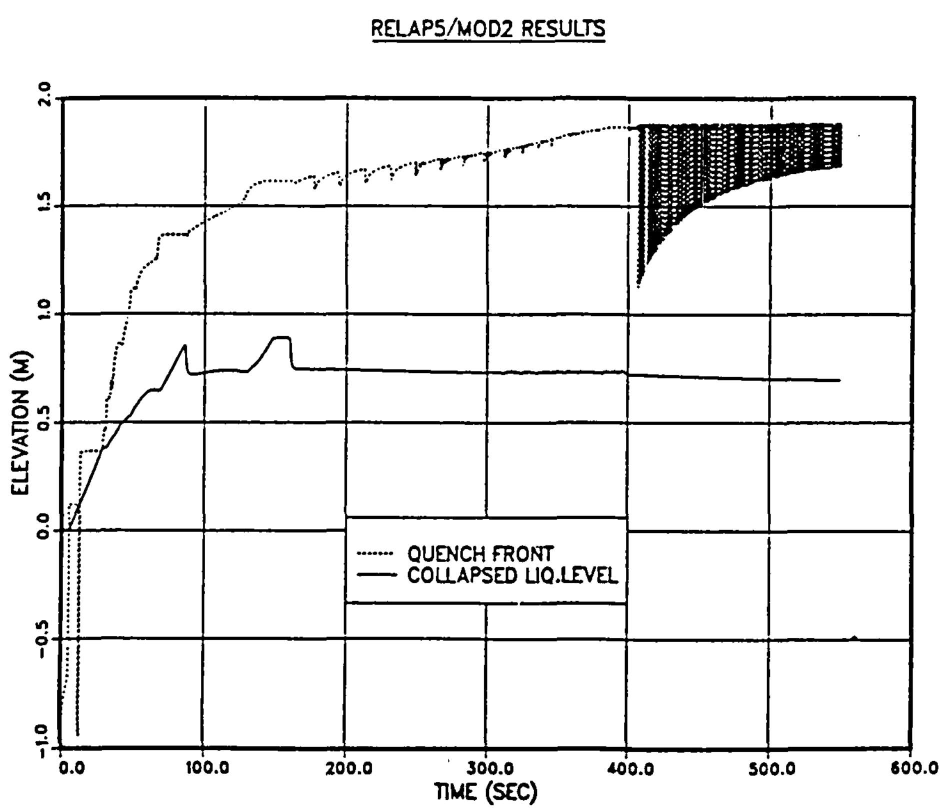


Figure 4.58. EXP 3216; Calculated quench front and collapsed liquid level.

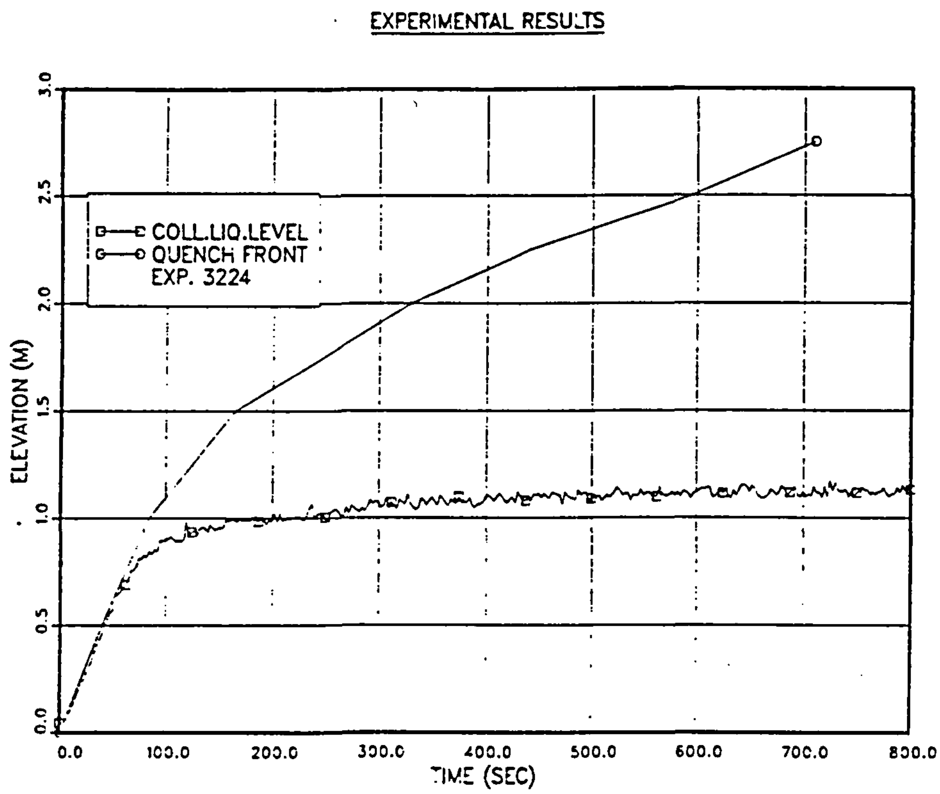


Figure 4.59. EXP 3224; Experimental quench front and collapsed liquid level.

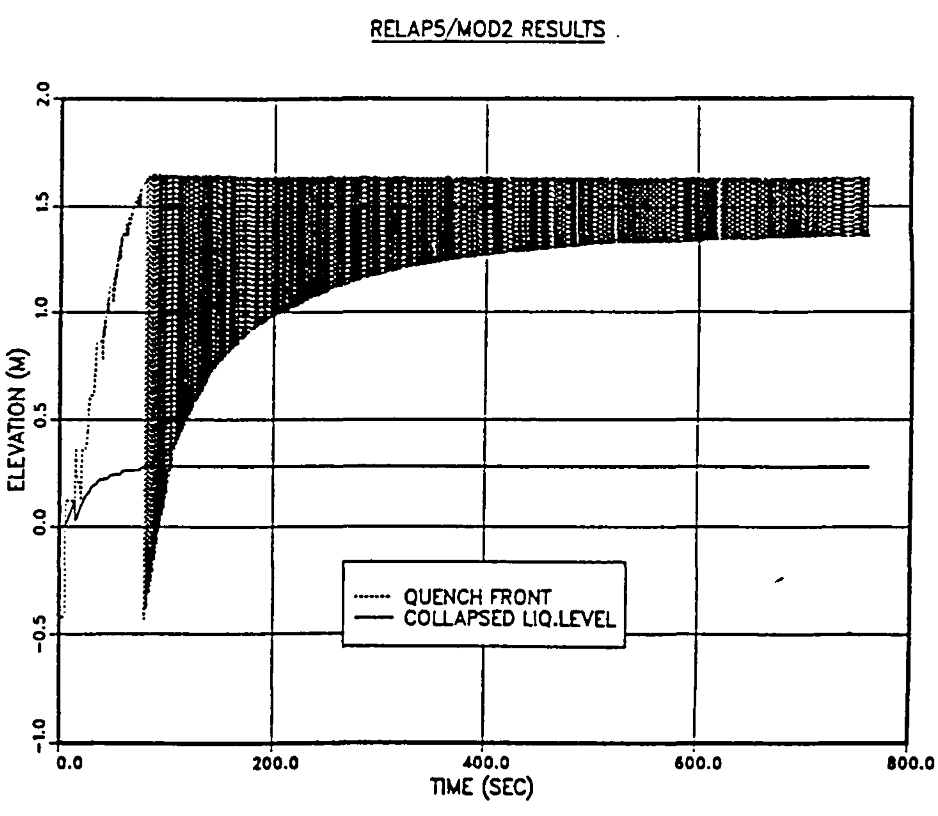


Figure 4.60. EXP 3224; Calculated quench front and collapsed liquid level.

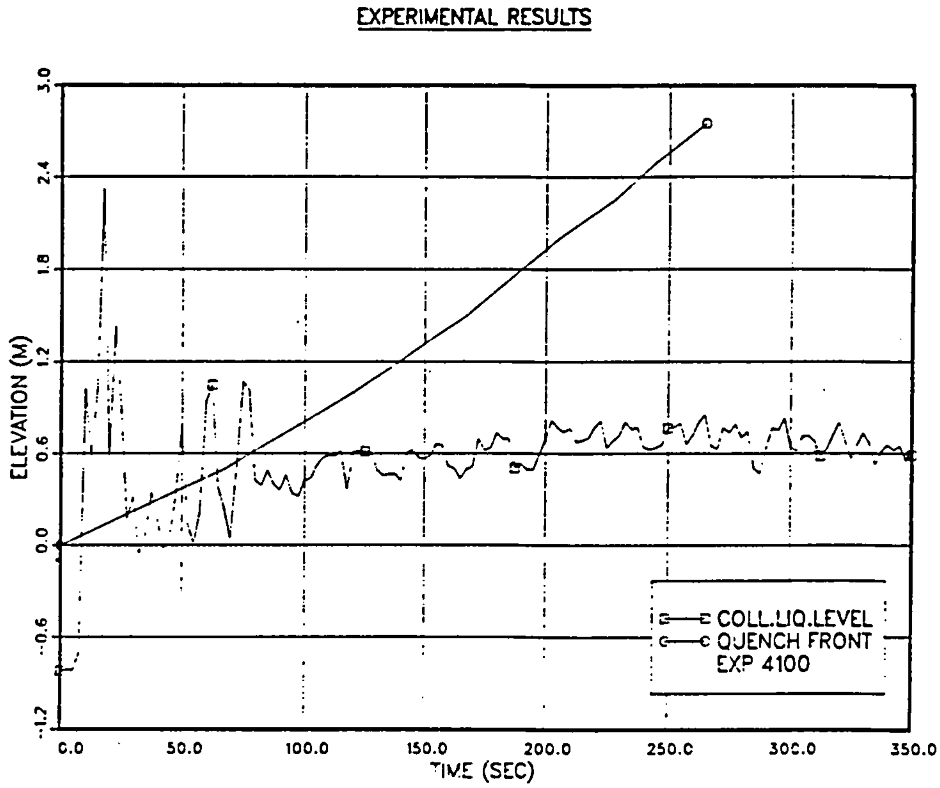


Figure 4.61. EXP 4100; Experimental quench front and collapsed liquid level.

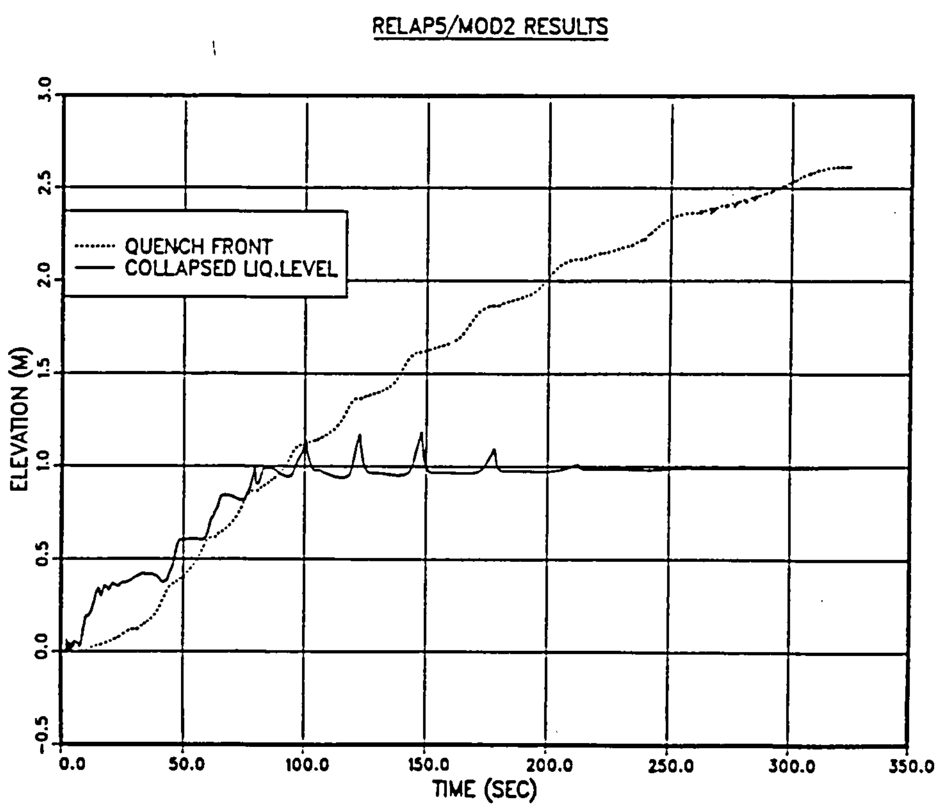


Figure 4.62. EXP 4100; Calculated quench front and collapsed liquid level.

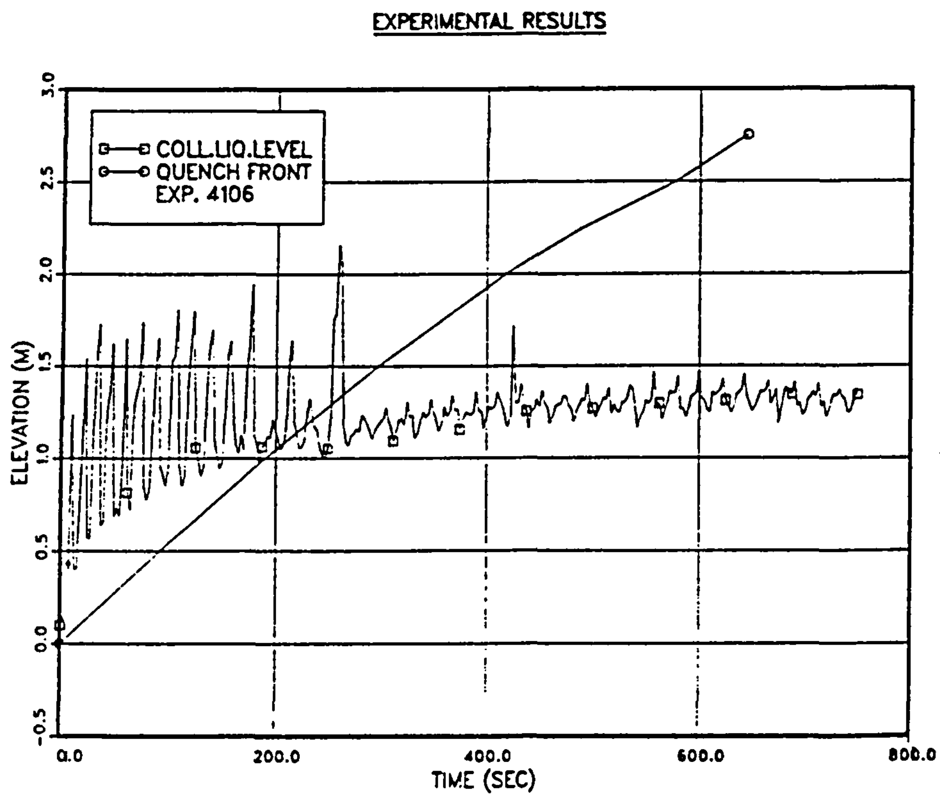


Figure 4.63. EXP 4106; Experimental quench front and collapsed liquid level.

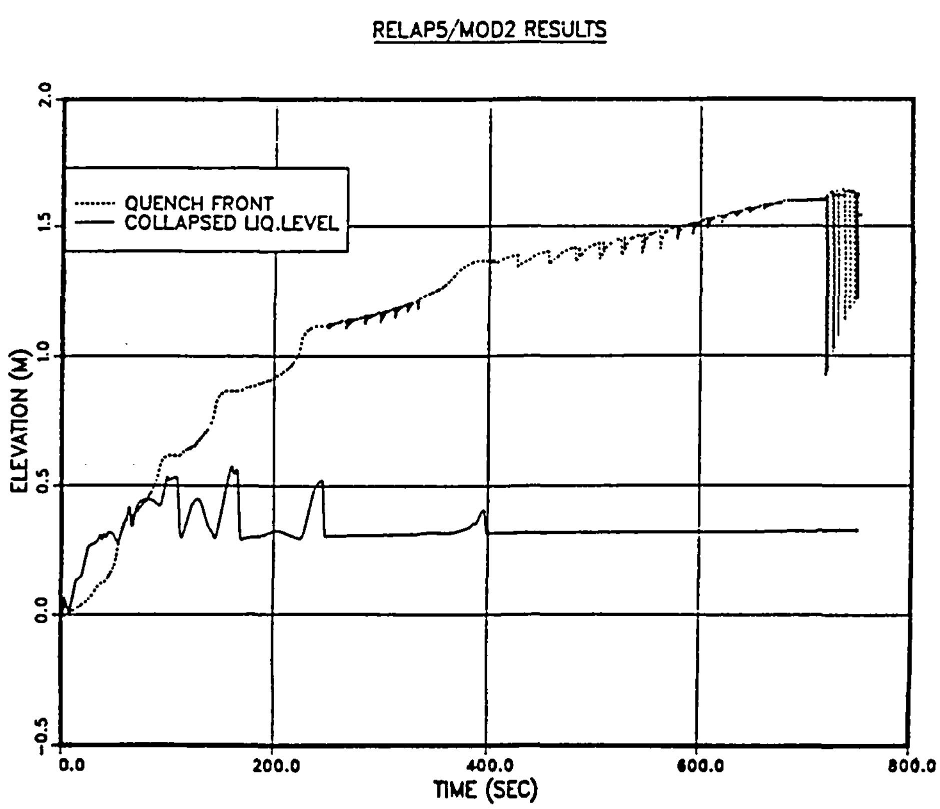


Figure 4.64. EXP 4106; Calculated quench front and collapsed liquid level.

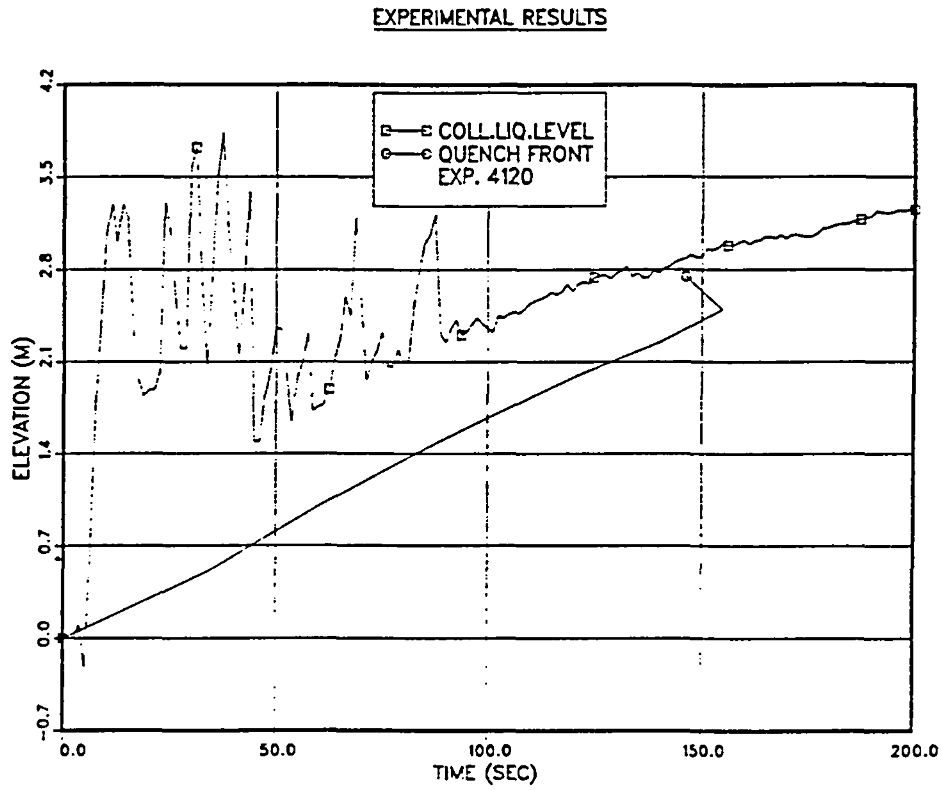


Figure 4.65. EXP 4120; Experimental quench front and collapsed liquid level.

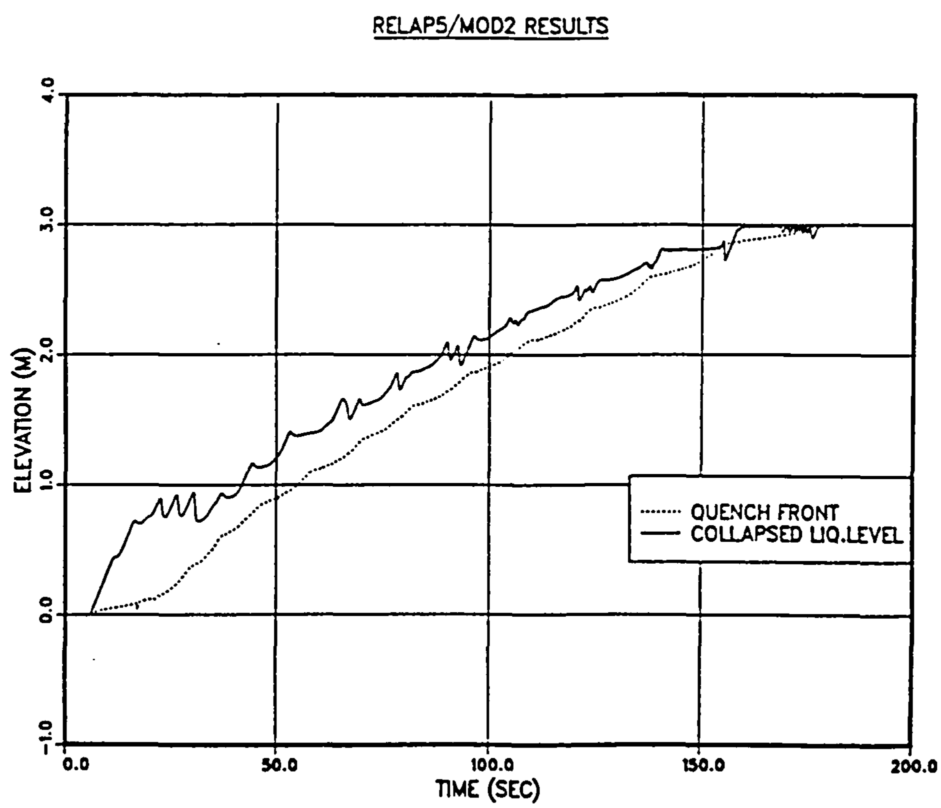


Figure 4.66. EXP 4120; Calculated quench front and collapsed liquid level.

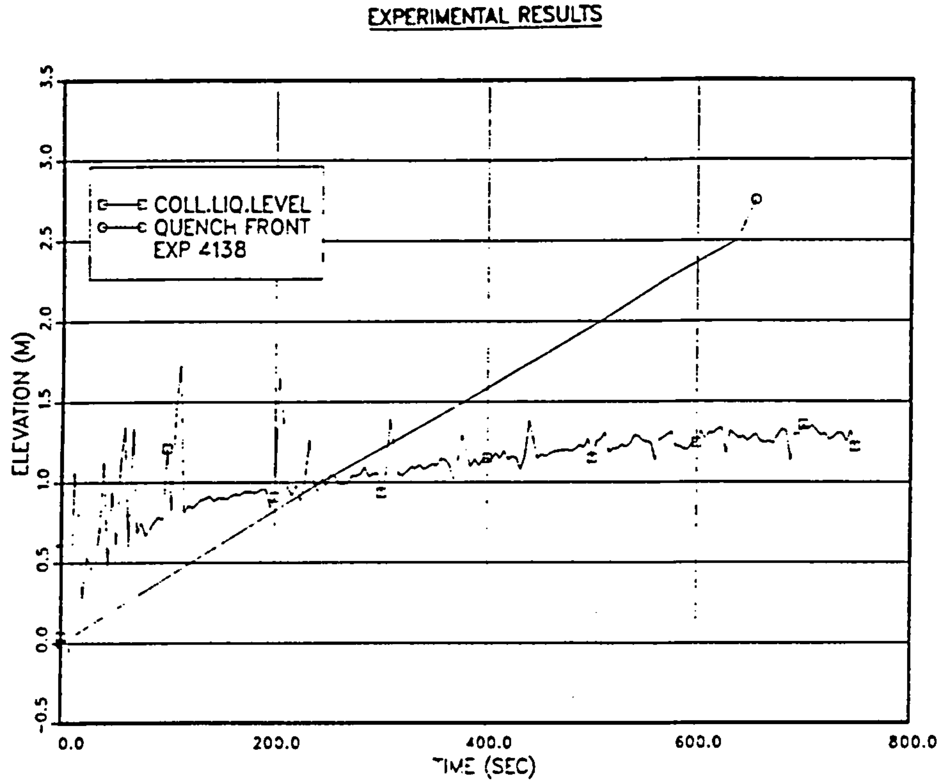


Figure 4.67. EXP 4138; Experimental quench front and collapsed liquid level.

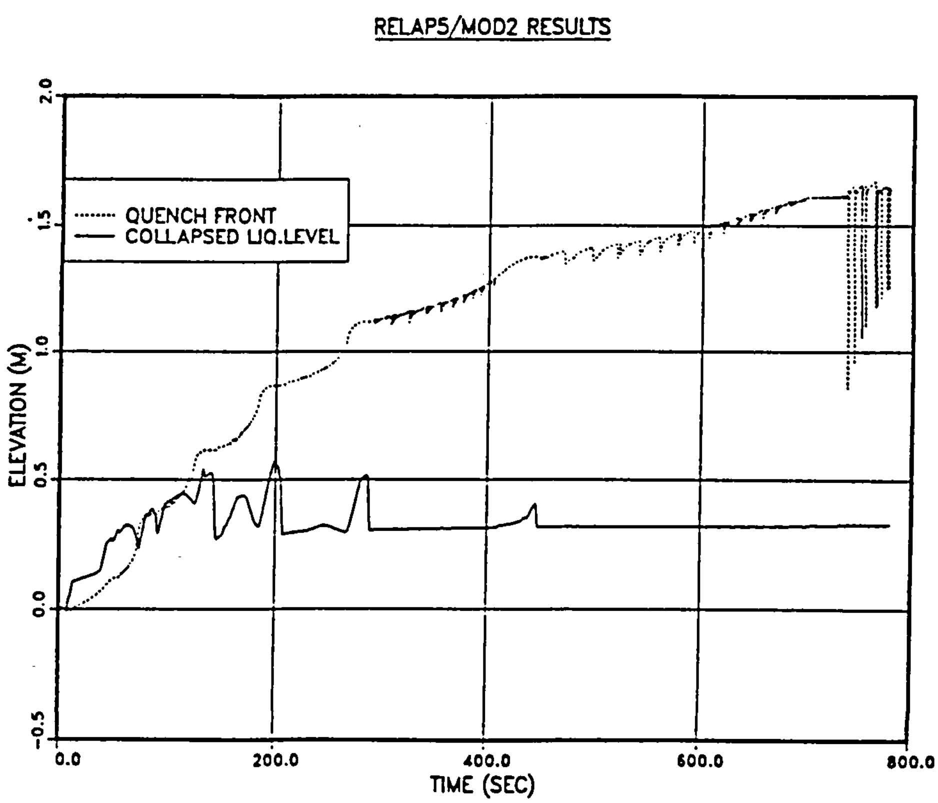


Figure 4.68. EXP 4138; Calculated quench front and collapsed liquid level.

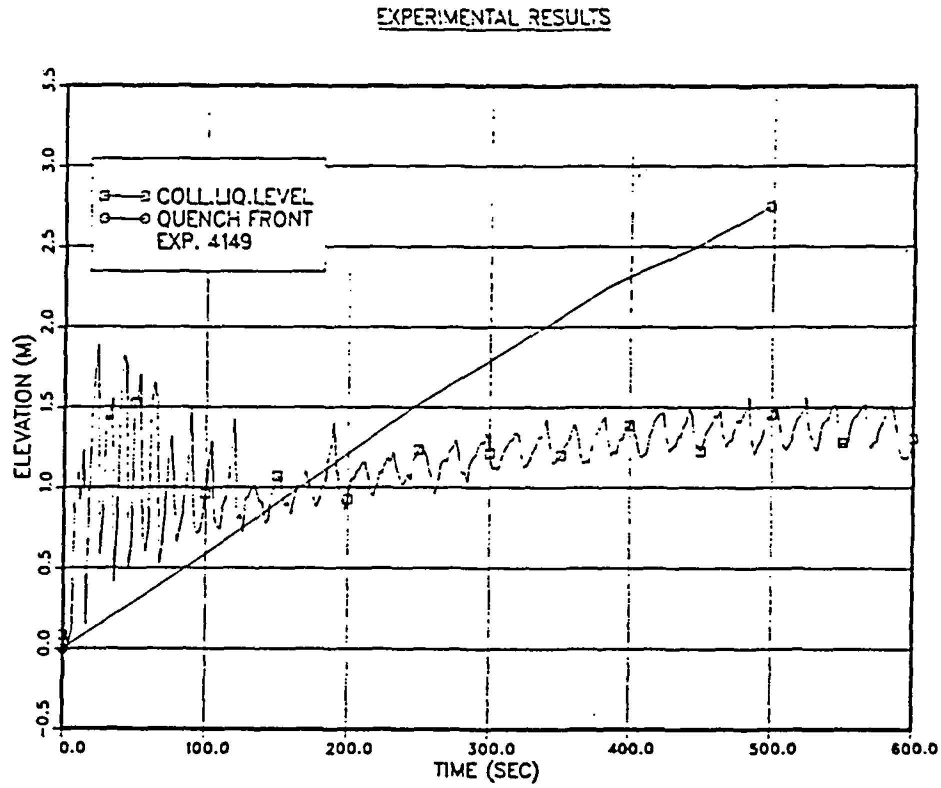


Figure 4.69. EXP 4149; Experimental quench front and collapsed liquid level.

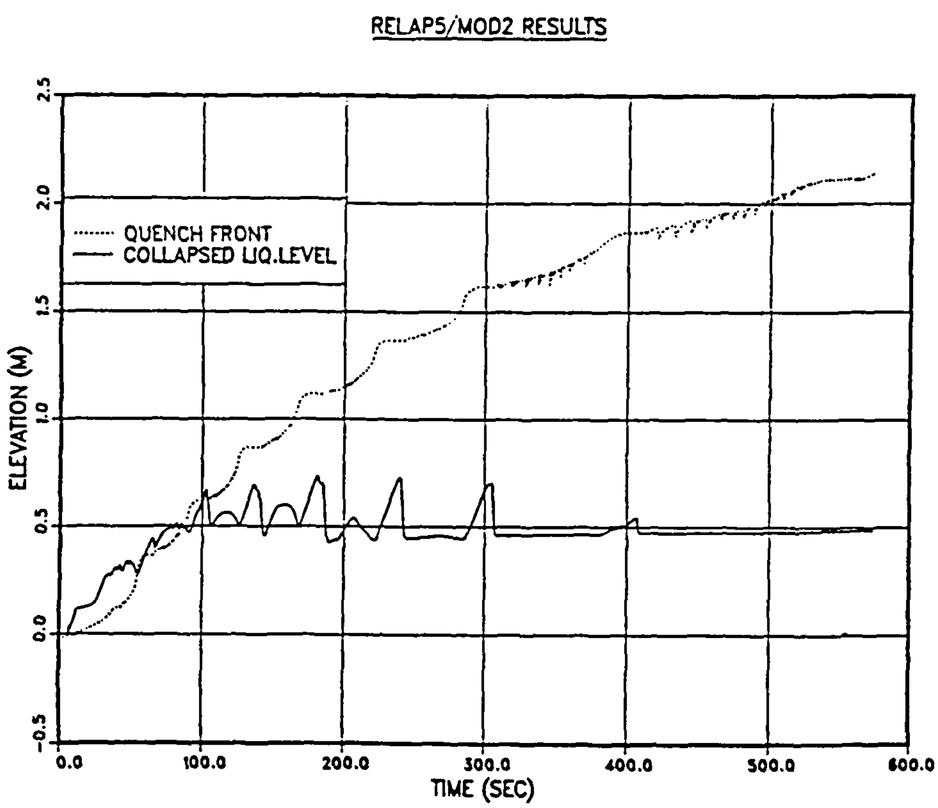


Figure 4.70. EXP 4149; Calculated quench front and collapsed liquid level.

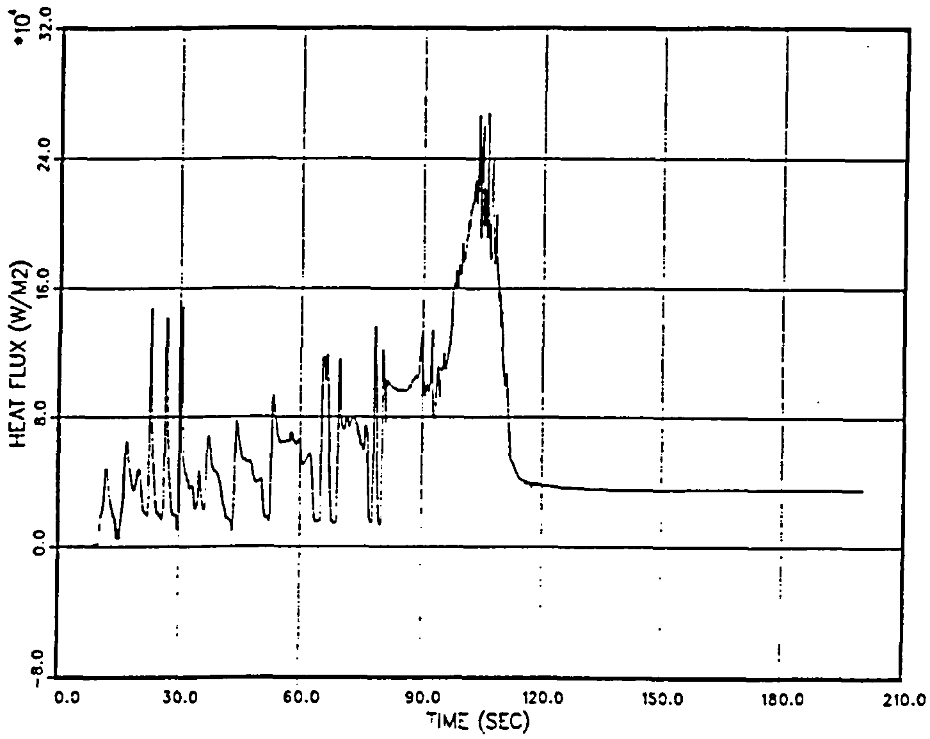


Figure 4.71. EXP 4120; Calculated heat flux at level 5.

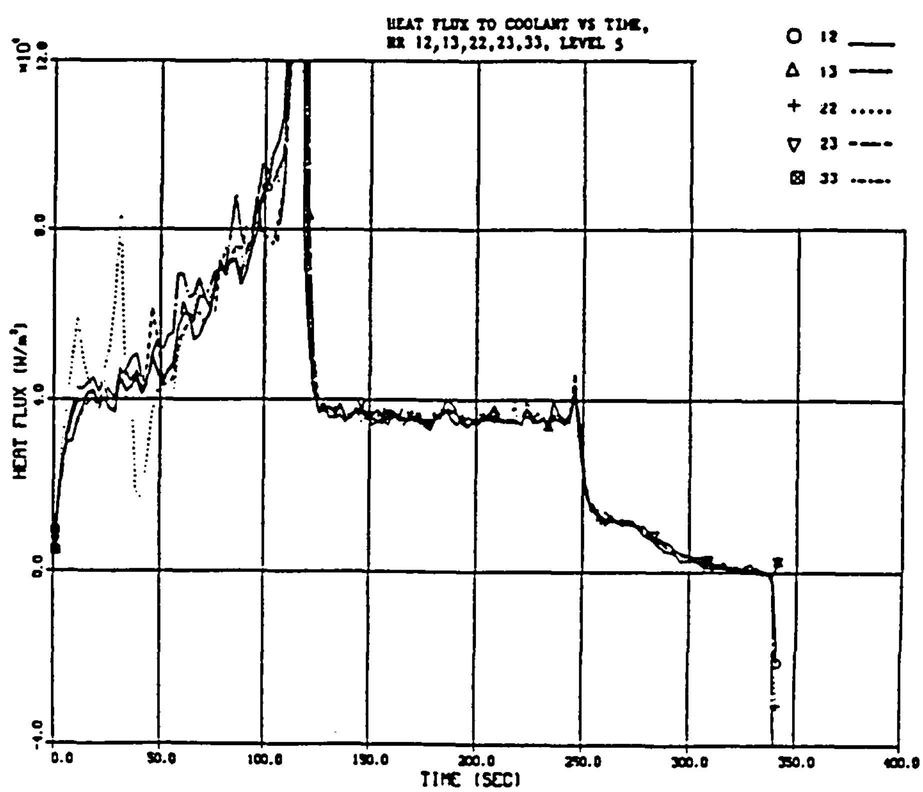


Figure 4.72. EXP 4120; Experimental heat flux at level 5.

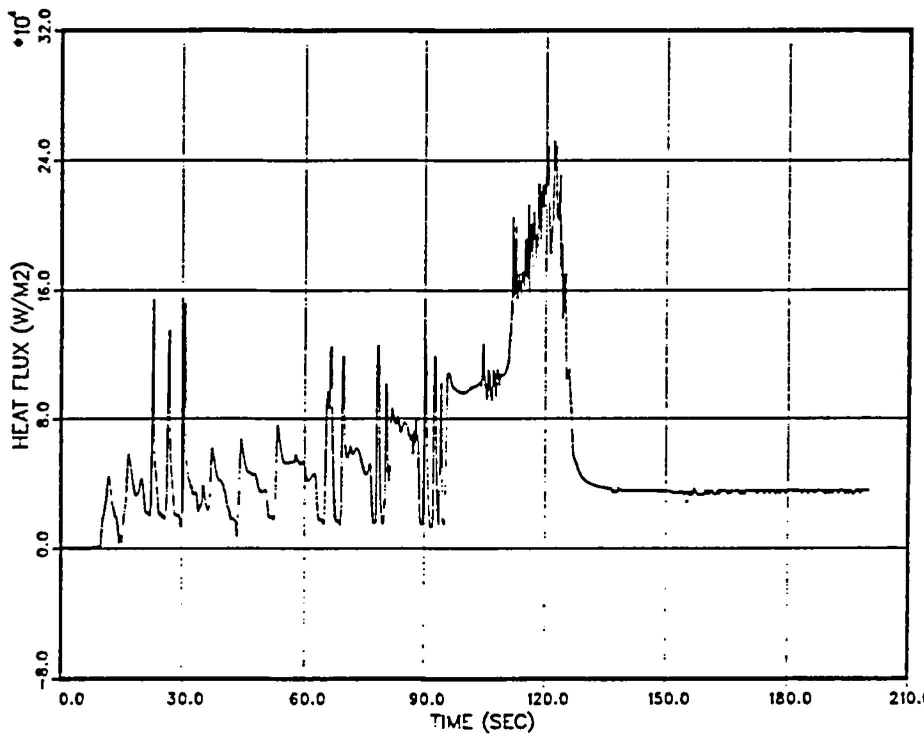


Figure 4.73. EXP 4120; Calculated heat flux at level 6.

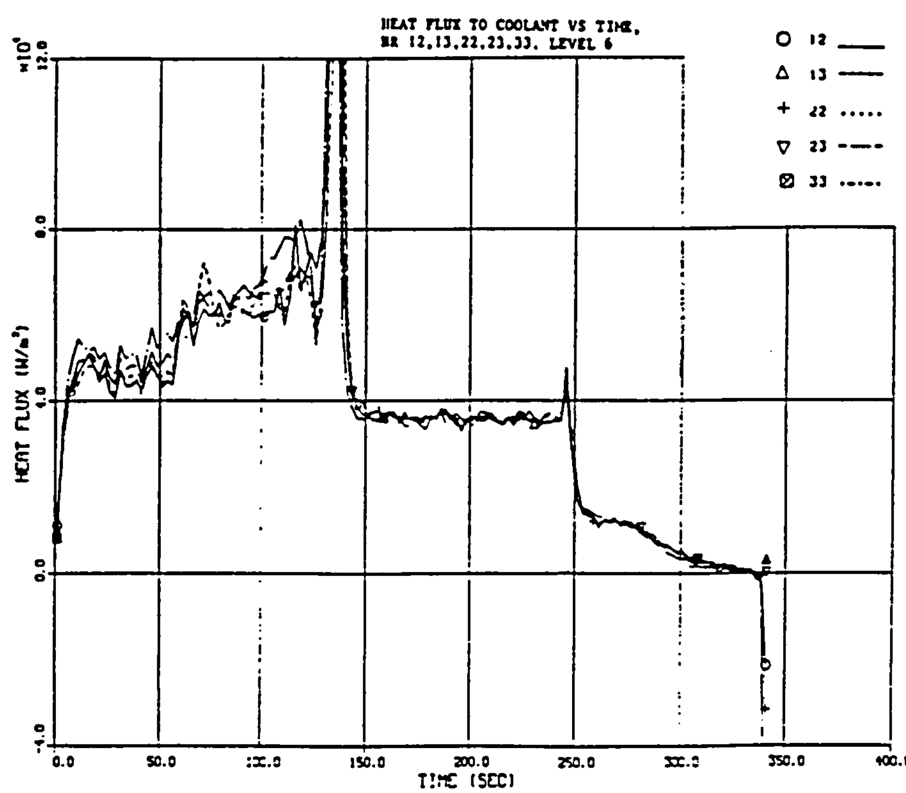


Figure 4.74. EXP 4120; Experimental heat flux at level 6.

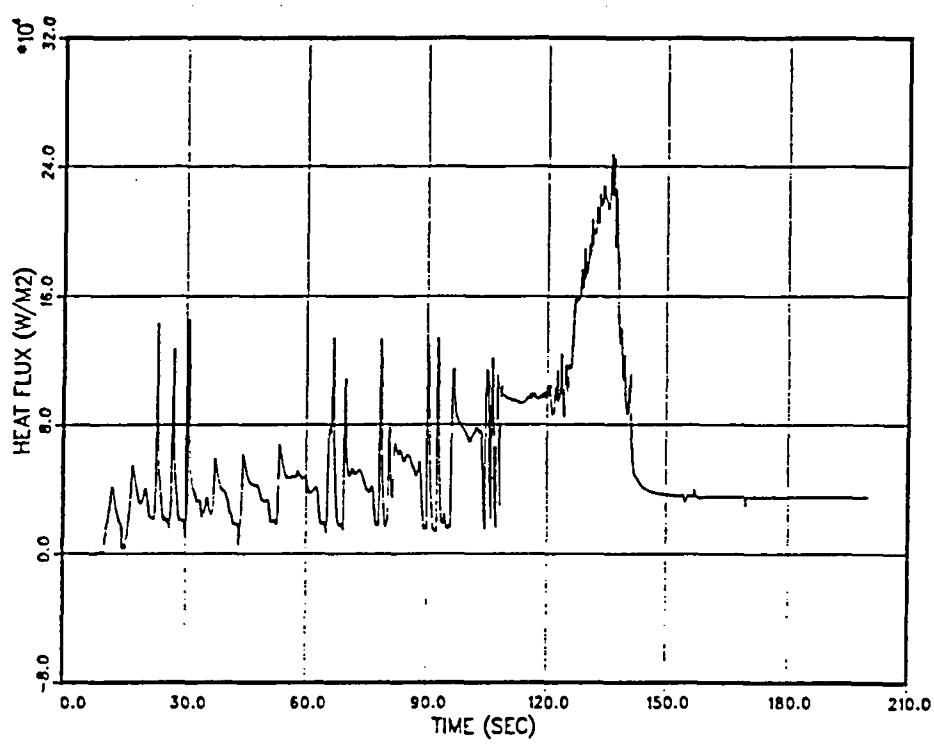


Figure 4.75. EXP 4120; Calculated heat flux at level 7.

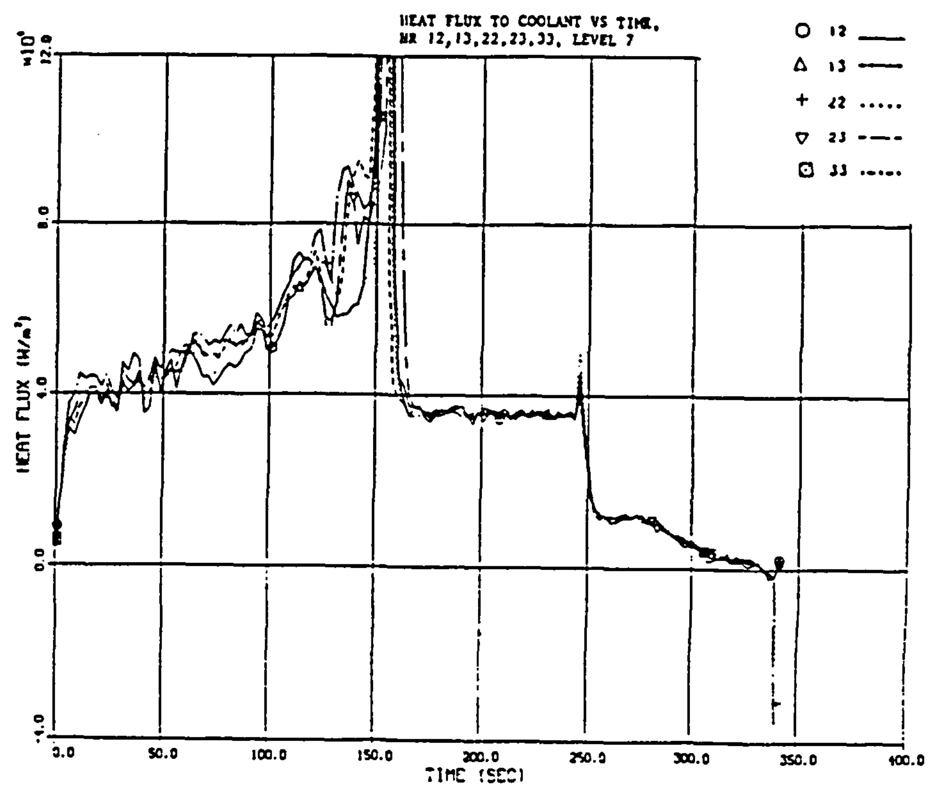


Figure 4.76. EXP 4120; Experimental heat flux at level 7.

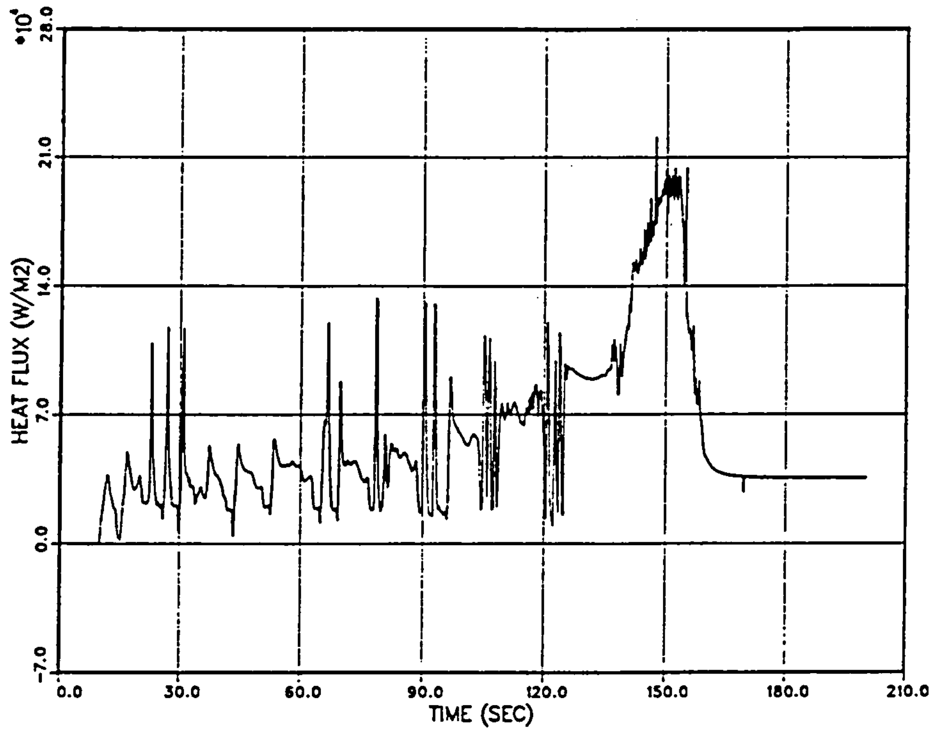


Figure 4.77. EXP 4120; Calculated heat flux at level 8.

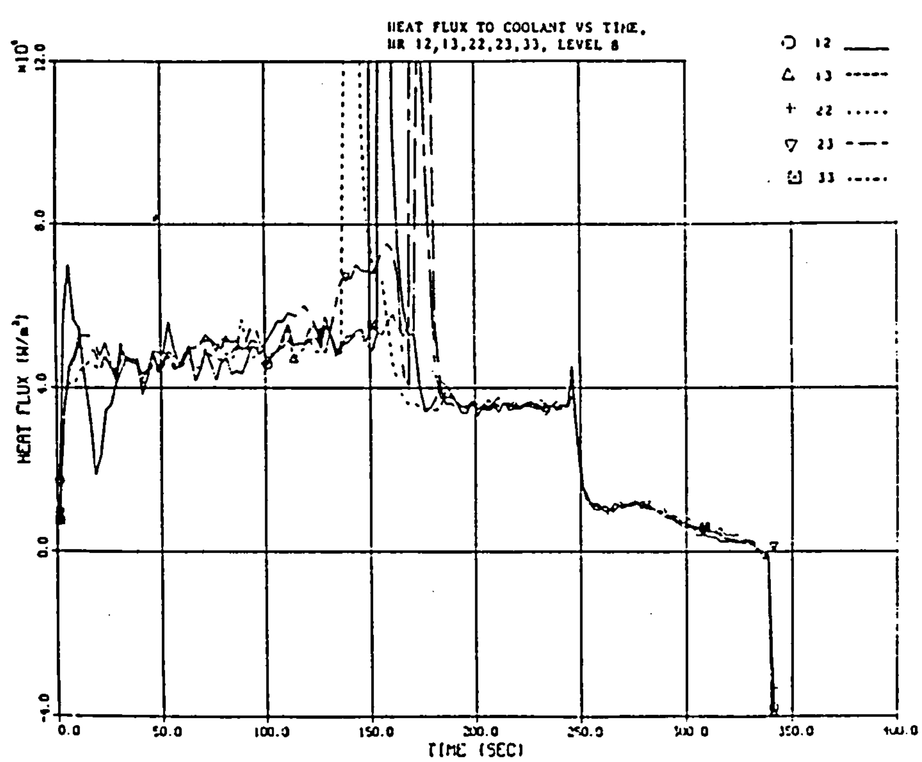


Figure 4.78. EXP 4120; Experimental heat flux at level 8.

5. RUN STATISTICS

The number of system seconds and the CPU time used for the four sensitivity analyses as presented in section 3.1. are given in Table 5.1. The numbers are based on 100 seconds process time. The analyses are performed on the Cyber 855 mainframe computer of the Technical Computing Center (ENR) at Petten, the Netherlands.

Table 5.1. Run statistics.

	Length of the hydrodynamic nodes	Axial fine mesh intervals	CPU (s)	Process time (s)
Run 1; Exp. 100	.125 m	16	2429	100
Run 2; Exp. 4100	.125 m	32	2554	100
Run 3; Exp. 4100	. 25 m	32	909	100
Run 4; Exp. 4100	. 50 m	32	593	100

6. CONCLUSIONS

The conclusions concerning the RELAP5/MOD2 analyses of some selected reflood experiments can be summarized as follows:

- The reflood heat transfer model in RELAP5/MOD2 is only valid for high reflood rates. This is the main reason that cladding temperatures are well predicted for high reflood velocities (0.08 m/s) while a poor comparison is obtained for low reflood velocities (0.015 m/s). Modification of the heat transfer model to include low reflood rates is recommended.
- Entrainment of water in the bundle is strongly overpredicted for all selected cases. For this reason modifications of the interfacial friction correlations for the bubbly and slug flow regime are recommended.
- Refinement of the axial nodalization (axial nodes smaller than recommended in the RELAP5/MOD2 users guidelines) does not improve the calculational results.

REFERENCES

[1] Ransom, V.H. et al.:
RELAP5/MOD2 Code Manual,
NUREG/CR-4312. August 1985.

[2] Boer. T.C., de; Molen, S.B., van der, et al.:
Heat Transfer to a Dispersed Two-Phase Flow and Detailed Quench Front Velocity Research, CEC Report EUR 10074 EN, 1985.

[3] Code improvement plan for TRAC-PF1 and RELAP5, INEL, November 1987. DRAFT.

[4] Compendium of ECCS Research for Realistic LOCA Analysis. NUREG-1230, April 1987. DRAFT.

[5] Guidelines and Procedures for the International Code Assessment and Applications Program. NUREG-1271, April 1987.

LIST OF TABLES

Page

LIST OF FIGURES

Page

Appendix A. RELAP5/MOD2 input deck.

```
= REFLOOD EXP 3216
*
100        NEW        STDY-ST
101        RUN
*
*TIME STEPS
*
*        END       MIN       MAX       CTRL      MINED     MAJED    REST
201      0.5       .5E-4     .01       202        25       1000     1250
*
*****20800001  TREWET     3101
*****20800002  ZTRWT      3101
*
*MINOR EDITS
*
301        P          310150000
*****302        ZTRWT      3101
303        HTTEMP     310100505
304        HTTEMP     310100705
305        HTTEMP     310100905
306        HTTEMP     310101105
307        HTTEMP     310101205
308        HTTEMP     310101305
309        HTTEMP     310101405
*
*TRIPS
*
501      TIME      0       GT    NULL    0     1000. N   *END
510      TIME      0       GT    NULL    0      10.0 L   *POWER
520      TIME      0,      GT    NULL    0      10.0 L   *FILL FLOW
530      TIME      0       GT    NULL    0        .0 L   *REFLOOD
600      501
*
*  *  *  *   *  ***   ***         ***    **    *   *   ***
*  *  *   * *   *  *  *  *        *      *  *   ** **   *  *
*  ****    *    *  *  ****        *      *  *   * * *   ****
*  *  *    *    *  *  *  *   **   *      *  *   * * *   *     **
*  *  *    *    ***   *   *  **   ***    **     * * *   *     **
*
* VOLUMES
*
01100000  INLET      TMDPVOL
01100101  1000000.   100.      .0       .0       90.      100.
01100102  4.0E-5     0.0       00
01100200  3
01100201  0.         200000.   313.
*
```

```
03100000  HEATER    PIPE
03100001  15
03100101  .004785  15
03100201  .0        1
03100202  .0        2
03100203  .004188   3
03100204  .0        4
03100205  .004188   5
03100206  .0        6
03100207  .004188   7
03100208  .0        8
03100209  .004188   9
03100210  .0       10
03100211  .004188  11
03100212  .0       12
03100213  .004188  13
03100214  .0       14
03100301  .125      3
03100302  .25      14
03100303  .125     15
03100601  90.      15
03100801  4.0E-5    .0118     15
03100901  .0        .0         1
03100902  .0        .0         2
03100903  .0717     .0717      3
03100904  .0        .0         4
03100905  .0717     .0717      5
03100906  .0        .0         6
03100907  .0717     .0717      7
03100908  .0        .0         8
03100909  .0717     .0717      9
03100910  .0        .0        10
03100911  .0717     .0717     11
03100912  .0        .0        12
03100913  .0717     .0717     13
03100914  .0        .0        14
03101001  00        15
03101101  31000     14
03101201  3         201309.   313.0  .0    .0    .0          1
03101202  0         200105.   166795.  2529480.   .10 .0     2
03101203  3         200029.   463.   .0    .0    .0          3
03101204  3         200027.   463.   .0    .0    .0          4
03101205  3         200024.   463.   .0    .0    .0          5
03101206  3         200017.   463.   .0    .0    .0         12
03101207  3         200007.   463.   .0    .0    .0         13
03101208  3         200005.   463.   .0    .0    .0         14
03101209  3         200003.   463.   .0    .0    .0         15
03101300  1
03101301    .0        .0        .0        14
*
```

```
04100000  UPPLEN     SEPARATR
04100001  3          0
04100101  .004785    .25        0.        0.        90.      .25
04100102  4.0E-5     .0118      00
04100200  3          200000.    453.
04101101  410010000  950000000  .004785   .5        .5       31000
04101201  0.0        0.0        0.0
04102101  410000000  955000000  .004785   .5        .5       31000
04102201  0.0        0.0        0.0
04103101  310010000  410000000  .004785   .0        .0       31000
04103201  0.0        0.0        0.0
*
09500000  OUTLET     TMDPVOL
09500101  1000000.   100.       .0        .0         90.     100.
09500102  4.0E-5     0.         00
09500200  3
09500201  0.         200000.    453.0
*
09550000  OUTLET     TMDPVOL
09550101  1000000.   100.       .0        .0         90.     100.
09550102  4.0E-5     0.         00
09550200  3
09550201  0.         200000.    453.0
*
01150000  INLET      TMDPJUN
01150101  110000000  310000000   .0
01150200  0          520
01150201  0.0        .0          .0       .0
01150202  4.9        .0          .0       .0
01150203  5.0        .015486     .0       .0
01150204  805.0      .014356     .0       .0
*
*
```

```
*  *  *  ****    *    *****      ****  *****  ***
*  *  *  *      * *     *        *       *    *  *
*  ****  ***   *****    *         **     *    ****
*  *  *  *     *   *    *    **     *    *    * *   **
*  *  *  ****  *   *    *    **  ****    *    *  *  **
*
13101000  15        5       2     0      0.     530    1    32
13101100  0         1
13101101  1         .0023
13101102  1         .0025
13101103  1         .00446
13101104  1         .00535
13101201  1         1
13101202  2         2
13101203  1         3
13101204  3         4
13101301  0.        1
13101302  1.        2
13101303  0.        4
13101400  -1
13101401  313.      313.      313.      313.      313.
13101402  330.      330.      330.      330.      330.
13101403  441.      441.      441.      441.      441.
13101404  445.      445.      445.      445.      445.
13101405  450.      450.      450.      450.      450.
13101406  454.      454.      454.      454.      454.
13101407  459.      459.      459.      459.      459.
13101408  461.      461.      461.      461.      461.
13101409  463.      463.      463.      463.      463.
13101410  468.      468.      468.      468.      468.
13101411  473.      473.      473.      473.      473.
13101412  473.      473.      473.      473.      473.
13101413  464.      464.      464.      464.      464.
13101414  449.      449.      449.      449.      449.
13101415  433.      433.      433.      433.      433.
13101501  0         0         0       1       4.0         3
13101502  0         0         0       1       8.0        14
13101503  0         0         0       1       4.0        15
13101601  310010000 10000     1       1       4.0         3
13101602  310040000 10000     1       1       8.0        14
13101603  310150000 0         1       1       4.0        15
13101701  777       .0        .0      .0       2
13101702  777       .0416666  .0      .0       3
13101703  777       .0833333  .0      .0      14
13101704  777       .0416666  .0      .0      15
13101901  0         .0118     .0      .0      15
*
```

```
* *****  *  *  *****  ***       ***   ***
*   *    *  *  *       *  *      *  *  *  *
*   *    ****  ****   ****      ****  ****
*   *    * ' *  *       *  *   **  *      *  *   **
*   *    *  *  *****  *  *    **  *      *   *   **
*
*
20100100  TBL/FCTN   1   1      *BORONNITR.
20100101   20.0
20100151   3.22E+6
*
20100200  TBL/FCTN   1   1      *HEATER
20100201   16.7
20100251   3.266E+6
*
20100300  TBL/FCTN   1   1      *CLAD
20100301   273.15  12.9805  1199.82  25.1060  2000.0  25.1060
*
20100351   255.37 3561611.  422.04  3964814.  477.59  4099214.
20100352   533.15 4233615.  588.71  4334415.  644.26  4435081.
20100353   699.82 4502416.  810.93  4636816. 1366.48  5376019.
20100354  2000.00 5376019.
*
* TABLES
*
20277700  POWER     510      1.          1.
20277701  0.0  426. 14.5  426. 17.5  114805.3 587.5  115736.9
*
```

```
*CONTROL VARIABLES
*
20500100  COLLVL     SUM       1.0      0.0        1
20500101  0.0        0.125     VOIDF    310030000
20500102             0.250     VOIDF    310040000
20500103             0.250     VOIDF    310050000
20500104             0.250     VOIDF    310060000
20500105             0.250     VOIDF    310070000
20500106             0.250     VOIDF    310080000
20500107             0.250     VOIDF    310090000
20500108             0.250     VOIDF    310100000
20500109             0.250     VOIDF    310110000
20500110             0.250     VOIDF    310120000
20500111             0.250     VOIDF    310130000
20500112             0.250     VOIDF    310140000
20500113             0.125     VOIDF    310150000
20500200  STEAM-OUT  MULT      .004785  0.0        1
20500201  VELGJ      410030000
20500202  RHOGJ      410030000
20500203  VOIDGJ     410030000
20500300  WATER-OUT  MULT      .004785  0.0        1
20500301  VELFJ      410030000
20500302  RHOFJ      410030000
20500303  VOIDFJ     410030000
20500400  WATER-IN   MULT      .004785  0.0        1
20500401  VELFJ      115000000
20500402  RHOFJ      115000000
20500403  VOIDFJ     115000000
20500500  INJECTED   INTEGRAL  1.0      0.0        1
20500501  CNTRLVAR   4
20500600  STEAM-OUT  INTEGRAL  1.0      0.0        1
20500601  CNTRLVAR   2
20500700  WATER-OUT  INTEGRAL  1.0      0.0        1
20500701  CNTRLVAR   3
20500800  MASS       SUM       1.0      0.0        1
20500801  0.0        1.0       CNTRLVAR     5
20500802            -1.0       CNTRLVAR     6
20500803            -1.0       CNTRLVAR     7
*
```

```
= REFLOOD EXP 3216
*
100       RESTART   TRANSNT
101       RUN
103       54
*
*TIME STEPS
*
*      END     MIN        MAX      CTRL     MINED    MAJED   REST
201    550.0   .5E-4      .01      202       25      1000    1250
*
20800001  TREWET    3101
20800002  ZTRWT     3101
*
*MINOR EDITS
*
301       P         310010000
302       ZTRWT     3101
303       HTTEMP    310100505
304       HTTEMP    310100705
305       HTTEMP    310100905
306       HTTEMP    310101105
307       HTTEMP    310101305
308       HTTEMP    310101405
*
*TRIPS
*
501       TIME     0      GT   NULL   0    1000. N   *END
510       TIME     0      GT   NULL   0      0.0 L   *POWER
520       TIME     0      GT   NULL   0      0.0 L   *FILL FLOW
530       TIME     0      GT   NULL   0       .0 L   *REFLOOD
600       501
*
20501000  Q-FRONT   SUM        1.0     0.0       1
20501001  -0.250    1.0        ZTRWT          3101
*
```

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC. Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/IA-0112
ECN-C—92-008

2. TITLE AND SUBTITLE

Assessment of RELAP5/MOD2 Against ECN-Reflood Experiments

3. DATE REPORT PUBLISHED

MONTH	YEAR
July	1993

4. FIN OR GRANT NUMBER

L2245

5. AUTHOR(S)

A. Woudstra, J. P. A. Van De Bogaard, P. M. Stoop

6. TYPE OF REPORT

Technical

7. PERIOD COVERED (Inclusive Dates)

8. PERFORMING ORGANIZATION — NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Netherlands Energy Research Foundation ECN
Service Unit General Services
P. O. Box 1, NL-1755 ZG Petten
The Netherlands

9. SPONSORING ORGANIZATION — NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, DC 20555 -0001

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

As part of the ICAP (International Code Assessment and Applications Program) agreement between ECN (Netherlands Energy Research Foundation) and USNRC, ECN has performed a number of assessment calculations with the computer program RELAP5.

This report describes the results as obtained by ECN from the assessment of the thermohydraulic computer program RELAP5/MOD2/CY 36.05 versus a series of reflood experiments in a bundle geometry. A total number of seven selected experiments have been analyzed, from the reflood experimental program as previously conducted by ECN under contract of the Commission of the European Communities (CEC). In this document, the results of the analyses are presented and a comparison with the experimental data is provided.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

RELAP5/MOD2, ICAP, thermohydraulic

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page)
Unclassified

(This Report)
Unclassified

15. NUMBER OF PAGES

16. PRICE

NRC FORM 335 (2-89)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

SPECIAL FOURTH-CLASS RATE
POSTAGE AND FEES PAID
USNRC
PERMIT NO. G-67