NUREG/IA-0009

International Agreement Report

Assessment of RELAP5/MOD2 Against 25 Dryout Experiments Conducted at the Royal Institute of Technology

Prepared by
A. Sjoberg, D. Caraher

Swedish Nuclear Power Inspectorate
S-102 52 Stockholm, Sweden

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

October 1986

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

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STUDSVIK ENERGITEKNIK AB

STUDSVIK/NP-86/66

1986-06-02

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ICAP

Assessment of RELAP5/MOD2 Against Twenty Five Dryout Experiments Conducted at the Royal Institute of Technology

Swedish Nuclear Power Inspectorate

Project 85026, Reference 13.3-917/84

ABSTRACT

RELAP5/MOD2 simulations of post-dryout heat transfer in a 7 m long, 1.5 cm diameter heated tube are reported. The Biasi critical heat flux correlation is shown to be inadequate for predicting the experimental dryout. RELAP5 accurately predicted the measured temperatures downstream of the dryout once it was forced to predict dryout at the experimentally measured location.

* Engineering Software Consulting

Approved by Eric Wellstrand

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EXECUTIVE SUMMARY

RELAP5/MOD2 simulations have been conducted for 25 of the post-dryout heat transfer experiments performed at the Royal Institute of Technology in Stockholm, Sweden. The experimental test section was a 7 m long, 1.5 cm diameter heated tube. Experimental pressures ranged from 3 to 20 MPa; mass fluxes ranged from 500 to 2 000 kg/m^2-s; heat fluxes from 10 to 125 W/cm^2; and inlet subcooling from 7 to 13 K.

The RELAP5 model used for the simulations consisted of 47 fluid volumes - fairly coarse noding was used in the lower 3 m of the test section while cell lengths of 10 cm were used above the 3 m elevation. For nearly all experiments being simulated the tube region below 3 m remained in nucleate boiling. Time dependent pressure, temperature, and flow boundary conditions were imposed to simulate the fluid entering the test section. The region downstream of the test section was modelled by a time dependent pressure boundary condition. A constant, axially uniform heat flux was imposed on the tube, replicating the experimentally measured heat flux. An insulated boundary condition was imposed upon the outside edge of the tube wall while the inner edge received its boundary condition - a heat transfer coefficient and temperature sink - from the RELAP5 heat transfer package. Once the RELAP5 simulations reached steady state the calculated axial temperature distribution along the tube was compared to experimental measurements.

The first series of RELAP5 simulations showed very poor agreement with the experimental data because RELAP5 predicted CHF to occur much farther

downstream than it actually did. A subsequent comparison of the Biasi CHF correlation (used in RELAP5) to 177 of the post-dryout experiments showed that the mean difference between the measured and Biasi CHF was -60.8 %, the negative sign indicating that the Biasi heat flux was greater than the actual heat flux.

A second series of simulations were conducted using a version of RELAP5 which was updated so that the calculated CHF location corresponded to the measured location. This technique allowed the objectives of the simulations - assessing post-CHF heat transfer - to be achieved.

The forced-CHF simulations showed that RELAP5 accurately simulated the temperature distribution in the region more than 30 cm downstream of the CHF point. In all but one simulation the difference between measured and calculated temperatures in this region was less than 10 %. In general, RELAP5 underpredicted the temperature for the higher (P>10 MPa) pressure experiments and overpredicted the temperatures for the lower pressure experiments.

In the region immediately (0 - 30 cm) downstream of the CHF point large differences between measured and calculated temperatures were evident. In this region the axial temperature gradient is very large (200 - 300 K over 10 to 20 cm).The differences between calculated and measured temperatures could, in some cases, be attributed to the discreteness of both the RELAP5 model and the temperature measurements. In other cases the differences were due to transition boiling occurring in the experiment but not being calculated by RELAP5.

Nodalization studies showed that, if CHF were forced to agree with experimental measurements, adequate simulation of the measured temperature distribution could be achieved with a RELAP5 model having only 14 equally sized nodes representing the test section. For this case the node length (0.5 m) corresponded to that typically used in power plant simulations.

Examination of time history plots from several of the RELAP5 simulations revealed that the steady state convergence algorithm in RELAP5 could probably be relaxed and still yield an acceptable steady state while reducing running time by up to 40 %.

A potential numerical problem with the a CHF calculation was discovered during the RELAP5 simulations in which CHF was not forced. In subroutine PREDNB the calculated CHF is altered based upon results from the iteration scheme used to obtain a wall temperature corresponding to CHF. This alteration sometimes induces discontinuities into the CHF calculated at adjacent time steps in the RELAP5 solution.

NOMENCLATURE

Symbol	Definition	Units
d_i	Inner diameter	m
d_o	Outer diamter	m
G	Mass velocity	kg/m^2s
L	Heated length	m
P	Pressure	bar
q/A	Surface heat flux	W/m^2
q'''	Volumetric heat generation	W/m^3
twi	Inner wall temperature	°C
two	Outer wall temperature	°C
Δt_i	Inlet sub-cooling °C	
U	Voltage over test section	volts
x	Steam quality	dimensionless
λ	Thermal conductivity	kJ/m°Cs
ρ	Electrical resistivity	Ωm
ϕ	Critical heat flux	W/m^2

Subsrcipts

PDO	Post Dryout
P	predicted
M	measured

1 INTRODUCTION

The International Thermal-Hydraulic Code Assessment and Applications Program (ICAP) is being conducted by several countries and coordinated by the USNRC. The goal of ICAP is to make quantitative statements regarding the accuracy of the current state-of-the-art thermal-hydraulic computer programs developed under the auspices of the USNRC.

Sweden's contributions to ICAP relate both to TRAC-PWR (1) and RELAP5 (2). The assessment calculations are being conducted by Studsvik Energiteknik AB for the Swedish Nuclear Power Inspectorate. The assessment matrix is shown in Table 1.

In this report results obtained from an assessment of the RELAP5 Post-CHF heat transfer package are presented. Twenty five post-CHF experiments (3) have been simulated using RELAP5. The experiments were conducted at the Royal Institute of Technology in Stockholm, Sweden. RELAP5/MOD2 version 36.02 was used to perform the simulations.

This report is organized as follows: section 2 describes the experimental facility and section 3 describes the RELAP5 model used to simulate the experiments. In section 4 results from the simulations are presented and discussed. Computational efficiency of RELAP5 and numerical problems encountered during the simulations are given in section 5. Conclusions are presented in section 6.

Table 1

ICAP Assessment Matrix - Sweden.

Code	Facility	Type		Description
		Sep. effect	Integral	
RELAP5	Marviken22	X		Subcooled Critical Flow
RELAP5	Marviken11	X		Critical Flow, level swell
RELAP5	FIX-II		X	Recirculation Line (10 %) break
RELAP5	FIX-II		X	Recirculation Line (31 %) break
RELAP5	FIX-II		X	Recirculation Line (200 %) break
RELAP5	LOFT		X	Cold Leg Break (4") pumps off
RELAP5	LOFT		X	Cold Leg Break (4") pumps on
RELAP5	FRIGG	X		Subcooled Void Distribution
RELAP5	FRIGG	X		Critical Heat Flux
RELAP5	RIT	X		Post Dryout Heat Transfer
TRAC/PF1	Ringhals		X	Loss of Load

2 FACILITY AND TEST DESCRIPTION

The test facility was designed for the purpose of studying post-CHF heat transfer in electrically heated tubes. The facility is located at the department of Nuclear Reactor Engineering of the Royal Institute of Technology in Stockholm, Sweden.

2.1 The loop

The loop employed for the post-CHF experiments was designed for an operating pressure of 250 bar. All parts of the loop in contact with water were made from stainless steel. A simplified flow diagram for the loop is shown in Figure 1. Test sections with heated lengths up to 7 300 mm can be accomodated. Power is supplied from a direct current generator. The maximum available current is 6 000 amps and voltages ranging from 0 to 140 volts can be supplied.

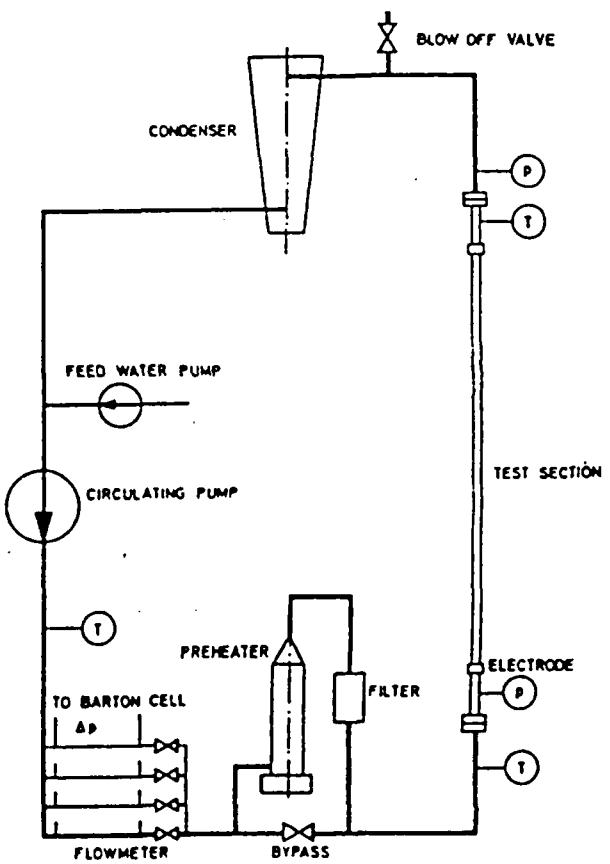

Figure 1

Flow diagram.

Before entering the test section the water passes a 150-kW preheater and a filter. The preheater is used for adjusting the inlet water temperature.

After the test section the steam-water mixture flows through a condenser, and the water then enters a circulation pump, which has a pressure head of 100 meters of water. The major portion of this pressure head is used in the duct system between the pump and the test section inlet, thus providing sufficient throttling in order to secure stable operation of the loop.

The flowmeter system consists of four 1 000 mm long ducts of 3.80, 6.29, and 13.2 mm inner diameter The flow rate measurements were based on measuring the pressure drop over one of these ducts with a Barton cell. The accuracy of this flowmeter system is better than 1 per cent over the whole range of application.

The static pressure of the loop was measured with Barton cells connected to pressure taps, which were located just below and above the test section. The accuracy of the pressure measurements is 0.1 percent.

The water temperature was measured before the flowmeter, before the test section and after the test section. This was accomplished by means of thermocouples mounted in wells 100 mm deep and 3 mm inner diameter. The accuracy of the fluid temperature measurement is ±0.5 K.

The power input was obtained by measuring the current through and the voltage over the test section. The voltage was measured with a precision

voltmeter of 0.25 percent rated accuracy, and the current was obtained by measuring the voltage over a calibrated shunt. For the latter measurements a millivoltmeter with a rated accuracy of 0.25 percent was used.

In order to check the accuracy of the instrumentation, heat balances for one-phase flow, relating the electric heat input to the enthalpy increase of the water were taken every day before starting the ordinary measurements. The error of the heat balances was generally less than 1 per cent. If larger errors were encountered, the instrumentation was checked and new heat balances were taken before carrying out the experimental program.

2.2 Test sections

Three electrically heated round tubes with the following dimensions were employed:

Test section	Heated length	Inner diameter	Outer diameter
1	7 000 mm	14.9 mm	20.8 mm
2	7 000 mm	10.0 mm	14.0 mm
3	7 100 mm	24.69 mm	31.7 mm

Test sections 1 and 2 were made from Nimonic and test section 3 from stainless steel.

In order to make it possible to mount the thermocouples on the outer wall of the test sections, a 0.1 m thick layer of ZrO_2 was sprayed on the outer walls. 55 Chromel-Alumel thermocouples were

placed along the heated length of test sections 1 and 2 in accordance with the axial positions given in Figure 2. Test section 3 was supplied with 49 Chromel-Alumel thermocouples, employing the axial locations shown in Figure 3.

Two copper rings were silver soldered to the test sections. The distance between these rings are referred to as the heated length. Finally, a 10 cm thick layer of stone wool insulation was mounted around the test section, keeping the heat losses at an insignificant level, which was verified by means of the earlier mentioned one-phase flow heat balances.

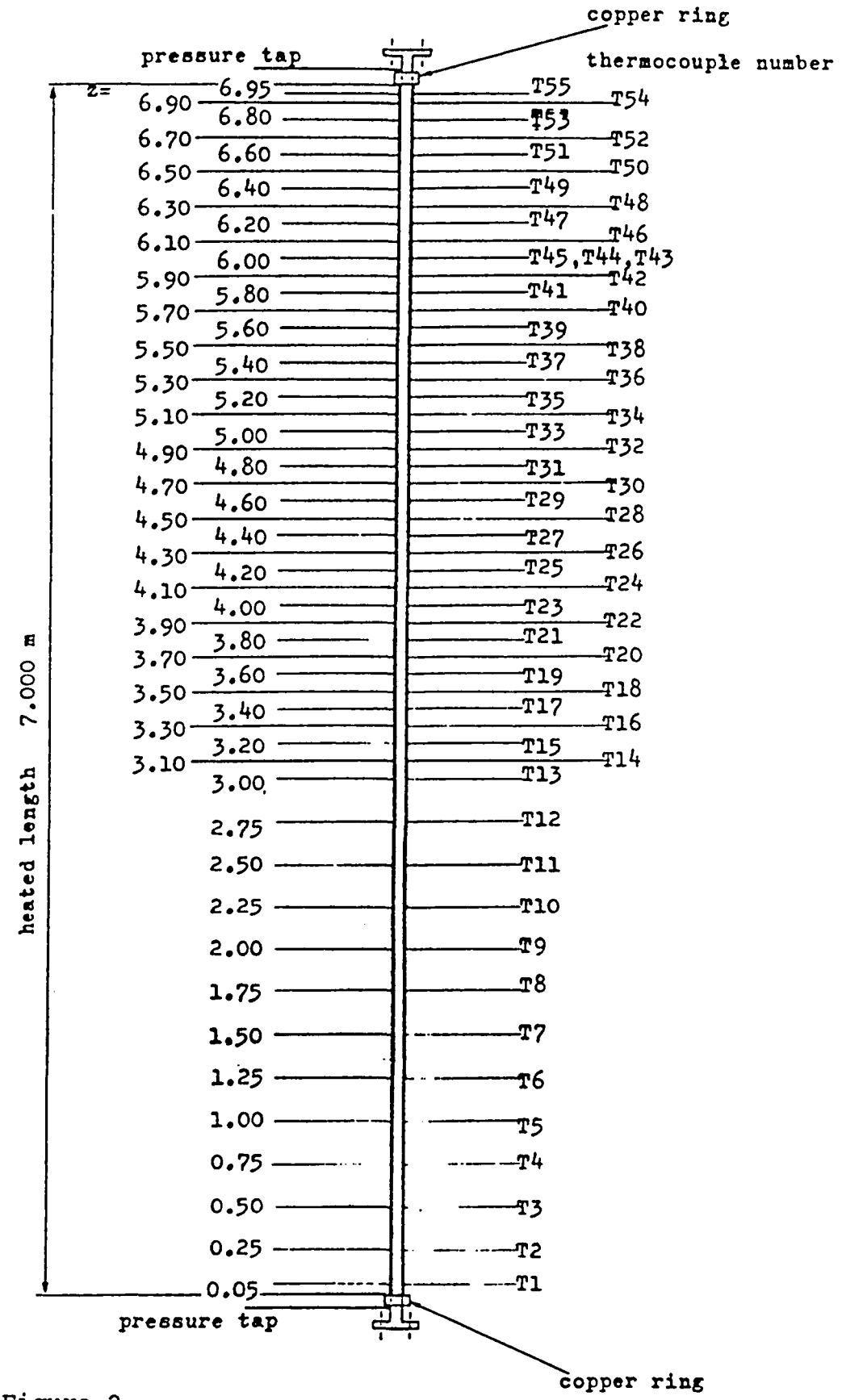

Figure 2

Location of thermocouples.

Testsection 3

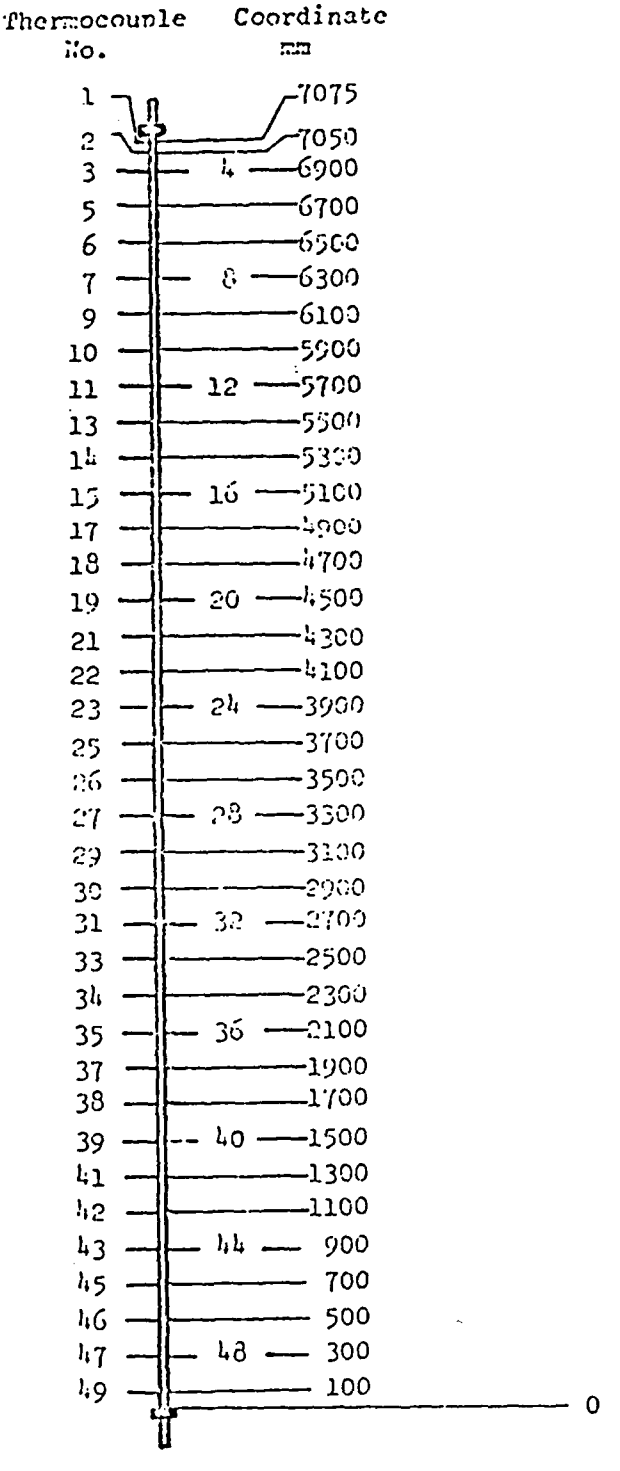

Figure 3

Location of thermocouples.

The outer wall thermocouples were calibrated by means of adiabatic one-phase flow experiments, which were carried out at 100, 200 and 300°C. The majority of the thermocouples indicated temperature dependent correction terms less than 1.5°C. The maximum correction term, which was observed at 300°C, was 3.6°C.

All of the data were recorded by a 100 channel Schlumberger data recorder, punched on paper tape and evaluated by an IBM-360/60 computer.

The inner wall temperatures were obtained from the outer wall temperatures by stepwise integration of the following equation

$$\frac{\partial^2 T}{\partial R^2} + \frac{1}{R}\frac{\partial T}{\partial R} = - \frac{q'''}{\lambda\ (T)} = \frac{U^2}{\rho L^2} \quad \frac{1}{\lambda(T)}$$

This calculation involved the division of the tube into 20 concentric tubes, and demanded information about the temperature-dependent electrical resitivity and thermal conductivity of the test sections' materials. With regard to test sections 1 and 2, the manufacturer's curve for Nimonic 75 was used for the thermal conductivity, while the electrical resistivity was measured in a temperature regulated oven. The thermal properties are given in Table 2.

Table 2

Thermal Properties of Test Sections 1 and 2

Temp (C)	Thermal conductivity (W/m-C)	Electrical resistivity (56 mm^2/m)
100	14.0	1.118
200	15.9	1.130
300	17.6	1.142
400	19.0	1.154
500	21.1	1.160
600	22.4	1.146
700	24.2	1.139
800	26.0	1.138

2.3 Experimental program

In all, 510 runs were carried out in the following ranges of variables:

Test section 1

Heated length	L	= 7 000 mm
Inner diameter	d_i	= 14.9 mm
Outer diameter	d_o	= 20.8 mm
Inlet subcooling	Δt_i	= 10 ± 3°C
Pressure	P	= 30, 50, 70, 100, 120, 140, 160, 180, and 200 bar
Mass velocity	G	= 500, 1 000, 1 500, 2 000, 2 500 and 3 000 kg/m^2s
Heat flux	q/A	= 10 - 125 W/cm^2
PDO steam quality	x_{PDO}	= 0.03-1.60

For each combination of pressure and mass velocity (9 x 6 = 54), 4-8 axial temperature profiles were obtained by variation of the heat flux in steps of 5-10 W/cm^2. The maximum obtainable heat flux was limited by the requirement not to exceed a wall temperature of ~700°C. 334 runs were carried out with this test section.

Test section 2

Heated length	L	= 7 000 mm
Inner diameter	d_i	= 10.0 mm
Outer diameter	d_o	= 14.0 mm
Inlet subcooling	Δt_i	= 10 ± 3°C
Pressure	P	= 30, 70, 120, 160 and 200 bar
Mass velocity	G	= 500, 1 000, 1 500, 2 000, 2 500 and 3 000 kg/m^{2}s
Heat flux	q/A	= 9-85 W/cm^2
PDO steam quality	x_{PDO}	= 0.19-1.66

138 runs were carried out with this test section.

Test section 3

Heated length	L	= 7 100 mm
Inner diameter	d_i	= 24.69
Outer diameter	d_o	= 31.70 mm
Inlet subcooling	Δt_i	5 ± 1°C and 10 ± 1.5°C
Pressure	P	= 150, 180, 196, and 201 bar
Mass velocity	G	= 780-2 475 kg/m^{2}s
Heat flux	q/A	= 29-94 W/cm^2
PDO steam quality	x_{PDO}	= 0.12-0.66

38 runs were carried out with this test section.

3 CODE AND MODEL DESCRIPTION

Simulations of the Royal Institute of Technology (RIT) steady state post-CHF experiments were made with RELAP5/MOD2, cycle 36.02. For the first series of simulations no changes were introduced into the computer program. As shown in section 4, this first set of simulations were in poor agreement with the experimental data because RELAP5, in general, failed to predict CHF near the locations where it actually occurred. Instead, it generally predicted CHF to occur much farther downstream. The disagreement between the measured and predicted CHF points precluded making meaningful assessment of the post-CHF heat transfer package in RELAP5.

In order to facilitate the assessment of post-CHF heat transfer RELAP5 was updated so that CHF could be forced to occur at the same location as it did in the experiment. The simulations were repeated using this updated version of the code.

3.1 Input description

The RELAP5 model of the experimental facility is shown in Figure 4. The test section was modelled with 47 fluid cells. Large cell lengths were used in the lower part of the test section because, in the experiments, CHF never occurred below the 2.7 m elevation. The bulk of the test section was modelled by a uniform mesh of cells having a length of 10 cm.

Boundary conditions were imposed upon the lower and upper end of the test section via time dependent volumes. The lower time dependent volumes specified the inlet pressure and fluid

temperature corresponding to experimental inlet conditions. The experimental flow rate was specified by a time dependent junction at the entrance to the test section.

The heated wall was represented by 47 heat structures (one per fluid volume). Each heat structure used two heat transfer nodes - one at the wall inner edge and one at the wall outer edge. A heat transfer coefficient (determined by RELAP5) was specified as the inner wall edge boundary condition while the outer wall edge was specified to the be completely insulated. The latter specification was justified by the experimental heat balances which showed negligable heat loss through the insulation surrounding the test section.

3.2 Code updates

In order to force RELAP5 to obtain CHF at the same locations as the experiments modifications were made to subroutines PREDNB and HTRC1. The updates are shown in Table 3. These updates were activated only when the CHF and heat transfer correlation flags (word 1 on card 1GCCG801) were set to 10 or 20 for a heat structure.

Table 3

Updates to specify CHF point.

```
*IDENT DLCCHF1
*COMPILE SEGDIR,DEFINE,HTRC1,PREDNB
*/
*I PREDNB.106
C  EXTRACT CHF FLAG.  IF 1 FORCE CHF ; IF 2 INHIBIT CHF
       JCHF=.NOT.MASK(54).AND.SHIFT(HTINCO(LS),54)
       IF(JCHF.EQ.1)  CHF=HTRNRO(LS)
       IF(JCHF.EQ.2)  CHF=HTRNRO(LS)*100.
*I HTRC1.125
C  EXTRACT CHF FLAG.  IF 1 FORCE CHF ; IF 2 INHIBIT CHF
       JCHF=.NOT.MASK(54).AND.SHIFT(HTINCO(LS),54)
       IF(JCHF.EQ.1)  GO TO 2000
       IF(JCHF.EQ.2)  GO TO 3000
```

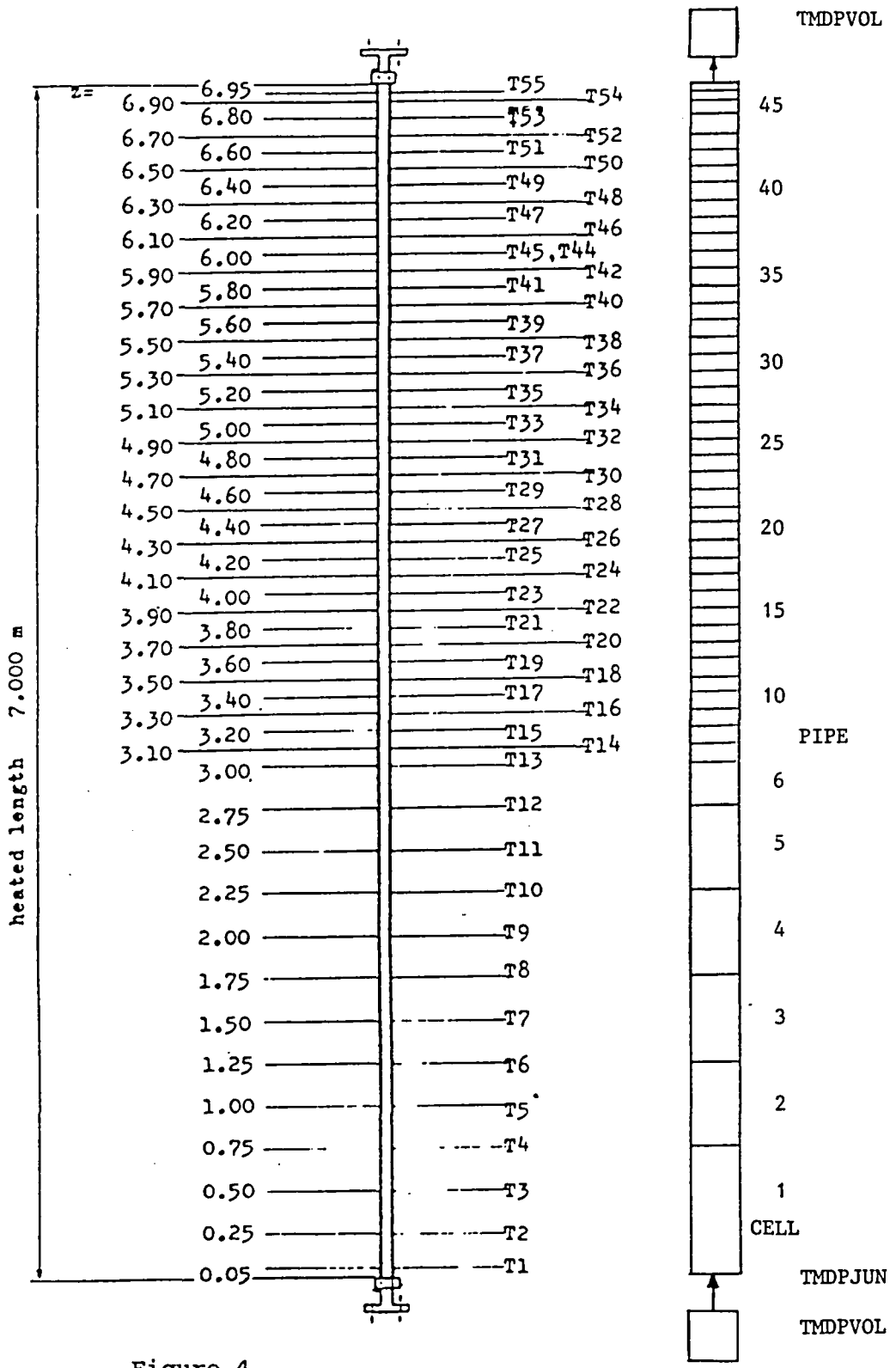

Figure 4

Test section and RELAP5 model.

4 RESULTS AND DISCUSSIONS

RELAP5 simulations were conducted for 25 of the RIT post-CHF experiments. All the results reported here pertain to experimental test section 1.

4.1 Base case simulations

The results of the RELAP5 base case simulations of 25 experiments are summarized in Table 4. Table 4 shows that in nearly all cases RELAP5 predicted CHF to occur a considerable distance downstream of the measured CHF point. From these results one concludes that the Biasi CHF correlation can be nonconservative; that is, it can predict CHF to occur at much higher qualities than it actually does.

The poor agreement of the RELAP5 results and the experimental results was unexpected because the experiments are within the range of validity quoted for the correlation (4) and the correlation was reported to have a mean error of 0.1 % and a mean quadratic error of 7.3 %. The mean error being defined as

$$\varepsilon = \frac{\sum \frac{\phi_{mi}-\phi_{pi}}{\phi_{mi}} 100}{N}$$

and the mean quadratic error as

$$\varepsilon = \frac{\sqrt{\sum \left(\frac{\phi_{mi}-\phi_{pi}}{\phi_{mi}}\right)^2} 100}{N}$$

where N is the number of data points in the comparison.

Table 4

Comparison of the RELAP5 CHF location with the measured location.

Run	Pressure P(MPa)	Mass flux $G(kg/m^2s)$	Inlet temp $T_m(K)$	Heat flux $q''(MW/m^2)$	Measured CHF location Z_m (m)	Calculated CHF location Z_{R5} (m)
136	13.99	1976.6	599.65	0.509	5.55	5.70
139	14.00	1970.5	600.05	0.757	2.88	3.50
147	14.00	1494.3	600.05	0.704	2.88	3.10
154	13.98	1006.6	600.35	0.552	3.15	3.00
161	13.99	503.2	600.25	0.405	2.88	3.60
220	10.00	1981.2	574.45	0.511	-*	-
221	10.01	1973.8	574.15	0.665	5.55	-
224	10.02	1990.3	573.35	0.860	4.25	5.80
232	10.00	1499.8	573.75	0.758	4.15	6.30
238	10.01	997.3	572.15	0.556	4.85	-
244	9.98	502.0	573.05	0.405	5.05	5.70
259	6.99	1989.3	548.95	0.870	6.05	-
261	7.02	1988.2	548.45	1.053	4.65	6.30
264	6.99	1500.2	547.85	0.766	6.05	-
269	7.01	995.4	547.75	0.564	-	-
270	7.02	996.5	547.15	0.660	5.85	-
272	7.02	999.6	547.43	0.815	4.55	5.60
275	7.04	500.9	547.25	0.410	6.45	6.60
315	3.01	1986.3	498.05	0.873	5.95	-
317	3.03	1987.3	497.25	1.058	5.05	-
320	2.99	1499.3	497.65	0.769	6.05	-
325	3.01	1010.6	496.25	0.561	-	-
327	3.00	1005.6	497.15	0.667	6.05	-
331	3.00	497.2	498.55	0.413	-	-
332	3.00	496.4	497.75	0.464	6.25	6.80

* means no CHF occurred

To ensure that the poor agreement between RELAP5 and the experimental CHFs was not due to the limited number of experiments chosen the Biasi correlation was programmed and compared to all the experimental data obtained with test section 1 for pressures less than 15 MPa. This comparison included 177 different experimental runs and gave a mean error of -60.8 % and a mean quadratic error of 88.9 % (see Appendix A). These results clearly demonstrate that the Biasi correlation is of little value for predicting CHF for these experiments.

Using the Biasi correlation in RELAP5 precluded reaching the objective of the simulations which was assessment of post-CHF heat transfer in RELAP5.

4.2 Forced CHF simulations

The RELAP5 simulations were rerun using a code version which forced CHF to occur at the experimentally measured location in each experiment. In Figures 5 through 24 the temperature distributions along the inner wall of the test section are shown.

For those points more than 20-30 cm downstream of the CHF location the agreement between the RELAP5 temperatures and the measured temperatures is very good. The discrepancy between predicted and measured temperatures is less than 10 % in all cases except one (run 139). In many cases the discrepancy is less than 5 %. RELAP5 underpredicted the temperature for the high pressure cases (P>10 MPa) except for those cases having high pressure and high flow (runs 136 and 139). For lower pressures (P<10 MPa) RELAP5 overpredicted the temperature, the degree of overprediction increasing with decreasing pressure.

In the region (0-30 cm) immediately downstream of the CHF location there is considerable disagreement between RELAP5 and the experimental data. In some cases this is due to the discreteness of both the RELAP5 nodalization and the temperature measurements (runs 139, 147, 154 and 161). In other cases the disagreement is probably due to transition boiling occurring over several centimeters in the experiment whereas no transition boiling was calculated to occur in the RELAP5 simulation.

Examination of the RELAP5 results showed that more than 95 % of the heat being added in the post-CHF regime was being deposited in the vapor. Thus, the good agreement exhibited in Figures 5 - 24 indicate that the amount of vapor superheat (40-90K) calculated by RELAP5 is close to that which occurred in the experiments. In this respect, RELAP5/MOD2 represents a definite improvement over RELAP5/MOD1. The earlier version of the program failed to calculate any superheat of the vapor when it was used (5) to simulate some of the experiments being reported here.

4.3 Nodalization studies

The sensitivity of computed results to noding in the tube wall was investigated by rerunning the simulation of test 136 using 10 heat transfer nodes instead of two to represent the wall. Differences in computed wall temperatures for the 10 node and the 2 node cases were less than 0.5 K.

The number of fluid cells (47) used to represent the 7 m test section is much greater than would be used for normal simulations of reactor systems. Typically, cell lengths of 0.5 m are used to re-

present a reactor core's heated length. To investigate the effect of noding upon computed results the simulation of test 272 was rerun using 14 fluid cells rather than 47 to represent the test section. Figure 25 shows the temperature from the 14 node simulation. Comparison of this figure with Figure 19 shows the change in the computed temperature distribution due to the noding change. Except for the difference in the immediate region of the CHF point, the calculated temperature distributions are in good agreement with one another. Thus, reasonable simulations of the RIT experiments could have been obtained with a nodalization comparable to that used in power plant analyses, so long as the CHF location was specified in the simulations.

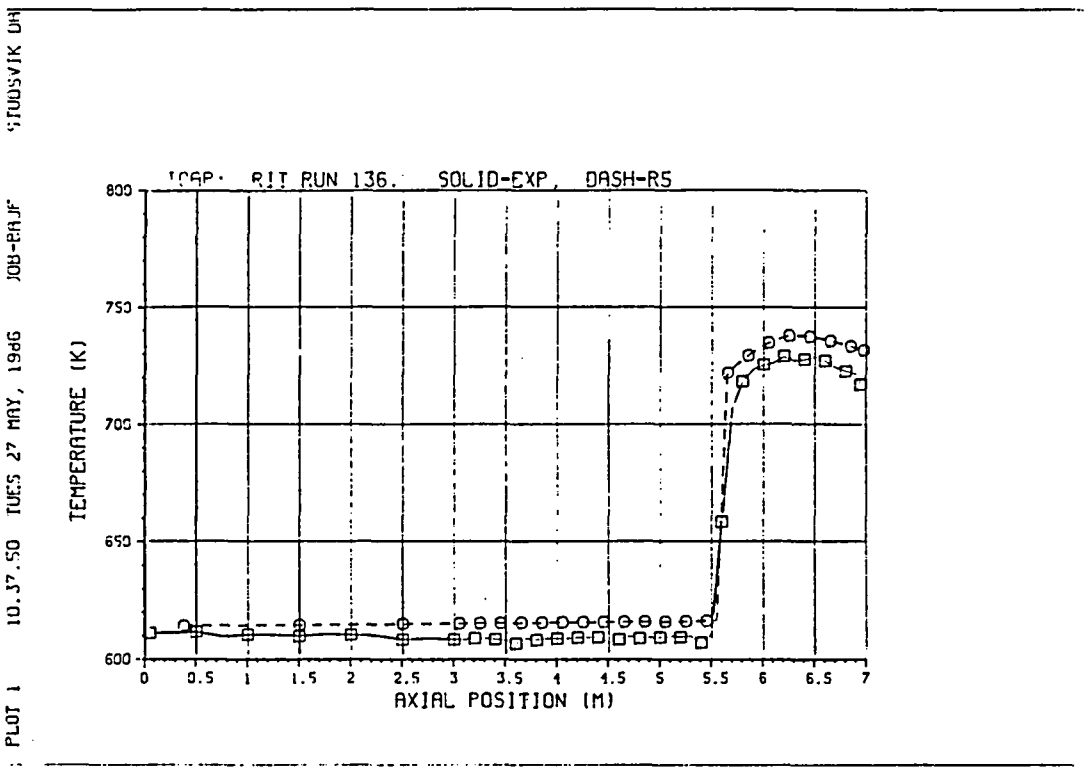

Figure 5

Temperature Distribution for run 136. P = 14 MPa, G = 2 000 kg/m^2-s.

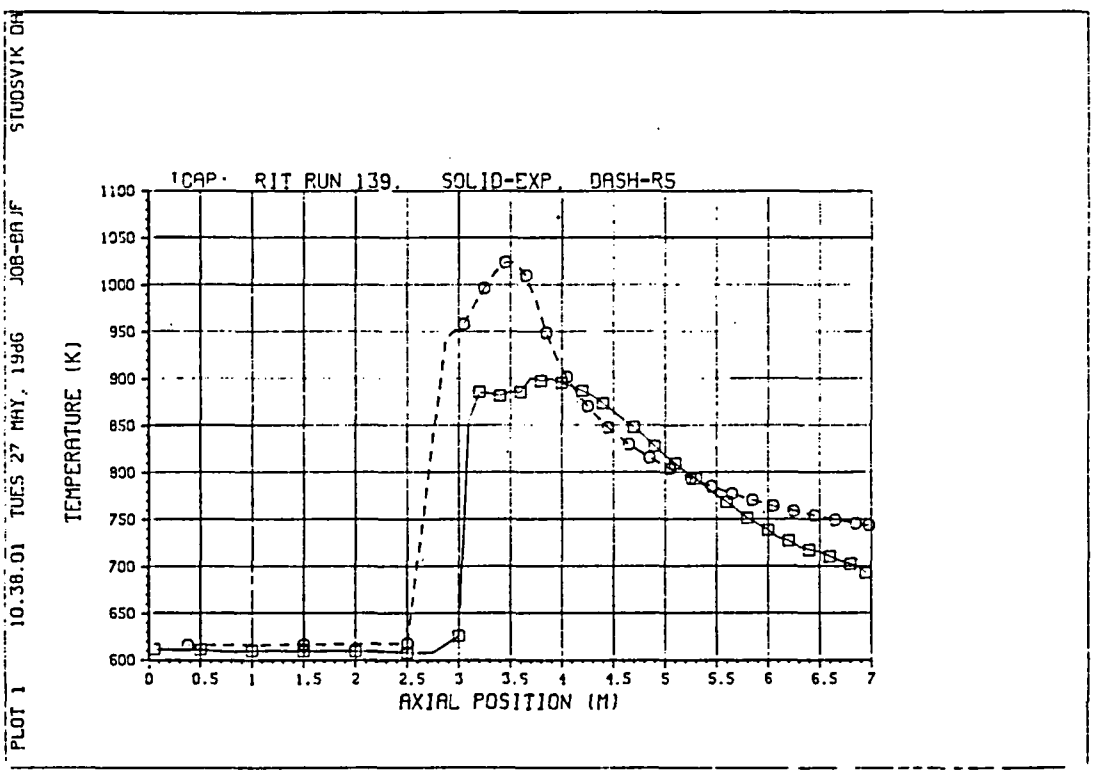

Figure 6

Temperature Distribution for run 139. P = 14 MPa, G = 1 500 kg/m^2-s.

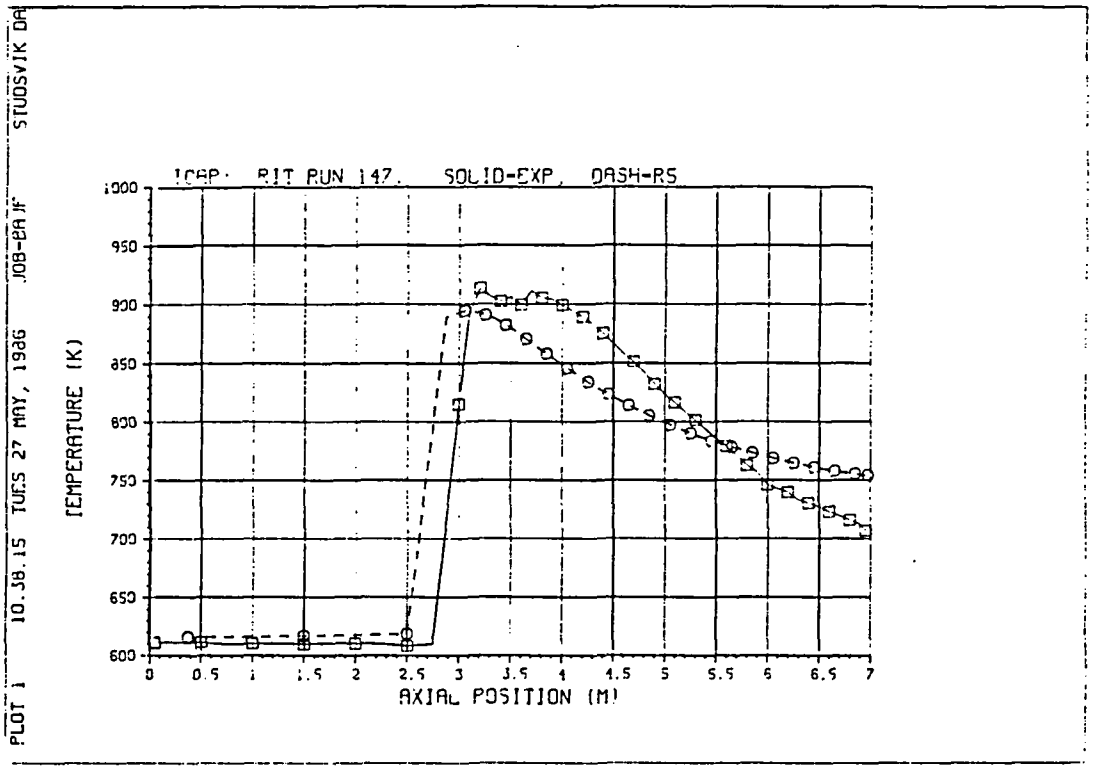

Figure 7

Temperature Distribution for run 147. P = 14 MPa, G = 1 500 kg/m²-s.

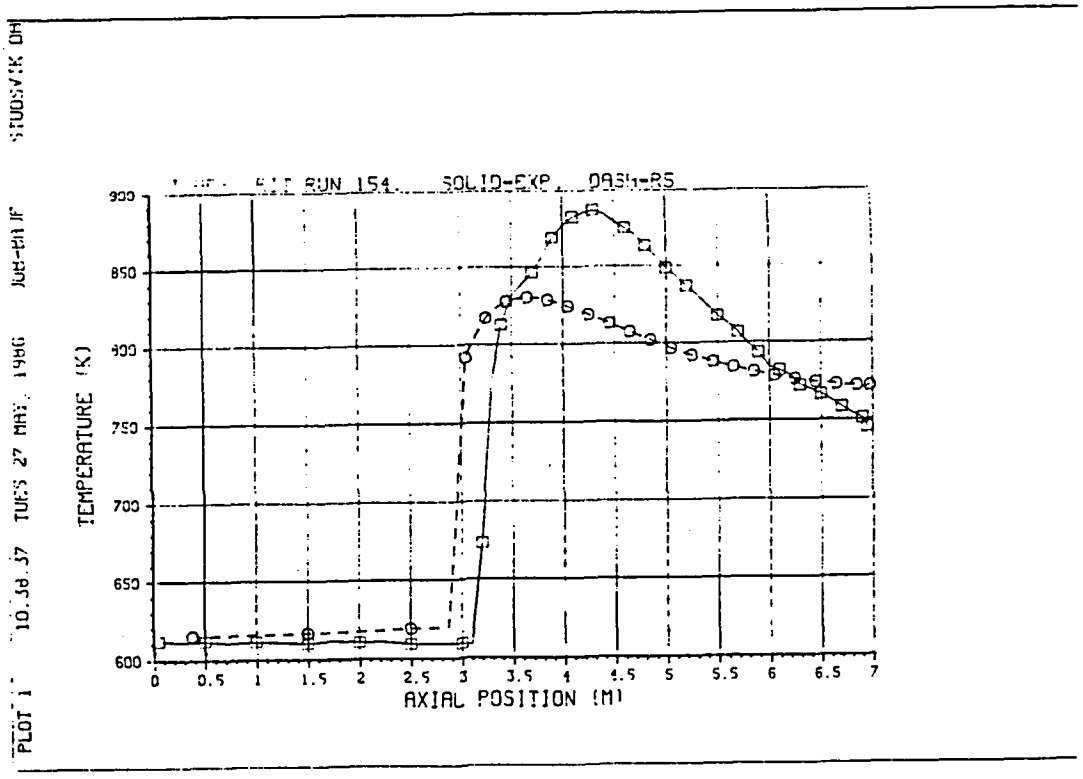

Figure 8

Temperature Distribution for run 154. P = 14 MPa, G = 1 000 kg/m²-s.

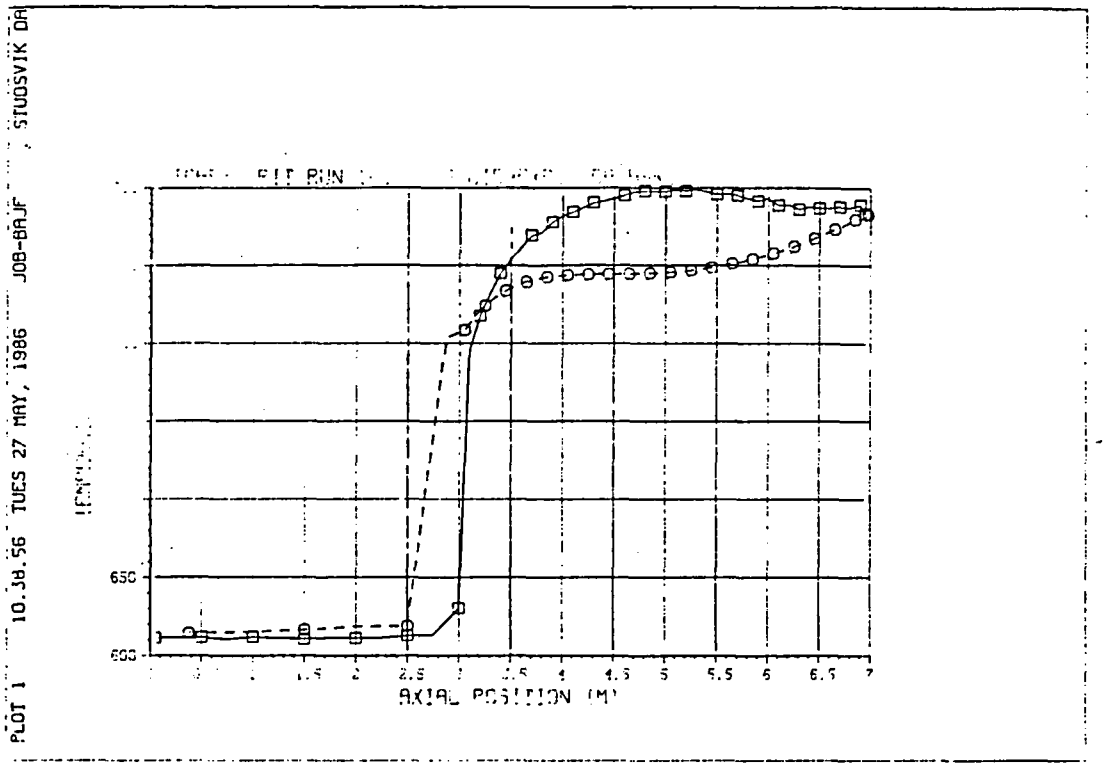

Figure 9

Temperature Distribution for run 161. P = 14 MPa, G = 500 kg/m²-s.

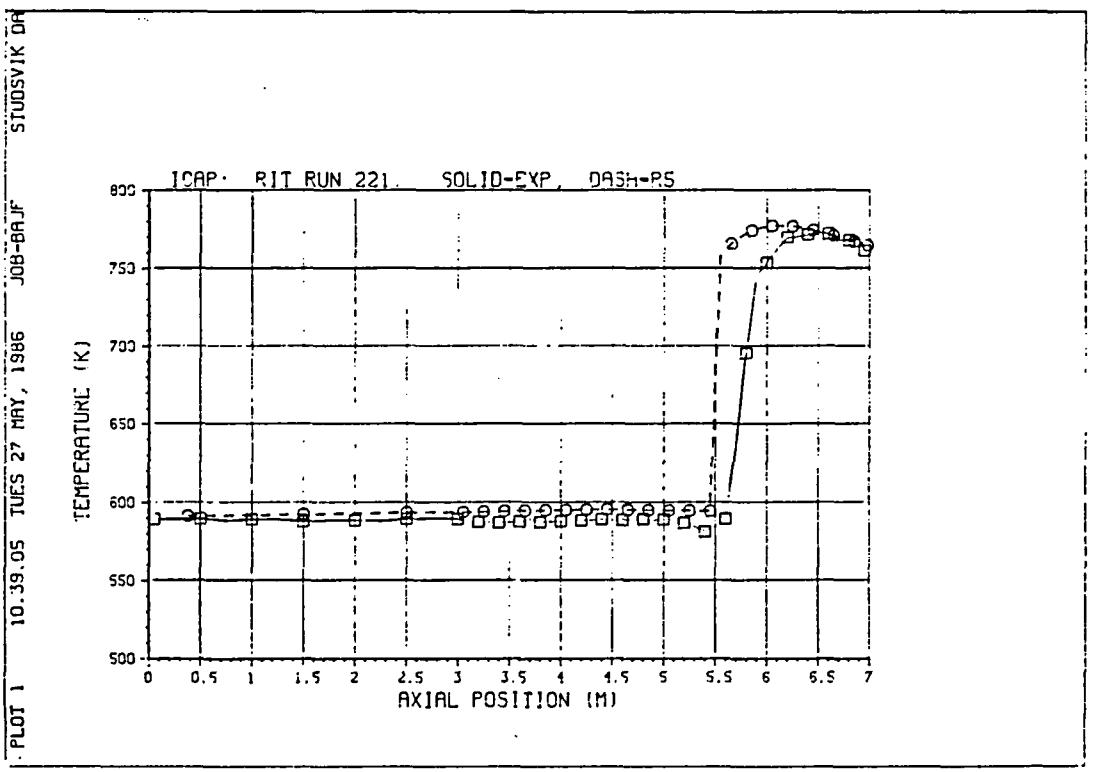

Figure 10

Temperature Distribution for run 221. P = 10 MPa, G = 2 000 kg/m²-s.

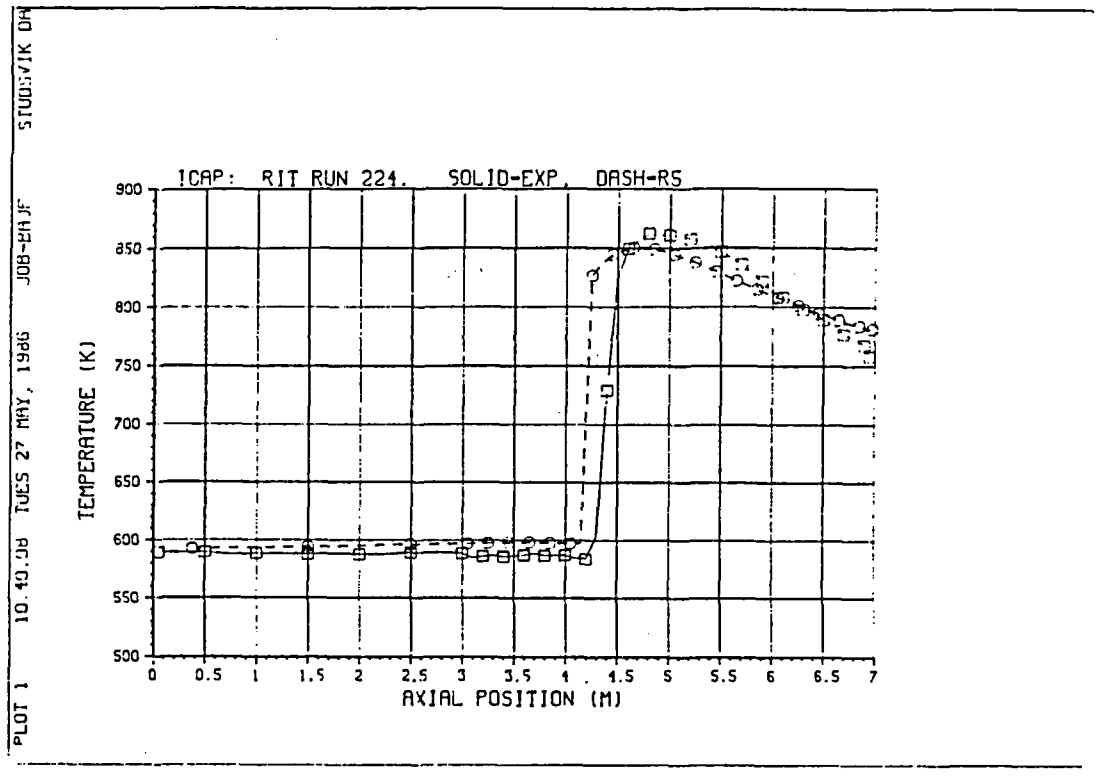

Figure 11

Temperature Distribution for run 224. P = 10 MPa, G = 2 000 kg/m^2-s.

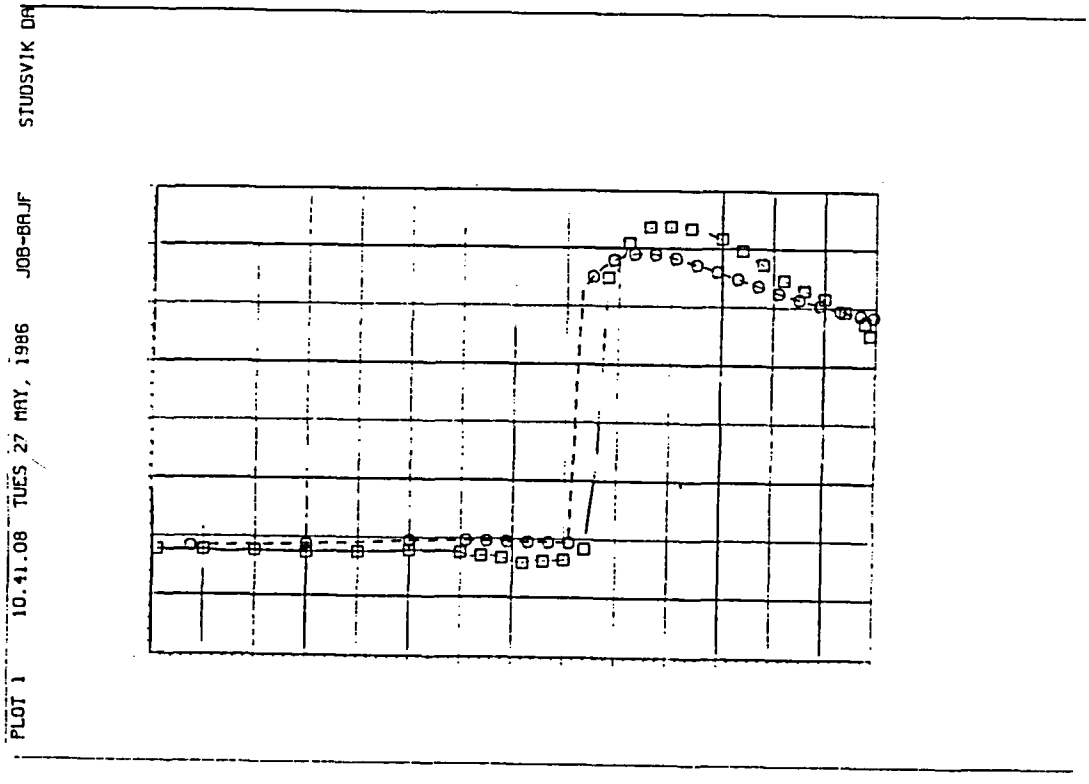

Figure 12

Temperature Distribution for run 232. P = 10 MPa, G = 1 500 kg/m^2-s.

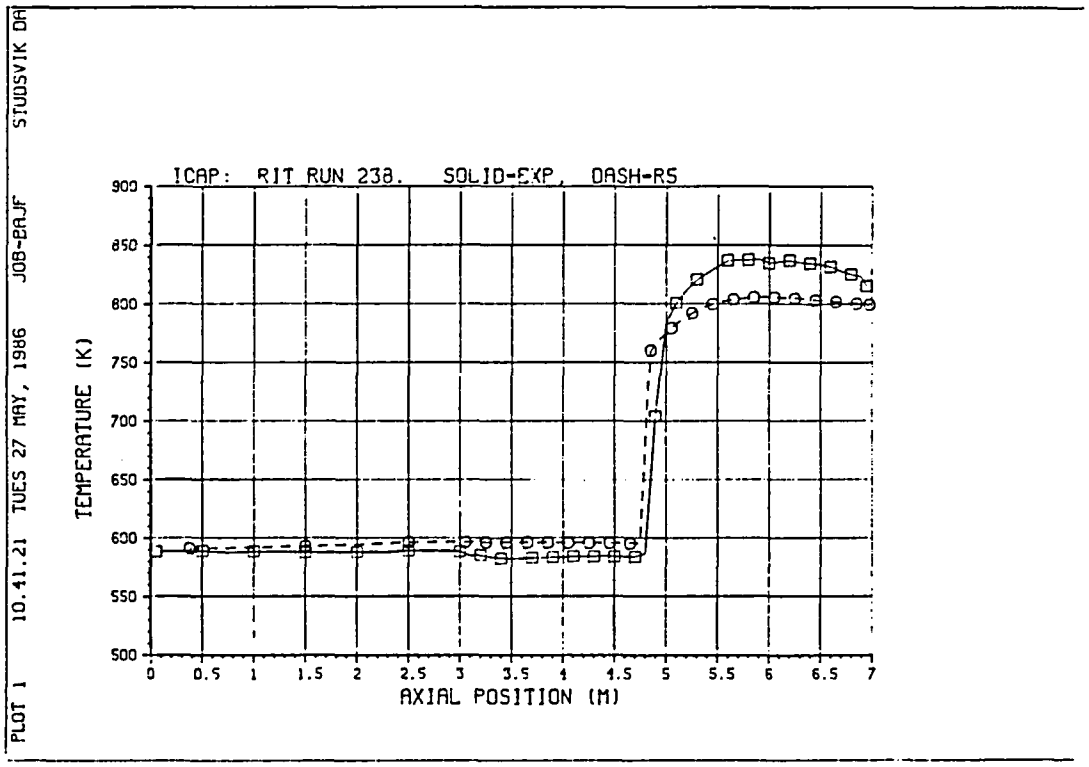

Figure 13

Temperature Distribution for run 238. P = 10 MPa, G = 1 000 kg/m^2-s.

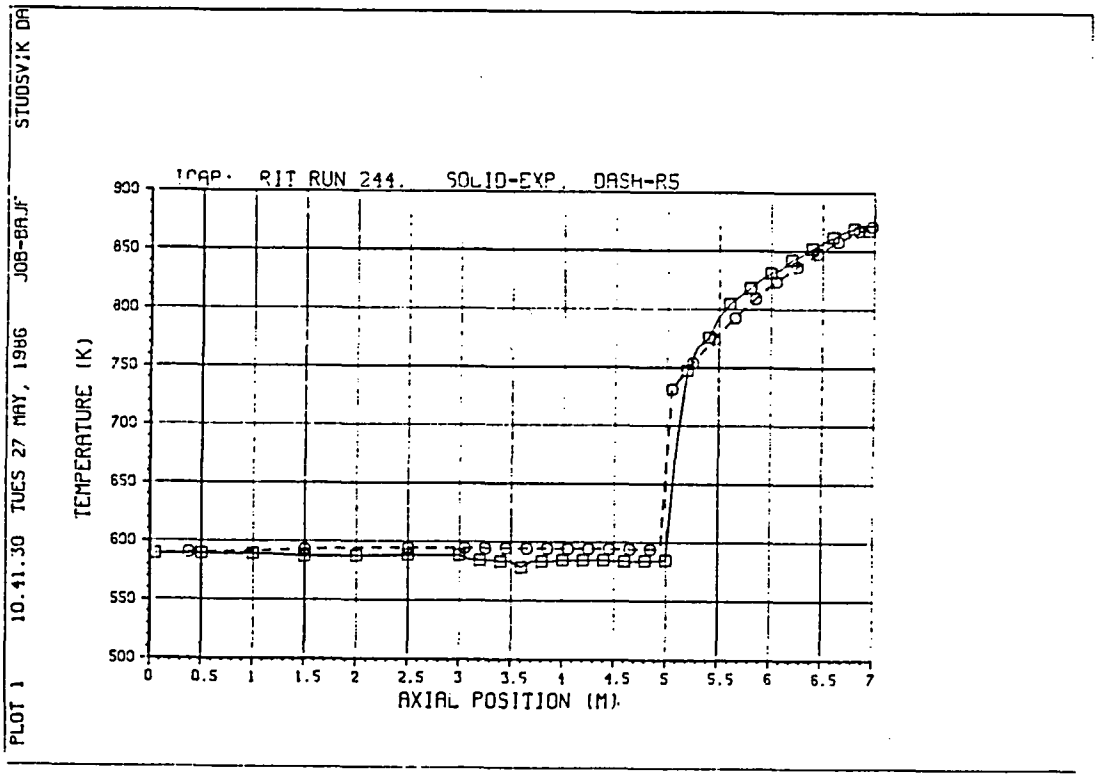

Figure 14

Temperature Distribution for run 244. P = 10 MPa, G = 500 kg/m^2-s.

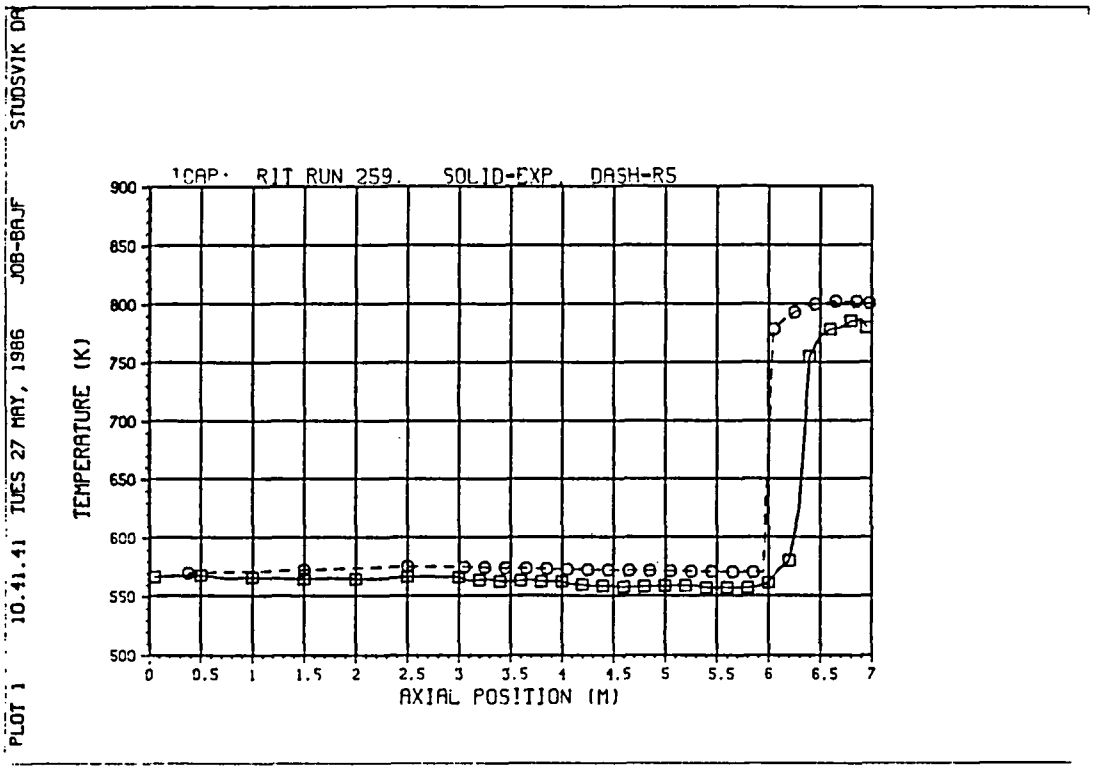

Figure 15

Temperature Distribution for run 259. P = 7 MPa, G = 2 000 kg/m^2-s.

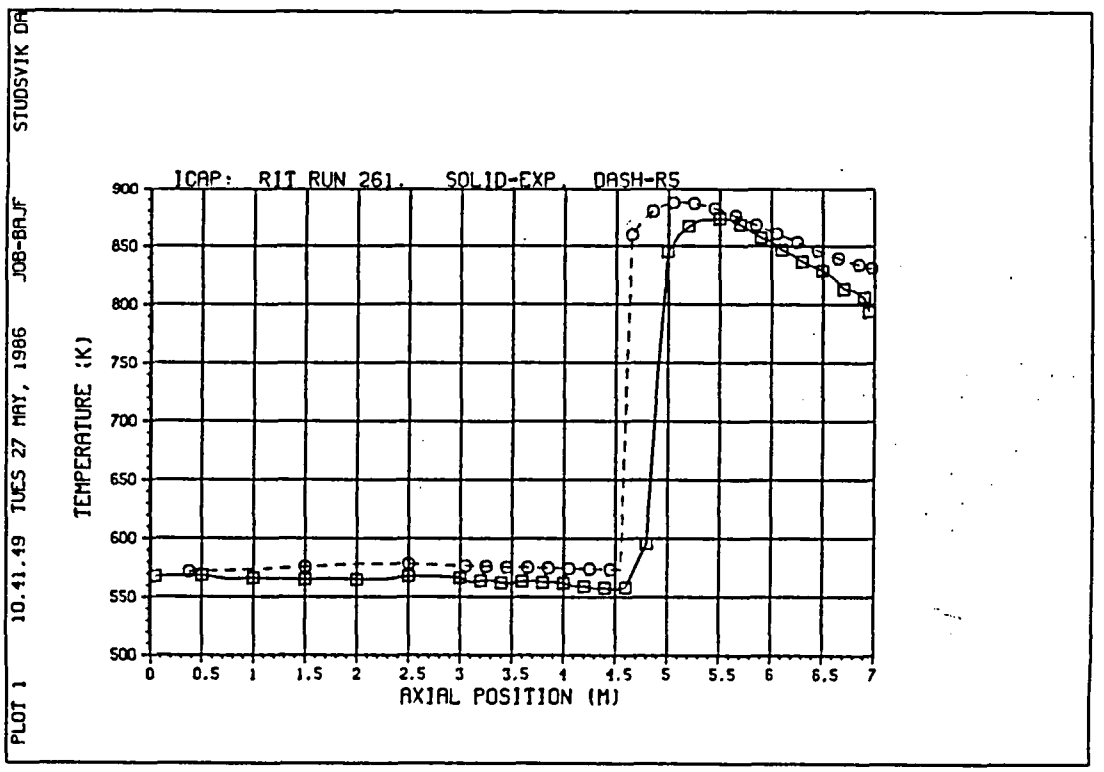

Figure 16

Temperature Distribution for run 261. P = 7 MPa, G = 2 000 kg/m^2-s.

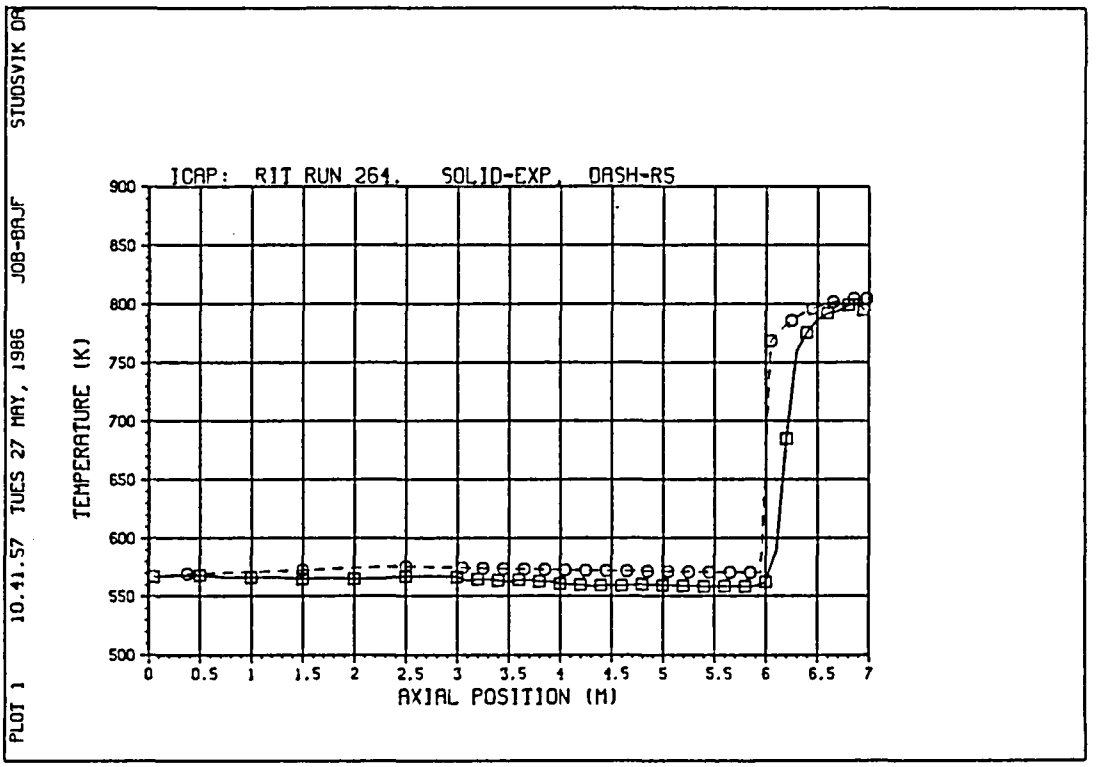

Figure 17

Temperature Distribution for run 264. P = 7 MPa, G = 1 500 kg/m^2-s.

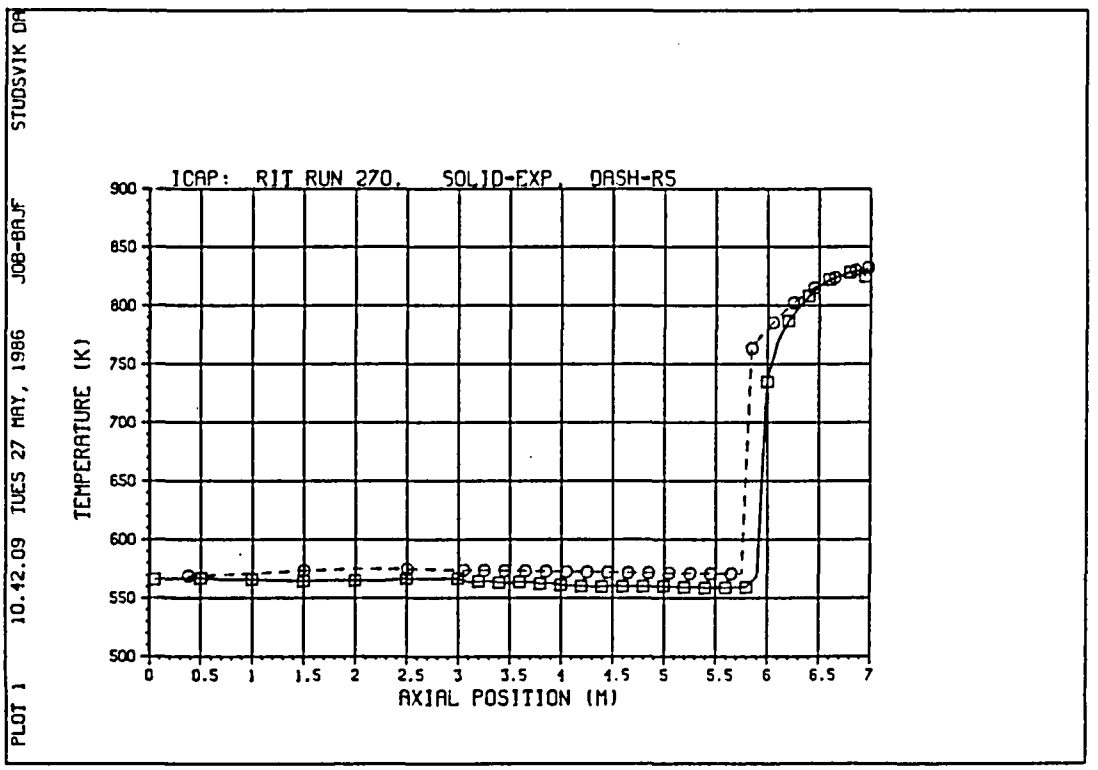

Figure 18

Temperature Distribution for run 270. P = 7 MPa, G = 1 000 kg/m^2-s.

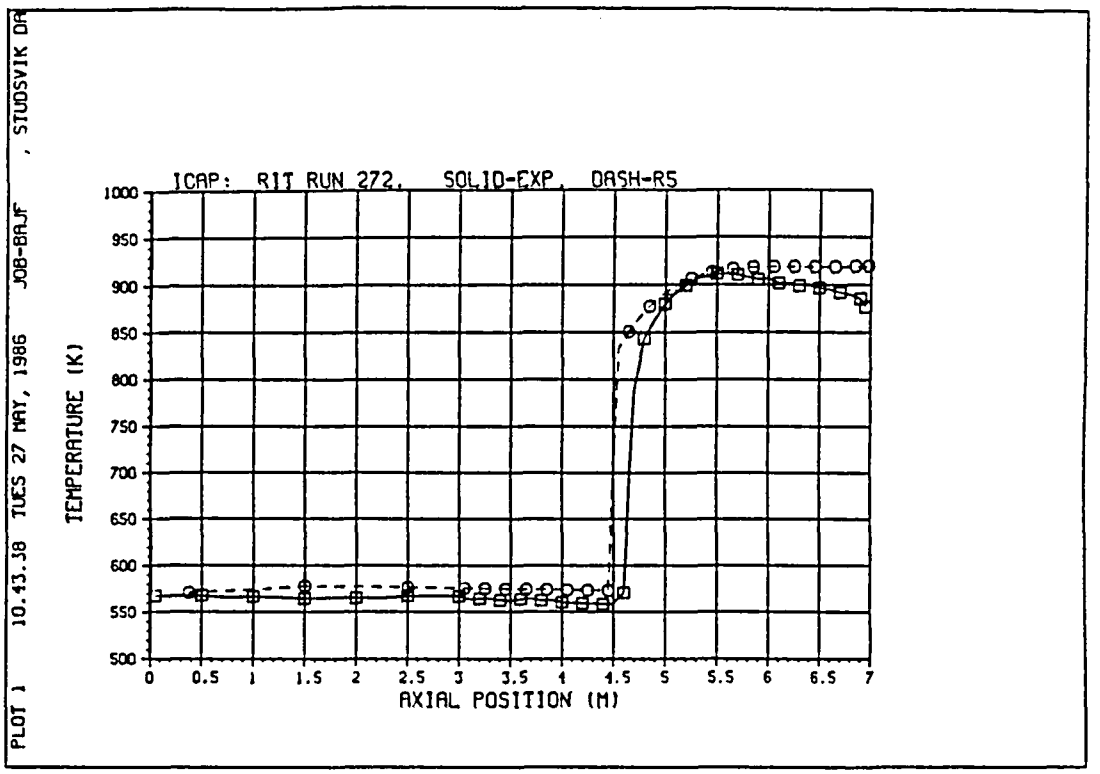

Figure 19

Temperature Distribution for run 272. P = 7 MPa, G = 1 000 kg/m^2-s.

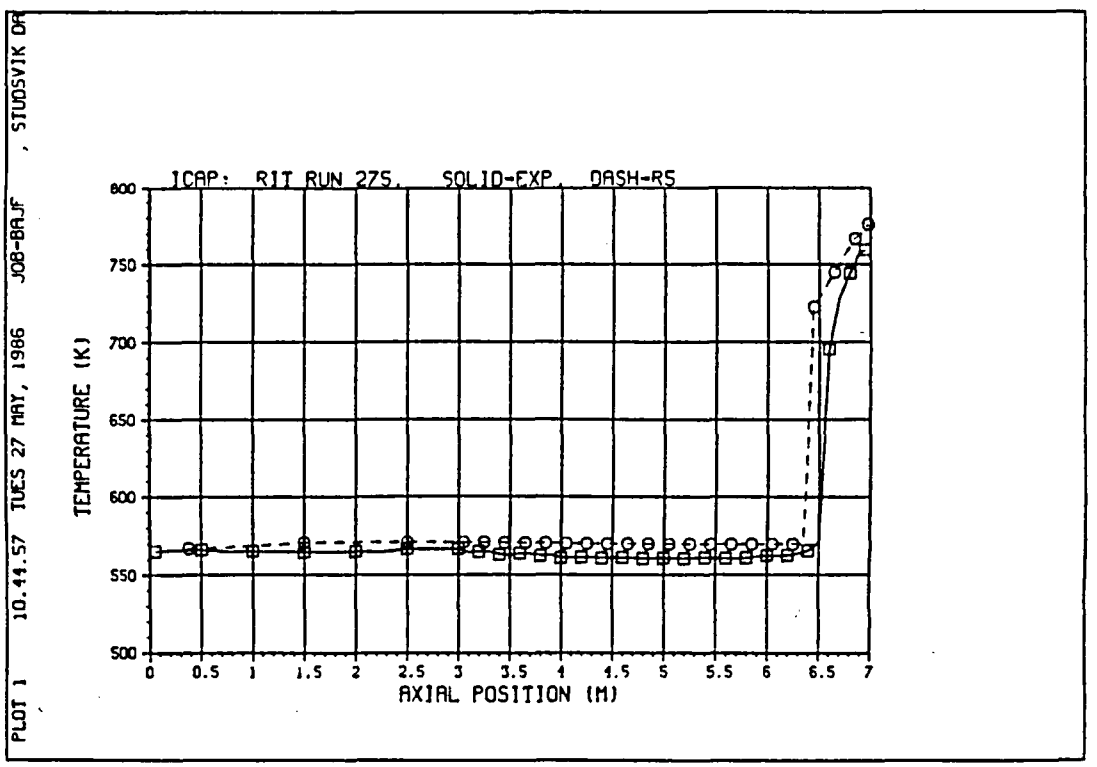

Figure 20

Temperature Distribution for run 275. P = 7 MPa, G = 500 kg/m^2-s.

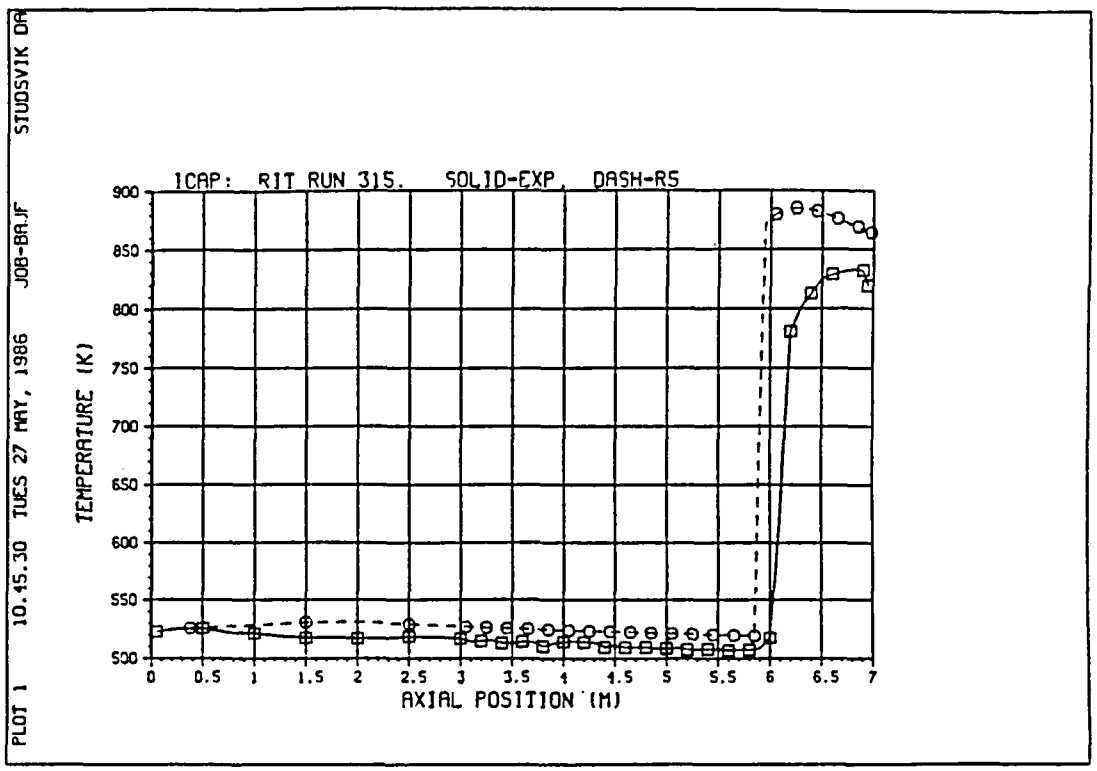

Figure 21

Temperature Distribution for run 315. P = 3 MPa, G = 2 000 kg/m²-s.

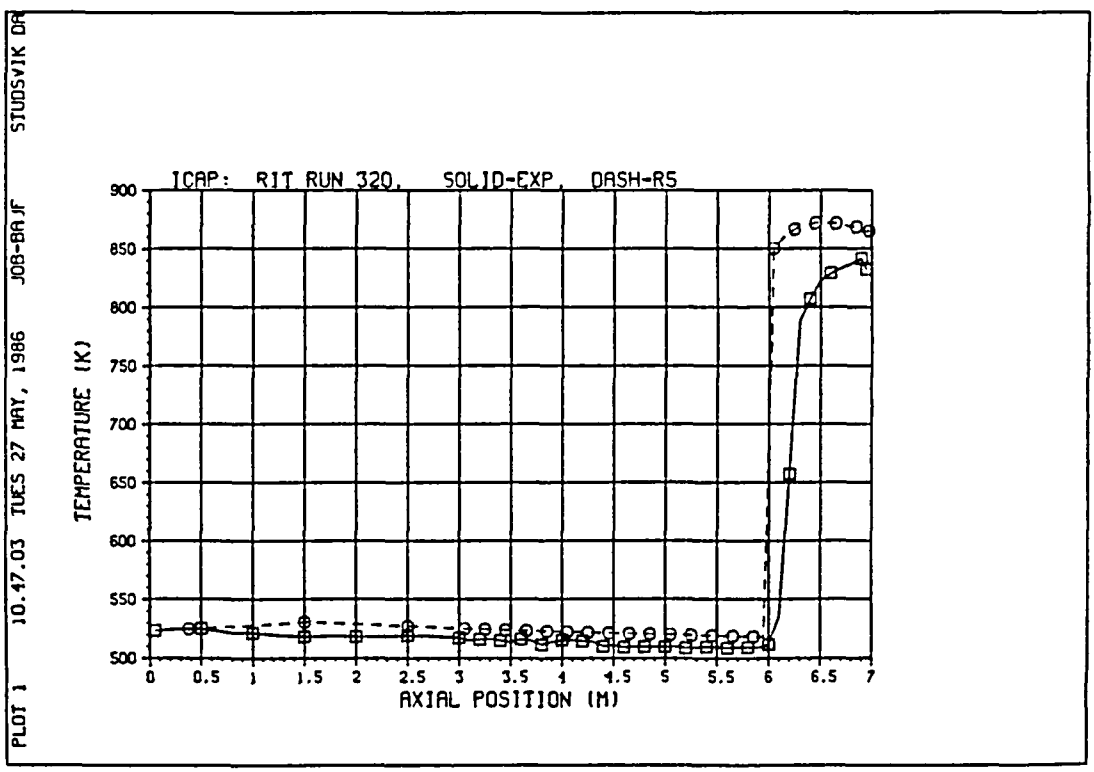

Figure 22

Temperature Distribution for run 320. P = 3 MPa, G = 1 500 kg/m²-s.

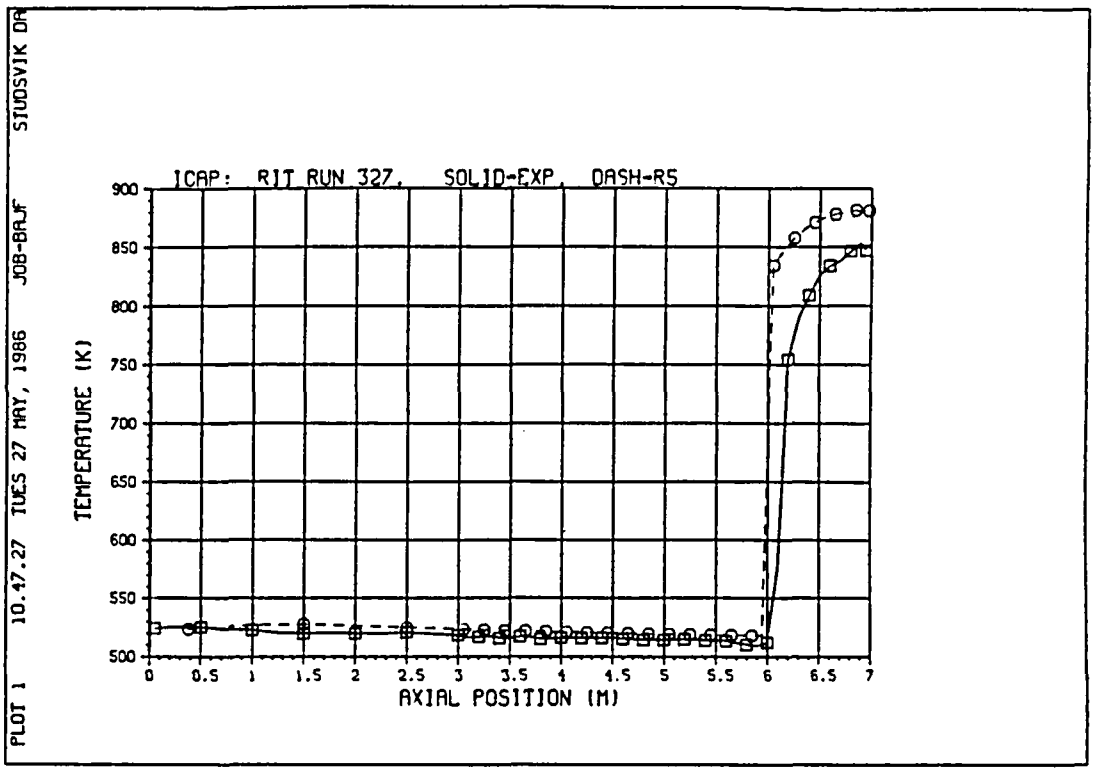

Figure 23

Temperature Distribution for run 327. P = 3 MPa, G = 1 000 kg/m²-s.

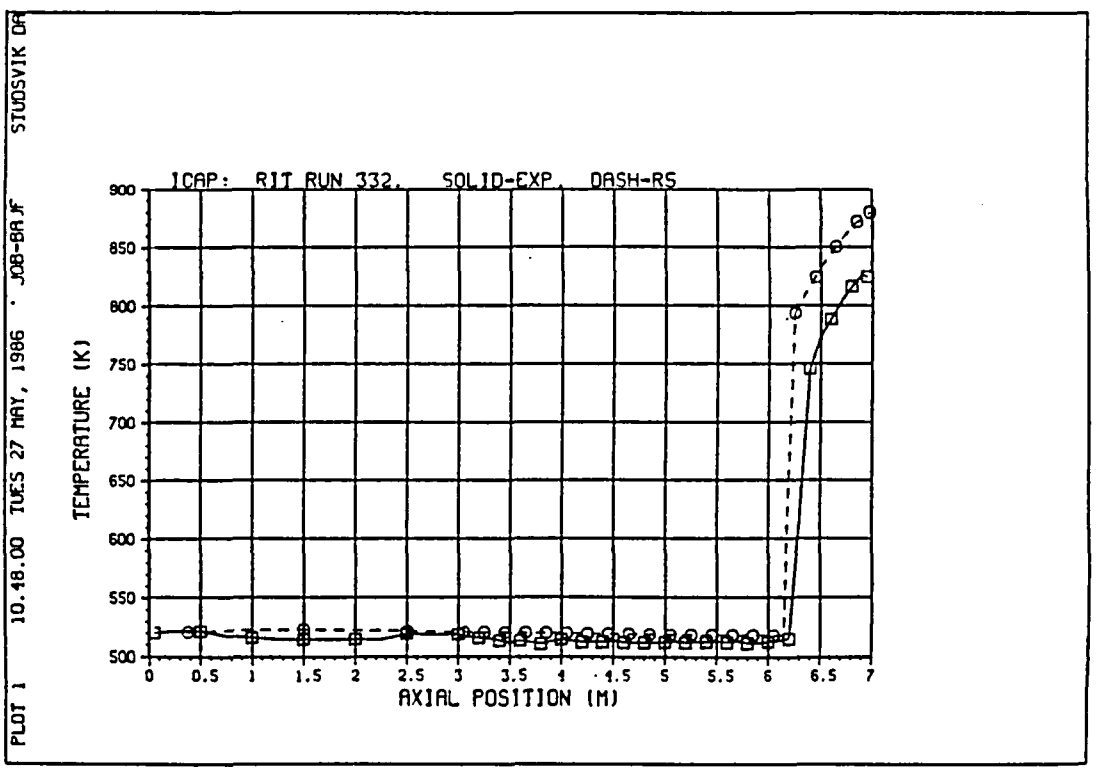

Figure 24

Temperature Distribution for run 332. P = 3 MPa, G = 500 kg/m²-s.

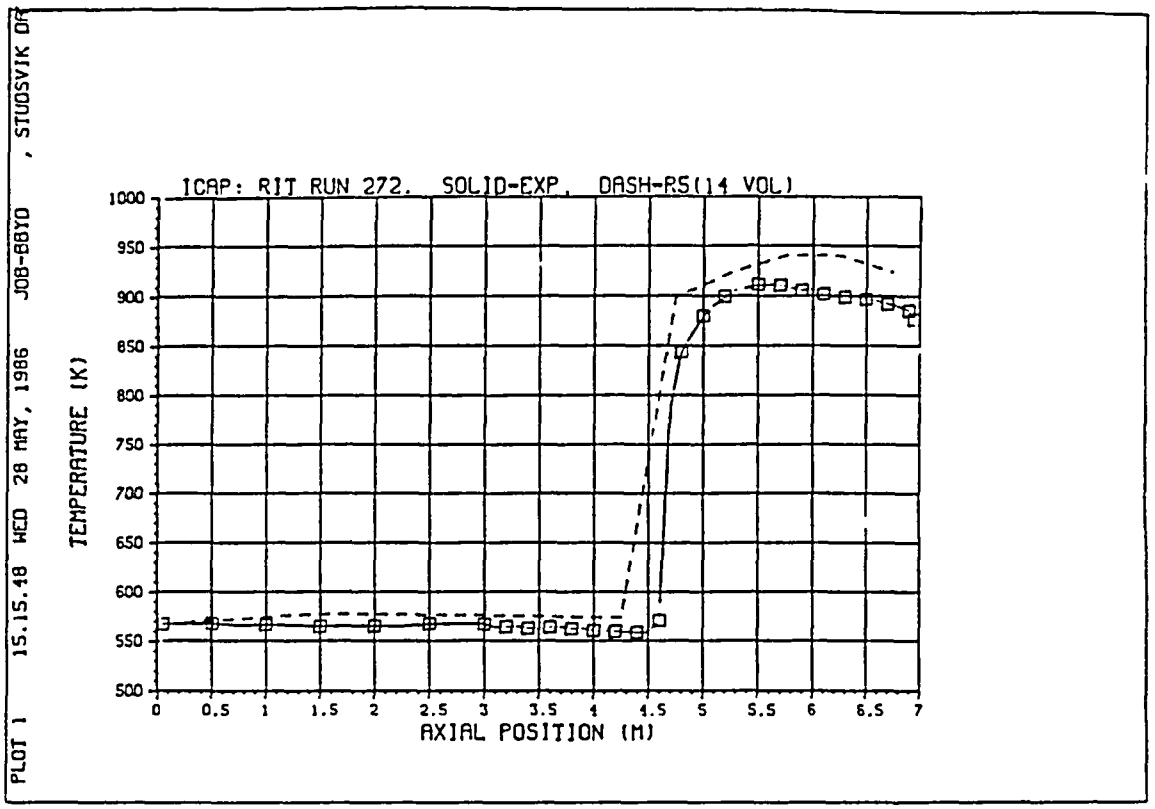

Figure 25

Temperature Distribution for run 272. Four Node RELAP5 model.

5 COMPUTATIONAL EFFICIENCY

The simulations reported here were run using the steady state option and the nearly implicit hydrodynamic numerical scheme option. Preliminary runs in which maximum time step sizes were set to 0.1 sec executed using large time step sizes but failed to reach steady state. Therefore, the maximum time step for all simulations reported here was specified to be slightly smaller than the material Courant limit. All simulations ran at this user specified maximum time limit. The simulations required from 14 to 28 seconds of transient time to achieve a steady state. The computational time required was 0.045 seconds per time step per volume on a Cyber 180-185.

Time history plots of key parameters from many of the RELAP5 simulations has revealed that the relaxation of the convergence criteria of the steady state algorithm in RELAP5 could substantially increase the computational efficiency with no loss in accuracy. Figures 26 and 27 illustrate this observation (in the RELAP5 simulations, the power was ramped from zero to full power over 10 seconds). All other thermal-hydraulic variables calculated by RELAP5 show a similar behavior to that exhibited in Figures 26 and 27. That is, for all practical purpose, steady state was achieved at 12 seconds. However, the steady state algorithm continued to 20 seconds before deciding steady state had been achieved.

5.1 Discontinuities in the CHF calculation

The RELAP5 base case simulations reported here used the CHF calculation inherent in RELAP5. During these simulations it was noted that the calculated CHF exhibited discontinuous behaviour (Figure 28) even though the relevant thermal-hydraulic parameters were continuous (Figures 26 and 27). While the discontinous behaviour did not cause problems in these particular RELAP5 simulations it is easy to imagine a case in which it could: In a case where the CHF is close to the actual heat flux the discontinuous nature of the CHF calculation could lead to a erroneous excursion into the post-CHF regime with its concomitant high wall temperatures.

Examination of the RELAP5 coding showed that the discontinous CHF calculation is due to the iterative scheme used in subroutine PREDNB to calculate the wall temperature corresponding to CHF. The CHF is held constant while the wall temperature is calculated but is modified slightly, based upon parameters calculated in the iteration, when the iteration is completed.

The convergence criterion of the iteration, which is that the change in temperature between iterates is less than one degree Kelvin, is not restrictive enough to prevent a fairly large change between the CHF entering the iteration and the CHF leaving. A situation arises wherein the iteration may be tightly converged ($\Delta T \ll 1K$) for several steps of the overall hydrodynamic solution and then, for unknown reasons, may change so that it barely satisfies the convergence criterion ($\Delta T \cong 1K$). This slight change in the convergence induces a large change into the calculated CHF.

The numerical discontinuities can be removed by simply not changing the CHF at the end of the iteration for the wall temperature. In this way the CHF edited by RELAP5 will be truly that which is calculated by the CHF correlation.

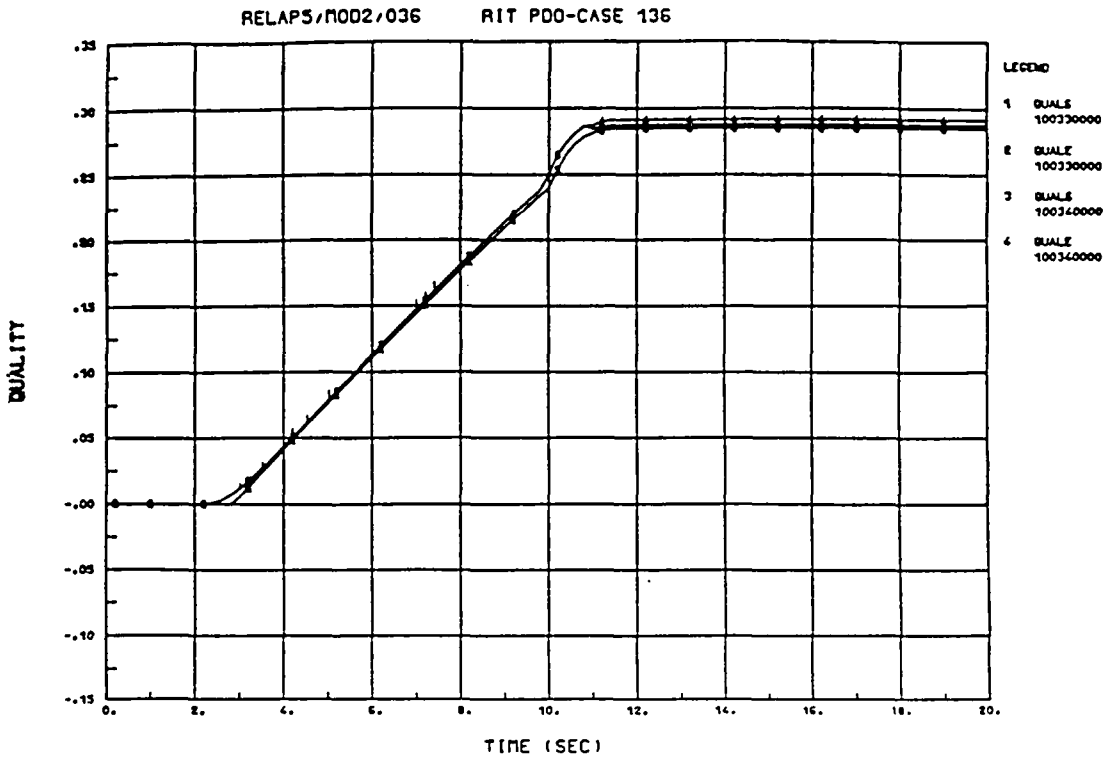

Figure 26
Time history of calculated quality for Run 136.

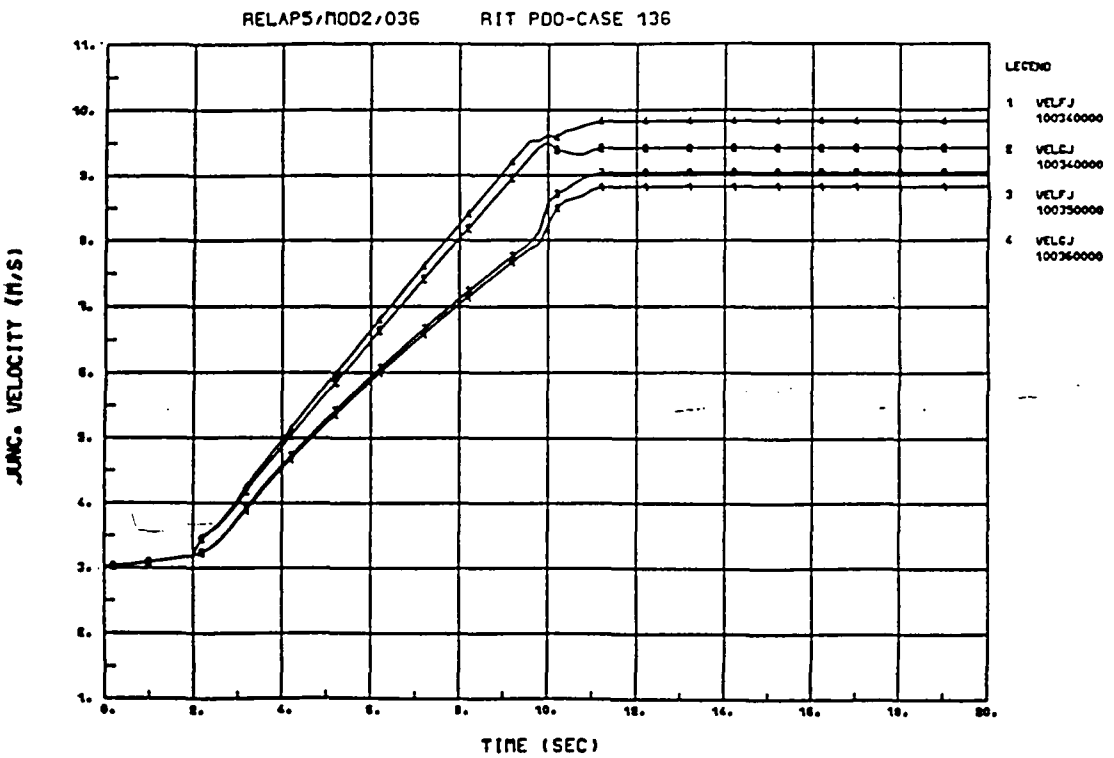

Figure 27
Time history of calculated velocities for Run 136.

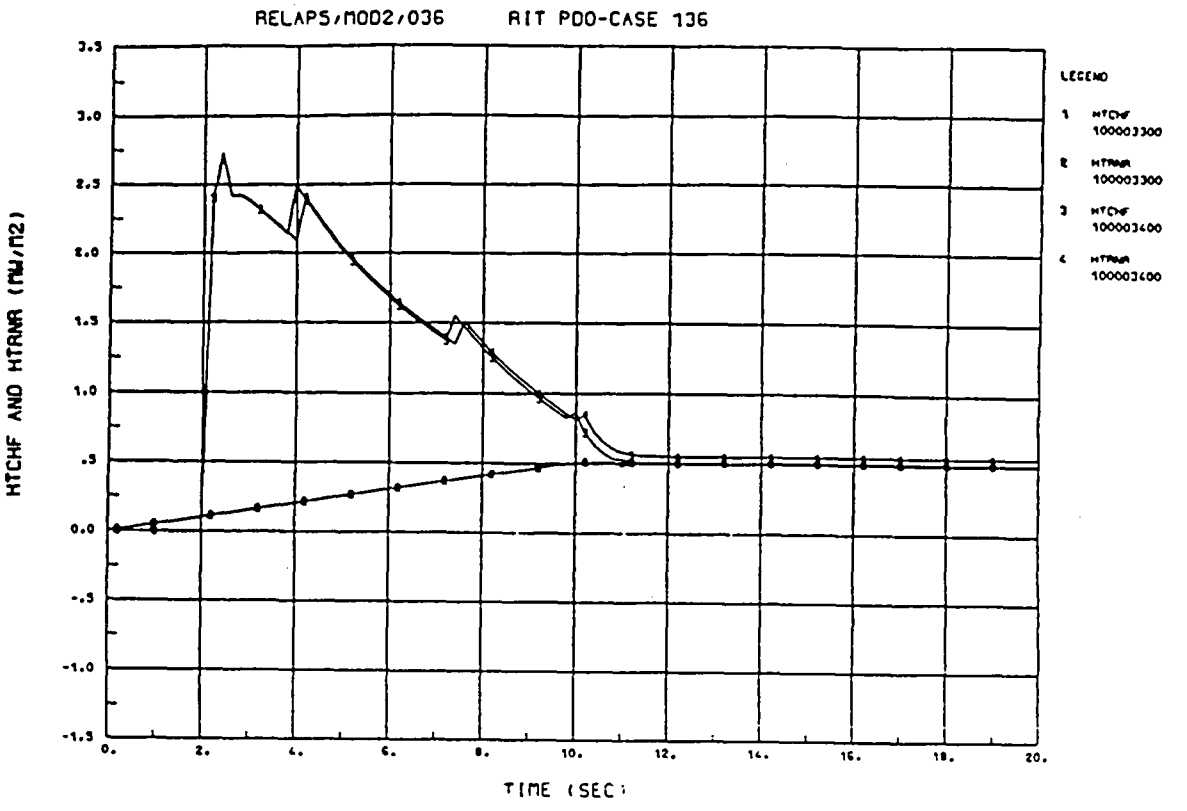

Figure 28

Calculated Critical Heat Fluxes for Run 136, Cells 33 and 34.

6 CONCLUSIONS

Assessment of RELAP5 against the RIT post dryout heat transfer experiments led to the following conclusions:

1. The Biasi CHF correlation cannot adequately predict the CHF location in the experiments. The mean error between the measured critical heat flux and that predicted by the Biasi correlation was -60.8 %; the negative value meaning that Biasi generally predicted the critical heat flux to be much greater than it actually was.

2. In order to assess the post-CHF heat transfer RELAP5 had to be updated so that the calculated CHF point corresponded to the experimental one.

3. For points more than 30 cm downstream of the CHF point RELAP5 accurately simulated the temperature distributions in the 20 experiments which were compared to. The difference between measured and calculated temperatures was less than 10 % in all cases except one. RELAP5 generally underpredicted the temperature at the higher ($P \geq 10$ MPa) pressures and overpredicted the temperatures at lower ($P < 10$ MPa) pressures.

4. In the region immediately downstream (0-30 cm) of the CHF location large differences occurred between calculated and measured temperatures. In some cases these differences could be attributed to the discreteness of the RELAP5 model and the temperature measurements. In other cases, it was evident that transition film boiling occurred in the experiment but was not calculated to occur by RELAP5.

5. The computational efficiency of the RELAP5 steady state procedure could probably be improved by loosening the convergence criterion used to detect steady state.

6. The CHF calculation in RELAP5 exhibits discontinuous behaviour due to its alteration following the iteration for the wall temperature at CHF in subroutine PREDNB.

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August 1985.

3. K M BECKER, et al
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Studsvik Technical Note
NR-84/452, Oct 1984.

APPENDIX A

COMPARISON OF BIASI WITH MEASURED CHF

RUN NUM	P (MPA)	G (KG/M2-S)	X	QEXP (MW/M2)	QBIASI (MW/M2)	FRAC DIFF
124	14.0	3086.0	.264	.759	.465	.387
125	14.0	3082.0	.249	.858	.558	.350
126	14.0	3082.0	.228	.959	.688	.283
127	14.0	3100.0	.221	1.043	.728	.302
128	14.0	3089.0	.196	1.146	.884	.228
130	14.0	2573.0	.271	.660	.501	.241
131	14.0	2576.0	.245	.759	.666	.122
132	14.0	2598.0	.235	.859	.725	.155
133	14.0	2590.0	.209	.956	.892	.067
134	14.0	2579.0	.185	1.003	1.047	-.044
136	14.0	1977.0	.289	.509	.508	.001
137	14.0	1967.0	.274	.553	.611	-.104
138	14.0	1975.0	.239	.655	.841	-.285
139	14.0	1971.0	.209	.757	1.042	-.377
141	14.0	1507.0	.322	.407	.420	-.032
142	14.0	1502.0	.308	.458	.519	-.133
143	14.0	1495.0	.307	.505	.528	-.047
144	14.0	1496.0	.309	.552	.514	.068
145	14.0	1496.0	.303	.608	.556	.086
146	14.0	1498.0	.286	.655	.674	-.029
147	14.0	1494.0	.272	.704	.773	-.098
149	14.0	1008.0	.376	.306	.460	-.503
150	14.0	1007.0	.377	.358	.460	-.284
151	14.0	1006.0	.381	.405	.457	-.128
152	14.0	1006.0	.383	.457	.455	.003
153	14.0	1007.0	.383	.509	.455	.106
154	14.0	1007.0	.367	.552	.467	.154
155	14.0	1005.0	.364	.605	.470	.224
157	14.0	502.0	.496	.205	.565	-1.754
158	14.0	502.0	.507	.253	.552	-1.183
159	14.0	502.0	.512	.304	.547	-.798
160	14.0	502.0	.530	.357	.526	-.475
161	14.0	503.0	.514	.405	.544	-.343
163	12.0	3102.0	.273	.865	.640	.260
164	12.0	3110.0	.218	.965	.978	-.014
165	12.0	3113.0	.188	1.001	1.163	-.161
166	12.0	3106.0	.160	1.045	1.337	-.279
168	12.0	2578.0	.279	.713	.697	.022
169	12.0	2574.0	.264	.759	.793	-.045
170	12.0	2568.0	.229	.810	1.018	-.256
171	12.0	2583.0	.199	.854	1.205	-.411
172	12.0	2584.0	.181	.901	1.319	-.464
174	12.0	1968.0	.305	.555	.701	-.263
175	12.0	1962.0	.297	.657	.730	-.111
176	12.0	1967.0	.285	.709	.809	-.141
177	12.0	1968.0	.261	.757	.968	-.279
178	12.0	1974.0	.238	.804	1.119	-.392

RUN NUM	P (MPA)	G (KG/M2-S)	X	QEXP (MW/M2)	QBIASI (MW/M2)	FRAC DIFF
179	12.0	1965.0	.224	.859	1.215	-.415
181	12.0	1487.0	.336	.461	.792	-.719
182	12.0	1483.0	.330	.557	.801	-.438
183	12.0	1487.0	.323	.610	.808	-.325
184	12.0	1496.0	.328	.658	.799	-.214
185	12.0	1487.0	.321	.709	.810	-.143
186	12.0	1487.0	.313	.758	.820	-.082
187	12.0	1482.0	.295	.807	.915	-.134
189	12.0	1001.0	.389	.307	.925	-2.012
190	12.0	1001.0	.399	.357	.910	-1.548
191	12.0	995.0	.403	.407	.907	-1.228
192	12.0	998.0	.400	.458	.910	-.986
193	12.0	1000.0	.401	.508	.907	-.786
194	12.0	1001.0	.403	.554	.903	-.631
195	12.0	998.0	.409	.608	.896	-.474
196	12.0	1003.0	.399	.654	.908	-.389
197	12.0	1000.0	.398	.707	.912	-.289
199	12.0	502.0	.591	.252	.936	-2.716
200	12.0	501.0	.592	.304	.935	-2.077
201	12.0	502.0	.582	.356	.957	-1.688
202	12.0	502.0	.595	.404	.927	-1.295
203	12.0	502.0	.574	.456	.975	-1.139
205	10.0	3088.0	.325	.910	.809	.111
206	10.0	3076.0	.332	.965	.802	.168
207	10.0	3081.0	.309	1.011	.829	.180
208	10.0	3090.0	.290	1.053	.889	.156
209	10.0	3078.0	.275	1.113	.984	.116
210	10.0	3096.0	.257	1.155	1.092	.055
211	10.0	3083.0	.229	1.207	1.267	-.050
213	10.0	2550.0	.340	.813	.887	-.091
214	10.0	2548.0	.313	.865	.924	-.068
215	10.0	2544.0	.303	.911	.938	-.030
216	10.0	2542.0	.294	.964	.985	-.021
217	10.0	2541.0	.295	1.011	.978	.032
218	10.0	2541.0	.282	1.049	1.061	-.012
219	10.0	2541.0	.265	1.112	1.170	-.052
221	10.0	1974.0	.334	.665	1.044	-.570
222	10.0	1973.0	.324	.716	1.060	-.480
223	10.0	1979.0	.326	.812	1.055	-.299
224	10.0	1990.0	.323	.860	1.056	-.228
225	10.0	1983.0	.326	.905	1.054	-.164
226	10.0	1983.0	.311	.963	1.077	-.119
227	10.0	1984.0	.307	1.011	1.083	-.071
229	10.0	1488.0	.393	.558	1.127	-1.020
230	10.0	1489.0	.390	.664	1.132	-.706
231	10.0	1485.0	.379	.713	1.155	-.620
232	10.0	1500.0	.378	.758	1.150	-.517

RUN NUM	P (MPA)	G (KG/M2-S)	X	QEXP (MW/M2)	QBIASI (MW/M2)	FRAC DIFF
233	10.0	1492.0	.379	.809	1.152	-.423
234	10.0	1496.0	.366	.856	1.174	-.371
235	10.0	1492.0	.356	.906	1.194	-.318
237	10.0	1000.0	.496	.512	1.188	-1.321
238	10.0	997.0	.494	.556	1.195	-1.149
239	10.0	996.0	.482	.659	1.224	-.858
240	10.0	992.0	.468	.712	1.260	-.770
241	10.0	994.0	.470	.761	1.254	-.648
243	10.0	502.0	.792	.357	.741	-1.077
244	10.0	502.0	.777	.405	.795	-.963
245	10.0	502.0	.767	.457	.831	-.817
246	10.0	502.0	.751	.489	.888	-.815
248	7.0	3079.0	.359	1.060	1.259	-.188
249	7.0	3085.0	.323	1.165	1.480	-.271
250	7.0	3104.0	.314	1.218	1.531	-.257
251	7.0	3102.0	.315	1.268	1.525	-.203
253	7.0	2561.0	.363	.914	1.385	-.515
254	7.0	2554.0	.356	.968	1.432	-.479
255	7.0	2527.0	.339	1.055	1.550	-.469
256	7.0	2550.0	.336	1.163	1.561	-.342
257	7.0	2552.0	.321	1.265	1.656	-.309
259	7.0	1989.0	.435	.870	1.314	-.510
260	7.0	1988.0	.407	.966	1.379	-.428
261	7.0	1988.0	.399	1.053	1.398	-.328
262	7.0	1986.0	.380	1.162	1.499	-.290
264	7.0	1500.0	.510	.766	1.350	-.762
265	7.0	1484.0	.497	.867	1.394	-.608
266	7.0	1492.0	.486	.913	1.420	-.556
267	7.0	1489.0	.473	.966	1.458	-.509
268	7.0	1483.0	.474	1.013	1.459	-.440
270	7.0	996.0	.648	.660	1.240	-.878
271	7.0	1001.0	.631	.765	1.296	-.693
272	7.0	1000.0	.617	.815	1.345	-.651
273	7.0	1003.0	.608	.863	1.375	-.593
275	7.0	501.0	.899	.410	.537	-.310
276	7.0	501.0	.884	.461	.617	-.338
277	7.0	501.0	.895	.511	.558	-.093
279	5.0	3069.0	.330	1.060	2.064	-.947
280	5.0	3072.0	.324	1.168	2.100	-.798
281	5.0	3068.0	.317	1.219	2.145	-.759
282	5.0	3067.0	.316	1.270	2.151	-.694
284	5.0	2530.0	.326	1.058	2.296	-1.170
285	5.0	2521.0	.355	1.165	2.114	-.815
286	5.0	2522.0	.356	1.218	2.108	-.730
287	5.0	2521.0	.348	1.270	2.159	-.700
289	5.0	1975.0	.423	.972	1.939	-.995
290	5.0	1978.0	.418	1.058	1.971	-.863

RUN NUM	P (MPA)	G (KG/M2-S)	X	QEXP (MW/M2)	QBIASI (MW/M2)	FRAC DIFF
291	5.0	1979.0	.414	1.162	1.997	-.719
292	5.0	1980.0	.404	1.216	2.063	-.696
294	5.0	1475.0	.503	.870	1.726	-.984
295	5.0	1476.0	.500	.917	1.746	-.904
296	5.0	1473.0	.498	.969	1.763	-.819
297	5.0	1476.0	.491	1.015	1.809	-.782
298	5.0	1470.0	.489	1.053	1.828	-.736
300	5.0	1000.0	.650	.667	1.353	-1.029
301	5.0	992.0	.655	.766	1.340	-.750
302	5.0	999.0	.628	.867	1.439	-.660
303	5.0	1000.0	.627	.911	1.442	-.583
305	5.0	498.0	.897	.462	.605	-.310
306	5.0	497.0	.885	.513	.676	-.318
307	5.0	498.0	.876	.560	.728	-.301
309	3.0	2542.0	.311	.875	2.735	-2.126
310	3.0	2560.0	.308	.975	2.746	-1.816
311	3.0	2555.0	.310	1.019	2.735	-1.684
312	3.0	2551.0	.312	1.061	2.725	-1.568
313	3.0	2534.0	.312	1.123	2.733	-1.434
315	3.0	1986.0	.366	.873	2.691	-2.083
316	3.0	1992.0	.361	.971	2.720	-1.802
317	3.0	1987.0	.373	1.058	2.644	-1.499
318	3.0	1986.0	.381	1.165	2.591	-1.224
320	3.0	1499.0	.439	.769	2.570	-2.342
321	3.0	1493.0	.436	.818	2.596	-2.174
322	3.0	1487.0	.440	.869	2.574	-1.962
323	3.0	1490.0	.445	.969	2.536	-1.617
324	3.0	1486.0	.447	1.015	2.526	-1.488
326	3.0	1008.0	.573	.618	2.159	-2.494
327	3.0	1006.0	.573	.667	2.162	-2.242
328	3.0	1003.0	.566	.718	2.219	-2.090
329	3.0	1005.0	.570	.767	2.186	-1.850
330	3.0	1004.0	.571	.865	2.180	-1.520
332	3.0	496.0	.848	.464	1.034	-1.228
333	3.0	497.0	.834	.515	1.148	-1.229
334	3.0	498.0	.825	.562	1.220	-1.171

MEAN FRACTIONAL ERROR = -.608 RMS ERROR = .889

APPENDIX B

RELAP5 INPUT DECK

```
*         RELAP5/MOD2/036     RIT PDO-CASE 136
*
*
*         THIS CASE IS A SIMULATION OF A POST DRY-OUT EXPERIMENT
*         CONDUCTED BY K.M. BECKER ET AL. IN THE NUCLEAR ENGINEERING
*         LABORATORY AT THE ROYAL INTITUTE OF TECHNOLOGY (RIT) IN
*         STOCKHOLM AND IS REPORTED IN REF (1). THE TEST SECTION
*         COMPRISED A SEVEN METER LONG HEATED VERTICAL PIPE WITH WALL
*         THERMOCOUPLES LOCATED THROUGHOUT THE HEATED LENGTH. THE
*         INNER DIAMETER WAS 0.0149 M.
*
*         THE EXPERIMENT WAS RUN WITH TIME-INVARIANT BOUNDARY CONDITIONS
*         WITH AN UNIFORM AXIAL POWER DISTRIBUTION AND THE DATA WERE
*         RECORDED WHEN THE CONDITIONS IN THE TEST SECTION WERE STABLE.
*
*         THE CONSTANT BOUNDARY CONDITIONS FOR THE CASE NUMBER 136 WERE:
*
*                     OUTLET PRESSURE     13.99  MPA
*                     MASSFLUX          1976.6  KG/M2/S
*                     INLET TEMPERATURE   599.65 K
*                     HEAT FLUX           0.509  MW/M2
*
*         THE TEST SECTION WAS MODELED AS A PIPE COMPONENT WITH 47
*         VOLUMES. THE HEATED WALL WAS MODELED BY USING CONDUCTING
*         MATERIAL WITH A CYLINDRICAL GEOMETRY INCLUDING TWO MESH
*         POINTS, ONE ON EACH SURFACE. THE INNER SURFACE WAS CONNECTED
*         TO THE HYDRO-DYNAMIC PIPE VOLUMES THROUGH THE HEAT TRANSFER
*         PACKAGE WHILE THE OUTER SURFACE WAS ASSUMED COMPLETELY INSULATED.
*         CHECKING OF HEAT BALANCE WAS PART OF THE EXPERIMENTAL ROUTINE
*         AND REVEALED AN INSIGNIFICANT LEVEL OF HEAT LOSSES TO THE
*         AMBIENT THUS JUSTIFYING THE ASSUMPTION OF THE INSULATED OUTER
*         SURFACE.
*
*         REFERENCE 1  K.M. BECKER ET AL.
*                      AN EXPERIMENTAL INVESTIGATION OF POST DRYOUT
*                      HEAT TRANSFER
*                      KTH-NEL-33
*                      DEPARTMENT OF NUCLEAR REACTOR ENGINEERING
*                      ROYAL INSTITUTE OF TECHNOLOGY
*                      STOCKHOLM, SWEDEN
*                      MAY 1983
*
*
0000100   NEW  STDY-ST
0000101   RUN
*
*         CPU TIME REMAINING CARD
0000105   10.0      20.0
*
*         TIME STEP CONTROL CARDS
*         TIME-END  DT-MIN  DT-MAX  SSDXX  MIN-EDIT  MAJ-EDIT  RESTART
0000201   20.0      1.0E-6  0.0025  00011   80       2000      4000
*
*
* ==================================================================
*
*         MINOR EDIT REQUESTS
*
0000301   CPUTIME   0                    * CPU-TIME
*
* ==================================================================
*
*
*    ***** HYDRODYNAMIC COMPONENTS *****
```

```
*
*
*
*        THE HEATED PIPE IS MODELED AS A PIPE COMPONENT NR 100
*
1000000   HOT-CHA   PIPE
*
*         NVOL
1000001   47
*
*         AREA            NVOL
1000101   1.74366E-04     47
*
*         LENGTH          NVOL
1000301   0.750           1
1000302   0.500           5
1000303   0.250           6
1000304   0.100           45
1000305   0.050           47
*
*         V-ANGLE         NVOL
1000601   90.0            47
*
*         ROUGH     D-HYD     NVOL
1000801   20.0E-06  0.0149    47
*
*         PIPE VOLUME CONTROL FLAGS
*         FE        NVOL
1001001   00        47
*
*         PIPE JUNCTION CONTROL FLAGS
*         VCAHS     NVOL-1
1001101   31000     46
*
*         PIPE VOLUME INITIAL CONDITIONS
*         EBT   PRESSURE   TEMP.     DUMMY1    DUMMY2    DUMMY3    NVOL
1001201   003   13.99E+06  599.65    0.0       0.0       0.0       47
*
*         PIPE JUNCTION DATA
*         CTRL-WRD
1001300   1
*
*         INITIAL COND.
*         FLOW-F    FLOW-G    FLOW-FG    NJUNC
1001301   3.4465E-1 0.0       0.0        46
*
*
*     * * HEAT STRUCTURE DATA * *
*
*         NH   NP   TYPE  SS-FL  LCOORD
11000000  47   2    2     1      7.45E-03
*
*         LOC  FMT
11000100  0    1
*
*         NINT - RCOORD
11000101  1      1.04E-02
*
*         COMPOSITION - INTERVAL
11000201  1    1
*
*         SOURCE - INTERVAL
11000301  1.0  1
*
*         TFLG
11000400  0
*
*         INITEMP FOR EACH HEAT-STR.
*         INITEMP   MESH
11000401  599.65    2
*
```

```
*          BNDVOL     INCR       BNDCON     SAC  FACTOR     HSNR
11000501   100010000 010000     1          1    0.750      1      * LEFT
11000502   100020000 010000     1          1    0.500      5      * LEFT
11000503   100060000 010000     1          1    0.250      6      * LEFT
11000504   100070000 010000     1          1    0.100      45     * LEFT
11000505   100460000 010000     1          1    0.050      47     * LEFT
*
11000601   0          0          0          1    0.750      1      * RIGHT
11000602   0          0          0          1    0.500      5      * RIGHT
11000603   0          0          0          1    0.250      6      * RIGHT
11000604   0          0          0          1    0.100      45     * RIGHT
11000605   0          0          0          1    0.050      47     * RIGHT
*
*          SRCTYP     MULT       DHL     DHR     HSNR
11000701   1          0.750      0.0     0.0     1
11000702   1          0.500      0.0     0.0     5
11000703   1          0.250      0.0     0.0     6
11000704   1          0.100      0.0     0.0     45
11000705   1          0.050      0.0     0.0     47
*
*          CHF     DE     DH     LENGTH     HSNR
11000801   0       0.0    0.0    0.0        47
*
*          HEAT STRUCTURE TH. PROP.  COMPOSITION IS NIMONIC 75
*          MATERIAL-TYPE          FOR-FLG1          FOR-FLG2
20100100   TBL/FCTN               1                 1
*
*          TEMP.          TH.COND.
20100101   270.0          12.0
20100102   5000.0         93.4
*
*          VOL.HEAT-CAP.
20100151   4.0E+06
*
*          GENERAL TABLE FOR HEAT STRUCTURE POWER (SRCTYP 1)
*          TBL-TYPE  TRIP     FACTOR-T     FACTOR-P
20200100   POWER     0        1.0          1.0
*
*          TIME      LINEAR POWER (W/M)
20200101   0.0       0.0
20200102   10.0      23.8262E+03
20200103   20.0      23.8262E+03
*
*     * * END OF HEAT STRUCTURE DATA * *
*
* ==================================================================
*
*          LOWER BOUNDARY CONDITION
*
*          TMDPVOL - COMPONENT 200
*          TMDPJUN - COMPONENT 250
*
2000000    LO-BNDRY  TMDPVOL
*
*          AREA      LENGTH VOL. H-ANGLE V-ANGLE ELEV. ROUGH D-HYD FE
2000101    1.0       1.0    0.0  0.0     90.0    1.0   0.0   1.0   10
*
*          EBT  TBL-NR
2000200    003  0
*
*          TIME      PRESSURE     TEMP.
2000201    0.0      13.99E+06    599.65
*
*
*
*
2500000    LO-FLOW   TMDPJUN
*
*          FROM-CODE      TO-CODE      AREA
2500101    200000000      100000000    0.0
*
```

```
*          CTRL-WRD
2500200    1
*
*          TIME       FLOW-F     FLOW-G     FLOW-FG
2500201    0.0        3.4465E-1  0.0        0.0
*
*
* ==================================================================
*
*          UPPER BOUNDARY CONDITION
*
*          TMDPVOL - COMPONENT 300
*          SNGLJUN - COMPONENT 350
*
3000000    UP-BNDRY   TMDPVOL
*
*          AREA       LENGTH VOL. H-ANGLE V-ANGLE ELEV. ROUGH D-HYD FE
3000101    1.0        1.0    0.0  0.0     90.0    1.0   0.0   1.0   10
*
*          EBT  TBL-NR
3000200    003  0
*
*          TIME       PRESSURE    TEMP.
3000201    0.0       13.99E+06   700.0
*
*
*
*
3500000    UP-FLOW    SNGLJUN
*
*          FROM-CODE  TO-CODE   AREA  F-LOSS  R-LOSS  VCAHS  DIS-COEFFS.
3500101    100010000  300000000 0.0   0.0     0.0     31100  0.0    0.0
*
*          CW   FLOW-F     FLOW-G     FLOW-FG
3500201    1    3.4465E-1  0.0        0.0
*
*
*          ==================================================================
*
           END OF CASE
```

APPENDIX C

AXIAL TEMPERATURE DISTRIBUTION - MEASURED AND RELAP5

RUN NUMBER 136

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	611.16	.38	614.34
.25	611.36	1.00	614.57
.50	611.66	1.50	614.65
.75	609.66	2.00	614.85
1.00	610.56	2.50	615.14
1.25	610.36	2.88	615.25
1.50	609.86	3.05	615.28
1.75	610.76	3.15	615.34
2.00	610.46	3.25	615.39
2.25	610.06	3.35	615.44
2.50	608.36	3.45	615.49
2.75	608.86	3.55	615.54
3.00	608.36	3.65	615.58
3.10	608.26	3.75	615.63
3.20	608.96	3.85	615.68
3.30	608.86	3.95	615.72
3.40	608.46	4.05	615.77
3.50	607.96	4.15	615.81
3.60	606.66	4.25	615.86
3.70	608.96	4.35	615.90
3.80	608.26	4.45	615.94
3.90	608.86	4.55	615.98
4.00	608.86	4.65	616.02
4.10	608.86	4.75	616.06
4.20	609.26	4.85	616.10
4.30	609.36	4.95	616.14
4.40	609.36	5.05	616.19
4.50	607.26	5.15	616.21
4.60	608.46	5.25	616.30
4.70	609.86	5.35	616.45
4.80	608.96	5.45	616.56
4.90	609.36	5.55	616.65
5.00	609.36	5.65	721.70
5.10	609.96	5.75	725.77
5.20	609.56	5.85	729.22
5.30	610.06	5.95	732.24
5.40	607.16	6.05	734.68
5.50	610.56	6.15	736.48
5.60	658.46	6.25	737.66
5.70	706.86	6.35	737.81
5.80	718.16	6.45	737.35
5.90	723.56	6.55	736.60
6.00	725.46	6.65	735.65
6.10	726.36	6.75	734.41
6.20	729.06	6.85	733.40
6.30	727.36	6.93	731.97
6.40	727.76	6.98	731.79
6.50	728.86		
6.60	727.16		
6.70	724.26		
6.80	722.66		
6.90	721.46		
6.95	717.06		

RUN NUMBER 139

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	611.26	.38	615.95
.25	610.86	1.00	616.04
.50	611.06	1.50	616.61
.75	609.06	2.00	617.18
1.00	610.06	2.50	617.79
1.25	609.86	2.88	943.26
1.50	609.36	3.05	958.00
1.75	610.16	3.15	978.04
2.00	609.26	3.25	996.51
2.25	609.56	3.35	1013.10
2.50	607.76	3.45	1024.00
2.75	608.26	3.55	1023.60
3.00	625.76	3.65	1010.00
3.10	856.26	3.75	983.76
3.20	885.76	3.85	948.61
3.30	884.46	3.95	921.78
3.40	881.56	4.05	901.36
3.50	886.06	4.15	884.37
3.60	885.36	4.25	870.19
3.70	901.06	4.35	858.12
3.80	897.36	4.45	847.57
3.90	899.76	4.55	838.25
4.00	895.46	4.65	829.96
4.10	891.16	4.75	822.52
4.20	886.66	4.85	815.79
4.30	881.26	4.95	809.64
4.40	873.26	5.05	804.00
4.60	855.26	5.15	798.79
4.70	848.06	5.25	793.93
4.80	838.56	5.35	789.38
4.90	827.96	5.45	785.12
5.00	818.26	5.55	781.13
5.10	809.66	5.65	777.38
5.20	800.76	5.75	773.85
5.30	793.26	5.85	770.52
5.50	775.46	5.95	767.38
5.60	768.46	6.05	764.40
5.70	759.86	6.15	761.58
5.80	751.16	6.25	758.91
5.90	744.46	6.35	756.37
6.00	738.46	6.45	753.96
6.10	730.16	6.55	751.65
6.20	726.86	6.65	749.51
6.30	720.16	6.75	747.32
6.40	716.96	6.85	745.72
6.50	715.06	6.93	743.70
6.60	710.26	6.98	743.95
6.70	705.46		
6.80	702,56		
6.90	698.36		
6.95	693.26		

RUN NUMBER 147

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	610.96	.38	615.80
.25	611.26	1.00	616.18
.50	611.46	1.50	616.90
.75	609.46	2.00	617.65
1.00	610.46	2.50	618.60
1.25	610.26	2.88	889.51
1.50	609.76	3.05	894.62
1.75	610.56	3.15	893.44
2.00	610.36	3.25	890.83
2.25	609.96	3.35	887.26
2.50	608.16	3.45	882.38
2.75	609.96	3.55	876.76
3.00	815.26	3.65	870.75
3.10	894.46	3.75	864.56
3.20	913.56	3.85	858.32
3.30	906.66	3.95	852.14
3.40	902.66	4.05	846.07
3.50	906.46	4.15	840.18
3.60	899.66	4.25	834.50
3.70	911.76	4.35	829.05
3.80	905.46	4.45	823.83
3.90	904.26	4.55	818.86
4.00	899.36	4.65	814.13
4.10	894.46	4.75	809.63
4.20	889.36	4.85	805.36
4.30	882.76	4.95	801.31
4.40	875.36	5.05	797.47
4.60	858.06	5.15	793.84
4.70	851.46	5.25	790.40
4.80	842.06	5.35	787.15
4.90	832.66	5.45	784.07
5.00	823.56	5.55	781.16
5.10	816.76	5.65	778.40
5.20	808.56	5.75	775.80
5.30	801.76	5.85	773.34
5.50	785.76	5.95	771.02
5.60	779.36	6.05	768.83
5.70	771.46	6.15	766.76
5.80	762.76	6.25	764.81
5.90	756.76	6.35	762.97
6.00	745.86	6.45	761.25
6.10	742.46	6.55	759.62
6.20	739.76	6.65	758.14
6.30	733.06	6.75	756.60
6.40	730.46	6.85	755.66
6.50	727.36	6.93	753.88
6.60	723.16	6.98	754.57
6.70	719.66		
6.80	716.16		
6.90	712.56		
6.95	706.86		
6.90	721.46		
6.95	717.06		

RUN NUMBER 154

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	611.66	.38	615.00
.25	611.26	1.00	615.59
.50	611.56	1.50	616.37
.75	610.16	2.00	617.49
1.00	611.06	2.50	618.97
1.25	610.26	2.88	619.73
1.50	609.76	3.05	792.17
1.75	611.26	3.15	805.10
2.00	610.36	3.25	817.32
2.25	610.56	3.35	823.62
2.50	608.86	3.45	827.81
2.75	608.76	3.55	829.71
3.00	608.86	3.65	830.29
3.10	608.16	3.75	829.89
3.20	673.46	3.85	828.58
3.30	774.36	3.95	826.67
3.40	812.66	4.05	824.38
3.50	831.56	4.15	821.82
3.70	846.36	4.25	819.08
3.80	856.56	4.35	816.24
3.90	868.66	4.45	813.34
4.00	877.16	4.55	810.43
4.10	882.06	4.65	807.57
4.20	884.76	4.75	804.78
4.30	886.16	4.85	802.08
4.40	883.76	4.95	799.49
4.60	874.96	5.05	797.00
4.70	870.26	5.15	794.64
4.80	862.76	5.25	792.39
4.90	855.86	5.35	790.25
5.00	848.56	5.45	788.23
5.10	843.06	5.55	786.34
5.20	836.76	5.65	784.56
5.30	831.16	5.75	782.89
5.50	817.76	5.85	781.34
5.60	812.66	5.95	779.90
5.70	806.66	6.05	778.57
5.80	799.26	6.15	777.35
5.90	793.76	6.25	776.24
6.00	784.26	6.35	775.23
6.10	782.06	6.45	774.34
6.20	778.86	6.55	773.52
6.30	772.16	6.65	772.87
6.40	769.66	6.75	772.15
6.50	766.46	6.85	772.05
6.60	762.36	6.93	770.64
6.70	758.26	6.98	771.73
6.80	754.16		
6.90	751.16		
6.95	745.56		
6.95	693.26		

RUN NUMBER 161

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	611.16	.38	614.55
.25	611.46	1.00	615.34
.50	611.66	1.50	616.65
.75	610.36	2.00	618.80
1.00	611.86	2.50	619.08
1.25	611.06	2.88	803.64
1.50	610.56	3.05	808.60
1.75	611.36	3.15	817.49
2.00	611.16	3.25	824.34
2.25	611.36	3.35	829.69
2.50	612.76	3.45	833.86
2.75	613.16	3.55	837.05
3.00	630.36	3.65	839.45
3.10	796.16	3.75	841.18
3.20	817.86	3.85	842.39
3.30	832.16	3.95	843.20
3.40	844.96	4.05	843.72
3.50	854.06	4.15	844.03
3.70	869.46	4.25	844.20
3.80	871.16	4.35	844.29
3.90	877.76	4.45	844.33
4.00	881.96	4.55	844.37
4.10	884.36	4.65	844.47
4.20	887.16	4.75	844.66
4.30	890.26	4.85	844.86
4.40	891.46	4.95	845.12
4.60	894.86	5.05	845.51
4.70	897.36	5.15	846.06
4.80	897.76	5.25	846.75
4.90	897.46	5.35	847.62
5.00	897.46	5.45	848.66
5.10	898.66	5.55	849.88
5.20	897.76	5.65	851.19
5.30	898.86	5.75	852.57
5.50	895.66	5.85	854.10
5.60	896.06	5.95	855.81
5.70	894.86	6.05	857.72
5.80	892.96	6.15	859.81
5.90	891.16	6.25	862.11
6.00	893.06	6.35	864.60
6.10	888.46	6.45	867.31
6.20	888.86	6.55	870.21
6.30	885.86	6.65	873.22
6.40	887.56	6.75	876.14
6.50	886.76	6.85	879.66
6.60	886.86	6.93	880.02
6.70	887.66	6.98	882.65
6.80	887.16		
6.90	889.06		
6.95	883.46		
6.95	706.86		
6.90	721.46		
6.95	717.06		

RUN NUMBER 221

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	589.06	.38	591.42
.25	589.26	1.00	591.71
.50	589.56	1.50	592.40
.75	588.16	2.00	593.03
1.00	589.06	2.50	593.61
1.25	588.86	2.88	593.79
1.50	587.76	3.05	593.82
1.75	588.56	3.15	593.90
2.00	588.36	3.25	593.99
2.25	587.96	3.35	594.16
2.50	589.36	3.45	594.36
2.75	589.86	3.55	594.53
3.00	589.26	3.65	594.68
3.10	586.66	3.75	594.81
3.20	587.46	3.85	594.91
3.30	587.36	3.95	595.01
3.40	586.96	4.05	595.11
3.50	587.06	4.15	595.21
3.60	587.56	4.25	595.31
3.70	589.26	4.35	595.41
3.80	587.36	4.45	595.51
3.90	587.36	4.55	595.40
4.00	587.96	4.65	595.29
4.10	589.16	4.75	595.18
4.20	588.36	4.85	595.08
4.30	588.46	4.95	594.97
4.40	589.06	5.05	594.87
4.50	588.76	5.15	594.77
4.60	588.76	5.25	594.68
4.70	588.96	5.35	594.58
4.80	589.26	5.45	594.49
4.90	588.46	5.55	758.36
5.00	589.06	5.65	765.50
5.10	589.06	5.75	770.52
5.20	586.86	5.85	773.95
5.30	584.26	5.95	775.96
5.40	581.26	6.05	776.90
5.50	584.76	6.15	777.05
5.60	589.46	6.25	776.57
5.70	635.66	6.35	775.55
5.80	695.36	6.45	774.16
5.90	745.76	6.55	772.48
6.00	753.26	6.65	770.69
6.10	762.56	6.75	768.52
6.20	769.66	6.85	766.98
6.30	770.26	6.93	764.54
6.40	771.36	6.98	764.62
6.50	773.06		
6.60	771.96		
6.70	767.86		
6.80	767.96		
6.90	768.66		
6.95	761.16		

RUN NUMBER 224

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	589.26	.38	592.80
.25	589.56	1.00	593.56
.50	589.76	1.50	594.58
.75	587.76	2.00	595.60
1.00	588.76	2.50	596.80
1.25	588.46	2.88	597.33
1.50	588.06	3.05	597.40
1.75	588.86	3.15	597.61
2.00	587.96	3.25	597.82
2.25	588.26	3.35	598.04
2.50	589.56	3.45	598.26
2.75	590.06	3.55	598.41
3.00	588.96	3.65	598.25
3.10	585.06	3.75	598.09
3.20	586.46	3.85	597.95
3.30	586.96	3.95	597.80
3.40	585.96	4.05	597.66
3.50	586.66	4.15	597.52
3.60	587.26	4.25	826.80
3.70	588.96	4.35	837.48
3.80	586.96	4.45	844.57
3.90	586.96	4.55	848.67
4.00	587.56	4.65	850.54
4.10	585.06	4.75	850.68
4.20	584.16	4.85	849.58
4.30	603.66	4.95	847.56
4.40	729.36	5.05	844.77
4.50	825.06	5.15	841.49
4.60	849.66	5.25	837.93
4.70	857.76	5.35	834.18
4.80	862.46	5.45	830.35
4.90	861.06	5.55	826.49
5.00	861.06	5.65	822.64
5.10	860.96	5.75	818.85
5.20	857.56	5.85	815.14
5.30	855.56	5.95	811.52
5.50	846.86	6.05	808.00
5.60	841.66	6.15	804.60
5.70	836.16	6.25	801.31
5.80	828.06	6.35	798.14
5.90	821.86	6.45	795.09
6.00	812.16	6.55	792.13
6.10	808.16	6.65	789.38
6.20	804.76	6.75	786.46
6.30	798.06	6.85	784.49
6.40	794.86	6.93	781.47
6.50	789.86	6.98	782.02
6.60	784.96		
6.70	777.16		
6.80	773.56		
6.90	768.06		
6.95	758.06		
6.95	717.06		

RUN NUMBER 232

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	588.56	.38	592.23
.25	588.76	1.00	593.34
.50	589.06	1.50	594.50
.75	587.06	2.00	596.03
1.00	588.66	2.50	597.91
1.25	587.76	2.88	598.59
1.50	587.26	3.05	598.62
1.75	588.16	3.15	598.45
2.00	587.86	3.25	598.29
2.25	588.16	3.35	598.14
2.50	589.46	3.45	597.99
2.75	589.36	3.55	597.84
3.00	588.26	3.65	597.70
3.10	584.36	3.75	597.57
3.20	585.76	3.85	597.43
3.30	585.56	3.95	597.30
3.40	583.96	4.05	597.18
3.50	580.96	4.15	813.70
3.60	579.66	4.25	825.43
3.70	581.96	4.35	833.91
3.80	581.26	4.45	839.67
3.90	581.86	4.55	843.17
4.00	582.46	4.65	844.97
4.10	584.36	4.75	845.36
4.20	592.16	4.85	844.65
4.30	657.76	4.95	843.20
4.40	824.66	5.05	841.19
4.50	832.96	5.15	838.76
4.60	854.36	5.25	836.02
4.70	861.86	5.35	833.10
4.80	868.36	5.45	830.09
4.90	868.06	5.55	827.03
5.00	868.76	5.65	823.97
5.10	869.26	5.75	820.94
5.20	867.16	5.85	817.97
5.30	865.76	5.95	815.08
5.50	858.26	6.05	812.27
5.60	853.76	6.15	809.55
5.70	848.26	6.25	806.93
5.80	841.46	6.35	804.42
5.90	836.56	6.45	802.01
6.00	827.46	6.55	799.68
6.10	823.46	6.65	797.55
6.20	820.16	6.75	795.22
6.30	814.66	6.85	793.85
6.40	811.46	6.93	791.09
6.50	807.66	6.98	791.98
6.60	802.86		
6.70	796.26		
6.80	792.16		
6.90	786.76		
6.95	776.76		
6.95	761.16		

RUN NUMBER 238

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	588.36	.38	591.03
.25	588.66	1.00	592.03
.50	588.86	1.50	593.21
.75	587.46	2.00	594.71
1.00	588.46	2.50	596.64
1.25	588.26	2.88	596.96
1.50	587.76	3.05	596.82
1.75	587.96	3.15	596.74
2.00	588.36	3.25	596.66
2.25	587.96	3.35	596.58
2.50	589.26	3.45	596.50
2.75	589.16	3.55	596.42
3.00	588.66	3.65	596.34
3.10	584.86	3.75	596.27
3.20	585.56	3.85	596.19
3.30	583.56	3.95	596.11
3.40	582.66	4.05	596.04
3.50	582.16	4.15	595.97
3.70	583.06	4.25	595.89
3.80	582.96	4.35	595.82
3.90	583.56	4.45	595.75
4.00	583.56	4.55	595.66
4.10	584.26	4.65	595.57
4.20	583.96	4.75	595.49
4.30	584.06	4.85	760.30
4.40	584.76	4.95	770.74
4.50	583.86	5.05	779.42
4.60	583.86	5.15	786.47
4.70	583.96	5.25	792.11
4.80	586.76	5.35	796.56
4.90	704.26	5.45	799.89
5.00	783.46	5.55	802.34
5.10	800.96	5.65	804.04
5.20	812.16	5.75	805.11
5.30	821.06	5.85	805.72
5.50	831.86	5.95	805.94
5.60	837.06	6.05	805.84
5.70	837.66	6.15	805.50
5.80	837.56	6.25	805.00
5.90	838.16	6.35	804.35
6.00	834.66	6.45	803.60
6.10	836.06	6.55	802.75
6.20	837.06	6.65	801.96
6.30	835.26	6.75	800.87
6.40	834.56	6.85	800.63
6.50	833.76	6.93	798.47
6.60	832.06	6.98	799.69
6.70	828.56		
6.80	825.66		
6.90	823.96		
6.95	815.86		
6.95	758.06		
6.95	717.06		

RUN NUMBER 244

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	589.06	.38	590.25
.25	589.36	1.00	591.47
.50	589.56	1.50	593.06
.75	588.86	2.00	594.69
1.00	589.16	2.50	594.78
1.25	588.36	2.88	594.75
1.50	587.26	3.05	594.69
1.75	587.46	3.15	594.66
2.00	587.86	3.25	594.63
2.25	588.06	3.35	594.59
2.50	588.76	3.45	594.56
2.75	588.66	3.55	594.53
3.00	588.76	3.65	594.50
3.10	584.96	3.75	594.47
3.20	584.46	3.85	594.44
3.30	584.36	3.95	594.41
3.40	583.36	4.05	594.38
3.50	583.46	4.15	594.36
3.60	578.46	4.25	594.33
3.70	583.86	4.35	594.31
3.80	583.76	4.45	594.28
3.90	583.76	4.55	594.26
4.00	584.96	4.65	594.24
4.10	584.36	4.75	594.22
4.20	584.76	4.85	594.21
4.30	584.86	4.95	594.19
4.40	584.86	5.05	731.46
4.50	583.96	5.15	742.86
4.60	583.96	5.25	753.80
4.70	584.06	5.35	764.28
4.80	584.46	5.45	774.28
4.90	584.26	5.55	783.79
5.00	584.86	5.65	792.79
5.10	684.96	5.75	801.28
5.20	747.56	5.85	809.28
5.30	767.86	5.95	816.79
5.40	775.86	6.05	823.82
5.50	793.56	6.15	830.39
5.60	804.76	6.25	836.54
5.70	811.96	6.35	842.30
5.80	818.36	6.45	847.72
5.90	825.56	6.55	852.80
6.00	831.16	6.65	857.67
6.10	834.96	6.75	862.10
6.20	842.56	6.85	866.94
6.30	846.76	6.93	867.59
6.40	852.06	6.98	870.69
6.50	856.66		
6.60	861.56		
6.70	865.96		
6.80	869.06		
6.90	872.16		
6.95	867.16		

RUN NUMBER 259

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	566.66	.38	569.80
.25	567.56	1.00	571.26
.50	567.86	1.50	572.69
.75	565.16	2.00	574.24
1.00	566.16	2.50	575.69
1.25	565.26	2.88	575.42
1.50	564.76	3.05	574.97
1.75	565.66	3.15	574.74
2.00	564.76	3.25	574.52
2.25	564.96	3.35	574.31
2.50	566.96	3.45	574.10
2.75	566.86	3.55	573.90
3.00	566.36	3.65	573.71
3.10	563.06	3.75	573.52
3.20	563.86	3.85	573.33
3.30	564.36	3.95	573.15
3.40	562.66	4.05	572.98
3.50	562.16	4.15	572.81
3.60	563.36	4.25	572.64
3.70	563.86	4.35	572.47
3.80	562.46	4.45	572.31
3.90	562.46	4.55	572.16
4.00	562.46	4.65	572.00
4.10	559.96	4.75	571.85
4.20	559.66	4.85	571.70
4.30	558.56	4.95	571.55
4.40	558.56	5.05	571.41
4.50	558.96	5.15	571.27
4.60	557.66	5.25	571.13
4.70	557.76	5.35	570.99
4.80	558.16	5.45	570.86
4.90	558.56	5.55	570.73
5.00	558.56	5.65	570.60
5.10	559.16	5.75	570.47
5.20	558.76	5.85	570.34
5.30	558.66	5.95	570.21
5.40	556.96	6.05	778.09
5.50	557.26	6.15	786.50
5.60	557.06	6.25	792.79
5.70	557.06	6.35	797.06
5.80	556.86	6.45	799.82
5.90	558.16	6.55	801.42
6.00	561.36	6.65	802.23
6.10	573.06	6.75	802.01
6.20	580.26	6.85	802.06
6.30	624.56	6.93	799.53
6.40	754.96	6.98	800.78
6.50	772.06		
6.60	778.36		
6.70	779.76		
6.80	785.36		
6.90	786.66		
6.95	779.76		

RUN NUMBER 261

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	567.86	.38	571.94
.25	568.76	1.00	573.87
.50	569.06	1.50	576.12
.75	565.66	2.00	578.65
1.00	566.66	2.50	578.60
1.25	565.76	2.88	577.44
1.50	565.36	3.05	576.94
1.75	566.16	3.15	576.69
2.00	565.26	3.25	576.45
2.25	565.56	3.35	576.22
2.50	568.16	3.45	576.00
2.75	568.06	3.55	575.78
3.00	566.86	3.65	575.57
3.10	562.96	3.75	575.36
3.20	564.36	3.85	575.16
3.30	564.86	3.95	574.96
3.40	562.56	4.05	574.77
3.50	562.06	4.15	574.58
3.60	563.86	4.25	574.40
3.70	564.36	4.35	574.22
3.80	562.96	4.45	574.05
3.90	562.96	4.55	573.88
4.00	562.36	4.65	859.70
4.10	559.76	4.75	871.89
4.20	559.56	4.85	879.78
4.30	557.76	4.95	884.64
4.40	558.36	5.05	887.08
4.50	556.86	5.15	887.47
4.60	558.76	5.25	886.49
4.70	577.26	5.35	884.58
4.80	595.86	5.45	881.99
4.90	734.46	5.55	878.94
5.00	845.16	5.65	875.57
5.10	859.36	5.75	872.00
5.20	867.16	5.85	868.32
5.30	872.66	5.95	864.59
5.50	873.76	6.05	860.83
5.60	872.86	6.15	857.11
5.70	868.56	6.25	853.46
5.80	862.76	6.35	849.89
5.90	857.16	6.45	846.44
6.00	854.06	6.55	843.05
6.10	846.96	6.65	839.90
6.20	843.06	6.75	836.48
6.30	836.86	6.85	834.34
6.40	832.96	6.93	830.35
6.50	829.06	6.98	831.45
6.60	822.96		
6.70	813.16		
6.80	812.06		
6.90	805.96		
6.95	793.96		
6.95	867.16		

RUN NUMBER 264

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	566.96	.38	569.23
.25	567.86	1.00	570.87
.50	568.06	1.50	572.66
.75	566.06	2.00	574.75
1.00	566.36	2.50	575.67
1.25	566.16	2.88	574.82
1.50	565.06	3.05	574.39
1.75	565.86	3.15	574.18
2.00	565.06	3.25	573.98
2.25	565.26	3.35	573.79
2.50	567.26	3.45	573.60
2.75	567.16	3.55	573.42
3.00	566.66	3.65	573.24
3.10	563.36	3.75	573.07
3.20	564.76	3.85	572.90
3.30	564.66	3.95	572.74
3.40	563.66	4.05	572.58
3.50	562.46	4.15	572.42
3.60	564.26	4.25	572.27
3.70	564.16	4.35	572.12
3.80	562.76	4.45	571.98
3.90	562.76	4.55	571.84
4.00	560.86	4.65	571.70
4.10	560.26	4.75	571.57
4.20	559.96	4.85	571.43
4.30	558.86	4.95	571.30
4.40	559.46	5.05	571.18
4.50	559.86	5.15	571.05
4.60	559.26	5.25	570.93
4.70	559.96	5.35	570.81
4.80	560.36	5.45	570.70
4.90	560.06	5.55	570.58
5.00	559.46	5.65	570.47
5.10	559.46	5.75	570.36
5.20	559.06	5.85	570.25
5.30	558.96	5.95	570.14
5.40	558.46	6.05	768.60
5.50	558.86	6.15	778.11
5.60	558.56	6.25	785.77
5.70	558.56	6.35	791.64
5.80	558.46	6.45	796.14
5.90	559.06	6.55	799.49
6.00	562.26	6.65	801.82
6.10	589.46	6.75	803.04
6.20	684.76	6.85	804.52
6.30	759.96	6.93	802.73
6.40	775.76	6.98	804.62
6.50	786.66		
6.60	792.26		
6.70	794.26		
6.80	799.26		
6.90	801.16		
6.95	794.86		

RUN NUMBER 270

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	566.16	.38	569.13
.25	567.06	1.00	571.13
.50	567.26	1.50	573.71
.75	565.86	2.00	575.49
1.00	566.26	2.50	574.81
1.25	565.36	2.88	574.25
1.50	564.86	3.05	573.98
1.75	565.76	3.15	573.84
2.00	565.46	3.25	573.71
2.25	565.06	3.35	573.58
2.50	567.06	3.45	573.45
2.75	566.96	3.55	573.32
3.00	567.06	3.65	573.18
3.10	563.86	3.75	573.03
3.20	564.56	3.85	572.89
3.30	565.06	3.95	572.75
3.40	563.46	4.05	572.61
3.50	562.96	4.15	572.48
3.60	564.16	4.25	572.36
3.70	563.96	4.35	572.23
3.80	562.56	4.45	572.11
3.90	563.26	4.55	572.00
4.00	561.36	4.65	571.88
4.10	560.76	4.75	571.77
4.20	560.46	4.85	571.67
4.30	559.96	4.95	571.57
4.40	559.96	5.05	571.47
4.50	560.96	5.15	571.37
4.60	560.36	5.25	571.28
4.70	560.46	5.35	571.19
4.80	560.26	5.45	571.10
4.90	560.56	5.55	571.01
5.00	560.56	5.65	570.93
5.10	559.96	5.75	570.85
5.20	559.56	5.85	763.48
5.30	560.06	5.95	775.21
5.40	558.96	6.05	785.53
5.50	559.36	6.15	794.55
5.60	559.06	6.25	802.37
5.70	559.76	6.35	809.04
5.80	559.56	6.45	814.79
5.90	568.36	6.55	819.62
6.00	734.96	6.65	823.72
6.10	768.76	6.75	826.92
6.20	786.86	6.85	830.35
6.30	798.36	6.93	829.59
6.40	808.06	6.98	832.31
6.50	816.36		
6.60	821.96		
6.70	825.16		
6.80	828.36		
6.90	830.26		
6.95	824.56		

RUN NUMBER 272

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	567.56	.38	571.25
.25	567.76	1.00	574.58
.50	568.06	1.50	578.43
.75	566.06	2.00	577.69
1.00	566.96	2.50	576.88
1.25	566.06	2.88	576.20
1.50	564.96	3.05	575.82
1.75	565.86	3.15	575.63
2.00	565.56	3.25	575.44
2.25	565.26	3.35	575.27
2.50	567.86	3.45	575.10
2.75	567.76	3.55	574.93
3.00	567.16	3.65	574.77
3.10	563.96	3.75	574.62
3.20	564.66	3.85	574.47
3.30	565.16	3.95	574.33
3.40	562.96	4.05	574.20
3.50	562.46	4.15	574.07
3.60	564.26	4.25	573.94
3.70	564.66	4.35	573.82
3.80	562.66	4.45	573.71
3.90	563.26	4.55	833.64
4.00	560.76	4.65	850.89
4.10	560.16	4.75	865.56
4.20	559.86	4.85	877.67
4.30	559.46	4.95	887.66
4.40	558.76	5.05	895.66
4.50	559.16	5.15	901.92
4.60	571.06	5.25	906.77
4.70	788.06	5.35	910.47
4.80	843.66	5.45	913.26
4.90	863.66	5.55	915.29
5.00	880.26	5.65	916.74
5.10	891.86	5.75	917.77
5.20	899.56	5.85	918.42
5.30	906.86	5.95	918.84
5.50	911.66	6.05	919.06
5.60	912.06	6.15	919.16
5.70	910.76	6.25	919.17
5.80	908.16	6.35	919.16
5.90	905.76	6.45	919.15
6.00	906.96	6.55	919.13
6.10	901.76	6.65	919.27
6.20	901.56	6.75	919.14
6.30	899.06	6.85	920.09
6.40	898.96	6.93	917.75
6.50	897.06	6.98	919.99
6.60	895.26		
6.70	892.26		
6.80	889.96		
6.90	885.76		
6.95	876.96		
6.95	794.86		

RUN NUMBER 275

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	565.16	.38	566.88
.25	566.06	1.00	568.57
.50	566.26	1.50	570.60
.75	564.96	2.00	571.07
1.00	565.26	2.50	571.02
1.25	565.06	2.88	570.83
1.50	564.56	3.05	570.71
1.75	564.76	3.15	570.65
2.00	565.16	3.25	570.59
2.25	564.76	3.35	570.53
2.50	566.76	3.45	570.48
2.75	566.66	3.55	570.42
3.00	566.76	3.65	570.36
3.10	564.16	3.75	570.30
3.20	564.86	3.85	570.25
3.30	564.76	3.95	570.20
3.40	563.16	4.05	570.14
3.50	562.66	4.15	570.09
3.60	563.76	4.25	570.04
3.70	563.66	4.35	569.99
3.80	562.26	4.45	569.95
3.90	562.86	4.55	569.90
4.00	561.06	4.65	569.86
4.10	561.06	4.75	569.82
4.20	561.46	4.85	569.78
4.30	561.56	4.95	569.74
4.40	560.96	5.05	569.70
4.50	561.26	5.15	569.67
4.60	561.26	5.25	569.64
4.70	560.76	5.35	569.61
4.80	560.56	5.45	569.59
4.90	560.96	5.55	569.57
5.00	560.96	5.65	569.55
5.10	560.86	5.75	569.54
5.20	560.56	5.85	569.53
5.30	561.06	5.95	569.53
5.40	561.16	6.05	569.53
5.50	560.36	6.15	569.54
5.60	560.66	6.25	569.56
5.70	560.66	6.35	569.59
5.80	561.16	6.45	722.56
5.90	561.76	6.55	733.79
6.00	562.46	6.65	744.91
6.10	562.16	6.75	755.76
6.20	562.56	6.85	766.45
6.30	563.76	6.93	770.56
6.40	565.56	6.98	775.82
6.50	570.96		
6.60	695.56		
6.70	728.06		
6.80	744.36		
6.90	757.66		
6.95	759.26		

RUN NUMBER 315

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	522.86	.38	526.12
.25	525.66	1.00	529.00
.50	525.96	1.50	531.36
.75	521.96	2.00	531.84
1.00	521.76	2.50	529.62
1.25	518.86	2.88	528.01
1.50	517.76	3.05	527.30
1.75	517.96	3.15	526.94
2.00	517.06	3.25	526.61
2.25	517.36	3.35	526.28
2.50	518.76	3.45	525.96
2.75	517.96	3.55	525.65
3.00	516.86	3.65	525.34
3.10	514.16	3.75	525.04
3.20	514.86	3.85	524.75
3.30	515.46	3.95	524.45
3.40	513.06	4.05	524.17
3.50	512.56	4.15	523.88
3.60	514.36	4.25	523.61
3.70	513.66	4.35	523.33
3.80	510.26	4.45	523.05
3.90	512.86	4.55	522.78
4.00	514.16	4.65	522.51
4.10	514.76	4.75	522.24
4.20	513.86	4.85	521.98
4.30	513.36	4.95	521.71
4.40	509.56	5.05	521.45
4.50	511.16	5.15	521.19
4.60	509.26	5.25	520.92
4.70	509.36	5.35	520.66
4.80	509.16	5.45	520.40
4.90	508.26	5.55	520.14
5.00	508.26	5.65	519.88
5.10	508.86	5.75	519.61
5.20	507.26	5.85	519.35
5.30	507.76	5.95	871.97
5.40	507.86	6.05	879.85
5.50	507.56	6.15	883.76
5.60	506.66	6.25	885.07
5.70	507.36	6.35	884.48
5.80	507.26	6.45	882.55
5.90	508.46	6.55	879.66
6.00	517.46	6.65	876.39
6.10	625.36	6.75	872.19
6.20	780.96	6.85	869.34
6.30	801.26	6.93	863.65
6.40	812.86	6.98	864.33
6.50	825.66		
6.60	828.86		
6.80	833.46		
6.90	832.26		
6.95	819.16		
6.95	794.86		

RUN NUMBER 320

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	523.36	.38	524.86
.25	524.86	1.00	528.04
.50	525.16	1.50	530.79
.75	521.86	2.00	528.96
1.00	521.56	2.50	527.21
1.25	519.46	2.88	525.78
1.50	518.26	3.05	525.15
1.75	519.16	3.15	524.83
2.00	518.26	3.25	524.54
2.25	518.56	3.35	524.25
2.50	519.26	3.45	523.97
2.75	518.56	3.55	523.69
3.00	517.36	3.65	523.42
3.10	515.36	3.75	523.16
3.20	516.06	3.85	522.90
3.30	516.56	3.95	522.65
3.40	514.96	4.05	522.40
3.50	513.76	4.15	522.16
3.60	516.26	4.25	521.92
3.70	514.86	4.35	521.68
3.80	511.56	4.45	521.44
3.90	514.06	4.55	521.21
4.00	515.36	4.65	520.98
4.10	515.36	4.75	520.75
4.20	514.46	4.85	520.53
4.30	513.96	4.95	520.31
4.40	510.06	5.05	520.09
4.50	511.16	5.15	519.87
4.60	509.16	5.25	519.65
4.70	509.96	5.35	519.43
4.80	509.76	5.45	519.21
4.90	509.46	5.55	519.00
5.00	509.46	5.65	518.78
5.10	510.06	5.75	518.57
5.20	508.46	5.85	518.36
5.30	509.56	5.95	518.14
5.40	509.76	6.05	850.08
5.50	509.46	6.15	859.99
5.60	508.56	6.25	866.30
5.70	509.26	6.35	870.04
5.80	509.06	6.45	871.73
5.90	509.06	6.55	871.90
6.00	511.66	6.65	871.25
6.10	535.56	6.75	869.30
6.20	657.16	6.85	868.24
6.30	788.16	6.93	863.59
6.40	807.06	6.98	864.94
6.50	822.26		
6.60	829.06		
6.80	837.26		
6.90	841.66		
6.95	832.26		
6.95	759.26		

RUN NUMBER 327

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	524.46	.38	524.06
.25	525.96	1.00	527.73
.50	525.56	1.50	528.09
.75	523.56	2.00	526.63
1.00	523.26	2.50	525.22
1.25	520.56	2.88	524.15
1.50	520.06	3.05	523.66
1.75	520.86	3.15	523.41
2.00	520.06	3.25	523.15
2.25	520.26	3.35	522.91
2.50	521.06	3.45	522.67
2.75	519.66	3.55	522.44
3.00	518.46	3.65	522.21
3.10	516.46	3.75	521.99
3.20	517.16	3.85	521.77
3.30	517.76	3.95	521.56
3.40	516.06	4.05	521.36
3.50	515.56	4.15	521.16
3.60	517.36	4.25	520.96
3.70	516.56	4.35	520.77
3.80	515.16	4.45	520.58
3.90	515.76	4.55	520.39
4.00	516.46	4.65	520.21
4.10	516.46	4.75	520.03
4.20	516.16	4.85	519.85
4.30	516.36	4.95	519.68
4.40	516.36	5.05	519.51
4.50	516.66	5.15	519.34
4.60	515.46	5.25	519.17
4.70	514.96	5.35	519.01
4.80	514.66	5.45	518.84
4.90	514.46	5.55	518.68
5.00	514.46	5.65	518.53
5.10	515.06	5.75	518.37
5.20	515.26	5.85	518.22
5.30	514.56	5.95	518.06
5.40	514.06	6.05	834.16
5.50	513.76	6.15	847.25
5.60	513.56	6.25	857.47
5.70	511.66	6.35	865.17
5.80	510.26	6.45	870.94
5.90	508.96	6.55	875.02
6.00	512.16	6.65	878.02
6.10	575.96	6.75	879.46
6.20	754.46	6.85	881.38
6.30	790.36	6.93	878.50
6.40	809.16	6.98	880.91
6.50	826.06		
6.60	834.06		
6.70	838.46		
6.80	846.46		
6.90	853.86		
6.95	846.96		

RUN NUMBER 332

ZEX(M)	TEX(K)	ZR5(M)	TR5(K)
.05	520.06	.38	520.69
.25	521.56	1.00	522.84
.50	521.26	1.50	522.80
.75	517.36	2.00	522.35
1.00	515.86	2.50	521.55
1.25	514.26	2.88	520.90
1.50	514.46	3.05	520.60
1.75	514.06	3.15	520.46
2.00	514.46	3.25	520.32
2.25	514.06	3.35	520.18
2.50	519.16	3.45	520.05
2.75	518.46	3.55	519.92
3.00	518.56	3.65	519.80
3.10	516.56	3.75	519.67
3.20	515.46	3.85	519.55
3.30	514.66	3.95	519.44
3.40	513.06	4.05	519.32
3.50	511.26	4.15	519.21
3.60	513.06	4.25	519.10
3.70	511.66	4.35	519.00
3.80	510.26	4.45	518.90
3.90	512.16	4.55	518.80
4.00	514.06	4.65	518.71
4.10	512.76	4.75	518.62
4.20	511.86	4.85	518.53
4.30	512.06	4.95	518.45
4.40	512.06	5.05	518.37
4.50	513.06	5.15	518.29
4.60	511.76	5.25	518.22
4.70	511.26	5.35	518.15
4.80	511.66	5.45	518.09
4.90	511.36	5.55	518.03
5.00	512.06	5.65	517.97
5.10	512.66	5.75	517.92
5.20	511.66	5.85	517.88
5.30	512.16	5.95	517.85
5.40	512.26	6.05	517.82
5.50	512.66	6.15	517.79
5.60	511.76	6.25	793.62
5.70	513.06	6.35	809.70
5.80	511.06	6.45	824.47
5.90	511.06	6.55	837.99
6.00	512.36	6.65	850.38
6.10	513.26	6.75	861.56
6.20	514.96	6.85	872.15
6.30	613.36	6.93	874.69
6.40	745.66	6.98	879.91
6.50	772.66		
6.60	788.36		
6.70	803.56		
6.80	816.26		
6.90	826.56		
6.95	824.56		

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)

NUREG/IA-0009
STUDSVIK/NP-86/66

2. TITLE AND SUBTITLE

Assessment of RELAP5/MOD2, Against Twenty Five Dryout Experiments Conducted at the Royal Institute Technology

3. LEAVE BLANK

4. DATE REPORT COMPLETED

MONTH	YEAR
June	1986

5. AUTHOR(S)

A. Sjöberg, D. Caraher

6. DATE REPORT ISSUED

MONTH	YEAR
October	1986

7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Swedish Nuclear Power Inspectorate
Box 27106
S-102 52 Stockholm, Sweden

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

11a. TYPE OF REPORT

Technical Report

b. PERIOD COVERED (Inclusive dates)

12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

RELAP5/MOD2 simulations of post-dryout heat transfer in a 7 m long, 1.5 cm diameter heated tube are reported. The Biasi critical heat flux correlation is shown to be inadequate for predicting the experimental dryout. RELAP5 accurately predicted the measured temperatures downstream of the dryout once it was forced to predict dryout at the experimentally measured location.

14. DOCUMENT ANALYSIS - a. KEYWORDS/DESCRIPTORS

RELAP5/MOD2, Post-dryout heat transfer, ICAP Program

b. IDENTIFIERS/OPEN-ENDED TERMS

15. AVAILABILITY STATEMENT

Unlimited

16. SECURITY CLASSIFICATION

(This page)

Unclassified

(This report)

Unclassified

17. NUMBER OF PAGES

18. PRICE

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

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

SPECIAL FOURTH-CLASS RATE
POSTAGE & FEES PAID
USNRC
WASH. D.C.
PERMIT No. G-67

NUREG/IA-0009

ASSESSMENT OF RELAP5/MOD2 AGAINST 25 DRYOUT EXPERIMENTS
CONDUCTED AT THE ROYAL INSTITUTE OF TECHNOLOGY

OCTOBER 1986