NUREG/IA-0007

# International Agreement Report

# Assessment of RELAP5/MOD 2 Against Critical Flow Data From Marviken Tests JIT 11 and CFT 21

Prepared by
Ö. Rosdahl, D. Caraher

Swedish Nuclear Power Inspectorate
P.O. Box 27106
S102 #52 Stockholm, Sweden

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

**September 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

NOTICE

This report was prepared under an international cooperative agreement for the exchange of technical information. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use, or the results of such use, of any information, apparatus product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

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-0007

# International Agreement Report

# Assessment of RELAP5/MOD 2 Against Critical Flow Data From Marviken Tests JIT 11 and CFT 21

Prepared by
Ö. Rosdahl, D. Caraher

Swedish Nuclear Power Inspectorate
P.O. Box 27106
S102 #52 Stockholm, Sweden

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

**September 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

NOTICE

This report documents work performed under the sponsorship of the SKI/STUDSVIK of Sweden. The information in this report has been provided to the USNRC under the terms of an information exchange agreement between the United States and Sweden (Technical Exchange and Cooperation Arrangement Between the United States Nuclear Regulatory Commission and the Swedish Nuclear Power Inspectorate and Studsvik Energiteknik AB of Sweden in the field of reactor safety research and development, February 1985). Sweden has consented to the publication of this report as a USNRC document in order that it may receive the widest possible circulation among the reactor safety community. Neither the United States Government nor Sweden or any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, or any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

STUDSVIK ENERGITEKNIK AB

STUDSVIK/NP-86/99



1986-07-25

Project 85026, 13.3-917/84

Östen Rosdahl
David Caraher*

Swedish Nuclear Power Inspectorate

# ICAP
# Assessment of RELAP5/MOD Against Critical Flow Data from Marviken Tests JIT 11 and CFT 21

ABSTRACT

RELAP5/ MOD2 simulations of the critical flow of saturated steam are reported together with simulations of the critical flow of subcooled liquid and a low quality two-phase mixture. The experiments which were simulated used nozzle diameters of 0.3 m and 0.5 m. RELAP5 overpredicted the experimental flow rates by 10 to 25 percent unless discharge coefficients were applied.

* Software Engineering Consulting

Approved by

Eric Wellstrand

## EXECUTIVE SUMMARY

RELAP5/MOD2 simulations have been conducted to assess the critical flow model in RELAP5. The experiments chosen for the simulations were Marviken Jet Impingement Test (JIT) 11 (saturated steam flow) and Marviken Critical Flow Test (CFT) 21 (subcooled and two-phase flow).

The experimental facility consisted of a large vessel 5.2 m in diameter and 22 m high having a total volume of 420 $m^3$. A discharge pipe containing a valve, a nozzle, rupture discs and assorted transducers was attached to the bottom of the vessel. For JIT 11 a standpipe, 1 m in diameter and 18 m tall, was mounted within the vessel to prevent any liquid from entering the discharge pipe. The nozzle used for the saturated steam flow test (JIT 11) had a diameter of 0.3 m and a length of 1.18 m. The nozzle used for the subcooled critical flow test (CFT 21) had a 0.5 m diameter and was 0.96 m in length.

For all the RELAP5 simulations the experimentally measured fluid conditions in the vessel were used as boundary conditions. This technique allowed the simulations to focus on the flow in the discharge pipe.

The simulations of saturated steam flow overpredicted the experimental discharge flow rate by 20 to 25 percent. Explicity representing the nozzle region by up to five computational cells had little effect on computed results. It was concluded that, when simulating saturated steam critical flow with RELAP5, a discharge coefficient of ~ 0.8 needs to be applied. Furthermore, short lengths of pipe (L/D < 4) at the discharge should not be explicitly modeled.

Numerical discontinuities in calculated critical flow rate were found to occur in some of the saturated steam flow simulations. The cause of the discontinuities was traced to an approximation made in the equation used for determining the internal energy at a junction in subroutine JCHOKE.

When simulating CFT 21 RELAP5 was found to overpredict critical flow rates of subcooled liquid by 18 to 20 percent when the nozzle was not explicitly included in the RELAP5 model (only its flow area was included). Good agreement with experimental results was attained by using a discharge coefficient of 0.85.

When the nozzle was included in the RELAP5 model RELAP5 underpredicted the measured flow rates. Applying discharge coefficients greater than unity did little to improve computed results but greatly increased computational times. It was concluded that when modeling discharge regions using RELAP5 explicit representation of short lengths of piping near the discharge location should be avoided.

For low quality two phase flow RELAP5 was in good agreement with experimental data when the vessel fluid state (RELAP5 boundary condition) was based upon gamma densitometer measurements. When the fluid state was based upon dP measurements RELAP5 overpredicted the measured flow rate by up to 30 percent. Since the actual fluid state in the vessel probably lies between those used as boundary conditions it was concluded that RELAP5 would generally need a discharge coefficient of between 0.80 and 0.95 when used to simulate low quality critical flow.

Application of a discharge coefficient to the RELAP5 simulation of low quality two-phase flow did not achieve an expected result. Using a discharge coefficient of 0.85 instead of 1.0 resulted in only a 8 percent reduction in flow rate rather than the 15 percent expected.

It was discovered that, because of the logic used in subroutine JCHOKE to select between the subcooled and saturated flow calculations and because of an apparent dependency of local equilibrium quality on discharge coefficient, the sonic velocities used in the RELAP5 choking criterion could increase when a discharge coefficient was applied, thus partially offsetting the velocity reduction represented by the discharge coefficient.

LIST OF CONTENTS

| | | Page |
|---|---|---|
| ABSTRACT | | iii |
| EXECUTIVE SUMMARY | | v |
| 1 | INTRODUCTION | 1 |
| 2 | FACILITY AND TEST DESCRIPTION | 3 |
| 3 | CODE AND MODEL DESCRIPTION | 8 |
| 3.1 | Input description - JIT 11 simulations | 8 |
| 3.2 | Input description - CFT 21 simulations | 9 |
| 4 | RESULTS AND DISCUSSION | 11 |
| 4.1 | Critical flow of saturated steam - JIT 11 | 11 |
| 4.2 | Subcooled critical flow - CFT 21 | 15 |
| 4.2.1 | Nodalization study | 17 |
| 4.3 | Low quality critical flow - CFT 21 | 18 |
| 5 | COMPUTATIONAL EFFICIENCY AND NUMERICAL PROBLEMS | 30 |
| 5.1 | Critical flow model numerical problems | 32 |
| 6 | CONCLUSIONS | 33 |
| REFERENCES | | 35 |

APPENDIX A - Input for RELAP5 for JIT 11 simulation
APPENDIX B - Listing of input data for case CFT01
APPENDIX C - Listing of input data for case CFT04

# 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 the results of an assessment of the RELAP5's critical flow model is presented. The ability of RELAP5 to simulate the critical flow of saturated steam is assessed by comparison to data from Marviken Jet Impingement Test (JIT) number 11 (5). The subcooled critical flow model is assessed by comparison to data from Marviken Critical Flow Test (CFT) number 21 (6).

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 | Marviken21 | 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 Marviken Power plant was built as a boiling heavy water direct cycle nuclear reactor but was never commissioned. The nuclear steam supply system was left intact and an oil fired boiler was built to provide steam for the turbine.

During 1978 and 1979 Marviken was the site of the Critical Flow Test (CFT) program. This test program generated full scale critical flow data for subcooled liquid and low quality two-phase mixtures.

Subsequent to the CFT program, Marviken became the site of the Jet Impingement Test (JIT) program. This program, which focused on measuring loads due to a fluid jet impinging upon a flat plate, also generated full scale critical flow data. One of the tests, JIT 11, allowed only saturated steam to be discharged.

Figure 2-1 depicts the Marviken pressure vessel and the location of the differential pressure measurements. For JIT 11 a standpipe (dotted line) was inserted into the vessel to ensure that only steam flowed out of the vessel. In other tests no standpipe was used; the fluid entered the discharge pipe at the bottom of the vessel directly. The nozzle was located beneath the pressure vessel. The piping leading to the nozzle and the nozzle are depicted in Figures 2-2 and 2-3. Initial and boundary condition for JIT 11 and CFT 21 are summarized in Table 2-1. Complete descriptions of the experimental facility for the JIT program and for the CFT program are given in References 3 and 4 respectively. A description of JIT 11 is presented along with test results in Reference 5 and a description of CFT 21

is given in Reference 6. The probable error (one standard deviation) in the measured differential pressure values shown in this report is 0.6 kPa; the 99 % confidence error is 1.5 kPa.

Table 2-1

Important parameters for Marviken JIT 11 and CFT 21

| | JIT 11 | CFT 21 |
|---|---|---|
| Vessel volume (net internal) | 420 $m^3$ | 420 $m^3$ |
| Vessel inside diameter | 5.22 m | 5.22 |
| Standpipe: height | 18 m | - |
| outside diameter | 1.04 m | - |
| wall thickness | 8.8 mm | - |
| Disharge nozzle: diameter | 0.299 m | 0.500 m |
| area | 702 x $10^{-4} m^2$ | 0.1963 $m^2$ |
| length | 1.18 m | 1.5 m |
| Initial pressure | 5.0 MPa | 4.9 MPa |
| Final pressure | 1.88 MPa | 2.5 MPa |
| Initial water level | 10.2 m | 19.9 m |
| Final water level | 8.0 m | <0.8 m |
| Initial inventory: water | 145 x $10^3$ kg | 330 x $10^3$ kg |
| steam | 5 x $10^3$ kg | 6 x $10^2$ kg |
| Maximum subcooling | < 3 K | 33 K |

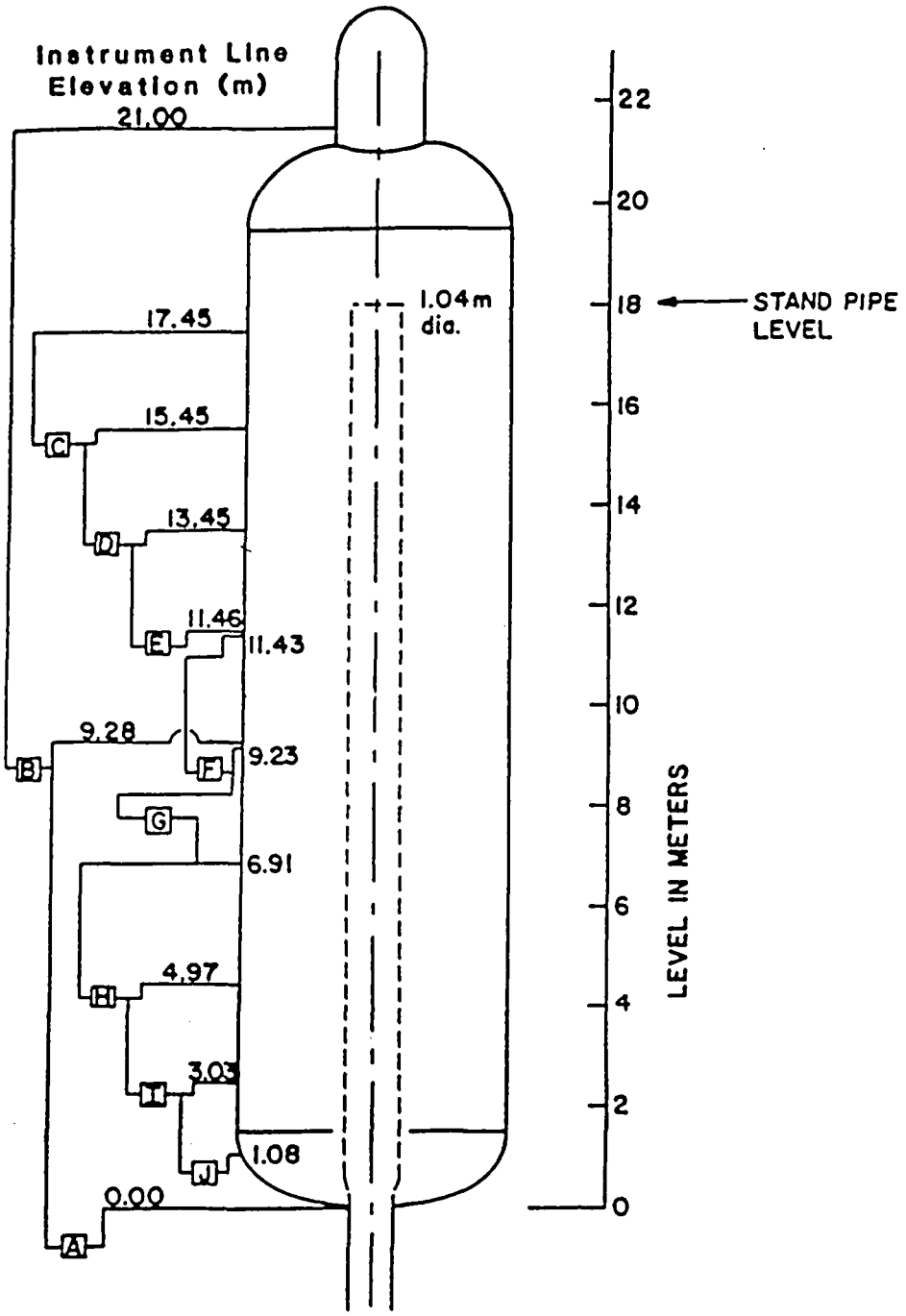


Figure 2-1

Marviken test vessel. Differential pressure transducers A through J.

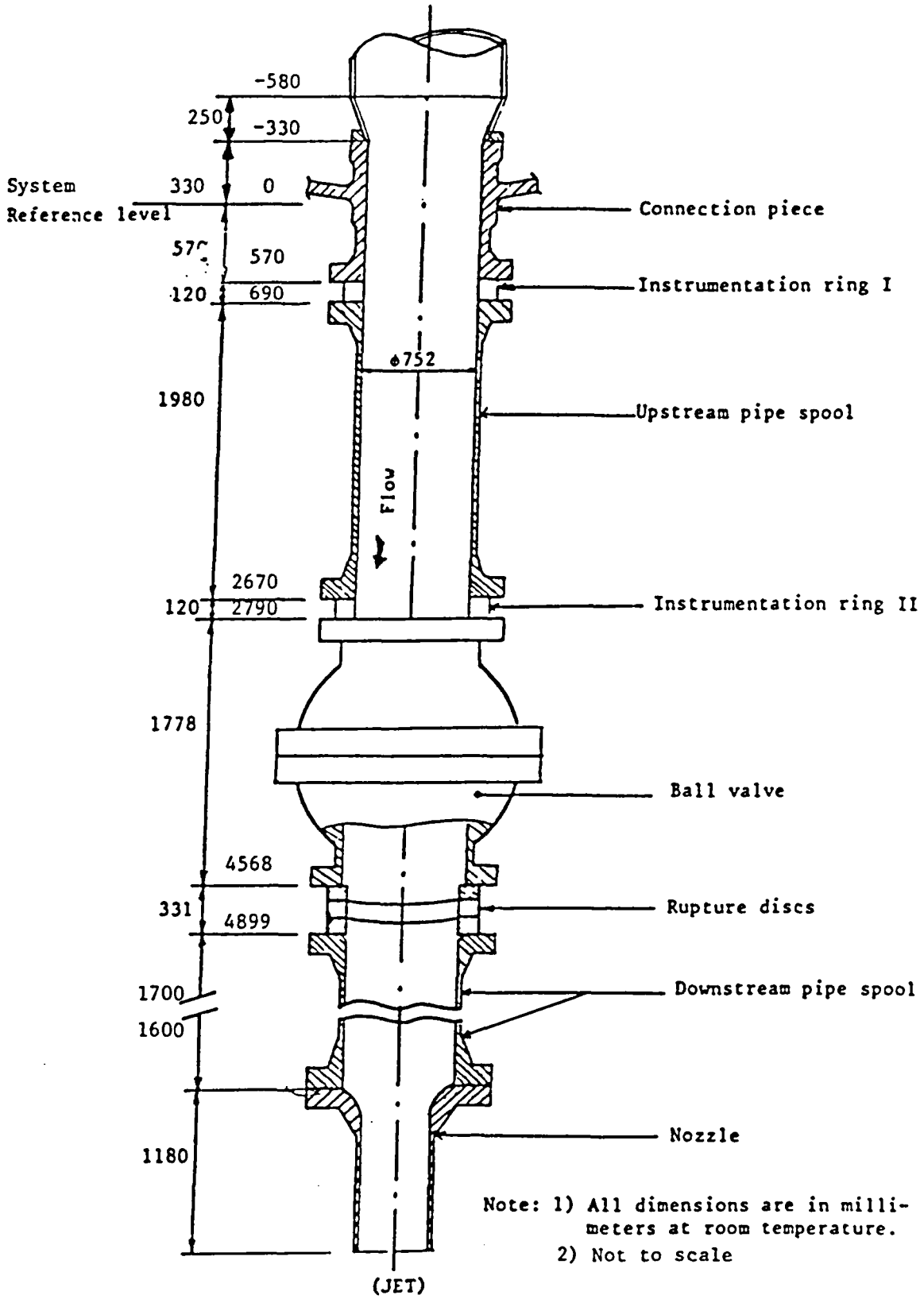


Figure 2-2

Arrangement of components in the discharge pipe for Jet Impingement Test 11.

Note: All dimensions are in millimeters at room temperature.

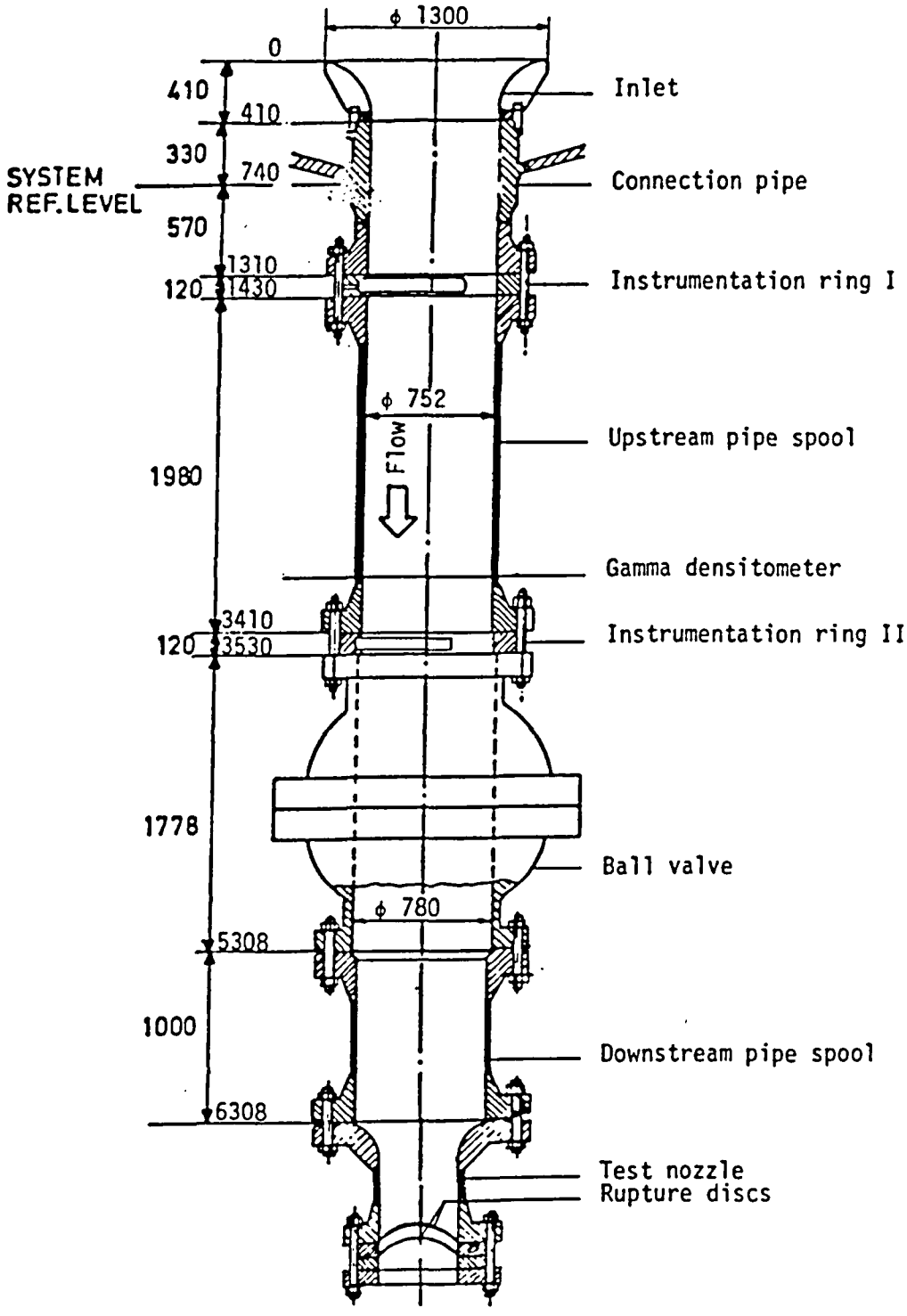


Figure 2-3

Arrangement of components in the discharge pipe for Critical Flow Test 21.

# 3 CODE AND MODEL DESCRIPTION

The critical flow simulations of JIT 11 and CFT 21 were performed with RELAP5/MOD2, cycle 36.02.

## 3.1 Input description - JIT 11 simulations

In order to focus on the critical flow model in RELAP5 it was decided to drive RELAP5 with vessel boundary conditions determined from the experimental data. A TMDPVOL component was used to represent the vessel for all the simulations of JIT 11. The containment was also represented by a TMDPVOL component (with constant P = 0.1 MPa). The piping between the vessel and the containment (see Figures 2-1, 2-2) was represented several different ways, as described in Table 3-1.

Table 3-1
Description of the JIT 11 simulation cases

| Case | Description |
|---|---|
| 0 node | Vessel modeled as time dependent volume. Standpipe and discharge pipe not modeled. A single junction component used to represent the discharge area. |
| 7 node | Vessel model as time dependent volume. Standpipe modeled as pipe component (4 cells). Discharge pipe modeled as pipe component (3 cells). Single junction component used to represent the discharge area. |
| 9 node | Same as 7 node model except nozzle included. Nozzle modeled by pipe component (2 cells). |
| 12 node | Same as 9 node model except nozzle now represented with 5 cells. |

## 3.2 Input description - CFT 21 simulations

For the simulations of CFT 21 a TMDPVOL component was used to represent the fluid conditions at the bottom of the vessel. For the simulations of subcooled flow the pressure and temperature measured at the vessel bottom were fed to RELAP5. For the simulations of saturated liquid or two-phase flow the pressure and fluid quality at the vessel bottom were fed to RELAP5. The fluid quality history was determined from experimental measurements of density, pressure, and differential pressure combined with the assumption of adiabatic flow between the vessel bottom and the gamma densitometer location (refer to Figure 2-3).

The RELAP5 simulations are described in Table 3-2. For simulations CFT01 to CFT06 the discharge pipe was modeled by a PIPE component with three cells. The discharge area was represented by a SNGLJUN component but the nozzle was not explicitly modeled. For simulations CFT07 and CFT08 the nozzle was modeled as a PIPE component having one cell.

The saturated flow simulations (CFT04, CFT05, CFT06) all began at 26.7 seconds into the blowdown. Each of these simulations was initiated by restarting case CFT03 and inputting a new (saturated conditions) set of boundary conditions representing the experimental measurements made between 26.7 and 60 seconds.

Table 3-2

Description of the CFT 21 simulation cases.

| RELAP5 case | Description |
|---|---|
| CFT01 | Subcooled boundary conditions. No discharge coefficients. Nozzle not modeled. |
| CFT02 | Subcoooled boundary conditions. Subcooled discharge coefficient ($C_D$) = 0.85. Nozzle not modeled. |
| CFT03 | Subcooled boundary conditions. $C_D$ = 0.85. Boundary condition temperature reduced 2K for t>18 s. Nozzle not modeled. |
| CFT04 | Saturated boundary conditions. Restarted from CFT03 at 26.5 s. No discharge coefficient for two-phase flow. |
| CFT05 | Saturated boundary conditions. Restarted from CFT03 at 26.5 s. No discharge coefficient. Boundary condition quality limited to upper value of 0.003. |
| CFT06 | Same as CFT05 except $C_D$ = 0.85. |
| CFT07 | Subcooled boundary conditions. No discharge coefficient. Nozzle modeled with one node. |
| CFT08 | Same as CFT07 except $C_D$ = 1.09 for subcooled flow and 1.13 for two-phase flow. |

# 4 RESULTS AND DISCUSSION

RELAP5 simulations of the critical flow of saturated steam (JIT 11) are reported in section 4.1. Simulations of the subcooled critical flow and the low quality two-phase critical flow of CFT 21 are discussed in sections 4.2 and 4.3, respectively.

## 4.1 Critical flow of saturated steam - JIT 11

For the RELAP5 simulation of the critical flow in JIT 11 the experimentally measured pressure in the vessel was used as a boundary condition. Calculated discharge flow rate was then compared to the measured flow rate. The pressure history and the discharge mass flow rate history for JIT 11 are given in Figures 4-1 and 4-2.

The results of all the RELAP5 simulations of JIT 11 are shown together with the experimental data in Figure 4-3. Error bounds on the measured mass flow rate are also indicated.

Regardless of the nodalization used, RELAP5 overpredicted the discharge flow rate. Except for anomalous flow increases in the 0 node, and 9 node cases, the 0 node, 7 node, and 9 node cases yielded nearly the same flow rate. The 12 node calculation yielded a slightly better prediction of the measured flow rate.

The anomalous (and incorrect) increases in flow rate for the 0 node and the 7 node cases have been traced to an approximation made in the calculation of the internal energy at a junction experiencing choked flow. This is discussed further in section 5.

Figure 4-3 indicates that there is little incentive to nodalize discharge piping extensively in RELAP5. Computational costs rise rapidly as nodes are added in the nozzle region (due to the material Courant limit on time step size) yet little improvement is obtained in computed results.

The computed results shown in Figure 4-3 can be brought into fairly good agreement with the experimental results by application of a 0.83 multiplier. This suggests that when using RELAP5 for calculating the discharge of saturated steam through a nozzle having a well rounded entrance, a discharge coefficient of 0.83 should be applied.

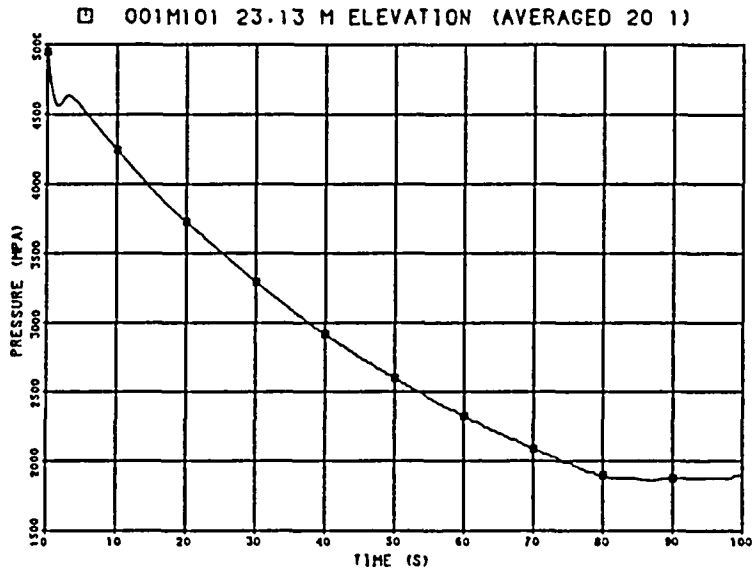


Figure 4-1

Measured vessel pressure for Marviken JIT 11.
RELAP5 boundary condition.

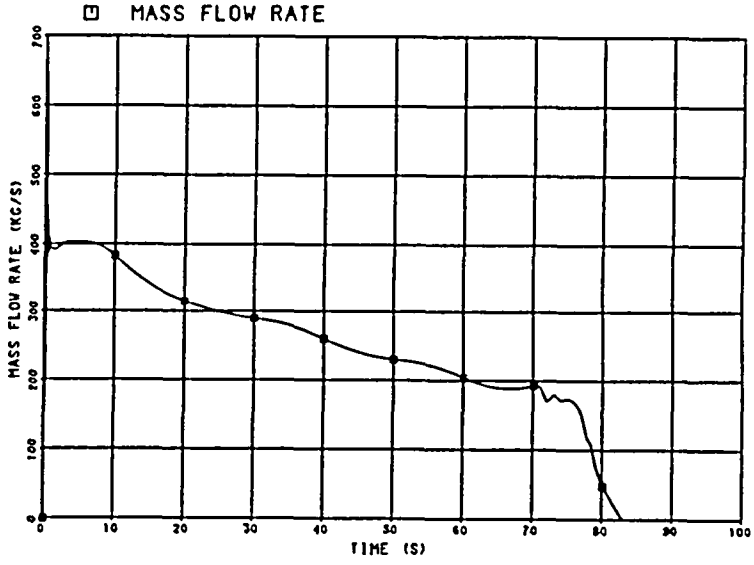


Figure 4-2

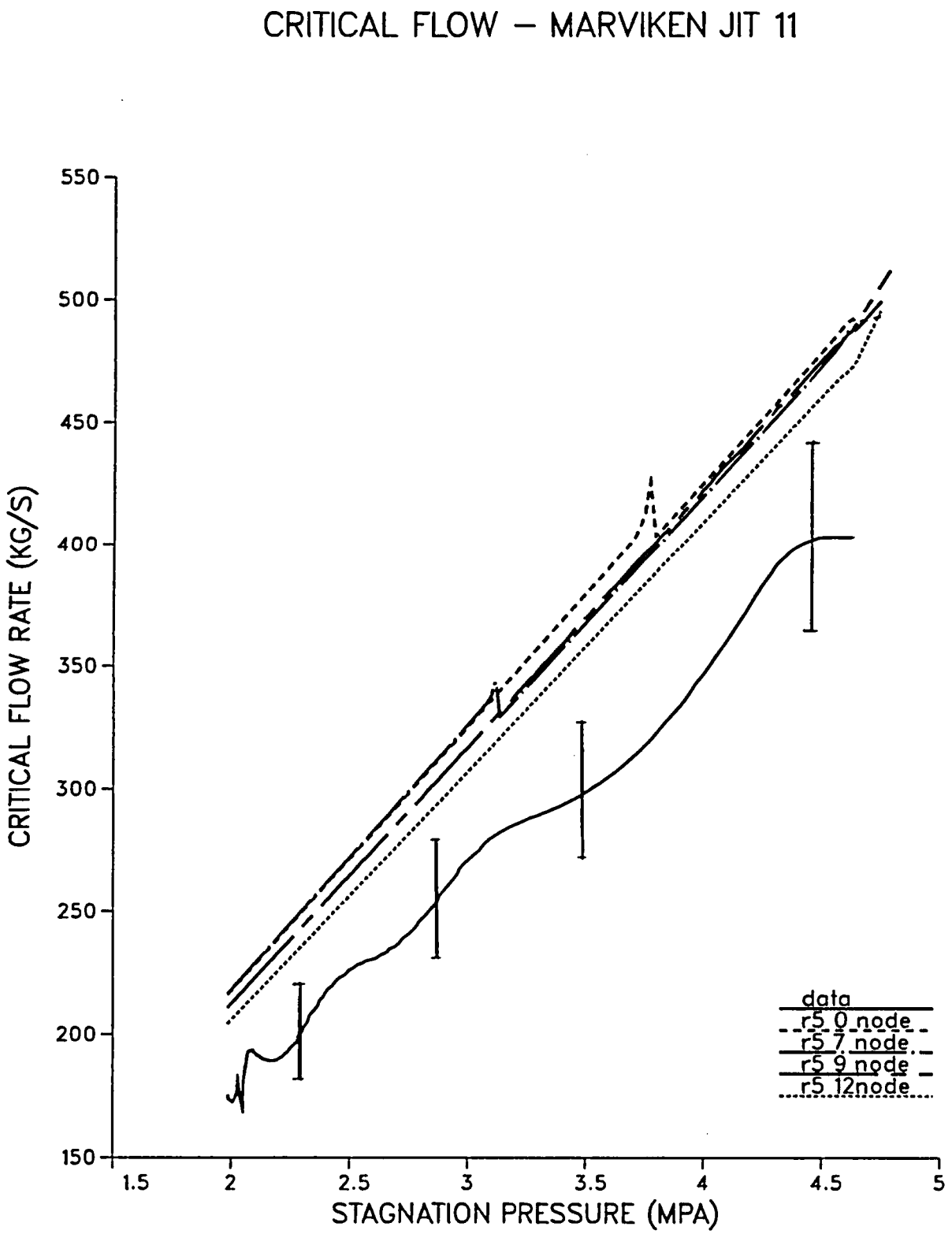


Figure 4-3

Critical flow of saturated steam.
RELAP5 simulations and JIT 11 data.

## 4.2 Subcooled critical flow - CFT 21

The subcooled critical flow model in RELAP5 was assessed against Marviken experiment CFT 21 by driving a RELAP5 model of the discharge piping with boundary conditions (pressure and temperature) measured near the inlet to the discharge piping. Calculated values of discharge flow rate, pressure drop across the discharge pipe inlet, and fluid quality in the discharge pipe were compared to measured values.

In CFT 21 the subcooled blowdown lasted for the first 25-30 seconds of the 60 second test period.

The pressure boundary condition used in RELAP5 was taken from pressure transducer 001M106 (Figure 4-4). The temperature boundary condition was taken as the average reading from thermocouples 001M521 and 001M402. These thermocouples are located at the 0.74 m elevation and 0.75 m from the vessel axis. The amount of subcooling (saturation temperature minus liquid temperature) in the boundary conditions is shown in Figure 4-5.

Figure 4-6 compares the RELAP5 base case (CFT01) calculated discharge flow rate history to the measured one. RELAP5 overpredicted the discharge flow rate. The gradual decline in the measured flow rate beginning at 22 s is associated with vapour formation in the discharge piping. Figure 4-7 shows the experimentally determined fluid quality in the discharge pipe based upon a gamma densitometer measurement. RELAP5 calculated only a brief period of two-phase flow in the discharge pipe. The calculated flow rate dropped sharply when bubbles were calculated to exist.

In Figure 4-8 the differential pressure from the discharge pipe to the vessel interior is shown. The calculated pressure loss across the discharge pipe inlet agrees well with the measured pressure loss. It is slightly larger than the measured loss but this may be the result of calculated velocities in the discharge pipe being higher than measured ones. The good agreement between calculated and measured pressure loss rules out pressure discrepancies in the discharge pipe as a cause of the flow rate discrepancies seen in Figure 4-6.

Rerunning the RELAP5 calculation and using a discharge coefficient of 0.85 (case CFT02) brought the calculated and measured flow rates into agreement for the first 22 seconds of the transient (Figure 4-9). For this RELAP5 calculation the pressure loss across the discharge pipe inlet was slightly less than the measured loss (Figure 4-10). The difference between the calculated and measured loss is probably due to no form loss coefficient being used in the RELAP5 model. A form loss coefficient of 0.15, if used in the RELAP5 model, would bring the calculated pressure loss into very good agreement with the measured loss.

The inability of RELAP5 to calculate the decline in flow rate after 22 s is due to the fact that RELAP5 calculated essentially no vapour formation in the discharge pipe. The experimental data indicate vapour formation beginning at 22 s.

One possible reason for the discrepancy between calculated and measured flow rates after 22 s is that the fluid temperature boundary condition used in RELAP5 is not a true measure of the tem-

perature at the entrance to the discharge piping. The thermocouples whence the boundary condition is taken are 0.75 m from the vessel central axis. Moreover a radial temperature distribution did exist during the experiment (6).

In order to test the hypothesis that the RELAP5 overprediction of flow rate after 22 seconds was partly due to uncertainty in the boundary temperature, a RELAP5 simulation (case CFT03) was conducted in which the boundary fluid temperature was reduced 2K for t > 18s (the discharge coefficient was left at a value of 0.85). Two degrees Kelvin corresponds to the maximum error associated with the temperature measurements (the 1σ error is 0.6K) and is believed to be encompass the probable radial temperaure variation.

The good agreement between calculated and measured flow rates (Figure 4-11) which resulted when the boundary temperature was changed proved the hypothesis. The calculation ended at 26.7s when the boundary condition subcooling vanished.

### 4.2.1 Nodalization study

In the RELAP5 simulations discussed thus far the nozzle was not included in the model and a discharge coefficient of 0.85 was required to bring the calculated flow rate into agreement with the experimental flow rate. To explore the sensitivity of calculated results to nodalization a RELAP5 simulation (case CFT07) was performed in which the nozzle was modelled by one computational cell. It was thought that this simulation might yield computed flow rates which agreed with experimental ones without using any discharge coefficient. Choking was allowed only at the nozzle outlet for this simulation.

The results of the one-node-nozzle simulation are depicted in Figures 4-12 and 4-13.

The discharge mass flow was underpredicted by RELAP5 and the pressure in the nozzle was overpredicted. From these results one concludes that, if a complete description of the experimental geometry is included in the RELAP5 model a discharge coefficient greater than 1.0 is required to bring computed flow rates into agreement with measured ones.

The one-node-nozzle simulation was rerun (case CFT 08) using values of 1.09 and 1.13 for the subcooled and saturated critical flow coefficients. This simulation did not improve calculated discharge flow rate (Figure 4-14). The computed flow rate exhibited erratic behaviour generally associated with numerical problems and, indeed, this RELAP5 simulation was very inefficient, taking 2 947 time steps and repeating 1 416 time steps for the 30s transient. When no discharge coefficients were used the simulation required only 1 242 time steps and repeated 620.

## 4.3 Low quality critical flow - CFT 21

In order to study the RELAP5 critical flow model's response to low quality two phase flow the subcooled flow simulation which gave the best agreement with experimental data (case CFT 03) was restarted (at 26.7 s) and saturated boundary conditions were imposed at the discharge pipe inlet. The boundary condition pressure was taken from pressure transducer 001M106. The boundary condition fluid quality was calculated (6) based upon the gamma densitometer reading and the assumption of an adiabatic fluid expansion

between the vessel bottom and the location of the densitometer in the discharge pipe. The boundary conditions as depicted in Figure 4-16 and 4-17.

The flow rate history from the saturated boundary condition base simulation (case CFT 04) is shown together with the measured flow rate in Figure 4-18. For completeness, the subcooled portion of the transient (case CFT 03) has also been included. The computed and measured mass flow rates agree well with one another. These results imply that RELAP needs no discharge coefficient when simulating low quality two phase critical flow through large pipes.

Subsequent to the CFT 04 simulation it was discovered that the experimental data offered conflicting indications of what the boundary condition fluid quality was during the 30 to 60 s time range. While the gamma densitometer indicated a fluid quality history as shown in Figure 4-17, the differential pressure measurement 007M246 indicated that the fluid quality never rose beyond 0.003. Thus, the rapid increase in quality occurring around 40 s may not have been real.

To explore the effect which the uncertainty in the boundary condition quality had upon computed results, the RELAP5 CFT 04 simulation was rerun with the boundary condition quality limited to a value of 0.003 (case CFT 05). This change only affected the condition for t > 35 seconds.

The flow rate calculated by case CFT 05 was higher than the measured flow rate (Fig 4-19). The results suggested that a two-phase discharge coefficient value simular to that used for the subcooled blow-

down might be applicable. For t > 40 s the average value of the ratio of measured to calculated flow rate is 0.85.

RELAP5 simulation CFT 06 was a rerun of CFT 05 but utilized a two phase flow discharge coefficient of 0.85. It was thought that CFT 06 would give a flow rate wich was in much better (relative to CFT 05) agreement with the experimental data. In fact, this was not the case, as can be seen by comparing Figures 4-19 and 4-20. In spite of applying a discharge coefficient which should have reduced the calculated flow rate so that it fell upon or below the experimental data, the calculated flow rate remained greater than the measured flow rate. This result implied a feedback existed between the flow solution and the discharge coefficient - an unexpected feedback.

Having feedback between a critical flow discharge coefficient and the flow solution is undesirable because one wants to use discharge coefficients as free parameters - ones which can be used to reduce the discharge flow by a predictable amount.

In order to explain the feedback between the discharge coefficient and the flow solution a degression - a brief review of the mechanics of choking in RELAP5 - is needed.

The RELAP choking criterion is (Eq 333 of Ref 2)

$$\frac{\alpha_f \rho_f V_f + \alpha_g \rho_g V_g}{\alpha_f \rho_f + \alpha_g \rho_g} = C_D a_{HE} \qquad \text{(Eq 4-1)}$$

The discharge coefficient, $C_D$, is the two phase discharge coefficient (input by the user) whenever the void fraction, $\alpha_g$, is greater than 0.02. Otherwise $C_D$ is the subcooled discharge coefficient.

For subcooled choking the quantity $a_{HE}$ is the maximum of the local homogeneous equilibrium (HE) sound speed and a speed calculated by applying Bernoulli's flow equation together with the Alamer-Lienhard-Jones correlation.

Detailed examination of the RELAP5 simulations CFT 05 and CFT 06 showed that the sonic velocity being used for subcooled flow calculations in JCHOKE was generally six to eight percent greater than that used for saturated calculations in JCHOKE.

Two-phase choking is applied if choking is indicated and the local void fraction is greater than $10^{-7}$ and the local equilibrium quality is greater than $2.5 \times 10^{-4}$. If these criteria are not met then single phase liquid choking is applied.

Underrelaxation is applied to the choked flow model velocities as long as the local equilibrium quality is less than $2.5 \times 10^{-3}$ and the local void fraction is greater than $10^{-7}$. For the cases being considered the underrelaxation was always applied. The underrelaxation algorithm ($V^{n+1} = 0.9\ V^{n} + 0.1\ V^{n+1}$) is heavily weighted to old time values. Thus, once a junction velocity is established a large change in velocity resulting from the solution of Eq 4-1 will not show up in the choked junction velocity unless the change persists for several time steps.

With the above points in mind one can return to the RELAP5 cases. The discharge junction velocities and void fractions from the RELAP5 simulations are illustrated in Figures 4-21 and 4-22. The discharge velocity was the same for cases CFT 04 and CFT 05 but the discharge void fraction was much larger after 40 s in case CFT 04. Thus the difference in discharge flow rate between

case CFT04 and CFT05 can be attributed to a changing void fraction. On the other hand, the discharge void fraction was nearly the same for cases CFT05 and CFT06 but the discharge velocity was lower - but not 15 percent lower in case CFT06.

The reason the application of $C_D$ = 0.85 did not reduce the discharge velocity by 15 % is contained in Figures 4-23 and 4-24. These figures illustrate the fluid equilibrium quality at the discharge junction. For completeness the static quality has also been plotted. Recall that the equilibrium quality value determines whether the saturated or subcooled critical flow model is active.

Comparing Figure 4-23 to Figure 4-24 one sees that when the discharge coefficient was applied, the equilibrium quality at the discharge junction was depressed - on the average, it remained less than $2.5 \times 10^{-4}$ more time than it did when no discharge coefficient was used. Thus the choked flow velocities coming from the subcooled critical flow model played a stronger role (because of the underrelaxation algorithm, the model, subcooled or two phase, which is selected for most of the time steps dominates the calculation of the local junction velocity) in CFT06 compared to CFT05.

Because sonic velocities ($a_{HE}$ in Eq 4-1) used in the subcooled critical flow logic were six to eight percent greater than those in the two-phase critical flow logic the longer time which case CFT 06 spent in the subcooled flow logic led to a value of $a_{HE}$ which was greater than that seen in CFT 05, enough greater to offset half of the 15 % reduction represented by the discharge coefficient.

The above analysis has revealed why application of a discharge coefficient may not reduce computed flow rates in a predictable manner during low quality flow simulations. The next question to address is how the situation might be rectified.

The undesirable feedback could be eliminated by introducing logic into subroutine JCHOKE to ensure that the velocity $a_{HE}$ used in the RELAP5 choking criterion is continuous at the interface between the subcooled choking model and the two-phase flow choking model.

The feedback could also probably be eliminated by eliminating the erratic behavior of the equilibrium quality evident in Figures 4-21 and 4-22 or else having the critical flow model selection logic depend more upon static rather than equilibrium quality. Since the erratic behaviour of the equilibrium quality is undoubtably of numerical origin, it would appear to be a likely candidate for improvement.

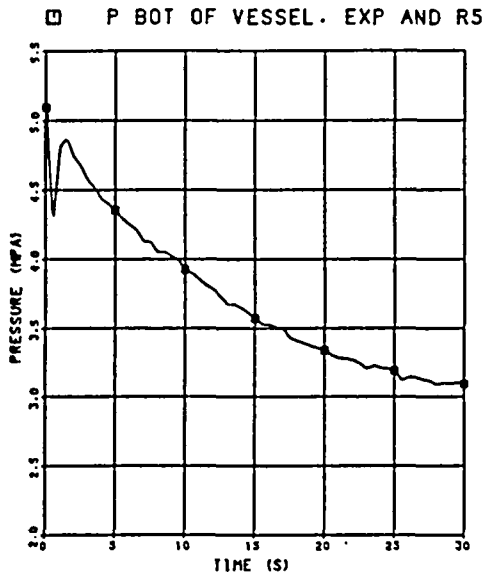


Figure 4-4

Pressure Boundary Condition for Case CFT 01.

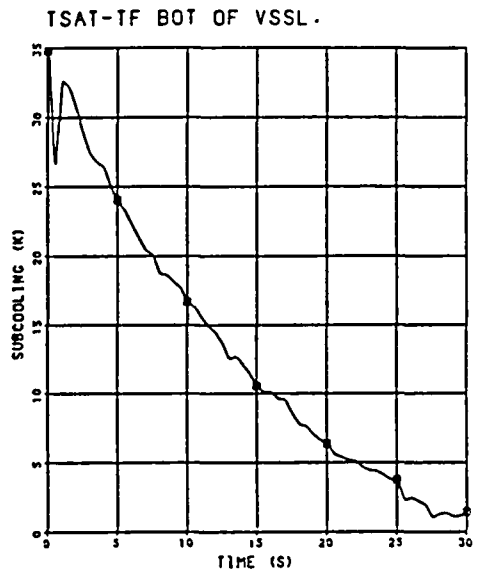


Figure 4-5

Subcooling Boundary Condition for Case CFT 01.

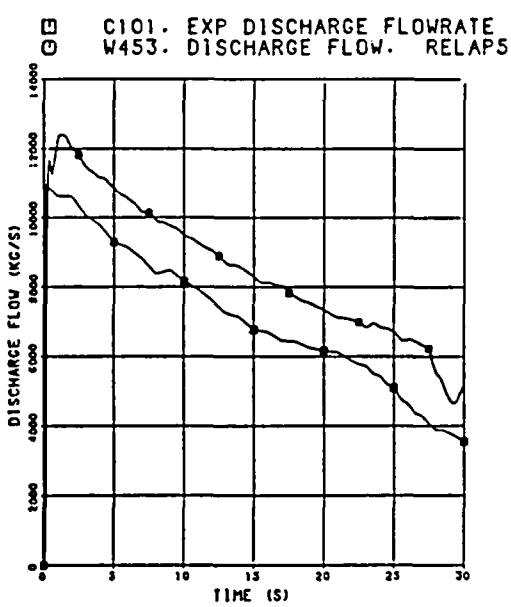


Figure 4-6

Discharge Flow Rate. Measured and Case CFT 01.

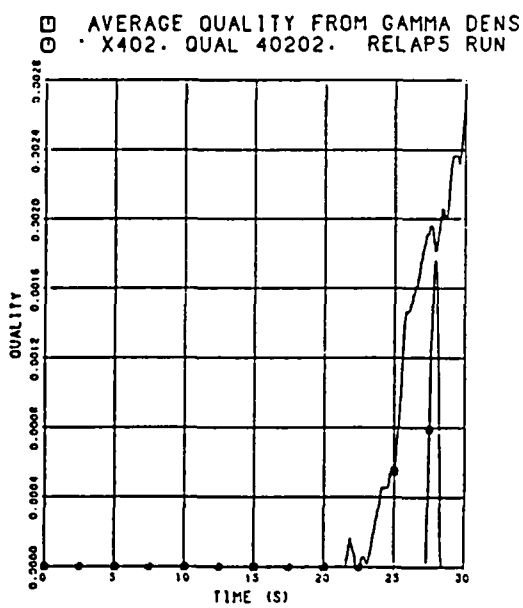


Figure 4-7

Fluid Quality in the Discharge Pipe.

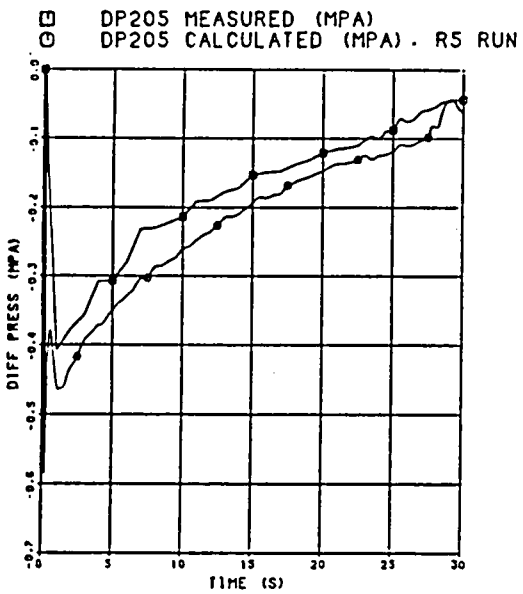


Figure 4-8

dP Across the Vessel Outlet. Measured and Case CFT 01.

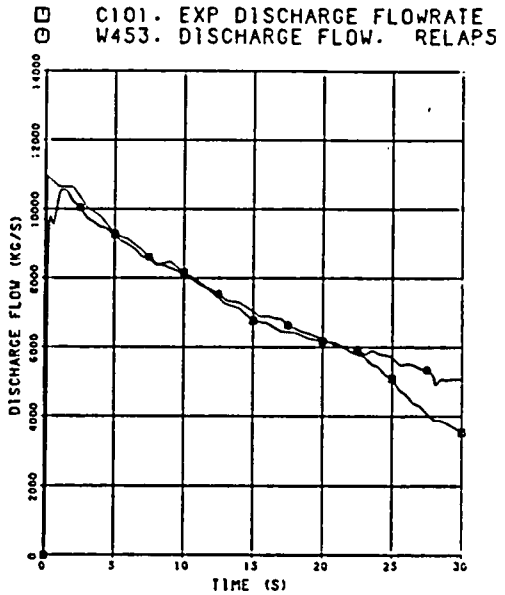


Figure 4-9

Discharge Flow Rate. Measured and Case CFT 02.

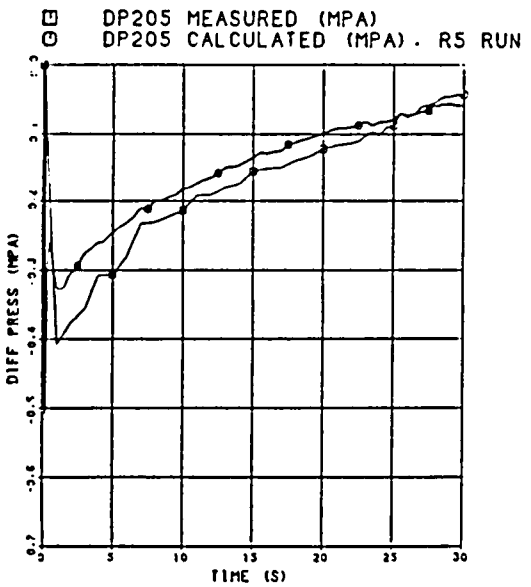


Figure 4-10

dP Across the Vessel Outlet. Measured and Case CFT 02.

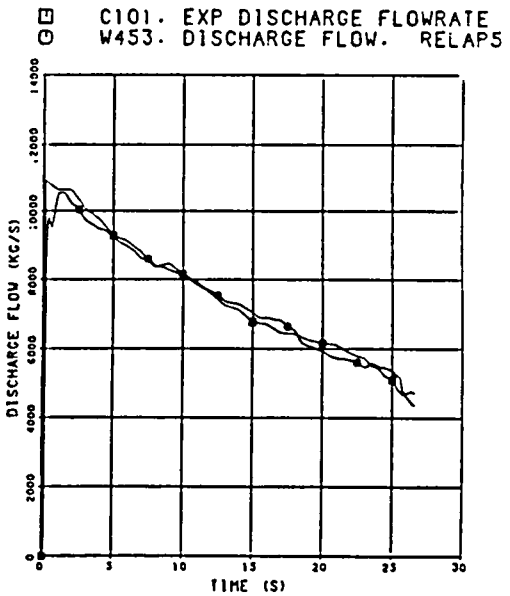


Figure 4-11

Discharge Flow Rate. Measured and Case CFT 03.

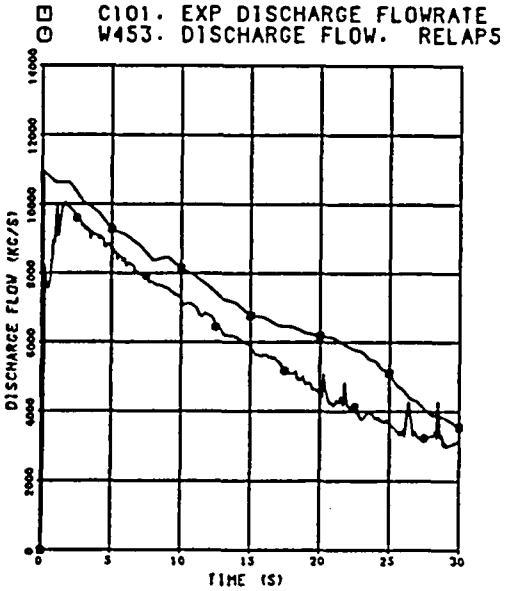


Figure 4-12

Measured and Calculated (Case CFT 07) Discharge Flow Rate.

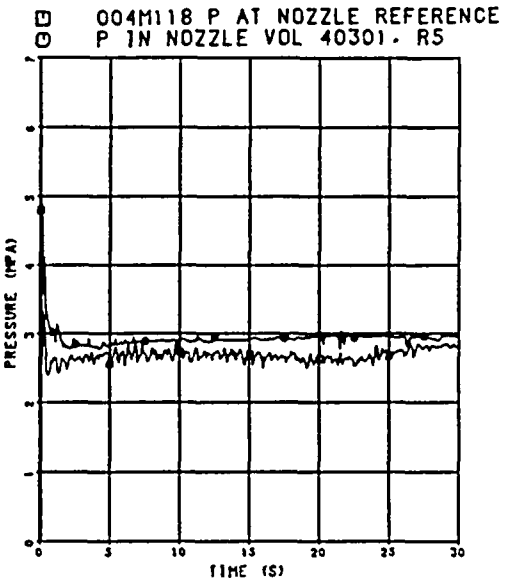


Figure 4-13

Measured and Calculated (CFT 07) Pressure in the Nozzle.

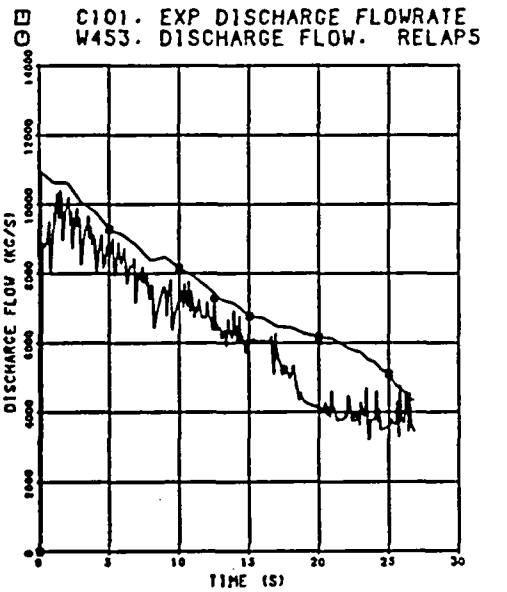


Figure 4-14

Measured and Calculated (CFT 08) Discharge Flow Rate.

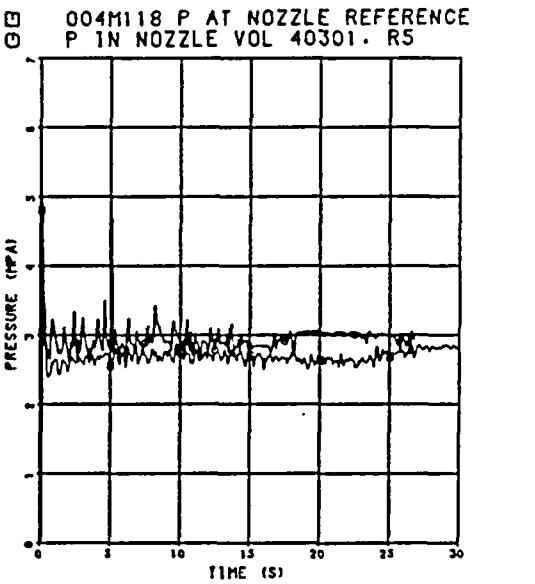


Figure 4-15

Measured and Calculated (CFT 08) Pressure in the Nozzle.

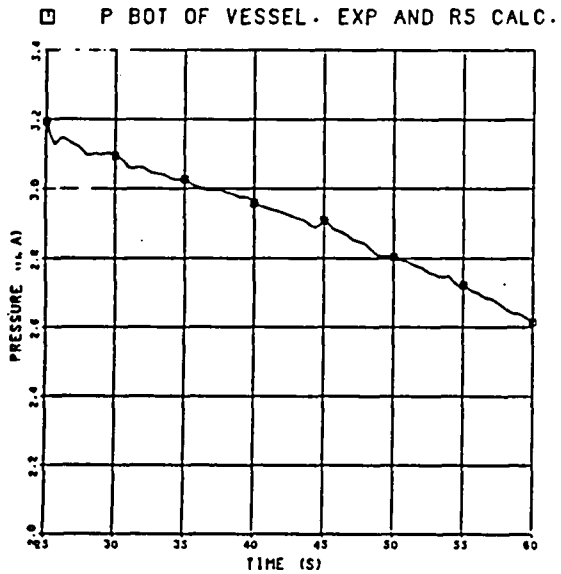


Figure 4-16

Pressure Boundary Condition of Saturated Flow Simulations.

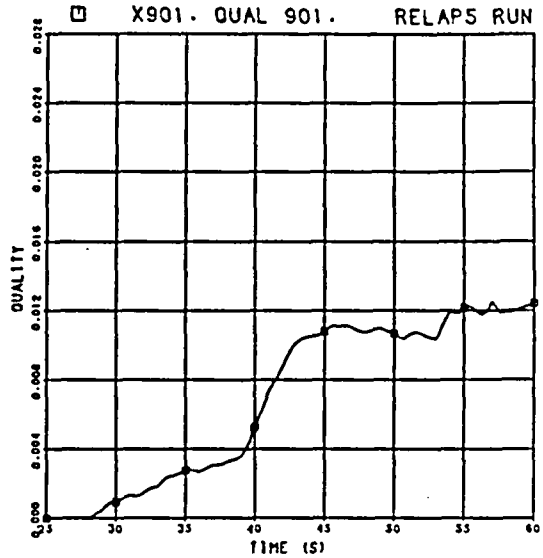


Figure 4-17

Fluid Quality Boundary Condition for Saturated Flow simulations.

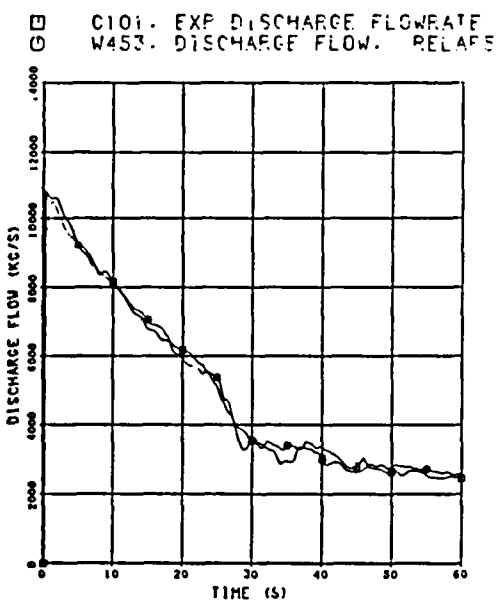


Figure 4-18

Discharge Flow Rate. Measured and Calculated (CFT 03 + CFT 04).

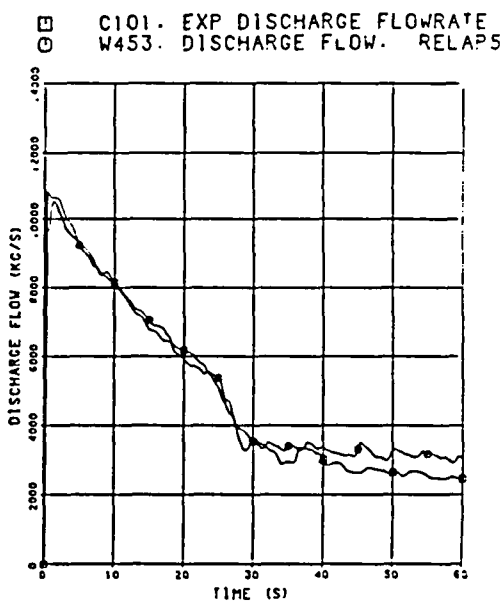


Figure 4-19

Discharge Flow Rate. Measured and Calculated (CFT 03 + CFT 05).

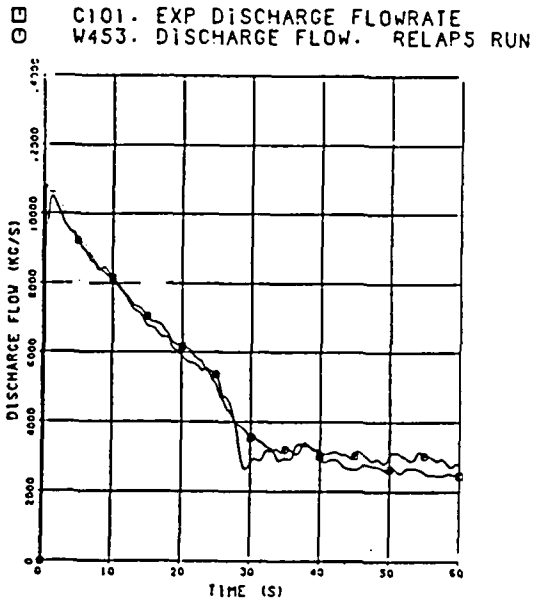


Figure 4-20

Discharge Flow Rate. Measured and Calculated (CFT 03 + CFT 06).

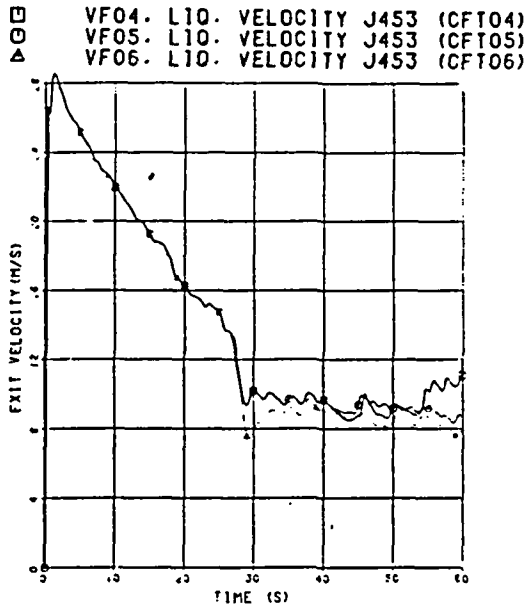


Figure 4-21

Liquid Velocity at the Discharge Junction. RELAP5 Cases CFT 04, CFT 05 and CFT 06.

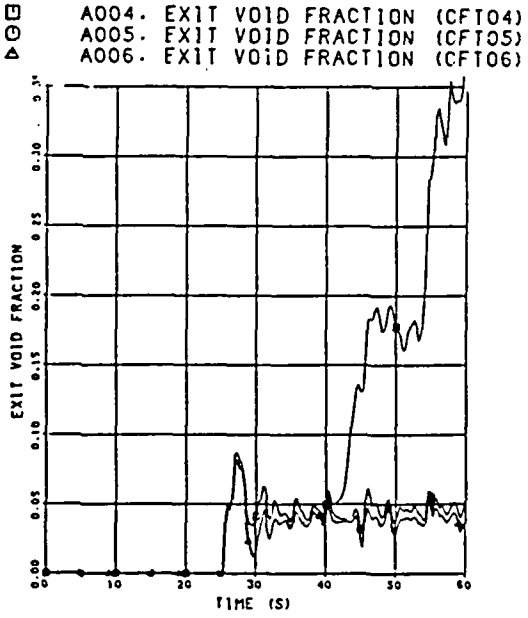


Figure 4-22

Void Fraction at the Discharge Junction. RELAP5 Cases CFT 04, CFT 05 and CFT 06.

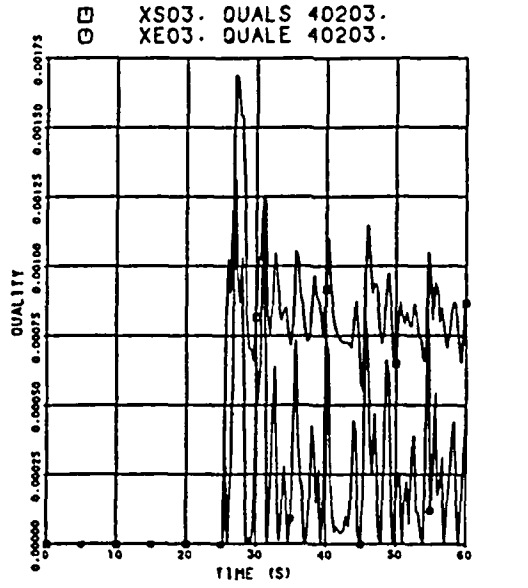


Figure 4-23

Static and Equilibrium Quality at the Discharge Junction. Case CFT 05.

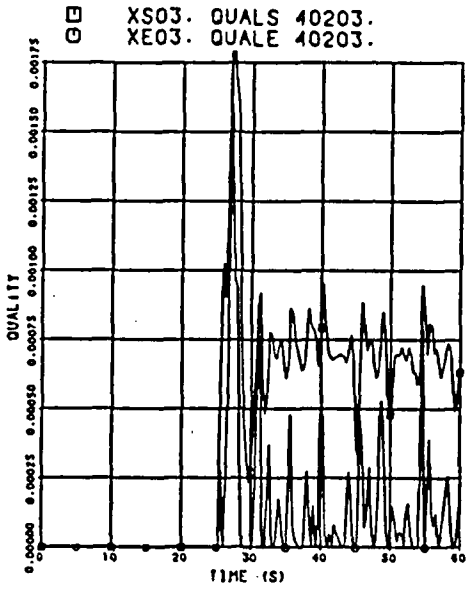


Figure 4-24

Static and Equilibrium Quality at the Discharge Junction. Case CFT 06.

# 5 COMPUTATIONAL EFFICIENCY AND NUMERICAL PROBLEMS

The computational efficiency of the RELAP5 simulations are summarized in Tables 5-1 and 5-2. The simulations were conducted on a CYBER 180-810 computer.

The simulations of JIT 11 were limited by the material Courant limit except for the case in which the standpipe and discharge pipe were not included in the model. Simulation times increased dramatically when the nozzle was introducted into the model (9 mode and 12 mode simulations). Considering the similarity of computed results amongst the various simulations it is apparent that including the nozzle in the RELAP5 model was not cost effective.

The simulations of CFT 21 proceeded at the maximum allowed time step size when the saturated portion of the test was being simulated (CFT 04, CFT 05, CFT 06). For the simulations of the subcooled portion of the test the time step size was restricted to 0.05 s for the first 15 s due to the material Courant limit. Simulations CFT 07 and CFT 08 in which the nozzle was modeled proceeded quite slowly and had to repeat a large number (about 50 % of the total shown in the table) of time steps.

Table 5-1

Run Statistic For The JIT 11 Simulations.

| Case | DT Max | Actual time steps | CPU (s) | CPU/Cell/ Step |
|---|---|---|---|---|
| 0 Node | 0.001 (t < 0.01)<br>0.01 (0.01 < t < 0.5)<br>0.10 (0.5 < t < 75.) | 808 | 43. | 0.05 |
| 7 Node | 0.001 (t < 0.01)<br>0.01 (0.01 < t < 0.5)<br>0.10 (0.5 < t < 75.) | 1 552 | 296. | 0.03 |
| 9 Node | 0.001 (t < 0.01)<br>0.01 (t > 0.01) | 60 002 | 13 995. | 0.03 |
| 12 Node | 0.001 (t < 0.01)<br>0.01 (t > 0.01) | 239 969 | 70 481. | 0.02 |

Table 5-2

Run Statistics for the CFT 21 Simulations.

| Case | Transient | DT Max | Actual time steps | CPU (s) | CPU/Cell/ Step |
|---|---|---|---|---|---|
| CFT01 | 0 - 30 s | 0.1 | 481 | 60. | 0.04 |
| CFT02 | 0 - 30 s | 0.1 | 419 | 47. | 0.04 |
| CFT03 | 0 - 26.7 s | 0.1 | 386 | 42. | 0.04 |
| CFT04 | 26.7 - 60 s | 0.1 | 334 | 36. | 0.04 |
| CFT05 | 26.7 - 60 s | 0.1 | 334 | 37. | 0.04 |
| CFT06 | 26.7 - 60 s | 0.1 | 334 | 37. | 0.04 |
| CFT07 | 0 - 30 s | 0.1 | 1 242 | 211. | 0.06 |
| CFT08 | 0 - 30 s | 0.1 | 2 947 | 484. | 0.05 |

## 5.1 Critical Flow Model numerical problems

Two of the RELAP5 simulations of JIT11 exhibited nonphysical jumps (see Figure 4-1). An investigation showed that the jumps occurred because the thermodynamic state at the discharge junction was calculated to switch from two phase to single phase vapor. Physically the junction should have remained in a two-phase state throughout the transient.

It was discovered that the erroneous thermodynamic state was calculated because of the approximation being used to find the internal energy at a choked junction (subroutine JCHOKE).

Assuming a quasi-steady, adiabatic flow, the internal energy at a junction may be calculated from (j = junction; up = upstream):

$$e_j = e_{up} + \frac{P_{up}}{\rho_{up}} - \frac{P_j}{\rho_j} - \frac{V_{up}^2 - V_j^2}{2}$$

In RELAP5, the term $P_j/\rho_j$ is replaced by $P_j/\rho_{up}$. This approximation can result in an $e_j$ value corresponding to vapor when the true value would correspond to two-phase. Because the sound speed (determined from ($P_j$, $e_j$)) is discontinous at the two phase/vapor interface a jump in the calculated choked flow velocity occurs when the approximation for $P_j/\rho_j$ leads to an incorrect value of $e_j$.

# 6 CONCLUSIONS

1. RELAP5 critical flow model overpredicts the critical flow of saturated steam. For the JIT 11 simulations the calculated critical flow could be brought into agreement with the measured flow by applying a discharge coefficient of 0.82.

2. Computed results for JIT 11 were not substantially improved by modeling the nozzle. Considering the empirical nature of the RELAP5 choked flow model it is concluded that there is no benefit in modeling discharge piping having L/D < 4 when steam is being discharged.

3. An approximation made in the calculation of junction internal energy in subroutine JCHOKE is responsible for nonphysical jumps in computed discharge mass flow rate evident in two of the JIT 11 simulations.

4. RELAP5 overpredicted the subcooled critical mass flow rate for CFT 21 when the nozzle was not explicitly modeled. Calculated mass flow rates could be made to agree with measured ones by using a discharge coefficient of 0.85 in RELAP5.

5. When the nozzle geometry was explicitly modeled in RELAP5 mass flow rates for CFT 21 were underpredicted. Application of discharge cofeficients (greater than unity) did not improve computed results; on the contrary, doing so gave rise to a very numerically noisy solution. It is concluded that short discharge nozzles or pipes (L/D < 2) should not be modeled explicitly in RELAP5.

6. For the saturated blowdown portion of CFT 21 RELAP5 simulated the discharge flow quite accurately when the bounding condition fluid quality was based upon the gamma densitometer measurement. No discharge coefficient was needed to achieve agreement with the experimental data.

7. When the fluid quality boundary condition was lowered (based upon vessel differential pressure measurements) RELAP5 overpredicted the discharge flow rate.

8. The RELAP5 simulation of the discharge of low quality two-phase fluid did not respond in a predictable manner when discharge coefficients were applied. It was determined that a feedback exists for low quality flow such that application of a discharge coefficient may increase the value of the sonic velocity used in the choking criterion (Eq 4-1) partially offsetting the sonic velocity reduction represented by the discharge coefficient. Application of a discharge coefficient of say, 0.85, will reduce computed flow by only 7 or 8 percent instead of the 15 percent one might expect.

REFERENCES

1. TRAC-PF1/MOD1:
An Advanced Best-Estimate Computer Program for Pressurized Water Reactor Thermal-Hydraulic Analysis.
NUREG/CR-3858.

2. RANSOM, V et al.
RELAP5/MOD2 Code Manual.
NUREG/CR-4312.
August 1985.

3. The Marviken Full Scale Jet Impingement Tests. Facility Description.
MXD-101.
February 1982.

4. The Marviken Full Scale Critical Flow Tests. Description of the Test Facility.
MXC-101.

5. The Marviken Full Scale Jet Impingement Tests. Test 11 Results.
MXD-211.
March 1982.

6. The Marviken Full Scale Critical Flow Tests. Results from Test 21.
MXC-221.
September 1979.

7. The Marviken Full Scale Critical Flow Tests. Summary Report.
MXC-301.
December 1979.

# APPENDIX A

## INPUT FOR RELAP5 FOR JIT 11 SIMULATION

```
=  CRITICAL FLOW TEST MARVIKEN TEST 11
*  HIGH QUALITY STEAM.
*
*  INPUT PREPARED BY \STEN ROSDAHL
*                    STUDSVIK ENERGITEKNIK AB,SWEDEN
*
*
0000100   NEW  STDY-ST
0000101   RUN
0000102   SI   SI
0000105   30.       40.
*
*          REF VOL     LEVEL   FLUID
0000120    200010000   18.33   WATER   MARVIKEN
*
***** TIME STEP CONTROL CARDS
*         END-TIME  DTMIN     DTMAX     OPT     MINOR   MAJOR  RESTART
0000201    0.01     1.0-6     .001    00003       1     100     200
0000202    0.5      1.0-6     .01     00003       5     100     200
*0000203   10.0      1.0-6     .01     00003      50    1000    1000
*0000204   75.0      1.0-6     .01     00003      50    1000    1000
0000203   10.0      1.0-6     .1      00003      50    1000    1000
*
***** MINOR EDIT REQUESTS
301   MFLOWJ   450000000
302   MFLOWJ   451000000
303   MFLOWJ   452000000
304   MFLOWJ   453000000
*
***** TRIP INPUT DATA
0000501   TIME     0          GT  NULL     0     10000.0   L  *
*
*
*
*****  HYDRAULIC COMPONENTS
*
*====================================
*
2000000  VESSEL      SNGLVOL                 * 18.330 TO  18.830
4010000  STPIPE      PIPE                    * 18.330 TO   0.330
4020000  DCPIPE      PIPE                    *  0.330 TO  -7.599
4030000  NOZZLE      PIPE                    * -7.599 TO  -8.779
9010000  P-CONST     TMDPVOL
9020000  ATMOS       TMDPVOL
*
*
*   JUNCTIONS
*
2510000  VESSFILL     SNGLJUN
4500000  STAND-IN     SNGLJUN
4510000  DISCH-IN     SNGLJUN
```

```
4520000  NOZZ-IN      SNGLJUN
4530000  NOZZ-OUT     VALVE
*
*
*****  COMPONENT INFORMATION CARDS
4010001  4
4020001  3
4030001  2
*
*****  SNGLVOL, BRANCH AND TMDPVOL GEOMETRY CARDS
*
*       AREA LENGTH VOLUME  HA  VANG ELEVCH  ROUGH   DIAH    FE
2000101 0.   0.5  10.79     0.   90.  0.5     0.    .0      00
9010101 20.  1.    0.       0.  -90.   .000  20.-6  .0      00
9020101 0.   1.    1.       0.  -90.   .000  20.-6  .0      00
*
*****  PIPE AND ANNULUS GEOMETRY CARDS
*
*         VOLAREA   NR
4010101  0.7854      4                        * D = 1.000
4020101  0.4441      3                        * D = 0.752
4030101  0.07022     2                        * D = 0.299
*
*         LENGTH    NR
4010301  4.5         4                        * 18.000/4
4020301  2.643       3                        *  7.929/3
4030301  0.59        2                        *  1.180/2
*
*         VOLUME    NR
4010401  0.00000     4
4020401  0.00000     3
4030401  0.00000     2
*
*         VANG      NR
4010601  -90.        4
4020601  -90.        3
4030601  -90.        2
*
*         ROUGH     DIAH      NR
4010801  20.E-6    0.0         4
4020801  20.E-6    0.0         3
4030801  20.E-6    0.0         2
*
***  PIPE JUNCTION LOSS COEFFICIENTS
*        FORWARD  REVERSE  NR
4010901     0.00     0.00   3
4020901     0.00     0.00   2
4030901     0.00     0.00   1
*         FE        NR
4011001   00         4
4021001   00         3
4031001   00         2
*
*****  PIPE JUNCTION CONTROL FLAGS
*         CAHS     NR
4011101   0000      3
4021101   0000      2
4031101   0000      1
*
*****  SNGLJUN, VALVE AND TMDPJUN GEOMETRY CARDS.
```

```
*          FROM        TO          JUNAREA   FJUNF  FJUNR    CAHS
2510101   901000000   200010000   0.        0.0    0.0      0000
4500101   200000000   401000000   0.        0.0    0.0      0100
4510101   401010000   402000000   0.        0.0    0.0      0000
4520101   402010000   403000000   0.        0.0    0.0      0000
4530101   403010000   902000000   0.        0.0    0.0      0100
*
*****  SNGLVOL AND PIPE VOLUME INITIAL CONDITIONS
*
*          CW     PRESSURE    QUAL                          NR
2000200    2      5.0000E6    1.00
4011201    2      5.0000E6    1.00       0.    0.    0.      4
4021201    2      5.0000E6    1.00       0.    0.    0.      3
4031201    2      5.0000E6    1.00       0.    0.    0.      2
*
*****  TMDPVOL DATA CONTROL CARD
*          CW    TRIP    ALPHA     NUM
9010200    2     501
9020200    2
***** TMDPVOL DATA CARD
*            TIME        PRESS     QUAL
9010201    0.000        4981900.  1.000
9010202     .100        4927880.  1.000
9010203     .200        4866110.  1.000
9010204     .300        4829747.  1.000
9010205     .400        4794753.  1.000
9010206     .500        4747376.  1.000
9010207     .600        4718367.  1.000
9010208     .700        4691854.  1.000
9010209     .800        4657311.  1.000
9010210     .900        4637825.  1.000
9010211    1.000        4613516.  1.000
9010212    1.100        4600787.  1.000
9010213    1.200        4589881.  1.000
9010214    1.300        4575948.  1.000
9010215    1.400        4569016.  1.000
9010216    1.500        4565032.  1.000
9010217    1.600        4563218.  1.000
9010218    1.700        4563401.  1.000
9010219    1.800        4567248.  1.000
9010220    1.900        4572064.  1.000
9010221    2.000        4576934.  1.000
9010222    2.100        4584592.  1.000
9010223    2.200        4591024.  1.000
9010224    2.300        4600115.  1.000
9010225    2.400        4606497.  1.000
9010226    2.500        4613723.  1.000
9010227    2.600        4620684.  1.000
9010228    2.700        4623998.  1.000
9010229    2.800        4628821.  1.000
9010230    2.900        4634576.  1.000
9010231    3.000        4635503.  1.000
9010232    3.100        4636305.  1.000
9010233    3.200        4636456.  1.000
9010234    3.300        4635035.  1.000
9010235    3.400        4630834.  1.000
9010236    3.500        4626632.  1.000
9010237    3.600        4622737.  1.000
9010238    3.700        4619639.  1.000
```

```
9010239    3.800        4616288.  1.000
9010240    3.900        4608276.  1.000
9010241    4.000        4603496.  1.000
9010242    5.000        4550326.  1.000
9010243    6.000        4483077.  1.000
9010244    7.000        4427020.  1.000
9010245    8.000        4362641.  1.000
9010246    9.000        4303644.  1.000
9010247   10.000        4248200.  1.000
9010248   11.000        4189435.  1.000
9010249   12.000        4132475.  1.000
9010250   13.000        4075548.  1.000
9010251   14.000        4020970.  1.000
9010252   15.000        3963155.  1.000
9010253   16.000        3918553.  1.000
9010254   18.000        3815226.  1.000
9010255   20.000        3727483.  1.000
9010256   22.000        3643477.  1.000
9010257   24.000        3556808.  1.000
9010258   26.000        3469451.  1.000
9010259   28.000        3381221.  1.000
9010260   30.000        3299092.  1.000
9010261   32.000        3218463.  1.000
9010262   34.000        3133862.  1.000
9010263   36.000        3058316.  1.000
9010264   38.000        2985187.  1.000
9010265   40.000        2921124.  1.000
9010266   42.000        2853242.  1.000
9010267   44.000        2784410.  1.000
9010268   46.000        2717872.  1.000
9010269   48.000        2663770.  1.000
9010270   50.000        2601918.  1.000
9010271   52.000        2538747.  1.000
9010272   54.000        2490818.  1.000
9010273   56.000        2430753.  1.000
9010274   58.000        2372546.  1.000
9010275   60.000        2326299.  1.000
9010276   62.000        2283809.  1.000
9010277   64.000        2223326.  1.000
9010278   66.000        2178751.  1.000
9010279   68.000        2135757.  1.000
9010280   70.000        2092031.  1.000
9010281   72.000        2050116.  1.000
9010282   74.000        2008471.  1.000
9010283   76.000        1965180.  1.000
9010284   78.000        1922647.  1.000
9010285   80.000        1901403.  1.000
9010286   82.000        1880158.  1.000
9010287   84.000        1880158.  1.000
9010288   85.000        1876141.  1.000
9010289   86.000        1868512.  1.000
9010290   87.000        1865495.  1.000
9010291   88.000        1872848.  1.000
9010292   89.000        1879907.  1.000
9010293   90.000        1880158.  1.000
9010294   95.000        1880158.  1.000
*
9020201   0.      0.100E6        1.
*
*****  SNGLJUN AND VALVE INITIAL CONDITION CARD
```

```
2510201    1        0.0       0.        0.
4500201    1        0.0       0.        0.
4510201    1        0.0       0.        0.
4520201    1        0.0       0.        0.
4530201    1        0.0       0.        0.
*
*****  PIPE JUNCTION CONDITIONS CONTROL CARD
4011300    1
4021300    1
4031300    1
*
*****  PIPE AND BRANCH JUNCTION INITIAL CONDITION CARD
4011301     0.0       0.        0.       3
4021301     0.0       0.        0.       2
4031301     0.0       0.        0.       1
*
*****  VALVE TYPE CARD
4530300     TRPVLV
*
*****  VALVE DATA
4530301   501
*
.
```

# APPENDIX B

## LISTING OF INPUT DATA FOR CASE CFT01

```
=  MARVIKEN CFT 21. SUBCOLD CRIT FLOW. P,T BC AT VSL BOT.
*
*
0000100   NEW  TRANSNT
0000101   RUN
0000102   SI   SI
0000105   30.       40.
*
*
***** TIME STEP CONTROL CARDS
*         END-TIME  DTMIN     DTMAX     OPT    MINOR   MAJOR  RESTART
0000201   30.00     1.0-6     .100    00003        1      50       50
*
***** MINOR EDIT REQUESTS
301         P   901010000
303   CNTRLVAR 105     * RATIO  (MEAS FLOW / CALC FLOW)
304  CNTRLVAR  110   *  QUAL  RING II EXP
305   QUALE  402020000   * CALC QUAL RING II
306  CNTRLVAR  122   * DP205  CALC-EXP
307  CNTRLVAR  130   * T - TSAT IN VOL 901
*
***** TRIP INPUT DATA
0000501   TIME     0          GT  NULL     0     0.0   L  *
0000502   CNTRLVAR   130    GE  NULL     0      -0.1   L  *
*
*     STOP SUBCOOLED TRANSIENT WHEN T-TSAT GT -0.1K
*
600   502
*
*
*
*****  HYDRAULIC COMPONENTS
*
*=====================================
*
4020000  DCPIPE      PIPE                    * -0.690 TO  -5.570
*4030000  NOZZLE      PIPE                    * -5.570 TO  -6.565
9010000  P-T(BC)     TMDPVOL
9020000  ATMOS       TMDPVOL
*
*
*   JUNCTIONS
*
4510000  DISCH-IN     SNGLJUN
*4520000  NOZZ-IN      SNGLJUN
4530000  NOZZ-OUT     VALVE
*
*
*****  COMPONENT INFORMATION CARDS
4020001  3
```

```
*4030001  5
*
*****  SNGLVOL, BRANCH AND TMDPVOL GEOMETRY CARDS
*
*       AREA LENGTH VOLUME  HA  VANG ELEVCH  ROUGH   DIAH    FE
9010101 19.6  0.5  0.0   0.  -90.   .000  20.-6  .0       00
9020101 0.   1.    1.       0.  -90.   .000  20.-6  .0       00
*
*****  PIPE AND ANNULUS GEOMETRY CARDS
*
*         VOLAREA   NR
4020101  0.4441      3                        * D = 0.752
*4030101  0.07022     5                        * D = 0.299
*
*         LENGTH    NR
4020301  2.100       3                        *  6.3  /3
*4030301  0.236       5                        *  1.180/5
*
*         VOLUME    NR
4020401  0.00000     3
*4030401  0.00000     5
*
*         VANG      NR
4020601  -90.        3
*4030601  -90.        5
*
*         ROUGH     DIAH      NR
4020801  20.E-6    0.0         3
*4030801  20.E-6    0.0         5
*
***  PIPE JUNCTION LOSS COEFFICIENTS
*        FORWARD  REVERSE  NR
4020901     0.00     0.00   2
*4030901     0.00     0.00   4
*         FE        NR
4021001   00         3
*4031001   00         5
*
*****  PIPE JUNCTION CONTROL FLAGS
*         CAHS     NR
4021101   0000      2
*4031101   0000      4
*
*****  SNGLJUN, VALVE AND TMDPJUN GEOMETRY CARDS
*
*        FROM       TO          JUNAREA   FJUNF  FJUNR    CAHS
4510101  901000000  402000000  0.         0.0    0.0      0000
*4520101  402010000  403000000  0.         0.0    0.0      0000
4530101  402010000  902000000  0.1963    0.0    0.0      0100
*
*****  SNGLVOL AND PIPE VOLUME INITIAL CONDITIONS
*
*         CW     PRESSURE    QUAL                          NR
4021201    3     4.2131E6   508.54     0.   0.   0.       3
*4031201    2     5.0000E6   1.00       0.   0.   0.       5
*
*****  TMDPVOL DATA CONTROL CARD
*         CW    TRIP    ALPHA     NUM
*
*********  CFT21 PRESSURE AND TEMPERATURE AT BOTTOM OF VESSEL  *****
```

```
111    ***** PRESSURE FROM 001M106.   TEMP FROM AVG OF 001M521 AND 001M402
112    *
113    9010200  3  501
114    9010201   .00  .509680E+07  503.46
115    9010202   .50  .425960E+07  501.31
116    9010203  1.00  .481560E+07  502.01
117    9010204  1.50  .487560E+07  503.31
118    9010205  2.00  .474530E+07  503.11
119    9010206  2.50  .467900E+07  504.01
120    9010207  3.00  .457180E+07  504.11
121    9010208  3.50  .451670E+07  504.01
122    9010209  4.00  .443460E+07  503.21
123    9010210  4.50  .439870E+07  504.21
124    9010211  5.00  .435300E+07  504.61
125    9010212  5.50  .429500E+07  504.46
126    9010213  6.00  .425320E+07  504.86
127    9010214  6.50  .421590E+07  505.31
128    9010215  7.00  .413030E+07  505.01
129    9010216  7.50  .412930E+07  505.26
130    9010217  8.00  .405310E+07  505.56
131    9010218  8.50  .405760E+07  505.71
132    9010219  9.00  .402270E+07  505.71
133    9010220  9.50  .399420E+07  505.71
134    9010221 10.00  .391990E+07  505.71
135    9010222 10.50  .390030E+07  505.71
136    9010223 11.00  .385400E+07  505.76
137    9010224 11.50  .381230E+07  505.71
138    9010225 12.00  .378470E+07  505.71
139    9010226 12.50  .373310E+07  505.71
140    9010227 13.00  .367460E+07  506.01
141    9010228 13.50  .367360E+07  505.76
142    9010229 14.00  .364710E+07  505.96
143    9010230 14.50  .361170E+07  506.06
144    9010231 15.00  .357140E+07  506.36
145    9010232 15.50  .353010E+07  506.06
146    9010233 16.00  .352910E+07  506.01
147    9010234 16.50  .350600E+07  506.16
148    9010235 17.00  .350400E+07  506.16
149    9010236 17.50  .343420E+07  506.01
150    9010237 18.00  .340910E+07  506.41
151    9010238 18.50  .339340E+07  506.26
152    9010239 19.00  .337180E+07  506.51
153    9010240 19.50  .335560E+07  506.66
154    9010241 20.00  .333930E+07  506.66
155    9010242 20.50  .330200E+07  506.76
156    9010243 21.00  .328360E+07  506.66
157    9010244 21.50  .327840E+07  506.76
158    9010245 22.00  .326950E+07  506.66
159    9010246 22.50  .324540E+07  506.71
160    9010247 23.00  .320660E+07  506.26
161    9010248 23.50  .323270E+07  506.76
162    9010249 24.00  .321400E+07  506.71
163    9010250 24.50  .320710E+07  506.96
164    9010251 25.00  .319280E+07  506.71
165    9010252 25.50  .312160E+07  506.96
166    9010253 26.00  .314810E+07  507.21
167    9010254 26.50  .314610E+07  507.46
168    9010255 27.00  .312890E+07  507.41
169    9010256 27.50  .311980E+07  508.16
170    9010257 28.00  .308910E+07  507.31
```

```
171    9010258 28.50  .310730E+07  507.56
172    9010259 29.00  .309650E+07  507.66
173    9010260 29.50  .310880E+07  507.81
174    9010261 30.00  .305500E+07  507.26
175    *
176    *
177    *
178    9020200  2
179    9020201   0.      0.100E6        1.
180    *
181    *****  SNGLJUN AND VALVE INITIAL CONDITION CARD
182    4510201    1        0.0       0.        0.
183    *4520201    1        0.0       0.        0.
184    4530201    1        0.0       0.        0.
185    *
186    *****  PIPE JUNCTION CONDITIONS CONTROL CARD
187    4021300    1
188    *4031300    1
189    *
190    *****  PIPE AND BRANCH JUNCTION INITIAL CONDITION CARD
191    4021301     0.0       0.        0.      2
192    *4031301     0.0       0.        0.      4
193    *
194    *****  VALVE TYPE CARD
195    4530300     TRPVLV
196    *
197    *****  VALVE DATA
198    4530301   501
199    *
200    *
201    *        CONTROL COMPONENT 101, EXPERIMENTAL MASSFLOW
202    20510100   NOZZFLOW-X   FUNCTION   1.   0.  0
203    20510101   TIME   0    801
204    *
205    *        CONTROL COMPONENT 102, CALC - EXP CRITICAL FLOW
206    20510200   FLOWERR      SUM        1.   0.  0
207    20510201   0.    1.   MFLOWJ    453000000
208    20510202        -1.   CNTRLVAR  101
209    *
210    *        CONTROL COMPONENT 103, REL.ERR. OF CRITICAL FLOW
211    20510300   CF-REL-ERR   DIV      100.   0.  0
212    20510301   CNTRLVAR  101      CNTRLVAR  102
213    *
214    *        CONTROL COMPONENT 104, COMPUTED MASSFLOW
215    20510400   NOZZFLOW-C   SUM        1.   0.0001  0
216    20510401   0.0001   1.   MFLOWJ    453000000
217    *
218    *        CONTROL COMPONENT 105, RATIO
219    20510500   CF-RATIO     DIV        1.   1.  0
220    20510501   CNTRLVAR  104      CNTRLVAR  101
221    *
222    *        GENERAL TABLE USED BY CONTROL COMPONENT 101
223    *      MASS FLOW FROM CFT 21 ( FROM FILE T21EVAL, VARNAM=FAVE)
224    *
225    *         GENERAL TABLE 801.  MEASURED DISCHARGE FLOW RATE  (FAVE)
226    *
227    20280100   REAC-T
228    20280101   .00 11000.00
229    20280102  1.00 10634.00
230    20280103  2.00 10632.00
```

| | | | |
|---|---|---|---|
| 231 | 20280104 | 3.00 | 10063.00 |
| 232 | 20280105 | 4.00 | 9791.20 |
| 233 | 20280106 | 5.00 | 9281.40 |
| 234 | 20280107 | 6.00 | 9125.90 |
| 235 | 20280108 | 7.00 | 8815.60 |
| 236 | 20280109 | 8.00 | 8377.10 |
| 237 | 20280110 | 9.00 | 8493.10 |
| 238 | 20280111 | 10.00 | 8162.90 |
| 239 | 20280112 | 11.00 | 7937.20 |
| 240 | 20280113 | 12.00 | 7622.30 |
| 241 | 20280114 | 13.00 | 7262.10 |
| 242 | 20280115 | 14.00 | 7138.30 |
| 243 | 20280116 | 15.00 | 6771.10 |
| 244 | 20280117 | 16.00 | 6718.70 |
| 245 | 20280118 | 17.00 | 6468.00 |
| 246 | 20280119 | 18.00 | 6439.30 |
| 247 | 20280120 | 19.00 | 6261.30 |
| 248 | 20280121 | 20.00 | 6175.60 |
| 249 | 20280122 | 21.00 | 6127.90 |
| 250 | 20280123 | 22.00 | 5880.20 |
| 251 | 20280124 | 22.50 | 5789.90 |
| 252 | 20280125 | 23.00 | 5737.50 |
| 253 | 20280126 | 23.50 | 5519.70 |
| 254 | 20280127 | 24.00 | 5443.80 |
| 255 | 20280128 | 24.50 | 5212.50 |
| 256 | 20280129 | 25.00 | 5106.70 |
| 257 | 20280130 | 25.50 | 4774.20 |
| 258 | 20280131 | 26.00 | 4632.10 |
| 259 | 20280132 | 26.50 | 4381.10 |
| 260 | 20280133 | 27.00 | 4299.60 |
| 261 | 20280134 | 27.50 | 4075.40 |
| 262 | 20280135 | 28.00 | 3887.80 |
| 263 | 20280136 | 28.50 | 3896.40 |
| 264 | 20280137 | 29.00 | 3800.80 |
| 265 | 20280138 | 29.50 | 3685.00 |
| 266 | 20280139 | 30.00 | 3555.90 |
| 267 | 20280140 | 30.50 | 3652.90 |
| 268 | 20280141 | 31.00 | 3450.10 |
| 269 | 20280142 | 31.50 | 3450.00 |
| 270 | 20280143 | 32.00 | 3359.50 |
| 271 | 20280144 | 32.50 | 3253.00 |
| 272 | 20280145 | 33.00 | 3272.70 |
| 273 | 20280146 | 33.50 | 3133.70 |
| 274 | 20280147 | 34.00 | 2832.30 |
| 275 | 20280148 | 34.50 | 2926.90 |
| 276 | 20280149 | 35.00 | 3005.70 |
| 277 | 20280150 | 35.50 | 2900.70 |
| 278 | 20280151 | 36.00 | 2962.60 |
| 279 | 20280152 | 36.50 | 3359.50 |
| 280 | 20280153 | 37.00 | 3373.30 |
| 281 | 20280154 | 37.50 | 3381.90 |
| 282 | 20280155 | 38.00 | 3297.10 |
| 283 | 20280156 | 38.50 | 3338.60 |
| 284 | 20280157 | 39.00 | 3204.70 |
| 285 | 20280158 | 39.50 | 3251.80 |
| 286 | 20280159 | 40.50 | 2812.30 |
| 287 | 20280160 | 41.50 | 2940.70 |
| 288 | 20280161 | 42.50 | 2936.30 |
| 289 | 20280162 | 43.50 | 2694.00 |
| 290 | 20280163 | 44.50 | 2646.10 |

```
20280164 45.50  2634.00
20280165 46.50  2823.30
20280166 47.50  2745.90
20280167 48.50  2728.10
20280168 49.50  2604.40
20280169 50.50  2715.10
20280170 51.50  2500.30
20280171 52.50  2695.40
20280172 53.50  2692.30
20280173 54.50  2634.60
20280174 55.50  2481.00
20280175 56.50  2491.70
20280176 57.50  2458.00
20280177 58.50  2542.70
20280178 59.50  2467.70
*
*   CONTROL COMPONENT 110.  EXPERIMENTAL CALCULATED QUAL AT RING II
20511000  X-RINGII  FUNCTION  1.  0.  0
20511001   TIME  0  803
*
*
*  GENERAL TABLE 803.   QUALITY AT RING II   (XGAV)
20280300  REAC-T
20280301   .00  .00000
20280302  1.00  .00000
20280303  2.00  .00000
20280304  3.00  .00000
20280305  4.00  .00000
20280306  5.00  .00000
20280307  6.00  .00000
20280308  7.00  .00000
20280309  8.00  .00000
20280310  9.00  .00000
20280311 10.00  .00000
20280312 11.00  .00000
20280313 12.00  .00000
20280314 13.00  .00000
20280315 14.00  .00000
20280316 15.00  .00000
20280317 16.00  .00000
20280318 17.00  .00000
20280319 18.00  .00000
20280320 19.00  .00000
20280321 20.00  .00000
20280322 21.00  .00000
20280323 22.00  .00013
20280324 22.50  .00000
20280325 23.00  .00005
20280326 23.50  .00016
20280327 24.00  .00037
20280328 24.50  .00046
20280329 25.00  .00055
20280330 25.50  .00099
20280331 26.00  .00147
20280332 26.50  .00161
20280333 27.00  .00176
20280334 27.50  .00193
20280335 28.00  .00182
20280336 28.50  .00206
20280337 29.00  .00223
```

```
20280338 29.50  .00237
20280339 30.00  .00263
20280340 30.50  .00237
20280341 31.00  .00247
20280342 31.50  .00262
20280343 32.00  .00267
20280344 32.50  .00282
20280345 33.00  .00316
20280346 33.50  .00348
20280347 34.00  .00365
20280348 34.50  .00377
20280349 35.00  .00400
20280350 35.50  .00381
20280351 36.00  .00416
20280352 36.50  .00430
20280353 37.00  .00445
20280354 37.50  .00443
20280355 38.00  .00468
20280356 38.50  .00473
20280357 39.00  .00474
20280358 39.50  .00605
20280359 40.50  .00793
20280360 41.50  .00979
20280361 42.50  .01141
20280362 43.50  .01181
20280363 44.50  .01193
20280364 45.50  .01251
20280365 46.50  .01245
20280366 47.50  .01217
20280367 48.50  .01228
20280368 49.50  .01205
20280369 50.50  .01175
20280370 51.50  .01213
20280371 52.50  .01152
20280372 53.50  .01274
20280373 54.50  .01293
20280374 55.50  .01364
20280375 56.50  .01369
20280376 57.50  .01316
20280377 58.50  .01347
20280378 59.50  .01358
*
*
*   CONTROL COMPONENT 120.  EXPERMENTAL DP205.  RINGI TO VESL BOT
*
20512000   DP205MEAS   FUNCTION  1.  0.  0
20512001   TIME  0  802
*
*   CONTROL COMPONENT 121.  CALC DP 205.
20512100   DP205CALC  SUM  1.  0.  0
20512101   0.   1.   P   402020000
20512102       -1.   P   901010000
*
*
*    CONTROL COMPONENT 122.  CALC MINUS MEAS DP205
20512200   DIFFDP205  SUM  1.  0.  0
20512201   0.   1.  CNTRLVAR  121
20512202       -1.  CNTRLVAR  120
*
*
```

```
411    *     GENERAL TABLE 802.   DP205 (RING1 TO VESSEL BOTTOM)  001M205
412    *
413    20280200   REAC-T
414    20280201    .00  .596140E+04
415    20280202   1.00 -.407560E+06
416    20280203   2.00 -.376360E+06
417    20280204   3.00 -.355610E+06
418    20280205   4.00 -.306570E+06
419    20280206   5.00 -.305870E+06
420    20280207   6.00 -.279860E+06
421    20280208   7.00 -.231390E+06
422    20280209   8.00 -.229750E+06
423    20280210   9.00 -.221960E+06
424    20280211  10.00 -.213740E+06
425    20280212  11.00 -.190830E+06
426    20280213  12.00 -.189630E+06
427    20280214  13.00 -.177610E+06
428    20280215  14.00 -.172230E+06
429    20280216  15.00 -.153120E+06
430    20280217  16.00 -.148750E+06
431    20280218  17.00 -.147300E+06
432    20280219  18.00 -.137490E+06
433    20280220  19.00 -.131160E+06
434    20280221  20.00 -.120660E+06
435    20280222  21.00 -.115030E+06
436    20280223  22.00 -.112490E+06
437    20280224  22.50 -.109900E+06
438    20280225  23.00 -.102120E+06
439    20280226  23.50 -.962950E+05
440    20280227  24.00 -.101420E+06
441    20280228  24.50 -.891450E+05
442    20280229  25.00 -.876260E+05
443    20280230  25.50 -.697820E+05
444    20280231  26.00 -.759200E+05
445    20280232  26.50 -.711110E+05
446    20280233  27.00 -.602270E+05
447    20280234  27.50 -.581390E+05
448    20280235  28.00 -.540890E+05
449    20280236  28.50 -.465590E+05
450    20280237  29.00 -.457360E+05
451    20280238  29.50 -.432690E+05
452    20280239  30.00 -.427620E+05
453    20280240  30.50 -.383330E+05
454    20280241  31.00 -.404840E+05
455    20280242  31.50 -.368140E+05
456    20280243  32.00 -.399780E+05
457    20280244  32.50 -.350430E+05
458    20280245  33.00 -.327650E+05
459    20280246  33.50 -.342200E+05
460    20280247  34.00 -.364350E+05
461    20280248  34.50 -.379530E+05
462    20280249  35.00 -.356750E+05
463    20280250  35.50 -.360550E+05
464    20280251  36.00 -.358020E+05
465    20280252  36.50 -.381430E+05
466    20280253  37.00 -.378270E+05
467    20280254  37.50 -.372570E+05
468    20280255  38.00 -.376370E+05
469    20280256  38.50 -.375100E+05
470    20280257  39.00 -.378270E+05
```

```
20280258 39.50 -.361820E+05
20280259 40.50 -.393450E+05
20280260 41.50 -.377000E+05
20280261 42.50 -.370040E+05
20280262 43.50 -.363080E+05
20280263 44.50 -.353590E+05
20280264 45.50 -.355490E+05
20280265 46.50 -.345360E+05
20280266 47.50 -.364350E+05
20280267 48.50 -.373210E+05
20280268 49.50 -.365610E+05
20280269 50.50 -.355490E+05
20280270 51.50 -.349160E+05
20280271 52.50 -.343460E+05
20280272 53.50 -.340300E+05
20280273 54.50 -.347260E+05
20280274 55.50 -.346630E+05
20280275 56.50 -.367510E+05
20280276 57.50 -.341570E+05
20280277 58.50 -.320050E+05
20280278 59.50 -.319420E+05
*   CONTROL COMP 130.   T901-TSAT901
*     USE THIS CONTROL VARIABLE TO END SUBCOOLED B.C TRANSIENT
20513000    T-TSAT901  SUM  1.  -34.  1
20513001   0.   1.   TEMPF   901010000
20513002       -1.  SATTEMP  901010000
*
.
```

# APPENDIX C

## LISTING OF INPUT DATA FOR CASE CFT04

```
*
*  MARVIKEN CFT 21. SAT CRIT FLOW. P,X BC AT VSL BOT.
*  RESTARTME0FGCFT01( SUBCOOLED RUN WITH CD=0.85, AND T901 INCRESED 2K
*
*
*
0000100   RESTART  TRANSNT
0000101   RUN
0000102   SI   SI
103   387
0000105   30.       40.
*
*
***** TIME STEP CONTROL CARDS
*         END-TIME  DTMIN     DTMAX     OPT    MINOR   MAJOR  RESTART
2000201 6030.00  1.E+50-6 0.1 .020 00000003      315     1800     1800
*
***** MINOR EDIT REQUESTS
301         P   901010000
303   CNTRLVAR 105     * RATIO  (MEAS FLOW / CALC FLOW)
304  CNTRLVAR  110   *  QUAL  RING II EXP
305   QUALE  402020000   * CALC QUAL RING II
306  CNTRLVAR  122   * DP205  CALC-EXP
*
***** TRIP INPUT DATA
0000502   TIME         0    GE  NULL     0      60.0   L  *
*
*  INPUT P,X BC AT VOL 901.
9010000  P-X(BC)   TMDPVOL
9010101  19.6  0.5  0.0  0.  -90.  0.000  20.-6  0.  00
*
*
*
***********  CFT 21  PRESSURE AND QUALITY AT BOTTOM OF VESSEL  ****
*       P FROM 001M106    X FROM XVGB
*
*
***********  CFT 21  PRESSURE AND QUALITY AT BOTTOM OF VESSEL  ****
*       P FROM 001M106    X FROM XVGB
*
9010200  2  501
9010201  0.0   3.13406E6  0.0
9010202 25.00  .313406E+07  .00000
9010203 25.50  .313406E+07  .00000
9010204 26.00  .313406E+07  .00000
9010205 26.50  .313406E+07  .00000
9010206 27.00  .312890E+07  .00000
9010207 27.50  .311980E+07  .00000
9010208 28.00  .308910E+07  .00000
9010209 28.50  .310730E+07  .00028
9010210 29.00  .309650E+07  .00046
```

| | | | | |
|---|---|---|---|---|
| 56 | 9010211 | 29.50 | .310880E+07 | .00098 |
| 57 | 9010212 | 30.00 | .309500E+07 | .00095 |
| 58 | 9010213 | 30.50 | .308760E+07 | .00118 |
| 59 | 9010214 | 31.00 | .305270E+07 | .00140 |
| 60 | 9010215 | 31.50 | .306430E+07 | .00122 |
| 61 | 9010216 | 32.00 | .306350E+07 | .00151 |
| 62 | 9010217 | 32.50 | .304710E+07 | .00179 |
| 63 | 9010218 | 33.00 | .304440E+07 | .00183 |
| 64 | 9010219 | 33.50 | .304190E+07 | .00238 |
| 65 | 9010220 | 34.00 | .302770E+07 | .00245 |
| 66 | 9010221 | 34.50 | .302620E+07 | .00259 |
| 67 | 9010222 | 35.00 | .303010E+07 | .00282 |
| 68 | 9010223 | 35.50 | .301040E+07 | .00277 |
| 69 | 9010224 | 36.00 | .300600E+07 | .00267 |
| 70 | 9010225 | 36.50 | .299620E+07 | .00290 |
| 71 | 9010226 | 37.00 | .299570E+07 | .00316 |
| 72 | 9010227 | 37.50 | .300060E+07 | .00304 |
| 73 | 9010228 | 38.00 | .298830E+07 | .00332 |
| 74 | 9010229 | 38.50 | .298640E+07 | .00340 |
| 75 | 9010230 | 39.00 | .297460E+07 | .00359 |
| 76 | 9010231 | 39.50 | .298190E+07 | .00423 |
| 77 | 9010232 | 40.00 | .295440E+07 | .00543 |
| 78 | 9010233 | 40.50 | .295190E+07 | .00628 |
| 79 | 9010234 | 41.00 | .294410E+07 | .00747 |
| 80 | 9010235 | 41.50 | .293870E+07 | .00806 |
| 81 | 9010236 | 42.00 | .293230E+07 | .00887 |
| 82 | 9010237 | 42.50 | .292540E+07 | .00975 |
| 83 | 9010238 | 43.00 | .291560E+07 | .01030 |
| 84 | 9010239 | 43.50 | .291260E+07 | .01047 |
| 85 | 9010240 | 44.00 | .289440E+07 | .01059 |
| 86 | 9010241 | 44.50 | .289660E+07 | .01055 |
| 87 | 9010242 | 45.00 | .291210E+07 | .01085 |
| 88 | 9010243 | 45.50 | .288560E+07 | .01119 |
| 89 | 9010244 | 46.00 | .287770E+07 | .01105 |
| 90 | 9010245 | 46.50 | .287080E+07 | .01120 |
| 91 | 9010246 | 47.00 | .285260E+07 | .01103 |
| 92 | 9010247 | 47.50 | .284720E+07 | .01081 |
| 93 | 9010248 | 48.00 | .284040E+07 | .01077 |
| 94 | 9010249 | 48.50 | .281970E+07 | .01092 |
| 95 | 9010250 | 49.00 | .280250E+07 | .01107 |
| 96 | 9010251 | 49.50 | .280940E+07 | .01078 |
| 97 | 9010252 | 50.00 | .280450E+07 | .01071 |
| 98 | 9010253 | 50.50 | .279410E+07 | .01028 |
| 99 | 9010254 | 51.00 | .279070E+07 | .01062 |
| 100 | 9010255 | 51.50 | .277790E+07 | .01082 |
| 101 | 9010256 | 52.00 | .277500E+07 | .01062 |
| 102 | 9010257 | 52.50 | .275630E+07 | .01046 |
| 103 | 9010258 | 53.00 | .275280E+07 | .01027 |
| 104 | 9010259 | 53.50 | .274150E+07 | .01126 |
| 105 | 9010260 | 54.00 | .274990E+07 | .01208 |
| 106 | 9010261 | 54.50 | .271600E+07 | .01170 |
| 107 | 9010262 | 55.00 | .272680E+07 | .01232 |
| 108 | 9010263 | 55.50 | .270220E+07 | .01228 |
| 109 | 9010264 | 56.00 | .270120E+07 | .01181 |
| 110 | 9010265 | 56.50 | .268400E+07 | .01172 |
| 111 | 9010266 | 57.00 | .268250E+07 | .01262 |
| 112 | 9010267 | 57.50 | .267070E+07 | .01181 |
| 113 | 9010268 | 58.00 | .265550E+07 | .01195 |
| 114 | 9010269 | 58.50 | .263880E+07 | .01193 |
| 115 | 9010270 | 59.00 | .264170E+07 | .01217 |

| | | | | |
|---|---|---|---|---|
| 116 | 9010271 | 59.50 | .262850E+07 | .01226 |
| 117 | 9010272 | 60.00 | .261370E+07 | .01245 |
| 118 | . | | | |

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-0007
STUDSVIK/NP-86/99

2. TITLE AND SUBTITLE

Assessment of RELAP5/MOD2 Against Critical Flow Data From Marviken Tests JIT 11 and CFT 21

3. LEAVE BLANK

4. DATE REPORT COMPLETED

| MONTH | YEAR |
|---|---|
| | |


5. AUTHOR(S)

Ö. Rosdahl, D. Caraher


6. DATE REPORT ISSUED

| MONTH | YEAR |
|---|---|
| September | 1986 |


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

Swedish Nuclear Power Inspectorate
P.O. Box 27106
S102 #52 Stockholm, Sweden


8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER

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

Division of Reactor System Safety
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a. TYPE OF REPORT

Technical

b. PERIOD COVERED (Inclusive dates)

12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)


RELAP5/MOD2 simulations of the critical flow of saturated steam are reported together with simulations of the critical flow of subcooled liquid and low-quality two-phase mixture. The experiments which were simulated used nozzle diameters of 0.3 m and 0.5 m. RELAP5 overpredicted the experimental flow rates by 10 to 25 percent unless discharge coefficients were applied.


14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS

RELAP5/MOD2
Marviken test
critical flow of saturated steam
ICAP code assessment

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-0007

ASSESSMENT OF RELAP5/MOD 2 AGAINST CRITICAL FLOW DATA FROM MARVIKEN TESTS JIT II AND CFT 21

SEPTEMBER 1986