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International Agreement Report

Assessment of Subcooled Boiling Model Used in RELAP5/MOD2 (Cycle 36.05, Version E03) Against Experimental Data

Prepared by
C. R. Brain

Central Electricity Generating Board
Generation Development and Construction Division
Barnett Way
Barnwood, Gloucester GL4 7R5
United Kingdom

Office of Nuclear Regulatory Research
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March 1992

Prepared as part of
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GD/PE-N/729
PWR/PKWG/P(88)366 Revised
PWR/RUG/P(88)6 Revised

CENTRAL ELECTRICITY GENERATING BOARD
GENERATION DEVELOPMENT AND CONSTRUCTION DIVISION
PLANT ENGINEERING DEPARTMENT
NUCLEAR PLANT BRANCH

Assessment of the subcooled boiling model used in RELAP5/Mod2 (cycle 36.05, version E03) against experimental data.

Author : C R Brain - Safety Technology Section

Approved by :

Head of Safety Technology Section

Summary : In order to test the ability of RELAP5/Mod2 to describe subcooled nucleate boiling under conditions similar to those anticipated during intact circuit fault scenarios in pressurised water reactors the code has been assessed against results of high pressure sub-cooled boiling experiments reported in the literature. For cases with low inlet subcooling, agreement between the calculations and the test data is very good, but with increased inlet subcooling the code tends to over estimate the void fraction. It is concluded that RELAP5/Mod2 can be applied with reasonable confidence to the prediction of subcooled boiling void fraction for conditions expected during PWR intact circuit faults.

Date : February 1989

<u>CONTENTS</u>

1. INTRODUCTION

In some intact circuit faults in PWRs, sub-cooled voiding within the reactor core may significantly influence the primary coolant volume and hence the peak system over-pressure. RELAP5/Mod2 calculations of an ATWT test in the LOBI test facility, reported in reference 1, show a significant over-prediction of system peak pressure. The authors of reference 1 attribute the error, in part, to an over-estimation of vapour generation in the core for conditions of subcooled nucleate boiling. In view of this reported discrepancy, it was considered that further investigation in this area would be worthwhile. Therefore two simple sub-cooled boiling experiments have been modelled with the thermal hydraulics code RELAP5/Mod2 (cycle 36.05, version EO3) which is described in references 5 and 6. The results of these comparisons are described in the present report.

The first of the two experiments modelled (reference 2) involved sub-cooled nucleate boiling of water in a vertical tube at pressures of up to 6.9 MPa (1000 psi). This experiment was chosen since it had already been used in the assessment of two previous versions of RELAP5 (reference 4). The second experiment (reference 3) involved sub-cooled boiling water in a vertical tube at a pressure of 13.8 MPa (2000 psi), which is closer to the conditions of interest in reactor fault analysis.

2. THE EXPERIMENTS

In both the experiments the test section consisted of a vertical tube which was electrically heated by passage of an alternating electrical current through the tube walls. The inlet flow to the test section consisted of subcooled water at a known constant temperature, pressure and flow-rate.

The void fraction along the test section was measured with a gamma densitometer. Further details of the individual experiments are as follows.

2.1 THE CHRISTENSEN EXPERIMENT (reference 2)

The test section in this experiment consisted of a 127 cm long stainless steel tube of rectangular cross-section (dimensions 1.11 cm x 4.44 cm). Seven different runs were simulated with RELAP5/Mod2, the test conditions for these runs are given in Table 1 below.

Table 1 - Christensen tests selected for analysis.

Run *No*	Pressure *(MPa)*	Power *(kW)*	Flow rate *(kg/m^2s)*	Temperature *(Kelvin)*	Inlet Subcooling *(Kelvin)*
9	2.76	30	640.9	499.5	2.9
10	2.76	30	646.9	493.7	8.7
11	4.14	50	940.0	511.1	14.4
12	4.14	50	927.8	518.3	7.2
13	4.14	50	920.9	522.2	1.3
15	5.51	70	907.2	530.8	12.5
16	6.89	70	907.7	545.9	12.1

Tables giving the measured variation of void fraction along the tube are presented in reference 2. Void is produced very close to the inlet of this heated length, and the void fraction increases along the tube reaching a maximum value of between .315 and .65 depending on the run conditions.

2.2 THE EGEN, DINGEE AND CHASTAIN EXPERIMENT (reference 3)

The test section used in this experiment consisted of a 68.6 cm long type 304 stainless steel tube also of rectangular cross-section, (dimensions 2.5 cm by 0.26 cm). Five of the twenty different experimental runs carried out in the experiment were selected for modelling with RELAP5/Mod2. The test conditions for these runs are given in table 2 below.

Table 2 - Egen tests selected for analysis.

Run No	Pressure (*MPa*)	Power (*kW*)	Flow rate (kg/m^2s)	Temperature (*Kelvin*)	Inlet Subcooling (*Kelvin*)
7	13.79	24	922.2	577.3	31.4
13	13.79	24	922.3	605.0	3.6
15	13.79	48	1166.4	534.0	74.7
16	13.79	60	1153.0	534.0	74.7
19	13.79	24	1123.0	602.0	6.7

The experimental results were expressed as void fraction and steam quality at various locations along the test section.

3. THE RELAP5/Mod2 MODELS

3.1 MODEL OF THE CHRISTENSEN EXPERIMENT

This experiment was modelled using the noding arrangement shown in figure 13. The test section was modelled as a tube divided into 20 equal volumes, with an attached heat structure consisting of a cylindrical shell having the same internal surface area as the rectangular tube in the experiment. The outside surface of the heat structure was defined as an adiabatic boundary so that all the heat energy flows into the fluid. The initial conditions for each of the runs as tabulated in section 2.1 were set up by specifying the characteristics of the bottom time dependent junction and volume. This model was chosen so as to be very similar to the model used to represent the same experiment in reference 4. The input data is given in full in appendix 1.

3.2 MODEL OF THE EGEN, DINGEE AND CHASTAIN EXPERIMENT

The noding arrangement used in this case is shown in figure 14. This input model is generally the same as used for the Christensen experiment except that 27 volumes were used to represent the test section in more detail. The input data is given in appendix 2.

4. RESULTS AND DISCUSSION

The void fraction calculated by RELAP5/Mod2 in each hydrodynamic volume within the test section was plotted against height, for each of the experimental cases. Results are given in figures 1-12. Comparison is made with experimental data giving the measured void fraction at selected points along the tube.

It is observed that in each of the RELAP5/Mod2 calculations the predicted voidage in the volume at the top of the test section is artificially high. This is due to averaging procedures used in modelling the junction between the test section outlet and the outlet time dependent volume. The anomaly could be removed by adding extra volumes at the test section outlet, but it was deemed unnecessary to undertake this modification since the anomaly is localised and in any case there is no experimental void fraction data available very close to the tube outlet.

For cases of low inlet subcooling, (all the Christensen runs and Egen runs 13 and 19), the agreement between experiment and theory is generally very good, with RELAP5/Mod2 adequately predicting both the slope and magnitude of the experimental data. Where discrepancies arise between the two sets of data, the cause is probably experimental measurement errors. In several of the cases, the experimental void fraction is seen to decrease with increasing elevation, and this cannot be a real effect. It is therefore taken as an indication of the experimental uncertainty.

RELAP5 calculations of Christensens' experimental run15 were carried out as one of the developmental assessment problems for RELAP5/Mod2 (reference 4). Reference 4 compares predictions of RELAP5/Mod1, and an unspecified version of RELAP5/Mod2 with the experimental data for this run. These comparisons along with the present calculations performed with RELAP5/Mod2 (cycle 36.05, version E03) are included in figure 6. It is seen from the figure that the version of RELAP5/Mod2 used in the present work gives the best agreement with experiment. It is noticeable that RELAP5/Mod1 greatly underestimates voidage close to the tube inlet. This is because RELAP5/Mod1 did not have a thermal disequilibrium modelling capability, and therefore was unable to model vapour generation under subcooled conditions.

However for cases of high inlet subcooling, (Egen runs 7, 15 and 16) RELAP5/Mod2 is not able to predict the experimental results with such precision. The code tends to calculate the production of void very close to the test section inlet, which is not observed in the experimental results. As a result it predicts a much greater voidage along the whole channel.

It is the total voidage throughout the channel and not the void distribution that has the dominant effect on primary pressure, therefore any inaccuracies in the RELAP5 prediction of total void could give rise to the phenomena observed in reference 1. In view of this, the total void throughout the channel for each of the runs has been calculated and compared with estimated upper and lower bounds for the test results in table 3.

Table 3 - Channel average void fraction.

Run Number	Measured (Lower)	Measured (Upper)	Calculated
Christensen run9	0.29	0.37	0.42
Christensen run10	0.20	0.28	0.27
Christensen run11	0.08	0.16	0.17
Christensen run12	0.21	0.29	0.31
Christensen run13	0.34	0.42	0.39
Christensen run15	0.26	0.30	0.28
Christensen run16	0.23	0.27	0.27
Egen run7	0.14	0.20	0.23
Egen run13	0.45	0.51	0.49
Egen run15	0.06	0.12	0.17
Egen run16	0.18	0.24	0.30
Egen run19	0.33	0.39	0.40

Inspection of the table reveals that RELAP5 systematically over predicts the system mean void fraction in these tests. However in five of the twelve cases the calculation falls within the experimental uncertainty band, and in three other cases the calculation falls just (< 0.02) outside it. In the worst case (Egen run 16) the calculated void fraction falls 0.06 outside the experimental band.

5. THE HEAT TRANSFER CORRELATIONS USED IN RELAP5/Mod2

As noted previously, reference 1 attributed errors in a RELAP5/Mod2 calculation of a LOBI ATWT test, to inadequate modelling of subcooled vapour generation in the core region. In particular the authors of reference 1 noted that the Unal correlation for interfacial heat transfer in subcooled boiling had been incorrectly coded in RELAP5/Mod2.

To investigate the above assertion, a brief investigation was carried out into the interfacial heat transfer models used by RELAP5/Mod2 in vertical flows for 'wet wall' conditions of present interest. The interfacial heat transfer coefficient is flow regime dependent.

In the bubbly flow regime a modified form of the Unal correlation is used to calculate liquid/interface heat transfer as noted in reference 1, while other correlations are applied in the slug and annular mist regimes. The flow regime boundaries in vertical up flow are defined by the following equations:-

$0 \leq \alpha_g \leq \alpha_{AB}$ BUBBLY FLOW

$\alpha_{AB} \leq \alpha_g \leq \alpha_{AC}$ SLUG FLOW

$\alpha_{AC} \leq \alpha_g \leq \alpha_{AD}$ ANNULAR MIST

The following equation is used for α_{AB}

$$\alpha_{AB} = \max[0.25\min(1, (0.04D')^6), 10^{-3}] \quad \text{Where,} \quad D' = D\left[g\frac{(\rho_f - \rho_g)}{\sigma}\right]^{0.5}$$

For pressures of 10 MPa and values of hydraulic diameter below 0.017 m $\alpha_{AB} < 0.013$. Hence for the conditions analysed in the present report, and for PWR reactor core or steam generator components where subcooled boiling may occur, bubbly flow will not normally be calculated. Consequently the Unal correlation will not normally be applied in subcooled boiling conditions of interest in PWR transient calculations. The errors in the calculation reported in reference 1 could not therefore have been due to incorrect coding of this model (in fact the authors of reference 1 no longer hold this view, but have shown that the calculation was poor because of inadequate convergence, ref 8). Generally the flow regime of interest will be the slug flow regime, according to reference 5 the liquid/interface heat transfer coefficient in vertical slug flow is:-

$$H_{if} = H_{if,TB} + H_{if,bub} \tag{1}$$

$$\text{Where} \quad H_{if,TB} = 1.18942 Re_f^{0.5} Pr_f^{0.5} \frac{K_f}{D} a'_{gf,TB}\, \alpha_{TB} \tag{2}$$

$$\text{And} \quad H_{if,bub} = \left[\max\left\{ \begin{matrix} \dfrac{K_f}{d_b}\dfrac{12}{\pi}\Delta T_{sf}\dfrac{\rho_f (C_p)_f F_6}{\rho_g h_{fg}} \\ \dfrac{K_f}{d_b}(2.0 + 0.74 Re_b^{0.5}) \end{matrix} \right\} + 0.4\,|V_f|\,\rho_f (C_p)_f F_1 \right] a_{gf} F_2 F_3 \tag{3}$$

Equations defining the terms composing equations(1), (2) and (3) are as follows -

$$Pr_f = \frac{(C_p)_f \mu_f}{K_f} \tag{4}$$

$$Re_f = \rho_f D \min(|V_f - V_g|, 0.8)/\mu_f \tag{5}$$

$$\alpha_{TB} = \textit{Taylor bubble void fraction} = \frac{(\alpha_g - \alpha_{gs})}{(1 - \alpha_{gs})} \tag{6}$$

$$a'_{gf,TB} = \textit{volumetric interfacial area} = \frac{4.5}{D} \tag{7}$$

$$\alpha_{bub} = \alpha_{AB} F_9 \tag{8}$$

$$V_{fg} = (V_g - V_f)F_9^2 \tag{9}$$

$$a_{gf,bub} = (a_{gf})_{bub}(1 - \alpha_{TB})F_9 \tag{10}$$

$$F_9 = \exp\left[-8 \frac{(\alpha_g - \alpha_{AB})}{(\alpha_{AC} - \alpha_{AB})} \right] \tag{11}$$

$$F_1 = \min[0.001, \alpha_{bub}]/\alpha_{bub} \tag{12}$$

$$F_2 = \min[0.25, \alpha_{bub}]/\alpha_{bub} \tag{13}$$

$$F_3 = \begin{Bmatrix} 1 & \Delta T_{sf} \leq -1 \\ \max[0.0, F_4(1 + \Delta T_{sf}) - \Delta T_{sf}] & -1 < \Delta T_{sf} < 0 \\ \max[0.0, F_4] & \Delta T_{sf} \geq 0 \end{Bmatrix} \tag{14}$$

$$Re_b = \frac{We\,\sigma\,(1 - \alpha_{bub})}{\mu_f (V_{fg}^2)^{1/2}} \qquad \textit{Where } We\,\sigma = \max(We\,\sigma, 10^{-10}) \tag{15}$$

$$F_4 = \min[10^{-5}, \alpha_g(1 - Q)](10^5) \tag{16}$$

$$We = \rho_f d_b V_{fg}^2/\sigma \tag{17}$$

$$a_{gf} = \textit{interfacial area per unit volume} = 3.6\alpha_{bub}/d_b \tag{18}$$

The RELAP5/Mod2, (cycle 36.05, version E03), code listing has been examined in order to verify that the code does indeed contain the above equations.

6. CONCLUSIONS

To test the ability of RELAP5/Mod2 to describe subcooled vapour generation under conditions similar to those expected in some PWR intact circuit faults, calculations have been performed of two sets of subcooled boiling experiments from the literature.

For the cases of low inlet subcooling, agreement between calculations and experiment is very good, with void fraction normally being predicted to within the apparent uncertainty on the measured data.

Agreement between calculations and experiment in the high subcooling cases is not as close, with RELAP5/Mod2 over predicting the void produced, particularly near the test section inlet. However the error in the channel average void fraction is not large.

The study indicates that RELAP5/Mod2 (cycle 36.05 version E03) can be used with reasonable confidence to calculate the subcooled void fraction under conditions encountered in PWR pressurised fault sequences.

7. NOMENCLATURE

SYMBOL	MEANING
ρ_g	gas density (kg/m^3)
ρ_f	liquid density (kg/m^3)
g	acceleration due to gravity (m/s^2)
$(C_p)_f$	specific heat capacity of liquid (J/kgK)
h_{fg}	latent heat of vaporisation (J/kg)
ΔT_{sf}	$T_s - T_f$ (K)
d_b	average bubble diameter (m)
D	hydraulic diameter (m)
Q	noncondensible quality
K_f	thermal conductivity of liquid (W/mK)
μ_f	liquid viscosity (kg/ms)
V_f	liquid velocity (m/s)
V_g	gas velocity (m/s)
σ	surface tension (N/m)
α_g	void fraction
α_{gs}	average void fraction in the liquid film and slug region
α_{bub}	bubble void fraction
H_{if}	heat transfer coefficient
α_{AB}	α_g for bubbly-slug transition
α_{AC}	α_g for slug-annular mist transition
α_{AD}	α_g for annular mist - dispersed transition

8. REFERENCES

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7. MAXIMUM BUBBLE DIAMETER, MAXIMUM BUBBLE-GROWTH TIME AND BUBBLE-GROWTH RATE DURING THE SUBCOOLED NUCLEATE FLOW BOILING OF WATER UP TO $17.7 MN/m^2$. H.C.UNAL, 1975.

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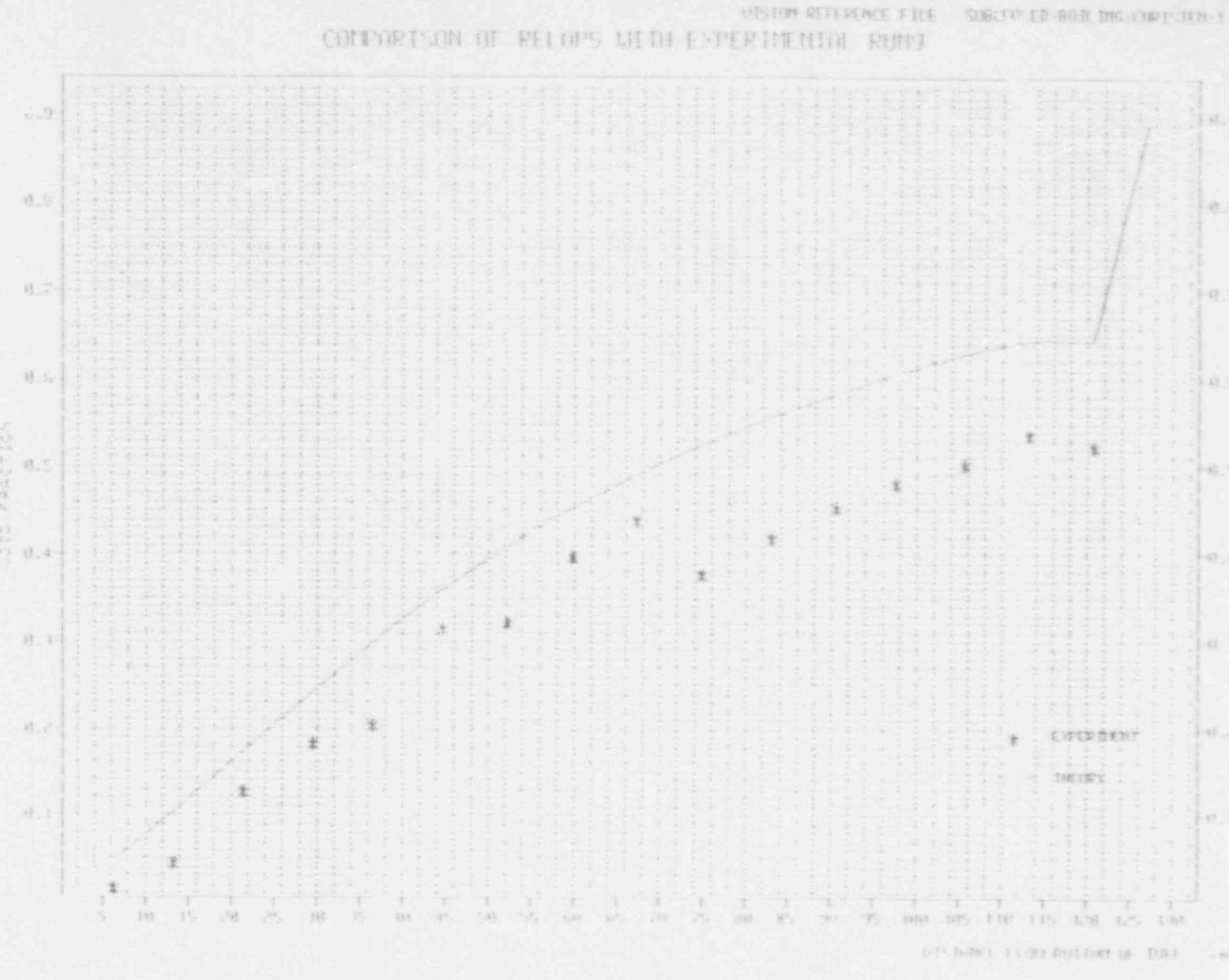
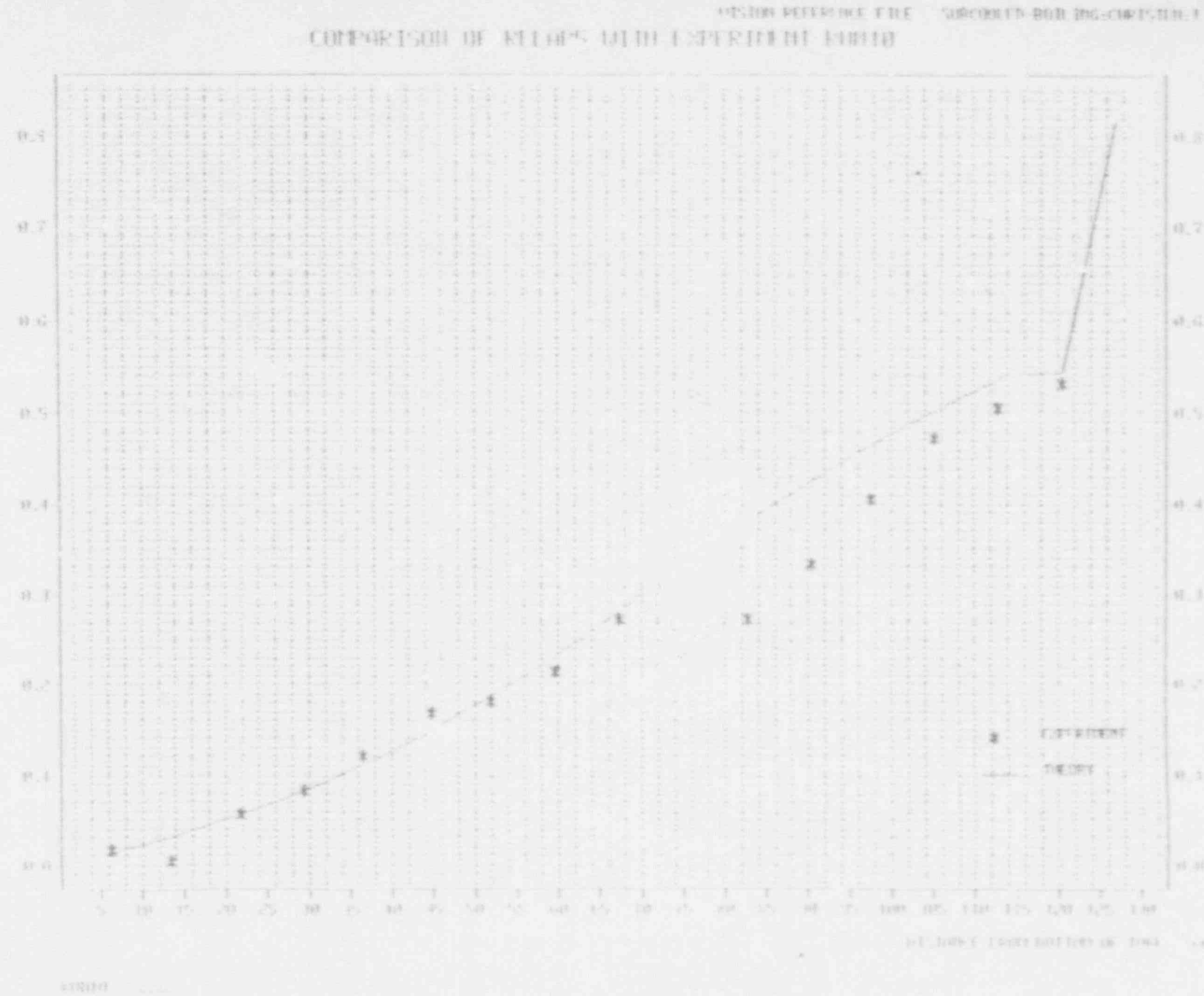


FIGURE 1

COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH CHRISTENSEN RUN9



COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH CHRISTENSEN RUN10

FIGURE 2

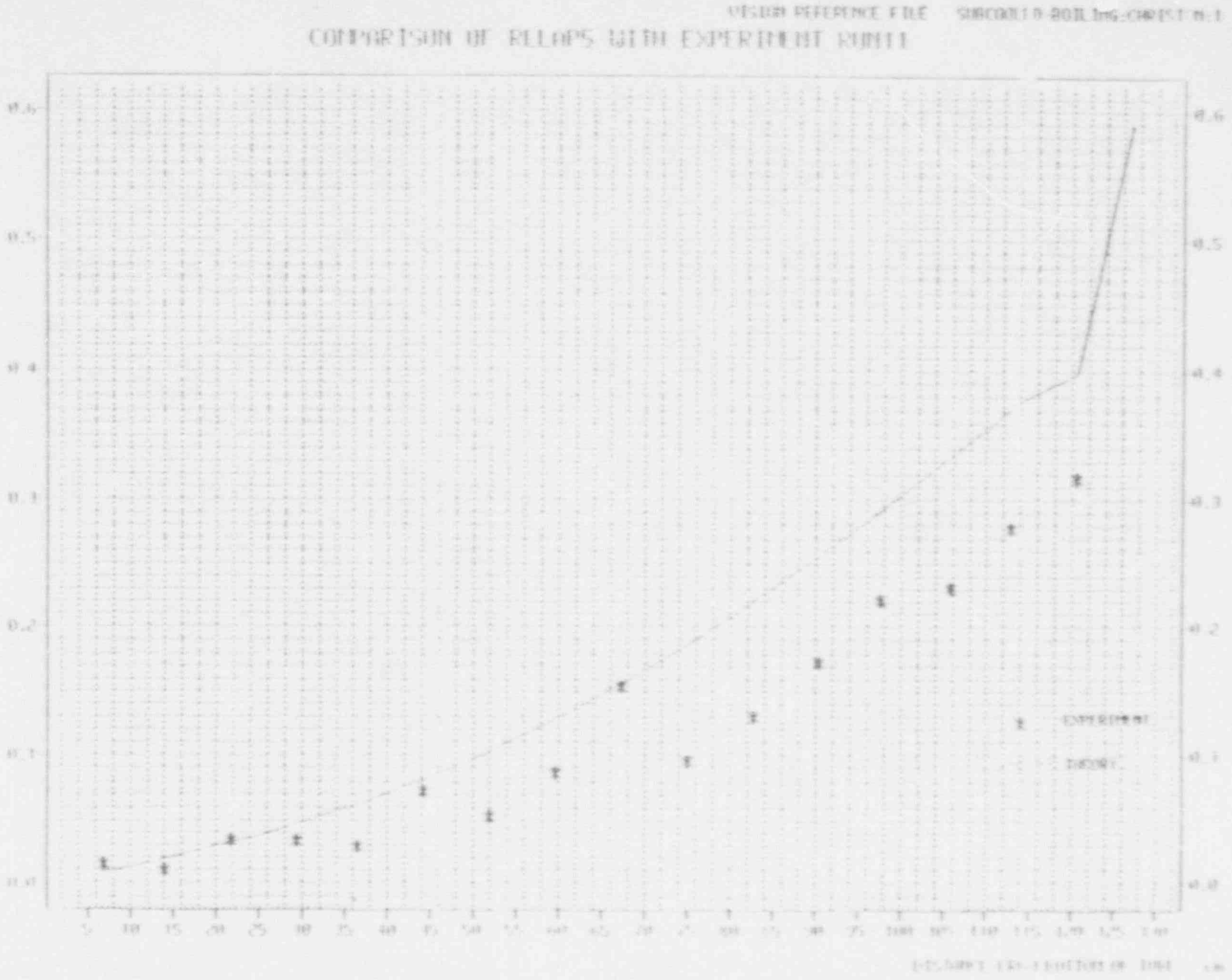


FIGURE 3

COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH CHRISTENSEN RUN11

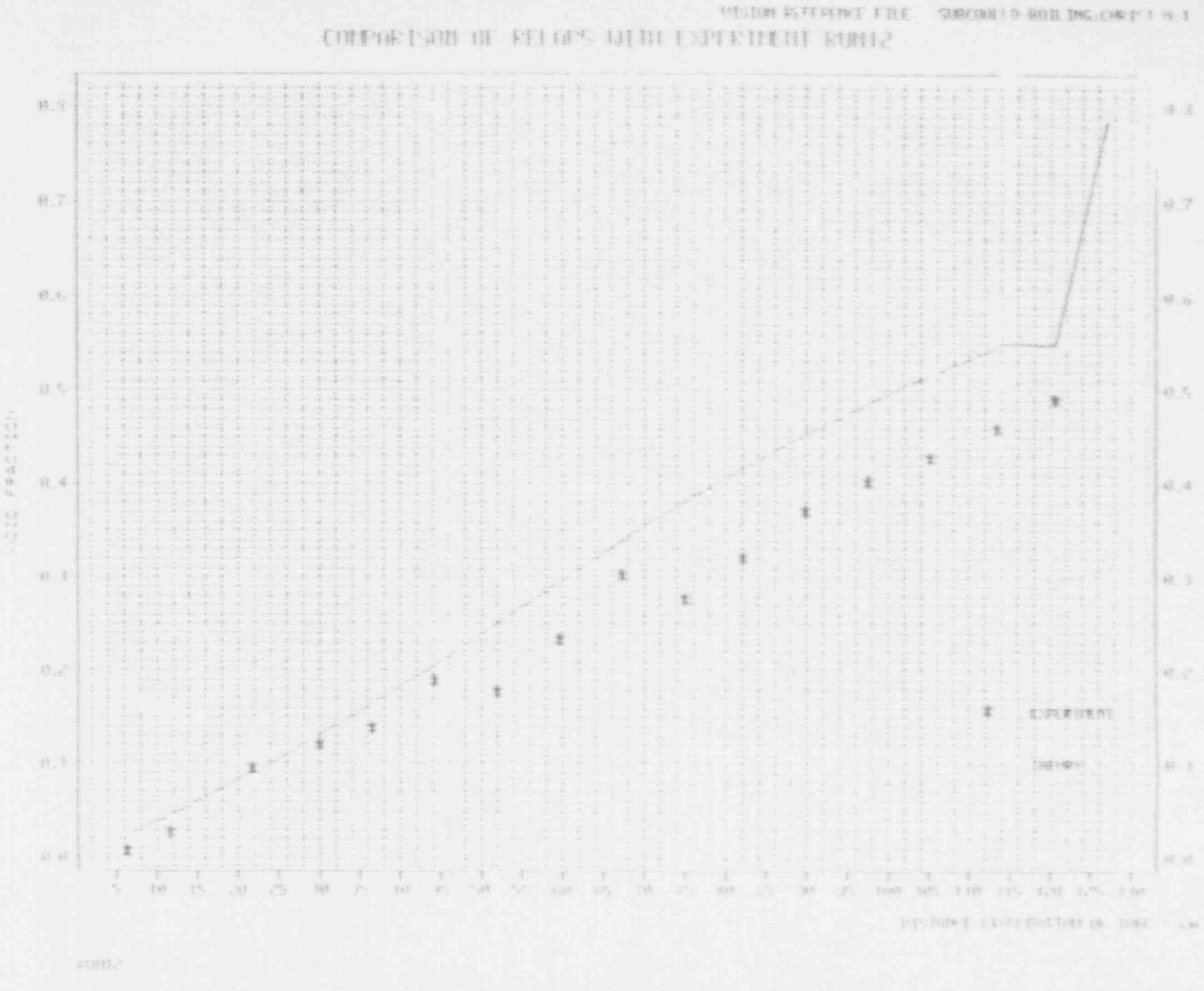
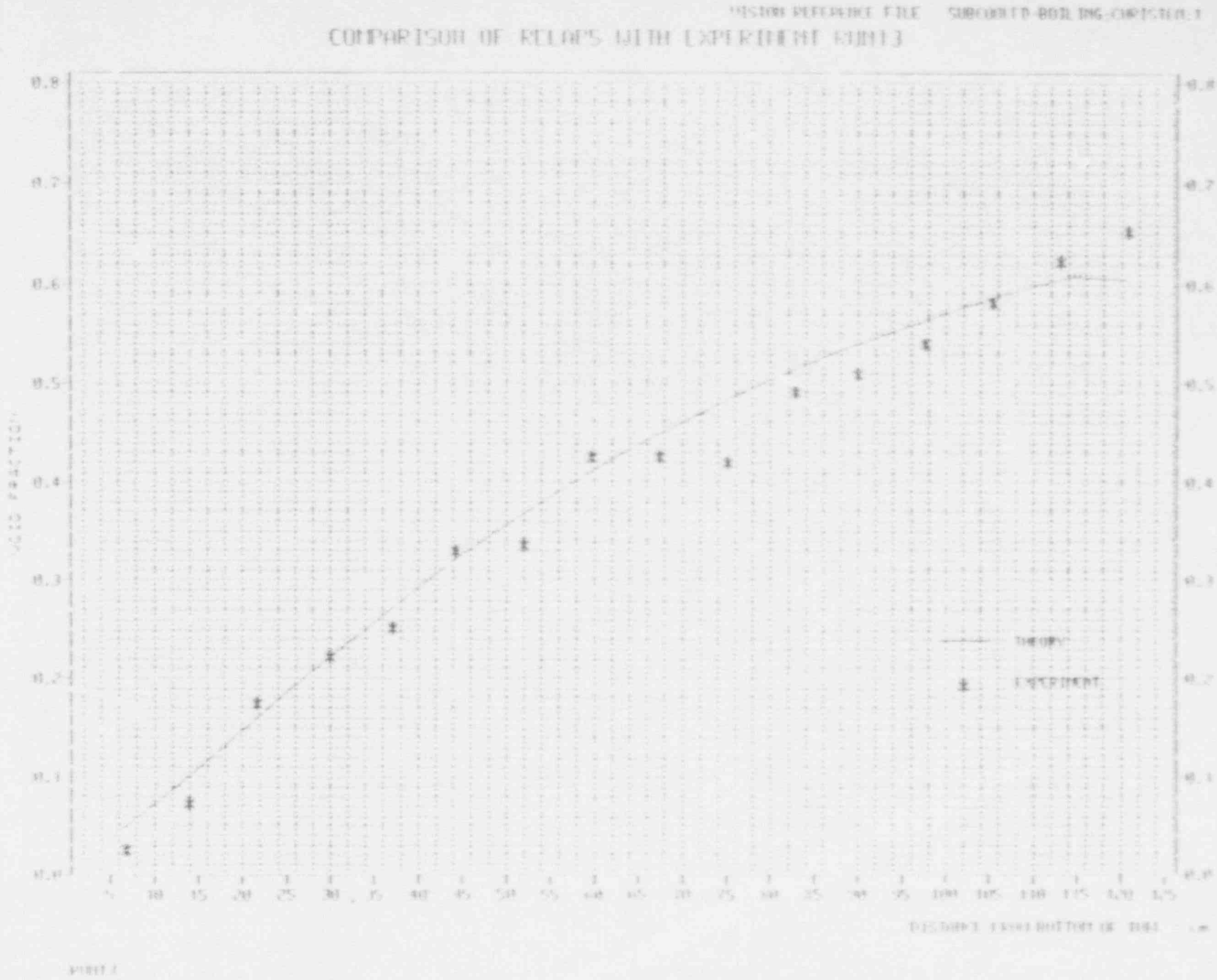


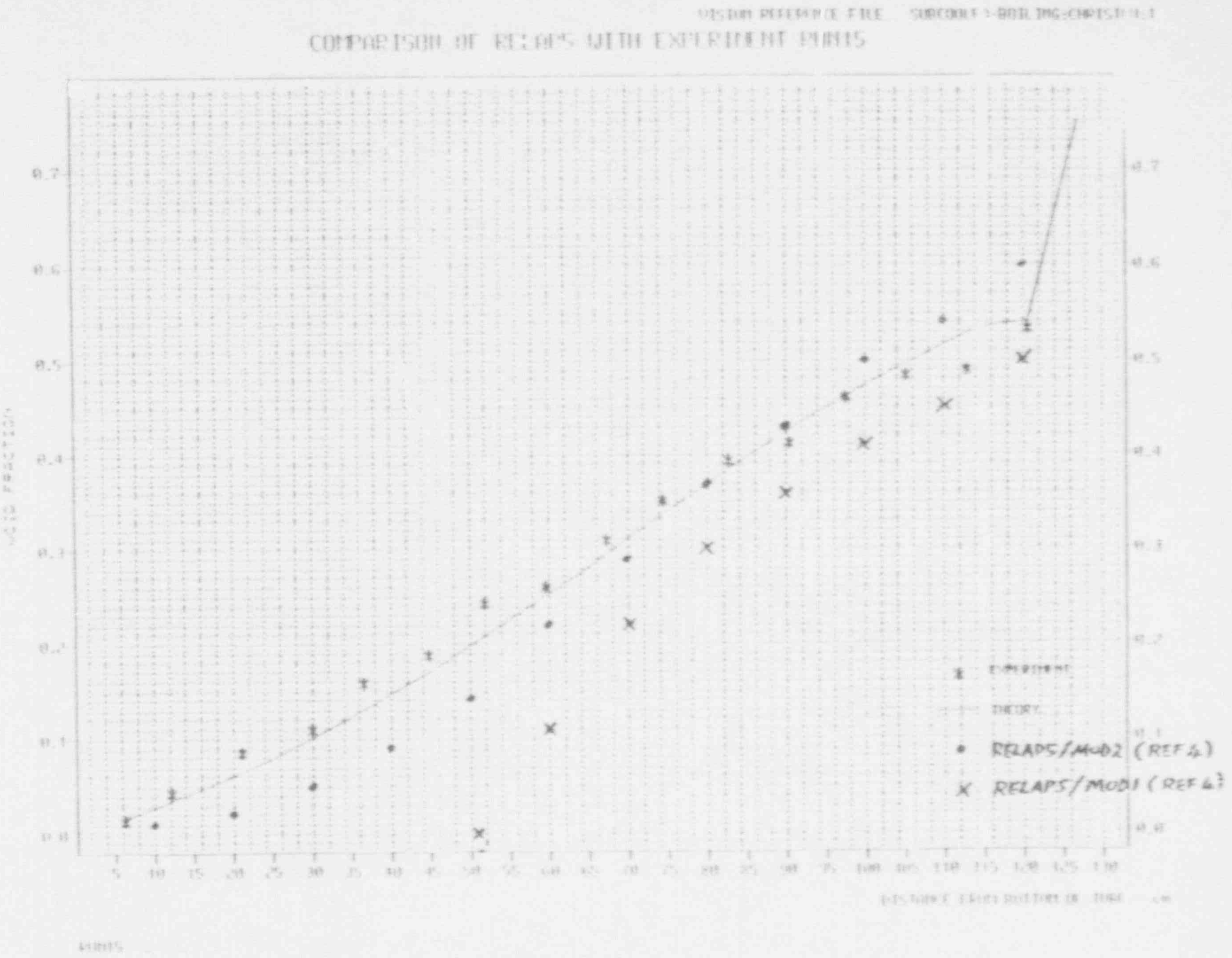
FIGURE 4

COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH CHRISTENSEN RUN12



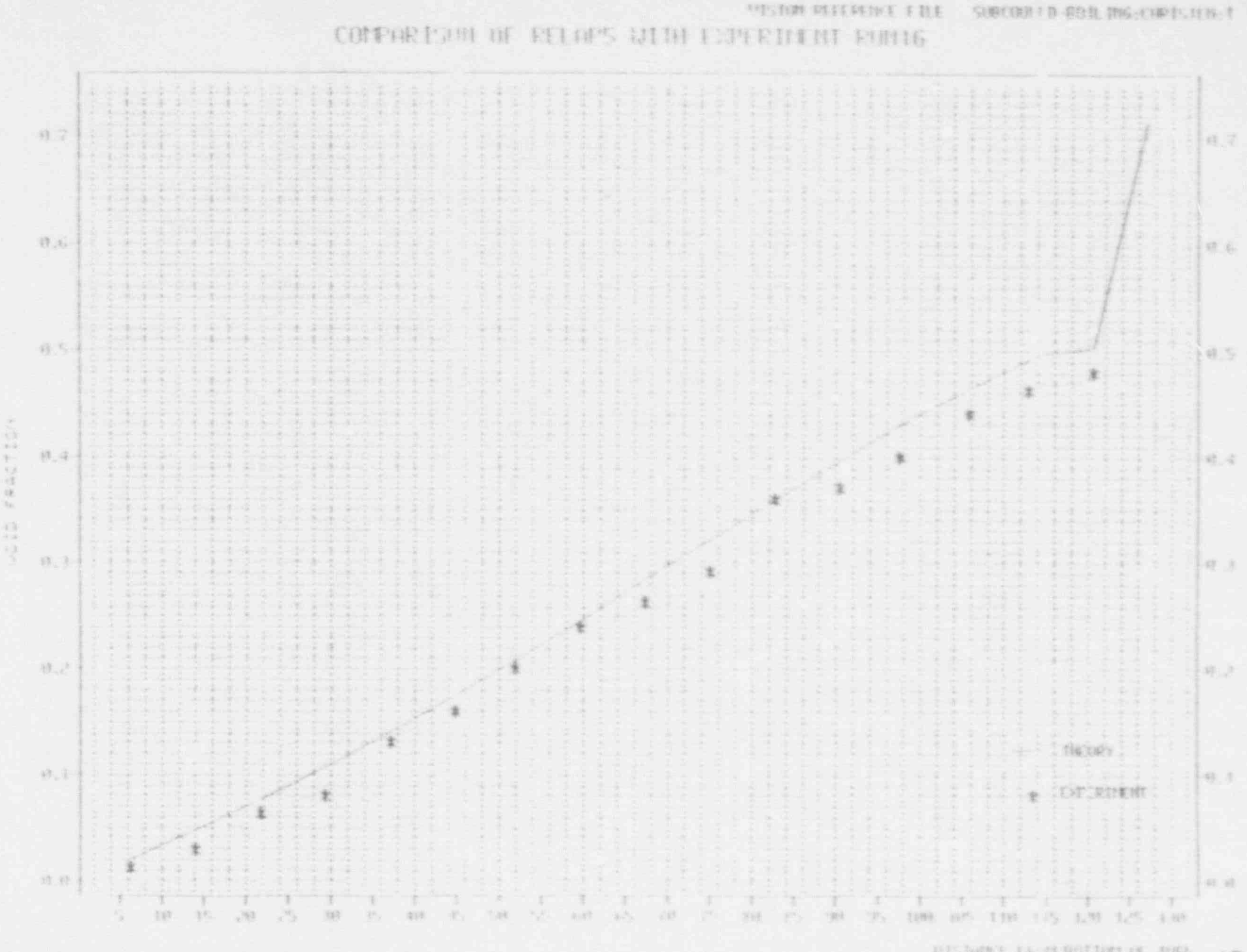
COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH CHRISTENSEN RUN13

FIGURE 5



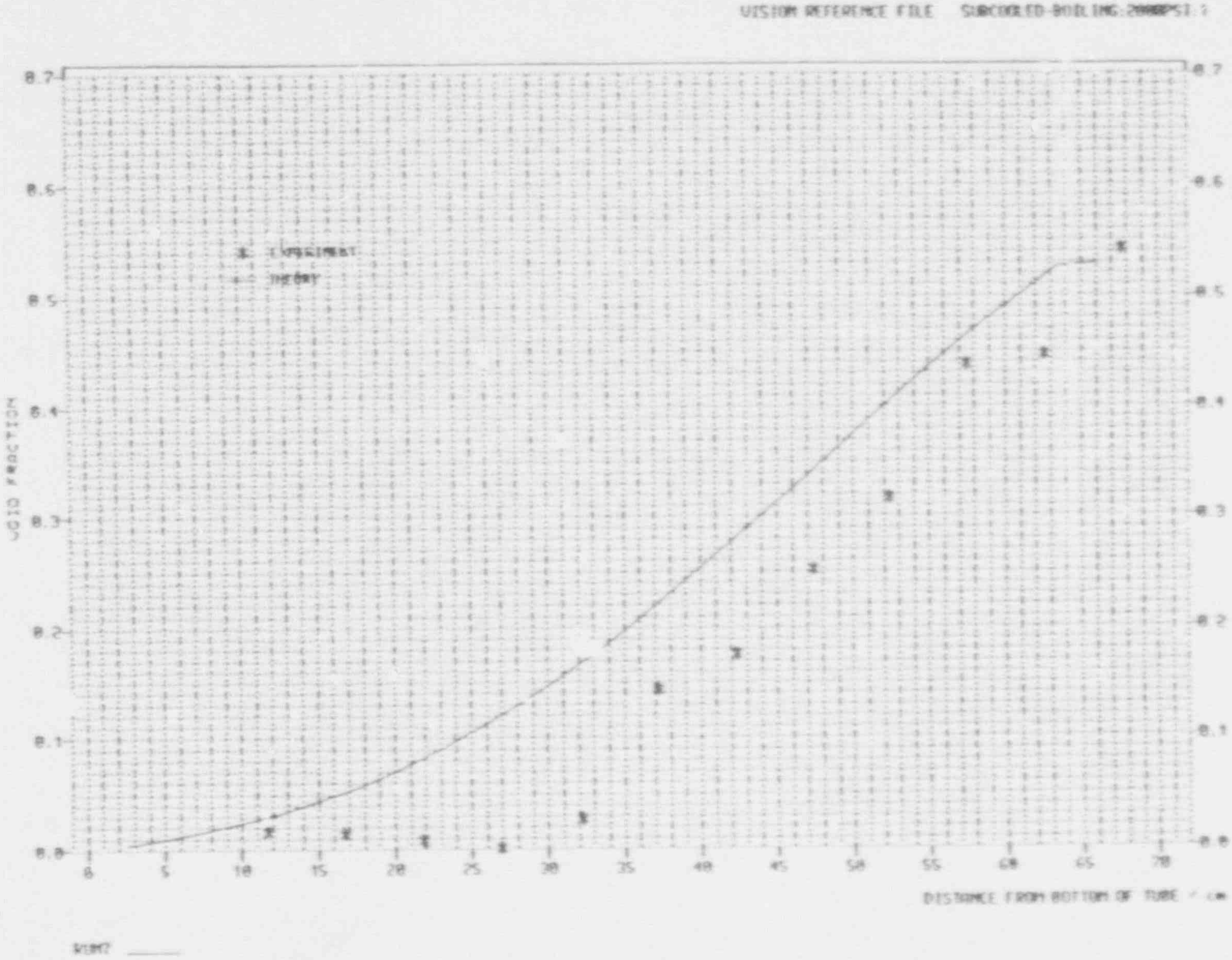
COMPARISON OF RELAP5 VERSIONS WITH CHRISTENSEN RUN15

FIGURE 6



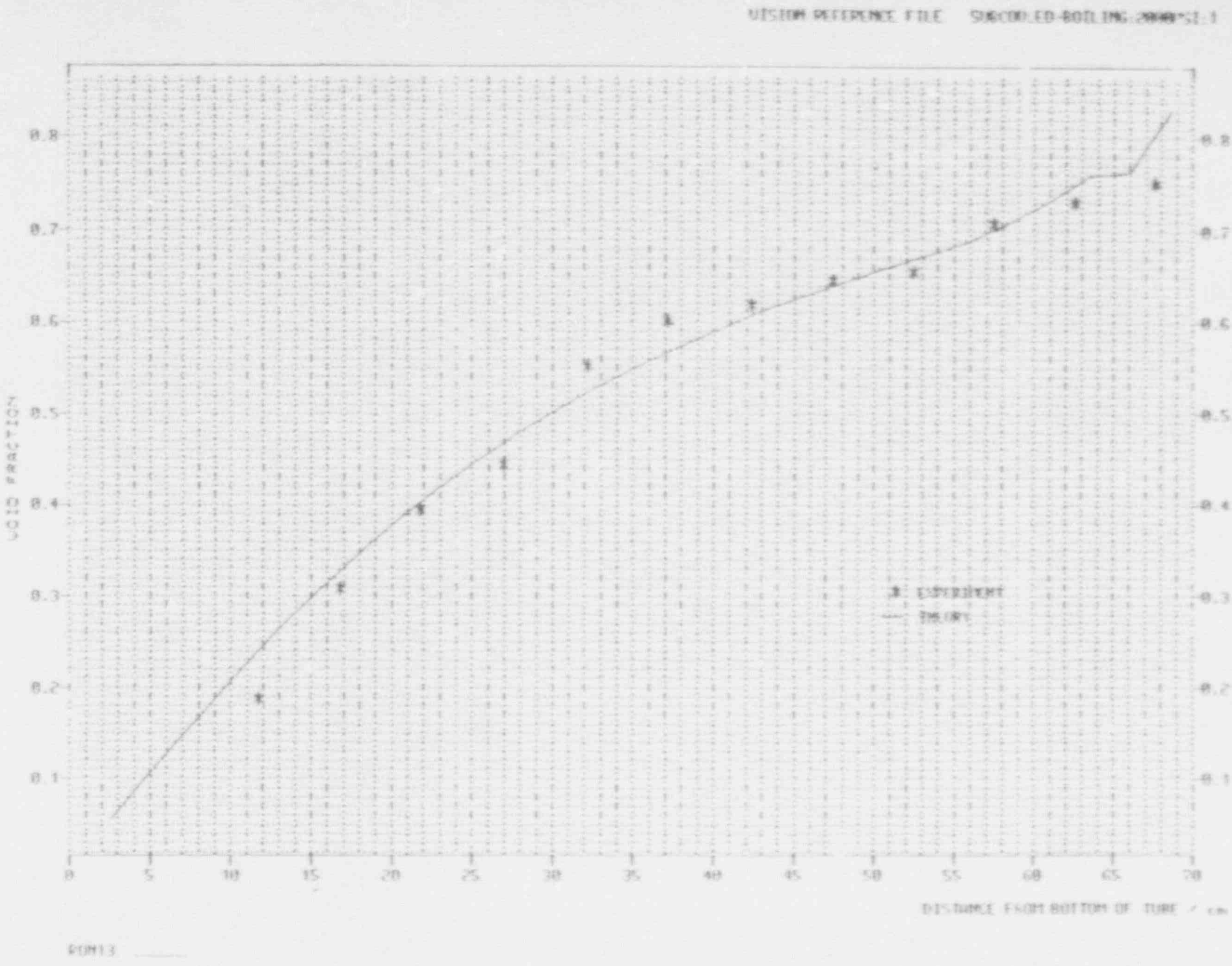
COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH CHRISTENSEN RUN16

FIGURE 7



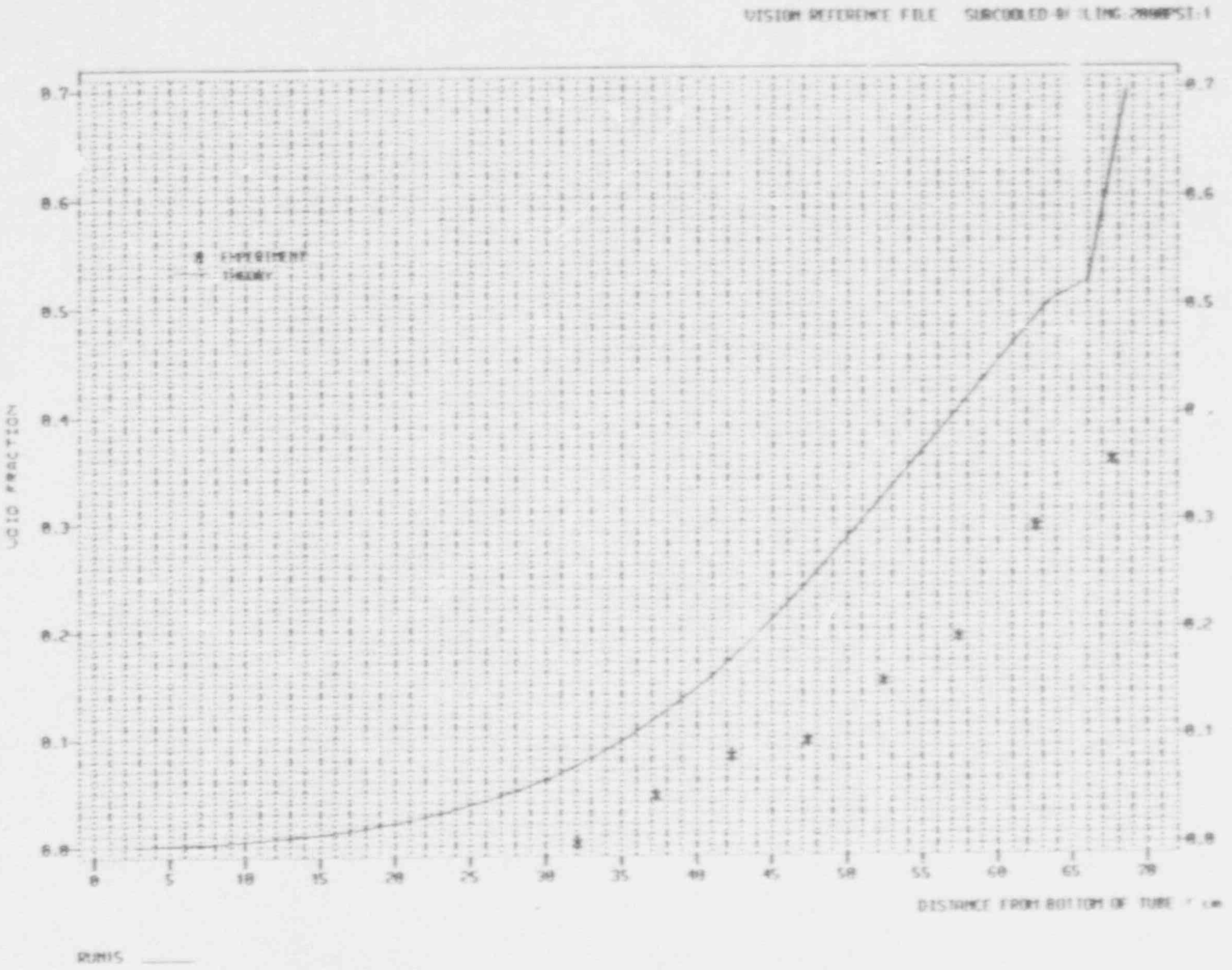
COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH EGEN RUN7

FIGURE 8



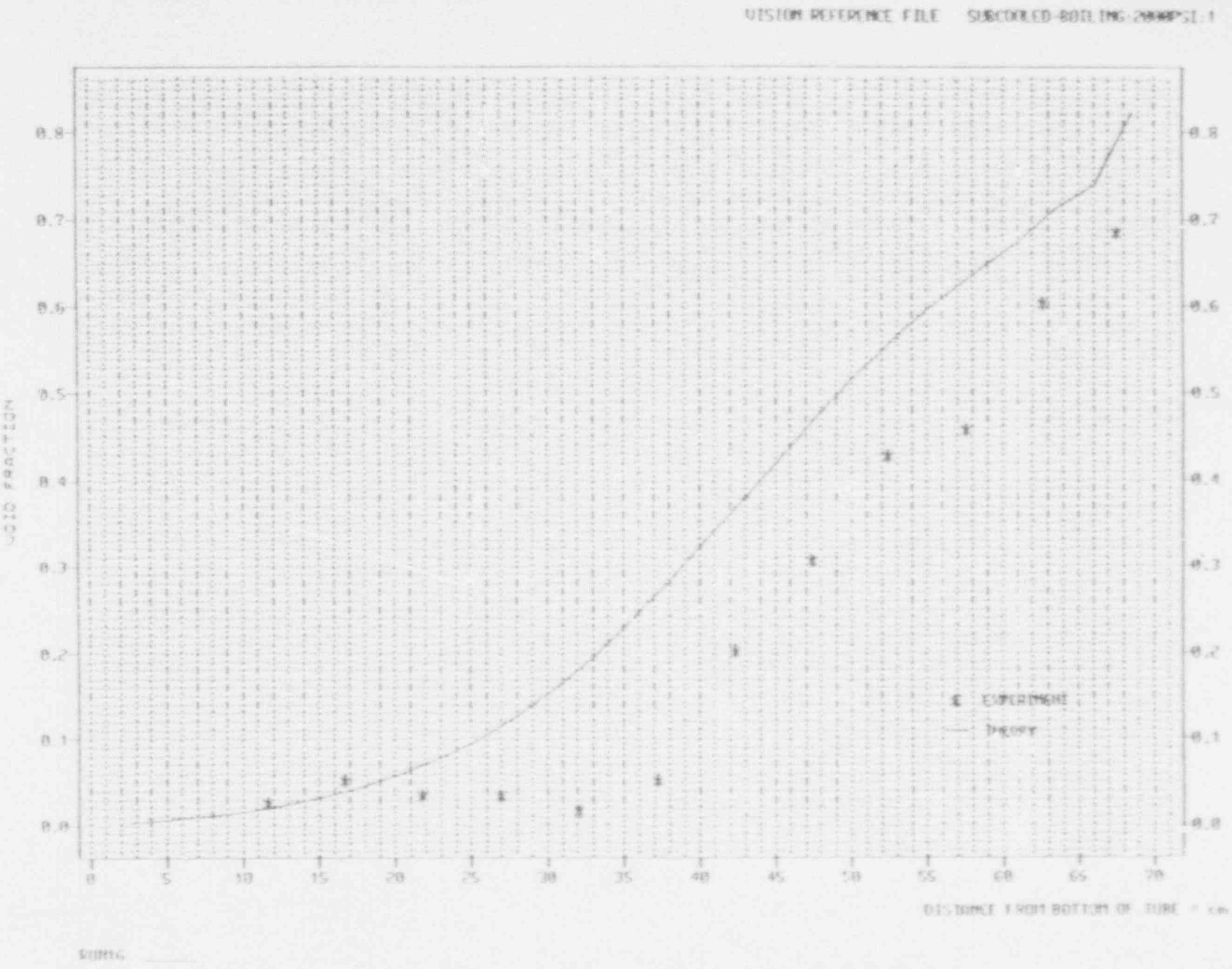
COMPARISON OF RELAP5/MOD2 (36.05 E03) WITH EGEN RUN13

FIGURE 9



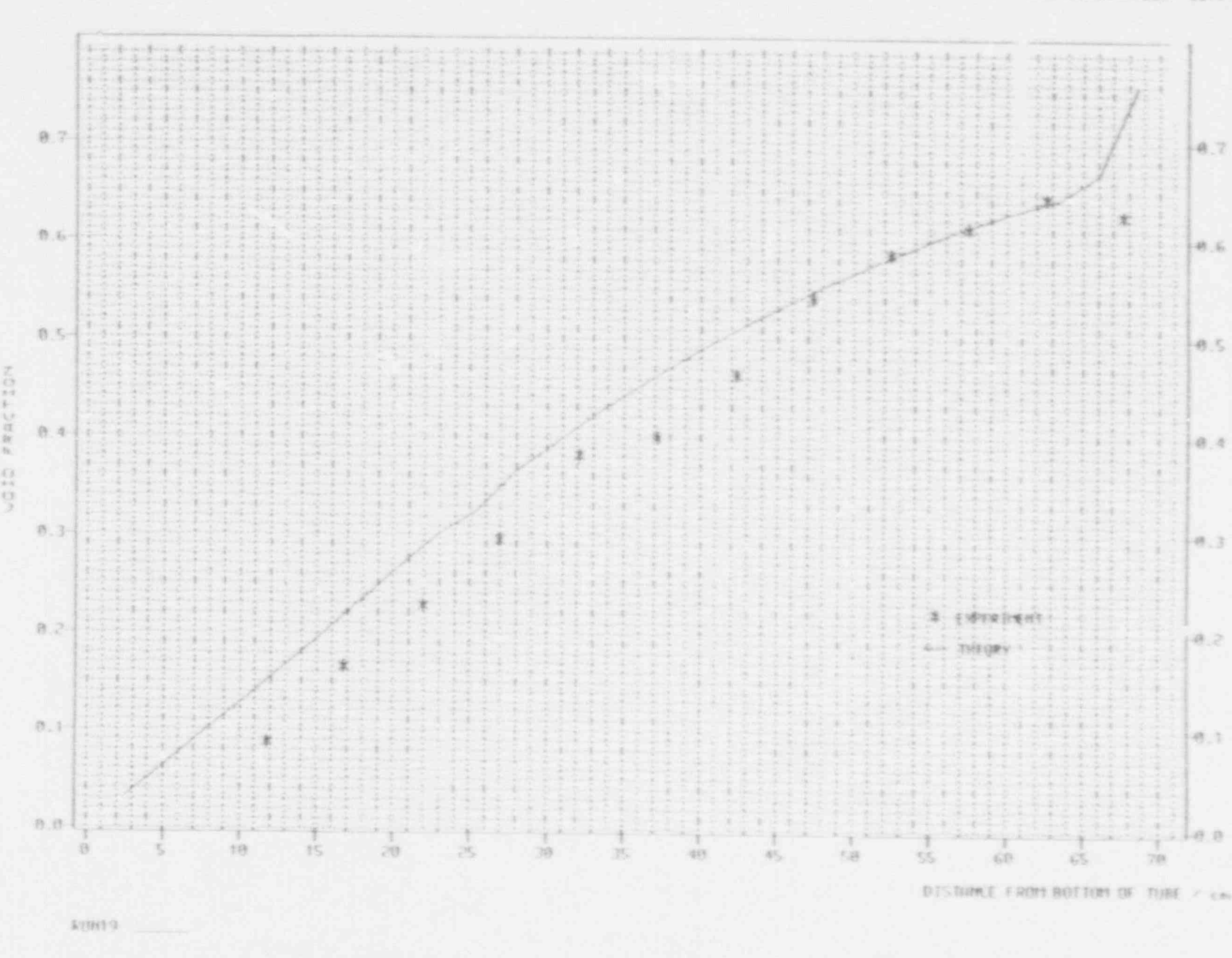
COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH EGEN RUN15

FIGURE 10



COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH EGEN RUN16

FIGURE 11



COMPARISON OF RELAP5/MOD2 (36.05, E03) WITH EGEN RUN19

FIGURE 12

NODAL DIAGRAM FOR CHRISTENSEN EXPERIMENT

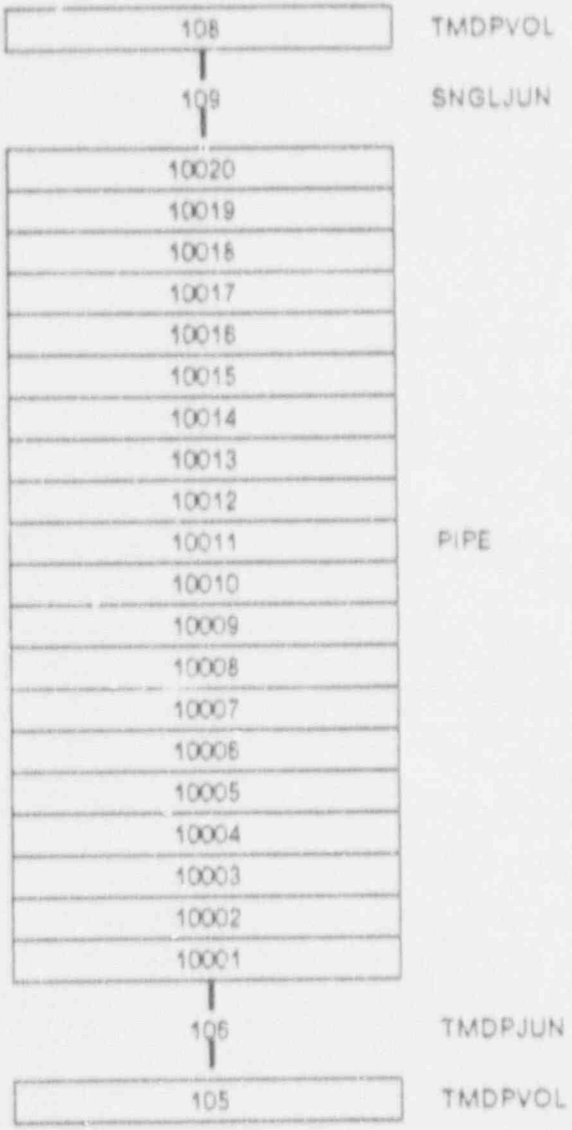


FIGURE 13

NODAL DIAGRAM FOR EGEN EXPERIMENT

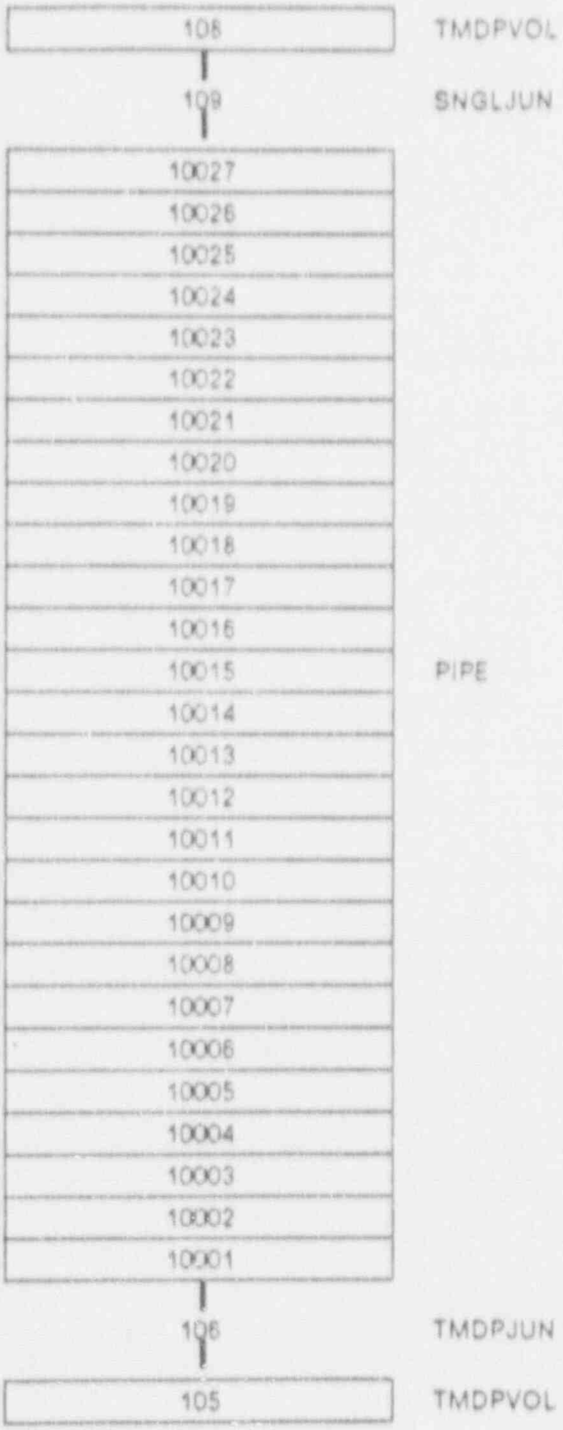


FIGURE 14

APPENDIX 1 RELAP5/Mod2 INPUT FOR THE CHRISTENSEN EXPERIMENT

```
=CARL09   CHRISTENSEN SUB-COOLED BOILING EXPERIMENT
0000100 NEW TRANSNT
0000102 SI SI
0000105 2.0   5.0
*       REF VOL   ELEV  FLUID  NAME
0000120 100010000   0.0  WATER PRIMARY
*       ETIME MINTS RTS FLAG MN MJR RSTART
0000201  10.0 1.0-7 0.1 0003  2  50  100
0000202 100.0 1.0-7 0.1 0003 20 500 1000
*----------------------------------------------------------
0000301 VOIDG 100010000
0000302 VOIDG 100020000
0000303 VOIDG 100030000
0000304 VOIDG 100040000
0000305 VOIDG 100050000
0000306 VOIDG 100060000
0000307 VOIDG 100070000
0000308 VOIDG 100080000
0000309 VOIDG 100090000
0000310 VOIDG 100100000
0000311 VOIDG 100110000
0000312 VOIDG 100120000
0000313 VOIDG 100130000
0000314 VOIDG 100140000
0000315 VOIDG 100150000
0000316 VOIDG 100160000
0000317 VOIDG 100170000
0000318 VOIDG 100180000
0000319 VOIDG 100190000
0000320 VOIDG 100200000
*----------------------------------------------------------
0000000 TUBE PIPE
0000001 20 * NVOLS
0000101 4.9284E-4 20 * VAREA  +  NV
0000201 4.9284E-4 19 * JAREA  +  NJ
0000301 6.35E-2 20 * VLENGTH  +  NV
1000401  0   20 * VVOL  +  NV
1000601  +90. 20 * INC-ANGLE  +  NV
1000801 4.E-5 0.01776 20 * ROUGHNESS  +  HYD DIA(4A/P)  +  NV
1001001 00  20 * FRICTION.EQUILIB  +  NV
1001101 00000 19
1001201 103 2.7579E+6 499.5 0.0 0.0 0.0 20 * PRESSURE  +  TEMP
1001301 0.77 0.77 0. 19 * LIQUID VEL  +  VAPOUR VEL
*----------------------------------------------------------
1050000 BOTTOM TMDPVOL
1050101 1.0E+6   1.0  1.0E+6
1050102 0. 0. 0. 0. 0. 10
1050200 103
1050201 0.0 2.7579E+6 499.5208
*----------------------------------------------------------
1060000 BOTTOM TMDPJUN
1060101 105000000 100000000 4.9284E-4
1060201 0 0.77 0.77 0.
```

```
1080000 TOP TMDPVOL
1080101 1.0E+6 1.0  1.0E+6 * VAREA + VLENGTH + VVOL
1080102 0. 0. 0. 0. 0. 10
1080200 103
1080201 0.0 2.7579E+6 499.5 * T'ME  +  PRESSURE  +  TEMPERATURE
*-----------------------------------------------
1090000 TOP SNGLJUN
1090101 100010000 108000000 4.9284E-4 0.0 0.0 31000
1090201 0.0.77 0.77 0.
*-----------------------------------------------
* heat structures

*          NH    NP    GEOM    STDY    LCO-ORD
11001000     20    4     2       1      1.25E-2
*          MLFLAG  MFFLAG
11001100      0       1
*          N-INT
11001101      3    1.34E-2
*          COMP     N-INT
11001201      1       3
*          SOURCE   N-INT
11001301      1.      3
*          TEMP     N-MESH
11001401      499.5    4
*          LBOUND   INC      BTYPE   SA   LEN  HSNO
11001501     100010000 000010000 1      1  8.9565E-2 20
*          RBOUND     INC   TYPE   SA   LEN      HSNO
11001601     -939         0   3949    1  8.9565E-2    20
*         S-TYPE   IS-MULT  DHLEFT DHRIGHT  HSNO
11001701      999      0.05     0.0      0.0    20
*          CHF      HY-DIAM  H-DIAM  LEN      HSNO
11001801       0     0.01776    0.0    0.0      20
* MATERIAL 1    S-STEEL
20100100 TBL/FCTN  1   1
20100101 273.15  12.98
20100102 1199.82 25.1
20100151 273.15  3.83E6
20100152 366.5  3.83E6
20100153 477.59 4.190E6
20100154 588.59 4.336E6
20100155 699.82 4.504E6
20100156 810.93 4.639E6
20100157 922.04 4.773E6
20100158 1144.26 5.076E6
20100159 1366.5  5.376E6
20100160 1477.59 5.546E6
*---------------------
20299900 POWER
20299901 0.0  30.E+3
20299902 1.0E+10  30.E+3
*---------------------
20293900 TEMP
20293901 0.0  499.5
*---------------------
20294900 HTC-T
20294901 0.0 0.0
  * END
```

APPENDIX 2 RELAP5/Mod2 INPUT FOR THE EGEN EXPERIMENT

```
=CARL09   SUB-COOLED BOILING EXPERIMENT AT 2000 psi
0000100 NEW TRANSNT
0000102 SI BRITISH
0000105 2.0   5.0
*       REF VOL   ELEV  FLUID  NAME
0000120 100010000   0.0  WATER PRIMARY
*      ETIME MINTS RTS FLAG MN MJR RSTART
0000201  10.0 1.0-7 0.1 0003  2  5    100
0000202 100.0 1.0-7 0.1 0003 20 5     000
*-----------------------------------------     -----
0000301 VOIDG 100010000
0000302 VOIDG 100020000
0000303 VOIDG 100030000
0000304 VOIDG 100040000
0000305 VOIDG 100050000
0000306 VOIDG 100060000
0000307 VOIDG 100070000
0000308 VOIDG 100080000
0000309 VOIDG 100090000
0000310 VOIDG 100100000
0000311 VOIDG 100110000
0000312 VOIDG 100120000
0000313 VOIDG 100130000
0000314 VOIDG 100140000
0000315 VOIDG 100150000
0000316 VOIDG 100160000
0000317 VOIDG 100170000
0000318 VOIDG 100180000
0000319 VOIDG 100190000
0000320 VOIDG 100200000
0000321 VOIDG 100210000
0000322 VOIDG 100220000
0000323 VOIDG 100230000
0000324 VOIDG 100240000
0000325 VOIDG 100250000
0000326 VOIDG 100260000
0000327 VOIDG 100270000
*--------------------------------------------------------
0000000 TUBE PIPE
0000001 27 * NVOLS
0000101 6.650E-5 27 * VAREA  +  NV
0000201 6.650E-5 26 * JAREA  +  NJ
0000301 2.54E-2 27 * VLENGTH  +  NV
1000401  0   27 * VVOL  +  NV
1000601  +90  27 * INC-ANGLE  +  NV
1000801 4.E-5 4.7473E-3 27 * ROUGHNESS  +  HYD DIA(4A/P)  +  NV
1001001 00  27 * FRICTION,EQUILIB  +  NV
1001101 00000 26
1001201 103 1.379E+7 602.0 0.0 0.0 0.0 27 * PRESSURE  +  TEMP
1001300 1 * flag for flows
1001301 7.479E-2 7.479E-2 0. 26 * LIQUID FLO  +  VAPOUR FLO
*--------------------------------------------------------
1050000 BOTTOM TMDPVOL
1050101 1.0E+6   1.0  1.0E+6
1050102 0. 0. 0. 0. 0. 10
1050200 103
1050201 0.0 1.379E+7 602.0400
```

```
1060000 BOTTOM TMDPJUN
1060101 105000000 100000000 6.6500E-4
1060200 1 * flow flag
1060201 0 7.4798E-2 7.4798E-2 0.
*------------------------------------------------
1080000 TOP TMDPVOL
1080101 1.0E+6 1.0  1.0E+6 * VAREA+VLENGTH+VVOL
1080102 0. 0. 0. 0. 0. 10
1080200 103
1080201 0.0 1.379E+7 602.04 * TIME  +  PRESSURE  +  TEMPERATURE
*---------------------------------------------
1090000 TOP SNGLJUN
1090101 100010000 108000000 6.6500E-4 0.0 0.0 31000
1090201 1 7.4798E-2 7.4798E-2 0.
*---------------------------------------------
* TUBE        heat structures
*           NH    NP    GEOM    STDY    LCO-ORD
11001000      27    4     2       1      4.5992E-3
11001100       0      1
11001101       3    5.4992E-3 * assumes .09 cm thick
11001201       1      3
11001301       1.     3
*           TEMP     N-MESH
11001401      602.04   4
            LBOUND   INC      BTYPE   SA    LEN  HSNO
11001501     100010000 000010000 1       1  4.9253E-2 27
*           RBOUND      INC   TYPE   SA   LEN      HSNO
11001601     -939          0   3949    1  4.9253E-2    27
*          S-TYPE   IS-MULT  DHLEFT DHRIGHT  HSNO
11001701      900      0.03704    0.0      0.0    27
*           CHF     HY-DIAM  H-DIAM  LEN      HSNO
11001801       0     4.7473E-3    0.0    0.0     27
* MATERIAL 1    S-STEEL
20100100 TBL/FCTN  1   1
20100101 273.15  12.98
20100102 1199.82 25.1
20100151 273.15  3.83E6
20100152 366.5  3.83E6
20100153 477.59 4.190E6
20100154 588.59 4.336E6
20100155 699.82 4.504E6
20100156 810.93 4.639E6
20100157 922.04 4.773E6
20100158 1144.26 5.076E6
20100159 i366.5  5.376E6
20100160 1477.59 5.546E6
*--------------------
20290000 POWER
20290001 0.0  2.387E+4
20290002 1.0E+10  2.387E+4
*--------------------
20293900 TEMP
20293901 0.0  602.04
*--------------------
20294900 HTC-T
20294901 0.0 0.0
 * END
```

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11. ABSTRACT (200 words or less)

In order to test the ability of RELAP5/MOD2 to describe sub-cooled nucleate boiling under conditions similar to those anticipated during intact circuit fault scenarios in pressurized water reactors the code has been assessed against results of high pressure sub-cooled boiling experiments reported in literature.

It is concluded that RELAP5/MOD2 can be applied with reasonable confidence to the prediction of sub-cooled boiling void fraction for conditions expected during PWR intact circuit faults.

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ASSESSMENT OF SUBCOOLED BOILING MODEL USED IN RELAP5/MOD2
(CYCLE 36.05, VERSION E03) AGAINST EXPERIMENTAL DATA

MARCH 1992