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TRAC-PF1/MOD1 Independent Assessment: NEPTUNUS Pressurizer Test Y05

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ABSTRACT

The TRAC independent assessment project at Sandia National Laboratories is part of an overall effort funded by the NRC to determine the capability of various system codes to predict the detailed thermal/hydraulic response of light water reactors during accident and off-normal conditions. The TRAC computer code is being assessed at SNLA against test data from various integral and separate effects test facilities. As part of this assessment effort, a separate effects component test performed in the NEPTUNUS pressurizer test facility, located at the Laboratory for Thermal Power Engineering at Delft University of Technology, was analyzed with TRAC-PF1/MOD1. The test simulated insurges, combined with spray flow, and outsurges from a pressurizer, and was selected for code assessment because the capability of the computer codes used in safety analyses to calculate the correct pressurizer response is an important concern of the NRC.

Our TRAC-PF1/MOD1 results showed that somewhat higher pressures and fluid temperatures were calculated during insurges with spray flow than were measured in the test. A contributing factor to the calculation of high pressures and fluid temperatures appears to be that the interfacial heat transfer from superheated vapor to subcooled liquid was too low.

Sensitivity studies were performed on both the maximum time step size used and the type of components and number of cells used to simulate the test vessel. When the maximum time step was not controlled, liquid temperatures in the volumes into which the spray was flowing were lower than the initial temperature of the spray, which was the coldest liquid in the vessel. However, the calculation of unrealistically low fluid temperatures in some volumes did not affect the system pressure response or the fluid temperatures near the vapor-to-liquid interface. Nearly identical results were calculated when the test vessel was modeled with a single PRIZER (using 4 and 13 cells), 2 PRIZERs and 1 PIPE, and 3 PIPE components.

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ACKNOWLEDGEMENTS

I would like to express my thanks to the following individuals for their support in the TRAC assessment project: Mildred Elrick for maintaining TRAC-PF1/MOD1 on the Sandia computer system and for graphics support and Jan Frey for final preparation of the report.

1.0 INTRODUCTION

The TRAC independent assessment project at Sandia National Laboratories in Albuquerque (SNLA) is part of an overall effort funded by the U. S. Nuclear Regulatory Commission (NRC) to determine the capability of various system codes to predict the detailed thermal/hydraulic response of light water reactors (LWRs) during accident and off-normal conditions.

The TRAC-PF1/MOD1 computer code [1] has a full two-fluid, nonequilibrium hydrodynamics model with a flow-regime-dependent constitutive equation treatment. TRAC is under development at the Los Alamos National Laboratory (LANL). Earlier versions of TRAC (TRAC-P1A and TRAC-PD2) were primarily designed to simulate large break loss-of-coolant accidents. TRAC-PF1/MOD1 has additional models to allow simulation of a wide range of accidents relevant to current licensing issues. The version used for the analyses reported here is TRAC-PF1/MOD1 version 11.1.

The TRAC computer code is being assessed at SNLA against test data from various integral and separate effects test facilities. A separate effects component test, Y05, from the NEPTUNUS pressurizer test facility located in the Laboratory for Thermal Power Engineering at the Delft University of Technology in the Netherlands was included in the tests to be analyzed by SNLA. Test Y05 simulated successive insurges, combined with spray, and outsurges in a pressurizer.

This report summarizes our TRAC-PF1/MOD1 analyses of NEPTUNUS test Y05. The facility and test are described in Section 2, and the TRAC models used for the analyses are presented in Section 3. The calculational results for tne base analysis and some modeling studies are discussed in Section 4. A summary and conclusions are given in Section 5. A TRAC-PF1/MOD1 input listing of the base case model is provided in Appendix I.

2.0 FACILITY AND TEST DESCRIPTION

This section describes the test facility and the test conditions, both of which were obtained from a paper by H. A. Bloemen in which an analysis of test Y05 using RELAP5/MOD1 was discussed [2].

The NEPTUNUS pressurizer test facility is about 1/40-scale on a volume basis, and consists of a pressure vessel with a surge line at the bottom and a spray line at the top. The basic flow paths in the facility are shown in Figure 2.1. The flow in the spray line was controlled by a pump connected to a vessel containing hot water. The surge line was connected through a buffer vessel to a cold water vessel pressurized with nitrogen. The flow in the surge line was controlled by varying the nitrogen pressure. The buffer vessel was used to keep a boundary between the hot (548 K) water surging into and out of the pressurizer and the cold (ambient) water in the vessel pressurized with nitrogen. The boundary between the hot and cold fluid was kept in the buffer vessel to prevent thermal shock to the system piping. The spray line and surge line nozzles contained thermal sleeves to prevent thermal shock to the vessel. The flows and fluid temperatures in each line were measured.

The geometric details of the carbon steel test vessel are shown in Figure 2.2. The vessel was 2.51 m high and 0.8 m in diameter. The surge line nozzle diameter was 0.084 m and the spray line nozzle diameter was 0.027 m. Heater elements with a total power of 17 kW were installed to compensate for environmental heat losses.

The test was initiated with the vessel partially filled (to a level of 1.12 m) with water at 600 K; then an insurge of 548 K water flowed into the vessel, followed shortly by the initiation of spray flow. The temperature of the spray varied from 500 K to 591 K. The test consisted of four successive insurges, combined with spray flow, and outsurges. The magnitude and timing of the spray and surge line flows are shown in Figure 2.3.

The measured data in the vessel were very limited. One pressure and four fluid temperatures were all that were reported [2]. These data were digitized from the report for comparison with our calculations. The exact location of the measurements was not documented, but in Bloemen's report they were compared with calculated results between the 1.52 m and 1.72 m elevations. These same elevations were used for comparisons in our analyses.

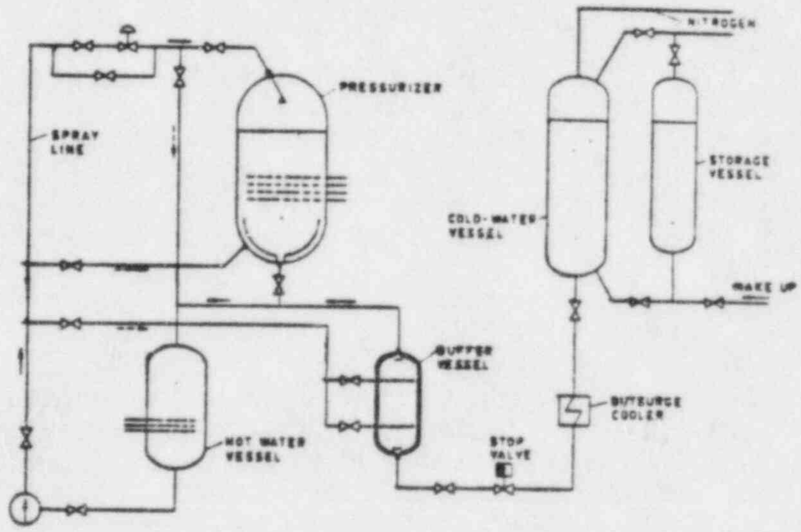


Figure 2.1 NEPTUNUS Test Facility

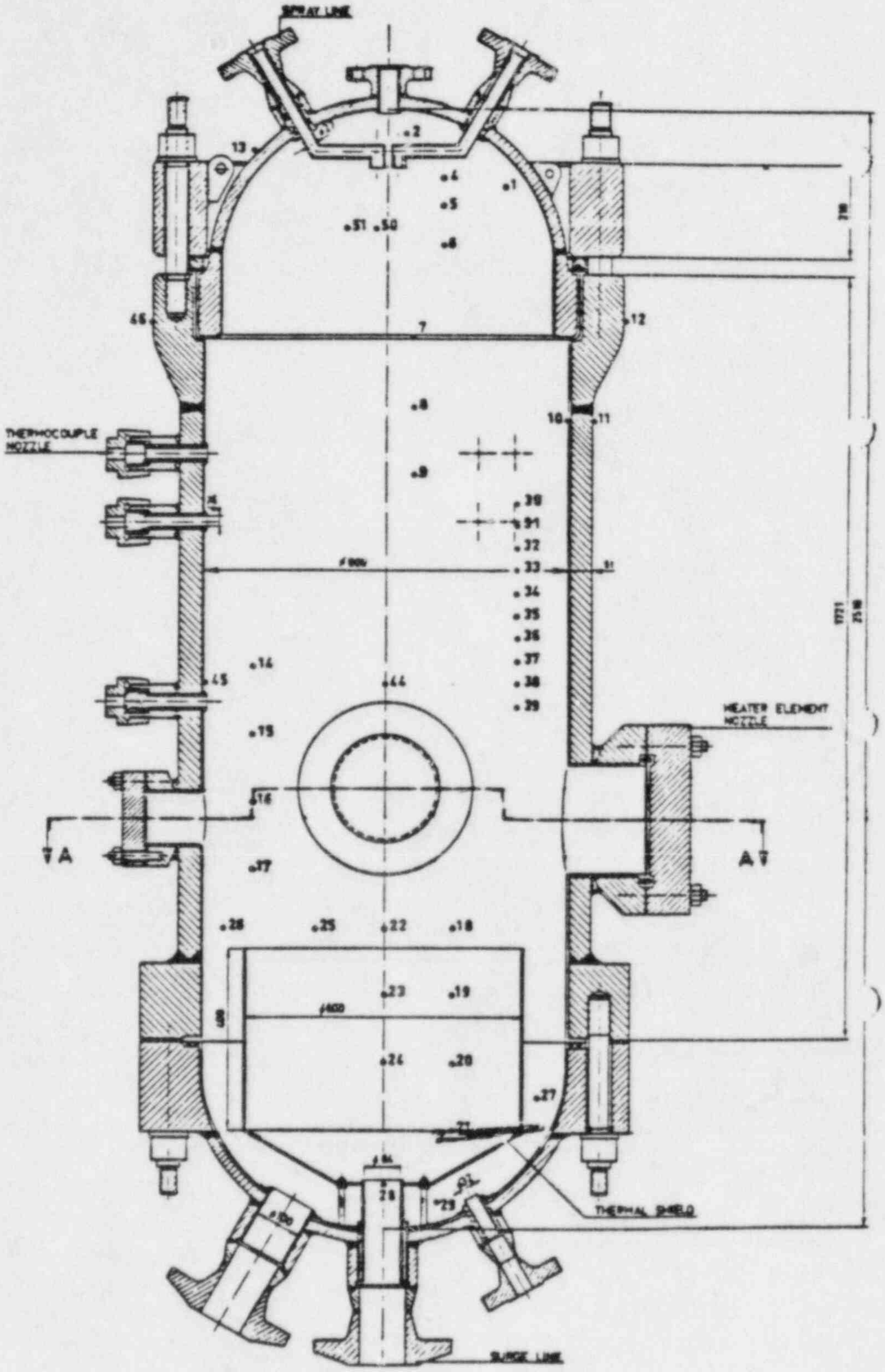


Figure 2.2 NEPTUNUS Test Vessel

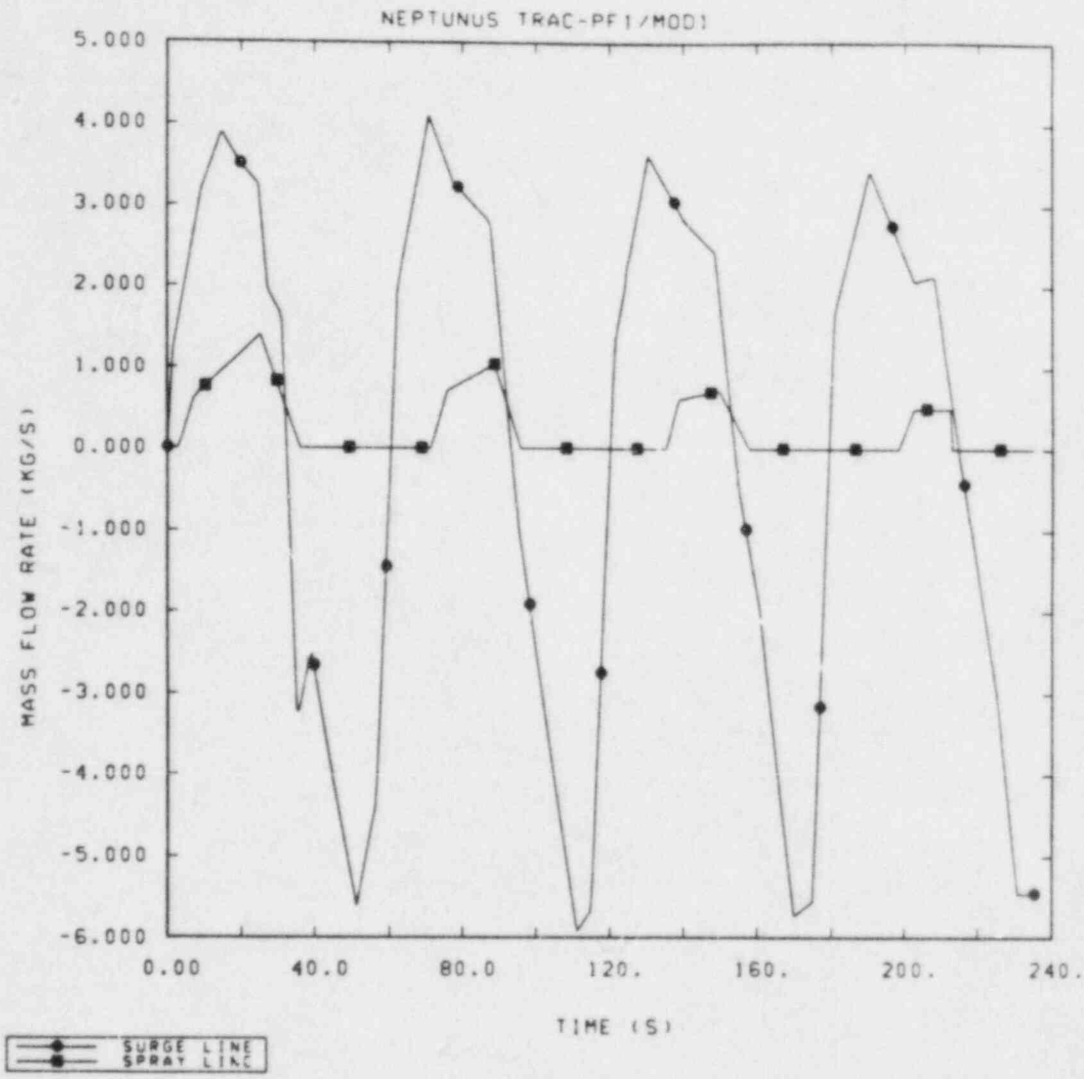


Figure 2.3 Measured Spray and Surge Line Flows

3.0 TRAC-PF1/MOD1 MODELS

This section describes the TRAC-PF1/MOD1 models used for our analyses of NEPTUNUS test Y05. The TRAC input was developed from the RELAP5/MOD1 input reported by H. A. Bloemen [2]. However, there are two differences in the models: (1) the RELAP5 model did not account for the pressurizer heaters or the environmental heat losses and (2) a spray line area that seemed to be too small was used in the RELAP5 analysis.

Several slightly different models for this simple test were used. The models differed in the type of components used for the test vessel and in the number of cells used. The TRAC computer code has a PRIZER component to model pressurizers in LWRs. When this analysis was begun, the test vessel was modeled with a single PRIZER component with 13 cells. A 4-cell model using a single PRIZER was also used for a noding study. The relative lengths of the cells for the two single PRIZER models are shown in Figure 3.1. For these models, the 17 kW of energy from the heaters was input as a heat source through the wall at the elevation of the heaters. The 17 kW of environmental heat loss from the vessel were accounted for by applying a heat transfer coefficient of 8.9 kW/m^2 from the outside walls.

The PRIZER component distributes the energy throughout all the liquid present, rather than only at the location of the heaters, if its heater model is used. A better simulation of the energy input from the heaters would put the energy directly into the coolant at the location of the heaters. With a single PRIZER component, this could only be done by using heat sources in appropriate cell walls. Therefore, the test vessel was next modeled with multiple components that included a PIPE, so that the 17 kW from the heaters could be input directly into the coolant only at the elevation of the heaters. This model was our base case model.

The model used for the base analyses is shown in Figure 3.2. The total model consisted of five components. Two PRIZERs and a one-cell PIPE modeled the test vessel and two FILLs supplied the surge line and spray line flow boundary conditions. A calculation was also performed using PIPE components in place of the two PRIZER components. The same environmental heat loss was used in both of these models as was used for the single PRIZER models.

The spray line flow was modeled with a FILL using the generalized state versus time option, so that both the flow rate and temperature could be varied as occurred in the test. The diameter for the spray line FILL was taken from Figure 2.2, which gave an area of 5.7225E-4 m^2, rather than the value of 4.016E-6 m^2 used by Bloemen [2]. The area reported by Bloemen resulted in spray velocities of up to 432 m/s, which we thought were too high. We did perform a calculation using the same spray velocity as in the RELAP5 model and the calculated pressure and temperature were nearly the same as with the lower velocity; however, the code had many TF1D failures with the higher velocity. Since the temperature of the surge line flow did not vary, it was modeled with a FILL using the velocity versus time option.

Appendix I contains an input listing for the final base model.

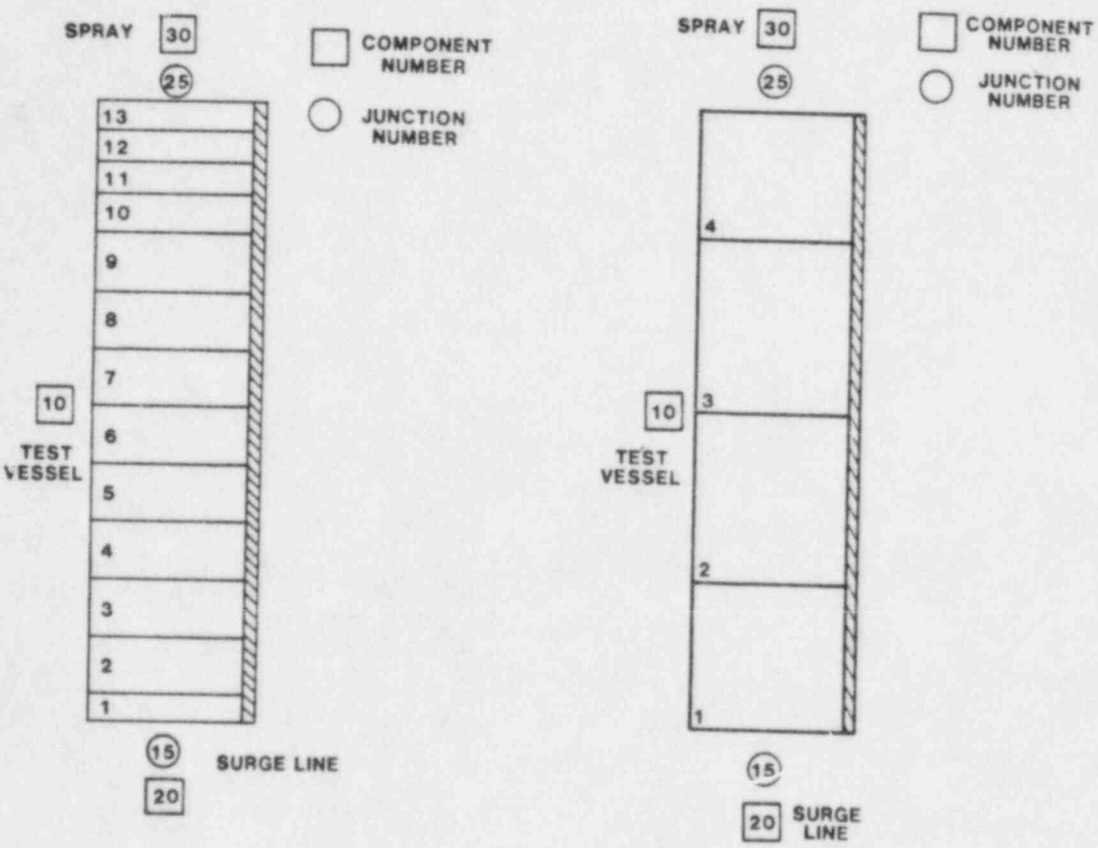


Figure 3.1 Noding Diagram for 13-Cell and 4-Cell Single PRIZER Models

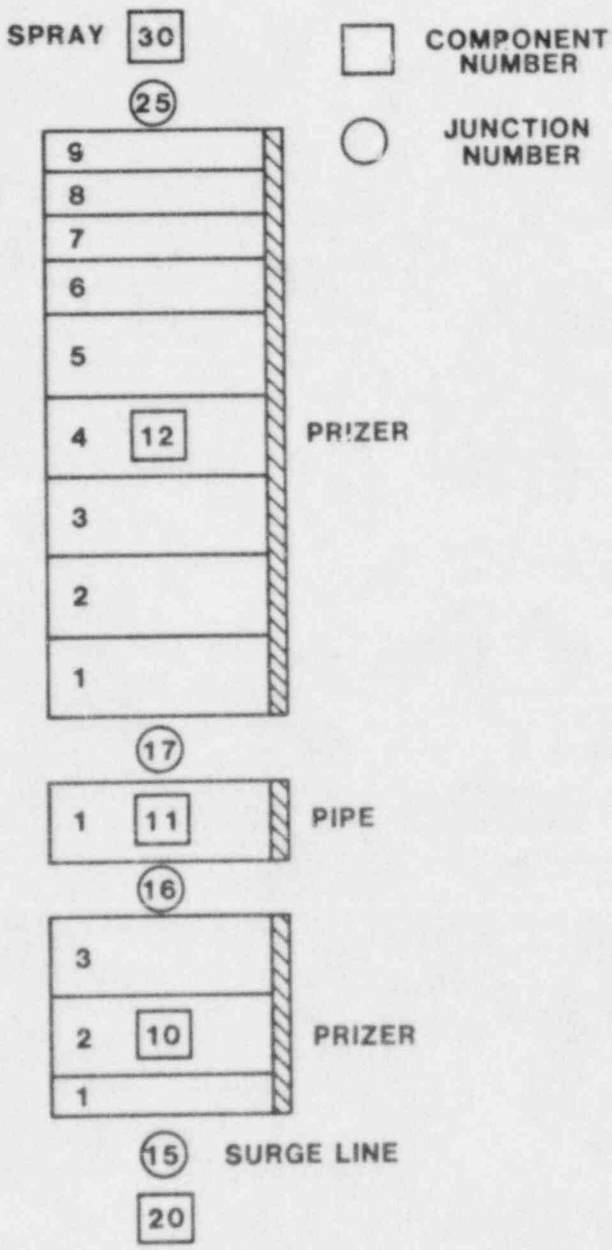


Figure 3.2 Noding Diagram for Base Model

4.0 RESULTS

Section 4.1 presents the results of our TRAC-PF1/MOD1 calculations with the base model and comparisons with the limited data. The data correspond to the elevation of cell 5 of component 12 shown in Figure 3.2. The modeling studies that were performed are presented in Section 4.2. Section 4.3 summarizes the computational speed for the calculations.

4.1 Base Analysis

As previously discussed, the base analysis was performed with the test vessel modeled by two PRIZERs and one PIPE component. Figure 4.1.1 compares the calculated and measured pressures in the test vessel during the transient. The results show that the calculated pressure increases during insurges and decreases during outsurges were larger than were measured. There was, however, good agreement in the minimum pressure reached during the outsurges. In the test, the rate of increase in pressure during the insurges decreased quickly after the initiation of spray flow, and the overall increase in pressure stopped a few seconds later. In the calculation, the pressure did not appear to stop increasing until there was a significant decrease in surge line flow.

The calculated and measured saturation and fluid temperatures are compared in Figure 4.1.2. Three measurements of the fluid temperatures are shown and indicate some variation in the response. (The difference in the location of the measurements was not reported.) In both the test and the calculation, the vapor was superheated during the insurges and saturated during the outsurges. Similar to the results from the pressure comparisons, the calculated temperatures were higher than measured during insurges. The calculated fluid temperature increased at a much more rapid rate than the measured temperatures, while the calculated saturation temperature changed at a rate more similar to the measured value. The difference between the calculated and measured peak temperatures during periods of flow into the pressurizer increased for each successive insurge. The probable reason for this increase in the difference in peak temperatures was that the time from the initiation of the insurge until the start of spray flow increased with each of the insurges. Since the calculated fluid temperature did not start to decrease until the initiation of spray flow, there was a longer time period for the temperature to increase before it was turned around by the spray flow, resulting in a higher calculated temperature.

The calculated void fractions in the 9 cells of the upper PRIZER (component 12) are shown in Figure 4.1.3. Examining this figure shows that the void fractions in cells 5 through 9 were always nearly 1.0, indicating that these cells were essentially steam-filled for the entire transient. As indicated by the change in void fractions, the liquid level moved up into cell 4 during insurges and dropped back into cell 3 during outsurges. No measurements of the liquid level were reported.

The calculated interfacial and heat structure heat flows in cells 9, 7, and 5 of component 12 (the upper PRIZER component) are shown in Figures 4.1.4 through 4.1.6, respectively. Positive values of the interfacial heat flow indicate the transfer of energy from the vapor to the liquid; negative values indicate heat flow from the liquid to the vapor. The interfacial heat flow was mostly positive during insurges and spray flow and negative during outsurges. Positive values of the slab heat flow indicate a net energy transfer from the slab to the fluids (liquid and vapor), whereas negative values indicate flow from the fluids to the slab. The heat transfer between the wall and the vapor was the dominant factor in the net energy flow for the slab. The slab heat flow was negative during spray flow and slightly positive during outsurges. For each of the cells shown, the interfacial heat transfer was much larger than the heat transfer at the vessel structures during insurges with spray flow, except for the first insurge.

The heat flow at the slabs was nearly the same in all three cells, whereas, except for a brief period at 80 s in cell 9, the peak interfacial heat transfer increased from cell 9 down toward cell 5, where the highest interfacial heat transfer in the vessel was calculated. The total interfacial heat transfer is calculated from an interfacial heat transfer coefficient and an interfacial area. The fact that the initiation of spray flow in the calculation did not quickly turn around the pressure, as occurred in the test, may indicate that the interfacial area and/or interfacial heat transfer coefficient were too small. The largest uncertainty is in the interfacial area and a low value for this area probably caused the apparently low interfacial heat transfer.

The calculated vapor, wall, and saturation temperatures for cell 9 of the upper PRIZER are shown in Figure 4.1.7. The difference between the vapor and saturation temperatures indicates that a significant amount of vapor superheat was calculated during the last three insurges. Examining the figure shows that, during the periods when the vapor was superheated and the saturation temperature was lower than the wall temperature, the wall continued to cool down because the heat flux from the superheated vapor to the inside of the wall was less than the environmental heat loss. When the system saturation temperature increased to above the wall temperature, the heat transfer regime in the calculation changed from convection to single-phase vapor to condensation. This change in heat transfer regime resulted in an increase by a factor of about 100 in the heat transfer coefficient from the vapor to the wall and the wall temperature started to increase. The initiation of spray flow and this change in the heat transfer regime occurred at about the same time; thus, the effect of condensation on the system temperature response could not be identified. As seen in Figure 4.1.7, most of the increases in the vapor temperature occurred when the wall temperature was above the saturation temperature and the heat transfer was between the wall and single-phase vapor.

The measured spray temperature and the calculated liquid and saturation temperatures in the top cell (cell 9) of the upper PRIZER are compared in Figure 4.1.8. Large fluctuations in liquid temperature were calculated during the periods of spray flow and the calculated liquid temperature was lower than that of the spray flowing into the cell, which should be the lowest temperature in the system. These temperature fluctuations and unphysically low values were caused by the large time step the code selected. A maximum time step of 0.25 s was used for most of this calculation and, after the first few seconds, the code selected the maximum time step for the remainder of the calculation. Even though the calculated liquid temperature was too low in cell 9, the calculated liquid temperature increased as the liquid dropped into the test vessel, and by the time the liquid reached cell 6 all of the subcooling was gone. Figure 4.1.9 compares the calculated liquid, saturation and vapor temperatures in cell 6 and shows that the calculated liquid and saturation temperatures there were always nearly equal.

4.2 Modeling Studies

Several modeling studies were performed to determine the sensitivity of the calculated results to changes in the components used to simulate the test vessel. Initial calculations were performed with a single PRIZER component with the energy from the heaters input through the pressurizer wall. Two nodings were used with the single PRIZER component: 13 cells and 4 cells. Subsequent to these initial calculations, we decided that using a PIPE component, in which the energy from the heaters could be deposited directly into the coolant might be a better model, and the calculation was repeated with the overall results discussed in Section 4.1. The original single PRIZER calculations are discussed here to indicate the effect of a coarser noding on the pressure and temperature. The effect of reducing the time step on the results was also determined with the single PRIZER model. Calculations were also run with the test vessel simulated by 3 PIPE components, and with no wall heat transfer in the upper PRIZER of the base model.

The 13-cell PRIZER model was used in the first calculations performed; that noding was a direct conversion from the RELAP5 model reported by H. A. Bloemen [2]. The calculated pressures with the 13-cell PRIZER are compared with those from the final base model in Figure 4.2.1; the measured pressure is also shown for reference. A comparison of the calculations shows that there was no significant difference between the results obtained from the two models. Thus, for this test it was not important to have the energy from the heaters deposited directly into the coolant rather than into and through the vessel walls.

To determine the effect of a coarser noding on the calculated results, the 13-cell calculation was repeated with a 4-cell PRIZER. The pressures calculated with the 4- and 13-cell models and the measured pressure are compared in Figure 4.2.2. There were some small differences in the maximum pressure during insurges, and the minimum pressure with the 4-cell model was slightly lower than with the 13-cell model. These differences in pressure appear to be caused by the calculated fluid temperature at the measurement location being lower with the 4-cell than with the 13-cell model, as shown in Figure 4.2.3. The generally lower temperatures with the 4-cell model result from the calculated void fraction being lower at the measurement elevation with the coarser noding because some liquid flows into this cell during insurges, which did not occur with the 13-cell model.

The calculated liquid temperature in the cell into which the subcooled spray was injected (the top cell in the model) can be too low, as was previously discussed in Section 4.1. A similar result was calculated with the 13-cell PRIZER model, when a maximum time step of 0.25 s was used. The calculation with the 13-cell model was repeated using a maximum time step of 0.05 s. The calculated liquid temperatures for maximum time steps of 0.25 s and 0.05 s are shown in Figure 4.2.4, together with the inlet spray temperature. The fluctuations in liquid temperature to below the spray temperature were not calculated with the reduced time step. The elimination of the unphysically low liquid temperatures did not affect the calculated pressure, which was nearly identical with both maximum time steps.

As previously mentioned, the vessel was also modeled using only PIPE components to determine if there were models unique to the PRIZER component that affected the results. The calculated pressures for the base model and the model using only PIPE components are compared with the measured pressure in Figure 4.2.5. The calculated pressures were nearly identical with both models; the calculated fluid temperatures were also nearly identical.

As a result of a suggestion by the LANL staff [3], the heat slabs were removed from the upper PRIZER component of the base model to see if the heat slabs were removing the subcooling from the spray liquid and thus affecting the calculated pressure. The measured pressure and the calculated pressures using no upper PRIZER heat slabs and using the base model are compared in Figure 4.2.6. The calculated pressure was higher and farther from the data with no heat slabs, contrary to the original idea. Part of this difference in pressure was probably caused by environmental heat losses in the upper PRIZER not being accounted for when there is no wall heat transfer. The calculated interfacial heat flows in cells 9 and 5 for both models are compared in Figures 4.2.7 and 4.2.8, respectively. The calculated interfacial heat flow in each cell was slightly higher without the heat slabs, because the liquid temperatures were slightly lower.

4.3 Computational Speed

TRAC contains an automatic time step control algorithm based on the rate of change of several thermal/hydraulic properties. For this simple test the time step (TS) selected, after the first few seconds, was usually the maximum time step specified in the input. For most of the calculations a maximum time step of 0.25 s was used. A larger maximum time step was not used since unphysically low liquid temperatures, discussed in Sections 4.1 and 4.2, were already being calculated at 0.25 s.

The run time statistics for the various calculations are summarized in Table 4.3.1. All of the transient calculations were run to 235 s on a CDC Cyber-76 computer.

Table 4.3.1 Run Time Statistics

Model	CPU(s)	CPU/#TS (s)	CPU/#TS/Cell (ms)
Base*	103.2	0.088	6.8
PIPEs	93.6	0.086	6.6
13-Cell PRIZER	76.7	0.071	5.5
13-Cell PRIZER (MAX TS=0.05 s)	278.9	0.059	4.6
4-Cell PRIZER	52.0	0.048	12.0

* maximum time step reduced to 0.05 s from 225 s to 235 s to eliminate convergence difficulty

Since these were very simple models that required little CPU time to run, no attempts were made to optimize the calculational speed. The number of components, signal variables and control blocks was increased for the base and 3-PIPE models, which increased the CPU time for these models compared to the other models. Decreasing the maximum time step by a factor of 5 increased the total CPU time by a factor of 3.6. The total number of time steps increased by about a factor of 5 with the lower maximum time step; however, less CPU/#TS was required. The simplest model, a 4-cell PRIZER, required the least CPU time, but had the largest CPU/#TS/CELL.

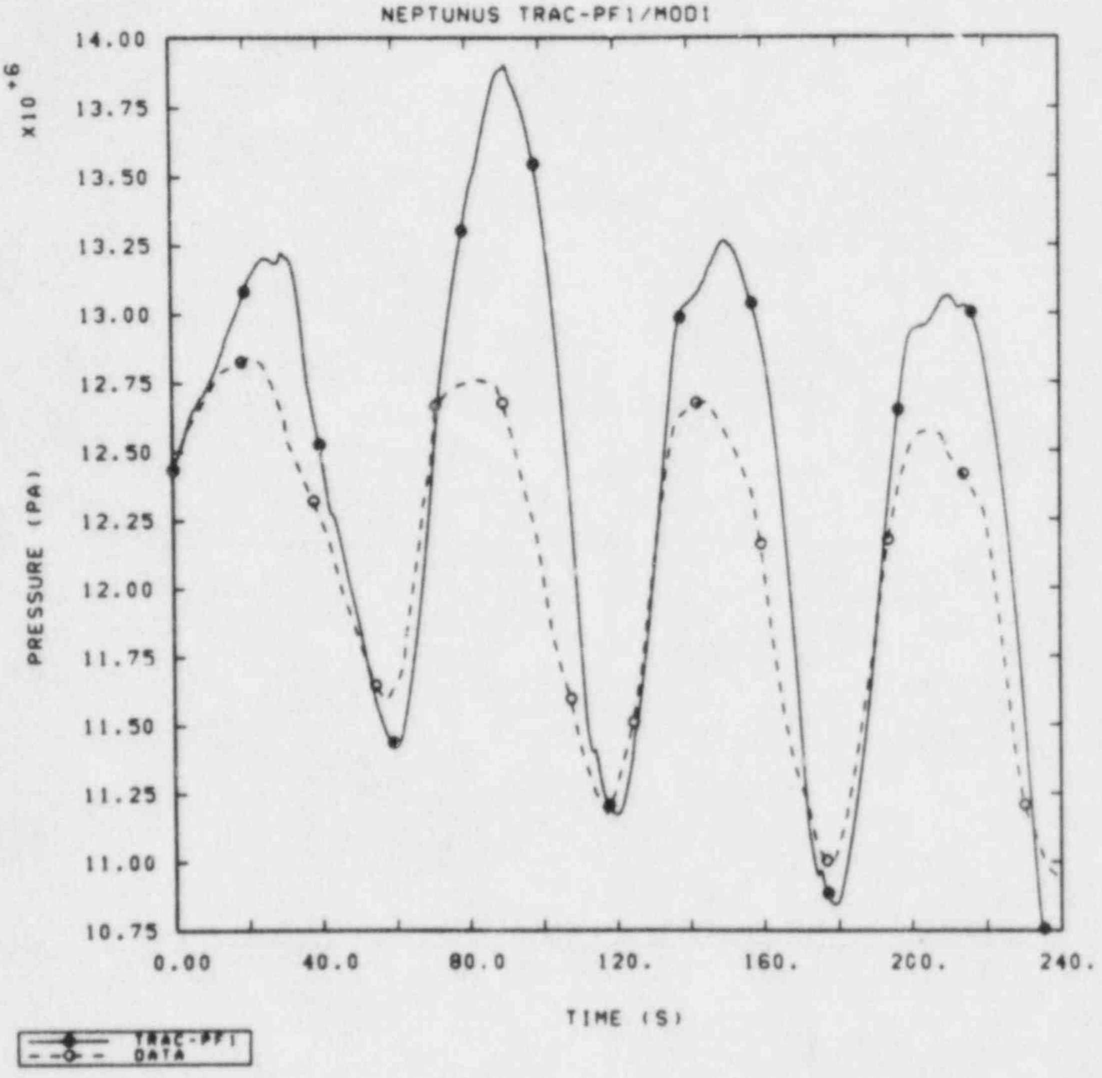


Figure 4.1.1 Comparison of Calculated and Measured Pressures

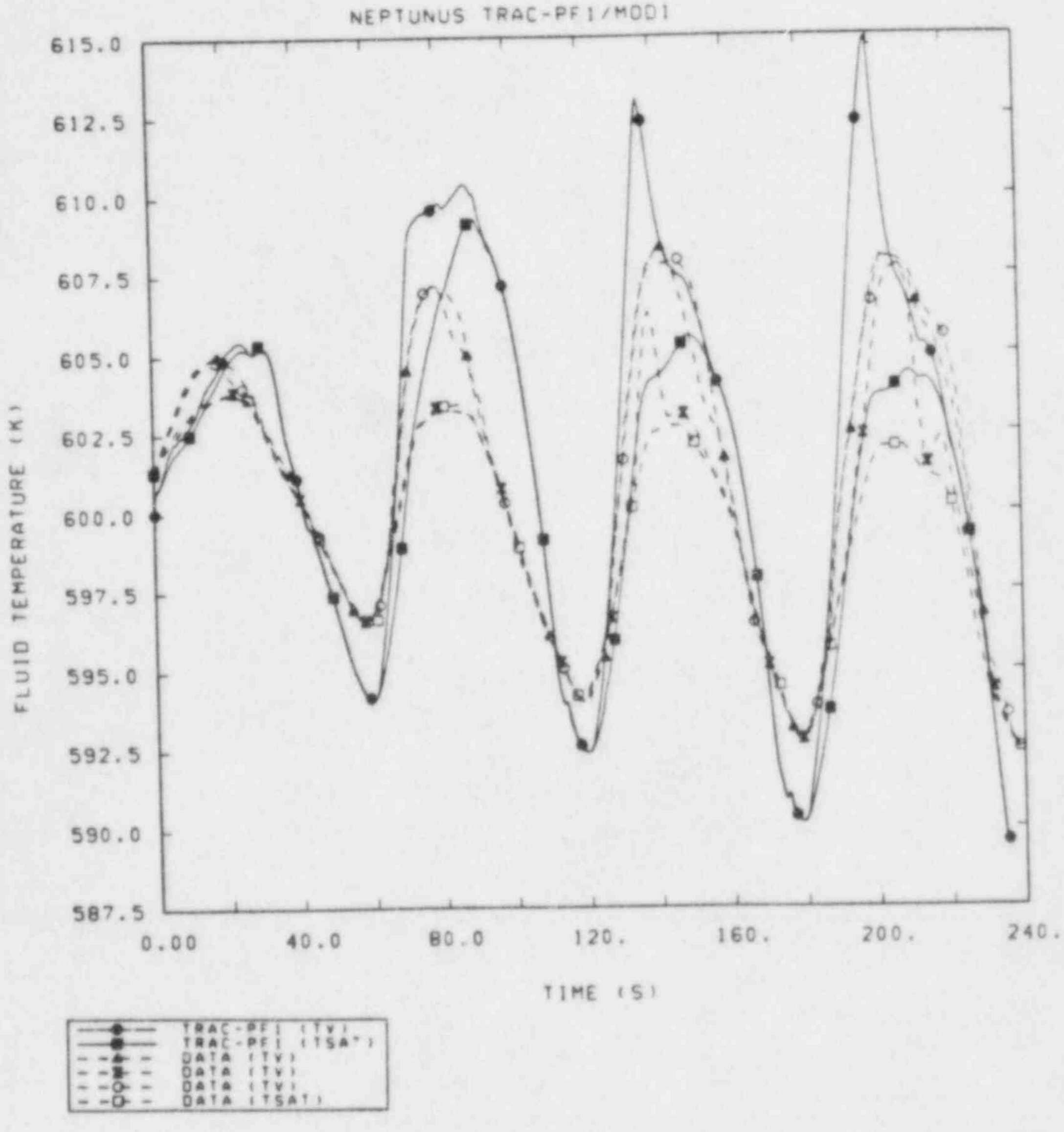


Figure 4.1.2 Comparison of Calculated and Measured Temperatures

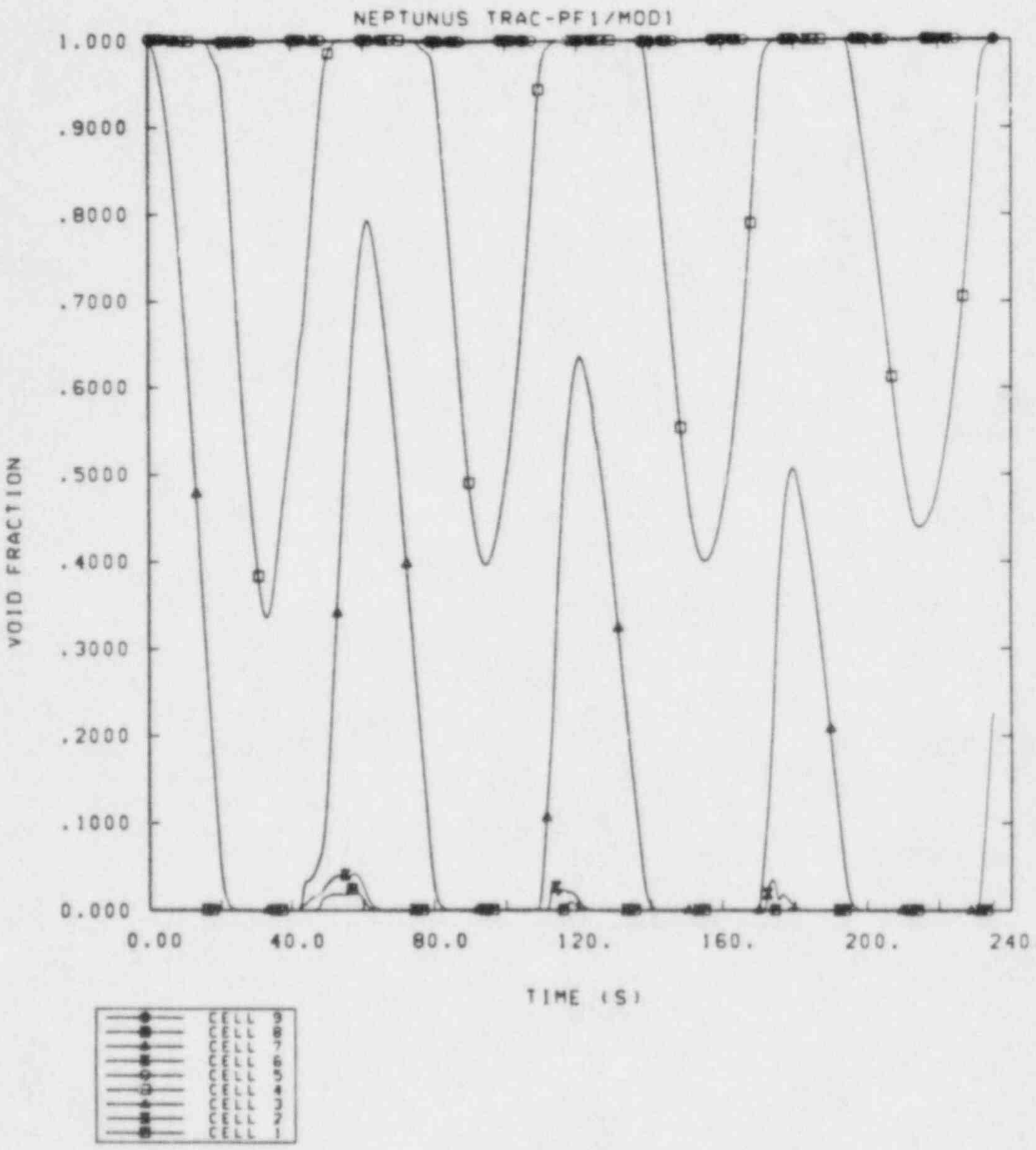


Figure 4.1.3 Calculated Void Fractions in Base Model Upper PRIZER

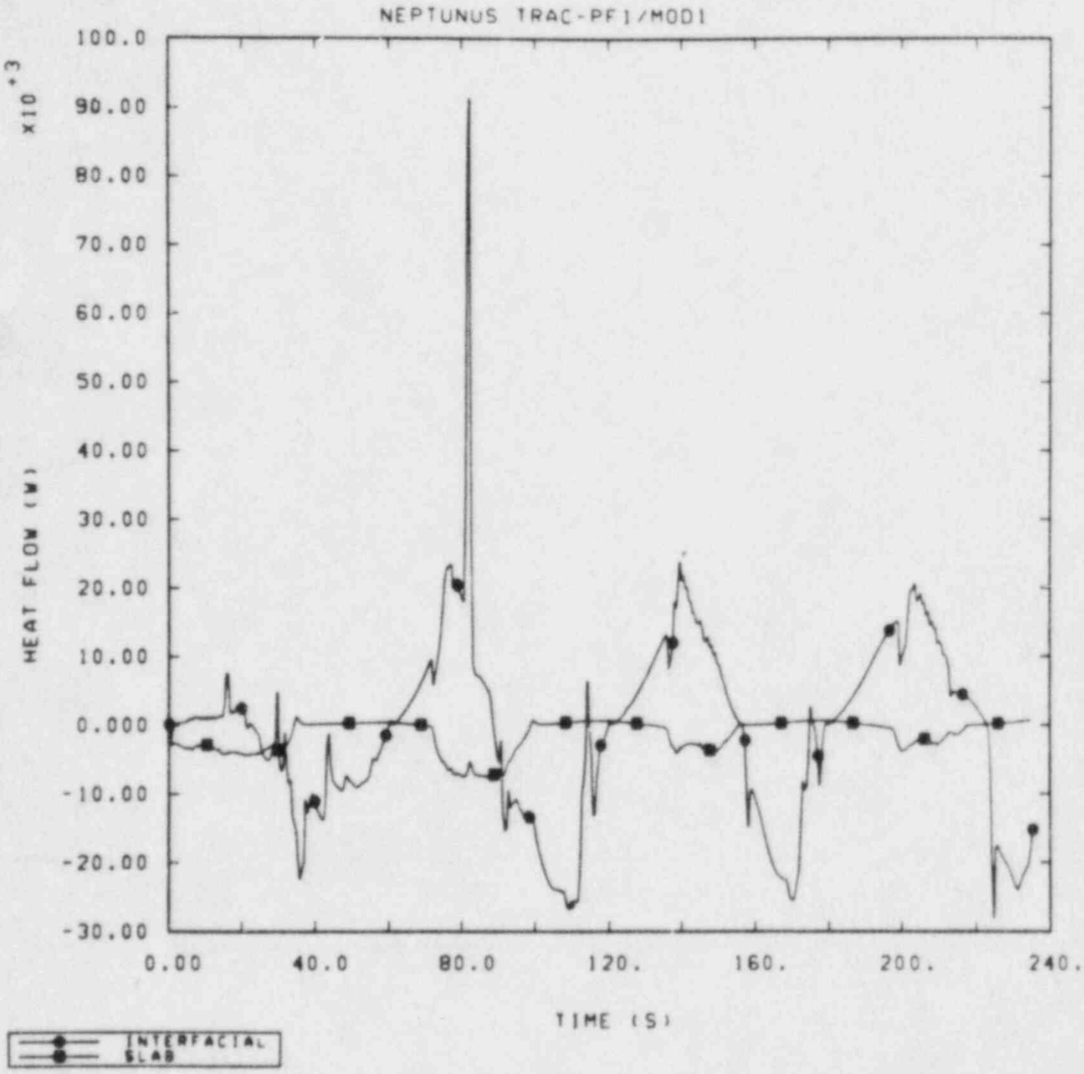


Figure 4.1.4 Calculated Heat Flow in Cell 9 of Base Model Upper PRIZER

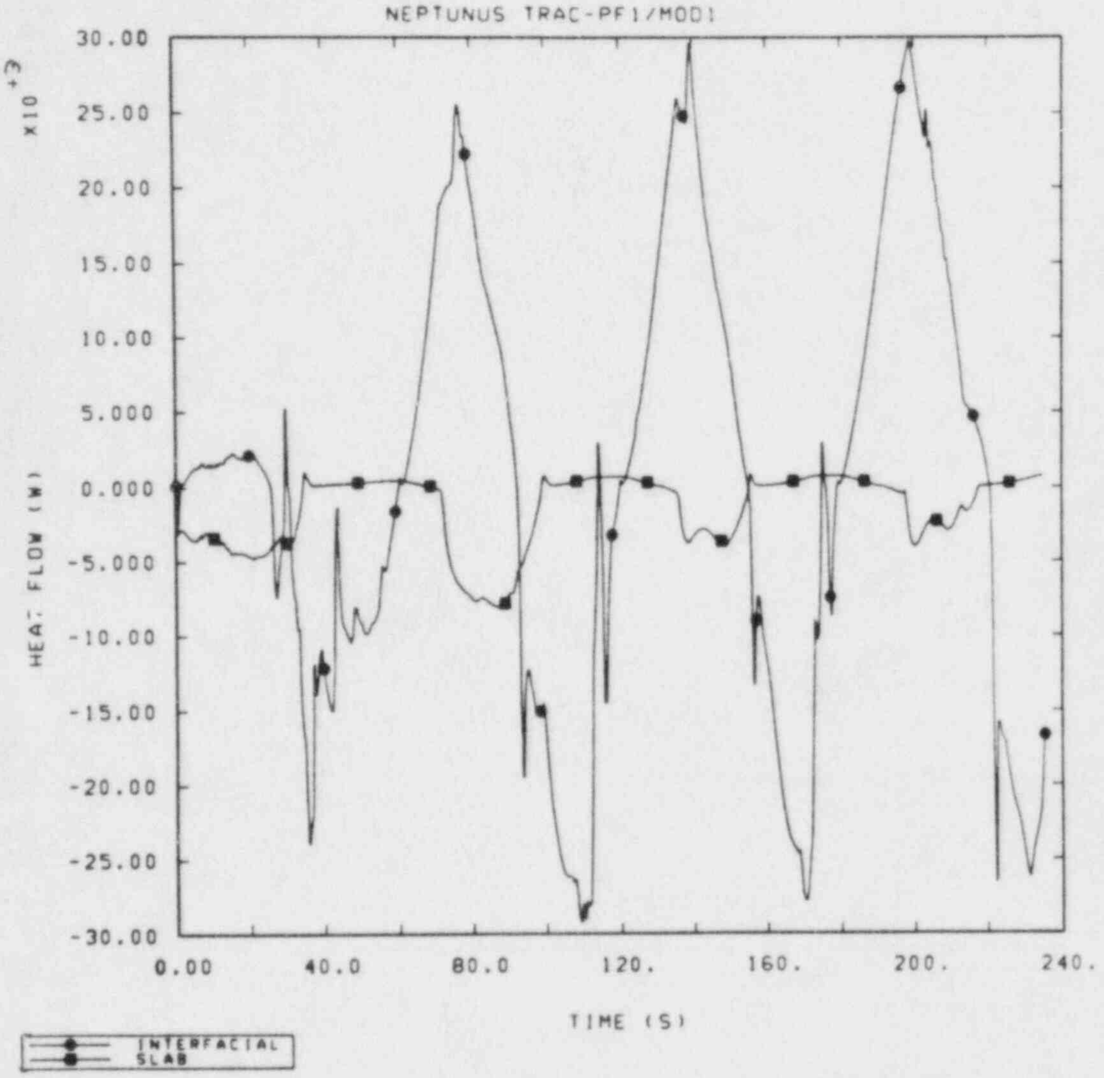


Figure 4.1.5 Calculated Heat Flow in Cell 7 of Base Model Upper PRIZER

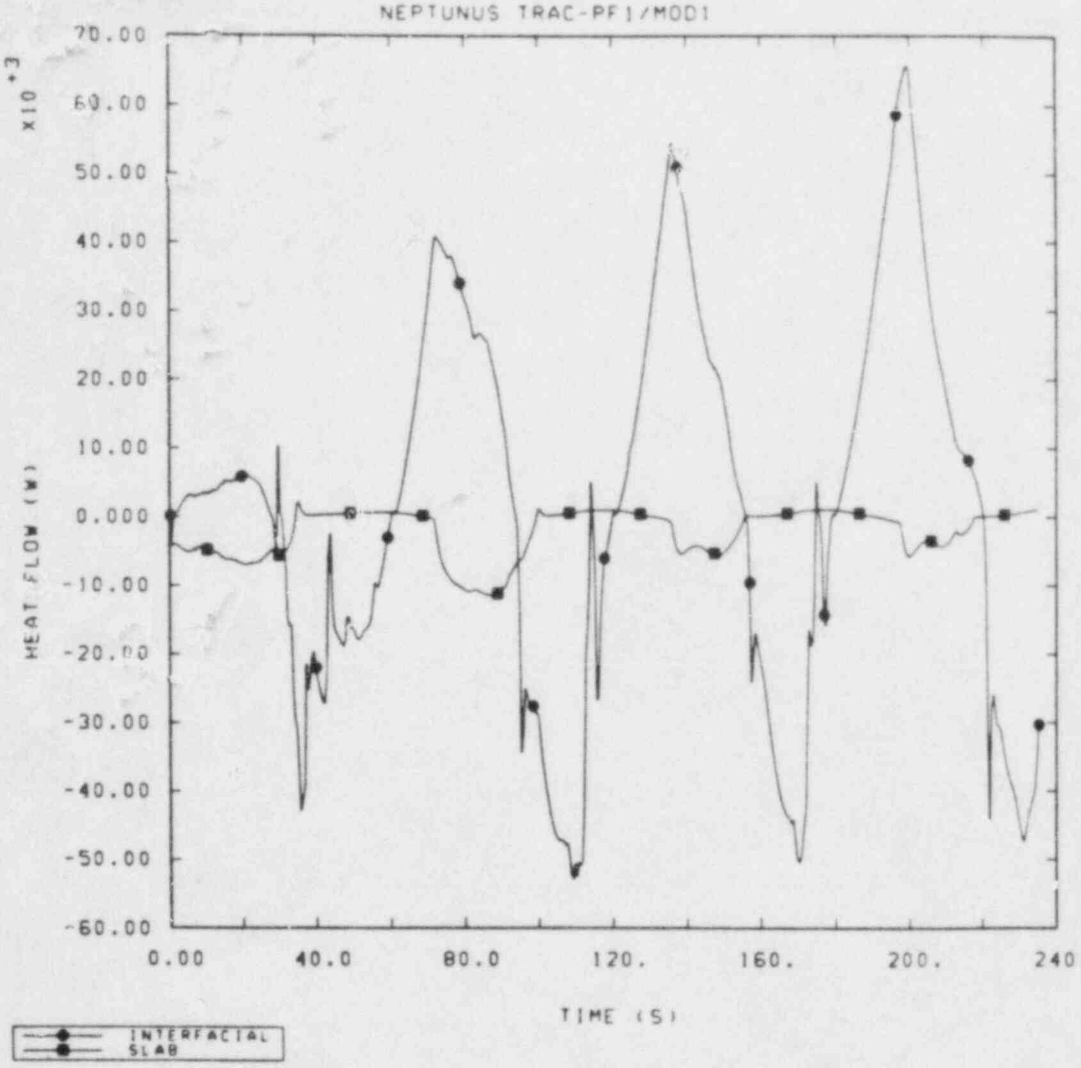


Figure 4.1.6 Calculated Heat Flow in Cell 5 of Base Model Upper PRIZER

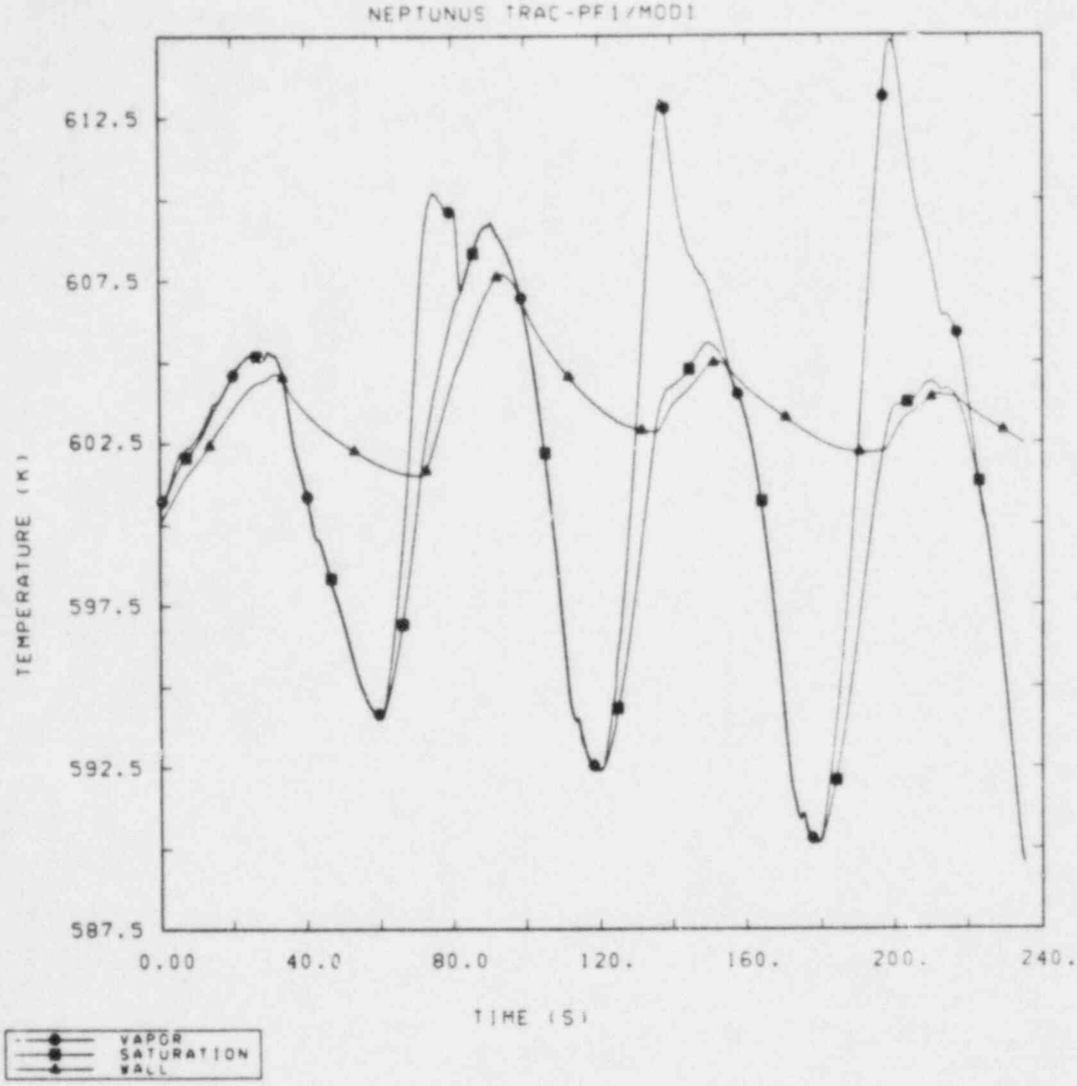


Figure 4.1.7 Calculated Temperatures in Cell 9 of Base Model Upper PRIZER

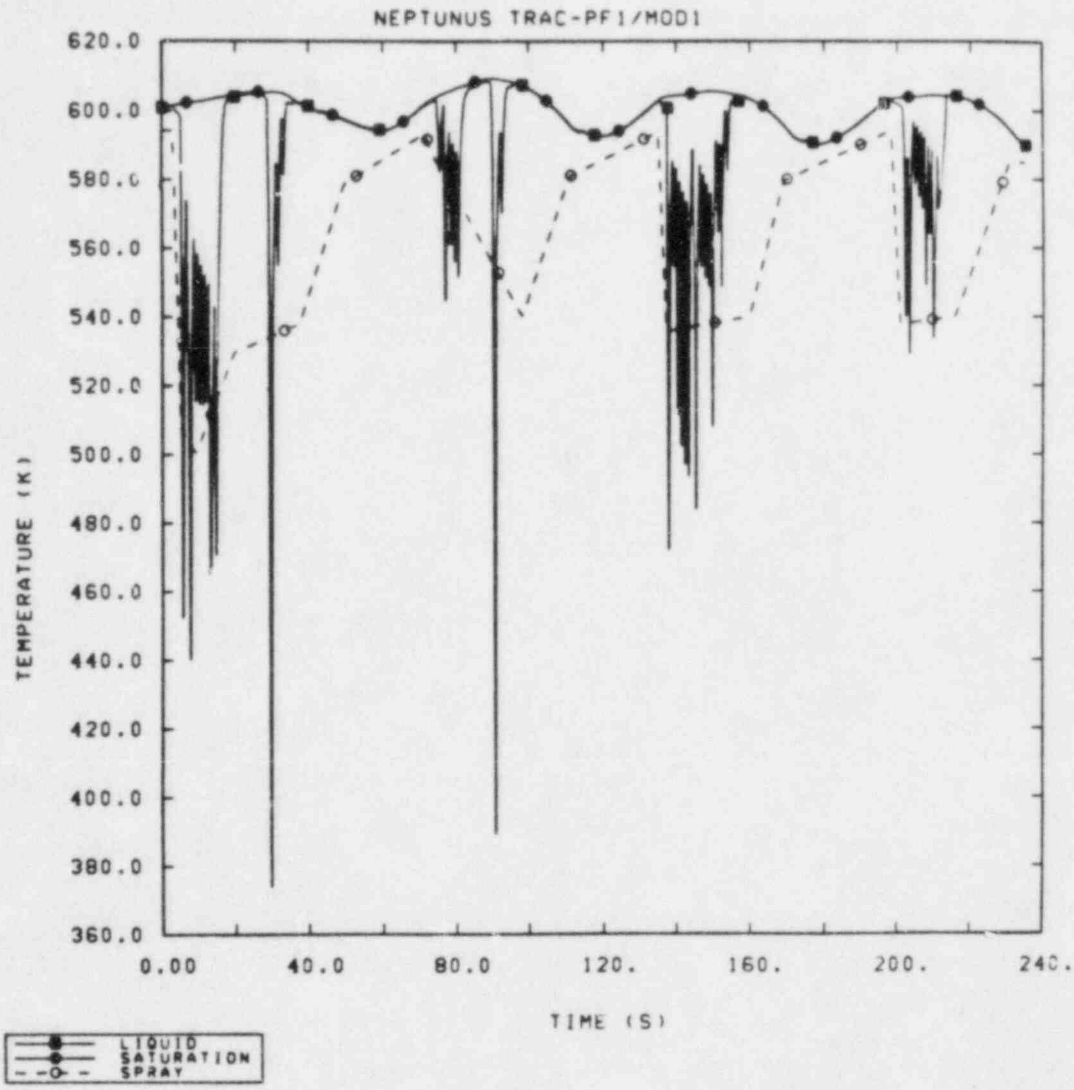


Figure 4.1.8 Calculated Saturation and Liquid Temperatures and Measured Spray Temperature in Cell 9 of Base Model Upper PRIZER

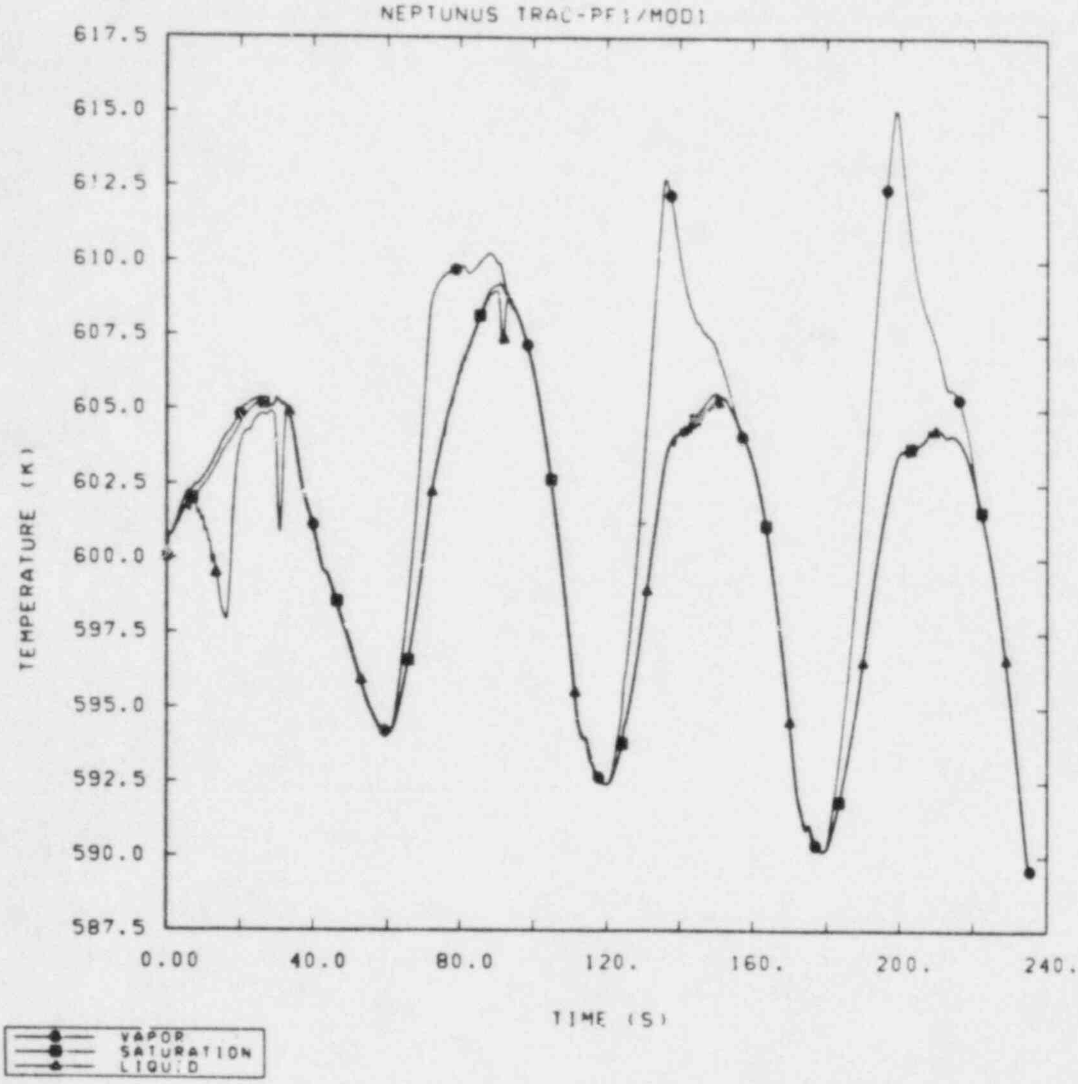


Figure 4.1.9 Calculated Temperatures in Cell 6 of Base Model Upper PRIZER

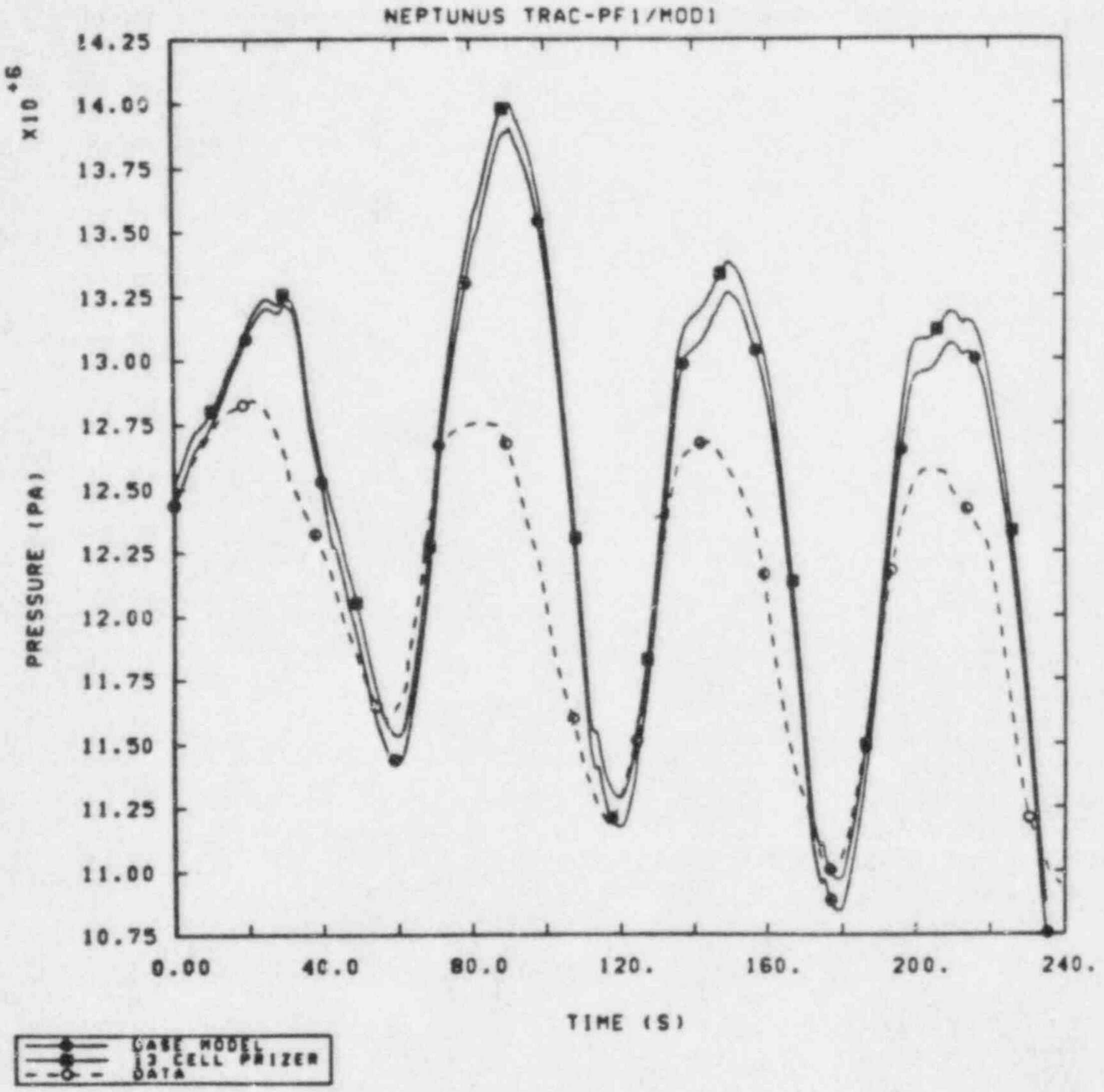


Figure 4.2.1 Comparison of 13-Cell PRIZER and Base Model Calculated Pressures

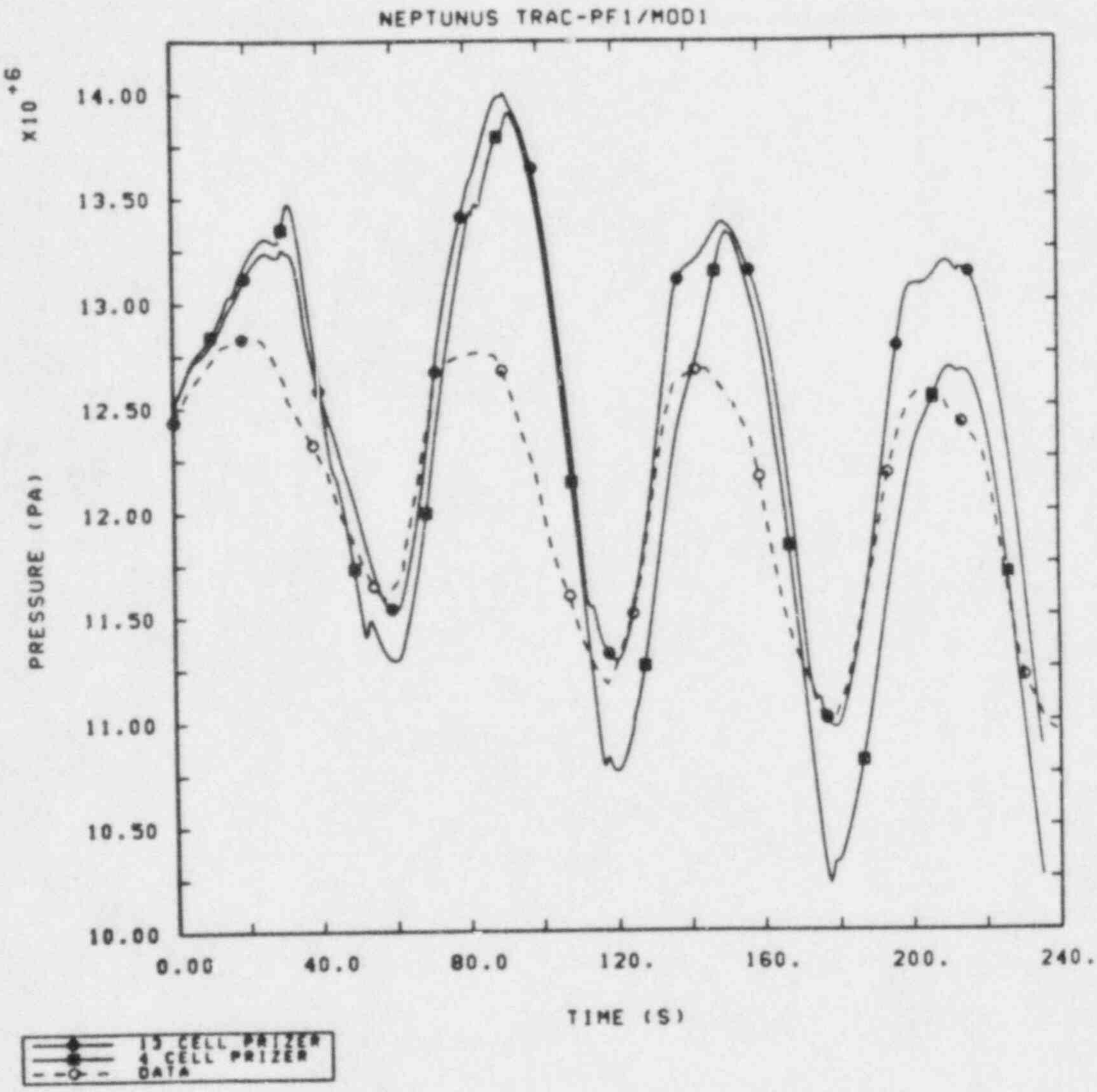


Figure 4.2.2 Effect of PRIZER Noding on the Calculated Pressure

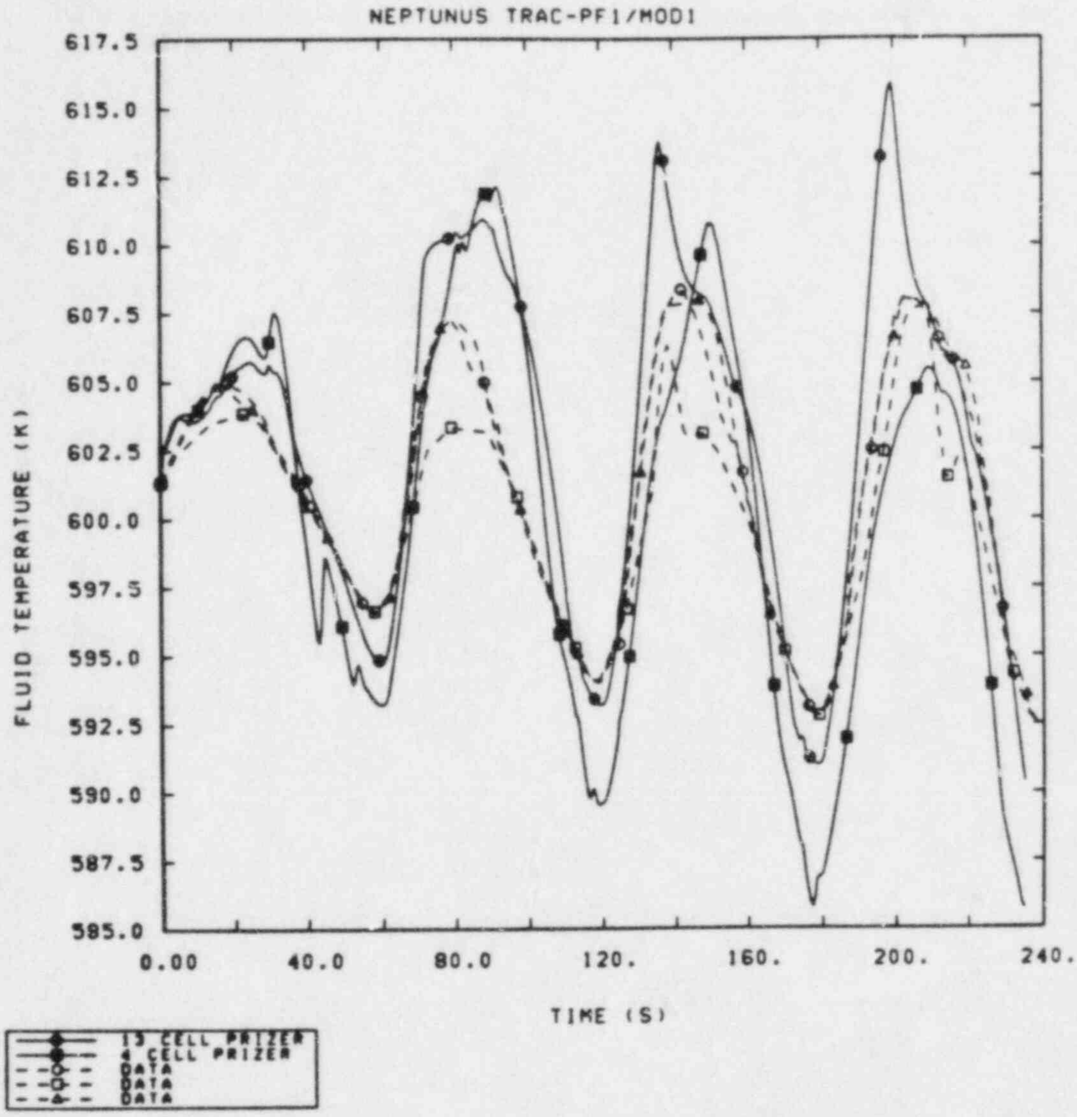


Figure 4.2.3 Effect of PRIZER Noding on the Calculated Fluid Temperature

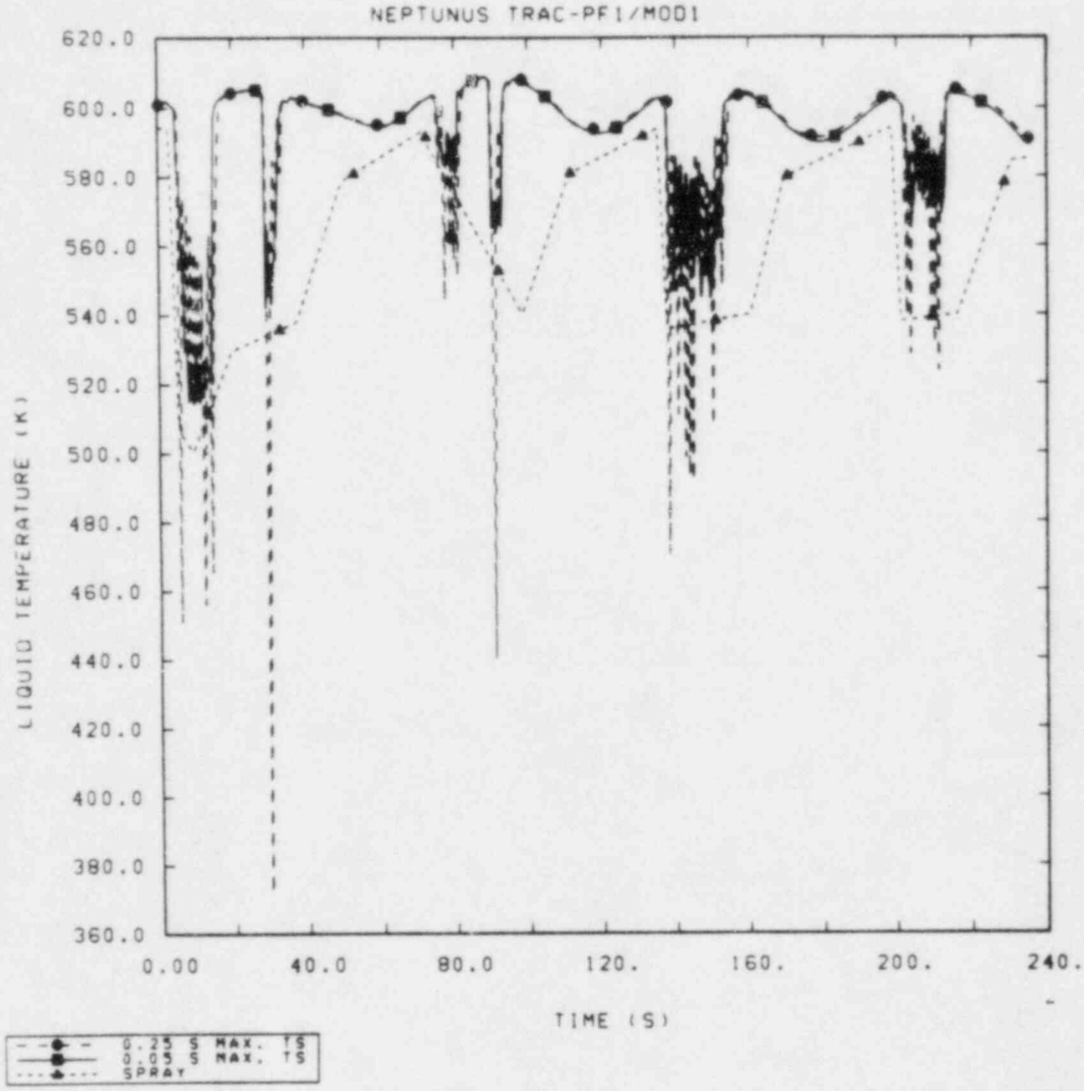


Figure 4.2.4 Effect of Maximum Time Step on the Calculated Liquid Temperature

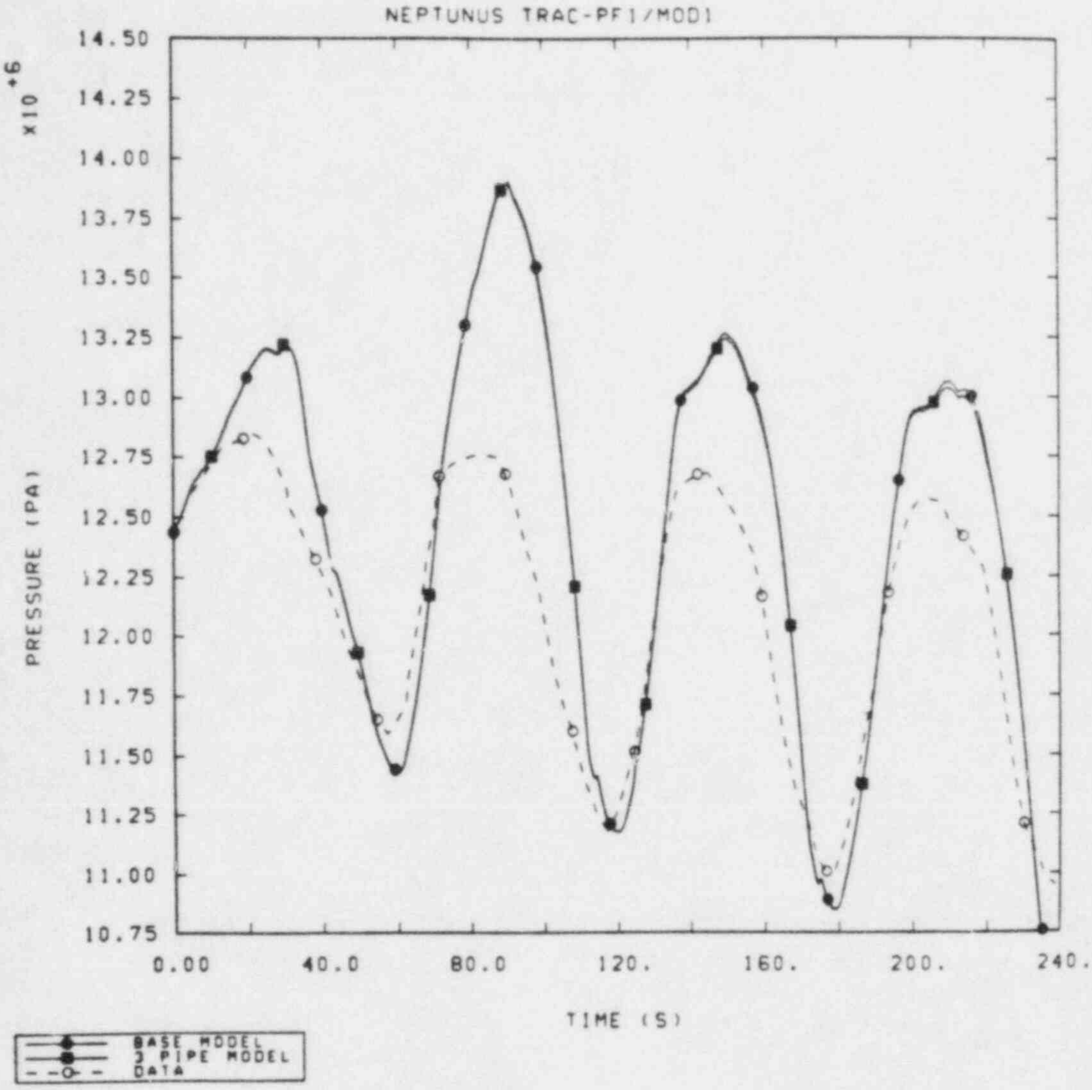


Figure 4.2.5 Comparison of Calculated Pressures Using PRIZER and PIPE Components

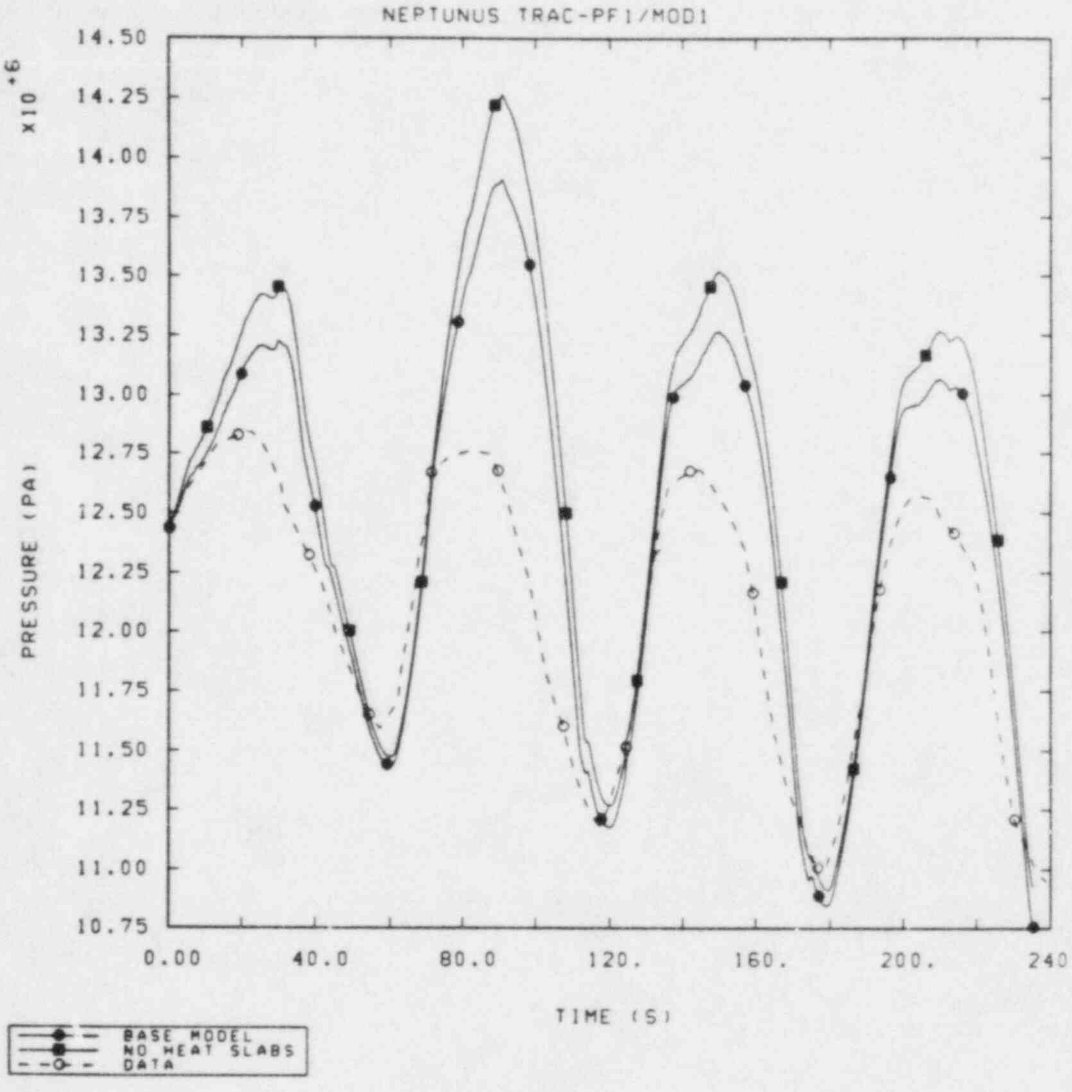
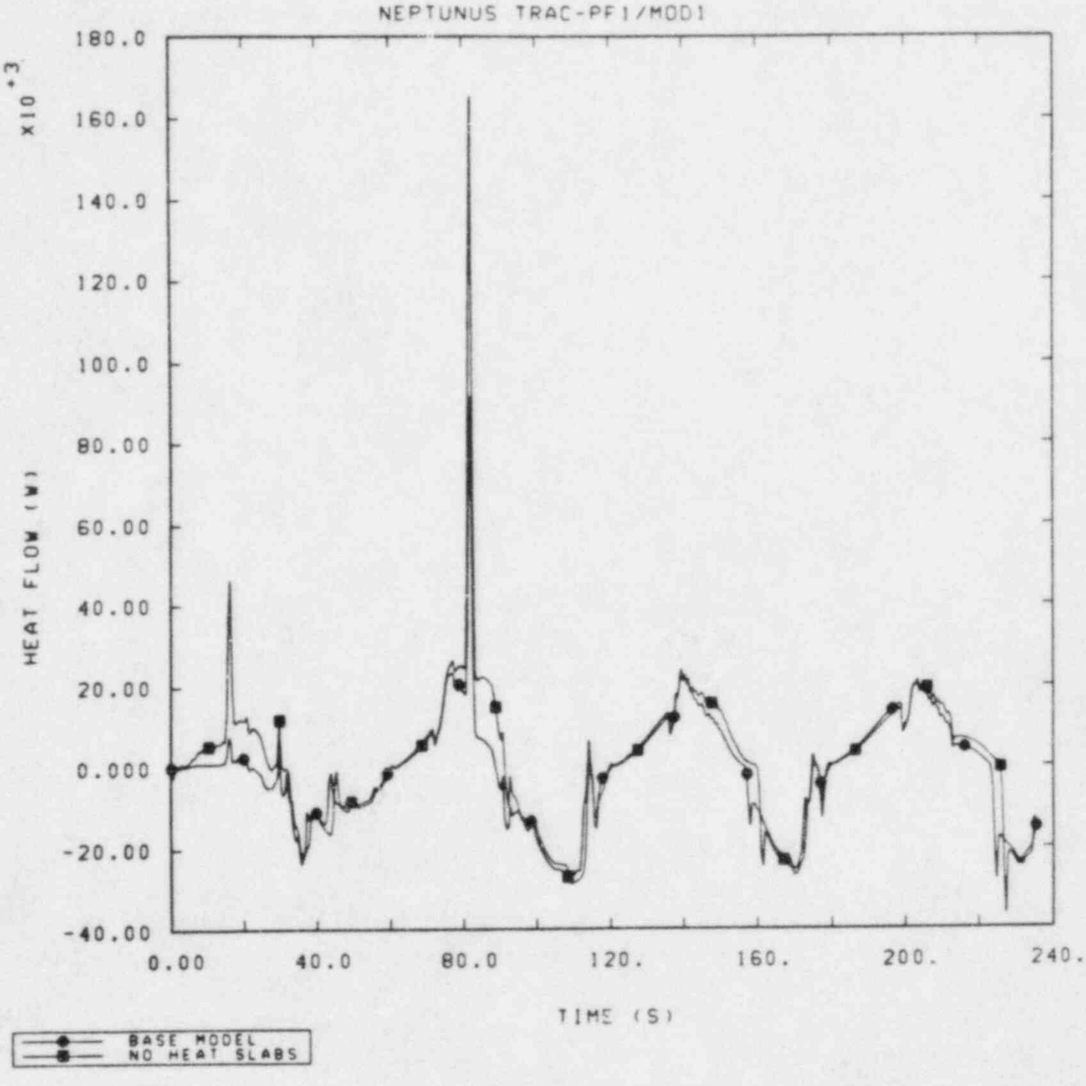


Figure 4.2.6 Effect of Modeling Heat Slabs on the Calculated Pressure



Pressure 4.2.7 Effect of Modeling Heat Slabs on the Calculated Heat Flow in Cell 9 of Base Model Upper PRIZER

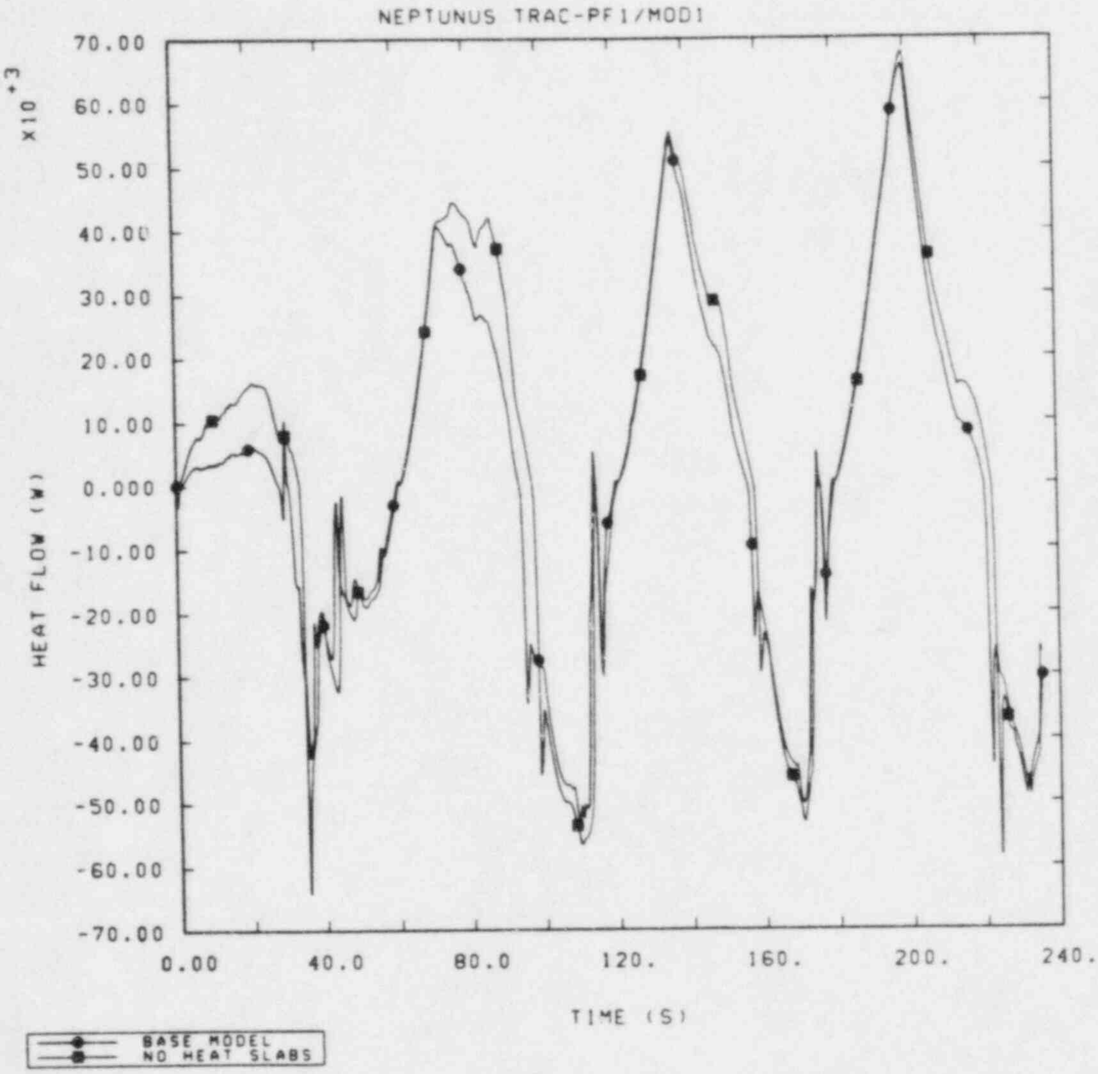


Figure 4.2.8 Effect of Modeling Heat Slabs on the Calculated Heat Flow in Cell 5 of Base Model Upper PRIZER

5.0 SUMMARY AND CONCLUSIONS

Our analyses of NEPTUNUS pressurizer test Y05, 4 successive insurges and outsurges combined with spray flow, showed that the peak pressures and fluid temperatures calculated by TRAC-PF1/MOD1 were too high for each insurge; however, good agreement with the measured minimum pressure during outsurges was calculated. During insurges the pressure continued to increase until the surge line flow started to decrease. The spray line flow did not seem to affect the calculated pressure, unlike the data. During insurges, the calculated fluid temperature continued to increase until the initiation of spray line flow and then quickly decreased. In the test, shortly after the initiation of spray flow the pressures and fluid temperatures were both turned around and had started to decrease.

Contributing to the calculation of too high a pressure and fluid temperature appears to be too little interfacial heat transfer from superheated vapor to subcooled liquid.

The calculated liquid temperature in the top cell into which the subcooled spray flow was injected was unphysically low when the time step was not user-controlled. Reducing the maximum time step eliminated the calculation of such low liquid temperatures; however, the pressure response was nearly identical for both calculations, higher than the data.

The test vessel was modeled with a single PRIZER, with 2 PRIZERs and a PIPE, and with 3 PIPEs. With the single PRIZER the energy from the heaters was input through the walls, and for the models using a PIPE component the heater energy was input directly into the coolant at the heater location. The results from each of the models were nearly identical, indicating that, for this simple test facility, none of these model changes were significant.

Based on the results of these analyses, it appears that TRAC-PF1/MOD1 would calculate too high a pressure for transients in which there are insurges combined with spray flow into the pressurizer, although during outsurges the minimum pressure calculated would probably be accurate.

6.0 References

1. TRAC-PF1/MOD1: an Advanced Best-Estimate Computer Program for Pressurized Water Reactor Thermal-Hydraulic Analysis (Draft), Safety Code Development Group, Energy Division, Los Alamos National Laboratory, 1983.

2. H. A. Bloemen, Verification of the Pressurizer Model in RELAP5/Mod1, Energieonderzoek Centrum Nederland, Memo No.0.375.10 GR 26 (OD 79-24), May 1983.

3. Personal Communication, A. C. Peterson with T. D. Knight, Los Alamos National Laboratory.

APPENDIX I   TRAC-PF1/MOD1 BASE CASE MODEL INPUT LISTING

```
FREE
1   0   0   0
NEPTUNUS RUN Y05
************************
0         0.0
0     1     5     4     1
1.0E-5  1.5E-5  1.0E-4
15  50  10  0
55   18   0  1   0
10   11   12   20   30E
************************
*SIGNAL VARIABLES*
1    0
2    90    12    1    0
3    90    12    2    0
4    90    12    3    0
5    90    12    4    0
6    90    12    5    0
7    90    12    6    0
8    90    12    7    0
9    90    12    8    0
10   90    12    9    0
11   89    12    1    0
12   89    12    2    0
13   89    12    3    0
14   89    12    4    0
15   89    12    5    0
16   89    12    6    0
17   89    12    7    0
18   89    12    8    0
19   89    12    9    0
20   96    12    1    0
21   96    12    2    0
22   96    12    3    0
23   96    12    4    0
24   96    12    5    0
25   96    12    6    0
26   96    12    7    0
27   96    12    8    0
28   96    12    9    0
29   93    12    1    0
30   93    12    2    0
31   93    12    3    0
32   93    12    4    0
33   93    12    5    0
34   93    12    6    0
```

```
35   93     12     7      0
36   93     12     8      0
37   93     12     9      0
38   94     12     1      0
39   94     12     2      0
40   94     12     3      0
41   94     12     4      0
42   94     12     5      0
43   94     12     6      0
44   94     12     7      0
45   94     12     8      0
46   94     12     9      0
47   95     12     1      0
48   95     12     2      0
49   95     12     3      0
50   95     12     4      0
51   95     12     5      0
52   95     12     6      0
53   95     12     7      0
54   95     12     8      0
55   95     12     9      0
******************************
*CONTROL BLOCKS*
-1   56     11
0.5047    -1.0E10    1.E10    0.0
-2   56     12
0.5047     -1.0E10    1.E10     0.0
-3   56     13
0.5047     -1.0E10    1.E10     0.0
-4   56     14
0.5047     -1.0E10    1.E10     0.0
-5   56     15
0.5047     -1.0E10    1.E10     0.0
-6   56     16
0.3896     -1.0E10    1.E10     0.0
-7   56     17
0.3418     -1.0E10    1.E10    0.0
-8   56     18
0.3129     -1.E10    1.E10    0.0
-9   56     19
0.3129     -1.E10    1.E10     0.0
-10    54     2      -1
1.0          -1.0E10     1.E10      0.0
 11    54     3      -2
1.0          -1.0E10     1.E10      0.0
-12    54     4      -3
1.0          -1.0E10     1.E10      0.0
-13    54     5      -4
1.0          -1.0E10     1.0E10     0.0
-14    54     6      -5
1.0          -1.0E10     1.0E10     0.0
```

```
-15   54    7      -6
1.0        -1.0E10    1.0E10    0.0
-16   54    8      -7
1.0        -1.0E10    1.0E10    0.0
-17   54    9      -8
1.0        -1.0E10    1.0E10    0.0
-18   54   10      -9
1.0        -1.0E10    1.0E10    0.0
0    0     0    0     0
****************************
*TRIP INPUT*
101   2    0    1    1
-.1     0.0
0.0000  0.0000
0       0
**************************
PRIZER     10        10        TEST VESSEL(1)
3          4         15        16         9
1          0         0.0
0.4        0.055      0.0      8.9        305.
305.     0.0        1.2E6    10.
****
0.119      0.200      0.200E
****
0.00404    0.05655   0.05655E
****
0.005542    .03398    0.2874  0.2874E
****
F    0.0E
****
F    1.0E
****
0.208  R02  0.600     0.800E
****
F    -1E
****
R03  0.0E
****
F   0.0E
****
F   0.0E
****
F   600.0E
****
F   600.0E
****
F   1.243E07E
****
F   0.0E
****
```

```
R12  0.0E
****
F   9E
****
F  600.0E
*****************************************************
PIPE     11      11       TEST VESSEL(2)
 1        4      16       17        9
 1        0       0        1
101       1       2        0         0
101       1       2        0         0
0.4      0.055   0.0      8.9       305.
305.     17000.  0.0      1.0        1.0
0.0      0.0       1.0      0.0
***
.20083E
***
0.10095E
***
0.2874   0.50265E
***
F    0.0E
***
F    1.0E
***
F    0.8E
***
F   -1E
***
F    0.0E
***
F    0.0E
***
F    0.0E
***
F    600.E
***
F    600.E
***
F    1.243E07E
***
F    0.0E
***
F    0.0E
***
F     9E
***
F     600.E
***
```

```
0.0      17000.0S
300.     17000.0E
***
0.0       0.0S
300.      0.0E
*****************************************************
PRIZER    12       12       TEST VESSEL(3)
9         4       17      25      9
1         0        0.0
0.4    0.055     0.0     8.9   305.
305.    0.0      1.2E6    10.0
***
R05   0.20083   0.1550   0.1360S
R02   0.1245E
***
R05   0.10095   0.07791   0.05599S
0.05126   0.0512E
***
R06   0.50265   R03  0.41169  0.00057225E
***
F   0.0E
***
F    1.0E
***
R07  0.800   R03   0.724E
***
F    -1E
***
R02   0.0   R07  1.0E
***
F    0.0E
***
F    0.0E
***
F   600.E
***
F   600.E
***
F   1.243E07E
***
F   0.0E
***
F   0.0E
***
F    9E
***
F    600.E
*****************************************************
FILL     20      20      SURGE LINE
15        4       1
```

```
101        1        34        0      0
0.0        1.0E10       0.0        0.0
0.119      0.00404      0.0        0.0        548.0
125.0E5      0.0        0.0        0.0        548.0
1.0          1.0
0.00      0.00000      1.42     0.27968S
8.82      0.73981     14.28     0.90581S
19.38     0.81559     24.32     0.75604S
26.96     0.45291     30.83     0.37712S
35.00     -.79394     38.76     -.60447S
50.91    -1.43450     56.19    -1.13316S
61.95     0.45651     70.40     0.95272S
77.18     0.76146     87.30     0.64778S
95.0      -.22735    110.79     -1.47239S
114.67   -1.4345     121.18     0.30134S
130.33   0.84266     140.20     0.65319S
148.47   0.56297     155.00     -.11368S
160.45   -.45651     169.96     -1.40563S
175.0    -1.39119    180.7      0.38073S
190.22    0.79755    202.54     0.47817S
207.83    0.49441    225.0      -.72176S
230.72   -1.32984    237.77     -1.36774E
*************************************
FILL       30        30       SPRAY
25          9         2
101         1        20       0       0
0.0        1.0E6    0.0        0.05545
0.119      0.00404    0.0       0.0        593.98
128.E05    0.0        0.0       0.0        593.98
593.98     593.98      128.E5      128.E5       0.0
1.0        1.0
1.0        1.0    1.0      1.0      1.0
  0.00     0.0000     2.74     0.0000S
  6.94    1.285639   24.96     3.032196S
35.86     0.00000    70.96     0.00000S
75.49     1.770833   88.51     2.377237S
95.58     0.00000    135.35    0.00000S
138.75    1.334194   149.79     1.576791S
157.86    0.00000    198.33     0.00000S
202.58    1.091598   212.77     1.091598S
212.78    0.00000    300.0      0.00000S
301.0     0.000      302.0      0.00000E
*
0.00      0.000     0.5       0.000S
1.0       0.0       2.0         0.0S
4.0       0.0       5.0          0.0S
6.0       0.0       7.0         0.0S
8.0       0.0       9.0         0.0S
10.0      0.0       11.0        0.0S
12.0      0.0       13.0        0.0S
```

```
16.0     0.0      17.0       0.0S
18.0     0.0      19.0       0.0S
20.0     0.0     300.0       0.0E
*
  0.00   593.98     2.74     593.98S
  5.00   506.48     8.92     500.23S
 19.30   529.40    37.19     537.73S
 49.20   578.57    71.40     593.15S
 72.67   588.57    97.97     539.82S
110.69   580.65   135.00     593.57S
137.35   535.50   159.94     539.82S
169.12   579.40   198.34     593.98S
200.88   537.73   215.99     539.82S
230.53   584.40   300.0      591.07E
*
0.00     593.0      1.0     593.0S
2.0      593.       3.0     593.S
4.0      593.0      5.0     593.S
6.0      593.0      7.0     593.S
8.0      593.0      9.0     593.0S
10.0     593.0     11.0     593.0S
12.0     593.0     13.0     593.0S
14.0     593.0     15.0     593.0S
16.0     593.0     17.0     593.0S
18.0     593.0    300.0     593.0E

0.0      0.0        1.0     0.0S
2.0      0.0        3.0     0.0S
4.0      0.0        5.0     0.0S
6.0      0.0        7.0     0.0S
8.0      0.0        9.0     0.0S
10.0     0.0       11.0     0.0S
12.0     0.0       13.0     0.0S
14.0     0.0       15.0     0.0S
16.0     0.0       17.0     0.0S
18.0     0.0      300.0     0.0E
*****
0.0      128.E5     1.0     128.E5S
2.0      128.E5     3.0     128.E5S
4.0      128.E5     5.0     128.E5S
6.0      128.E5     7.0     128.E5S
8.0      128.E5     9.0     128.E5S
10.0     128.E5    11.0     128.E5S
12.0     128.E5    13.      128.E5S
14.0     128.E5    15.0     128.E5S
16.0     128.E5    17.0     128.E5S
18.0     128.E5   300.0     128.E5E
****
0.00     0.00       1.0     0.00S
2.0      0.0        3.0     0.0S
```

```
4.0      0.0          5.0    0.0S
6.0      0.0          7.0    0.0S
8.0      0.0          9.0    0.0S
10.0     0.0         11.0    0.0S
12.0     0.0         13.0    0.0S
14.0     0.0         15.0    0.0S
16.0     0.0         17.0    0.0S
18.0     0.0        300.0    0.0E
**************************************
1.0E-4       0.25      210.0        1000.0
10.0     0.25       100.0     5.0
1.0E-5       0.05      215.0        1000.0
10.0     0.25     100.0       5.0
1.0E-4       0.25      235.0        1000.0
10.0    0.25      100.0     5.0
-1.000
END
```

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13. ABSTRACT (200 words or less)

The TRAC independent assessment project at Sandia National Laboratories is part of an overall effort funded by the NRC to determine the capability of various system codes to predict the detailed thermal/hydraulic response of light water reactors during accident and off-normal conditions. The TRAC computer code is being assessed at SNLA against test data from various integral and separate effects test facilities. As part of this assessment effort, a separate effects component test performed in the NEPTUNUS pressurizer test facility, located at the Laboratory for Thermal Power Engineering at Delft University of Technology, was analyzed with TRAC-PF1/MOD1. The test simulated insurges, combined with spray flow, and outsurges from a pressurizer, and was selected for code assessment because the capability of the computer codes used in safety analyses to calculate the correct pressurizer response is an important concern of the NRC.

Our TRAC-PF1/MOD1 results showed that somewhat higher pressures and fluid temperatures were calculated during insurges with spray flow than were measured in the test. A contributing factor to the calculation of high pressures and fluid temperatures appears to be that the interfacial heat transfer from superheated vapor to subcooled liquid was too low.

Sensitivity studies were performed on both the maximum time step size used and the type of components and number of cells used to simulate the test vessel. When the maximum time step was not controlled, liquid temperatures in the volumes into which the spray was flowing were lower than the initial temperature of the spray, which was the coldest liquid in the vessel. However, the calculation of unrealistically low fluid temperatures in some volumes did not affect the system pressure response or the fluid temperatures near the vapor-to-liquid interface. Nearly identical results were calculated when the test vessel was modeled with a single PRIZER (using 4 and 13 cells), 2 PRIZERs and 1 PIPE, and 3 PIPE components.

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