NUREG/CR-4001
BNL-NUREG-51824

CONTEMPT4/MOD5: An Improvement to CONTEMPT4/MOD4 Multicompartment Containment System Analysis Program for Ice Containment Analysis

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Prepared for
U.S. Nuclear Regulatory
Commission

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Manuscript Completed: September 1984
Date Published: September 1984

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NRC FIN A3752

Executive Summary

This document is a supplement to the previously published user's manual of the CONTEMPT4/MOD4 computer code (NUREG/CR-3716). It describes the additional modifications made to the MOD4 version of the code since its publication in March 1984.

In order to improve its capability in the analysis of intermediate and long-term transient problems, BNL has incorporated into the CONTEMPT4 computer code an implicit routine for junction flow calculations. The implicit routine provided in MOD4 works for all types of containment systems except for ice condenser containment systems. This restriction is removed in the most recent version of the code, MOD5, by taking into consideration the special characteristics of an ice condenser compartment.

This report describes the analytical model of the implicit routine and the additional modifications required for MOD4 to upgrade its implicit routine for ice condenser analysis. It also presents the analysis of a typical ice condenser containment problem, both with and without the use of the implicit routine, to demonstrate the effectiveness of the implicit routine in the analysis of such problems.

The problem analyzed is a four-compartment, three-junction ice containment system with both vapor and liquid blowdowns. Results of this analysis show that the explicit time advancement algorithm originally in the CONTEMPT4 code will cause numerically induced flow oscillations and artificial mixing of gases between compartments. The mixing of gases between a compartment at a high temperature level (the blowdown compartment) with one at low temperature (the ice compartment) will result in a lower predicted temperature in the blowdown compartment. The artificial mixing also causes more steam to be transferred into the ice compartment and condensed there and therefore results in an excessively rapid pressure drop in all compartments. The results by the explicit algorithm are unacceptable for the sample problem analyzed here even with the use of very small integration time step (e.g., 0.001 seconds). On the other hand, the use of the implicit routine eliminates numerically induced flow oscillations completely and yields good results with the use of a time step size several orders of magnitude larger.

The incorporation of the additional modification to the MOD4 code will not affect the user's preparation of the input data as that described in the MOD4 manual. The CONTEMPT4/MOD4 user's manual will therefore remain valid for all other program applications.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The author wishes to thank J. Kudrick, L. Ruth, A. Notafrancesco and R. Palla of NRC, K. Almenas of the University of Maryland, and G. Maise and C. Economos of BNL for their advice and assistance during this work.

1. Introduction

Appendix G of the CONTEMPT4/MOD4 user's manual (NUREG/CR-3716) has discussed the need of an implicit algorithm for junction flow calculation to supplement the normal explicit time advancement algorithm which sometimes causes unacceptable numerical oscillation and artificial flow mixing across a junction. Such an implicit algorithm has been incorporated into the CONTEMPT4/MOD4 computer code for standard junctions, as well as for BWR vapor suppression vent junctions. However, its applicability to junctions involving an ice compartment is restricted because of certain special characteristics of an ice compartment.

This report discusses the additional modifications made by BNL to extend the applicability of the existing implicit routine to the ice condenser containment system. The report also presents analyses of a typical ice containment problem, both with and without the use of the implicit algorithm, to demonstrate the effectiveness of the implicit algorithm in the analysis of such problems.

2. Analytical Models

The analytical model of the implicit routine for junctions involving an ice compartment is similar to that for standard compartments which has already been incorporated into the CONTEMPT4/MOD4 computer code as discussed in the MOD4 user's manual.[1] The only difference between them is that all the energy transferred into a standard compartment contributes to its pressure increase, while only the energy associated with the noncondensible gases transferred into an ice compartment contributes significantly to the pressure increase in the ice compartment. This is because most of the water vapor which enters in an ice compartment will immediately be condensed. Thus, for the ice compartment, the rate of change of pressure with energy influx, which governs the implicit algorithm, needs to be modified accordingly.

2.1 The Analytical Model for Standard Compartments

The implicit routine in the CONTEMPT4/MOD4 computer program is based on the algorithm presented in References 2 and 3. It is used to predict junction flows whenever the use of the explicit time advancement algorithm will result in physically unrealistic pressure reversal, and consequently numerically induced flow oscillation conditions. The implicit routine uses a finite difference form of a first order Taylor expansion of compartment pressure in terms of its energy-pressure derivative:

$$p_i^{n+1} = p_i^{n} + \sum \left(\frac{dp}{dE}\right)_i^n \Delta E_k^{n+1} \qquad (1)$$

where

p_i^{n+1} = pressure in compartment i at the end of the time step

p_i^{n} = pressure in compartment i at the beginning of the time step

$\left(\frac{dp}{dE}\right)_i^n$ = pressure derivative with respect to energy for the gas mixture in compartment i, evaluated at the beginning of the time step

ΔE_k^{n+1} = energy flow across junction k during the time step

$\sum\limits_k$ = summation over all junctions that are connected to compartment i.

As pressures in adjoining compartments approach each other, which is likely to occur during an intermediate or long term transient analysis, numerically induced flow reversal will occur, irrespective of the time step used in the analysis. It is therefore more realistic to assume pressure equilibrium between compartments at the end of the time step:

$$p_{jL}^{n+1} = p_{jR}^{n+1} \qquad (2)$$

where

p_{jL}^{n+1} = pressure in the left-hand side compartment of junction j at the end of the time step

p_{jR}^{n+1} = pressure in the right-hand side compartment of junction j at the end of the time step

Substitution of Eq. (1) into Eq. (2) for all junctions will yield a system of simultaneous equations which can be solved for energy flows, ΔE_j^{n+1}, across all junctions,

$$\sigma_{jk}^{n} \, \Delta E_k^{n+1} = \Delta p_j^{n} \qquad (3)$$

where $\Delta p_j^n = p_{jL}^n - p_{jk}^n$ is the pressure differential at the beginning of the time step. The $\sigma_{nk's}$ are functions of $\left(\frac{dp}{dE}\right)^n$ whose functional forms depend on the compartment-junction arrangement of a particular problem.

The above procedure will yield dependent equations in the system of simultaneous equations if there are multiple junctions connecting the same two compartments. In this case, the following relations for the parallel junctions are used to replace the dependent equations in Eq. (3).

$$\frac{\Delta E_m}{R_m} = \frac{\Delta E_n}{R_n} = \ldots. \qquad (4)$$

where m and n are parallel junctions and Rm and Rn are the path resistance coefficients for junctions m and n, respectively. The junction path resistance depends on pressure difference along the path, the flow area, and the junction loss coefficient.

Once the energy flows are obtained from solution of Equation (3), the mass flows can be obtained by the following relations:

$$\Delta m_j = \Delta E_j/(C_{pD}T_D) \qquad (5)$$

where

Δm_j = mass flow across junction j

ΔE_j = energy flow across junction j

C_{pD} = specific heat at constant pressure for the noncondensible gas and steam mixture in the donor compartment

T_D = absolute temperature for the noncondensible gas and steam mixture in the donor compartment

An analytical form of the pressure-energy derivative can be defined if one assumes that the gas mixture in the compartment atmosphere obeys the ideal gas law.

$$\frac{dp}{dE} = \frac{R}{c_v V} \qquad (6)$$

where

R = gas constant for the noncondensible gas and steam mixture in the compartment vapor region

C_v = specific heat at constant volume for the noncondensible gas and steam mixture in the compartment vapor region

V = volume of the compartment vapor region

In Eq. (6) it is also assumed that both R and Cv are independent of the energy flow because of the small flow associated with this approach.

2.2 The Analytical Model for Ice Compartments

The ice condenser in a PWR ice condenser plant is a completely enclosed, refrigerated annular compartment formed between the crane wall and the containment shell. The CONTEMPT4/MOD4 ice condenser model is based on a user input table which specifies the performance of the ice chest and assumes that thermodynamic equilibrium is established instantaneously within the ice compartment. The steam transferred into an ice compartment is therefore condensed instantaneously, with only noncondensible gases contributing significantly to its pressure variation. The derivative of compartment pressure with respect to junction energy flow is therefore different for an ice compartment than that for a standard compartment. The derivative for an ice compartment is

$$\left(\frac{dp}{dE}\right)_{ice} = \frac{R_a T}{V} \frac{m_{aD}}{m_D C_{pD} T_D} \tag{7}$$

where

R_a = gas constant for the mixture of noncondensible gases in the ice compartment

T = absolute temperature of the gas mixture in the ice compartment

V = volume of the ice compartment vapor region

m_{aD} = mass of noncondensible gases in the donor compartment vapor region

m_D = total mass of the gas mixture in the donor compartment vapor region

C_{pD} = specific heat at constant pressure for the gas mixture in the donor compartment vapor region

T_D = absolute temperature for the gas mixture in the donor compartment vapor region.

It is noted that the pressure-energy derivative in an ice compartment depends on the flow direction which is not known prior to the solution of the simultaneous equations. Although normally the flow is from a compartment at higher pressure to that at lower pressure, it may not be the case for a multicompartment-multijunction containment system. Iteration may therefore be needed if the assumed flow direction is not consistent with the final solution.

3. Program Implementation

The CONTEMPT4 computer program uses primarily an explicit time advancement algorithm for problem solution. The flow across a junction is calculated explicitly by either an orifice or a nozzle model according to user's selection. This remains the first approximation even with use of the implicit routine. The implicit routine is actually used to predict junction flow only if the flow predicted by the explicit algorithm will result in a pressure reversal condition at the end of the time step.

In CONTEMPT4/MOD4, the flow across a junction during a time step is first calculated by the nozzle or the orifice model. The pressure drop across the junction resulting from this explicitly predicted junction flow is then estimated by the pressure-energy derivative given in Equations (6) and (7).

$$\Delta p_{est} = \lambda \, \dot{m}_{exp} \, C_{pD} T_D \, \Delta t \left[\left(\frac{dp}{dE}\right)_D + \left(\frac{dp}{dE}\right)_R \right] \qquad (8)$$

where

Δp_{est} = estimated pressure drop across the junction due to the predicted junction flow for this time step

λ = pressure multiplier whose theoretical value is unity

$\dot{m}_{exp}$ = mass flow rate across the junction by orifice or nozzle model

C_{pD} = specific heat at constant pressure for the gas mixture in the donor compartment

T_D = absolute temperature in the donor compartment

Δt = integration time step

$\left(\frac{dp}{dE}\right)_D$ = pressure-energy derivative for the gas mixture in the donor compartment

$\left(\frac{dp}{dE}\right)_R$ = pressure-energy derivative for the gas mixture in the receiving compartment

If the predicted pressure drop is greater than the pressure differential at the beginning of the time step, it indicates that the use of the explicit method will cause a pressure reversal condition at the end of the time step and the implicit routine is therefore needed for this particular junction.

The estimated pressure drop obtained from Eq. (8) is only an approximate indicator because it is derived from a simple two-compartment case. In order to assure the elimination of numerically induced flow oscillations, a pressure multiplier greater than one is used in Eq. (8) to provide a conservative estimate of the pressure drop by the explicit algorithm. This may cause the use of the implicit routine to predict the flows for some junctions where the use of the explicit algorithm provides acceptable and probably more accurate results. The effect of this overprediction is not a concern, however, because the pressure differentials between compartments are small to begin with.

The value of the pressure multiplier employed in the computer code is a function of the pressure differential across the junction at the beginning of the time step. It is 69 at 0.015 psi, 1.5 at 0.5 psi, 1.5 at 1.0 psi and 1.1 at 10 psi and greater. Linear interpolation is used for pressure differentials between the above values and implicit routine is always used for pressure differentials less than 0.015 psi. Large values are used for small initial pressure differentials to assure the avoidance of numerically induced flow oscillations for multicompartment-multijunction containment systems where Eq. (8) may be a poor approximation. The code will identify all such junctions and the associated compartments as discussed above and construct from them the simultaneous equations, Eq. (3), to be solved for junction flows that will result in pressure equilibrium among all involved compartments.

The use of the ideal gas law in the problem solution, Equations (6) and (7), may cause a slight over- or underprediction of the flow across the junctions. To avoid overprediction, which is the origin of numerically induced flow oscillations, the mass and energy flow rates obtained by Eq. (3) may be slightly reduced by use of a flow reduction factor. The effect of this underprediction on the accuracy of solutions will be negligible for the same reason as discussed above.

The flow reduction factor used in the computer code is also a function of the initial pressure differential across the junction, with greater flow reduction for smaller pressure differential. Its values are 10 for pressures of 0.0015 psi and less, 5 for 0.01 psi, 1.5 for 0.1 psi, 1.1 for 0.5 psi, and 1.05 for 1 psi and greater. Linear interpolation is used for pressure differentials between these values. Large reduction factors are used for small pressure differentials because clearly defined flow directions are lacking for multicompartment-multijunction containment systems with small pressure differentials.

4. Sample Problem Analysis

A typical ice containment problem was analyzed to demonstrate the effectiveness of the implicit routine that is incorporated into the CONTEMPT4 code. Figure 1 presents the mathematical model of the problem and Figures 2 through 5 show the mass and energy discharge rates for both the vapor and the liquid blowdowns. The problem is analyzed by CONTEMPT4 code both with and without the use of the implicit algorithm option.

A total of five cases were analyzed. The difference between the cases was in the selection of the implicit algorithm and the time step size. Table 1 describes the five cases in terms of these differences. Table 2 is the input listing for Case 2. Input listings for other cases are similar except for the values of the parameters controlling the use of implicit routine in Card 100 and the time step sizes in Card 9001.

4.1 Case 1 - Explicit Algorithm, 0.01 Seconds Integration Time Step

Figures 6 through 14 present the results for Case 1, where the explicit method and a 0.01 second time step size were used. Figure 7 shows the pressure variation in all four compartments and Figure 8 to Figure 11 show the pressure variations in individual compartments. It is observed from these figures that the pressure differential between the lower compartment, where blowdowns originate, and the ice compartment changes sign from time step to time step after about 15 seconds. This results in a severe numerically induced flow oscillation and mixing between these two compartments as revealed by the mass flow rate between them exhibited in Figure 13. Numerically induced oscillation and mixing also occur for the other two junctions as shown in Figure 12 and Figure 14. The consequence of this numerically induced mixing is a spurious reduction in temperature in the lower compartment and near thermal equilibrium between the lower compartment and the dead-end compartment and between the upper compartment and the ice compartment.

4.2 Case 2 - Implicit Algorithm, 0.01 Seconds Integration Time Step

Figures 15 through 19 present results for Case 2 which utilizes the implicit routine but the same time step size as in Case 1. Use of the implicit routine suppresses the flow oscillation as shown in Figures 17 through 19. The temperature in the lower compartment is therefore much higher than that obtained in the previous case and is the highest among all compartments, followed by that in compartments 2, 3 and 4. The temperature in Compartment 1 starts to rise more rapidly at about 25 seconds because superheated steam is being discharged into the compartment at that time: the enthalpy of the blowdown steam is 1159 Btu/lb before 25 seconds and 1297 Btu/lb after 25 seconds.

At the onset of the blowdown, pressure in the lower compartment starts to rise. This drives the steam and air mixture in this compartment to neighboring compartments and causes the pressure and the temperature in the other compartments to increase. However, because of the large energy removal capability of the ice compartment, this trend is reversed at about 3 seconds and pressures in all compartments begin to drop. Although blowdown continues at this time, the energy sink provided by the ice condenser exceeds the energy input from the blowdown. The flow direction is therefore reversed for all junctions (although of very small magnitude) except for the junction between the lower compartment and the ice compartment. The temperatures in the dead-end compartment and the upper compartment therefore remain about constant while the temperature in the lower compartment continues to rise (due to the introduction of higher enthalpy steam by vapor blowdown). The temperature in the lower compartment reaches a maximum value of 460°F at 61 seconds and starts to drop more rapidly at about 85 seconds due to a reduction in the enthalpy of the blowdown steam (from 1259 Btu/lb at 84 seconds to 1159 Btu/lb at 100 seconds).

Because of the large cross-sectional flow areas between compartments, the pressure differences between compartments after about 30 seconds are expected to be smaller than that exhibited in Figure 16. This pressure difference of about 0.1 psi is caused by the use of flow reduction factors in the implicit routine. They are employed to intentionally underpredict the flow rate in order to assure the avoidance of flow oscillation.

After about 10 seconds, all compartment pressures (Figure 16) are greater than the corresponding ones obtained by the explicit algorithm (Figure 7). The lower pressures are the results of excessive steam flow, caused by the numerically induced flow oscillation, into the ice compartment where it condenses.

It is emphasized that the implicit method should be used only when pressure differentials across junctions are so small that clearly defined flow directions are lacking or that the flow direction is changed after a time step due to the combined effect of a small pressure differential and a large time step size. If the pressure differential is large due to other sources such as steam blowdowns, a small time step, consistent with the time scale associated with the blowdowns, should be used. Such consideration in the determination of time step size should eliminate any concern about the effect of the implicit routine on the accuracy of the problem solution.

4.3 Case 3 - Explicit Algorithm, 0.002 Seconds Integration Time Step

Figures 20 through 24 present results for Case 3 which uses a smaller time step size (0.002 seconds) and the explicit algorithm. Flow oscillations across junctions are smaller than in Case 1 because of the use of the smaller time step but they do exist as shown in Figures 22 through 24. They result in severe numerically induced thermal mixing between compartments as revealed by the compartment temperature variations given in Figure 20. Pressures in all compartments are lower than those obtained in Case 2 because of excessive steam condensation in the ice compartment caused by numerically induced flow oscillation.

4.4 Case 4 - Implicit Algorithm, 0.1 Seconds Integration Time Step

Figures 25 through 29 present results for Case 4 which is the same as Case 2 except that a larger time step (0.1 seconds versus 0.01 seconds) is used for this case after 25 seconds. Results of this case show very good agreement with that of Case 2. The very minor difference in the predicted pressure profiles between Figures 16 and 26 is attributed to the use of flow reduction factors for the elimination of numerically induced flow oscillations.

4.5 Case 5 - Explicit Algorithm and 0.001 Seconds Integration Time Step

Figure 30 through 34 present results for Case 5 which is similar to Case 3 except for the use of an even smaller integration time step (0.001 seconds). The pressure and temperature predictions are slightly improved over that of Case 3 but still show a significant effect of numerically induced flow oscillation.

4.6 Case Results Summary

Flow oscillations across junctions are observed in the calculational results for the sample problem analyzed in this report using explicit algorithm

These flow oscillations are numerically induced in nature because there is no physical mechanism in the sample problem that will cause such oscillations.

The use of the implicit routine eliminates flow oscillations completely. The maximum temperature obtained by the implicit method in the blowdown compartment (460°F at 61 seconds) is closely related to the temperature of the blowdown steam, which has a maximum value of about 520°F at 25 seconds, decreases to 460°F at 61 seconds and further decreases after 61 seconds. This is what would be expected since no energy removal mechanism, such as heat structures, was considered in the blowdown compartment.

Table 3 presents the maximum pressure and temperature in the four compartments for all five cases. It shows that the numerically induced mixing from the use of a time step of 0.01 seconds and the explicit routine grossly underpredict the maximum temperature in the blowdown compartment (Case 1). The pressure and temperature profiles (Figures 6 and 7) are also quite different from the more correct results (Figures 15 and 16). The use of a smaller time step (from 0.01 seconds to 0.001 seconds) improves the results, but the error introduced by the numerically induced flow oscillation is still unacceptable (Figures 20, 21, 30 and 31). On the other hand, with the implicit algorithm, good results are obtained, even with the use of a larger time step (0.1 seconds, Figures 25 and 26).

5. Discussions and Conclusions

The analysis of a typical ice containment problem shows that the explicit time advancement algorithm of the CONTEMPT4 code produces undesirable numerically induced flow oscillations across junctions which diminish, but cannot be eliminated, with reduced integration time steps. Results obtained from the explicit algorithm with a reasonably small integration time step of 0.001 seconds are unacceptable for the sample problem studied in this report. This is because the numerically induced flow oscillation and artificial mixing are particularly undesirable for the analysis of an ice containment problem where large differences in gas composition and thermal conditions exist in different compartments and instantaneous steam condensing capability is assumed in the ice compartment. Calculational results can be improved with reduced integration time step sizes, but the convergence seems to be slow. Computer cost will therefore be prohibitive if accurate results are to be obtained for an intermediate or long term transient analysis.

Through the analysis of the sample problem, it has also been demonstrated that the implicit routine incorporated in the CONTEMPT4 computer code by BNL eliminates numerically induced oscillations completely. It produces accurate results even with the use of a much larger integration time step (0.1 seconds) and therefore makes the analysis of the long term ice containment problem more feasible.

References

1. C. C. Lin, C. Economos, J. R. Lehner, G. Maise, and K. K. Ng, "CONTEMPT4/MOD4, A Multicompartment Containment System Analysis Program", NUREG/CR-3716, BNL-NUREG-51754, March 1984.

2. K. Almenas, "Numerical Limitations and Computer Time Requirements of the CONTEMPT4 Code for Ice Condenser Containment Analysis", MDNE-82-110, University of Maryland, July 1982.

3. G. Pertmer, K. Almenas, Z. Jin and H. Dezfuli, "The Effect of Steam Bypass on Ice Condenser Containment Pressurization", MDNE-82-111, University of Maryland, July 1982.

Table 1. Case Description

Case No.	Use of Implicit Method	Time Step Size (Sec)
1	No	0.01
2	Yes	0.01
3	No	0.002
4	Yes	0.01 up to 25 sec and 0.1 thereafter
5	No	0.001

Table 2. Input Listing for Case 2

```
=          ICE CONDENSER PROBLEM - CASE 2
100     SEC 0.0   100.0  0  BRT  500000
105     0  0  0.0
9000    SEC
9001    10.00    0.01    0.0    20    1  0   1   0
9002    50.00    0.01     0.0   50    1  0  5   0
9003    100.0    0.01     0.0   250   5   0   25   0
9004    200.0    0.01    0.0   200   4   0   100  0
9005    500.0    0.01     0.0   50    0  0  20   0
9006    1000.0   0.01     0.0   500   0  0  20   0
9007    5000.0   0.01     0.0   500   0  0  20   0
9008    1.0E4    200.0    0.0   50    0  0  20   0
9009    5.0E4    1.0E3    0.0   50    0  0  20   0
9010    1.0E5    2.0E3    0.0   50    0  0  20   0
9011    5.0E5    1.0E4    0.0   50    0  0  20   0
9012    1.0E6    2.0E4    0.0   50    0  0  20   0
*
*          MINOR EDIT
*
9101   PRT 1  PRT 2  PRT 3  PRT 4  TG 1  TG 2  TG 3  TG 4
*
*         COMPARTMENT DESCRIPTIONS
*
40000     FT3  FT3  DEGF  LBF/IN2  FT2  FT  SEC-1
40010     'LOWER COMPARTMENT'
40020     'DEAD END VOLUME'
40030     'UPPER COMPARTMENT'
40040     'ICE COMPARTMENT NO. 4'
*         ALL ICE CONDENSER SPECIFICATIONS ARE IDENTICAL
*         EXCEPT COMPARTMENT VOLUME
40011   DRY 289014.0 0.0 100.0 100.0 15.0 0.1 8700.0  1.0 1.0 0. 0.25 1.0
40021   STD  94000.0 0.0 100.0 100.0 15.0  0.1 4100.0  1.0 1.0 0. 0.25
40031   STD 698000.0 0.0  85.0  85.0 15.0  0.1 1.5E4   1.0 1.0 0. 0.25
40041   ICE 111241.0 0.0  33.0  33.0 15.0  1.0  1063.5  1.0  1.0  0.0 0.25
*
*         JUNCTION DESCRIPTIONS
*
8000      FT  FT2
8002    1  2 0  4.20 4.20  2  298.0  1.0  1.0
8004    1  4 0  1.16 1.16  2 1063.0  1.0  1.0
8005    4  3 0  1.16 1.16  2  984.0  1.0  1.0
```

Table 2 (Cont'd.)

```
*                                                                                   000042
* DRAIN DESCRIPTION                                                                 000043
*                                                                                   000044
6000      LB  BTU  FT2  FT                                                          000045
6041   4  1  2  0.0  0.0  1063.5  1063.5  120. 120. 120. 0.000046  -1.0             000046
6031   3  1  2  0.0  0.0  2003.1  2003.1   30.  30.  30. 0.000046  -1.0             000047
*                                                                                   000048
*         ICE CHEST DESCRIPTIONS                                                    000049
*                                                                                   000050
60000     DEGF  LB                                                                  000051
60041     15.0  2.450006E6  7  * NOTE: DESIGN  SPEC USED FOR TEMP.                  000052
100701    SEC    DEGF    DEGF    NONE                                               000053
100702      0.0      33.0      33.0        1.0                                      000054
100703      0.5     200.0      90.0        1.0                                      000055
100704      1.0     210.0     147.0        1.0                                      000056
100705      2.0     230.0     140.0        1.0                                      000057
100706     10.0     175.0      75.0        1.0                                      000058
100707    100.0     130.0      75.0        1.0                                      000059
100708     1.E6     130.0      75.0        1.0                                      000060
*                                                                                   000061
*    ICE CONDENSER PROBLEM BLOWDOWN TABLES                                          000062
*    THE BLOWDOWN IS SEPARATED INTO  PARTS, THE VAPOR PORTION                       000063
*    AND THE LIQUID PORTIONS                                                        000064
*                                                                                   000065
1010     'VAPOR BLOWDOWN TABLE'                                                     000066
1011     1  ATM  1.0  1.0  1  VAP                                                   000067
100101   SEC  LB/SEC  BTU/SEC  0                                                    000068
100102   0.0          0.0          0.0                                              000069
100103   1.00000E-8  2.61361E4  3.02913E7                                           000070
100104   2.50331E-2  2.61361E4  3.02913E7                                           000071
100105   1.25218E-1  3.05446E4  3.54006E7                                           000072
100106   2.50276E-1  3.12901E4  3.62646E7                                           000073
100107   3.50283E-1  3.04523E4  3.52936E7                                           000074
100108   4.50334E-1  2.84610E4  3.29857E7                                           000075
100109   5.75504E-1  2.77046E4  3.21091E7                                           000076
100110   7.24750E-1  2.69557E4  3.12411E7                                           000077
100111   8.75455E-1  2.61061E4  3.02564E7                                           000078
100112   1.07552E+0  2.49137E4  2.88744E7                                           000079
100113   1.35026E+0  2.35809E4  2.73297E7                                           000080
100114   1.65024E+0  2.20030E4  2.55010E7                                           000081
```

Table 2 (Cont'd.)

100115	1.90023E+0	2.04405E4	2.36902E7		000082
100116	2.75014E+0	1.72135E4	1.99500E7		000083
100117	4.25035E+0	1.44838E4	1.67865E7		000084
100118	5.75034E+0	1.33139E4	1.54[illegible]6E7		000085
100119	7.25076E+0	1.46885E4	1.70237E7		000086
100120	8.75090E+0	1.14149E4	1.32296E7		000087
100121	1.02590E+1	1.04018E4	1.20555E7		000088
100122	1.20026E+1	9.16474E3	1.06217E7		000089
100123	1.37519E+1	7.86157E3	9.11140E6		000090
100124	1.52506E+1	6.65855E3	7.71712E6		000091
100125	1.67506E+1	5.33876E3	6.18752E6		000092
100126	1.82507E+1	3.49836E3	4.05453E6		000093
100127	1.97504E+1	2.12191E3	2.45925E6		000094
100128	2.15006E+1	9.04012E2	1.04773E6		000095
100129	2.32505E+1	2.52914E2	2.93123E5		000096
100130	2.40056E+1	8.38995E0	9.72378E3	h = 1159 Btu/lb	000097
100131	2.40112E+1	0.00000E0	0.00000E0		000098
100132	2.500E+1	4.45356E+2	5.77598E+5	h = 1297 Btu/lb	000099
100133	2.521E+1	2.36488E+2	3.06703E+5		000100
100134	2.601E+1	3.60590E+2	4.67649E+5		000101
100135	3.101E+1	9.72217E+2	1.25882E+6		000102
100136	3.201E+1	1.05466E+3	1.36443E+6		000103
100137	3.201E+1	1.05792E+3	1.36853E+6		000104
100138	3.601E+1	1.01941E+3	1.31538E+6		000105
100139	4.701E+1	9.27829E+2	1.18826E+6		000106
100140	5.000E+1	9.04452E+2	1.15593E+6		000107
100141	5.400E+1	8.78376E+2	1.12005E+6		000108
100142	6.401E+1	7.22574E+2	9.16259E+5		000109
100143	6.401E+1	7.21867E+2	9.15343E+5		000110
100144	7.401E+1	6.13547E+2	7.74924E+5		000111
100145	8.401E+1	5.43446E+2	6.84181E+5	h = 1259 Btu/lb	000112
100146	1.000E+2	5.49086E+2	6.36380E+5	h = 1159 Btu/lb	000113
100147	1.440E+2	4.25076E+2	5.27367E+5		000114
100148	1.949E+2	4.03635E+2	4.95865E+5		000115
100149	1.950E+2	2.97000E+2	3.54000E+5		000116
100150	2.000E+2	2.97000E+2	3.53000E+5		000117
100151	3.000E+2	2.97000E+2	3.44000E+5		000118
100152	3.050E+2	2.97000E+2	3.44000E+5		000119

Table 2 (Cont'd.)

```
100153  3.100E+2    1.49000E+2  1.72000E+5                                             000120
100154  4.000E+2    1.40000E+2  1.61000E+5                                             000121
100155  5.000E+2    1.31000E+2  1.52000E+5                                             000122
100156  6.000E+2    1.31000E+2  1.52000E+5                                             000123
100157  7.000E+2    1.24000E+2  1.43000E+5                                             000124
100158  8.000E+2    1.18000E+2  1.36000E+5                                             000125
100159  9.000E+2    1.18000E+2  1.37000E+5                                             000126
100160  1.000E+3    1.12000E+2  1.29000E+5                                             000127
100161  1.200E+3    1.05000E+2  1.21000E+5                                             000128
100162  1.400E+3    1.00000E+2  1.16000E+5                                             000129
100163  1.600E+3    9.66000E+1  1.12000E+5                                             000130
100164  1.765E+3    9.71000E+1  1.12000E+5                                             000131
100165  2.000E+3    0.00000E+0  0.00000E+0                                             000132
100166  1.000E+6    0.00000E+0  0.00000E+0                                             000133
1020    'LIQUID BLOWDOWN TABLE'                                                        000134
1021    1  ATM  1.0  1.0  2  LIQ                                                       000135
100201  SEC  LB/SEC   BTU/SEC  0                                                       000136
100202  0.0            0.0          0.0                                                000137
100203  1.00000E-8     4.39774E4    8.95713E6                                          000138
100204  2.50331E-2     4.39774E4    8.95713E6                                          000139
100205  1.25218E-1     3.95689E4    8.05924E6                                          000140
100206  2.50276E-1     5.15058E4    1.04905E7                                          000141
100207  3.50283E-1     4.92365E4    1.00283E7                                          000142
100208  4.50334E-1     4.48718E4    9.13932E6                                          000143
100209  5.75504E-1     4.25130E4    8.65887E6                                          000144
100210  7.24750E-1     4.01771E4    8.18312E6                                          000145
100211  8.75455E-1     3.80746E4    7.75489E6                                          000146
100212  1.07552E+0     3.56756E4    7.26627E6                                          000147
100213  1.35026E+0     3.30606E4    6.73366E6                                          000148
100214  1.65024E+0     2.99505E4    6.10021E6                                          000149
100215  1.90023E+0     2.71178E4    5.52324E6                                          000150
100216  2.75014E+0     2.14205E4    4.36285E6                                          000151
100217  4.25035E+0     1.70920E4    3.48122E6                                          000152
100218  5.75034E+0     1.55812E4    3.17351E6                                          000153
100219  7.25076E+0     1.68873E4    3.43953E6                                          000154
100220  8.75090E+0     1.16114E4    2.36496E6                                          000155
100221  1.02590E+1     1.01436E4    2.06600E6                                          000156
100222  1.20026E+1     8.48186E3    1.72755E6                                          000157
100223  1.37519E+1     6.76563E3    1.37800E6                                          000158
```

Table 2 (Cont'd.)

```
100224  1.52506E+1   5.78295E3   1.17785E6                                   000159
100225  1.67060E+1   4.84854E3   9.87531E5                                   000160
100226  1.82507E+1   3.78445E3   7.70802E5                                   000161
100227  1.97504E+1   2.03756E3   4.15003E5                                   000162
100228  2.15000E+1   1.36530E3   2.78078E5                                   000163
100229  2.32505E+1   3.96102E2   8.06764E4                                   000164
100230  2.40056E+1   8.53612E1   1.73860E4                                   000165
100231  2.40112E+1   0.00000E0   0.00000E0                                   000166
100232  2.500E+1     0.0         0.0                                         000167
100233  8.401E+1     0.0         0.0                                         000168
100234  1.000E+2     1.03471E1   2.17046E3                                   000169
100235  1.400E2      0.0         0.0                                         000170
100236  1.949E2      0.0         0.0                                         000171
100237  1.950E2      3.70E2      7.29E4                                      000172
100238  2.000E2      3.70E2      7.29E4                                      000173
100239  3.000E2      3.71E2      7.30E4                                      000174
100240  3.050E2      3.71E2      7.30E4                                      000175
100241  3.100E2      5.19E2      1.02E5                                      000176
100242  4.000E2      5.28E2      1.04E5                                      000177
100243  5.000E2      5.36E2      1.06E5                                      000178
100244  6.000E2      5.36E2      1.06E5                                      000179
100245  7.000E2      5.43E2      1.07E5                                      000180
100246  8.000E2      5.49E2      1.08E5                                      000181
100247  9.000E2      5.49E2      1.08E5                                      000182
100248  1.000E3      5.56E2      1.09E5                                      000183
100249  1.200E3      5.63E2      1.11E5                                      000184
100250  1.400E3      5.67E2      1.12E5                                      000185
100251  1.600E3      5.71E2      1.12E5                                      000186
100252  1.765E3      5.70E2      1.12E5                                      000187
100253  2.000E3      0.0         0.0                                         000188
100254  1.000E6      0.0         0.0                                         000189
*                                                                            000190
. END OF ICE CONDENSER PROBLEM                                               000191
```

Table 3. Case Results Summary

Case No.	Maximum Pressure (psi)				Maximum Temperature (°F)			
Compartment No.	1	2	3	4	1	2	3	4
1	24.10	24.10	23.7	23.9	238.7	212.6	150.5	146.9
2	23.4	23.0	22.9	22.9	461.9	186.5	146.4	146.9
3	23.7	23.6	23.1	23.1	287.1	244.7	149.0	146.9
4	23.4	23.0	23.0	23.0	461.0	186.5	146.4	146.9
5	23.6	23.5	23.0	23.0	314.0	265.6	146.6	146.9

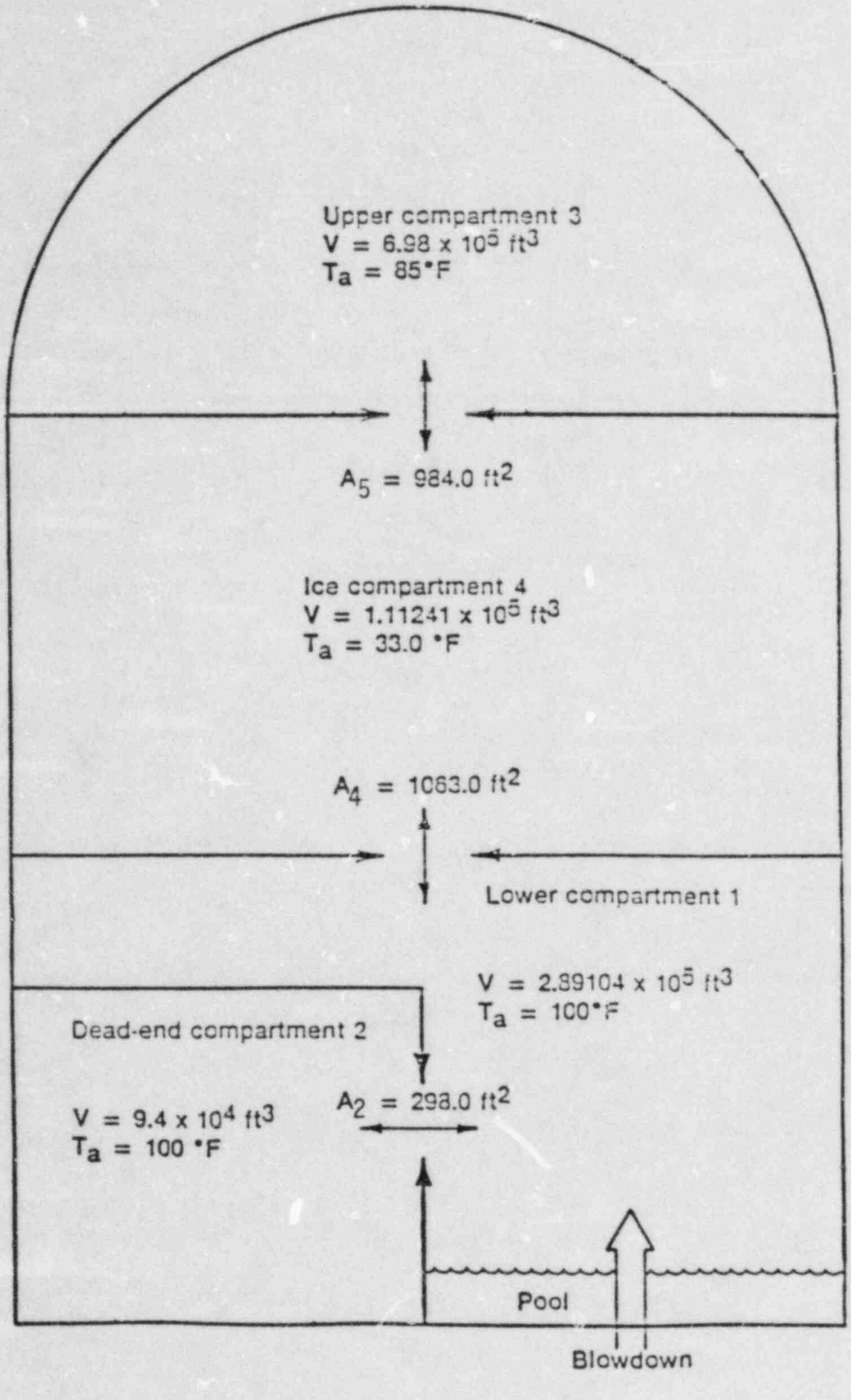

Figure 1. Problem Mathematical Model

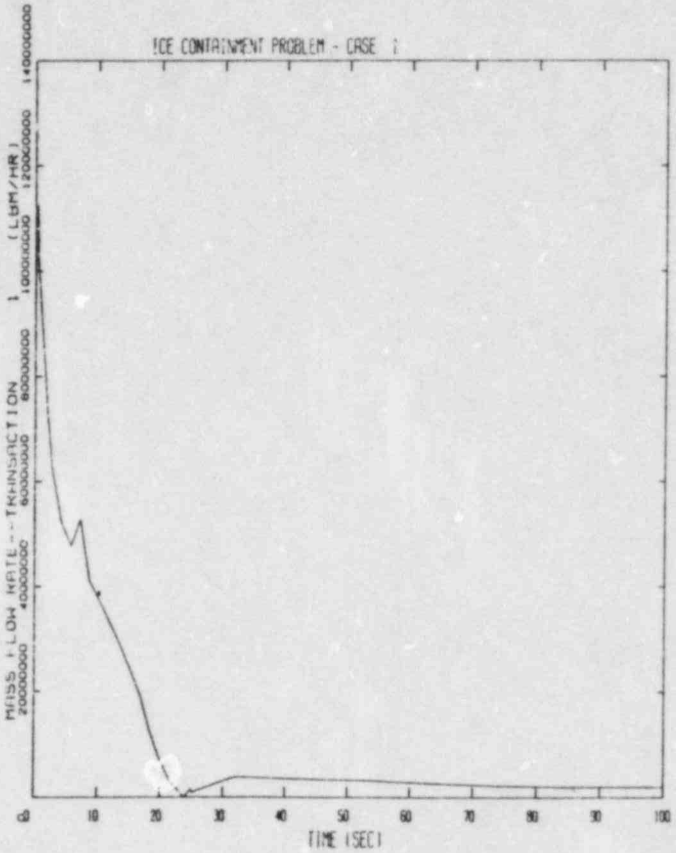

Figure 2. Mass Flow Rate for Steam Blowdown

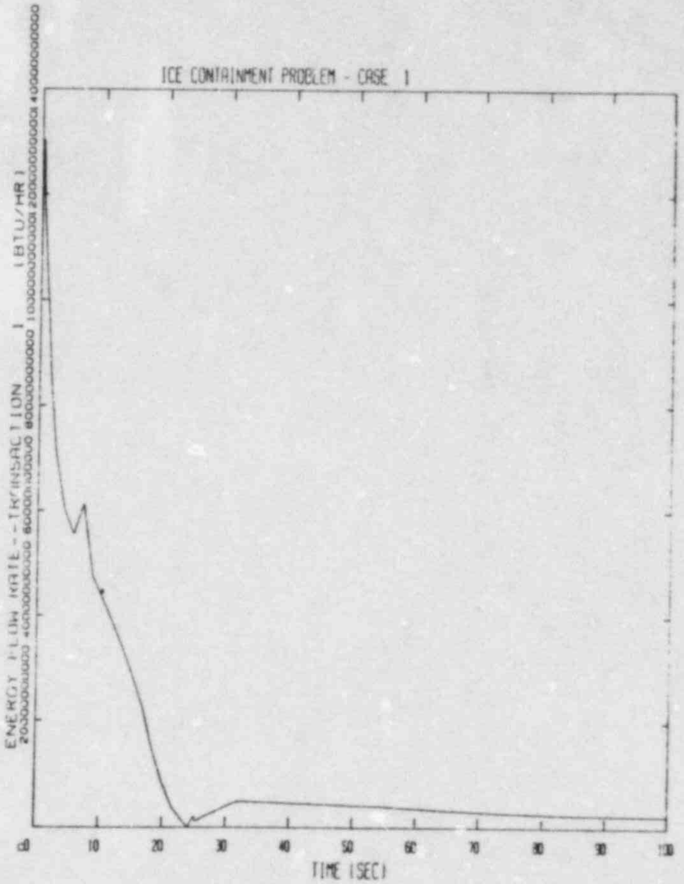

Figure 3. Energy Flow Rate for Steam Blowdown

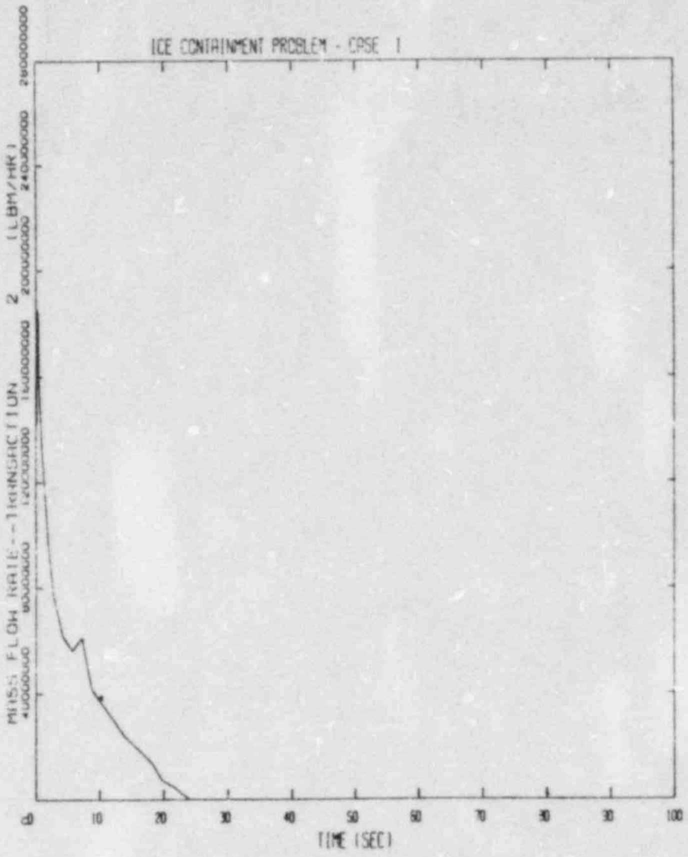

Figure 4. Mass Flow Rate for Liquid Blowdown

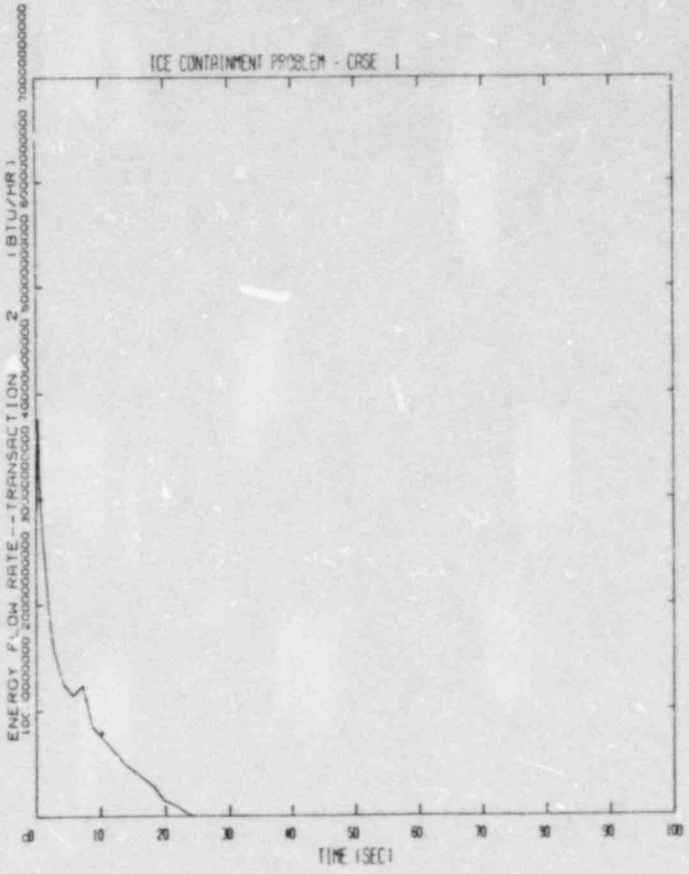

Figure 5. Energy Flow Rate for Liquid Blowdown

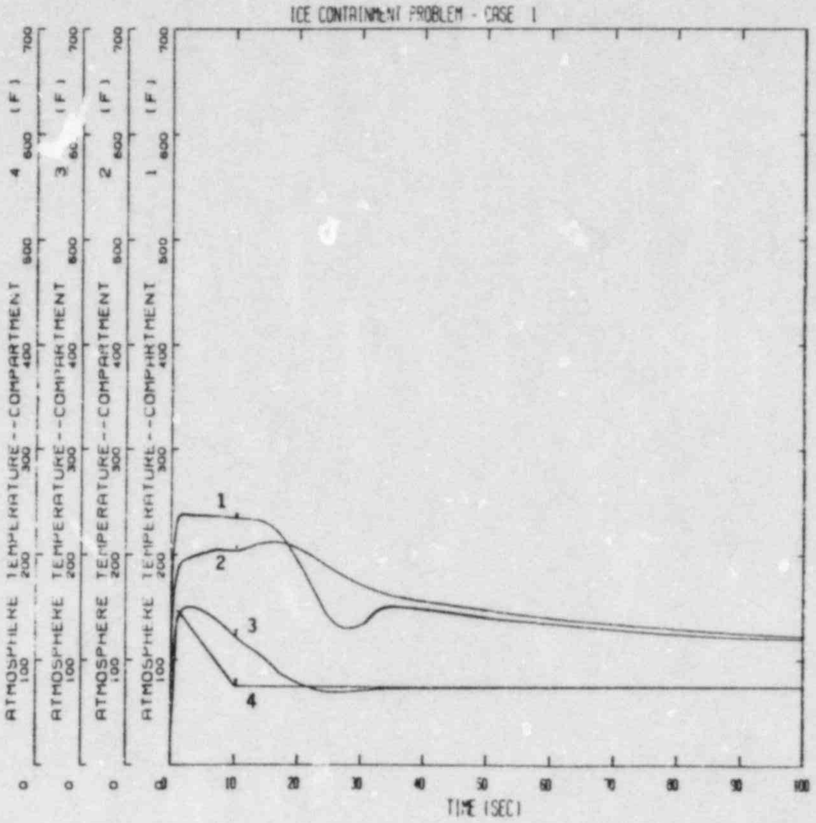

Figure 6. Compartment Temperature - Case 1

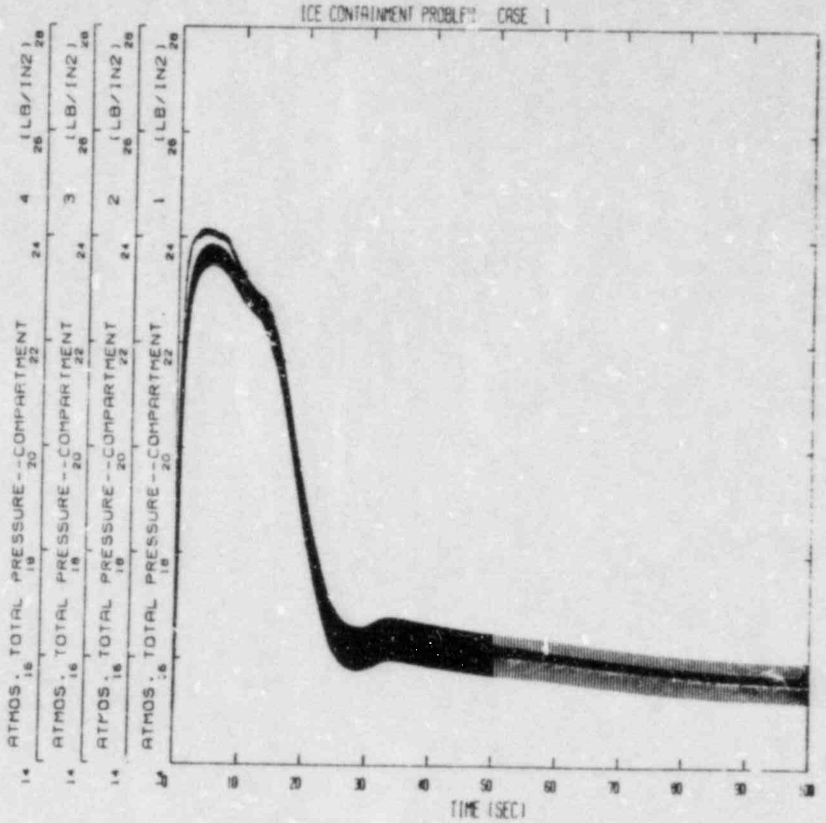

Figure 7. Compartment Pressure - Case 1

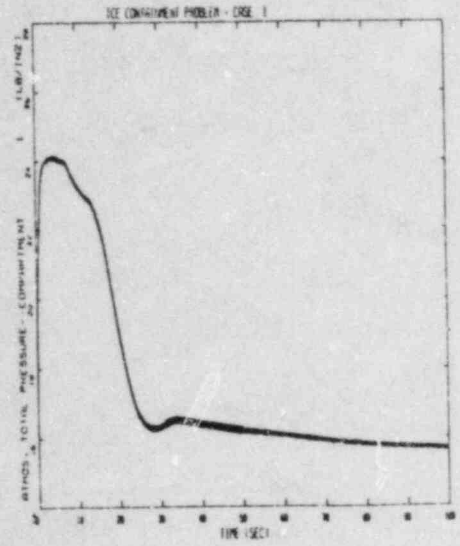

Figure 8. Pressure in Compartment 1 - Case 1

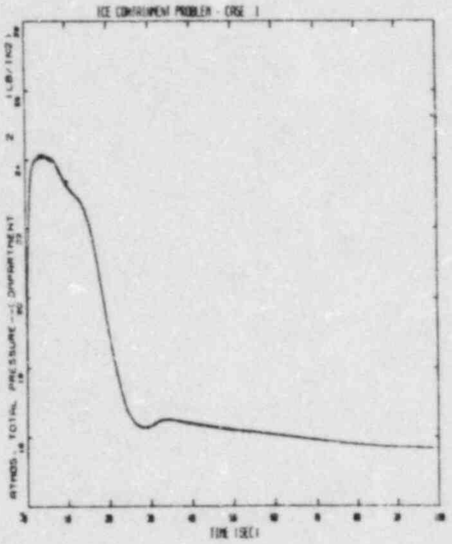

Figure 9. Pressure in Compartment 2 - Case 1

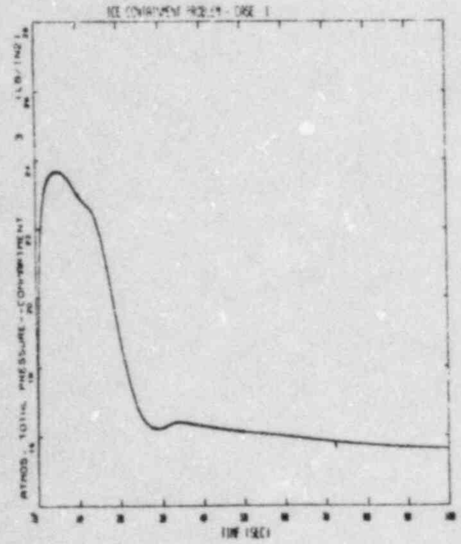

Figure 10. Pressure in Compartment 3 - Case 1

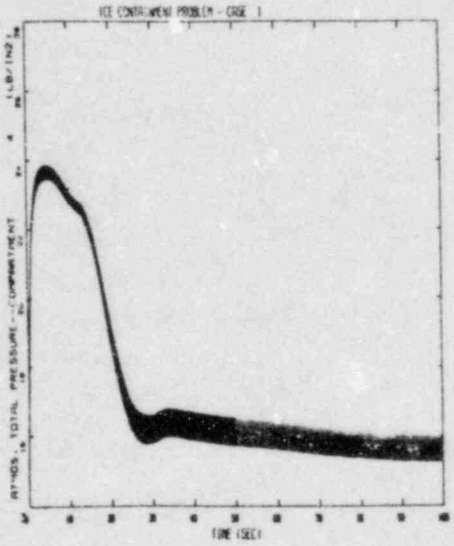

Figure 11. Pressure in Compartment 4 - Case 1

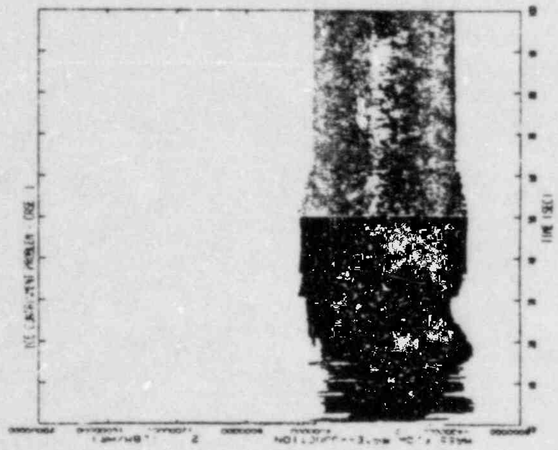

Figure 12. Mass Flow Rate of Junction 2 - Case 1

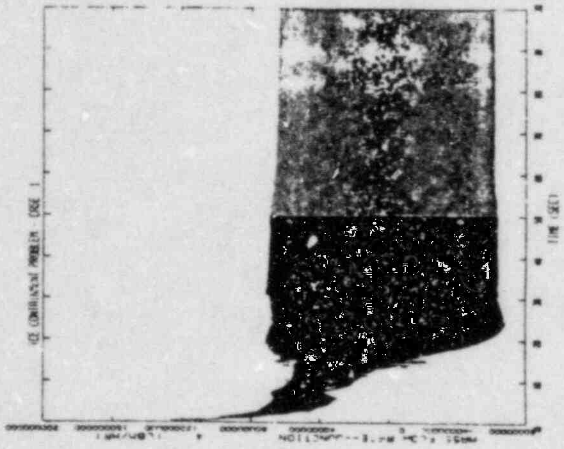

Figure 13. Mass Flow Rate of Junction 4 - Case 1

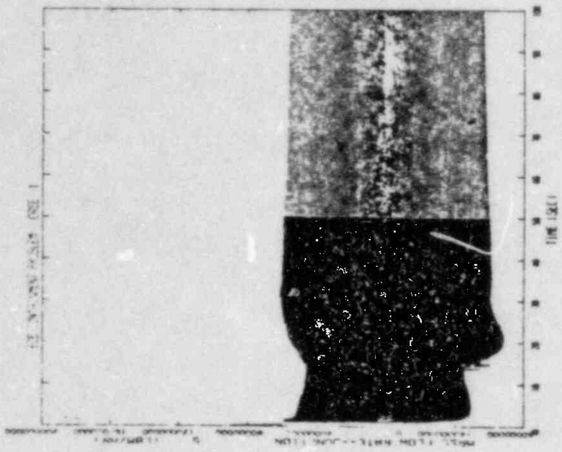

Figure 14. Mass Flow Rate of Junction 5 - Case 1

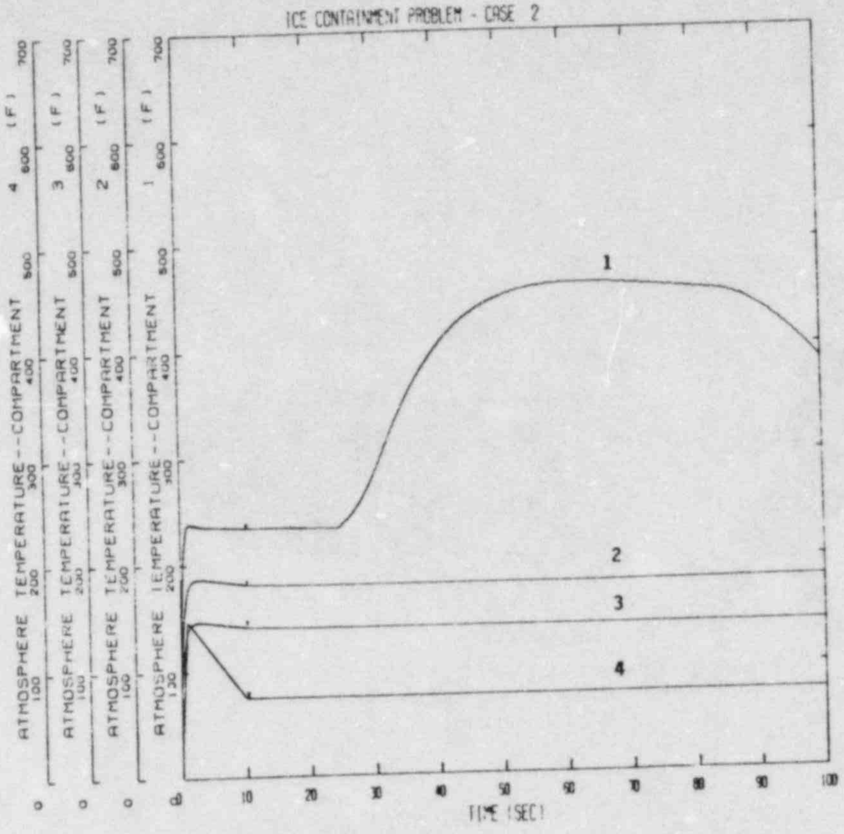

Figure 15. **Compartment Temperature** - Case 2

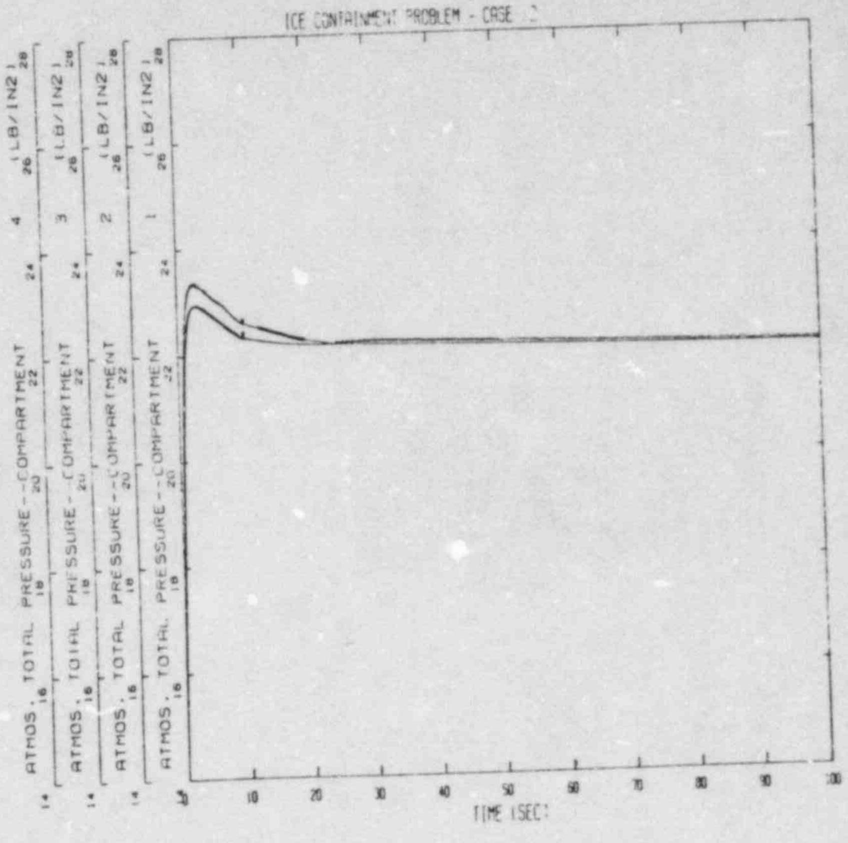

Figure 16. Compartment Pressure - Case 2

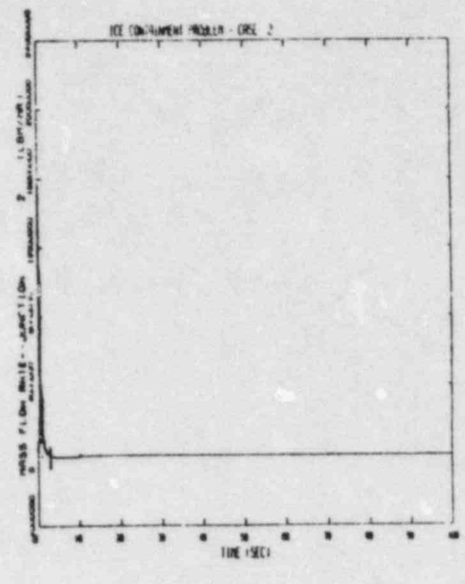

Figure 17. Mass Flow Rate of Junction 2 - Case 2

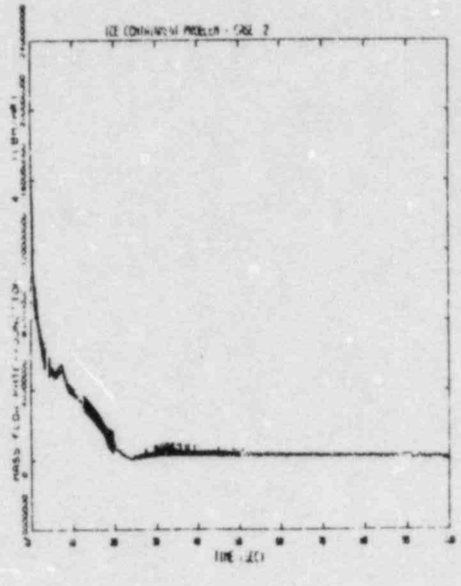

Figure 18. Mass Flow Rate of Junction 4 - Case 2

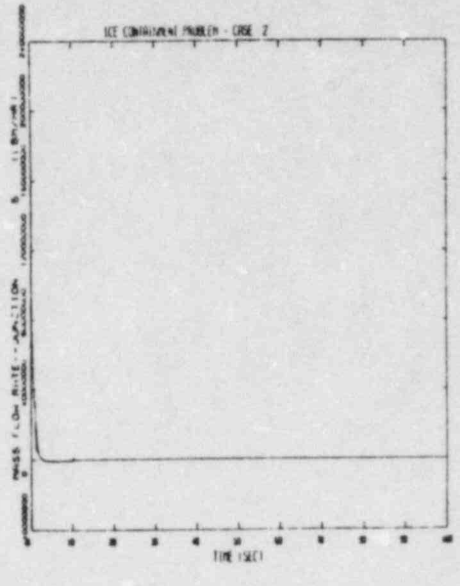

Figure 19. Mass Flow Rate of Junction 5 - Case 2

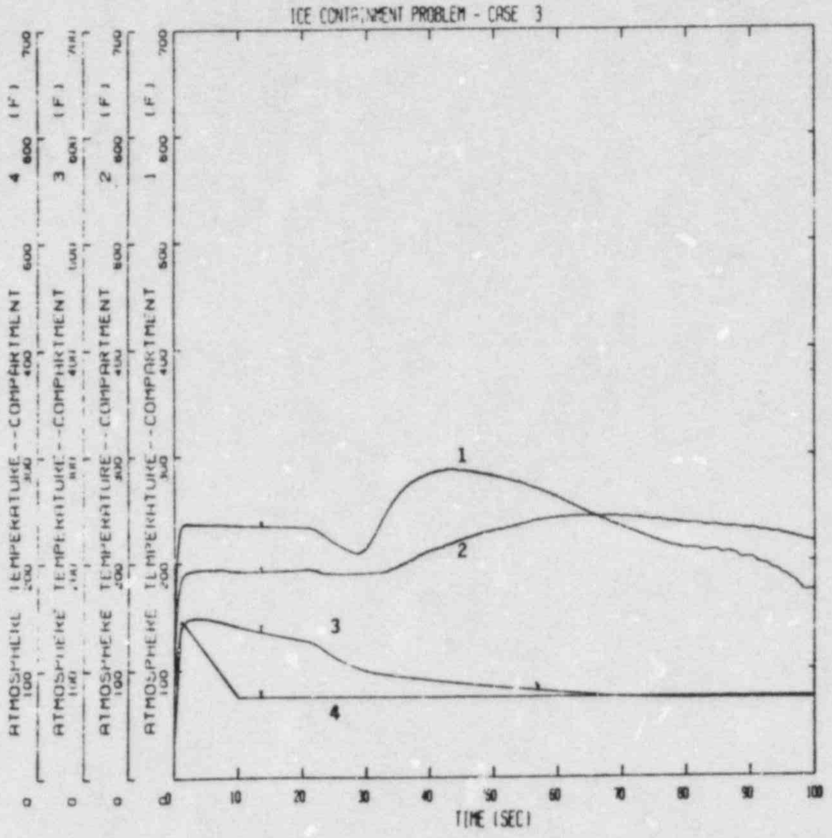

Figure 20. Compartment Temperature - Case 3

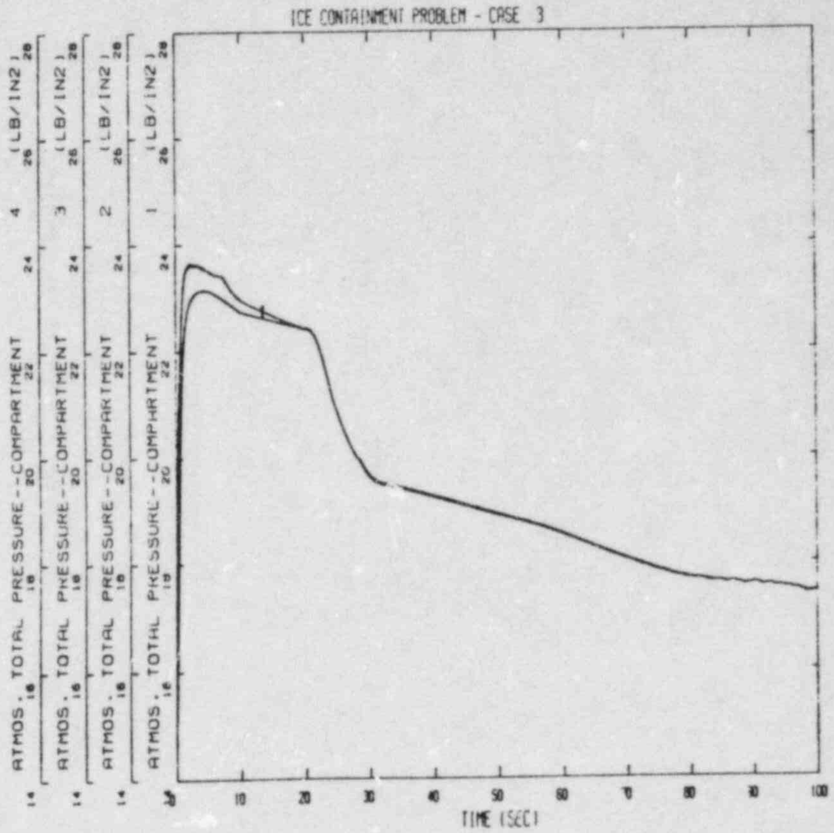

Figure 21. Compartment Pressure - Case 3

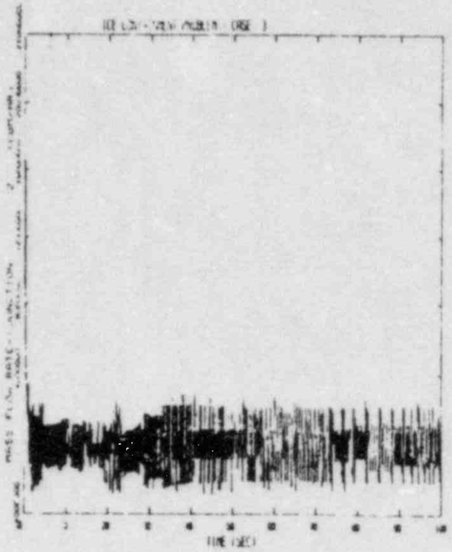

Figure 22. Mass Flow Rate of Junction 2 - Case 3

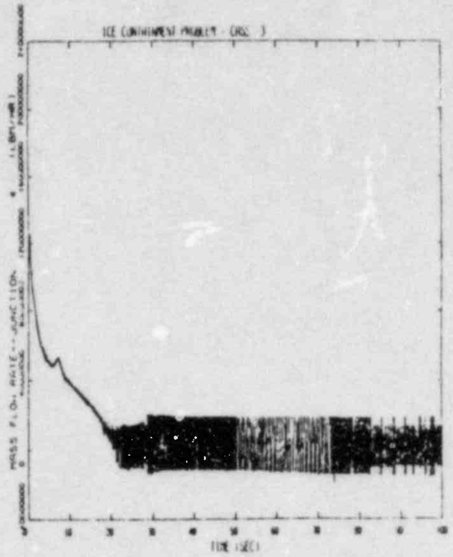

Figure 23. Mass Flow Rate of Junction 4 - Case 3

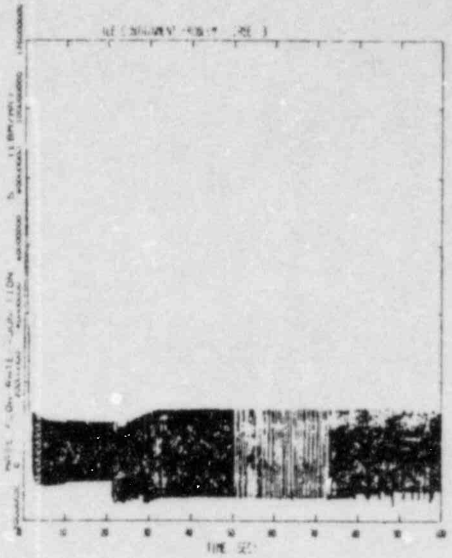

Figure 24. Mass Flow Rate of Junction 5 - Case 3

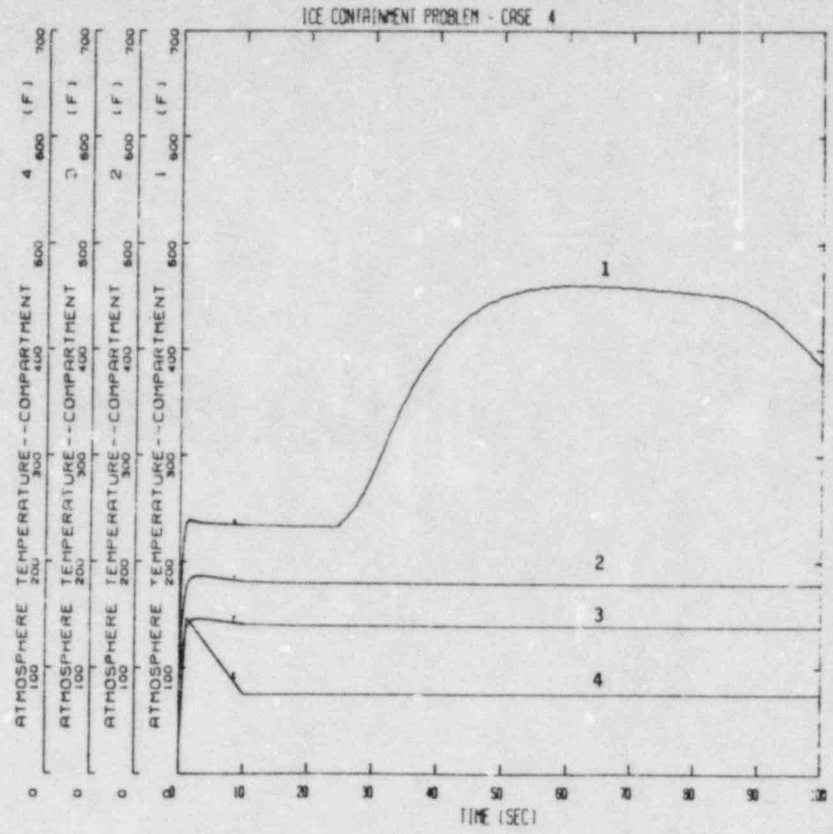

Figure 25. Compartment Temperature - Case 4

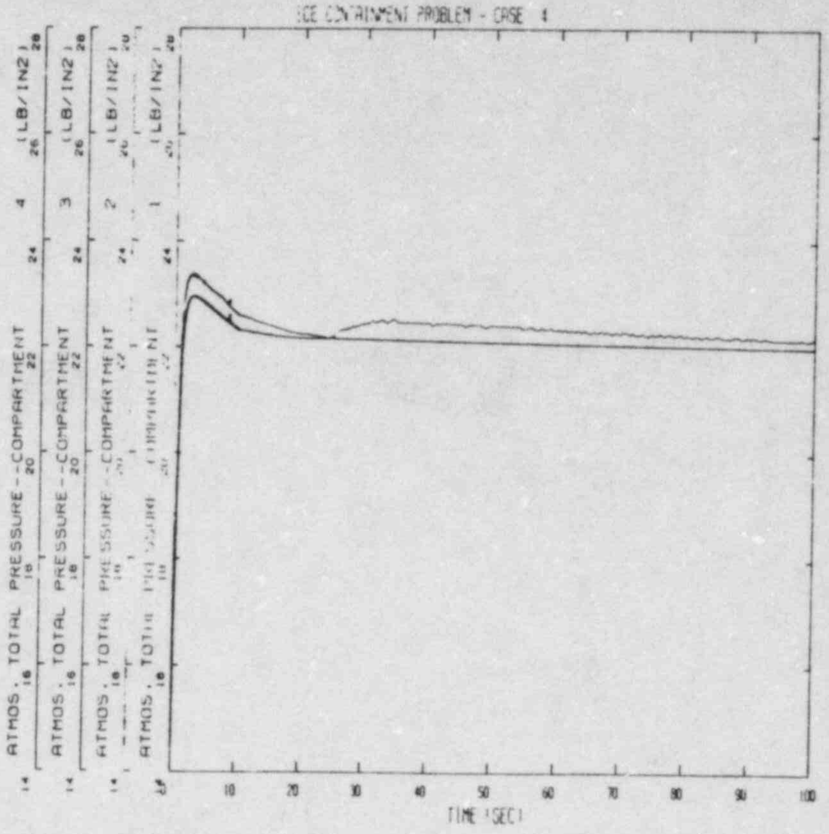

Figure 26. Compartment Pressure - Case 4

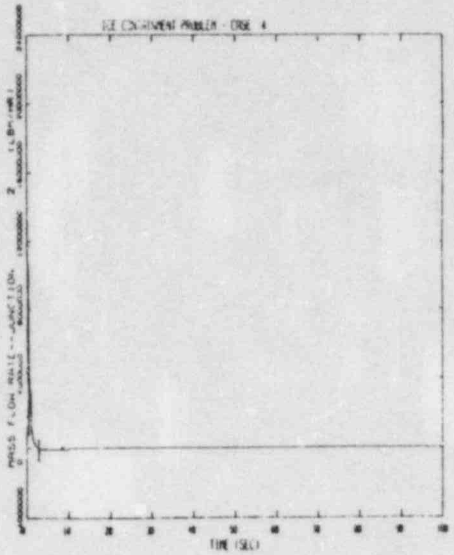

Figure 27. Mass Flow Rate of Junction 2 - Case 4

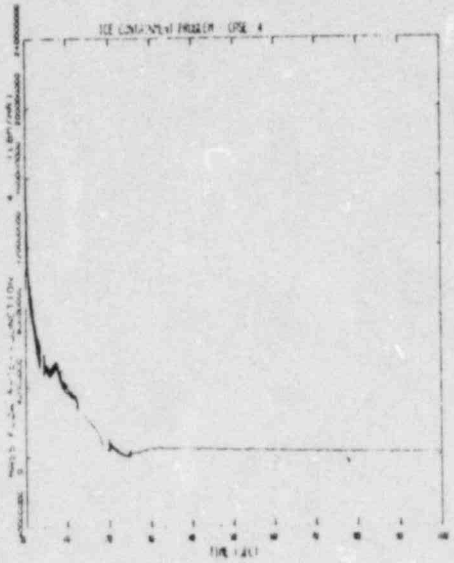

Figure 28. Mass Flow Rate of Junction 4 - Case 4

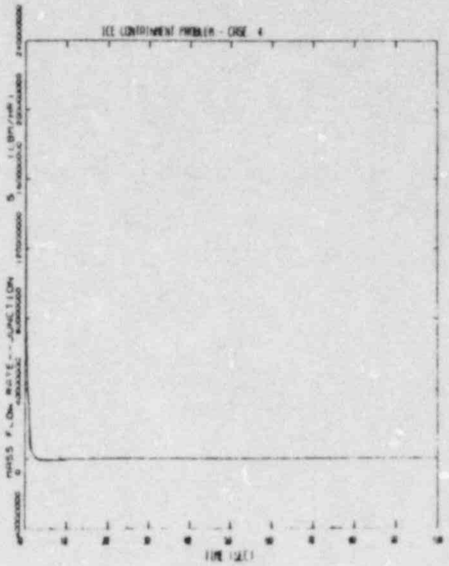

Figure 29. Mass Flow Rate of Junction 5 - Case 4

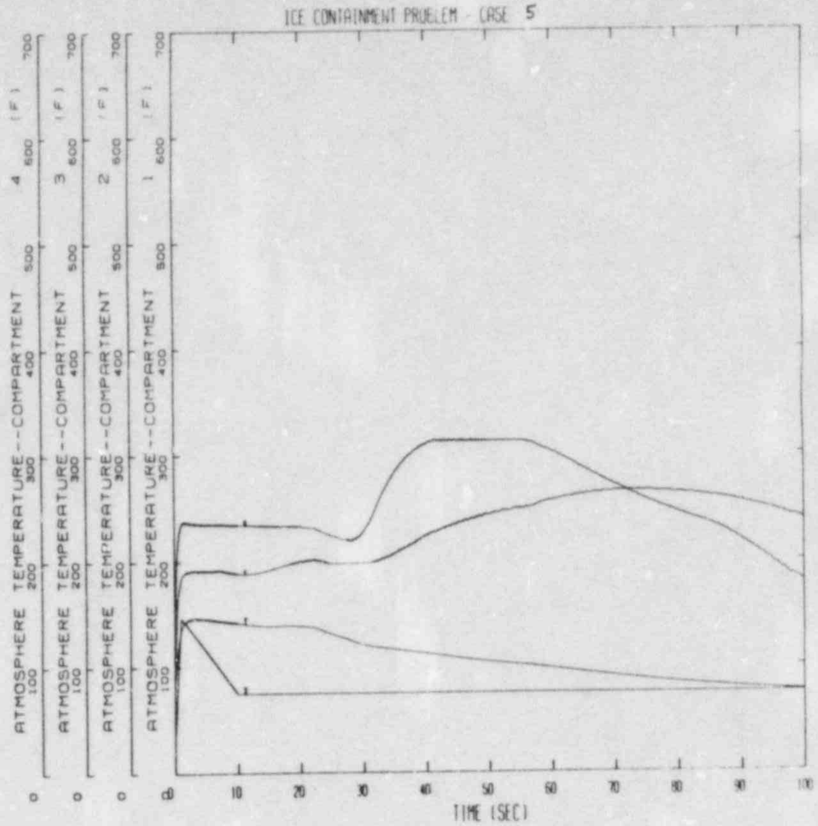

Figure 30. Compartment Temperature - Case 5

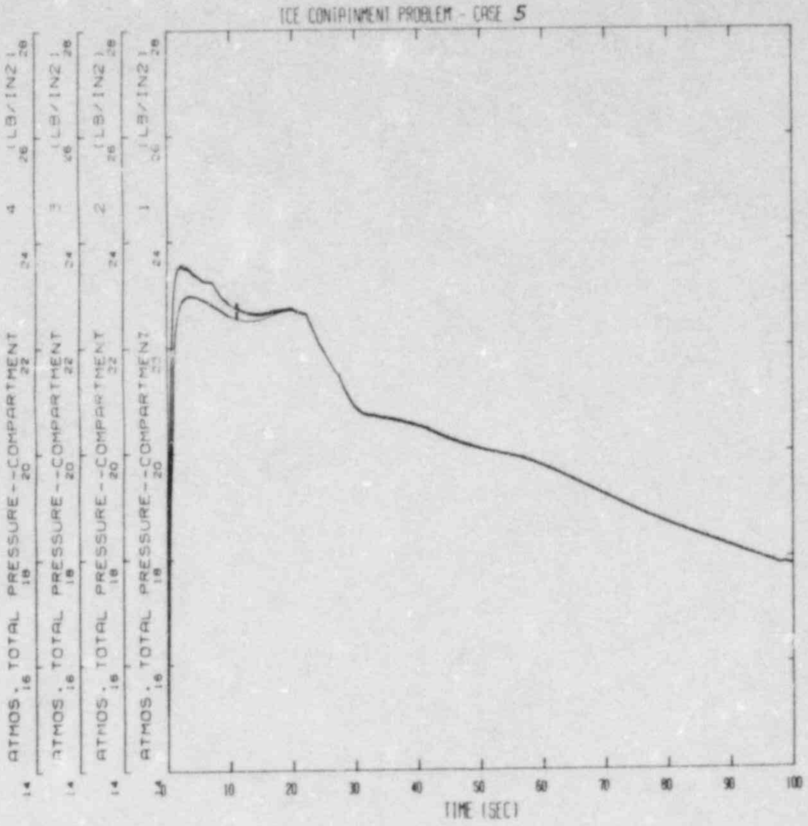

Figure 31. Compartment Pressure - Case 5

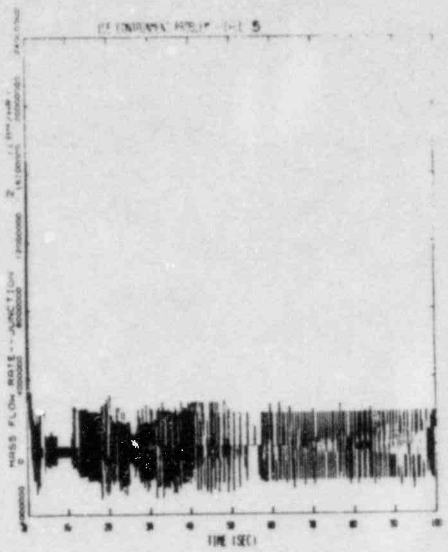

Figure 32. Mass Flow Rate of Junction 2 - Case 5

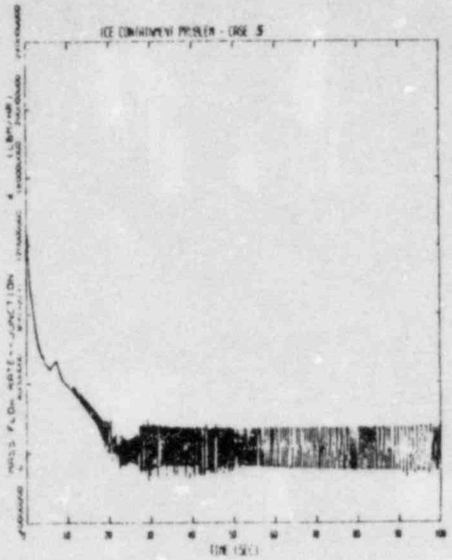

Figure 33. Mass Flow Rate of Junction 4 - Case 5

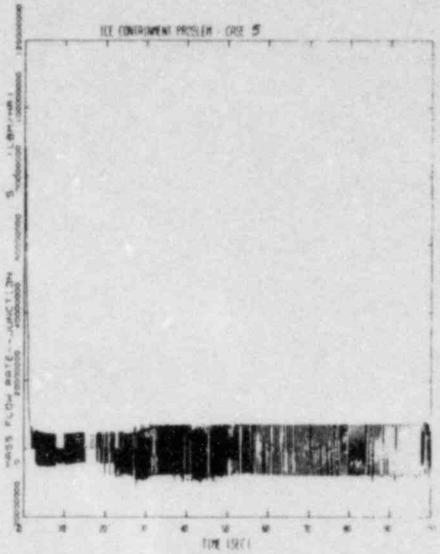

Figure 34. Mass Flow Rate of Junction 5 - Case 5

NRC FORM 335
(11 81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)
NUREG/CR-4001
BNL-NUREG-51824

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
CONTEMPT4/MOD5: An Improvement to CONTEMPT4/MOD4
Multicompartment Containment System Analysis Program
For Ice Containment Analysis

7. AUTHOR(S)
C. C. Lin

5. DATE REPORT COMPLETED

MONTH	YEAR
September	1984

DATE REPORT ISSUED

MONTH	YEAR
September	1984

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

Brookhaven National Laboratory
Dept. of Nuclear Energy, Building 475B
Upton, New York 11973

6. (Leave blank)

8. (Leave blank)

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

Division of Systems Integration
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO.
A-3752

13. TYPE OF REPORT

PERIOD COVERED (Inclusive dates)

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

CONTEMPT4 is a digital computer program for multicompartment containment system analysis. Previous version of the CONTEMPT4 code, MOD4, consists of an implicit algorithm to computer junction flow when numerically induced flow oscillations are encountered. This document presents analytical model and UPDATE statements that are required to extend the capability of the MOD4 implicit routine for ice containment analysis. A sample problem is analyzed both with and without the use of the implicit routine to demonstrate the effectiveness and the need of an implicit algorithm for such problems.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Containment analysis, LOCA, ice condenser, CONTEMPT code.

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS (This report)
Unclassified

20. SECURITY CLASS (This page)

21. NO. OF PAGES

22. PRICE

NRC FORM 335 (11 81)

UNITED STATES
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CONTEMPT4/MOD5: AN IMPROVEMENT TO CONTEMPT4/MOD4 MULTICOMPARTMENT CONTAINMENT SYSTEM ANALYSIS PROGRAM FOR ICE CONTAINMENT ANALYSIS

SEPTEMBER 1984