LaSalle Main Steam Tunnel Temperature Response due to Steam Leakage with Ventilation System in Operation

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(Date Issued)

Statement of Disclaimer

Release of Information Statement

Abstract

The LaSalle main steam tunnel (MST) leak detection system consists of temperature sensors that monitor the MST temperature and the ventilation system supply and exhaust air temperatures. The system functions to isolate the main steam line whenever abnormal conditions exist as indicated by high MST temperature or high differential temperature between ventilation system supply and exhaust air. The trip settings are established based on the temperature response of the MST due to steam leakage. This calculation uses a GOTHIC system model to determine the MST temperature response due to a variety of leak rates and supply air temperatures. The results are intended to be used to determine the appropriate setpoints in conjunction with other design considerations, such as allowable leakage rate and instrument uncertainties, which are addressed in other design calculations.

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1. Introduction

The main steam tunnel leak detection system is a part of the reactor coolant pressure boundary (RCPB) leakage detection system. Its design basis satisfies the requirements of 10CFR50 Appendix A General Design Criteria 54. One of the safety design bases given in Section 7.6.2.1.1 of the LaSalle UFSAR is "signals are provided to permit isolation of abnormal leakage before the results of this leakage become unacceptable." This basis can be achieved through monitoring of the MST temperature and the trip logic used to isolate the steamline whenever abnormal leakage exists. Trip setpoints must be set high enough to avoid spurious trip under normal operating conditions and low enough to provide early detection of abnormal leakage.

The purpose of this calculation is to determine the temperature response of the main steam tunnel (MST) due to different amounts of steam leakage for different supply air temperatures. The temperature response can then be used to specify a setpoint for leak detection.

2. Methodology/Model Description and Assumptions

The main steam tunnel temperature response was calculated by a GOTHIC system model. The following sections describe the tunnel configuration, the transient due to a steam leak, the analytical model, the computer code, and the input parameters and assumptions used in the analysis.

2.1 Physical Configuration

A sketch of the MST is shown in Figure 1. In this analysis, the MST is subdivided into three areas denoted as the lower, middle and upper MST. The lower and upper MST extend from Elevation 687 to 706 ft and from Elevation 736 ft 7 in to 768 ft 4.5 in, respectively. The middle MST consists of the vertical section of the tunnel between Elevation 706 ft and 736 ft 7 in.

The temperature of the MST is maintained by the reactor building ventilation (VR) system. Two streams of VR air enter the MST at different elevations and exit the tunnel via an exhaust riser located at the top of the MST. Air from the area between the primary containment and core standby cooling system (CSCS) cubicles enters the lower MST at the floor level (A). The air inlet at A is configured to yield a high velocity stream capable of sweeping the lower MST regions. In the current plant configuration, there are two exhaust vents at B. The majority of the air introduced at A sweeps toward B and then reverses direction, flowing to the upper regions. After flowing through the middle MST and the upper MST, the air exits the tunnel via the exhaust riser (D). The other air stream, which comes from the refueling floor and the reactor water cleanup (RWCU) area, enters the upper MST at (E) and exhaust through the exhaust riser (D).

This analysis is based on a revised configuration without the exhaust flow path at B, except for the heat load calculation which is based on data for the current configuration.

2.2 Description of Transient

The analysis assumes continuous steam leakage from cracks in the main steam line. The cracks are postulated to occur at any location along the full length of the steamline inside the MST. In the event of steam leakage with VR in operation, the temperature at locations downstream of the crack will experience a temperature rise, while locations upstream of the crack may not experience (except locally) any temperature increase at all. For example, cracks in the upper MST will not result in temperature rise in the lower MST. Hence, for leak detection purposes, a sensor located near the exhaust riser in the upper MST is capable of detecting leaks that occur anywhere in the MST. For a given amount of leakage, the temperature rise is greatest near the vicinity of the crack and decreases as the distance between the crack and the location of interest increases. Therefore, the basis for the leak detection setpoint for a sensor located in the upper MST is leakage from a crack located in the lower MST near the area where the steam lines exit the tunnel. Thus, in this analysis, only a leak in the lower MST is considered

for the purpose of establishing a leak detection setpoint. However, upper MST leaks are also considered to confirm that the lower MST leak location is bounding.

2.3 Analytical Model

The temperature response of the MST due to steam leakage is calculated by considering the mass and energy balances for the MST. A schematic of these quantities is shown in Figure 2. A GOTHIC system model is constructed based on this schematic. It consists of three control volumes representing the upper, middle and lower MST. Five additional control volumes are used to model the structures adjacent to the MST. A flow path is used to represent the flow from the lower to the middle MST and another path from the middle to the upper MST. Three additional flow paths are used to model the VR inlet and exhaust flows. Heat transfer through the walls, ceilings and floors to the adjacent structures is modeled with 16 heat structures. The heat load in the MST is produced predominantly from the main steam and feedwater lines and is represented by one heater located in each of the control volumes. Additional model features and assumptions are listed in Section 2.5.

2.4 Computer Code

The GOTHIC (Reference 1) computer code is used in the analysis. This code was developed by Numerical Applications, Incorporated for the Electric Power Research Institute (EPRI). GOTHIC is a general purpose thermal-hydraulics computer program for design, licensing, safety and operating analysis of nuclear power plant containments and other confinement buildings. Applications of GOTHIC include evaluation of containment and containment sub-compartment response to the full spectrum of high energy line breaks within the design basis envelope. Applications may include pressure and temperature determination, equipment qualification profiles and inadvertent system initiation, and degradation and failure of engineered safety features.

The code was verified and validated by ComEd and was installed in the company computer system in accordance with approved Company procedures and requirements for design application computer codes (Reference 2).

2.5 Input Assumptions and Parameters

As described in Section 2.2, the basis for establishing a leak detection setpoint is the lowest temperature rise in the MST. Therefore, the input assumptions and parameters are chosen conservatively to yield a low estimate of the temperature rise due to steam leakage. The following input assumptions and parameters were used in the analysis:

1. The heat transfer area of the walls, ceiling and floors were conservatively calculated without taking any allowances for obstructions. This assumption maximizes the heat transfer out of the MST. Likewise, the gross volume of the MST is used.

Calculations for heat transfer areas, volumes and other geometrical parameters are given in Appendix C.

2. The mechanism of heat transfer between air and the heat structures is specified to be either convection plus radiation or condensation. The Uchida correlation is used to calculate the condensation heat transfer coefficient.

3. The thermal conductivity, density and specific heat of the reinforced concrete walls are taken as 0.92 Btu/hr-ft-F, 145 lb/cu ft and 0.156 Btu/lb-F, respectively, based on Reference 3.

4. The temperatures of the VR supply air into the upper and lower MST are assumed to be equal. The VR supply air originates from outside the plant and enters the MST after passing through various areas in the reactor building. Hence, the VR supply air temperature is dependent on the outdoor air temperature. Two different supply air temperature values, 65 and 110 deg F, are used to bound the conditions expected year-round. Another temperature value, 95 deg F, is used which represents a typical condition expected during a moderately hot summer day. The relative humidity of the VR inlet air corresponding to the assumed temperatures are:

Temperature, F	Relative Humidity, %
65	30
95	50
110	30

The temperatures of the upper and lower MST supply air may be different. Plant data indicates that the lower MST supply air temperature may be 6 to 7 deg F warmer. It is conservative to assume the upper and lower MST supply air temperatures to be equal because it results in a lower temperature rise in the upper MST.

5. The assumed conditions for the adjacent volumes corresponding to the assumed VR supply air temperatures, are:

VR supply air temperature, deg F	65	95	110
Auxiliary Building	65	104	110
Auxiliary Building (conditioned space)	75	75	75
Reactor Building	65	95	110
Containment	130	130	130

The assumed conditions provide the boundary conditions for the problem. They are also used by the code to calculate the initial temperature profiles in the heat structures. They have only a secondary effect on the through-wall heat transfer to the outside due to the thickness of the concrete and its low thermal diffusivity. The tunnel temperature response is quick and reaches steady state in a short period of

time. Only a fraction of the wall thickness experiences an appreciable change from the initial conditions.

6. The VR flows are induced by the VR system exhaust fans. The upper MST exhaust flow, which consists of ventilation air and steam, is assumed to be at a constant volumetric flow rate. The VR flow rates used in the analysis are based on plant data and they are:

Upper MST supply air (initial condition)	24,000 cfm
Lower MST supply air (initial condition)	40,000 cfm
Upper MST exhaust air	64,000 cfm

The flow rates are based on a temperature of 95 deg F.

Because the VR flows are induced by the VR exhaust fans, the inlet VR flows are reduced by the presence of steam. The reduced inlet flow phenomenon may affect the temperature indication from a sensor located in the VR inlet. As the inlet flow reduces to zero due to increased leakage flow, the temperature indicated will be that of the MST instead of the inlet flow. The analysis takes into account the effects of reduced flow phenomenon as follows:

a. Analyses were performed by assuming only the lower VR inlet flow is reduced. With no reduction in upper MST VR inlet flow, a conservative upper MST temperature will be calculated for leaks in the lower MST. These results form the bases for the analytical values for setpoint determination.

b. Confirmatory analyses were performed to determine that the bases are bounding by allowing both the upper and lower MST inlet flows to vary according to the thermodynamic conditions in the MST. These analyses consider steam leaks in both upper and lower MST.

7. The heat load for each of the three volumes in the MST is calculated using the GOTHIC analytical model of the MST using the following input:

Lower MST supply air flowrate	40,000 cfm
Lower MST supply air temperature	95 deg F
Lower MST supply air relative humidity	50%
Lower MST temperature	110 deg F
Lower MST exhaust air (through duct) flowrate	4,600 cfm
Middle MST temperature	114 deg F
Upper MST supply air flowrate	24,000 cfm
Upper MST supply air temperature	95 deg F
Upper MST supply air relative humidity	50 %
Upper MST temperature	124.6 deg F

The calculated heat load is valid at the ambient temperature resulting from the above input conditions. It is multiplied by a normalized heat load vs. temperature curve to yield the heat load for a different tunnel temperature. Because the heat load in the MST is produced predominantly by the main steam and feedwater lines, the normalized curve is assumed to have the form:

$$Q/Q_o = U/U_o \times (T - T_{fluid})/(T_o - T_{fluid})$$

where U is the overall heat transfer coefficient of an insulated pipe and it is a function of temperature. Details of the heat load calculations are given in Appendix C.

8. The amount of steam leakage is expressed in gpm. By definition, the mass flow rate of one gpm of steam leakage is equal in numerical value to the mass flow rate of one gpm of water with a density of 62.4 lb/cu ft. For example,

   1 gpm of steam leakage = 1 gpm x 62.4 lb/cu ft /7.48 gal/cu ft = 8.34 lb/min of steam

9. During normal plant operating conditions, the steam pressure at the throttle valve is 965 psia (Table 10.1-1, UFSAR) and the steam dome pressure is limited by Tech Spec to less than 1020 psig (Tech Spec Sec. 3.4.6.2). Over this range of pressure, the enthalpy of saturated steam varies inversely with pressure. For this analysis, it is conservative to assume a low enthalpy value. Therefore, the condition of steam is assumed to be saturated at 1050 psia with an enthalpy of 1189.9 Btu/lbm.

10. The leak is located in the lower MST. As discussed in Section 2.2, this location gives the most conservative temperature setpoint.

11. A linear 100 sec leakage development profile is used in the analysis. The temperature response is expected to be quick and a near steady state condition is expected to be reached in a short period of time. Hence, the temperature results are not affected by the assumed profile shape.

3. Model Benchmark

The validity of the analytical model is established by comparing the GOTHIC model results with plant measured data. Figure 3 shows the results of the calculated upper MST temperature during normal operation at different VR inlet temperatures. The plant measured data taken in the period from October 8, 1995 to November 20, 1995 are also plotted in the same Figure for comparison. The plot shows very good agreement between the calculated results and plant data.

4. Results

Figure 4 shows the upper MST temperature response as a result of 100 gpm of steam leakage. The VR inlet temperature is 110 deg F and the leak is initiated at time equal to 1000 sec. The temperature increased 45.1 degrees from 137.4 to 182.5 deg F in the first 10 minutes but added only 1.1 degrees in the next 30 minutes. The quick temperature response is typical for all the cases analyzed. The quick response assures that a leak of sufficient quantity produces a sufficient temperature rise which can be detected in a timely fashion.

Figure 5 shows the upper MST temperature for different leakage rates and for different VR inlet temperatures. These are the temperatures at approximately 10 minutes after the leak. In most cases, the temperature has reached a steady state value, and if it has not, it is very close to the steady state value. The results show that the temperature varies directly with the quantity of steam leakage. For a given leakage rate, the upper MST temperature is highest for a VR inlet temperature of 110 deg F and lowest for a VR inlet temperature of 65 deg F.

Figure 6 shows the temperature difference between the upper MST exhaust and supply air (VR Delta T). These are the Delta T's at approximately 10 minutes after the leak. In most cases, the Delta T has reached a steady state value, and if it has not, it is very close to the steady state value. The results show that the Delta T varies directly with the quantity of steam leakage. For a given leakage rate, the upper MST Delta T is highest for a VR inlet temperature of 65 deg F and lowest for a VR inlet temperature of 110 deg F.

The results presented in Figures 5 and 6 are also listed in Tables 1 and 2.

5. Conclusions/Discussion

There are two basic requirements needed in choosing a process variable to monitor for leak detection. First, the response of this variable should be quick so that the leak can be detected in a reasonable time. Second, the change in magnitude of this variable to a given amount of leakage should be ample enough to account for measurement uncertainties and to avoid spurious trips when no leakage is present. The results presented in Section 3 show that in looking at each VR inlet condition separately, the upper MST temperature and upper MST VR delta-T satisfy these two requirements. Therefore, a high temperature and a high delta-T trip setpoint can be set for each of the VR inlet condition. However, a single trip setpoint that is valid for all VR inlet conditions is desired. This Section discusses how a leak detection trip setpoint can be established for use year-round. It also shows that under some conditions, it is not possible to establish a year-round setpoint. An example is given to show that the high temperature trip setpoint can not be established to detect a leak of 100 gpm.

The first step in determining the trip setpoint is to establish the allowable leakage. This is determined from the critical crack flow, which is the leakage rate from a crack whose dimensions are calculated to rapidly propagate and result in pipe failure. Therefore, the allowable leakage is obtained by applying a design safety factor to the critical crack flow. The determination of the allowable leakage is not within the scope of this calculation.

If one assumes that the allowable leak rate has been determined to be 100 gpm, and the instrument uncertainties are $+\delta_1$ and $-\delta_2$, a proposed setpoint value can be established by using the analytical results as follows:

$$\text{Setpoint} \leq \text{Analytical value for 100 gpm leak} - \delta_2$$

To avoid spurious trips, the proposed setpoint must have ample margin from the maximum expected temperature with no leakage during normal or no VR operation. Therefore:

$$\text{Setpoint} \geq \text{Analytical value for no leak} + \delta_1$$

The right hand side of both inequalities may contain other margins and uncertainties due to operational transients such as loss of station heat or changes in outside air temperature, but for this discussion it is sufficient to include them in δ_1 and δ_2.

Therefore, the setpoint will be adequate if the difference between the analytical values for 100 gpm and no leak, the analytical margin, is greater than the sum of the measurement uncertainties:

$$\text{Analytical margin} \geq \delta_1 + \delta_2$$

From Figure 5, the upper MST temperatures at 10 minutes for a 100 gpm leak are 151.3, 173.5 and 182.5 deg F respectively for VR inlet temperatures of 65, 95 and 110 deg F. If one setpoint value is used to cover the whole range of expected VR inlet temperature conditions, then the lowest calculated temperature for 100 gpm leak must be higher than the highest temperature for no leak. The analytical temperature value for 100 gpm leak is 151.3 deg F which is less than the temperature experienced in the MST when the VR system is out of service. **Therefore, the single year-round high temperature setpoint can not be established based on an allowable leakage of 100 gpm.**

From Figure 6, the upper MST VR delta-T's at 10 minutes for a 100 gpm leak are 86.3, 78.5 and 72.5 deg F respectively for VR inlet temperatures of 65, 95 and 110 deg F. Corresponding to these VR inlet temperatures, the delta-T's for no leak condition are 28.2, 27.9 and 27.3 deg F. If one setpoint value is used to cover the whole range of expected VR inlet temperature conditions, then the lowest calculated delta-T for 100 gpm leak and the highest calculated delta-T for no leak should be used in its determination. This would result in an available margin of 72.5 - 28.2 = 44.3 degrees. The available margin is also sufficient to cover the delta-T experienced in the MST when the VR system is out of service. The delta-T has been observed as high as 46 deg F.

The calculated upper MST temperatures are higher when both the upper and lower VR inlet flows are varied according to MST conditions for both upper and lower MST steam leaks. Both upper and lower VR flows are reduced to zero for a 250 gpm leak. The results of the calculations show that the analytical value of 72.5 deg F for a 100 gpm leak is conservative

6. References

1) "GOTHIC Containment Analysis Package", Version 4.1, NAI 8907-02, Rev 5, Numerical Applications, Incorporated, September 1994.

2) "Release of GOTHIC 4.1c for Controlled Analysis", NFS Memo NFS:CMD:95-030, D. C. Barringer to K. N. Kovar and R. W. Tsai, June 29, 1995.

3) "Heat Sink Thermophysical Properties", Table 3 of Branch Technical Position CSB 6-1 of Standard Review Plan 6.2.1, NUREG 0800, Revision 2, July, 1981.

gpm	65 F VR inlet	95 F VR inlet	110 F VR inlet
0	93.2	122.9	137.4
25	104.6	135.7	148.0
75	137.3	161.8	171.8
100	151.3	173.5	182.5
125	164.4	181.9	190.0
175	183.7	201.5	206.4

Table 1: Upper MST Temperature due to Steam Leakage

gpm	65 F VR inlet	95 F VR inlet	110 F VR inlet
0	28.2	27.9	27.4
25	39.6	40.7	38.0
75	72.3	66.8	61.8
100	86.3	78.5	72.5
125	99.4	86.9	80.0
175	118.7	106.5	96.4

Table 2: Upper MST VR Delta T due to Steam Leakage

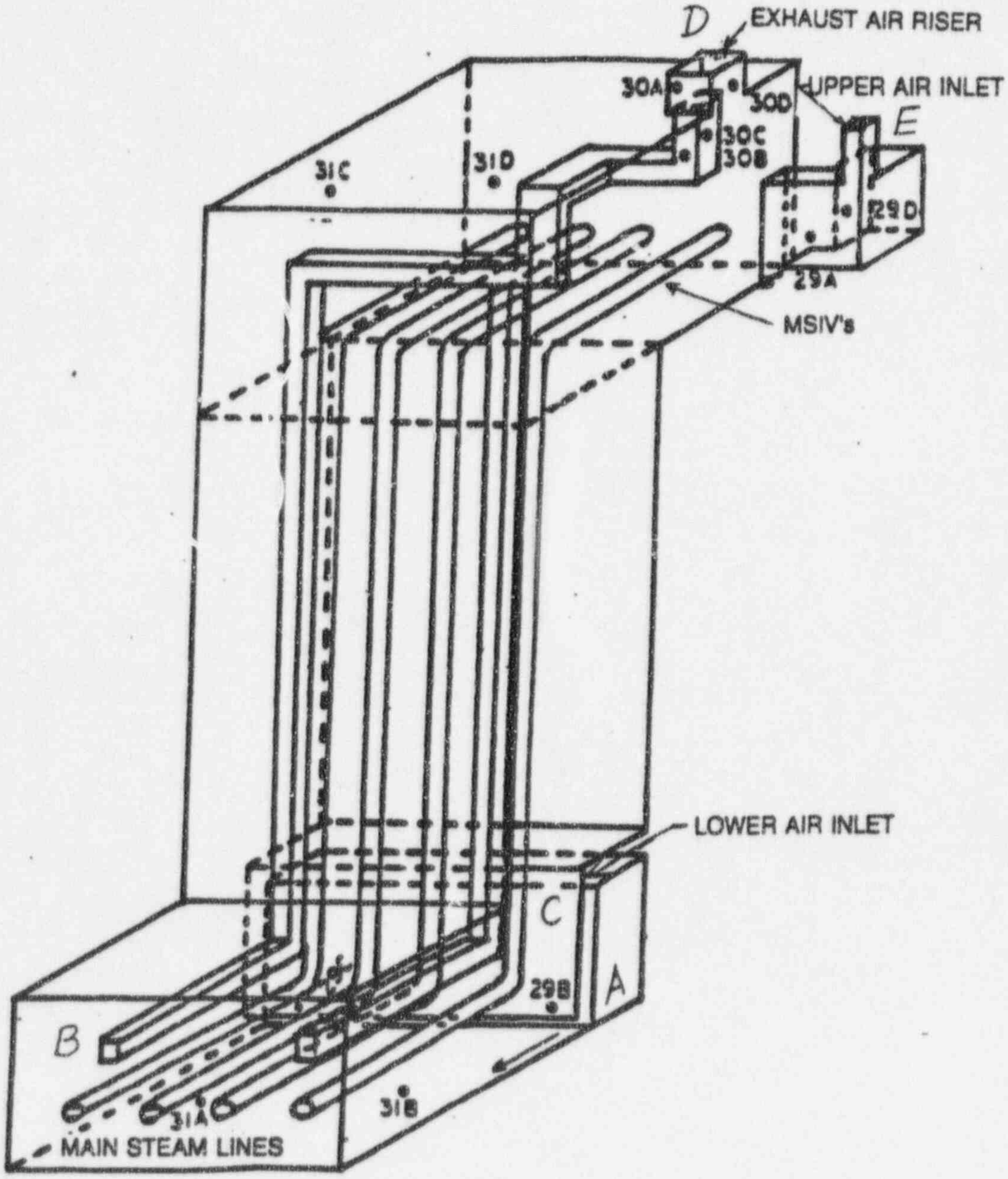

Figure 1: Sketch of Main Steam Tunnel

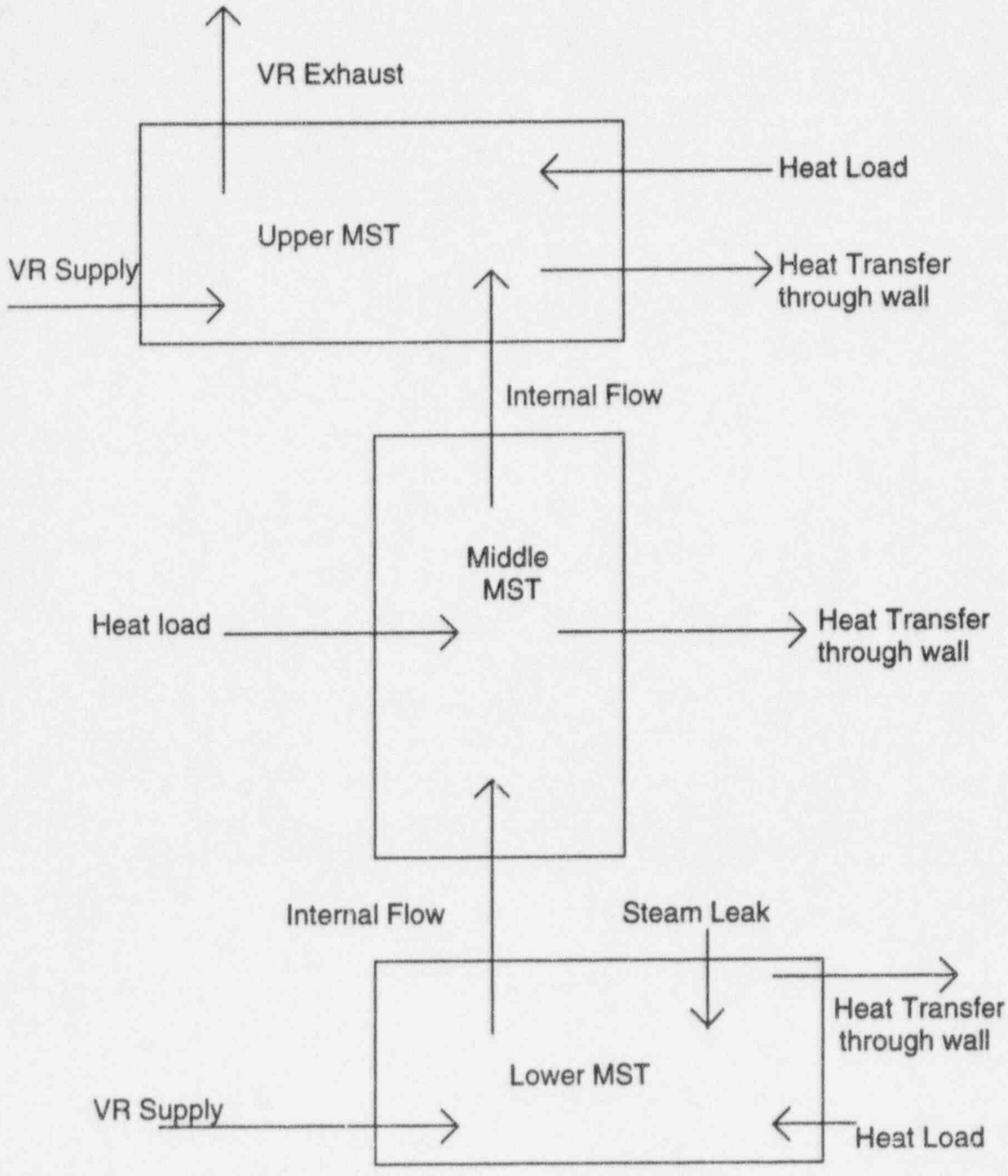

Figure 2: MST Mass and Energy Balance

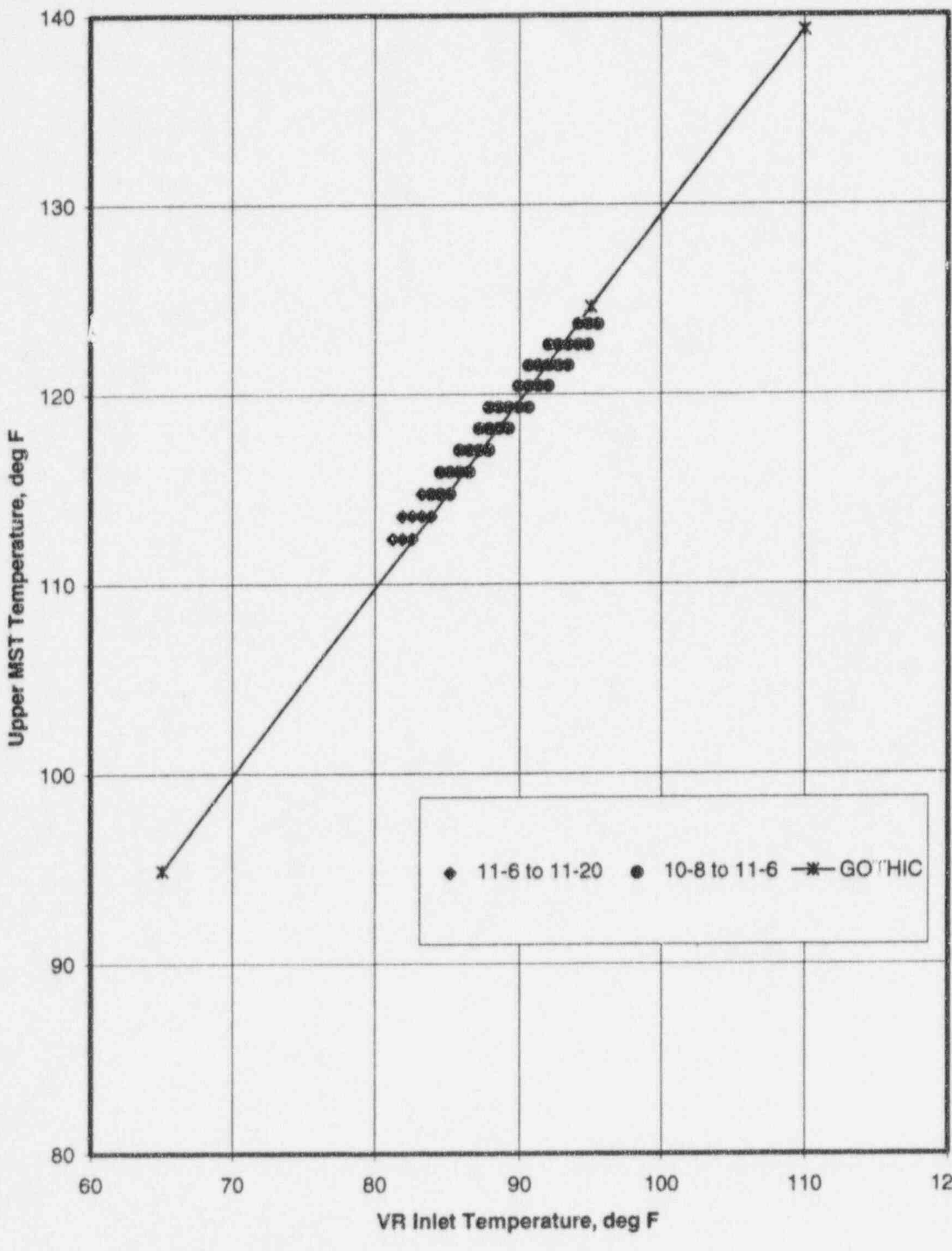

Figure 3: Benchmark Results

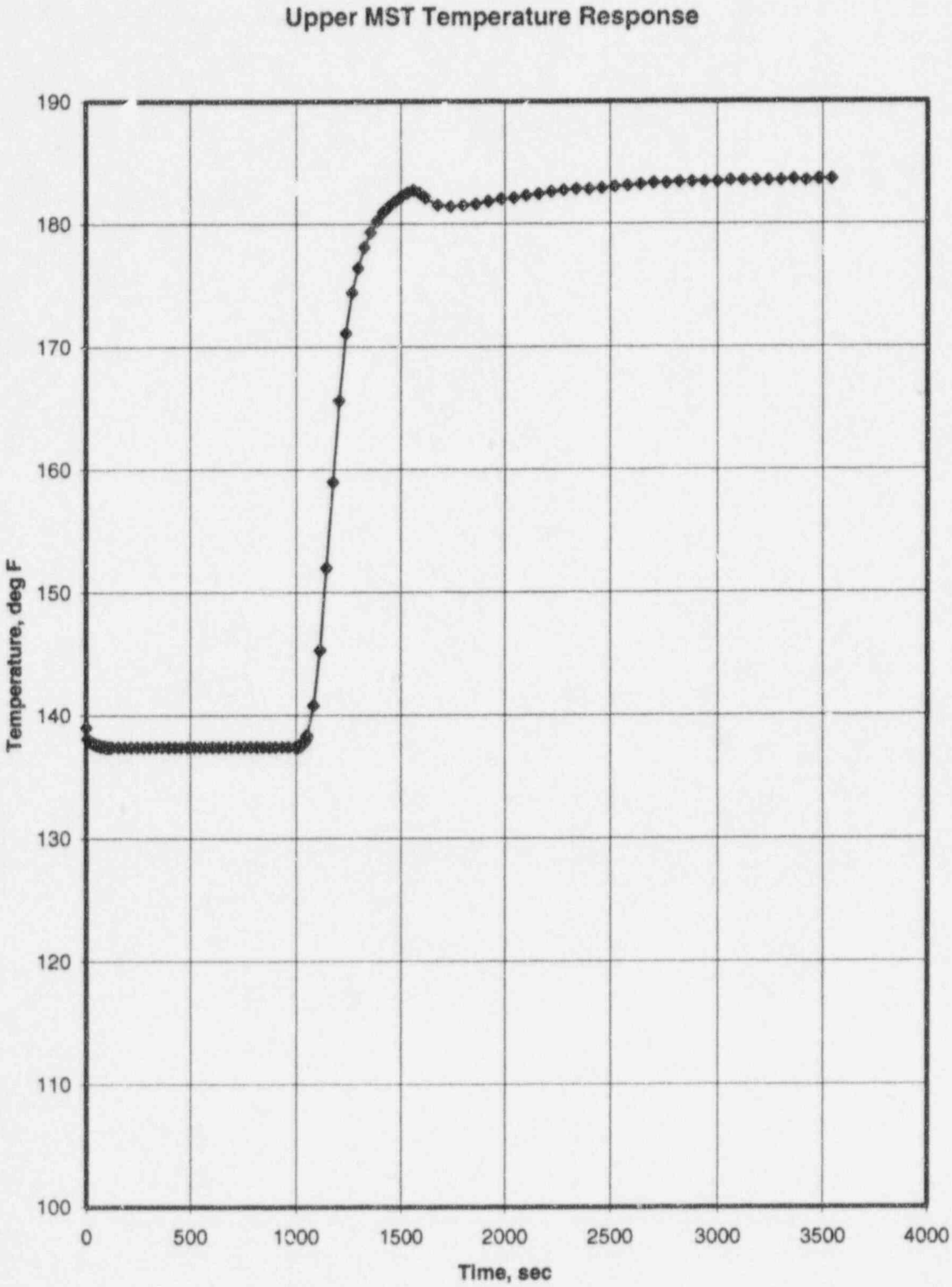

Figure 4: Upper MST Temperature Response for 110 deg F VR Inlet, 100 gpm

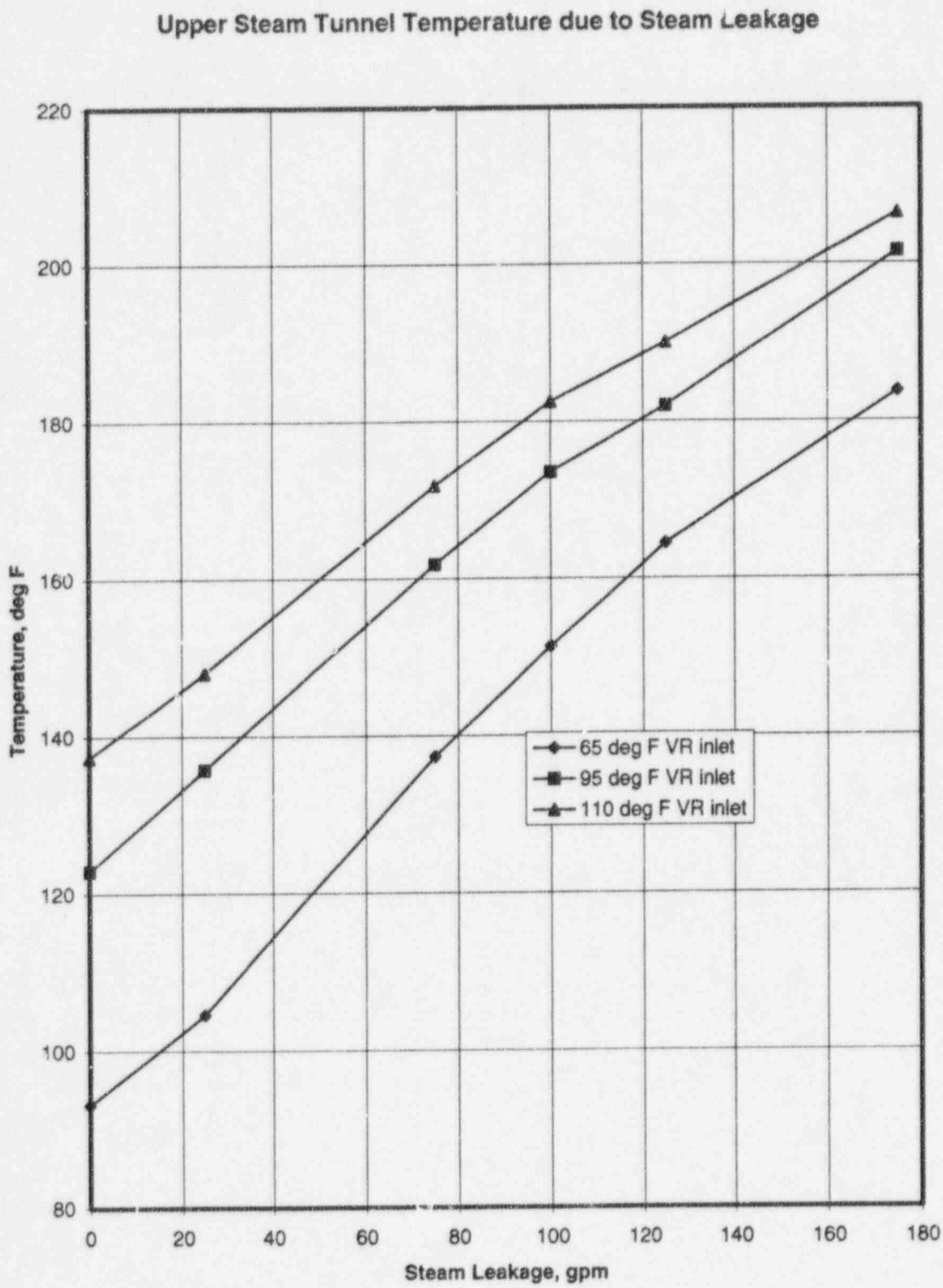

Figure 5: Upper MST Temperature due to Steam Leakage

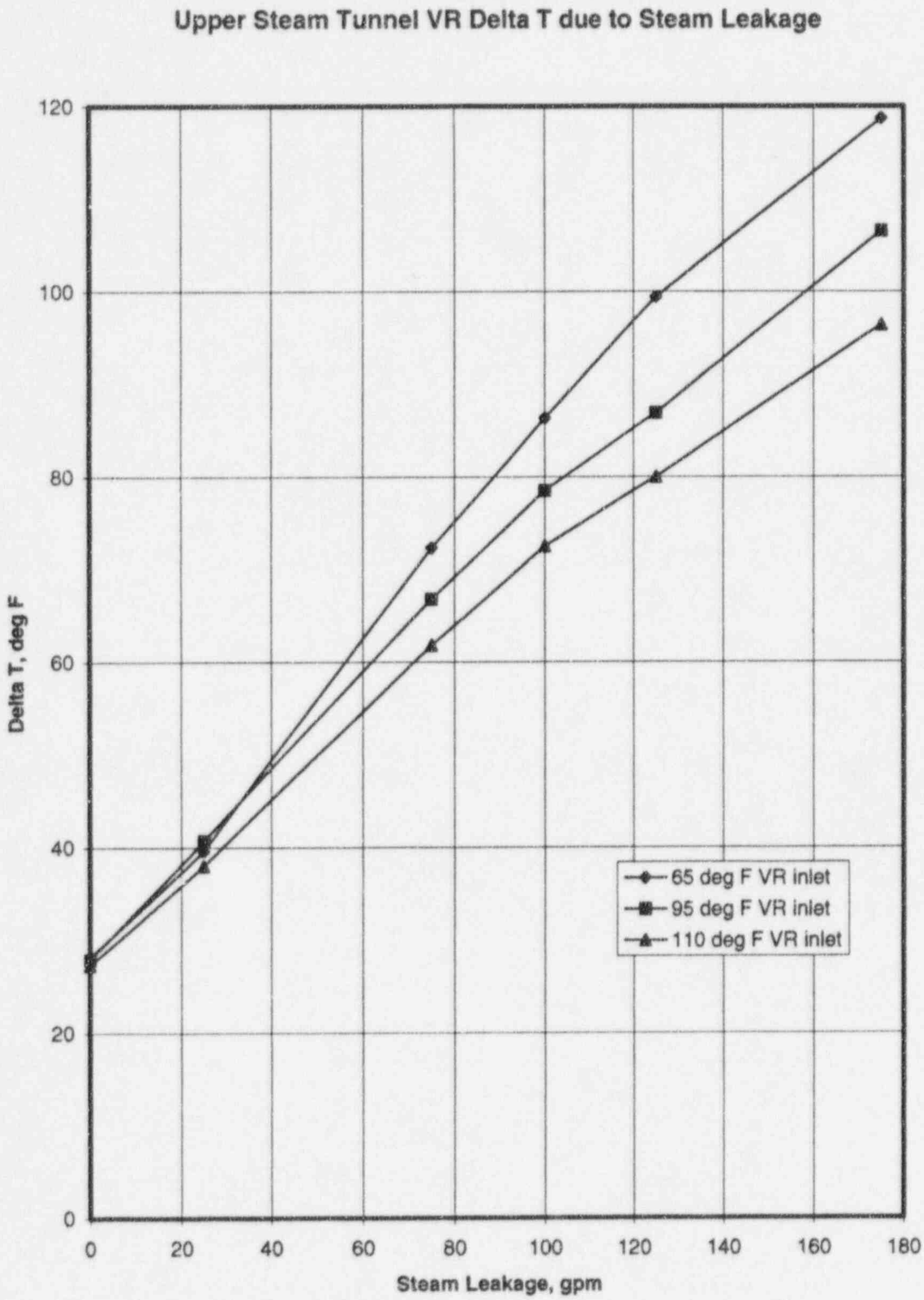

Figure 6: Upper MST VR Delta T due to Steam Leakage

Appendix A - Microfiche Index

Microfiche ID	# of fiche	Description
NFSEBX 7537	3	Case C65-25, 65 F VR inlet, 25 gpm leak
NFSEBX 7549	3	Case C65-75, 65 F VR inlet, 75 gpm leak
NFSEBX 7595	3	Case C65-100, 65 F VR inlet, 100 gpm leak
NFSEBX 7613	3	Case C65-125, 65 F VR inlet, 125 gpm leak
NFSEBX 7624	3	Case C65-175, 65 F VR inlet, 175 gpm leak
NFSEBX 7659	3	Case C95-25, 95 F VR inlet, 25 gpm leak
NFSEBX 7681	3	Case C95-75, 95 F VR inlet, 75 gpm leak
NFSEBX 7699	3	Case C95-100, 95 F VR inlet, 100 gpm leak
NFSEBX 7723	3	Case C95-125, 95 F VR inlet, 125 gpm leak
NFSEBX 7758	3	Case C95-175, 95 F VR inlet, 175 gpm leak
NFSEBX 0451	3	Case C110-25, 110 F VR inlet, 25 gpm leak
NFSEBX 0464	3	Case C110-75, 110 F VR inlet, 75 gpm leak
NFSEBX 0478	3	Case C110-100, 110 F VR inlet, 100 gpm leak
NFSEBX 0498	3	Case C110-125, 110 F VR inlet, 125 gpm leak
NFSEBX 0505	3	Case C110-175, 110 F VR inlet, 175 gpm leak
NFSEBX 0646	1	Case C65-0-B, 65 F VR inlet, no leak
NFSEBX 7852	1	Case C95-0-B, 95 F VR inlet, no leak
NFSEBX 7874	1	Case C110-0-B, 110 F VR inlet, no leak
NFSEBX 8063	3	Case C110-100, 110 F VR inlet, 100 gpm UST leak
NFSEBX 8108	3	Case C110-200, 110 F VR inlet, 125 gpm UST leak
NFSEBX 8111	3	Case C110-250, 110 F VR inlet, 175 gpm UST leak
NFSEBX 8283	3	Case C110-100, 100 gpm LST leak VR's Floated

Appendix B - Input Data Set Protection Form

Station: LaSalle **Unit:** 1, 2 **Cycle/Analysis:** ____________

	Current File Location[1]	(Shaded Area for QA Admin. Only) Copy To[2]	CheckSum #[3] sum -r	CheckSum #[3] sum -p
1.	nfseb/gothic/ls/new/ramp/v400_v667/c65-25	/ls/bsal9505/c65-25	13763	2536318488
2.	nfseb/gothic/ls/new/ramp/v400_v667/c65-75	/ls/bsal9505/c65-75	21152	2405625224
3.	nfseb/gothic/ls/new/ramp/v400_v667/c65-100	/ls/bsal9505/c65-100	60935	1024722309
4.	nfseb/gothic/ls/new/ramp/v400_v667/c65-125	/ls/bsal9505/c65-125	18203	3959230561
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Notes: 1) **/nfs/sa** is not required. Begin each file location with user id. File name should be descriptive and include a means of identifying associated computer code.
2) Station, Unit, and Cycle/Analysis will define part of the destination location in **/nfs.databank/SA** therefore, these are not need in the "Copy To" column.
3) The SA Admin will place a check mark next to the verified checksum numbers.

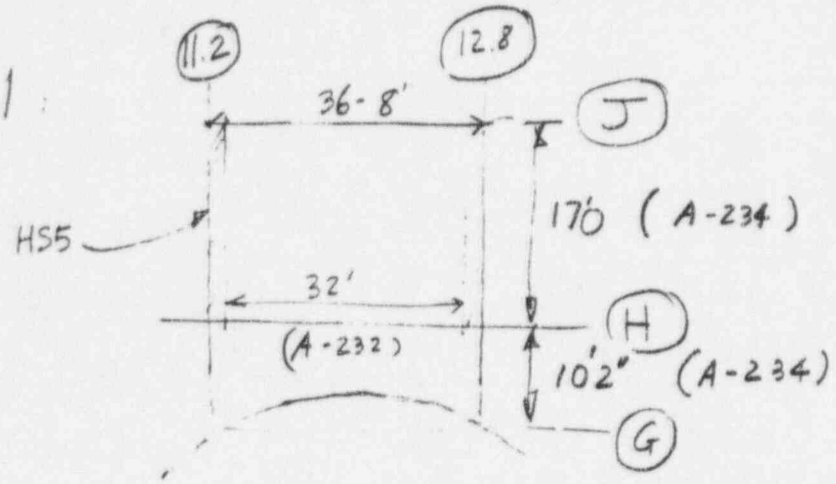
Author: ____ **Reviewer:** ____ **SA Admin:** ____ **Date:** ____

Appendix C - Supporting Calculations

Contents

1. Heat transfer areas, volumes and other geometrical parameters
2. Heat load forcing function
3. VR inlet flow properties

HS1:



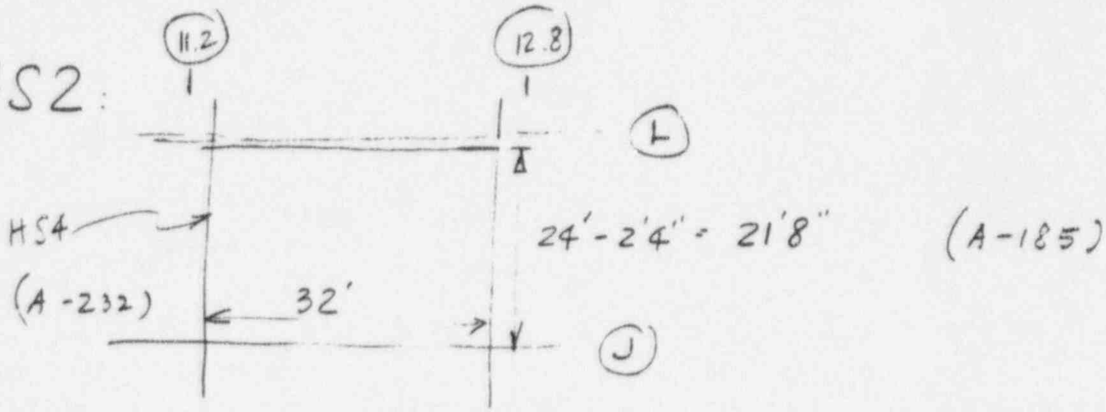
~Elev 761'0"

$A \approx (17 + 10'2") \times 32$

$= 869\ ft^2$

- Adjacent to Reactor Bldg

HS2:



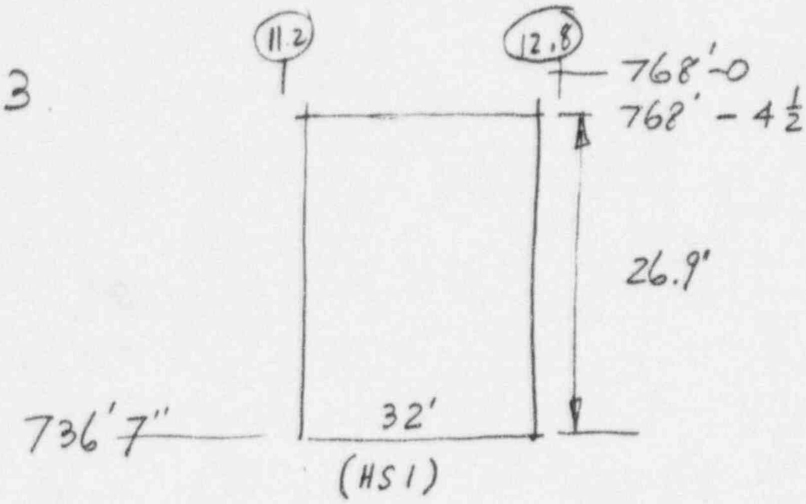
$A = 21'8" \times 32 = 693\ ft^2$

Elev 768'

Note. Area does not include area of return air riser. (Conservative)

- Adjacent to Aux Bldg @ 78°F.

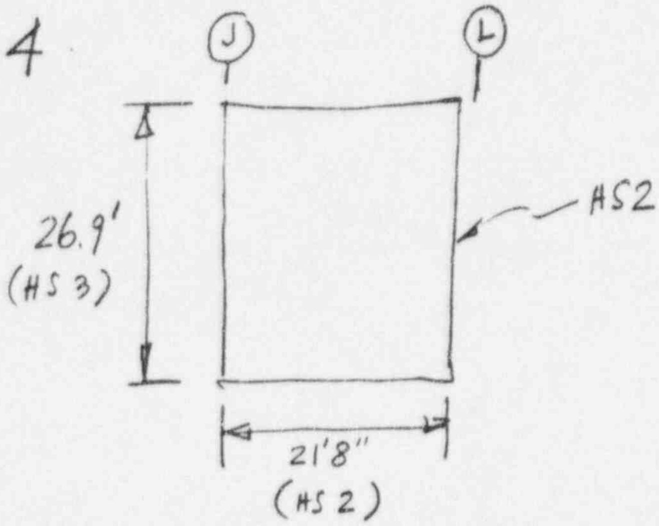
HS3



floor thickness is assumed equal to 4.5 ft based on S&L calc 3C7-0885-001 and UFSAR Appendix H, Sec H.3.2.21.

$A = 32 \times 26.9 = 861\ ft^2$

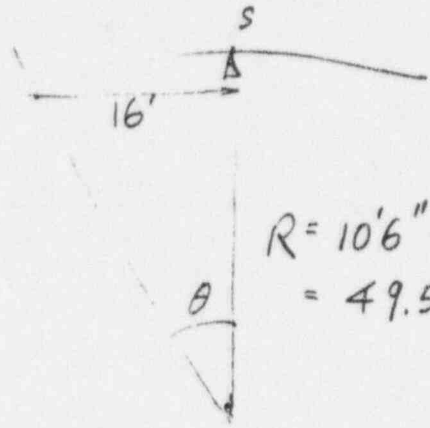
HS4



$A = 2 \times 26.9' \times 21'8'' = 1166$

HS7 (Containment wall)

At 740'0"



(A-230)

$R = 10'6" + 3'6" + 25'4" + 10'2"$
$= 49.5'$

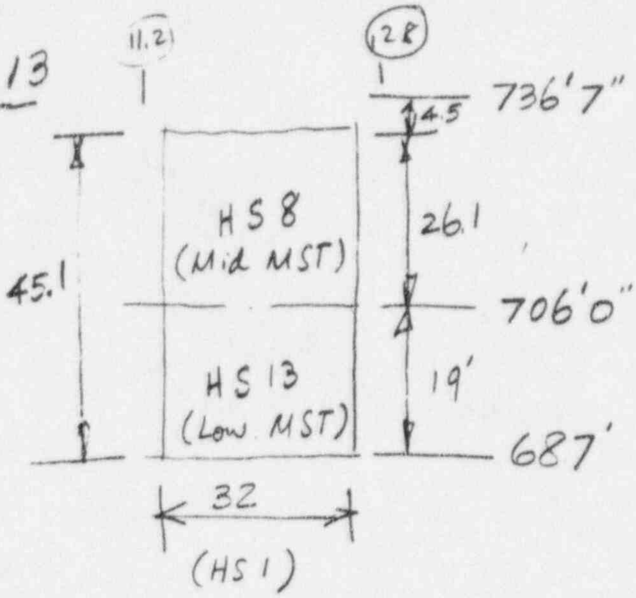
$\theta = \tan^{-1} \frac{16}{49.5} = 18^\circ$

$S = 2 \times 49.5 \left(\frac{2 \times 18}{360}\right)\pi = 31.1$

$A = S \times$ ht of HS5

$= 31.1 \times 19.9 = 619\ ft^2$

HS 8, HS 13

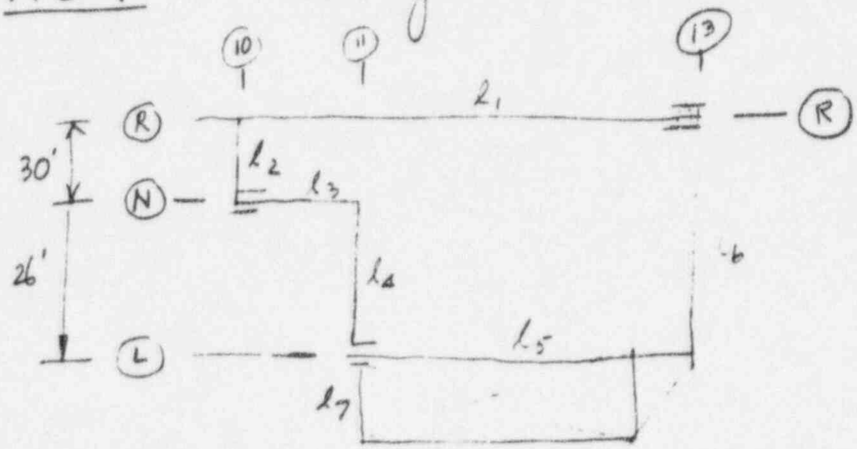


$A_8 = 26.1 \times 32 = 835\ ft^2$

$t = 4.5'$ (UFSAR Appendix H.3.2.21)

$A_{13} = 19 \times 32 = 608\ ft^2$

HS 9 Ceiling



$l_1 = (10) \rightarrow (13) - t_1 - t_2$

$= 3 \times 26 - 1'7\frac{1}{2}" - 2'4"$ (A-91, A-92)

$= 78 - 1.625 - 2.33 = 74'$

$l_2 = 30 - 1'7\frac{1}{2}" - 2'4" = 26'$ (")

$l_3 = 23' - 1'7\frac{1}{2}" + 2'4" = 19'$ (")

$l_4 = 26' + 2'4" + 2'4" = 30.7'$

$l_5 = l_1 - l_3 = 55$

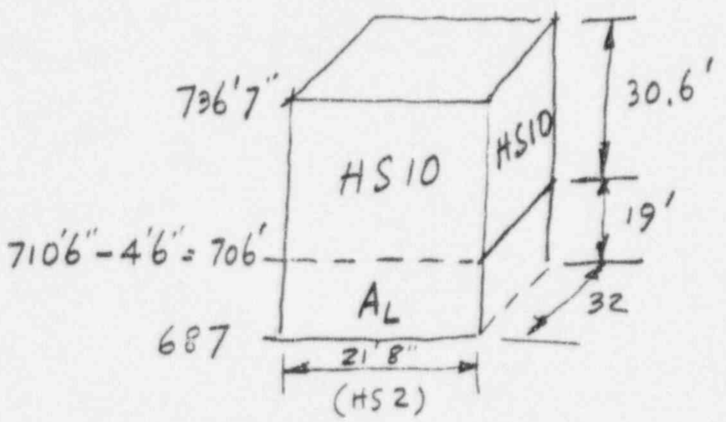
HS 9 (cont'd)

$$l_6 = l_2 + l_4 - (3 - 1'7\tfrac{1}{2}'')$$
$$= 26 + 30.7 - 1.375 = 55.3'$$

$$A_\nabla = \tfrac{1}{2}(10 \times 10) = 50 \text{ ft}^2$$

$$A_{Total} = l_1 \times l_2 + l_4 \times l_3 + A_\nabla$$
$$= 74 \times 26 + 30.7 \times 5.5 + 50$$
$$= 3663 \text{ ft}^2$$

HS 10

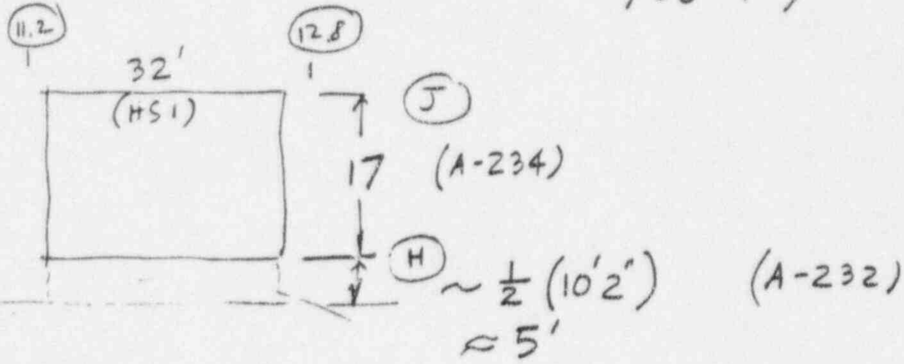


$$A = (21.67 + 32) \times 30.6$$
$$= 1642 \text{ ft}^2$$

$$A_L = (21.67 + 21.67) \times 19$$
$$= 823 \text{ ft}^2$$

(A_L is part of lower MST)

HS 11 (Floor of upper MST at 736' 7")



$A = 32 \times (5+17) = 704$

thickness = 4.5 (HS 3)

HS 12 (Floor of lower MST excluding area under shaft)

$A = A_{HS9} = 3663 \ ft^2$

HS13

See HS8

$A_{13} = 608 \ ft^2$

HS13 connects to lower MST

HS 14 (lower MST walls)

$h = 706 - 687 = 19'$

Perimeter $= l_1 + l_2 + l_3 + l_4 + l_6$ (HS 9)

$= 74 + 26 + 19 + 30.7 + 55.3$

$= 205'$

see HS10 for A_L

$A = 205 \times 19 + A_L = 3895 + 823 = 4718 \text{ ft}^2$

thick = 3.5' (UFSAR Appendix H 3.2.21)

HS15 (lower MST floor under vertical shaft)

HS1 — A-92

$A = 32 \times (24 - 2'4'' - 6')$

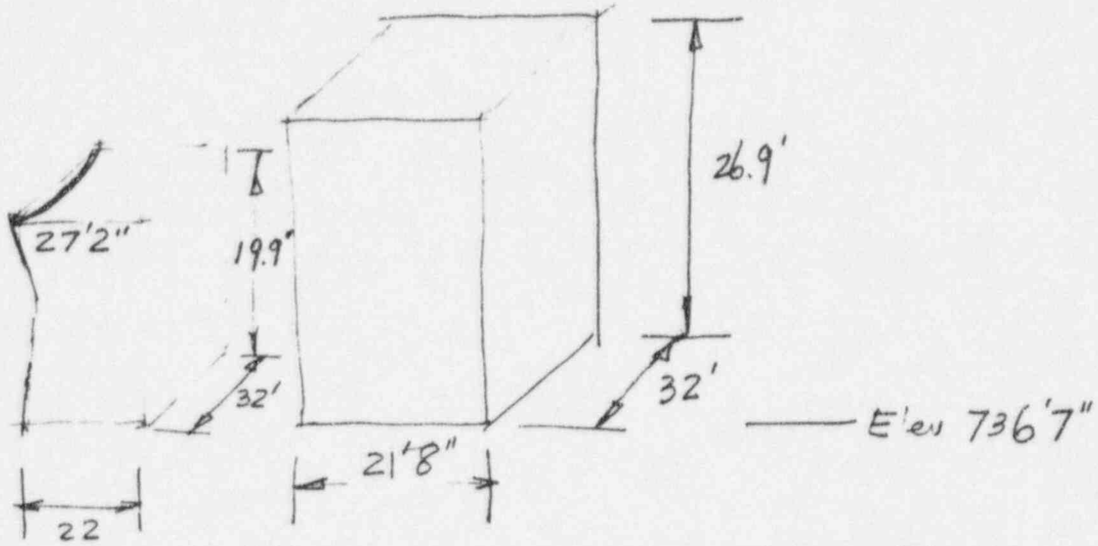
$= 501$ ft

HS16 (Mid MST side wall)

$A = 30.6 \times 21.67 = 663 \text{ ft}^2$

HS16 is adjacent to Aux Bldg conditioned space at 78°F.

Volume of upper MST (Vol 1)



conservative to use ceiling dimension

$$\text{Volume} = 19.9 \times 32 \times 27.17 + 26.9 \times 32 \times 21.67$$

$$= 17,302 + 18,654 = 35,956 \text{ ft}^3$$

$$\text{Pool area} = 32 \times 22 = 704 \text{ ft}^2$$

$$D_e = \frac{4 \times 32 \times 19.9}{2(32 + 19.9)} = 24.5 \text{ ft}$$

Volume of lower MST (Vol 5)

$V = A_{HS9} \times 19 + A_{HS15} \times ht\ of\ HS13$

$= 3663 \times 19 + 501 \times 19 = 79,116\ ft^2$

Pool area $= A_{HS9} + A_{HS15} = 3663 + 501 = 4164\ ft^2$

$D_{h_1} = \frac{4 \times 55 \times 19}{2(55+19)} = 28.2'$

(Sec HS 9)

$D_{h_2} = \frac{4 \times 74 \times 19}{2(74+19)} = 30.2'$

$D_h = \frac{1}{2}(D_{h_1} + D_{h_2}) = 29.2'$

Volume of middle MST (Vol 6)

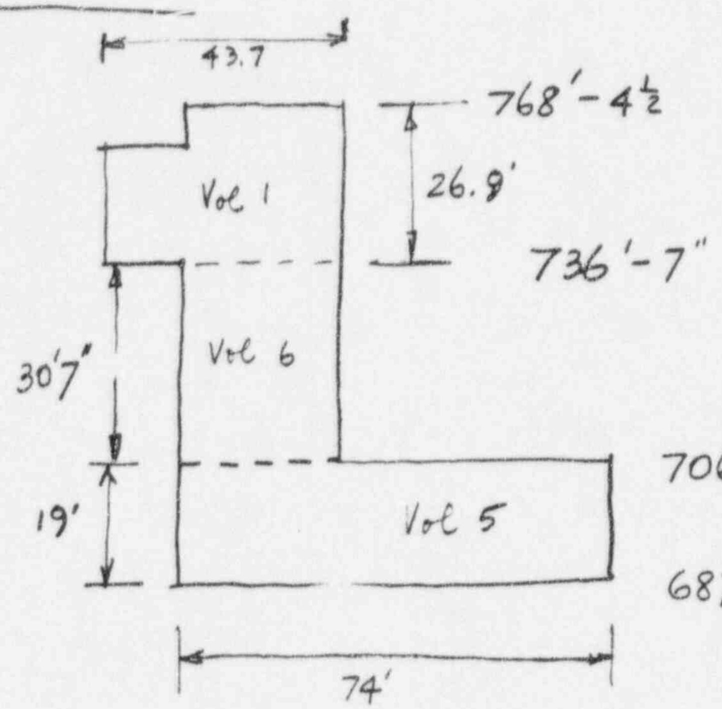
$V = 21.7 \times 32 \times 30.6$

$= 21,249\ ft^2$

Pool area = 0

$D_h = \frac{4 \times 21.7 \times 32}{2(21.7+32)} = 25.9\ ft$

Elevations



Flow Paths

FP #1

$$A = 32 \times 21'8''$$
$$= 693 \text{ ft}^2$$

$$D_h = \frac{4 \times 693}{2 \times (32 + 21.7)} = 25.8 \text{ ft}$$

$$L = (30.7 + 26.9)\tfrac{1}{2} = 28.8 \text{ ft.}$$

FP #11

$$A = 32 \times 21.7 = 693 \text{ ft}^2$$
$$D_h = \frac{4 \times 693}{2 \times (32 + 21.7)} = 25.8 \text{ ft}$$

$$L = \tfrac{1}{2}(74 + 30.7) = 52.4 \text{ ft}$$

Heat Loss Thru Insulated Pipe

$$\frac{q}{A} = U \Delta T$$

$$\frac{1}{U} = \frac{r_3}{r_1 h_i} + \frac{r_3 \ln\left(\frac{r_2}{r_1}\right)}{k_1} + \frac{r_3 \ln\left(\frac{r_3}{r_2}\right)}{k_2} + \frac{1}{h_o}$$

(Eq. (2-19), Kreith)

For a fixed fluid temperature and flowrate inside the pipe, the first term is constant, because h_i is constant.

Within a small temperature, k_1 and k_2 can be assumed constants. Therefore the second and third terms are constant. In general, k varies with temperature, therefore, the sum of the second and third terms decreases as the temperature increases.

The outside HTC, h_o, is the sum of the natural and radiative HTCs.

$$h_C = C \, \Delta T^{1/n}$$

$$h_R = C \, \frac{(T_1^4 - T_2^4)}{\Delta T} = C \, \frac{(T_1^2 + T_2^2)(T_1 + T_2)(T_1 - T_2)}{\Delta T}$$

$h_O = h_C + h_R$ increases as temperature increases, or, the last term decreases.

Heat Loss Thru Insulated Pipe (p.2)

∴ U increases as temperature increases

Diameter of MS line = 26"
Diameter of FW line = 24"

From S&L Standard MES-7.2:
The data for 500°F at 26" line and 400°F at 26" line, $\epsilon = 0.8$, show that U increases as the temperature increases.
To conservatively predict a low heat load at temperatures beyond 148°F, one can assume that U is constant beyond 148°F. A heat load curve is generated for the analysis using this conservative assumption. (See EXCEL spreadsheet.)
For the heat load below 75°F, one can use the value at 75°F, since temperatures below 75°F are not limiting. These points are needed as code input.

Heat Loss from Horizontal and Vertical Pipes

$\frac{1}{UA}$ = inside film resistance + pipe resistance + insulation resistance + outside film resistance

outside film resistance $= \frac{1}{h_o A}$

$h_o = h_{conv} + h_{radiation}$

From S&L standard ; UA varies between 1.31 to 1.37.

For 36" pipe insulation thickness is 2.5 in

$$A = \pi D \times L = \pi \left(\frac{36+5}{12}\right)(1)$$
$$= 10.7 \text{ ft}^2$$

$$U = \frac{1.37}{10.7} = 0.128$$

$$\frac{1}{U} = 7.8$$

$h_{radiation}$ is independent of pipe orientation

$h_{conv} = 0.27\left(\frac{\Delta t}{L}\right)^{1/4}$ or $= 0.18\,(\Delta t)^{1/3}$ for horizontal cylinder

$h_{conv} = 0.29\left(\frac{\Delta t}{L}\right)^{1/4}$ or $= 0.19\,(\Delta t)^{1/3}$ for vertical cylinder

(1981 ASHRAE Handbook of Fundamentals, p. 2.12)

∴ h_{conv} may be 10% higher for vertical pipe

h_{conv} is in the order of 0.3

h_{rad} is in the order of 0.7

Heat loss from horizontal pipes (p.2)

$$h_{conv,\,vert} = 0.3(1.1) = 0.33$$

$$h_0 = 0.33 + 0.7 = 1.03$$

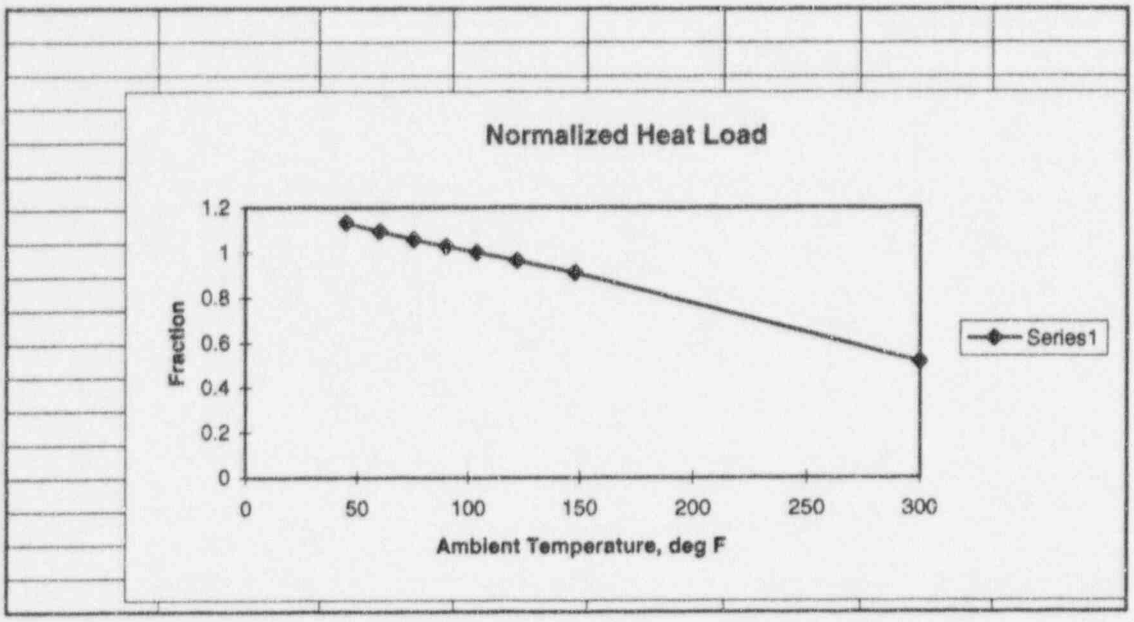
$$\left(\frac{1}{U}\right)_{vertical} = \left(\frac{1}{U}\right)_{horizontal} + \frac{1}{1.03} - \frac{1}{1}$$

$$= 7.8 - .03 = 7.74$$

$U_{vertical} = 0.129$ compared to 0.128

∴ Increase in heat load is negligible.

From Table 10.1-1, LaSalle UFSAR: MS temperature = 540.3 Fand							
FW temperature = 420 F.							
For 26-in MS pipe							
Ambient T	Operating T	Delta T	Q(500)	Q(600)	Q(540)	UA=Q/DT	
75	540	465	556.8	619.1	581.72	1.251011	
90	540	450	541.7	606.3	567.54	1.2612	
104	540	436	527.4	594.3	554.16	1.271009	
122	540	418	508.6	578.4	536.52	1.283541	
148	540	392	480.6	555	510.36	1.301939	
Assume U=1.301939 at T=300:							
300	540	240			312.4653		
Assume U=1.251011 at T<75							
45	540	495			619.2503		
60	540	480			600.4852		
For 24-in FW pipe							
Ambient T	Operating T	Delta T	Q(400)	Q(500)	Q(420)	UA=Q/DT	
75	420	345	454.6	517.8	467.24	1.354319	
90	420	330	437.4	503.7	450.66	1.365636	
104	420	316	421	490.4	434.88	1.376203	
122	420	298	399.6	472.9	414.26	1.390134	
148	420	272	367.8	446.9	383.62	1.410368	
Assume U=1.410368 at T=300:							
300	420	120			169.2441		
Assume U=1.354319 at T<75							
45	420	375			507.8696		
60	420	360			487.5548		
Composite Q curve							
Ambient T		4*Q26+2*Q24	Norm				
45		3492.74	1.131655				
60		3377.05	1.094171				
75		3261.36	1.056687				
90		3171.48	1.027566				
104		3086.4	1				
122		2974.6	0.963777				
148		2808.68	0.910018				
300		1588.349	0.514629				


Normalized Heat Load
Fraction
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
Ambient Temperature, deg F
Series1

Moist air properties

$T = 120\,°F$

$\phi = 50\%$

$p_{sat} = 1.6924$ psia @ 120 °F

$p_w = \phi \times p_{sat} = 0.8462$

$$W = 0.62198 \frac{p_w}{p - p_w}$$

$$= 0.62198 \times \frac{0.8462}{14.696 - 0.8462}$$

(13.8498)

$$= 0.038 \text{ lbw/lba}$$

$$V = \frac{R_a T}{p - p_w} = \frac{53.352 \times (460 + 120)}{13.8498 \times 144}$$

$$= 15.52 \text{ ft}^3/\text{lb}_a$$

$$\rho = \frac{1}{V}(1 + W)$$

$$= \frac{1}{15.52}(1 + 0.038) = 0.067$$

$$\dot{m}_{lo,in} = 40{,}000 \times 0.067 \times \frac{1}{60} = 44.7 \text{ lb/sec}$$

$$\dot{m}_{up,in} = 24{,}000 \times 0.067 \times \frac{1}{60} = 26.8 \text{ lb/sec}$$

Estimate $\dot{m}_{lo,out}$ and $\dot{m}_{up,out}$

$$\dot{m}_{lo,out} = 4600 \times 0.067 \left(\frac{120 + 460}{140 + 460}\right) \frac{1}{60} = 5.0$$

$$\dot{m}_{up,out} = 44.7 + 26.8 - 5 = 66.5$$

Moist air properties

$T = 95\ °F$

$\phi = 50\%$

$p_{sat} = 0.8153$ psia @ 95°F

$p_w = \phi \times p_{sat} = 0.5 \times 0.8153 = 0.4077$ psia

humidity ratio:

$$W = 0.62198 \frac{p_w}{p - p_w}$$

(Eq. 20, Chapter 5, 1981 ASHRAE Fundamentals)

$$= 0.62198 \frac{0.4077}{14.696 - 0.4077}$$

$$= 0.0178\ lb_w / lb_a$$

sp. vol.:

$$v = \frac{R_a T}{p - p_w}$$

(Eq. 25)

$$= \frac{53.352 \times (460 + 95)}{(14.696 - 0.4077) \times 144}$$

$$= 14.39\ ft^3/lb_a$$

density:

$$\rho = \frac{1}{v}(1 + W)$$

(Eq. after Eq 9)

$$= \frac{1}{14.39}(1 + .0178)$$

$$= 0.0707\ lb/ft^3$$

Air Properties			
T	65	95	110
Relative Humidity	30	50	30
Sat. press.	0.3056	0.8153	1.2748
Vapor pressure	0.09168	0.40765	0.38244
Humidity ratio, W	0.00390454	0.017745	0.016619
Specific volume, lbw/lba	13.3188331	14.39127	14.75419
density, lbmix/cu ft	0.07537481	0.07072	0.068904
Lo HVAC in, cfm	40000.00	40000.00	40000.00
Lo HVAC in, lb/s	50.25	47.15	45.94
Up HVAC in, cfm	24000.00	24000.00	24000.00
Up HVAC in, lb/s	30.15	28.29	27.56
Lo HVAC out, cfm	4600.00	4600.00	4600.00
Assume temp rise	15.00	15.00	15.00
Lo HVAC out, lb/s	5.62	5.28	5.15
Up HVAC out, Lb/s	74.78	70.16	68.35

Appendix D - Summary of Inputs and Results

Case		Base									
Filename	C95-25	C95-75	C95-100	c95-125	C95-175		c65-25	c65-75	c65-100	c65-125	c65-175
HTC options	C	C	C	C	C		C	C	C	C	C
Steam leakage, gpm	25	75	100	125	175		25	75	100	125	175
Steam leakage, lb/s	3.48	10.4	13.9	17.4	24.3		3.48	10.4	13.9	17.4	24.3
Boundary Conditions:											
Lo MST HVAC in											
Temp	95	95	95	95	95		65	65	65	65	65
RH	50	50	50	50	50		30	30	30	30	30
Up MST HVAC in	V400	V400	V400	V400	V400		V400	V400	V400	V400	V400
Temp	95	95	95	95	95		65	65	65	65	65
RH	50	50	50	50	50		30	30	30	30	30
Lo MST HVAC out	0	0	0	0	0		0	0	0	0	0
Up MST HVAC out	V-1159.0	V-1159.0	V-1159.0	V-1159.0	V-1159.0		V-1163.67	V-1163.67	V-1163.67	V-1163.67	V-1163.67
Add.Lo HVAC out	0	0	0	0	0		0	0	0	0	0
Add.Up HVAC out	0	0	0	0	0		0	0	0	0	0
Volume initial temp: (init RH)											
1. Up MST	124.6(30)	124.6(30)	124.6(30)	124.6(30)	124.6(30)		95.5(15)	95.5(15)	95.5(15)	95.5(15)	95.5(15)
2. Aux Bldg	104	104	104	104	104		65	65	65	65	65
3. Rx Bldg	95	95	95	95	95		65	65	65	65	65
4. Containment	130	130	130	130	130		130	130	130	130	130
5. Lo MST	110(30)	110(30)	110(30)	110(30)	110(30)		80(15)	80(15)	80(15)	80(15)	80(15)
6. Mid MST	114(30)	114(30)	114(30)	114(30)	114(30)		84.5(15)	84.5(15)	84.5(15)	84.5(15)	84.5(15)
7. Reactor Bldg	95	95	95	95	95		65	65	65	65	65
8. Aux Bldg (conditioned)	75	75	75	75	75		75	75	75	75	75
up MST heat load	332.5	332.5	332.5	332.5	332.5		332.5	332.5	332.5	332.5	332.5
mid	45	45	45	45	45		45	45	45	45	45
lo	175	175	175	175	175		175	175	175	175	175

Case					
Filename	c110-25	c110-75	c110-100	c110-125	c110-175
HTC options	C	C	C	C	C
Steam leakage, gpm	25	75	100	125	175
Steam leakage, lb/s	3.48	10.4	13.9	17.4	24.3
Boundary Conditions:					
Lo MST HVAC in					
Temp	110	110	110	110	110
RH	30	30	30	30	30
Up MST HVAC in	V400	V400	V400	V400	V400
Temp	110	110	110	110	110
RH	30	30	30	30	30
Lo MST HVAC out	0	0	0	0	0
Up MST HVAC out	V-1157.17	V-1157.17	V-1157.17	V-1157.17	V-1157.17
Add.Lo HVAC out	0	0	0	0	0
Add.Up HVAC out	0	0	0	0	0
Volume initial temp: (init RH)					
1. Up MST	139(10)	139(10)	139(10)	139(10)	139(10)
2. Aux Bldg	110	110	110	110	110
3. Rx Bldg	110	110	110	110	110
4. Containment	130	130	130	130	130
5. Lo MST	124.5(20)	124.5(20)	124.5(20)	124.5(20)	124.5(20)
6. Mid MST	128.5(15)	128.5(15)	128.5(15)	128.5(15)	128.5(15)
7. Reactor Bldg	110	110	110	110	110
8. Aux Bldg (conditioned)	75	75	75	75	75
up MST heat load	332.5	332.5	332.5	332.5	332.5
mid	45	45	45	45	45
lo	175	175	175	175	175

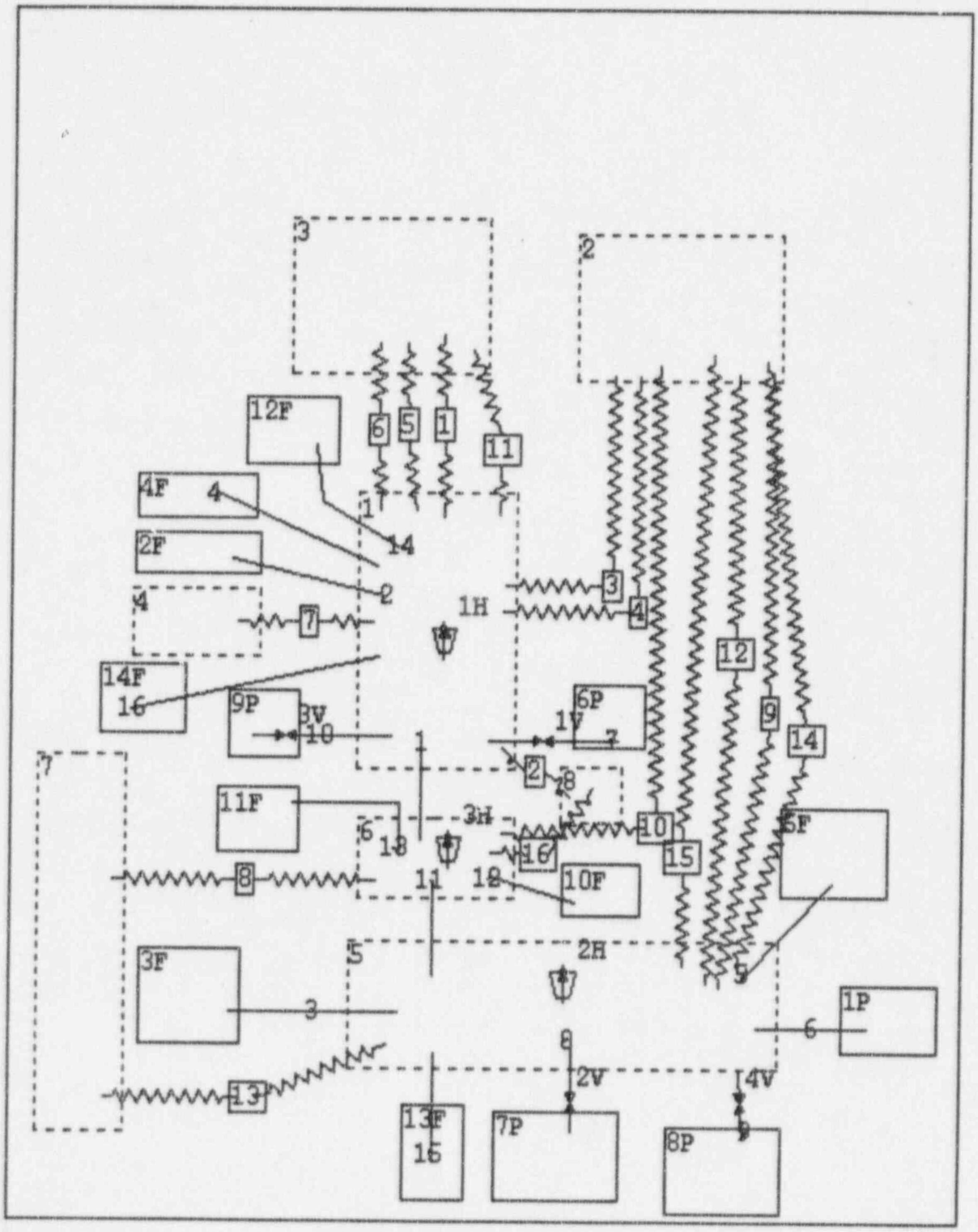
Case	UST Leak	UST Leak	UST Leak		LST Leak		
Filename	c110-100	c110-200	c110-250		c110-100		
HTC options	C	C	C		C		
Steam leakage, gpm	100	200	250		100		
Steam leakage, lb/s	13.9	27.8	34.75		13.9		
Boundary Conditions:							
Lo MST HVAC in							
Temp	110	110	110		110		
RH	30	30	30		30		
Up MST HVAC in							
Temp	110	110	110		110		
RH	30	30	30		30		
Lo MST HVAC out	0	0	0		0		
Up MST HVAC out	V-1130.5	V-1130.5	V-1130.5		V-1130.5		
Add.Lo HVAC out	0	0	0		0		
Add.Up HVAC out	0	0	0		0		
Volume initial temp: (init RH)							
1. Up MST	139(10)	139(10)	139(10)		139(10)		
2. Aux Bldg	110	110	110		110		
3. Rx Bldg	110	110	110		110		
4. Containment	130	130	130		130		
5. Lo MST	124.5(20)	124.5(20)	124.5(20)		124.5(20)		
6. Mid MST	128.5(15)	128.5(15)	128.5(15)		128.5(15)		
7. Reactor Bldg	110	110	110		110		
8. Aux Bldg (conditioned)	75	75	75		75		
up MST heat load	332.5	332.5	332.5		332.5		
mid	45	45	45		45		
lo	175	175	175		175		

Case		Base									
Filename	C95-25	C95-75	C95-100	c95-125	C95-175		c65-25	c65-75	c65-100	c65-125	c65-175
Results:											
At t = 1000 secs											
Up MST T (Vol 1)	122.9	122.9	122.9	122.9	122.9		93.2	93.2	93.2	93.2	93.2
Mid MST T (Vol 6)	112.8	112.8	112.8	112.8	112.8		82.8	82.8	82.8	82.8	82.8
Lo MST T (Vol 5)	109.3	109.3	109.3	109.3	109.3		79.2	79.2	79.2	79.2	79.2
Lo HVAC T increase	14.3	14.3	14.3	14.3	14.3		14.2	14.2	14.2	14.2	14.2
Up HVAC T increase	27.9	27.9	27.9	27.9	27.9		28.2	28.2	28.2	28.2	28.2
At t=1592 secs											
Up MST T (Vol 1)	135.7	161.8	173.5	181.9	201.5		104.6	137.3	151.3	164.4	183.7
Mid MST T (Vol 6)	135.6	180.0	200.3	214.1	249.1		112.0	159.0	182.2	204.7	238.5
Lo MST T (Vol 5)	132.7	178.4	199.6	214.6	251.9		112.8	157.2	181.1	204.5	241.1
Up MST T increase	12.8	38.9	50.6	59.0	78.6		11.4	44.1	58.1	71.2	90.5
Mid MST T increase	22.8	67.2	87.5	101.3	136.3		29.2	76.2	99.4	121.9	155.7
Lo MST T increase	23.4	69.1	90.3	105.3	142.6		33.6	78.0	101.9	125.3	161.9
Lo HVAC T increase	37.7	83.4	104.6	119.6	156.9		47.8	92.2	116.1	139.5	176.1
Up HVAC T increase	40.7	66.8	78.5	86.9	106.5		39.6	72.3	86.3	99.4	118.7
At t=2762 secs											
Up MST T (Vol 1)	135.9	164.1	174.6	186.0	204.3		107.9	142.6	157.2	168.1	190.8
Mid MST T (Vol 6)	136.1	183.4	201.4	221.2	256.8		114.6	165.6	191.0	210.1	250.6
Lo MST T (Vol 5)	133.2	181.6	200.7	221.7	261.4		114.9	162.7	189.2	209.8	254.6
Up MST T increase	13.0	41.2	51.7	63.1	81.4		14.7	49.4	64.0	74.9	97.6
Mid MST T increase	23.3	70.6	88.6	108.4	144.0		31.8	82.8	108.2	127.3	167.8
Lo MST T increase	23.9	72.3	91.4	112.4	152.1		35.7	83.5	110.0	130.6	175.4
Lo HVAC T increase	38.2	86.6	105.7	126.7	166.4		49.9	97.7	124.2	144.8	189.6
Up HVAC T increase	40.9	69.1	79.6	91.0	109.3		42.9	77.6	92.2	103.1	125.8

Case						
Filename		c110-25	c110-75	c110-100	c110-125	c110-175
Results:						
At t = 1000 secs						
Up MST T (Vol 1)		137.4	137.4	137.4	137.4	137.4
Mid MST T (Vol 6)		127.3	127.3	127.3	127.3	127.3
Lo MST T (Vol 5)		124.0	124.0	124.0	124.0	124.0
Lo HVAC T increase		14.0	14.0	14.0	14.0	14.0
Up HVAC T increase		27.4	27.4	27.4	27.4	27.4
At t=1592 secs						
Up MST T (Vol 1)		148.0	171.8	182.5	190.0	206.4
Mid MST T (Vol 6)		146.5	188.3	205.6	219.0	252.9
Lo MST T (Vol 5)		144.2	187.3	204.8	220.0	255.9
Up MST T increase		10.6	34.4	45.1	52.6	69.0
Mid MST T increase		19.2	61.0	78.3	91.7	125.6
Lo MST T increase		20.2	63.3	80.8	96.0	131.9
Lo HVAC T increase		34.2	77.3	94.8	110.0	145.9
Up HVAC T increase		38.0	61.8	72.5	80.0	96.4
At t=2762 secs						
Up MST T (Vol 1)		148.0	173.1	183.3	192.3	211.1
Mid MST T (Vol 6)		146.5	189.8	207.3	225.7	258.9
Lo MST T (Vol 5)		144.3	188.6	207.0	226.5	263.7
Up MST T increase		10.6	35.7	45.9	54.9	73.7
Mid MST T increase		19.2	62.5	80.0	98.4	131.6
Lo MST T increase		20.3	64.6	83.0	102.5	139.7
Lo HVAC T increase		34.3	78.6	97.0	116.5	153.7
Up HVAC T increase		38.0	63.1	73.3	82.3	101.1

Case	UST Leak	UST Leak	UST Leak		LST Leak		
Filename	c110-100	c110-200	c110-250		c110-100		
Results:							
At t = 10[illegible] secs							
Up MST T (Vol 1)	137.9	137.9	137.9		137.9		
Mid MST T (Vol 6)	127.9	127.9	127.9		127.9		
Lo MST T (Vol 5)	124.5	124.5	124.5		124.5		
Lo HVAC T increase	14.5	14.5	14.5		14.5		
Up HVAC T increase	27.9	27.9	27.9		27.9		
At t=1592 secs							
Up MST T (Vol 1)	196.7	253.0	229.3*		188.2		
Mid MST T (Vol 6)	135.7	150.1	132.8*		195.1		
Lo MST T (Vol 5)	131.1	144.5	129.8*		194.3		
Up MST T increase	58.8	115.1	91.4		50.3		
Mid MST T increase	7.8	22.2	4.9		67.2		
Lo MST T increase	6.6	20.0	5.3		69.8		
Lo HVAC T increase	21.1	34.5	19.9		84.3		
Up HVAC T increase	86.7	143.0	119.3		78.2		
At t=2762 secs							
Up MST T (Vol 1)	195.9	252.5	N/A		187.8		
Mid MST T (Vol 6)	136.1	153.5	N/A		193.7		
Lo MST T (Vol 5)	131.4	147.1	N/A		193.0		
Up MST T increase	58.0	114.6			49.9		
Mid MST T increase	8.2	25.6			65.8		
Lo MST T increase	6.9	22.6			68.5		
Lo HVAC T increase	21.4	37.1			83.0		
Up HVAC T increase	85.9	142.5			77.8		
			* Time at which either VR inlets choke (1092 seconds)				

Appendix E - GOTHIC Input Tables and Results for Case C110-100


3
2
6
5
1
11
12F
4F
4
14
1
2F
2
3
4
1H
4
7
12
14F
16
9P
3V
10
6P
1V
7
9
14
7
1
2
8
11F
3H
10
6
13
16
15
5F
8
11
12
10F
5
2H
5
3F
3
1P
6
8
2V
4V
13
13F
15
7P
8P

Control Volumes							
Vol #	Description	Vol (ft3)	Elev (ft)	Ht (ft)	Hyd. D. (ft)	Pl Area (ft2)	Burn Opt
1	Upper MST	35956.	736.6	26.9	24.5	704.	NONE
2	Aux Bldg	1000000.	687.	87.	30.		NONE
3	Reactor Bldg	1000000.	687.	87.	30.		NONE
4	Containment	1000000.	736.	87.	30.		NONE
5	Lower MST	79116.	687.	19.	29.2	4164.	NONE
6	Middle MST	21249.	706.	30.6	25.9	0.	NONE
7	Reactor Bldg	1000000.	687.	87.	30.		NONE
8	Aux Bldg (contr	1000000.	687.	87.	30.		NONE

Fluid Boundary Conditions - Table 1									
BC#	Description	Press. (psia)	FF	Temp. (F)	FF	Flow (lbm/s)	FF	ON Trip	OFF Trip
1P	Lo MST HVAC in	14.7	3	110	0	0	0	8	
2F	Up MST HVAC in	14.7		110		v400.0	3	8	
3F	Lo MST HVAC out	15.				0	3	8	
4F	Up MST HVAC out	15.			0	v-1157.	3	8	0
5F	Lo Steam leakag	55.		E1189.9		13.9	2	4	0
6P	Pressure sink	14.7		100					
7P	Pressure sink	14.7		100					
8P	Pressure sink	14.7		100					
9P	Pressure sink	14.7		100					
10F	Mid MST HVAC in	15.		93.3		0			
11F	Mid Steam leaka	55.		E1189.9		3.48	2	7	0
12F	Up Steam Leakag	55.		E1189.9		3.48	2	8	0
13F	Lo HVAC out - e	15.			0	0	2	8	
14F	Up HVAC out - e	15.				-3.09	2	8	

Fluid Boundary Conditions - Table 2

BC#	Liq. V Frac.	FF	Stm. P.R.	FF	Drop D (in)	FF	Cpld BC#	Flow Frac.	FF	Heat (Btu/s)	FF
1P			h30								
2F			h30								
3F			h40								
4F			h40								
5F			1		0.004						
6P			h40								
7P			h40								
8P			h40								
9P			h40								
10F			h52								
11F			1		0.004						
12F			1		0.004						
13F			h40								
14F			h40								

Fluid Boundary Conditions - Table 3
Gas Pressure Ratios

BC#	Air	FF	Ar	FF	He	FF	H2	FF
1P								
2F								
3F								
4F								
5F			0.					
6P								
7P								
8P								
9P								
10F								
11F								
12F								
13F								
14F								

Fluid Boundary Conditions - Table 4
Gas Pressure Ratios

BC#	Kr	FF	N2	FF	O2	FF	Xe	FF
1P								
2F								
3F								
4F								
5F								
6P								
7P								
8P								
9P								
10F								
11F								
12F								
13F								
14F								

Flow Paths - Table 1

F.P. #	Description	Vol A	Elev (ft)	Ht (ft)	Vol B	Elev (ft)	Ht (ft)
1	MST internal fl	6	736.1	0.1	1	737.1	0.1
2	Up MST HVAC in	1	760.	0.5	2F	760.	0.5
3	Lo MST HVAC out	5	700.	0.5	3F	700.	0.5
4	Up MST HVAC out	1	760.	0.5	4F	760.	0.5
5	Lo Steam leakag	5	700.	0.5	5F	700.	0.5
6	Lo MST HVAC in	5	700.	0.5	1P	700.	0.5
7	Up MST Blowout	1	760.	0.5	6P	760.	0.5
8	Lo MST Blowout	5	700.	0.5	7P	700.	0.5
9	Lo MST flow bal	5	700.	0.5	8P	700.	0.5
10	Up MST flow bal	1	760.	0.5	9P	760.	0.5
11	MST internal fl	5	705.5	0.5	6	706.5	0.5
12	Mid MST HVAC in	6	707.	0.1	10F	707.	0.1
13	Mid Steam Leaka	6	721.	0.5	11F	721.	0.5
14	Up Steam Leakag	1	750.	0.5	12F	750.	0.5
15	Lo HVAC out - e	5	700.	0.5	13F	700.	0.5
16	Up HVAC out - e	1	760.	0.5	14F	760.	0.5

Flow Paths - Table 2

Flow Path #	Flow Area (ft2)	Hyd. Diam. (ft)	Inertia Length (ft)	Friction Length (ft)	Critical Flow Model	De-Entrmt Frac.	Mom Trn Opt
1	693.	25.8	28.8	28.8	NO	0.	-
2	10.	10.	10.	10.	NO		-
3	10.	10.	10.	10.	NO		-
4	10.	10.	10.	10.	NO		-
5	10.	10.	10.	10.	NO		-
6	10.	10.	10.	10.	NO		-
7	50.	50.	10.	10.	NO		-
8	50.	50.	10.	10.	NO		-
9	5.	5.	10.	10.	NO		-
10	5.	5.	10.	10.	NO		-
11	693.	25.8	52.4	52.4	NO		-
12	10.	10.	10.	10.	NO		-
13	10.	10.	10.	10.	NO		-
14	10.	10.	10.	10.	NO		-
15	10.	10.	10.	10.	NO		-
16	10.	10.	10.	10.	NO		-

Flow Paths - Table 3

Flow Path #	Fwd. Loss Coeff.	Rev. Loss Coeff.	Comp. Opt.
1	0.	0.	OFF
2			OFF
3			OFF
4			OFF
5			OFF
6	1e+09	1.5	OFF
7	1.5	1e+09	OFF
8	1.5	1e+09	OFF
9	1.5	1e+09	OFF
10	1.5	1e+09	OFF
11	0.	0.	OFF
12			OFF
13			OFF
14			OFF
15			OFF
16			OFF

Thermal Conductors									
Cond #	Description	Vol A	HT Co	Vol B	HT Co	Cond Type	S. A. (ft2)	Init. T.(F)	Or
1	Up Ceiling E of	1	3	3	2	1	869.	134.	X
2	Up Ceiling W of	1	3	8	2	1	693.	134.	X
3	Up Sidewall alo	1	1	2	1	1	861.	134.	X
4	Up N & S wall W	1	1	2	1	1	1166.	134.	X
5	Up N & S wall E	1	1	3	1	1	1081.	134.	X
6	Up Wall along J	1	1	3	1	2	80.	134.	X
7	Up Containment	1	1	4	1	2	619.	134.	X
8	Mid E wall alon	6	1	7	1	1	835.	124.	X
9	Lo Ceiling	5	3	2	2	1	3663.	120.	X
10	Mid MST walls	6	1	2	1	3	1642.	124.	X
11	Upper MST floor	1	2	3	3	1	704.	134.	X
12	Lower MST floor	5	2	2	3	1	3663.	120.	X
13	Low E wall alo	5	1	7	1	1	608.	120.	X
14	Lower MST walls	5	1	2	1	3	4718.	120.	X
15	Lo MST floor	5	2	2	3	1	501.	120.	X
16	Mid MST side wa	6	1	8	1	3	663.	124.	X

Heat Transfer Coefficient Types - Table 1									
Type #	Heat Transfer Option	Nominal Value	FF	Cnd Cnv Opt	Cnd Opt	Sp Cnv HTC	Nat Cnv Opt	For Cnv Opt	Rad Opt
1	Direct			XOR	UCHI		VERT SURF	OFF	ON
2	Direct			XOR	UCHI		FACE UP	OFF	ON
3	Direct			XOR	UCHI		FACE DOWN	OFF	ON

Heat Transfer Coefficient Types - Table 2							
Type #	Phase Opt	Min Liq Fract	Max Liq Fract	Convect Bulk T Model	FF	Condensa Bulk T Model	FF
1	VAP			Tg-Tf		Tb-Tw	
2	VAP			Tg-Tf		Tb-Tw	
3	VAP			Tg-Tf		Tb-Tw	

Heat Transfer Coefficient Types - Table 3								
Type #	Char. Length (ft)	Nat Coef FF	Exp FF	For Coef FF	Exp FF	Nom Vel (ft/s)	Vel FF	Minimum Conv HTC (B/h-f2-F)
1								-1.
2								-1.
3								-1.

HTC Types - Table 4				
Type #	Total Heat (Btu)	Peak Time (sec)	Initial Value (B/h-f2-F)	Post-BD Direct FF
1				
2				
3				

Thermal Conductor Types							
Type #	Description	Geom	Thick. (in)	O.D. (in)	Regions	Heat (Btu/ft3-s)	Heat FF
1	4.5 ft slab	WALL	54.	0.	11	0.	
2	6.0 ft slab	WALL	72.	0.	12	0.	
3	3.5 ft slab	WALL	42.	0.	13	0.	

Thermal Conductor Type 1 4.5 ft slab					
Region	Mat. #	Bdry. (in)	Thick (in)	Sub-regs.	Heat Factor
1	1	0.	1.104	1	0.
2	1	1.104	2.208	1	0.
3	1	3.312	4.416	1	0.
4	1	7.728	8.832	1	0.
5	1	16.56	9.36	1	0.
6	1	25.92	9.36	1	0.
7	1	35.28	5.496	1	0.
8	1	40.776	5.496	1	0.
9	1	46.272	4.416	1	0.
10	1	50.688	2.208	1	0.
11	1	52.896	1.104	1	0.

Thermal Conductor Type 2 6.0 ft slab					
Region	Mat. #	Bdry. (in)	Thick (in)	Sub-regs.	Heat Factor
1	1	0.	1.104	1	0.
2	1	1.104	2.208	1	0.
3	1	3.312	4.416	1	0.
4	1	7.728	8.832	1	0.
5	1	16.56	17.664	1	0.
6	1	34.224	9.444	1	0.
7	1	43.668	9.444	1	0.
8	1	53.112	5.58	1	0.
9	1	58.692	5.58	1	0.
10	1	64.272	4.416	1	0.
11	1	68.688	2.208	1	0.
12	1	70.896	1.104	1	0.

Thermal Conductor Type 3 3.5 ft slab					
Region	Mat. #	Bdry. (in)	Thick (in)	Sub-regs.	Heat Factor
1	1	0.	0.1104	1	0.
2	1	0.1104	0.2208	1	0.
3	1	0.3312	0.4416	1	0.
4	1	0.7728	0.8832	1	0.
5	1	1.656	1.7664	1	0.
6	1	3.4224	3.5328	1	0.
7	1	6.9552	7.0656	1	0.
8	1	14.0208	6.9948	1	0.
9	1	21.0156	6.9948	1	0.
10	1	28.0104	5.3388	1	0.
11	1	33.3492	5.3388	1	0.
12	1	38.688	2.208	1	0.
13	1	40.896	1.104	1	0.

Materials	
Type #	Description
1	Concrete

Material Type 1 Concrete			
Temp. (F)	Density (lbm/ft3)	Cond. (Btu/hr-ft-F)	Sp. Heat (Btu/lbm-F)
100.	145.	0.92	0.156

Cooler/Heater											
Heater Cooler #	Description	Vol. #	On Trip #	Off Trip #	Flow Rate (CFM)	Flow Rate FF	Heat Rate (Btu/s)	Heat Rate FF	Phs Opt	Ct L
1H	Up MST heat 1	1	3				332.5	1	VTE	
2H	Lo MST heat 1	5	3				175.	1	VTE	
3H	Mid MST heat	6	3				45.	1	VTE	

Valves & Doors						
Valve #	Description	Flow Path #	Open Trip #	Close Trip #	Valve Type #	Disch. Vol.
1V	Upper MST blowo	7	1	9	1	6P
2V	Lower MST blowd	8	2	10	1	7P
3V	Up MST flow bal	10	8	0	2	9P
4V	LO MST flow bal	9	8	0	2	8P

Valve/Door Types				
Valve Type #	Valve Option	Stem Travel Curve	Loss Coeff. Curve	Flow Area (ft2)
1	QUICK OPEN	0	0	50.
2	QUICK OPEN	0	0	5.

Component Trips									
Trip #	Sense Var.	Sensor 1 Loc.	Sensor 2 Loc.	Var. Limit	Set Point	Delay Time	Rset Trip	Cond Trip	Cond Type
1	PRESS	1		UPPER	15.7	0.	9		AND
2	PRESS	5		UPPER	15.7	0.	10		AND
3	TIME			UPPER	0.	0.			AND
4	TIME			UPPER	1000.	0.			AND
5	PRESS	1		UPPER	14.71	0.			AND
6	PRESS	5		UPPER	14.71	0.			AND
7	TIME			UPPER	3600.	0.			AND
8	TIME			UPPER	3600.	0.			AND
9	PRESS	1		LOWER	15.2	0.			AND
10	PRESS	5		LOWER	15.2	0.			AND

Functions				
FF#	Description	Ind. Var.	Dep. Var.	Points
0	Constant	-	-	0
1	Heat load	Temperatur	Multiplier	8
2	Crack Propogati	Time, sec.	Value	3
3	Step down	Time, sec	Dep. Var.	3

Function 1 Heat load Ind. Var.: Temperature Dep. Var.: Multiplier			
Ind. Var.	Dep. Var.	Ind. Var.	Dep. Var.
45.	1.132	60.	1.094
75.	1.057	90.	1.028
104.	1.	122.	0.9638
148.	0.91	300.	0.5146

Function 2 Crack Propogation Ind. Var.: Time, sec. Dep. Var.: Value			
Ind. Var.	Dep. Var.	Ind. Var.	Dep. Var.
0.	0.	100.	1.
1e+30	1.		

Function 3 Step down Ind. Var.: Time, sec Dep. Var.:			
Ind. Var.	Dep. Var.	Ind. Var.	Dep. Var.
0.	1.	0.1	0.
1e+30	0.		

Control Variables

CV #	Description	Func. Form	Initial Value	Coeff. G	Coeff. a0	Min	Max
1	Junction 4 Fl	div	0.	60.	0.	-1e+32	1e+32
2	Volume 1 dens	sum	0.	1.	0.	-1e+32	1e+32
3	Junction 6 Fl	mult	0.	847.457	0.	-1e+32	1e+32
4	Junction 2 Fl	mult	0.	847.457	0.	-1e+32	1e+32
5	Junction 3 Fl	div	0.	60.	0.	-1e+32	1e+32
6	Volume 5 dens	sum	0.	1.	0.	-1e+32	1e+32
7	Junction 5 Fl	mult	0.	1608.	0.	-1e+32	1e+32
8	J5 + J6 Flow	sum	0.	1.	0.	-1e+32	1e+32

Function Components
Control Variable 1
Junction 4 Flow
div
Y=G(a0+a2X2)/(a1X1)

#	Gothic_s Name	Variable location	Coef. a
1	cvval	cv2	1.
2	wgjnc	cJ4	1.

Function Components
Control Variable 2
density
sum
Y=G(a0+a1X1+a2X2+...+anXn)

#	Gothic_s Name	Variable location	Coef. a
1	rv	cV1	1.
2	rmgas	cV1	1.

Function Components
Control Variable 3
Junction 6 Flow
mult
Y=G(a1X1*a2X2*...*anXn)

#	Gothic_s Name	Variable location	Coef. a
1	wgjnc	cJ6	1.

Function Components Control Variable 4 Junction 2 Flow mult Y=G(a0+a2X2)/(a1X1)			
#	Gothic_s Name	Variable location	Coef. a
1	wgjnc	cJ2	1.

Function Components Control Variable 5 Junction 3 Flow div equation			
#	Gothic_s Name	Variable location	Coef. a
1	cvval	cv6	1.
2	wgjnc	cJ3	1.

Function Components Control Variable 6 Volume 5 density sum Y=G(a0+a1X1+a2X2+...+anXn)			
#	Gothic_s Name	Variable location	Coef. a
1	rv	cV5	1.
2	rmgas	cV5	1.

Function Components Control Variable 7 Junction 5 Flow mult Y=G(a1X1*a2X2*...*anXn)			
#	Gothic_s Name	Variable location	Coef. a
1	wgjnc	cJ5	1.

Function Components Control Variable 8 J5 + J6 Flow sum Y=G(a0+a1X1+a2X2+...+anXn)			
#	Gothic_s Name	Variable location	Coef. a
1	cvval	cv3	1.
2	cvval	cv7	1.

Volume Initial Conditions							
Vol #	Pressure (psia)	Vapor Temp. (F)	Liquid Temp. F	Relative Humidity (%)	Liquid Volume Fractio	Ice Volume Fract.	Ice Surf.A. (ft2)
def	14.7	80.	80.	60.	0.	0.	0.
1	14.7	139.	139.	10.	0.	0.	0.
2	14.7	110.	110.	40.	0.	0.	0.
3	14.7	110.	110.	40.	0.	0.	0.
4	14.7	130.	130.	40.	0.	0.	0.
5	14.7	124.5	124.5	20.	0.	0.	0.
6	14.7	128.5	128.5	15.	0.	0.	0.
7	14.7	110.	110.	40.	0.	0.	0.
8	14.7	75.	75.	40.	0.	0.	0.

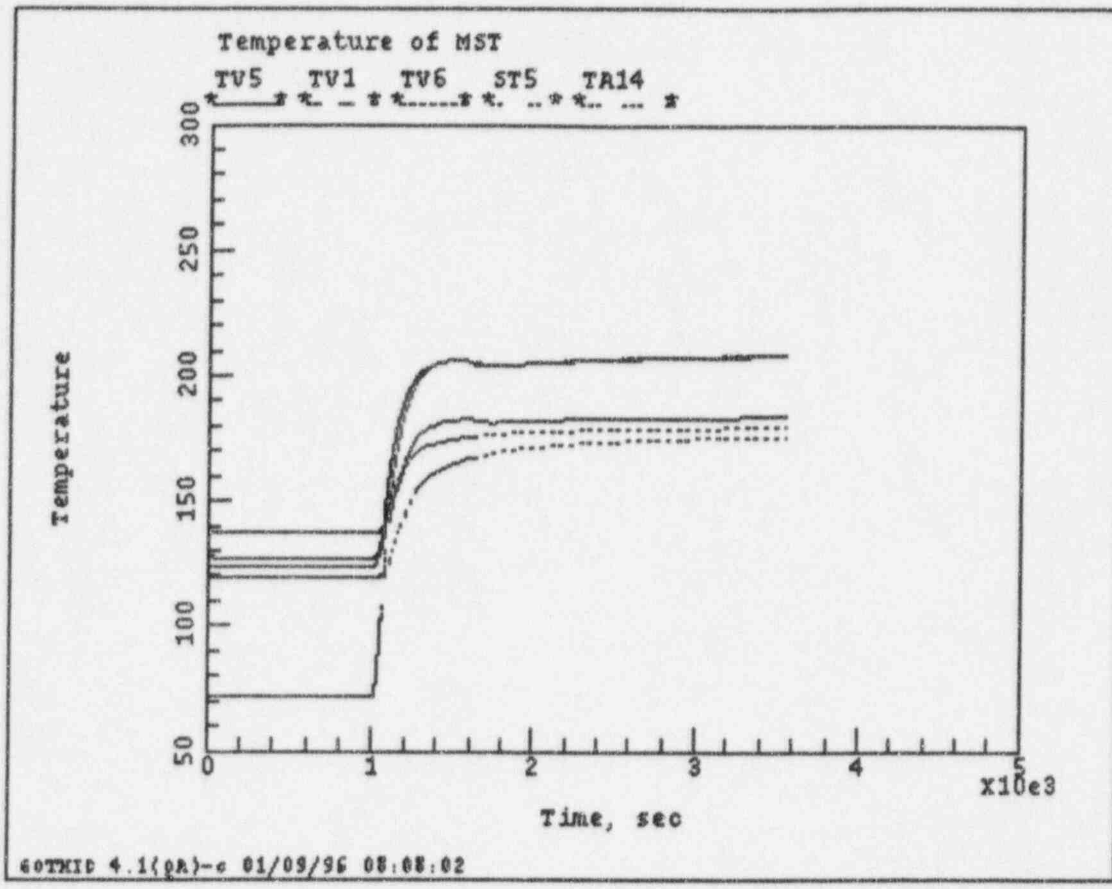
Initial Gas Pressure Ratios								
Vol #	Air	Ar	He	H	Kr	N	O	Xe
def	1.	0.	0.	0.	0.	0.	0.	0.
1	1.	0.	0.	0.	0.	0.	0.	0.
2	1.	0.	0.	0.	0.	0.	0.	0.
3	1.	0.	0.	0.	0.	0.	0.	0.
4	1.	0.	0.	0.	0.	0.	0.	0.
5	1.	0.	0.	0.	0.	0.	0.	0.
6	1.	0.	0.	0.	0.	0.	0.	0.
7	1.	0.	0.	0.	0.	0.	0.	0.
8	1.	0.	0.	0.	0.	0.	0.	0.

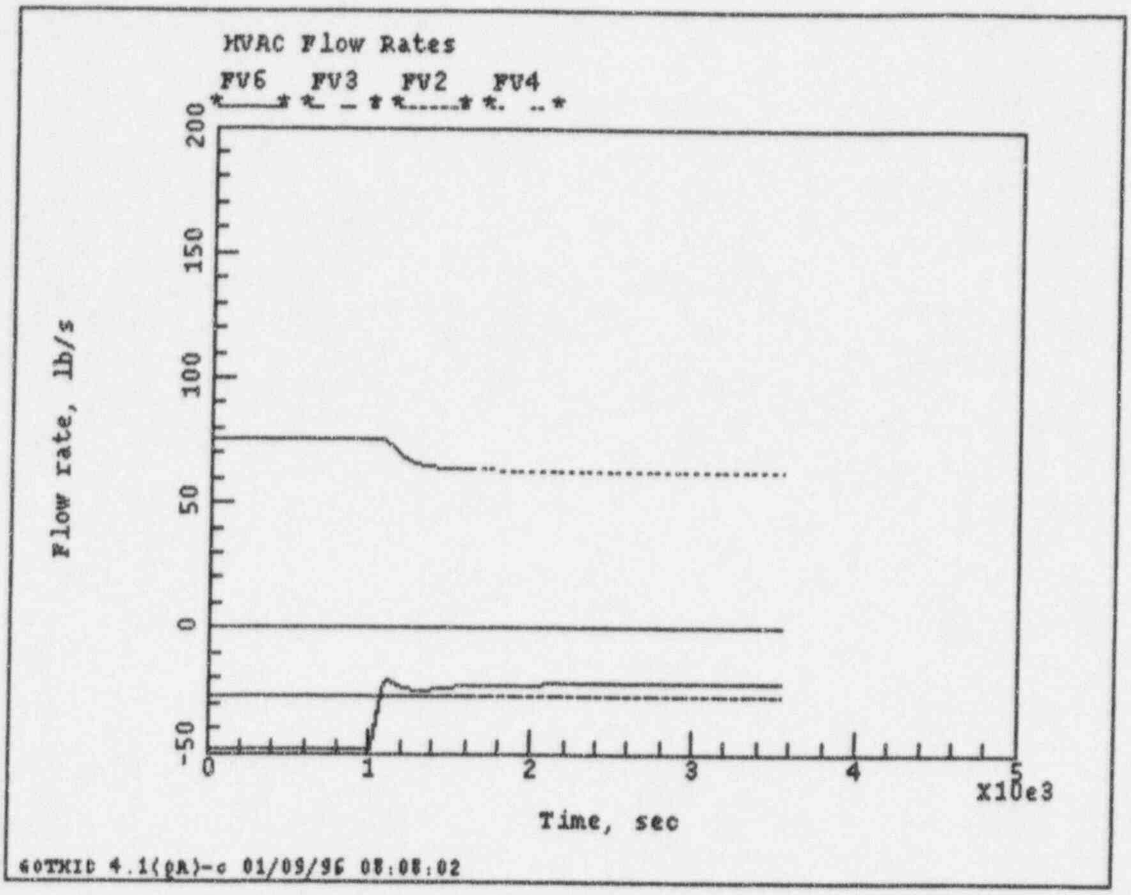
Run Control Parameters (Seconds)								
Time Int	DT Min	DT Max	DT Ratio	End Time	Print Int	Graph Int	Max CPU	Dump Int
1	0.001	0.001	1e+10	0.001	0.001	0.001	60.	0.
2	0.001	1.	1.	120.	10.	5.	600.	0.
3	0.1	1.	1.	970.	30.	30.	600.	0.
4	0.001	1.	1.	1050.	1.	1.	600.	0.
5	0.01	1.	1.	1600.	30.	30.	600.	0.
6	0.01	1.	1.	3600.	60.	60.	600.	0.

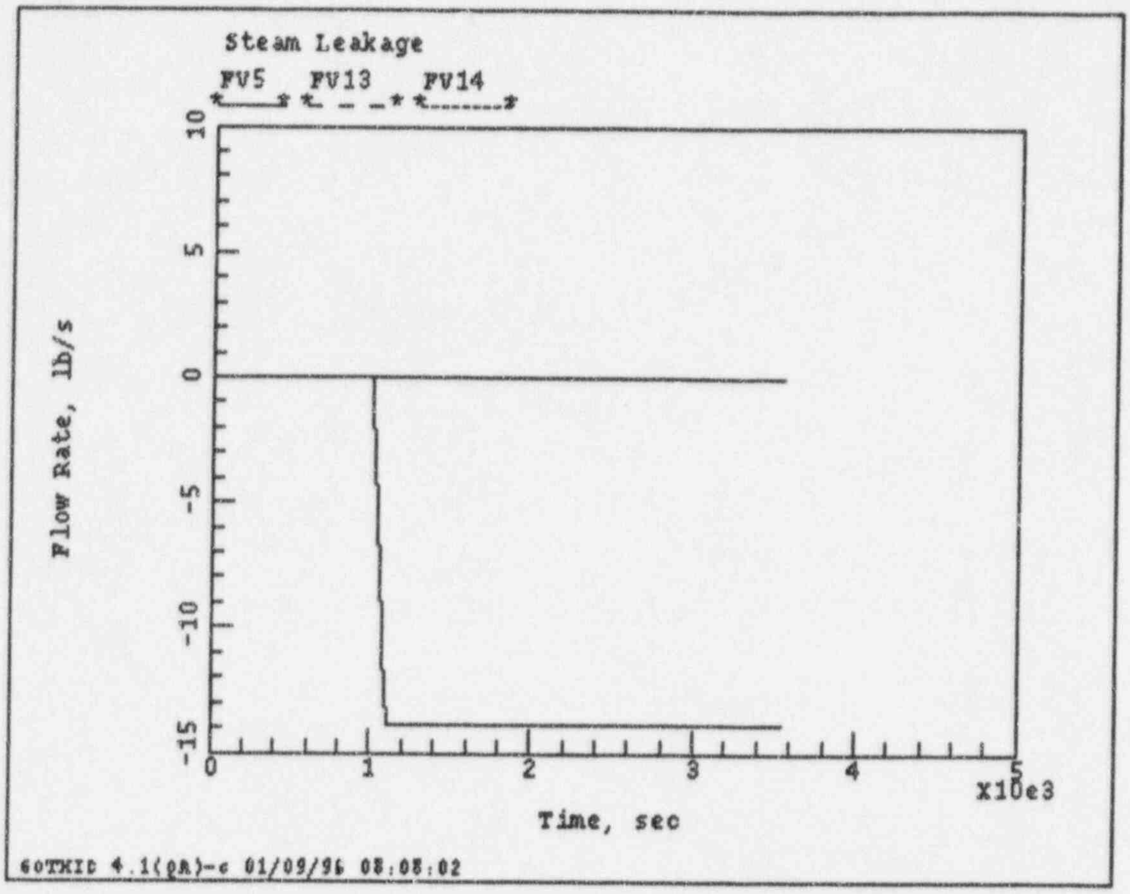
Run Parameters Menu	
Parameter	Value
Restart Time (sec)	0
Restart Time Step #	0
Restart Time Control	NEW
Revap. Fraction	0
Hetero. Nucleation?	YES
Min. NC HT Coeff. (Btu/ft2-hr-F)	0
Reference Pressure (psia)	0
Forced Ent. Drop Dia. (ft)	0.00833

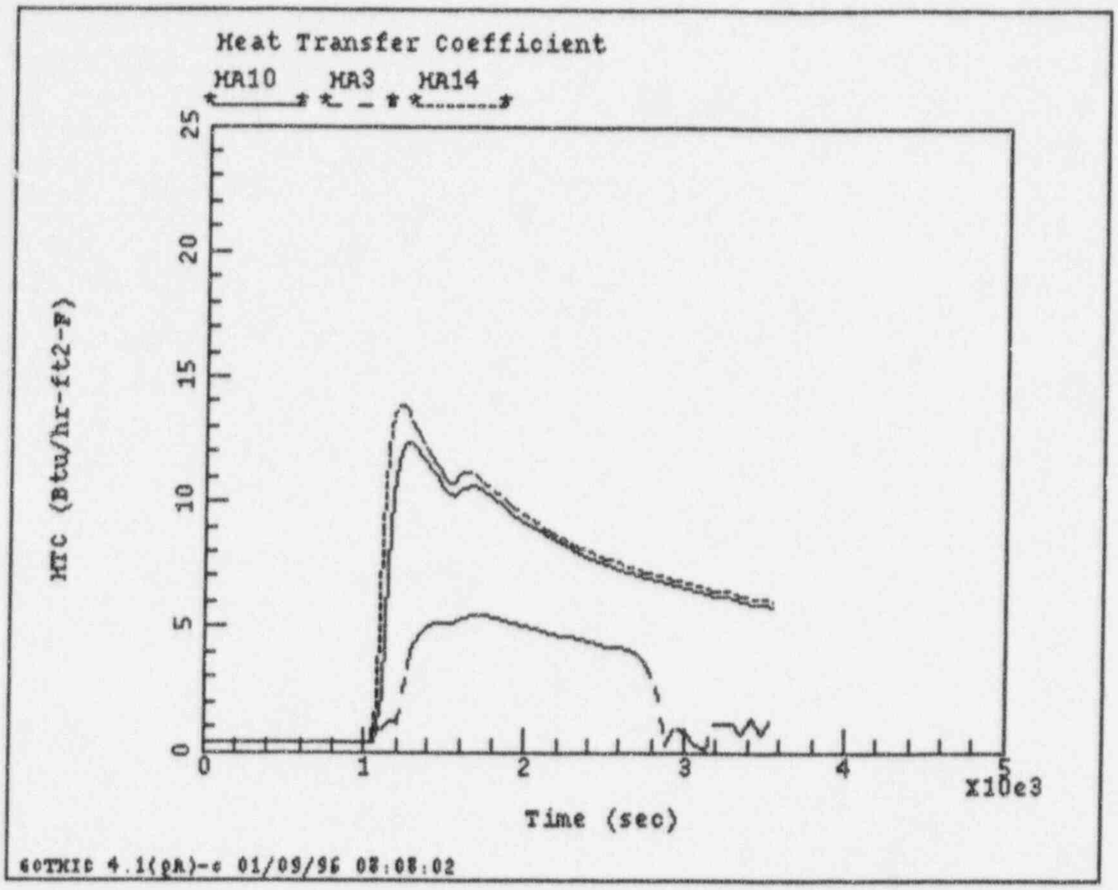
Ice Condenser Parameters			
Initial Temp. (F)	Bulk Density (lbm/ft3)	Surface Area Multiplier Function	Heat Transfer Option
15.	33.43	0	UCHIDA

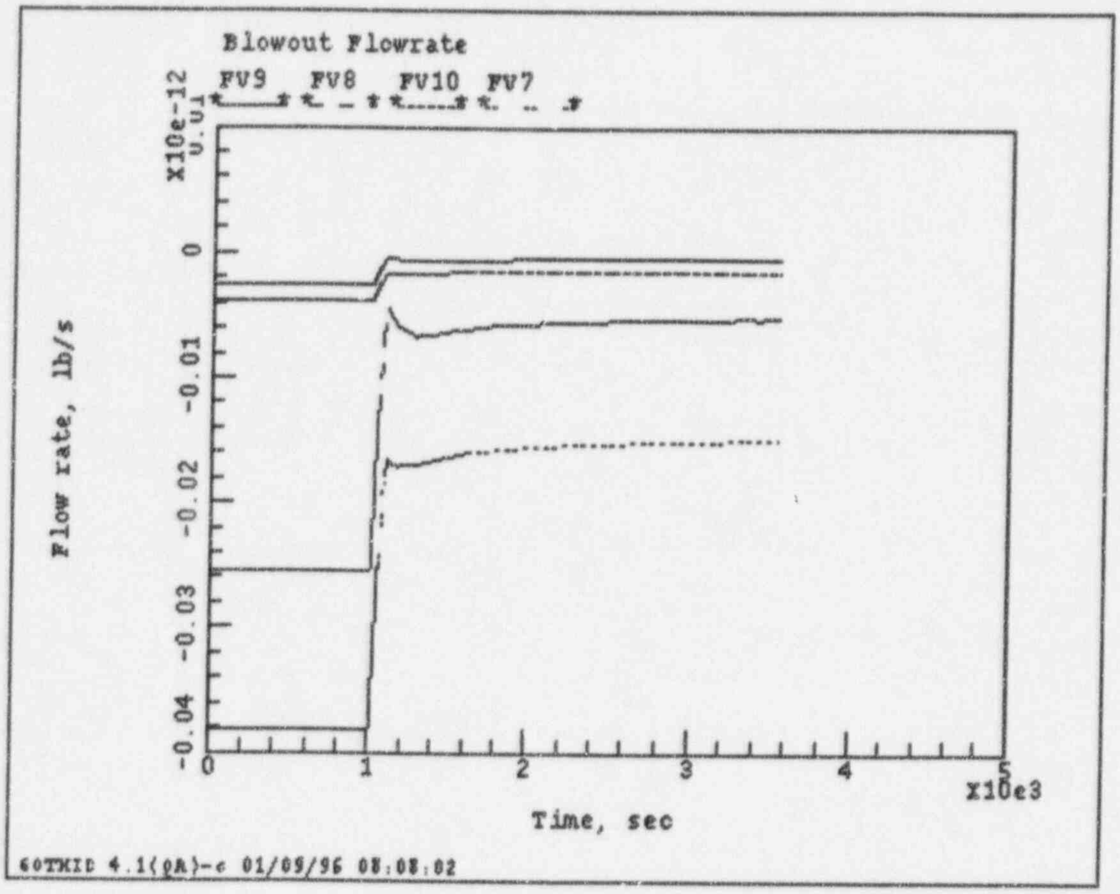
Graphs							
Graph #	Title	Mon	Curve Number 1	2	3	4	5
1	Temperature of		TV5	TV1	TV6	ST5	TA14
2	HVAC Flow Rates		FV6	FV3	FV2	FV4	
3	Steam Leakage		FV5	FV13	FV14		
4	Heat Transfer C		HA10	HA3	HA14		
5	Blowout Flowrat		FV9	FV8	FV10	FV7	
6	Pressure		PR1	PR5	PR6		
7	Temp Profile HS		TP10t10	TP10t.0	TP14t16	TP3t300	TP14t30
8	Extra HVAC		FV15	FV16			
9	Volume Fraction		AL5	AL6	AL1		
10	Internal Flow		FV11	FV1			
11	Heat Load		CQ2H	CQ3H	CQ1H		
12			cv1	cv3	cv4	cv7	cv8

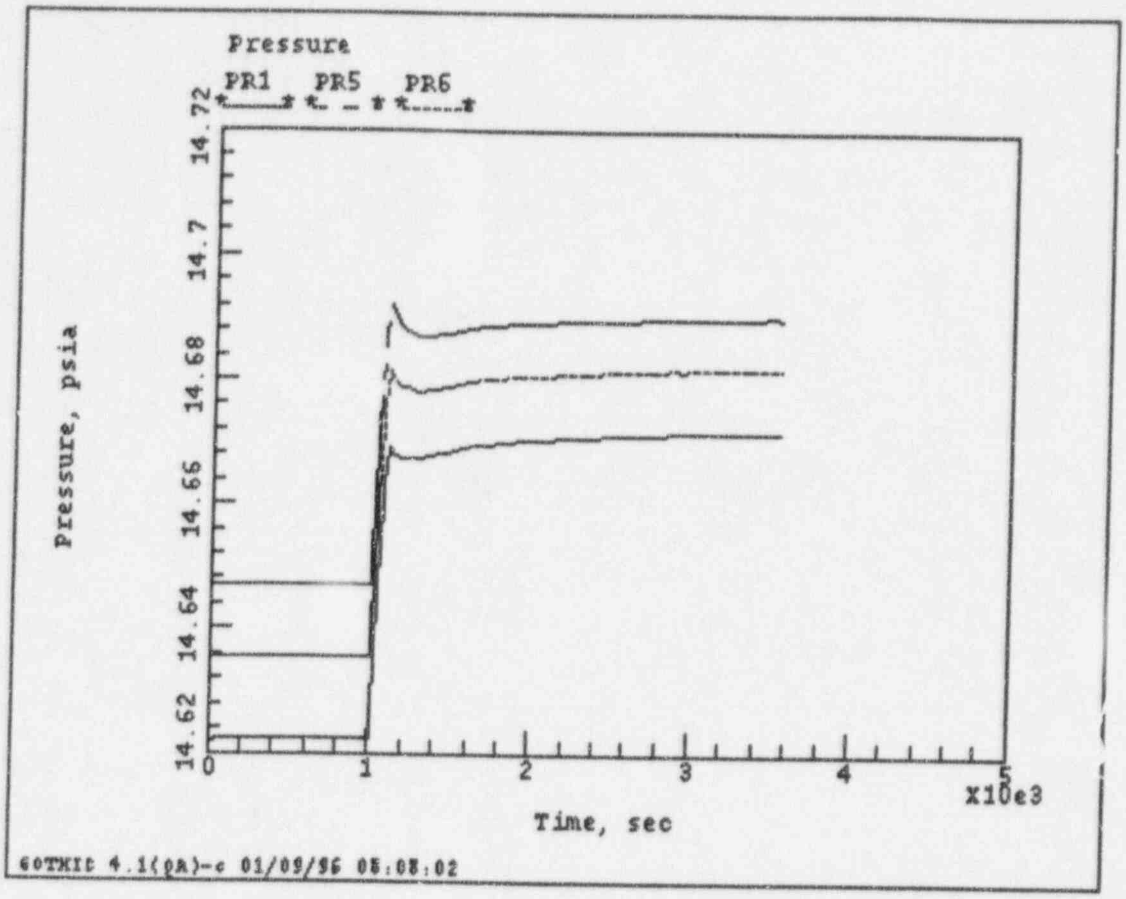

Temperature of MST
TV5
TV1
TV6
ST5
TA14
Temperature
300
250
200
150
100
50
0
1
2
3
4
5
X10e3
Time, sec
GOTHIC 4.1(QA)-c 01/09/96 08:08:02

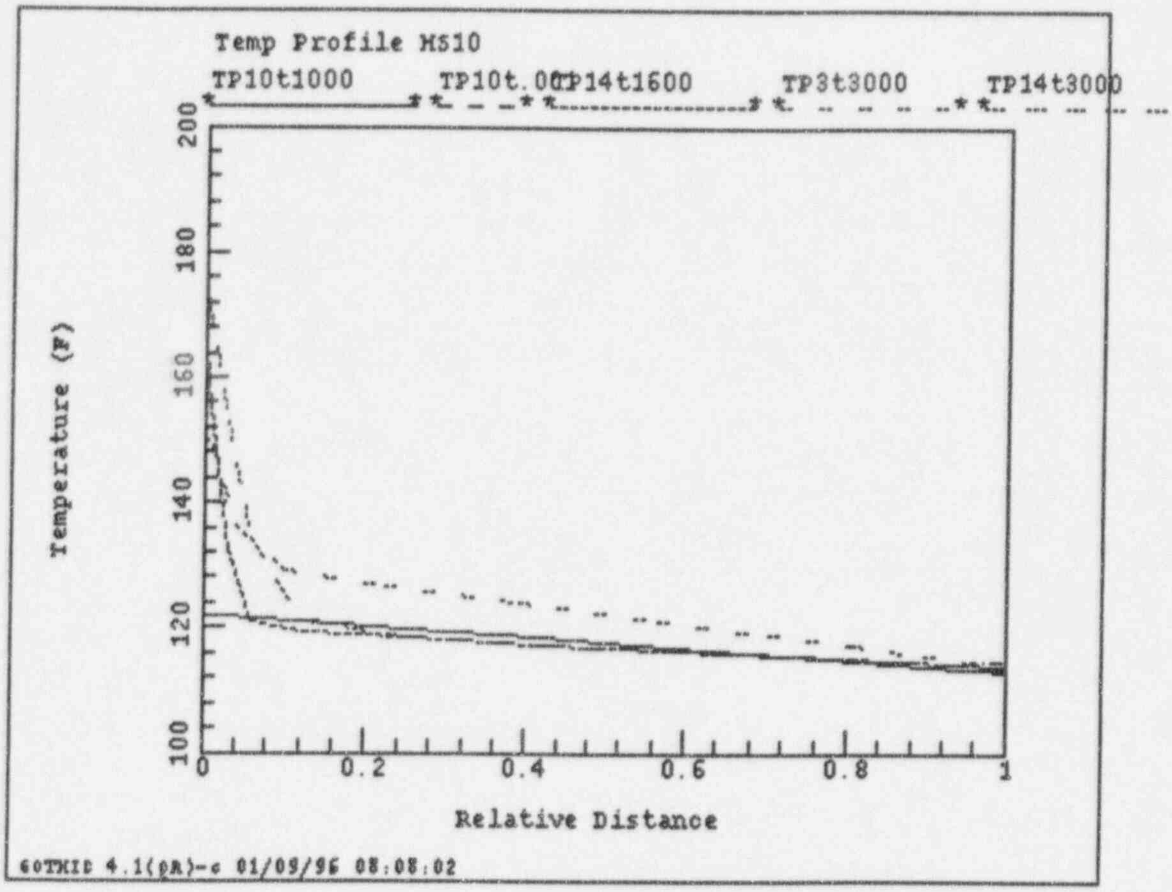

HVAC Flow Rates
FV6
FV3
FV2
FV4
200
150
100
50
0
-50
Flow rate, lb/s
0
1
2
3
4
5
X10e3
Time, sec
GOTHIC 4.1(QA)-c 01/09/96 08:08:02

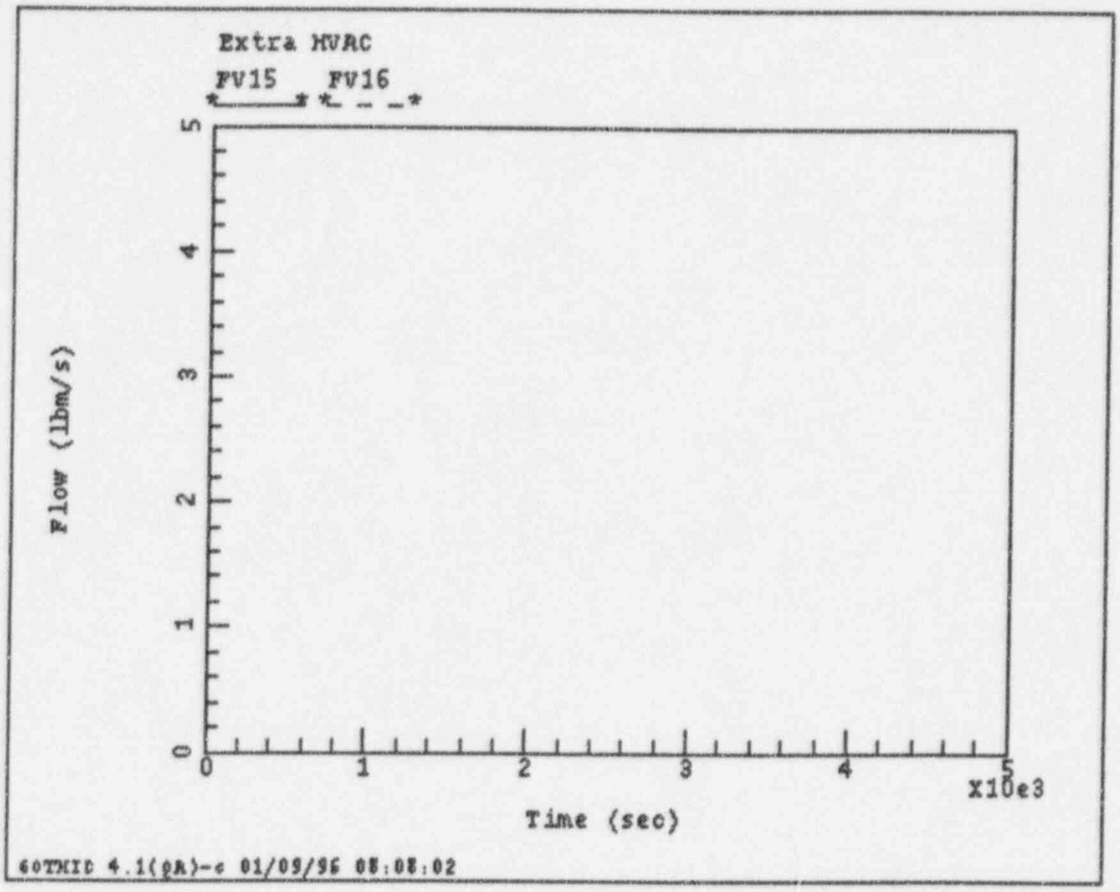

Steam Leakage
FV5
FV13
FV14
Flow Rate, lb/s
10
5
0
-5
-10
-15
0
1
2
3
4
5
X10e3
Time, sec
GOTHIC 4.1(QA)-c 01/09/96 08:08:02

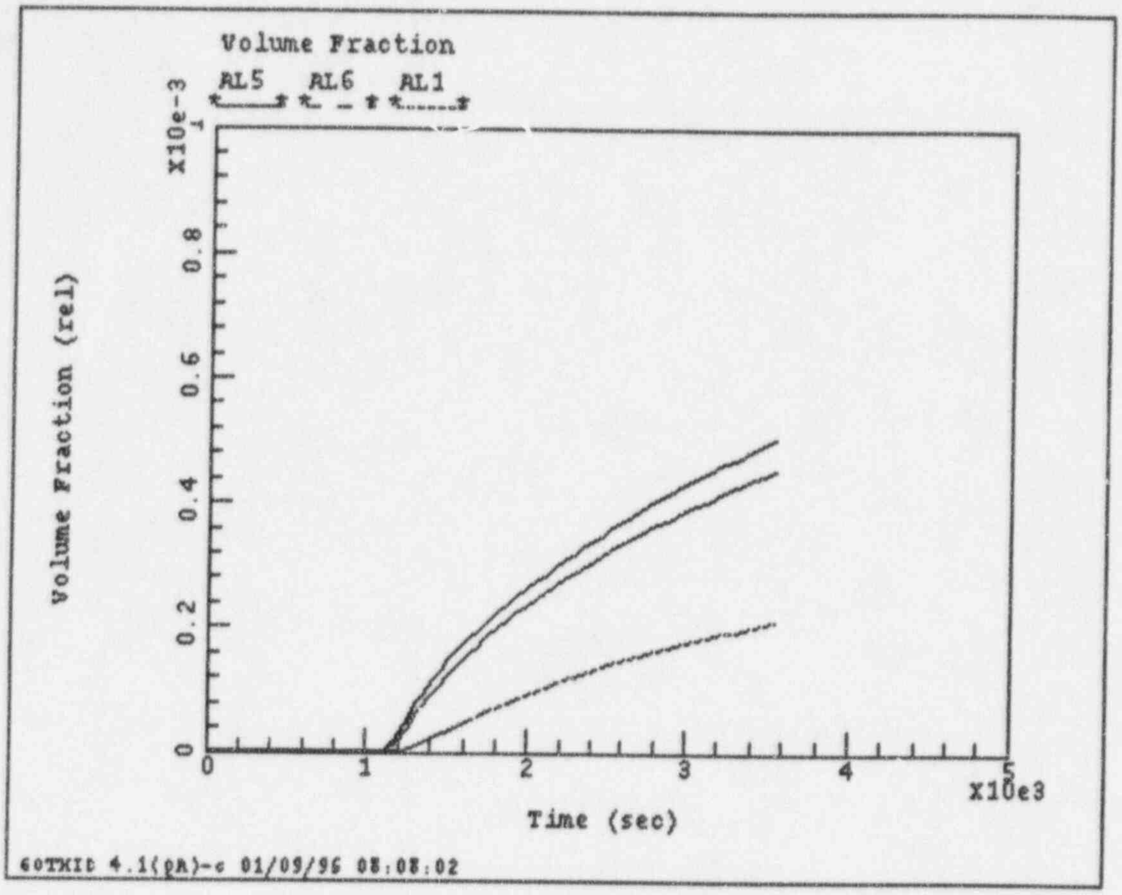

Heat Transfer Coefficient
HA10
HA3
HA14
HTC (Btu/hr-ft2-F)
0
5
10
15
20
25
0
1
2
3
4
5
X10e3
Time (sec)
GOTHIC 4.1(QA)-c 01/09/96 08:08:02


Blowout Flowrate
FV9
FV8
FV10
FV7
X10e-12
0
-0.01
-0.02
-0.03
-0.04
Flow rate, lb/s
0
1
2
3
4
5
X10e3
Time, sec
GOTHIC 4.1(QA)-c 01/09/96 08:08:02

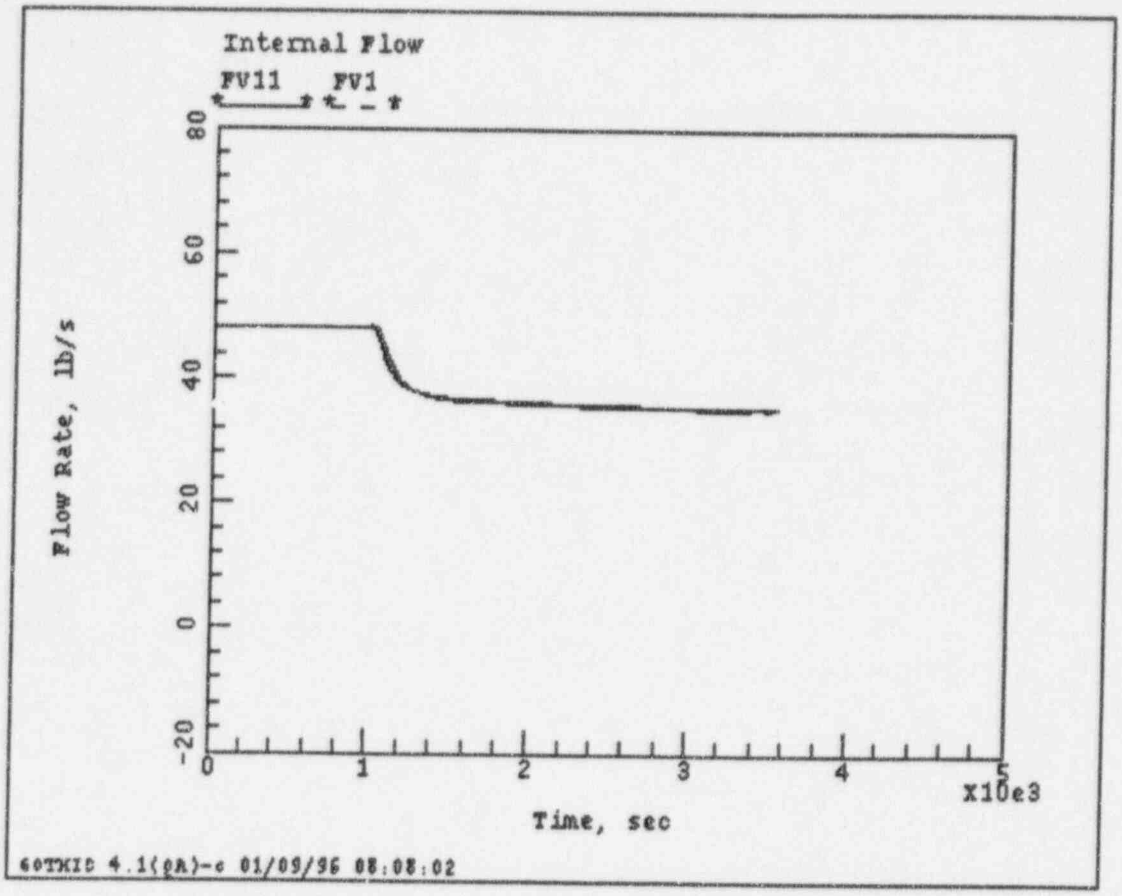

Pressure
PR1
PR5
PR6
14.72
14.7
14.68
14.66
14.64
14.62
Pressure, psia
0
1
2
3
4
5
X10e3
Time, sec
GOTHIC 4.1(QA)-c 01/09/96 05:05:02

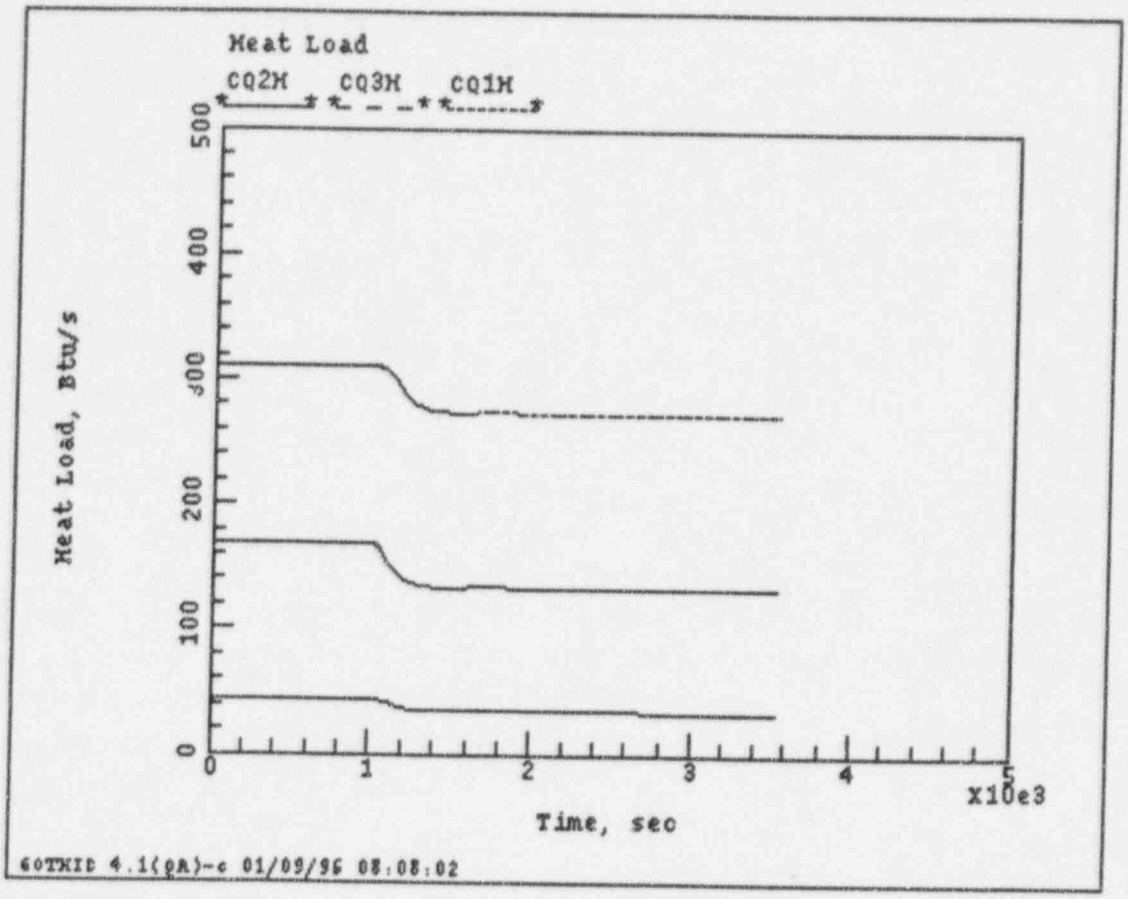

Temp Profile HS10
TP10t1000
TP10t.00
TP14t1600
TP3t3000
TP14t3000
Temperature (F)
200
180
160
140
120
100
0
0.2
0.4
0.6
0.8
1
Relative Distance
GOTHIC 4.1(QA)-c 01/09/96 08:08:02

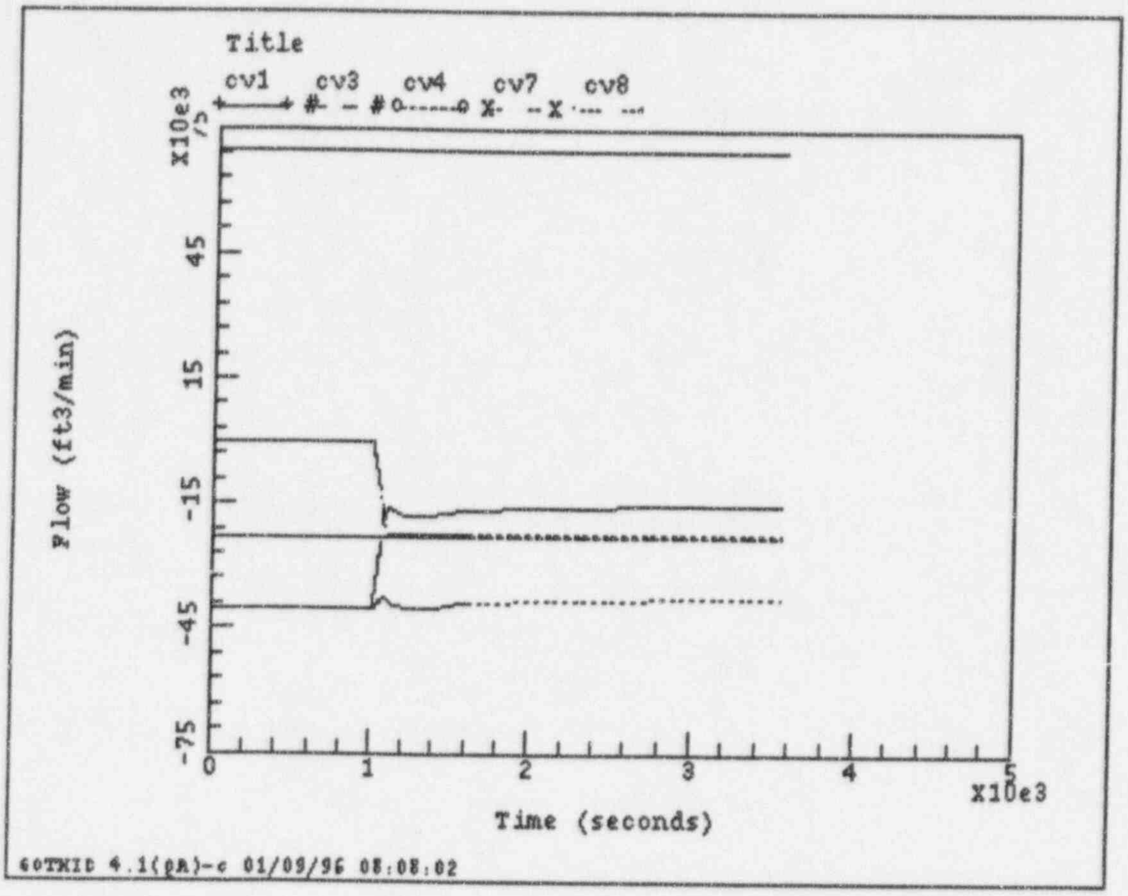

Extra HVAC
FV15
FV16
Flow (lbm/s)
0
1
2
3
4
5
Time (sec)
X10e3
GOTHIC 4.1(QA)-c 01/09/96 08:08:02


Volume Fraction
AL5
AL6
AL1
X10e-3
1
0.8
0.6
0.4
0.2
0
Volume Fraction (rel)
0
1
2
3
4
5
X10e3
Time (sec)
GOTHIC 4.1(QA)-c 01/09/96 08:08:02

c110-100
Sat Jan 13 14:13:19 1996
GOTHIC Version 4.1(QA)-c - May 1995




Heat Load
CQ2H
CQ3H
CQ1H
Heat Load, Btu/s
0
100
200
300
400
500
0
1
2
3
4
5
X10e3
Time, sec
GOTHIC 4.1(QA)-c 01/09/96 08:08:02


Title
cv1
cv3
cv4
cv7
cv8
X10e3
75
45
15
-15
-45
-75
Flow (ft3/min)
0
1
2
3
4
5
X10e3
Time (seconds)
GOTHIC 4.1(QA)-c 01/09/96 08:08:02