METHODOLOGY FOR ADDRESSING SUPERHEATED STEAM RELEASES TO ICE CONDENSER CONTAINMENTS

Purpose

The purpose of this report is to document the information presented on March 19, 1984 in a meeting with the U.S. NRC Containment Systems Branch on the status of progress made in addressing the confirmatory item on the Catawba Nuclear Plant Safety Evaluation Report. This confirmatory item deals with the effects of superheated steam generator mass and energy releases following main steamline break accidents. Attachment 1 includes the list of attendees at the meeting and the overhead slides covered in the Westinghouse presentations.

Technical presentations were made describing the modeling of the steam generator and heat transfer from the uncovered tube bundle during the steam generator blowdown along with a description of the containment model and transient response. A proposed plan of action was also presented and discussed with the Staff. In accordance with that plan, this report represents the first milestone in the proposed plan of action. As committed to in the meeting, the appendices present proprietary information which relates to the specifics of the models and sensitivities that were not directly addressed in the meeting.

Attachment 2 is an explanation of, and refers to, the overhead slides (Figures) presented at the March 19 meeting.

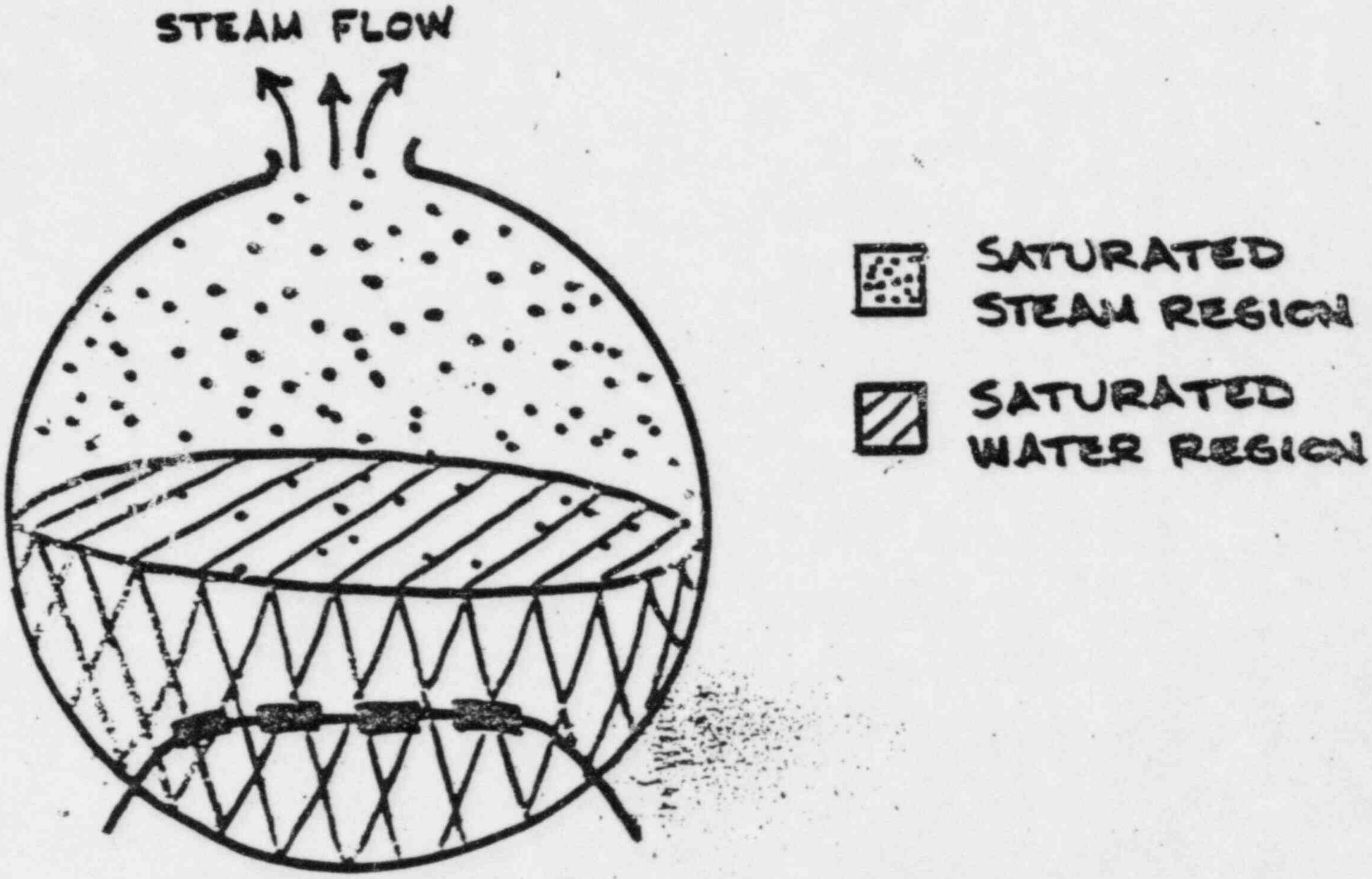
ATTACHMENT 1

Attendance at 3/19/84
Meeting w/ Duke + W on
Main Steam Line Break Analysis

Name	Organization
K. N. JABBOUR	NRC/DL
R. O. SHARPE	DUKE/NPD
J. L. LITTLE	W NUCLEAR SAFETY
H.V. JULIAN	W NUCLEAR SAFETY
TJ Kenyon	NRC/DL
DS. Love	W NUCLEAR SAFETY
MP Osborne	W Nuclear Safety
P.A. Linn	W Nuclear Safety
L.E. Hochreiter	W Nuclear Safety
F.F. CADEK	W Nuclear Safety
F J Twogood	W NOD, project mgr.
S D Alexander	Duke, Design Engineering
R E Miller	Duke, Design Engineering
J. E. Wills	TVA, Nuclear Licensing Staff
B. AMELI	SERCH LICENSING STAFF, BECH.
C. DRAUGHON	W NUCLEAR SAFETY
W.D. Crouch	TVA, Engineering "Design
S. P. Nesbit	Duke, Nuclear Production Department
S.A. Swamy	W, NTD/SME
R.H. Owoc	W NTD/NUCLEAR SAFETY
J SHAPAKER	NRC/CSB
Jack Kudrick	" "
J. Pulsipher	NRC/CSB
C. Li	NRC/CSB
A. Notafrancesco	NRC/CSB

LOFTRAN MODEL

STEAM GENERATOR SECONDARY

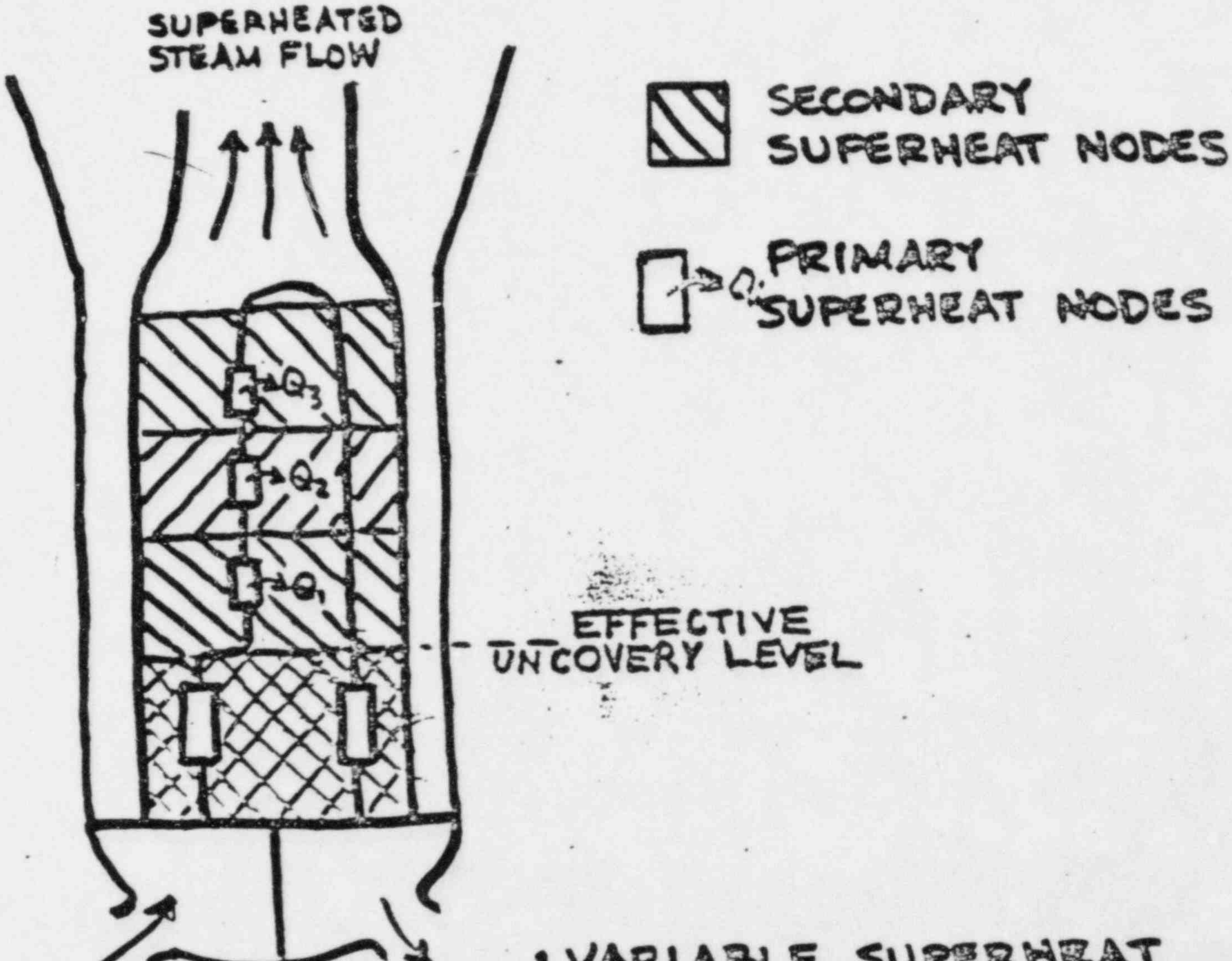


- SINGLE NODE, 2 REGION MODEL
- NO HEAT TRANSFER TO SATURATED STEAM REGION
- HEAT TRANSFER TO SATURATED WATER REGION IS MODIFIED FOR TUBE 'UNCOVERY'

FIGURE 1

LOFTRAN MODEL

SUPERHEAT HEAT TRANSFER



- VARIABLE SUPERHEAT NODES MODEL

- CONSTANT PRIMARY TEMPERATURE IN SUPERHEAT REGION ASSUMED FOR HEAT TRANSFER CALCULATIONS

- CALCULATED SUPERHEAT HEAT TRANSFER ACCOUNTED FOR IN PRIMARY TRANSIENT

FIGURE 2

TUBE UNCOVERY

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

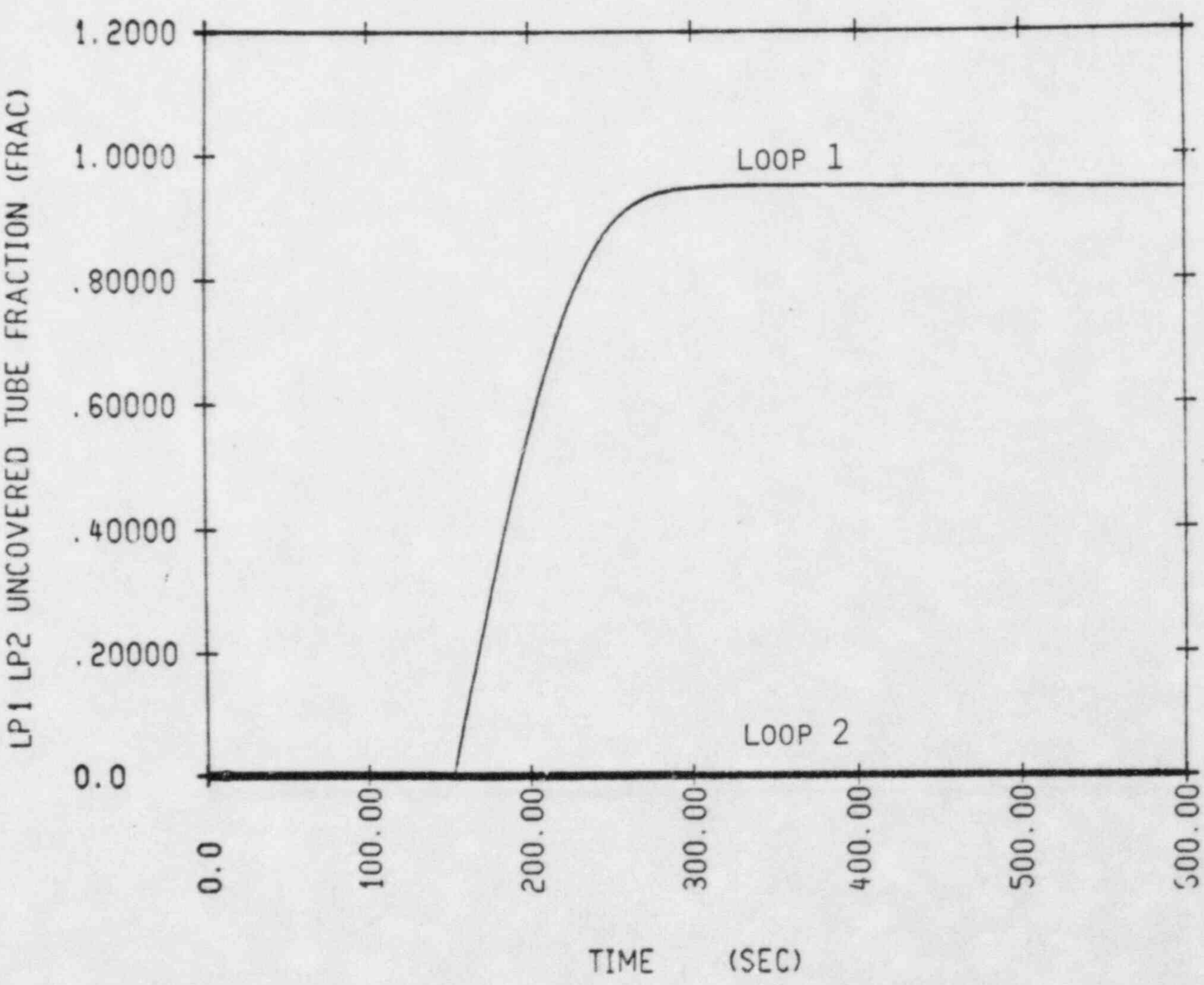


FIGURE 3

MASS BLOWDOWN

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

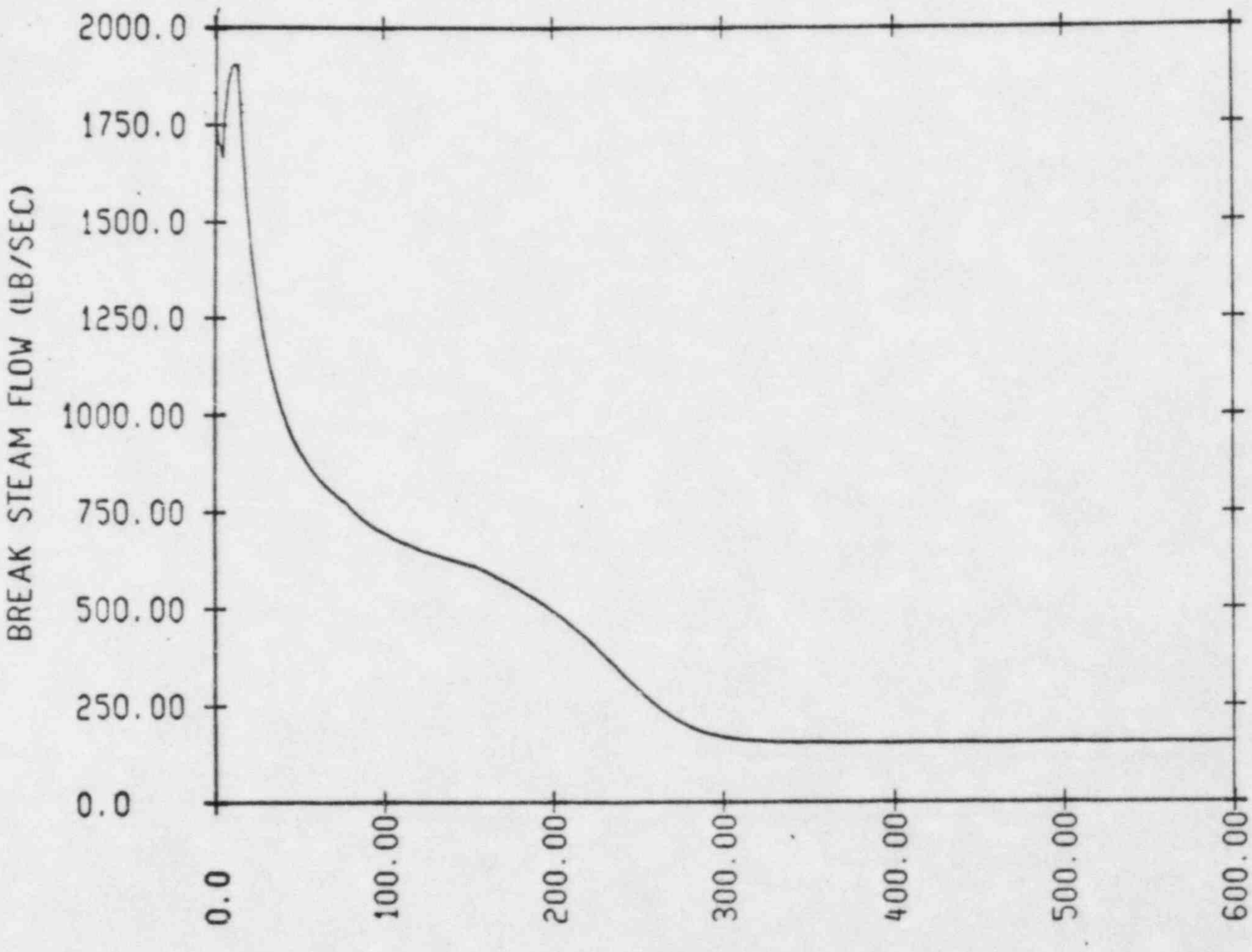


FIGURE 4

ENERGY RELEASE

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

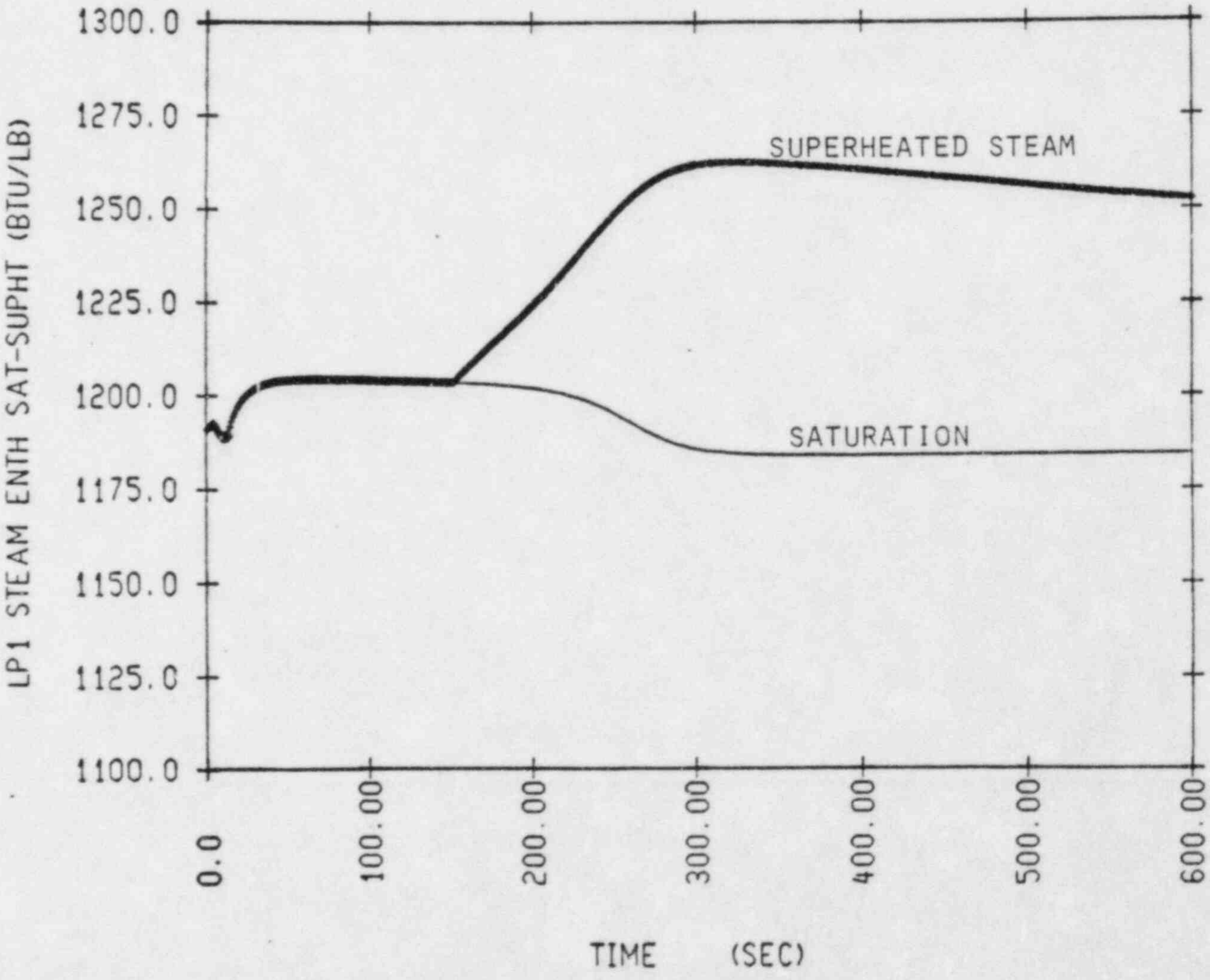
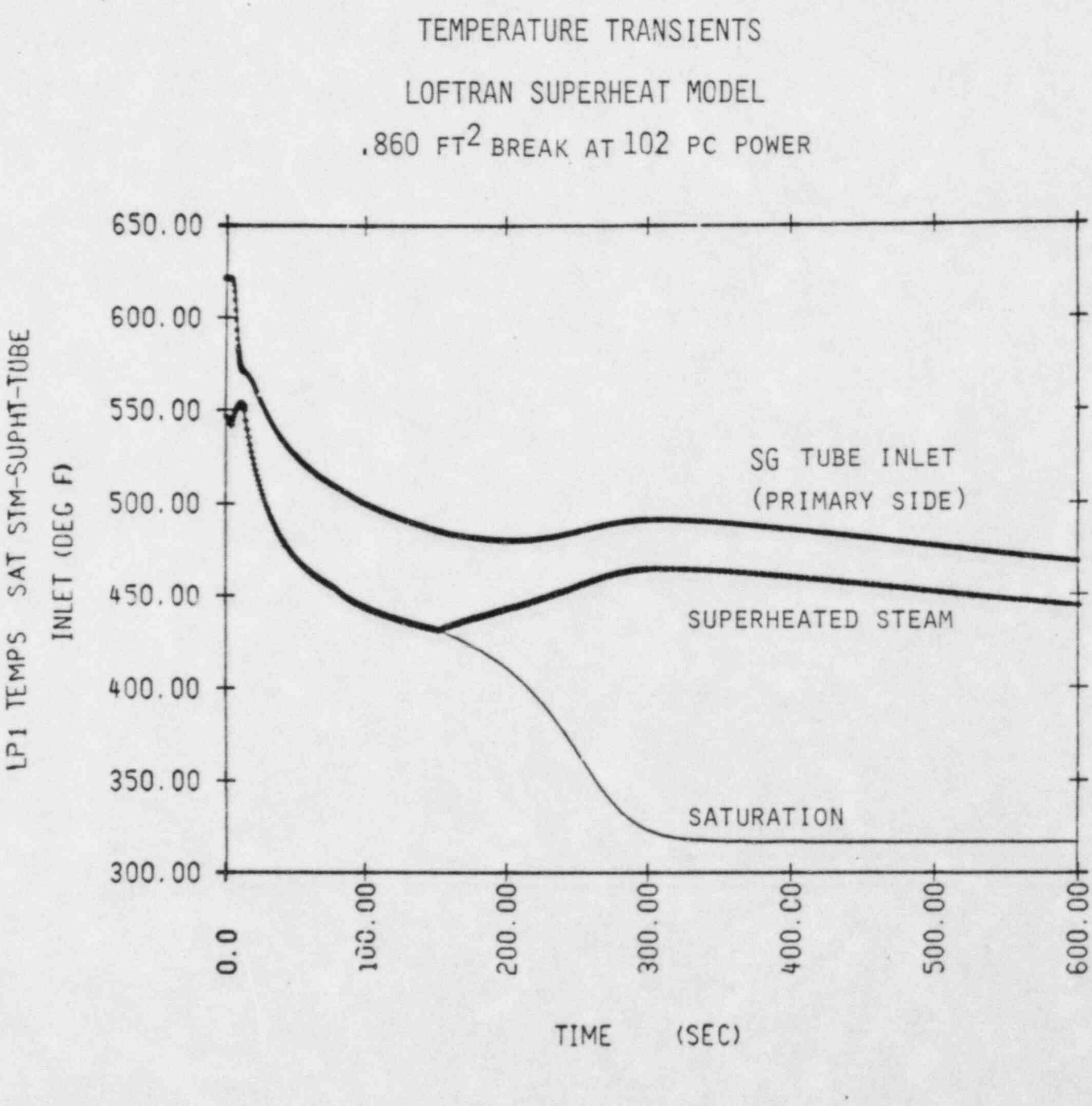
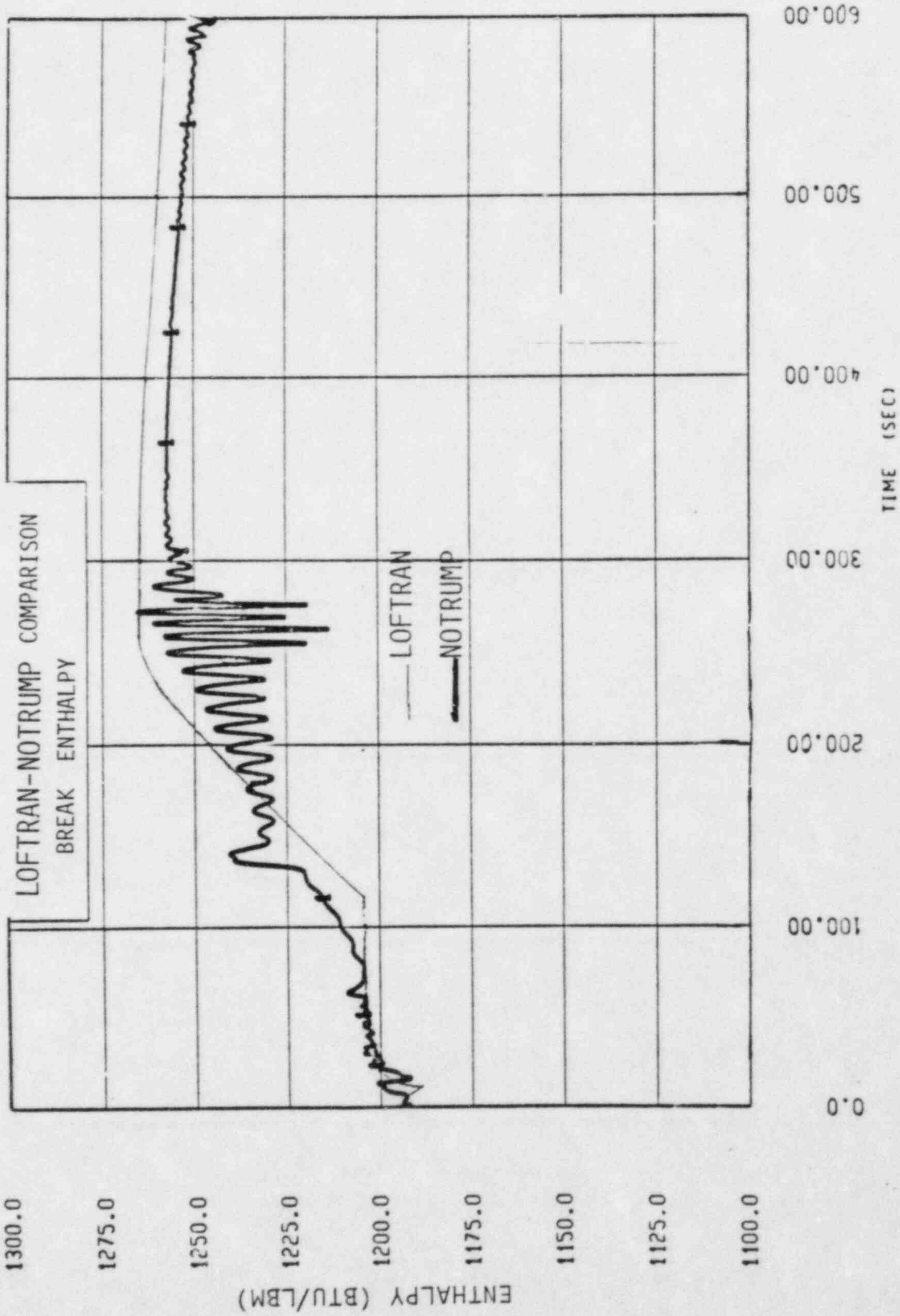


FIGURE 5



TEMPERATURE TRANSIENTS
LOFTRAN SUPERHEAT MODEL
.860 FT2 BREAK AT 102 PC POWER
LP1 TEMPS SAT STM-SUPHT-TUBE
INLET (DEG F)
650.00
600.00
550.00
500.00
450.00
400.00
350.00
300.00
SG TUBE INLET
(PRIMARY SIDE)
SUPERHEATED STEAM
SATURATION
0.0
100.00
200.00
300.00
400.00
500.00
600.00
TIME (SEC)

FIGURE 6



LOFTRAN-NOTRUMP COMPARISON
BREAK ENTHALPY
LOFTRAN
NOTRUMP
ENTHALPY (BTU/LBM)
1300.0
1275.0
1250.0
1225.0
1200.0
1175.0
1150.0
1125.0
1100.0
TIME (SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00

FIGURE 7

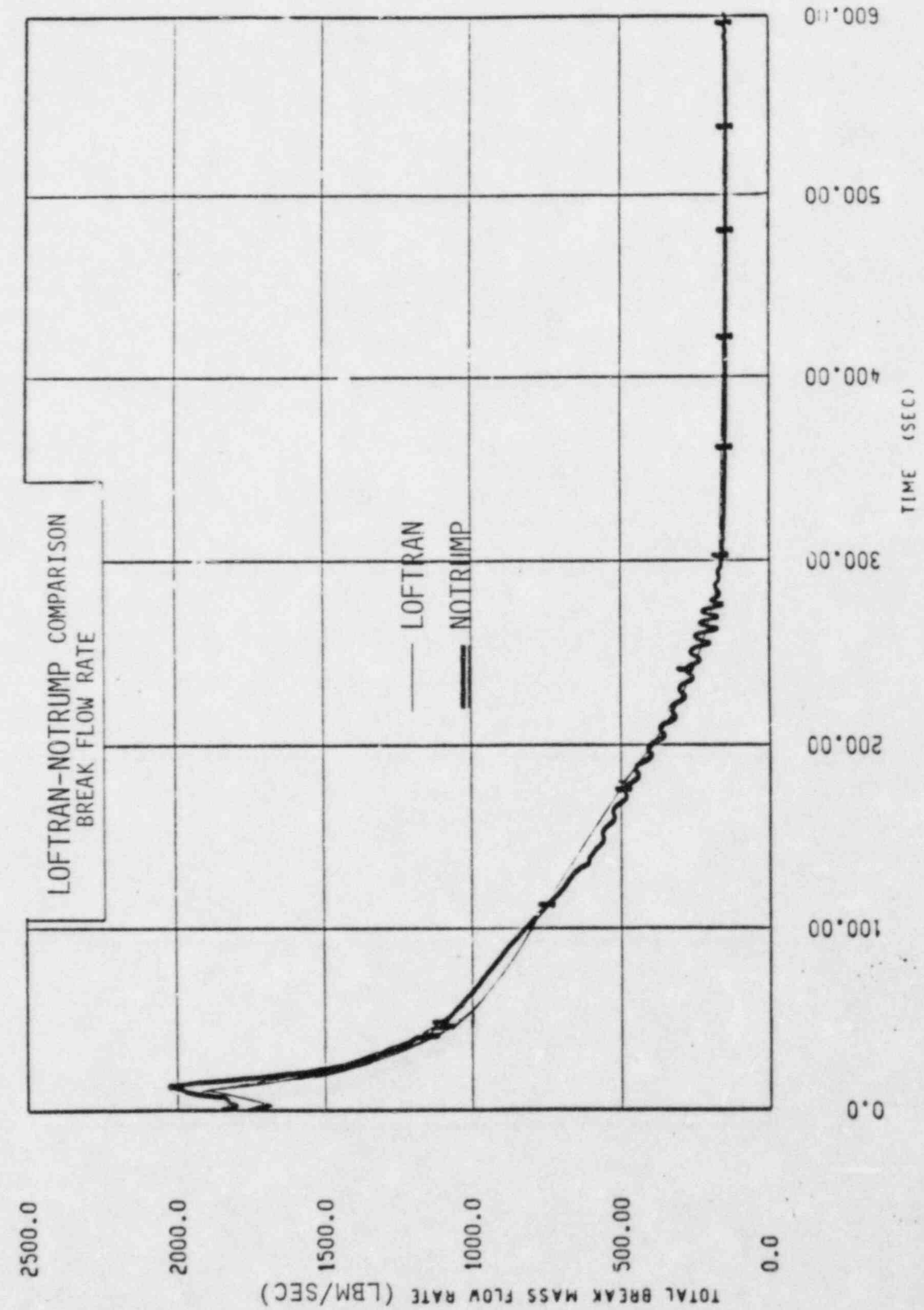

LOFTRAN-NOTRUMP COMPARISON
BREAK FLOW RATE
LOFTRAN
NOTRUMP
TIME (SEC)
TOTAL BREAK MASS FLOW RATE (LBM/SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00
0.0
500.00
1000.0
1500.0
2000.0
2500.0

FIGURE 8

EFFECTS OF ANALYSIS ASSUMPTIONS

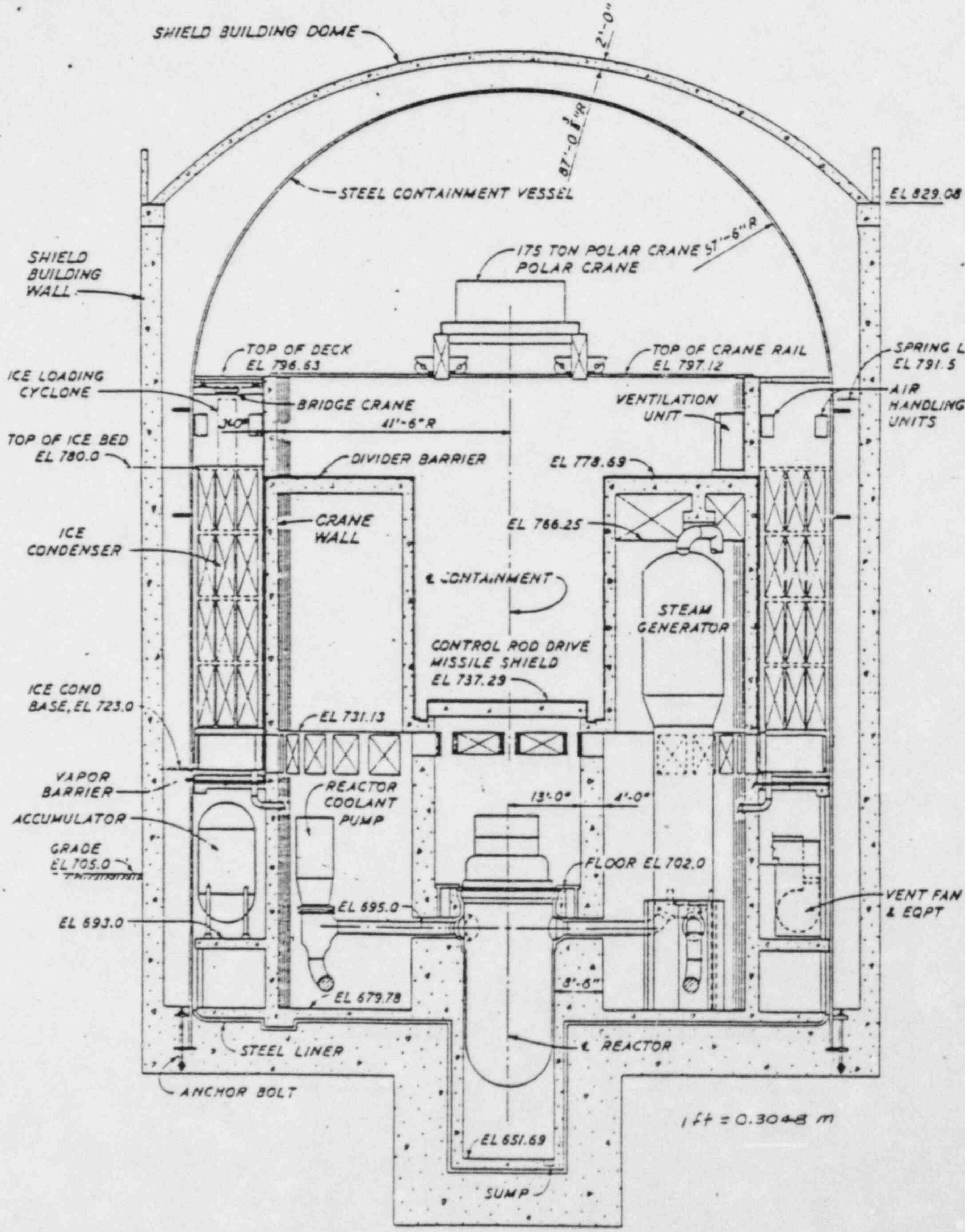
- INITIAL STEAM GENERATOR INVENTORY
- AUXILIARY FEEDWATER FLOWRATE
- FEEDWATER SYSTEM FAILURES
- PROTECTION SYSTEM ERRORS

FIGURE 9

ADDITIONAL MODEL CONSIDERATIONS

- LIQUID-STEAM INTERACTION
- IMPROVED STEAM HEADER MODEL
- HEAT TRANSFER THROUGH TUBE WRAPPER
- TEMPERATURE DROP IN PRIMARY SUPERHEAT NODES
- OPTIONAL VOID CORRELATIONS

FIGURE 10



Reactor Building Elevation

FIGURE 11

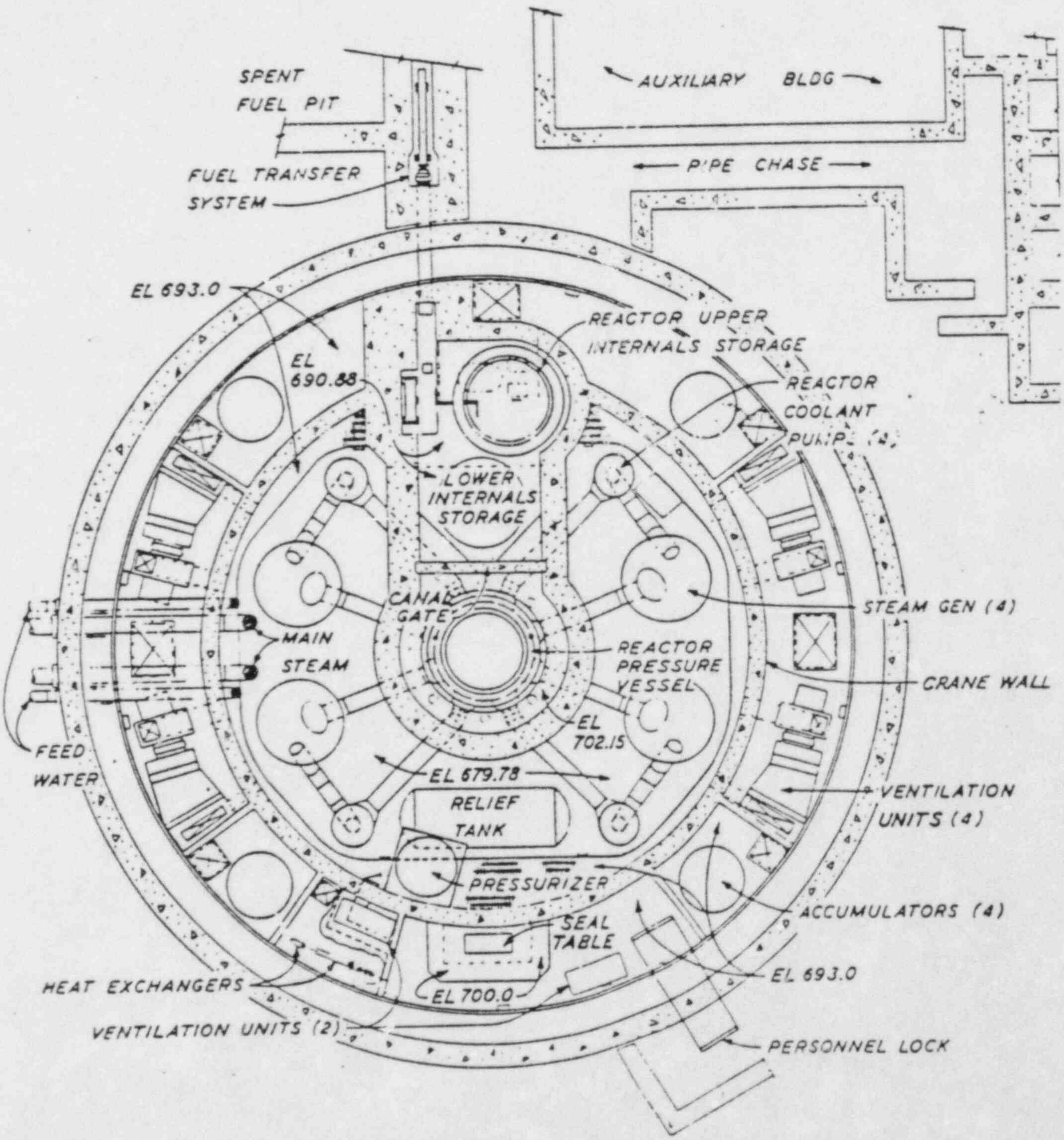


Figure 3.8.3-7 Plan-Lower Compartment

FIGURE 12

LOTIC-3 CONTAINMENT CODE

* 4 NODE CONTAINMENT MODEL
* CONDENSATE/REVAPORIZATION MODELS
  - LARGE BREAK (TOTAL REVAPORIZATION)
  - SMALL BREAK (CONVECTIVE HEAT FLUX)
* WALL HEAT TRANSFER MODEL
* MODELS SUMP RECIRCULATION SYSTEM

FIGURE 13

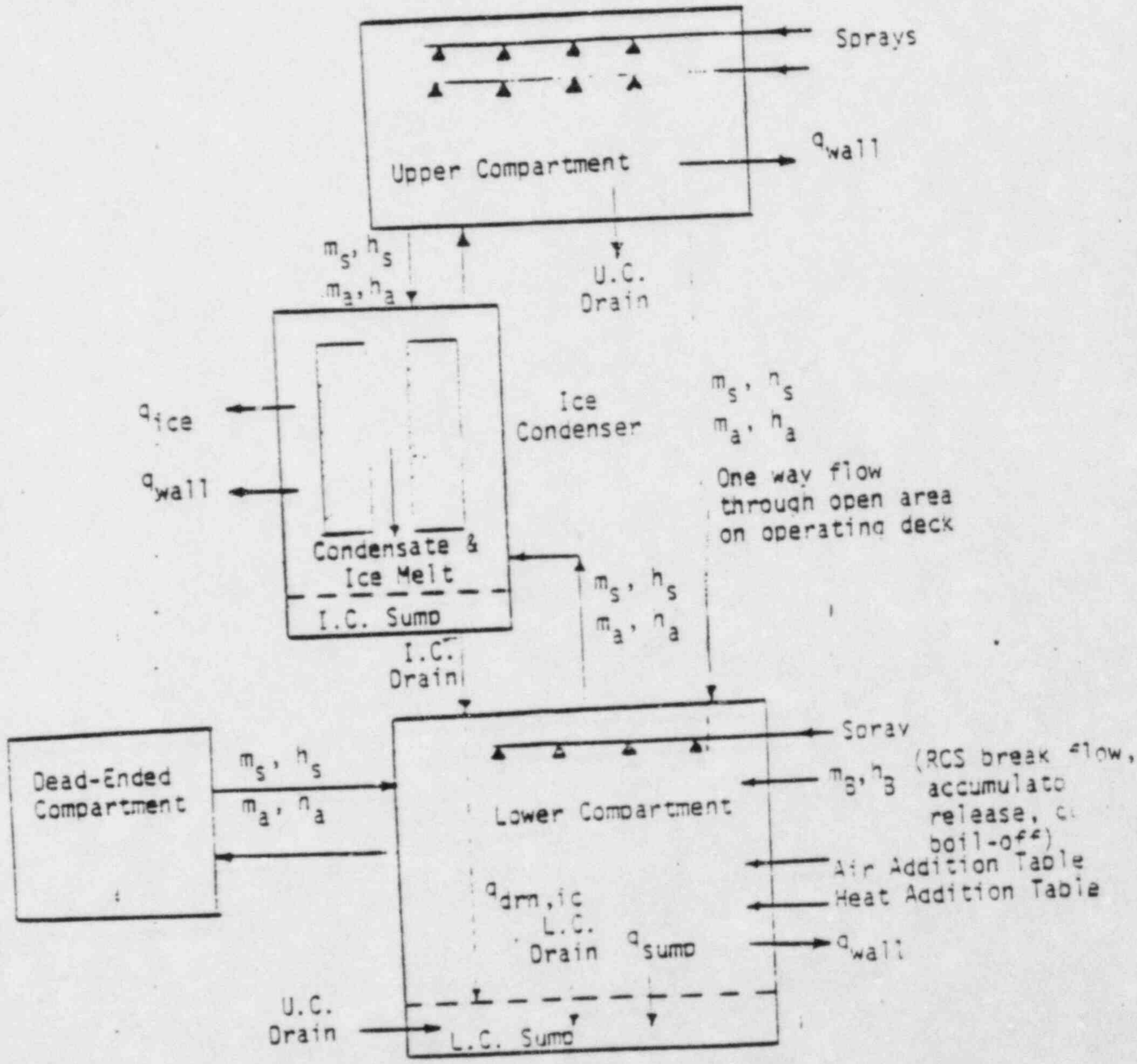


FIGURE 3.3 MASS AND ENERGY FLOW DIAGRAM FOR THE COMPARTMENTS

FIGURE 14

LOTIC-3 - METHOD OF SOLUTION

- SOLVES CONSERVATION OF MASS, ENERGY, AND MOMENTUM FOR UPPER, LOWER, AND ICE CONDENSER REGIONS
- ONCE NEW LOWER COMPARTMENT CONDITIONS ARE DETERMINED, CONSERVATION EQUATIONS ARE SOLVED FOR THE DEAD-ENDED COMPARTMENT AND FOR THE FLOW RATE BETWEEN THE TWO COMPARTMENTS

FIGURE 15

TYPICAL CONTAINMENT TEMPERATURE

TRANSIENT (DRAINS MODELLED)

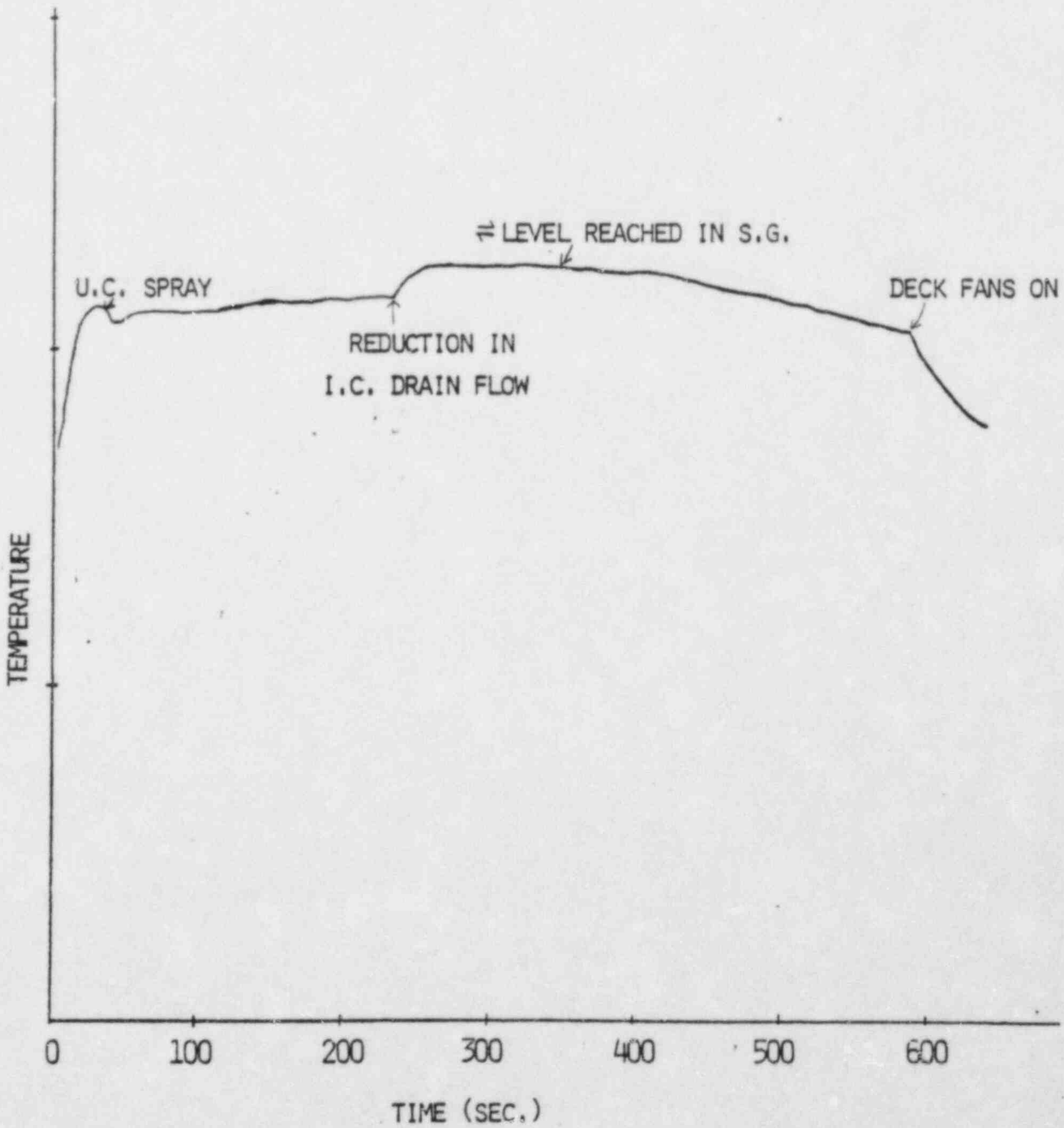


FIGURE 16

MODIFICATIONS TO THE CONTAINMENT MODEL

WALL HEAT TRANSFER MODEL

CONVECTIVE HEAT FLUX MODEL

ICE CONDENSER DRAIN MODEL

DEAD ENDED COMPARTMENT MODEL

FIGURE 17

WALL HEAT TRANSFER MODEL

ORIGINAL LOTIC MODEL

$$q'' = h_{Tagami} (T_{SAT} - T_{Wall})$$

MODIFIED LOTIC MODEL

$$q'' = h_{COND} (T_{SAT} - T_{Wall}) + h_{conv} (T_{Bulk} - T_{ref})$$

$$h_{COND} = f\left(\frac{m_{STEAM}}{m_{air}}\right)$$

$$h_{conv} = f(T_{Wall}, T_{SAT})$$

$$T_{ref} = f(T_{Wall}, T_{SAT})$$

FIGURE 18

CONVECTIVE HEAT FLUX MODEL

ORIGINAL LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X}\right]$$

MODIFIED LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X_{SAT}}\right]\left[1 - \frac{h_{CONV}(T_{BULK} - T_{ref})}{q_{TOTAL}}\right]$$

FIGURE 19

ICE CONDENSER DRAINS

-APPROXIAMATELY 20 ICE CONDNESER DRAINS

-DRAIN ELEVATION IS ABOUT 40 FEET FROM FLOOR

-DRAIN PIPE IS 1 FOOT IN DIAMETER

-FOR TYPICAL MSLB TRANSIENT, DRAIN FLOW VARIES FROM 4000 LB/S TO 500 LB/S

FIGURE 20

ICE CONDENSER DRAIN MODEL

-CONDENSATION OCCURS AT THE SURFACE OF THE STREAM

-FLOW IS WELL MIXED

$$q = h A \Delta T$$

-MODEL AS A WALL AT A CONSTANT TEMPERATURE

-A IS THE SURFACE AREA OF THE STREAM

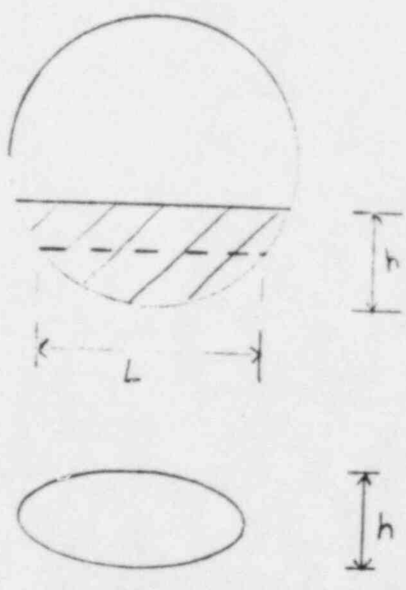
-h IS A CONDENSING TYPE HEAT TRANSFER COEFFICIENT

FIGURE 21

CALCULATION OF THE STREAM FLOW AREA

$$A = n(P \times L) = 20(P \times 40) = 800\,P$$

WHERE P IS THE PERIMETER OF THE STREAM



$$P \approx 2\pi\sqrt{\frac{\left(\frac{L}{2}\right)^2 + \left(\frac{h}{2}\right)^2}{2}}$$

FIGURE 22

MODIFIED LOTIC DRAIN MODEL

-WALL WITH A VARIABLE AREA

$$q = h_{COND} A (T_{BULK} - T_{SAT})$$

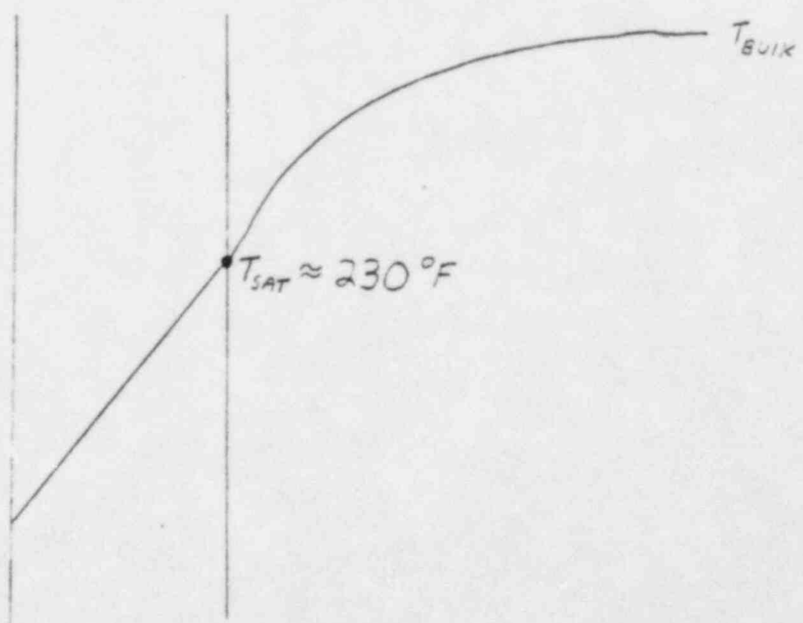


FIGURE 23

DEAD ENDED COMPARTMENT MODEL

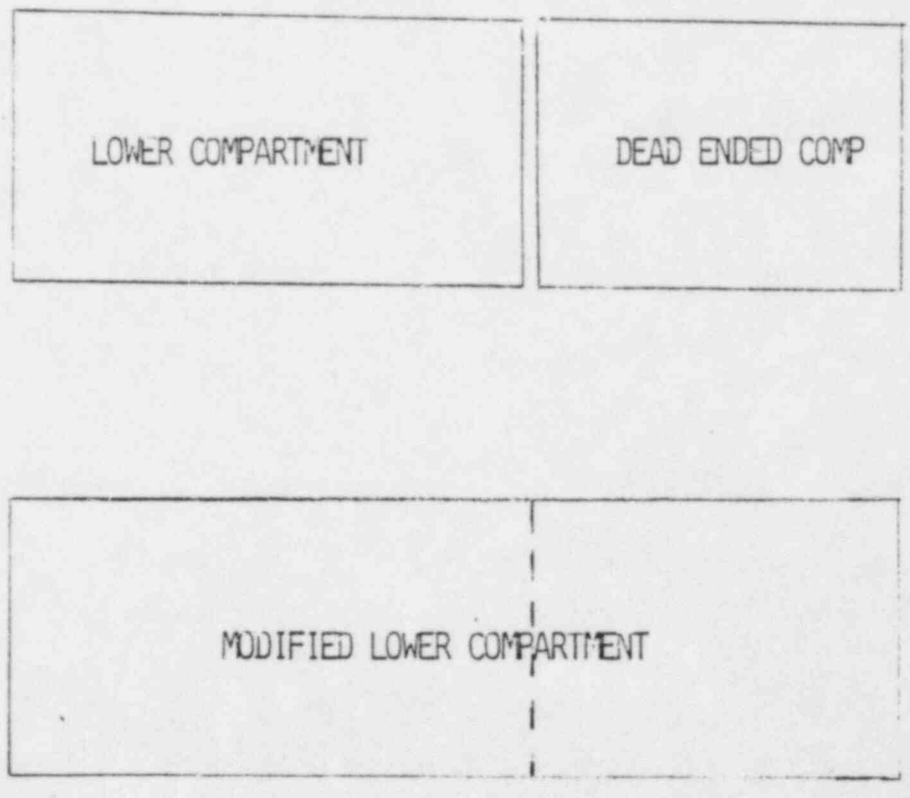


FIGURE 24

CATAWBA RESULTS

- 102% POWER
- 0.86 FT^2 BREAK
- MAXIMUM AFW FLOW
- FSAR HEAT SINKS
- MAXIMUM S.G. INITIAL MASS

$T_{MAX} = 324°F$ (LOWER COMPARTMENT)

FIGURE 25

ADDITIONAL MODEL CONSIDERATIONS

-WALL HEAT TRANSFER MODEL

-DRAIN MODEL

-DEAD ENDED COMPARTMENT MODEL

FIGURE 26

ATTACHMENT 2

OUTLINE OF THE REPORT

I. Introduction

II. Mass & Energy Release Modeling

III. Containment Modeling

IV. Action Plan

V. Appendix

VI. References

I. Introduction

During the Containment Systems Branch review of the Westinghouse topical report, "Mass and Energy Releases Following a Steam Line Rupture", WCAP-8822 (Proprietary) the Staff noted that heat transfer to steam from the uncovered portion of the steam generator tube bundle was unaccounted for and questioned the effect upon the calculated mass/energy release and the subsequent effect on the containment temperature response. Westinghouse responded in a letter to the Staff (NS-EPR-2563, February 14, 1982, E.P. Rahe to J. R. Miller) that it had determined the impact of the effect by conservatively treating the maximum amount of superheat to be the difference between the primary coolant temperature and the steam temperature. The letter noted that there would be an insignificant effect on dry type containments and that, based on the conservative model used, there would be an expected increase in containment temperature for ice condenser type containments. In the Containment Systems Branch Safety Evaluation Reports on the topical report and the Catawba Plant Safety Evaluation Report, the Staff required that a more refined steam line break analysis be performed to determine the effect on containment temperature which might impact the environmental qualification envelope used for safety related equipment.

Since that time, Westinghouse has investigated the effects of tube bundle heat transfer from the viewpoint of a more refined modeling approach. Subject to the final review and approval of the NRC Staff, the efforts and results obtained to date indicate that there is little impact on the containment response from the effects of the additional tube bundle heat transfer to steam.

II. Mass and Energy Release Modeling

A. LOFTRAN Computer Code

Mass/energy releases are calculated using the LOFTRAN code. LOFTRAN is a FORTRAN language, digital computer code, developed to simulate transient behavior in a multi-loop pressurized water reactor system. The program simulates neutron kinetics, thermal hydraulic conditions, pressurizer, steam generators, reactor coolant pumps, and control and protection systems. Up to four independent loops may be modeled. LOFTRAN is used for analysis of non-LOCA transients and is documented in Reference 3.

The model of importance to blowdown calculations is the steam generator model. The primary side contains multiple nodes to model the tube bundle. The standard LOFTRAN steam generator secondary side model, (Figure 1), is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur only to saturated water. If tube uncovery occurs the amount of surface area available for heat transfer is accordingly reduced. The LOFTRAN code incorporates a more detailed steam generator model which is used to predict tube bundle uncovery.

B. LOFTRAN Model for Superheated Steam

The LOFTRAN code has been modified to account for heat transfer to steam from the uncovered tube bundle region. (Figure 2). In the modified version of LOFTRAN, all heat transfer occuring in the uncovered region is assumed to add superheat to the steam exiting the steam generator. The primary side temperature in the uncovered tube region is conservatively assumed to remain constant through the nodes which are uncovered. In reality, there will be a drop in temperature due to heat removal to the secondary side, but this is expected to be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is discussed in the Appendix. This correlation bases the heat transfer on the difference between the tube wall surface temperature and the bulk steam temperature in the region. In the LOFTRAN modification, the conservative assumption is made that no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall surface temperature of the tube is assumed equal to the primary fluid temperature.

The modified version of LOFTRAN automatically determines the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the modified LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient

calculation. The superheat/tube uncovery modeling is applicable to all steam generators.

Figures 3 through 6 show typical results for a 0.86 ft^2 steamline break from 102 percent power using the modified version of LOFTRAN. Figure 3 shows the fraction of tube uncovery versus time with uncovery of Loop 1 (faulted) starting at 152 seconds into the transient. At approximately 300 seconds, the uncovery transient reaches an equilibrium point where the steam flow out of the steam generator matches the auxiliary feedwater flow into the steam generator. Additionally, the tube uncovery transient for Loop 2 (non faulted) is plotted but shows no tube uncovery for the entire transient. Figure 4 presents the steam flow transient for this case. Figure 5 includes plots of both the superheated steam enthalpy and the saturation enthalpy for the Loop 1 steam generator. Figure 6 includes the Loop 1 temperatures for the steam generator tube inlet (primary side), steam exit temperature (superheated steam), and the saturation temperature for the steam pressure.

C. NOTRUMP Model Comparison

The NOTRUMP computer code (Reference 4) was used to verify the LOFTRAN modeling of superheat. The computer code was originally developed to analyze transients of secondary systems with two-phase conditions. In the past, it has been used to analyze various transients in the primary and secondary coolant systems. NOTRUMP has recently undergone major revisions to enable it to model non-equilibrium nodes (i.e., separate liquid temperature and steam temperature modeling). Using NOTRUMP, the steam generator can be broken down into sufficient nodes to model the nonequilibrium effects of the steam generator, as well as the tube region during uncovery. NOTRUMP can model all modes of heat transfer associated with a steamline break transient, including heat transfer from the uncovered tubes to the superheated steam and the feedback effects between the primary and secondary sides. The two phase mixture level calculation accounts for primary to secondary heat transfer and the swell associated with rapid depressurization of the steam generator during the blowdown.

A comparison of LOFTRAN and NOTRUMP blowdown results is presented in Figures 7 and 8. The mass releases shown in Figure 8 show excellent agreement. The LOFTRAN prediction of superheat enthalpy is slightly higher than NOTRUMP, while the predicted time of tube uncovery is somewhat later. NOTRUMP shows a chugging effect during the uncovery phase of the blowdown. This is believed to be in part due to oscillations in the flow link between the downcomer region and the steam dome region. (The flow link is the drain path for the moisture separators to the downcomer region.) With the flow direction towards the downcomer, superheated steam goes into the downcomer region and is condensed. This alternates with a flashing of a portion of the water volume in the downcomer region. This raises the pressure of the downcomer, resulting in a flow reversal in the link with saturated steam from the downcomer mixing with the superheated steam in the dome. This mixing results in the variations in the superheat enthalpy seen in Figure 7. Although LOFTRAN does not show the enthalpy variation since the detailed modeling of the downcomer and dome are not included, the overall agreement with NOTRUMP is very good.

D. Effects Of Analysis Assumptions

The effects of superheated steam are dependent upon the occurrence and extent of tube uncovery. The major parameters affecting tube uncovery are: initial steam generator inventory, auxiliary feedwater flowrate, assumed feedwater system failures, and protection system errors. Variations in these parameters are in the process of being evaluated for their effects on the containment temperature response (Figure 9).

Refinements in the mass and energy release modeling (Figure 10), are being evaluated and several areas show a potential for reducing the degree of superheat being generated. Some of these areas are:

- Evaluation of liquid-steam interactions such as the phenomenon of tube support plate flooding and heat transfer across the tube wrapper from the superheated steam to the auxiliary feedwater flowing down outside the tube wrapper.

- A more detailed steam header model in LOFTRAN.

- Modeling temperature drops in the primary superheat nodes.

- Evaluating other void correlations for use in predicting tube uncovery.

III. Containment Modeling

A. Description of Containment

The general phenomena taking place inside an ice condenser containment during a steamline break transient can be described utilizing a typical ice condenser elevation drawing (Figure 11). Steam is discharged to the main (or lower) compartment where heat is removed by the internal structures, steam flow to the ice condenser, and the ice condenser drain water. The dead ended compartments are the regions which are located below the ice condenser and outside the crane wall (Figure 12). Air is discharged from the main compartment to the dead ended compartment and ice condenser so that the resulting steam to air ratio is that region is much higher than in dry containments. At ten minutes following the containment hi-2 signal, deck fans are actuated which direct air flow from the upper compartment to the dead-ended compartments. Most of the safety related equipment is located in the dead-ended compartments although some equipment and cabling are located in the main compartment.

B. Containment Models

Figure 13 outlines the major models and assumptions utilized in the LOTIC-3 containment code. In the currently approved version of LOTIC-3 documented in Reference 5, four distinct regions of the containment are modeled; the lower compartment, the dead-ended compartment, the ice condenser, and the upper compartment. Two condensate/revaporization models are used depending on the size of the break. For large steamline breaks, 100% condensate revaporization is assumed. For small steamline breaks, a convective heat flux model is used which calculates partial revaporization during the transient. The wall heat transfer model utilizes the Tagami heat transfer correlation for condensation heat transfer and the convective heat flux model derived from the work of Sparrow (Reference 6) which calculates the convective heat transfer for small steamline breaks. The sump recirculation system is only modeled for the large break LOCA transient containment response.

Figure 14 shows the four regions modeled with the mass and energy flows that can be assumed in the analysis. The Catawba nuclear plant does not have lower compartment sprays and they are not modeled in the analysis. Superheat heat transfer is conservatively assumed to be zero for the steamline break containment analysis. In the model described in Reference 5, wall heat transfer is not modeled in the dead-ended compartments although these regions do contain structures which will remove heat. The analysis does include the upper compartment sprays, flow through the ice condenser, deck fan flow, and flow to the dead-ended compartments.

LOTIC-3 solves the conservation of mass, energy, and momentum equations for upper, lower, and ice condensor regions (Figure 15). After the new lower compartment conditions are determined, conservation equations are solved for the dead ended compartment and the flow rate between the compartments is determined.

Figure 16 presents a typical steamline break containment temperature transient that is calculated using superheated steam blowdowns from the LOFTRAN code and the modeling of ice condenser drains as a heat removal source. The transient shows that initially the containment temperature increases rapidly during the

blowdown. When the upper compartment sprays actuate there is a slight decrease in the main compartment temperature. The temperature then rises slowly until ice condenser drain flow decreases to the point at which time the temperature begins to rise again (approximately 250 seconds). This rise in containment temperature coincides with the steam generator tubes uncovering at 152 seconds and the maximum superheat occurring at approximately 250 seconds. The steam generator level stablizes when the auxiliary feedwater flow is equal to the steam discharge at approximately 300 seconds. The containment temperature then starts decreasing with decreasing decay heat. At ten minutes, the deck fans actuate which results in a rapid decrease in containment temperature.

C. LOTIC-3 Code Modifications

Four modifications have been incorporated in the LOTIC-3 containment model which are (Figure 17);

1) wall heat transfer model
2) convective heat flux model
3) ice condenser drain model
4) dead-ended compartment model

D. Wall Heat Transfer

The modification to the wall heat transfer model is described in Figure 18. In the LOTIC-3 model, only condensation heat transfer, utilizing a Tagami heat transfer coefficient and a temperature difference between the wall and saturation, was previously modeled. The modification includes a convection term with a conservative convection heat transfer coefficient and a temperature difference between the containment atmosphere and an appropriate interface temperature. The Appendix presents a more detailed description of this model.

E. Convective Heat Flux

The modification to the convective heat flux model is described in Figure 19. A term has been added to the convective heat flux model to account for the feedback effect from including a convective term in the wall heat transfer model. The Appendix presents a more detailed description of this model.

F. Ice Condenser Drain Model

In an ice condenser containment there is approximately twenty drains exiting from the ice condenser into the lower compartment at an elevation of about forty feet above the compartment floor. The drain pipes are one foot in diameter. The drain flowrate is calculated by the LOTIC-3 containment code. For a typical small steamline break transient the drain flowrate varies from approximately 4000 lbm/sec to 500 lbm/sec during the timeframe of interest. The temperature of the drain water is approximately 130°F (Figure 20).

Figure 21 presents the assumptions and the basic model used to estimate the heat removal from the lower compartment atmosphere to the ice condenser drain water. It is conservatively assumed that the drain water stream does not break up prior to reaching the floor even though many of the drains have equipment and structures located below them. Therefore, heat transfer is assumed to occur at

the stream surface only. It is also assumed that the stream surface temperature is at the saturation temperature of the containment.

The heat transfer to the stream is:

$$q=hA\Delta T$$

where

h = condensation heat transfer coefficient
A = surface area of the stream
ΔT = appropriate temperature difference

The calculation of the heat transfer surface area is described in Figure 22. In order to model the drains in LOTIC-3, the drains are modeled as a wall heat sink with a surface at a constant temperature (see Figure 23). Currently, in the version of LOTIC-3, the surface temperature is assumed to be 230°F which is close to the containment saturation temperature. The drain surface area is calculated at two points in time during the transient; early in time with a high flowrate and later in time with a low flowrate. To ensure conservatism in the area calculation a 10% reduction of the surface area was assumed.

As described previously (Figures 14 & 15), the LOTIC-3 containment model did not account for wall heat removal in the dead-ended compartments. To obtain a conservative estimate of the temperature transient in the dead ended compartment, the heat sinks located in the dead ended compartment region along with the heat sinks in the lower compartment are modeled in a combined volume (see Figure 24). This "modified" lower compartment model is used to determine a conservative dead-ended compartment temperature transient. Since the lower compartment will be hotter than the dead-ended compartment, this methodology results in a higher temperature in the dead-ended compartment than would be expected.

G. Transient Results

With the modifications described for LOFTRAN and LOTIC-3, the previous FSAR limiting case for Catawba was reanalyzed to determine the impact of superheated steam. The case selected is a 0.86 square foot break at 102% power (Figure 25). The peak lower containment temperature for this case is 324°F. This temperature is calculated for the lower compartment only. It is expected that the dead-ended compartment temperature will be significantly lower.

In addition to the model modifications incorporated in LOTIC-3, Westinghouse is pursuing further improvements in the areas noted on Figure 26. One area is in the wall heat and mass transfer models. Since condensation is a mass transfer type phenomena, the heat and mass transfer should be linked. This approach has been used in Reference 7.

An improved drain model is also being investigated. This improved model will calculate the drain surface area as a function of flowrate. It will also calculate the average temperature rise of the drainwater. This model will more accurately represent the actual phenomena in the containment.

V. Appendix

WESTINGHOUSE STEAMLINE BREAK BLOWDOWN AND CONTAINMENT ANALYSIS METHODOLOGY

The following sections describe the Westinghouse methodology for determining the containment response for a steamline break incorporating the effects of superheated steam. These sections describe in detail changes from the methodologies described in References 1 and 5.

I. Steamline Rupture Mass/Energy Blowdown Analysis

A. LOFTRAN and MARVEL Computer Modeling

Mass/energy releases can be calculated using either the LOFTRAN code (Reference 3) or the MARVEL code (Reference 8). The LOFTRAN code is used for non-LOCA FSAR accident analyses. The MARVEL code was specifically developed for assymmetric transients such as steamline breaks. These two codes are very similar because they were developed in an interrelating fashion and much of the modeling is common to both codes. The MARVEL code was used in the development of Reference 1 because LOFTRAN at that time was a lumped model which was used for symmetric loop transients. Furthermore, for steamline break analysis purposes, MARVEL contains a model for water entrainment. However, the current version of LOFTRAN is a multiloop version which also contains a water entrainment model. With the development of a multiloop version of LOFTRAN and the inclusion of an entrainment model, the use of MARVEL has been generally discontinued. This enables the use of LOFTRAN as a single system analysis code for non-LOCA transient analyses. LOFTRAN is used in the analyses presented here.

The model of importance to blowdown calculations is the steam generator model. The primary side of the steam generator contains multiple nodes to model the tube bundle for both the modified version of LOFTRAN and MARVEL. Heat transfer calculations from the primary to secondary side are identical in the two codes, although the methods for initializing the heat transfer resistances are slightly different. The secondary side is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur to saturated water. If tube uncovery is predicted, the amount of surface area available for heat transfer is reduced.

Both codes contain a detailed steam generator model which is used to predict tube uncovery. This model calculates the liquid volume in the steam generator shell and accounts for the detailed steam generator geometry. The [ ][a,c] correlation is used in both codes to predict the voiding in the tube region, although the correlation is modified for use in LOFTRAN. In MARVEL, tube uncovery is calculated based

on comparison with the actual water level and the height of the tube bundle. In LOFTRAN, the user specifies either a water volume in the steam generator corresponding to tube uncovery, or a void fraction in the riser section of the steam generator at which tube uncovery begins.

Both codes have similar models accounting for reverse heat transfer, thick metal heat transfer, feedline flashing, and safety injection system operation. Auxiliary feedwater flow can be input as a fraction of nominal feedwater flow, although LOFTRAN has an additional capability to model auxiliary feedwater flow as a separate system. For analysis of double ended ruptures, MARVEL accounts for the volume of steam in the piping downstream of the steam generators in the blowdown calculations. In LOFTRAN, this consideration is added on to the blowdown mass and energy results by hand. For split ruptures, which the analysis presented here addresses, the steam piping masses are handled identically in both codes.

In summary, LOFTRAN and MARVEL are very similar codes, and either can be used to calculate mass/energy blowdowns. To demonstrate this, a comparison of the blowdowns for a typical case is presented in Figures A.1 and A.2. Figure 1 presents the mass release rate for a .86 ft2 split rupture from 102% power. For this case, Figure A.2 shows the saturated steam enthalpy as a function of time. This blowdown is typical of results used in FSAR analyses prior to the modification noted in this report for the LOFTRAN code. As can be seen from the figures, the results are extremely close.

B. LOFTRAN Model for Superheated Steam

As mentioned previously, the LOFTRAN code has been modified to model heat transfer which may occur in the uncovered tube bundle region. This effect is modeled in both the faulted and intact loops. In the modified version of LOFTRAN, all heat transfer occurring in the uncovered region is assumed to add superheat the steam exiting the steam generator. The temperature of the primary coolant flowing through in the uncovered tube region mode is conservatively assumed to remain constant. Realistically there would be a drop in temperature due to heat removal to the secondary side, but this will be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is based on the [(1)]^{a,c}. The heat transfer coefficient (U) is calculated by the following expression:

[ ]^{a,c}

This correlation is presently used for superheated forced convection heat transfer by the [ ]^{a,c} computer codes. Additionally,

this correlation is based upon the heat transfer from the surface of the tube wall to the average bulk temperature of the steam. In the LOFTRAN modification, no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall temperature of the tube is conservatively assumed equal to the primary fluid temperature.

(1) [ ]a,c

The modified version of LOFTRAN automatically selects the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the modified LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. Each node is evaluated to determine the steam temperature exiting the node with a convergence criteria that is based upon the total number of nodes used. The exit steam temperature of one node is used as the inlet steam temperature of the next node.

The heat transfer calculation to determine the outlet temperature of the node is based upon the following expression:

$$Q = UA*(T_{pri}-(T_{out}+T_{in})/2) = M_s*C_s*(T_{out}-T_{in})$$

where Q = Heat transfer to the steam

U = [ ] a,c

T_{pri} = Primary node temperature

T_{out} = Steam node outlet temperature

T_{in} = Steam node inlet temperature

M_s = Mass flowrate of the steam

C_s = Heat capacity of the steam

A = Heat transfer area in the node including both hot and cold leg sides of the tube bundle

The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient.

C. Blowdown Sensitivity to Plant Conditions

The effects of superheated steam are dependent upon the occurrance and extent of tube bundle uncovery. Parameters affecting tube uncovery are: initial steam generator inventory, break size, auxiliary feedwater flowrate, and the single failure assumed.

The initial steam generator inventory depends upon the measurement errors associated with steam generator level and upon initial power level. Steam generator mass increases with decreasing power, thus, breaks intitiating from low power levels will result in later tube uncovery.

Larger break sizes result in faster blowdown of the steam generator and earlier tube uncovery.

Large auxiliary feedwater flowrates only delay tube uncovery, but will also cause the final equilibrium steam generator level to be higher. This equilibrium condition corresponds to the point when the break flow rate is equal to the auxiliary feedwater flow rate.

The single failure assumed in the transient may impact the amount of water supplied to the steam generator. Auxiliary feedwater runout will increase the amount of water supplied to the steam generator. Failure of the feedwater isolation valve will also cause extra water to be supplied to the generator as the additional mass between the isolation valve and the check valve flashes to the generator.

II. Containment Analysis

A. Wall Heat Transfer Model

The original LOTIC-3 wall heat transfer model is based on the stagnant Tagami heat transfer correlation. That is,

$$q''=h_{TAGAMI}(T_{SAT}-T_{WALL})$$

$$h_{TAGAMI} = 2 + 50\ M_{STEAM}/M_{AIR} \quad h_{(TAGAMI,MAX)}=72\ BTU/hr\text{-}ft^2\text{-}^oF$$

This model was developed for saturated steam in the presence of large amounts of non-condensable gases. In the lower compartment of an ice condenser, most of the air is swept out of the lower compartment through the ice condenser and into the upper compartment. Therefore, after about 30 seconds, there is almost no non-condensables in the lower compartment. Typical values for the condensation of pure steam are in the range of 1000 to 3000 Btu/hr-ft2-^{o}F (Ref. 5). The correlation used in the modified LOTIC-3 code is in extension of the Tagami correlation for nearly pure steam.

$$q''=h_{COND}\ (T_{SAT}-T_{WALL})$$

$$h_{cond} = 2+50\ M_{STEAM}/M_{AIR} \quad h_{(cond,max)} = [\qquad\qquad]^{a,c}$$

A maximum value of [ ]^{a,c} was chosen as a conservatively low condensing heat transfer coefficient in a nearly pure steam environment.

In addition to this modification, an additional term is needed to account for the convective heat transfer from the superheated steam to the condensate film. This convective heat transfer is dependent upon whether there is condensation occurring on the walls. If condensation is occurring, the correlation used is:

$$q''_{conv}=h_{conv}(T_{bulk}-T_{sat})$$

where: [ ]^{a,c}

If the wall temperature increases to above the saturation temperature then the convective currents will be reduced such that the correlation used is

$$q''_{conv}=h_{conv}(T_{bulk}-T_{wall})$$

where:

[ ]^{a,c}

Thus in summary, if $T_{wall} < T_{sat}$ then

[ ]a,c

If $T_{wall} > T_{sat}$, then the correlation used is:

[ ]a,c

B. Convective Heat Flux Model

When the containment atmosphere is superheated, the containment temperature is a strong function of the amount of steam mass in the atmosphere. Thus the amount of mass condensed on the heat sink surfaces is a key parameter. The actual amount of condensate formed is

$$M_{cond} = q_{cond}/h_{fg}$$

Unfortunately, with the use of a heat transfer correlation based only on test data (such as Tagami or Uchida), only the total heat transfer coefficient is obtained. This total heat transfer coefficient includes both the condensation heat transfer and the convective heat transfer. Based on the work of Sparrow (Reference 6), the Westinghouse Convective Heat Flux model in the original LOTIC-3 code calculates the ratio of the convective heat transfer to the condensation heat transfer. Therefore the calculation of the amount of mass condensed is

[ ]^{a,c}

In the modified LOTIC-3 model, the amount of superheat convection is calculated. The amount of convective heat transfer at saturation is not known explicitly in this model. Therefore, in the modified LOTIC-3 code the original convective heat flux model will be used to calculate the fraction of convective heat transfer for saturated conditions. The actual correlation is

[ ]^{a,c}

where, $(q_{conv}/q_{cond})_{sat}$ is determined from original convective heat flux model and $q_{conv,sh}$ is the amount of convective heat transfer calculated in the wall heat transfer model

In summary, the modified LOTIC-3 model is consistent with the original LOTIC-3 model in its calculation of the mas condensed. The only difference is that in the modified LOTIC-3 code, the amount of superheat convective heat transfer is known explicitly, while in the original LOTIC-III model, only the ratio of convective heat transfer to condensation heat transfer is known.

IV. References:

1. Land, R. E., "Mass and Energy Releases Following A Steam Line Rupture" WCAP-8822 (Proprietary) September, 1976 and WCAP-8859 (Non-Proprietary).

2. NS-EPR-2563, February 14, 1982, E. P. Rahe of Westinghouse to J. R. Miller, NRC, "Additional Information on WCAP-8822".

3. Burnett, T. W. T., et al., "LOFTRAN Code Description," WCAP-7907, June, 1972 (Proprietary).

4. Meyer, P. E., and Kornfilt, J., "NOTRUMP - A Nodal Transfer Small Break and General Network Code," November, 1982, WCAP-10079 (Proprietary) and WCAP-10080 (Non-Proprietary).

5. Hsieh, T. and Liparulo, N. J., "Westinghouse Long Term Ice Condenser Containment Code - LOTIC-3 Code," February, 1979, WCAP-8354-P-A Sup. 2 (Proprietary),WCAP-8355-NP-A (Non-Proprietary).

6. Sparrow, E. M., Minkowycz, W. J., and Saddy, M., "Forced Convection Condensation in the Presence of Noncondensables and Interfacial Resistance", Int. J. Heat Mass Transfer, Volume 10, 1967.

7. Corradini, M. L., "Turbulent Condensation on a Cold Wall in the Presence of a Non-condensable Gas" Nuclear Technology Vol. 64, pp 186 - 195, February, 1984.

8. Krise, R. and Miranda, S., "MARVEL - A Digital Computer Code for Transient Analysis of a Multiloop PWR System," November, 1977, WCAP-8843 (Proprietary) and WCAP-8844 (Non-Proprietary).

9. McCabe, W. L., and Smith, J. C., "Unit Operatons of Chemical Engineering", 3rd Edition, 1976.

LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

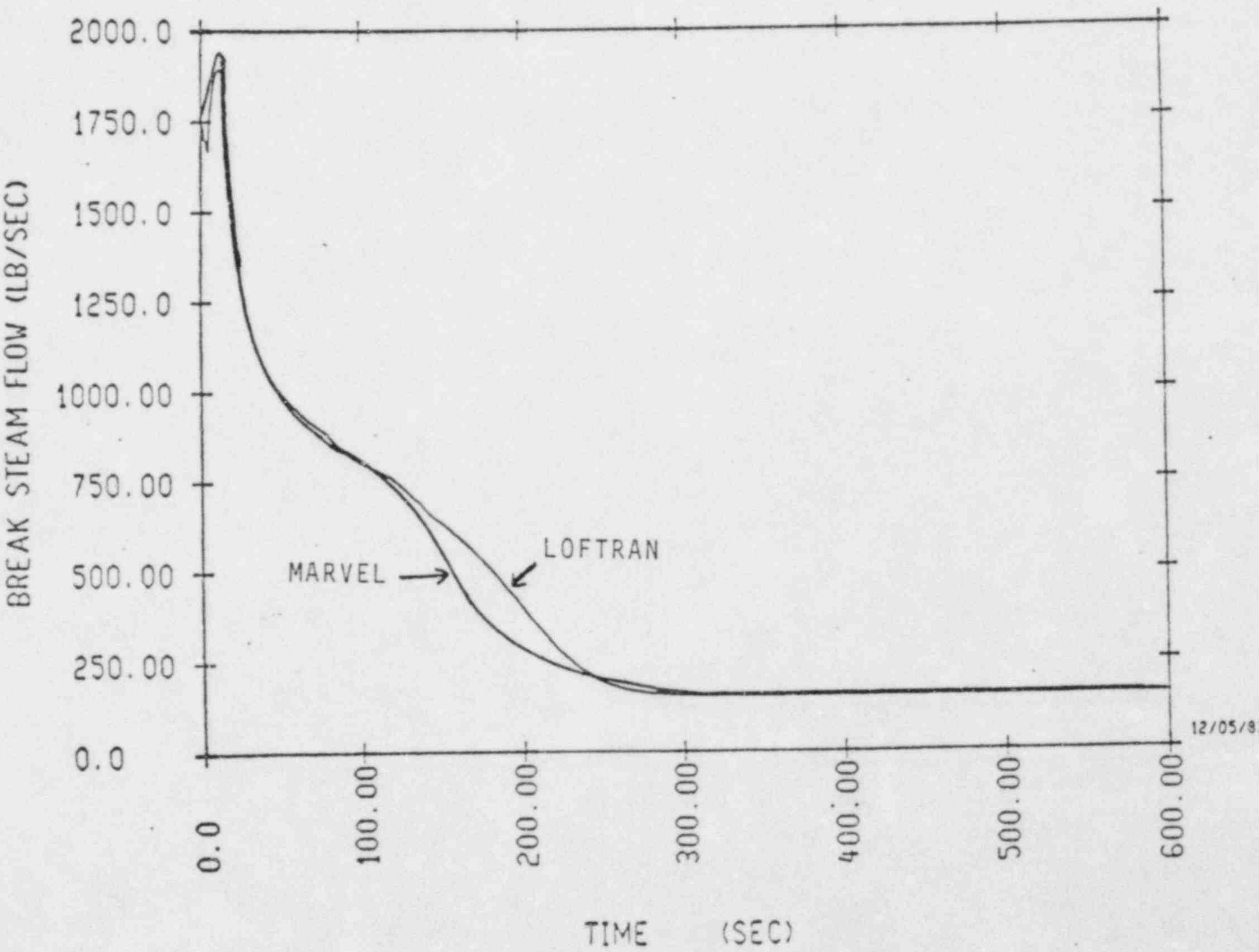


FIGURE A.1

LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

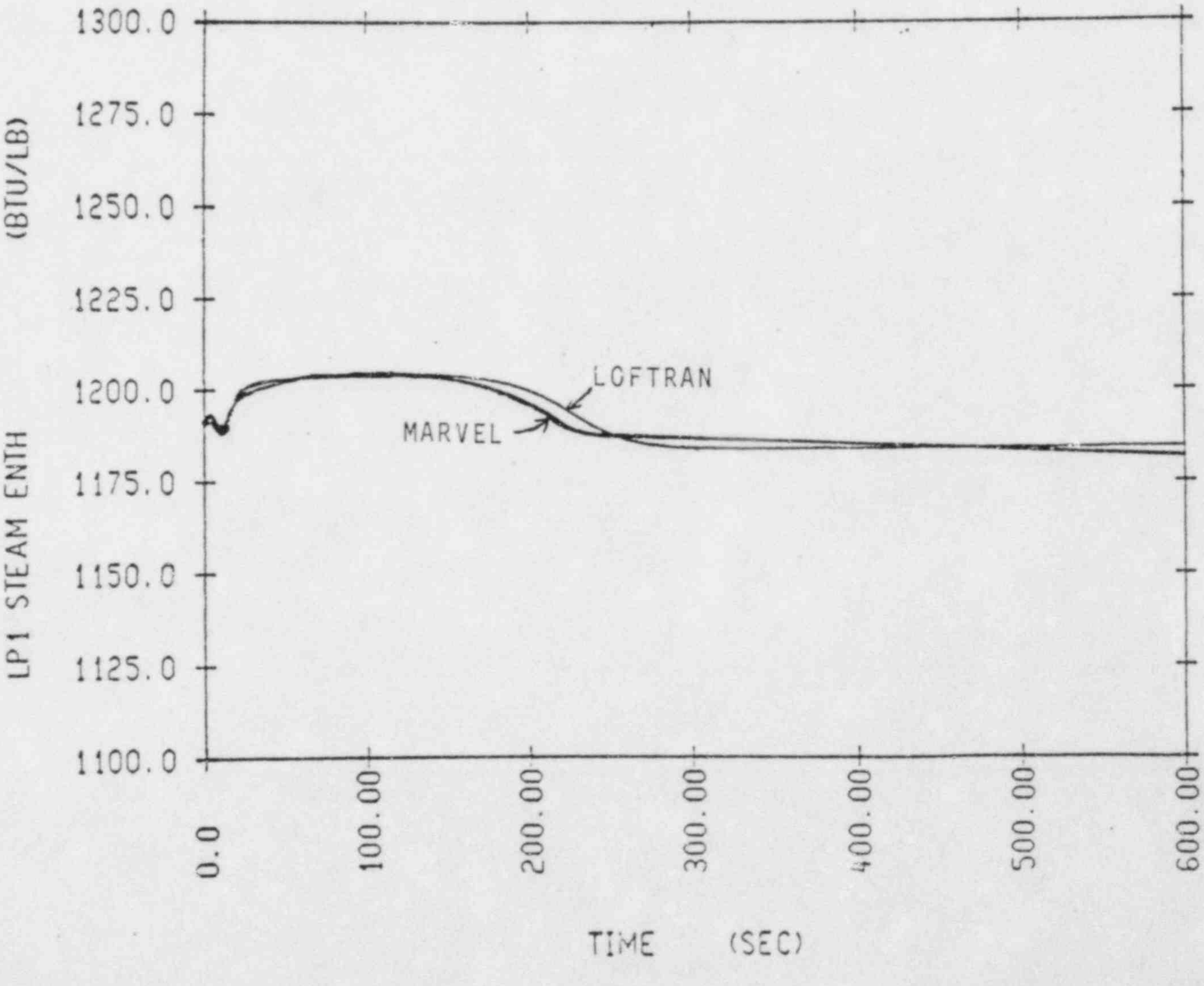


FIGURE A.2

METHODOLOGY FOR ADDRESSING SUPERHEATED STEAM RELEASES
TO
ICE CONDENSER CONTAINMENTS

Purpose

The purpose of this report is to document the information presented on March 19, 1984 in a meeting with the U.S. NRC Containment Systems Branch on the status of progress made in addressing the confirmatory item on the Catawba Nuclear Plant Safety Evaluation Report. This confirmatory item deals with the effects of superheated steam generator mass and energy releases following main steamline break accidents. Attachment 1 includes the list of attendees at the meeting and the overhead slides covered in the Westinghouse presentations.

Technical presentations were made describing the modeling of the steam generator and heat transfer from the uncovered tube bundle during the steam generator blowdown along with a description of the containment model and transient response. A proposed plan of action was also presented and discussed with the Staff. In accordance with that plan, this report represents the first milestone in the proposed plan of action. As committed to in the meeting, the appendices present proprietary information which relates to the specifics of the models and sensitivities that were not directly addressed in the meeting.

Attachment 2 is an explanation of, and refers to, the overhead slides (Figures) presented at the March 19 meeting.

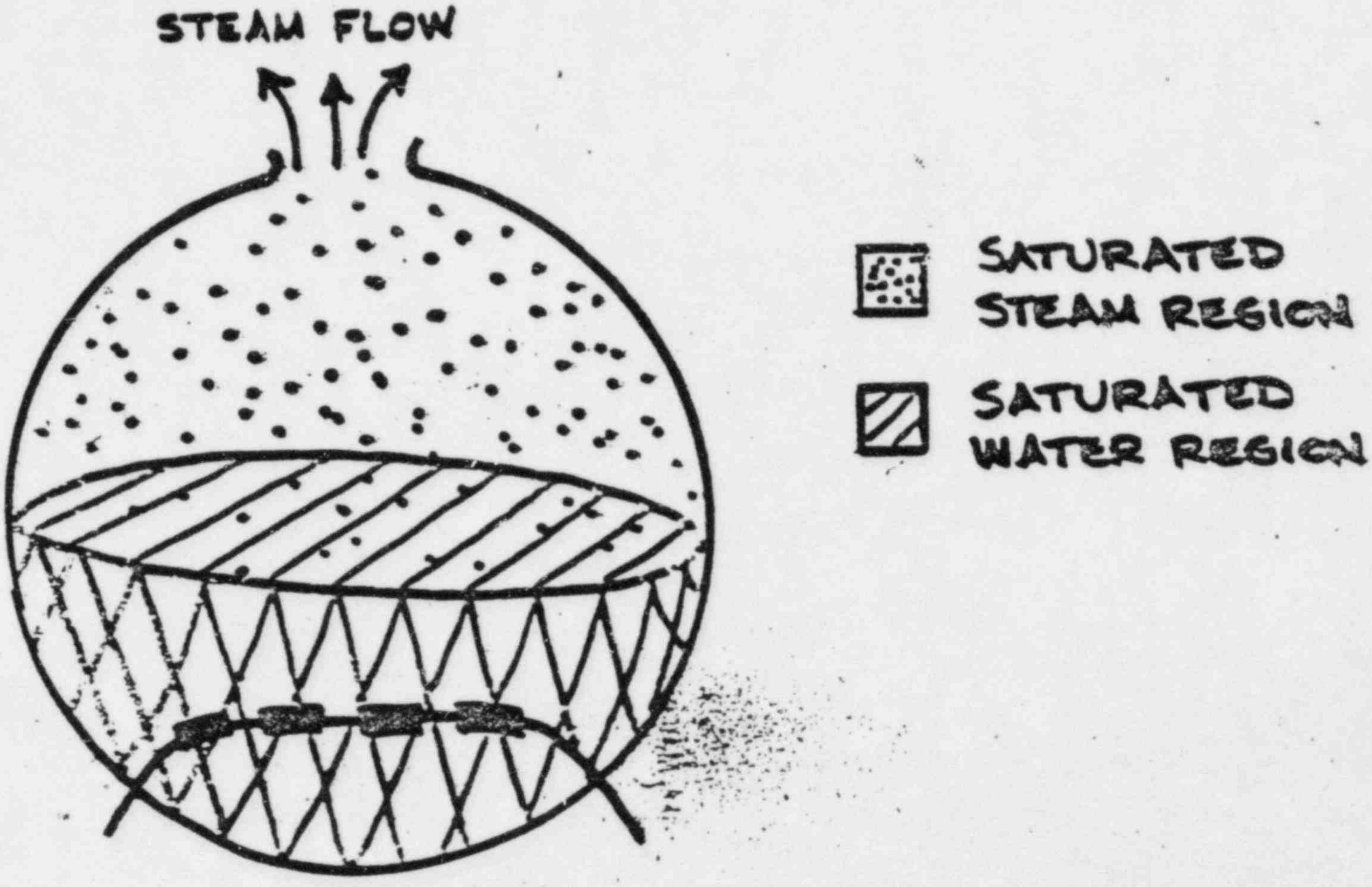
ATTACHMENT 1

Attendance at 3/19/84
Meeting w/ Duke + W on
Main Steam Line Break Analysis

Name	Organization
K. N. JABBOUR	NRC/DL
R. O. SHARPE	DUKE/NPD
J. L. LITTLE	W NUCLEAR SAFETY
H.V. JULIAN	W NUCLEAR SAFETY
TJ Kenyon	NRC/DL
DS. Love	W NUCLEAR SAFETY
MP Osborne	W Nuclear Safety
P.A. Linn	W Nuclear Safety
L.E. Hochreiter	W Nuclear Safety
F.F. CADEK	W Nuclear Safety
F J Twogood	W NOD, project mgr.
S D Alexander	Duke, Design Engineering
R E Miller	Duke, Design Engineering
J. E. Wills	TVA, Nuclear Licensing Staff
B. AMELI	SERCH LICENSING STAFF, BECH
C. DRAUGHON	W NUCLEAR SAFETY
W.D. Crouch	TVA, Engineering Design
S. P. Nesbit	Duke, Nuclear Production Dept. Staff
S.A. Swamy	W, NTD/SME
R.H. Owoc	W NTD/NUCLEAR SAFETY
J SHAPAKER	NRC/CSB
Jack Kudrick	" "
J. Pulsipher	NRC/CSB
C. Li	NRC/CSB
A. Notafrancesco	NRC/CSB

LOFTRAN MODEL

STEAM GENERATOR SECONDARY

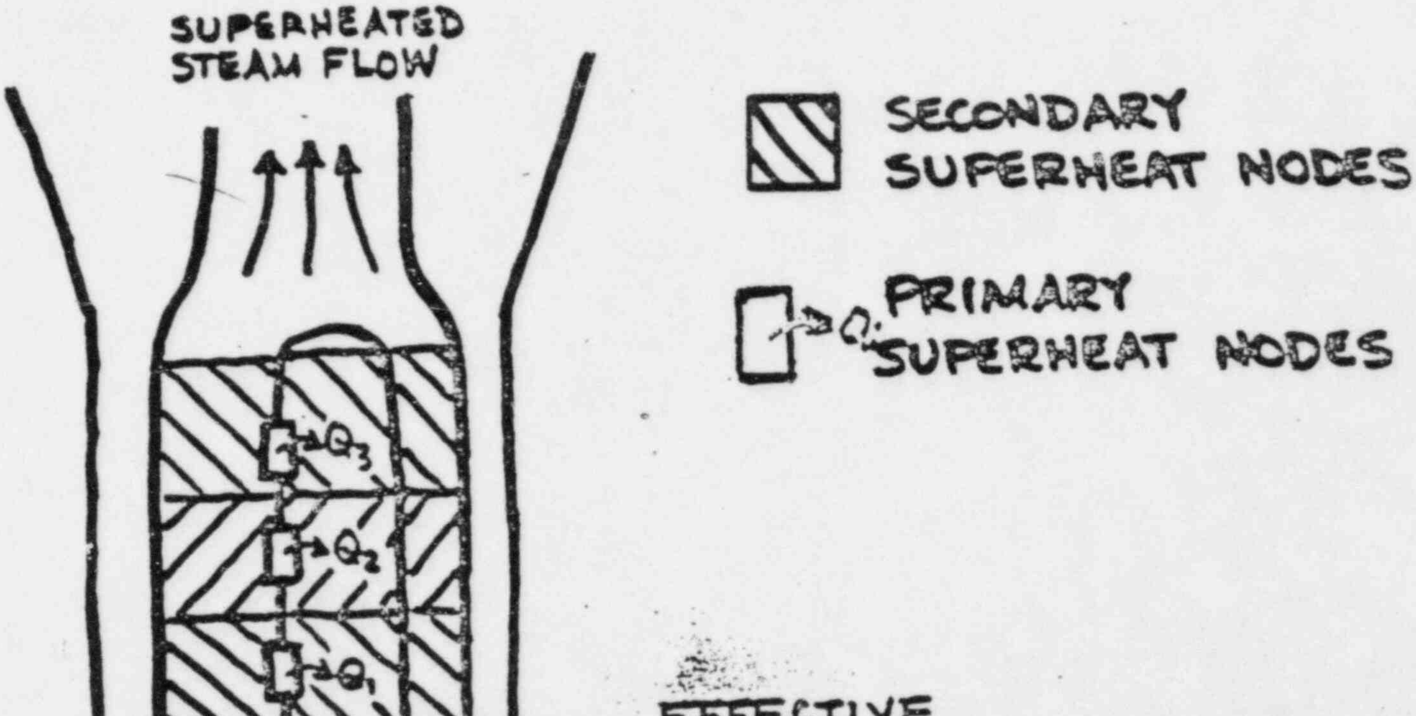


- SINGLE NODE, 2 REGION MODEL
- NO HEAT TRANSFER TO SATURATED STEAM REGION
- HEAT TRANSFER TO SATURATED WATER REGION IS MODIFIED FOR TUBE 'UNCOVERY'

FIGURE 1

LOFTRAN MODEL

SUPERHEAT HEAT TRANSFER



- VARIABLE SUPERHEAT NODES MODEL

- CONSTANT PRIMARY TEMPERATURE IN SUPERHEAT REGION ASSUMED FOR HEAT TRANSFER CALCULATIONS

- CALCULATED SUPERHEAT HEAT TRANSFER ACCOUNTED FOR IN PRIMARY TRANSIENT

FIGURE 2

TUBE UNCOVERY

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

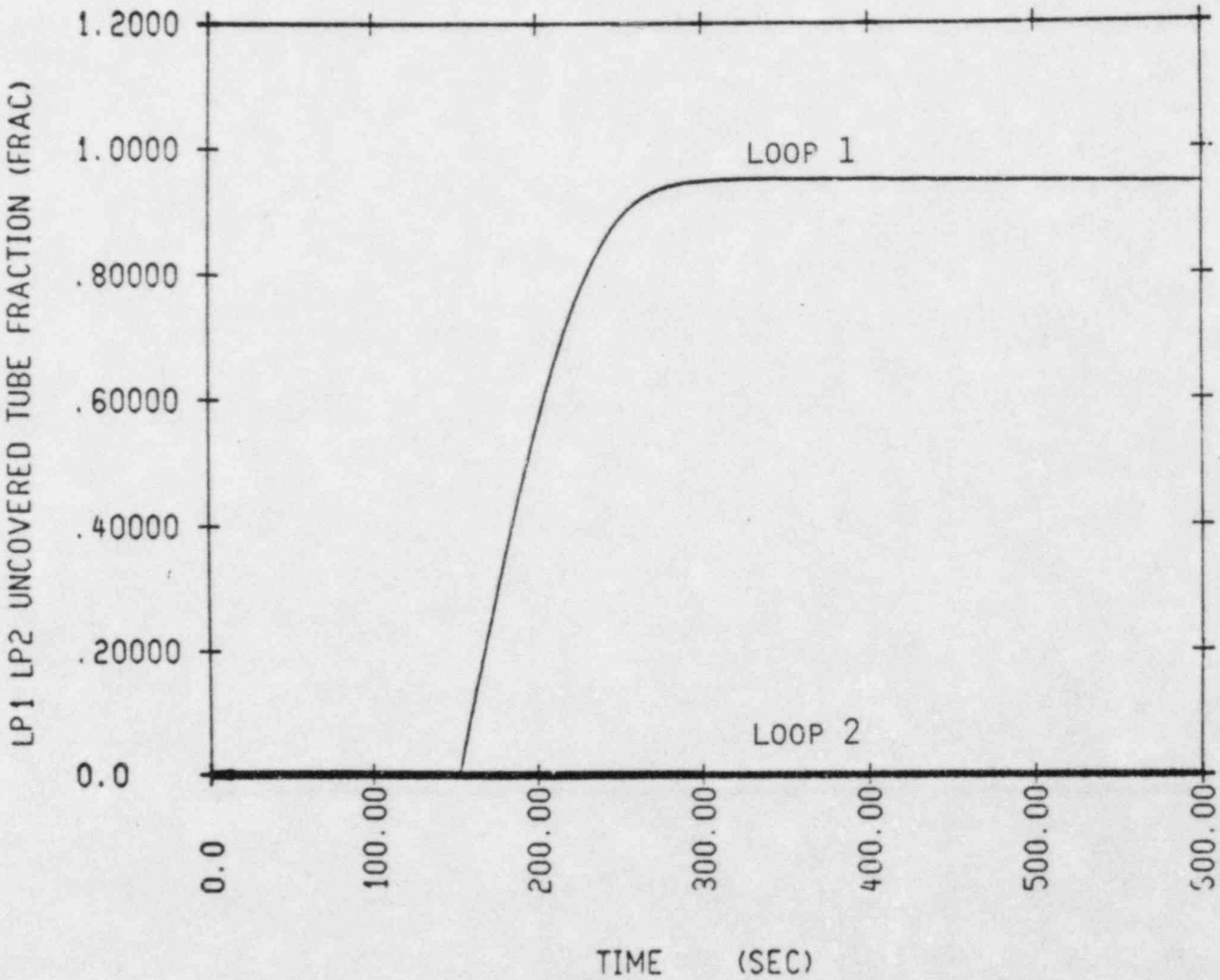


FIGURE 3

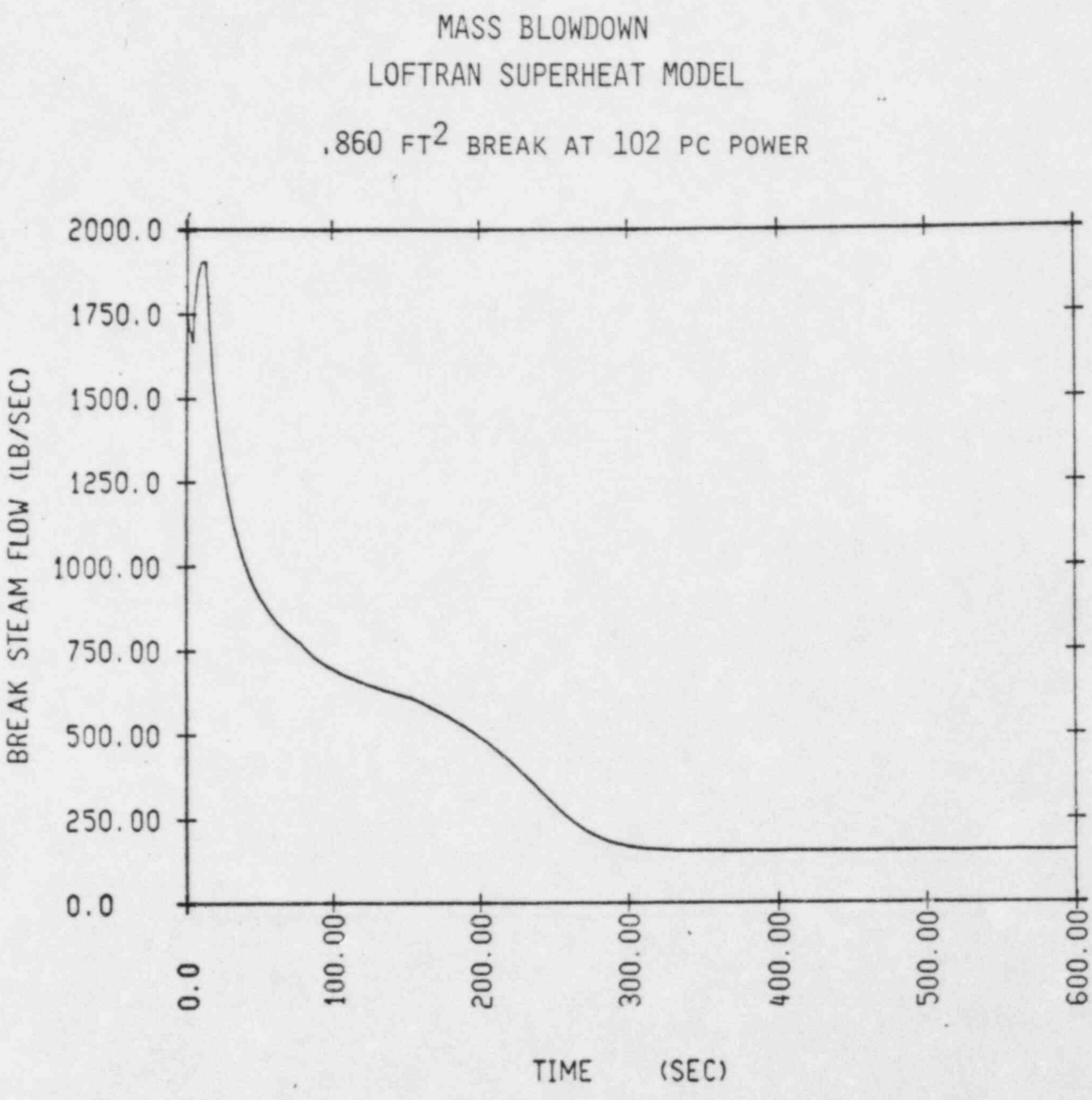

MASS BLOWDOWN
LOFTRAN SUPERHEAT MODEL
.860 FT2 BREAK AT 102 PC POWER
BREAK STEAM FLOW (LB/SEC)
2000.0
1750.0
1500.0
1250.0
1000.00
750.00
500.00
250.00
0.0
0.0
100.00
200.00
300.00
400.00
500.00
600.00
TIME (SEC)

FIGURE 4

ENERGY RELEASE

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

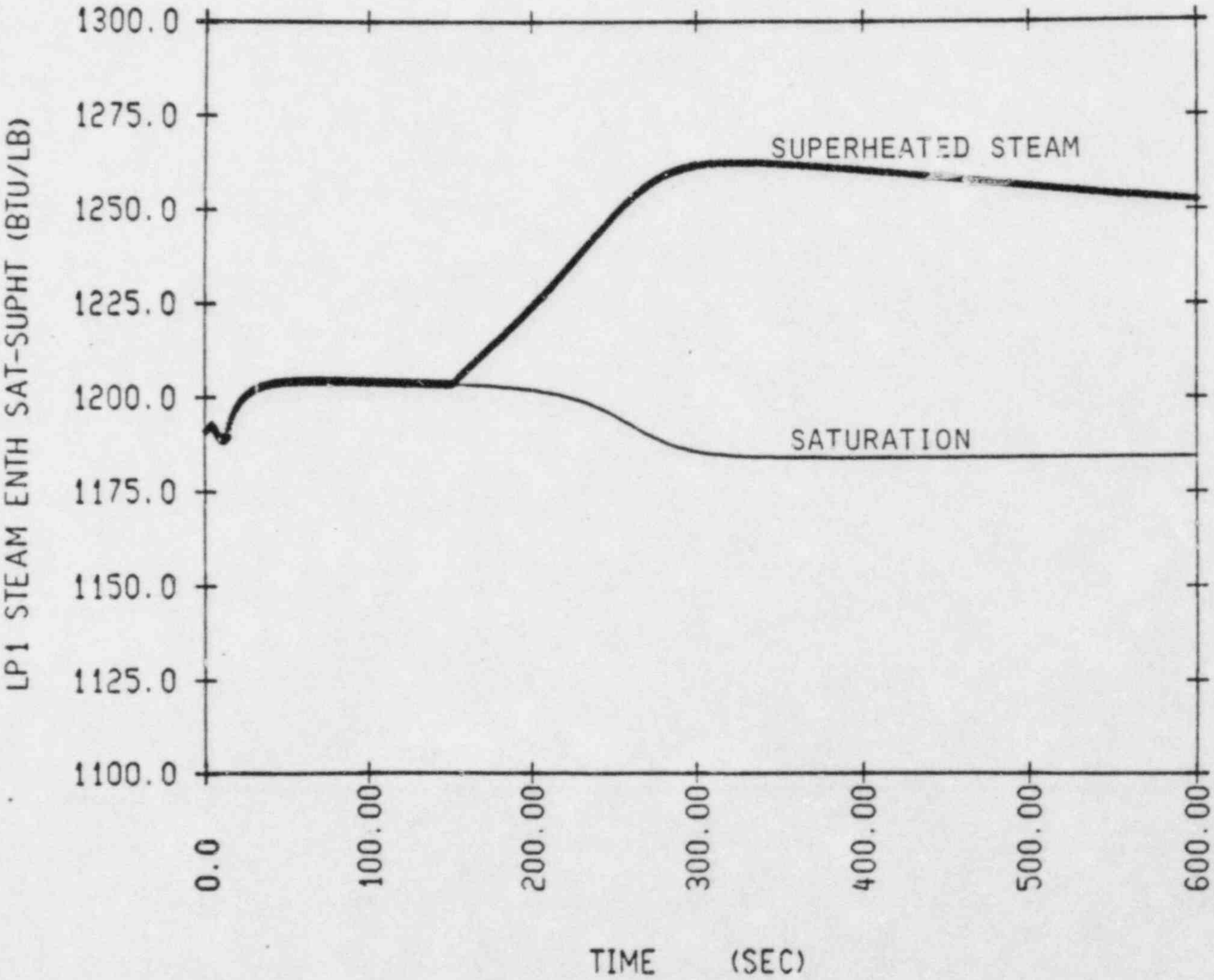


FIGURE 5

TEMPERATURE TRANSIENTS

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

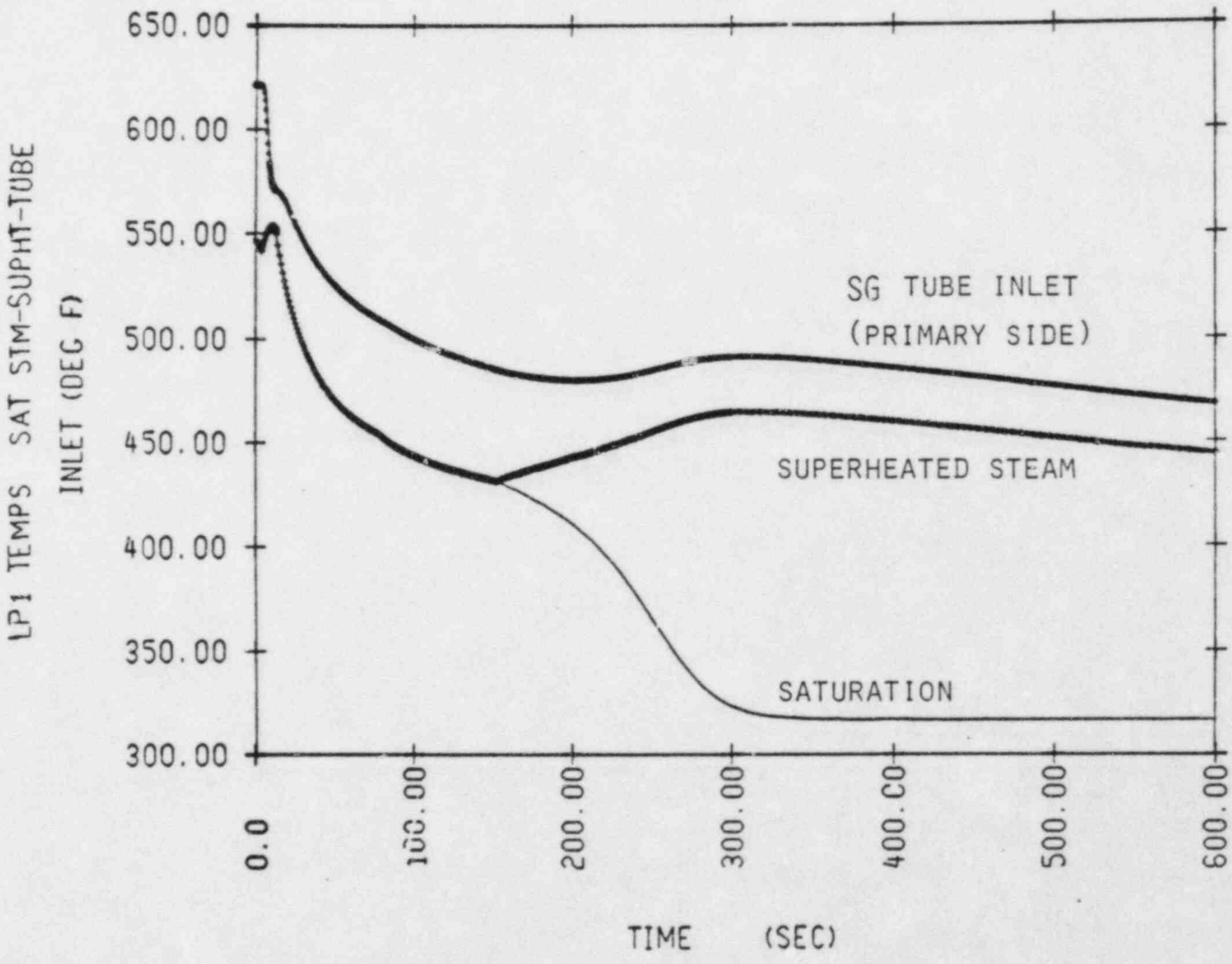


FIGURE 6

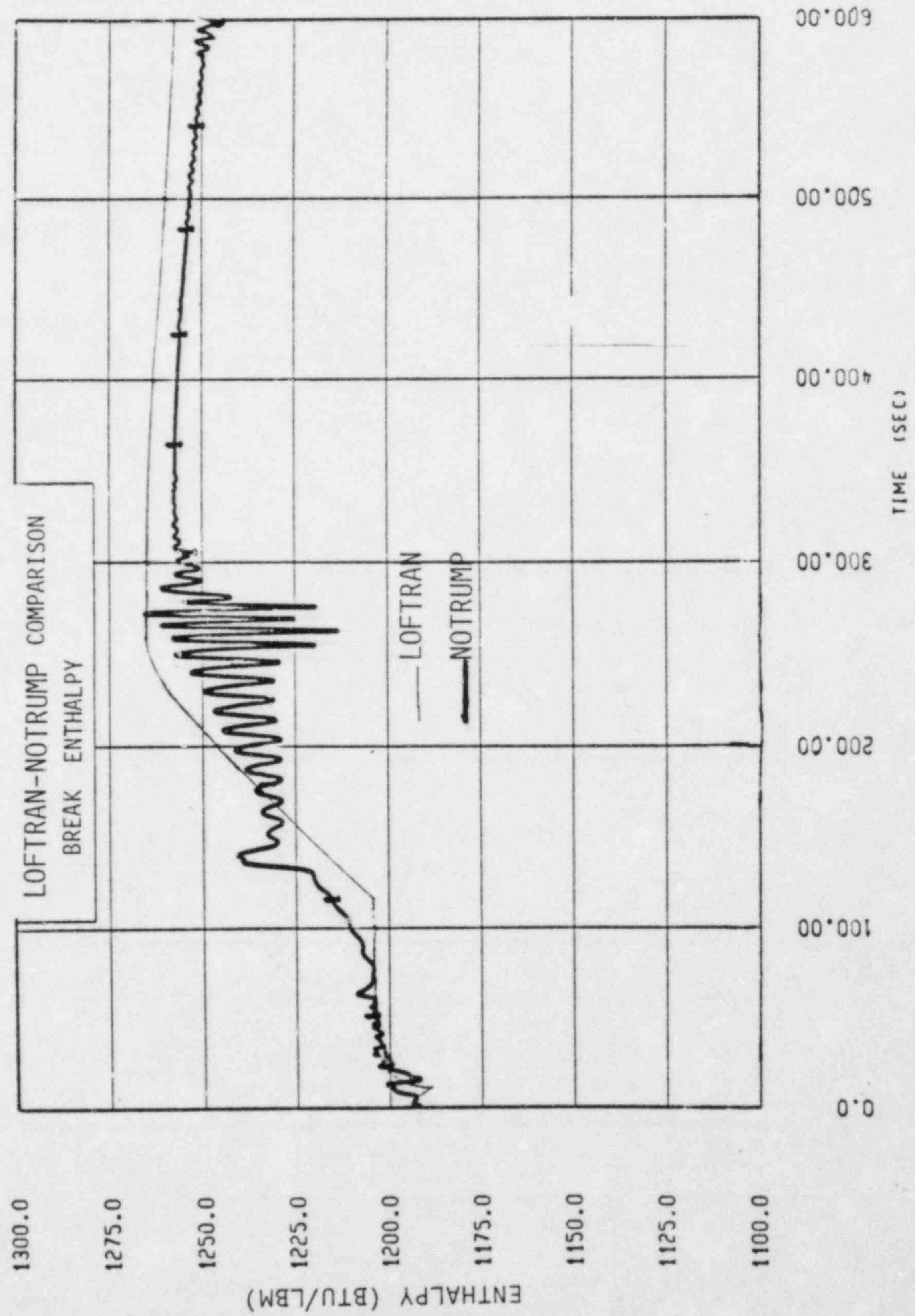
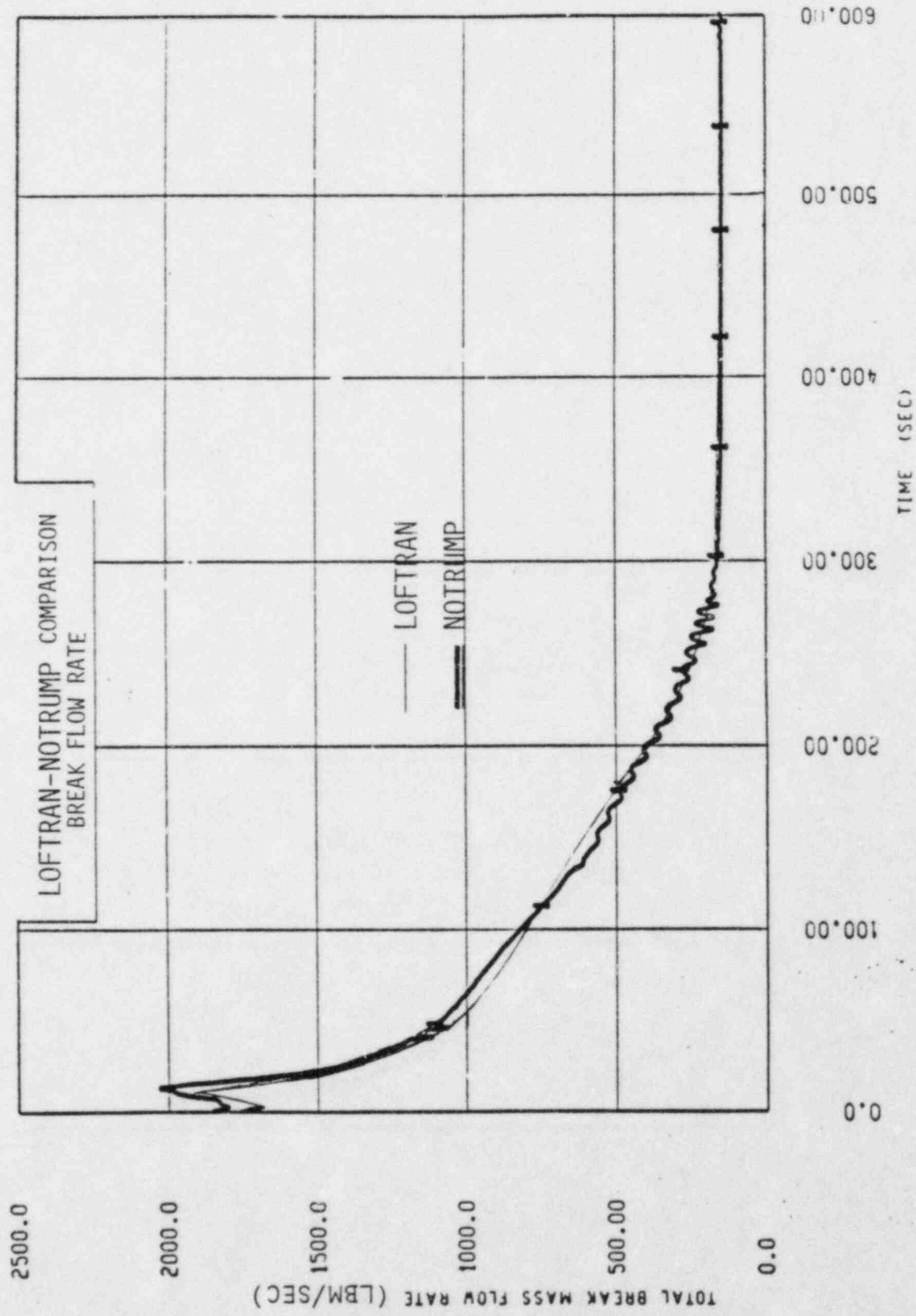

LOFTRAN-NOTRUMP COMPARISON
BREAK ENTHALPY
LOFTRAN
NOTRUMP
ENTHALPY (BTU/LBM)
1300.0
1275.0
1250.0
1225.0
1200.0
1175.0
1150.0
1125.0
1100.0
TIME (SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00

FIGURE 7



LOFTRAN-NOTRUMP COMPARISON
BREAK FLOW RATE
LOFTRAN
NOTRUMP
TIME (SEC)
TOTAL BREAK MASS FLOW RATE (LBM/SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00
0.0
500.00
1000.0
1500.0
2000.0
2500.0

FIGURE 8

EFFECTS OF ANALYSIS ASSUMPTIONS

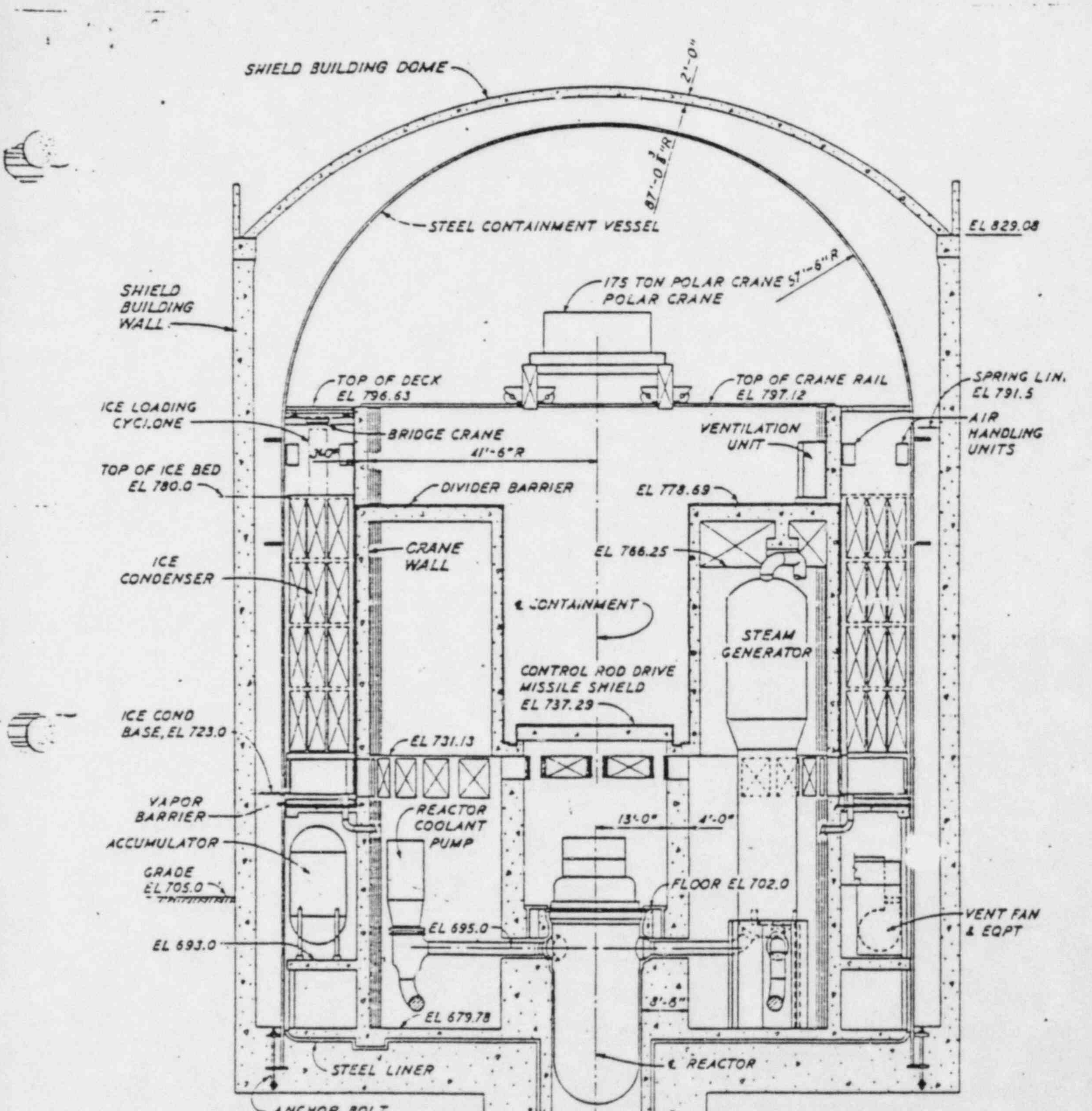
- INITIAL STEAM GENERATOR INVENTORY
- AUXILIARY FEEDWATER FLOWRATE
- FEEDWATER SYSTEM FAILURES
- PROTECTION SYSTEM ERRORS

FIGURE 9

ADDITIONAL MODEL CONSIDERATIONS

- LIQUID-STEAM INTERACTION
- IMPROVED STEAM HEADER MODEL
- HEAT TRANSFER THROUGH TUBE WRAPPER
- TEMPERATURE DROP IN PRIMARY SUPERHEAT NODES
- OPTIONAL VOID CORRELATIONS

FIGURE 10



Reactor Building Elevation

FIGURE 11

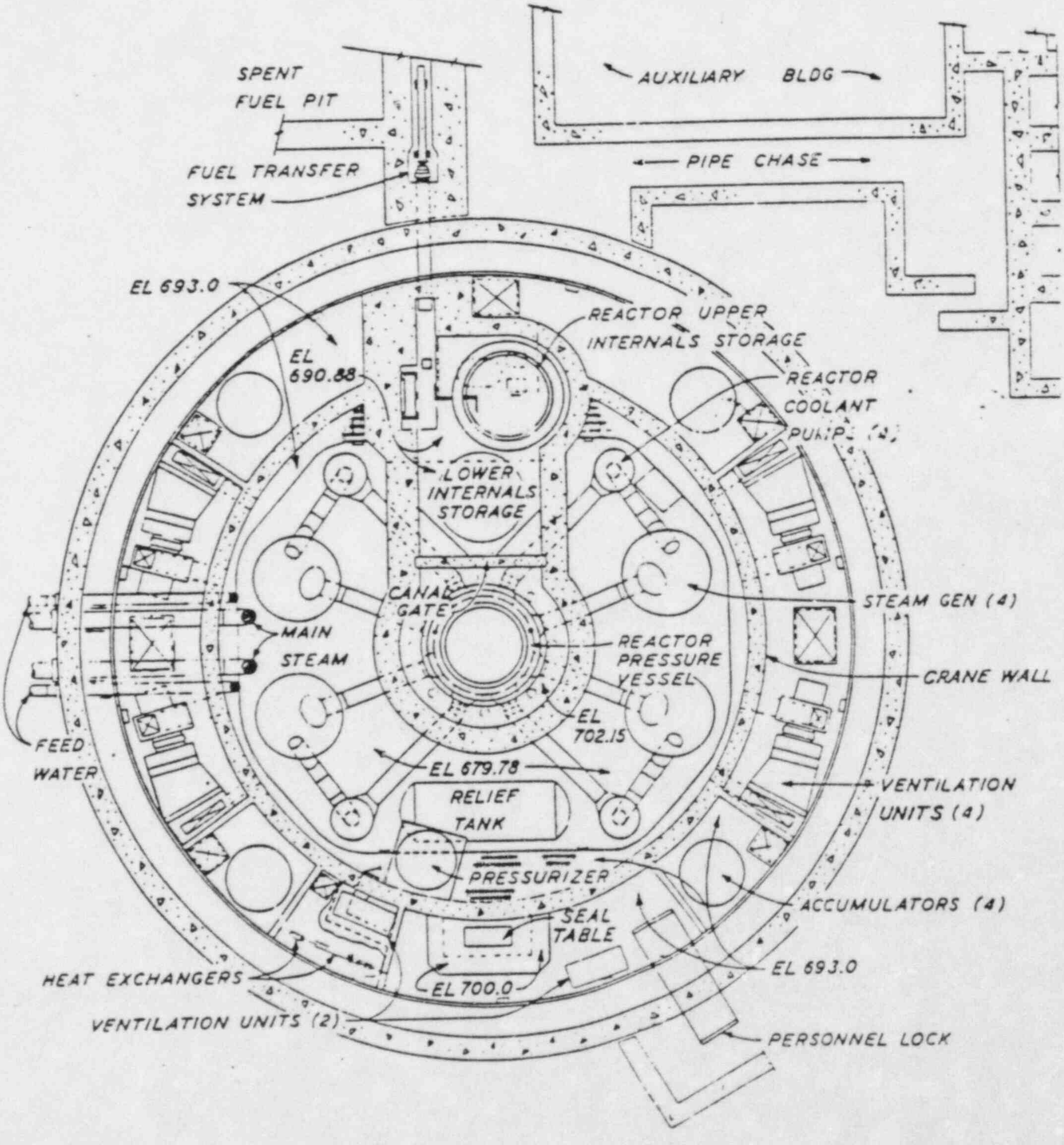


Figure 3.8.3-7 Plan-Lower Compartment

FIGURE 12

LOTIC-3 CONTAINMENT CODE

* 4 NODE CONTAINMENT MODEL
* CONDENSATE/REVAPORIZATION MODELS
  - LARGE BREAK (TOTAL REVAPORIZATION)
  - SMALL BREAK (CONVECTIVE HEAT FLUX)
* WALL HEAT TRANSFER MODEL
* MODELS SUMP RECIRCULATION SYSTEM

FIGURE 13

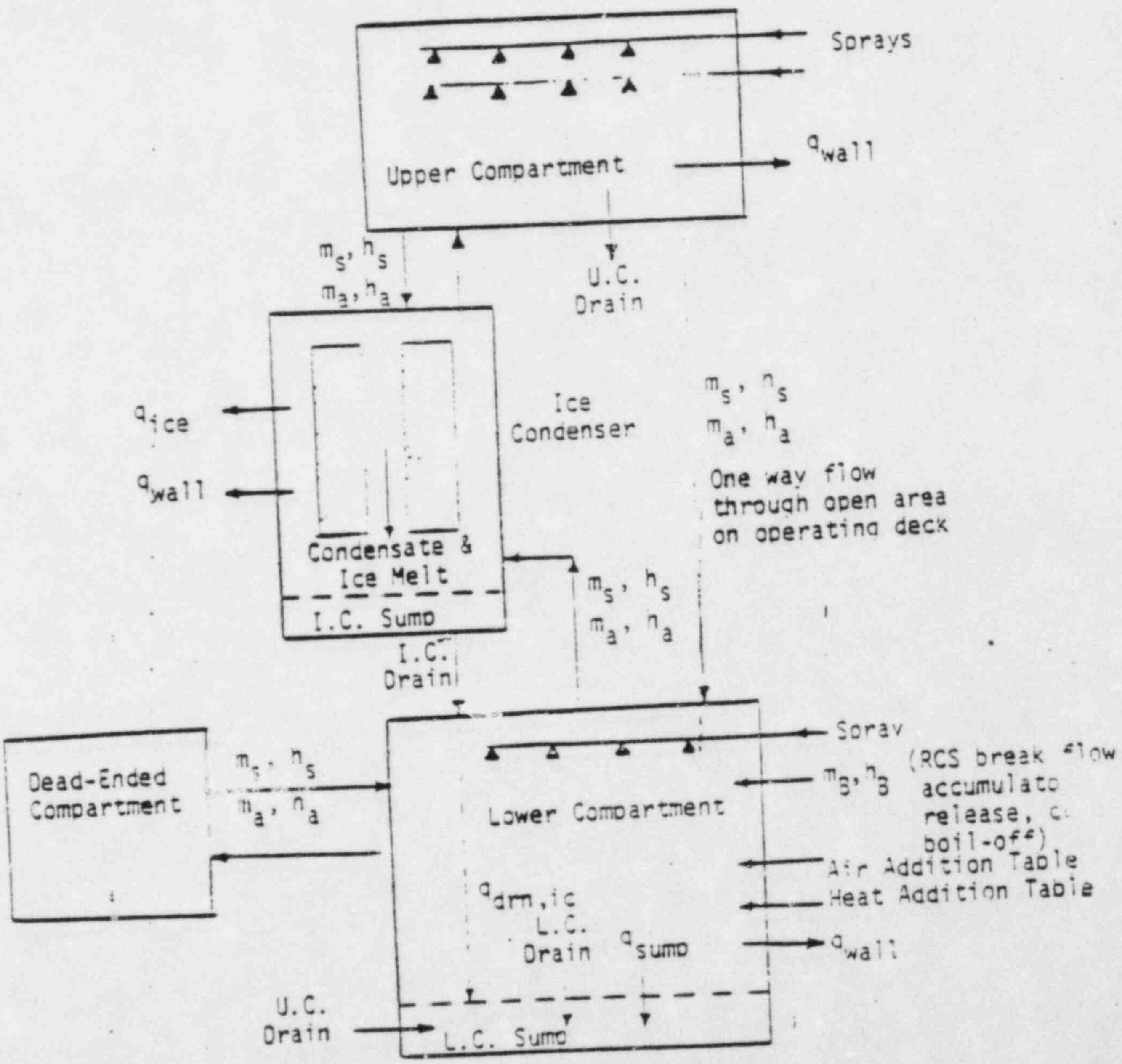


FIGURE 3.3 MASS AND ENERGY FLOW DIAGRAM FOR THE COMPARTMENTS

FIGURE 14

LOTIC-3 - METHOD OF SOLUTION

- SOLVES CONSERVATION OF MASS, ENERGY, AND MOMENTUM FOR UPPER, LOWER, AND ICE CONDENSER REGIONS

- ONCE NEW LOWER COMPARTMENT CONDITIONS ARE DETERMINED, CONSERVATION EQUATIONS ARE SOLVED FOR THE DEAD-ENDED COMPARTMENT AND FOR THE FLOW RATE BETWEEN THE TWO COMPARTMENTS

FIGURE 15

TYPICAL CONTAINMENT TEMPERATURE TRANSIENT (DRAINS MODELLED)

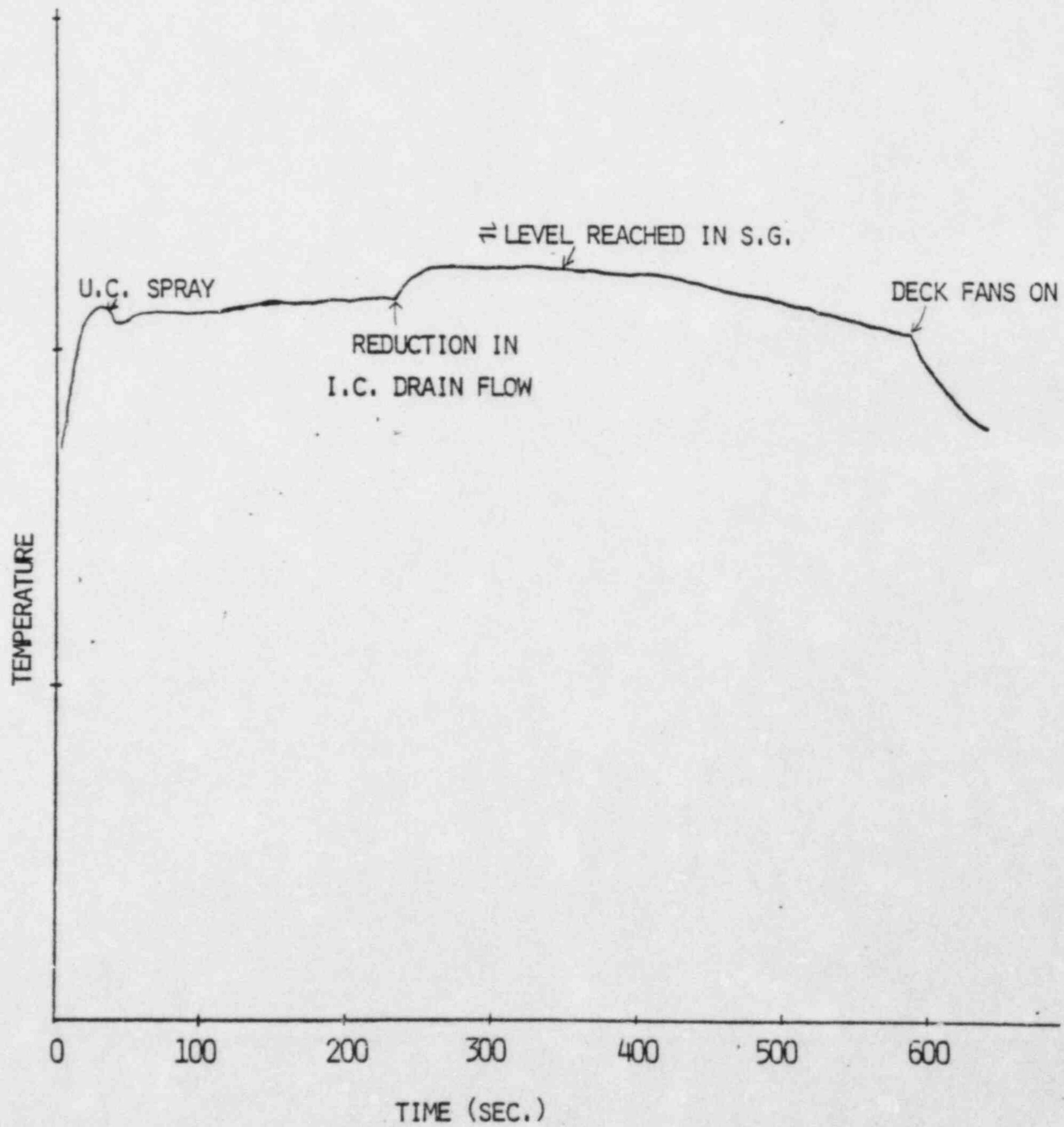


FIGURE 16

MODIFICATIONS TO THE CONTAINMENT MODEL

WALL HEAT TRANSFER MODEL

CONVECTIVE HEAT FLUX MODEL

ICE CONDENSER DRAIN MODEL

DEAD ENDED COMPARTMENT MODEL

FIGURE 17

WALL HEAT TRANSFER MODEL

ORIGINAL LOTIC MODEL

$$q'' = h_{Tagami} (T_{SAT} - T_{Wall})$$

MODIFIED LOTIC MODEL

$$q'' = h_{COND} (T_{SAT} - T_{Wall}) + h_{conv} (T_{Bulk} - T_{ref})$$

$$h_{COND} = f\left(\frac{m_{STEAM}}{m_{air}}\right)$$

$$h_{conv} = f(T_{Wall}, T_{SAT})$$

$$T_{ref} = f(T_{wall}, T_{SAT})$$

FIGURE 18

CONVECTIVE HEAT FLUX MODEL

ORIGINAL LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X}\right]$$

MODIFIED LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X_{SAT}}\right]\left[1 - \frac{h_{CONV}(T_{BULK} - T_{ref})}{q_{TOTAL}}\right]$$

FIGURE 19

ICE CONDENSER DRAINS

-APPROXIAMATELY 20 ICE CONDNESER DRAINS

-DRAIN ELEVATION IS ABOUT 40 FEET FROM FLOOR

-DRAIN PIPE IS 1 FOOT IN DIAMETER

-FOR TYPICAL MSLB TRANSIENT, DRAIN FLOW VARIES FROM 4000 LB/S TO 500 LB/S

FIGURE 20

ICE CONDENSER DRAIN MODEL

- CONDENSATION OCCURS AT THE SURFACE OF THE STREAM

- FLOW IS WELL MIXED

$$q = h A \Delta T$$

- MODEL AS A WALL AT A CONSTANT TEMPERATURE

- A IS THE SURFACE AREA OF THE STREAM

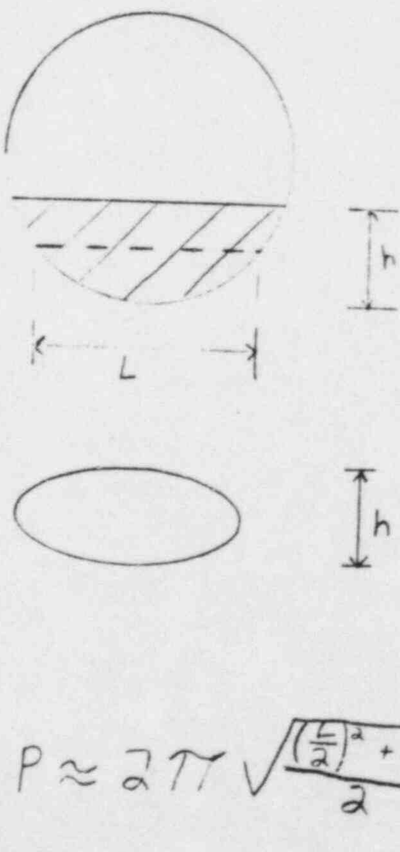
- h IS A CONDENSING TYPE HEAT TRANSFER COEFFICIENT

FIGURE 21

CALCULATION OF THE STREAM FLOW AREA

$$A = n(P \times L) = 20(P \times 40) = 800\,P$$

WHERE P IS THE PERIMETER OF THE STREAM



$$P \approx 2\pi \sqrt{\frac{\left(\frac{L}{2}\right)^2 + \left(\frac{h}{2}\right)^2}{2}}$$

FIGURE 22

MODIFIED LOTIC DRAIN MODEL

-WALL WITH A VARIABLE AREA

$$q = h_{COND} A (T_{BULK} - T_{SAT})$$

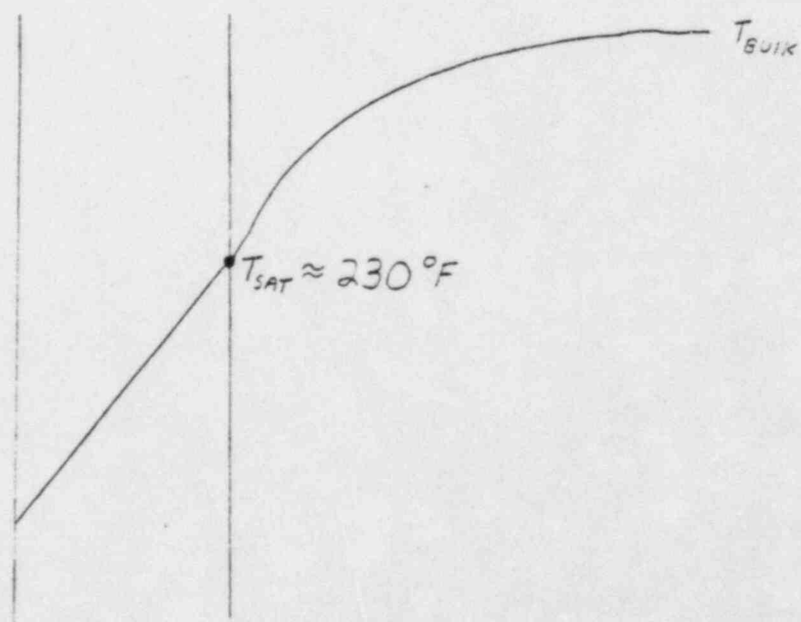


FIGURE 23

DEAD ENDED COMPARTMENT MODEL

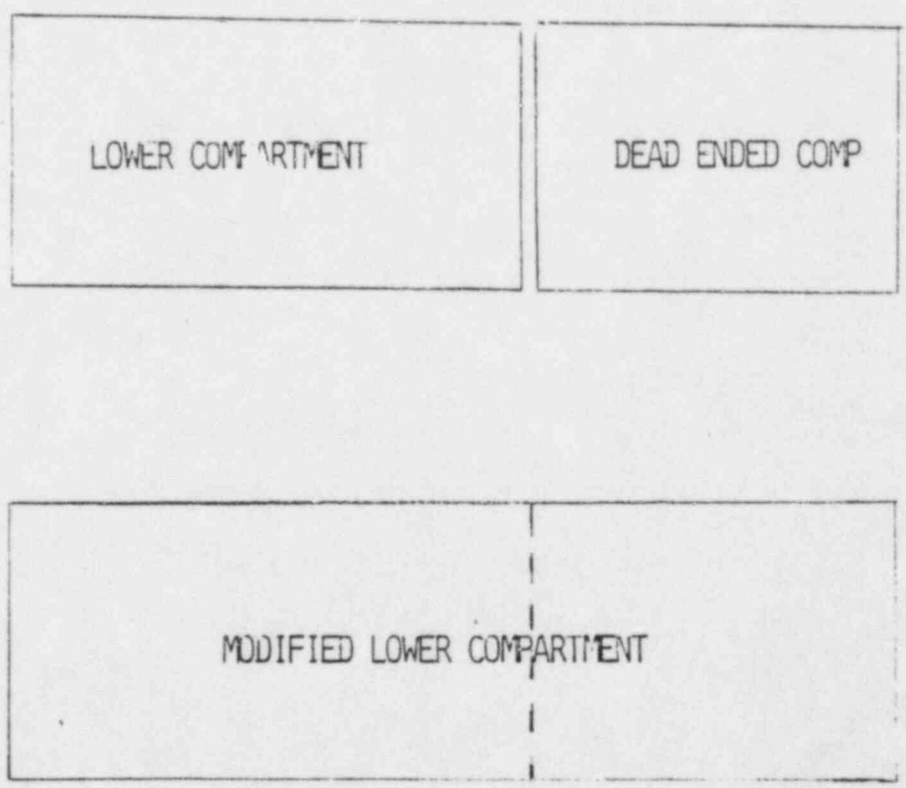


FIGURE 24

CATAWBA RESULTS

- 102% POWER
- 0.86 FT^2 BREAK
- MAXIMUM AFW FLOW
- FSAR HEAT SINKS
- MAXIMUM S.G. INITIAL MASS

T_{MAX} = 324°F (LOWER COMPARTMENT)

FIGURE 25

ADDITIONAL MODEL CONSIDERATIONS

-WALL HEAT TRANSFER MODEL

-DRAIN MODEL

-DEAD ENDED COMPARTMENT MODEL

FIGURE 26

ATTACHMENT 2

OUTLINE OF THE REPORT

I. Introduction

II. Mass & Energy Release Modeling

III. Containment Modeling

IV. Action Plan

V. Appendix

VI. References

I. Introduction

During the Containment Systems Branch review of the Westinghouse topical report, "Mass and Energy Releases Following a Steam Line Rupture",WCAP-8822 (Proprietary) the Staff noted that heat transfer to steam from the uncovered portion of the steam generator tube bundle was unaccounted for and questioned the effect upon the calculated mass/energy release and the subsequent effect on the containment temperature response. Westinghouse responded in a letter to the Staff (NS-EPR-2563, February 14, 1982, E.P. Rahe to J. R. Miller) that it had determined the impact of the effect by conservatively treating the maximum amount of superheat to be the difference between the primary coolant temperature and the steam temperature. The letter noted that there would be an insignificant effect on dry type containments and that, based on the conservative model used, there would be an expected increase in containment temperature for ice condenser type containments. In the Containment Systems Branch Safety Evaluation Reports on the topical report and the Catawba Plant Safety Evaluation Report, the Staff required that a more refined steam line break analysis be performed to determine the effect on containment temperature which might impact the environmental qualification envelope used for safety related equipment.

Since that time, Westinghouse has investigated the effects of tube bundle heat transfer from the viewpoint of a more refined modeling approach. Subject to the final review and approval of the NRC Staff, the efforts and results obtained to date indicate that there is little impact on the containment response from the effects of the additional tube bundle heat transfer to steam.

II. Mass and Energy Release Modeling

A. LOFTRAN Computer Code

Mass/energy releases are calculated using the LOFTRAN code. LOFTRAN is a FORTRAN language, digital computer code, developed to simulate transient behavior in a multi-loop pressurized water reactor system. The program simulates neutron kinetics, thermal hydraulic conditions, pressurizer, steam generators, reactor coolant pumps, and control and protection systems. Up to four independent loops may be modeled. LOFTRAN is used for analysis of non-LOCA transients and is documented in Reference 3.

The model of importance to blowdown calculations is the steam generator model. The primary side contains multiple nodes to model the tube bundle. The standard LOFTRAN steam generator secondary side model, (Figure 1), is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur only to saturated water. If tube uncovery occurs the amount of surface area available for heat transfer is accordingly reduced. The LOFTRAN code incorporates a more detailed steam generator model which is used to predict tube bundle uncovery.

B. LOFTRAN Model for Superheated Steam

The LOFTRAN code has been modified to account for heat transfer to steam from the uncovered tube bundle region. (Figure 2). In the modified version of LOFTRAN, all heat transfer occuring in the uncovered region is assumed to add superheat to the steam exiting the steam generator. The primary side temperature in the uncovered tube region is conservatively assumed to remain constant through the nodes which are uncovered. In reality, there will be a drop in temperature due to heat removal to the secondary side, but this is expected to be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is discussed in the Appendix. This correlation bases the heat transfer on the difference between the tube wall surface temperature and the bulk steam temperature in the region. In the LOFTRAN modification, the conservative assumption is made that no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall surface temperature of the tube is assumed equal to the primary fluid temperature.

The modified version of LOFTRAN automatically determines the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the modified LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient

calculation. The superheat/tube uncovery modeling is applicable to all steam generators.

Figures 3 through 6 show typical results for a 0.86 ft^2 steamline break from 102 percent power using the modified version of LOFTRAN. Figure 3 shows the fraction of tube uncovery versus time with uncovery of Loop 1 (faulted) starting at 152 seconds into the transient. At approximately 300 seconds, the uncovery transient reaches an equilibrium point where the steam flow out of the steam generator matches the auxiliary feedwater flow into the steam generator. Additionally, the tube uncovery transient for Loop 2 (non faulted) is plotted but shows no tube uncovery for the entire transient. Figure 4 presents the steam flow transient for this case. Figure 5 includes plots of both the superheated steam enthalpy and the saturation enthalpy for the Loop 1 steam generator. Figure 6 includes the Loop 1 temperatures for the steam generator tube inlet (primary side), steam exit temperature (superheated steam), and the saturation temperature for the steam pressure.

C. NOTRUMP Model Comparison

The NOTRUMP computer code (Reference 4) was used to verify the LOFTRAN modeling of superheat. The computer code was originally developed to analyze transients of secondary systems with two-phase conditions. In the past, it has been used to analyze various transients in the primary and secondary coolant systems. NOTRUMP has recently undergone major revisions to enable it to model non-equilibrium nodes (i.e., separate liquid temperature and steam temperature modeling). Using NOTRUMP, the steam generator can be broken down into sufficient nodes to model the nonequilibrium effects of the steam generator, as well as the tube region during uncovery. NOTRUMP can model all modes of heat transfer associated with a steamline break transient, including heat transfer from the uncovered tubes to the superheated steam and the feedback effects between the primary and secondary sides. The two phase mixture level calculation accounts for primary to secondary heat transfer and the swell associated with rapid depressurization of the steam generator during the blowdown.

A comparison of LOFTRAN and NOTRUMP blowdown results is presented in Figures 7 and 8. The mass releases shown in Figure 8 show excellent agreement. The LOFTRAN prediction of superheat enthalpy is slightly higher than NOTRUMP, while the predicted time of tube uncovery is somewhat later. NOTRUMP shows a chugging effect during the uncovery phase of the blowdown. This is believed to be in part due to oscillations in the flow link between the downcomer region and the steam dome region. (The flow link is the drain path for the moisture separators to the downcomer region.) With the flow direction towards the downcomer, superheated steam goes into the downcomer region and is condensed. This alternates with a flashing of a portion of the water volume in the downcomer region. This raises the pressure of the downcomer, resulting in a flow reversal in the link with saturated steam from the downcomer mixing with the superheated steam in the dome. This mixing results in the variations in the superheat enthalpy seen in Figure 7. Although LOFTRAN does not show the enthalpy variation since the detailed modeling of the downcomer and dome are not included, the overall agreement with NOTRUMP is very good.

D. Effects Of Analysis Assumptions

The effects of superheated steam are dependent upon the occurrence and extent of tube uncovery. The major parameters affecting tube uncovery are: initial steam generator inventory, auxiliary feedwater flowrate, assumed feedwater system failures, and protection system errors. Variations in these parameters are in the process of being evaluated for their effects on the containment temperature response (Figure 9).

Refinements in the mass and energy release modeling (Figure 10), are being evaluated and several areas show a potential for reducing the degree of superheat being generated. Some of these areas are:

- Evaluation of liquid-steam interactions such as the phenomenon of tube support plate flooding and heat transfer across the tube wrapper from the superheated steam to the auxiliary feedwater flowing down outside the tube wrapper.

- A more detailed steam header model in LOFTRAN.

- Modeling temperature drops in the primary superheat nodes.

- Evaluating other void correlations for use in predicting tube uncovery.

III. Containment Modeling

A. Description of Containment

The general phenomena taking place inside an ice condenser containment during a steamline break transient can be described utilizing a typical ice condenser elevation drawing (Figure 11). Steam is discharged to the main (or lower) compartment where heat is removed by the internal structures, steam flow to the ice condenser, and the ice condenser drain water. The dead ended compartments are the regions which are located below the ice condenser and outside the crane wall (Figure 12). Air is discharged from the main compartment to the dead ended compartment and ice condenser so that the resulting steam to air ratio is that region is much higher than in dry containments. At ten minutes following the containment hi-2 signal, deck fans are actuated which direct air flow from the upper compartment to the dead-ended compartments. Most of the safety related equipment is located in the dead-ended compartments although some equipment and cabling are located in the main compartment.

B. Containment Models

Figure 13 outlines the major models and assumptions utilized in the LOTIC-3 containment code. In the currently approved version of LOTIC-3 documented in Reference 5, four distinct regions of the containment are modeled; the lower compartment, the dead-ended compartment, the ice condenser, and the upper compartment. Two condensate/revaporization models are used depending on the size of the break. For large steamline breaks, 100% condensate revaporization is assumed. For small steamline breaks, a convective heat flux model is used which calculates partial revaporization during the transient. The wall heat transfer model utilizes the Tagami heat transfer correlation for condensation heat transfer and the convective heat flux model derived from the work of Sparrow (Reference 6) which calculates the convective heat transfer for small steamline breaks. The sump recirculation system is only modeled for the large break LOCA transient containment response.

Figure 14 shows the four regions modeled with the mass and energy flows that can be assumed in the analysis. The Catawba nuclear plant does not have lower compartment sprays and they are not modeled in the analysis. Superheat heat transfer is conservatively assumed to be zero for the steamline break containment analysis. In the model described in Reference 5, wall heat transfer is not modeled in the dead-ended compartments although these regions do contain structures which will remove heat. The analysis does include the upper compartment sprays, flow through the ice condenser, deck fan flow, and flow to the dead-ended compartments.

LOTIC-3 solves the conservation of mass, energy, and momentum equations for upper, lower, and ice condensor regions (Figure 15). After the new lower compartment conditions are determined, conservation equations are solved for the dead ended compartment and the flow rate between the compartments is determined.

Figure 16 presents a typical steamline break containment temperature transient that is calculated using superheated steam blowdowns from the LOFTRAN code and the modeling of ice condenser drains as a heat removal source. The transient shows that initially the containment temperature increases rapidly during the

blowdown. When the upper compartment sprays actuate there is a slight decrease in the main compartment temperature. The temperature then rises slowly until ice condenser drain flow decreases to the point at which time the temperature begins to rise again (approximately 250 seconds). This rise in containment temperature coincides with the steam generator tubes uncovering at 152 seconds and the maximum superheat occurring at approximately 250 seconds. The steam generator level stablizes when the auxiliary feedwater flow is equal to the steam discharge at approximately 300 seconds. The containment temperature then starts decreasing with decreasing decay heat. At ten minutes, the deck fans actuate which results in a rapid decrease in containment temperature.

C. LOTIC-3 Code Modifications

Four modifications have been incorporated in the LOTIC-3 containment model which are (Figure 17);

1) wall heat transfer model
2) convective heat flux model
3) ice condenser drain model
4) dead-ended compartment model

D. Wall Heat Transfer

The modification to the wall heat transfer model is described in Figure 18. In the LOTIC-3 model, only condensation heat transfer, utilizing a Tagami heat transfer coefficient and a temperature difference between the wall and saturation, was previously modeled. The modification includes a convection term with a conservative convection heat transfer coefficient and a temperature difference between the containment atmosphere and an appropriate interface temperature. The Appendix presents a more detailed description of this model.

E. Convective Heat Flux

The modification to the convective heat flux model is described in Figure 19. A term has been added to the convective heat flux model to account for the feedback effect from including a convective term in the wall heat transfer model. The Appendix presents a more detailed description of this model.

F. Ice Condenser Drain Model

In an ice condenser containment there is approximately twenty drains exiting from the ice condenser into the lower compartment at an elevation of about forty feet above the compartment floor. The drain pipes are one foot in diameter. The drain flowrate is calculated by the LOTIC-3 containment code. For a typical small steamline break transient the drain flowrate varies from approximately 4000 lbm/sec to 500 lbm/sec during the timeframe of interest. The temperature of the drain water is approximately 130°F (Figure 20).

Figure 21 presents the assumptions and the basic model used to estimate the heat removal from the lower compartment atmosphere to the ice condenser drain water. It is conservatively assumed that the drain water stream does not break up prior to reaching the floor even though many of the drains have equipment and structures located below them. Therefore, heat transfer is assumed to occur at

the stream surface only. It is also assumed that the stream surface temperature is at the saturation temperature of the containment.

The heat transfer to the stream is:

$$q = hA\Delta T$$

where

h = condensation heat transfer coefficient
A = surface area of the stream
ΔT = appropriate temperature difference

The calculation of the heat transfer surface area is described in Figure 22. In order to model the drains in LOTIC-3, the drains are modeled as a wall heat sink with a surface at a constant temperature (see Figure 23). Currently, in the version of LOTIC-3, the surface temperature is assumed to be 230°F which is close to the containment saturation temperature. The drain surface area is calculated at two points in time during the transient; early in time with a high flowrate and later in time with a low flowrate. To ensure conservatism in the area calculation a 10% reduction of the surface area was assumed.

As described previously (Figures 14 & 15), the LOTIC-3 containment model did not account for wall heat removal in the dead-ended compartments. To obtain a conservative estimate of the temperature transient in the dead ended compartment, the heat sinks located in the dead ended compartment region along with the heat sinks in the lower compartment are modeled in a combined volume (see Figure 24). This "modified" lower compartment model is used to determine a conservative dead-ended compartment temperature transient. Since the lower compartment will be hotter than the dead-ended compartment, this methodology results in a higher temperature in the dead-ended compartment than would be expected.

G. Transient Results

With the modifications described for LOFTRAN and LOTIC-3, the previous FSAR limiting case for Catawba was reanalyzed to determine the impact of superheated steam. The case selected is a 0.86 square foot break at 102% power (Figure 25). The peak lower containment temperature for this case is 324°F. This temperature is calculated for the lower compartment only. It is expected that the dead-ended compartment temperature will be significantly lower.

In addition to the model modifications incorporated in LOTIC-3, Westinghouse is pursuing further improvements in the areas noted on Figure 26. One area is in the wall heat and mass transfer models. Since condensation is a mass transfer type phenomena, the heat and mass transfer should be linked. This approach has been used in Reference 7.

An improved drain model is also being investigated. This improved model will calculate the drain surface area as a function of flowrate. It will also calculate the average temperature rise of the drainwater. This model will more accurately represent the actual phenomena in the containment.

V. Appendix

WESTINGHOUSE STEAMLINE BREAK BLOWDOWN AND CONTAINMENT ANALYSIS METHODOLOGY

The following sections describe the Westinghouse methodology for determining the containment response for a steamline break incorporating the effects of superheated steam. These sections describe in detail changes from the methodologies described in References 1 and 5.

I. Steamline Rupture Mass/Energy Blowdown Analysis

A. LOFTRAN and MARVEL Computer Modeling

Mass/energy releases can be calculated using either the LOFTRAN code (Reference 3) or the MARVEL code (Reference 8). The LOFTRAN code is used for non-LOCA FSAR accident analyses. The MARVEL code was specifically developed for assymmetric transients such as steamline breaks. These two codes are very similar because they were developed in an interrelating fashion and much of the modeling is common to both codes. The MARVEL code was used in the development of Reference 1 because LOFTRAN at that time was a lumped model which was used for symmetric loop transients. Furthermore, for steamline break analysis purposes, MARVEL contains a model for water entrainment. However, the current version of LOFTRAN is a multiloop version which also contains a water entrainment model. With the development of a multiloop version of LOFTRAN and the inclusion of an entrainment model, the use of MARVEL has been generally discontinued. This enables the use of LOFTRAN as a single system analysis code for non-LOCA transient analyses. LOFTRAN is used in the analyses presented here.

The model of importance to blowdown calculations is the steam generator model. The primary side of the steam generator contains multiple nodes to model the tube bundle for both the modified version of LOFTRAN and MARVEL. Heat transfer calculations from the primary to secondary side are identical in the two codes, although the methods for initializing the heat transfer resistances are slightly different. The secondary side is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur to saturated water. If tube uncovery is predicted, the amount of surface area available for heat transfer is reduced.

Both codes contain a detailed steam generator model which is used to predict tube uncovery. This model calculates the liquid volume in the steam generator shell and accounts for the detailed steam generator geometry. The [ ]^{a,c} correlation is used in both codes to predict the voiding in the tube region, although the correlation is modified for use in LOFTRAN. In MARVEL, tube uncovery is calculated based

on comparison with the actual water level and the height of the tube bundle. In LOFTRAN, the user specifies either a water volume in the steam generator corresponding to tube uncovery, or a void fraction in the riser section of the steam generator at which tube uncovery begins.

Both codes have similar models accounting for reverse heat transfer, thick metal heat transfer, feedline flashing, and safety injection system operation. Auxiliary feedwater flow can be input as a fraction of nominal feedwater flow, although LOFTRAN has an additional capability to model auxiliary feedwater flow as a separate system. For analysis of double ended ruptures, MARVEL accounts for the volume of steam in the piping downstream of the steam generators in the blowdown calculations. In LOFTRAN, this consideration is added on to the blowdown mass and energy results by hand. For split ruptures, which the analysis presented here addresses, the steam piping masses are handled identically in both codes.

In summary, LOFTRAN and MARVEL are very similar codes, and either can be used to calculate mass/energy blowdowns. To demonstrate this, a comparison of the blowdowns for a typical case is presented in Figures A.1 and A.2. Figure 1 presents the mass release rate for a .86 ft2 split rupture from 102% power. For this case, Figure A.2 shows the saturated steam enthalpy as a function of time. This blowdown is typical of results used in FSAR analyses prior to the modification noted in this report for the LOFTRAN code. As can be seen from the figures, the results are extremely close.

B. LOFTRAN Model for Superheated Steam

As mentioned previously, the LOFTRAN code has been modified to model heat transfer which may occur in the uncovered tube bundle region. This effect is modeled in both the faulted and intact loops. In the modified version of LOFTRAN, all heat transfer occurring in the uncovered region is assumed to add superheat the steam exiting the steam generator. The temperature of the primary coolant flowing through in the uncovered tube region mode is conservatively assumed to remain constant. Realistically there would be a drop in temperature due to heat removal to the secondary side, but this will be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is based on the [(1)]a,c. The heat transfer coefficient (U) is calculated by the following expression:

[ ]a,c

This correlation is presently used for superheated forced convection heat transfer by the [ ]a,c computer codes. Additionally,

this correlation is based upon the heat transfer from the surface of the tube wall to the average bulk temperature of the steam. In the LOFTRAN modification, no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall temperature of the tube is conservatively assumed equal to the primary fluid temperature.

(1) [ ] [a,c]

The modified version of LOFTRAN automatically selects the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the modified LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. Each node is evaluated to determine the steam temperature exiting the node with a convergence criteria that is based upon the total number of nodes used. The exit steam temperature of one node is used as the inlet steam temperature of the next node.

The heat transfer calculation to determine the outlet temperature of the node is based upon the following expression:

$$Q = UA*(T_{pri}-(T_{out}+T_{in})/2) = M_s*C_s*(T_{out}-T_{in})$$

where Q = Heat transfer to the steam

U = [ ] a,c

T_{pri} = Primary node temperature

T_{out} = Steam node outlet temperature

T_{in} = Steam node inlet temperature

M_s = Mass flowrate of the steam

C_s = Heat capacity of the steam

A = Heat transfer area in the node including both hot and cold leg sides of the tube bundle

The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient.

C. Blowdown Sensitivity to Plant Conditions

The effects of superheated steam are dependent upon the occurrance and extent of tube bundle uncovery. Parameters affecting tube uncovery are: initial steam generator inventory, break size, auxiliary feedwater flowrate, and the single failure assumed.

The initial steam generator inventory depends upon the measurement errors associated with steam generator level and upon initial power level. Steam generator mass increases with decreasing power, thus, breaks intitiating from low power levels will result in later tube uncovery.

Larger break sizes result in faster blowdown of the steam generator and earlier tube uncovery.

Large auxiliary feedwater flowrates only delay tube uncovery, but will also cause the final equilibrium steam generator level to be higher. This equilibrium condition corresponds to the point when the break flow rate is equal to the auxiliary feedwater flow rate.

The single failure assumed in the transient may impact the amount of water supplied to the steam generator. Auxiliary feedwater runout will increase the amount of water supplied to the steam generator. Failure of the feedwater isolation valve will also cause extra water to be supplied to the generator as the additional mass between the isolation valve and the check valve flashes to the generator.

II. Containment Analysis

A. Wall Heat Transfer Model

The original LOTIC-3 wall heat transfer model is based on the stagnant Tagami heat transfer correlation. That is,

$$q''=h_{TAGAMI}(T_{SAT}-T_{WALL})$$

$h_{TAGAMI} = 2 + 50\ M_{STEAM}/M_{AIR}$ $h_{(TAGAMI,MAX)}=72$ BTU/hr-ft^2-^oF

This model was developed for saturated steam in the presence of large amounts of non-condensable gases. In the lower compartment of an ice condenser, most of the air is swept out of the lower compartment through the ice condenser and into the upper compartment. Therefore, after about 30 seconds, there is almost no non-condensables in the lower compartment. Typical values for the condensation of pure steam are in the range of 1000 to 3000 Btu/hr-ft2-^oF (Ref. 5). The correlation used in the modified LOTIC-3 code is in extension of the Tagami correlation for nearly pure steam.

$$q''=h_{COND}\ (T_{SAT}-T_{WALL})$$

$h_{cond} = 2+50\ M_{STEAM}/M_{AIR}$ $h_{(cond,max)} = [$ $]^{a,c}$

A maximum value of [ ]^{a,c} was chosen as a conservatively low condensing heat transfer coefficient in a nearly pure steam environment.

In addition to this modification, an additional term is needed to account for the convective heat transfer from the superheated steam to the condensate film. This convective heat transfer is dependent upon whether there is condensation occurring on the walls. If condensation is occurring, the correlation used is:

$$q''_{conv}=h_{conv}(T_{bulk}-T_{sat})$$

where: [ ]^{a,c}

If the wall temperature increases to above the saturation temperature then the convective currents will be reduced such that the correlation used is

$$q''_{conv}=h_{conv}(T_{bulk}-T_{wall})$$

where:

[ ]^{a,c}

Thus in summary, if $T_{wall} < T_{sat}$ then

[ ]^{a,c}

If $T_{wall} > T_{sat}$, then the correlation used is:

[ ]^{a,c}

B. Convective Heat Flux Model

When the containment atmosphere is superheated, the containment temperature is a strong function of the amount of steam mass in the atmosphere. Thus the amount of mass condensed on the heat sink surfaces is a key parameter. The actual amount of condensate formed is

$$M_{cond} = q_{cond}/h_{fg}$$

Unfortunately, with the use of a heat transfer correlation based only on test data (such as Tagami or Uchida), only the total heat transfer coefficient is obtained. This total heat transfer coefficient includes both the condensation heat transfer and the convective heat transfer. Based on the work of Sparrow (Reference 6), the Westinghouse Convective Heat Flux model in the original LOTIC-3 code calculates the ratio of the convective heat transfer to the condensation heat transfer. Therefore the calculation of the amount of mass condensed is

[ ]^{a,c}

In the modified LOTIC-3 model, the amount of superheat convection is calculated. The amount of convective heat transfer at saturation is not known explicitly in this model. Therefore, in the modified LOTIC-3 code the original convective heat flux model will be used to calculate the fraction of convective heat transfer for saturated conditions. The actual correlation is

[ ]^{a,c}

where, $(q_{conv}/q_{cond})_{sat}$ is determined from original convective heat flux model and $q_{conv,sh}$ is the amount of convective heat transfer calculated in the wall heat transfer model

In summary, the modified LOTIC-3 model is consistent with the original LOTIC-3 model in its calculation of the mas condensed. The only difference is that in the modified LOTIC-3 code, the amount of superheat convective heat transfer is known explicitly, while in the original LOTIC-III model, only the ratio of convective heat transfer to condensation heat transfer is known.

IV. References:

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9. McCabe, W. L., and Smith, J. C., "Unit Operatons of Chemical Engineering", 3rd Edition, 1976.

LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

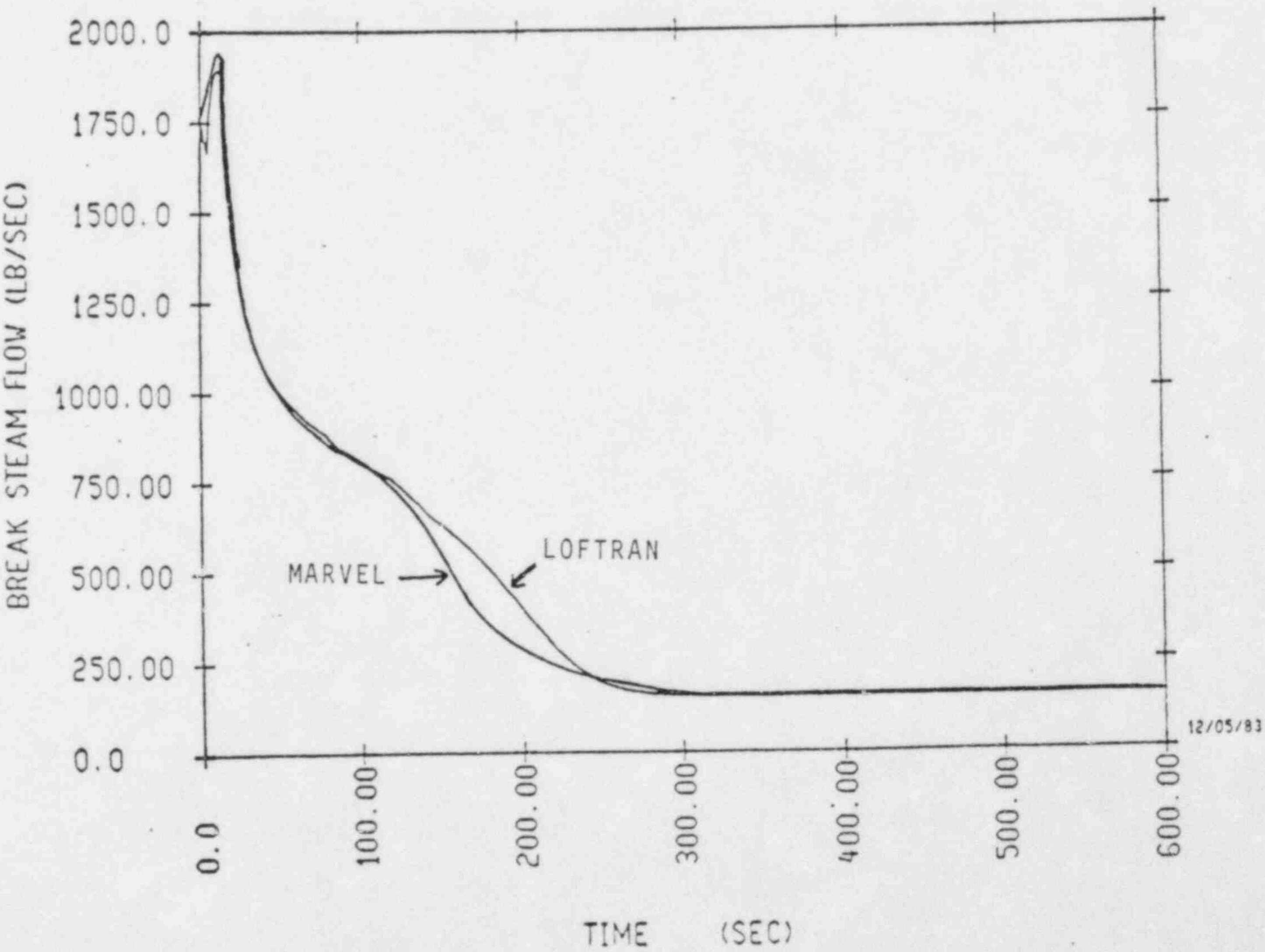


FIGURE A.1

LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

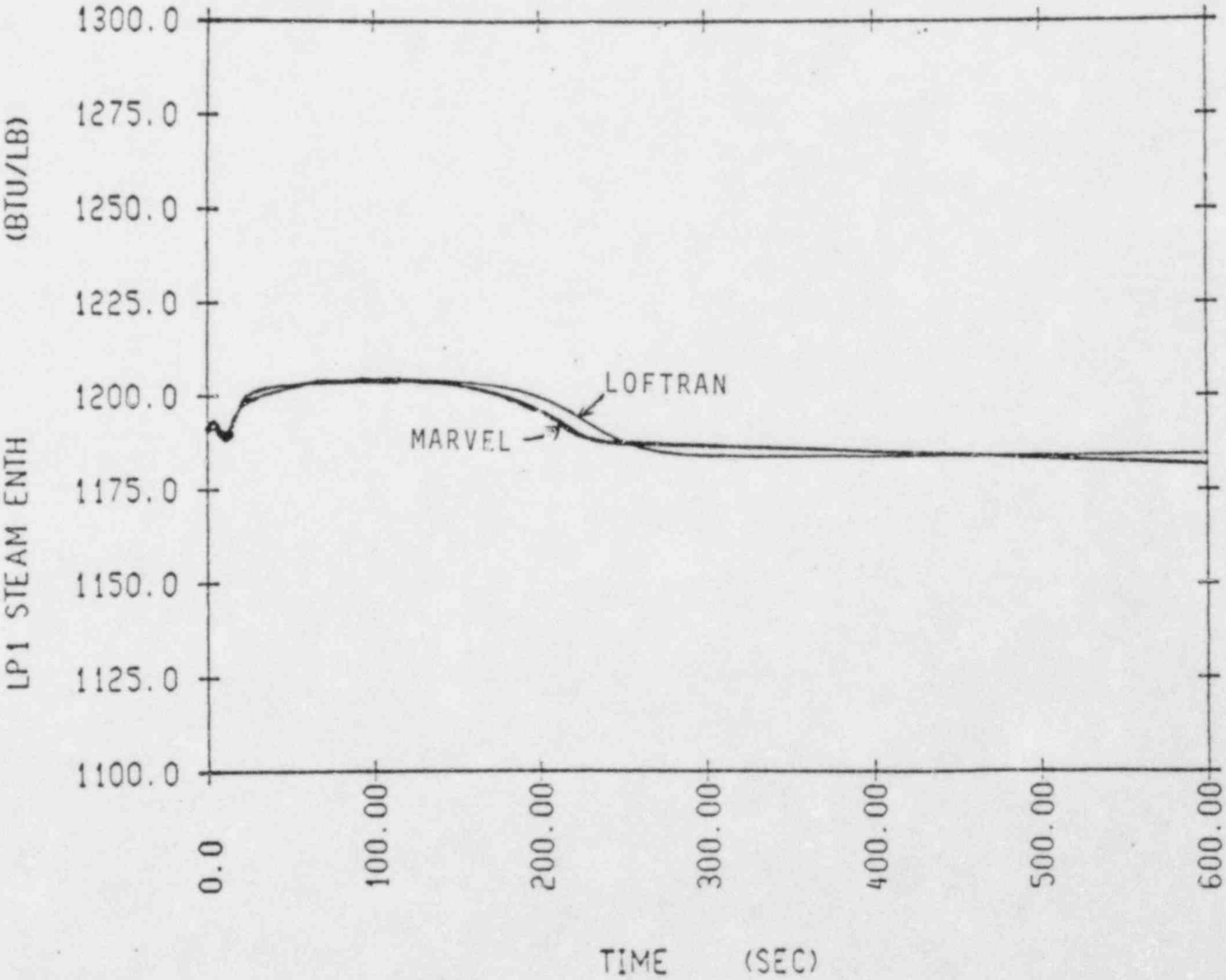


FIGURE A.2

METHODOLOGY FOR ADDRESSING SUPERHEATED STEAM RELEASES TO ICE CONDENSER CONTAINMENTS

Purpose

The purpose of this report is to document the information presented on March 19, 1984 in a meeting with the U.S. NRC Containment Systems Branch on the status of progress made in addressing the confirmatory item on the Catawba Nuclear Plant Safety Evaluation Report. This confirmatory item deals with the effects of superheated steam generator mass and energy releases following main steamline break accidents. Attachment 1 includes the list of attendees at the meeting and the overhead slides covered in the Westinghouse presentations.

Technical presentations were made describing the modeling of the steam generator and heat transfer from the uncovered tube bundle during the steam generator blowdown along with a description of the containment model and transient response. A proposed plan of action was also presented and discussed with the Staff. In accordance with that plan, this report represents the first milestone in the proposed plan of action. As committed to in the meeting, the appendices present proprietary information which relates to the specifics of the models and sensitivities that were not directly addressed in the meeting.

Attachment 2 is an explanation of, and refers to, the overhead slides (Figures) presented at the March 19 meeting.

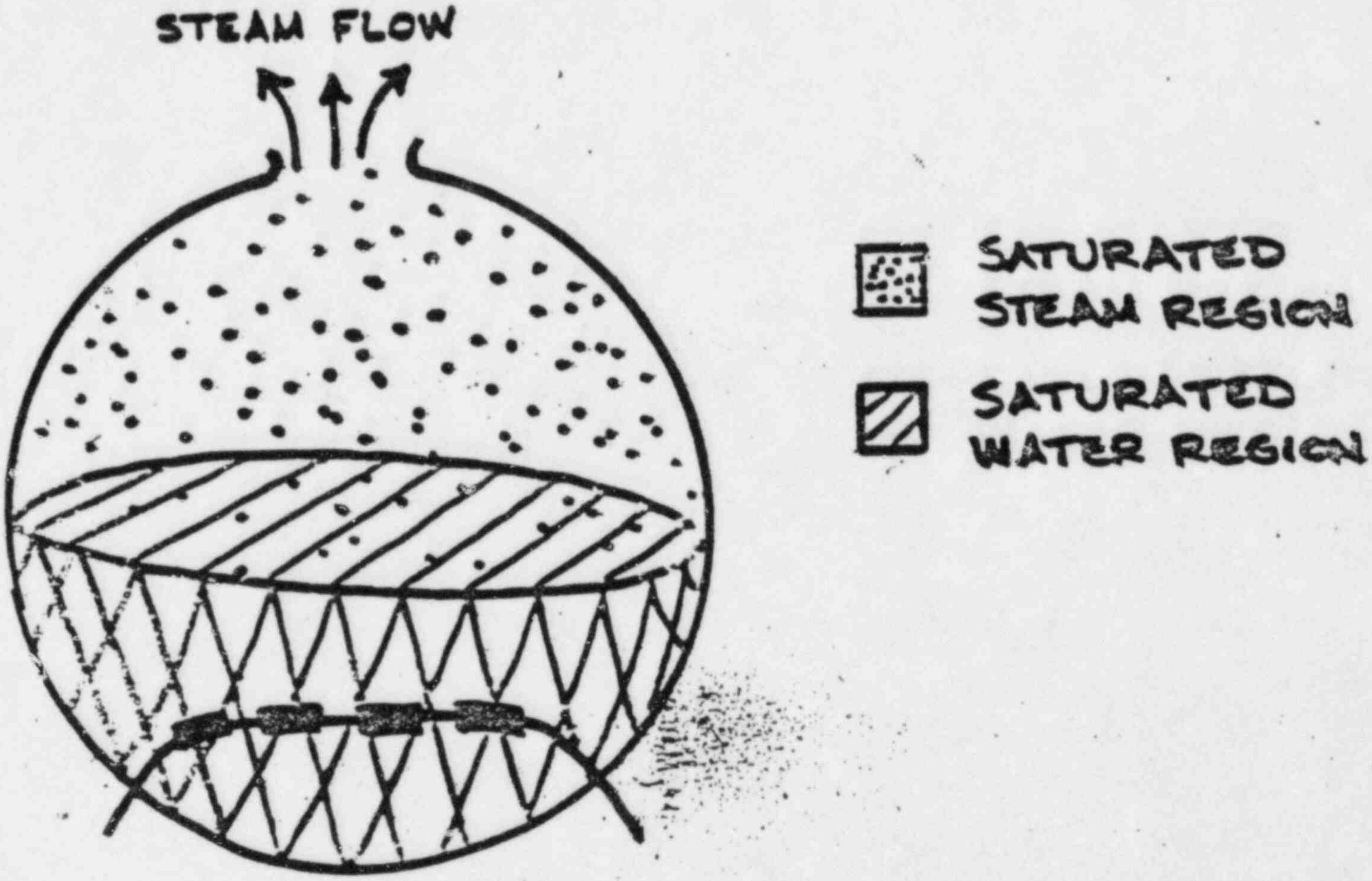
ATTACHMENT 1

Attendance at 3/19/84 Meeting w/ Duke + W on Main Steam Line Break Analysis

Name	Organization
K. N. JABBOUR	NRC/DL
R. O. SHARPE	DUKE/NPD
J. L. LITTLE	W NUCLEAR SAFETY
H.V. JULIAN	W NUCLEAR SAFETY
TJ Kenyon	NRC/DL
DS. Love	W NUCLEAR SAFETY
MP Osborne	W Nuclear Safety
P.A. Linn	W Nuclear Safety
L.E. Hochreiter	W Nuclear Safety
F.F. CADEK	W Nuclear Safety
F J Twogood	W NOD, project mgr.
S D Alexander	Duke, Design Engineering
R E Miller	Duke, Design Engineering
J. E. Wills	TVA, Nuclear Licensing Staff
B. AMELI	SERCH LICENSING STAFF, BECHT.
C. DRAUGHON	W NUCLEAR SAFETY
W.D. Crouch	TVA, Engineering Design
S. P. Nesbit	Duke, Nuclear Production Department staff
S.A. Swamy	W, NTD/SME
R.H. Owoc	W NTD/NUCLEAR SAFETY
J SHAPAKER	NRC/CSB
Jack Kudrick	" "
J. Pulsipher	NRC/CSB
C. Li	NRC/CSB
A. Notafrancesco	NRC/CSB

LOFTRAN MODEL

STEAM GENERATOR SECONDARY

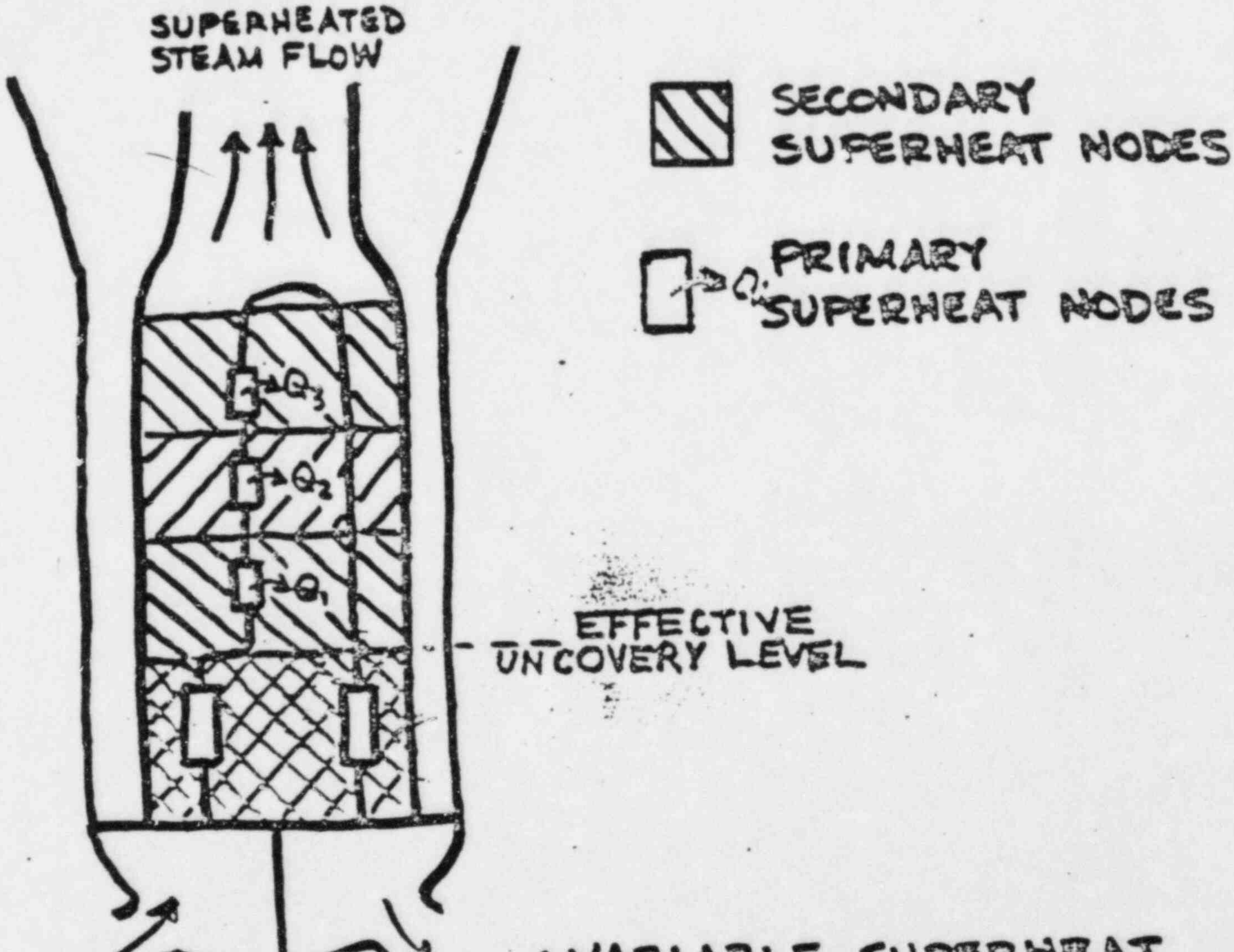


- SINGLE NODE, 2 REGION MODEL
- NO HEAT TRANSFER TO SATURATED STEAM REGION
- HEAT TRANSFER TO SATURATED WATER REGION IS MODIFIED FOR TUBE 'UNCOVERY'

FIGURE 1

LOFTRAN MODEL

SUPERHEAT HEAT TRANSFER



- VARIABLE SUPERHEAT NODES MODEL

- CONSTANT PRIMARY TEMPERATURE IN SUPERHEAT REGION ASSUMED FOR HEAT TRANSFER CALCULATIONS

- CALCULATED SUPERHEAT HEAT TRANSFER ACCOUNTED FOR IN PRIMARY TRANSIENT

FIGURE 2

TUBE UNCOVERY

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

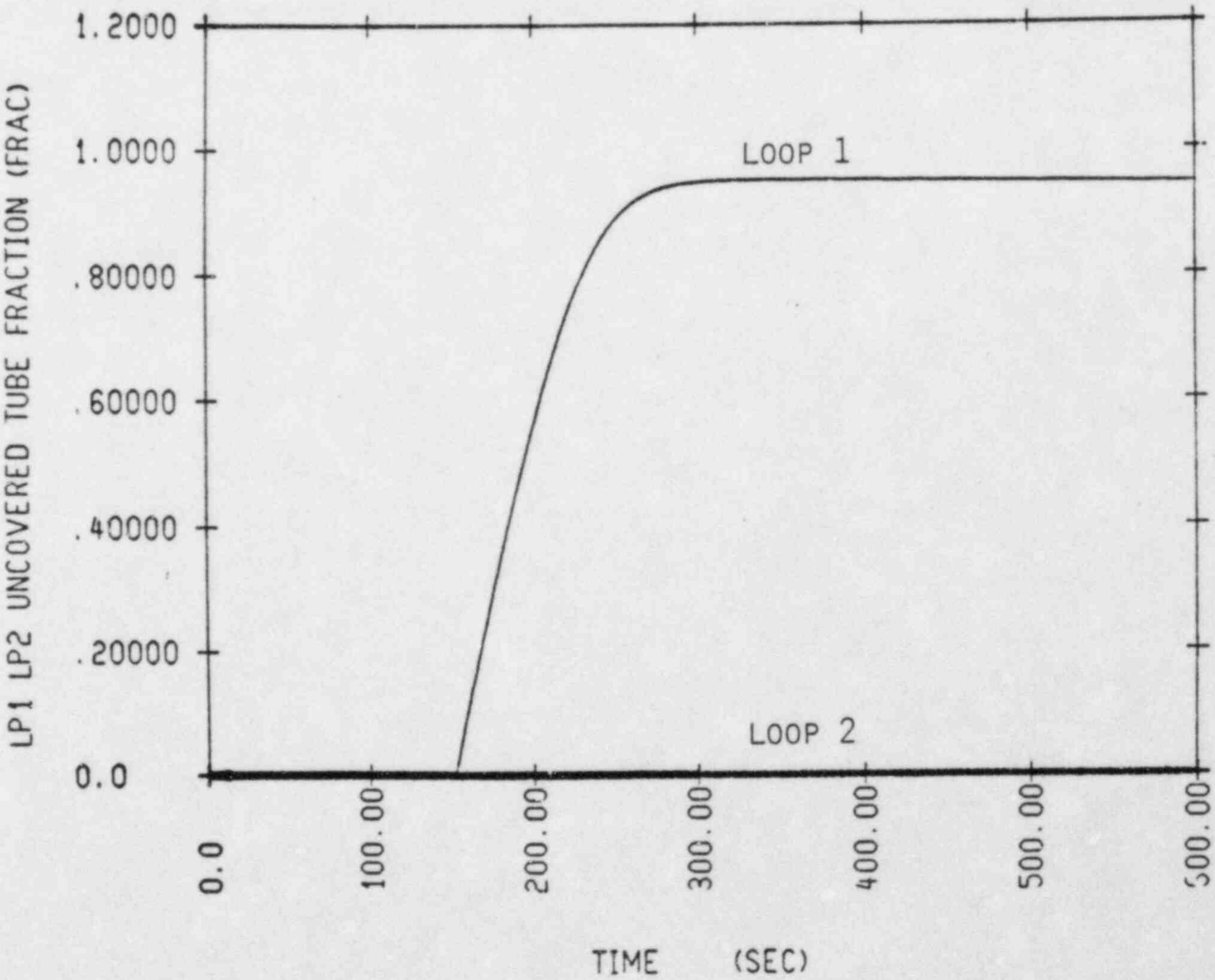


FIGURE 3

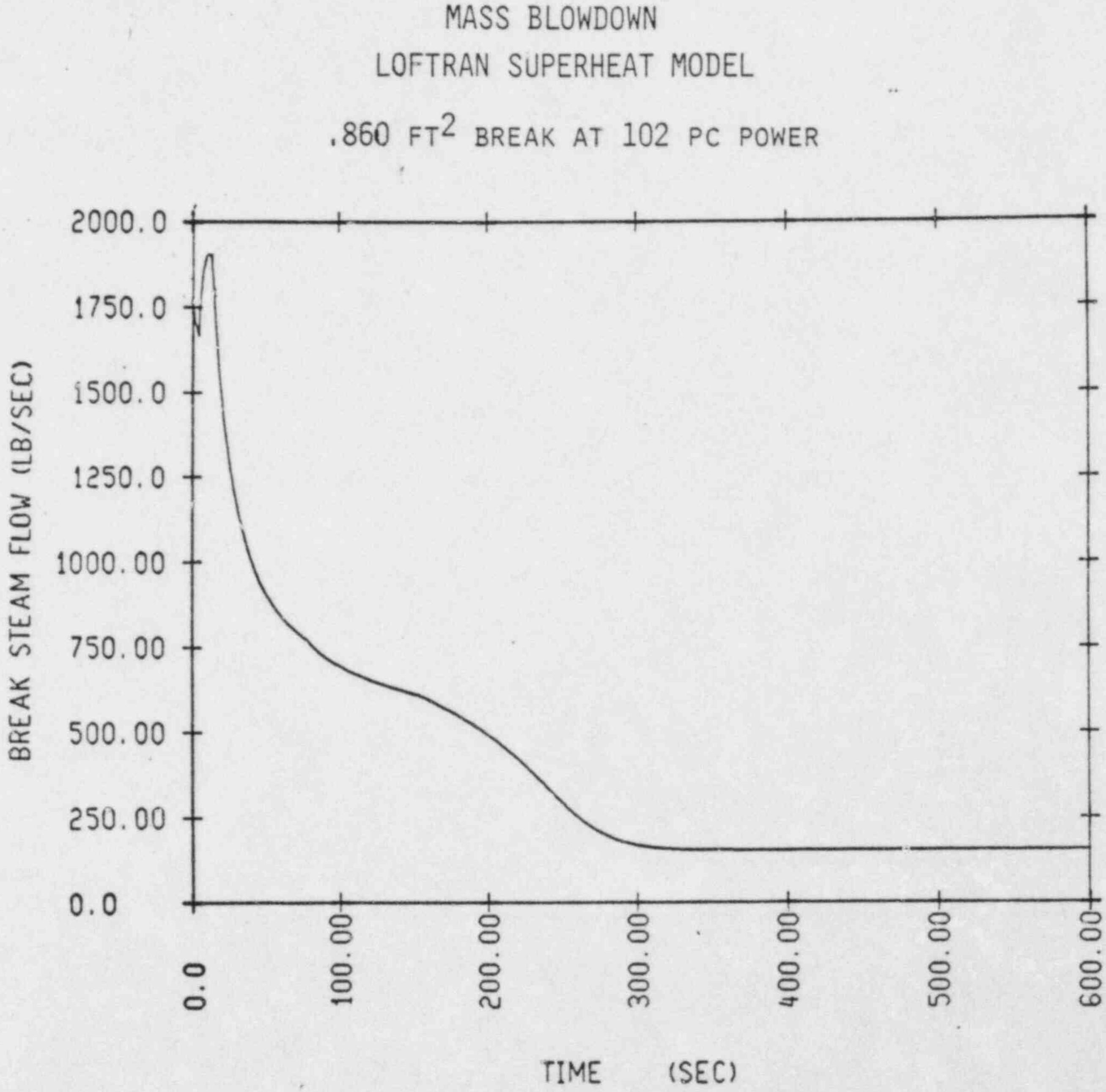

MASS BLOWDOWN
LOFTRAN SUPERHEAT MODEL
.860 FT2 BREAK AT 102 PC POWER
2000.0
1750.0
1500.0
1250.0
1000.00
750.00
500.00
250.00
0.0
BREAK STEAM FLOW (LB/SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00
TIME (SEC)

FIGURE 4

ENERGY RELEASE

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

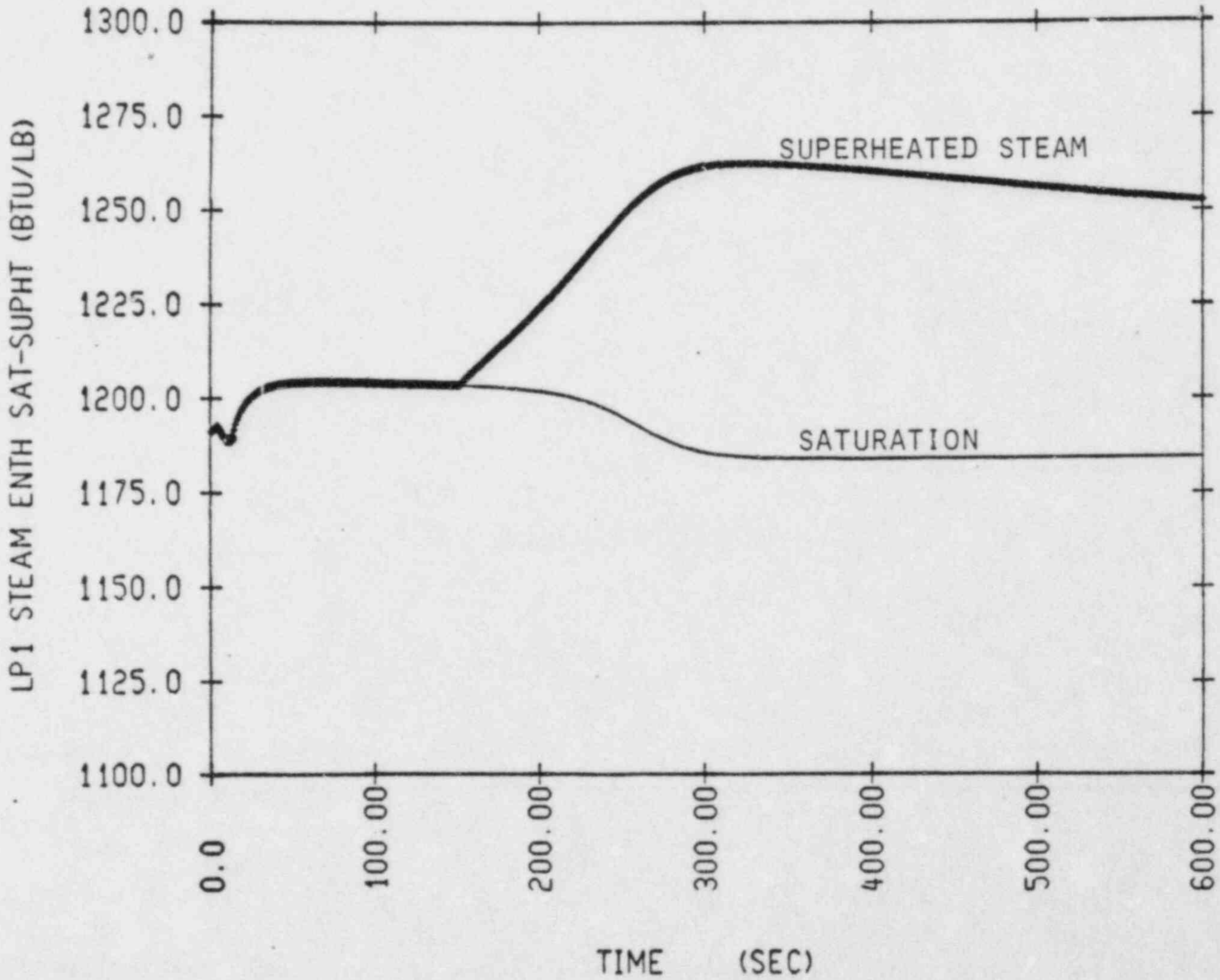


FIGURE 5

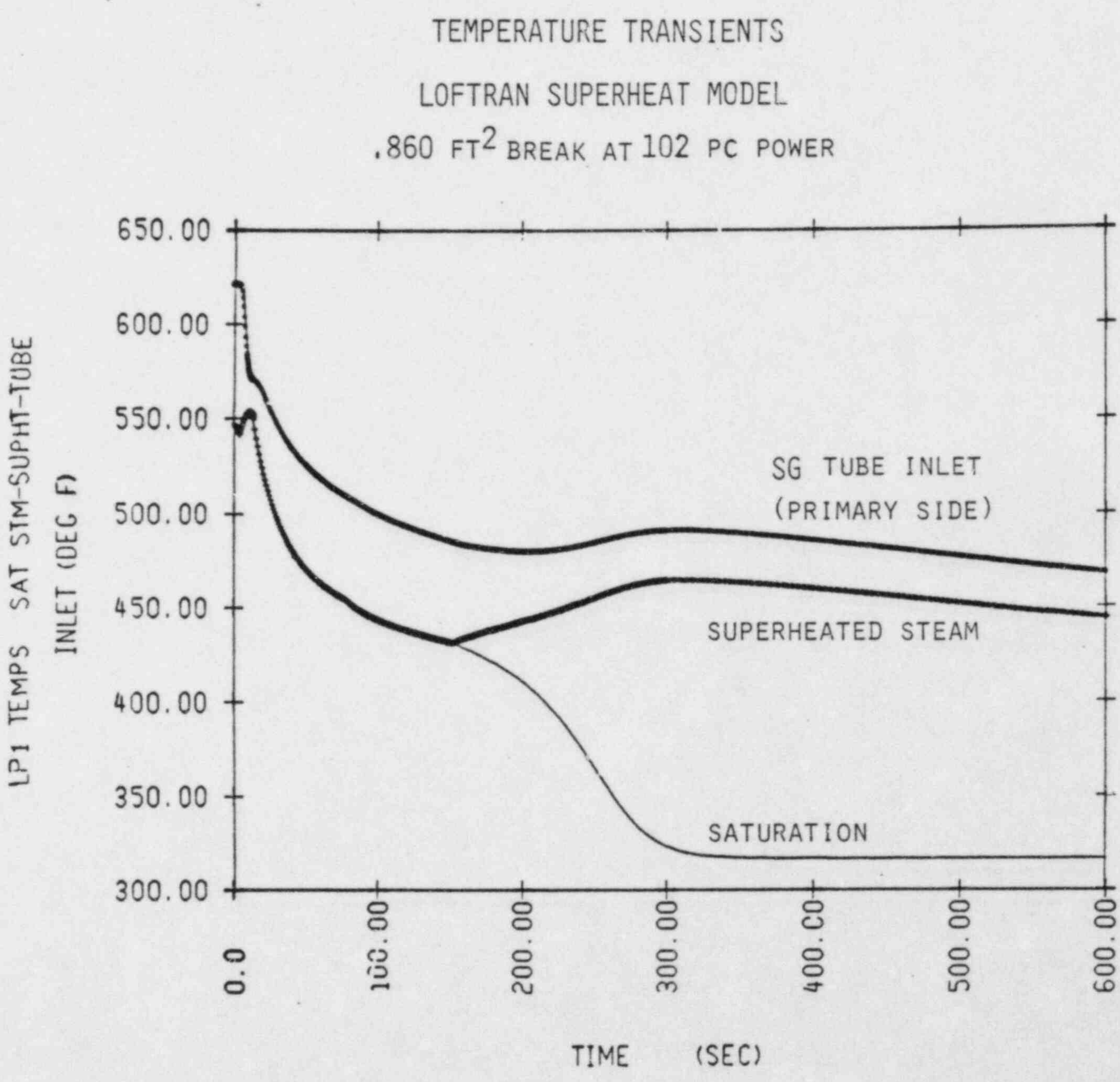
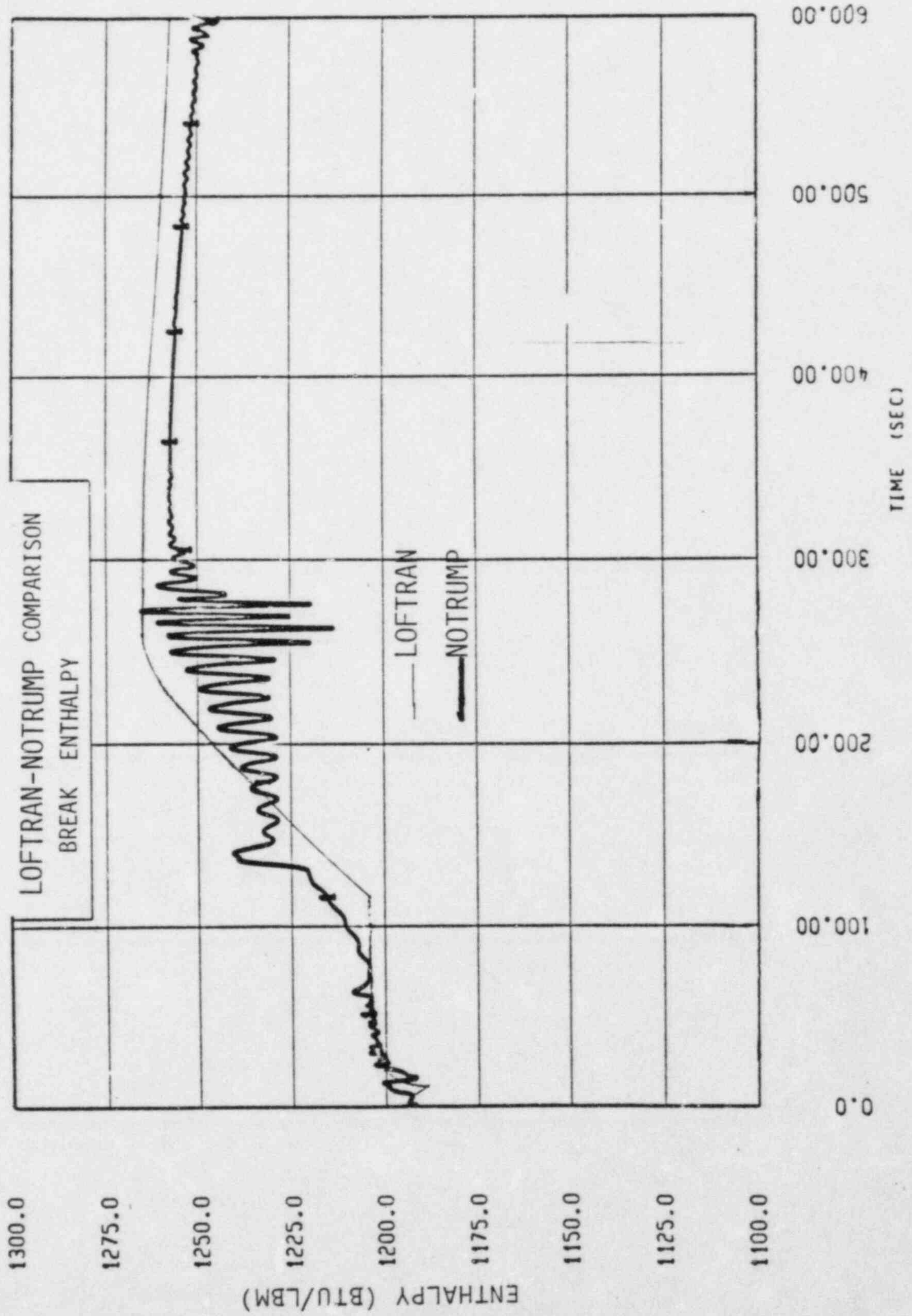

TEMPERATURE TRANSIENTS
LOFTRAN SUPERHEAT MODEL
.860 FT2 BREAK AT 102 PC POWER
650.00
600.00
550.00
500.00
450.00
400.00
350.00
300.00
LP1 TEMPS SAT STM-SUPHT-TUBE
INLET (DEG F)
SG TUBE INLET
(PRIMARY SIDE)
SUPERHEATED STEAM
SATURATION
0.0
100.00
200.00
300.00
400.00
500.00
600.00
TIME (SEC)

FIGURE 6



LOFTRAN-NOTRUMP COMPARISON
BREAK ENTHALPY
LOFTRAN
NOTRUMP
ENTHALPY (BTU/LBM)
1300.0
1275.0
1250.0
1225.0
1200.0
1175.0
1150.0
1125.0
1100.0
TIME (SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00

FIGURE 7

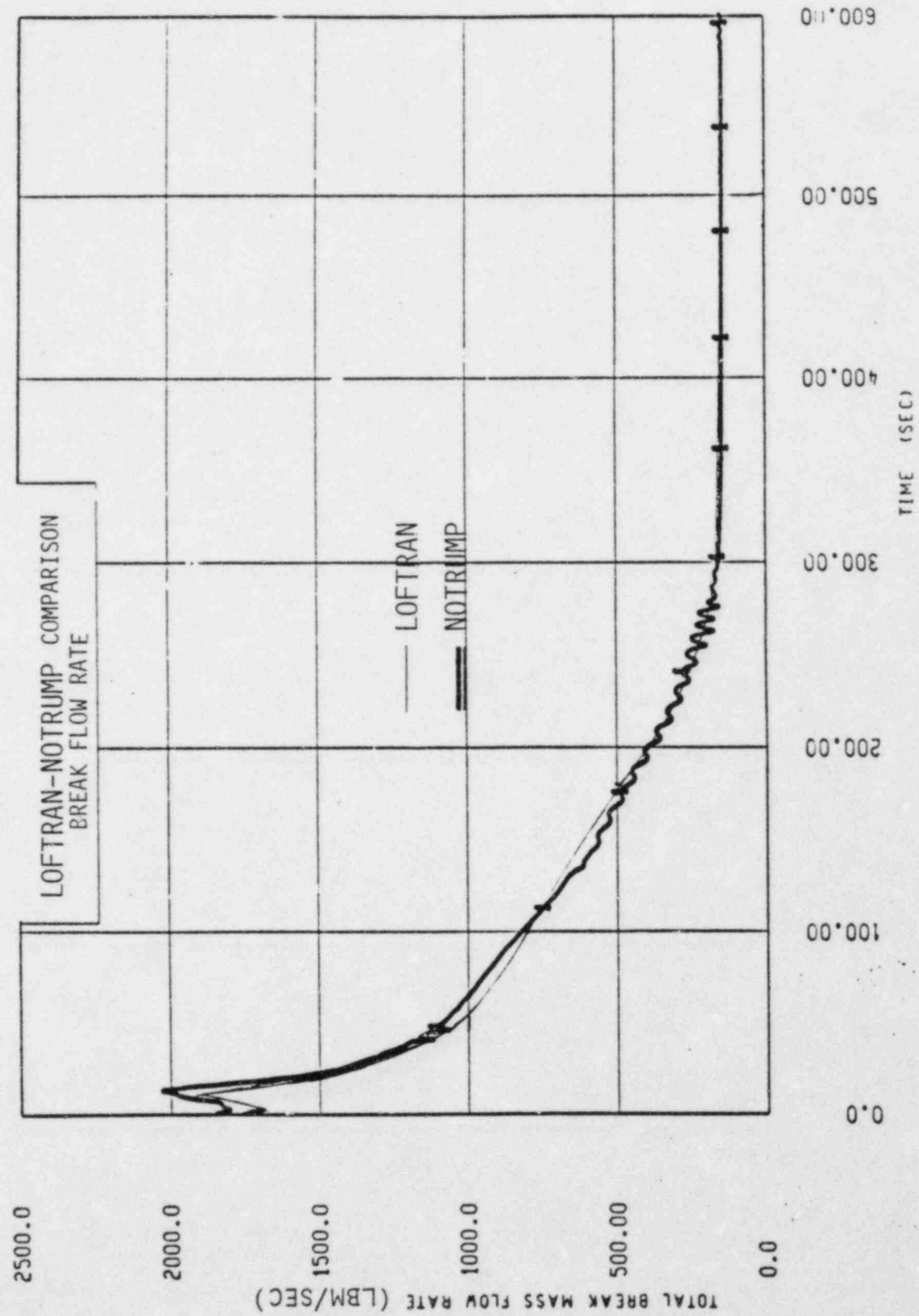

LOFTRAN-NOTRUMP COMPARISON
BREAK FLOW RATE
LOFTRAN
NOTRUMP
TOTAL BREAK MASS FLOW RATE (LBM/SEC)
2500.0
2000.0
1500.0
1000.0
500.00
0.0
TIME (SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00

FIGURE 8

EFFECTS OF
ANALYSIS ASSUMPTIONS

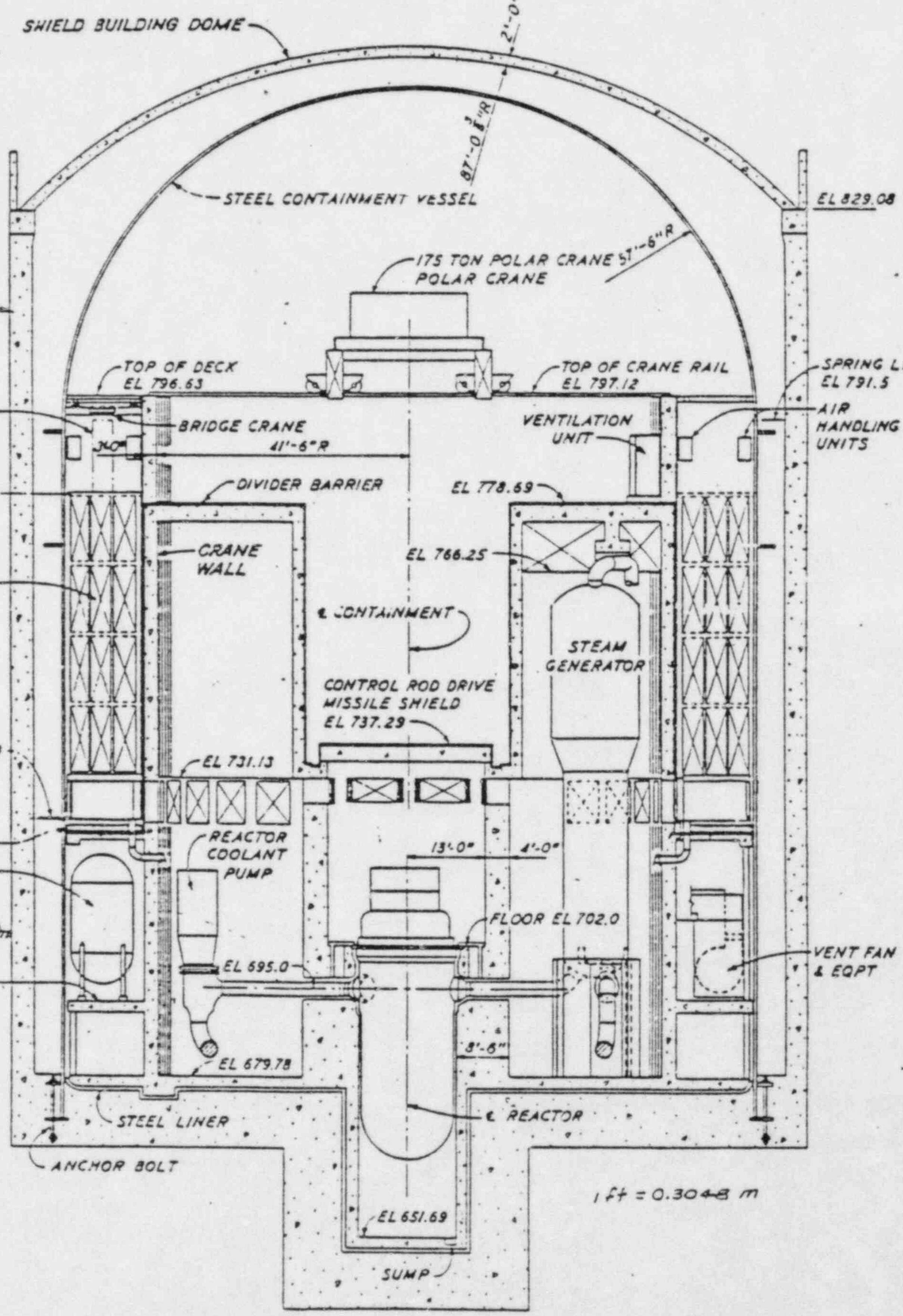
- INITIAL STEAM GENERATOR INVENTORY
- AUXILIARY FEEDWATER FLOWRATE
- FEEDWATER SYSTEM FAILURES
- PROTECTION SYSTEM ERRORS

FIGURE 9

ADDITIONAL MODEL CONSIDERATIONS

- LIQUID-STEAM INTERACTION
- IMPROVED STEAM HEADER MODEL
- HEAT TRANSFER THROUGH TUBE WRAPPER
- TEMPERATURE DROP IN PRIMARY SUPERHEAT NODES
- OPTIONAL VOID CORRELATIONS

FIGURE 10



Reactor Building Elevation

FIGURE 11

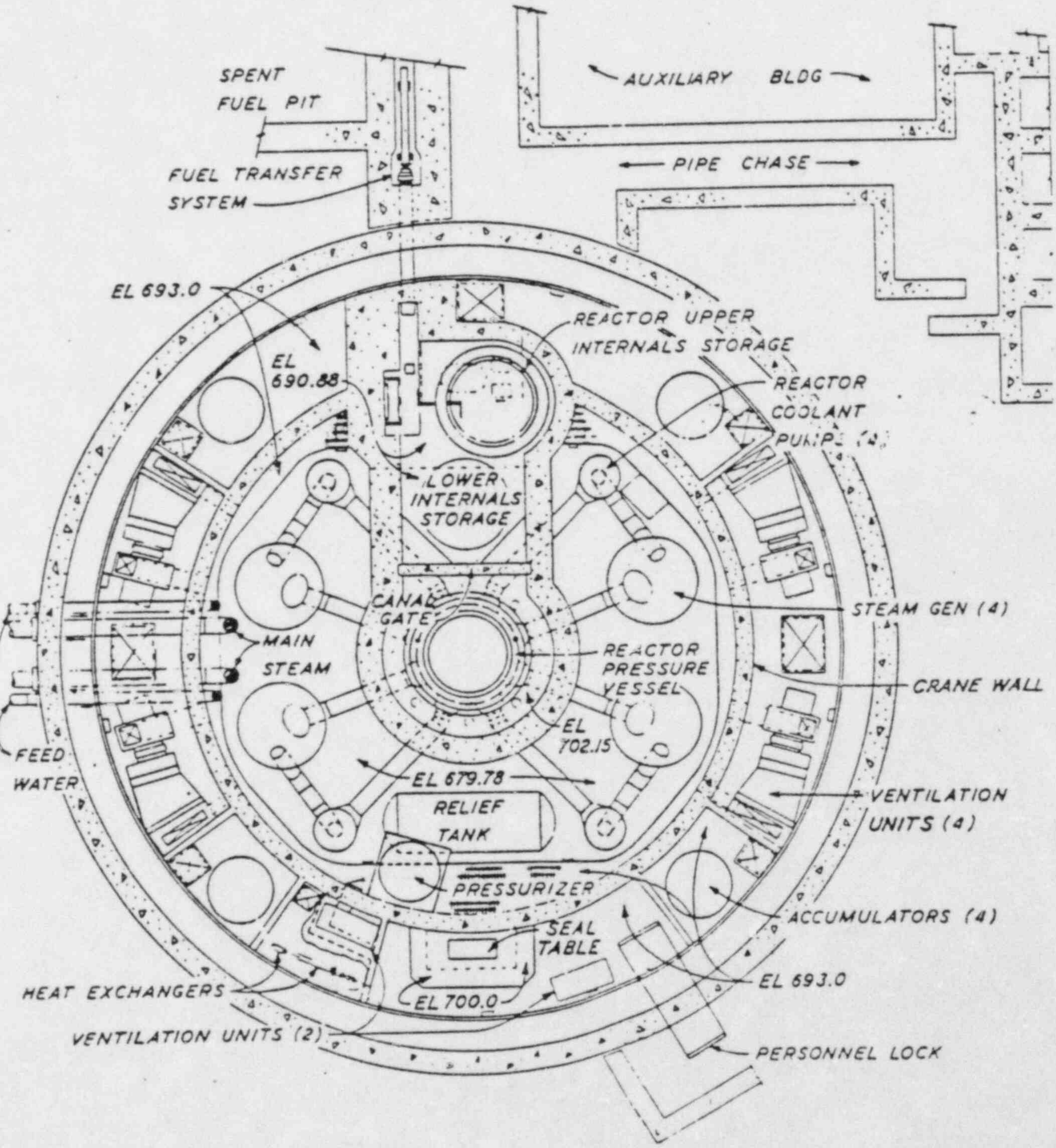


Figure 3.8.3-7 Plan-Lower Compartment

FIGURE 12

LOTIC-3 CONTAINMENT CODE

* 4 NODE CONTAINMENT MODEL
* CONDENSATE/REVAPORIZATION MODELS
  - LARGE BREAK (TOTAL REVAPORIZATION)
  - SMALL BREAK (CONVECTIVE HEAT FLUX)
* WALL HEAT TRANSFER MODEL
* MODELS SUMP RECIRCULATION SYSTEM

FIGURE 13

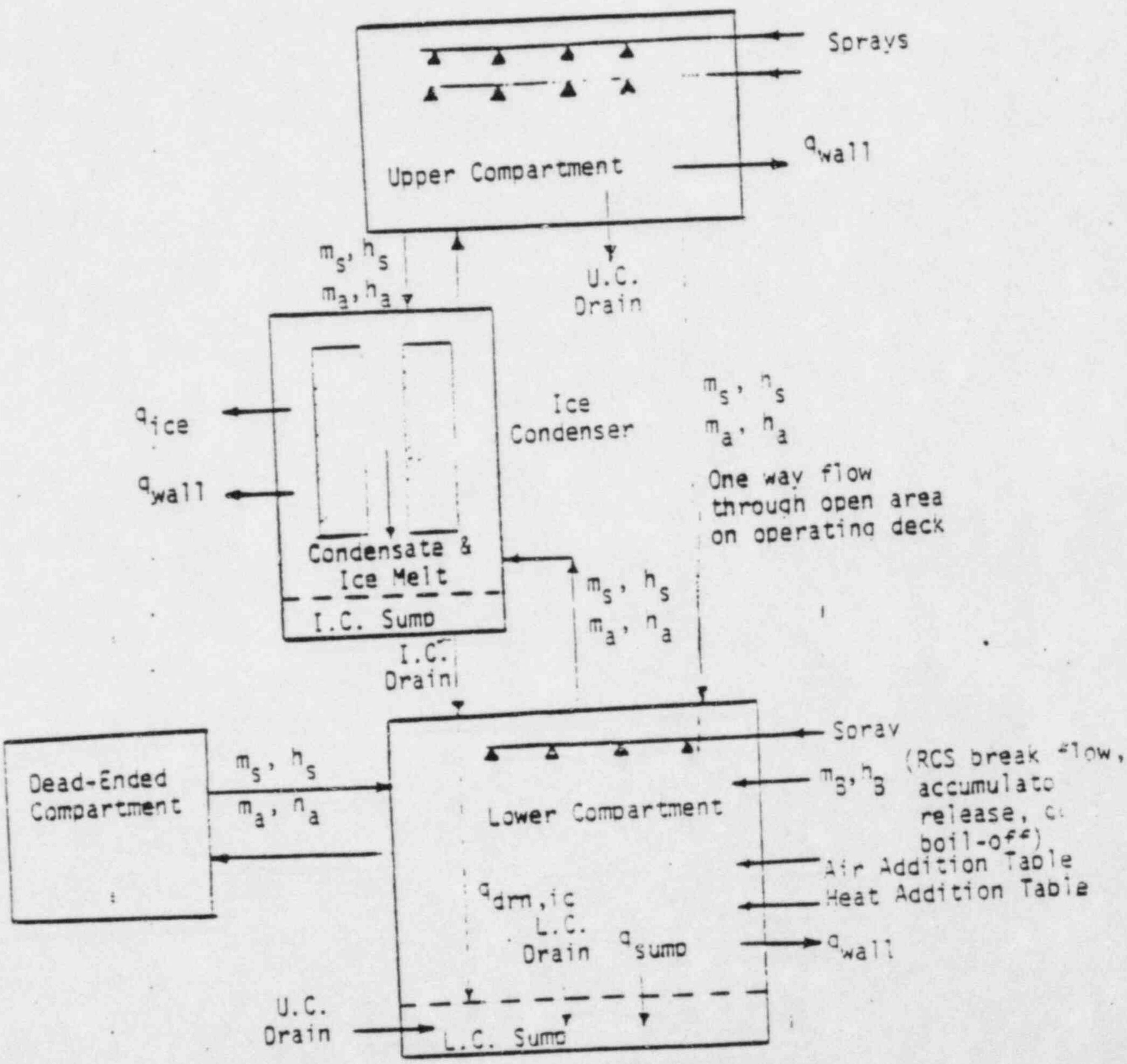


FIGURE 3.3 MASS AND ENERGY FLOW DIAGRAM
FOR THE COMPARTMENTS

FIGURE 14

LOTIC-3 - METHOD OF SOLUTION

- SOLVES CONSERVATION OF MASS, ENERGY, AND MOMENTUM FOR UPPER, LOWER, AND ICE CONDENSER REGIONS

- ONCE NEW LOWER COMPARTMENT CONDITIONS ARE DETERMINED, CONSERVATION EQUATIONS ARE SOLVED FOR THE DEAD-ENDED COMPARTMENT AND FOR THE FLOW RATE BETWEEN THE TWO COMPARTMENTS

FIGURE 15

TYPICAL CONTAINMENT TEMPERATURE TRANSIENT (DRAINS MODELLED)

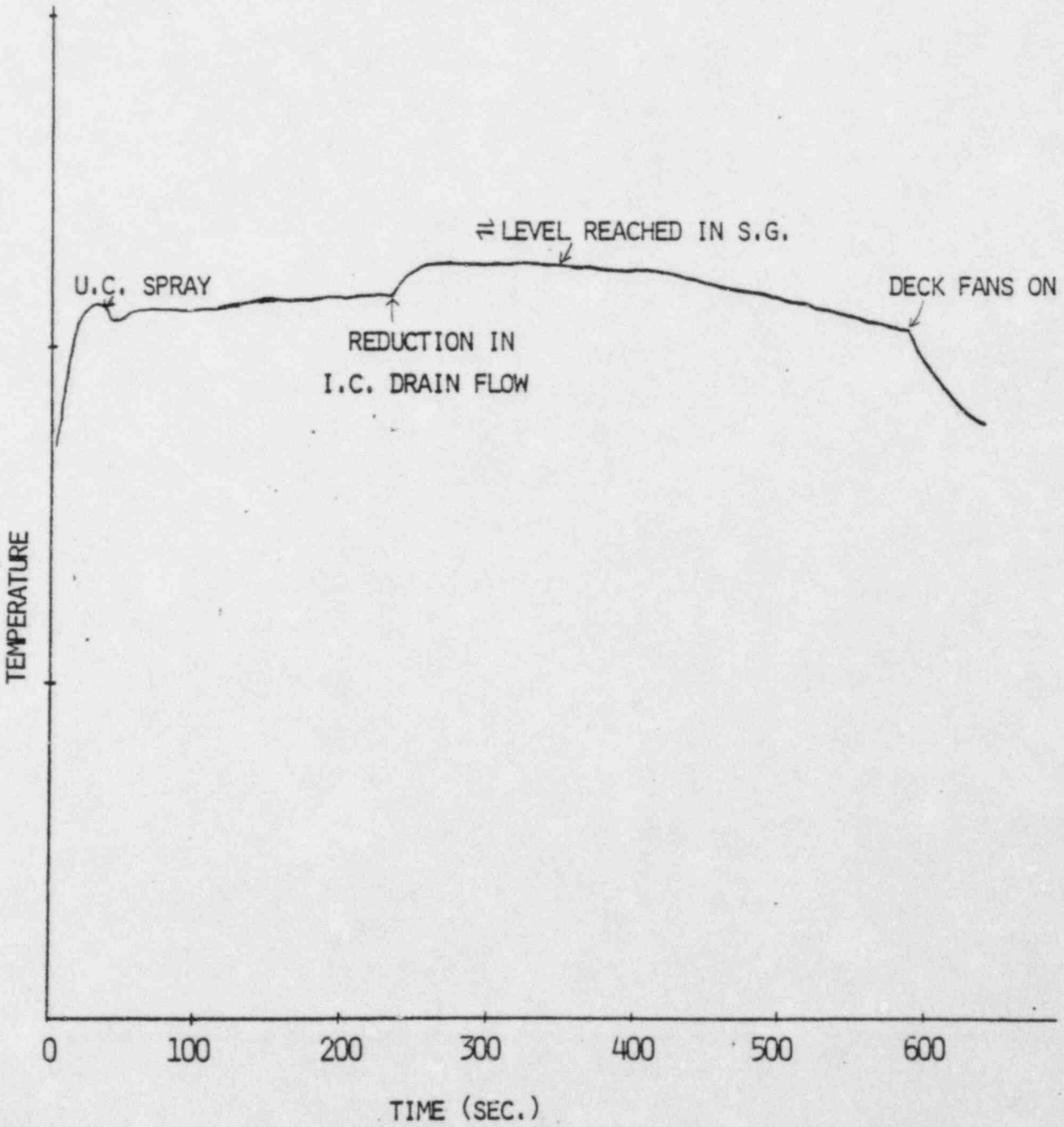


FIGURE 16

MODIFICATIONS TO THE CONTAINMENT MODEL

WALL HEAT TRANSFER MODEL

CONVECTIVE HEAT FLUX MODEL

ICE CONDENSER DRAIN MODEL

DEAD ENDED COMPARTMENT MODEL

FIGURE 17

WALL HEAT TRANSFER MODEL

ORIGINAL LOTIC MODEL

$$q'' = h_{Tagami} (T_{SAT} - T_{Wall})$$

MODIFIED LOTIC MODEL

$$q'' = h_{COND} (T_{SAT} - T_{Wall}) + h_{conv} (T_{Bulk} - T_{ref})$$

$$h_{COND} = f\left(\frac{m_{STEAM}}{m_{air}}\right)$$

$$h_{CONV} = f(T_{Wall}, T_{SAT})$$

$$T_{ref} = f(T_{Wall}, T_{SAT})$$

FIGURE 18

CONVECTIVE HEAT FLUX MODEL

ORIGINAL LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X}\right]$$

MODIFIED LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X_{SAT}}\right]\left[1 - \frac{h_{CONV}(T_{BULK} - T_{ref})}{q_{TOTAL}}\right]$$

FIGURE 19

ICE CONDENSER DRAINS

-APPROXIAMATELY 20 ICE CONDNESER DRAINS

-DRAIN ELEVATION IS ABOUT 40 FEET FROM FLOOR

-DRAIN PIPE IS 1 FOOT IN DIAMETER

-FOR TYPICAL MSLB TRANSIENT, DRAIN FLOW VARIES FROM 4000 LB/S TO 500 LB/S

FIGURE 20

ICE CONDENSER DRAIN MODEL

-CONDENSATION OCCURS AT THE SURFACE OF THE STREAM

-FLOW IS WELL MIXED

$$q = h A \Delta T$$

-MODEL AS A WALL AT A CONSTANT TEMPERATURE

-A IS THE SURFACE AREA OF THE STREAM

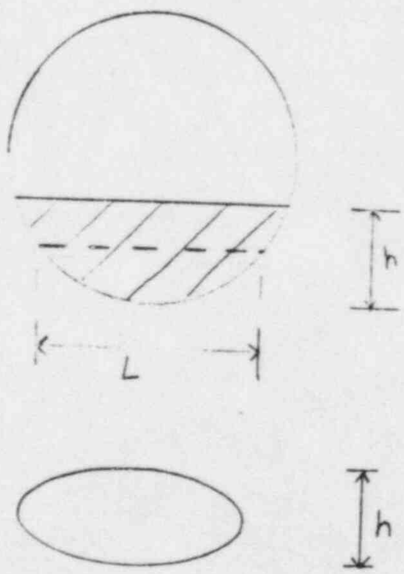
-h IS A CONDENSING TYPE HEAT TRANSFER COEFFICIENT

FIGURE 21

CALCULATION OF THE STREAM FLOW AREA

$$A = n(P \times L) = 20(P \times 40) = 800\,P$$

WHERE P IS THE PERIMETER OF THE STREAM



$$P \approx 2\pi \sqrt{\frac{\left(\frac{L}{2}\right)^2 + \left(\frac{h}{2}\right)^2}{2}}$$

FIGURE 22

MODIFIED LOTIC DRAIN MODEL

-WALL WITH A VARIABLE AREA

$$q = h_{COND} A (T_{BULK} - T_{SAT})$$

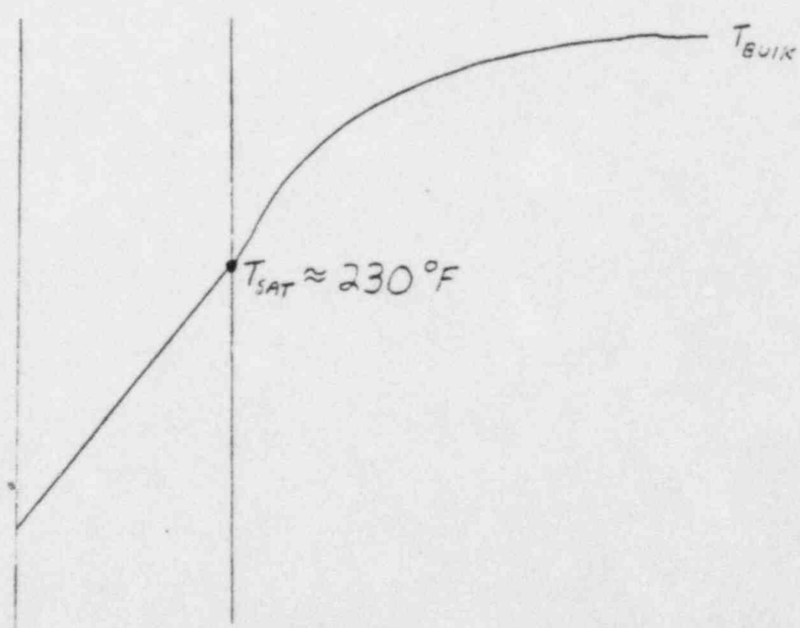


FIGURE 23

DEAD ENDED COMPARTMENT MODEL

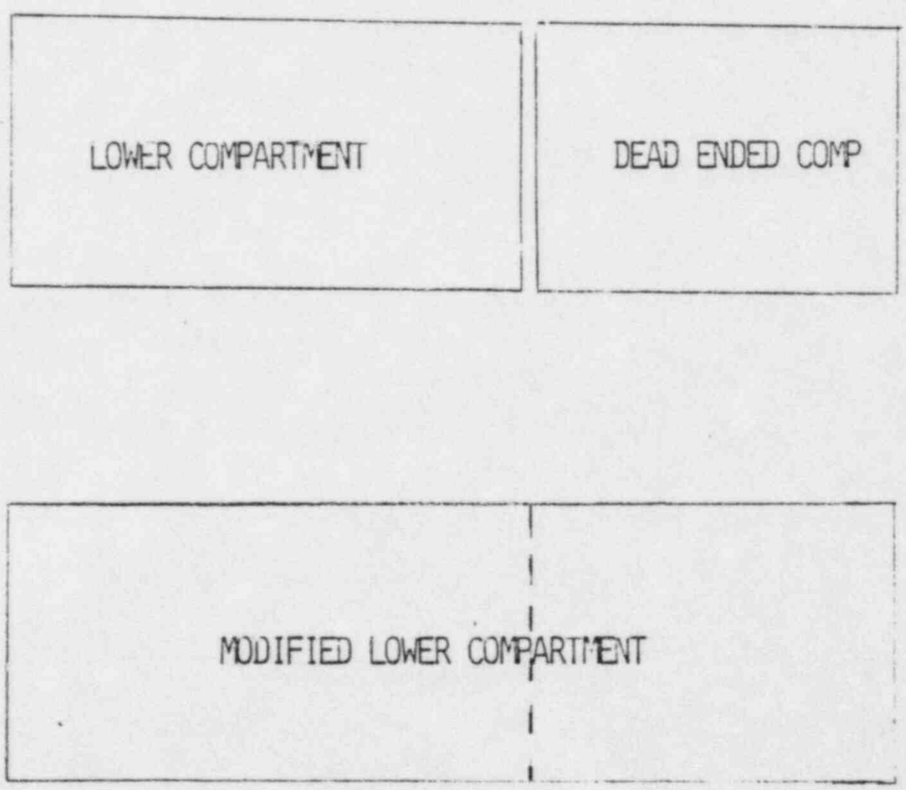


FIGURE 24

CATAWBA RESULTS

- 102% POWER
- 0.86 FT^2 BREAK
- MAXIMUM AFW FLOW
- FSAR HEAT SINKS
- MAXIMUM S.G. INITIAL MASS

$T_{MAX} = 324°F$ (LOWER COMPARTMENT)

FIGURE 25

ADDITIONAL MODEL CONSIDERATIONS

- WALL HEAT TRANSFER MODEL

- DRAIN MODEL

- DEAD ENDED COMPARTMENT MODEL

FIGURE 26

ATTACHMENT 2

OUTLINE OF THE REPORT

I. Introduction

II. Mass & Energy Release Modeling

III. Containment Modeling

IV. Action Plan

V. Appendix

VI. References

I. Introduction

During the Containment Systems Branch review of the Westinghouse topical report, "Mass and Energy Releases Following a Steam Line Rupture", WCAP-8822 (Proprietary) the Staff noted that heat transfer to steam from the uncovered portion of the steam generator tube bundle was unaccounted for and questioned the effect upon the calculated mass/energy release and the subsequent effect on the containment temperature response. Westinghouse responded in a letter to the Staff (NS-EPR-2563, February 14, 1982, E.P. Rahe to J. R. Miller) that it had determined the impact of the effect by conservatively treating the maximum amount of superheat to be the difference between the primary coolant temperature and the steam temperature. The letter noted that there would be an insignificant effect on dry type containments and that, based on the conservative model used, there would be an expected increase in containment temperature for ice condenser type containments. In the Containment Systems Branch Safety Evaluation Reports on the topical report and the Catawba Plant Safety Evaluation Report, the Staff required that a more refined steam line break analysis be performed to determine the effect on containment temperature which might impact the environmental qualification envelope used for safety related equipment.

Since that time, Westinghouse has investigated the effects of tube bundle heat transfer from the viewpoint of a more refined modeling approach. Subject to the final review and approval of the NRC Staff, the efforts and results obtained to date indicate that there is little impact on the containment response from the effects of the additional tube bundle heat transfer to steam.

II. Mass and Energy Release Modeling

A. LOFTRAN Computer Code

Mass/energy releases are calculated using the LOFTRAN code. LOFTRAN is a FORTRAN language, digital computer code, developed to simulate transient behavior in a multi-loop pressurized water reactor system. The program simulates neutron kinetics, thermal hydraulic conditions, pressurizer, steam generators, reactor coolant pumps, and control and protection systems. Up to four independent loops may be modeled. LOFTRAN is used for analysis of non-LOCA transients and is documented in Reference 3.

The model of importance to blowdown calculations is the steam generator model. The primary side contains multiple nodes to model the tube bundle. The standard LOFTRAN steam generator secondary side model, (Figure 1), is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur only to saturated water. If tube uncovery occurs the amount of surface area available for heat transfer is accordingly reduced. The 'OFTRAN code incorporates a more detailed steam generator model which is used to predict tube bundle uncovery.

B. LOFTRAN Model for Superheated Steam

The LOFTRAN code has been modified to account for heat transfer to steam from the uncovered tube bundle region. (Figure 2). In the <u>modified</u> version of LOFTRAN, all heat transfer occuring in the uncovered region is assumed to add superheat to the steam exiting the steam generator. The primary side temperature in the uncovered tube region is conservatively assumed to remain constant through the nodes which are uncovered. In reality, there will be a drop in temperature due to heat removal to the secondary side, but this is expected to be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is discussed in the Appendix. This correlation bases the heat transfer on the difference between the tube wall surface temperature and the bulk steam temperature in the region. In the LOFTRAN modification, the conservative assumption is made that no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall surface temperature of the tube is assumed equal to the primary fluid temperature.

The modified version of LOFTRAN automatically determines the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the <u>modified</u> LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient

calculation. The superheat/tube uncovery modeling is applicable to all steam generators.

Figures 3 through 6 show typical results for a 0.86 ft^2 steamline break from 102 percent power using the modified version of LOFTRAN. Figure 3 shows the fraction of tube uncovery versus time with uncovery of Loop 1 (faulted) starting at 152 seconds into the transient. At approximately 300 seconds, the uncovery transient reaches an equilibrium point where the steam flow out of the steam generator matches the auxiliary feedwater flow into the steam generator. Additionally, the tube uncovery transient for Loop 2 (non faulted) is plotted but shows no tube uncovery for the entire transient. Figure 4 presents the steam flow transient for this case. Figure 5 includes plots of both the superheated steam enthalpy and the saturation enthalpy for the Loop 1 steam generator. Figure 6 includes the Loop 1 temperatures for the steam generator tube inlet (primary side), steam exit temperature (superheated steam), and the saturation temperature for the steam pressure.

C. NOTRUMP Model Comparison

The NOTRUMP computer code (Reference 4) was used to verify the LOFTRAN modeling of superheat. The computer code was originally developed to analyze transients of secondary systems with two-phase conditions. In the past, it has been used to analyze various transients in the primary and secondary coolant systems. NOTRUMP has recently undergone major revisions to enable it to model non-equilibrium nodes (i.e., separate liquid temperature and steam temperature modeling). Using NOTRUMP, the steam generator can be broken down into sufficient nodes to model the nonequilibrium effects of the steam generator, as well as the tube region during uncovery. NOTRUMP can model all modes of heat transfer associated with a steamline break transient, including heat transfer from the uncovered tubes to the superheated steam and the feedback effects between the primary and secondary sides. The two phase mixture level calculation accounts for primary to secondary heat transfer and the swell associated with rapid depressurization of the steam generator during the blowdown.

A comparison of LOFTRAN and NOTRUMP blowdown results is presented in Figures 7 and 8. The mass releases shown in Figure 8 show excellent agreement. The LOFTRAN prediction of superheat enthalpy is slightly higher than NOTRUMP, while the predicted time of tube uncovery is somewhat later. NOTRUMP shows a chugging effect during the uncovery phase of the blowdown. This is believed to be in part due to oscillations in the flow link between the downcomer region and the steam dome region. (The flow link is the drain path for the moisture separators to the downcomer region.) With the flow direction towards the downcomer, superheated steam goes into the downcomer region and is condensed. This alternates with a flashing of a portion of the water volume in the downcomer region. This raises the pressure of the downcomer, resulting in a flow reversal in the link with saturated steam from the downcomer mixing with the superheated steam in the dome. This mixing results in the variations in the superheat enthalpy seen in Figure 7. Although LOFTRAN does not show the enthalpy variation since the detailed modeling of the downcomer and dome are not included, the overall agreement with NOTRUMP is very good.

D. **Effects Of Analysis Assumptions**

The effects of superheated steam are dependent upon the occurrence and extent of tube uncovery. The major parameters affecting tube uncovery are: initial steam generator inventory, auxiliary feedwater flowrate, assumed feedwater system failures, and protection system errors. Variations in these parameters are in the process of being evaluated for their effects on the containment temperature response (Figure 9).

Refinements in the mass and energy release modeling (Figure 10), are being evaluated and several areas show a potential for reducing the degree of superheat being generated. Some of these areas are:

- Evaluation of liquid-steam interactions such as the phenomenon of tube support plate flooding and heat transfer across the tube wrapper from the superheated steam to the auxiliary feedwater flowing down outside the tube wrapper.

- A more detailed steam header model in LOFTRAN.

- Modeling temperature drops in the primary superheat nodes.

- Evaluating other void correlations for use in predicting tube uncovery.

III. Containment Modeling

A. Description of Containment

The general phenomena taking place inside an ice condenser containment during a steamline break transient can be described utilizing a typical ice condenser elevation drawing (Figure 11). Steam is discharged to the main (or lower) compartment where heat is removed by the internal structures, steam flow to the ice condenser, and the ice condenser drain water. The dead ended compartments are the regions which are located below the ice condenser and outside the crane wall (Figure 12). Air is discharged from the main compartment to the dead ended compartment and ice condenser so that the resulting steam to air ratio is that region is much higher than in dry containments. At ten minutes following the containment hi-2 signal, deck fans are actuated which direct air flow from the upper compartment to the dead-ended compartments. Most of the safety related equipment is located in the dead-ended compartments although some equipment and cabling are located in the main compartment.

B. Containment Models

Figure 13 outlines the major models and assumptions utilized in the LOTIC-3 containment code. In the currently approved version of LOTIC-3 documented in Reference 5, four distinct regions of the containment are modeled; the lower compartment, the dead-ended compartment, the ice condenser, and the upper compartment. Two condensate/revaporization models are used depending on the size of the break. For large steamline breaks, 100% condensate revaporization is assumed. For small steamline breaks, a convective heat flux model is used which calculates partial revaporization during the transient. The wall heat transfer model utilizes the Tagami heat transfer correlation for condensation heat transfer and the convective heat flux model derived from the work of Sparrow (Reference 6) which calculates the convective heat transfer for small steamline breaks. The sump recirculation system is only modeled for the large break LOCA transient containment response.

Figure 14 shows the four regions modeled with the mass and energy flows that can be assumed in the analysis. The Catawba nuclear plant does not have lower compartment sprays and they are not modeled in the analysis. Superheat heat transfer is conservatively assumed to be zero for the steamline break containment analysis. In the model described in Reference 5, wall heat transfer is not modeled in the dead-ended compartments although these regions do contain structures which will remove heat. The analysis does include the upper compartment sprays, flow through the ice condenser, deck fan flow, and flow to the dead-ended compartments.

LOTIC-3 solves the conservation of mass, energy, and momentum equations for upper, lower, and ice condensor regions (Figure 15). After the new lower compartment conditions are determined, conservation equations are solved for the dead ended compartment and the flow rate between the compartments is determined.

Figure 16 presents a typical steamline break containment temperature transient that is calculated using superheated steam blowdowns from the LOFTRAN code and the modeling of ice condenser drains as a heat removal source. The transient shows that initially the containment temperature increases rapidly during the

blowdown. When the upper compartment sprays actuate there is a slight decrease in the main compartment temperature. The temperature then rises slowly until ice condenser drain flow decreases to the point at which time the temperature begins to rise again (approximately 250 seconds). This rise in containment temperature coincides with the steam generator tubes uncovering at 152 seconds and the maximum superheat occurring at approximately 250 seconds. The steam generator level stablizes when the auxiliary feedwater flow is equal to the steam discharge at approximately 300 seconds. The containment temperature then starts decreasing with decreasing decay heat. At ten minutes, the deck fans actuate which results in a rapid decrease in containment temperature.

C. LOTIC-3 Code Modifications

Four modifications have been incorporated in the LOTIC-3 containment model which are (Figure 17);

1) wall heat transfer model
2) convective heat flux model
3) ice condenser drain model
4) dead-ended compartment model

D. Wall Heat Transfer

The modification to the wall heat transfer model is described in Figure 18. In the LOTIC-3 model, only condensation heat transfer, utilizing a Tagami heat transfer coefficient and a temperature difference between the wall and saturation, was previously modeled. The modification includes a convection term with a conservative convection heat transfer coefficient and a temperature difference between the containment atmosphere and an appropriate interface temperature. The Appendix presents a more detailed description of this model.

E. Convective Heat Flux

The modification to the convective heat flux model is described in Figure 19. A term has been added to the convective heat flux model to account for the feedback effect from including a convective term in the wall heat transfer model. The Appendix presents a more detailed description of this model.

F. Ice Condenser Drain Model

In an ice condenser containment there is approximately twenty drains exiting from the ice condenser into the lower compartment at an elevation of about forty feet above the compartment floor. The drain pipes are one foot in diameter. The drain flowrate is calculated by the LOTIC-3 containment code. For a typical small steamline break transient the drain flowrate varies from approximately 4000 lbm/sec to 500 lbm/sec during the timeframe of interest. The temperature of the drain water is approximately 130°F (Figure 20).

Figure 21 presents the assumptions and the basic model used to estimate the heat removal from the lower compartment atmosphere to the ice condenser drain water. It is conservatively assumed that the drain water stream does not break up prior to reaching the floor even though many of the drains have equipment and structures located below them. Therefore, heat transfer is assumed to occur a

the stream surface only. It is also assumed that the stream surface temperature is at the saturation temperature of the containment.

The heat transfer to the stream is:

$$q=hA\Delta T$$

where

h = condensation heat transfer coefficient
A = surface area of the stream
ΔT = appropriate temperature difference

The calculation of the heat transfer surface area is described in Figure 22. In order to model the drains in LOTIC-3, the drains are modeled as a wall heat sink with a surface at a constant temperature (see Figure 23). Currently, in the version of LOTIC-3, the surface temperature is assumed to be 230°F which is close to the containment saturation temperature. The drain surface area is calculated at two points in time during the transient; early in time with a high flowrate and later in time with a low flowrate. To ensure conservatism in the area calculation a 10% reduction of the surface area was assumed.

As described previously (Figures 14 & 15), the LOTIC-3 containment model did not account for wall heat removal in the dead-ended compartments. To obtain a conservative estimate of the temperature transient in the dead ended compartment, the heat sinks located in the dead ended compartment region along with the heat sinks in the lower compartment are modeled in a combined volume (see Figure 24). This "modified" lower compartment model is used to determine a conservative dead-ended compartment temperature transient. Since the lower compartment will be hotter than the dead-ended compartment, this methodology results in a higher temperature in the dead-ended compartment than would be expected.

G. Transient Results

With the modifications described for LOFTRAN and LOTIC-3, the previous FSAR limiting case for Catawba was reanalyzed to determine the impact of superheated steam. The case selected is a 0.86 square foot break at 102% power (Figure 25). The peak lower containment temperature for this case is 324°F. This temperature is calculated for the lower compartment only. It is expected that the dead-ended compartment temperature will be significantly lower.

In addition to the model modifications incorporated in LOTIC-3, Westinghouse is pursuing further improvements in the areas noted on Figure 26. One area is in the wall heat and mass transfer models. Since condensation is a mass transfer type phenomena, the heat and mass transfer should be linked. This approach has been used in Reference 7.

An improved drain model is also being investigated. This improved model will calculate the drain surface area as a function of flowrate. It will also calculate the average temperature rise of the drainwater. This model will more accurately represent the actual phenomena in the containment.

V. Appendix

WESTINGHOUSE STEAMLINE BREAK
BLOWDOWN AND CONTAINMENT ANALYSIS METHODOLOGY

The following sections describe the Westinghouse methodology for determining the containment response for a steamline break incorporating the effects of superheated steam. These sections describe in detail changes from the methodologies described in References 1 and 5.

I. Steamline Rupture Mass/Energy Blowdown Analysis

A. LOFTRAN and MARVEL Computer Modeling

Mass/energy releases can be calculated using either the LOFTRAN code (Reference 3) or the MARVEL code (Reference 8). The LOFTRAN code is used for non-LOCA FSAR accident analyses. The MARVEL code was specifically developed for assymmetric transients such as steamline breaks. These two codes are very similar because they were developed in an interrelating fashion and much of the modeling is common to both codes. The MARVEL code was used in the development of Reference 1 because LOFTRAN at that time was a lumped model which was used for symmetric loop transients. Furthermore, for steamline break analysis purposes, MARVEL contains a model for water entrainment. However, the current version of LOFTRAN is a multiloop version which also contains a water entrainment model. With the development of a multiloop version of LOFTRAN and the inclusion of an entrainment model, the use of MARVEL has been generally discontinued. This enables the use of LOFTRAN as a single system analysis code for non-LOCA transient analyses. LOFTRAN is used in the analyses presented here.

The model of importance to blowdown calculations is the steam generator model. The primary side of the steam generator contains multiple nodes to model the tube bundle for both the modified version of LOFTRAN and MARVEL. Heat transfer calculations from the primary to secondary side are identical in the two codes, although the methods for initializing the heat transfer resistances are slightly different. The secondary side is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur to saturated water. If tube uncovery is predicted, the amount of surface area available for heat transfer is reduced.

Both codes contain a detailed steam generator model which is used to predict tube uncovery. This model calculates the liquid volume in the steam generator shell and accounts for the detailed steam generator geometry. The [ ]^{a,c} correlation is used in both codes to predict the voiding in the tube region, although the correlation is modified for use in LOFTRAN. In MARVEL, tube uncovery is calculated based

on comparison with the actual water level and the height of the tube bundle. In LOFTRAN, the user specifies either a water volume in the steam generator corresponding to tube uncovery, or a void fraction in the riser section of the steam generator at which tube uncovery begins.

Both codes have similar models accounting for reverse heat transfer, thick metal heat transfer, feedline flashing, and safety injection system operation. Auxiliary feedwater flow can be input as a fraction of nominal feedwater flow, although LOFTRAN has an additional capability to model auxiliary feedwater flow as a separate system. For analysis of double ended ruptures, MARVEL accounts for the volume of steam in the piping downstream of the steam generators in the blowdown calculations. In LOFTRAN, this consideration is added on to the blowdown mass and energy results by hand. For split ruptures, which the analysis presented here addresses, the steam piping masses are handled identically in both codes.

In summary, LOFTRAN and MARVEL are very similar codes, and either can be used to calculate mass/energy blowdowns. To demonstrate this, a comparison of the blowdowns for a typical case is presented in Figures A.1 and A.2. Figure 1 presents the mass release rate for a .86 ft2 split rupture from 102% power. For this case, Figure A.2 shows the saturated steam enthalpy as a function of time. This blowdown is typical of results used in FSAR analyses prior to the modification noted in this report for the LOFTRAN code. As can be seen from the figures, the results are extremely close.

B. LOFTRAN Model for Superheated Steam

As mentioned previously, the LOFTRAN code has been modified to model heat transfer which may occur in the uncovered tube bundle region. This effect is modeled in both the faulted and intact loops. In the modified version of LOFTRAN, all heat transfer occurring in the uncovered region is assumed to add superheat the steam exiting the steam generator. The temperature of the primary coolant flowing through in the uncovered tube region mode is conservatively assumed to remain constant. Realistically there would be a drop in temperature due to heat removal to the secondary side, but this will be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is based on the [(1)][a,c]. The heat transfer coefficient (U) is calculated by the following expression:

[ ][a,c]

This correlation is presently used for superheated forced convection heat transfer by the [ ][a,c] computer codes. Additionally,

this correlation is based upon the heat transfer from the surface of the tube wall to the average bulk temperature of the steam. In the LOFTRAN modification, no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall temperature of the tube is conservatively assumed equal to the primary fluid temperature.

(1) [ ]a,c

The modified version of LOFTRAN automatically selects the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the modified LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. Each node is evaluated to determine the steam temperature exiting the node with a convergence criteria that is based upon the total number of nodes used. The exit steam temperature of one node is used as the inlet steam temperature of the next node.

The heat transfer calculation to determine the outlet temperature of the node is based upon the following expression:

$$Q = UA*(T_{pri}-(T_{out}+T_{in})/2) = M_s*C_s*(T_{out}-T_{in})$$

where Q = Heat transfer to the steam

U = [ ] a,c

T_{pri} = Primary node temperature

T_{out} = Steam node outlet temperature

T_{in} = Steam node inlet temperature

M_s = Mass flowrate of the steam

C_s = Heat capacity of the steam

A = Heat transfer area in the node including both hot and cold leg sides of the tube bundle

The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient.

C. Blowdown Sensitivity to Plant Conditions

The effects of superheated steam are dependent upon the occurrance and extent of tube bundle uncovery. Parameters affecting tube uncovery are: initial steam generator inventory, break size, auxiliary feedwater flowrate, and the single failure assumed.

The initial steam generator inventory depends upon the measurement errors associated with steam generator level and upon initial power level. Steam generator mass increases with decreasing power, thus, breaks intitiating from low power levels will result in later tube uncovery.

Larger break sizes result in faster blowdown of the steam generator and earlier tube uncovery.

Large auxiliary feedwater flowrates only delay tube uncovery, but will also cause the final equilibrium steam generator level to be higher. This equilibrium condition corresponds to the point when the break flow rate is equal to the auxiliary feedwater flow rate.

The single failure assumed in the transient may impact the amount of water supplied to the steam generator. Auxiliary feedwater runout will increase the amount of water supplied to the steam generator. Failure of the feedwater isolation valve will also cause extra water to be supplied to the generator as the additional mass between the isolation valve and the check valve flashes to the generator.

II. Containment Analysis

A. Wall Heat Transfer Model

The original LOTIC-3 wall heat transfer model is based on the stagnant Tagami heat transfer correlation. That is,

$$q''=h_{TAGAMI}(T_{SAT}-T_{WALL})$$

$h_{TAGAMI} = 2 + 50\ M_{STEAM}/M_{AIR}$ $h_{(TAGAMI,MAX)}=72\ BTU/hr\text{-}ft^2\text{-}^oF$

This model was developed for saturated steam in the presence of large amounts of non-condensable gases. In the lower compartment of an ice condenser, most of the air is swept out of the lower compartment through the ice condenser and into the upper compartment. Therefore, after about 30 seconds, there is almost no non-condensables in the lower compartment. Typical values for the condensation of pure steam are in the range of 1000 to 3000 Btu/hr-ft2-^{o}F (Ref. 5). The correlation used in the modified LOTIC-3 code is in extension of the Tagami correlation for nearly pure steam.

$$q''=h_{COND}\ (T_{SAT}-T_{WALL})$$

$h_{cond} = 2+50\ M_{STEAM}/M_{AIR}$ $h_{(cond,max)}$ = [ ]^{a,c}

A maximum value of [ ]^{a,c} was chosen as a conservatively low condensing heat transfer coefficient in a nearly pure steam environment.

In addition to this modification, an additional term is needed to account for the convective heat transfer from the superheated steam to the condensate film. This convective heat transfer is dependent upon whether there is condensation occurring on the walls. If condensation is occurring, the correlation used is:

$$q''_{conv}=h_{conv}(T_{bulk}-T_{sat})$$

where: [ ]^{a,c}

If the wall temperature increases to above the saturation temperature then the convective currents will be reduced such that the correlation used is

$$q''_{conv}=h_{conv}(T_{bulk}-T_{wall})$$

where:

[ ]^{a,c}

Thus in summary, if $T_{wall} < T_{sat}$ then

[ ]^{a,c}

If $T_{wall} > T_{sat}$, then the correlation used is:

[ ]^{a,c}

B. Convective Heat Flux Model

When the containment atmosphere is superheated, the containment temperature is a strong function of the amount of steam mass in the atmosphere. Thus the amount of mass condensed on the heat sink surfaces is a key parameter. The actual amount of condensate formed is

$$M_{cond} = q_{cond}/h_{fg}$$

Unfortunately, with the use of a heat transfer correlation based only on test data (such as Tagami or Uchida), only the total heat transfer coefficient is obtained. This total heat transfer coefficient includes both the condensation heat transfer and the convective heat transfer. Based on the work of Sparrow (Reference 6), the Westinghouse Convective Heat Flux model in the original LOTIC-3 code calculates the ratio of the convective heat transfer to the condensation heat transfer. Therefore the calculation of the amount of mass condensed is

[ ]^{a,c}

In the modified LOTIC-3 model, the amount of superheat convection is calculated. The amount of convective heat transfer at saturation is not known explicitly in this model. Therefore, in the modified LOTIC-3 code the original convective heat flux model will be used to calculate the fraction of convective heat transfer for saturated conditions. The actual correlation is

[ ]^{a,c}

where, $(q_{conv}/q_{cond})_{sat}$ is determined from original convective heat flux model and $q_{conv,sh}$ is the amount of convective heat transfer calculated in the wall heat transfer model

In summary, the modified LOTIC-3 model is consistent with the original LOTIC-3 model in its calculation of the mas condensed. The only difference is that in the modified LOTIC-3 code, the amount of superheat convective heat transfer is known explicitly, while in the original LOTIC-III model, only the ratio of convective heat transfer to condensation heat transfer is known.

IV. References:

1. Land, R. E., "Mass and Energy Releases Following A Steam Line Rupture" WCAP-8822 (Proprietary) September, 1976 and WCAP-8859 (Non-Proprietary).

2. NS-EPR-2563, February 14, 1982, E. P. Rahe of Westinghouse to J. R. Miller, NRC, "Additional Information on WCAP-8822".

3. Burnett, T. W. T., et al., "LOFTRAN Code Description," WCAP-7907, June, 1972 (Proprietary).

4. Meyer, P. E., and Kornfilt, J., "NOTRUMP - A Nodal Transfer Small Break and General Network Code," November, 1982, WCAP-10079 (Proprietary) and WCAP-10080 (Non-Proprietary).

5. Hsieh, T. and Liparulo, N. J., "Westinghouse Long Term Ice Condenser Containment Code - LOTIC-3 Code," February, 1979, WCAP-8354-P-A Sup. 2 (Proprietary),WCAP-8355-NP-A (Non-Proprietary).

6. Sparrow, E. M., Minkowycz, W. J., and Saddy, M., "Forced Convection Condensation in the Presence of Noncondensables and Interfacial Resistance", Int. J. Heat Mass Transfer, Volume 10, 1967.

7. Corradini, M. L., "Turbulent Condensation on a Cold Wall in the Presence of a Non-condensable Gas" Nuclear Technology Vol. 64, pp 186 - 195, February, 1984.

8. Krise, R. and Miranda, S., "MARVEL - A Digital Computer Code for Transient Analysis of a Multiloop PWR System," November, 1977, WCAP-8843 (Proprietary) and WCAP-8844 (Non-Proprietary).

9. McCabe, W. L., and Smith, J. C., "Unit Operatons of Chemical Engineering", 3rd Edition, 1976.

LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

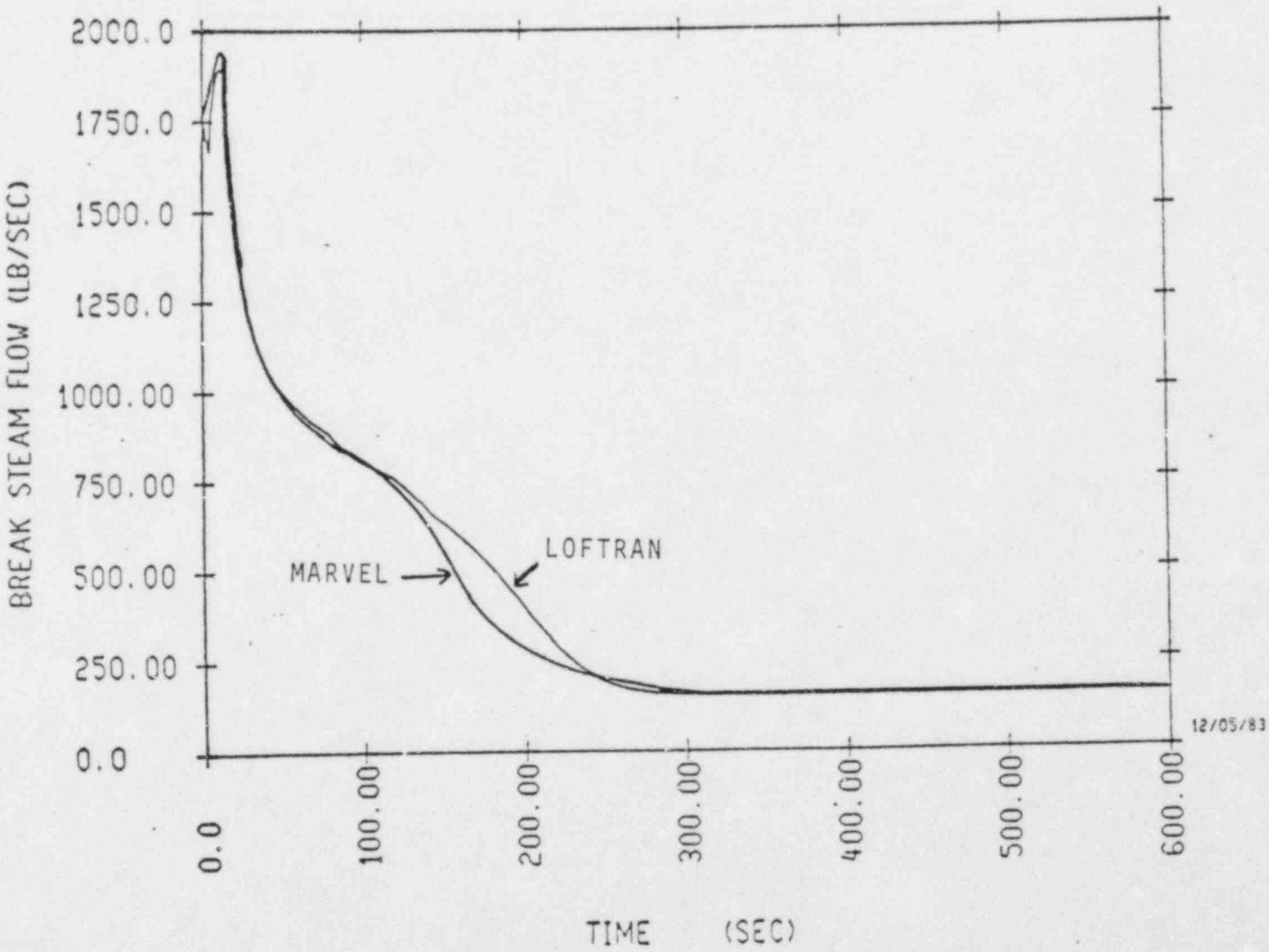


FIGURE A.1

LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

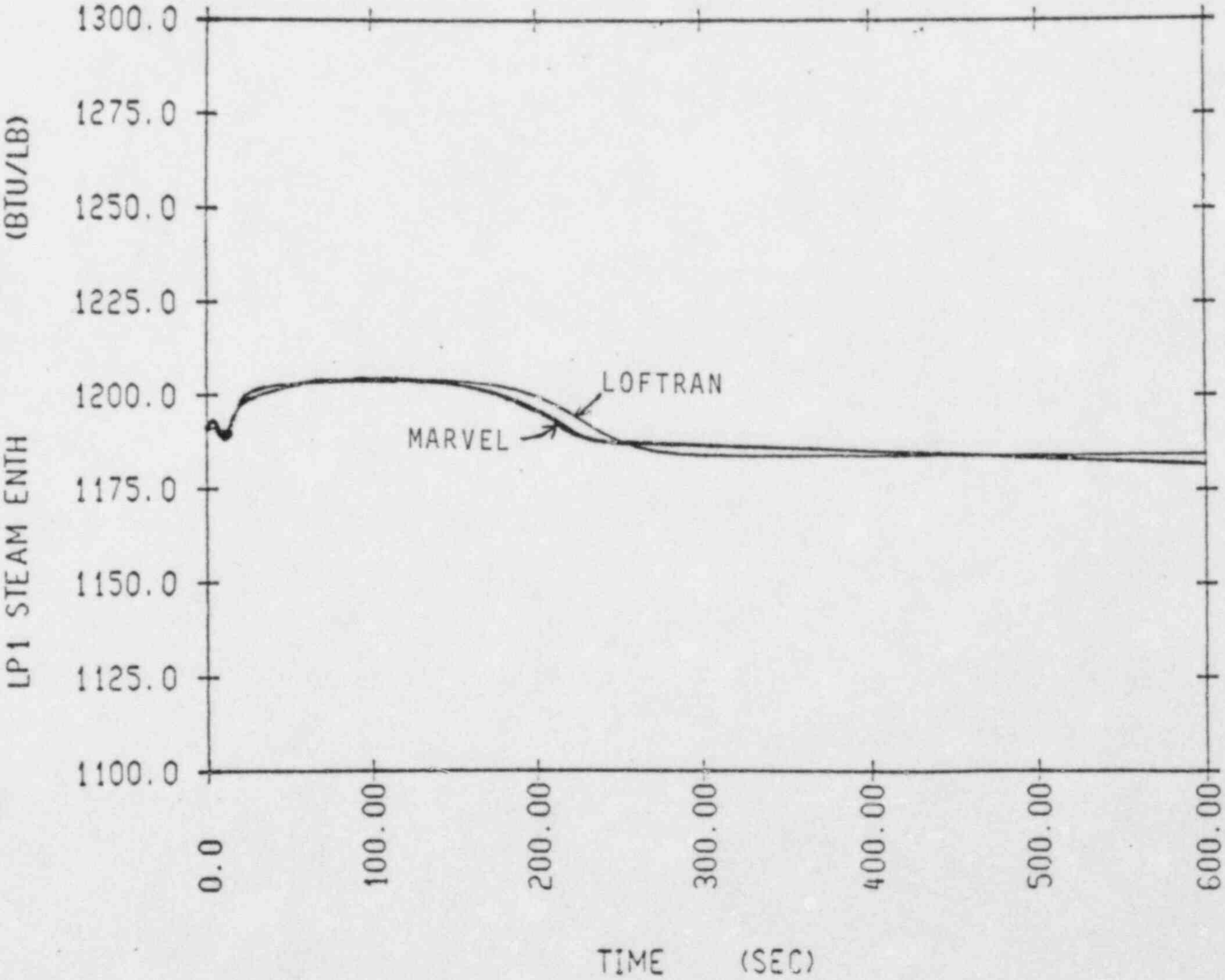


FIGURE A.2

METHODOLOGY FOR ADDRESSING SUPERHEATED STEAM RELEASES TO ICE CONDENSER CONTAINMENTS

Purpose

The purpose of this report is to document the information presented on March 19, 1984 in a meeting with the U.S. NRC Containment Systems Branch on the status of progress made in addressing the confirmatory item on the Catawba Nuclear Plant Safety Evaluation Report. This confirmatory item deals with the effects of superheated steam generator mass and energy releases following main steamline break accidents. Attachment 1 includes the list of attendees at the meeting and the overhead slides covered in the Westinghouse presentations.

Technical presentations were made describing the modeling of the steam generator and heat transfer from the uncovered tube bundle during the steam generator blowdown along with a description of the containment model and transient response. A proposed plan of action was also presented and discussed with the Staff. In accordance with that plan, this report represents the first milestone in the proposed plan of action. As committed to in the meeting, the appendices present proprietary information which relates to the specifics of the models and sensitivities that were not directly addressed in the meeting.

Attachment 2 is an explanation of, and refers to, the overhead slides (Figures) presented at the March 19 meeting.

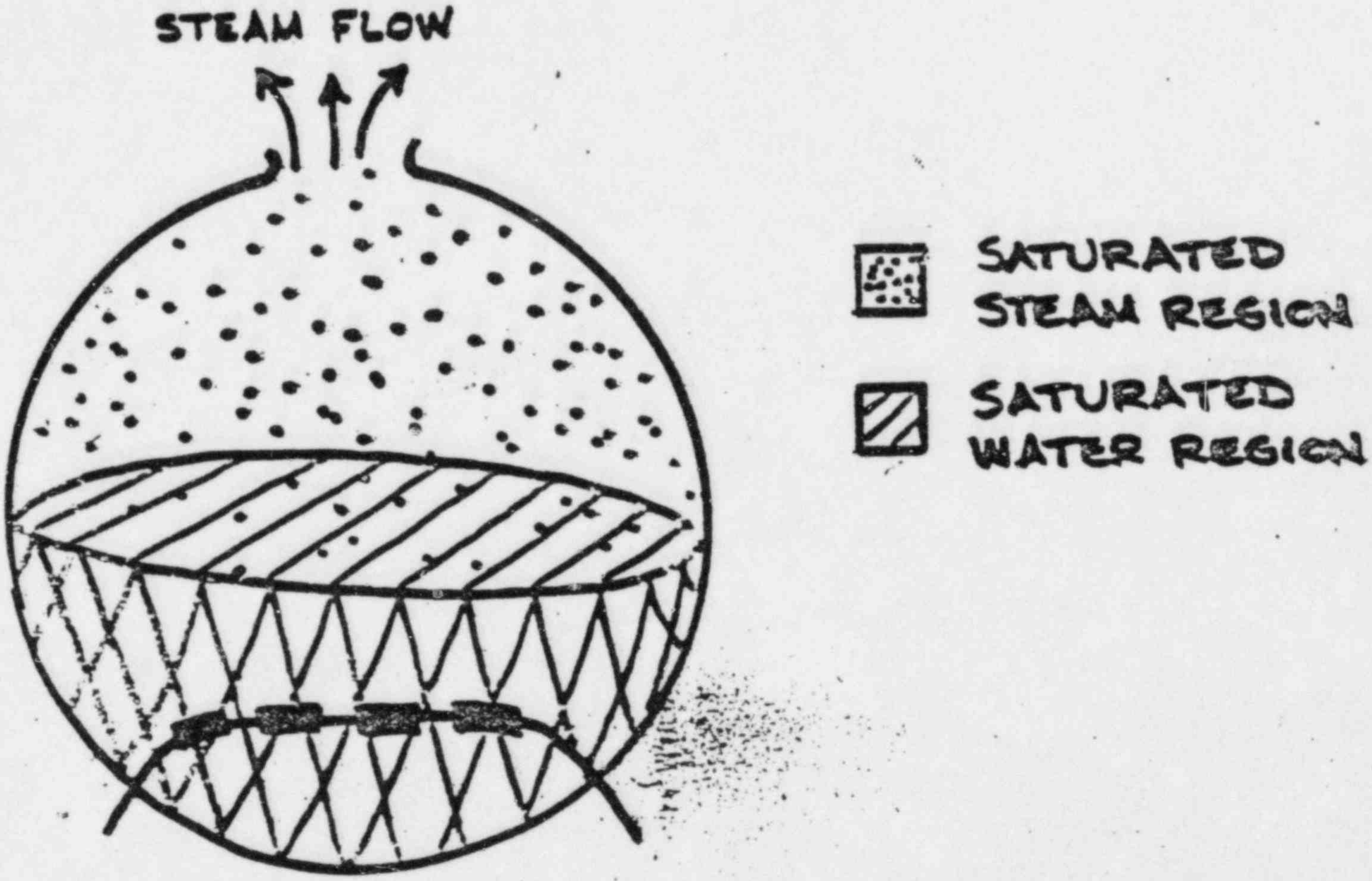
ATTACHMENT 1

Attendance at 3/19/84
Meeting w/ Duke + W on
Main Steam Line Break Analysis

Name	Organization
K. N. JABBOUR	NRC/DL
R. O. SHARPE	DUKE/NPD
J. L. LITTLE	W NUCLEAR SAFETY
H.V. JULIAN	W NUCLEAR SAFETY
TJ Kenyon	NRC/DL
DS. LOVE	W NUCLEAR SAFETY
MP Osborne	W Nuclear Safety
P.A. Linn	W Nuclear Safety
L.E. Hochreiter	W Nuclear Safety
F.F. CADEK	W Nuclear Safety
F J Twogood	W NOD, project mgr.
S D Alexander	Duke, Design Engineering
R E Miller	Duke, Design Engineering
J. E. Wills	TVA, Nuclear Licensing Staff
B. AMELI	SERCH LICENSING STAFF, BECH
C. DRAUGHON	W NUCLEAR SAFETY
W.D. Crouch	TVA, Engineering Design
S. R. Nesbit	Duke, Nuclear Production Department Staff
S.A. Swamy	W, NTD/SME
R.H. Owoc	W NTD/NUCLEAR SAFETY
J SHAPAKER	NRC/CSB
Jack Kudrick	" "
J. Pilsitker	NRC/CSB
C. Li	NRC/CSB
A. Notafrancesco	NRC/CSB

LOFTRAN MODEL

STEAM GENERATOR SECONDARY

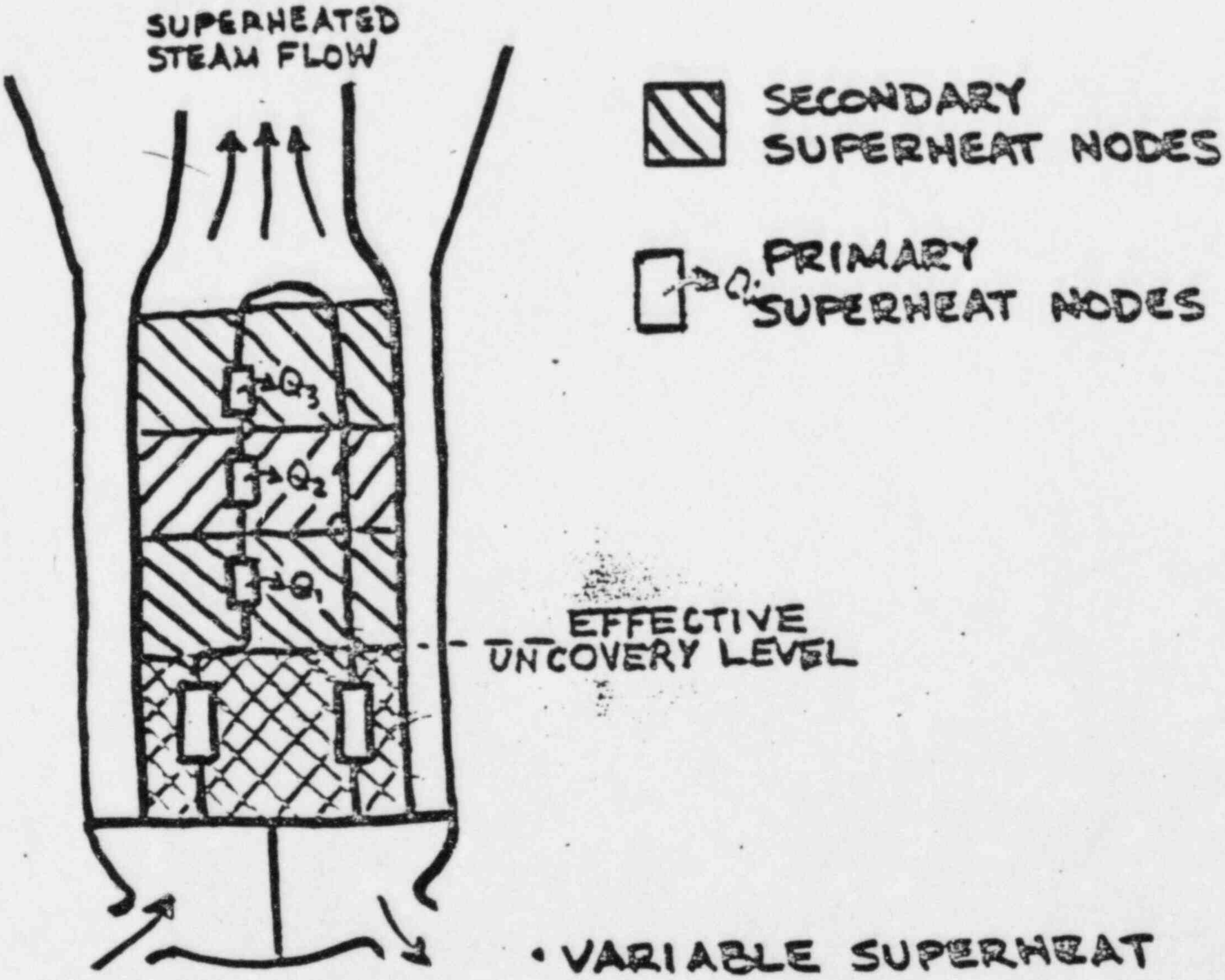


- SINGLE NODE, 2 REGION MODEL
- NO HEAT TRANSFER TO SATURATED STEAM REGION
- HEAT TRANSFER TO SATURATED WATER REGION IS MODIFIED FOR TUBE 'UNCOVERY'

FIGURE 1

LOFTRAN MODEL

SUPERHEAT HEAT TRANSFER



- VARIABLE SUPERHEAT NODES MODEL

- CONSTANT PRIMARY TEMPERATURE IN SUPERHEAT REGION ASSUMED FOR HEAT TRANSFER CALCULATIONS

- CALCULATED SUPERHEAT HEAT TRANSFER ACCOUNTED FOR IN PRIMARY TRANSIENT

FIGURE 2

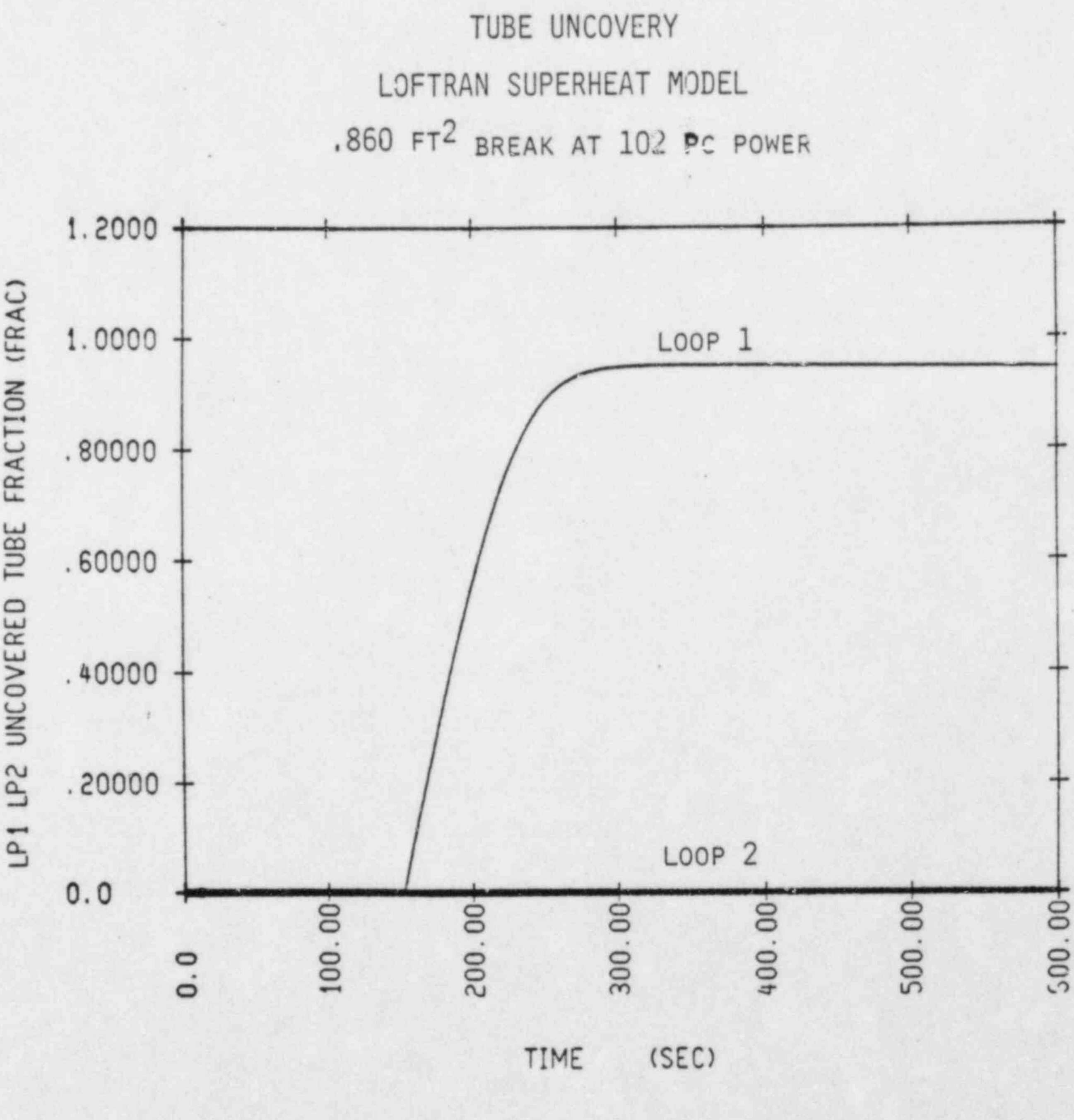

TUBE UNCOVERY
LOFTRAN SUPERHEAT MODEL
.860 FT2 BREAK AT 102 PC POWER
1.2000
1.0000
.80000
.60000
.40000
.20000
0.0
LP1 LP2 UNCOVERED TUBE FRACTION (FRAC)
LOOP 1
LOOP 2
0.0
100.00
200.00
300.00
400.00
500.00
600.00
TIME (SEC)

FIGURE 3

MASS BLOWDOWN

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

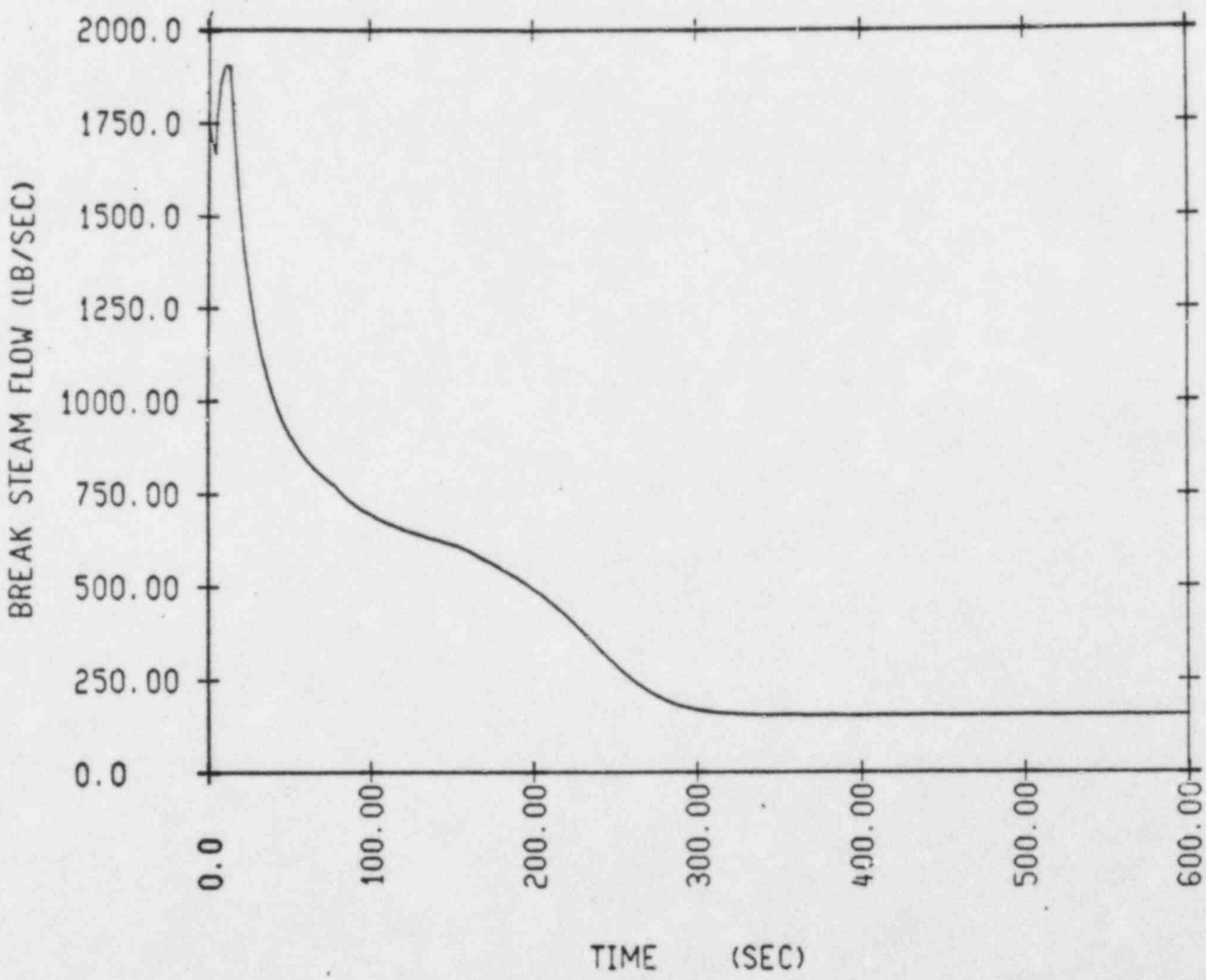


FIGURE 4

ENERGY RELEASE

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

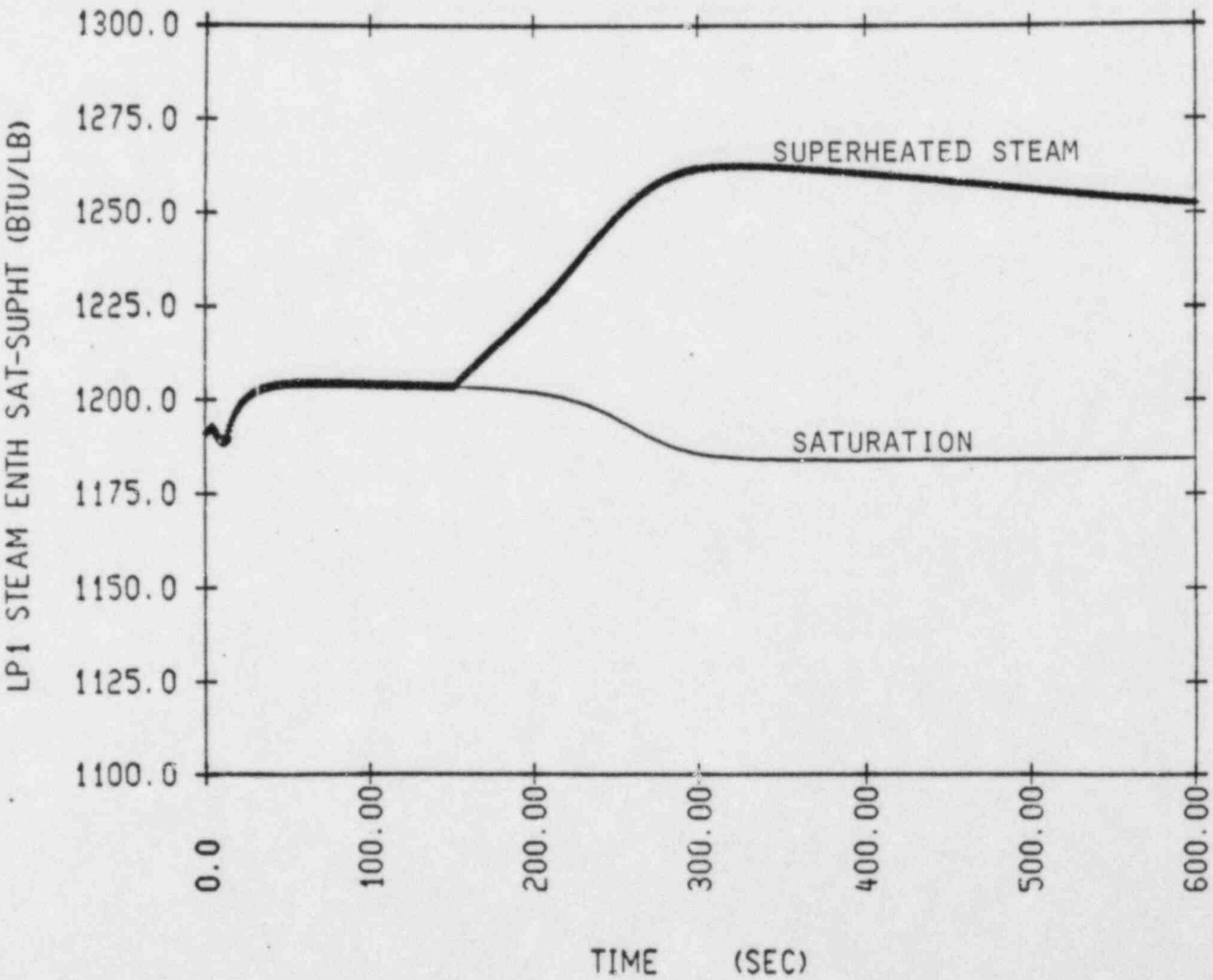


FIGURE 5

TEMPERATURE TRANSIENTS

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

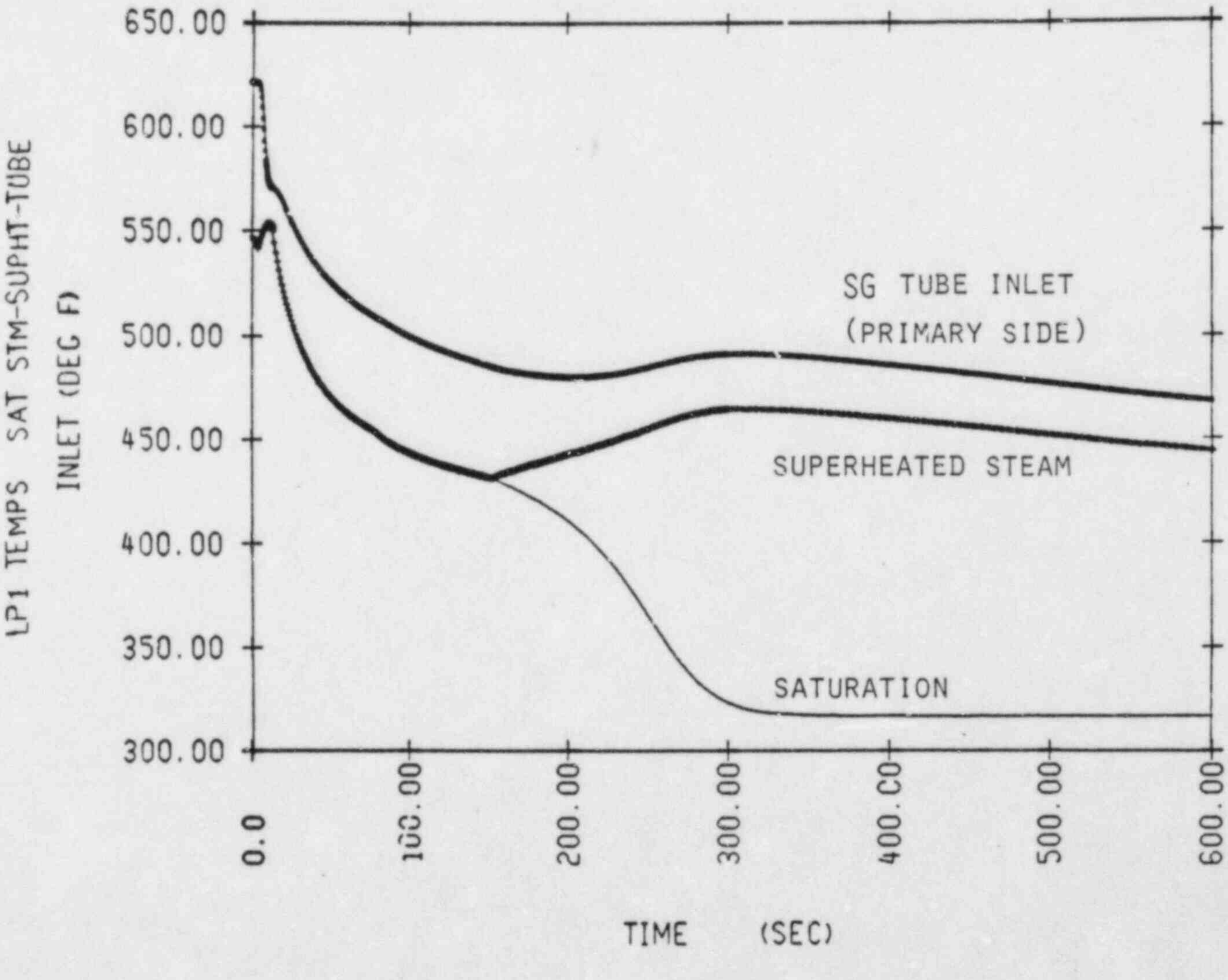


FIGURE 6

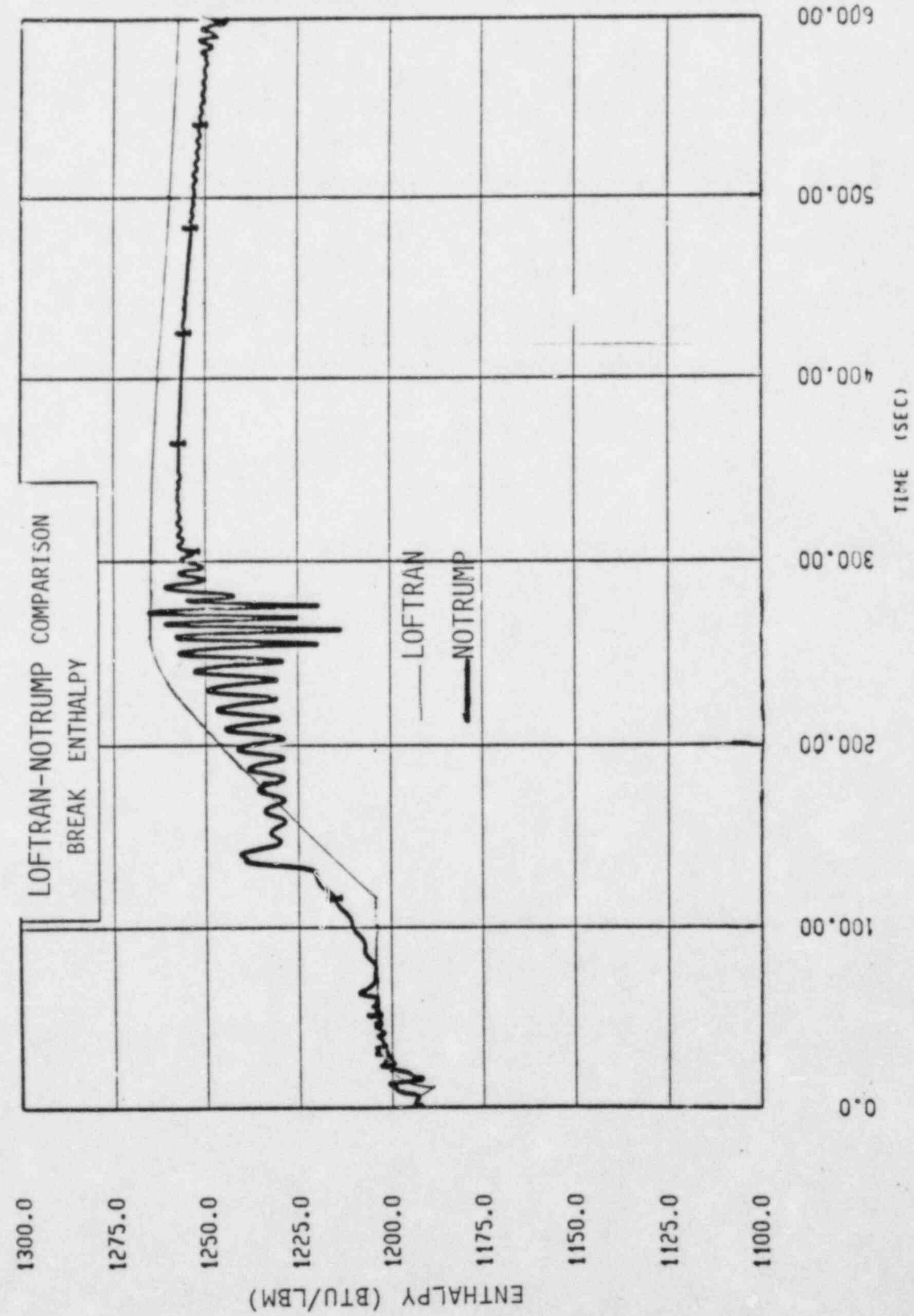

LOFTRAN-NOTRUMP COMPARISON
BREAK ENTHALPY
LOFTRAN
NOTRUMP
ENTHALPY (BTU/LBM)
1300.0
1275.0
1250.0
1225.0
1200.0
1175.0
1150.0
1125.0
1100.0
TIME (SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00

FIGURE 7

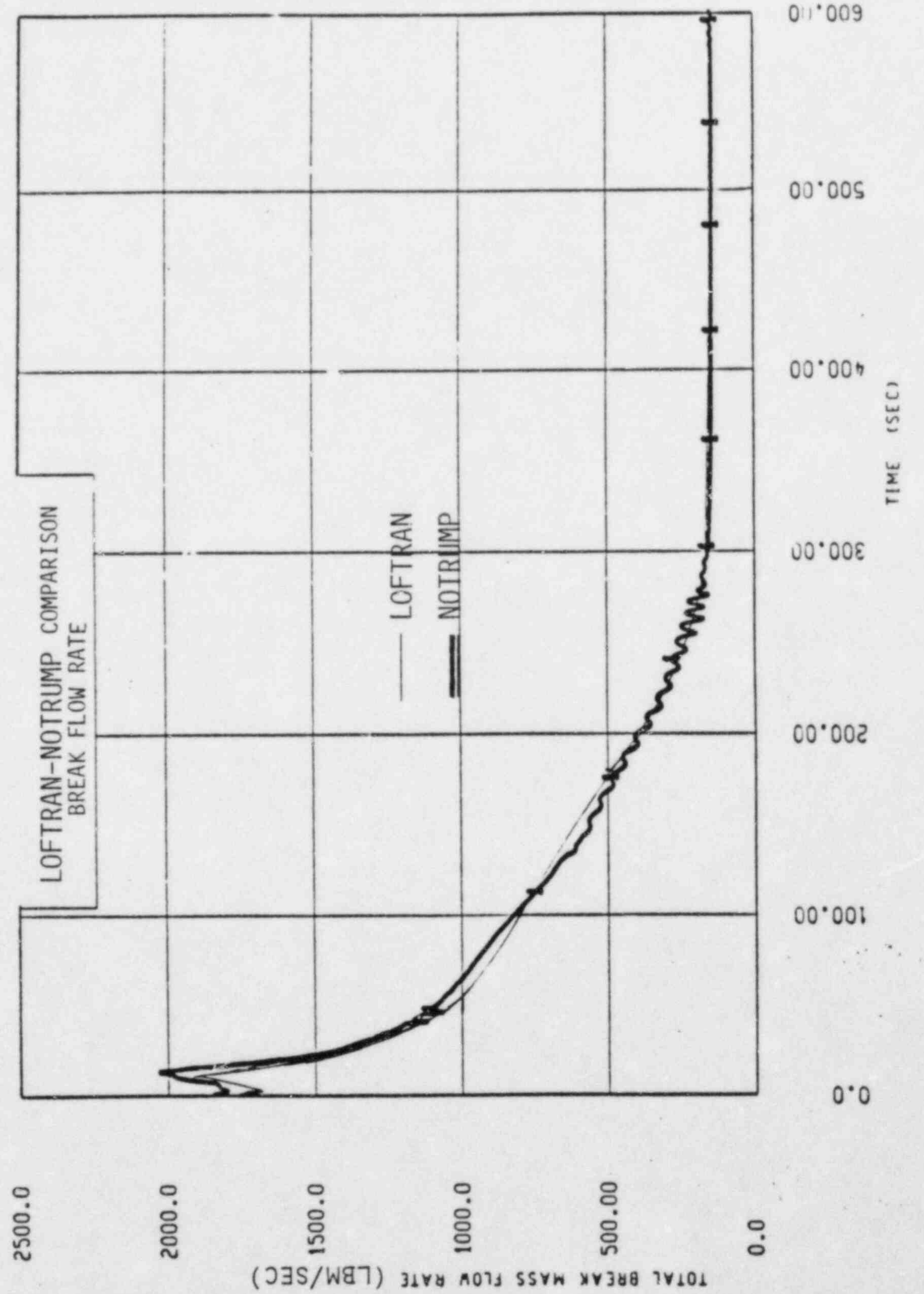

LOFTRAN-NOTRUMP COMPARISON
BREAK FLOW RATE
LOFTRAN
NOTRUMP
TOTAL BREAK MASS FLOW RATE (LBM/SEC)
2500.0
2000.0
1500.0
1000.0
500.00
0.0
TIME (SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00

FIGURE 8

EFFECTS OF
ANALYSIS ASSUMPTIONS

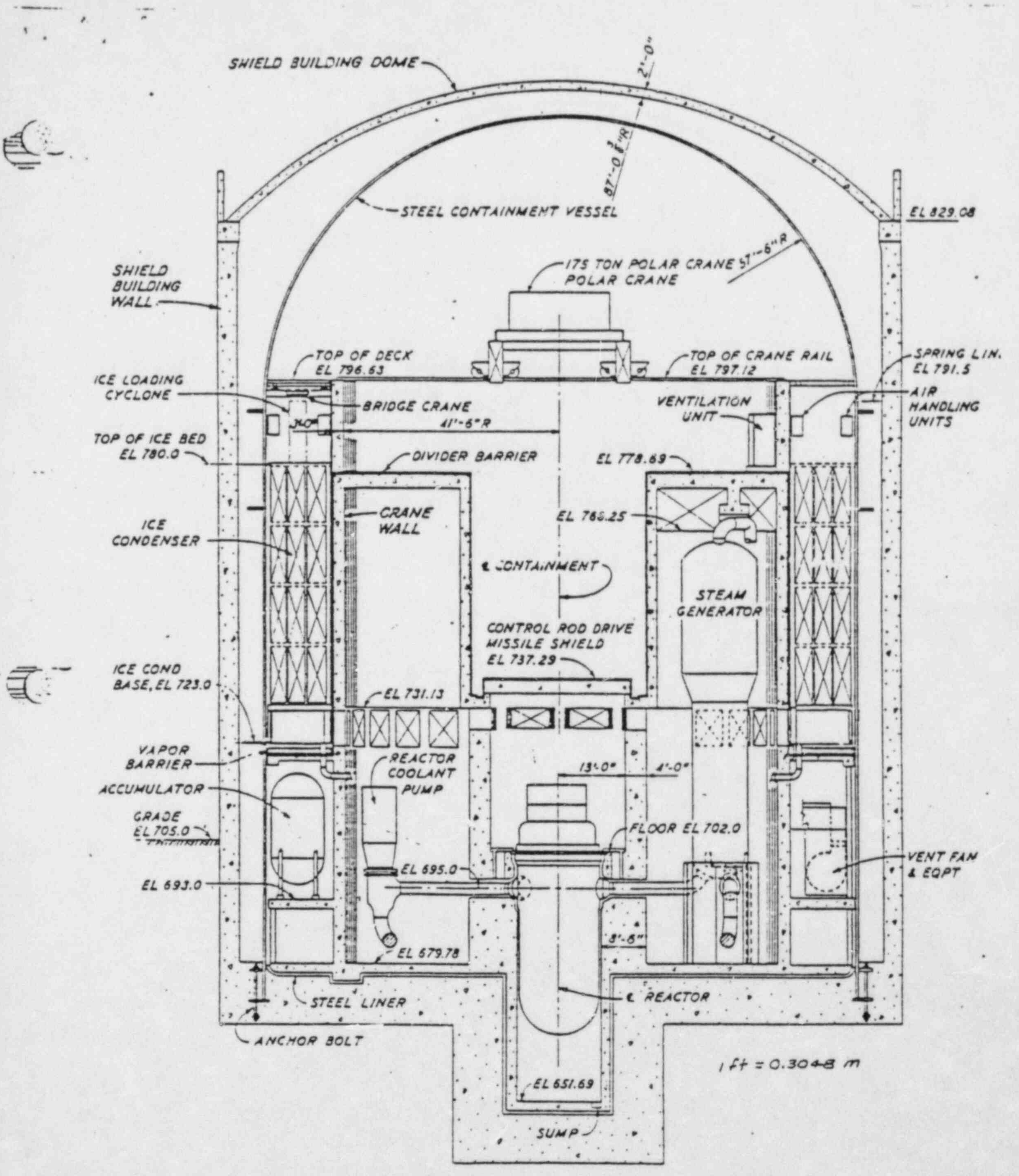
- INITIAL STEAM GENERATOR INVENTORY
- AUXILIARY FEEDWATER FLOWRATE
- FEEDWATER SYSTEM FAILURES
- PROTECTION SYSTEM ERRORS

FIGURE 9

ADDITIONAL MODEL CONSIDERATIONS

- LIQUID-STEAM INTERACTION
- IMPROVED STEAM HEADER MODEL
- HEAT TRANSFER THROUGH TUBE WRAPPER
- TEMPERATURE DROP IN PRIMARY SUPERHEAT NODES
- OPTIONAL VOID CORRELATIONS

FIGURE 10



Reactor Building Elevation

FIGURE 11

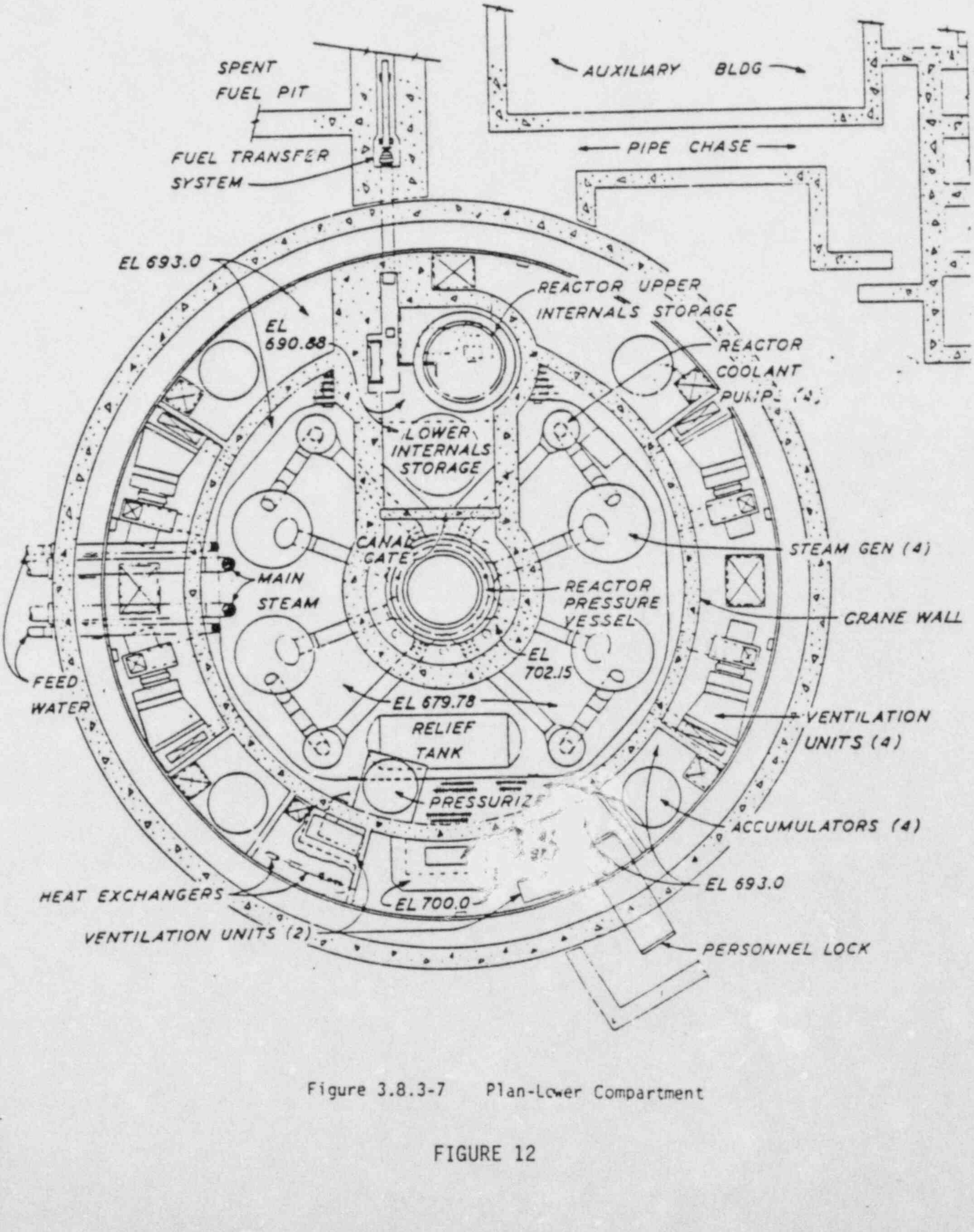


Figure 3.8.3-7 Plan-Lower Compartment

FIGURE 12

LOTIC-3 CONTAINMENT CODE

* 4 NODE CONTAINMENT MODEL
* CONDENSATE/REVAPORIZATION MODELS
    - LARGE BREAK (TOTAL REVAPORIZATION)
    - SMALL BREAK (CONVECTIVE HEAT FLUX)
* WALL HEAT TRANSFER MODEL
* MODELS SUMP RECIRCULATION SYSTEM

FIGURE 13

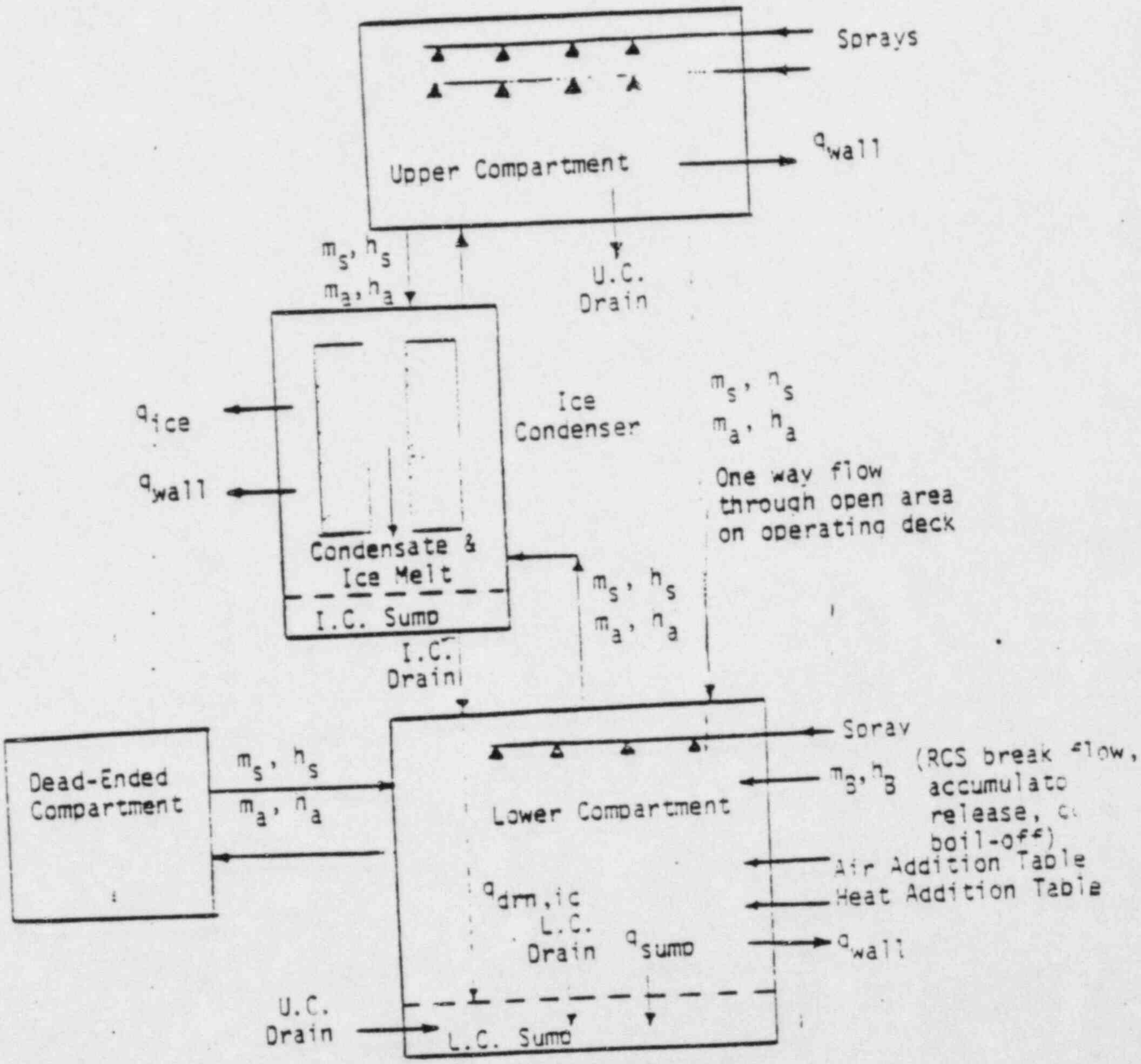


FIGURE 3.3 MASS AND ENERGY FLOW DIAGRAM
FOR THE COMPARTMENTS

FIGURE 14

LOTIC-3 - METHOD OF SOLUTION

- SOLVES CONSERVATION OF MASS, ENERGY, AND MOMENTUM FOR UPPER, LOWER, AND ICE CONDENSER REGIONS

- ONCE NEW LOWER COMPARTMENT CONDITIONS ARE DETERMINED, CONSERVATION EQUATIONS ARE SOLVED FOR THE DEAD-ENDED COMPARTMENT AND FOR THE FLOW RATE BETWEEN THE TWO COMPARTMENTS

FIGURE 15

TYPICAL CONTAINMENT TEMPERATURE

TRANSIENT (DRAINS MODELLED)

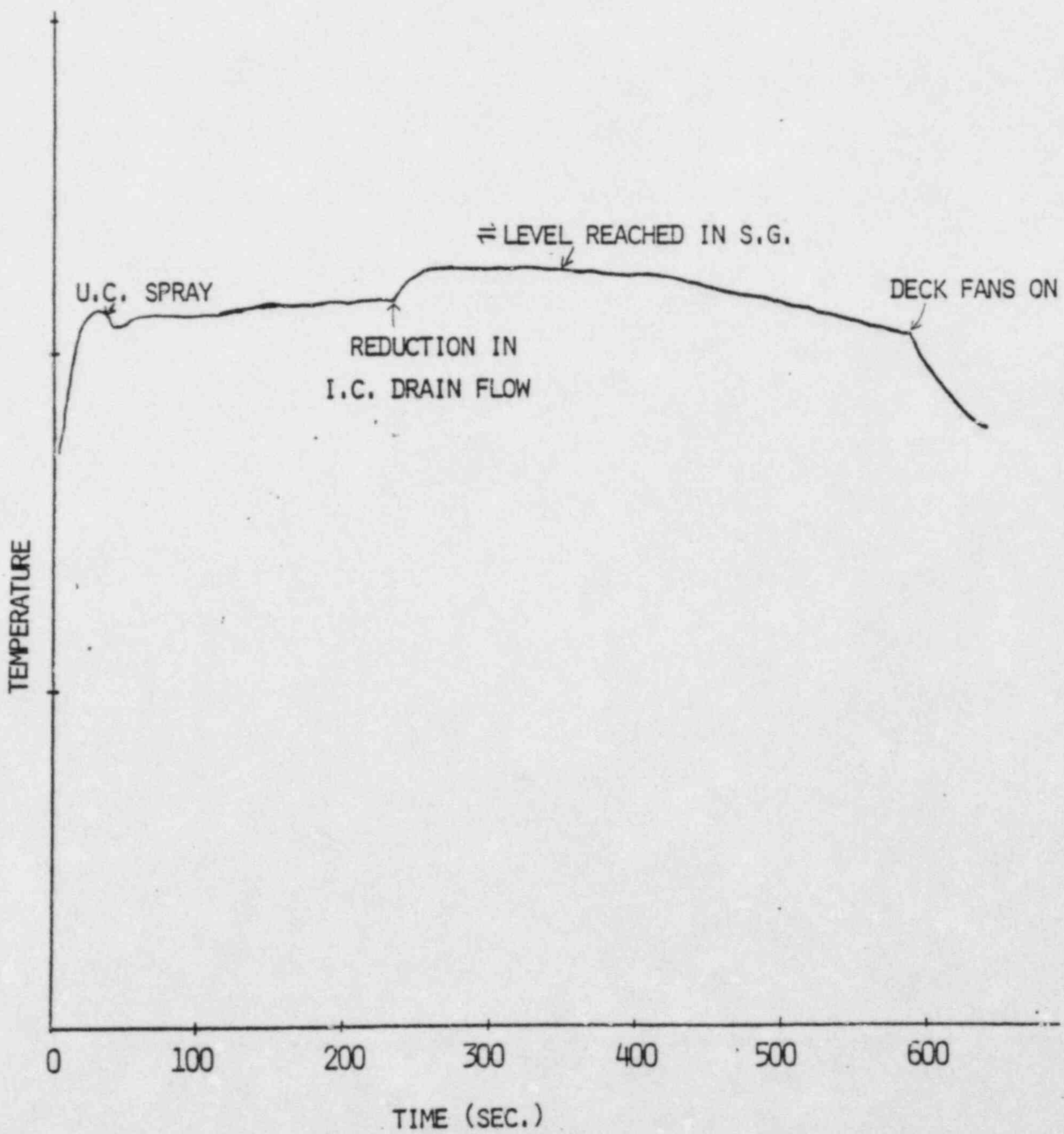


FIGURE 16

MODIFICATIONS TO THE CONTAINMENT MODEL

WALL HEAT TRANSFER MODEL

CONVECTIVE HEAT FLUX MODEL

ICE CONDENSER DRAIN MODEL

DEAD ENDED COMPARTMENT MODEL

FIGURE 17

WALL HEAT TRANSFER MODEL

ORIGINAL LOTIC MODEL

$$q'' = h_{Tagami} (T_{SAT} - T_{Wall})$$

MODIFIED LOTIC MODEL

$$q'' = h_{COND} (T_{SAT} - T_{Wall}) + h_{conv} (T_{Bulk} - T_{ref})$$

$$h_{COND} = f\left(\frac{m_{STEAM}}{m_{air}}\right)$$

$$h_{conv} = f(T_{Wall}, T_{SAT})$$

$$T_{ref} = f(T_{Wall}, T_{SAT})$$

FIGURE 18

CONVECTIVE HEAT FLUX MODEL

ORIGINAL LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X}\right]$$

MODIFIED LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X_{SAT}}\right]\left[1 - \frac{h_{CONV}(T_{BULK} - T_{ref})}{q_{TOTAL}}\right]$$

FIGURE 19

ICE CONDENSER DRAINS

-APPROXIAMATELY 20 ICE CONDNESER DRAINS

-DRAIN ELEVATION IS ABOUT 40 FEET FROM FLOOR

-DRAIN PIPE IS 1 FOOT IN DIAMETER

-FOR TYPICAL MSLB TRANSIENT, DRAIN FLOW VARIES FROM 4000 LB/S TO 500 LB/S

FIGURE 20

ICE CONDENSER DRAIN MODEL

-CONDENSATION OCCURS AT THE SURFACE OF THE STREAM

-FLOW IS WELL MIXED

$$q = h A \Delta T$$

-MODEL AS A WALL AT A CONSTANT TEMPERATURE

-A IS THE SURFACE AREA OF THE STREAM

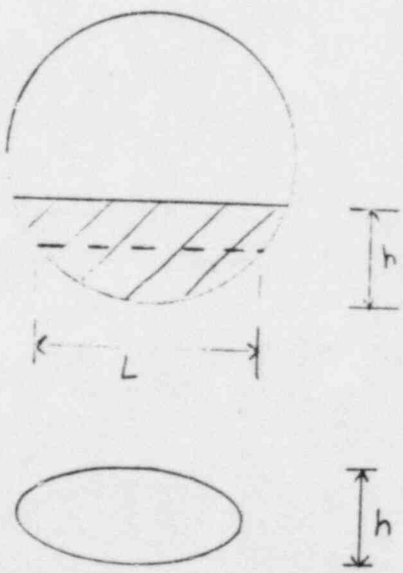
-h IS A CONDENSING TYPE HEAT TRANSFER COEFFICIENT

FIGURE 21

CALCULATION OF THE STREAM FLOW AREA

$$A = n(P \times L) = 20(P \times 40) = 800\,P$$

WHERE P IS THE PERIMETER OF THE STREAM



$$P \approx 2\pi\sqrt{\frac{\left(\frac{L}{2}\right)^2 + \left(\frac{h}{2}\right)^2}{2}}$$

FIGURE 22

MODIFIED LOTIC DRAIN MODEL

-WALL WITH A VARIABLE AREA

$$q = h_{COND} A (T_{BULK} - T_{SAT})$$

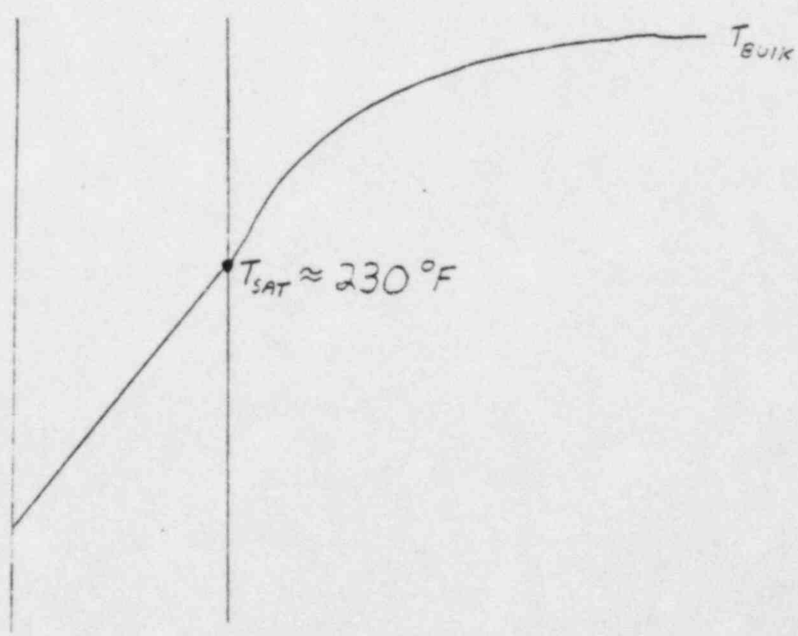


FIGURE 23

DEAD ENDED COMPARTMENT MODEL

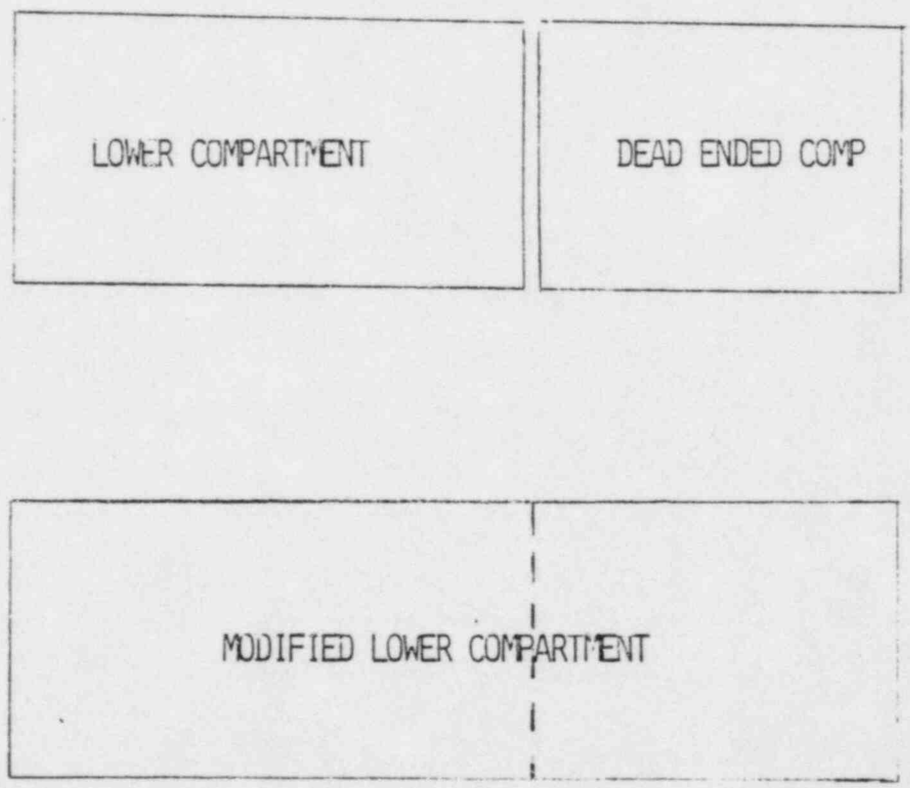


FIGURE 24

CATAWBA RESULTS

- 102% POWER
- 0.86 FT^2 BREAK
- MAXIMUM AFW FLOW
- FSAR HEAT SINKS
- MAXIMUM S.G. INITIAL MASS

$T_{MAX} = 324°F$ (LOWER COMPARTMENT)

FIGURE 25

ADDITIONAL MODEL CONSIDERATIONS

-WALL HEAT TRANSFER MODEL

-DRAIN MODEL

-DEAD ENDED COMPARTMENT MODEL

FIGURE 26

ATTACHMENT 2

OUTLINE OF THE REPORT

I. Introduction

II. Mass & Energy Release Modeling

III. Containment Modeling

IV. Action Plan

V. Appendix

VI. References

I. Introduction

During the Containment Systems Branch review of the Westinghouse topical report, "Mass and Energy Releases Following a Steam Line Rupture", WCAP-8822 (Proprietary) the Staff noted that heat transfer to steam from the uncovered portion of the steam generator tube bundle was unaccounted for and questioned the effect upon the calculated mass/energy release and the subsequent effect on the containment temperature response. Westinghouse responded in a letter to the Staff (NS-EPR-2563, February 14, 1982, E.P. Rahe to J. R. Miller) that it had determined the impact of the effect by conservatively treating the maximum amount of superheat to be the difference between the primary coolant temperature and the steam temperature. The letter noted that there would be an insignificant effect on dry type containments and that, based on the conservative model used, there would be an expected increase in containment temperature for ice condenser type containments. In the Containment Systems Branch Safety Evaluation Reports on the topical report and the Catawba Plant Safety Evaluation Report, the Staff required that a more refined steam line break analysis be performed to determine the effect on containment temperature which might impact the environmental qualification envelope used for safety related equipment.

Since that time, Westinghouse has investigated the effects of tube bundle heat transfer from the viewpoint of a more refined modeling approach. Subject to the final review and approval of the NRC Staff, the efforts and results obtained to date indicate that there is little impact on the containment response from the effects of the additional tube bundle heat transfer to steam.

II. Mass and Energy Release Modeling

A. LOFTRAN Computer Code

Mass/energy releases are calculated using the LOFTRAN code. LOFTRAN is a FORTRAN language, digital computer code, developed to simulate transient behavior in a multi-loop pressurized water reactor system. The program simulates neutron kinetics, thermal hydraulic conditions, pressurizer, steam generators, reactor coolant pumps, and control and protection systems. Up to four independent loops may be modeled. LOFTRAN is used for analysis of non-LOCA transients and is documented in Reference 3.

The model of importance to blowdown calculations is the steam generator model. The primary side contains multiple nodes to model the tube bundle. The standard LOFTRAN steam generator secondary side model, (Figure 1), is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur only to saturated water. If tube uncovery occurs the amount of surface area available for heat transfer is accordingly reduced. The LOFTRAN code incorporates a more detailed steam generator model which is used to predict tube bundle uncovery.

B. LOFTRAN Model for Superheated Steam

The LOFTRAN code has been modified to account for heat transfer to steam from the uncovered tube bundle region. (Figure 2). In the modified version of LOFTRAN, all heat transfer occuring in the uncovered region is assumed to add superheat to the steam exiting the steam generator. The primary side temperature in the uncovered tube region is conservatively assumed to remain constant through the nodes which are uncovered. In reality, there will be a drop in temperature due to heat removal to the secondary side, but this is expected to be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is discussed in the Appendix. This correlation bases the heat transfer on the difference between the tube wall surface temperature and the bulk steam temperature in the region. In the LOFTRAN modification, the conservative assumption is made that no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall surface temperature of the tube is assumed equal to the primary fluid temperature.

The modified version of LOFTRAN automatically determines the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the modified LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient

calculation. The superheat/tube uncovery modeling is applicable to all steam generators.

Figures 3 through 6 show typical results for a 0.86 ft^2 steamline break from 102 percent power using the modified version of LOFTRAN. Figure 3 shows the fraction of tube uncovery versus time with uncovery of Loop 1 (faulted) starting at 152 seconds into the transient. At approximately 300 seconds, the uncovery transient reaches an equilibrium point where the steam flow out of the steam generator matches the auxiliary feedwater flow into the steam generator. Additionally, the tube uncovery transient for Loop 2 (non faulted) is plotted but shows no tube uncovery for the entire transient. Figure 4 presents the steam flow transient for this case. Figure 5 includes plots of both the superheated steam enthalpy and the saturation enthalpy for the Loop 1 steam generator. Figure 6 includes the Loop 1 temperatures for the steam generator tube inlet (primary side), steam exit temperature (superheated steam), and the saturation temperature for the steam pressure.

C. NOTRUMP Model Comparison

The NOTRUMP computer code (Reference 4) was used to verify the LOFTRAN modeling of superheat. The computer code was originally developed to analyze transients of secondary systems with two-phase conditions. In the past, it has been used to analyze various transients in the primary and secondary coolant systems. NOTRUMP has recently undergone major revisions to enable it to model non-equilibrium nodes (i.e., separate liquid temperature and steam temperature modeling). Using NOTRUMP, the steam generator can be broken down into sufficient nodes to model the nonequilibrium effects of the steam generator, as well as the tube region during uncovery. NOTRUMP can model all modes of heat transfer associated with a steamline break transient, including heat transfer from the uncovered tubes to the superheated steam and the feedback effects between the primary and secondary sides. The two phase mixture level calculation accounts for primary to secondary heat transfer and the swell associated with rapid depressurization of the steam generator during the blowdown.

A comparison of LOFTRAN and NOTRUMP blowdown results is presented in Figures 7 and 8. The mass releases shown in Figure 8 show excellent agreement. The LOFTRAN prediction of superheat enthalpy is slightly higher than NOTRUMP, while the predicted time of tube uncovery is somewhat later. NOTRUMP shows a chugging effect during the uncovery phase of the blowdown. This is believed to be in part due to oscillations in the flow link between the downcomer region and the steam dome region. (The flow link is the drain path for the moisture separators to the downcomer region.) With the flow direction towards the downcomer, superheated steam goes into the downcomer region and is condensed. This alternates with a flashing of a portion of the water volume in the downcomer region. This raises the pressure of the downcomer, resulting in a flow reversal in the link with saturated steam from the downcomer mixing with the superheated steam in the dome. This mixing results in the variations in the superheat enthalpy seen in Figure 7. Although LOFTRAN does not show the enthalpy variation since the detailed modeling of the downcomer and dome are not included, the overall agreement with NOTRUMP is very good.

D. Effects Of Analysis Assumptions

The effects of superheated steam are dependent upon the occurrence and extent of tube uncovery. The major parameters affecting tube uncovery are: initial steam generator inventory, auxiliary feedwater flowrate, assumed feedwater system failures, and protection system errors. Variations in these parameters are in the process of being evaluated for their effects on the containment temperature response (Figure 9).

Refinements in the mass and energy release modeling (Figure 10), are being evaluated and several areas show a potential for reducing the degree of superheat being generated. Some of these areas are:

- Evaluation of liquid-steam interactions such as the phenomenon of tube support plate flooding and heat transfer across the tube wrapper from the superheated steam to the auxiliary feedwater flowing down outside the tube wrapper.

- A more detailed steam header model in LOFTRAN.

- Modeling temperature drops in the primary superheat nodes.

- Evaluating other void correlations for use in predicting tube uncovery.

III. Containment Modeling

A. Description of Containment

The general phenomena taking place inside an ice condenser containment during a steamline break transient can be described utilizing a typical ice condenser elevation drawing (Figure 11). Steam is discharged to the main (or lower) compartment where heat is removed by the internal structures, steam flow to the ice condenser, and the ice condenser drain water. The dead ended compartments are the regions which are located below the ice condenser and outside the crane wall (Figure 12). Air is discharged from the main compartment to the dead ended compartment and ice condenser so that the resulting steam to air ratio is that region is much higher than in dry containments. At ten minutes following the containment hi-2 signal, deck fans are actuated which direct air flow from the upper compartment to the dead-ended compartments. Most of the safety related equipment is located in the dead-ended compartments although some equipment and cabling are located in the main compartment.

B. Containment Models

Figure 13 outlines the major models and assumptions utilized in the LOTIC-3 containment code. In the currently approved version of LOTIC-3 documented in Reference 5, four distinct regions of the containment are modeled; the lower compartment, the dead-ended compartment, the ice condenser, and the upper compartment. Two condensate/revaporization models are used depending on the size of the break. For large steamline breaks, 100% condensate revaporization is assumed. For small steamline breaks, a convective heat flux model is used which calculates partial revaporization during the transient. The wall heat transfer model utilizes the Tagami heat transfer correlation for condensation heat transfer and the convective heat flux model derived from the work of Sparrow (Reference 6) which calculates the convective heat transfer for small steamline breaks. The sump recirculation system is only modeled for the large break LOCA transient containment response.

Figure 14 shows the four regions modeled with the mass and energy flows that can be assumed in the analysis. The Catawba nuclear plant does not have lower compartment sprays and they are not modeled in the analysis. Superheat heat transfer is conservatively assumed to be zero for the steamline break containment analysis. In the model described in Reference 5, wall heat transfer is not modeled in the dead-ended compartments although these regions do contain structures which will remove heat. The analysis does include the upper compartment sprays, flow through the ice condenser, deck fan flow, and flow to the dead-ended compartments.

LOTIC-3 solves the conservation of mass, energy, and momentum equations for upper, lower, and ice condensor regions (Figure 15). After the new lower compartment conditions are determined, conservation equations are solved for the dead ended compartment and the flow rate between the compartments is determined.

Figure 16 presents a typical steamline break containment temperature transient that is calculated using superheated steam blowdowns from the LOFTRAN code and the modeling of ice condenser drains as a heat removal source. The transient shows that initially the containment temperature increases rapidly during the

blowdown. When the upper compartment sprays actuate there is a slight decrease in the main compartment temperature. The temperature then rises slowly until ice condenser drain flow decreases to the point at which time the temperature begins to rise again (approximately 250 seconds). This rise in containment temperature coincides with the steam generator tubes uncovering at 152 seconds and the maximum superheat occurring at approximately 250 seconds. The steam generator level stablizes when the auxiliary feedwater flow is equal to the steam discharge at approximately 300 seconds. The containment temperature then starts decreasing with decreasing decay heat. At ten minutes, the deck fans actuate which results in a rapid decrease in containment temperature.

C. LOTIC-3 Code Modifications

Four modifications have been incorporated in the LOTIC-3 containment model which are (Figure 17);

1) wall heat transfer model
2) convective heat flux model
3) ice condenser drain model
4) dead-ended compartment model

D. Wall Heat Transfer

The modification to the wall heat transfer model is described in Figure 18. In the LOTIC-3 model, only condensation heat transfer, utilizing a Tagami heat transfer coefficient and a temperature difference between the wall and saturation, was previously modeled. The modification includes a convection term with a conservative convection heat transfer coefficient and a temperature difference between the containment atmosphere and an appropriate interface temperature. The Appendix presents a more detailed description of this model.

E. Convective Heat Flux

The modification to the convective heat flux model is described in Figure 19. A term has been added to the convective heat flux model to account for the feedback effect from including a convective term in the wall heat transfer model. The Appendix presents a more detailed description of this model.

F. Ice Condenser Drain Model

In an ice condenser containment there is approximately twenty drains exiting from the ice condenser into the lower compartment at an elevation of about forty feet above the compartment floor. The drain pipes are one foot in diameter. The drain flowrate is calculated by the LOTIC-3 containment code. For a typical small steamline break transient the drain flowrate varies from approximately 4000 lbm/sec to 500 lbm/sec during the timeframe of interest. The temperature of the drain water is approximately 130°F (Figure 20).

Figure 21 presents the assumptions and the basic model used to estimate the heat removal from the lower compartment atmosphere to the ice condenser drain water. It is conservatively assumed that the drain water stream does not break up prior to reaching the floor even though many of the drains have equipment and structures located below them. Therefore, heat transfer is assumed to occur at

the stream surface only. It is also assumed that the stream surface temperature is at the saturation temperature of the containment.

The heat transfer to the stream is:

$$q=hA\Delta T$$

where

h = condensation heat transfer coefficient

A = surface area of the stream

ΔT = appropriate temperature difference

The calculation of the heat transfer surface area is described in Figure 22. In order to model the drains in LOTIC-3, the drains are modeled as a wall heat sink with a surface at a constant temperature (see Figure 23). Currently, in the version of LOTIC-3, the surface temperature is assumed to be 230°F which is close to the containment saturation temperature. The drain surface area is calculated at two points in time during the transient; early in time with a high flowrate and later in time with a low flowrate. To ensure conservatism in the area calculation a 10% reduction of the surface area was assumed.

As described previously (Figures 14 & 15), the LOTIC-3 containment model did not account for wall heat removal in the dead-ended compartments. To obtain a conservative estimate of the temperature transient in the dead ended compartment, the heat sinks located in the dead ended compartment region along with the heat sinks in the lower compartment are modeled in a combined volume (see Figure 24). This "modified" lower compartment model is used to determine a conservative dead-ended compartment temperature transient. Since the lower compartment will be hotter than the dead-ended compartment, this methodology results in a higher temperature in the dead-ended compartment than would be expected.

G. Transient Results

With the modifications described for LOFTRAN and LOTIC-3, the previous FSAR limiting case for Catawba was reanalyzed to determine the impact of superheated steam. The case selected is a 0.86 square foot break at 102% power (Figure 25). The peak lower containment temperature for this case is 324°F. This temperature is calculated for the lower compartment only. It is expected that the dead-ended compartment temperature will be significantly lower.

In addition to the model modifications incorporated in LOTIC-3, Westinghouse is pursuing further improvements in the areas noted on Figure 26. One area is in the wall heat and mass transfer models. Since condensation is a mass transfer type phenomena, the heat and mass transfer should be linked. This approach has been used in Reference 7.

An improved drain model is also being investigated. This improved model will calculate the drain surface area as a function of flowrate. It will also calculate the average temperature rise of the drainwater. This model will more accurately represent the actual phenomena in the containment.

V. Appendix

WESTINGHOUSE STEAMLINE BREAK BLOWDOWN AND CONTAINMENT ANALYSIS METHODOLOGY

The following sections describe the Westinghouse methodology for determining the containment response for a steamline break incorporating the effects of superheated steam. These sections describe in detail changes from the methodologies described in References 1 and 5.

I. Steamline Rupture Mass/Energy Blowdown Analysis

A. LOFTRAN and MARVEL Computer Modeling

Mass/energy releases can be calculated using either the LOFTRAN code (Reference 3) or the MARVEL code (Reference 8). The LOFTRAN code is used for non-LOCA FSAR accident analyses. The MARVEL code was specifically developed for assymmetric transients such as steamline breaks. These two codes are very similar because they were developed in an interrelating fashion and much of the modeling is common to both codes. The MARVEL code was used in the development of Reference 1 because LOFTRAN at that time was a lumped model which was used for symmetric loop transients. Furthermore, for steamline break analysis purposes, MARVEL contains a model for water entrainment. However, the current version of LOFTRAN is a multiloop version which also contains a water entrainment model. With the development of a multiloop version of LOFTRAN and the inclusion of an entrainment model, the use of MARVEL has been generally discontinued. This enables the use of LOFTRAN as a single system analysis code for non-LOCA transient analyses. LOFTRAN is used in the analyses presented here.

The model of importance to blowdown calculations is the steam generator model. The primary side of the steam generator contains multiple nodes to model the tube bundle for both the modified version of LOFTRAN and MARVEL. Heat transfer calculations from the primary to secondary side are identical in the two codes, although the methods for initializing the heat transfer resistances are slightly different. The secondary side is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur to saturated water. If tube uncovery is predicted, the amount of surface area available for heat transfer is reduced.

Both codes contain a detailed steam generator model which is used to predict tube uncovery. This model calculates the liquid volume in the steam generator shell and accounts for the detailed steam generator geometry. The [ ][a,c] correlation is used in both codes to predict the voiding in the tube region, although the correlation is modified for use in LOFTRAN. In MARVEL, tube uncovery is calculated based

on comparison with the actual water level and the height of the tube bundle. In LOFTRAN, the user specifies either a water volume in the steam generator corresponding to tube uncovery, or a void fraction in the riser section of the steam generator at which tube uncovery begins.

Both codes have similar models accounting for reverse heat transfer, thick metal heat transfer, feedline flashing, and safety injection system operation. Auxiliary feedwater flow can be input as a fraction of nominal feedwater flow, although LOFTRAN has an additional capability to model auxiliary feedwater flow as a separate system. For analysis of double ended ruptures, MARVEL accounts for the volume of steam in the piping downstream of the steam generators in the blowdown calculations. In LOFTRAN, this consideration is added on to the blowdown mass and energy results by hand. For split ruptures, which the analysis presented here addresses, the steam piping masses are handled identically in both codes.

In summary, LOFTRAN and MARVEL are very similar codes, and either can be used to calculate mass/energy blowdowns. To demonstrate this, a comparison of the blowdowns for a typical case is presented in Figures A.1 and A.2. Figure 1 presents the mass release rate for a .86 ft2 split rupture from 102% power. For this case, Figure A.2 shows the saturated steam enthalpy as a function of time. This blowdown is typical of results used in FSAR analyses prior to the modification noted in this report for the LOFTRAN code. As can be seen from the figures, the results are extremely close.

B. LOFTRAN Model for Superheated Steam

As mentioned previously, the LOFTRAN code has been modified to model heat transfer which may occur in the uncovered tube bundle region. This effect is modeled in both the faulted and intact loops. In the modified version of LOFTRAN, all heat transfer occurring in the uncovered region is assumed to add superheat the steam exiting the steam generator. The temperature of the primary coolant flowing through in the uncovered tube region mode is conservatively assumed to remain constant. Realistically there would be a drop in temperature due to heat removal to the secondary side, but this will be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is based on the [(1)]a,c. The heat transfer coefficient (U) is calculated by the following expression:

[ ]a,c

This correlation is presently used for superheated forced convection heat transfer by the [ ]a,c computer codes. Additionally,

this correlation is based upon the heat transfer from the surface of the tube wall to the average bulk temperature of the steam. In the LOFTRAN modification, no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall temperature of the tube is conservatively assumed equal to the primary fluid temperature.

(1) [ ]a,c

The modified version of LOFTRAN automatically selects the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the modified LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. Each node is evaluated to determine the steam temperature exiting the node with a convergence criteria that is based upon the total number of nodes used. The exit steam temperature of one node is used as the inlet steam temperature of the next node.

The heat transfer calculation to determine the outlet temperature of the node is based upon the following expression:

$$Q = UA*(T_{pri}-(T_{out}+T_{in})/2) = M_s*C_s*(T_{out}-T_{in})$$

where Q = Heat transfer to the steam

U = [ ] a,c

T_{pri} = Primary node temperature

T_{out} = Steam node outlet temperature

T_{in} = Steam node inlet temperature

M_s = Mass flowrate of the steam

C_s = Heat capacity of the steam

A = Heat transfer area in the node including both hot and cold leg sides of the tube bundle

The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient.

C. Blowdown Sensitivity to Plant Conditions

The effects of superheated steam are dependent upon the occurrance and extent of tube bundle uncovery. Parameters affecting tube uncovery are: initial steam generator inventory, break size, auxiliary feedwater flowrate, and the single failure assumed.

The initial steam generator inventory depends upon the measurement errors associated with steam generator level and upon initial power level. Steam generator mass increases with decreasing power, thus, breaks intitiating from low power levels will result in later tube uncovery.

Larger break sizes result in faster blowdown of the steam generator and earlier tube uncovery.

Large auxiliary feedwater flowrates only delay tube uncovery, but will also cause the final equilibrium steam generator level to be higher. This equilibrium condition corresponds to the point when the break flow rate is equal to the auxiliary feedwater flow rate.

The single failure assumed in the transient may impact the amount of water supplied to the steam generator. Auxiliary feedwater runout will increase the amount of water supplied to the steam generator. Failure of the feedwater isolation valve will also cause extra water to be supplied to the generator as the additional mass between the isolation valve and the check valve flashes to the generator.

II. Containment Analysis

A. Wall Heat Transfer Model

The original LOTIC-3 wall heat transfer model is based on the stagnant Tagami heat transfer correlation. That is,

$$q''=h_{TAGAMI}(T_{SAT}-T_{WALL})$$

$$h_{TAGAMI} = 2 + 50\ M_{STEAM}/M_{AIR} \quad h_{(TAGAMI,MAX)}=72\ BTU/hr\text{-}ft^2\text{-}^oF$$

This model was developed for saturated steam in the presence of large amounts of non-condensable gases. In the lower compartment of an ice condenser, most of the air is swept out of the lower compartment through the ice condenser and into the upper compartment. Therefore, after about 30 seconds, there is almost no non-condensables in the lower compartment. Typical values for the condensation of pure steam are in the range of 1000 to 3000 Btu/hr-ft2-°F (Ref. 5). The correlation used in the modified LOTIC-3 code is in extension of the Tagami correlation for nearly pure steam.

$$q''=h_{COND}\ (T_{SAT}-T_{WALL})$$

$h_{cond} = 2+50\ M_{STEAM}/M_{AIR} \quad h_{(cond,max)} =$ [ ]^{a,c}

A maximum value of [ ]^{a,c} was chosen as a conservatively low condensing heat transfer coefficient in a nearly pure steam environment.

In addition to this modification, an additional term is needed to account for the convective heat transfer from the superheated steam to the condensate film. This convective heat transfer is dependent upon whether there is condensation occurring on the walls. If condensation is occurring, the correlation used is:

$$q''_{conv}=h_{conv}(T_{bulk}-T_{sat})$$

where:

[ ]^{a,c}

If the wall temperature increases to above the saturation temperature then the convective currents will be reduced such that the correlation used is

$$q''_{conv}=h_{conv}(T_{bulk}-T_{wall})$$

where:

[ ]^{a,c}

Thus in summary, if $T_{wall} < T_{sat}$ then

[ ]^{a,c}

If $T_{wall} > T_{sat}$, then the correlation used is:

[ ]^{a,c}

B. Convective Heat Flux Model

When the containment atmosphere is superheated, the containment temperature is a strong function of the amount of steam mass in the atmosphere. Thus the amount of mass condensed on the heat sink surfaces is a key parameter. The actual amount of condensate formed is

$$M_{cond} = q_{cond}/h_{fg}$$

Unfortunately, with the use of a heat transfer correlation based only on test data (such as Tagami or Uchida), only the total heat transfer coefficient is obtained. This total heat transfer coefficient includes both the condensation heat transfer and the convective heat transfer. Based on the work of Sparrow (Reference 6), the Westinghouse Convective Heat Flux model in the original LOTIC-3 code calculates the ratio of the convective heat transfer to the condensation heat transfer. Therefore the calculation of the amount of mass condensed is

[ ]a,c

In the modified LOTIC-3 model, the amount of superheat convection is calculated. The amount of convective heat transfer at saturation is not known explicitly in this model. Therefore, in the modified LOTIC-3 code the original convective heat flux model will be used to calculate the fraction of convective heat transfer for saturated conditions. The actual correlation is

[ ]a,c

where, $(q_{conv}/q_{cond})_{sat}$ is determined from original convective heat flux model and $q_{conv,sh}$ is the amount of convective heat transfer calculated in the wall heat transfer model

In summary, the modified LOTIC-3 model is consistent with the original LOTIC-3 model in its calculation of the mas condensed. The only difference is that in the modified LOTIC-3 code, the amount of superheat convective heat transfer is known explicitly, while in the original LOTIC-III model, only the ratio of convective heat transfer to condensation heat transfer is known.

IV. References:

1. Land, R. E., "Mass and Energy Releases Following A Steam Line Rupture" WCAP-8822 (Proprietary) September, 1976 and WCAP-8859 (Non-Proprietary).

2. NS-EPR-2563, February 14, 1982, E. P. Rahe of Westinghouse to J. R. Miller, NRC, "Additional Information on WCAP-8822".

3. Burnett, T. W. T., et al., "LOFTRAN Code Description," WCAP-7907, June, 1972 (Proprietary).

4. Meyer, P. E., and Kornfilt, J., "NOTRUMP - A Nodal Transfer Small Break and General Network Code," November, 1982, WCAP-10079 (Proprietary) and WCAP-10080 (Non-Proprietary).

5. Hsieh, T. and Liparulo, N. J., "Westinghouse Long Term Ice Condenser Containment Code - LOTIC-3 Code," February, 1979, WCAP-8354-P-A Sup. 2 (Proprietary),WCAP-8355-NP-A (Non-Proprietary).

6. Sparrow, E. M., Minkowycz, W. J., and Saddy, M., "Forced Convection Condensation in the Presence of Noncondensables and Interfacial Resistance", Int. J. Heat Mass Transfer, Volume 10, 1967.

7. Corradini, M. L., "Turbulent Condensation on a Cold Wall in the Presence of a Non-condensable Gas" Nuclear Technology Vol. 64, pp 186 - 195, February, 1984.

8. Krise, R. and Miranda, S., "MARVEL - A Digital Computer Code for Transient Analysis of a Multiloop PWR System," November, 1977, WCAP-8843 (Proprietary) and WCAP-8844 (Non-Proprietary).

9. McCabe, W. L., and Smith, J. C., "Unit Operatons of Chemical Engineering", 3rd Edition, 1976.

LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

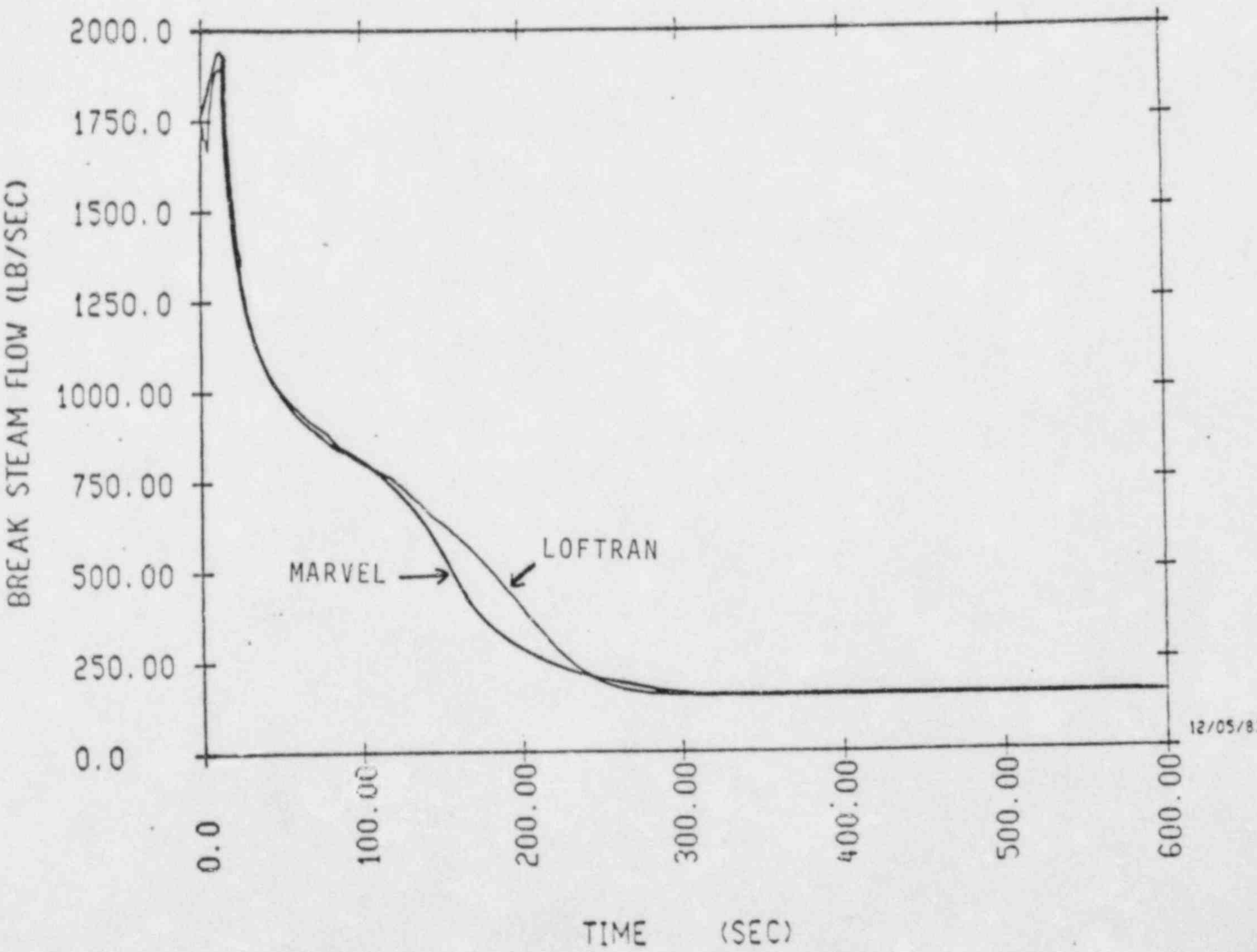


FIGURE A.1

LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

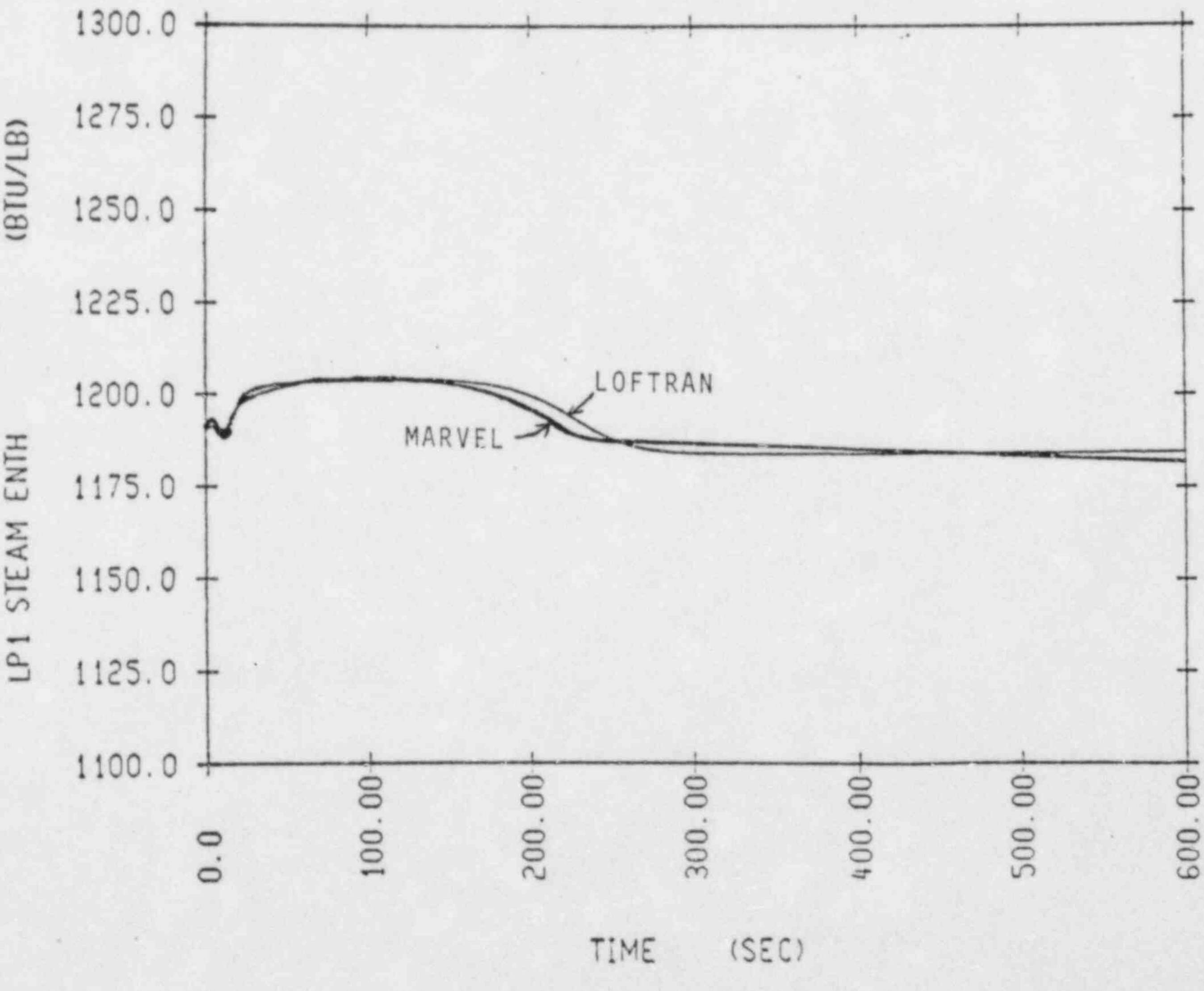


FIGURE A.2

METHODOLOGY FOR ADDRESSING SUPERHEATED STEAM RELEASES TO ICE CONDENSER CONTAINMENTS

Purpose

The purpose of this report is to document the information presented on March 19, 1984 in a meeting with the U.S. NRC Containment Systems Branch on the status of progress made in addressing the confirmatory item on the Catawba Nuclear Plant Safety Evaluation Report. This confirmatory item deals with the effects of superheated steam generator mass and energy releases following main steamline break accidents. Attachment 1 includes the list of attendees at the meeting and the overhead slides covered in the Westinghouse presentations.

Technical presentations were made describing the modeling of the steam generator and heat transfer from the uncovered tube bundle during the steam generator blowdown along with a description of the containment model and transient response. A proposed plan of action was also presented and discussed with the Staff. In accordance with that plan, this report represents the first milestone in the proposed plan of action. As committed to in the meeting, the appendices present proprietary information which relates to the specifics of the models and sensitivities that were not directly addressed in the meeting.

Attachment 2 is an explanation of, and refers to, the overhead slides (Figures) presented at the March 19 meeting.

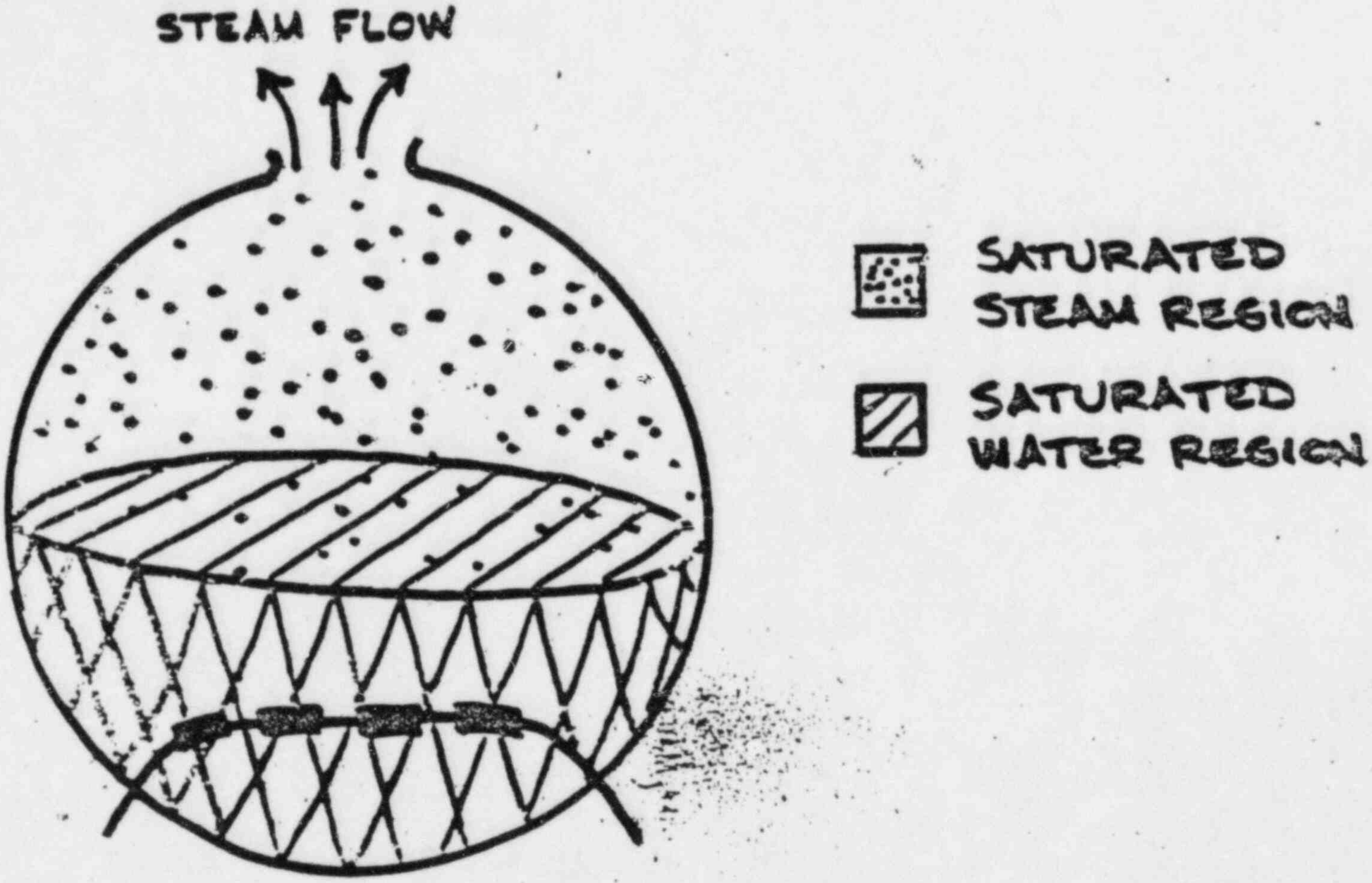
ATTACHMENT 1

Attendance at 3/19/84
Meeting w/ Duke + W on
Main Steam Line Break Analysis

Name	Organization
K. N. JABBOUR	NRC/DL
R.O. SHARPE	DUKE/NPD
J. L. LITTLE	W NUCLEAR SAFETY
H.V. JULIAN	W NUCLEAR SAFETY
TJ Kenyon	NRC/DL
DS. Love	W NUCLEAR SAFETY
MP Osborne	W Nuclear Safety
P.A. Linn	W Nuclear Safety
L.E. Hochreiter	W Nuclear Safety
F.F. CADEK	W Nuclear Safety
F J Twogood	W NOD, project mgr.
S D Alexander	Duke, Design Engineering
R E Miller	Duke, Design Engineering
J. E. Wills	TVA, Nuclear Licensing Staff
B. AMELI	SERCH LICENSING STAFF, BECH.
C. DRAUGHON	W NUCLEAR SAFETY
W.D. Crouch	TVA, Engineering Design
S. P. Nesbit	Duke, Nuclear Production Department [illegible]
S.A. Swamy	W, NTD/SME
R.H. Owoc	W NTD/NUCLEAR SAFETY
J SHAPAKER	NRC/CSB
Jack Kudrick	" "
J. Pulsipher	NRC/CSB
C. Li	NRC/CSB
A. Notafrancesco	NRC/CSB

LOFTRAN MODEL

STEAM GENERATOR SECONDARY

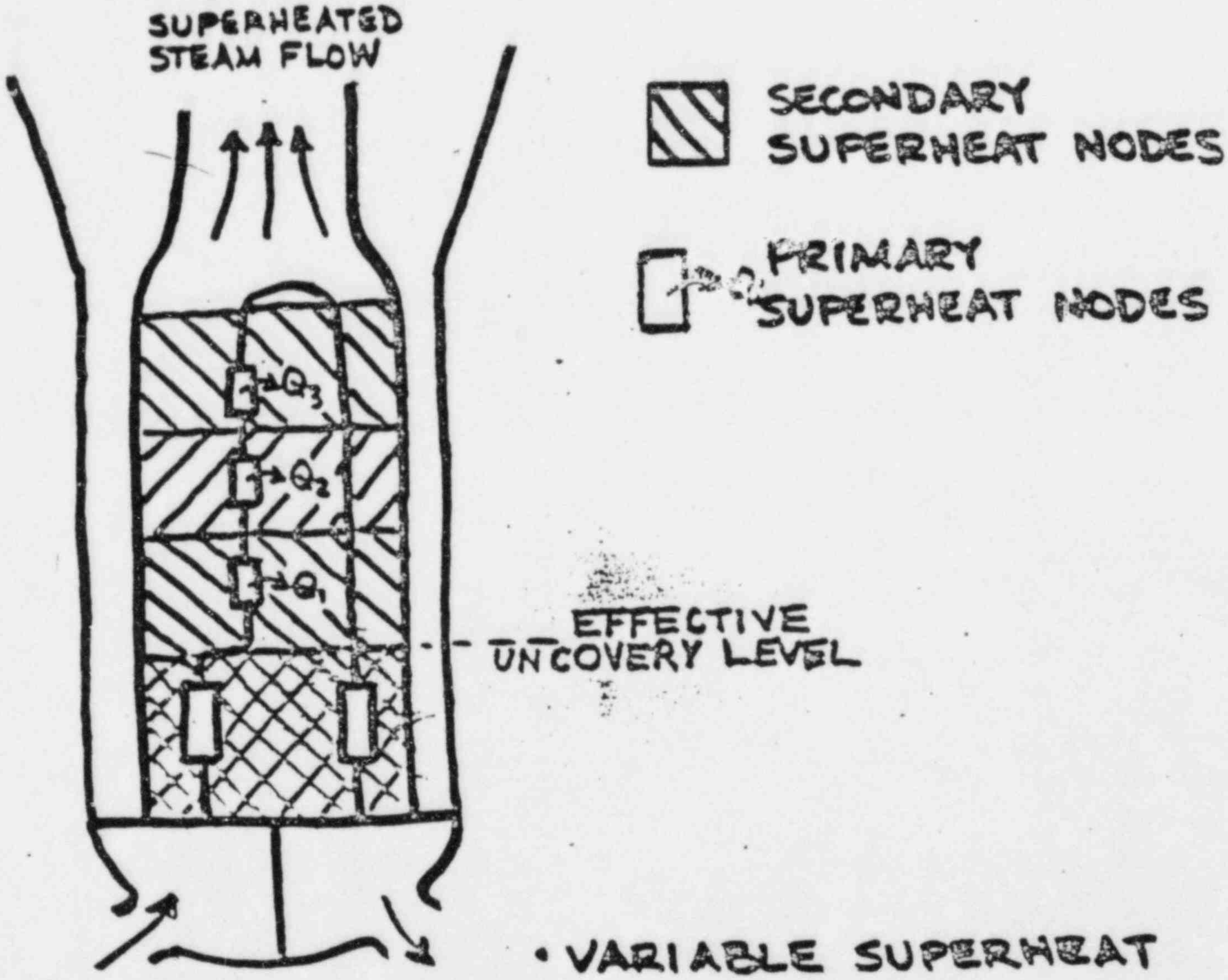


- SINGLE NODE, 2 REGION MODEL
- NO HEAT TRANSFER TO SATURATED STEAM REGION
- HEAT TRANSFER TO SATURATED WATER REGION IS MODIFIED FOR TUBE 'UNCOVERY'

FIGURE 1

LOFTRAN MODEL

SUPERHEAT HEAT TRANSFER



- VARIABLE SUPERHEAT NODES MODEL

- CONSTANT PRIMARY TEMPERATURE IN SUPERHEAT REGION ASSUMED FOR HEAT TRANSFER CALCULATIONS

- CALCULATED SUPERHEAT HEAT TRANSFER ACCOUNTED FOR IN PRIMARY TRANSIENT

FIGURE 2

TUBE UNCOVERY

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

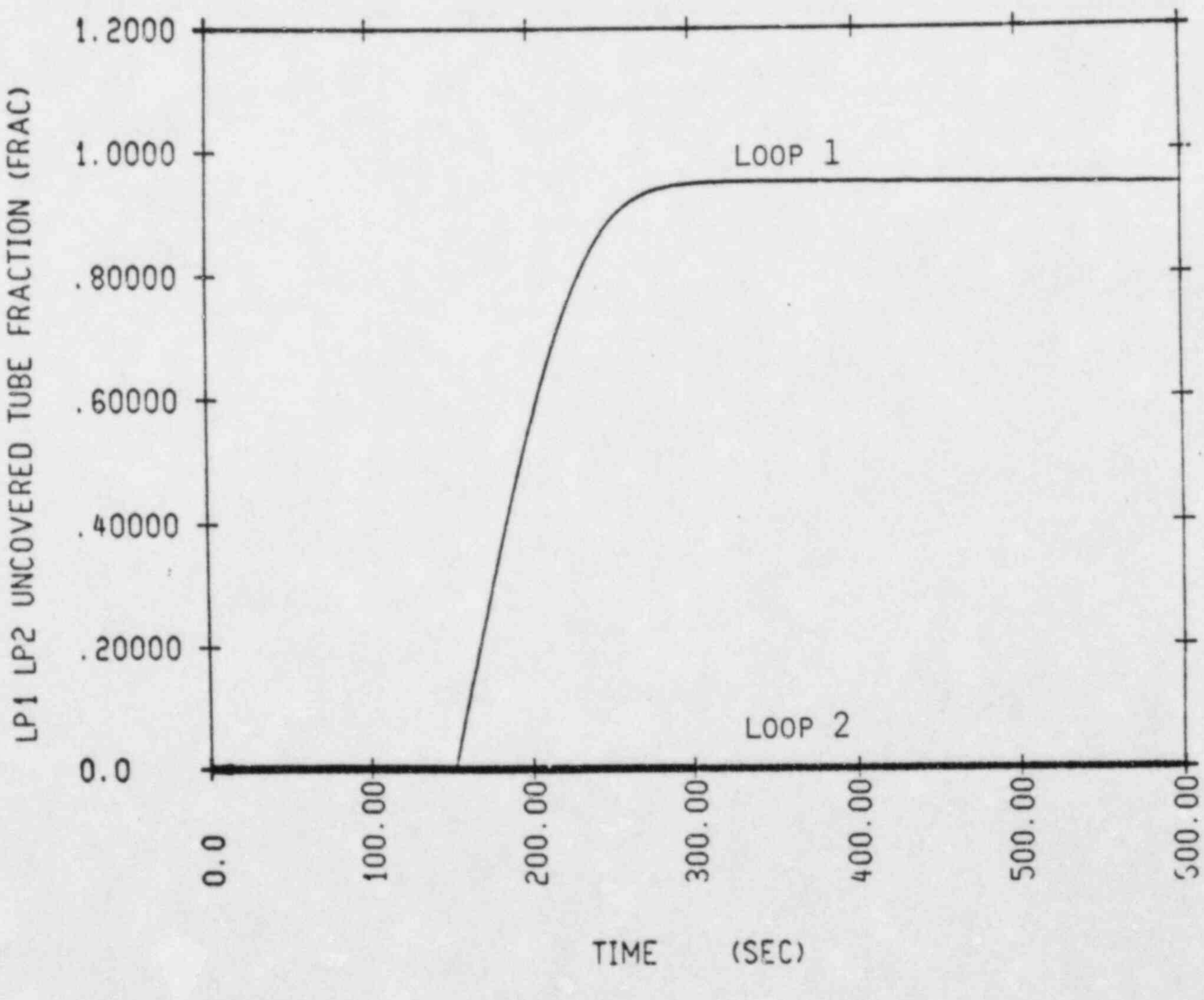


FIGURE 3

MASS BLOWDOWN

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

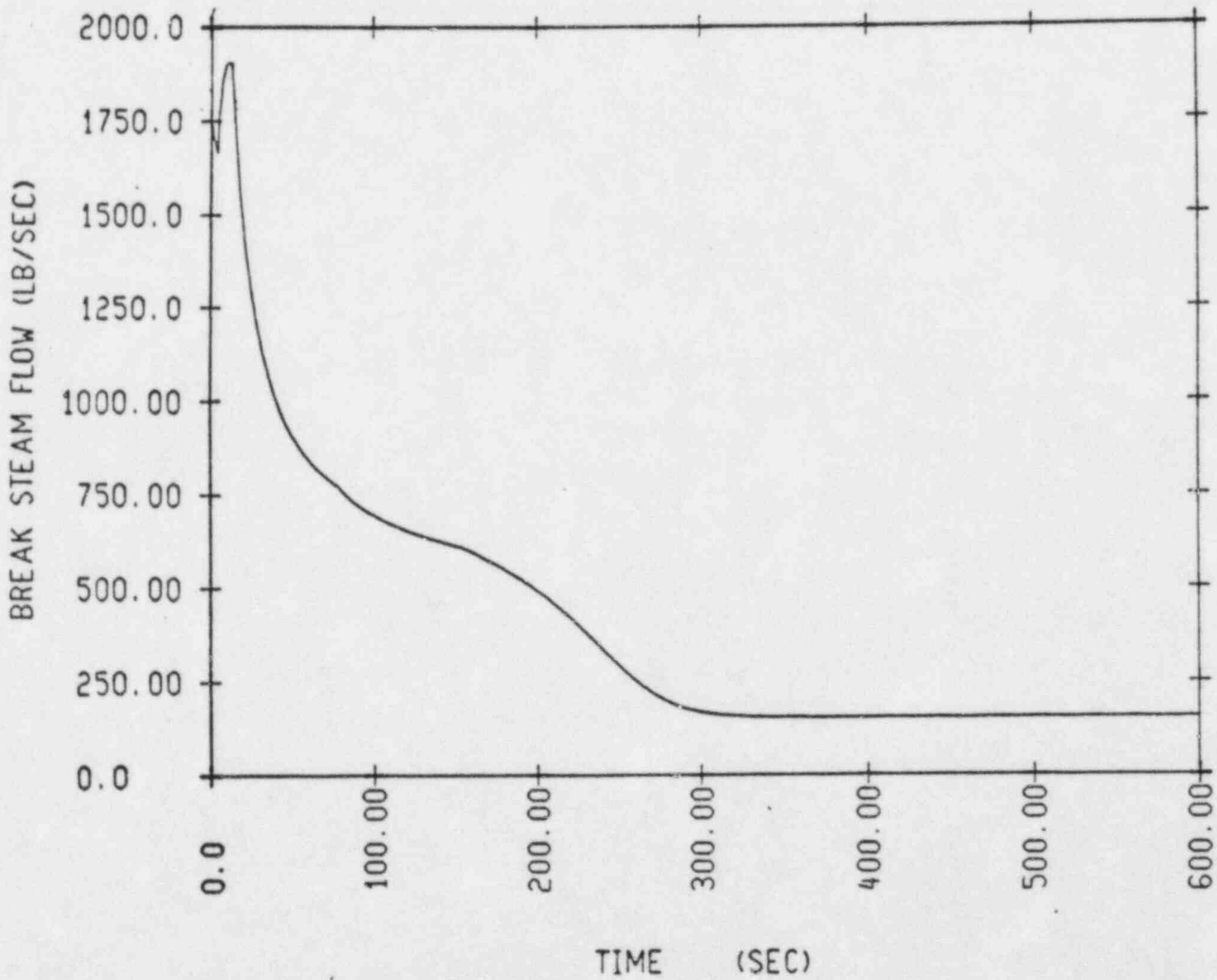


FIGURE 4

ENERGY RELEASE

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

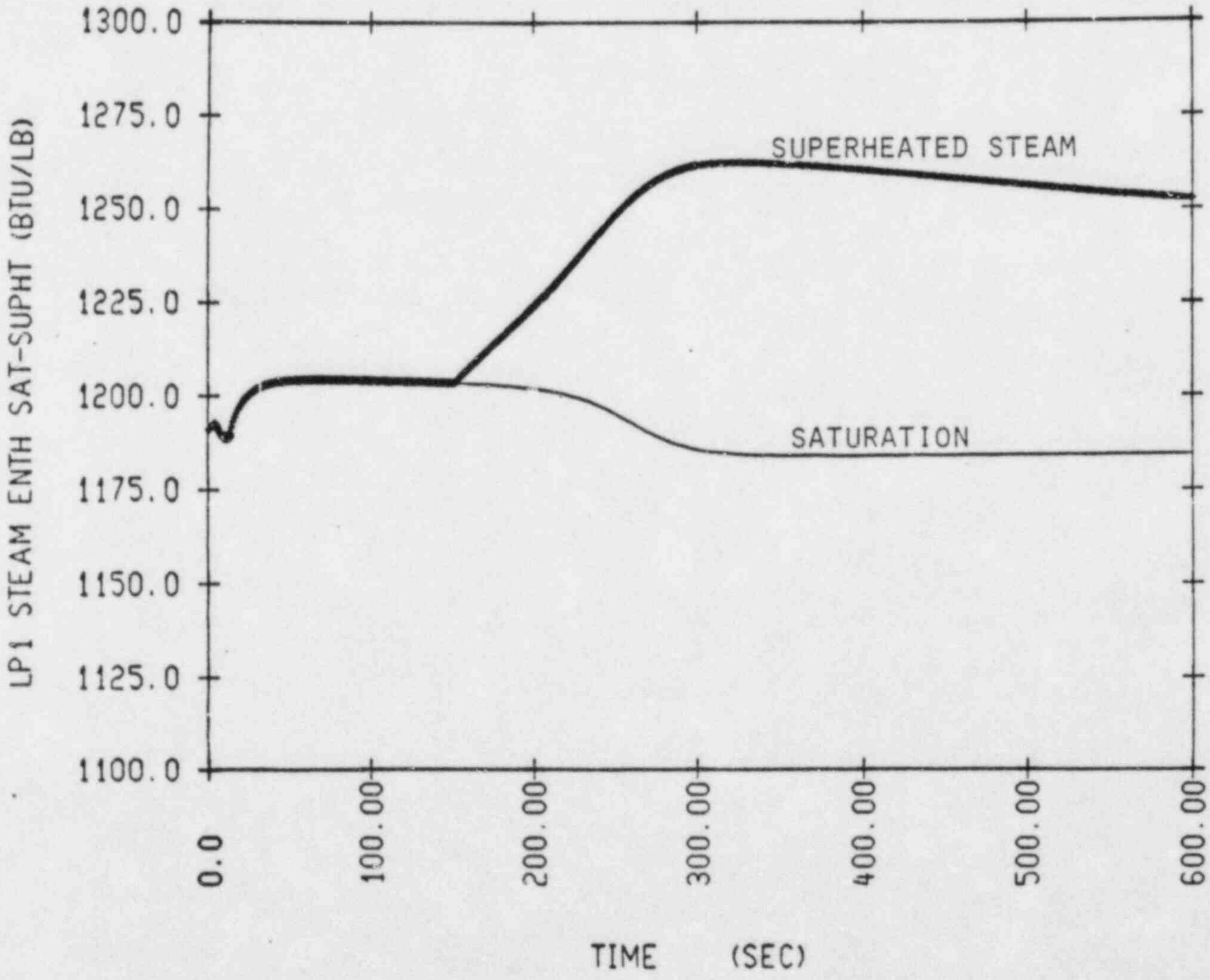


FIGURE 5

TEMPERATURE TRANSIENTS

LOFTRAN SUPERHEAT MODEL

.860 FT^2 BREAK AT 102 PC POWER

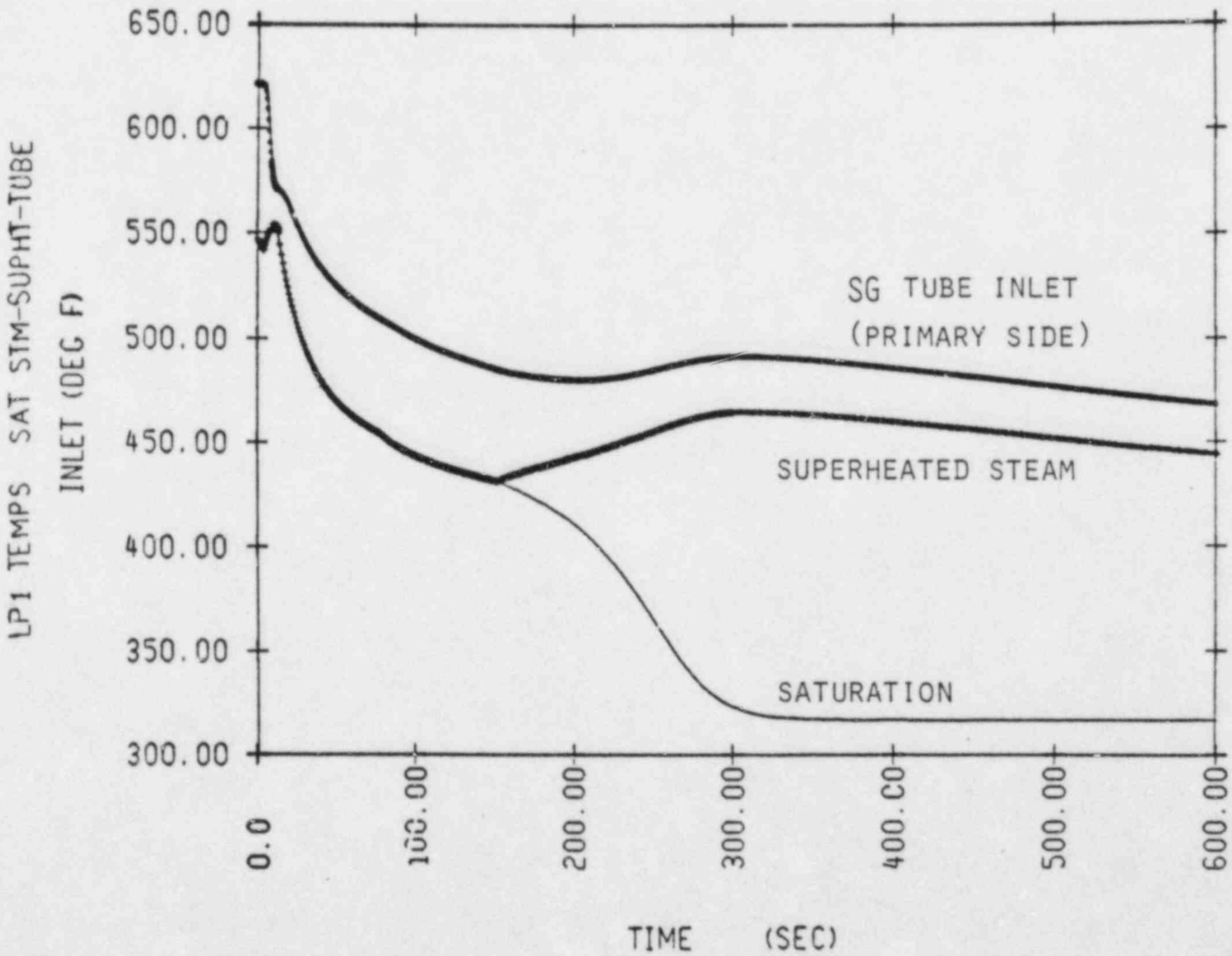
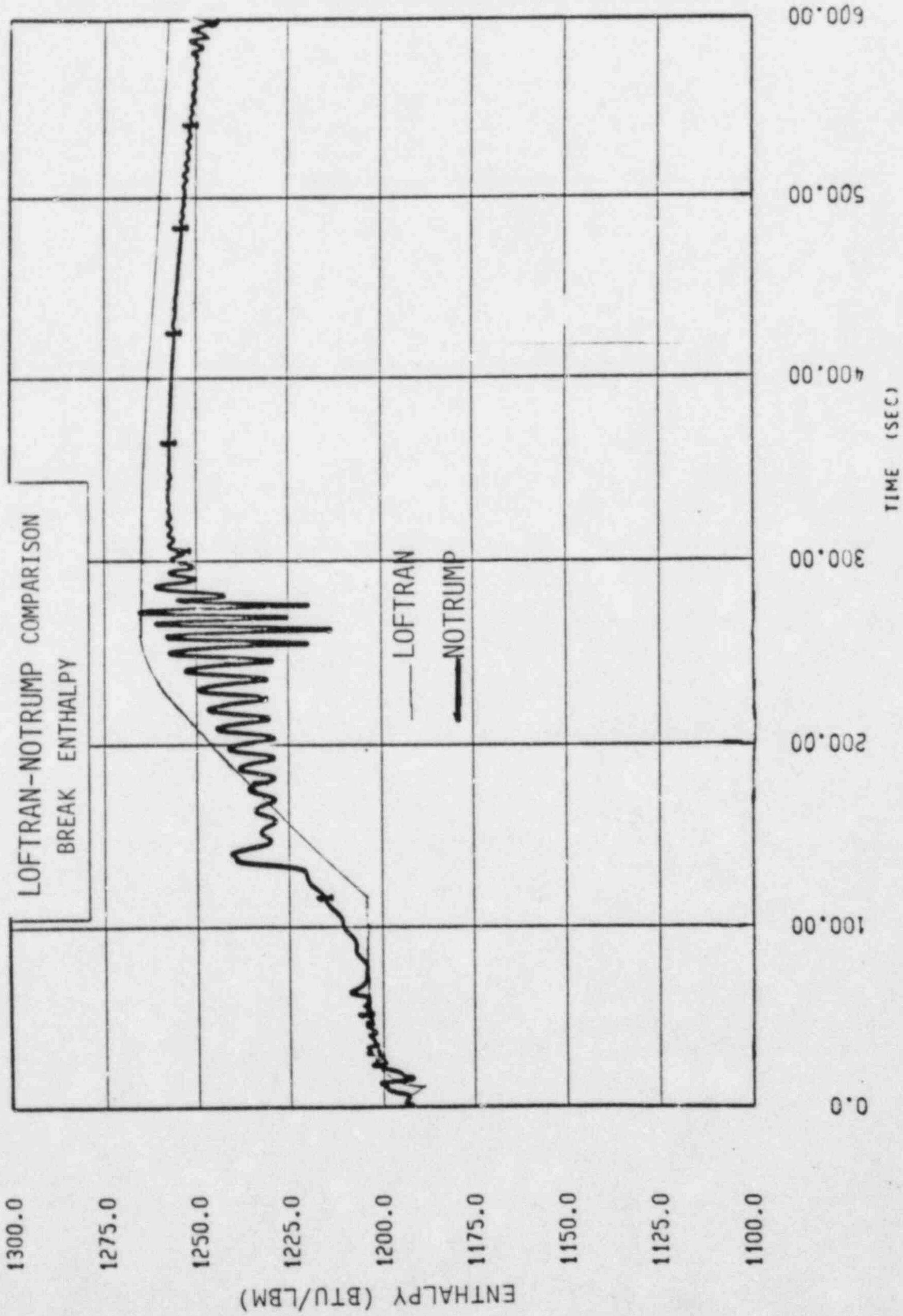


FIGURE 6



LOFTRAN-NOTRUMP COMPARISON
BREAK ENTHALPY
LOFTRAN
NOTRUMP
ENTHALPY (BTU/LBM)
1300.0
1275.0
1250.0
1225.0
1200.0
1175.0
1150.0
1125.0
1100.0
TIME (SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00

FIGURE 7

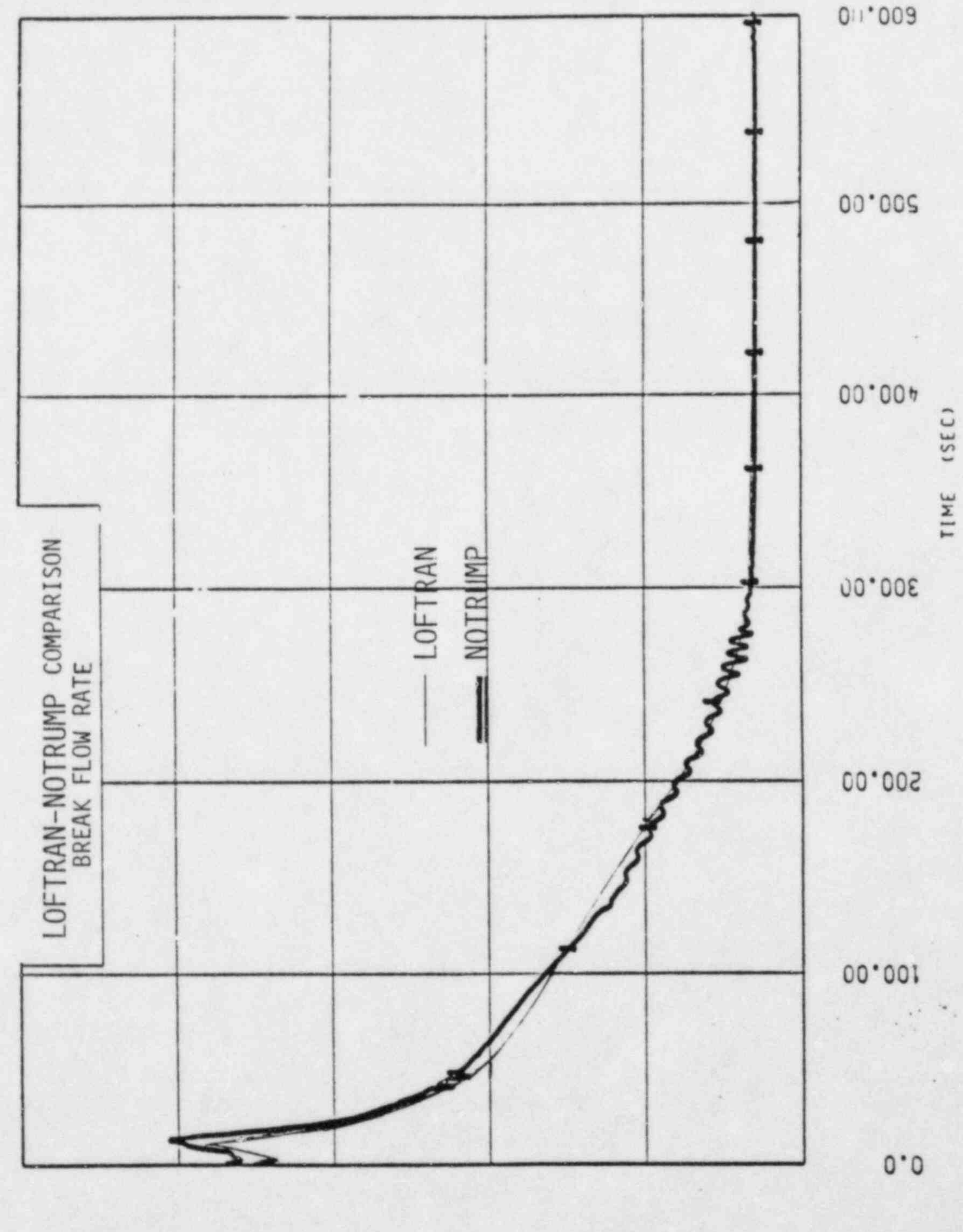

LOFTRAN-NOTRUMP COMPARISON
BREAK FLOW RATE
LOFTRAN
NOTRUMP
TOTAL BREAK MASS FLOW RATE (LBM/SEC)
0.0
500.00
1000.0
1500.0
2000.0
2500.0
TIME (SEC)
0.0
100.00
200.00
300.00
400.00
500.00
600.00

FIGURE 8

EFFECTS OF ANALYSIS ASSUMPTIONS

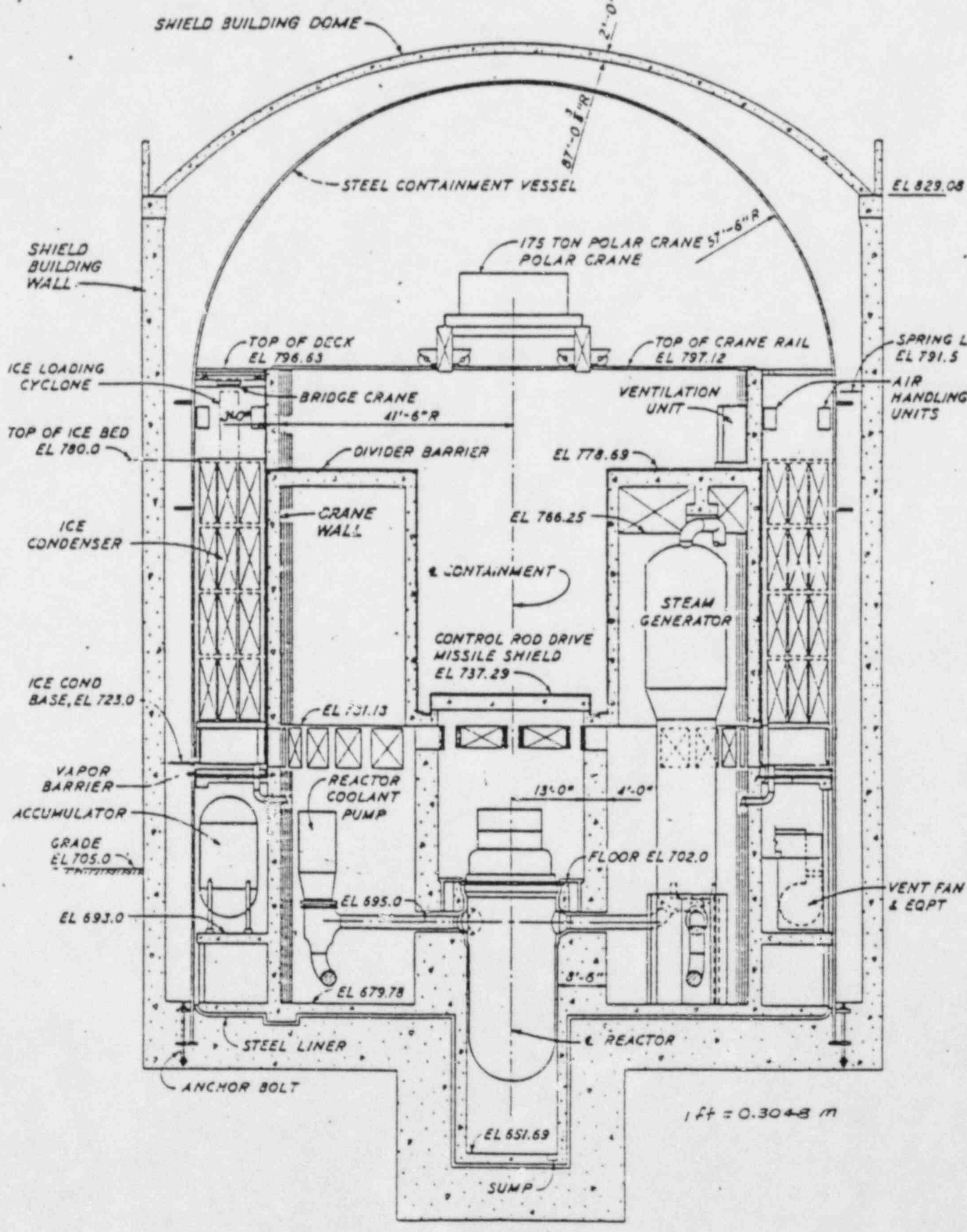
- INITIAL STEAM GENERATOR INVENTORY
- AUXILIARY FEEDWATER FLOWRATE
- FEEDWATER SYSTEM FAILURES
- PROTECTION SYSTEM ERRORS

FIGURE 9

ADDITIONAL MODEL CONSIDERATIONS

- LIQUID-STEAM INTERACTION
- IMPROVED STEAM HEADER MODEL
- HEAT TRANSFER THROUGH TUBE WRAPPER
- TEMPERATURE DROP IN PRIMARY SUPERHEAT NODES
- OPTIONAL VOID CORRELATIONS

FIGURE 10



Reactor Building Elevation

FIGURE 11

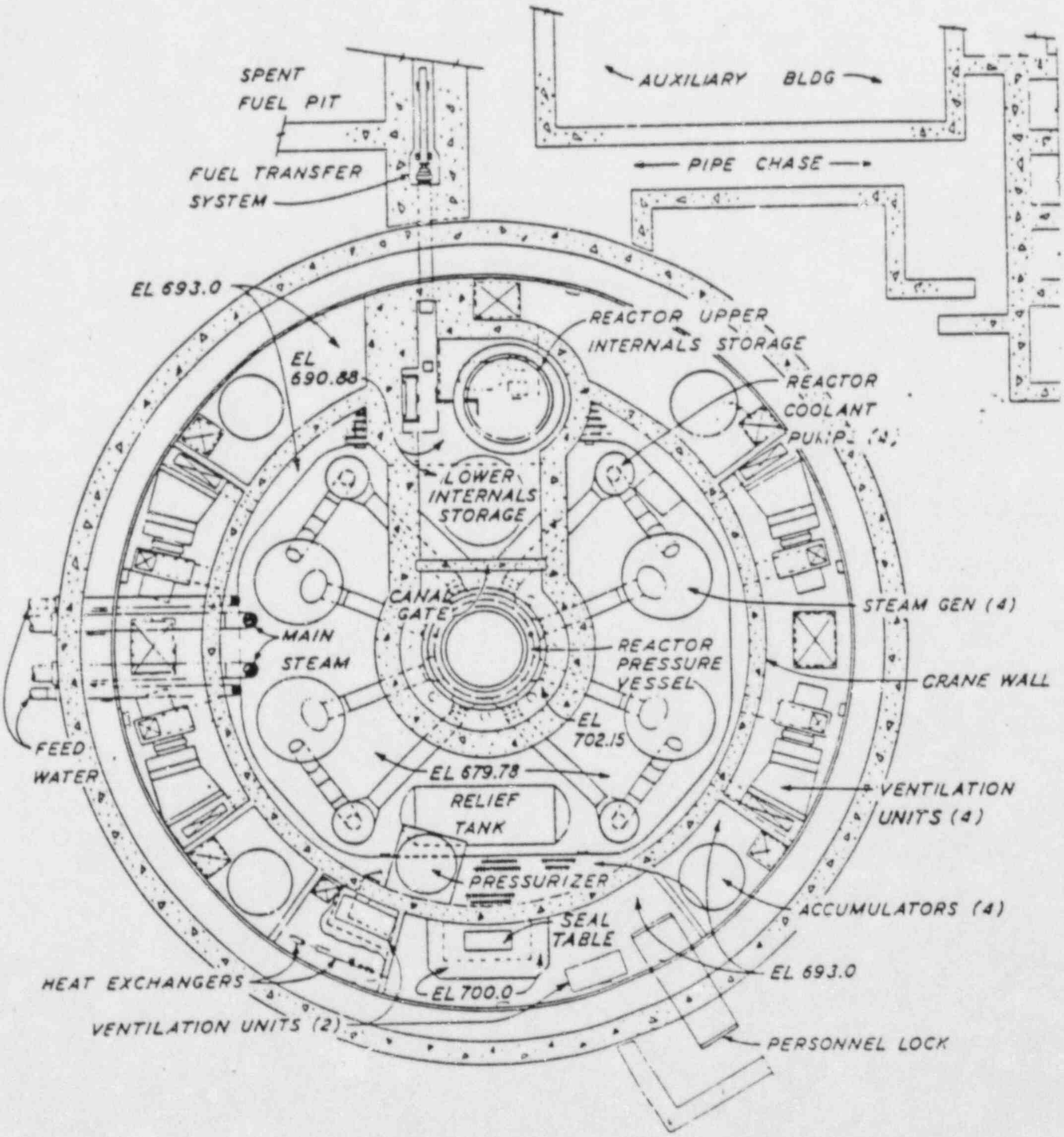


Figure 3.8.3-7 Plan-Lower Compartment

FIGURE 12

LOTIC-3 CONTAINMENT CODE

* 4 NODE CONTAINMENT MODEL

* CONDENSATE/REVAPORIZATION MODELS

  - LARGE BREAK (TOTAL REVAPORIZATION)

  - SMALL BREAK (CONVECTIVE HEAT FLUX)

* WALL HEAT TRANSFER MODEL

* MODELS SUMP RECIRCULATION SYSTEM

FIGURE 13

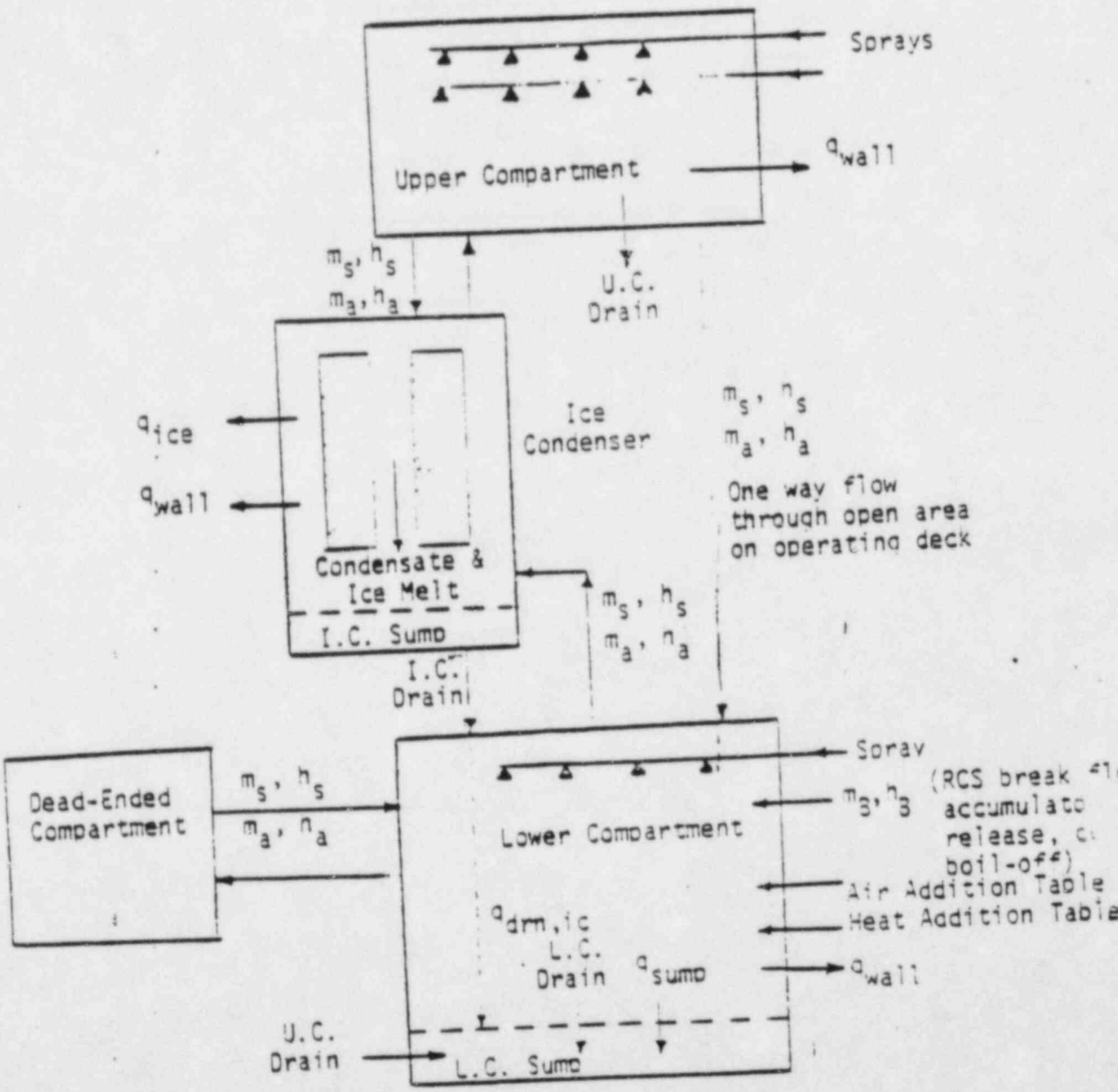


FIGURE 3.3 MASS AND ENERGY FLOW DIAGRAM
FOR THE COMPARTMENTS

FIGURE 14

LOTIC-3 - METHOD OF SOLUTION

- SOLVES CONSERVATION OF MASS, ENERGY, AND MOMENTUM FOR UPPER, LOWER, AND ICE CONDENSER REGIONS

- ONCE NEW LOWER COMPARTMENT CONDITIONS ARE DETERMINED, CONSERVATION EQUATIONS ARE SOLVED FOR THE DEAD-ENDED COMPARTMENT AND FOR THE FLOW RATE BETWEEN THE TWO COMPARTMENTS

FIGURE 15

TYPICAL CONTAINMENT TEMPERATURE

TRANSIENT (DRAINS MODELLED)

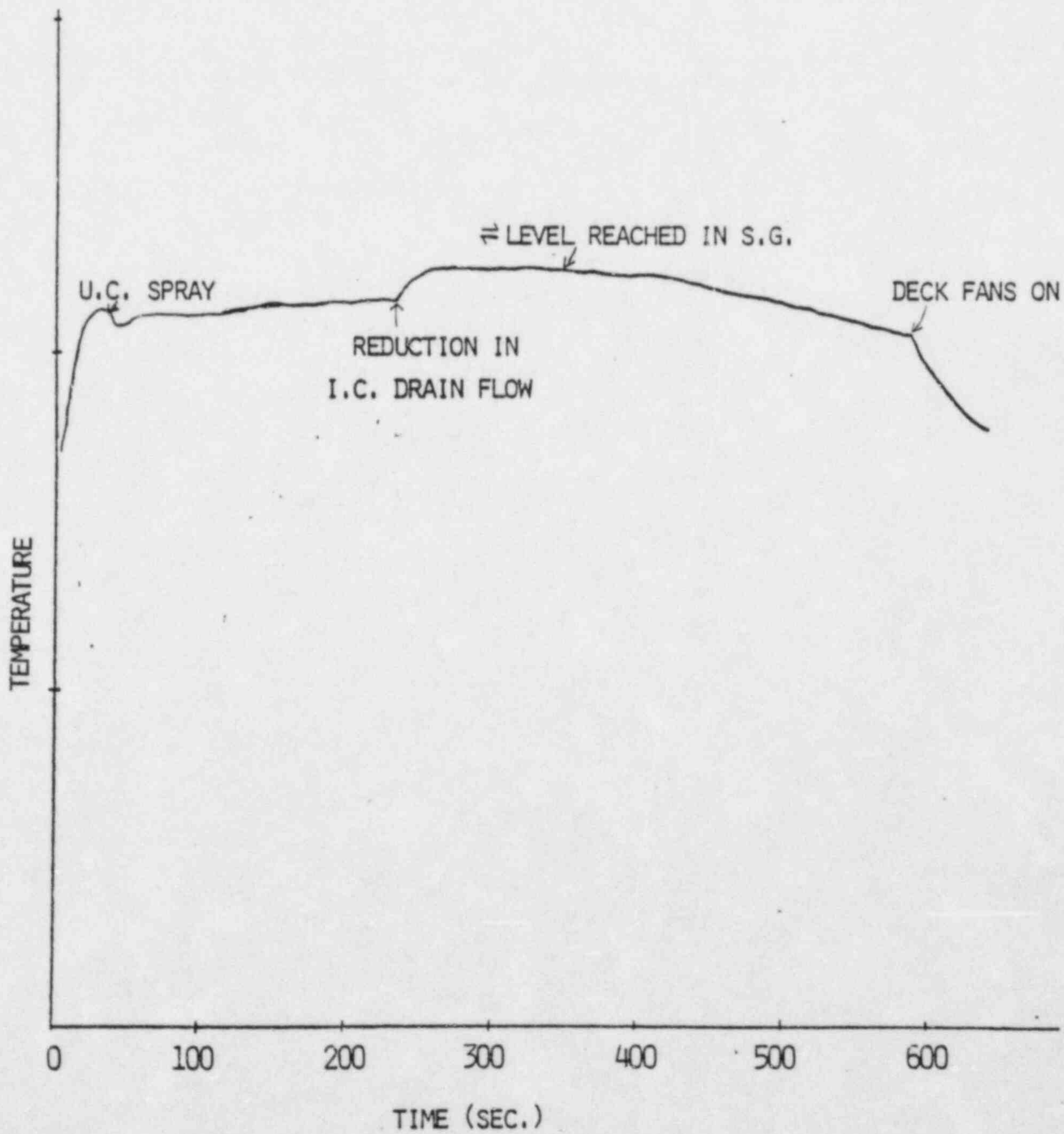


FIGURE 16

MODIFICATIONS TO THE CONTAINMENT MODEL

WALL HEAT TRANSFER MODEL

CONVECTIVE HEAT FLUX MODEL

ICE CONDENSER DRAIN MODEL

DEAD ENDED COMPARTMENT MODEL

FIGURE 17

WALL HEAT TRANSFER MODEL

ORIGINAL LOTIC MODEL

$$q'' = h_{Tagami} (T_{SAT} - T_{Wall})$$

MODIFIED LOTIC MODEL

$$q'' = h_{COND} (T_{SAT} - T_{Wall}) + h_{conv} (T_{Bulk} - T_{ref})$$

$$h_{COND} = f\left(\frac{m_{STEAM}}{m_{air}}\right)$$

$$h_{conv} = f(T_{Wall}, T_{SAT})$$

$$T_{ref} = f(T_{Wall}, T_{SAT})$$

FIGURE 18

CONVECTIVE HEAT FLUX MODEL

ORIGINAL LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X}\right]$$

MODIFIED LOTIC MODEL

$$\dot{m}_{COND} = \frac{q_{COND}}{h_{fg}} = \frac{q_{TOTAL}}{h_{fg}}\left[\frac{1}{1 + X_{SAT}}\right]\left[1 - \frac{h_{CONV}(T_{BULK} - T_{ref})}{q_{TOTAL}}\right]$$

FIGURE 19

ICE CONDENSER DRAINS

-APPROXIAMATELY 20 ICE CONDNESER DRAINS

-DRAIN ELEVATION IS ABOUT 40 FEET FROM FLOOR

-DRAIN PIPE IS 1 FOOT IN DIAMETER

-FOR TYPICAL MSLB TRANSIENT, DRAIN FLOW VARIES FROM 4000 LB/S TO 500 LB/S

FIGURE 20

ICE CONDENSER DRAIN MODEL

-CONDENSATION OCCURS AT THE SURFACE OF THE STREAM

-FLOW IS WELL MIXED

$$q = hA\Delta T$$

-MODEL AS A WALL AT A CONSTANT TEMPERATURE

-A IS THE SURFACE AREA OF THE STREAM

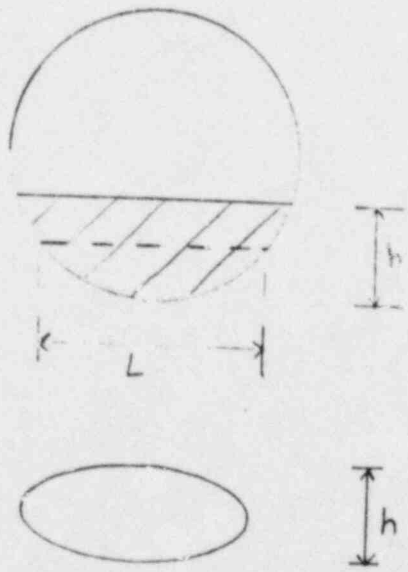
-h IS A CONDENSING TYPE HEAT TRANSFER COEFFICIENT

FIGURE 21

CALCULATION OF THE STREAM FLOW AREA

$$A = n(P \times L) = 20(P \times 40) = 800\,P$$

WHERE P IS THE PERIMETER OF THE STREAM



$$P \approx 2\pi \sqrt{\frac{\left(\frac{L}{2}\right)^2 + \left(\frac{h}{2}\right)^2}{2}}$$

FIGURE 22

MODIFIED LOTIC DRAIN MODEL

-WALL WITH A VARIABLE AREA

$$q = h_{COND} A (T_{BULK} - T_{SAT})$$

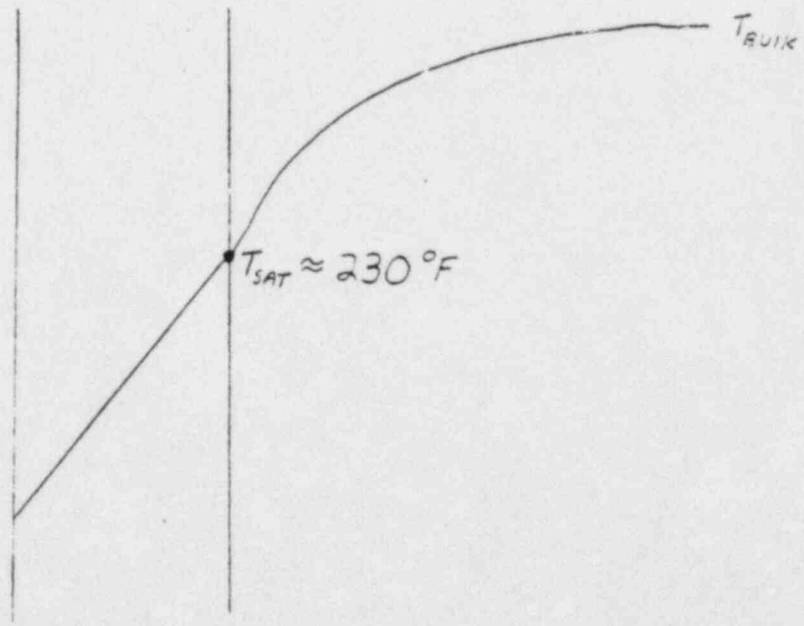


FIGURE 23

DEAD ENDED COMPARTMENT MODEL

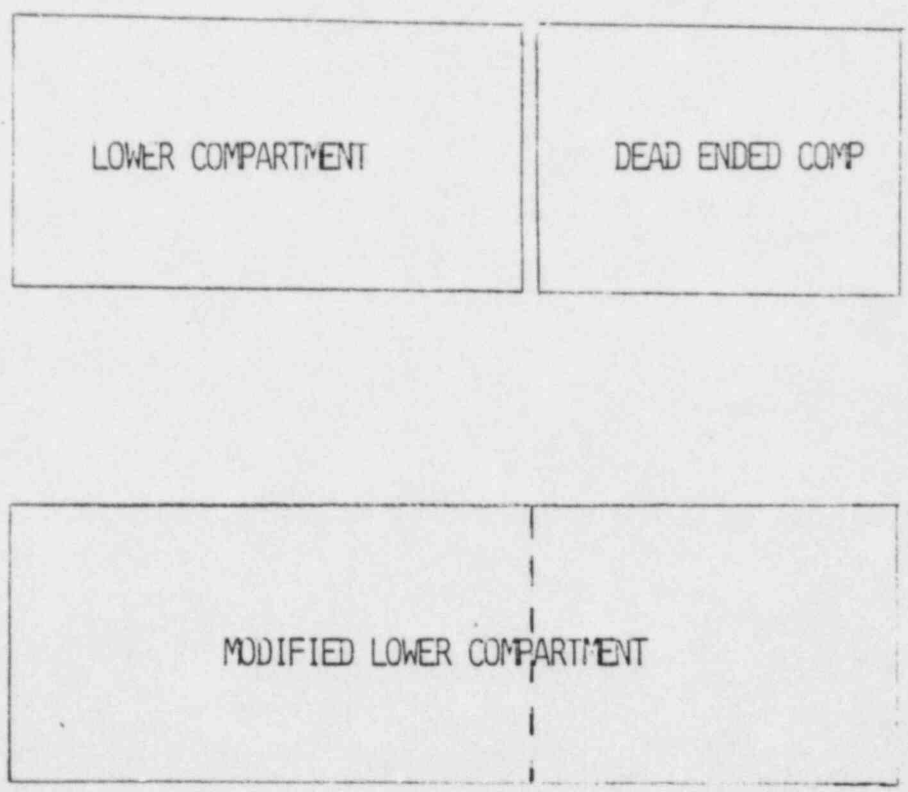


FIGURE 24

CATAWBA RESULTS

- 102% POWER
- 0.86 FT^2 BREAK
- MAXIMUM AFW FLOW
- FSAR HEAT SINKS
- MAXIMUM S.G. INITIAL MASS

$T_{MAX} = 324°F$ (LOWER COMPARTMENT)

FIGURE 25

ADDITIONAL MODEL CONSIDERATIONS

- WALL HEAT TRANSFER MODEL

- DRAIN MODEL

- DEAD ENDED COMPARTMENT MODEL

FIGURE 26

ATTACHMENT 2

OUTLINE OF THE REPORT

I. Introduction

II. Mass & Energy Release Modeling

III. Containment Modeling

IV. Action Plan

V. Appendix

VI. References

I. Introduction

During the Containment Systems Branch review of the Westinghouse topical report, "Mass and Energy Releases Following a Steam Line Rupture",WCAP-8822 (Proprietary) the Staff noted that heat transfer to steam from the uncovered portion of the steam generator tube bundle was unaccounted for and questioned the effect upon the calculated mass/energy release and the subsequent effect on the containment temperature response. Westinghouse responded in a letter to the Staff (NS-EPR-2563, February 14, 1982, E.P. Rahe to J. R. Miller) that it had determined the impact of the effect by conservatively treating the maximum amount of superheat to be the difference between the primary coolant temperature and the steam temperature. The letter noted that there would be an insignificant effect on dry type containments and that, based on the conservative model used, there would be an expected increase in containment temperature for ice condenser type containments. In the Containment Systems Branch Safety Evaluation Reports on the topical report and the Catawba Plant Safety Evaluation Report, the Staff required that a more refined steam line break analysis be performed to determine the effect on containment temperature which might impact the environmental qualification envelope used for safety related equipment.

Since that time, Westinghouse has investigated the effects of tube bundle heat transfer from the viewpoint of a more refined modeling approach. Subject to the final review and approval of the NRC Staff, the efforts and results obtained to date indicate that there is little impact on the containment response from the effects of the additional tube bundle heat transfer to steam.

II. Mass and Energy Release Modeling

A. LOFTRAN Computer Code

Mass/energy releases are calculated using the LOFTRAN code. LOFTRAN is a FORTRAN language, digital computer code, developed to simulate transient behavior in a multi-loop pressurized water reactor system. The program simulates neutron kinetics, thermal hydraulic conditions, pressurizer, steam generators, reactor coolant pumps, and control and protection systems. Up to four independent loops may be modeled. LOFTRAN is used for analysis of non-LOCA transients and is documented in Reference 3.

The model of importance to blowdown calculations is the steam generator model. The primary side contains multiple nodes to model the tube bundle. The standard LOFTRAN steam generator secondary side model, (Figure 1), is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur only to saturated water. If tube uncovery occurs the amount of surface area available for heat transfer is accordingly reduced. The LOFTRAN code incorporates a more detailed steam generator model which is used to predict tube bundle uncovery.

B. LOFTRAN Model for Superheated Steam

The LOFTRAN code has been modified to account for heat transfer to steam from the uncovered tube bundle region. (Figure 2). In the <u>modified</u> version of LOFTRAN, all heat transfer occuring in the uncovered region is assumed to add superheat to the steam exiting the steam generator. The primary side temperature in the uncovered tube region is conservatively assumed to remain constant through the nodes which are uncovered. In reality, there will be a drop in temperature due to heat removal to the secondary side, but this is expected to be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is discussed in the Appendix. This correlation bases the heat transfer on the difference between the tube wall surface temperature and the bulk steam temperature in the region. In the LOFTRAN modification, the conservative assumption is made that no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall surface temperature of the tube is assumed equal to the primary fluid temperature.

The modified version of LOFTRAN automatically determines the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the <u>modified</u> LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient

calculation. The superheat/tube uncovery modeling is applicable to all steam generators.

Figures 3 through 6 show typical results for a 0.86 ft^2 steamline break from 102 percent power using the modified version of LOFTRAN. Figure 3 shows the fraction of tube uncovery versus time with uncovery of Loop 1 (faulted) starting at 152 seconds into the transient. At approximately 300 seconds, the uncovery transient reaches an equilibrium point where the steam flow out of the steam generator matches the auxiliary feedwater flow into the steam generator. Additionally, the tube uncovery transient for Loop 2 (non faulted) is plotted but shows no tube uncovery for the entire transient. Figure 4 presents the steam flow transient for this case. Figure 5 includes plots of both the superheated steam enthalpy and the saturation enthalpy for the Loop 1 steam generator. Figure 6 includes the Loop 1 temperatures for the steam generator tube inlet (primary side), steam exit temperature (superheated steam), and the saturation temperature for the steam pressure.

C. NOTRUMP Model Comparison

The NOTRUMP computer code (Reference 4) was used to verify the LOFTRAN modeling of superheat. The computer code was originally developed to analyze transients of secondary systems with two-phase conditions. In the past, it has been used to analyze various transients in the primary and secondary coolant systems. NOTRUMP has recently undergone major revisions to enable it to model non-equilibrium nodes (i.e., separate liquid temperature and steam temperature modeling). Using NOTRUMP, the steam generator can be broken down into sufficient nodes to model the nonequilibrium effects of the steam generator, as well as the tube region during uncovery. NOTRUMP can model all modes of heat transfer associated with a steamline break transient, including heat transfer from the uncovered tubes to the superheated steam and the feedback effects between the primary and secondary sides. The two phase mixture level calculation accounts for primary to secondary heat transfer and the swell associated with rapid depressurization of the steam generator during the blowdown.

A comparison of LOFTRAN and NOTRUMP blowdown results is presented in Figures 7 and 8. The mass releases shown in Figure 8 show excellent agreement. The LOFTRAN prediction of superheat enthalpy is slightly higher than NOTRUMP, while the predicted time of tube uncovery is somewhat later. NOTRUMP shows a chugging effect during the uncovery phase of the blowdown. This is believed to be in part due to oscillations in the flow link between the downcomer region and the steam dome region. (The flow link is the drain path for the moisture separators to the downcomer region.) With the flow direction towards the downcomer, superheated steam goes into the downcomer region and is condensed. This alternates with a flashing of a portion of the water volume in the downcomer region. This raises the pressure of the downcomer, resulting in a flow reversal in the link with saturated steam from the downcomer mixing with the superheated steam in the dome. This mixing results in the variations in the superheat enthalpy seen in Figure 7. Although LOFTRAN does not show the enthalpy variation since the detailed modeling of the downcomer and dome are not included, the overall agreement with NOTRUMP is very good.

D. Effects Of Analysis Assumptions

The effects of superheated steam are dependent upon the occurrence and extent of tube uncovery. The major parameters affecting tube uncovery are: initial steam generator inventory, auxiliary feedwater flowrate, assumed feedwater system failures, and protection system errors. Variations in these parameters are in the process of being evaluated for their effects on the containment temperature response (Figure 9).

Refinements in the mass and energy release modeling (Figure 10), are being evaluated and several areas show a potential for reducing the degree of superheat being generated. Some of these areas are:

- Evaluation of liquid-steam interactions such as the phenomenon of tube support plate flooding and heat transfer across the tube wrapper from the superheated steam to the auxiliary feedwater flowing down outside the tube wrapper.

- A more detailed steam header model in LOFTRAN.

- Modeling temperature drops in the primary superheat nodes.

- Evaluating other void correlations for use in predicting tube uncovery.

III. Containment Modeling

A. Description of Containment

The general phenomena taking place inside an ice condenser containment during a steamline break transient can be described utilizing a typical ice condenser elevation drawing (Figure 11). Steam is discharged to the main (or lower) compartment where heat is removed by the internal structures, steam flow to the ice condenser, and the ice condenser drain water. The dead ended compartments are the regions which are located below the ice condenser and outside the crane wall (Figure 12). Air is discharged from the main compartment to the dead ended compartment and ice condenser so that the resulting steam to air ratio is that region is much higher than in dry containments. At ten minutes following the containment hi-2 signal, deck fans are actuated which direct air flow from the upper compartment to the dead-ended compartments. Most of the safety related equipment is located in the dead-ended compartments although some equipment and cabling are located in the main compartment.

B. Containment Models

Figure 13 outlines the major models and assumptions utilized in the LOTIC-3 containment code. In the currently approved version of LOTIC-3 documented in Reference 5, four distinct regions of the containment are modeled; the lower compartment, the dead-ended compartment, the ice condenser, and the upper compartment. Two condensate/revaporization models are used depending on the size of the break. For large steamline breaks, 100% condensate revaporization is assumed. For small steamline breaks, a convective heat flux model is used which calculates partial revaporization during the transient. The wall heat transfer model utilizes the Tagami heat transfer correlation for condensation heat transfer and the convective heat flux model derived from the work of Sparrow (Reference 6) which calculates the convective heat transfer for small steamline breaks. The sump recirculation system is only modeled for the large break LOCA transient containment response.

Figure 14 shows the four regions modeled with the mass and energy flows that can be assumed in the analysis. The Catawba nuclear plant does not have lower compartment sprays and they are not modeled in the analysis. Superheat heat transfer is conservatively assumed to be zero for the steamline break containment analysis. In the model described in Reference 5, wall heat transfer is not modeled in the dead-ended compartments although these regions do contain structures which will remove heat. The analysis does include the upper compartment sprays, flow through the ice condenser, deck fan flow, and flow to the dead-ended compartments.

LOTIC-3 solves the conservation of mass, energy, and momentum equations for upper, lower, and ice condensor regions (Figure 15). After the new lower compartment conditions are determined, conservation equations are solved for the dead ended compartment and the flow rate between the compartments is determined.

Figure 16 presents a typical steamline break containment temperature transient that is calculated using superheated steam blowdowns from the LOFTRAN code and the modeling of ice condenser drains as a heat removal source. The transient shows that initially the containment temperature increases rapidly during the

blowdown. When the upper compartment sprays actuate there is a slight decrease in the main compartment temperature. The temperature then rises slowly until ice condenser drain flow decreases to the point at which time the temperature begins to rise again (approximately 250 seconds). This rise in containment temperature coincides with the steam generator tubes uncovering at 152 seconds and the maximum superheat occurring at approximately 250 seconds. The steam generator level stablizes when the auxiliary feedwater flow is equal to the steam discharge at approximately 300 seconds. The containment temperature then starts decreasing with decreasing decay heat. At ten minutes, the deck fans actuate which results in a rapid decrease in containment temperature.

C. LOTIC-3 Code Modifications

Four modifications have been incorporated in the LOTIC-3 containment model which are (Figure 17);

1) wall heat transfer model
2) convective heat flux model
3) ice condenser drain model
4) dead-ended compartment model

D. Wall Heat Transfer

The modification to the wall heat transfer model is described in Figure 18. In the LOTIC-3 model, only condensation heat transfer, utilizing a Tagami heat transfer coefficient and a temperature difference between the wall and saturation, was previously modeled. The modification includes a convection term with a conservative convection heat transfer coefficient and a temperature difference between the containment atmosphere and an appropriate interface temperature. The Appendix presents a more detailed description of this model.

E. Convective Heat Flux

The modification to the convective heat flux model is described in Figure 19. A term has been added to the convective heat flux model to account for the feedback effect from including a convective term in the wall heat transfer model. The Appendix presents a more detailed description of this model.

F. Ice Condenser Drain Model

In an ice condenser containment there is approximately twenty drains exiting from the ice condenser into the lower compartment at an elevation of about forty feet above the compartment floor. The drain pipes are one foot in diameter. The drain flowrate is calculated by the LOTIC-3 containment code. For a typical small steamline break transient the drain flowrate varies from approximately 4000 lbm/sec to 500 lbm/sec during the timeframe of interest. The temperature of the drain water is approximately 130°F (Figure 20).

Figure 21 presents the assumptions and the basic model used to estimate the heat removal from the lower compartment atmosphere to the ice condenser drain water. It is conservatively assumed that the drain water stream does not break up prior to reaching the floor even though many of the drains have equipment and structures located below them. Therefore, heat transfer is assumed to occur at

the stream surface only. It is also assumed that the stream surface temperature is at the saturation temperature of the containment.

The heat transfer to the stream is:

$$q = hA\Delta T$$

where

h = condensation heat transfer coefficient
A = surface area of the stream
ΔT = appropriate temperature difference

The calculation of the heat transfer surface area is described in Figure 22. In order to model the drains in LOTIC-3, the drains are modeled as a wall heat sink with a surface at a constant temperature (see Figure 23). Currently, in the version of LOTIC-3, the surface temperature is assumed to be 230°F which is close to the containment saturation temperature. The drain surface area is calculated at two points in time during the transient; early in time with a high flowrate and later in time with a low flowrate. To ensure conservatism in the area calculation a 10% reduction of the surface area was assumed.

As described previously (Figures 14 & 15), the LOTIC-3 containment model did not account for wall heat removal in the dead-ended compartments. To obtain a conservative estimate of the temperature transient in the dead ended compartment, the heat sinks located in the dead ended compartment region along with the heat sinks in the lower compartment are modeled in a combined volume (see Figure 24). This "modified" lower compartment model is used to determine a conservative dead-ended compartment temperature transient. Since the lower compartment will be hotter than the dead-ended compartment, this methodology results in a higher temperature in the dead-ended compartment than would be expected.

G. Transient Results

With the modifications described for LOFTRAN and LOTIC-3, the previous FSAR limiting case for Catawba was reanalyzed to determine the impact of superheated steam. The case selected is a 0.86 square foot break at 102% power (Figure 25). The peak lower containment temperature for this case is 324°F. This temperature is calculated for the lower compartment only. It is expected that the dead-ended compartment temperature will be significantly lower.

In addition to the model modifications incorporated in LOTIC-3, Westinghouse is pursuing further improvements in the areas noted on Figure 26. One area is in the wall heat and mass transfer models. Since condensation is a mass transfer type phenomena, the heat and mass transfer should be linked. This approach has been used in Reference 7.

An improved drain model is also being investigated. This improved model will calculate the drain surface area as a function of flowrate. It will also calculate the average temperature rise of the drainwater. This model will more accurately represent the actual phenomena in the containment.

V. Appendix

WESTINGHOUSE STEAMLINE BREAK
BLOWDOWN AND CONTAINMENT ANALYSIS METHODOLOGY

The following sections describe the Westinghouse methodology for determining the containment response for a steamline break incorporating the effects of superheated steam. These sections describe in detail changes from the methodologies described in References 1 and 5.

I. Steamline Rupture Mass/Energy Blowdown Analysis

A. LOFTRAN and MARVEL Computer Modeling

Mass/energy releases can be calculated using either the LOFTRAN code (Reference 3) or the MARVEL code (Reference 8). The LOFTRAN code is used for non-LOCA FSAR accident analyses. The MARVEL code was specifically developed for assymmetric transients such as steamline breaks. These two codes are very similar because they were developed in an interrelating fashion and much of the modeling is common to both codes. The MARVEL code was used in the development of Reference 1 because LOFTRAN at that time was a lumped model which was used for symmetric loop transients. Furthermore, for steamline break analysis purposes, MARVEL contains a model for water entrainment. However, the current version of LOFTRAN is a multiloop version which also contains a water entrainment model. With the development of a multiloop version of LOFTRAN and the inclusion of an entrainment model, the use of MARVEL has been generally discontinued. This enables the use of LOFTRAN as a single system analysis code for non-LOCA transient analyses. LOFTRAN is used in the analyses presented here.

The model of importance to blowdown calculations is the steam generator model. The primary side of the steam generator contains multiple nodes to model the tube bundle for both the modified version of LOFTRAN and MARVEL. Heat transfer calculations from the primary to secondary side are identical in the two codes, although the methods for initializing the heat transfer resistances are slightly different. The secondary side is effectively a one node, two region model of saturated steam and water. Heat transfer is assumed to occur to saturated water. If tube uncovery is predicted, the amount of surface area available for heat transfer is reduced.

Both codes contain a detailed steam generator model which is used to predict tube uncovery. This model calculates the liquid volume in the steam generator shell and accounts for the detailed steam generator geometry. The [ ]^{a,c} correlation is used in both codes to predict the voiding in the tube region, although the correlation is modified for use in LOFTRAN. In MARVEL, tube uncovery is calculated based

on comparison with the actual water level and the height of the tube bundle. In LOFTRAN, the user specifies either a water volume in the steam generator corresponding to tube uncovery, or a void fraction in the riser section of the steam generator at which tube uncovery begins.

Both codes have similar models accounting for reverse heat transfer, thick metal heat transfer, feedline flashing, and safety injection system operation. Auxiliary feedwater flow can be input as a fraction of nominal feedwater flow, although LOFTRAN has an additional capability to model auxiliary feedwater flow as a separate system. For analysis of double ended ruptures, MARVEL accounts for the volume of steam in the piping downstream of the steam generators in the blowdown calculations. In LOFTRAN, this consideration is added on to the blowdown mass and energy results by hand. For split ruptures, which the analysis presented here addresses, the steam piping masses are handled identically in both codes.

In summary, LOFTRAN and MARVEL are very similar codes, and either can be used to calculate mass/energy blowdowns. To demonstrate this, a comparison of the blowdowns for a typical case is presented in Figures A.1 and A.2. Figure 1 presents the mass release rate for a .86 ft2 split rupture from 102% power. For this case, Figure A.2 shows the saturated steam enthalpy as a function of time. This blowdown is typical of results used in FSAR analyses prior to the modification noted in this report for the LOFTRAN code. As can be seen from the figures, the results are extremely close.

B. LOFTRAN Model for Superheated Steam

As mentioned previously, the LOFTRAN code has been modified to model heat transfer which may occur in the uncovered tube bundle region. This effect is modeled in both the faulted and intact loops. In the modified version of LOFTRAN, all heat transfer occurring in the uncovered region is assumed to add superheat the steam exiting the steam generator. The temperature of the primary coolant flowing through in the uncovered tube region mode is conservatively assumed to remain constant. Realistically there would be a drop in temperature due to heat removal to the secondary side, but this will be small due to the low specific heat capacity of the steam and due the high primary side flow rate.

The heat transfer coefficient used in the uncovered tube region is based on the [(1)]^{a,c}. The heat transfer coefficient (U) is calculated by the following expression:

[ ]^{a,c}

This correlation is presently used for superheated forced convection heat transfer by the [ ]^{a,c} computer codes. Additionally,

this correlation is based upon the heat transfer from the surface of the tube wall to the average bulk temperature of the steam. In the LOFTRAN modification, no credit is taken for either a primary film heat transfer resistance or a tube metal heat transfer resistance. Therefore, the wall temperature of the tube is conservatively assumed equal to the primary fluid temperature.

(1) [ ]a,c

The modified version of LOFTRAN automatically selects the proper number of steam generator nodes for the superheat region of steam in the generator. The variable node capability is applied to both the primary and secondary side. At each time step during the tube uncovery, the modified LOFTRAN code makes a general evaluation of the uncovered tube region (e.g. steam flow rate, uncovered tube heat transfer area, estimated heat transfer coefficient, etc.) and determines the number of nodes to be used in the subsequent calculations. Each node is evaluated to determine the steam temperature exiting the node with a convergence criteria that is based upon the total number of nodes used. The exit steam temperature of one node is used as the inlet steam temperature of the next node.

The heat transfer calculation to determine the outlet temperature of the node is based upon the following expression:

$$Q = UA*(T_{pri}-(T_{out}+T_{in})/2) = M_s*C_s*(T_{out}-T_{in})$$

where Q = Heat transfer to the steam

$U = [\quad]^{a,c}$

T_{pri} = Primary node temperature

T_{out} = Steam node outlet temperature

T_{in} = Steam node inlet temperature

M_s = Mass flowrate of the steam

C_s = Heat capacity of the steam

A = Heat transfer area in the node including both hot and cold leg sides of the tube bundle

The total heat transfer for the uncovered tube region is determined and accounted for in the primary temperature transient.

C. Blowdown Sensitivity to Plant Conditions

The effects of superheated steam are dependent upon the occurrance and extent of tube bundle uncovery. Parameters affecting tube uncovery are: initial steam generator inventory, break size, auxiliary feedwater flowrate, and the single failure assumed.

The initial steam generator inventory depends upon the measurement errors associated with steam generator level and upon initial power level. Steam generator mass increases with decreasing power, thus, breaks intitiating from low power levels will result in later tube uncovery.

Larger break sizes result in faster blowdown of the steam generator and earlier tube uncovery.

Large auxiliary feedwater flowrates only delay tube uncovery, but will also cause the final equilibrium steam generator level to be higher. This equilibrium condition corresponds to the point when the break flow rate is equal to the auxiliary feedwater flow rate.

The single failure assumed in the transient may impact the amount of water supplied to the steam generator. Auxiliary feedwater runout will increase the amount of water supplied to the steam generator. Failure of the feedwater isolation valve will also cause extra water to be supplied to the generator as the additional mass between the isolation valve and the check valve flashes to the generator.

II. Containment Analysis

A. Wall Heat Transfer Model

The original LOTIC-3 wall heat transfer model is based on the stagnant Tagami heat transfer correlation. That is,

$$q''=h_{TAGAMI}(T_{SAT}-T_{WALL})$$

$$h_{TAGAMI} = 2 + 50\ M_{STEAM}/M_{AIR} \quad h_{(TAGAMI,MAX)}=72\ \text{BTU/hr-ft}^2\text{-}^oF$$

This model was developed for saturated steam in the presence of large amounts of non-condensable gases. In the lower compartment of an ice condenser, most of the air is swept out of the lower compartment through the ice condenser and into the upper compartment. Therefore, after about 30 seconds, there is almost no non-condensables in the lower compartment. Typical values for the condensation of pure steam are in the range of 1000 to 3000 Btu/hr-ft2-^{o}F (Ref. 5). The correlation used in the modified LOTIC-3 code is in extension of the Tagami correlation for nearly pure steam.

$$q''=h_{COND}\ (T_{SAT}-T_{WALL})$$

$h_{cond} = 2+50\ M_{STEAM}/M_{AIR} \quad h_{(cond,max)} =$ [ ]^{a,c}

A maximum value of [ ]^{a,c} was chosen as a conservatively low condensing heat transfer coefficient in a nearly pure steam environment.

In addition to this modification, an additional term is needed to account for the convective heat transfer from the superheated steam to the condensate film. This convective heat transfer is dependent upon whether there is condensation occurring on the walls. If condensation is occurring, the correlation used is:

$$q''_{conv}=h_{conv}(T_{bulk}-T_{sat})$$

where:

[ ]^{a,c}

If the wall temperature increases to above the saturation temperature then the convective currents will be reduced such that the correlation used is

$$q''_{conv}=h_{conv}(T_{bulk}-T_{wall})$$

where:

[ ]^{a,c}

Thus in summary, if $T_{wall} < T_{sat}$ then

[ ]^{a,c}

If $T_{wall} > T_{sat}$, then the correlation used is:

[ ]^{a,c}

B. Convective Heat Flux Model

When the containment atmosphere is superheated, the containment temperature is a strong function of the amount of steam mass in the atmosphere. Thus the amount of mass condensed on the heat sink surfaces is a key parameter. The actual amount of condensate formed is

$$M_{cond} = q_{cond}/h_{fg}$$

Unfortunately, with the use of a heat transfer correlation based only on test data (such as Tagami or Uchida), only the total heat transfer coefficient is obtained. This total heat transfer coefficient includes both the condensation heat transfer and the convective heat transfer. Based on the work of Sparrow (Reference 6), the Westinghouse Convective Heat Flux model in the original LOTIC-3 code calculates the ratio of the convective heat transfer to the condensation heat transfer. Therefore the calculation of the amount of mass condensed is

[ ]a,c

In the modified LOTIC-3 model, the amount of superheat convection is calculated. The amount of convective heat transfer at saturation is not known explicitly in this model. Therefore, in the modified LOTIC-3 code the original convective heat flux model will be used to calculate the fraction of convective heat transfer for saturated conditions. The actual correlation is

[ ]a,c

where, $(q_{conv}/q_{cond})_{sat}$ is determined from original convective heat flux model and $q_{conv,sh}$ is the amount of convective heat transfer calculated in the wall heat transfer model

In summary, the modified LOTIC-3 model is consistent with the original LOTIC-3 model in its calculation of the mas condensed. The only difference is that in the modified LOTIC-3 code, the amount of superheat convective heat transfer is known explicitly, while in the original LOTIC-III model, only the ratio of convective heat transfer to condensation heat transfer is known.

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LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

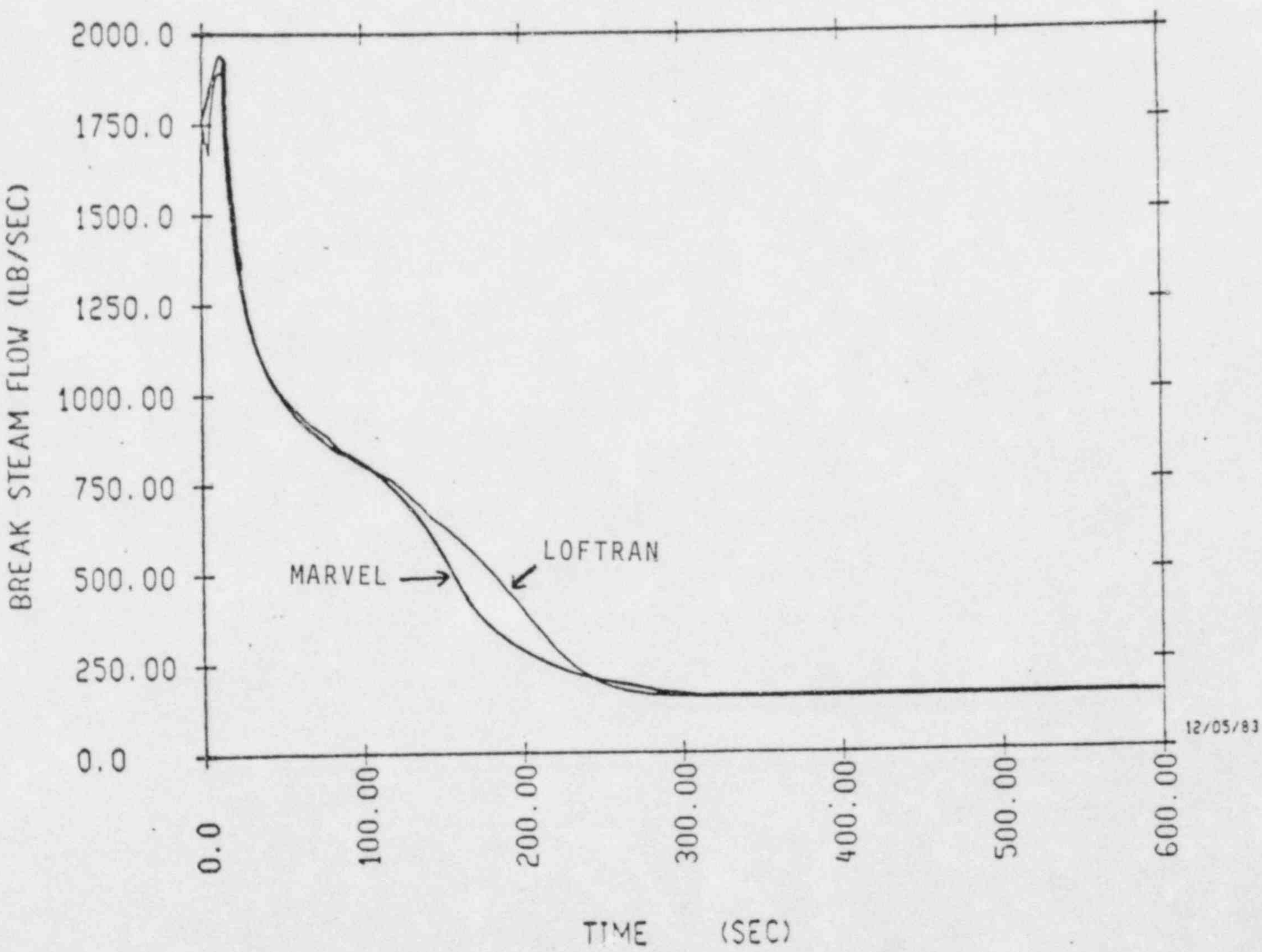

FIGURE A.1

LOFTRAN - MARVEL COMPARISON

.860 FT2 BREAK AT 102 PC POWER

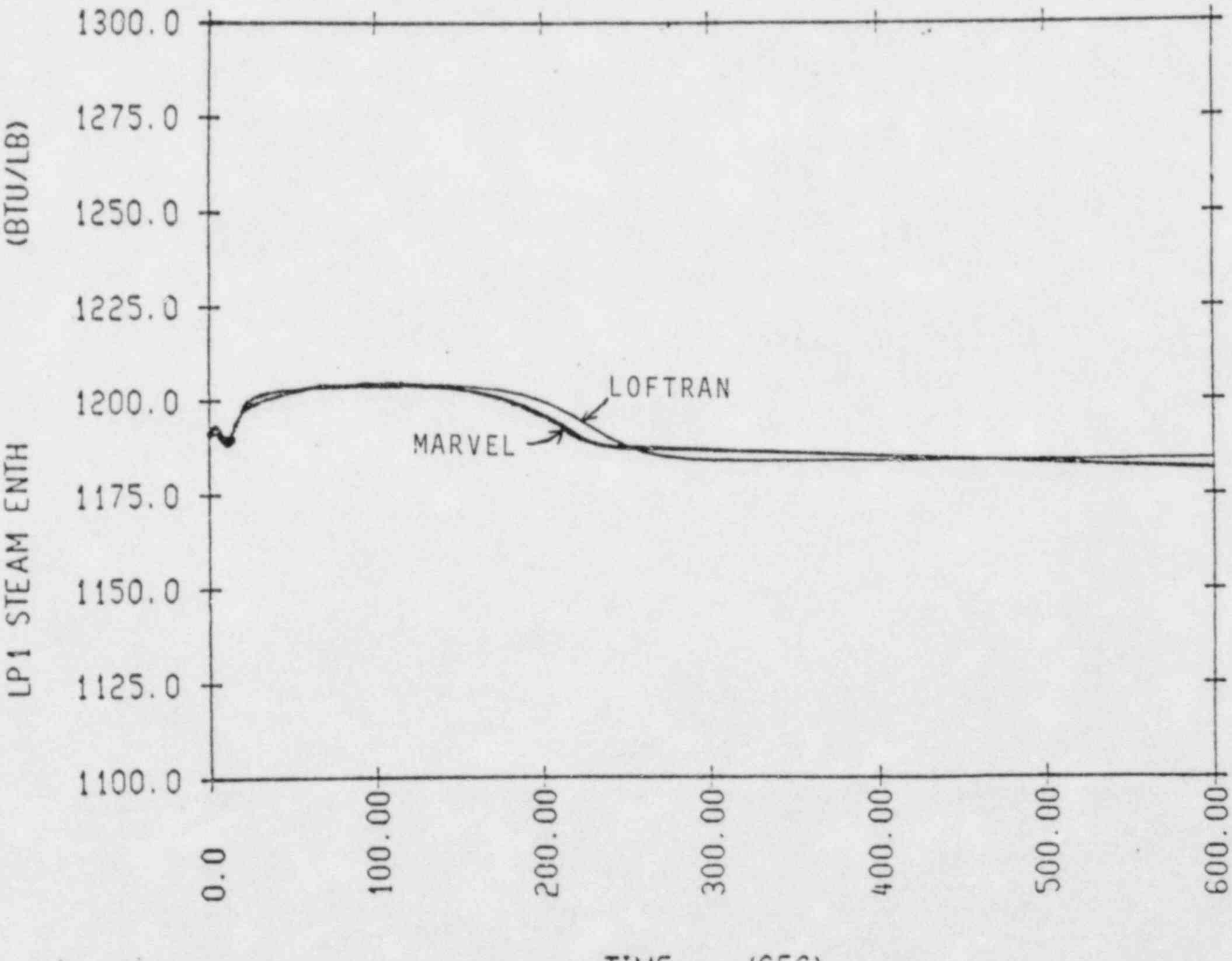

FIGURE A.2