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WCAP 8355-NP-Sup.2

WESTINGHOUSE NON-PROPRIETARY

WESTINGHOUSE LONG TERM ICE
CONDENSER CONTAINMENT CODE -
LOTIC - 3 CODE

T. Hsieh

N. J. Liparulo

FEBRUARY 1979

APPROVED: T. M. Anderson
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WESTINGHOUSE PROPREITARY DATA

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

MAY 3 1978

Mr. Thomas M. Anderson, Manager
Nuclear Safety Department
Westinghouse Electric Corporation
P. O. Box 355
Pittsburgh, Pennsylvania 15230

Dear Mr. Anderson:

SUBJECT: EVALUATION OF PROPOSED SUPPLEMENT TO WCAP-8354 (LOTIC-3)

The Nuclear Regulatory Commission staff has completed its review of a proposed supplement to WCAP-8354 (Proprietary) and WCAP-8355 (Non-proprietary) entitled "Long Term Ice Condenser Containment Code - LOTIC Code." The proposed supplement describes a version of the LOTIC computer code (designated LOTIC-3) which is intended to be used to conservatively calculate maximum pressure and temperature in the ice condenser containment following a postulated main steam pipe break or main feedwater pipe break. The description of LOTIC-3 was transmitted by Westinghouse letter dated October 22, 1976 and supplemented by Westinghouse letters dated June 14, 1977 and January 19, 1978. Our evaluation of LOTIC-3 is enclosed.

Other versions of the LOTIC code were previously reviewed and approved for use in analyses of postulated reactor coolant pipe breaks (LOCA); WCAP-8354-P-A dated April 1976 describes LOTIC-1 which is approved for use to conservatively calculate maximum ice condenser containment pressure and temperature for the purpose of evaluating containment design; WCAP-8354-P-A Supplement No. 1 dated April 1976 describes LOTIC-2 which is approved for use to conservatively calculate minimum containment pressure for input to ECCS performance analyses and also to conservatively calculate pressure differentials between containment upper and lower compartments. Our approval of LOTIC-1 and LOTIC-2 was transmitted by our January 29, 1976 letter to Mr. C. Eicheldinger.

As a result of our current review, we have concluded that LOTIC-3 is acceptable for conservatively calculating the maximum temperature and pressure of ice condenser containments following a postulated main steam line break or main feedwater line break provided the following three conditions are met:

1. The mass and energy release from the steam system is calculated with an approved model.
2. Option 2 of the code is used for break sizes producing no liquid entrainment and for all break sizes until liquid entrainment models are approved.
3. A break spectrum analysis is made for each plant to demonstrate that the most severe containment conditions have been identified.

Accordingly, the Westinghouse letters dated October 22, 1976, June 14, 1977, and January 19, 1978 are acceptable for reference in license applications to describe the LOTIC-3 version of the LOTIC code. Supplements to WCAP-8354 (Proprietary) and WCAP-8355 (Non-proprietary) should be provided within three months of receipt of this letter to include the NRC acceptance letter, the enclosed evaluation, and any changes resulting from our review.

We do not intend to repeat our review of these reports when they appear as references in a particular license application except to assure that the material presented in these reports is applicable to the specific plant involved.

Should Nuclear Regulatory Commission criteria or regulations change, such that our conclusions concerning these reports are invalidated, you will be notified and given an opportunity to revise and resubmit your topical reports, should you so desire.

Sincerely,

John F. Stolz

John F. Stolz, Chief
Light Water Reactors Branch No. 1
Division of Project Management

Enclosure:
Safety Evaluation

cc: D. Rawlins
Westinghouse Electric Corporation
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ENCLOSURE

TOPICAL REPORT EVALUATION

Report No.: WCAP-8354 (Proprietary) and WCAP-8355 (Non-Proprietary)
Report Date: April 1976
Report Title: Long-Term Ice Condenser Containment Code - LOTIC Code
Originating Organization: Westinghouse Nuclear Systems
Reviewed By: Analysis Branch, Office of Nuclear Reactor Regulation

Summary of Topical Reports

In letters to the NRC dated October 22, 1976; June 14, 1977; and January 19, 1978, Westinghouse has described proposed modifications to the LOTIC Ice Condenser Containment Analysis Computer Code. The proposed modifications are designed to extend the code's capability for the pressure-temperature analysis of ice condenser containments following a postulated main steam line break. The modified code is referred to as LOTIC-3. The code may also be used for the analysis of feedwater line breaks.

The LOTIC code is designed to provide a multinode analytical tool which is capable of describing the various regions of an ice condenser containment. These include a lower compartment enclosing the reactor system, an annular region containing ice baskets and an upper compartment to accommodate air displacement from the other compartments.

Inlet and outlet doors are provided at the bottom and top of the ice compartment. In the event of a piping rupture in the lower compartment the lower inlet doors will open and provide a path for steam flow into the ice condenser. The displaced air forces the outlet doors at the top of the ice chest to open and permits flow into the upper compartment.

Steam condensation by the ice reduces the pressure buildup in the containment to a low level which is maintained through the blowdown.

There is insufficient energy in the secondary system of a Westinghouse PWR to melt all the ice and after the blowdown the containment pressure will first decrease slowly through the action of passive heat sinks in the lower compartment and then more rapidly after about 600 seconds when circulation fans are actuated between the upper and lower compartments. The fans equalize the air concentration between the upper and lower compartment and cause the remaining steam in the lower compartment to be forced through the ice compartment for additional steam condensation. The primary purpose of the LOTIC-3 code is to evaluate the temperatures produced in the lower compartment as a result of releases of superheated steam from the secondary system. This analysis would be used as a basis for qualification of equipment within the containment. To accomplish this the code was modified to account for the thermodynamic properties of superheated steam; modifications were also made to the heat transfer calculations for heat flow to the ice and passive heat sinks.

Mass and energy releases from the break are an input to LOTIC and are not discussed in WCAP-8354 and WCAP-8355.

Summary of Staff Evaluation

Other versions of LOTIC are LOTIC-1 which is used to analyze containment pressures and temperature following a LOCA, for the purposes of evaluating the containment design, and LOTIC-2 which contains modifications to conservatively calculate minimum containment pressures following a LOCA for ECC analysis. LOTIC-1 and LOTIC-2 were reviewed by the NRC staff and were approved in our Topical Report Evaluation of WCAP-8354 (Proprietary) and WCAP-8355 (Non-proprietary) dated January 29, 1976. Westinghouse will continue to use the approved versions of LOTIC for LOCA analysis. LOTIC-3 will therefore be used only for analysis of main steam line breaks and feedwater line breaks.

Breaks in the main steam line have the potential of producing elevated temperatures within the containment that are within the superheated range. The high temperature results from the simultaneous processes of expansion of steam flowing from the break and the compression of the steam and air in the containment by the continuing steam release. The compression process causes the steam to reach a superheated temperature relative to the containment pressure.

For ice condenser containments the action of the ice in condensing steam maintains the containment at a relatively low pressure of about 22 psia. The LOTIC-3 code calculates maximum lower compartment temperatures of about 320°F for the steam line breaks. This temperature range appears reasonable. To obtain further verification an analysis was performed by the staff using an advanced containment code, CONTEMPT-4. These results compared favorably with those obtained using LOTIC-3. The analysis shows the steam in the lower compartment to be superheated but is at a lower temperature than would be calculated for a standard containment design without an ice condenser. The temperatures in the upper compartment and ice chest are substantially lower than the lower compartment because of steam condensation on the ice. The lower compartment temperature remains at approximately 320°F until the blowdown is terminated or the circulation fans are actuated. The fans mix the cooler air from the upper compartment with the lower compartment.

Westinghouse has presented sensitivity studies which indicate that the maximum temperature reached in the lower compartment is insensitive to break size as long as pure steam is assumed to be released from the break. Smaller breaks may produce a more severe condition for the containment instrumentation, however, since the duration of the blowdown will be longer, and the lower compartment temperature will be maintained in the 320°F range for a longer period of time.

For breaks when the steam release is accompanied by entrained liquid, the liquid acts to reduce the calculated containment temperature. Although about 1/3rd of the entrained liquid will flash to steam upon entering the containment atmosphere, the remainder will act to remove superheat through further evaporation. Westinghouse expects to calculate liquid entrainment for large steam line breaks and feedwater line breaks.

Heat transfer to the ice is calculated using a semi-empirical correlation which was approved for use with the Westinghouse TMD code. The correlation was found to be conservative in comparison with data from the Waltz Mill ice condenser test facility.

Heat transfer to the containment structures may have little effect on the containment temperature and pressure for ice condenser containments since the condensing effect of the ice is the dominant means of steam removal. Westinghouse will use the extended Tagami correlation for calculating the structural heat transfer. We have evaluated the extended Tagami correlation by comparing it to the Uchida correlation which the staff has found acceptable. For an ice condenser containment the comparison shows that the Westinghouse model "extended Tagami" is more conservative than the Uchida for the major portion of the time period of interest. As a result, we find the extended Tagami correlation to be conservative and therefore acceptable.

The assumptions made for liquid removal from the atmosphere by condensation of steam on the structural heat sinks is important since, if the heat transfer is assumed not to remove liquid, the condensed steam mass is in effect added back to the atmosphere as liquid and some of the atmosphere superheat will be lost and lower temperatures will be calculated. These assumptions are particularly important for plants without ice condensers since compression of the atmosphere may cause a high degree of superheat.

Westinghouse will calculate the amount of steam condensed in the LOTIC-3 code using one of two models.

1. For large breaks, when liquid is calculated to be entrained by the steam leaving the break, no liquid removal is assumed to occur on the containment heat sink surfaces. This assumption has little effect on the calculated containment temperature since the entrained liquid prevents the atmosphere from becoming superheated.

2. For breaks for which no liquid entrainment is calculated, a model is utilized which divides the total heat transfer between condensation and a small convective contribution. No condensation of steam is assumed to result from the convective portion of the heat transfer. For the condensation portion, an equivalent amount of vapor is condensed and added to the sump. Westinghouse has performed a comparison which shown this assumption to have no effect on the calculated temperature over the case when all heat transfer is assumed to produce condensation.

At this time we have not approved any models for main steam line break analysis of ice condenser plants which permit liquid entrainment, from the break. Until such a model is approved we require analyses to be performed using the second option for all break sizes. Without entrainment the double-ended break was shown to produce the same peak temperature as the small break of about 320°F. The duration of the temperature peak was longer for the small break because of the longer length of the blowdown.

Staff Position

We have concluded that LOTIC-3 is acceptable for calculating the maximum temperature and pressure of ice condenser containments under the following conditions:

1. The mass and energy release input to the code should be calculated using a model approved by the NRC.
2. The model (Option 2) which assumes steam to be condensed and added to the sump from structural heat transfer should be used for break sizes producing no liquid entrainment and for all break sizes until

models with liquid entrainment are approved.

3. Since small breaks have been shown to produce elevated temperatures within the containment for a longer period than a double-ended break, we require analyses using the LOTIC-3 code to include a break spectrum analysis to demonstrate that the most severe containment conditions have been identified.

TABLE OF CONTENTS

1.0 ABSTRACT

The LOTIC-3 computer code has been developed to analyze steamline breaks in the lower compartment of an ice condenser plant. The main intent for the development of the LOTIC-3 computer code was to provide a tool to analyze the temperature transient following a steamline break. Currently, the LOTIC-1 computer code is used for LOCA containment design calculations and the LOTIC-2 computer code is used for ECCS minimum backpressure calculations.

This report presents an analytical model for the calculations of pressure and temperature transients in the four major components of an ice condenser containment (lower, upper, dead-end, and ice). The method applies the conservation equations to these control volumes in order to calculate their conditions.

This report contains two separate lists of references. The list immediately after Appendix D should be used for that Appendix only. The preceding list Appendix D should be used for the remainder of the text.

2.0 INTRODUCTION

Following a steamline break in the lower compartment of an ice condenser plant, two distinct analyses must be performed. The first calculation, a short term pressure analysis, is performed with the TMD computer code[4]. The second analysis, a long-term analysis, does not require the large number of nodes which the TMD analysis requires. The computer code which is used to perform this analysis is the LOTIC computer code.

The LOTIC(1,2,3) code has been modified for application in the steam break analysis. It now includes the capability to calculate superheat conditions, and has the ability to begin calculations from time zero. The major thermo-dynamic assumption which is used in the steam break analysis is complete re-evaporation of the condensate under superheated conditions.

Since the mass and energy releases rates for a steamline break are considerably less than those for the RCS double-ended breaks, and their total integrated energy is not sufficient to cause ice bed melt out, the containment pressure transients generated for RCS breaks will be more severe. However, because of the higher release enthalpies of the steamline breaks, it is possible that their analysis may set the maximum temperatures. The purpose of the new LOTIC code is to analyze these breaks.

The code presented here is the third version of the LOTIC computer code which has been generated. It is a modified version of the LOTIC-2 computer code described in Reference 3. To avoid confusion between the other versions of the LOTIC code(1,2,3), for the remainder of this report this new code will be referred to as LOTIC-3.

3.0 THEORETICAL AND MATHEMATICAL CONSIDERATIONS

3.1 BASIC ASSUMPTIONS

a. The containment is assumed to be physically divided into four compartments; the upper, lower, ice condenser, and dead-end compartments (Figures 3.1 and 3.2). Each compartment is a control volume of uniform temperature, pressure, and mass distribution.

b. Flow between compartments is related to the pressure differential between the compartments by a flow resistance factor. Only steam and air are assumed to flow between the compartments (condensate carry-over is neglected) The directions of the flows are shown in Figure 3.3.

c. A two sump model is used. Temperature is considered to be uniform in each sump.

d. All the mass releases into the lower compartment from the RCS system and the accumulator are assumed to mix homogeneously with the compartment atmosphere.

e. Spray water is assumed to mix homogeneously with the compartment atmosphere and attains saturation temperature.

3.2 CONSERVATION EQUATIONS

For the remaining portion of this section, the basic forms of the governing conservation equation are provided and a brief discussion on their solutions is given. The purpose is to identify the physical meaning of each contributing term. An overview of the system is presented in Figure 3.4. For mathematical details in the derivation of the governing equations, the reader is referred to Appendix A.

For each control volume or compartment, the conservation equations of mass, energy, momentum, and volume; an ideal gas law for air, and the equation of state for saturated steam may be written.

a. Energy equation

$$\frac{d}{dt}\left(M_a h_a + M_s h_s + M_c h_c\right) - \frac{(V_{as} + V_c)}{J}\, d\, \frac{(P_s + P_a)}{dt} + (mh)_{out} - (mh)_{in} = R_e \qquad (3.1)$$

for the lower compartment:

R_e = [Rate of energy out of break]
+ [Rate of flow energy from accumulator in the form of water and nitrogen]
- [Rate of structural heat removal]
+ [Rate of flow energy of sprays if applicable]
- [Rate of heat transfer to the sump]
- [Rate of heat removal by the ice condenser drain flow, if acting as a spray]
- [Rate of energy associated with the loss of condensate from atmosphere falling to floor]
+ [Net rate of flow energy in from the dead ended compartment]

for the upper compartment:

Re = [Flow energy of the entering spray]
- [Structure heat removal rate]
- [Energy rate associated with condensate falling from atmosphere

for the ice condenser compartment:

Re = - [Structure heat removal rate]
- [Rate of heat transfer to the ice]
- [Energy rate associated with ice melt and steam condensate falling from atmosphere]

b. Conservation of steam and water masses

$$\frac{dM_s}{dt} + \frac{dM_c}{dt} + (m_s)_{out} - (m_s)_{in} = R_s \tag{3.2}$$

for the lower compartment:

R_s = [Rate of flow out of the RCS]
+ [Rate of water flow out of the accumulator]
+ [Flow rate of the entering spray if applicable]
- [Rate of condensate falling to the floor]
+ [Rate of steam flow from the dead-ended compartment]

for the upper compartment:

R_s = [Flow rate of the entering spray]
- [Rate of condensate falling to the floor]

for the ice condenser compartment:

R_s = - [Rate of condensate falling to the floor]

c. Conservation of air mass

$$\frac{dMa}{dt} + (m_a)_{out} - (m_a)_{in} = R_a \tag{3.3}$$

for the lower compartment:

R_a = [Rate of air flow out of the accumulator]
+ [Rate of air flow out of the dead-ended compartment]

for the upper compartment and the ice condenser:

$R_a = 0$

d. Conservation of momentum

$$P_i - P_j = \frac{1}{2}\left(\frac{K_{ij}}{A_{ij}^{2}}\right)\frac{m_{ij}^{2}}{\rho_i g_c} \tag{3.4}$$

e. Volume conservation

$$\frac{dV_{as}}{dt} + \frac{dV_c}{dt} = R_v \tag{3.5}$$

for the lower compartment:

R_v = - [Rate of increase in sump water volume]

for the upper compartment

$R_v = 0$

for the ice condenser compartment:

R_v = [Rate of increase in free volume due to ice melting]

f. Ideal gas law for air

$$P_a V_{as} = M_a R_a T \tag{3.6}$$

g. Equations of state for saturated steam

$$P_s = g_1 (T),\ h_s = g_2 (T),\ \nu_s = g_3 (T) \tag{3.7}$$

For superheated steam

$h_s = g_4 (P_s, T)$, $\nu_s = g_5 (P_s, T)$

h. Equations of state for the suspended condensate

The suspended condensate in the atmosphere is assumed to be subcooled at the compartment temperature and the total pressure.

$$h_c = f_1 (P,T), \ \nu_c = f_2 (P,T) \qquad (3.8)$$

i. Dead Ended Compartments

For the dead-ended compartment, the structures are included as part of the lower compartment structures, and the conservation equations of energy and mass simplified to:

$$\frac{d}{dt} (M_a h_a + M_s h_s) - \frac{V}{J} \, \frac{d \, (P_s + P_a)}{dt} \qquad (3.9)$$

= [Rate of flow energy from the lower compartment]

$$\frac{dM_a}{dt} = \text{[Rate of air flow from the lower compartment]}$$

$$\frac{dM_s}{dt} = \text{[Rate of steam flow from the lower compartment]}$$

The "two sump model" has been retained in this LOTIC version with some revisions to account for heat transfer with the lower compartment atmosphere. The entering ice condenser drain flow temperature is calculated based on the effectiveness of its approach to the lower compartment temperature. As was stated in the previous LOTIC WCAP, the "two sump model" was created because of the insufficient capacity of the active sump to contain all the water of the RCS system, the melted ice, and the refueling storage tank. The excess water was modelled as spillage into the pipe trench area outside the crane wall. This water was therefore no longer available for recirculation and is modelled as an inactive sump.

The water mass and temperature in the sump are calculated as follows:

$$M_{sump,N} = M_{sump,o} + (\Sigma M_{drn} + M_{spill} + M_{overflow}) \qquad (3.10)$$

the summation is for all the flows entering the sump.

$$H_{sump,N} = \frac{H_{sump,o} + [\Sigma M_{drn} h_{drn} + M_{spill} h_{sump,o} + M_{overflow}\ h_{drn} + Q_{sump}]}{M_{sump,o} + (\Sigma M_{drn} - M_{spill} + M_{overflow})} \qquad (3.11)$$

the term Q_{sump} included the heat transfer from the lower compartment atmosphere and the heat losses to the structures in direct contact with the sump water.

and the water volume in the active sump was

$$V_{sump} = M_{sump,N}/\rho_w \qquad (3.12)$$

If the sump water volume was greater than a specified maximum active sump volume, the spilling flow follows:

$$M_{spill} = (M_{sump,N} - \frac{V_{max}}{\nu_w}) \ / \ \Delta t \qquad (3.14)$$

and the water mass in the active sump was reset to

$$M_{sump,N} = \frac{V_{max}}{\nu_w} \qquad (3.15)$$

3.3 METHOD OF SOLUTION

(a,b)

After the conditions of the lower compartment had been calculated for a new time step, Equations (3.4) and (3.9) were then used to calculate new conditions for the dead-ended compartment and the flow rate between the two compartments.

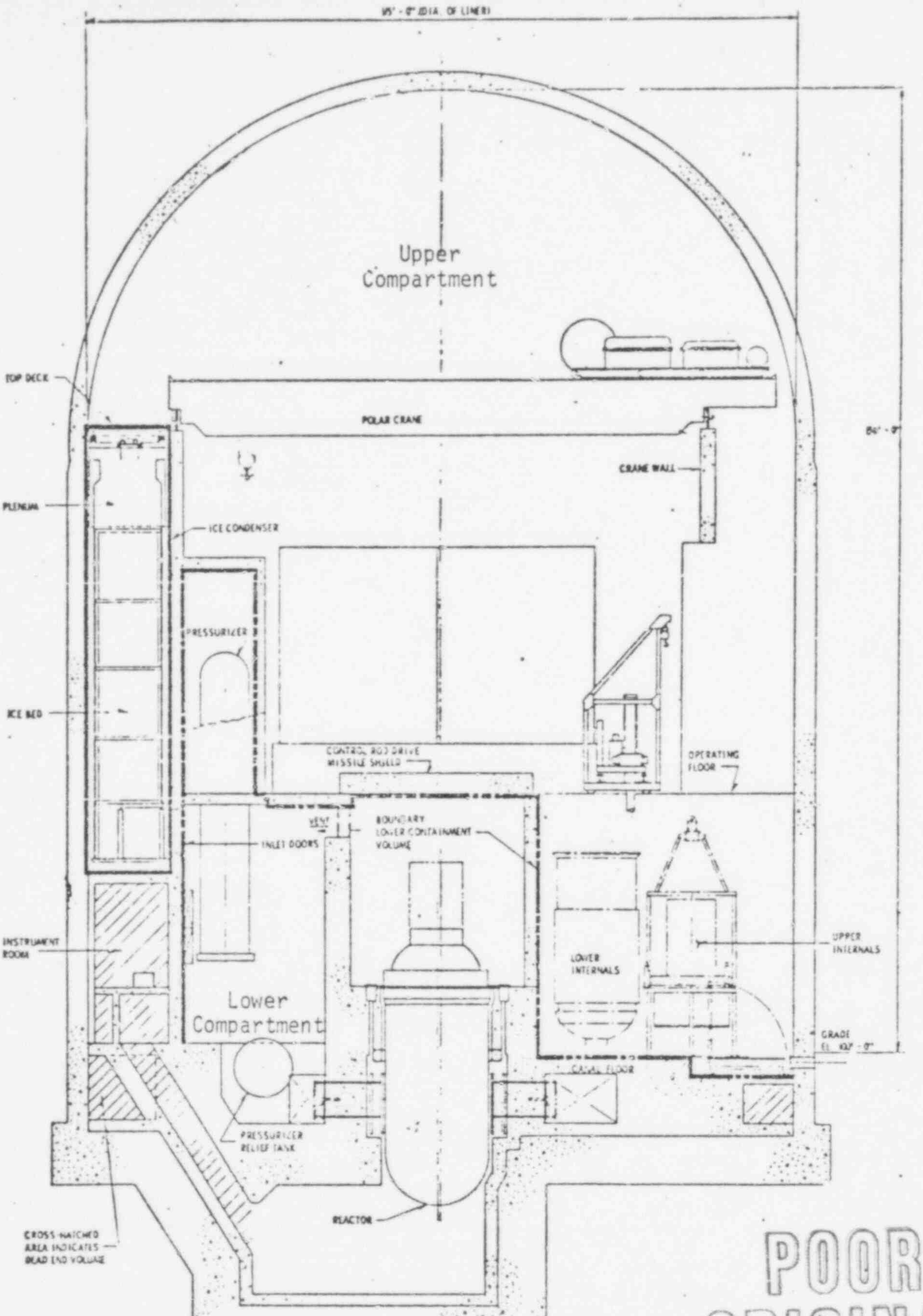

FIGURE 3-1 SECTIONAL ELEVATION
ICE CONDENSER CONTAINMENT
VOLUME BOUNDARIES

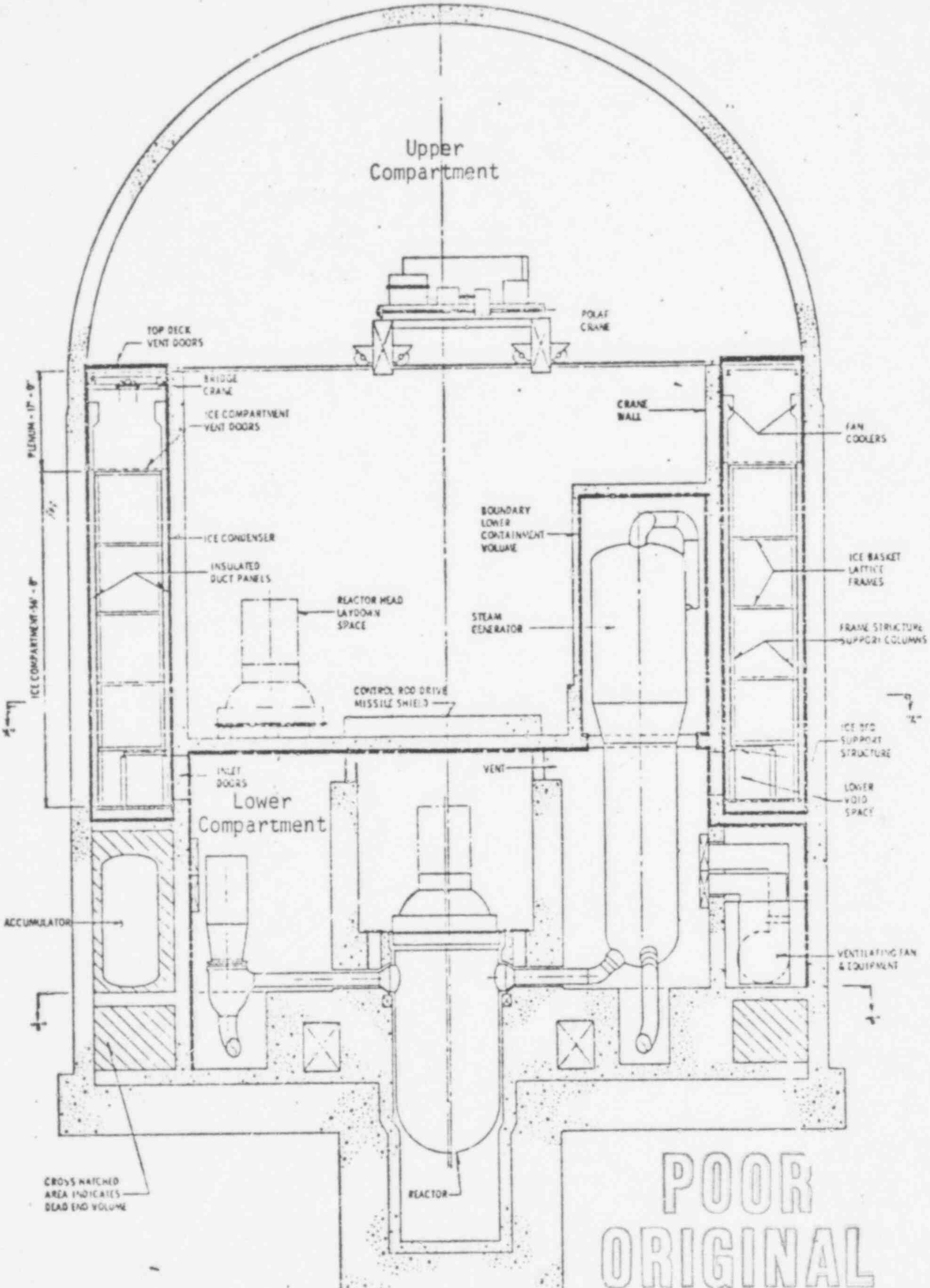

FIGURE 3-2 SECTIONAL ELEVATION
ICE CONDENSER CONTAINMENT
VOLUME BOUNDARIES

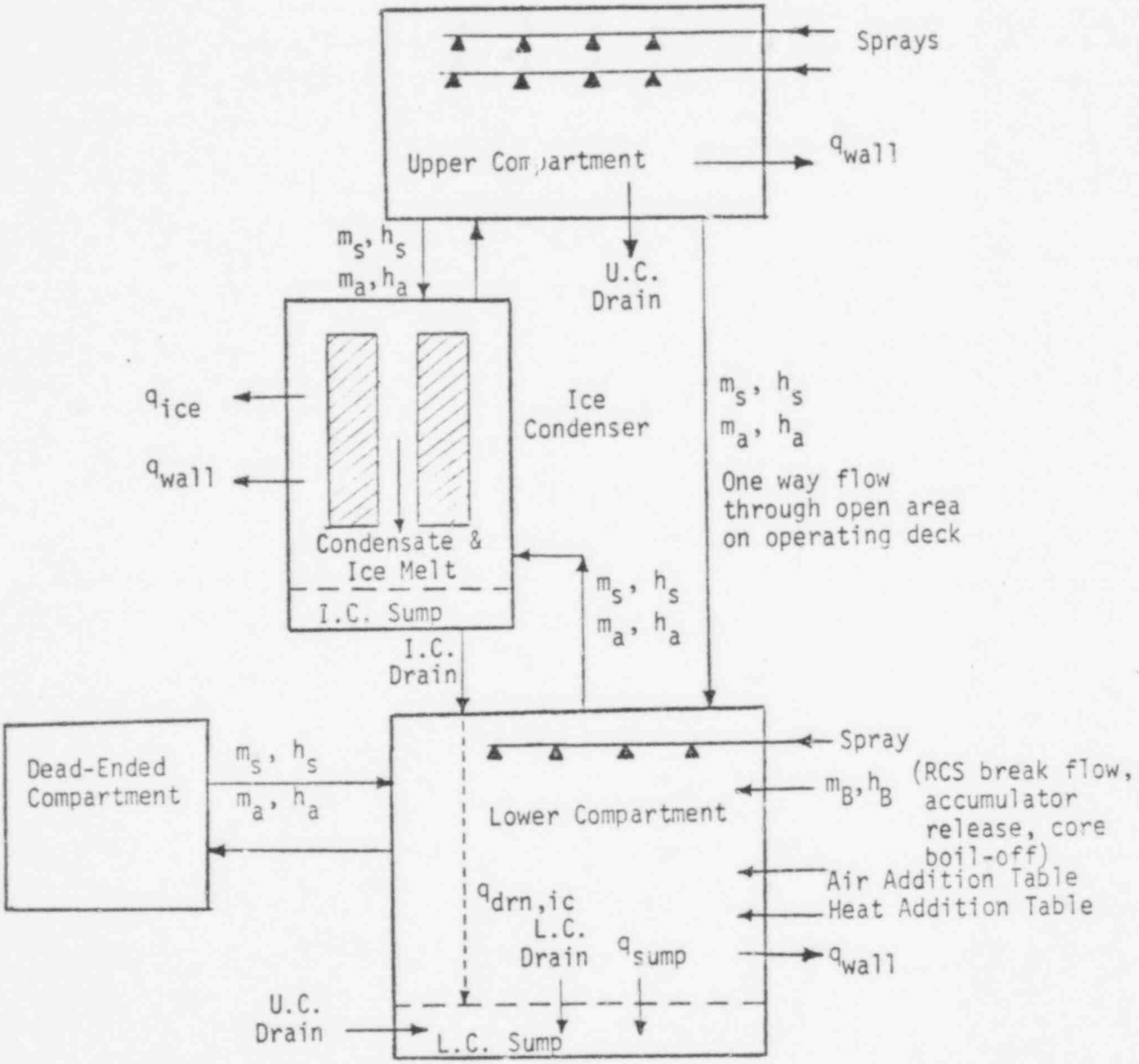

FIGURE 3.3 MASS AND ENERGY FLOW DIAGRAM
FOR THE COMPARTMENTS

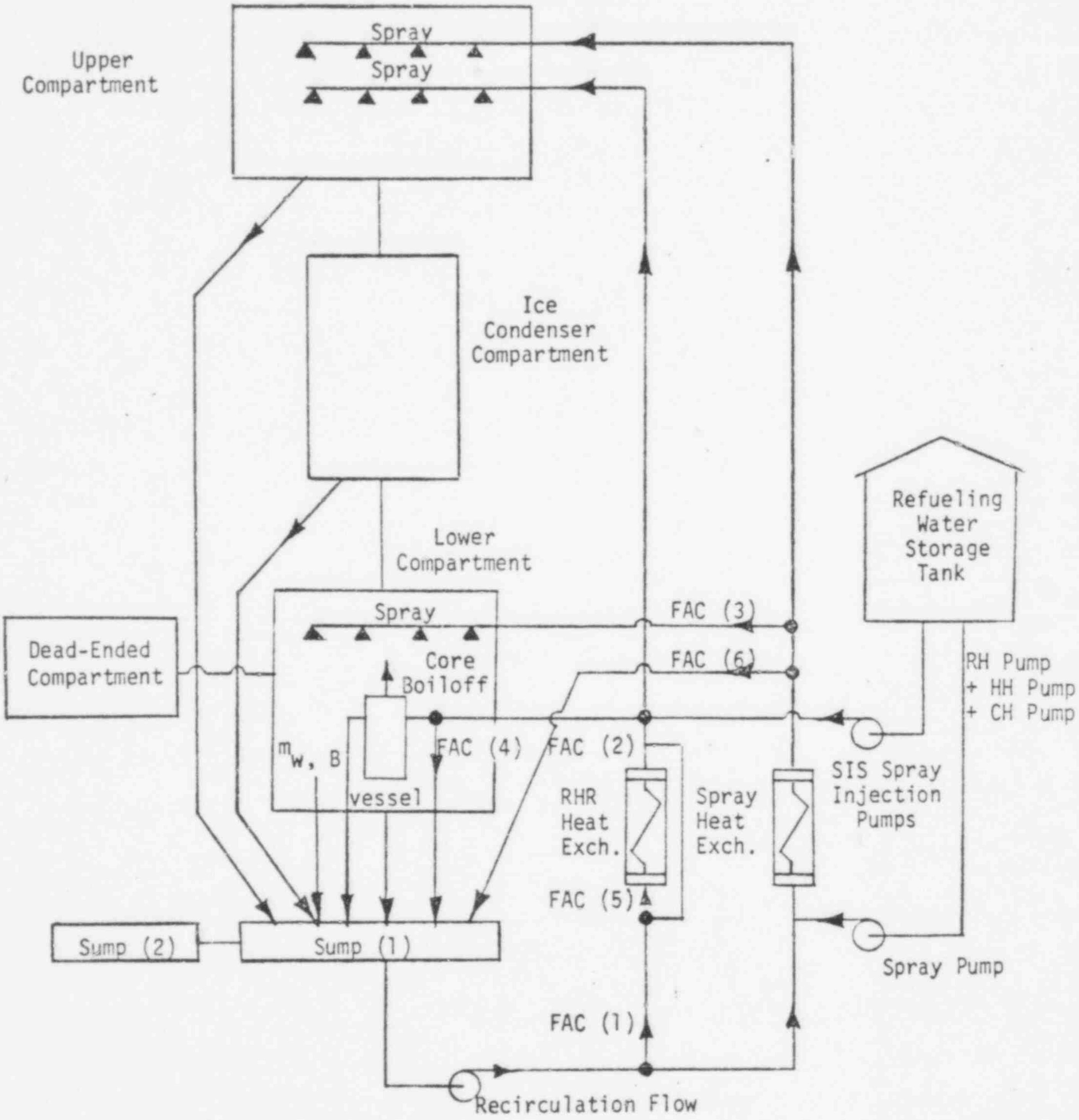

FIGURE 3.4 SCHEMATIC DIAGRAM OF WATER FLOW DISTRIBUTION FACTORS AND SUMP DRAINS

4.0 CONTAINMENT HEAT SINKS (EXCEPT SPRAYS)

4.1 STRUCTURAL HEAT TRANSFER

Experimental data indicate the presence of high heat transfer rates between the containment atmosphere and the containment structures during the blowdown period due to the turbulence sweeping along the walls. Following blowdown, the film heat transfer coefficient decreased to a smaller value as the condensate film was then fully developed, and a stagnant air layer formed next to the cold surfaces, reducing the rate of steam condensation.

The LOTIC code has the options of specifying heat transfer coefficients as a function of time or calculating a film coefficient similar to that employed in the COCO[5] code for analysis of "dry" containments.

The heat transfer coefficient to the containment structure is calculated by LOTIC based primarily on the work of Tagami.(6) From this work it was determined that the value of the heat transfer coefficient increased to a peak value near the time of peak containment pressure and then decreased exponentially to a stagnant heat transfer coefficient which was a function of steam to air weight ratio.

Based on experimental measurements from blowdown tests, Tagami presented a plot of the maximum value of H_{max} as a function of "coolant energy transfer speed," defined as:

$$\frac{\text{total coolant energy transferred into containment}}{\text{(containment vessel volume)} \quad \text{(time interval to peak containment pressure)}}$$

From this the maximum of H for steel was calculated (6, 9):

$$H_{max} = 75 \quad [\frac{E}{t_p V}]^{.6} \tag{4.1}$$

H_{max} = maximum value of H (Btu/hr ft^{2o}F)

t_p = time from start of accident to peak containment pressure (sec).

The increase to the peak value is given by:

$$H_s = H_{max} \sqrt{t/t_p} \quad ; 0 \leq t \leq t_p \tag{4.2}$$

H_s = heat transfer coefficient for steel (Btu/hr ft^{2o}F)

t = time from start of accident (sec)

The exponential decrease of the heat transfer coefficient is approximated by:

$$H_s = H_{stag} + [H_{max} - H_{stag}] e^{-.05 [t-t_p]}; \; t > t_p \tag{4.3}$$

where

$$H_{stag} = 2 + 50X; \; 0 \leq X \leq 1.4 \tag{4.4}$$

H_{stag} = H_s for stagnant conditions (Btu/hr ft^{2o}F)

X = steam to air weight ratio in containment

For concrete the heat transfer coefficient was taken as 40% of the value calculated for steel during the blowdown phase.

In applying the Tagami correlation to an ice condenser containment, it was noted that the total net energy transferred into the containment was no longer equal to the total blowdown energy because of the large removal of energy from the containment by ice melting. E/V should therefore be calculated as a prior condition for the use of equation 4.1. This was accomplished by

[ ] (a,b)
(4.5)

The subscripts "s" and "f" were used to designate the steam and water contents of the blowdown. The enthalpies were average values up to t_p.

The stagnant heat transfer coefficients were limited to 72 BTU/Hr-ft^2. This corresponds to a steam-air ratio of 1.4 (according to the Tagami correlation). The imposition of this limitation is to restrict the use of the Tagami correlation within the range of steam-air ratios from which the correlation was derived.

By imposing this limitation the stagnant Tagami data is kept conservative with respect to the Uchida data given in Reference [7]. This is illustrated in Table 4.1.

The above relations are suitable for the lower and ice compartments. For the upper compartment, since the main constituency is air and the rate of mass and energy flow from the ice compartment is small, it is appropriate to use Equation 4.4, the steady-state relation for the whole transient including the blowdown period.

For the transient conduction heat transfer in the structure, LOTIC assumes one-dimensional heat diffusion. A structure is divided into many layers and nodes according to the thermal properties and thickness of the structure. LOTIC allows for as many as 100 nodes for any structure if needed.

Table 4.1

Steam-Air Ratio M_S/M_A	Uchida Coefficients Btu/(hr-ft^2-^oF)	Lotic-3 Tagami Coefficients (Btu/(hr-ft^2-^oF)
.02	2.	3.
.05	8.	4.5
.05556	9.	4.8
.07143	10.	5.6
.1	14.	7.0
.14286	17.	9.14
.2	21.	12.0
.25	24.	14.5
.33333	29.	18.7
.43478	37.	23.7
.55556	46.	29.8
.76923	63.	40.5
1.25	98.	64.5
2.	140.	72.
10. or greater	280.	72.

5.0 COMPUTER CODE DESCRIPTION

5.1 GENERAL DESCRIPTION

The mathematical model described in this report has been implemented as a digital computer code having the name LOTIC-3 (Long-Term Ice Condenser Code). The input data consists of geometric, engineered safeguard system design and energy and mass release into the containment information. The format for input is discussed in Section 4.4 of this report. The output data are available in tabular and graphical formats.

5.2 LIST OF SUBROUTINES

LOTIC	Main program. Calls for major subroutines.
AUTOME	Adjusts time step length if necessary so that the percentage changes of certain compartment parameters will not exceed an input value.
CRAISE	Compares and records the maximum and minimum percentage changes of certain compartment parameters (for use in AUTOME).
READ	Inputs and prints the input data.
WREADF	Prints the input data on film.
INIT	Sets all constants and calculates compartment conditions for the blowdown period.
MAEN	Calculates the masses, enthalpies, internal energies and specific volumes of air and steam in a compartment for given pressure and temperature.
MAFLO	Calculates heat removal by ice.
BODRIV	Serves as a driver of matrix solution routines (also updates sump conditions).
DERIVE	Calculates derivatives of the "steam table" functions.
VECTOR	Calculates elements of the vector R as defined in Section A.7.
FILL	Calculates elements of the matrix as defined in Section A.7, matrix solution, calls for time step adjustment routine, checks flow reversals, and updates compartment conditions by rate integration.

BOOM	Sets saturated/superheated flags if necessary.
FLOW	Calculates SIS flow rates and enthalpies, mass and energy release rates from RCS and accumulator, and the cooling by heat exchangers.
RECALC	Updates ice melt and inventory for each of the six sub-compartments in the ice condenser. Also calculates sump conditions during the blowdown.
PCALC	Handles containment depressurization period.
RESPO	Calculates upper and lower compartment temperatures during long-term.
TRANS	Calculates air reverse flow to the lower compartment using "bubble model".
WRITE	Prints the results on paper and film.
PROP DERIV	Calculates the derivative of internal energy with respect to temperature for use in RESPO.
DCAY	Calculates decay heat as a function of time (an option usually suppressed by direct input of mass and energy release rates).
SID	Linear interpolation or extrapolation of tables.
HEAD	Prints title to describe the job.
WALLT	Computes temperature distribution and heat losses/gains for the compartment structures or walls.
CRMAK	Calculates the heat transfer coefficients between structures and compartment atmosphere.

HMCADM	Calculates the heat transfer coefficient between the containment structure and its external environment (including natural convection and solar radiation).
TUNAR	Calculates exit flow rate and temperature from the ice condenser drain pipe. Also updates the total mass and temperature of the accumulated water on the ice condenser floor.

The following routines are "steam table" routines:

HSV	Calculates enthalpy, temperature entropy and specific volume of saturated steam for a given pressure.
HSS	Calculates enthalpy, entropy and specific volume of superheated steam for given pressure and temperature.
HCSLV1 VEST VLIQ GRS	Internal to steam tables.
PSL	Calculates pressure of saturated steam and liquid for a given temperature.
TSL	Calculates temperature of saturated steam for a given pressure.
HCL	Calculates enthalpy and specific volume of a compressed liquid for given pressure and temperature.
HCSL	Internal to steam table.
HSL	Calculates enthalpy, entropy and specific volume of a saturated liquid for a given temperature.

Several subroutines for plotting are available for use with LOTIC.

5.3 FLOW DIAGRAM FOR LOTIC-3

(a,b)

5.4 INPUT DESCRIPTION

(a,c

Card I.D.	Format/Symbol	Description
1 and 2 (titles)		
3 (program control parameters)		
4 (program control parameters)		

Card I.D.	Format/Symbol	Description
5 (program control parameters)		

(a,c)

Card I.D.	Format/Symbol	Description
6 (program control parameters)		
7 (program control parameters)		

(a

Card I.D.	Format/Symbol	Description
8 (tabular data control parameters)		
9 (compartment wall data-1)		

(a,

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(a,c)

Card I.D.	Format/Symbol	Description
10 (compartment wall data-2)		
11 (external wall surface heat transfer controls)		
12 (external wall surface heat transfer coefficient tables)		

(a,

Card I.D.	Format/Symbol	Description
13 (external wall surface spray parameter)		
14 (inner wall heat transfer coefficient table controls)		
15 (inner wall heat transfer coefficient tables)		
16 (time step table)		
17 break flow table controls)		

Card I.D.	Format/Symbol •	Description
18 (break flow tables)		
19 (heat addition table controls)		
20 (heat addition tables)		
21 (air addition table controls)		
22 (air addition tables)		
23 (boil-spill table control)		
24 (boil-spill table)		

(a,c)

906279

(c

24A

(Alternate
Boiloff
Table
Control)

24B

(Alternate
Boiloff
Table 1)

25B

(Alternate
Boiloff
Table 2)

Card I.D.	Format/Symbol	Description
		(a,c)
25 (zirc heat table controls)		
26 (zirc heat tables)		
27 (compartment initial conditions)		
28 (safety injection and internal spray)		
29 (heat exchanger parameter-1)		

(a,c)

Card I.D.	Format/Symbol	Description
30 (heat exchanger parameters-2)		
31 (cooling tower/pond water parameters)		
32 (safety injection system (SIS) parameters)		
33 (second recirculation fan parameters)		

(a,c)

Card I.D.	Format/Symbol	Description
34 (safety injection system flow distribution) (Figure 1)		
35 (ice condenser flow distribution)		
36 (ice condenser flow distribution-2)		
37 (ice condenser flow distribution-3)		
38 (ice condenser angular section)		
39 (ice condenser parameters)		

(a,c)

Card I.D.	Format/Symbol	Description
40 (Ice column table)		
41 (Sump supplement)		
42 (Control volume temperature and pressure table controls)		
43 (Tables for temperature and pressure transients during blowdown)		

Card I.D.	Format/Symbol	Description
44 (Flow resistance K-factor per area square, K/A^2)		
45 (K-factor and blowdown conditions)		
46 (Heat transfer data for lower compartment)		
47		

(a,c)

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5.5 LIST OF CODE OPTIONS IN SPECIFYING STRUCTURAL HEAT TRANSFER COEFFICIENTS

Structural heat transfer coefficients may be input as a function of time, or calculated by the code using correlation based on the experimental work of Tagami. As an extension to the input description in the preceding section, the following lists the options of specifying structure heat transfer coefficients through the use of the input parameters, ITBL(I), CT(13), CT(14) and CT(31). The user must determine which option is most suitable for his application.

(1) Input of structure heat transfer coefficients as a function of time:

ITBL(I) ≥ 1

(2) Use of Tagami correlation as described in Sec. 4.1

ITBL(I) = -1, or -2
CT(13) = 0, CT(14) > 0.

where CT(14) denotes the time of the containment peak pressure.

(3) Use of Tagami stagnant heat transfer correlation, Eq. 4.4 over the whole transient

ITBL(I) = -1, or -2
CT(13) = CT(14) = 0.

(4) Input of an average structure heat transfer coefficient during blowdown and the use of Tagami correlation after blowdown

ITBL(I) = -1, or -2
CT(13) > 0., CT(14) = 0., and CT(31) > 0.

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where CT(13) and CT(31) denote respectively the structure heat transfer coefficients before and at the end of blowdown. After blowdown, the structure heat transfer coefficient is assumed to decay expontially following Eq. 4.3.

APPENDIX A

DERIVATION OF CONSERVATION EQUATIONS

The purpose here is to show the final mathematical forms of the conservation equations which are used for solving the compartment conditions and flow rates. The equations are derived by substituting the ideal gas law for air and the equations of state for steam into the conservation equations of energy, momentum, mass and volume for each compartment. The equations are derived separately for saturated* and superheated conditions. Four parameters, the steam pressure, the masses of air, steam and suspended water are used to define the condition of a saturated compartment. For a superheated compartment, temperature is used to replace the suspended water mass as the fourth parameter.

---

*The equations for saturated compartments have already been presented in Appendix A, Reference 3. They are included here for completeness.

A.1 IDEAL GAS LAW AND THE EQUATIONS OF STATE

For a Saturated Compartment

For the steam and suspended condensate in each compartment, the rates of change of pressure, enthalpy and specific volume may be related as

(a,c)

(A.1)

(A.2)

(A.3)

(A.4)

For the air in each compartment

(a,c)

(A.5)

(A.6)

Substituting Equation (A.3) into Equation (A.6), we have

(a,c)

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For a Superheated Compartment

The rates of change of pressure, temperature, enthalpy and specific volume for superheated steam are related as

(a,c)

(A.1a)

(A.3a)

s s

And for the air

(a,c)

(A.5a)

(A.6a)

Substituting Equation (A.3a) into Equation (A.6a),

(a,c)

(A.7a)

For the upper compartment, V = 0, Equation (A.6a) simply becomes

(a,c)

(A.7b)

Since the air and steam mixture in each compartment is assumed to be completely mixed and the flow leaving a compartment consists of steam and air, the following relationships also hold

(a,c)

(A.8)

(A.9)

(A.10)

The above equations are now ready to be substituted into the conservation equations of energy, mass, momentum and volume. For simplicity in derivation, we will consider a j-th compartment which normally receives flow from compartment i and exits flow into compartment K Subscripts 1, 2, 3 and 5 will be respectively used to designate the upper, lower, ice condenser and the dead-ended compartments.

A.2 ENERGY EQUATIONS FOR THE J-TH COMPARTMENT

If the compartment is saturated

(a,c)

(A.11)

Expanding and substituting Equations (A.1) through (A.10) into Equation (A.11), we obtain

(a,c)

(A.12)

where E abbreviates:

(a,c)

(A.13)

The subscripts ℓ and m in Equation (A.12) are used to designate:

$$\ell = \begin{cases} i \text{ if } m_{ij} > 0 \\ j \text{ if } m_{ij} < 0 \text{ (Reverse flow)} \end{cases} \qquad \text{(A.14)}$$

$$m = \begin{cases} j \text{ if } m_{jk} > 0 \\ k \text{ if } m_{jk} < 0 \text{ (Reverse flow)} \end{cases} \qquad \text{(A.15)}$$

If the compartment is superheated

[ ] (a,c)

(A.11a)

Expanding and substituting Equations (A.1a) through (A.7a) into Equation (A.11a),

[ ] (a,c)

(A.12a)

For the upper compartment, we use Equation (A.7b) in place of Equation (A.7a) for substituting into Equation (A.11a), and we obtain

[ ] (a,c)

(A.12b)

The expression for R_{ej}

The following expressions for R_{ej} are applicable whether the compartment is saturated or superheated even though the term for drain energy, $m_{drn}\ h_c$ loses its meaning and becomes zero under a superheated conditions.

(a,c)

(A.17)

(A.18)

A.3 CONSERVATION OF STEAM AND WATER MASSES

Using a similar procedure and the nomenclature as in the derivation of the energy equations, we obtain

For a Saturated Compartment

(a,c)

(A.19)

And

(a,c)

(A.20)

(A.21)

(A.22)

For a Superheated Compartment

Equations (A.19) through (A.20) are valid if $\dot{M}_{cj}$ and $\dot{m}_{drnj}$ are set to zero.

A.4 CONSERVATION OF AIR MASS

For any compartment saturated or superheated,

(a,c)

(A.23)

And

(a,c)

(A.24)

(A.25)

(A.26)

A.5 CONSERVATION OF MOMENTUM

The hydraulic equation between compartments j and k,

$$P_j - P_k = K_{jk} m_{jk}^2 / (2\rho_j g_c A_{jk}^2) \qquad (A.27)$$

But,

$$P_j = P_{jo} + \dot{P}_j \Delta t$$

$$= P_{jo} + (\dot{P}_{aj} + \dot{P}_{sj}) \Delta t$$

Substituting into Equation (A.27)

$$\dot{P}_{aj} + \dot{P}_{sj} - [K_{jk} m_{jk} / (2\rho_j g_c \Delta t A_{jk}^2)] m_{jk} = -(P_{jo} - P_{ko})/\Delta t \qquad (A.27a)$$

(a) <u>If both compartments j and k are saturated</u>,

Substituting Equation (A.7) for $\dot{P}_{aj}$ and $\dot{P}_{ak}$ into Equation (A.27a) we obtain

(a,c)

(A.28)

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(b) If both compartments j and k are superheated

Substituting Equation (A.7b) for $\dot{P}_{aj}$ and $\dot{P}_{bk}$ into Equation (A.27a) to obtain an equation similar to Equation (A.28). If one of these compartments is the upper compartment, use Equation (A.7c) for this compartment.

(c) If one compartment is saturated and an other superheated

Equation (A.27a) is substituted using $\dot{P}_{aj}$ and $\dot{P}_{ak}$ from Equations (A.7), (A.7a), or (A.7b) whichever is applicable.

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A.6 VOLUME CONSERVATION

For a saturated compartment

$$\frac{dV_{asj}}{dt} + \frac{dV_{cj}}{dt} = R_{vj} \qquad (A.29)$$

Applying Equations (A.3), (A.4) and (A.7) to (A.29),

(a,c)

(A.30)

For a superheated compartment

$$\frac{dV_{j}}{dt} = R_{vj} \qquad (A.29a)$$

Substituting Equation (A.3a) into Equation (A.29a),

(a,c)

(A.30a)

(A.31)

(A.32)

A.7 METHOD OF SOLUTION

Equations (A.12) through (A.32) are conservation equations which govern and inter-relate the conditions for the three compartments; upper, lower and ice condenser compartment. Since any of the compartment could be saturated or superheated anytime during the transient, there are a total of eight probable containment conditions (2^3). For each of these probable containment conditions, Equations (A.12) through (A.32) provide 15 appropriate simultaneous equations, and in matrix notation

(a,c)
(A.33

for a superheated compartment.

At the end of calculation for each time step, the compartments are checked for possible switching of states (saturated or superheated). A switch from saturated to superheated states occurs when the mass of suspended water, M_{cj} becomes zero or less. In order to avoid needless iterations and computation time, the switch is carried out when the water mass becomes small such that $(M_{cj}/M_{sj}) < \beta \ll 1$. The user may input appropriate β value for his particular application. It is expected that the containment conditions should be insensitive to the β value chosen as long as it is small. For our analysis, will be taken as 0.01. On the other hand, a switch from superheated to saturated states is carried out when a compartment temperature is equal to or less than the saturated temperature (evaluated at its compartment steam partial pressure).

A.8 CALCULATION OF THE DEAD-END COMPARTMENT CONDITIONS

After the conditions have been obtained for the upper, lower and the ice condenser compartments, a new flow rate between the dead-end compartment and the lower compartment may be calculated using Equation (A.27). The new conditions for the dead-end compartment may then be calculated easily using equations as presented at the end of Section 2 of the main test.

APPENDIX B

CODE VERIFICATION

A computer code can be verified in any number of ways. Two approaches are to compare the results with other accepted analytical tools, and to compare calculated results with test measured results. It is these two approaches which were used to verify the LOTIC-3 computer code.

B.1 CODE COMPARISIONS

Figure B1 gives a comparision between LOTIC-3 and the COCO[5] computer code (an acceptable, single volume, containment computer code[9]). The comparison made was for CVTR[8] test 3. [Later in this section further discussion of these tests will be made]. This excellent comparision indicates the required consistency, and uniformty between the two codes. Futhermore it demonstrates the correctness of the previously mentioned modifications to the LOTIC-2 computer code.

B.2 TEST MODELLING

In order to use the code to calculate containment temperature and pressure transients for steamline break accidents, the code modelling on structural surface condensation and revaporation, and the condensation heat transfer coefficient were evaluated to find their applicability and conservatism under superheated steam blowdown.

Condensation-revaporization was studied by computer code simulation of CVTR tests[8] using different assumptions and the Tagami heat transfer coefficients were compared to a more detailed heat transfer correlation based on Tagami and CVTR heat transfer test data.

B.2.1 Condensation-Revaporization

The CVTR tests were superheat steam blowdown tests. The containment free volume is about one-eight of a typical PWR 3-loop containment and one-tenth of a 4-loop containment. The blowdown steam enthalpy is 1195 Btu/lbm which was about the same as a postulated PWR main steamline blowdown under the assumption of no moisture carryover. The blowdown lasted 166.4 seconds and the average mass rate pervolume was equivalent to a 3-loop 4.6 ft^2 break under no load conditions.

Figure B2 shows the CVTR containment. The containment free volume was separated into three regions--operating, intermediate and basement regions. Steam blowdown occurred in the operating region and spread out into the other regions through an open area in the operating floor. Tests 3, 4, and 5 were essentially the same for the first 166.4 seconds, and therefore only test 3 will be considered here.

Two condensate models will be considered in the computer code simulation of the CVTR tests. The first one is the design model. This model assumes that an equilibrium condition exists between the condensate (attached on the cold structure) and the containment steam air atmosphere. At each time step, the conservation equations (mass, energy and state) are solved simultaneously to determine a new containment air-steam-condensate condition. If the calculated condition is a saturated state, water mass (condensate) forms and is assumed to fall instantly into the sump. On the other hand, if the condition is a superheated state, the water mass would not form at that time step. The assumption is conceptually justified by the rapid temperature increase at the condensate film surface due to increasing containment atmospheric temperature. The condensate which is at a saturated state based on the interfacial temperature at a previous time step revaporizes under the exposure to a superheat atmosphere.

The second condensate model assumes that the condensate is modelled separately from the calculation of containment atmospheric conditions. This model also maximizes the rate of condensate formation by assuming that heat transfer from the containment atmosphere to the cold structure is the result of a phase change only. At each time step, a rate of condensate formation is calculated by

$$\dot{m}_{condensation} = \dot{Q} / (h_v - h_f)$$

where $\dot{Q}$ is the rate of structural heat removal, h_v is the saturated vapor enthalpy, and h_f is the saturated liquid enthalpy. The condensate is assumed to drop out without being revaporized by the superheat atmosphere. For convenience, the results obtained using this model will be denoted as "condensation without re-evaporation".

The two condensate models were incorporated into the LOTIC-3 code to simulate the containment responses during a CVTR test transient. The input information required for the calculation were taken from Reference[8]. The CVTR containment was modelled by a 3-node LOTIC-2 code to represent the operating, intermediate and basement regions. Measured regional heat transfer coefficients were used. The comparison with test results is shown in Figure B3 for the design condensate model (condensate-re-evaporation) and in Figure B4 for the condensation without re-evaporation model. Good agreement with the measured temperature is obtained in all regions when the condensate-re-evaporation model is used. Extremely high temperatures were obtained if no re-evaporation is assumed for the condensate, and consequently an extremely poor test match.

The preceding code simulation of the CVTR test required input data on detail structure information. This was done by taking the data directly from the test report [8]. Because of the uncertainty in structure data as mentioned in the same report, a sensitivity study of the code calculation to structure data was performed and is shown in Figures B5 and B6. An arbitrary value of 60% increase in steel volume (exceeding uncertainty limit) was added to the structure data. While decreases in temperatures were observed, the complete condensate drop-out model (no re-evaporation) still yielded high temperatures which were not representative of the test.

B.2.2 Structural Condensing Heat Transfer Coefficient for Steamline Break

Tagami heat transfer coefficients[6] have been used widely in containment analysis. These heat transfer coefficients were the result from extensive experimental measurements based on simulated LOCA blowdowns of various blowdown fluid conditions and flow rates. The most important contribution from these tests was to provide a quantitative relationship between structural heat transfer coefficient with a turbulance parameter, the "energy transfer speed". Many correlations with only slight differences were developed and used by various containment analysts and were known as Tagami or modified Tagami heat transfer coefficients. The correlation of the Tagami heat transfer coefficients is contained in the this code* and the COCO code. The correlation will be used in steamline break as follows:

1. The peak heat transfer coefficient is assumed to occur at the end of the large blowdown rate period when the intact loop steamline isolation valve is closed.

2. Saturation temperature instead of superheated containment temperature is used for structural heat transfer calculations.

The first assumption is based on the similarity between the large blowdown rates during the early transient following a main steamline break and a LOCA blowdown.

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*See Section 4 of this report

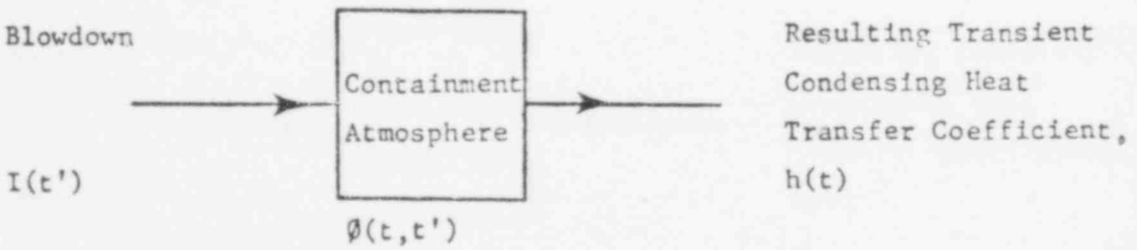
The assumption of saturation temperature for structural heat transfer rate calculations conservatively neglects any heat removal when the structural surface attains the saturation temperature of the containment steam.

Another conservatism is to recognize that the Tagami tests were two phase blowdown and the current steamline break assumes pure steam with no moisture carryover. Pure steam should have better contact with the structural wall and a thinner condensate film than a two phase fluid. Therefore, it should have higher heat transfer coefficients. This is probably one of the factors which could contribute to the underprediction of the Tagami correlation to CVTR test data.

Figure B7 compares the measured test pressure transient with those calculated by COCO using the W Tagami model and the average measured heat transfer coefficients. Both COCO calculations overpredict the test results, and the W Tagami model yields the highest pressure. Thus illustrates the basic conservatism in our models. Figure B6 shows similar results for the temperature transients.

As further verification of the conservatism of the Tagami model, a new correlation has been developed and compared to the Tagami results. The basics are as follows:

When steam is blown into a containment free volume, it induces turbulence in the containment atmosphere by its momentum and energy. The intensity of the turbulence depends on the blowdown rate, the size of the containment and the available heat sinks. The intensity of the turbulence will ultimately affect the magnitude of structural condensing heat transfer coefficient.



The condensing heat transfer coefficient h(t) may be written as

[ ] (a,c)

where C_1 is a correlating constant. The blowdown function I(t') and the containment response function $\phi(t,t')$ are correlated using Tagami heat transfer test data.

Only the final correlating equation will be given here:**

[ ]$^{(a,c)}$

where $\dot{M}_s$ - time dependent blowdown rate of steam mass

M_a - containment air mass

ΔM_s - Net increase of steam mass in the containment atmosphere

V - containment free volume

Results and comparison:

Case 1 - Comparison of the new correlation with Tagami data is shown in Figure B8. Good agreement is obtained for both large and small blowdown rates.

Case 2 - Comparison of the new correlation with the CVTR Test #3 is shown in Figure B9. Good agreement is obtained for all three regions of the containment. We note that the required flow rate for the evaluation of the new correlation were taken from LOTIC-3 results (See Section 2d).

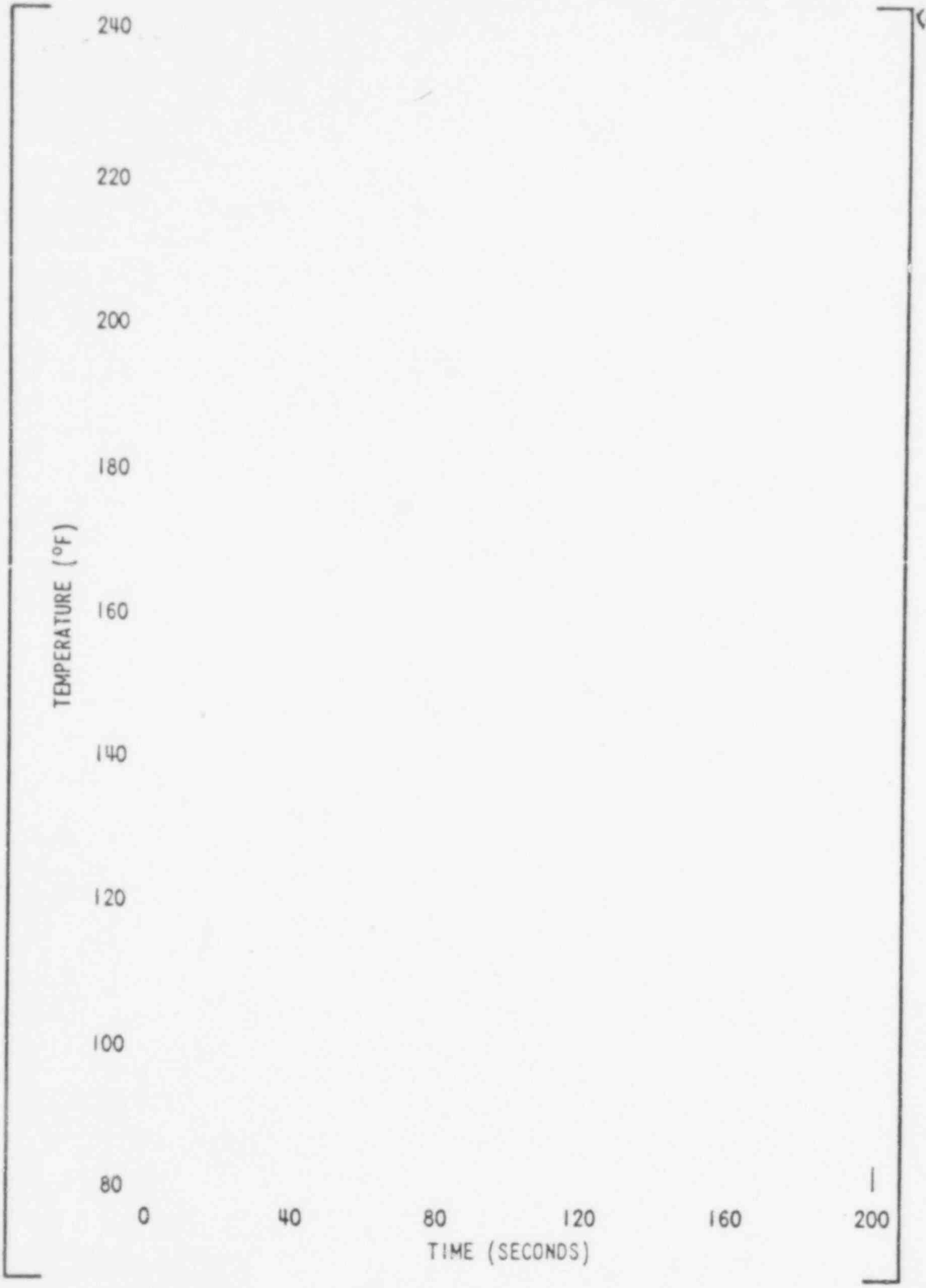
**Detail description in Appendix C

Case 3 - Comparison of the new correlation with COCO Tagami correlation is shown in Figure B10. The case analyzed is a 3-loop plant with a 4.6 ft^2 main steamline break. The Tagami correlation is shown to yield lower heat transfer coefficients in comparison with the new correlation.

In conclusion, we have shown that for steamline break analysis, the Westinghouse Tagami correlation calculates conservatively lower heat transfer coefficients in comparison with a new correlation which has been shown to agree well with the Tagami and CVTR test results.

(a.c)

°F



seconds

Figure B 1.

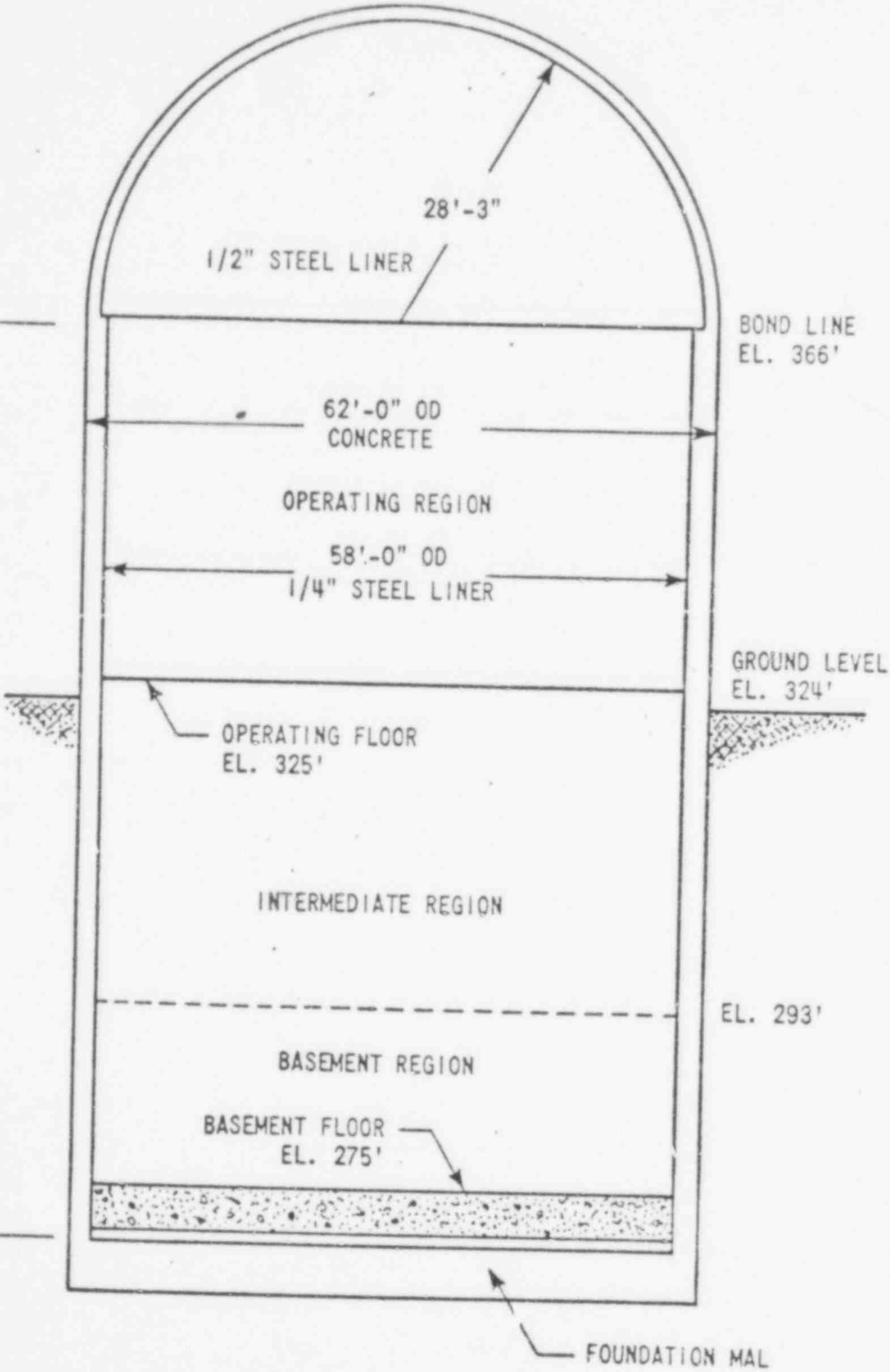

28'-3"
1/2" STEEL LINER
BOND LINE
EL. 366'
62'-0" OD
CONCRETE
OPERATING REGION
58'-0" OD
1/4" STEEL LINER
89'-6"
GROUND LEVEL
EL. 324'
OPERATING FLOOR
EL. 325'
INTERMEDIATE REGION
EL. 293'
BASEMENT REGION
BASEMENT FLOOR
EL. 275'
FOUNDATION MAL

Figure B 2.

10,586-3

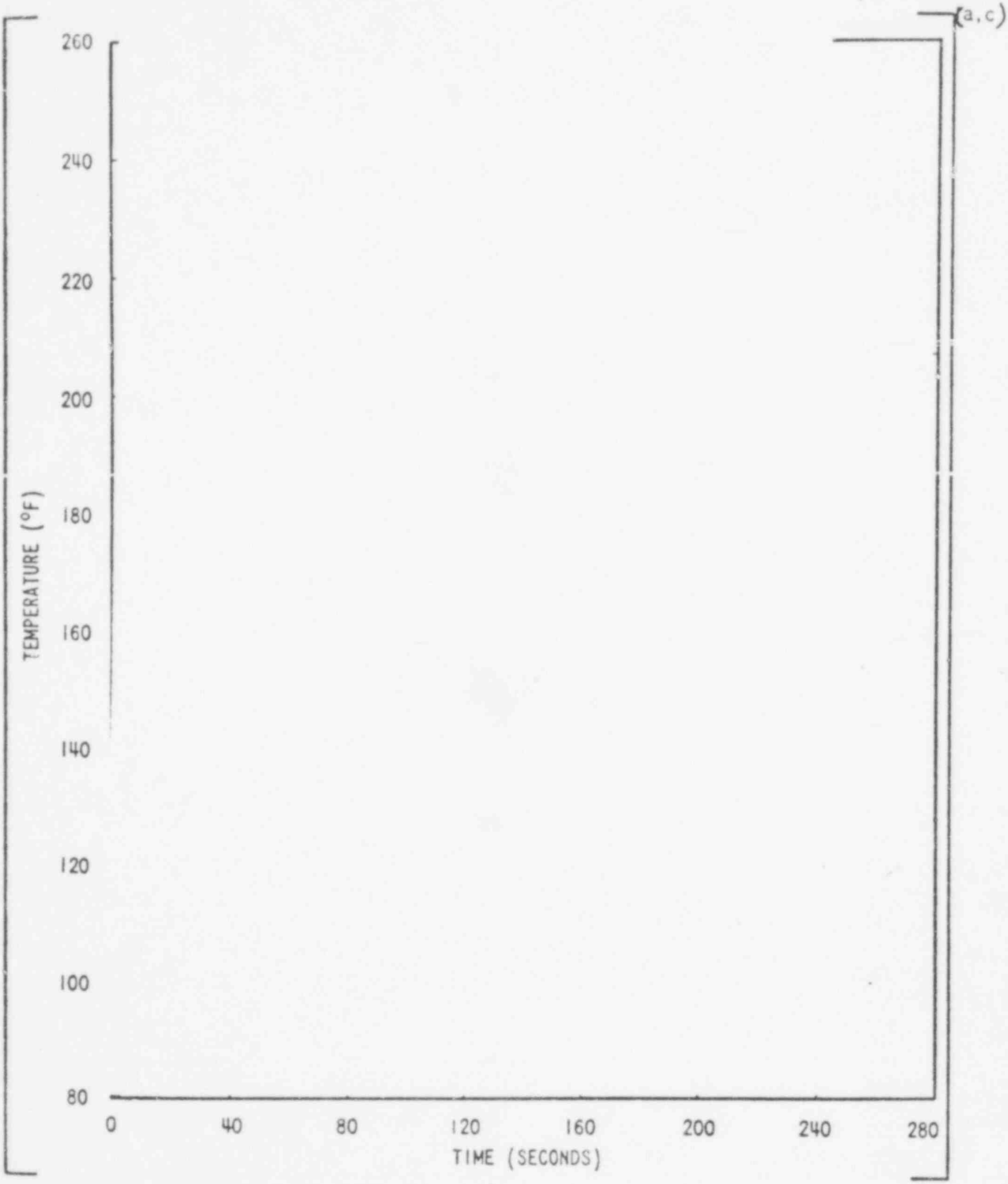


Figure B.3. Comparison of LOTIC 2 Results with CVTR Test Data

10,586-4

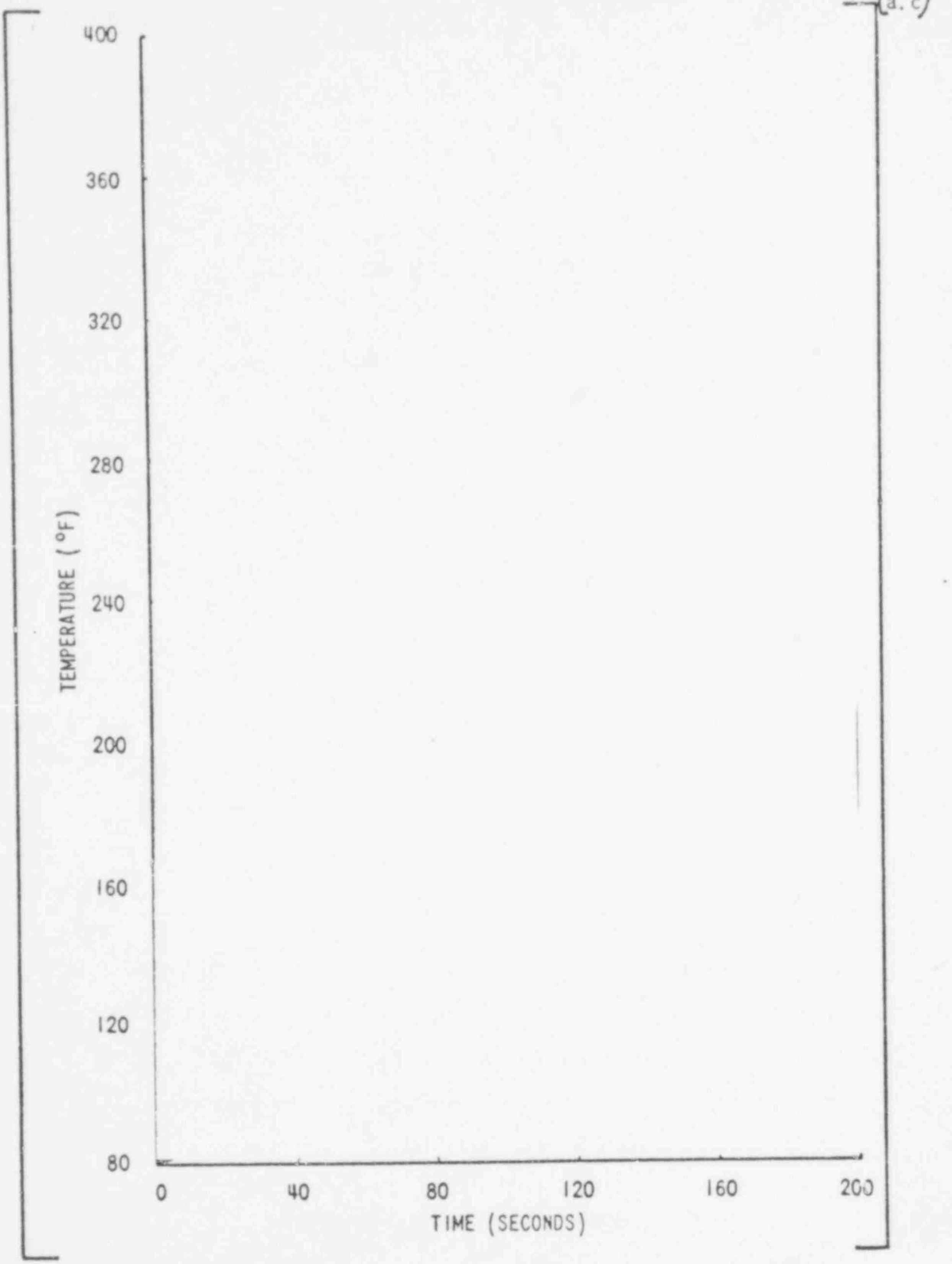


Figure B 4.

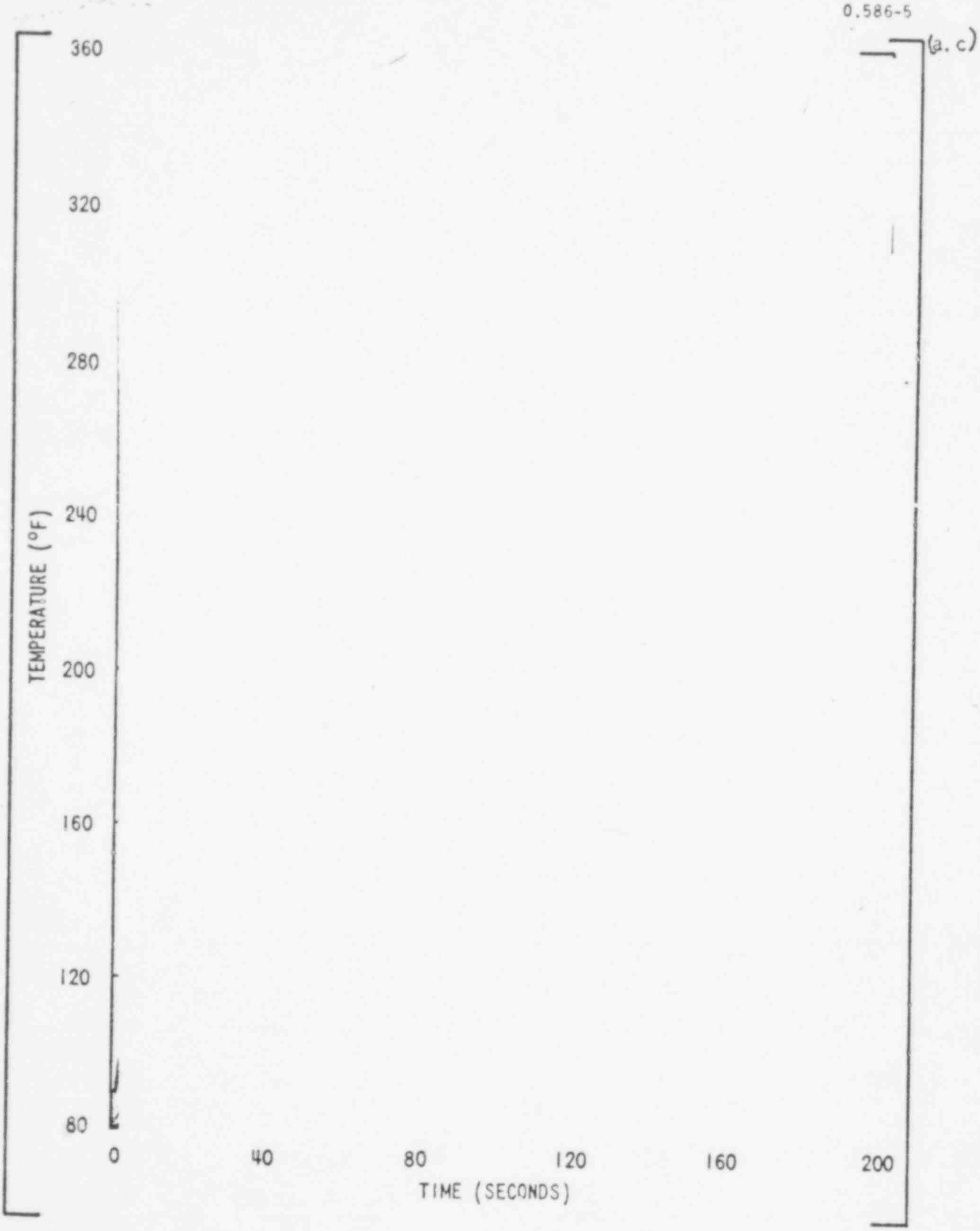

0.586-5
(a.c)
360
320
280
240
200
160
120
80
TEMPERATURE (°F)
0
40
80
120
160
200
TIME (SECONDS)

Figure B 5.

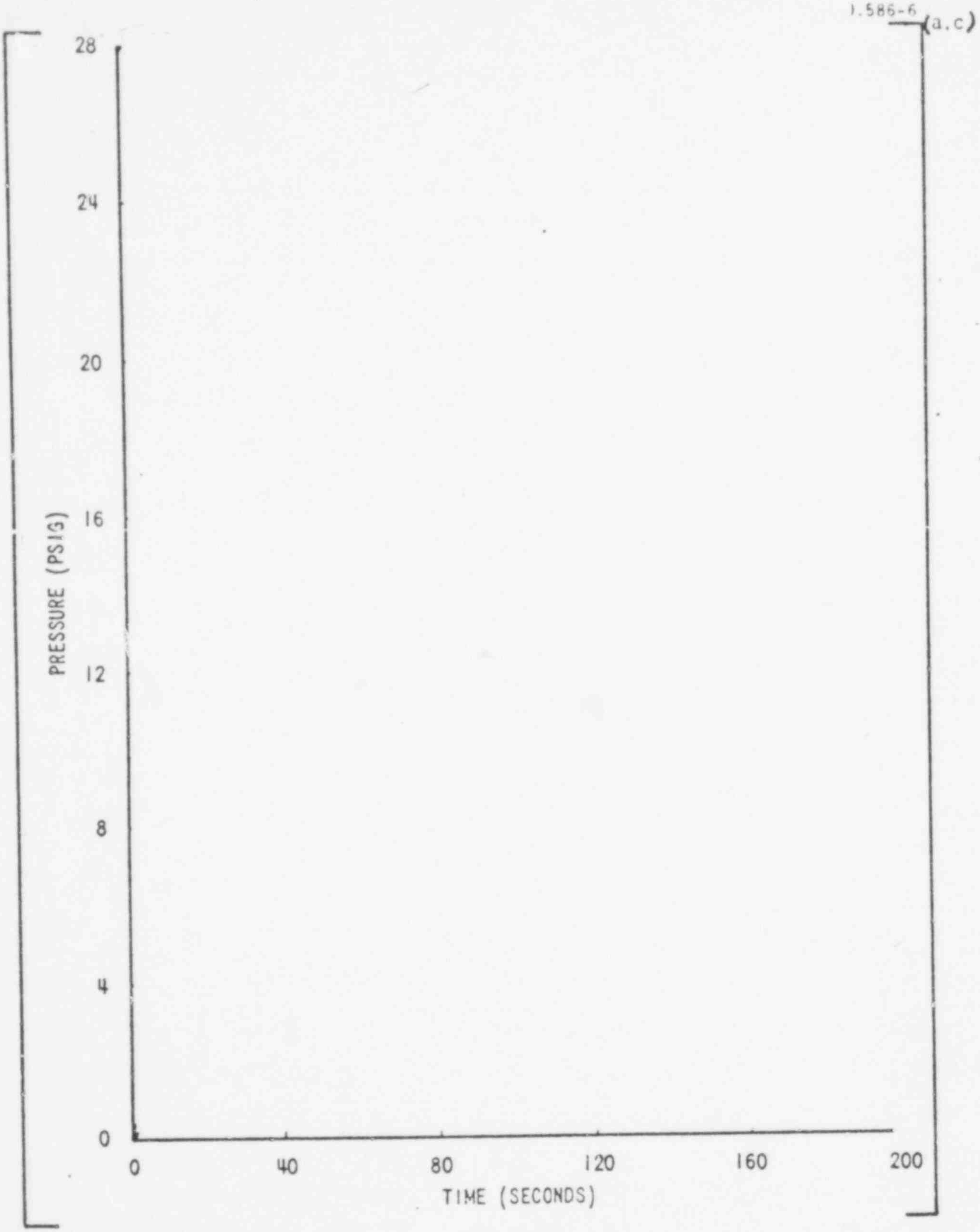

1.586-6
(a,c)
PRESSURE (PSIG)
28
24
20
16
12
8
4
0
0
40
80
120
160
200
TIME (SECONDS)

Figure B 6.

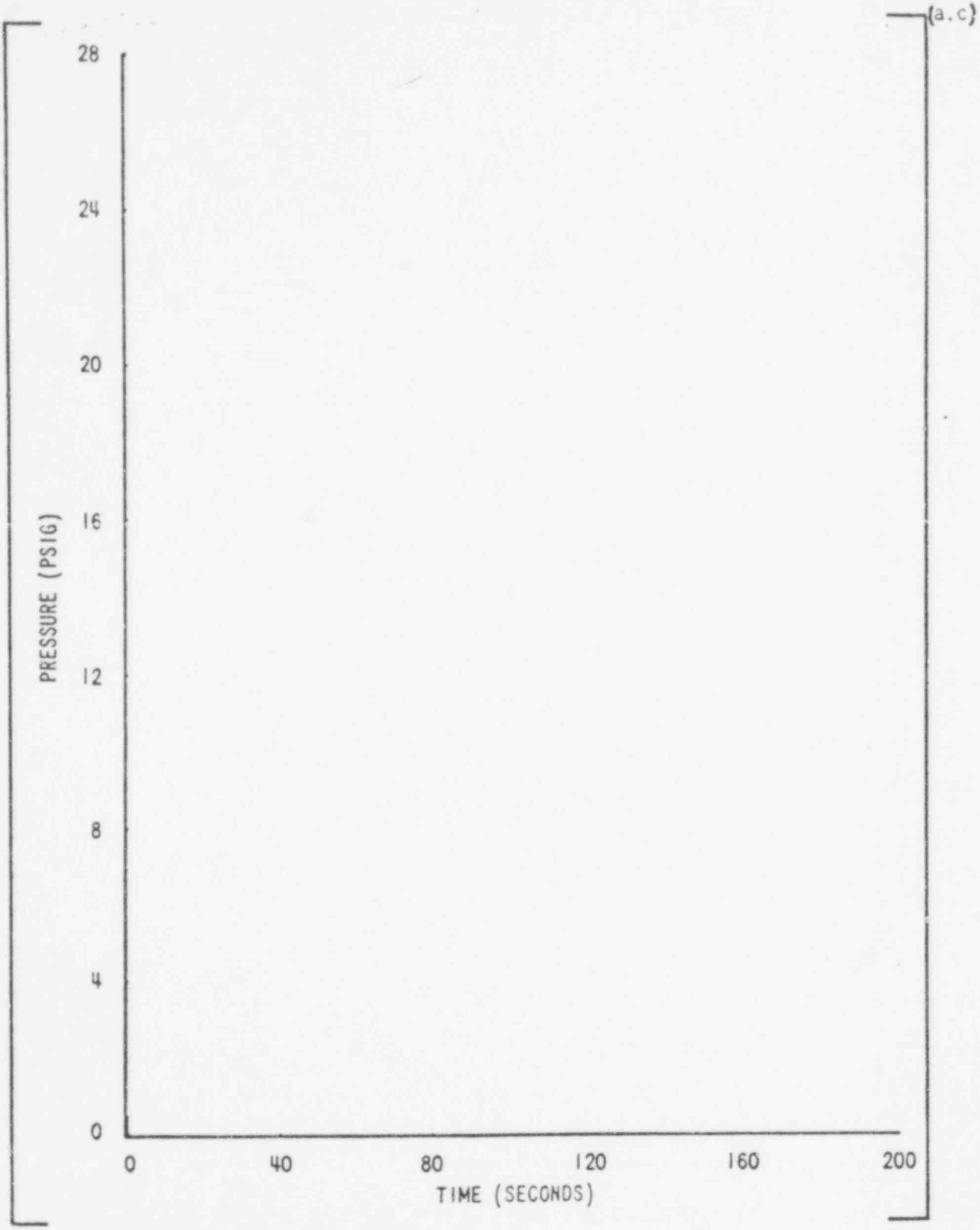

(a,c)
28
24
20
16
12
8
4
0
PRESSURE (PSIG)
0
40
80
120
160
200
TIME (SECONDS)

Figure B-7

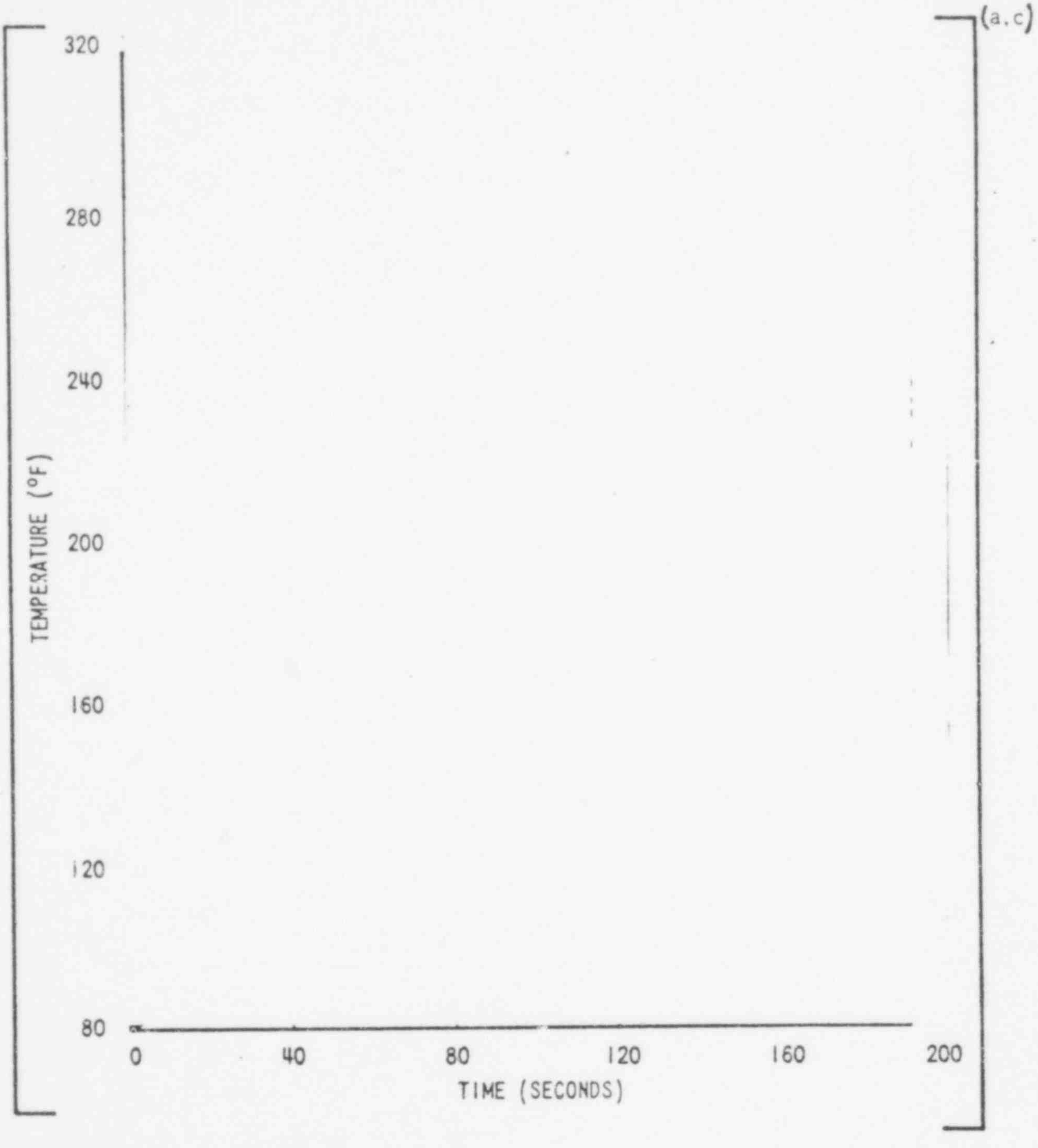

(a,c)
320
280
240
200
160
120
80
TEMPERATURE (°F)
0
40
80
120
160
200
TIME (SECONDS)

Figure B-8

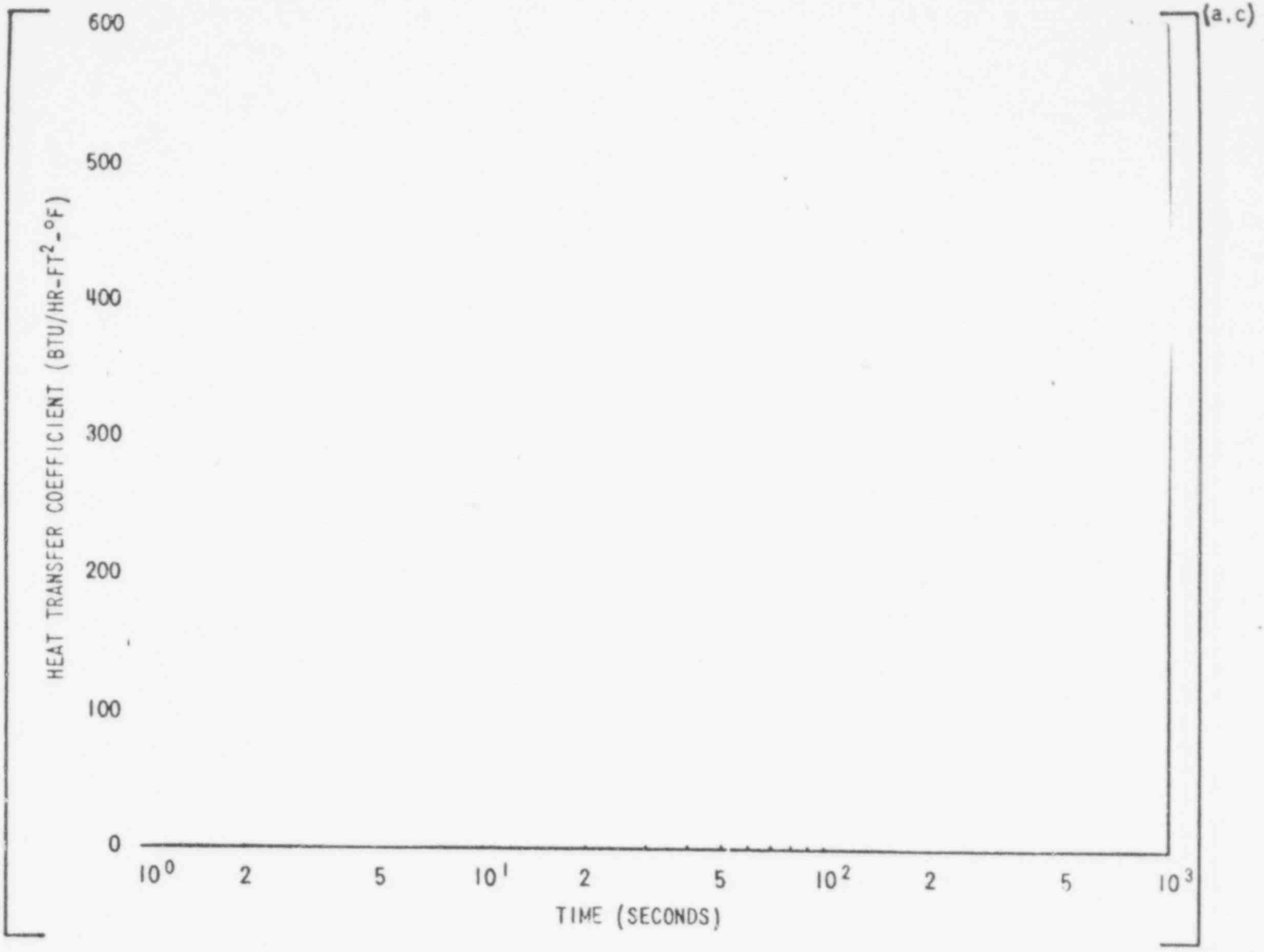
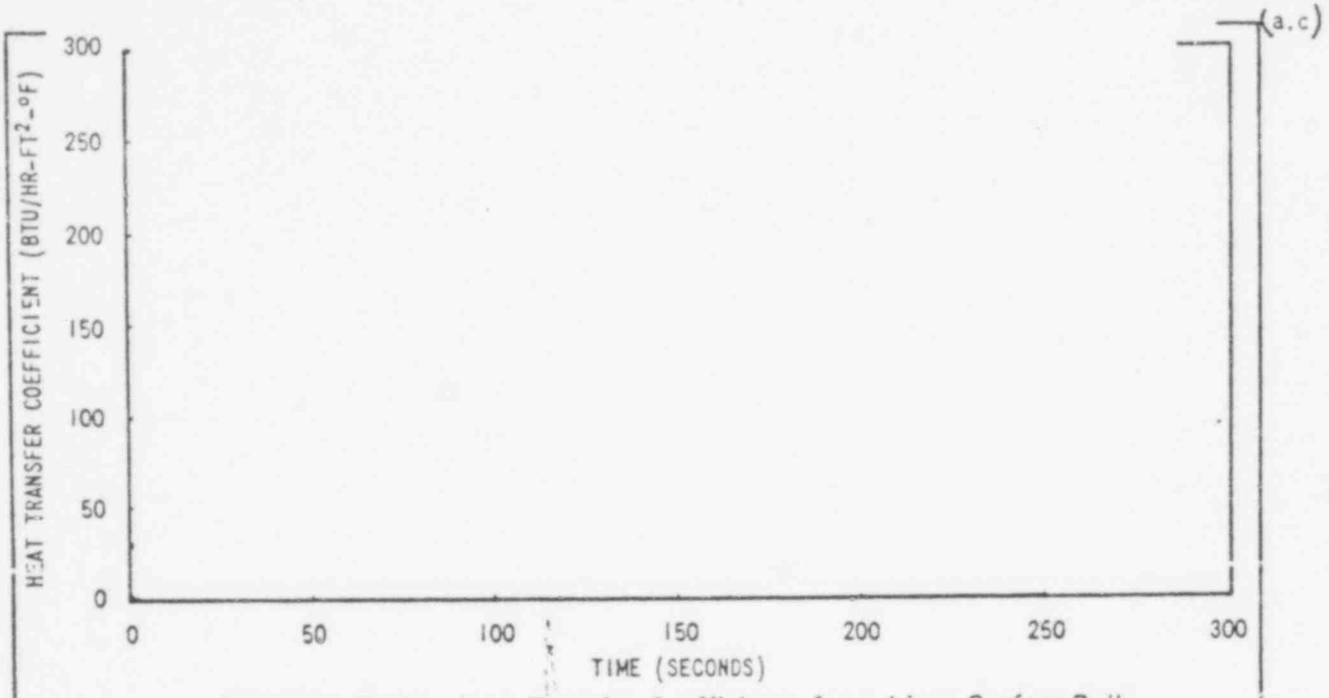
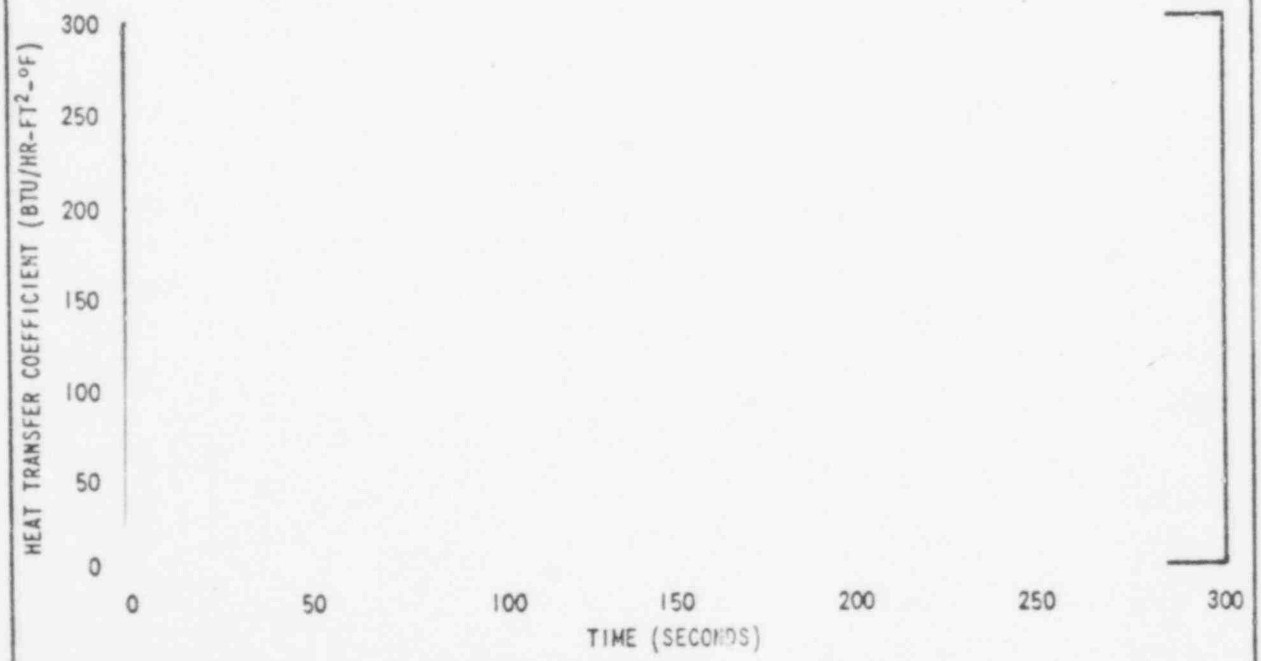

(a,c)
600
500
400
300
200
100
0
HEAT TRANSFER COEFFICIENT (BTU/HR-FT^2-°F)
10^0
2
5
10^1
2
5
10^2
2
5
10^3
TIME (SECONDS)

Figure B-9



Operating Region Heat Transfer Coefficients from Liner Surface-Bulk Atmosphere Temperature Differences, Test 3



Basement and Intermediate Regions Heat Transfer Coefficients from Liner Surface-Bulk Temperature Differences, Test 3

Figure B-10

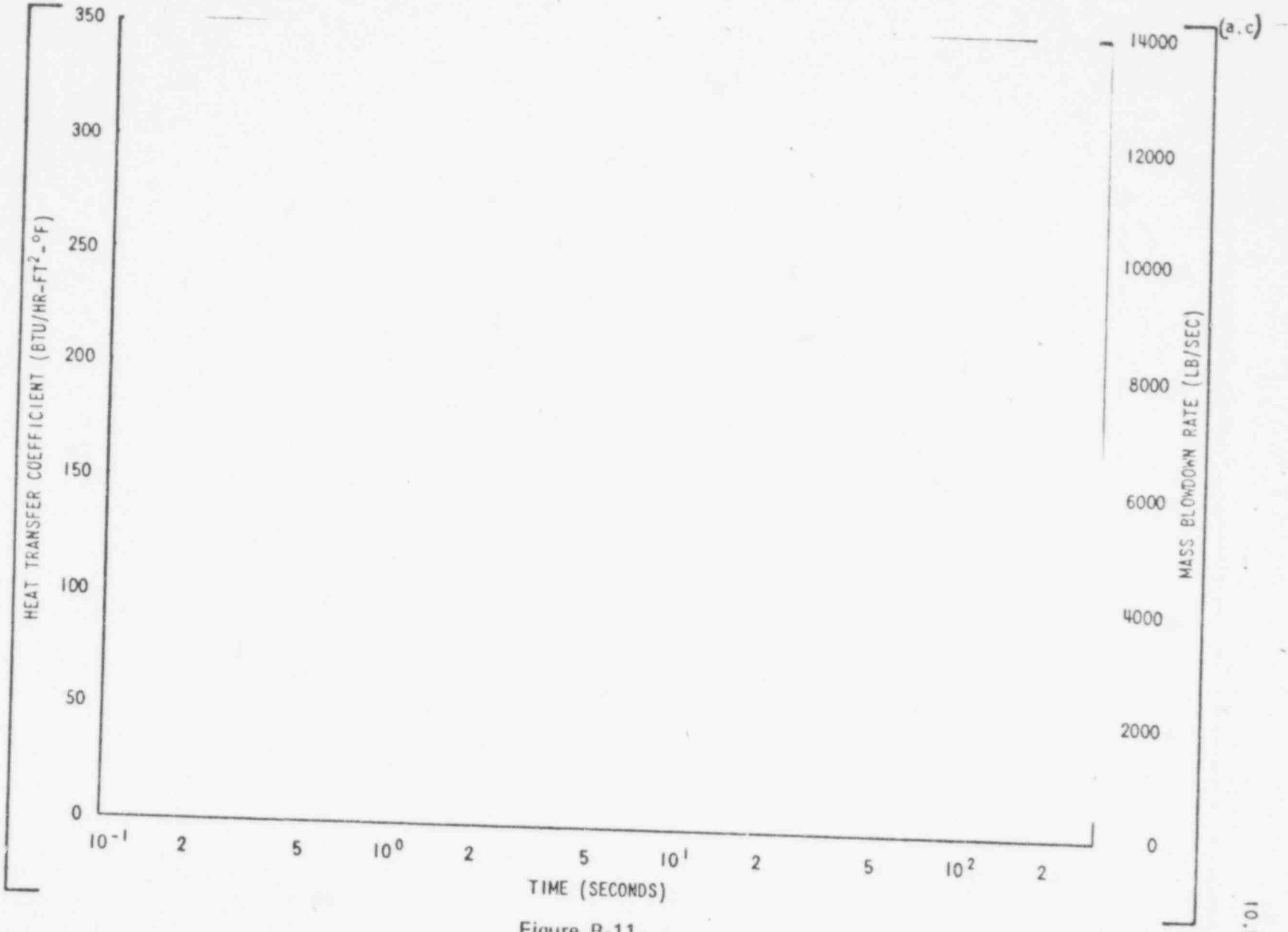

(a,c)
HEAT TRANSFER COEFFICIENT (BTU/HR-FT^2-°F)
350
300
250
200
150
100
50
0
MASS BLOWDOWN RATE (LB/SEC)
14000
12000
10000
8000
6000
4000
2000
0
10^{-1}
2
5
10^{0}
2
5
10^{1}
2
5
10^{2}
2
TIME (SECONDS)

Figure B-11.

APPENDIX C

CONTAINMENT HEAT TRANSFER COEFFICIENT CALCULATION

(a,

(a,c)

(a,c)

REFERENCES

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APPENDIX D

NRC ADDITIONAL INFORMATION

QUESTION 1

Provide and justify the assumption made for heat transfer to the ice baskets. Discuss the conservatism of these assumptions for containment analysis. Provide and justify the values assumed for the ice condenser air and water exit temperatures for the steamline break during the blowdown and post-blowdown periods.

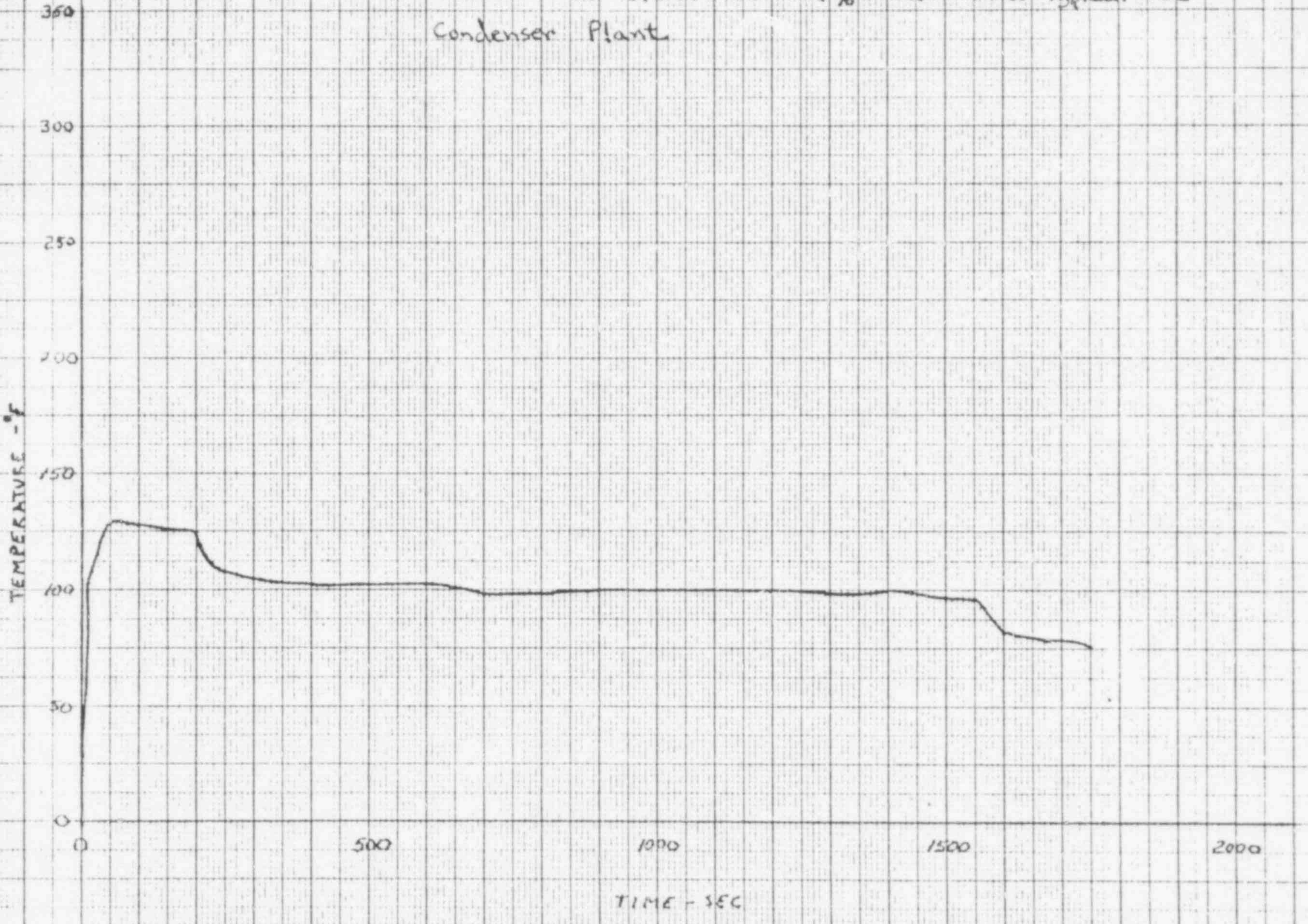
RESPONSE

Mass and energy release rates and integrals are considerably less for a steamline break than for double-ended RCS breaks. However because of the higher enthalpy of the steamline blowdown, it is probable that the maximum calculated atmospheric temperature will be set by a steamline break. The LOTIC-3 computer code was developed to analyze these secondary side accidents.

In a steamline break analysis the rate of ice melt is calculated using an ice condenser drain temperature based on the Waltz Mill test. During the Waltz Mill Test series it was found that ice condenser drain temperatures of [ ](a,b) conservatively predicted the ice melt during the blowdown and post-blowdown periods. Even though the limiting steamline break's mass and energy release rates are greater than the post-blowdown rates used at Waltz Mill, the [ ](a,b) ice condenser drain temperature will be used to calculate the rate of ice melt. Thus, LOTIC-3 calculations will conservatively overpredict the ice melt.

The steam and air exit temperatures from the ice bed help set the containment pressure during the transient. The method LOTIC-3 uses to calculate ice condenser heat transfer (exit temperatures) is basically the same as that used by TMD (WCAP-8077, with the modifications noted in WCAP-8282). The eljac used is [ ]$^{(a,b,c)}$, the same eljac as used by TMD. Since the limiting accidents are superheated, the lower compartment temperature transients are relatively insensitive to changes in containment pressure and thus to eljac. Figures 1 to 3 give ice condenser exit temperatures for three of the most severe small break accidents. (See Questions 7 and 12)

Figure 1 - Ice Condenser Exit Temperature vs. Time for Most Severe Small Break at 102% Power in a Typical Ice Condenser Plant



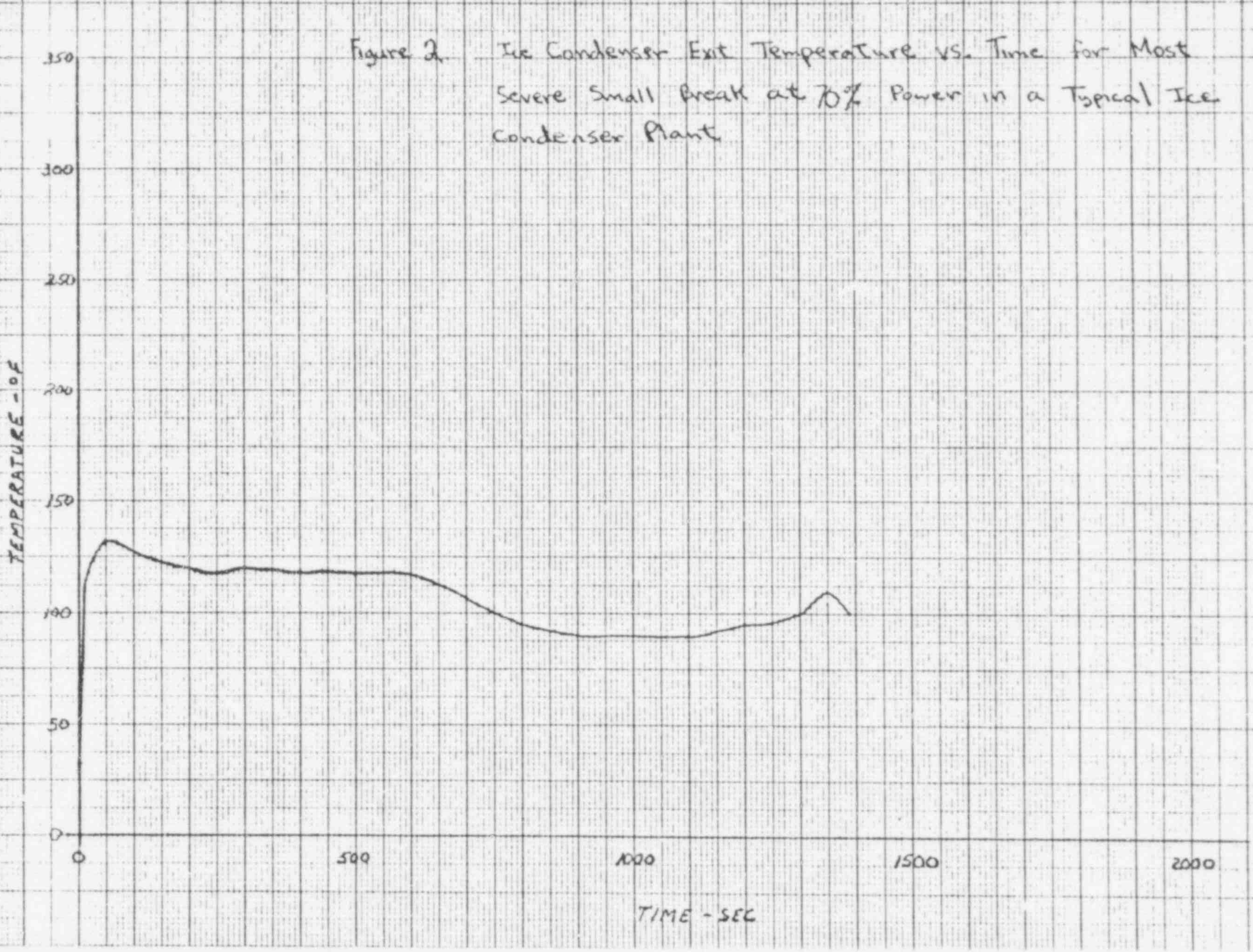
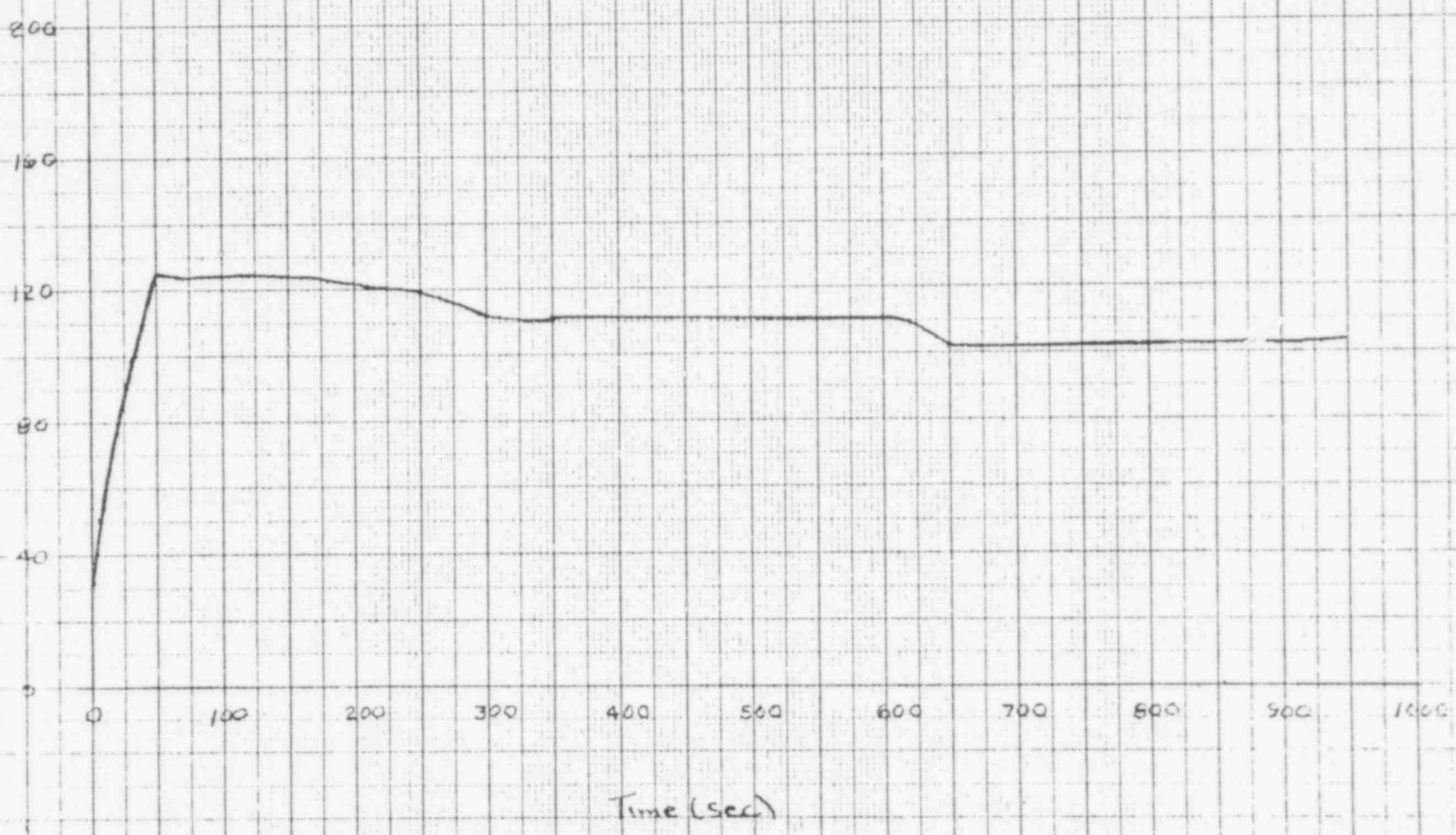


Figure 2. Ice Condenser Exit Temperature vs. Time for Most Severe Small Break at 70% Power in a Typical Ice Condenser Plant

Figure 3 Ice Condenser Exit Temperature vs. Time for Most Severe Small Break at 30% Power in a Typical Ice Condenser Plant



QUESTION 2

RESPONSE

See introduction

QUESTION 3

The energy removal and addition processes for the lower compartment and the ice condenser compartment are discussed on page 3.2-2. For analyses of steamline breaks, provide all equations and assumptions for each of the following processes. Indicate whether the quantities are added to the atmosphere or pool region. Provide this information also for primary system DBA and ECCS calculations if they are to be analyzed by LOTIC-3.

a. Rate of flow from the accumulator for water and nitrogen;
b. flow from the containment spray system;
c. heat transfer to the sump;
d. ice condenser drain flow;
e. condensate from the atmosphere;
f. energy associated with ice melt; and,
g. rate of heat transfer to the ice.

RESPONSE

In the energy removal and addition processes in a steamline break analysis with the LOTIC3 computer code, the following equations and assumptions are applicable:

a. The rate of flow from the accumulator for water and nitrogen is zero.

b. The flow from the containment spray system is mixed with the atmosphere and allowed to come to thermal equilibrium. Therefore, the rate of energy addition is $\dot{m}_{sp} \, h_{sp}$.

c. The heat transfer to the sump is zero.

d. The heat removal by the ice condenser drain flow is zero.

e. The rate of energy removal associated with the loss of condensate from the lower compartment atmosphere is $\dot{m}_c\, h_c$ (where $h_c = h_f = f(P_s)$), this is taken from the atmosphere and added into the sump.

For the ice condenser compartment, in the energy removal and addition processes during a LOTIC-3 analysis of a steamline break,

a. The rate of heat transfer to ice is simply,

$$\int_0^{A_{ice}} (H\Delta T)dA \quad \text{(See Response to Question 1)}$$

b. The energy rate associated with ice melt and steam condensate falling from the atmosphere is $(\dot{m}_{ice\ melt}\, h_{ice\ melt} + \dot{m}_c\, h_c)$; where $h_c = f(P_s)$.

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QUESTION 4

Page 3.2-5 states that suspended condensate is assumed to be subcooled at the compartment temperature and total pressure. We believe that a more appropriate assumption would be to assume the condensate is saturated at the partial pressure of steam in the containment. Discuss the conservatism of your assumption for containment analysis.

RESPONSE

Although the analysis is insensitive to this assumption, the LOTIC3 computer code has been modified such that condensate is now assumed to be saturated at the partial pressure of steam in the containment.

QUESTION 5 RESPONSE

See introduction

QUESTION 6

Provide and justify the assumptions made for heat flow to containment heat sink structures below the liquid surface in the sump, and the heat transfer from the atmosphere to the sump water. These are discussed on page 3.2-6.

RESPONSE

Even though the LOTIC3 computer code has the capability to include heat transfer to the containment sump, from the lower compartment atmosphere, in the LOTIC3 analysis of a steamline break this option is not used and no credit is taken for this heat removal mechanism.

The water of the sump in an ice condenser plant covers some structural heat sinks. Provision is made for heat transfer from the sump to these structures using the average temperature of the sump and the outermost wall temperature as the driving force. This mechanism is the only one which transfers heat to these structures. A contact heat transfer coefficient of 200 Btu/Hr-ft^2-°F is normally used in this analysis. However, the magnitude of the heat transfer coefficient does not impact on the analysis. Using heat transfer coefficients of 2, 200, or 2000 Btu/Hr-ft^2-°F would not change the containment temperature and pressure transients following a steamline break, since as mentioned previously no heat transfer is permitted between the lower compartment atmosphere and the sump.

QUESTION 7

Section 2.0 states that the LOTIC-3 assumes that all liquid condensed on the structural heat sinks is assumed to be instantaneously remixed with the containment atmosphere. This model artificially suppresses the amount of atmospheric superheat. As discussed in our Topical Report Evaluation in our letter dated January 29, 1976, we concluded that this assumption is unacceptable for analysis of steamline breaks. We believe that the major portion of the condensate will flow down the containment walls and internal structures into the sump without mixing with the containment atmosphere. The assumption of complete condensate removal is conservative for these calculations. Revise the LOTIC-3 code to include a conservative model for removal of condensed liquid from the containment atmosphere.

RESPONSE

7.1 MODEL DESCRIPITON

The LOTIC-3 computer code will be used to analyze large and small steamline breaks at various power levels. Small steamline breaks are defined as those which are sufficiently small such that an isolation and a trip signal from the high steam flow/low steamline pressure protection system is not generated, nor is this break large enough to result in liquid entrainment in the blowdown. Tables 12-1 to 12-3 (Question 12) give the mass and energy releases for these breaks at power levels of 102%, 70%, and 30% power for a typical 4 loop ice condenser plant. Even though it has been shown using the CVTR test data that condensate revaporization occurs under superheat steam environment, the LOTIC-3 computer code has been modified to include the assumption that no re-evaporation of the condensate occurs in the analysis of these most severe small breaks.

A model is described (in the following Section 7.2) which includes the effect of convective heat transfer from the containment vapor to the containment structures, this model has been incorporated into the LOTIC-3 computer code and is used in the analysis of small steamline breaks. (This is the same model which has been reported in WCAP-8936, ref. 1.)

For large steamline breaks inside of an ice containment the model previously presented in ref. 2 will be used. In large steamline breaks entrainment carryover is expected during the blowdown, and the high degree of turbulence makes revaporization of the condensate a realistic assumption. Verification of the condensation model has been provided in our previous LOTIC-3 submittal (ref. 2), in the form of a comparison with the CVTR test data. As this submittal has shown the LOTIC-3 condensation model conservatively predicted the CVTR test data, even when the steel structural heat sinks were increased by 60%. Another consideration when comparing the CVTR tests to the ice condenser plant is that turbulence even for small breaks as measured by the parameter[

], is considerably lower in the CVTR tests than in the lower compartment of an ice condenser plant during the early transients.

a,c

SUMMARIZING

1) The LOTIC-3 computer code has been modified to include the assumption that no re-evaporation of the condensate occurs for small steamline breaks. A model described in Section 7.2 which includes the effect of convective heat transfer from the containment vapor to the containment structures is used for small breaks.

2) For large breaks, liquid entrainment is expected and the condensate revaporization model is appropriate for use. Verification of this condensation model is based on the CVTR test comparison previously submitted (ref. 2).

7.2 CONVECTIVE HEAT TRANSFER ANALYSIS*

When a condensable vapor is in contact with a surface at a temperature below the saturation temperature of the vapor, condensation occurs. The rate of condensation has been found to be strongly affected by the presence of non-condensable gas (ref. 3 & 4) and the flow of the vapor steam (ref. 5 & 6). The problem of forced convection condensation in the presence of non-condensables and interfacial resistance has been solved analytically by Sparrow et.al. (ref. 7), under the assumption that the convective heat flux from the vapor-gas mixture is negligibly small compared with the contribution

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*See also Section 2.1 of Ref. 2

of the latent heat. This is generally the case in the evaluation of overall heat transfer. However, in the analysis of a containment transient condition under a superheated steam blowdown, the containment temperature is very sensitive to the amount of steam mass in the containment atmosphere. The convective heat flux, though only a few percent of the overall heat flux, can change the steam mass in the containment atmosphere and thus affect the containment temperature substantially. It should, therefore, be considered.

The physical model includes a liquid film adjacent to a cold surface, a velocity boundary layer due to mass diffusion, and a mixture temperature boundary layer due to heat diffusion. Mathematically, this requires the use of conservation equations of continuity, momentum, and energy for the liquid film and the gas mixture. These equations and their derivations have been clearly presented in reference 7. For the inclusion of the convective heat flux, the energy equation for the gas mixture is required and may be written as

$$\rho_m C_{p_m} \left(U_m \frac{\partial T_m}{\partial x} + V_m \frac{\partial T_m}{\partial y} \right) = k_m \frac{\partial^2 T_m}{\partial y^2} \tag{1}$$

where subscript m is used to designate the steam-air mixture.

The exact solution of this probelm requires that the boundary conditions as contained in reference 7 be solved in conjunction with the interface condition

$$\dot{m} h_{fg} + k_m \frac{\partial T_m}{\partial y} = k_L \frac{\partial T_L}{\partial y} \tag{2}$$

where subscript L denotes condensate.

(a,c,)

(3)

(4)

(a,c)

(a,c)

(6)

(7)

(8)

Finally, we note that the thermal properties for the condensate are evaluated at a reference temperature $T_R = T_W + .31\ (T_i - T_w)$ based on Reference 3. For the mixture, the film temperature $T_m = \frac{1}{2}\ (T_i + T\ )$ is used, and the following formulas are used to calculate the mixture properties (Reference 9).

$$\mu_m = \sum_{i=1}^{2} \frac{x_i \mu_i}{\sum_{j=1}^{2} x_i \phi_{ij}}$$

$$k_m = \sum_{i=1}^{2} \frac{x_i k_i}{\sum_{j=1}^{2} x_j \phi_{ij}}$$

$$\phi_{ij} = \frac{1}{8} \left(1 + \frac{M_i}{M_j}\right)^{-1/2} \left[1 + \left(\frac{\mu_i}{\mu_j}\right)^{1/2} \left(\frac{M_j}{M_i}\right)^{1/4} \right]^2$$

where

x_i = mole fraction of component i

μ_i = dynamic viscosity of component i

k_i = thermal conductivity of component i

M_i = molecular weight of component i

QUESTION 8

Discuss and justify the assumptions made for atmospheric cooling by the spray system when the atmosphere is superheated.

RESPONSE

The lower compartment is the only location in an ice condenser plant which becomes superheated to any extent. This compartment's air concentration is very low, and because of its relatively small volume it is very turbulent. Therefore, it is assumed that the spray flowrate mixes with the atmosphere and comes to equilibrium.

QUESTION 9

Provide a comparison of the steam and water properties used in the LOTIC-3 code with the 1967 ASME steam tables. Discuss the accuracy of the LOTIC-3 code in predicting containment pressure and temperatures relative to the ASME tables for saturated and superheated conditions.

RESPONSE

A comparison was made between the steam and water properties used in the LOTIC-3 computer code and those of the 1967 ASME tables. The temperature range investigated was [ ]$^{(a,c)}$ and the pressure range investigated was 0.12 psia to 30 psia. These are the ranges of interest to an ice condenser containment. Subcooled liquid, saturated vapor and liquid, and superheated vapor properties from LOTIC-3 were compared to those of the 1967 ASME steam tables. The maximum difference found was 0.01%. Therefore, relative to the 1967 ASME tables, the accuracy of the LOTIC-3 computer code is essentially identical.

QUESTION 10

The Westinghouse condensing heat transfer model discussed in Appendix C appears to be applicable only for blowdowns that are constant with time. Discuss how the model would be applied to a variable blowdown rate.

<u>RESPONSE</u>

The heat transfer model described in Appendix C was developed to illustrate the conservatism of the Tagami correlation. This model was not developed for use in the design calculations of the containment responses to steamline breaks. It is applicable for both variable and constant blowdown rates. Perhaps further discussion will clarify this point. The heat transfer correlation was developed based upon the following rationale:

(a,c)

906345

a,c

a,c

This is the completed correlation and is independent of the end of blowdown time and can be integrated for different blowdown rates.

QUESTION 11

See response to Question 2.

QUESTION 12

Discuss the conservatism of the Tagami condensing heat transfer data for a steamline break within an ice condenser containment. We believe that the correlation of Uchida would be conservative for this application. Provide a comparison of the heat transfer coefficient predicted by the two correlations for the lower compartment of a typical ice condenser containment.

a. Justify use of the time of peak pressure (t_p) in Equation 4.3 for the lower compartment and ice condenser compartments. This time corresponded to the end of blowdown in the Tagami experiments. Compare this time with the time of peak energy in the lower compartment and peak energy in the ice compartments.

b. Justify calculation of the energy per unit volume in the Tagami correlation for the lower compartment and the ice condenser compartments. You indicate that the calculation is based on the steam and water contents of the blowdown. Since a large fraction of steam will be exited from the lower compartment and condensed in the ice condenser, a more appropriate assumption would be to base this ratio on the conditions which exist in each compartment.

RESPONSE

Tables 12.1 to 12.3 give the mass and energy releases which correspond to the most severe small breaks identified in the answer to question 7. These break sizes will produce the most severe atmospheric temperature conditions, since no credit is taken for condensate revaporization for these break sizes (This is described in the answer to question 7). Using the containment data given in Table 12.4 and these mass and energy releases, the containment temperature transients have been calculated using the current version of the LOTIC3 computer code. The results are shown in Figures 12.1 to 12.3. As these results show the 70% power case generates a slightly more severe temperature transient than the other two. Using this most severe case as a base the LOTIC3 Tagami and the Uchida heat transfer coefficients were compared. The results are illustrated in Figure 12.4. This figure illustrates the conservatism of the LOTIC3 Tegami correlation.

QUESTION 12 a

The peak energy in the lower compartment of an ice condenser plant corresponds to the time of peak temperature, pressure and turbulence. The turbulence is affected by the blowdown rate. [ ](a

The ice condenser structural heat transfer coefficients are based on stagnant Tagami, and therefore do not use t_p.

QUESTION 12 b

[

s

t

-

]^{6,c}

TABLE 12.1

MOST SEVERE SMALL BREAK AT 102% POWER

Time (sec)	$\dot{m}$ (lb/sec)	$\dot{e}$ (BTU/sec)

(a,c)

TABLE 12-2

MOST SEVERE SMALL BREAK AT 70% POWER

Time (sec)	$\dot{m}$ (lb/sec)	$\dot{e}$ (BTU/sec)

(a,c)

TABLE 12.3

MOST SEVERE SMALL BREAK AT 30% POWER

Time (Sec)	$\dot{m}$ (lb/sec)	$\dot{e}$ (BTU/sec)

(a,c)

TABLE 12.4

1. VOLUME

Plant P Ice Condenser Design Parameters

Reactor Containment Volume (Net free volume, ft^3)	
Upper Compartment	670,101
Upper Plenum	47,000
Ice Condenser	86,300
Lower Plenum	24,200
Lower Compartment (Active)	235,481
Lower Compartment (Dead Ended)	130,899
Total Containment Volume	1,193,971
[illegible]	[illegible]
Tech Spec Weight of Ice in Condenser, lbs.	2.45×10^6

2. STRUCTURAL HEAT SINKS

	Area (ft^2)	Material and Thickness (ft)	
A. Upper Compartment			
1. Polar Crane Wall, Containment Shell, and Miscellaneous Steel			
Slab 1	8915	0.000583	Paint
		0.01017	Carbon Steel
Slab 2	31667	0.000583	Paint
		0.05758	Carbon Steel
Slab 3	720	0.00167	Paint
		0.1670	Carbon Steel
2. Refueling Canal and Miscellaneous Concrete			
Slab 4	25443	0.00167	Paint
		1.511	Concrete
Slab 5	680	0.00167	Paint
		4.82	Concrete

STRUCTURAL HEAT SINKS

	Area (ft^2)	Material and Thickness (ft)	
B. Lower Compartment			
1. Platforms			
Slab 1	1,375	0.000583	Paint
		0.007813	Carbon Steel
2. Steam Generator Supports and Reactor Coolant Pump Supports			
Slab 2	2,580	0.00583	Paint
		0.0605	Concrete
3. Miscellaneous Concrete			
Slab 3	23,300	0.00167	Paint
		1.645	Concrete
4. Reactor Cavity			
Slab 4	2,370	0.00167	Paint
		4.0	Concrete

5. Base Floor			
Slab 5*	4,228	0.00167	Paint
		2.0	Concrete
C. Ice Condenser			
1. Ice Baskets			
Slab 1	180,628	0.00663	Steel
2. Lattice Frames			
Slab 2	76,650	0.0217	Steel
3. Lower Support Structure			
Slab 3	28,670	0.0267	Steel
4. Ice Condenser Floor			
Slab 4	3,336	0.000833	Paint
		0.333	Concrete
5. Containment Wall Panels and Containment Shell			
Slab 5	19,100	1.0	Steel & Insulation
		0.0625	Steel Shell
6. Crane Wall Panels and Crane Wall			
Slab 6	13,055	1.0	Steel & Insulation
		1.0	Concrete

* In contact with sump.

3. Initial Conditions

A. Pressure	15.0 psia
B. Temperatures	
Upper Comp	100°F
Lower Comp.	120°F
Ice Bed	32°F

4. Containment Spray

A. Lower Comp. Spray Flow Rate	0
B. Upper Comp. Spray Flow Rate	3400 gpm
C. Initiation Time	50 sec.

Figure 12.1 Containment Temperature vs. Time for Break at 102% Power

(a,c)

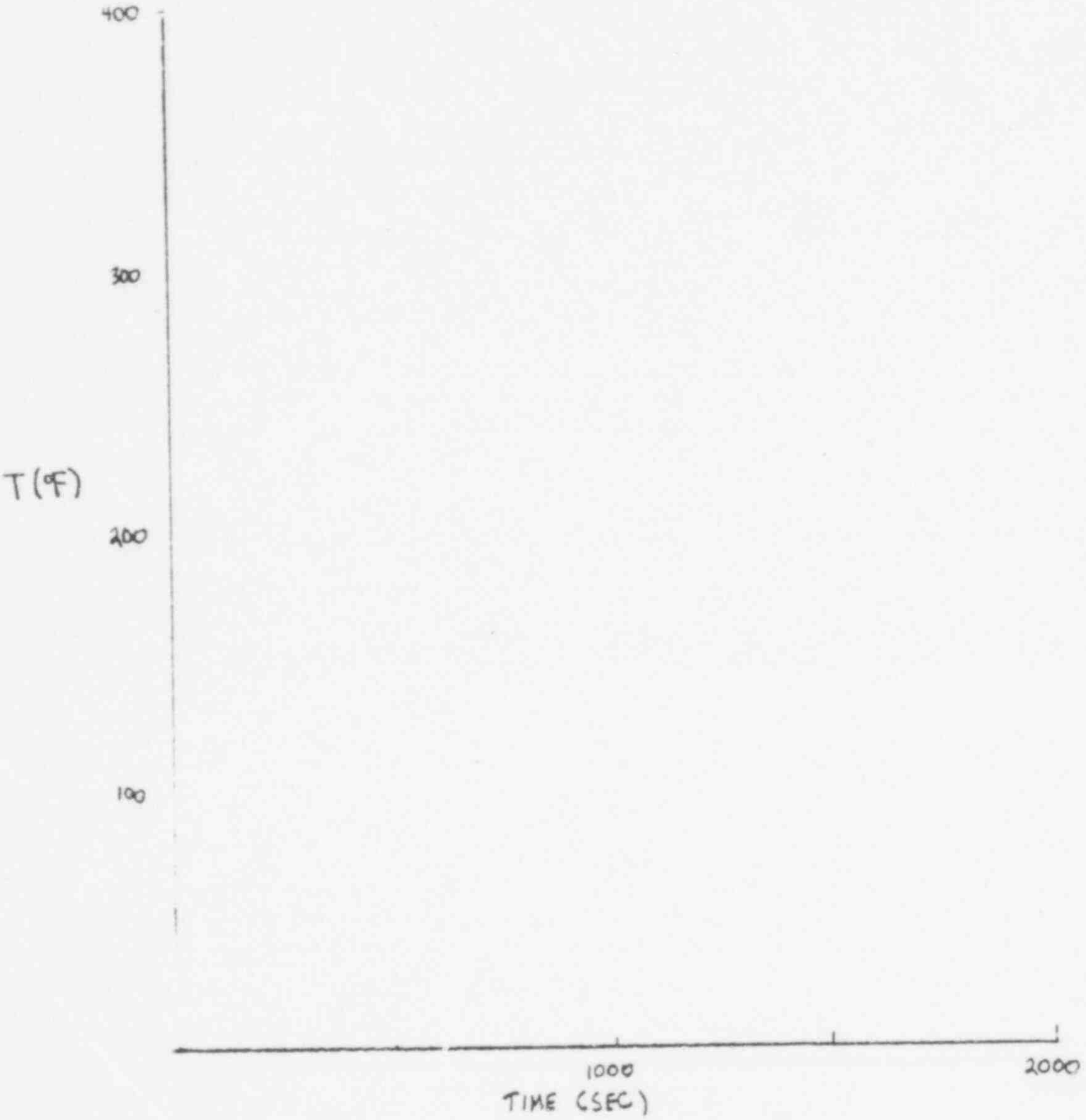

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Figure 12.2 Containment Temperature vs. Time for Break at 70% Power

(a,c)

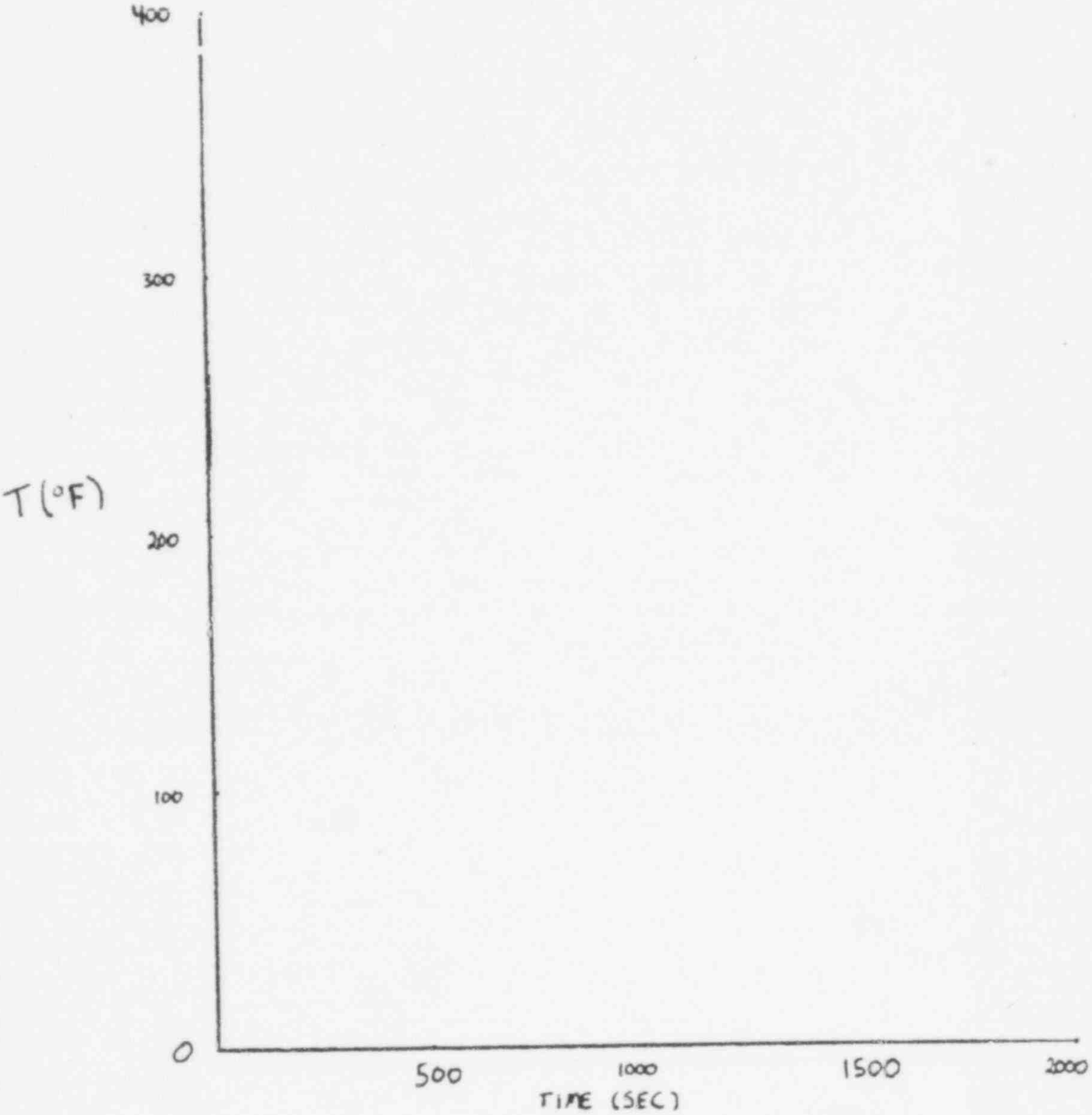
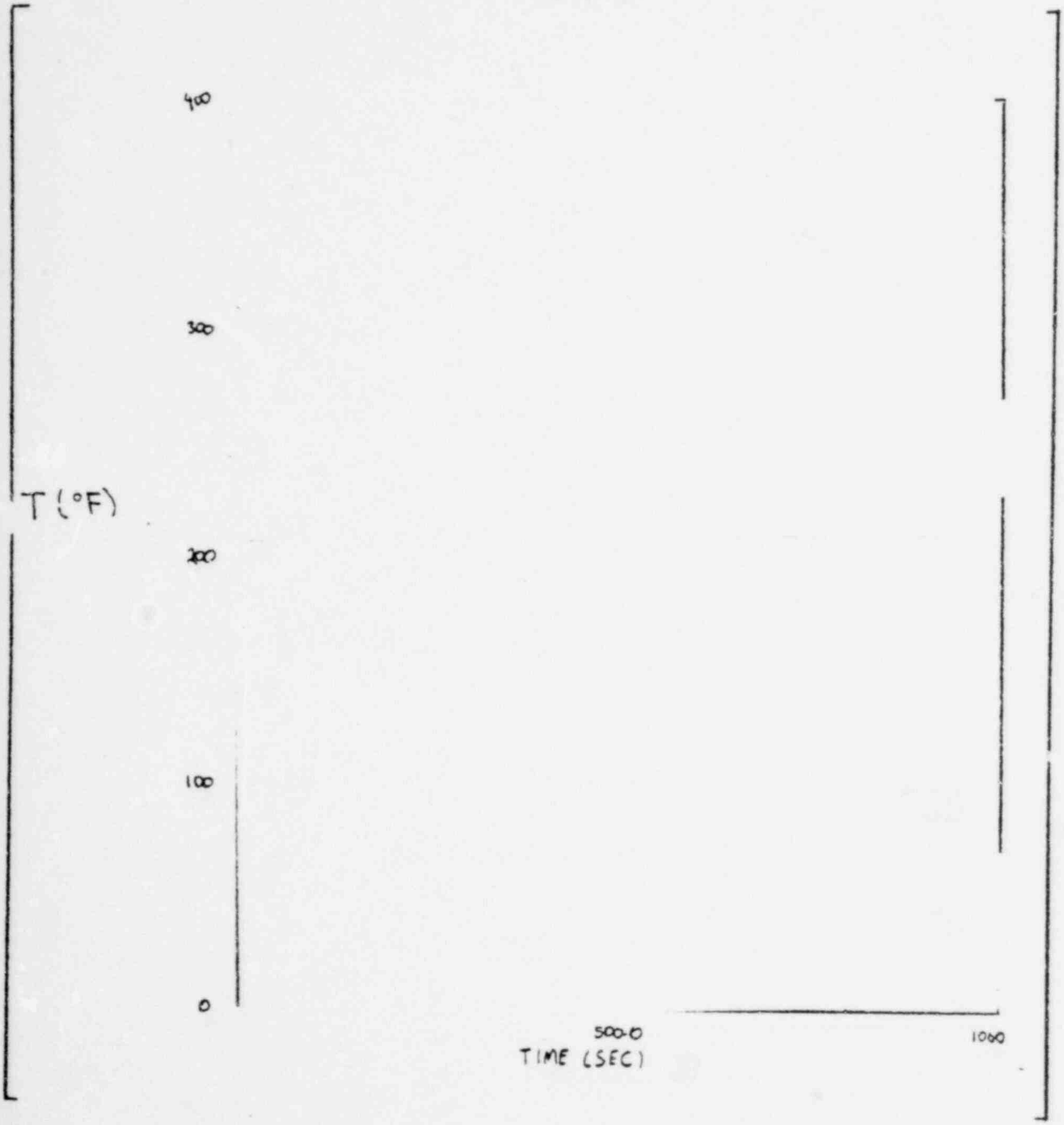


Figure 12.3 Containment Temperature vs. Time for Break at 30% Power



(a,c)

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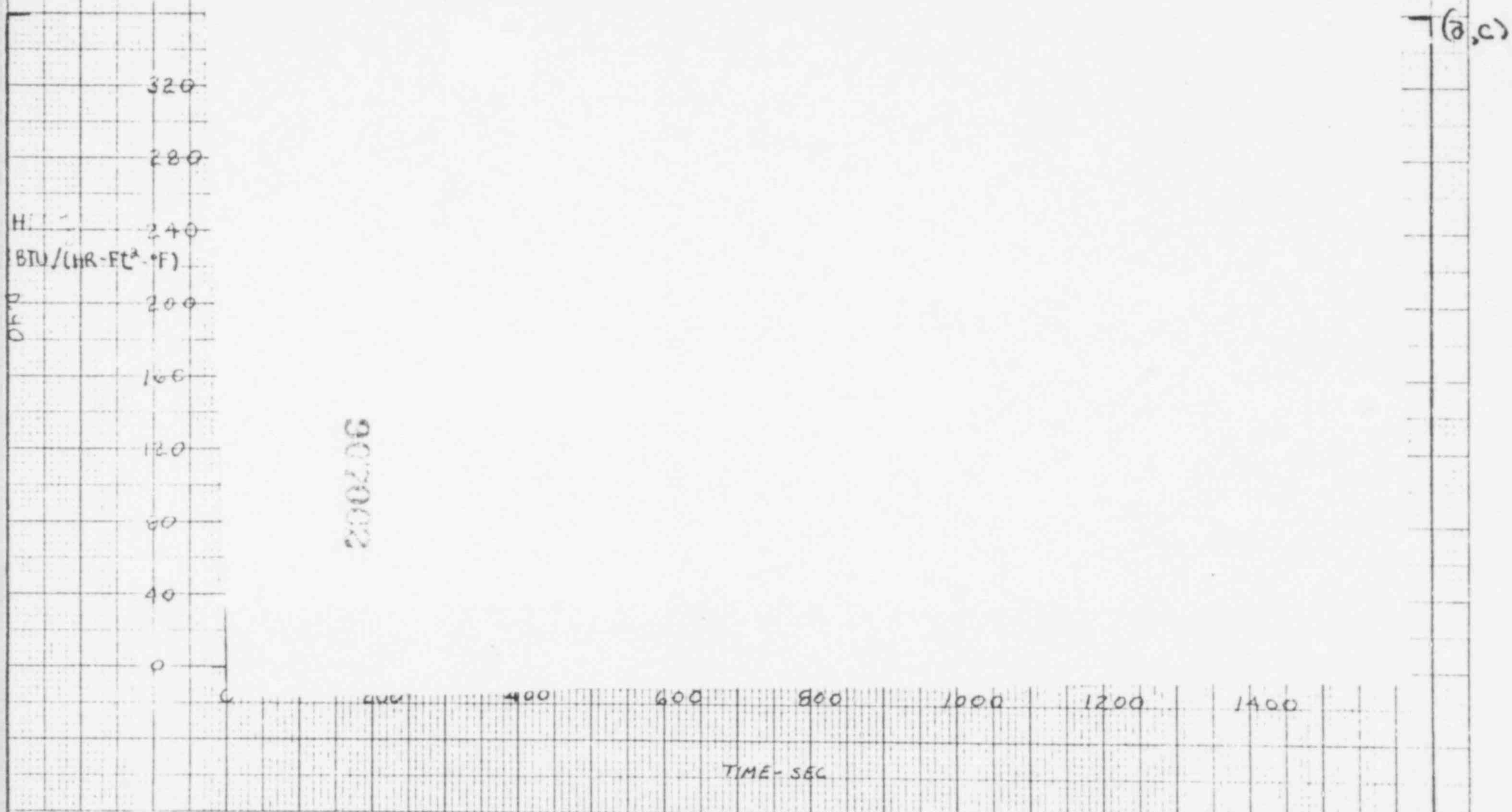
Figure 12.4 Comparision Between LOTIC3 Tagami and NRC Uchida Heat Transer Coefficients



QUESTION

A conservative assumption for mass transfer to structural heat sinks is that all heat transfer results in a corresponding amount of mass transfer in the form of condensed liquid. The amount of mass transfer is determined from the heat transfer divided by the change in enthalpy between the vapor and the condensed liquid.

When the containment atmosphere is superheated, the LOTIC-3 code assumes no mass transfer for double-ended steam line breaks and partial mass transfer for small steam line breaks.

These condensation models are also being reviewed for use in the COCO code to establish the maximum containment temperature for instrument qualification analysis for containments without ice condensers and are described in WCAP-8936. Although the mass transfer assumptions have a significant effect for containments without ice condensers, we understand that use of less than full condensation may have an insignificant effect on ice condenser analysis. To evaluate the significance of the condensation models, provide the following sensitivity studies.

a.) For a double-ended steam line break at hot standby for which no liquid entrainment is assumed, provide the containment temperature for a typical ice condenser plant assuming:

    1.) full condensation on the structural heat sinks with no revaporization, and

    2.) with no mass condensation.

b.) For a small steam line break at 70% power for which no liquid entrainment from the break is calculated, provide the containment temperature for a typical ice condenser plant assuming:

    1.) all heat transter to the structural heat sinks produces condensation with no revaporization, and

    2.) the method discusssd in Section 7.2 for fractional condensation is utilized.

Response

Four calculations were performed with the latest version of the LOTIC-3 computer code. The containment data used in this analysis were taken from Reference 1. Two separate sets of mass and energy release rates were used. The first, the large break, was a double-ended steamline break at hot standby with no liquid entrainment, the second was the most severe small break at [70%] power (see Reference 1). For each set of mass and energy release data, parameter studies were performed by varying the structural heat removal condensation assumptions. The small break studies analyzed two cases, one with all structural heat removal producing condensation with no revaporization, and the other utilizing the convective heat transfer calculation discussed in Reference 1. The results from these small break calculations were essentially identical. This temperature transient is shown in Figure 1. Two large break calculations were also performed; the first with full condensation due to structural heat removal and no revaporization, and the other with no condensation (when the containment steam is superheated). These results are shown in Figure 2. As this figure shows, there is a significant difference between these two cases. However, the small break transient is still more severe than the large break transient with complete condensation. This is illustrated in Figure 3. References 1 and 2 present studies which show that complete condensation does not occur for large breaks when the containment is superheated.

a,c

References

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2. C. Eicheldinger, Letter of 10/22/76, Letter #NS-CE-1250
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(a, c)

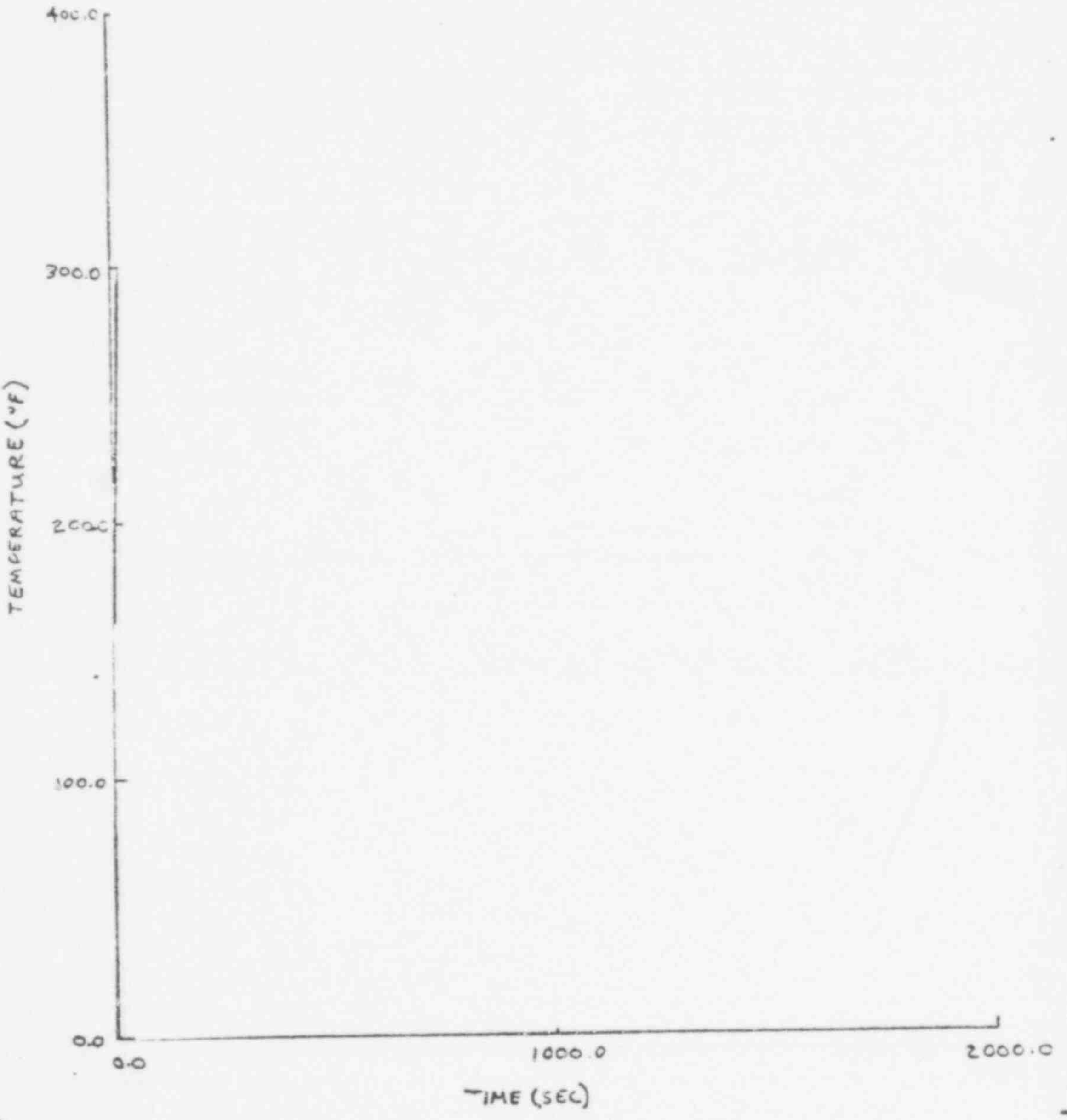

Figure 1 Small Break Condensation Parameter Study

(a,c)

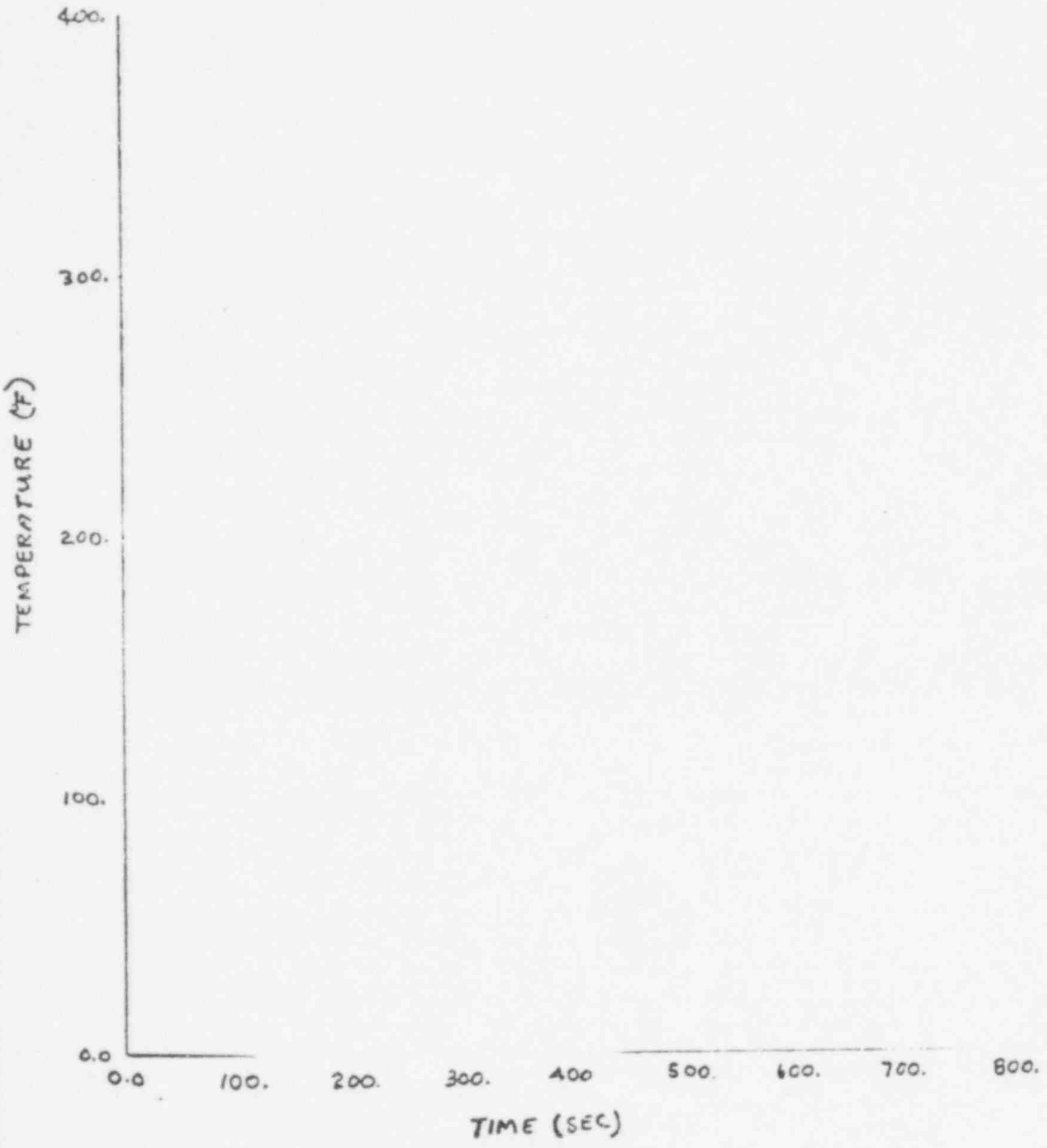

Figure 2 Large Break Condensation Parameter Study

(a,c)

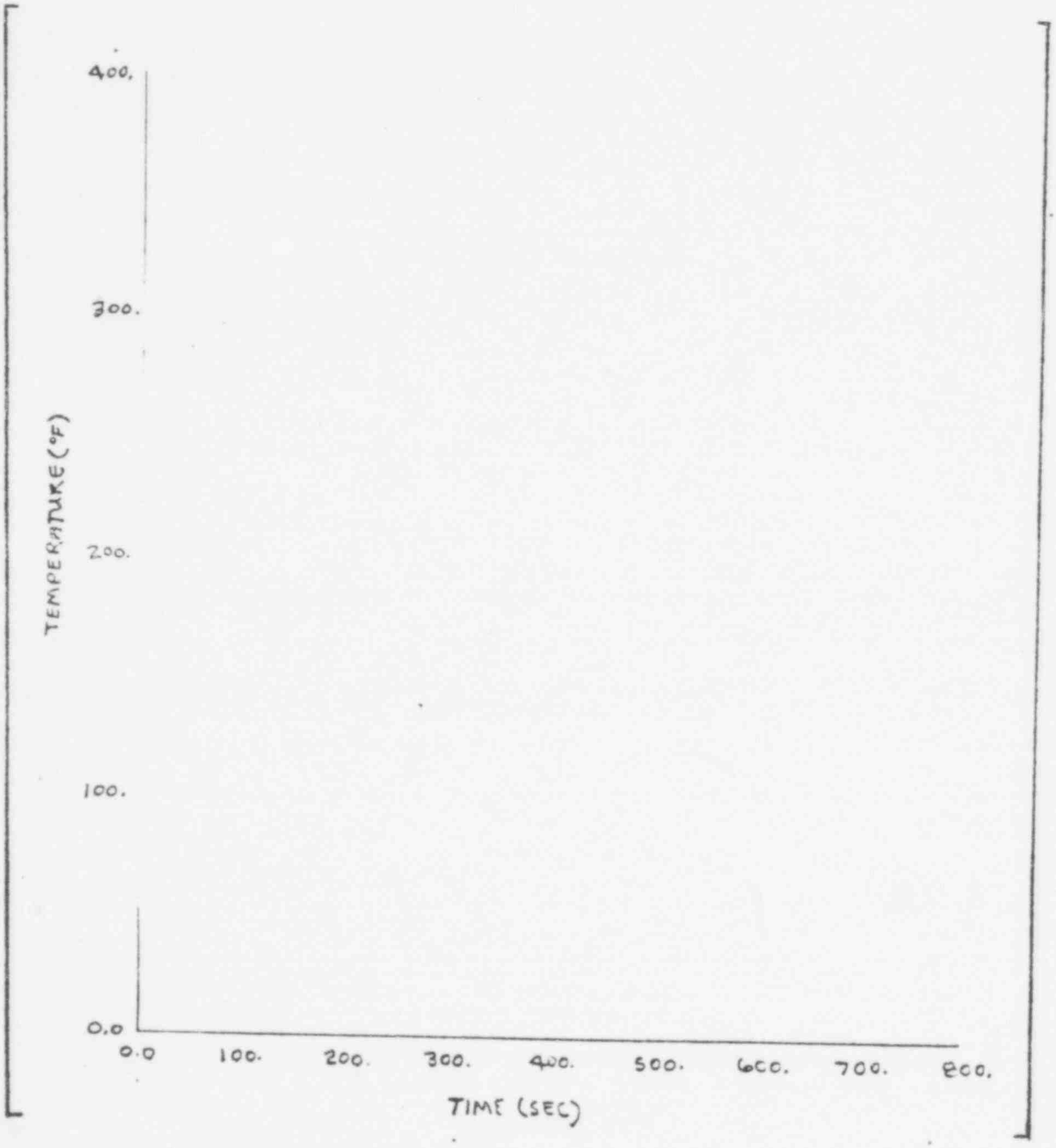

Figure 3 Small and Large Breaks with Complete Condensation

APPENDIX D

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NOMENCLATURE

SYMBOL	DESCRIPTION
A	Matrix, defined in Eq. (A.33).
A_{jk}	Flow area between compartments j and k.
C_p	Specific heat.
E	Total coolant energy transferred into containment.
g_c	Conversion Constant, 3262 ft-lb m/lb_f-sec^2.
h	Enthalpy.
H_s	Structure heat transfer coefficient for steel
H_{stag}	Stagnation heat transfer coefficient as defined in Eq. (4.4).
H_{max}	Maximum Tagami heat transfer coefficient.
$\vec{I}$	Column vector, defined in Eq. (A.33).
J	Conversion constant, 778 ft-lb_f/Btu.
K	Flow resistance factor.
m	Mass flow rate.
M	Mass.

SYMBOL	DESCRIPTION
P	Pressure.
q	Heat transfer rate.
$\vec{R}$	Column vector, defined in (A.33).
R_a	Gas constant for air.
t	Time.
T	Temperature.
t_p	Time from start of accident to peak containment pressure.
ν	Specific volume.
V	Volume.
V_{max}	Total active sump volume
α	Percentage change of certain selected parameter allowable for each time step.
η	Efficiency, defined in Eq. (4.6)
χ	Steam to air weight ratio
ρ	Density.
θ	Absolute temperature conversion constant, 459.7.

SUBSCRIPT	DESCRIPTION
a	Air.
as	Air and steam.
c	Suspended or entrained water.
dl	Deck leakage.
drn	Drain water.
e	Energy.
i	i-th compartment.
ice	Ice.
ij	from i-th compartment to j-th compartment.
j	j-th compartment.
L.C.	Lower compartment.
N	New.
O	Old.
Overflow	Water overflow through the ice condenser inlet doors.
s	Steam
Spill	Spilled Water.

SUBSCRIPT	DESCRIPTION
sump	Lower compartment sump water.
sump 1	Active sump.
sump 2	Inactive sump.
W	Water.
1	Upper compartment.
2	Lower compartment.
3	Ice condenser.
5	Dead-ended compartment.

SUBSCRIPT

A dot over a symbol, such as $\dot{P}$, means differentiation by time, $\dot{P} = \frac{dP}{dt}$