XN-CC-39(A)

REV. 1

ICECON: A COMPUTER PROGRAM USED TO CALCULATE CONTAINMENT BACK PRESSURE FOR LOCA ANALYSIS (INCLUDING ICE CONDENSER PLANTS)

SEPTEMBER 1978

RICHLAND, WA 99352

EXXON NUCLEAR COMPANY, Inc.

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Revision 1

ICECON: A COMPUTER PROGRAM USED TO CALCULATE CONTAINMENT BACK PRESSURE FOR LOCA ANALYSIS (INCLUDING ICE CONDENSER PLANTS)

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

JUNE 3 0 1978

Exxon Nuclear Company
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Gentlemen:

The Nuclear Regulatory Commission staff has completed its review of the Exxon Nuclear Company Topical Report XN-CC-39, dated August 1976, entitled, "Icecon: A Computer Program to Calculate Containment Back Pressure for LOCA Analysis (Including Ice Condenser Plants)". We concluded that Topical Report XN-CC-39 is acceptable for reference in application for construction permits, operating licenses, and operating license amendment for reload fuels. A copy of our evaluation is enclosed.

The staff does not intend to repeat its review of Topical Report XN-CC-39 when it appears as a reference in particular license applications. Should NRC criteria or regulations change, such that our conclusions concerning the Topical Report are invalidated, you will be notified and given the opportunity to revise and resubmit your Topical Report for review should you so desire.

As you know, the review of Topical Report XN-76-36, entitled, "Exxon Nuclear Company WREM-Based Generic PWR ECCS Evaluation Model (ENC-WREM-II); 4-Loop PWR With Ice Condenser Large Break Example Problem" has been in hold pending acceptance of XN-CC-39. Please submit a revised Topical Report XN-76-36 incorporating XN-CC-39 for staff review and approval.

We also request that you reissue Topical Report XN-CC-39 in accordance with the provisions of the "Nuclear Regulatory Commission Topical Report Program". If you have any questions, please contact John Hannon at (301) 492-7872.

Sincerely,

Thomas A. Ippolito, Chief
Operating Reactors Branch #3
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Enclosure:
Exxon Topical Report
Evaluation

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TOPICAL REPORT EVALUATION

Report No.: XN-CC-39
Report Date: November 1977
Report Title: ICECON: A Computer Program Used to Calculate Containment Back Pressure for LOCA Analysis (Including Ice Condenser Plants).
Originating Organization: Exxon Nuclear Company
Reviewed By: Analysis Branch, Office of Nuclear Reactor Regulation

Summary of Topical Reports

The ICECON computer code is a modified version of the CONTEMPT-LT MOD 22 computer code (Ref. 1). Modifications for standard containment types are discussed in Ref. 2. ICECON is designed to provide minimum containment pressure for ECCS analysis for ice condenser containments in fulfillment of the requirements of Appendix K to 10 CFR 50 of the Commission Regulations.

CONTEMPT-LT MOD 22 has been used by Exxon for the ECCS evaluation of reactors with standard containment types. The NRC staff reviewed the Exxon ECCS evaluation model and published a Safety Evaluation dated September 11, 1975. We concluded that Exxon's containment pressure model for dry containments was acceptable for ECCS evaluation. ICECON is the extension of this model for the analysis of plants with ice condenser containments.

The ICECON computer program provides 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 will be maintained until the ice is completely melted at about one hour following the accident.

The pressure is also reduced by the action of the containment sprays and structural heat sinks which provide for additional steam condensation.

Mass and energy releases from the break are an input to ICECON and are not discussed in XN-CC-39, but will be supplied from the appropriate ECCS evaluation model.

Summary of Regulatory Evaluation

Appendix K requires that the effect of operation of all containment installed pressure reducing systems and processes be included in ECCS evaluations. For the purposes of ECCS evaluation, it is conservative to minimize the containment pressure which increases the resistance to steam flow in the reactor loops and reduces the reflood rate in the core.

The principle mechanism for reducing the containment pressure in an ice condenser containment is the action of the ice in condensing steam. ICECON maximizes the effect of the ice condenser and minimizes the containment pressure by selection of a low ice condenser exit temperature during the blowdown period when the lower compartment air is forced through the ice chest into the upper compartment. This temperature (130°F) is lower than

measured at the Westinghouse Walz Mill Test Facility and reduces the containment pressure by minimizing the partial pressure of the air.

The ice condenser drain water from the melted ice is assumed to mix completely with the steam in the lower compartment which minimizes the partial pressure of steam in that compartment.

Spillage of ECCS water including the spillage from the broken loop accumulator is also assumed to mix completely with the steam in the lower compartment. The effect of containment sprays in condensing steam will be maximized by assuming they are 100% efficient.

The containment structural heat sinks have a small effect on the containment pressure by condensing steam before it reaches the ice chest. Exxon will maximize the effect of structural heat sinks by using the heat transfer coefficients recommended by NRC Branch Technical Position CSB 6-1.

The area and heat capacities of the structural heat sinks may vary between plants and we require that justification be provided for the values used in the analysis with each plant submittal.

Exxon made a calculation for a typical ice condenser plant using the above assumptions. Following the initial blowdown, a containment pressure of about 3 psig was calculated. A similar calculation was also performed by the staff using an advanced containment code, CONTEMPT-4. The CONTEMPT-4 results compared favorably with those obtained using ICECON.

<u>Regulatory Position</u>

We conclude that the ICECON code is an acceptable method for calculation

of containment pressures for ECCS analysis and that XN-CC-39 is an acceptable reference. We require, however, that the mass and energy release data supplied to the code be calculated using a model approved for ECCS evaluation and that this information be supplied with each application. We also require that plant dependent information such as containment structural heat sinks, compartment volumes and spray flow rates be supplied with appropriate justification for each plant analysis utilizing the ICECON code.

References

1. Wheat, L. L., CONTEMPT-LT/022 Program Transmittal, LLW-13-73, Letter to Argonne Code Center, Aerojet Nuclear Company, December 19, 1973.

2. Exxon Nuclear Company, Incorporated, Supplementary Information Relating to Blowdown and Heatup Analysis, Supplement 5, XN-75-41, September 4, 1976.

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ACKNOWLEDGEMENT

The ICECON computer code described in this document was developed with the assistance of Energy Incorporated under contract with Exxon Nuclear Company.

1.0 INTRODUCTION AND SUMMARY

The ICECON computer code was developed to provide the post-blowdown pressure transient in a Pressurized Water Reactor (PWR) ice condenser containment during a Loss-of-Coolant Accident (LOCA) as required by Appendix K to 10 CFR 50 for ECCS analysis. The calculated containment pressure is used to determine the backpressure for flow from the primary system to the containment during the refill and reflood portions of the LOCA transient.

The ICECON computer code was developed from the CONTEMPT/LT-022 code,[1,2] a digital computer code for analyzing pressure-temperature transients in dry containments and the Mark I and II pressure suppression containments. In 1975, Exxon Nuclear Company (ENC) created a CONTEMPT version called CONTEMPT/22ENC[3] which was reviewed by the Nuclear Regulatory Commission (NRC) in connection with ENC's Generic PWR Emergency Core Cooling System (ECCS) Evaluation Model. ICECON retains the calculational capability of CONTEMPT/22ENC and can be used for dry containments, as well as ice condenser contained systems.

Appendix K to 10 CFR 50 requires that a conservative containment pressure be used in the ECCS analysis of a PWR. The Appendix K criteria further requires that the containment pressure calculation include the effects of all pressure reducing systems and processes within the containment. The ICECON computer code was developed in accordance with these criteria and contains models which consider the effect of all pressure reducing systems, i.e., (1) ice chest,

(2) containment sprays, (3) heat transfer to passive heat slabs, and (4) fan coolers.

A conservative containment pressure for the post-blowdown portion of a LOCA implies a low containment pressure. A low containment pressure is conservative since it results in an increase in steam binding, and thus, reduced reflood rates to the core. Reduced reflood rates means a longer transient, and thus, higher cladding temperatures. Inclusion of pressure reducing systems coupled with the modeling assumptions ensure a conservative containment pressure. The modeling assumptions include: (1) uniform ice melt, (2) fixed outlet gas temperature from the ice chest, (3) fixed outlet condensate temperature from the ice chest, and (4) minimum force required for ice chest door opening.

The ICECON model considers the ice condenser containment as being comprised of four volumes: the lower compartment, the ice chest, the upper compartment, and the dead-end compartment (volume). Analytical models to compute the pressure response, fluid thermodynamics, and fluid flow within each of these volumes are contained in the ICECON model.

A discussion of the salient features of an ice condenser containment is provided in Section 2.0. Details of the analytical models unique to the ICECON model are detailed in Section 3.0. Models particular to CONTEMPT/LT-022, but common to ICECON, are detailed in References 1 and 2. The heat transfer correlations used in the ICECON Model are described in Section 4.0. Corrections and updates made to CONTEMPT/LT-022 during the development of ICECON

are contained in Section 5.0. The references are listed in Section 6.0. Appendix A presents the results for a sample problem and compares the ICECON results with the results of the NSSS vendor calculation for an ice condenser containment. The ICECON predicted pressure shows good agreement with the NSSS vendor results.

2.0 ICE CONDENSER CONTAINMENT DESCRIPTION

The four major compartments of a typical ice condenser containment system are shown in Figure 2.1. They are:

1. The lower compartment containing the reactor primary coolant system.
2. The upper compartment containing the refueling channel, refueling equipment and the polar cranes.
3. The ice chest containing borated ice for condensing steam discharged to the containment.
4. The dead-end volume containing the auxiliary pipe tunnel, the fan accumulator compartments and the instrument room.

The upper compartment is separated from the lower compartment by the operating deck, but communicates through recirculation fans. The ice chest consists of a number of ice chest bays located between the reactor coolant system and the outer containment wall. The dead-end volumes are adjacent to the lower compartment.

Following a rupture of a primary system pipe, fluid discharged from the break pressurizes the lower compartment and thereby forces flow into the ice chest through the lower doors. The lower doors between the lower compartment and ice chest open into the ice chest in response to the imposed pressure difference and are fully opened at 0.005 psid. The steam entering the ice chest is completely condensed by ice and uncovered ice basket structure until the ice is completely melted (estimate approximately 1/2 hour). Saturated

air exits through the upper ice chest doors into the upper compartment if the upper compartment pressure is less than that in the ice chest. A leakage flow path exists through the recirculation fans between the upper and lower compartments.

For ECCS licensing calculations, leakage flow through the fans is permitted only from the upper to the lower compartment which ensures a maximum condensation in the ice chest. It is assumed that the dead-end volume retains its initial air mass and has a pressure equal to that in the lower compartment. No flow is permitted between the dead-end volume and the lower compartment, but because of the increased lower compartment pressure, the dead-end volume may be compressed. This decrease in volume of the dead-end compartment is compensated for by an increase in lower compartment volume.

In the ice chest, the water formed by melted ice and condensed steam flows to the lower ice chest plenum where it accumulates if the ice bay drains are not large enough to accommodate the rate of water production. When the water level in the lower ice chest plenum rises above the bottom of the lower doors, water spillage through the lower doors as well as through the drain ports occurs. The water drainage (spillage plus drainage) from the ice chest falls through the lower compartment and mixes with the lower compartment vapor. This condenses steam and reduces the containment pressure. The ice chest drainage flow is treated as a 100% efficient spray during the post-blowdown period of the transient.

In addition to the ice chest, other pressure reducing systems are available in the containment. They are: (1) the containment sprays, (2)

passive heat slabs, and (3) recirculation fans. The spray systems are located in the upper and lower compartments, and are treated as 100% efficient sprays.

The passive heat slabs correspond to the metal and concrete structures in the containment. For licensing calculations, the maximum anticipated heat transfer coefficients are used to maximize the rate of heat addition to the containment structures.

The recirculation fans circulate the air-steam mixture through the ice chest, but are not actuated until several minutes after initiation of the transient. Therefore, they are not modeled as fans, but rather as a leakage flow path. This leakage path allows steam and air to flow between the upper and lower compartments. This treatment of the recirculation fans is appropriate since the peak cladding temperature for the LOCA is predicted to occur well in advance of the time when the fans are accuated.

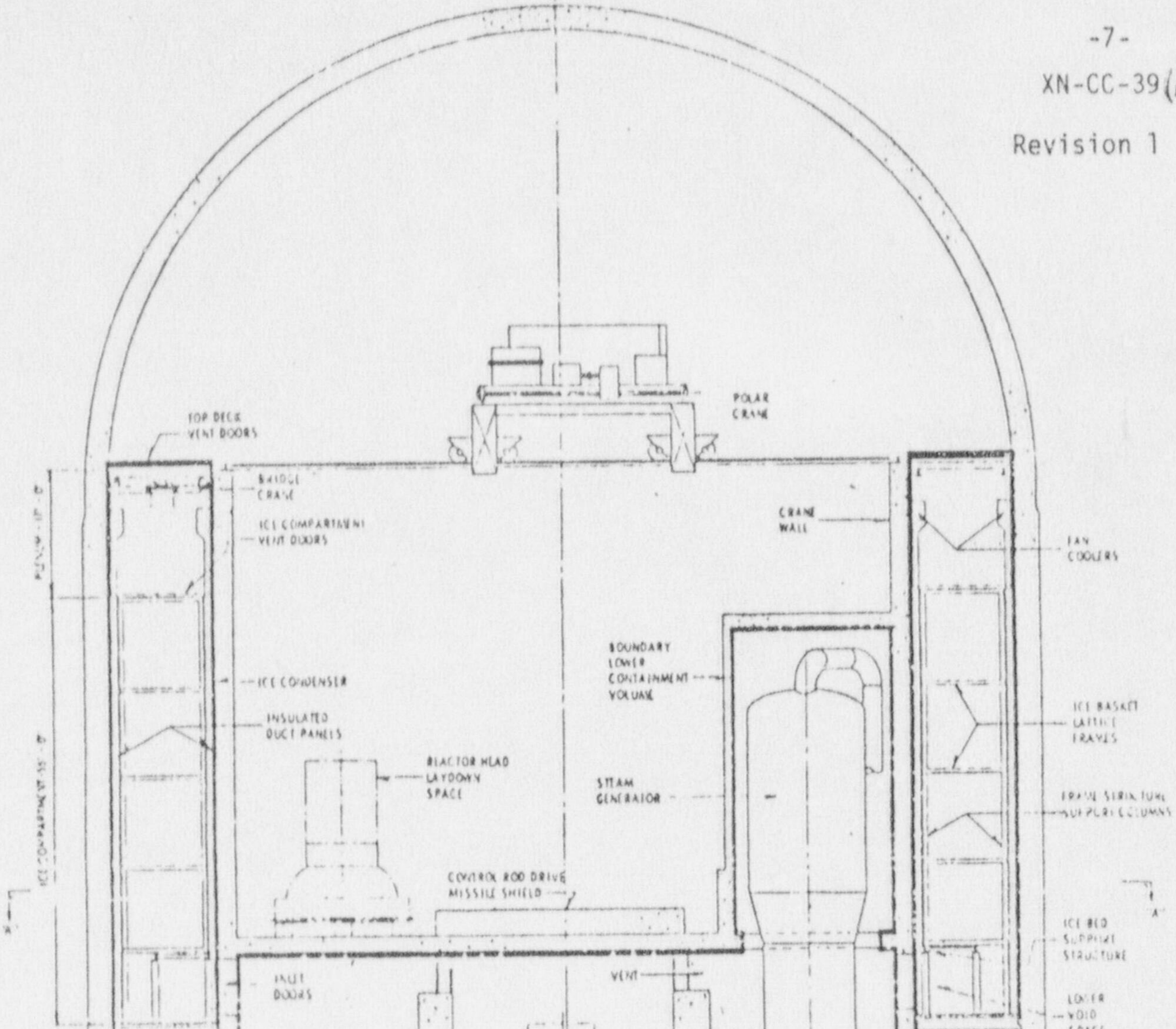

FIGURE 2.1 TYPICAL ICE CONDENSER CONTAINMENT

3.0 ICE CONDENSER MODEL

Figure 3.1 is a schematic representation of the ice condenser containment. The constitutive equations used to describe the thermal-hydraulic response in the containment can be reduced to a series of differential equations to describe: (1) fluid flows between major containment subcompartments (Sections 3.1 to 3.4), and (2) the mass and energy inventory in the ice chest, ice chest structures, and the lower and upper compartments (Sections 3.5 to 3.9). Sections 3.10, through 3.13 describe auxiliary physical models required to analyze a containment with an ice chest.

3.1 FLOW THROUGH THE ICE COMPARTMENT LOWER DOOR

The momentum equation for flow between the lower compartment and the ice chest is written for a junction located at the lower door. The junction extends from the lower compartment through the lower door to, and including, the ice melt-front. The density of fluid passing through the lower doors is the lower compartment fluid density, and the density of the vapor in the ice chest is determined from the state relations, given the current inventories of masses and energies, which are calculated from the conservation equations for mass and energy.

For the lower door flow, the momentum equation is

$$I_L \frac{dw_{ld}}{dt} = P_3 - P_{ic} - \frac{K_L \, w_{ld} \, | w_{ld} |}{2\rho_{ld} g_c \, A_{ld}^2}$$

The inertia for this junction, I_L, can be input or calculated in the code by the following relationship:

$$I_L = \frac{V_3}{2A_3^2} + \left\{\frac{V_{1p} - V_{sump}}{(A_f + A_i)^2} + \frac{z_i}{A_f + A_i}\right\} \frac{0.5}{NDOORS}$$

where

A_f = ice chest bay flow area

A_i = ice cross-sectional area

A_{1d} = lower door flow area

A_3 = horizontal area of lower compartment

K_L = lower door loss coefficient

NDOORS = number of ice chest bays

P_{ic} = ice chest pressure

P_3 = lower compartment pressure

V_{1p} = ice chest bay lower plenum volume

V_{sump} = lower compartment volume

V_3 = lower compartment volume

w_{1d} = lower door mass velocity

z_1 = height ice has melted

ρ_{1d} = lower door fluid density

The area for flow of the lower door is determined from a table lookup of flow area versus the difference in pressure across the door (Figure 3.2).

The loss coefficient K_L is:

$$K_L = K_{1p} + K_{ic} \frac{z_i}{Z_I} + K_D$$

where

K_D = drag loss coefficient

K_{lp} = flow loss coefficient for lower door, turning, and entrance to ice passages

K_{ic} = flow loss coefficient for the ice passage when empty

Z_I = initial height of ice column

The loss coefficient, K_L, is referenced to the lower door flow area.

3.2 FLOW THROUGH THE ICE COMPARTMENT UPPER DOOR

The momentum equation is written for a junction located at the upper door. The junction extends from the ice melt-front through the upper doors. The momentum equation is:

$$I_U \frac{dw_{ud}}{dt} = P_{ic} - P_2 - \frac{K_u}{2\rho_{ud}} \frac{w_{ud} |w_{ud}|}{g_c A^2_{ud}}$$

The inertia for this junction, I_U, can be input or calculated in the code by the following relationship:

$$I_U = \left\{ \frac{Z_I - z_i}{A_f + A_i} + \frac{V_{up}}{(A_f + A_i)^2} \right\} \frac{0.5}{NDOORS} + \frac{V_2}{2A_2^2}$$

where

A_{ud} = upper door flow area

A_2 = horizontal area of upper compartment

K_U = upper door loss coefficient

P_2 = upper compartment pressure

w_{ud} = upper door mass velocity

V_{up} = ice chest bay upper plenum volume

V_2 = upper compartment volume

ρ_{ud} = fluid density at upper door

The loss coefficient K_U is:

$$K_U = K_{up} + K_{io} (Z_I - z_i)/Z_I$$

where the separate components are referenced to the upper door flow area, and

K_{up} = flow loss coefficient for the ice chest passage exit and upper doors

K_{io} = flow loss coefficient for the ice passages when filled with ice.

3.3 FLOW THROUGH THE RECIRCULATION FAN

A leakage path between the upper and lower compartments is provided through the non-active recirculation fans. The momentum equation for the junction is:

$$I_{fn} \frac{dw_{fan}}{dt} = P_2 - P_3 - \frac{K_{fan} w_{fan} |w_{fan}|}{2\rho g_c A_{fan}^2}$$

The inertia for the fan junction, I_{fn}, can be input or calculated in the code by the following relationship:

$$I_{fn} = \frac{1}{2}\left[\frac{V_2}{A_2^2} + \frac{V_3}{A_3^2}\right]$$

where

A_{fan} = fan flow area (direction dependent)

K_{fan} = flow loss coefficient through the fan path (direction dependent, referenced to fan flow velocity).

w_{fan} = flow rate (lbm/sec) through the fan (positive for flow from upper to lower compartment)

ρ = density (flow direction dependent)

$$= \begin{cases} \rho_2 \text{ for } w_{fan} > 0 \text{ (upper compartment fluid density)} \\ \rho_3 \text{ for } w_{fan} < 0. \end{cases}$$

3.4 ICE CHEST SUMP DRAIN AND SPILL FLOWS

The flow of condensate from the ice compartment sump to the lower compartment is shown schematically in Figure 3.3, exluding spillage through the lower doors. The mass inventory to the ice chest sump is the result of melted ice and the condensed steam. The flow from the sump normally occurs through a bottom-drain and is calculated using a tank-draining relationship, but also can occur due to spillage through the lower door. Fluid discharged through the lower doors is calculated using a weir flow equation. The total flow of condensate from the ice chest sump is the sum of the two flows.

The simple tank-drain flow is calculated as follows:

$$w'_d = A_{drain} \left[\frac{2\rho_{sump}}{K_{drain}} \left\{ \frac{P_{ic} - P_3}{g_c} + g\, h_{sump} \right\} \right]^{1/2}$$

where

A_{drain} = sump drain flow area

g = gravitational acceleration

h_{sump} = height of sump water surface above drain exit. This is a function of V_{sump} and must be found from a specified table of height versus volume

K_{drain} = flow loss coefficient for sump drain

w'_d = mass velocity through sump drain

ρ_{sump} = fluid density of sump water

For the spillage flow through the lower door, a weir flow equation[6] is used:

$$w_{weir} = 3.33 \left[W_{dd} \left(h_{sump} - h_d \right)^{3/2} \right] \rho_{sump}$$

where

W_{dd} = width of lower door

h_d = height of lower door sill above sump drain exit

Obviously if h_{sump} is less than lower door sill height, h_d, then the flow is zero ($W_{weir} = 0$).

The total condensate flow rate from the ice chest sump, w_d, is:

$$w_d = w'_d + w_{weir}$$

3.5 ICE CHEST SUMP WATER MASS BALANCE

The mass conservation for the liquid contents of the ice chest sump is:

$$\rho_{sump} \left(A_i \frac{dz_i}{dt} - \frac{dV_{ic}}{dt} \right) = \frac{dM_w}{dt} - w_d$$

where

M_w = cumulative mass of liquid water added to sump

V_{ic} = vapor space volume in the ice chest

$= V_{lp} + V_{up} + A_f Z_I + A_i z_i$

w_d = total condensate flow from the ice chest sump

ρ_{sump} = density of liquid water in the sump

3.6 ICE CHEST AIR MASS BALANCE

The mass conservation equation for the air in the ice chest is:

$$\frac{dM_{aic}}{dt} = \frac{\rho_{ald}\ W_{ld}}{\rho_{ld}} - \frac{\rho_{aud}\ W_{ud}}{\rho_{ud}}$$

where

M_{aic} = mass of air in the ice chest vapor space

ρ_{ald} = air density at lower door

ρ_{aud} = air density at upper door

The change of air mass in the ice chest may result from changes of either the air density or the volume. Volume changes occur as ice melts and as water drains from the ice chest sump.

3.7 ICE CHEST WATER MASS BALANCE

The mass conservation equation for the water mass in the ice chest, excluding the water inventory in the ice chest sump, is:

$$\frac{d}{dt}(\rho_{sic} V_{ic}) = \rho_{sld}\ W_{ld}/\rho_{ld} - \rho_{sud}\ W_{ud}/\rho_{ud} + \frac{M_I}{Z_I}\ \frac{dz_i}{dt} - \frac{dM_w}{dt}$$

where

ρ_{sic} = steam density in ice compartment

ρ_{sld} = steam density at lower door

ρ_{sud} = steam density at upper door

The model assumes that the gas temperature of the ice chest is equal to the temperature of the gas exiting through the upper door. This gas temperature is based upon data from the Waltz-Mill test facility. The steam is in equilibrium with the air.

3.8 ICE CHEST ENERGY BALANCE

The equation for conservation of energy of the ice chest vapor is:

$$\frac{d}{dt}\left(M_{aic}\,U_{aic}\right) + \frac{d}{dt}\left(\rho_{sic}U_{sic}V_{sic}\right) = H_{ld}\,W_{ld} - H_{ud}\,W_{ud}$$

$$+ U_I\,\frac{M_I}{Z_I}\frac{dz_i}{dt} - H_w\,\frac{dM_w}{dt} - \frac{M_c}{Z_I}\frac{d}{dt}\left(z_i U_c\right)$$

where

H_{ld} = enthalpy of fluid entering lower door

H_{ud} = enthalpy of fluid leaving upper door

M_c = mass of conductor initially covered by ice

U_{aic} = energy per unit volume of air in ice chest

= $C_{pa}\,T_{ic}$ where C_{pa} is the heat capacity of air

U_{sic} = energy of saturated steam in ice chest (at T_{ic})

U_w = boundary condition, value of U for liquid water added to sump at temperature specified in input table

U_c = energy of exposed structure (conductor)

= C_{pc} $(T_c - T_{ice})$ where C_{pc} is specified heat and T_c is temperature of conductor. T_c is set to the current upper door boundary temperature.

U_I = energy of ice (a constant)

The temperature of the ice chest water, condensate and ice-melt, which falls to the ice chest sump is based upon the test results obtained at the Waltz-Mill testing facility.

3.9 MASS AND ENERGY EXCHANGE BETWEEN CONTAINMENT COMPARTMENT

The change of the mass and energy inventories resulting from fluid flow between compartments is computed by the following equation sets:

$$\Delta M_{an} = -\Delta M_{am} = -\frac{\rho_a}{\rho} w \,\Delta t$$

$$\Delta M_{sn} = -\Delta M_{sm} = -\frac{\rho_s}{\rho} w \,\Delta t$$

$$\Delta U_n = -\Delta U_m = -H\, w\, \Delta t$$

where

M_{an}, M_{am} = air mass in donor compartment (n) and receiver compartment (m)

M_{sn}, M_{am} = water vapor mass in compartment

U_n, U_m = internal energy of compartment

H = enthalpy

ρ_a = air density

ρ_s = steam density

ρ = density

Δt = time step size

w = mass flow between compartments

The value of H, ρ_a, and ρ_s are set equal to the fluid conditions in the donor compartment.

In addition to the mass and energy transport equations described above, the lower compartment thermodynamics are affected by the fluid discharged from the ice chest sump. The mass flow from the ice chest sump was described in Section 3.4. The energy exchange between this mass flow and the vapor contents of the lower compartment is.

$$\Delta U_{v3} = w_d \, [H_{13} - H_w] \, e$$

where

e = efficiency

H_{13} = specific enthalpy of saturated water at the lower compartment temperature

H_w = specific enthalpy of water at the sump drain temperature

The energy removed from the vapor phase, ΔU_{v3}, increases the temperature of the fluid discharged from the ice chest sump as well as condenses steam. The condensed steam and the discharged ice chest sump water falls to the lower compartment liquid pool where it achieves thermodynamic equilibrium.

3.10 HEAT TRANSFER TO ICE BAY BASKETS

The ice bay baskets are initially covered by the ice. The ice covered baskets remain at the ice temperature until the ice melt reveals the basket. Exposed basket temperatures are set equal to the ice chest gas temperature immediately upon uncovery. Should all the ice melt, the basket temperature is set to the temperature of the fluid entering the lower doors.

3.11 POOL BOILOFF MODEL

When the compartment pressure decreases, it is possible that the temperature of the fluid in the pool will exceed the saturation temperature. When this occurs, the fluid in the pool flashes, transferring mass from the pool to the vapor region of the compartment. Equilibrium is obtained when sufficient mass has been transferred to reduce the pool energy and to increase the system pressure to their equilibrium values.

The pool boiloff model yields a calculation of the mass required to be boiled off to bring the pool into equilibrium with the vapor when the pool flashes. To calculate the change in system pressure and pool energy, two equations are simultaneously solved: (1) an equation defining pool saturation energy (U_1^s) as a function of compartment pressure (p), and (2) an equation defining the decrease in pool energy (U_1) and increase in system pressure (p) with mass transfer. The increase in system pressure is calculated assuming that the generated vapor obeys the ideal gas law.

The operating and saturation curves shown in Figure 3.4 are in analytical form:

$$U_1^e = U_1^o + \frac{dU_1}{dp} (p^e - p^o)$$

$$U_1^e = U_1^{s,o} + \frac{dU_1^s}{dp} (p^e - p^o)$$

where

p^e, U_l^e = equilibrium pressure and pool energy,

p^o, U_l^o = initial pressure and pool energy, and

$U_l^{s,o}$ = initial saturation pool energy at the initial pressure p^o.

The change in mass in the vapor phase (ΔM) can then be calculated through the ideal gas law.

$$\Delta M = \frac{(p^e - p^o)\, V M_W}{ZRT}$$

where

V = volume of vapor space

M_W = molecular weight of water

Z = compressibility factor

The energy of the liquid pool and vapor are:

$$U_l^e = U_l^o - \Delta M\, U_v^s$$

$$U_v^e = U_v^o + \Delta M\, U_v^s$$

where

U_v^s = saturation energy of steam at p^e, and

U_v^o = initial energy of vapor region.

3.12 COMPARTMENT VAPOR STATE CALCULATIONS

The change in internal energy of the vapor region is given by

$$\Delta U_v = \sum_{i=1} \Delta U_v^{(i)}$$

where $\Delta U_v^{(i)}$ are the changes in internal energy of the vapor region due to heat transfer with the sump water, heat slabs, ice chest drain flow, etc. The total internal energy of the lower compartment vapor region is then given by

$$U_v = U_v^{old} - \Delta U_v$$

The program mass-energy balancing routine (COMPU) computes the stagnation conditions for a two-component, two-phase mixture of liquid water, water vapor, and air. The equations used to determine the vapor region conditions are:

$$V_v = M_{wv} v_w \tag{1}$$

$$U_v = M_{wv} u_w (T_v, v_w) + M_a c_v T_v \tag{2}$$

For the superheated single-phase condition, pressure is determined from:

$$p = p_{wv} (T_v, v_w) + \frac{M_a R_a T_v}{V_v} \tag{3}$$

and for the two-phase condition, pressure and specific volume are determined from:

$$p = p_{wv} (T_v, v_w) + \frac{M_a R_a T_v}{x M_{wv} v_g(T_v)} \tag{4}$$

$$v_w = (1-x) v_f(T_v) + x v_g(T_v) \tag{5}$$

where

c_v = constant volume heat capacity of air

M_a = mass of air

M_{wv} = mass of water

p = total pressure

p_{wv} = pressure of water

R_a = gas constant for air

T_v = temperature (absolute units)

U_v = total internal energy

u_w = specific internal energy of water

V_v = vapor volume

v_f = specific volume of saturated liquid

v_g = specific volume of saturated vapor

v_w = specific volume of water

x = quality of two-phase region

These equations are based on the assumptions of Gibbs-Dalton law for vapors, that no vapor is dissolved in the liquid, that air is a perfect gas, and that all components are at the same temperature. Equations (1) through (5) are solved iteratively. The quantities, V_v, U_v, M_{wv}, and M_a are given and T_v, p, and x are to be determined.

Once the temperature is determined, the total pressure is calculated from Equation (3) or Equation (4). Also, the mixture quality (x) is obtained from the solution process and the mass of steam (M_{wvv}) and mass of liquid water (M_{wvl}) within the vapor region are determined from:

$$M_{wvv} = x\, M_{wv}$$

$$M_{wvl} = (1-x)\, M_{wv}$$

The water in the vapor region M_{wv1} can be dropped from the vapor region into the liquid pool.

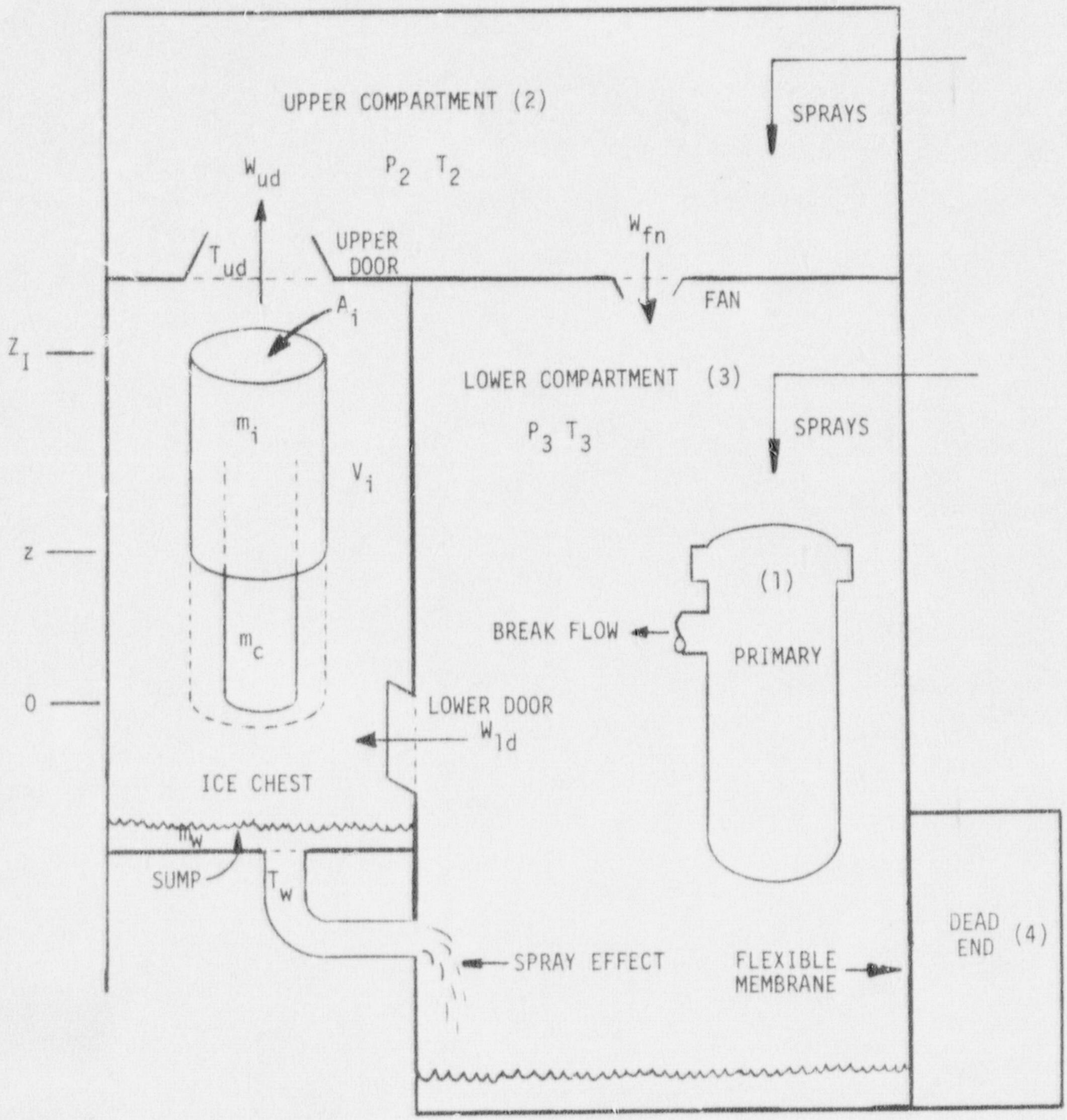

FIGURE 3.1 ICE CONDENSER MODEL

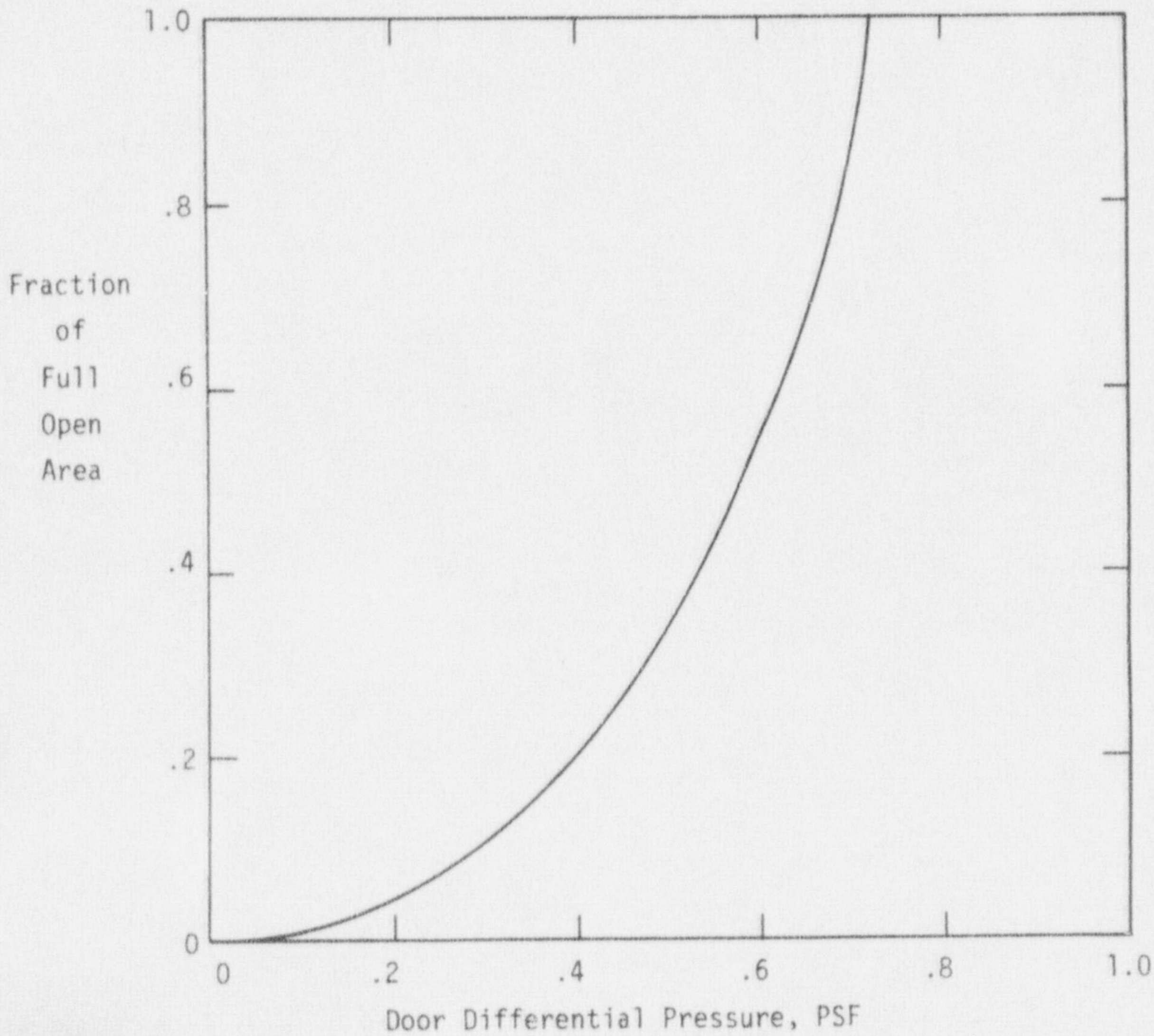

FIGURE 3.2 LOWER DOOR CHARACTERISTIC BEHAVIOR

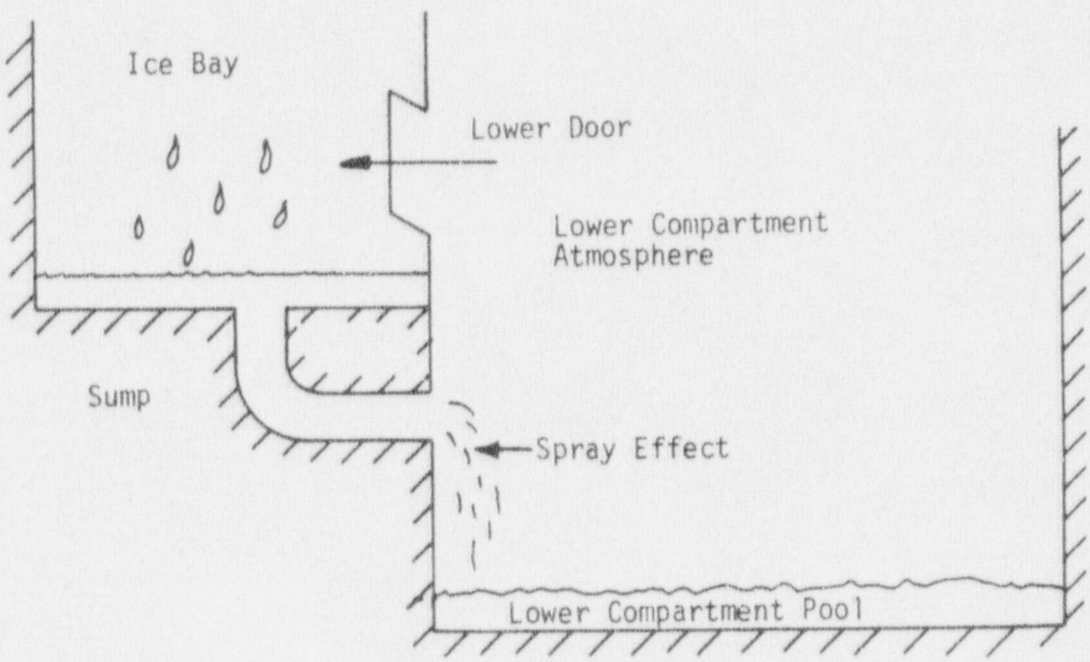

FIGURE 3.3 SUMP MODEL

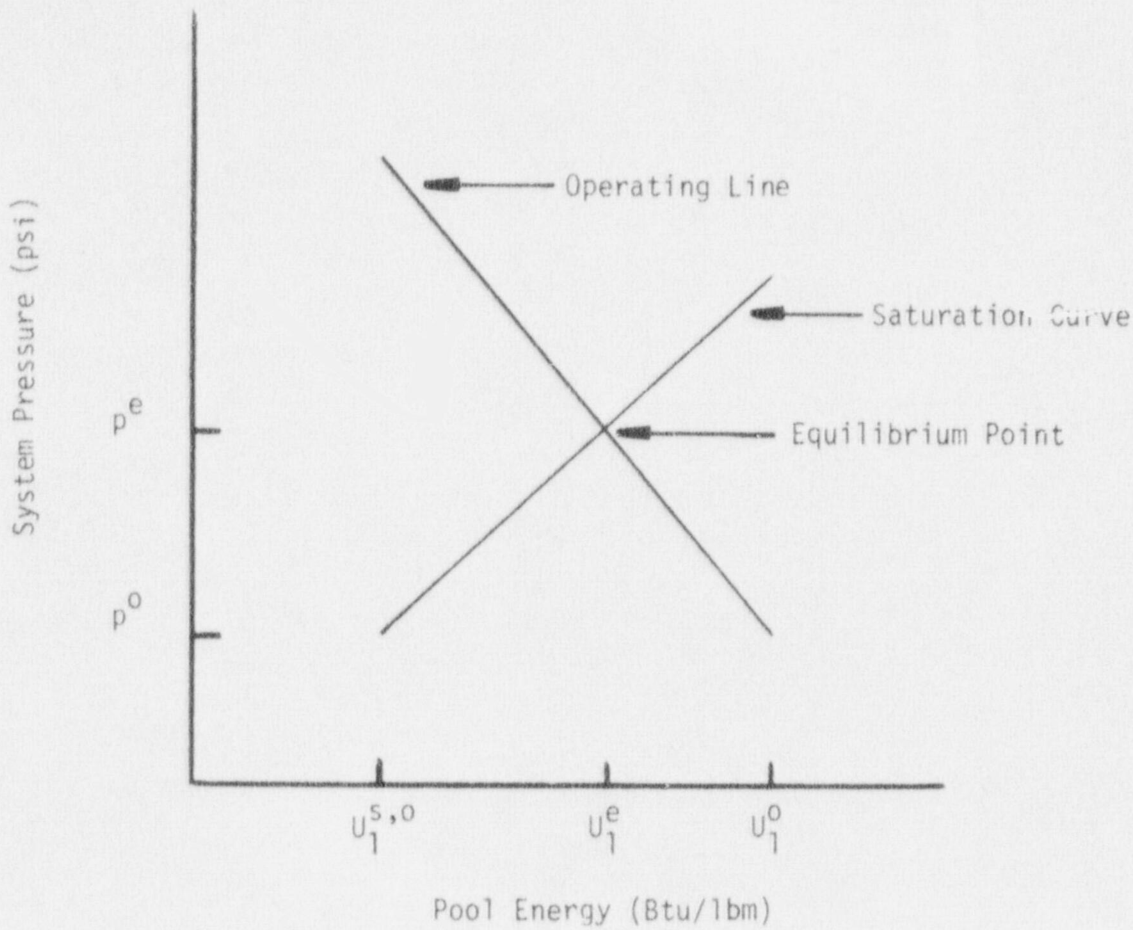

FIGURE 3.4 POOL ENERGY VERSUS SYSTEM PRESSURE

4.0 STRUCTURAL HEAT TRANSFER

The heat transfer coefficient to the containment structure is calculated using the results of Tagami.[12] Tagami found that the heat transfer coefficient peaked near the time of peak containment pressure and then decreased exponentially to a stagnant heat transfer coefficient. The stagnant heat transfer coefficient is a function of the mass fraction of air in the containment.

The Nuclear Regulatory Staff has published as a branch technical position, CSB 6-1,[13] guidelines for the use of the Tagami heat transfer correlation for use in LOCA ECCS analyses.

4.1 HEAT TRANSFER CORRELATIONS

4.1.1 Blowdown Heat Transfer

During the blowdown portion of the transient, the heat transfer coefficient peaks at about the time of peak containment pressure. The heat transfer coefficients from the start of the break to the time at which the peak value, h_{max}, occurs is given below.

$$h = 8.0 + (4h_{max} - 8.0)\, t/t_p$$

$$h_{max} = 72.5 \left[\frac{Q}{Vt_p} \right]^{0.62}$$

where

t_p = time at end-of-blowdown

V = containment vessel volume (i.e., lower compartment volume)

Q = energy transferred to heat slabs

4.1.2 Post Blowdown Heat Transfer

The heat transfer coefficient decays exponentially from the maximum value to a stagnation value, h_{stag}, during the post-blowdown period of the transient.

$$h = 1.2\, h_{stag} + (4\, h_{max} - 1.2\, h_{stag})\, e^{-0.025(t-t_p)}$$

h_{stag} = table lookup (see Table 4.1)

TABLE 4.1

UCHIDA HEAT TRANSFER COEFFICIENTS

lbm air/lbm steam	h(BTU/hr ft^2 °F)	lbm air/lbm steam	h(BTU/hr ft^2 °F)
50	2	3	29
20	8	2.3	37
18	9	1.8	46
14	10	1.3	63
10	14	0.8	98
7	17	0.5	140
5	21	0.1	280
4	24		

5.0 UPDATES TO CONTEMPT SUBROUTINE

5.1 INPUT/OUTPUT OPTIONS

In the course of adding the ice condenser models, it was determined at the beginning that several new subroutines would be added, that changes would be made to several other subroutines and more output information would be printed. Some changes were made to make the new code easier to use for both the programmer and the user.

The primary output for each time step in CONTEMPT-LT/022 is a jumbled collection of data pushed together with little organization or clarity. The output format has been much improved by organizing the data into groups for the pressures, temperatures, energies, masses, etc. The data is printed in column form for the compartments. The columns are clearly labeled with titles and units and regularly spaced across the page with blank spaces separating the rows and columns. The ice condenser output is printed as an additional row below the regular compartment data.

For the programmer, whether he be involved in the initial development of ICECON or in some possible future development, many changes were made to the organization of the code to make his job easier. The original CDC conversion was made for the old RUN compiler; it was converted for use with the more modern and more flexible FTN compiler. Most of the remaining changes involved alphabetical ordering and standardization.

The named commons were extraced and placed in COMDECK's to be used by the UPDATE package. In this manner only one change is required in order

to change a common everywhere it is used. The COMDECK's were named exactly after the name of the common and were placed in alphabetical order. The variables within each common were also placed in alphabetical order and standardized so that the common would have identically named variables in each subroutine in which it was used.

The subroutines were placed in DECK's which were placed in alphabetical order after the COMDECK's. The commons are copied back into the subroutines by CALL commands. The CALL commands are grouped together alphabetically at the front of each subroutine.

Using the FTN compiler and organizing the code in the above manner has already saved untold hours of programming and debug time. Likewise, the use of clearly printed output has speeded up the debug and checkout phases.

The RELAP4 environmental subroutines were added to the end of the ICECON subroutines. The environmental programs permit the use of free form input. The subroutines were added as a convenience to the user and the programmer.

A plot package was also added to ICECON.

5.2 CORRECTIONS TO CONTEMPT

In the course of adding the ice condenser models to CONTEMPT and debugging these models, three minor errors were discovered and corrected in CONTEMPT-LT/022.

The total volume (VOL) in a compartment is the sum of the vapor region volume (VOLV) and the liquid region volume (VOLL). A temporary vapor

region volume (VOLA) was being calculated incorrectly in CONT and used in the calculation of the state properties in the vapor region by the COMPU subroutine. Neither VOLL nor VOLV were ever recalculated to account for change in the liquid volume. The calculation of VOLV and VOLL are now being updated correctly, and VOLV is used in place of VOLA in the COMPU state calculation.

The internal energy of the liquid in the pool region is important to the determination of boiling and to the calculation of the quantity of mass boiled. The internal energy (ULB) of the liquid at saturation, was specified as the output to a search of the steam tables in GO; however, the search indicator actually pointed to HLB, the enthalpy of the liquid at saturation. This led to an inconsistency in the calculation of boiling. The correct search indicator is now used in GO.

Test runs, using the sample problem presented in Appendix B, have shown that ICECON was working when the heat conductors were absent, but failed in the energy balances when the heat conductors were included. The problem was traced to an error in the use of a dummy variable in GO. This error existed in the original code CONTEMPT. HEAT and CONT are called twice in GO for a two-step implicit advancement scheme involving the state conditions in the compartments and the heat transfer rates to the heat conductors. A dummy variable TEMP is used to establish a guess at the bulk temperature at the middle of the new time step from old time step data. When data conductors are present a different temporary value, also called TEMP, is calculated

between the place where the original TEMP was defined and a later place where it is used. The problem was cured by redefining the second TEMP as a new variable DUM.

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13. U. S. Nuclear Regulatory Commission, Minimum Containment Pressure Model for PWR ECCS Performance Evaluation, Branch Technical Position CSB 6-1.

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15. Exxon Nuclear Company, PLOTR4M (Revised) - A Generalized Plotting Output from RELAP4 and Other Computer Programs, XN-NF-CC-40, January, 1977.

APPENDIX A

ICECON SAMPLE PROBLEM

A1.0 PROBLEM DESCRIPTION

An example analysis of an ice condenser containment is presented to demonstrate the calculational capabilities of the ICECON code. The input data was obtained from the Donald C. Cook FSAR[4] and is summarized in Tables A1.1 and A1.2. A brief description of some of the input is given below.

Initial Conditions - As required by Technical Branch Position CSB 6-1, the minimum gas temperature, minimum containment pressure, maximum humidity, low outside ambient temperature, and the maximum net free containment volumes were input to the code.

Heat Sink Data - Nineteen heat slabs were modeled. Surface areas, construction material, thickness, and locations are given in Table A1.2. To ensure a conservative analysis, the condensing heat transfer option was input to heat slabs in the lower compartment as specified by Branch Technical Position CSB 6-1.

Sprays - Two spray systems are modeled, one in the upper compartment and one in the lower compartment. A temperature of 40°F was input for the spray water temperature.

Fans - Two fans are present in the Donald C. Cook plant which connect the lower and the upper compartments. The fans are not activiated until about ten minutes after the break initiation. Prior to the fan startup, a leakage flow path is allowed between the upper and lower compartments with flow allowed only in the direction from the upper to lower compartment. This ensures the maximum flow through the ice chest.

Ice Chest - The ice temperature was conservatively set equal to 15°F and the total mass of ice was set equal to 2.766×10^6 lbm. The ice chest sump and upper door fluid temperatures were fixed based on results obtained at the Waltz-Mill test facility.

TABLE A1.1

ICE CONDENSER CONTAINMENT DATA

Net Free Volume:	
Lower Compartment (LC)	249,466 ft.^{3}
Upper Compartment (UC)	746,829
Ice Chest (IC)	122,400
Dead End	116,168
Initial Conditions:	
Pressure	14.7 psia
Temperature Lower Compartment	120°F
Relative Humidity Lower Compartment	100%
Temperature Upper Compartment	100°F
Relative Humidity Upper Compartment	100%
Temperature Outside Containment	-7°F
Initial Spray Temperature	80°F
Active Drywell Sump Volume	40600 ft.^{3}
Spray System:	
Burnout Flow for a Spray Pump	3600 gpm
Number of Spray Pumps Operating	2
Post-Accident Initiation of Spray System	40 sec.
Spray Flow Lower Compartment	2835 gpm
Spray Flow Upper Compartment	4365 gpm
Spray Efficiency of Water from Ice Condenser Drains During Refill/Reflood Portions of Transient	100%
Ice Chest:	
Mass of Ice (Total)	2.766 x 10^6 lbm*
Height of Ice Column	48 ft.
Ice Temperature	15°F
Lower Door Flow Area	41.67 ft.^{2}
Number of Doors	24
Upper Door Area	20 ft.^{2}
Loss Coefficient Lower Door	1.34
Loss Coefficient Lower Door to Ice Basket	2.70
Loss Coefficient Ice Basket Empty	0.42
Loss Coefficient Ice Basket Full	0.42
Loss Coefficient Upper Door	1.50
Total Mass Structure in Ice Chest	480168 lbm
Specific Heat Ice Basket Structure	0.12 Btu/lbm°F
Temperature Sump Liquid	190°F to 20 sec. 130°F after 20 sec.
Temperature Upper Door	130°F

* Conservative input for ECCS calculations.

TABLE A1.1 (Continued)

ICE CONDENSER CONTAINMENT DATA

Fan (Leakage Path for Ten Minutes):	
Flow Area Forward Direction (UC to LC)	48 $ft.^2$
Loss Coefficient Forward Direction	4.0
Flow Area Reverse Direction	0 $ft.^2$
Loss Coefficient Reverse Direction	4.0
Thermal Properties:	
Thermal Conductivity	
Concrete	0.81 Btu/hr.-$ft.^2$
Carbon Steel	26.0
Stainless Steel	11.0
Lead	20.0
Volumetric Heat Capacity	
Concrete	30.4 Btu/$ft.^3$°F
Carbon Steel	58.8
Stainless Steel	62.0
Lead	22.8
Cross Sectional Areas	
Lower Compartment	6221.1 $ft.^2$
Upper Compartment	10386.9
Ice Chest Single Bay	55.25

TABLE A1.2

STRUCTURAL HEAT SINKS IN CONTAINMENT

SLAB NO.	COMPARTMENT*	AREA (ft^2)	THICKNESS (ft)	MATERIAL
1	LC	12105	0.0469/2.0	Steel/Concrete
2	LC	11700	2.0	Concrete
3	LC	65980	1.35	Concrete
4	LC	5481	0.0833	Steel
5	LC	4735	0.01147	Steel
6	LC	289	0.25	Lead
7	LC	14690	0.0079	Steel
8	LC	3439	0.1561	Steel
9	LC	5775	0.009	Steel
10	LC	4966	0.0096	Steel
11	LC	7013	0.037	Steel
12	LC	2457	0.0334	Stainless Steel
13	UC	378	0.0365/.1667	Steel/Concrete
14	UC	29772	0.0092	Steel
15	UC	8033	0.0209	Steel
16	UC	420	0.0052	Steel
17	UC	29330	1.47	Concrete
18	UC	34125	0.0469/2.0	Steel/Concrete
19	UC	210	0.0052	Stainless Steel

* LC - Lower Compartment

UC - Upper Compartment

A2.0 PROBLEM RESULTS

An example problem was run to show the capability of the ICECON code to calculate the containment pressure for an ice condenser plant. The input was selected to model the Donald C. Cook ice condenser plant. The NSSS vendor's mass and energy release rates for the 1.0 DECLG break to the containment were used.[4]

Plots of key output parameters for the sample problem are given in Figures A2.1 to A2.21. Figures A2.1 and A2.2 give the lower and upper compartment pressures. Figures A2.3 to A2.5 give the lower and upper ice chest door flows and the fan leakage flow. The rate of mass and energy addition into the lower compartment from the break are given in Figures A2.6 and A2.7 for water and Figures A2.8 and A2.9 for air. The drainage flow of water from the ice chest to the lower compartment is given in Figure A2.10, and the removal rate of energy from the lower compartment atmosphere by the flow is given in Figure A2.11. Figures A2.12 and A2.13 show the heat transfer coefficients at typical heat slabs in the lower and upper compartments. The rate of energy removal from the upper and lower compartment by the heat slabs is given in Figures A2.14 and A2.15. The rate of energy removal from the atmosphere and the upper and lower compartments by system sprays are given in Figures A2.16 and A2.17. Finally, the temperature of the lower and upper compartment vapor regions are given in Figures A2.18 and A2.19, while that for the lower compartment pool is given in Figure A2.20.

A comparison with containment pressure calculated by the NSSS vendor is given in Figure A2.21. The comparison shows that ICECON gives containment pressures which agree reasonably with that calculated by the NSSS vendor for the identical break.

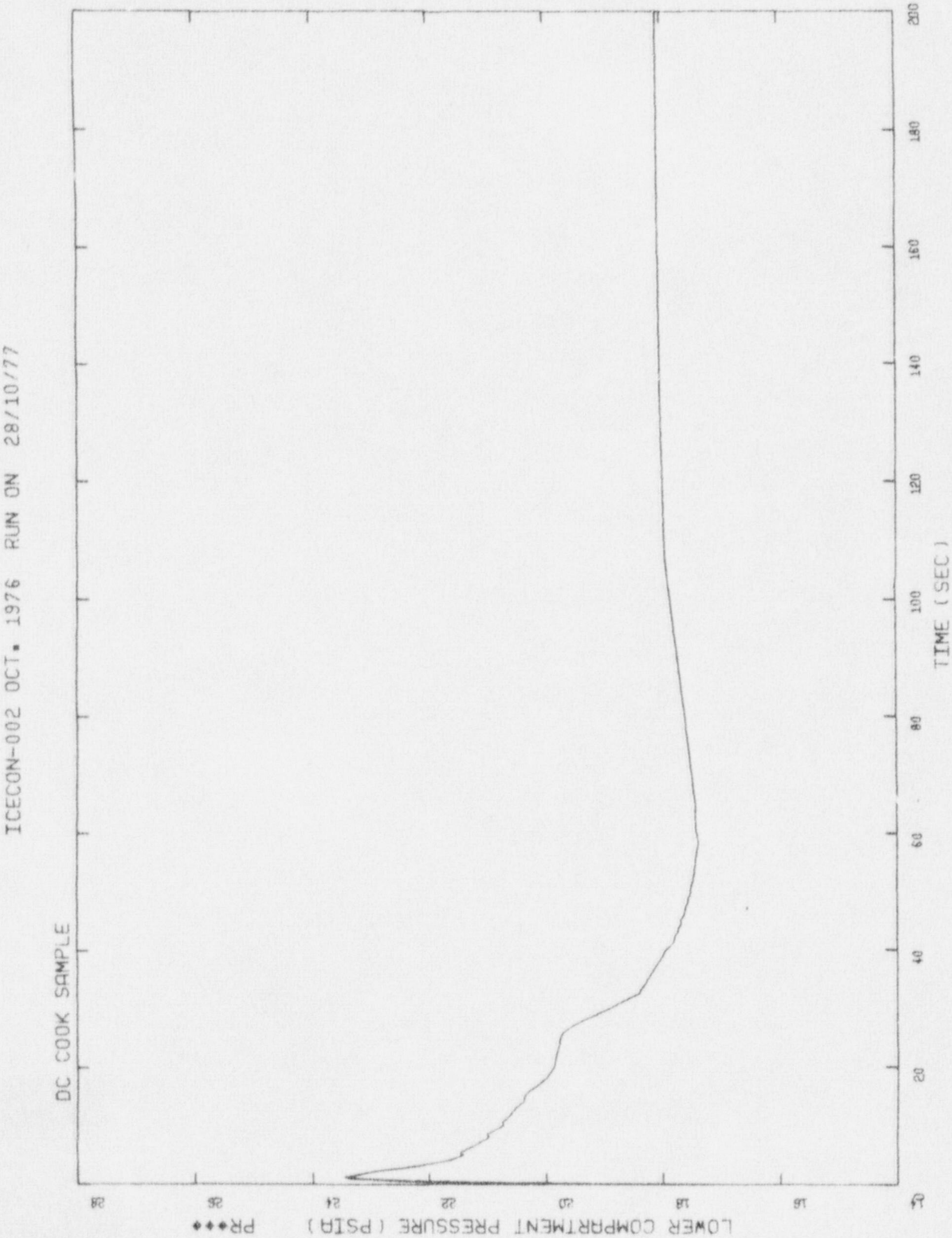

FIGURE A2.1 LOWER COMPARTMENT PRESSURE

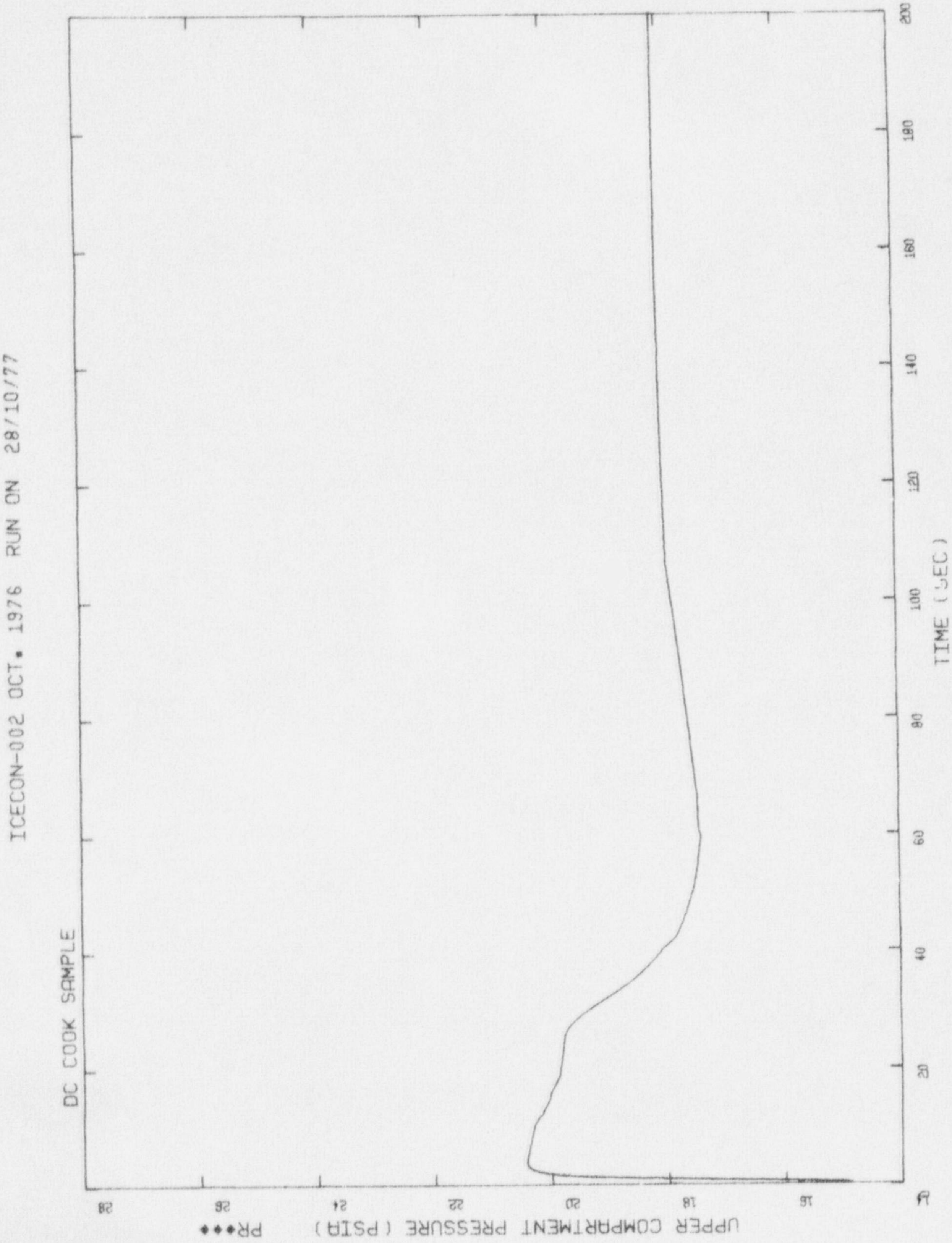

FIGURE A2.2 UPPER COMPARTMENT PRESSURE

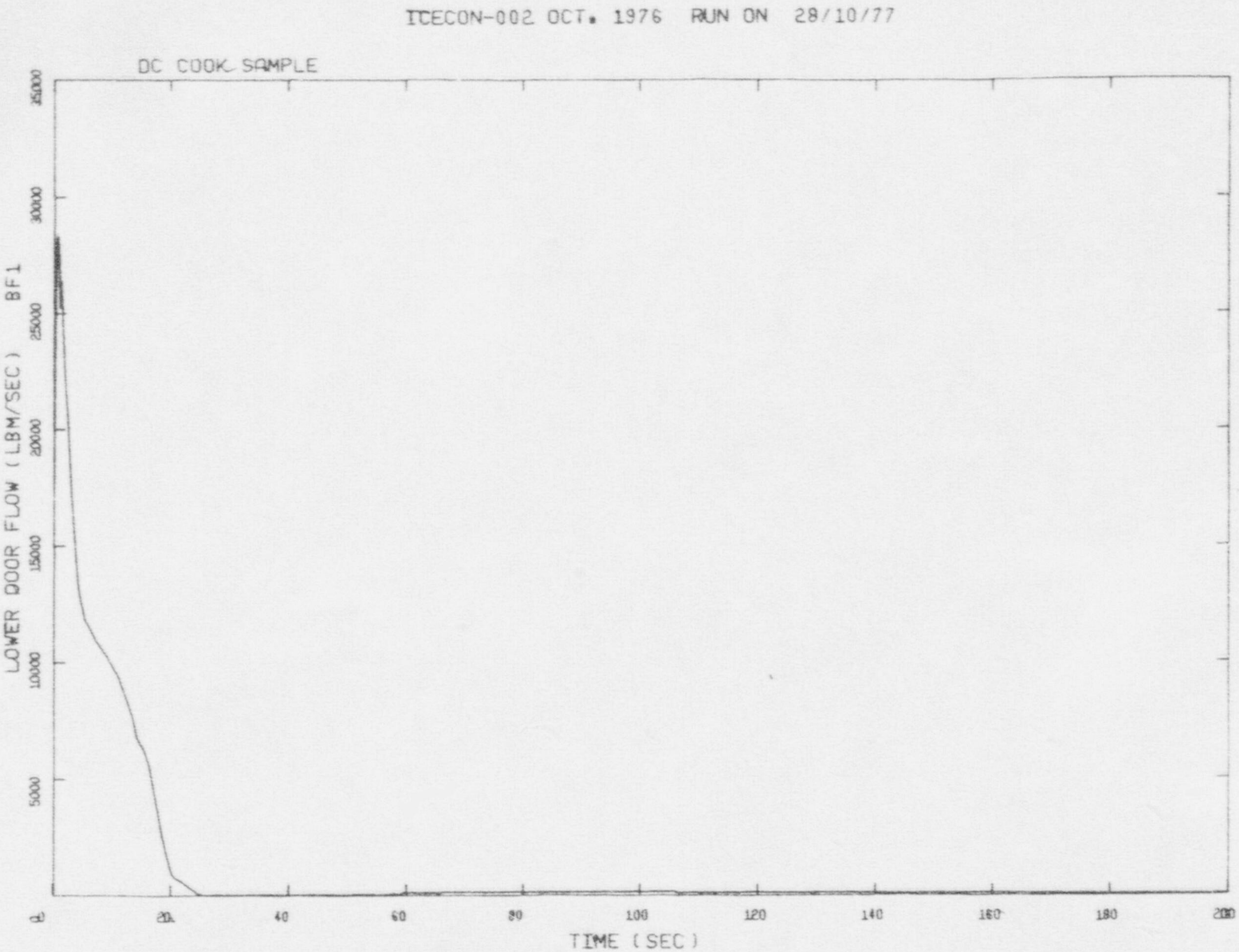

FIGURE A2.3 LOWER ICE CHEST DOOR FLOW

ICECON-002 OCT. 1976 RUN ON 28/10/77

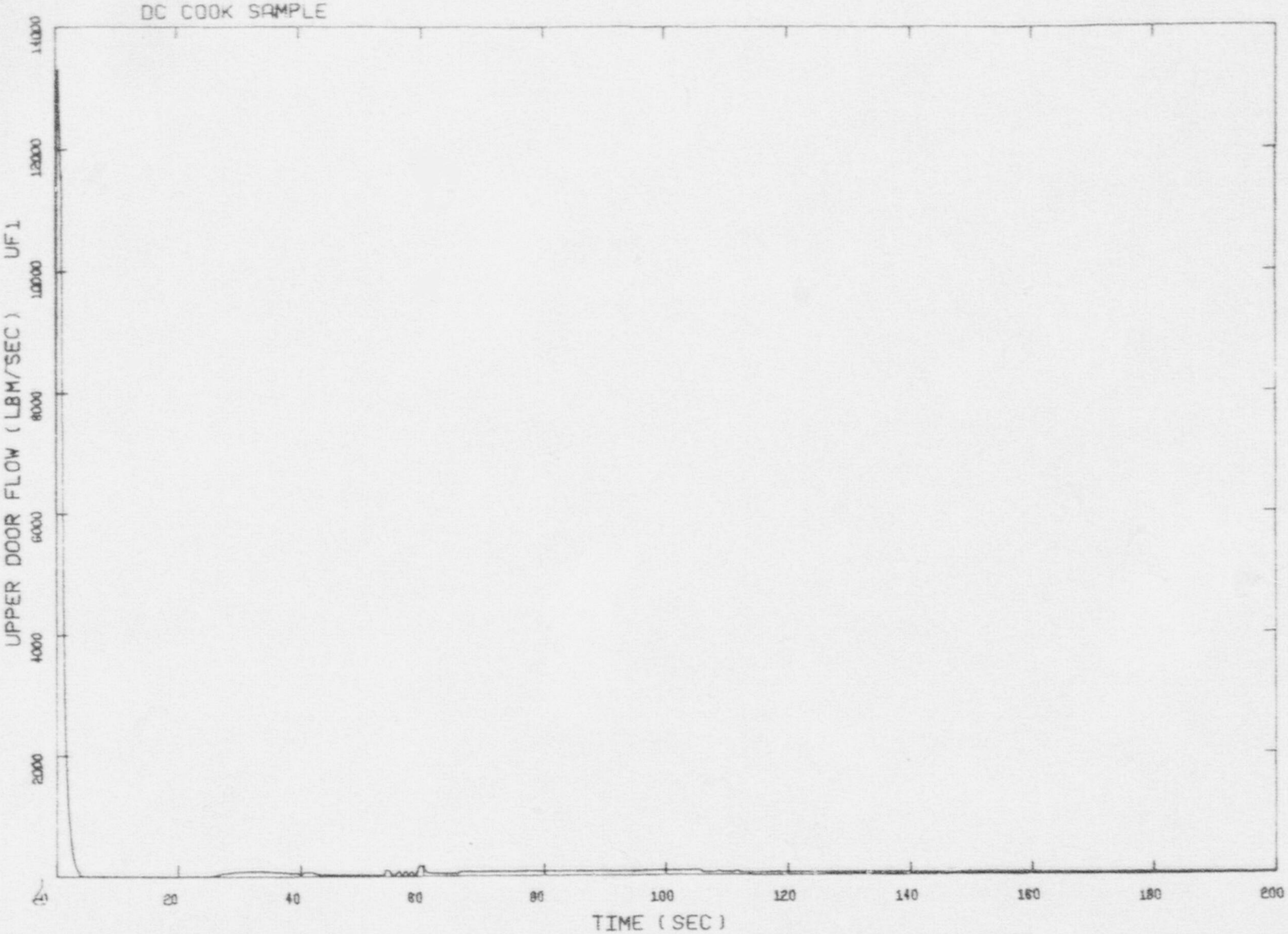

FIGURE A2.4 UPPER ICE CHEST DOOR FLOW

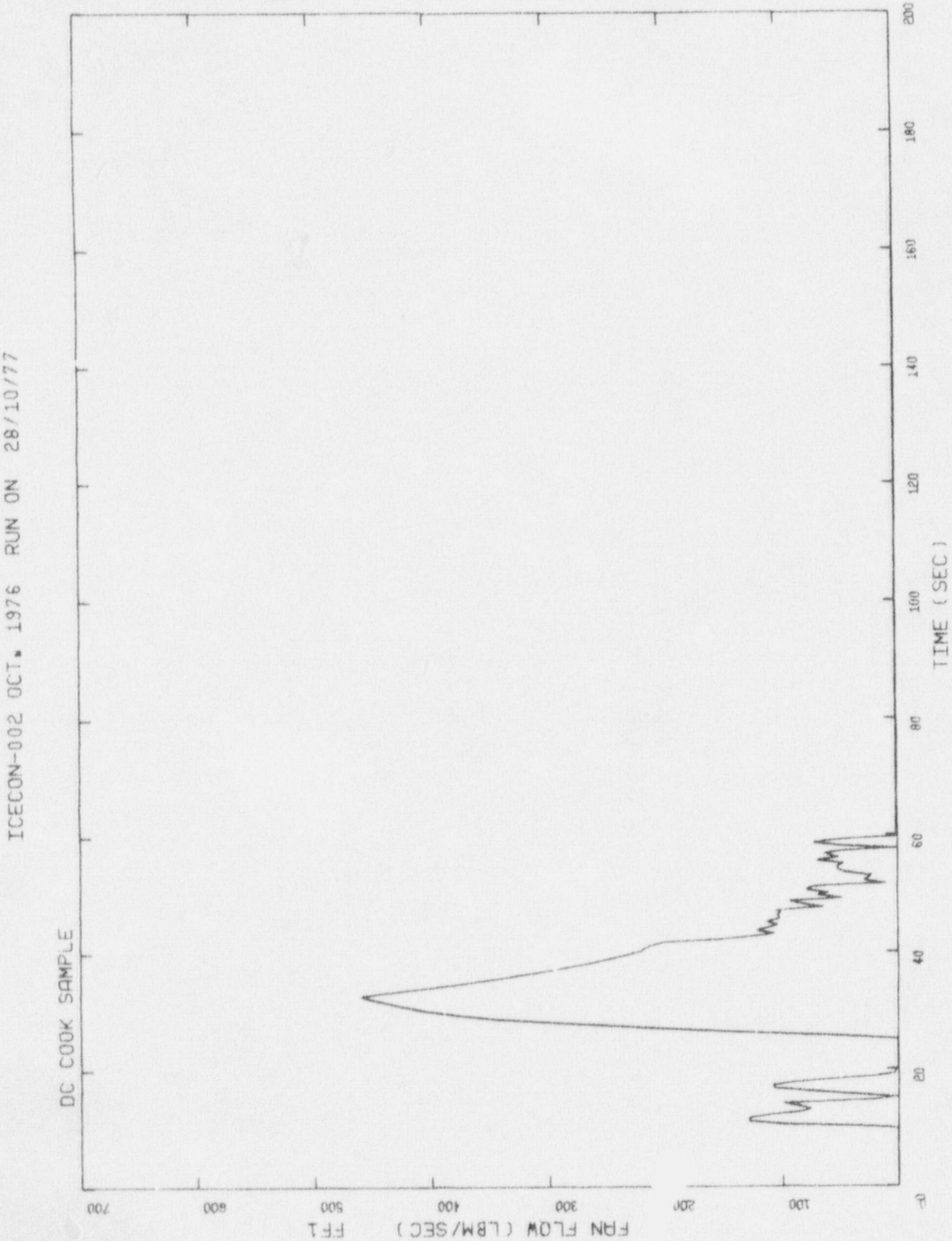

FIGURE A2.5 FAN LEAKAGE FLOW

ICECON-002 OCT. 1976 RUN ON 28/10/77

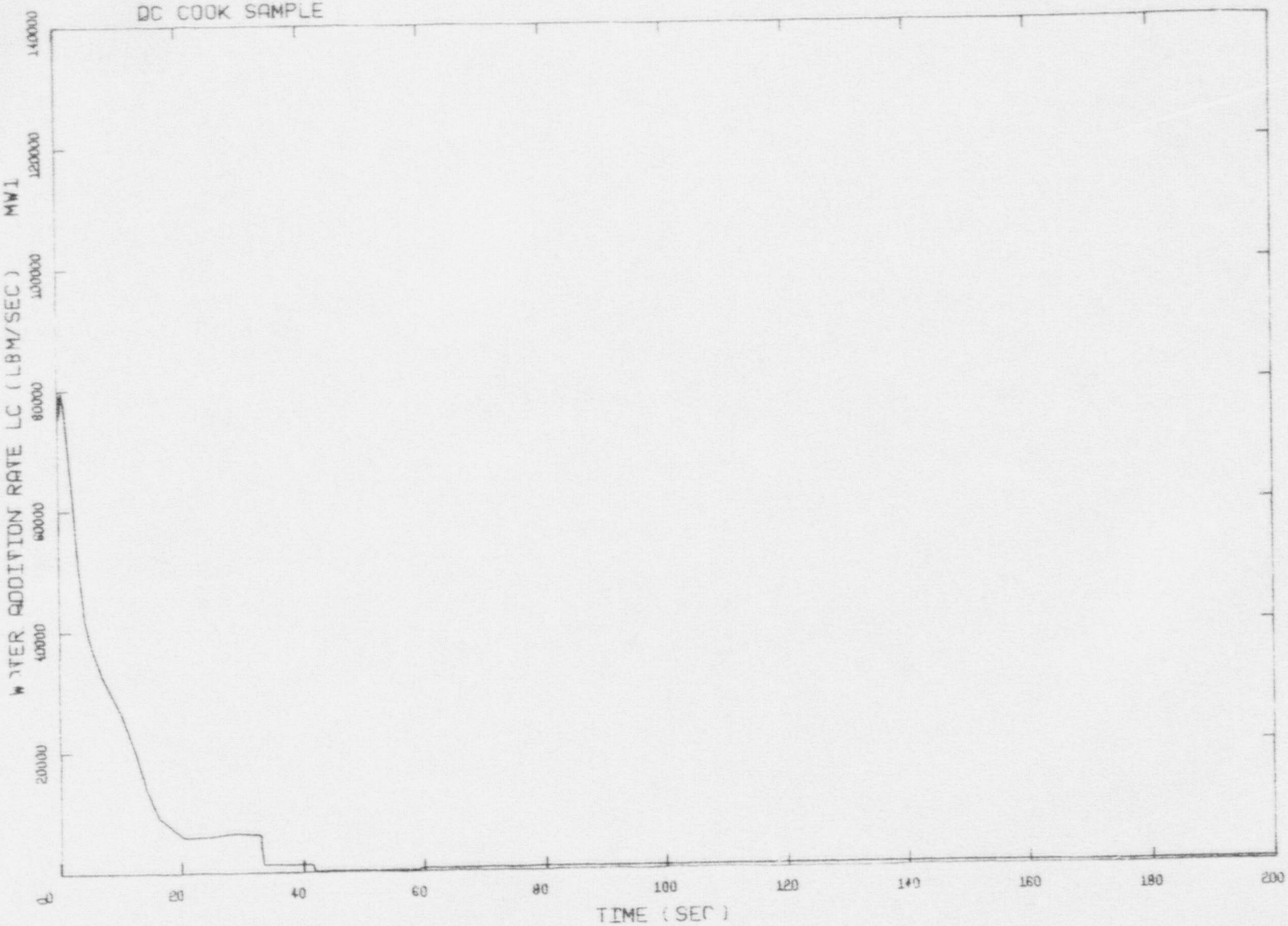

FIGURE A2.6 ADDITION RATE OF WATER TO LOWER COMPARTMENT

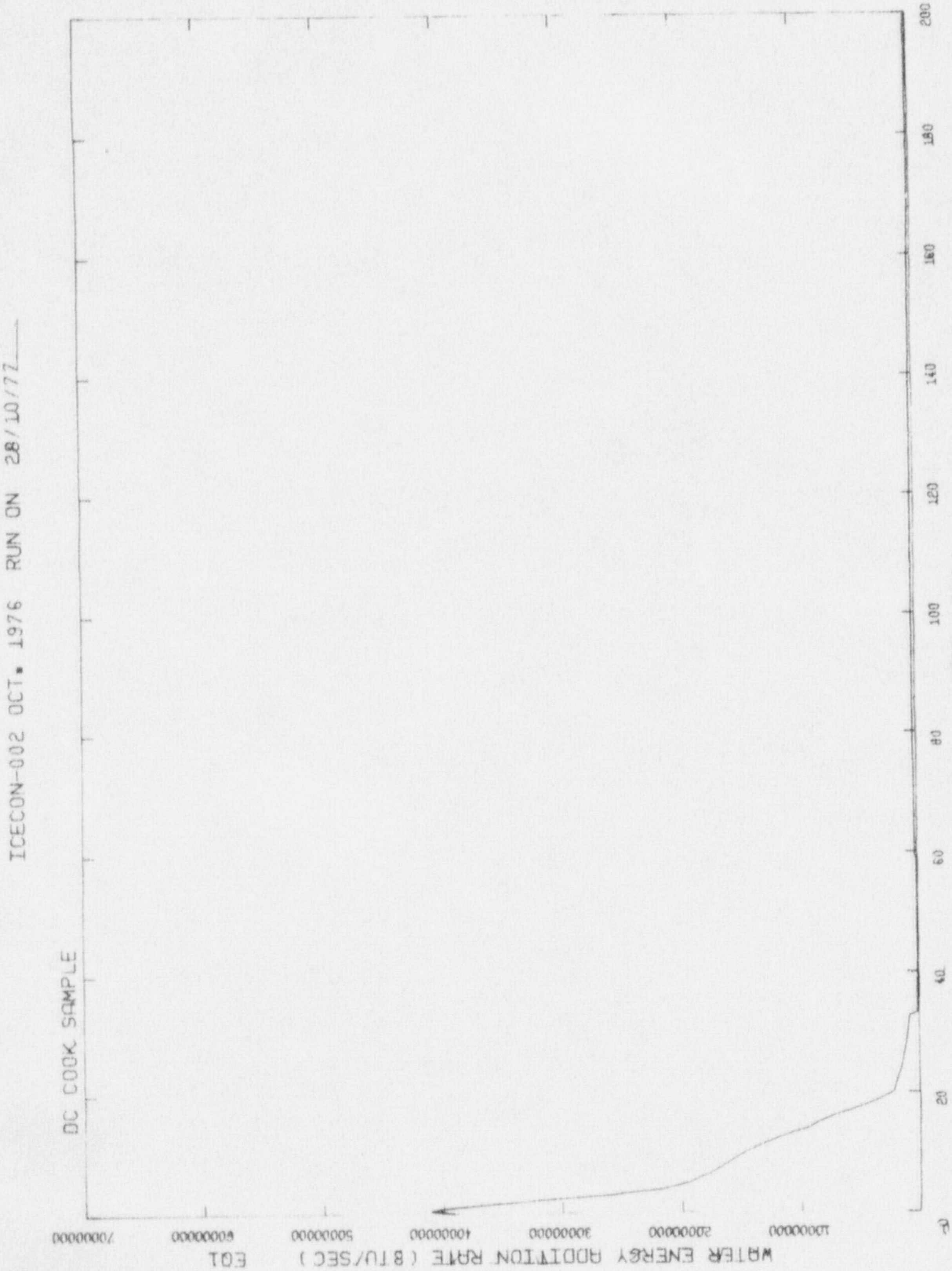

FIGURE A2.7 ENERGY ADDITION RATE OF WATER TO LOWER COMPARTMENT

FIGURE A2.8 ADDITION RATE OF AIR TO LOWER COMPARTMENT

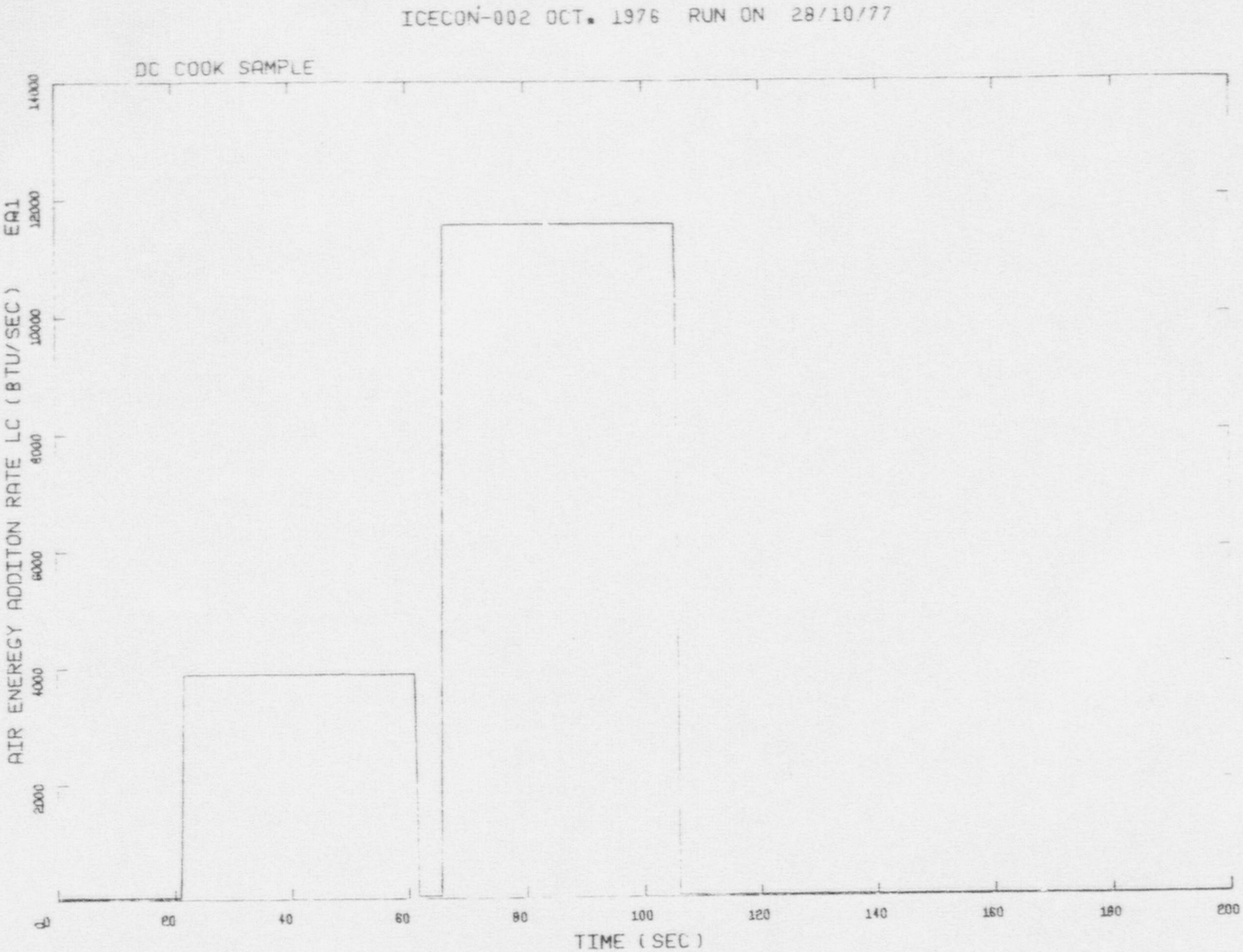

FIGURE A2.9 ENERGY ADDITION RATE OF AIR TO LOWER COMPARTMENT

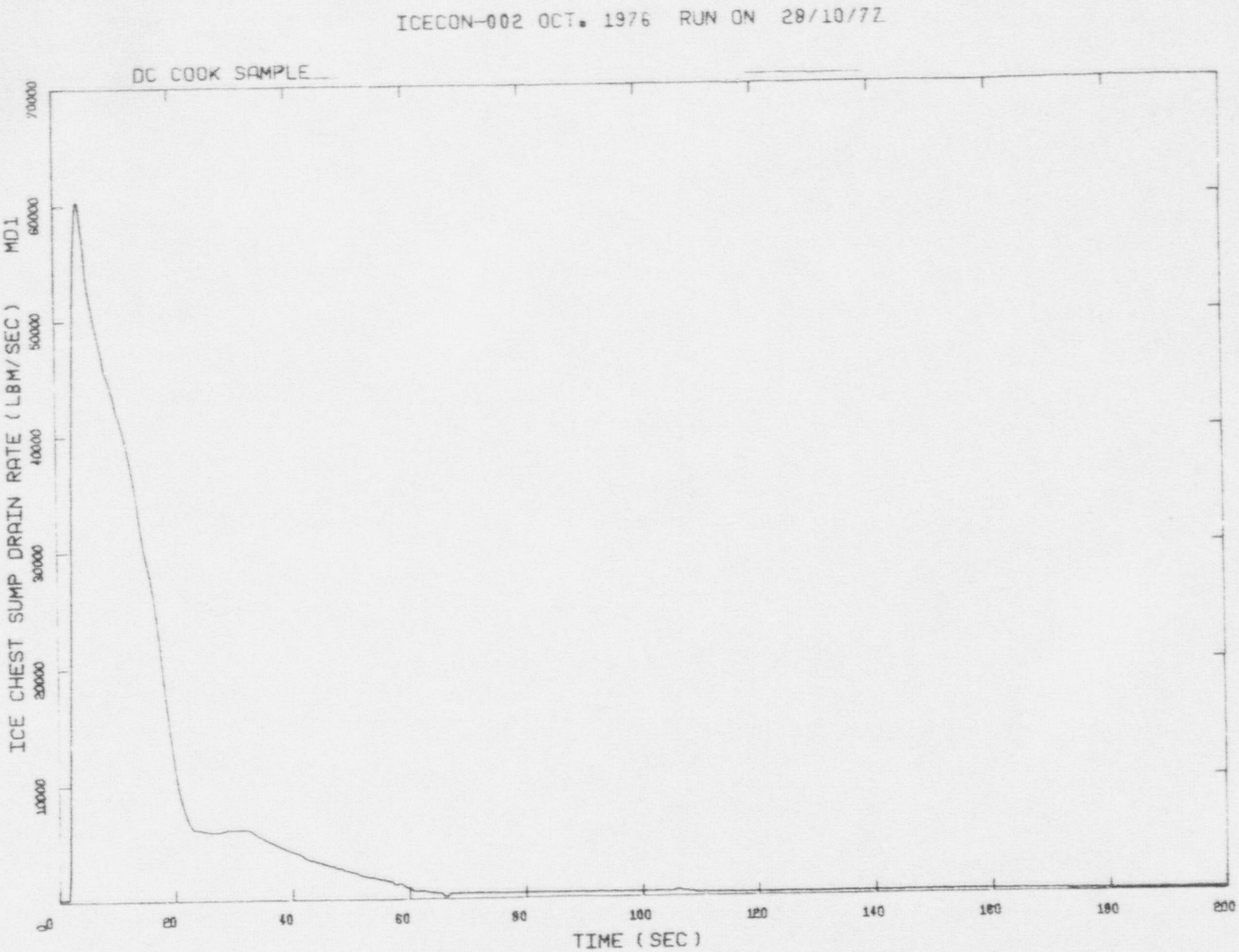

FIGURE A2.10 FLOW OF WATER TO LOWER COMPARTMENT
FROM ICE CHEST

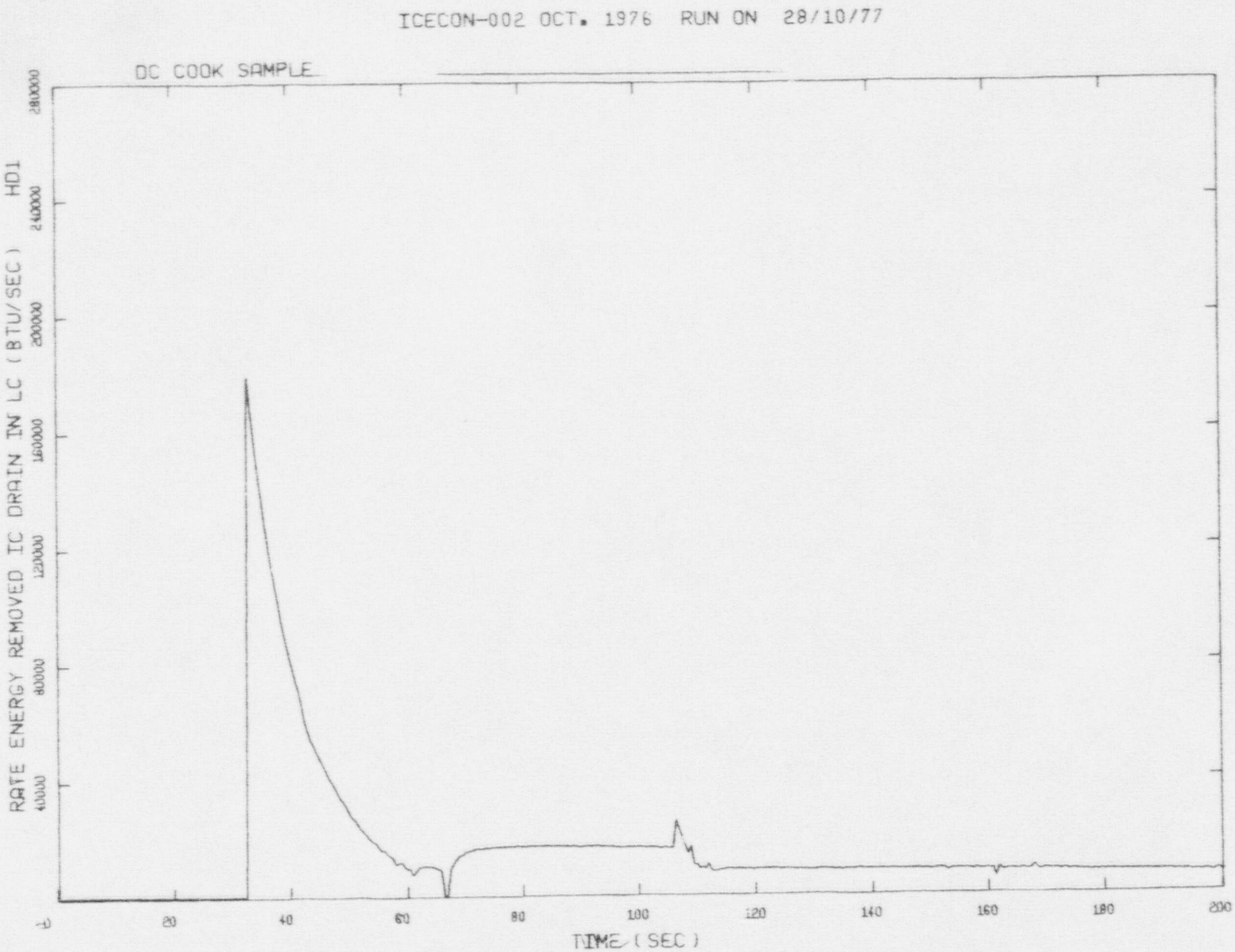

FIGURE A2.11 ENERGY REMOVED FROM LOWER COMPARTMENT BY ICE CHEST SUMP DRAIN FLOW

ICECON-002 OCT. 1976 RUN ON 28/10/77

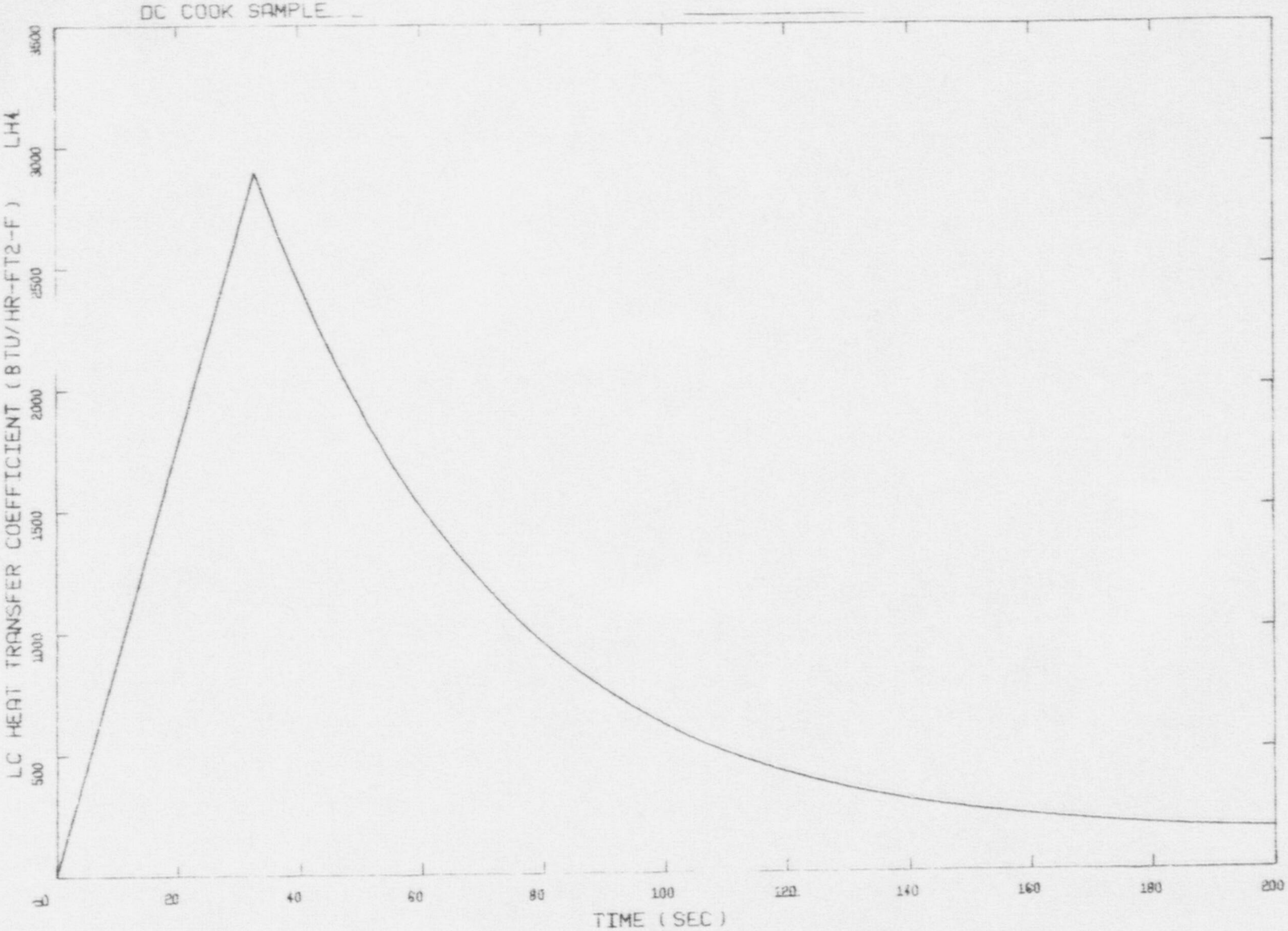

FIGURE A2.12 HEAT TRANSFER COEFFICIENT AT LOWER COMPARTMENT HEAT SLAB

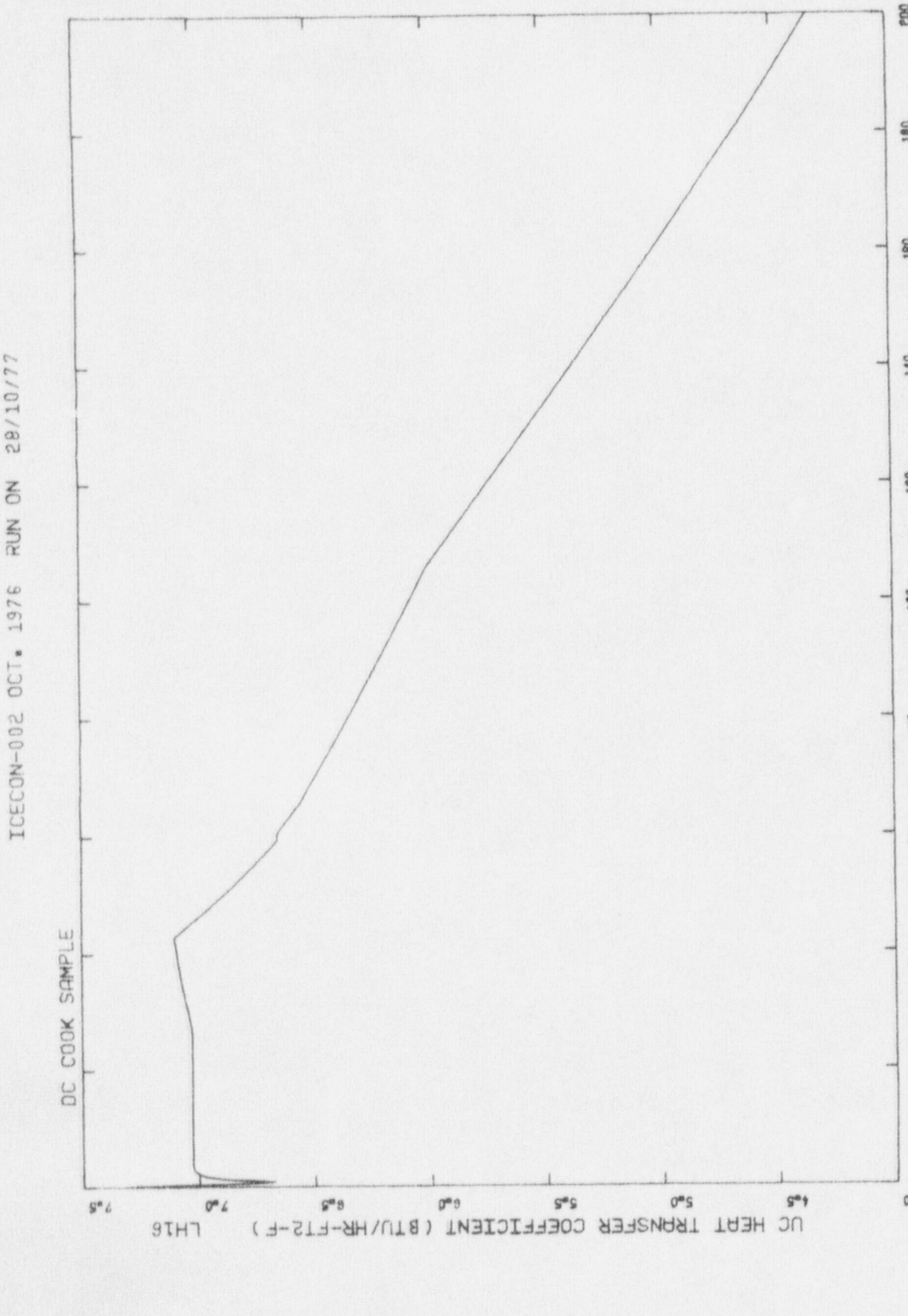

FIGURE A2.13 HEAT TRANSFER COEFFICIENT AT UPPER COMPARTMENT HEAT SLAB

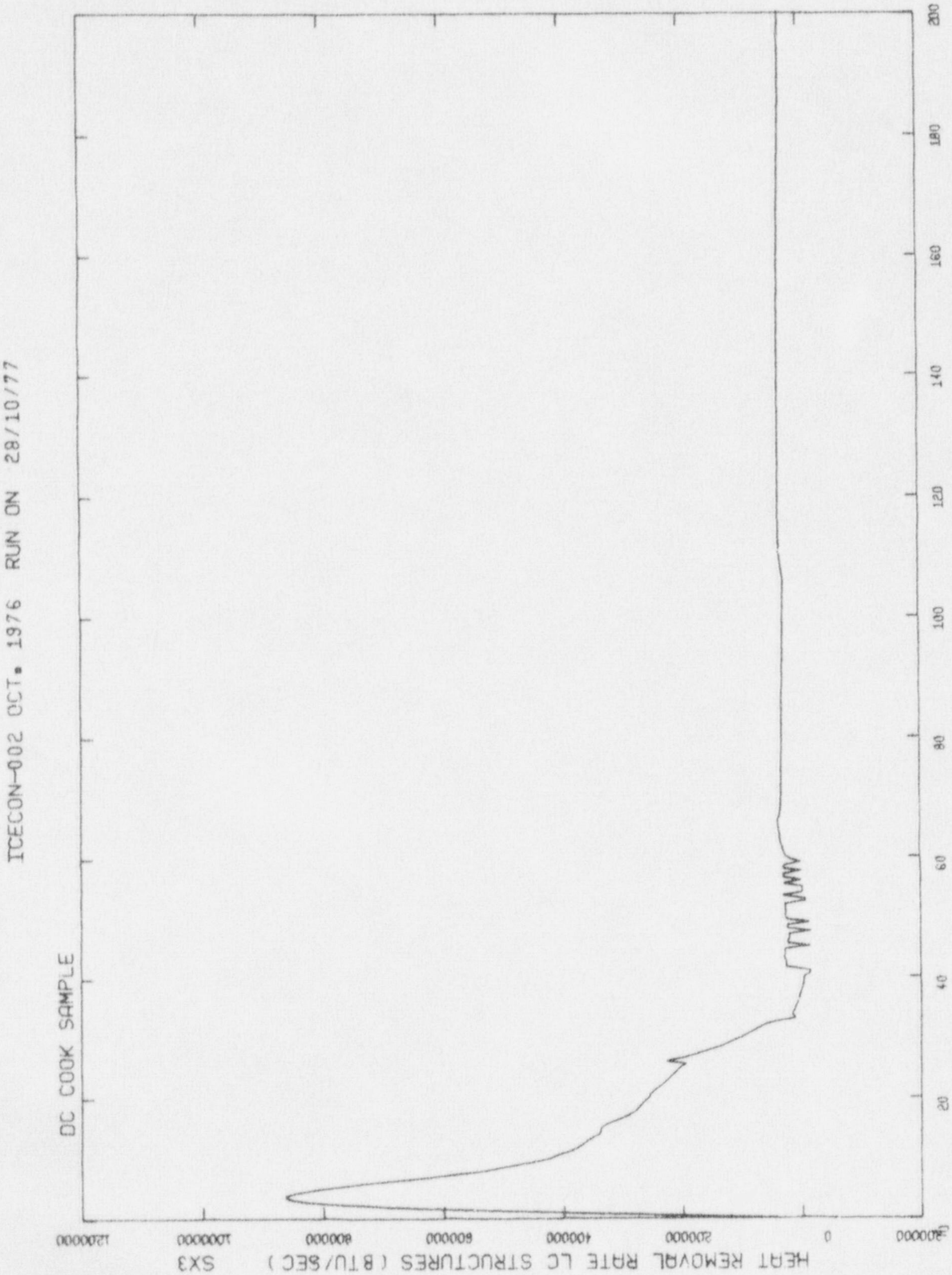

FIGURE A2.14 ENERGY REMOVAL RATE BY LOWER COMPARTMENT HEAT SLABS

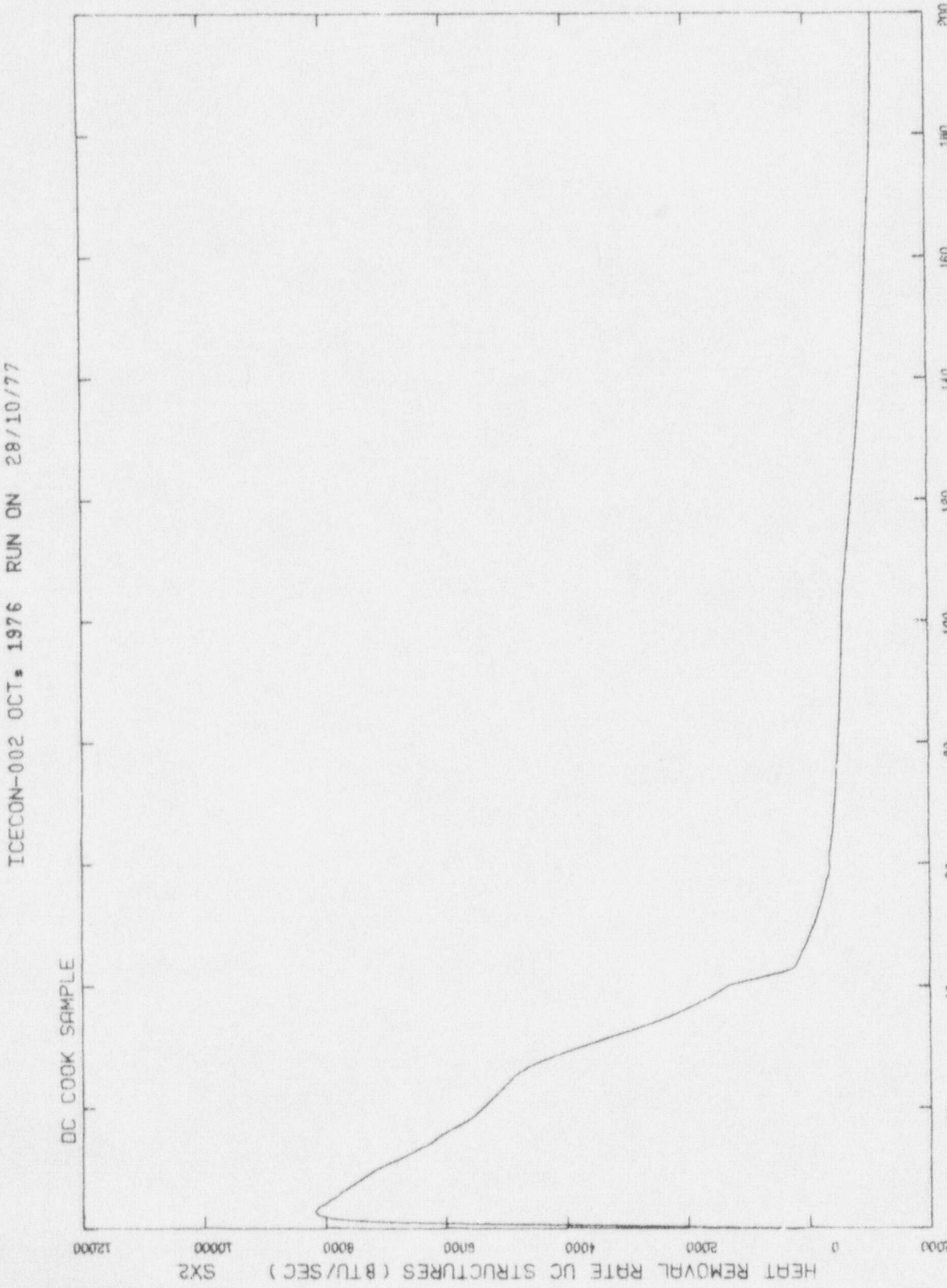

FIGURE A2.15 ENERGY REMOVAL RATE BY UPPER COMPARTMENT HEAT SLABS

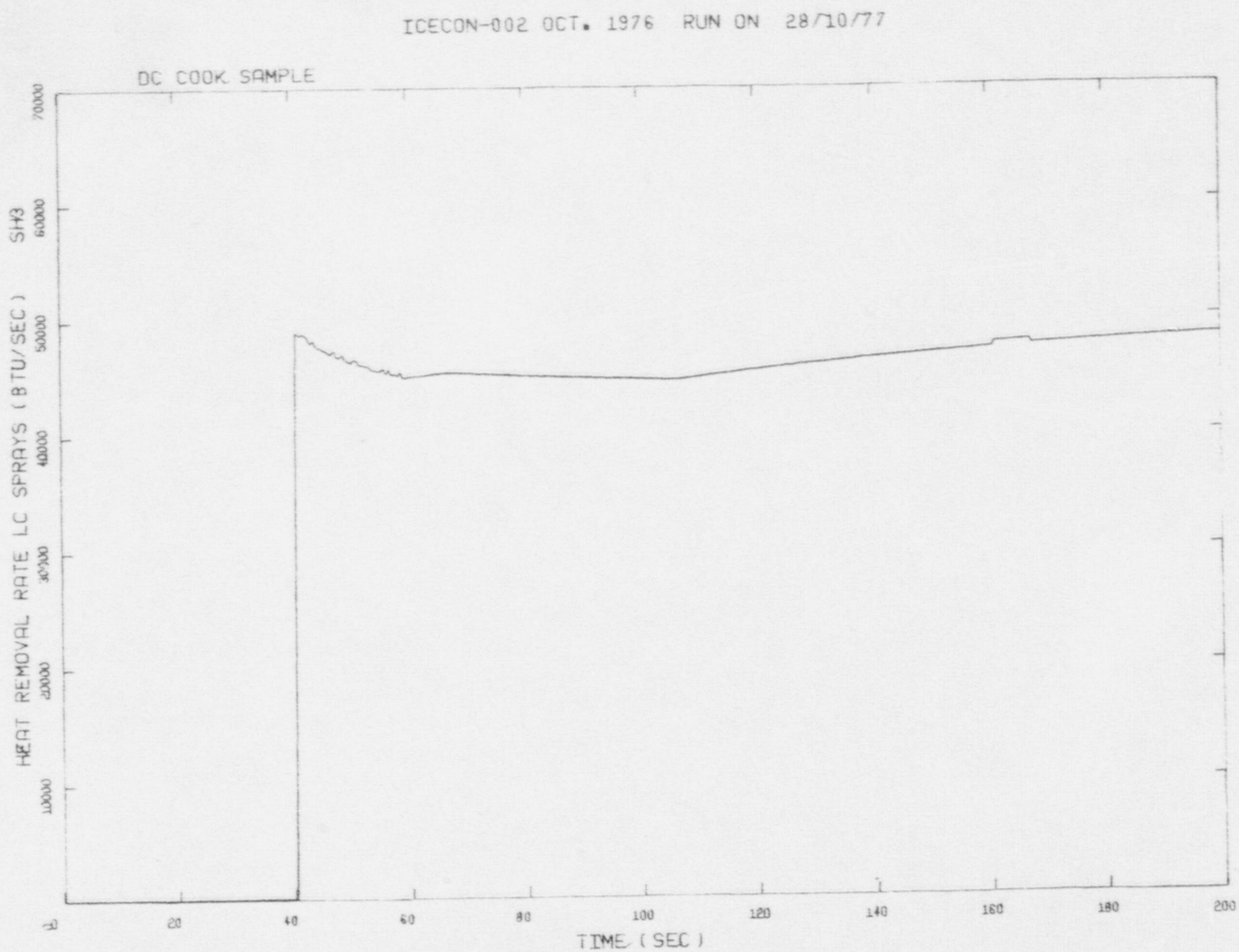

FIGURE A2.16 ENERGY REMOVAL RATE BY LOWER COMPARTMENT SPRAYS

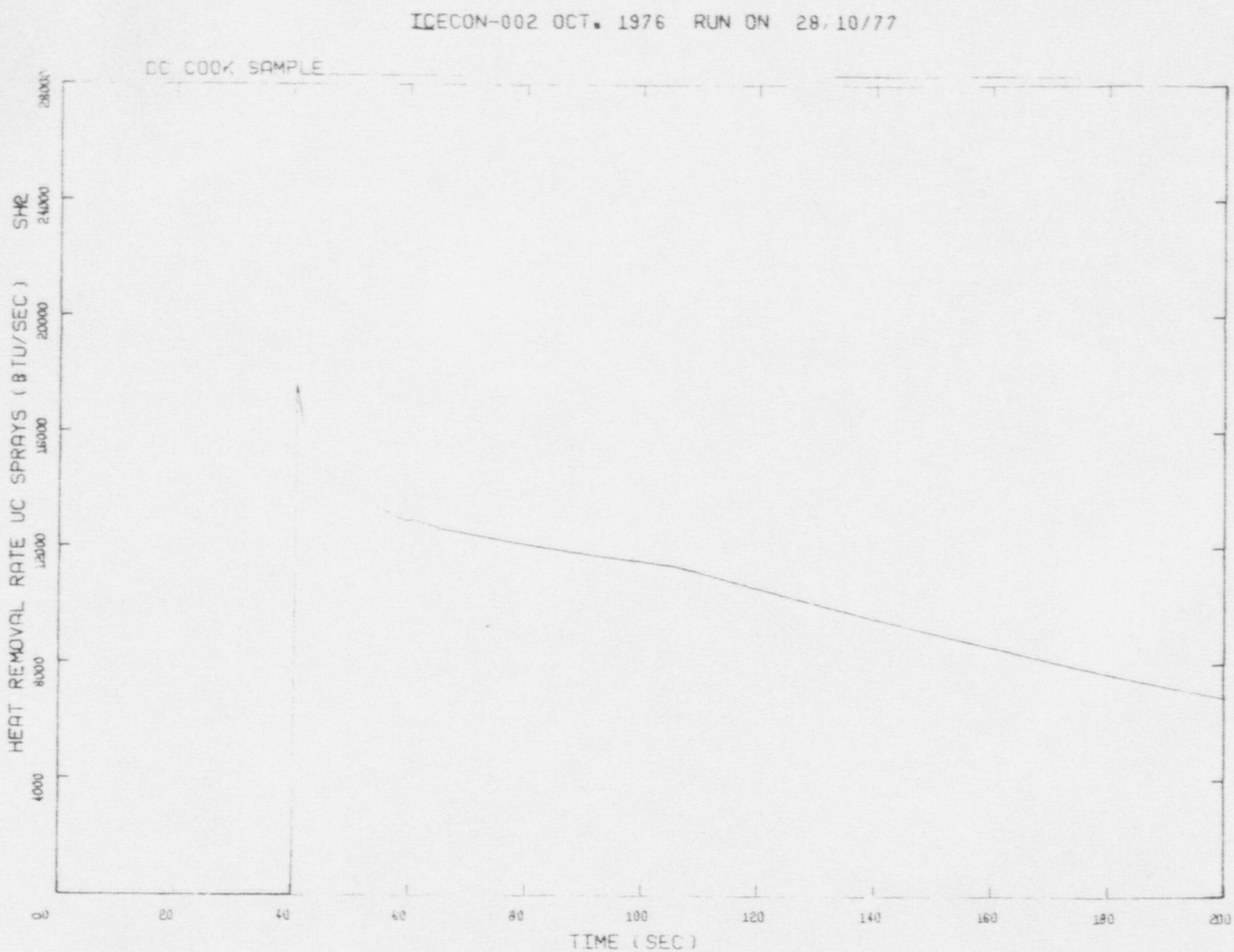

FIGURE A2.17 ENERGY REMOVAL RATE BY UPPER COMPARTMENT SPARYS

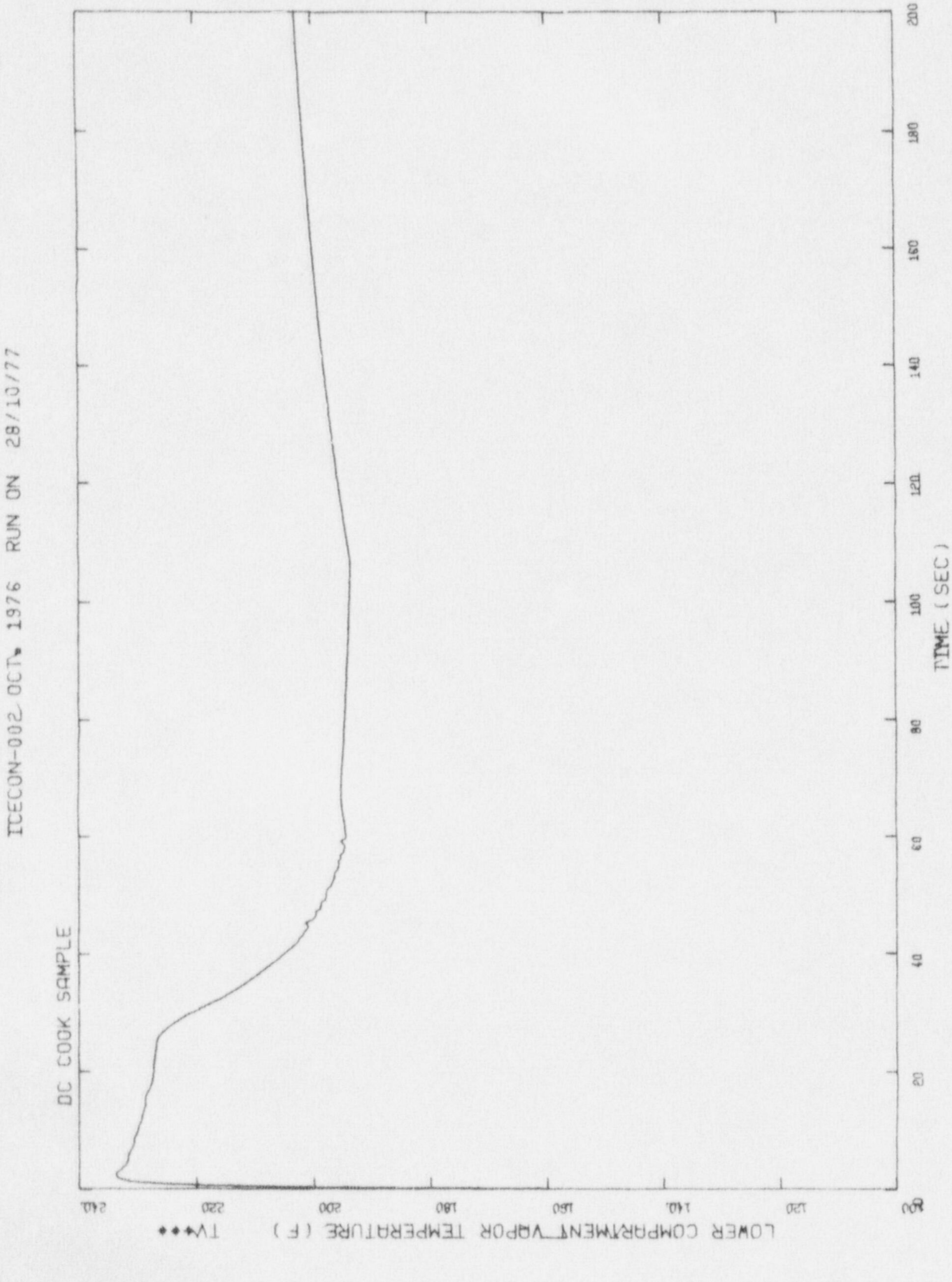

FIGURE A2.18 LOWER COMPARTMENT VAPOR TEMPERATURE

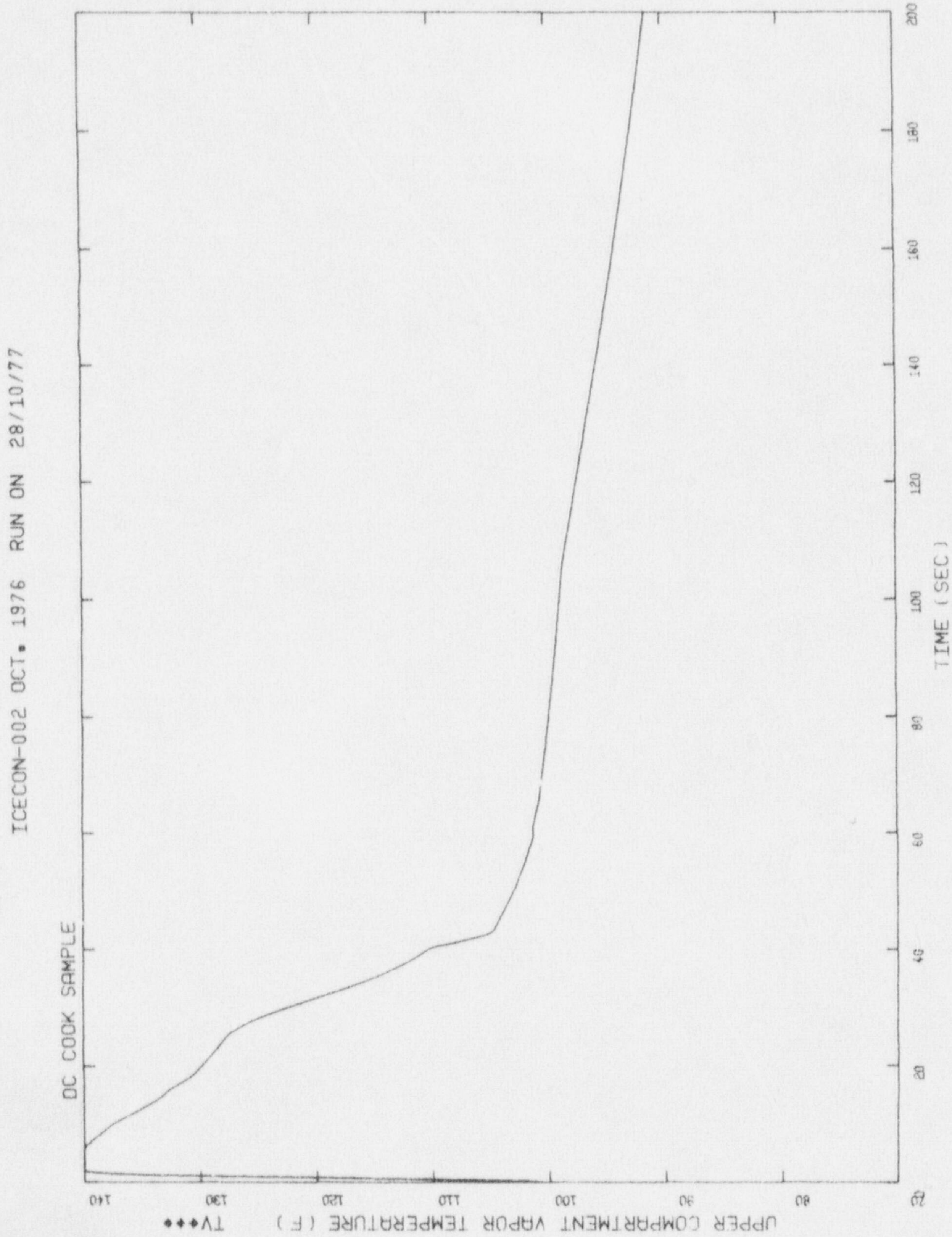

FIGURE A2.19 UPPER COMPARTMENT VAPOR TEMPERATURE

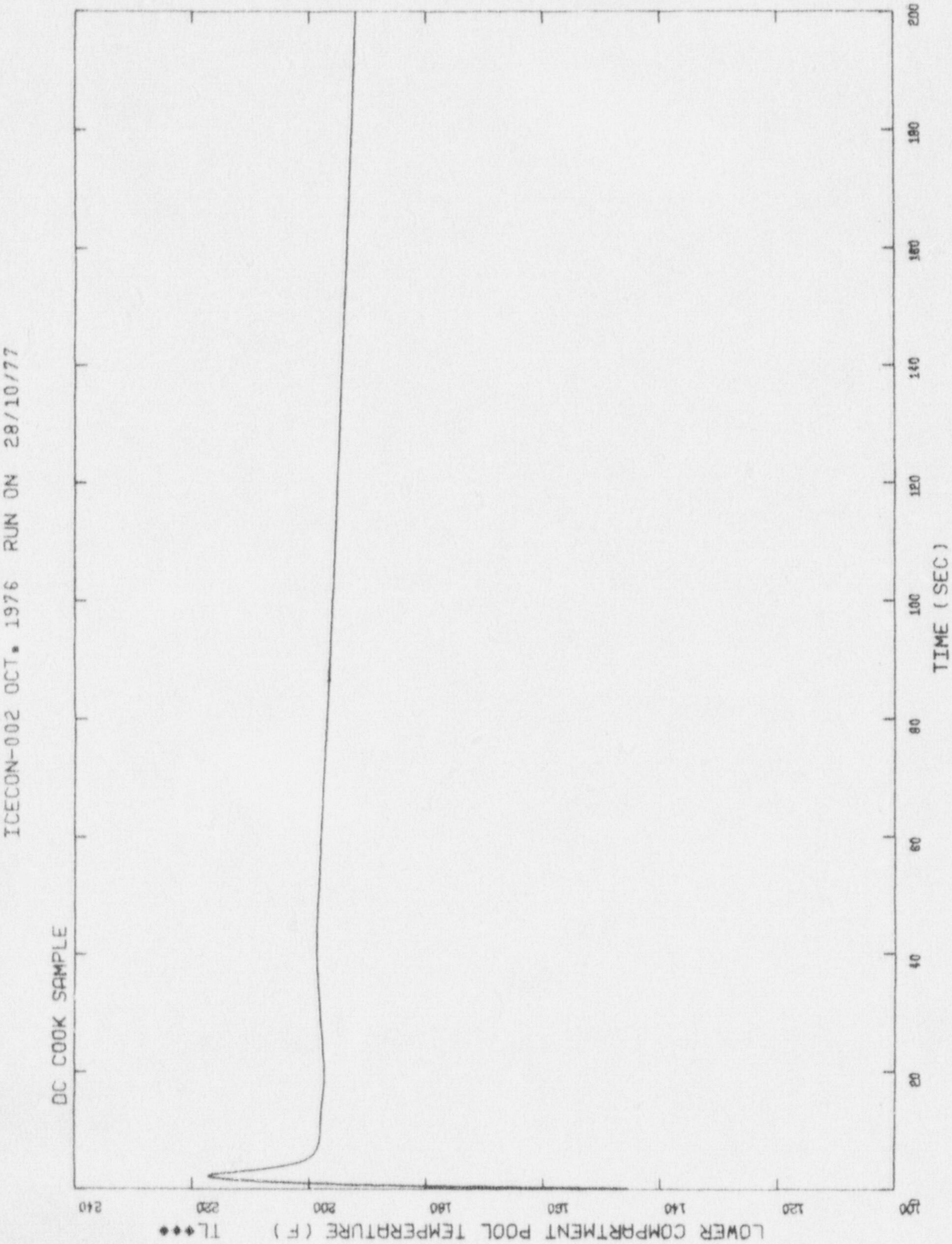

FIGURE A2.20 LOWER COMPARTMENT POOL TEMPERATURE

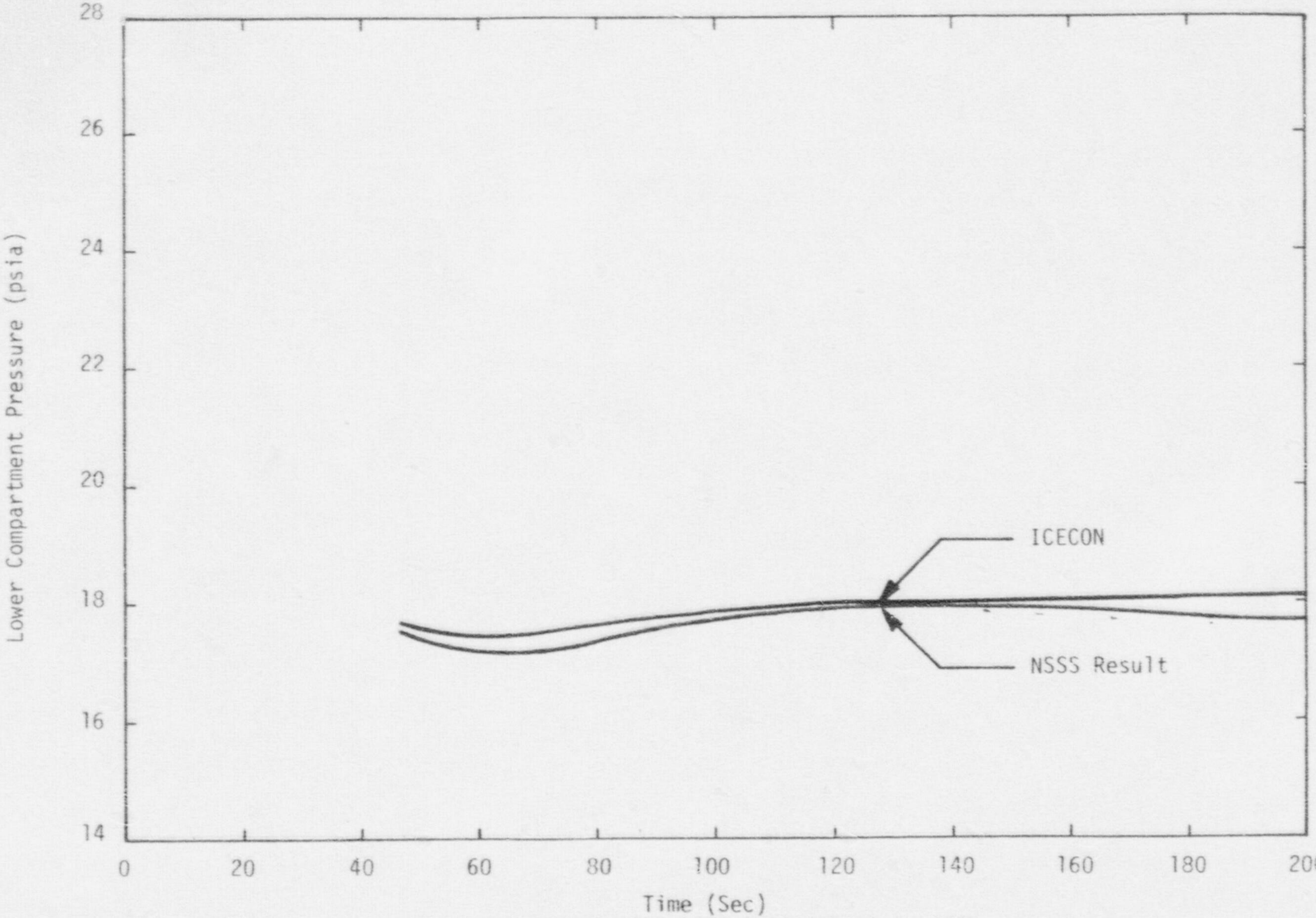

FIGURE A2.21 ICECON AND NSSS SUPPLIER CALCULATED CONTAINMENT PRESSURE

XN-CC-39 (A)

Revision 1

ICECON: A COMPUTER PROGRAM USED TO CALCULATE CONTAINMENT BACK PRESSURE FOR LOCA ANALYSIS (INCLUDING ICE CONDENSER PLANTS)

Distribution

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