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CONTEMPT 4/MOD 3: A Multicompartment Containment System-Analysis Program

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ABSTRACT

CONTEMPT4/MOD3 is a digital computer program, written in FORTRAN IV, that describes the behavior of multicompartment pressurized water reactor (PWR) containment systems and experimental containment systems subjected to postulated loss-of-coolant accident (LOCA) conditions. The program calculates the time variation of compartment pressures, temperatures, mass and energy inventories, heat structure temperature distributions, and intercompartment mass and energy exchange based on user-supplied values for compartment descriptions, time step and edit controls, and selected problem features. Analytical models available to describe containment systems include models for containment fans and pumps, cooling sprays, fan coolers, heat-conducting structures, sump drains, and PWR ice condensers. Dynamic storage allocation (DSA) is used to limit the amount of computer core used for each problem. Optional automatic time step control allows the code to determine time step sizes within limits dictated by the user. Multicompartment capability (up to 999 individual compartments) and generalized, user-oriented input-data descriptions permit improved flexibility over previous codes in the CONTEMPT series. Analytical model descriptions, input instructions, and sample problem results are presented.

FIN No. A6439—Containment Analysis II

SUMMARY

This document is the user's manual for the CONTEMPT4/MOD3 digital computer program. The thermal-hydraulic response of pressurized water reactor (PWR) containment systems and experimental containment systems during postulated accident conditions can be predicted using CONTEMPT4/MOD3. The physical description of the containment system and explicit time step requirements are input to the code which then calculates the time variation of compartment thermodynamic properties and inventories. The analytical models in CONTEMPT4/MOD3 are capable of describing all current PWR containment systems (dry, dual, or ice condenser).

The general logic developed for the CONTEMPT-LT[1] computer program was incorporated into CONTEMPT4/MOD3. The code calculates mass and energy transfer rates due to intercompartment junction flow, effects of containment cooling sprays and fans, temperature distributions in heat conducting structures, and effects of user-specified mass and energy additions. Improvements in CONTEMPT4/MOD3 over CONTEMPT-LT include generalized coding of all problem features to ensure compatibility with the multicompartment logic used throughout CONTEMPT4/MOD3, highly user-oriented input data descriptions, dynamic storage allocation (DSA) coding providing economical computer utilization, optional automatic time step control to calculate time step sizes within user-dictated limits, restart capability, and ice condenser pressure suppression system modeling. Analytical models associated with the ice condenser containment system coding include an ice melting model, an ice chest door model, and an ice chest drain model that redistributes condensation and ice melt water throughout the containment. Program users may input data in British or SI units and specify output in either system.

This report presents a program summary description, descriptions of analytical models with equations and assumptions, and input data requirements for correct program implementation. Appendixes are included which contribute added detail concerning descriptions of containment systems, the STH2O steam tables program used to obtain water properties, storage of tabular data in generalized table format, overall program organization including subroutine level flow charts, compilation of error messages, the PLOTCT4 plotting program, and input and output listings for a sample problem executed using CONTEMPT4/MOD3.

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A MULTICOMPARTMENT CONTAINMENT SYSTEM ANALYSIS PROGRAM

1. INTRODUCTION

This document is a user's manual for CONTEMPT4/MOD3, a digital computer program written in FORTRAN IV, developed at the Idaho National Engineering Laboratory (INEL) by EG&G Idaho, Inc., under the sponsorship of the Nuclear Regulatory Commission. This program can be used to predict the long-term, thermal-hydraulic behavior of water-cooled nuclear-reactor containment systems during postulated loss-of-coolant accident (LOCA) conditions. CONTEMPT4/MOD3 can analyze existing pressurized water reactor (PWR) containment systems (dry, dual, and ice condenser). Containment response in experimental containment systems can also be predicted. This document provides a description of the features and analytical models in CONTEMPT4/MOD3 and presents information needed for program implementation.

Boiling water reactor (BWR) pressure suppression containment systems may be evaluated using the CONTEMPT-LT[1] computer program. CONTEMPT4/MOD3 is an advanced containment analysis code similar to CONTEMPT-LT without the BWR models but with added features, including: generalized multicompartment capability, ice condenser pressure suppression system modeling, dynamic storage allocation coding, optional automatic time step control, restart capability, and flexible input data descriptions. The code calculates the time variation of compartment thermodynamic properties, heat structure temperature distributions, and mass and energy inventories in response to postulated LOCA conditions described by user input. The program is capable of describing the effect of mass and energy transfer due to intercompartment junction flow. Containment cooling spray, fan/pump, and fan cooler analytical models are provided. Any compartment may have both a liquid pool region and a vapor atmosphere region; each region is assumed to have a uniform temperature, although the liquid and pool regions may be at different temperatures. The multicompartment capability of CONTEMPT4/MOD3 allows several specific compartment types to be selected: standard compartment, primary coolant system, drywell, wetwell, ice chest, and outside air. Modeling for the standard compartment is used as the basis for generating the other five compartment types. The wetwell compartment is included for future code versions which will include capabilities for analyzing pool pressure suppression containment systems. Time advancement and output control are explicitly specified by the program user.

Section 2 of this report contains the program summary description. Section 3 describes the available analytical models. Section 4 contains the input instructions needed for correct program use. Topics discussed in the appendixes include:

1. A description of containment systems

2. An STH2O steam table program

3. A description of generalized table logic

4. Overall program organization

5. A summary of error messages

6. A description of the PLOTCT4 plotting program

7. Input and output listing for CONTEMPT4/MOD3 sample problems.

The results of the sample problem can be duplicated using the version of CONTEMPT4/MOD3 retained at INEL under Computer Code Configuration Control Number F00252.

2. PROGRAM SUMMARY DESCRIPTION

CONTEMPT4/MOD3 is a computer program developed to describe the thermal-hydraulic behavior of reactor containment systems subjected to postulated accident conditions. CONTEMPT4/MOD3 can perform numerical analyses of containment behavior for experimental containment systems and pressurized water reactors, including PWR ice condenser pressure suppression systems. The code predicts the effects of intercompartment mass and energy transfer, leakage flow between compartments, heat transfer to structures, mass transfer due to mechanical means such as cooling sprays, and energy removal by heat exchangers.

Each of the lumped parameter compartments (up to 999 compartments, chosen from six basic compartment types, may be specified) can contain a pool region and an atmosphere region at different, but uniform, temperatures. Intercompartment junction flow may be calculated using either sharp-edged orifices (single-phase, homogeneous, or two-phase flow) or nozzles (vapor flow only); junction inertia may be included or omitted for each junction at user option. Up to 99 heat-conducting structures using a variety of heat-transfer options and boundary conditions may be specified. Containment cooling spray analytical models with either single or coupled heat exchangers are provided, as is a common fan/pump analytical model which simulates circulation of either liquid or vapor between compartments, and a fan cooler analytical model which removes energy from compartment vapor regions.

The long-term ice condenser model calculates ice melting with key thermodynamic parameters controlled by user input. Liquid water from ice melting or vapor condensation may be treated as a source to a generalized ice chest drain model which calculates both drain and overflow fluid behavior. Both ice chest drain overflow and drain flow may be sprayed into the receiver compartment. An inertial valve model describes the action of ice condenser ice chest doors.

Containment thermodynamic conditions of air/steam/liquid water mixtures are determined by using modularized equation-of-state subroutines and tabulated water properties, similar to CONTEMPT-LT. The numerics in the code are completely explicit except for the predictor-corrector technique used to estimate heat structure effects on compartment conditions and an implicit calculation of junction flow with inertia.

Major improvements in the CONTEMPT4/MOD3 program over the CONTEMPT-LT program include modularization of features compatible with the generalized multicompartment logic in CONTEMPT4/MOD3, inclusion of an ice-condenser pressure suppression system modeling capability, the addition of dynamic storage allocation coding (allowing problems to be run using only the field length actually required for that particular run), optional automatic time step control, and input data descriptions which permit flexible use of the problem features available in CONTEMPT4/MOD3.

3. ANALYTICAL MODEL DESCRIPTION

This section describes the analytical models, assumptions, and available options used in CONTEMPT4/MOD3. Since this report is primarily a user's manual, details of equation derivations are not routinely presented, although some added detail of the equations and numerical technique is included for several analytical models.

3.1 Compartment Analytical Models

The CONTEMPT4/MOD3 multicompartment code uses a generalized compartment model, designated as the standard compartment, for modeling the various containment compartment types. Each standard compartment includes a vapor region and a liquid pool region. Evaporation, condensation, and pool boiling processes are modeled. The standard compartment model is modified as necessary to describe the five special-case compartment types used in CONTEMPT4/MOD3: ice chest, primary coolant system, drywell, wetwell, and outside air. Only one each of the latter four compartment types is allowed in any single problem. Up to 999 compartments may be specified for a single problem, any number of which may be ice chests or standard compartments. Only those compartment types used in a problem need be specified. Section 3.1.2 discusses the compartment types.

In the following sections, standard compartment features and various applicable analytical models are discussed. The procedure used to initialize compartment conditions at the start of problem execution is also included. The differences between the standard compartment and the five other compartment types are presented.

3.1.1 Standard Compartment Features. Each standard compartment may contain a liquid pool region with a vapor region above the pool. Each region is assumed to have a homogeneous composition and a uniform temperature, although the vapor and pool regions may be at different temperatures. Several features of the standard compartment model are discussed below.

3.1.1.1 Vapor Region—Compartment thermodynamic conditions are calculated at the end of each time step based on the compartment mass and energy inventories and additions for that time step. Mass and energy in a compartment vapor region may be modified by interactions with the pool region, heat transfer through structures, leakage or flow via junctions, pressure suppression systems, safeguard systems such as fans and sprays, and tabular additions input by the program user.

Thermodynamic properties for water and steam are generated by the STH2O water properties program described in Appendix B. These properties are then made available to CONTEMPT4/MOD3 in tabular form as a data set. At the end of each time step, a mass/energy balance, based on the temperature flash method, is performed on the vapor region to determine the atmosphere region temperature. This method assumes that the air/steam/liquid water mixture instantaneously and uniformly arrives at thermal equilibrium. A search is performed in the steam tables (STH2O4 in Appendix B), based on specific volume of water in the atmosphere region and trial temperature values, until a vapor temperature corresponding to the total vapor energy is found. The program mass and energy balancing subroutine (COMPU) computes 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

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

$$U_v = M_{wv} u_w + M_a c_v T_v . \tag{2}$$

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

$$P = P_{wv} + \frac{M_a R_a T_v}{V_v} \tag{3}$$

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

$$P = P_{wv} + \frac{M_a R_a T_v}{x M_{wv} v_g} \tag{4}$$

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

where

V_v = vapor region volume

M_{wv} = mass of water in vapor region

v_w = specific volume of water

U_v = total internal energy

u_w = specific internal energy of water as a function of T_v and v_w

M_a = mass of air

c_v = constant volume heat capacity of air

T_v = vapor temperature (absolute units)

P = total pressure

P_{wv} = partial pressure of water as a function of T_v and v_w

R_a = gas constant for air

x = quality of two-phase region

v_g = specific volume of saturated water vapor as a function of T_v

v_f = specific volume of saturated liquid as a function of T_v.

These equations are based on the assumptions of the Gibbs-Dalton law for vapors, with (a) no vapor dissolved in the liquid, (b) air as a perfect gas, and (c) all components 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 mixture quality x is also obtained from the solution process), the total pressure is calculated from Equation (3) or (4). The mass of steam M_{wvv} and mass of liquid water $M_{wv\ell}$ within the vapor region are determined from

$$M_{wvv} = xM_{wv} \quad (6)$$

$$M_{wv\ell} = (1 - x)\, M_{wv}. \quad (7)$$

The disposition of liquid water $M_{wv\ell}$ in the vapor region for each compartment is controlled by a user-input time constant which specifies the deentrainment rate per unit time for dropout of liquid water from the vapor region to the pool region. For example, dropout of 75% of the entrained liquid water to the pool region each second is represented by a deentrainment rate of 0.75 s^{-1} or 45.0 min^{-1}. The program calculates the fractional amount of entrained liquid water transferred to the pool each time step as the product of the time step size and the deentrainment rate. The amount of water deentrained per time step depends on the time step size. The default value (10^{12} s^{-1}) for this option generally gives conservative results by transferring all the entrained liquid water to the pool each time step. However, depending on the problem geometry and blowdown composition, selection of the default value may be unrealistic since carryover of liquid droplets to adjacent compartments will be precluded.

3.1.1.2 Liquid Region—The compartment model in CONTEMPT4/MOD3 does not require that a liquid pool region exist within a compartment. The liquid pool region mass and energy inventories may be modified by interactions with the vapor region, heat transfer through structures, sump flow, tabular additions input by the user, pressure suppression systems, and safeguard systems such as containment sprays.

Pool region thermodynamic conditions are determined after vapor region conditions are calculated. The compartment liquid region, if it exists, is assumed to be single-phase liquid (quality = 0). The pool specific energy for liquid $u_{\ell p}$ is calculated from

$$u_{\ell p} = \frac{U_\ell}{M_{w\ell}} \quad (8)$$

where

U_ℓ = total energy of liquid pool water

$M_{w\ell}$ = total mass of liquid pool water.

The region temperature, specific volume $v_{\ell p}$, and other specific properties are determined from the steam tables (STH2OU in Appendix B). The liquid pool volume, v_ℓ, is determined by

$$V_\ell = M_{w\ell} v_{\ell p}. \quad (9)$$

3.1.1.3 Liquid-Vapor Interactions—Each compartment, except ice chests that have ice present, may have energy transfer between the pool and vapor regions by models for the following:

1. Pool boiling
2. Pool evaporation
3. Vapor condensation
4. Sensible heat transfer through liquid-vapor interface.

The four liquid-vapor interaction models above do not apply to active ice chests; i.e., ice chests that have ice present. The liquid-vapor interaction models are applicable only for compartments that contain no ice. The following two sections describe the pool boiling and evaporation/condensation models.

3.1.1.3.1 Pool Boiling—Pool boiling occurs only if the pool specific energy is greater than the liquid region specific energy of saturated liquid based on total pressure $u_{\ell pb}$; that is, if

$$\frac{U_\ell}{M_{w\ell}} > u_{\ell pb} \tag{10}$$

where

U_ℓ = pool region total internal energy

$M_{w\ell}$ = pool region mass of water.

If boiling occurs, the mass of water boiled off is immediately transferred from the pool to the vapor region. The transferred mass, M_{boil}, is

$$M_{boil} = (U_\ell - M_{w\ell} u_{\ell pb}) / (u_{gpb} - u_{\ell pb}) \tag{11}$$

where

$u_{\ell pb}$ = specific energy of saturated liquid water based on total pressure

u_{gpb} = specific energy of saturated vapor based on total pressure.

The vapor and pool total water masses are appropriately adjusted, and the total energy content of each region is determined from the sum of U_v and U_ℓ:

$$U_v = U_v + u_{gpb} M_{boil} \tag{12}$$

$$U_\ell = u_{\ell pb} M_{w\ell}. \tag{13}$$

3.1.1.3.2 Evaporation, Condensation, and Sensible Heat—If pool boiling occurs during a time step, no evaporation or condensation is permitted during the same time step. The boiling model is an instantaneous mass transfer model whereas the evaporation-condensation model is time-dependent. The evaporation and condensation analytical equations are identical; only the direction of mass and energy movement changes.

Figure 1 depicts a simplified representation of a generalized compartment in CONTEMPT4/MOD3. A pool with bulk temperature T_f is considered. Saturation conditions are presumed to prevail at the interface; thus the interface temperature T_b equals T_f, and heat transfer between the pool and the vapor region is equal to that between the interface and the bulk vapor mixture at temperature T_g. Heat transfer from the surface has two parts: the sensible heat transferred by the temperature gradient and the latent heat of the mass transferred by the molar concentration gradient in the vapor. The following equation is used to evaluate evaporation and condensation:[2]

$$\phi = C_1 h_b (T_g - T_b) + [C_2 K_b \mathcal{M}_g (h_{fg} + h_f)(x_g - x_b)] / x_{am} \tag{14}$$

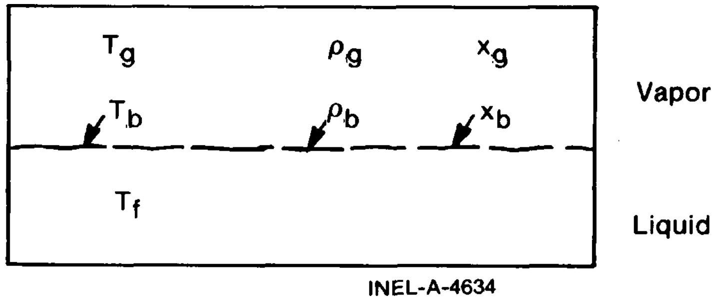

Figure 1. Compartment containing liquid and vapor regions.

where

ϕ = surface heat flux

C_1 = input heat transfer multiplier constant

h_b = sensible heat transfer coefficient at interfaces, for small mass transfer conditions

C_2 = input mass transfer multiplier constant

K_b = mass transfer coefficient

M_g = molecular weight of water

h_{fg} = latent heat of vaporization

h_f = specific internal enthalpy of fluid transferred

x_g = mole fraction of vapor in bulk

x_b = mole fraction of vapor at boundary

x_{am} = logarithmic mean mole fraction of air.

The constants C_1 and C_2 have been added to allow program users to choose either or both effects or to modify them for a given problem. Strict adherence to theory requires $C_1 = C_2 = 1$. The heat flux calculated by the second half of Equation (14) associated with the latent heat of mass transferred is used to calculate the mass transfer rate across the liquid-vapor interface. For both evaporation and condensation (the equation is the same; only the direction of mass movement changes), the mass transfer rate $\dot{m}_{ce}$ is calculated from

$$\dot{m}_{ce} = [C_2 K_b M_g (x_g - x_b)] / x_{am} . \tag{15}$$

The program will check to ensure that the mass transferred within a given time step does not exceed the total mass of water available in the region involved.

The remainder of this section describes how the terms in Equation (14) are evaluated. The logarithmic mean mole fraction, x_{am}, is used to account for the influence of air on interfacial resistance to mass transfer. It is defined by[3]

$$x_{am} = \frac{x_{ab} - x_a}{\ln(x_{ab} / x_a)} \tag{16}$$

where

x_{ab} = mole fraction of air at boundary

x_a = mole fraction of air in vapor mixture.

Heat transfer by natural convection for horizontal flat surfaces is modeled in CONTEMPT4/MOD3 and is dependent on the Grashof number (Gr) and the Prandtl number (Pr).

A value for h_b is obtained from the heat transfer coefficient correlations for surfaces facing upward, which are[4,5]

Heated surface, turbulent range, $2 \times 10^7 < Gr\,Pr < 3 \times 10^{10}$

$$\frac{h_b L}{k_b} = 0.14\,(Gr\;Pr)_b^{1/3} \quad . \tag{17}$$

Heated surface, laminar range, $10^5 < Gr\,Pr < 2 \times 10^7$

$$\frac{h_b L}{k_b} = 0.54\,(Gr\;Pr)_b^{1/4} \quad . \tag{18}$$

Cooled surface, laminar range, $3 \times 10^5 < Gr\,Pr < 3 \times 10^{10}$

$$\frac{h_b L}{k_b} = 0.27\,(Gr\;Pr)_b^{1/4} \quad . \tag{19}$$

where the subscript b refers to the saturated boundary layer (for example, air/steam mixture) properties. The data for these correlations were derived from horizontal square plates exposed to air, with the characteristic geometry factor L being the length of a side. Disturbance of the surface can result in larger heat transfer coefficients.

The Grashof and Prandtl numbers are defined by

$$Gr = \frac{\beta g\,\Delta T L^3 \rho^2}{\mu^2} \tag{20}$$

$$Pr = \frac{C_p \mu}{k} \tag{21}$$

where

β = coefficient of thermal expansion

g = acceleration due to gravity

ΔT = temperature difference $|T_g - T_b|$

L = characteristic length of surface

ρ = density

μ = viscosity

C_p = specific heat

k = thermal conductivity.

With h_b known, the mass transfer coefficient, K_b, is obtained from[3]

$$K_b = \frac{h_b}{C_{pg} M_g} \left(\frac{Pr}{Sc}\right)^{2/3} \tag{22}$$

where

C_{pg} = specific heat of vapor region

Sc = Schmidt number.

The Schmidt number is defined by

$$Sc = \frac{\mu}{\rho D_{AB}} \tag{23}$$

where

D_{AB} = mass diffusivity of binary mixture with components A and B.

Diffusivities of gases at low density are composition dependent, increase with temperature, and vary inversely with pressure.[3] Diffusivity, D_{AB}, can be estimated from [3]

$$D_{AB} = \frac{a}{P} \left(\frac{T}{\sqrt{T_{cA} T_{cB}}}\right)^b (P_{cA} P_{cB})^{1/3} (T_{cA} T_{cB})^{5/12} \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{1/2} \tag{24}$$

where

a = constant = 3.688×10^{-4} for water and air

P = pressure of mixture

T = temperature of mixture

T_{cX} = critical temperature of component X

b = constant = 2.334 for water and air

P_{cX} = critical pressure of component X

M_X = molecular weight of component X.

Constants a and b were derived from experimental data. For an air-steam mixture, Equation (24) reduces to

$$D_{AB} = \frac{4.40 \times 10^{-6} \, T^{2.334}}{P} \quad . \tag{25}$$

If a situation arises such that a given vapor region is unsaturated although the whole compartment is at the same temperature, the Grashof number is zero and Equation (22) cannot be used to calculate K_b. In this case, K_b is calculated from[6]

$$K_b = \frac{\gamma P D_{AB}}{LRT} \left[\frac{L^3 g \, (\rho_o - \rho_b)}{\mu D_{AB}} \right]^{0.373} \tag{26}$$

where

γ = constant = 1.02 for vertical walls (assumed 1.0 for horizontal, flat surfaces)

R = universal gas constant

ρ_o = vapor region density in bulk

ρ_b = vapor region density at interface.

The sensible heat transfer rate, h_b, must be changed if the mass transfer rate is large. Mass transfer coefficient, K_b, is kept constant. The transfer rate will also include sensible heat transfer by the vapor molecules, in which case the sensible heat transfer coefficient with mass transfer h_b' is related to that without mass transfer by[3]

$$h_b' = \left[\frac{a}{\exp(a) - 1} \right] h_b \tag{27}$$

where

$$a = \frac{K_b M_b C_{pg} (x_g - x_b)}{h_b x_{am}} \quad . \tag{28}$$

Equation (27) is used to determine h_b, if the mass transfer rate is large. If $|a|$ in Equation (27) is less than 0.0001, the correction for large mass transfer rate is not used.

3.1.1.4 Initialization of Standard Compartment Conditions—The problem input defines necessary compartment conditions at initial steady-state conditions. Initialization for either saturated or superheated compartment conditions can be performed. Steam tables (in Appendix B) provide specific property values for the compartment regions. The water vapor partial pressure in each compartment vapor region is determined from

$$P_{wv} = P_s HUM \quad (29)$$

where

P_s = saturation pressure in vapor region

HUM = input relative humidity for compartment, defined as the ratio of the pressure of water vapor present to the pressure of saturated water vapor at the atmosphere temperature.

The initial mass of water vapor in a compartment vapor region, M_{wvv}, is

$$M_{wvv} = V_v HUM / v_g \quad (30)$$

where

V_v = volume of vapor region

v_g = specific volume of water vapor in compartment vapor region.

The initial mass of air in the compartment, M_a, is calculated from

$$M_a = \frac{V_v (P - P_{wv})}{T_v R_a} \quad (31)$$

where

P = total pressure in vapor region

T_v = absolute temperature of compartment vapor region

R_a = gas constant for air.

The initial energy associated with the air, U_a, is

$$U_a = M_a c_{va} T_v \quad (32)$$

where

c_{va} = specific heat of air at constant volume.

The liquid pool region mass and energy are determined from the input volume of pool water and calculated specific thermodynamic properties. The total mass and energy in each compartment is determined from a combination of the preceding equations, input inventories, and specific thermodynamic properties.

3.1.2 Compartment Types. CONTEMPT4/MOD3 differentiates among six different compartment types: standard (described in Section 3.1.1), ice chest, drywell, wetwell, primary coolant system, and outside air. In CONTEMPT4/MOD3 all compartment types except ice chests and outside air are treated as standard compartments throughout the program. Future modifications to CONTEMPT4 will include installation of the BWR models presently contained in CONTEMPT-LT, in which case different models will be needed to represent the drywell, wetwell, and primary containment compartments.

3.1.2.1 Outside Air—The outside-air compartment type behaves similarly to the atmosphere. A table is provided which allows the program user to input the temperature of the outside air compartment as a function of time, thus simulating the daily fluctuations in ambient temperature. Mass and energy balances are performed for all compartment types except outside air.

3.1.2.2. Ice Chests—Thermodynamic conditions in ice chests are determined based on an ice condenser model described in Section 3.8.1. Key thermodynamic conditions are controlled by user input. The liquid-vapor interaction models described in Section 3.1.1.3 do not apply to ice chests. Ice chests that achieve total ice melt are treated as standard compartments for the remainder of the problem.

3.2 Tabular Mass and Energy Transfer Analytical Model

The transaction model in CONTEMPT4/MOD3 is used to describe user-controlled mass and energy transfer to specific compartment regions. Through the use of input sets of time-dependent mass and energy rate additions, the program user may simulate system blowdown, primary decay heat release, metal-water reaction heat release, and direct mass/energy additions. Any number of transaction tables needed may be entered to represent the tabular mass and energy additions for a problem.

3.2.1 Generalized Tables. Tabular input data for many of the analytical model descriptions in CONTEMPT4/MOD3, including the transaction model, are input using standardized input format and are stored in a common storage block by the generalized table feature. A generalized table consists of sets of one independent variable and one, two, or three dependent variables. A detailed description of generalized table format and input is given in Appendix C.

Generalized tables are used to input data for the transaction model. Transactions are divided into two categories: single transactions and double transactions, according to whether the transfer takes place between a compartment and a source or between two compartments, respectively.

3.2.2 Single Transactions. Direct transfer of mass and energy between any specified compartment region and an infinite source is called a single transaction. The single transaction model requires the user to provide a generalized table of time-dependent mass and energy transfer-rate additions. The user must also specify the compartment involved, the receiving region, the material transferred, and multipliers for the mass and energy transfer rates. Whenever a single transaction is specified, the mass and energy rate additions are obtained by interpolation of the appropriate generalized table. Depending upon the material transferred and the compartment region involved, the appropriate current time step mass and energy transfer rates are adjusted in accordance with:[a]

$$\dot{m}_{rmc} = \dot{m}_{rmc} + \Delta\dot{m}_t C_m \tag{33}$$

$$\dot{q}_{rc} = \dot{q}_{rc} + \Delta\dot{q}_t C_q \tag{34}$$

a. The notation Z = Z + X is used throughout this report to indicate that the quantity Z is updated by adding to it the quantity X, and the result is again Z.

where

$\dot{m}_{rmc}$ = mass addition rate of material m into region r of compartment c

$\Delta\dot{m}_t$ = mass rate addition term at time t obtained from generalized table

C_m = multiplier on mass rate addition

$\dot{q}_{rc}$ = energy addition rate into region r of compartment c

$\Delta\dot{q}_t$ = energy rate addition term at time t obtained from generalized table

C_q = multiplier on energy rate addition.

Transfer takes place only when the current time is within the range of a single transaction table.

3.2.3 Double Transactions. When both the donor and receiver compartments involved in a mass and energy transfer are specified, the exchange is called a double transaction. The user-input generalized table for a double transaction will list only one time-dependent rate addition (either mass or energy); the other rate addition will be determined based on conditions in the donor compartment at the beginning of the time step. For each double transaction the user must specify both the donor and receiver compartment regions involved and multipliers on the mass and energy rate additions. Average or homogeneous region material is transferred from the donor to the receiver compartment. In addition to Equations (33) and (34) listed for single transactions, the following equations are used for the double transaction model:

$$\Delta\dot{q}_{tg} = \Delta\dot{m}_{tg}\left(\frac{M_v}{M_g} h_{vg} + \frac{M_a}{M_g} c_{pa} T_g + \frac{M_\ell}{M_g} h_{\ell g}\right) \tag{35}$$

$$\Delta\dot{q}_{tp} = \Delta\dot{m}_{tp} h_{\ell p} \tag{36}$$

where

$\Delta\dot{q}_{tg}$ = energy rate addition term at time t into atmosphere region g of receiver compartment

$\Delta\dot{m}_{tg}$ = mass rate addition term at time t into atmosphere region g of receiver compartment

M_v = mass of water vapor in atmosphere region of donor compartment

M_g = mass of atmosphere of donor compartment

h_{vg} = specific enthalpy of water vapor in atmosphere region of donor compartment

M_a = mass of air in atmosphere region of donor compartment

c_{pa} = constant pressure heat capacity of air

T_g = temperature of atmosphere region of donor compartment

M_ℓ = mass of water liquid in atmosphere region of donor compartment

$h_{\ell g}$ = specific enthalpy of water liquid in atmosphere region of donor compartment

$\Delta \dot{q}_{tp}$ = energy rate addition term at time t into pool region p of receiver compartment

$\Delta \dot{m}_{tp}$ = mass rate addition term at time t into pool region p of receiver compartment

$h_{\ell p}$ = specific enthalpy of water liquid in pool region of donor compartment.

Equations (35) and (36) are used to calculate either the mass rate addition if energy rate addition is provided, or the energy rate addition if mass rate addition is provided. After the rate additions are determined, the compartment mass and energy transfer rates are adjusted using Equations (33) and (34).

3.3 Compartment Junction Flow Analytical Model

This section discusses the models used to describe a flow path (junction) between two compartments. The junction flow model allows flow between the atmosphere regions of adjacent compartments. Multiple junctions between compartments are permitted; up to 999 junctions may be specified for a single problem. Two junction types are available: nozzles, which are restricted to single-phase gas flow; and orifices, which have several flow options. In addition, junction flow inertia for either a nozzle or an orifice may be included in the flow rate calculation at user option.

Junction flow models for a nozzle and an orifice, a junction inertia model, and compartment mass/energy updating resulting from junction flow are described in the following sections.

3.3.1 Nozzle Model. Nozzle flow is restricted to single-phase gas flow between compartments. Choked flow is dependent on nozzle coefficients calculated during data input processing. Converging or diverging nozzle flow rates are calculated explicitly. The converging-diverging nozzle rate is calculated iteratively using Newton's method.

Based on isentropic flow of a perfect gas, the mass flow rate $\dot{m}$ through a nozzle is

$$\dot{m} = C_d A_* Z P_i \sqrt{\frac{2\gamma}{(\gamma - 1)\, R_m T_i}} \sqrt{1 - Z^{\gamma - 1}} \tag{37}$$

where

C_d = an input constant, usually 1.0

A_* = nozzle throat area

Z = function of pressure ratio (as defined subsequently)

P_i = pressure at inlet

T_i = absolute temperature of flowing mixture

γ = ratio of specific heats, for air c_p/c_v = 1.4

R_m = gas constant of the air and water vapor mixture.

The mass-averaged gas constant is determined from

$$R_m = \frac{M_a R_a + M_{wv} R_{wv}}{M_a + M_{wv}} \tag{38}$$

where

M_a = mass of air in mixture

R_a = gas constant for air

M_{wv} = mass of water vapor in mixture

R_{wv} = gas constant for water vapor.

The quantity Z depends on the type of nozzle and the pressure difference across the nozzle. For a converging or diverging nozzle, Z is determined by the equation

$$Z = \left(\frac{P_e}{P_i}\right)^{1/\gamma} \quad \text{for} \left(\frac{P_e}{P_i}\right) > \left(\frac{2}{\gamma + 1}\right)^{\gamma/\gamma-1} = 0.528 \tag{39}$$

or

$$Z = (0.528)^{1/\gamma} = \left(\frac{2}{\gamma + 1}\right)^{1/\gamma-1} \quad \text{for} \ \frac{P_e}{P_i} \leq 0.528 \tag{40}$$

where

P_e = pressure at the exit.

For a converging-diverging nozzle, Z is calculated from Equation (39) or (40) for sonic flow; for subsonic flow, the following equation is used:

$$Z = \left(\frac{P_*}{P_i}\right)^{1/\gamma} \tag{41}$$

where

P_* = pressure at the nozzle throat.

The following two equations are evaluated to determine whether the nozzle flow is sonic or subsonic:

$$\frac{A_e}{A_*} = \frac{M_*}{M_e}\left(\frac{1 + \frac{\gamma - 1}{2} M_e^{\ 2}}{1 + \frac{\gamma - 1}{2} M_*^{\ 2}}\right)^{\gamma+1/2(\gamma-1)} \tag{42}$$

$$\left(\frac{P_i}{P_e}\right)_c = \left[1 + \frac{\gamma - 1}{2}\left(M_e^2\right)_c\right]^{\gamma/\gamma-1} \tag{43}$$

where the subscript e stands for exit conditions, * stands for throat conditions, i stands for inlet conditions, c stands for critical conditions where flow changes from subsonic to sonic, and M is the Mach number. In order to determine whether the flow through the converging-diverging nozzle is sonic or subsonic, the following test is performed. The critical Mach number $(M_e)_c$ at the exit is found by setting M_* equal to unity in Equation (42) and solving the equation by using Newton's method. This value of $(M_e)_c$ is used in Equation (43) to calculate the pressure ratio $[(P_i/P_e)_c]$. If the actual pressure ratio (P_i/P_e) is greater than the pressure ratio $[(P_i/P_e)_c]$, the flow is sonic and Z is calculated by Equation (39).

If the ratio (P_i/P_e) is not greater than the pressure ratio $[(P_i/P_e)_c]$, the flow is subsonic. In this case, M_e^2 is calculated from Equation (44). The resulting value of M_e^2 is used in Equation (42) to calculate M_* by iteration, and Equation (45) is used to calculate (P_*/P_e). Equation (41) is then solved for Z.

$$M_e^2 = \frac{2}{\gamma - 1}\left[\left(\frac{P_i}{P_e}\right)^{(\gamma-1/\gamma)} - 1\right] \quad (44)$$

$$\frac{P_*}{P_e} = \left(\frac{1 + \frac{\gamma - 1}{2} M_e^2}{1 + \frac{\gamma - 1}{2} M_*^2}\right)^{\gamma/\gamma-1} \quad . \quad (45)$$

Updating of compartment mass and energy addition rates resulting from nozzle flow is discussed in Section 3.3.4.

3.3.2 Orifice Model. The orifice junction flow model describes incompressible flow through an orifice-type junction. The orifice model in CONTEMPT4/MOD3 distinguishes between three types of junction flow: single-phase flow (either all liquid or all vapor), two-phase homogeneous flow, and two-phase slip flow. The equations used to calculate mass flow rates for the three types of orifice junction flow are described below. None of these equations check for critical flow, as is done for the nozzle analytical model. Consequently, the orifice model should be selected only for those applications where flow choking is not expected.

The equation used to calculate single-phase flow or two-phase homogeneous flow relies on the pressure differential across the junction and the flow density of the transferred fluid to determine the mass flow rate. This equation is

$$\Delta P = \frac{K\dot{m}|\dot{m}|}{2\rho A^2} \quad (46)$$

where

ΔP = pressure drop across orifice for steady-state incompressible flow neglecting gravitational effects

K = single-phase loss coefficient

$\dot{m}$ = total mass flow rate

ρ = density of flow fluid based on donor compartment vapor region properties; for single-phase flow, ρ is based on liquid density if no vapor is present in donor compartment, or the combined water vapor-air density if vapor is present; for two-phase homogeneous flow, ρ is based on the density of all components in the vapor region

A = area of orifice.

The equation used to calculate two-phase slip flow is essentially the same as Equation (46), with the inclusion of a two-phase correction factor and different density term. This equation is[7]

$$\Delta P = \gamma \frac{K_\ell \dot{m}|\dot{m}|}{2\rho_\ell A^2} \tag{47}$$

$$\gamma = \frac{\rho_\ell}{\rho_g}\left[\frac{x^2}{R_g} + \frac{(1-x)^2}{R_\ell}\right] \tag{48}$$

$$R_g = 1 - R_\ell \tag{49}$$

$$R_\ell = \rho_{\ell,actual}\, v_\ell \tag{50}$$

where

γ	=	two-phase correction factor
K_ℓ	=	liquid single-phase loss coefficient
ρ_ℓ	=	liquid phase density based on temperature rather than mixture composition
ρ_g	=	gas density based on thermodynamic temperature and pressure
x	=	quality of flow mixture
R_g	=	volume fraction of gas in flow mixture
R_ℓ	=	volume fraction of liquid in flow mixture
$\rho_{\ell,\text{ actual}}$	=	actual liquid density in flow mixture
v_ℓ	=	specific volume of liquid in flow mixture.

Equation (46) is applicable in cases where high flow qualities (ratio of vapor mass over total atmosphere mass in donor compartment) are not encountered. If the program user selects Equation (46) for the orifice mass flow rate calculation and no liquid water is present in the donor compartment atmosphere, single-phase vapor flow will be calculated using Equation (45).

The orifice mass flow rate is calculated explicitly using either Equation (46) or (47). Updating of compartment mass and energy addition rates resulting from orifice flow is discussed in Section 3.3.4. The ice-chest door model described in Section 3.8.2 can be used only in conjunction with the orifice model.

3.3.3 Drywell/Ice Chest Flow Distribution. The program user may input an optional time-dependent relative flow distribution table to account for changes in flow path resistance in an ice-chest. This option is intended for use with the orifice model to predict preferential ice-melt patterns in ice condenser containment systems, although the coding for this option is general and any combination of nozzles and orifices can be used. The table contains the mass flow fraction through each drywell-ice chest junction as a function of time. CONTEMPT4/MOD3 will calculate the total mass flow rate from the drywell using the existing pressure distribution. The flow is then redistributed according to the input table. The user may specify the distribution for only a portion of the time period; CONTEMPT4/MOD3 will determine subsequent distributions. The flow from the drywell is redistributed according to

$$\dot{m}_i = a_i \dot{m}_T \text{ for } i = 1,2, \ldots N \quad (51)$$

where

$\dot{m}_i$ = mass flow rate leaving the drywell through junction i

a_i = relative flow fraction for junction i

$\dot{m}_T$ = total mass flow rate leaving the drywell

N = number of ice chests.

3.3.4 Junction Flow with Inertia Model. The basic junction flow models for nozzles and orifices described earlier neglect the effect of junction fluid inertness. As an option, the program user may include a term for geometric inertia in the mass flow rate calculation. The junction flow with inertia model is especially helpful in eliminating unrealistic oscillations in predicted flow rate. Junction flow in CONTEMPT4/MOD3 can be modeled accurately by assuming incompressible fluid flow, including fluid inertness but neglecting momentum flux. The equation can be written as

$$I\frac{d\dot{m}}{dt} = P_i - P_e - \frac{K\dot{m}|\dot{m}|}{2\rho A^2}\gamma \quad (52)$$

where

I = geometric inertia of junction

$\dot{m}$ = junction mass flow rate

t = time

P_i = donor compartment pressure

P_e = receiver compartment pressure

K = loss coefficient

ρ = applicable fluid density

A = junction flow area

γ = two-phase flow multiplier, if used.

Equation (52) is solved implicitly by grouping the terms as follows for solution:

$$P_i - P_e = \frac{K\gamma}{2\rho A^2} \dot{m}|\dot{m}| + \frac{I}{\Delta t} (\dot{m} - \dot{m}_o) \qquad (53)$$

where

$\dot{m}$ = current time step mass flow rate

$\dot{m}_o$ = previous time step mass flow rate.

The solution can be determined in two manners: by using the quadratic formula, or by using a Taylor series approximation of the quadratic formula when the argument DELX defined below is less then 0.0001. The quadratic solution is

$$\dot{m} = \frac{D}{2B} \pm \sqrt{\frac{D}{4B} \pm \frac{D\dot{m}_o}{B} \pm \frac{\Delta P}{B}} \qquad (54)$$

and the Taylor series solution is

$$\dot{m} = \pm \frac{D}{2B} \left(\frac{DELX}{2} - \frac{DELX^2}{8} + \frac{DELX^3}{16} \right) \qquad (55)$$

where the upper sign is used if $\Delta Pw_o + B \geq 0$, otherwise the lower sign is used; and where

ΔP = pressure differential term $P_i - P_e$ [see Equation (56)]

B = friction term $= \dfrac{K\gamma}{2\rho A^2}$

D = inertial term $= \dfrac{I}{\Delta t}$

DELX = argument $= \dfrac{4B}{D^2}(\Delta P + D\dot{m}_o)$.

The pressure differential term (ΔP) used by the code to determine the intercompartmental flow with inertia is actually an extrapolation of the pressure difference one-half time step ahead. Thus,

$$\Delta P = 1.5(P_i - P_e) + 0.5(\Delta P_{old}) \qquad (56)$$

where

ΔP_{old} = previous time-step pressure differential.

This approximation increases the stability of the junction flow rate for problems that have time step sizes near the characteristic time of the system. The program user must supply an appropriate junction geometric inertia term if the flow with inertia model is selected. Section 4.3.1.2 contains guidelines for selecting proper values for this term.

3.3.5 Mass and Energy Transfer. Compartment mass and energy addition rates affected by junction flow are updated following the determination of junction mass flow rate. The updating procedure is the same for nozzle and orifice junctions, except that entrained liquid addition rates are updated only for orifices. Positive junction flow is defined as mass and energy leaving the nominal donor compartment chosen during problem input. Mass and energy flow rates are based on upstream compartment properties.

The mass fractions of air, water vapor, and entrained liquid in the upstream compartment are used to calculate the component mass addition rates ($\dot{m}_a$, $\dot{m}_v$, and $\dot{m}_\ell$ for air, water vapor, and entrained liquid mass flow rates, respectively) from the total mass flow rate determined by the nozzle or orifice model. The energy flow rate $\dot{q}$ due to junction flow for a single junction is calculated from

$$\dot{q} = \dot{m}_a c_p T_v + \dot{m}_v h_g + \dot{m}_\ell h_\ell \qquad (57)$$

where

c_p = constant pressure heat capacity of air

T_v = absolute temperature of compartment vapor region

h_g = specific enthalpy of water vapor at T_v

h_ℓ = specific enthalpy of liquid water at T_v if compartment atmosphere is not superheated.

3.4 Containment Cooling Spray Analytical Model

The containment spray system is a safeguard system employed during a loss-of-coolant accident to reduce compartment pressures. The cooling spray model in CONTEMPT4/MOD3 permits any compartment to contain one or more cooling spray systems. Spray water may be routed through a heat exchanger to modify its temperature before entering the spray nozzle.

The cooling spray model is described below, followed by single and coupled heat-exchanger model descriptions.

3.4.1 Cooling Spray Model. The CONTEMPT4/MOD3 cooling spray model is illustrated in Figure 2. Symbols used to describe the spray analytical model are defined below:

$\dot{m}_S$ = spray water total flow rate

S_{P1} = suction fraction of W_S originating from Compartment 1 pool

S_{P2} = suction fraction of W_S originating from Compartment 2 pool

S_{OUT} = suction fraction of W_S originating from outside source

D_{PL} = discharge fraction of W_S into liquid pool of receiver compartment

D_{AT} = discharge fraction of W_S into atmosphere region of receiver compartment

η_S = spray heat transfer efficiency.

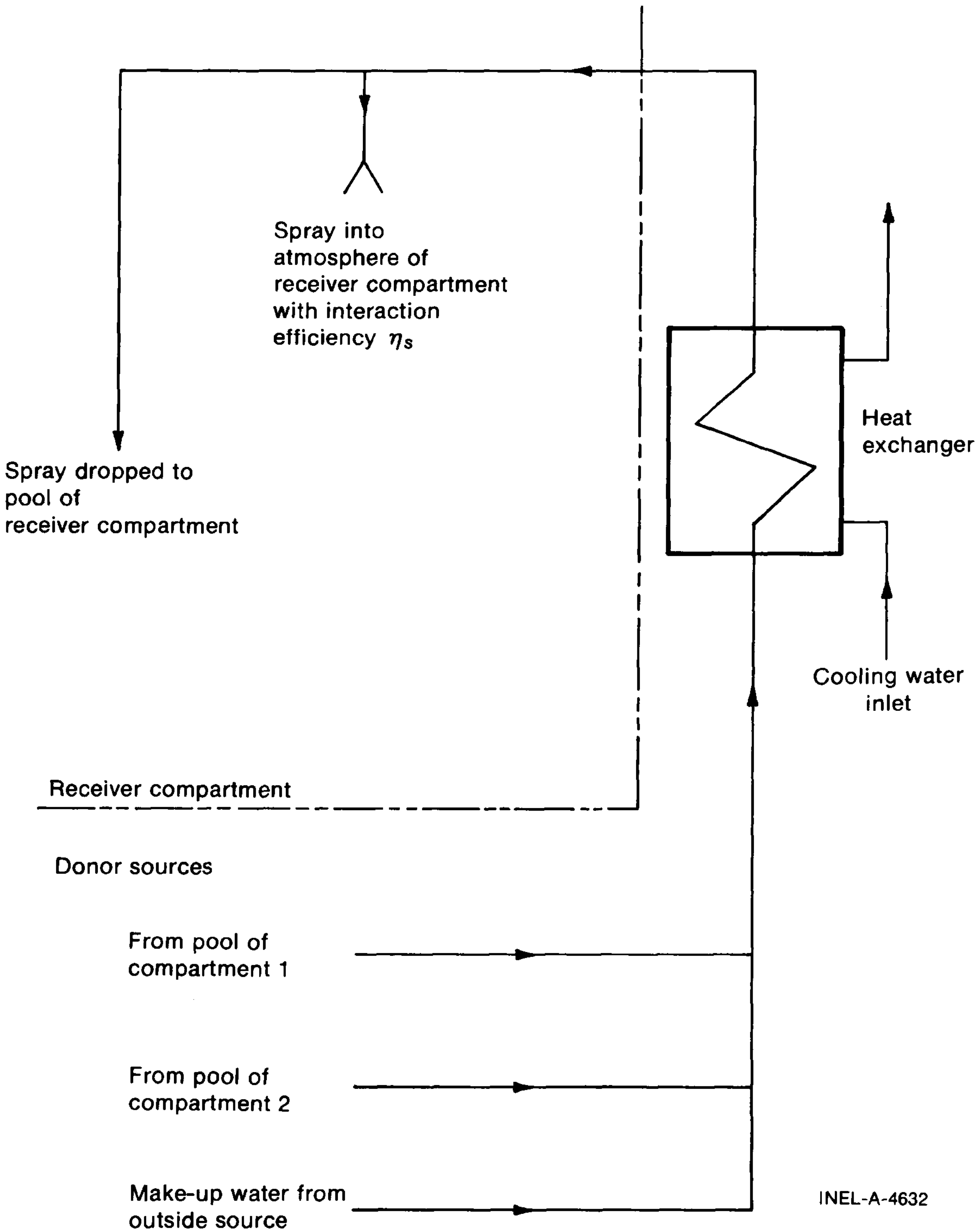

Figure 2. Containment cooling spray with single heat exchanger.

The spray system draws suction from one or two donor compartments and an optional outside source. A heat exchanger may be used to modify the spray water temperature. Spray water is distributed to the pool and atmosphere regions of the receiver compartment. The spray model, as shown in Figure 2, requires that

$$S_{P1} + S_{P2} + S_{OUT} = 1 \quad (58)$$

$$D_{PL} + D_{AT} = 1. \quad (59)$$

The final averaged specific enthalpy of the spray liquid is determined as follows if a heat exchanger is specified:

$$h_s = (S_{P1} + S_{P2})h_{hx} + S_{OUT}h_{OUT} \quad (60)$$

where

h_{OUT} = specific enthalpy of incoming liquid from outside source.

The value of h_{hx} is determined as described in Sections 3.4.2 and 3.4.3. If no heat exchanger is specified, the term h_{hx} in Equation (60) is replaced by h_{av}, the mass averaged specific enthalpy:

$$h_{av} = (S_{P1}h_{P1} + S_{P2}h_{P2}) / (S_{P1} + S_{P2}) \quad (61)$$

where

h_{P1} = specific enthalpy of liquid water in first donor compartment

h_{P2} = specific enthalpy of liquid water in second donor compartment.

The program user must input η_s, the spray heat transfer efficiency, since

$$\eta_s = \frac{h_{sf} - h_s}{h_e - h_s} \quad (62)$$

where

h_s = specific enthalpy of spray droplets leaving the spray header calculated from Equation (60)

h_{sf} = final specific enthalpy of spray droplets after exchanging energy with vapor region

h_e = end point specific enthalpy of water in vapor region prior to spray effects.

For a superheated vapor region, the spray is assumed to evaporate. The entire spray system is added to the liquid water component of the atmosphere.

Applicable compartment mass and energy addition rates are updated to reflect the influence of the cooling spray.

3.4.2 Single Heat Exchanger Model. One of five different types of heat exchangers can be selected to modify spray water temperature before reaching the spray nozzle. Heat exchanger types available are:

1. Shell and tube (U-tube), single-shell pass
2. Cross-flow, hot side unmixed, cold side mixed
3. Counter-flow
4. Parallel-flow
5. User input time-dependent energy removal rate.

The efficiency, η_{hx}, of the heat exchanger is calculated for the first four types by using the equations of Kays and London[8] for steady-state conditions as shown below.

For the shell and tube (U-tube) heat exchanger with parallel and counter flow in the tubes and a single pass in the shell:

$$\eta_{hx} = 2 \left\{ 1 + \frac{C_{min}}{C_{max}} \left[1 + \left(\frac{C_{min}}{C_{max}} \right)^2 \right]^{1/2} \left[\frac{1 + \exp(-\alpha)}{1 - \exp(-\alpha)} \right] \right\}^{-1} \tag{63}$$

$$\alpha = N_{tu} \left[1 + \left(\frac{C_{min}}{C_{max}} \right)^2 \right]^{1/2} \tag{64}$$

$$N_{tu} = A_{hx} H_{hx} \; / \; C_{min} . \tag{65}$$

N_{tu} represents the number of transfer units associated with the heat exchanger, A_{hx} is the effective surface area for heat transfer in the heat exchanger, and H_{hx} is the overall heat transfer coefficient. C_{min} and C_{max} are defined as the minimum and maximum total heat capacities, respectively, of c_{ph} $\dot{m}_{hx}$ and c_{pc} $\dot{m}_c$. $\dot{m}_c$ is the cold leg flow in the heat exchanger, and $\dot{m}_{hx}$ is the hot leg flow which is m_s $(Sp_1 + Sp_2)$ in Figure 2. Also, c_{pc} and c_{ph} are the specific heat capacities of the water on the cold and hot sides of the heat exchanger, respectively.

For a cross-flow heat exchanger with the hot-side fluid unmixed and the cold side mixed:

$$\eta_{hx} = 1 - \exp(-\alpha) \tag{66}$$

$$\alpha = \frac{C_{max}}{C_{min}} \left[1 - \exp\left(-N_{tu} \frac{C_{min}}{C_{max}} \right) \right] \tag{67}$$

if

$C_{max} = C_{unmixed}$ and $C_{min} = C_{mixed}$

or

$$\eta_{hx} = \frac{C_{max}}{C_{min}} [1 - \exp(-\alpha)] \qquad (68)$$

$$\alpha = \frac{C_{min}}{C_{max}} [1 - \exp(-N_{tu})] \qquad (69)$$

if

$C_{min} = C_{unmixed}$ and $C_{max} = C_{mixed}$.

Here, a "mixed" fluid is defined as one which has uniform temperature at any cross-sectional plane normal to the direction of flow of the fluid; for example, the fluid in the shell side of a cross-flow heat exchanger. An "unmixed" fluid is one which does not have a uniform temperature in a cross-sectional plane normal to the direction of flow of the fluid; for example, the fluid in the tubes of a cross-flow heat exchanger.

For the counter-flow heat exchanger

$$\eta_{hx} = [1 - \exp(-\alpha)] \left[1 - \frac{C_{min}}{C_{max}} \exp(-\alpha)\right]^{-1} \qquad (70)$$

$$\alpha = N_{tu} \left(1 - \frac{C_{min}}{C_{max}}\right) , \qquad (71)$$

or if

$\frac{C_{min}}{C_{max}} = 1$ within $\pm$ 0.002,

then

$$\eta_{hx} = \frac{N_{tu}}{1 + N_{tu}} . \qquad (72)$$

For the parallel-flow heat exchanger

$$\eta_{hx} = [1 - \exp(-\alpha)] \left(1 + \frac{C_{min}}{C_{max}}\right)^{-1} \qquad (73)$$

$$\alpha = N_{tu} \left(1 + \frac{C_{min}}{C_{max}}\right) . \qquad (74)$$

For all types of heat exchangers, circulation time of the water through the system is assumed to be zero. The water temperature at the heat-exchanger exit (T_{hx}) is obtained from

$$T_{hx} = T_h - \frac{C_c}{C_h} \eta_{hx} (T_h - T_c) \qquad (75)$$

where

T_h = hot leg water temperature

T_c = cold leg water temperature

C_h = $c_{ph} \dot{m}_{hx}$ = hot leg fluid capacity rate

C_c = $c_{pc} \dot{m}_c$ = cold leg fluid capacity rate.

For T_{hx}, a value of h_{hx} is obtained from the steam tables (STH2O1 in Appendix B), and Equation (60) is solved to obtain the spray enthalpy.

3.4.3 Coupled Heat Exchanger Model. In some containment systems, a pair of heat exchangers is used to modify the temperature of the spray water. For this reason, two heat exchangers coupled in parallel can be selected to change the spray water temperature.

The coupled heat exchanger model can use any of the first four heat exchanger types described in Section 3.4.2 for either of the heat exchangers; e.g., cross-flow and counter-flow heat exchangers for the component and spray heat exchangers, respectively, or parallel-flow types for both heat exchangers. The fifth type of heat exchanger, which is an input table of heat removal rates, was omitted from the options available for the coupled model; it is assumed that if the user has sufficient information to input an energy removal rate, a single heat exchanger can be used in place of the coupled model.

The logic of the coupled heat exchanger can best be seen in Figure 3. The piping which connects the component and spray heat exchangers forms a closed loop. The symbols used in Figure 3 are defined as

T = temperature

c_p = specific heat of water at constant pressure

$\dot{m}_{cmp}$ = mass flow rate of component heat exchanger cold leg

$\dot{m}_{spy}$ = mass flow rate of spray heat exchanger hot leg

$\dot{m}_{cen}$ = mass flow rate for center closed loop

Subscripts 1 and 2 refer to the component and spray heat exchangers, respectively

Subscripts c and h refer to the nominal cold and hot legs for each heat exchanger

Subscripts in and out refer to inlet side and outlet side, respectively.

Thus, $T_{out,2h}$ is the outlet temperature of the spray heat exchanger hot leg. Known values, including the specifications for each heat exchanger, are

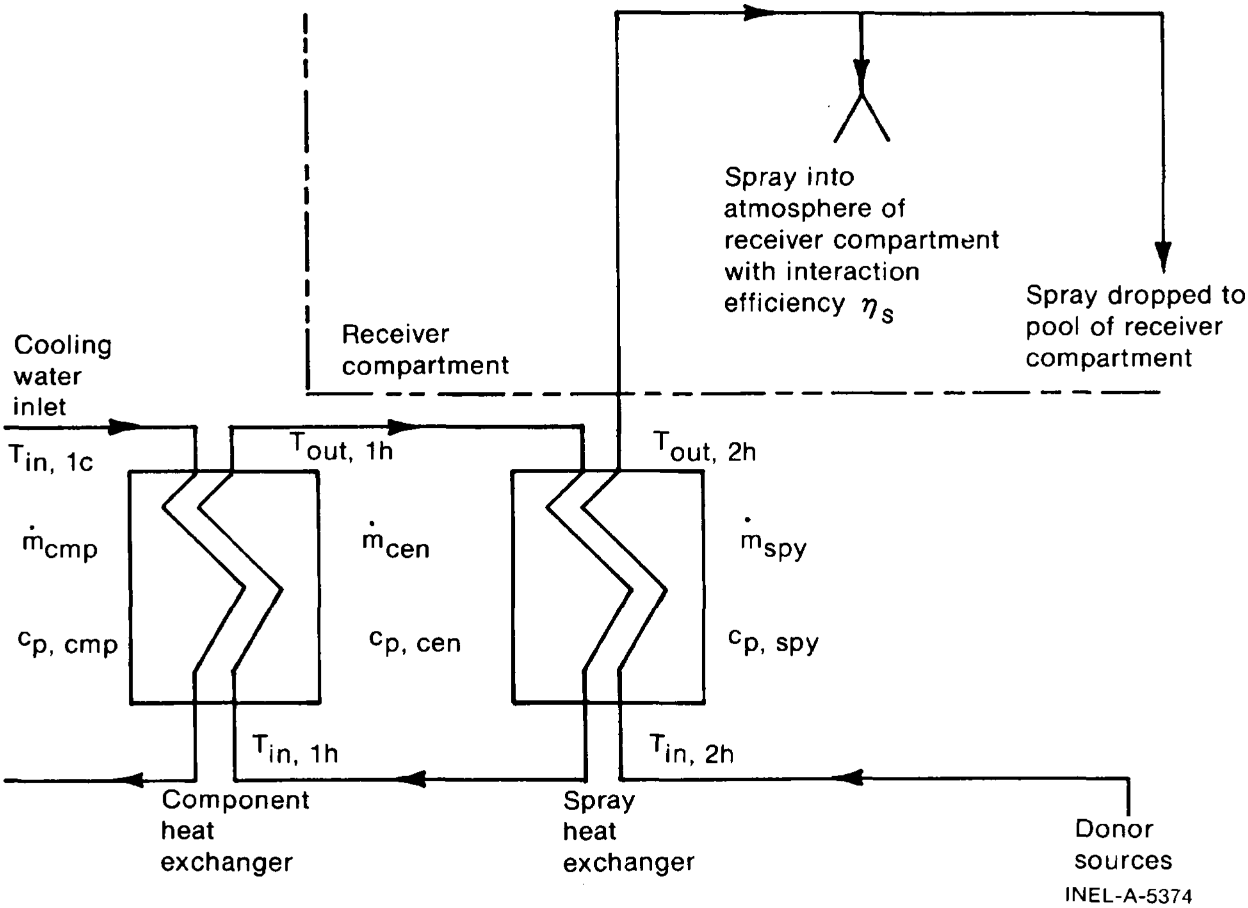

Figure 3. Schematic of coupled heat exchanger.

1. Mass flow rates for each loop

2. Cold leg component inlet temperature

3. Hot leg spray inlet temperature

4. Specific heat values for two outer loops, based on inlet temperatures and assuming specific heats are constant for each loop.

For steady-state operation, the actual heat lost through the spray hot leg pass equals the heat gained by the component cold leg pass.

$$\dot{m}_{cen} c_{p,cen} (T_{in,1h} - T_{out,1h}) = \dot{m}_{spy} c_{p,spy} (T_{in,2h} - T_{out,2h})$$

$$= \dot{m}_{cmp,} c_{p,cmp} (T_{out,1c} - T_{in,1c}) . \tag{76}$$

The effectiveness-NTU (number of transfer units) method can be used to define the hot-leg outlet temperature for each heat exchanger as

$$T_{out,2h} = \left(\frac{C_{min,2}\eta_{hx,2}}{\dot{m}_{spy}c_{p,spy}} \right) (T_{out,1h} - T_{in,2h}) + T_{in,2h} \quad (77)$$

$$T_{out,1h} = \left(\frac{C_{min,1}\eta_{hx,1}}{\dot{m}_{cen}c_{p,cen}} \right) (T_{in,1c} - T_{in,1h}) + T_{in,1h} \quad (78)$$

where

C_{min} = minimum total heat capacity for each heat exchanger ($c_p\dot{m}$ for either the hot leg or the cold leg); e.g., either $c_{p,spy}\ \dot{m}_{spy}$ or $c_{p,cen}\ \dot{m}_{cen}$ for the spray heat exchanger

η_{hx} = effectiveness of heat exchanger determined from equations in Section 3.4.3.

The outlet temperature of the spray hot leg can be calculated provided the following assumption is made:

$$c_{p,cen} = \frac{c_{p,cmp} + c_{p,spy}}{2} \quad (79)$$

This is a reasonable assumption for steady-state operation and values of specific heat at temperatures and pressures encountered in containment analysis.

Equation (76) can be rearranged to yield

$$T_{in,1h} = \left(\frac{\dot{m}_{spy}c_{p,spy}}{\dot{m}_{cen}c_{p,cen}} \right) (T_{in,2h} - T_{out,2h}) + T_{out,1h} \ . \quad (80)$$

By substituting Equation (80) into Equation (78) and substituting the resultant equation into Equation (77), the result is an expression for the water temperature at the exit of the spray heat exchanger.

$$T_{out,2h} = T_{in,2h} + \frac{1}{\gamma} \left(\frac{C_{min,2}\eta_{hx,2}}{\dot{m}_{spy}c_{p,spy}} \right) (T_{in,1c} - T_{in,2h}) \quad (81)$$

where

$$\gamma = 1 + C_{min,2}\eta_{hx,2} \left(\frac{1}{C_{min,1}\eta_{hx,1}} + \frac{1}{\dot{m}_{cen}c_{p,cen}} \right) \ . \quad (82)$$

3.5 Containment Fan and Pump Analytical Model

CONTEMPT4/MOD3 contains a fan/pump model which describes the performance of either a centrifugal pump or containment fan. The basic function of the fan/pump model is the transfer of mass from a donor compartment to a receiver compartment, or from an outside source to a receiver compartment. This model is described in the following sections.

3.5.1 Fan/Pump ON/OFF Switch Control. If the fan/pump model is used in the temperature transient calculations, the ON/OFF switch of the fan/pump is controlled by one of the following methods:

1. Pressure Control: If the pressure inside the specified compartment is greater than the input specified pressure value, the fan/pump is turned on to remove material from this compartment. If the pressure inside this compartment is less than the input specified pressure value, the fan/pump switch is turned off.

2. Pressure Difference Control: If the pressure difference between the donor and receiver compartment is greater than an input specified value for the pressure difference, the fan/pump is turned on to transfer material from the high-pressure compartment to the low-pressure compartment. If the pressure difference between those two compartments is less than the input value, the fan/pump switch is turned off.

3. Time Control: During a transient calculation, if the current calculation time is within the input specified time interval, the fan/pump is turned on to transfer material between a donor and receiver compartment. Otherwise, the fan/pump switch is turned off.

4. Temperature Control: If the temperature inside the specified compartment is greater than some input temperature value, the fan/pump is turned on to transfer material out of the compartment. Otherwise, the fan/pump switch is turned off.

3.5.2 Fan/Pump Mass and Energy Transfer Model. When the fan/pump is operating, the mass and energy transfer rates between the interacting compartments are calculated according to the following expressions

$$\dot{m}_r = Q\rho, \quad \dot{m}_d = -Q\rho, \quad \dot{E}_r = Qh\rho, \quad \dot{E}_d = -Qh\rho \qquad (83)$$

where

$\dot{m}_r$ = mass flow rate into receiving compartment

$\dot{m}_d$ = mass flow rate out of donor compartment

$\dot{E}_r$ = energy flow rate into receiving compartment

$\dot{E}_d$ = energy flow rate out of donor compartment

ρ = density of material transferred

h = specific enthalpy of the material transferred

Q = volumetric flow rate.

For a pump, the exchange takes place between compartment pool regions. When the pump discharge rate $Q > 0$, then

$\rho = (\rho_\ell)_d$ = liquid density of donor compartment

$h = (h_\ell)_d$ = liquid specific enthalpy of donor compartment.

When the pump discharge rate $Q < 0$, then

$\rho = (\rho_\ell)_r$ = liquid density of receiving compartment

$h = (h_\ell)_r$ = liquid specific enthalpy of receiving compartment.

For a fan, the exchange is between compartment atmosphere regions. When volumetric flow rate $Q > 0$, then

$$\rho = (\rho_a)_d + (\rho_v)_d + (\rho_\ell)_d$$

$$h\rho = (h_a\rho_a)_d + (h_v\rho_v)_d + (h_\ell\rho_\ell)_d \qquad (84)$$

when volumetric flow rate $Q > 0$, then

$$\rho = (\rho_a)_r + (\rho_v)_r + (\rho_\ell)_r$$

$$h\rho = (h_a\rho_a)_r + (h_v\rho_v)_r + (h_\ell\rho_\ell)_r \qquad (85)$$

where

subscript a = air

subscript v = water vapor

subscript ℓ = water droplet

subscript r = receiver compartment

subscript d = donor compartment

ρ = density

h = specific ethalpy.

As long as the volumetric flow rate, Q, is known, the mass and energy transfer rates due to the operation of the fan/pump are easily obtained from the above expressions.

3.5.3 Volumetric Flow Rate When the Fan/Pump is Turned On. There are three options for handling the volumetric flow rate.

1. Constant volumetric flow rate: The volumetric flow rate (Q) is maintained at some constant input value when the fan/pump is turned on.

2. User input volumetric flow rate table: This option is used for an outside source to a receiver compartment. There are three formats for the input table:

   a. Input table of volumetric flow rate versus pressure difference between an outside source and the specified compartment

   b. Input table of volumetric flow rate versus absolute pressure of the specified compartment

   c. Input table of volumetric flow rate versus time.

3. Volumetric flow rate obtained from the fan/pump characteristic curve when the fan/pump is turned on: This option assumes the fan/pump rotates at some input constant speed. The volumetric flow rate is then calculated according to the built-in fan/pump characteristic curve. The program user has the option to write his own fan/pump characteristic curve (designated UCURV) to calculate the fan/pump discharge rate.

3.5.4 Operation Modes After Fan/Pump is Turned Off. There are two operation modes in the fan/pump model when the fan/pump switch is turned off.

1. Locked: After the fan/pump switch is turned off, the fan/pump is set in a locked position. The volumetric flow rate is set to zero. There is no mass and energy exchange thereafter.

2. Freewheeling: After the fan/pump is turned off, the fan/pump is allowed to freewheel. The rotational speed (ω) of the fan/pump is then calculated as

$$\omega(t + \Delta t) = \omega(t) - \frac{T(t)}{I} \Delta t \tag{86}$$

and

$$T(t) = T_{hy} \frac{\rho}{\rho_r} + T_{f,r} \frac{\omega(t) | \omega(t) |}{[\omega(t)]^2} + T_{f,const} \tag{87}$$

where

t	=	time at the end of previous time step
Δt	=	time step
I	=	moment of inertia of the fan/pump (input)
T	=	total torque of the fan/pump at time t
ρ	=	density of fluid transferred
ρ_r	=	rated density of fluid for the fan/pump (input)

$T_{f,const}$ = constant friction torque of the fan/pump (input)

$T_{f,r}$ = rated friction torque of the fan/pump (input)

T_{hy} = hydraulic torque for the fan/pump system at time t.

The hydraulic torque (T_{hy}) is a function of the fan/pump system head (H) and the fan/pump discharge (Q), and is obtained from the built-in fan/pump characteristic curve (or user-supplied subroutine UCURV). Once the hydraulic torque (T_{hy}) is known, the new time-step rotational speed, $\omega(t + \Delta t)$, of the fan/pump is calculated from Equation (86). From the built-in fan/pump characteristic curve (or user-supplied routine UCURV), the new time-step volumetric flow rate, $Q(t + \Delta t)$, is obtained.

3.5.5 Built-In Homologous Curve for Fan/Pump Model. The fan/pump characteristic curves are empirically developed by fan/pump manufacturers to define the fan/pump head (H) and hydraulic torque (T_{hy}) response as functions of volumetric flow rate (Q) and rotational speed (ω). In this model, one can "nondimensionalize" these quantities with respect to the fan/pump rated values by

$$\tilde{H} = \frac{H}{H_R} , \quad \tilde{Q} = \frac{Q}{Q_R} , \quad \tilde{\omega} = \frac{\omega}{\omega_R} , \quad \tilde{T}_{hy} = \frac{T_{hy}}{T_R} \tag{88}$$

where H_R, Q_R, ω_R, T_R are the rated fan/pump head, rated discharge, rated rotational speed, and rated hydraulic torque, respectively.

A set of dimensionless homologous curves which relates the fan/pump $\tilde{H}$, $\tilde{Q}$, $\tilde{\omega}$, and $\tilde{T}_{hy}$ can be obtained from the fan/pump characteristic curves. A typical homologous curve of a dimensionless head-discharge/rotational-speed relation is given in Figure 4 for a centrifugal pump.[9] The corresponding homologous curve of dimensionless hydraulic torque discharge/rotational speed is given in Figure 5. According to fan/pump discharge and rotational speed, there are four zones of operation. These are

Normal Zone	$(\tilde{Q} > 0, \tilde{\omega} > 0)$
Dissipation Zone	$(\tilde{Q} < 0, \tilde{\omega} > 0)$
Turbine Zone	$(\tilde{Q} < 0, \tilde{\omega} < 0)$
Reverse Zone	$(\tilde{Q} > 0, \tilde{\omega} < 0)$.

From Figure 4, the head-discharge-speed homologous relation is described by different curves as listed in Table 1. From Figure 5, the hydraulic torque-discharge-speed homologous relation is described by another set of curves as listed in Table 2.

Following the suggestion of Reference 9, a parabolic curve can reasonably fit through each of these curves.

For fitting the head-discharge-speed homologous relation, the following parabolic equations are used.

$$\frac{\tilde{H}}{\tilde{\omega}^2} = C_1 + C_2 \frac{\tilde{Q}}{\tilde{\omega}} + C_3 \left(\frac{\tilde{Q}}{\tilde{\omega}} \right)^2 \qquad \text{for } 0 \le \left| \tilde{Q}/\tilde{\omega} \right| \le 1 \tag{89}$$

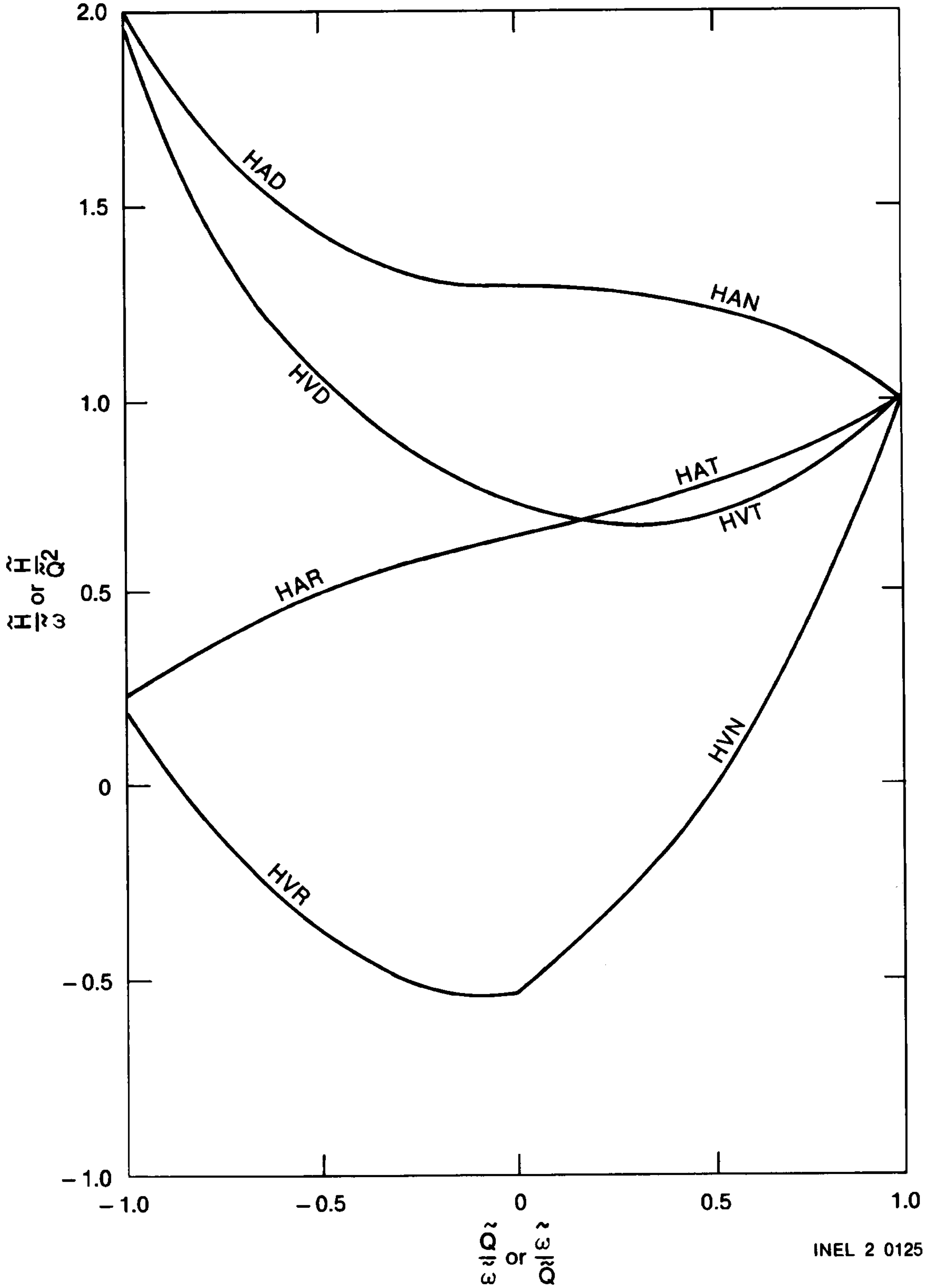

Figure 4. Complete $\tilde{H}$, $\tilde{\omega}$, and $\tilde{Q}$ curves for a centrifugal pump.

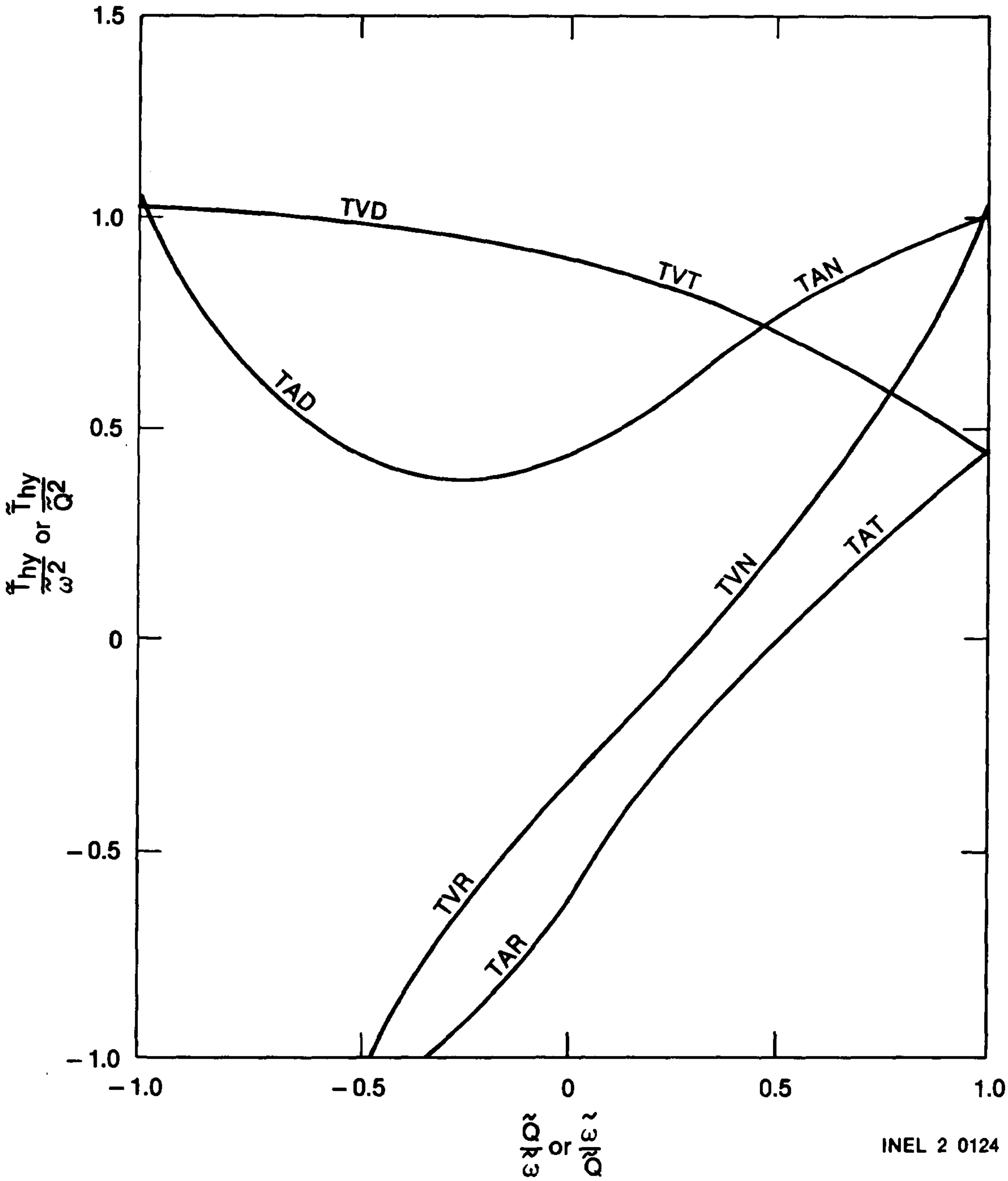

Figure 5. Complete $\tilde{T}_{hy}$, $\tilde{\omega}$, and $\tilde{Q}$ curves for a centrifugal pump.

Table 1. Head-discharge-speed homologous relation

Operation Condition	Curve Name	Boundary of the Curve
Normal Zone	HAN	$0 \le \tilde{Q}/\tilde{\omega} \le 1$
	HVN	$\tilde{Q}/\tilde{\omega} > 1$
Dissipation Zone	HAD	$0 \le \tilde{Q}/\tilde{\omega} \le 1$
	HVD	$\tilde{Q}/\tilde{\omega} > 1$
Turbine Zone	HAT	$0 \le \tilde{Q}/\tilde{\omega} \le 1$
	HVT	$\tilde{Q}/\tilde{\omega} > 1$
Reverse Zone	HAR	$0 \le \tilde{Q}/\tilde{\omega} \le 1$
	HVR	$\tilde{Q}/\tilde{\omega} > 1$

$$\frac{\tilde{H}}{\tilde{Q}^2} = C_3 + C_2 \frac{\tilde{\omega}}{\tilde{Q}} + C_1 \left(\frac{\tilde{\omega}}{\tilde{Q}}\right)^2 \qquad \text{for } \left|\tilde{Q}/\tilde{\omega}\right| > 1 \tag{90}$$

The fitting coefficients C_1, C_2, C_3 for Figure 4 are then obtained and are listed in Table 3.

Similarly, for fitting the hydraulic torque-discharge-speed homologous relation, the following parabolic equations are used.

$$\frac{\tilde{T}_{hy}}{\tilde{\omega}^2} = a_1 + a_2 \frac{\tilde{Q}}{\tilde{\omega}} + a_3 \frac{\tilde{Q}^2}{\tilde{\omega}} \qquad \text{for } 0 \le \left|\tilde{Q}/\tilde{\omega}\right| \le 1 \tag{91}$$

$$\frac{\tilde{T}_{hy}}{\tilde{Q}^2} = a_3 + a_2 \frac{\tilde{\omega}}{\tilde{Q}} + a_1 \frac{\tilde{\omega}^2}{\tilde{Q}} \qquad \text{for } \left|\tilde{Q}/\tilde{\omega}\right| > 1 . \tag{92}$$

Table 2. Hydraulic torque-discharge-speed homologous relation

Operation Condition	Curve Name	Boundary of the Curve
Normal Zone	TAN	$0 \le \tilde{Q}/\tilde{\omega} \le 1$
	TVN	$\tilde{Q}/\tilde{\omega} > 1$
Dissipation Zone	TAD	$0 \le \tilde{Q}/\tilde{\omega} \le 1$
	TVD	$\tilde{Q}/\tilde{\omega} > 1$
Turbine Zone	TAT	$0 \le \tilde{Q}/\tilde{\omega} \le 1$
	TVT	$\tilde{Q}/\tilde{\omega} > 1$
Reverse Zone	TAR	$0 \le \tilde{Q}/\tilde{\omega} \le 1$
	TVR	$\tilde{Q}/\tilde{\omega} > 1$

Again, the coefficients a_1, a_2, a_3 for different curves can be obtained for Figure 5 and are listed in Table 3.

The dimensionless discharge for the fan/pump and hydraulic torque can be expressed as the following two equations

$$\tilde{Q} = \frac{-C_2\tilde{\omega} + \text{SIGN}\sqrt{(C_2^2 - 4C_1C_3)\,\tilde{\omega}^2 + 4C_3\,\tilde{H}}}{2C_3} \tag{93}$$

$$\tilde{T}_{hy} = a_1\,\tilde{\omega}^2 + a_3\,\tilde{\omega}\,\tilde{Q} + a_3\tilde{Q}^2 \;. \tag{94}$$

The corresponding dimensional expressions are

$$Q = Q_R\left(\frac{-C_2\,\frac{\omega}{\omega_R} + \text{SIGN}\sqrt{(C_2^2 - 4C_1C_3)\,\frac{\omega}{\omega_R} + 4C_3\,\frac{H}{H_R}}}{2C_3}\right) \tag{95}$$

Table 3. Coefficients for Dimensionless-Homologous-Curve fit

	Head-Discharge-Speed Homologous Relation					Torque-Discharge Speed Homologous Relation			
		Discharge Constant					Torque Constant		
Operation Zone	Curve Name	C_1	C_2	C_3	SIGN	Curve Name	a_1	a_2	a_3
Normal Zone	HAN	1.30	-0.02	-0.28	-	TAN	-0.45	-0.85	-0.30
	HVN	0.70	0.85	-0.55	-	TVN	0.48	0.88	-0.36
Dissipation Zone	HAD	1.30	0.30	1.00	+	TAD	0.45	0.67	1.22
	HVD	1.20	-0.10	0.70	-	TVD	-0.20	0.34	0.86
Turbine Zone	HAT	0.65	0.25	0.10	+	TAT	-0.65	1.42	-0.32
	HVT	0.50	-0.15	0.65	+	TVT	-0.18	-0.23	0.86
Reverse Zone	HAR	0.65	0.15	-0.30	+	TAR	-0.65	1.25	0.28
	HVR	0.90	0.15	-0.55	+	TVR	-1.44	0.70	-0.36

$$T_{hy} = T_R\left[a_1\left(\frac{\omega}{\omega_R}\right)^2 + a_2\,\frac{\omega}{\omega_R}\,\frac{Q}{Q_R} + a_3\left(\frac{Q}{Q_R}\right)^2\right] \qquad (96)$$

where SIGN is either "+" or "-", and is dependent on the curve used.

The built-in homologous-curve subroutine has the logic to test the operation zone of the fan/pump for the current time step. The suitable curve is then chosen to obtain the corresponding fitting coefficients. Once these coefficients are obtained, the volumetric flow rate hydraulic torque can be calculated according to Equation (95) or (96), respectively.

3.6 Containment Fan Cooler Analytical Model

CONTEMPT4/MOD3 has the capability of modeling a fan cooler in any compartment. The fan cooler acts as a heat exchanger which circulates the containment atmosphere past cooling coils to either add or remove energy from the vapor region. The program user specifies the amount of energy added (or removed) by providing a temperature-dependent table of heat addition rates. Activation and deactivation of the fan cooler are dictated by user-input start and stop controls, either as a function of time or temperature.

The fan cooler heat addition rate, $\dot{q}_{fc}$, is determined from the input table based on the compartment vapor region saturation temperature. The compartment energy addition rate to the atmosphere, $\dot{q}$, is adjusted according to

$$\dot{q} = \dot{q} + \dot{q}_{fc} . \quad (97)$$

For vapor region temperatures at or below saturation, the amount of condensate which forms on the cooling coils is calculated implicitly as part of the general compartment thermodynamic balance discussed in Section 3.1.1.1. Whenever superheated vapor region conditions exist, the fan cooler condensate dropout rate must be explicitly calculated from

$$\dot{m} = f\dot{q}_{fc} \; / \; (h_v - h_\ell) \quad (98)$$

where

$\dot{m}$ = pool water addition rate due to condensation on cooling coils

f = user-specified fraction of condensate formed on cooling coils which is transferred to the pool region; this factor allows the user to control the condensation rate

h_v = specific enthalpy of water vapor in vapor region

h_ℓ = specific enthalpy of liquid water in vapor region.

The rate at which energy, $\dot{q}_p$, is transferred to the pool due to condensation is adjusted according to

$$\dot{q}_p = \dot{q}_p + \dot{m}h_\ell . \quad (99)$$

3.7 Ice Chest Drain Model

The ice chest drain analytical model predicts the behavior of an active compartment sump. The drain model was developed for use with the ice chest compartment model when describing an ice condenser pressure suppression system. However, the drain model is coded in a general fashion and is not necessarily associated with only the ice chest compartment model. The drain model allows water from one or several donor compartments to be collected in a drain region from which it is redistributed to the drain and overflow compartments. The model predicts the water level in the drain region and allows overflow into an overflow volume. The drain region referred to in this model description is a fictitious volume used to regulate the flow from the donor compartment to the drain and overflow compartments.

Water from the donor compartments is assumed to enter the ice chest drain instantaneously, but a one-dimensional incompressible pipe flow calculation is used to determine the mass flow rate leaving the drain region. The water entering the ice chest drain comes from one of several donor compartment sources (there may be several donor compartments): condensation due to liquid-vapor region interactions, ice melt, and dropout of entrained liquid. For the case where the donor compartment is an ice chest, all of the deentrained liquid and ice-melt water is directed to the drain region; this situation is analogous to the drain performance of an ice chest in an actual ice condenser containment system. For donor compartments other than ice chests, a fraction (controlled by the user) of the total flow from condensation and deentrainment is directed to the drain region based on the ratio of the cross-sectional area of the sump (A_2) over that of the donor compartment (A_1), with the remainder going to the donor compartment pool region. The ice chest drain model drains the pool region as it is forming; a preexisting pool cannot be drained using the present model.

The ice chest drain model allows the drained water to flow directly to the pool region of the receiver compartment without causing any immediate effect on the receiver compartment atmosphere region. In actual practice, the drain water which flows into the receiver compartment may to some degree interact with the atmosphere region, as depicted in Figure 6. Some of the water is sprayed into the drain volume atmosphere with considerable vapor region interaction, while some of the water flows down the wall with negligible interaction. The user may account for this redistribution of drained water between the pool and vapor regions by treating the drain exit flow as input for a cooling spray calculation. As an input option the program user may indicate that a fraction of the drain flow from the drain region be sprayed into the drain compartment vapor region. The user must specify the fraction of ice chest drain flow which enters the vapor region and a cooling spray efficiency (n_s). The coding logic then treats the drain flow as a spray source. Equation (62) represents the general relationship between the incoming spray water and the receiving compartment vapor region and also applies to the interaction of ice chest drain flow. Overflow is treated in the same manner as drain flow.

3.7.1 Ice Chest Drain Model. Figure 7 illustrates the basic ice chest drain model. The parameters used to describe the analytical model are listed below:

A_2 = cross-sectional area of the drain region surface

A_3 = drain pipe cross-sectional area

d = depth of fluid in drain pipe at the end of the old time step

d_m = vertical height of drain pipe

ℓ = length of fluid column in drain pipe

ℓ_m = length of drain pipe

$\dot{m}_1$ = water addition rate to drain region

$\dot{m}_2$ = mass flow rate in the drain region

$\dot{m}_3$ = mass flow rate in the drain pipe

P_1 = pressure in compartment atmosphere

P_4 = pressure at drain pipe exit

t = time

x = height of drain region water level

x_m = spill height for drain region overflow

v_2 = velocity of liquid in drain region

v_3 = velocity of liquid in drain pipe.

The upper control surfaces of the control volume formed from the liquid in the drain region moves with the drain water surface throughout the time step while the lower surface in the pipe is updated at the end of the time step.

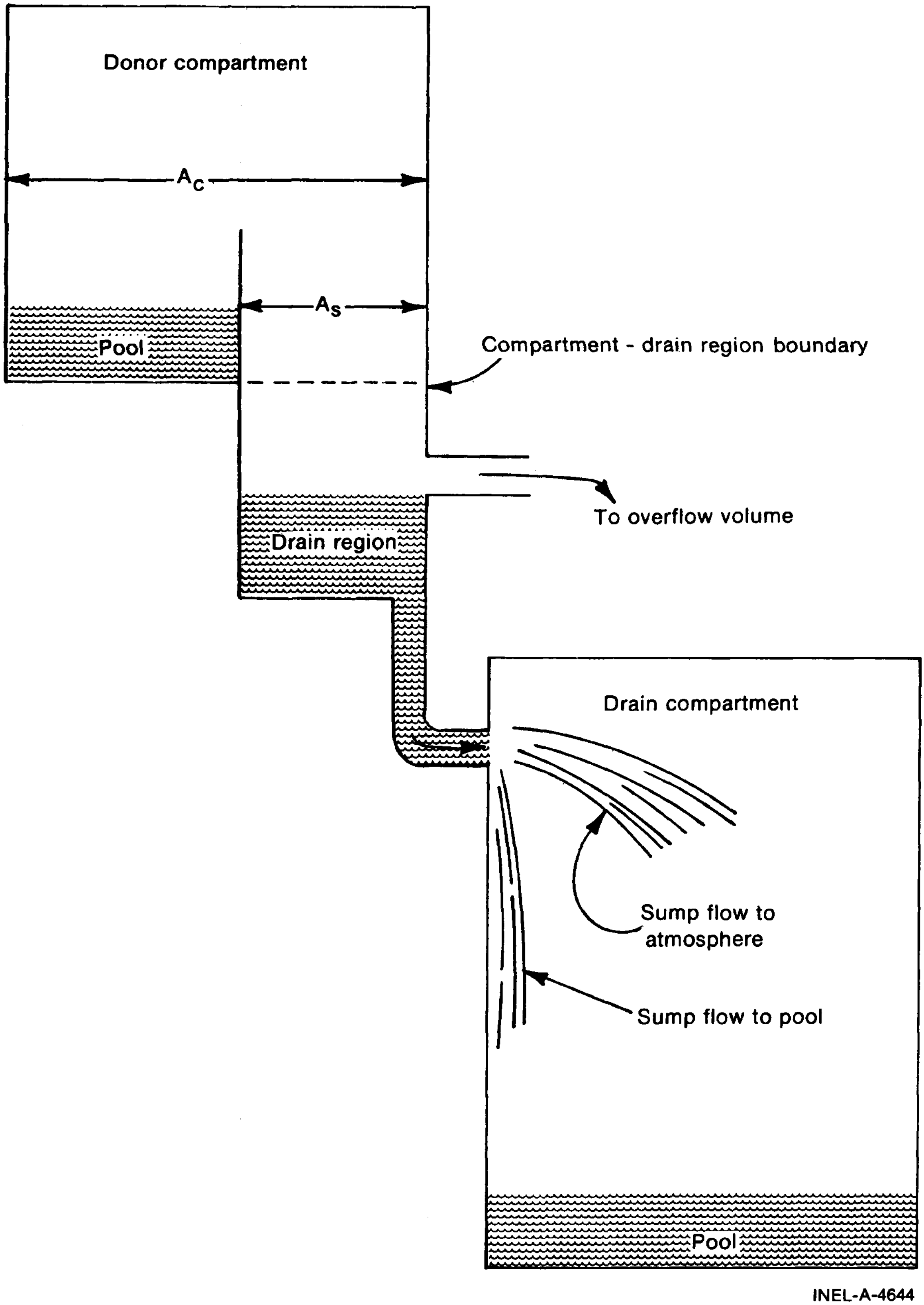

Figure 6. Example of water from drain region interacting with atmosphere region of receiver compartment.

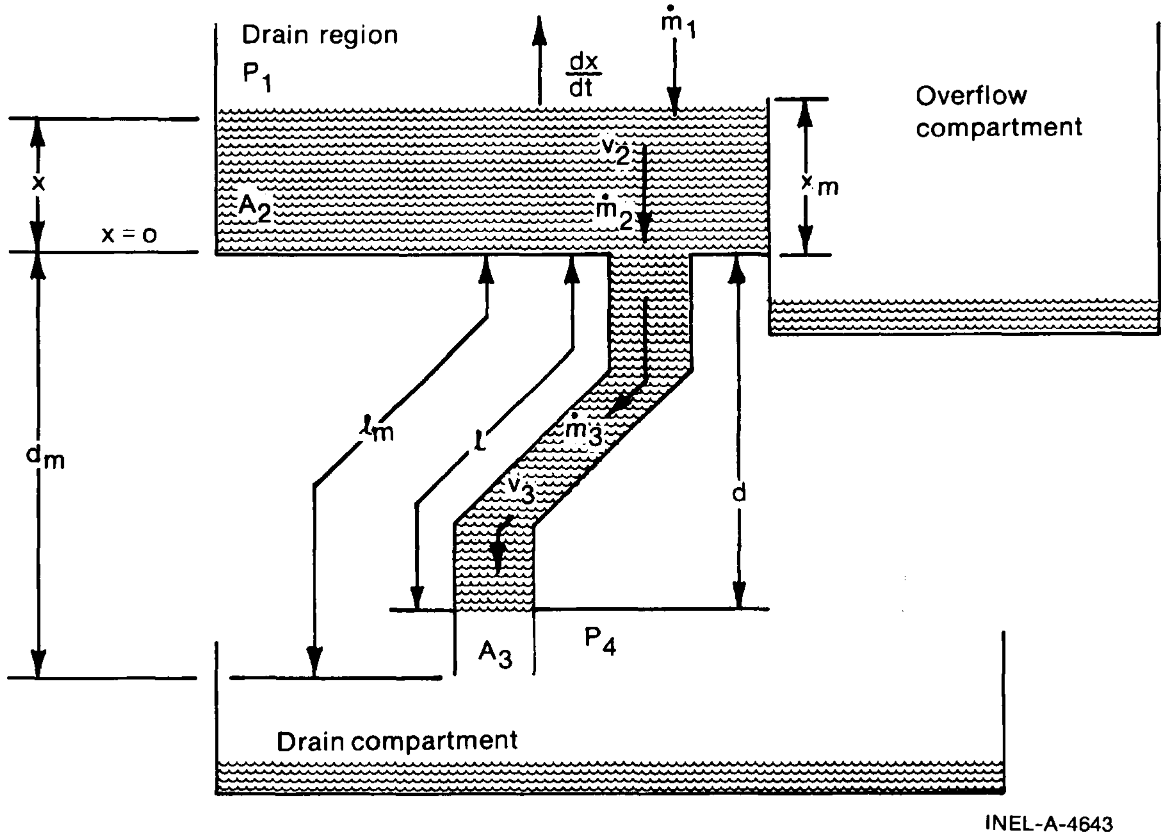

Figure 7. Sump drain model.

In the solution several assumptions are made:

1. The flow is one-dimensional and incompressible.

2. $\dot{m}_1$ is constant over a time step as determined by CONTEMPT4/MOD3 (or input).

3. The momentum flux due to $\dot{m}_1$ is negligible.

4. d is held constant over a time step.

5. ℓ is approximated by

$$\ell = d \frac{\ell_m}{d_m} \ .$$

The relevant continuity and momentum equations can then be written as

$$\frac{dx}{dt} = \frac{1}{\rho A_2} (\dot{m}_1 - \dot{m}_3) \qquad (100)$$

$$(P_4 - P_1) A_3 - \rho g A_3 (x + d) + \left[K + \frac{f\ell}{D_h}\right] \frac{\dot{m}_3^2}{2\rho A_3} = \frac{\dot{m}_3^2}{\rho A_3}$$

$$- (x + \ell) \frac{d\dot{m}_3}{dt} - \dot{m}_3 \frac{dx}{dt} \qquad (101)$$

where

g = acceleration due to gravity

K = form loss coefficient due to the sump pipe contraction and exit expansion (all form losses)

f = Moody friction factor

D_h = hydraulic flow diameter of sump pipe.

After substituting Equation (100) into Equation (101), and solving for $\frac{d\dot{m}_3}{dt}$, Equation (101) can be rewritten as

$$\frac{d\dot{m}_3}{dt} = \frac{1}{\left(x + d \frac{\ell_m}{d_m}\right)} \left[(P_1 - P_4) A_3 + \rho g A_3 (x + d) - \frac{\dot{m}_3 \dot{m}_1}{\rho A_2}\right.$$

$$\left. + \frac{\dot{m}_3^2}{\rho A_3} \left(\frac{A_3}{A_2} - \frac{K}{2} - \frac{f}{2} \frac{d\ell_m}{D_h d_m} - 1\right)\right] . \qquad (102)$$

In CONTEMPT4/MOD3, the loss coefficient for a sudden contraction is given by

$$K_c = 0.45 \left(1 - \frac{A_3}{A_2}\right) . \qquad (103)$$

The loss coefficient for sump pipe discharge is assumed to be unity. Thus, the default value of the loss coefficient K in the code is equal to 1 + K_e.

The Moody friction factor, f, is determined by the following expressions:

$$f = 64/Re , \text{ for } Re \leq 2200$$

$$f = \left\{-2 \log_{10} \left[\frac{2.51}{Re\sqrt{f_p}} + \frac{0.271 k_x}{D_h}\right]\right\}^{-2} , \text{ for } Re > 2200 \qquad (104)$$

where

f_p = preceding trial value of f

k_x = absolute roughness of wall surface

Re = Reynolds number.

Equations (100) and (102) are of the form

$$\frac{dx}{dt} = f_1 (\dot{m}_1, \dot{m}_3, x, d)$$

$$\frac{d\dot{m}_3}{dt} = f_2 (\dot{m}_1, \dot{m}_3, x, d). \quad (105)$$

By applying assumptions 2 and 4, the above two first-order differential equations can be solved for x and $\dot{m}_3$ by the Runge-Kutta method.

3.8 Pressure Suppression System Analytical Model

CONTEMPT4/MOD3 is capable of modeling a PWR ice condenser pressure suppression system. The ice condenser and ice door models are described in the following sections.

3.8.1 Ice Condenser Model. The ice condenser in a PWR ice condenser plant is a completely enclosed, refrigerated annular compartment formed between the crane wall and the containment shell. The CONTEMPT4/MOD3 ice condenser model is based on a user input table which specifies the performance of the ice chest. The temperature and quality of the water vapor leaving the ice chest and the temperature of the melt water are specified as a function of either the mass flow rate entering the ice chest, or time. The use of the ice performance input table eliminates the specification of several heat and mass transfer parameters such as heat transfer coefficient, ice surface area, liquid entrainment, convective flow rate across the ice surface, and two-phase effects. Thus, a normal compartment mass/energy balance, including heat exchange between the fluid and ice, is bypassed. The user may, by input option, introduce a heat slab in the ice chest, representing the uncovered ice support structure which is activated after total ice melt occurs in an ice chest.

3.8.1.1 Ice Condenser Analytical Model—Figure 8 illustrates the ice condenser model. The volume of an ice chest includes the vapor mixture volume, the ice volume, and the pool volume and does not include the ice chest drain region volume. Ice melt water and deentrained liquid may enter the ice chest drain region. The ice chest drain is located outside the ice chest compartment boundary. Section 3.7 describes the ice chest drain analytical model.

The quantities used in Figure 8 are described as follows:

$\dot{m}_{jk}$ = the mass flow rate from compartment j into compartment k

$\dot{m}_{k\ell}$ = the mass flow rate from compartment k into compartment ℓ

$\dot{m}_{fis}$ = mass flow rate of ice melt water into the compartment sump (pool)

$\dot{m}_{fks}$ = the condensate dropout rate in compartment k

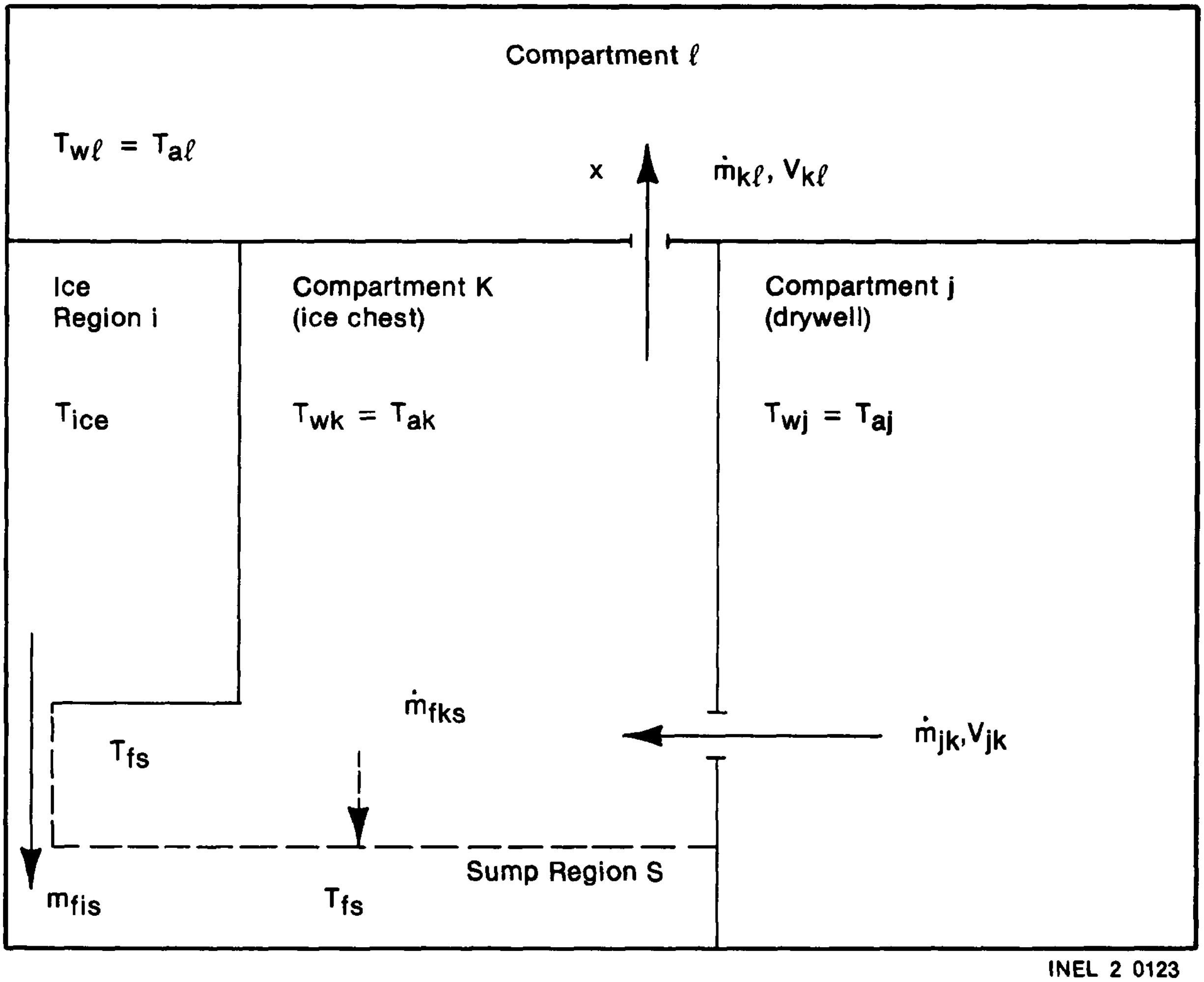

Figure 8. Ice melt schematic.

T_{wj}, T_{wk}, $T_{w\ell}$ = the temperature of water in the atmosphere of compartments j, k, and ℓ, respectively

T_{aj}, T_{ak}, $T_{a\ell}$ = the temperature of air in compartments j, k, and ℓ, respectively

T_{fs} = the temperature of the melt water

T_{ice} = the temperature of the ice

$V_{k\ell}$ = the velocity of the flow from compartment k to compartment ℓ

V_{jk} = the velocity of the flow from compartment j to compartment k.

From the energy balance, the energy transfer rate ($\dot{Q}_{ak}$) from the air to the ice in compartment k is given by

$$\dot{Q}_{ak} = \dot{m}_{ajk}\left(C_{pa}T_{aj} + \frac{V_{jk}^2}{2}\right) - \dot{m}_{ak\ell}\left(C_{pa}T_{ak} + \frac{V_{k\ell}^2}{2}\right) - \frac{d}{dt}\left(m_{ak}C_{va}T_{ak}\right). \quad (106)$$

Similarly, the energy transfer rate ($\dot{Q}_{wk}$) from the water in the atmosphere to the ice in compartment k is given by

$$\dot{Q}_{wk} = \dot{m}_{wjk}\left(h_{wj} + \frac{V_{jk}^2}{2}\right) - \dot{m}_{wk\ell}\left(h_{wk} + \frac{V_{k\ell}^2}{2}\right) - \frac{d}{dt}\left(m_{wk}u_{wk}\right) \tag{107}$$

where

$\dot{m}_{ajk}$, $\dot{m}_{wjk}$ = the mass flow rates of air and water, respectively, entering compartment k from compartment j.

$\dot{m}_{ak\ell}$, $\dot{m}_{wk\ell}$ = the mass flow rates of air and water, respectively, entering compartment ℓ from compartment k.

C_{pa}, C_{va} = the specific heat of air at constant pressure and at constant volume, respectively.

h_{wj}, h_{wk} = the specific enthalpies of water in compartments j and k, respectively.

m_{ak}, m_{wk} = the total masses of air and water, respectively, in the atmosphere of compartment k.

u_{wk} = the specific internal energy of water in the atmosphere of compartment k.

Due to the relatively small quantity, the kinetic energy of the air/water mixture within the ice compartment is neglected. The energy transferred ($\dot{Q}_{ak}^n$)from the air to the ice during the current time step is given by

$$Q_{ak}^n = m_{ajk}^n C_{pa} T_{aj}^n - m_{ak\ell}^n C_{pa} T_{ak}^n - \left(m_{ak}^n C_{va} T_{ak}^n - m_{ak}^o C_{va} T_{ak}^o\right) \tag{108}$$

The energy transferred $\left(Q_{wk}^n\right)$ from the water in the atmosphere to the ice during the current time step is given by

$$Q_{wk}^n = m_{wjk}^n h_{wj}^n - m_{wk\ell}^n h_{wk}^n - m_{wk}^n u_{wk}^n - m_{wk}^o u_{wk}^o \tag{109}$$

where

the superscripts n and o are used to denote the current and the previous time step, respectively. The same notations will be used through the following discussions.

m_{ajk}^n, m_{wjk}^n = total masses of air and water, respectively, transferred from compartment j to compartment k during the current time step.

$m_{ak\ell}^n$, $m_{wk\ell}^n$ = total masses of air and water, respectively, transferred from compartment k to compartment ℓ during the current time step.

Thus, the total energy $\left(Q_k^n\right)$ imparted to the ice from the atmosphere during the current time step is given by

$$Q_k^n = Q_{ak}^n + Q_{wk}^n \quad . \tag{110}$$

During the current time step, the energy $\left(\Delta U^n_{melt}\right)$ required to heat a unit mass of the ice at temperature T^n_{ice} up to the melting temperature (T_{melt}), cause a phase change to liquid state, and heat the melt water to the specified sump temperature T^n_{fs} is given by

$$\Delta U^n_{melt} = C_{ice}\left(T_{melt} - T^n_{ice}\right) + L_f + h^n_s\left(T^n_{fs}\right) \tag{111}$$

where

C_{ice} = specific heat of ice

L_f = heat of fusion of ice

$h^n_s\left(T^n_{fs}\right)$ = saturated specific enthalpy of the liquid water.

The total ice melt m^n_{fis} during the current time step is then obtained by

$$m^n_{fis} = \frac{Q^n_k}{\Delta U^n_{melt}} \quad . \tag{112}$$

The total mass of the condensate $\left(m^n_{fks}\right)$ during the current time step is given by

$$m^n_{fks} = m^o_{wk} - m^n_{wk} \quad . \tag{113}$$

Any liquid produced by melting immediately drops to the pool along with the condensate, and adds the energy to the pool.

3.8.2 Ice Chest Door Model. In the event of a loss-of-coolant accident, door panels located at the top and bottom of the ice chests (the lower, intermediate, and upper deck doors) open to allow the blowdown mixture to flow through the ice chests. The door panels are modeled by inertial valves having a significant inertia which controls the rate of opening for a given differential pressure across the door panel. The door panels are assumed to be hinged on each side and to open from the center. The differential pressure across the opening acts as a torque on the door panel. The door angle at any time is found by integrating the equation of motion. A viscous damping coefficient may be optionally used for the equation of motion. Once the panels reach a rotation of 90 degrees, they may be latched fully open or allowed to open and close repeatedly by selecting the appropriate option.

Orientation of the door panels and the effect of gravity are not considered in this model. Consequently, the opening rate calculated for the intermediate and upper deck panels which lie horizontally when closed may not be predicted accurately. The alternative to using the ice chest door model at those locations is to use an orifice without doors.

The differential equation of motion for the valve gate may be written as

$$I\,\ddot{\theta}(t) = \bar{A}\,P(t) - K\,\dot{\theta}(t) \tag{114}$$

where

θ = opening angle in degrees

$\dot{\theta}$ = $\frac{d\theta}{dt}$

$\ddot{\theta}$ = $\frac{d^2\theta}{dt^2}$

I = moment of inertia $= \int x^2 dm$

$\bar{A}$ = area times moment arm $= \int x dA$

P = differential pressure ($P = P_{in} - P_{out} - P_{cv}$) where P_{in} and P_{out} are the pressures on the nominal inlet and outlet sides of the door, respectively, and P_{cv} is an input closure pressure tending to hold the door closed

K = damping constant.

Converting Equation (114) from time function to angular velocity rate by substituting $\omega = \dot{\theta}$ and $\dot{\omega} = \ddot{\theta}$ along with grouping in terms of ω yields

$$I\,\dot{\omega} + K\,\omega = \bar{A}\,P. \tag{115}$$

This has the solution

$$\omega \exp(Kt / I) = \frac{\bar{A}}{I} \int \exp(Kt / I)\, P(t)dt + \omega_o \tag{116}$$

where ω_o is a constant representing angular velocity at the beginning of the time step. The pressure term can be taken out of the integral if the time steps are small enough for P to be considered constant. Performing the indicated integration gives

$$\omega \exp(Kt / I) = \frac{\bar{A}P}{K} \exp(Kt / I) + C + \omega_o . \tag{117}$$

Evaluating C at the beginning of the time step, where $t = 0$ and $\omega = \omega_o$, gives

$$C = -\frac{\bar{A}P}{K} . \tag{118}$$

Substitution for C and division by exp(Kt/I) gives

$$\omega = \omega_o \exp(-Kt / I) + \frac{\bar{A}P}{K} [1 - \exp(-Kt / I)]. \tag{119}$$

After rearranging terms, the above equation can be rewritten as:

$$\omega = \omega_o + \left(\frac{\bar{A}P}{K} - \omega_o\right) [1 - \exp(-Kt / I)]. \tag{120}$$

Substituting $\theta = \omega$ and integrating each side of the equation gives

$$\theta \Big|_0^{\theta_o} = \omega_o t + \left(\frac{\bar{A}P}{K} - \omega_o\right) \left\{t + \frac{I}{K} \exp(-Kt / I)\right\} \Big|_o^t \tag{121}$$

for an angular advance from θ_0 to θ over a discrete time step starting at t = 0. Evaluating the integrals for the limits shown and rearranging terms gives

$$\theta = \theta_o + \omega_o t + \left(\frac{\bar{A}P}{K} - \omega_o\right) \left\{t - \frac{I}{K} [1 - \exp(Kt / I)]\right\}. \tag{122}$$

The limiting value for K is 0 for nonviscous damping. Taking the limit of the above and considering K as the only variable in the limit process, then

$$\lim_{K \to 0} \theta = \theta_o + \omega_o t + \frac{\bar{A}Pt^2}{2I} . \tag{123}$$

Each ice chest door must have a table of normalized fractional cross-sectional area versus angle of opening so that the available cross-sectional flow area can be determined. The orifice junction model must be used for junctions where ice chest doors are present. Ice chest doors may not be specified for nozzle junctions.

3.9 Heat Conducting Structure Analytical Model

A heat conduction model is provided which can account for heat transfer to and from compartment regions for up to 99 heat structures. The heat addition rate to a compartment is calculated as the product of the surface heat flux and the structure heat transfer area. Heat structures may be described as cylinders, spheres, or slabs, with the physical location specified by the program user. Heat structures are activated by user input in ice chests only after total ice melt occurs. The temperature distribution within each heat structure is computed by the one-dimensional, time-dependent or steady-state heat conduction code HEAT-1[11] which uses a numerical solution of the one-dimensional heat conduction equations. The following sections describe the boundary conditions and options available in CONTEMPT4/MOD3 for heat transfer.

3.9.1 Boundary Conditions and Options. The boundary conditions are of the general form

$$-k \frac{\partial T}{\partial n} = h(T,t) [T - T_b(t)] \tag{124}$$

where

T = surface temperature

T_b = bulk temperature

$\bar{n}$ = a vector normal to the heat-conducting surface

k = thermal conductivity of the conducting material

t = time

h(T,t) = heat transfer coefficient.

Specification of h(T,t) and T_b for each boundary is done in the input data.

As indicated in Equation (124), boundary conditions for the solution of the heat conduction equations are specified by a heat transfer coefficient and a bulk temperature. The code provides for a variety of boundary conditions, permitting versatility in the use of the code. As selected by input data, the heat transfer coefficient [h(T,t)] can be one of the following (the index used to identify each option in the heat structure data input for Boundary Conditions Card 1YY1100 in Section 4.2.2.12 is shown in parentheses after each option): zero, indicating a symmetrical or insulated condition (0); the Uchida condensing steam heat transfer coefficient[12] dependent on the ratio of steam to air (2); 2.3 $W/m^2 \cdot K$ for heat transfer to the liquid region (3); 57,000 $W/m^2 \cdot K$ for a steam generating boundary condition (4); time-dependent input tables (5 or 1XXX); a temperature-dependent input table (6); a constant value from a miscellaneous input set (7-26); a turbulent natural convection correlation (50); a direct radiation correlation (51); a combination of direct radiation and natural convection correlations (52); or the Tagami[13] heat transfer correlation. All heat transfer calculations transfer sensible heat. Mass transfer due to superheated steam condensation on structures is allowed for the following options: 2, 5, 7 through 15, 53, and 1XXX (where XXX < 200).

The bulk temperature is selected by the input data and is one of the following: a constant value entered in the input, the outside air temperature, compartment vapor region temperature, or compartment liquid region temperature. The specified bulk temperature option must be the vapor region temperature for the condensing steam calculation to be performed for superheated vapor region conditions.

For user convenience in selecting proper heat transfer boundary conditions, Table 4 summarizes the principal features of the heat transfer coefficient options. Additional detail for several of these options and the information in Table 4 is given below.

3.9.1.1 Options That Transfer Condensed Steam—All boundary condition options transfer sensible heat. Options 2, 5, 7 through 15, 53, and 1XXX (for XXX < 200) also include mass transfer if certain compartment temperature conditions are met. For saturated vapor regions, an implicit condensing steam calculation is performed for all compartments when compartment thermodynamic conditions are calculated. For superheated regions, for which the temperature of the compartment vapor region T_v is greater than the saturation temperature T_{sat} based on compartment steam partial pressure, an explicit condensing steam calculation is normally performed for the options mentioned above. In addition, the bulk temperature is always equal to the saturation temperature based on the steam partial pressure. No explicit condensing steam calculation is performed if any of the following conditions are met:

1. The heat structure temperature T_{wall} is greater than the saturation temperature

2. The heat structure temperature is greater than the vapor temperature

3. The heat structure temperature is less than the vapor temperature and the bulk temperature is less than or equal to the saturation temperature.

The rate of mass transfer $\dot{m}_u$ from the vapor region to the liquid region is obtained from

$$\dot{m}_u = \frac{q_u}{h_v - h_\ell} \quad (125)$$

Table 4. Summary of heat transfer coefficient options for heat conducting structures

Heat Transfer Coefficient Option Index	Option Type	Mass Transfer Due to Superheated Steam Condensing[b]	Change of Heat Transfer Coefficient Option[c]
0	HTC = 0.0 $W/m^2 \cdot K$	No	No
2	Uchida correlation	Yes	Yes
3	HTC = 2.3 $W/m^2 \cdot K$	No	No
4	HTC = 57 000 $W/m^2 \cdot K$	No	No
	HTC table versus time	Yes	Yes
6	HTC table versus temperature	No	No
7-15	Input constant	Yes	Yes
16-26	Input constant	No	No
50	Turbulent natural convection correlation	No	No
51	Direct radiation correlation	No	No
52	Option 50 plus Option 51	No	No
53	Tagami correlation	Yes	--[d]
1001-1099	HTC table versus time	Yes	Yes
1100-1199	HTC table versus time	Yes	--[e]
1200-1999	HTC table versus time	No	No

a. The following symbols are used in this table and its footnotes:

HTC = heat transfer coefficient

T_{wall} = heat conducting structure surface temperature

T_{sat} = saturation temperature based on steam partial pressure

T_v = vapor region temperature

T_b = bulk temperature used in Equation (124) to determine heat flux.

Table 4. (continued)

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b. An implicit condensing steam calculation is always performed for all compartments if the vapor region is not superheated. For options listed "Yes" under this heading, explicit calculation of condensed steam is not performed for those compartments adjacent to heat structures if

$T_{wall} > T_{sat} + 1$ K

or

$T_{wall} > T_v$

or

$T_{wall} < T_v$ and $T_b \leq T_{sat}$.

In addition, the bulk temperature must be selected as the vapor temperature (Option 2 for Word 2 on Boundary Conditions Card 1YY1100). This option acts as a partial switch for superheated steam condensation; selection of this bulk temperature option does not necessarily allow steam condensation, but selection of a different bulk temperature option precludes any superheated steam condensation.

c. For options listed "Yes" under this heading, the input heat transfer coefficient option may be overridden. A change of option will automatically occur causing a change in heat transfer coefficient for the following conditions:

If

$T_{wall} > T_v$, the code uses Option 50.

If

$T_{wall} \leq T_v$ and $T_{wall} \geq T_{sat}$, the code uses Option 50.

If

$T_{wall} < T_v$ and $T_{wall} < T_{sat}$, the code uses a heat transfer coefficient which will give the maximum heat flux q based on either

$$q = h_u A(T_v - T_{wall})$$

or

$$q = h_N A(T_{sat} - T_{wall})$$

where h_u is 11.4 $W/m^2 \cdot K$, the lower bound for the Uchida option, and h_N is the user-chosen heat transfer coefficient.

In addition, the saturation temperature is usually used for the bulk temperature for those options listed "Yes" under this heading. If a change of heat transfer coefficient to Option 50 has occurred, the vapor temperature will then be used.

d. For Option 53 up until the time-to-pressure is reached, no change of option occurs; the heat transfer coefficients calculated by the Tagami correlation are used. Also, for Option 53, the bulk temperature always equals the saturation temperature. After the time-to-pressure is reached and a new user-input option comes into effect, the limitations under Option 53 are not applicable.

e. For Options 1100-1199, change of heat transfer coefficient option as outlined under (c) may occur, but the bulk temperature always equals the vapor temperature, not the saturation temperature.

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where

q_u = the heat transfer rate

h_v = specific enthalpy of vapor in the vapor region

h_ℓ = specific enthalpy of liquid in the vapor region at saturation.

Special conditions exist which require the code to override the heat structure boundary conditions chosen by the program user in order to more accurately predict the heat transfer phenomenon. These conditions involve a change in either the bulk temperature determination or heat transfer coefficient option.

For heat transfer Options 2, 5, 7 through 15, and 1XXX (for XXX < 200), the turbulent natural convection correlation (Option 50) will be used when either the heat structure temperature T_{wall} is greater than the vapor region temperature T_v, or T_{wall} is less than T_v and greater than the saturation temperature T_{sat}. If T_{wall} is less than both T_{sat} and T_v, the heat transfer rate q is calculated from either

$$q = h_u A \, (T_v - T_{wall}) \tag{126}$$

or

$$q = h_N A \, (T_{sat} - T_{wall}), \tag{127}$$

whichever is greater, where

h_u = 11.4 $W/m^2 \cdot K$, the lower bound for the Uchida option

h_N = heat transfer coefficient for Option N, and N = 2, 5, 7 through 15, or 1XXX (for XXX < 200)

A = heat transfer surface area.

In any event, the minimum heat transfer coefficient generated using Equations (126) and (127) is limited to 11.4 $W/m^2{\cdot}K$ which is the lower bound of the Uchida option.

For heat transfer Options 1XXX (for XXX from 100 to 199), a change of heat transfer coefficient option mentioned above may occur, and mass transfer due to condensing superheated steam is also allowed. However, the bulk temperature is always equal to the vapor temperature, not the saturation temperature. This allows the program user to input tables of heat transfer coefficients as a function of time when the heat transfer coefficients were obtained based on the vapor region temperature.

3.9.1.2 Heat Transfer Coefficient Correlations for Condensing Steam Situations—Several of the heat transfer coefficient options in CONTEMPT4/MOD3 transfer condensed superheated steam to the pool region as well as heat to the heat-conducting structure. However, two of these options calculate heat transfer coefficients from correlations based on empirical data for condensing steam situations. Heat transfer in a containment building following a loss-of-coolant accident (LOCA) can be divided into two periods of time. The first period occurs during blowdown of the primary coolant, when condensation on heat-conducting structures is characterized by natural convection in the atmosphere. Following the turbulent decompression of the primary coolant system is a period characterized by forced convection in the containment atmosphere. The two correlations included in CONTEMPT4/MOD3 which calculate heat transfer coefficients in the containment for these time periods are discussed next.

3.9.1.2.1 Tagami Heat Transfer Coefficient Option—An empirical correlation, which applies during the forced convection period following primary system blowdown, has been developed by Tagami. This correlation states that the maximum heat transfer coefficient depends on several parameters, including the total energy released from the primary coolant system during decompression, the volume of the containment building, and the time required for decompression.[13] This heat transfer correlation can be expressed as

$$h_{max} = C \left(\frac{U}{Vt_p}\right)^{0.62} \tag{128}$$

where

h_{max} = the maximum heat transfer coefficient during blowdown

C = a constant equal to 0.607 for SI units

U = the total energy released from blowdown of the primary system during time interval t_p

V = the free volume of the adjacent compartment

t_p = the time interval from the beginning of blowdown until the initial (but not necessarily the maximum) pressure peak caused by the blowdown. Time t_p marks the end of the blowdown-induced forced-convection period.

Several of these parameters require further explanation. The value for the total blowdown energy release, U, is calculated by the code by integration of energy rates from selected single transaction tables over time interval t_p. For a single-volume representation of the containment building, the volume term V is the total free volume; for multicompartment analyses, the correct value to use for the volume term for each heat structure is the total volume of the compartment or compartments that are directly influenced by the turbulence induced by the blowdown.

The Tagami heat transfer coefficient h is linearly increased to its maximum value depending on the actual problem time, t, using

$$h = h_{max} \frac{t}{t_p} \quad . \tag{129}$$

In addition, since the Tagami correlation is relevant only until t_p is reached, a second set of heat transfer coefficient and bulk temperature options must be input for the natural convection portion of the blowdown.

3.9.1.2.2 Uchida Heat Transfer Coefficient Option—The Uchida condensing steam heat transfer coefficient is applicable after the blowdown-induced forced convection period has ended. These coefficients are dependent on the mass ratio of air to steam present in the adjacent compartment atmosphere region, as described in Table 5.[12] For superheated regions for which the temperature of the vapor region is above the saturation temperature and the temperature of the wall is less than the saturated temperature, the heat transfer rate is calculated from either Equation (126) or (127), whichever is greater. For saturated atmosphere conditions, the standard Uchida heat transfer coefficient is used. Note that the lower bound for the Uchida heat transfer coefficient is 11.4 $W/m^2 \cdot K$.

3.9.1.3 Turbulent Natural Convection Correlation Option—The turbulent natural convection correlation option can be used when the product of Grashof and Prandtl[14] numbers is within the range

$\sim 10^7 \le (Gr\ PR) \le 10^{12}$.

This correlation is given by[4]

$$h_c = 0.13 \left(\rho_f^2\ g\ \beta_f\ \Delta T\ C_{cpf}\ k_f^2/\mu_f\right)^{1/3} \tag{130}$$

Table 5. Heat transfer coefficient vs. mass ratio of air to steam

Mass Ratio (air/steam)	Heat Transfer Coefficient ($W/m^2 \cdot K$)	Mass Ratio (air/steam)	Heat Transfer Coefficient ($W/m^2 \cdot K$)
≥50	11.4	3.0	165
20	45.4	2.3	210
18	51.1	1.8	261
14	56.8	1.3	358
10	79.5	0.8	557
7	96.5	0.5	795
5	119	≤0.1	1590
4	136		

where

h_c = heat transfer coefficient

ρ_f = density of gas region (air and water vapor)

g = acceleration due to gravity

β_f = $1/T_f$ is absolute temperature of film on wall (assumes ideal gas)

ΔT = temperature difference between wall and bulk gas region

C_{pf} = specific heat of gas at constant pressure

k_f = thermal conductivity of gas region

μ_f = viscosity of gas region.

The gas properties are evaluated at the average film temperature, defined as the average of the wall and bulk gas region temperatures. The model assumes an ideal gas to obtain β_f, assumes the gas to be air to evaluate C_{pf}, k_f, μ_f, and uses the actual gas density (air plus water vapor) rather than air density. Also, the absolute value of ΔT (where ΔT is $T_{wall} - T_b$) is used, and if ΔT is less than 0.5 K, a value of 1.08 $W/m^2 \cdot K$ is assigned to h_c'.

3.9.1.4 Direct Radiation Model Option—A simplified direct radiation heating model may be specified at any heat structure boundary. The user may specify only radiation heat transfer, or a combination of radiation and turbulent natural convection heat transfer. A basic equation for direct radiation heat transfer from Surface 1 to Surface 2 is[4]

$$q_{r12} = \sigma A_1 F_{12} \left(T_1^4 - T_2^4 \right) \quad (131)$$

where

q_{r12} = energy absorption rate at Surface 2

σ = the Stefan-Boltzmann constant

A_1 = area of Surface 1

F_{12} = view factor (unitless)

T_1 = absolute temperature of Surface 1

T_2 = absolute temperature of Surface 2.

For direct blackbody radiation theory, the view factor, F_{12}, represents the fraction of radiation leaving Surface 1 that is absorbed by Surface 2. For nonblackbody theory, the surface emissivities may also be combined into the view factor.

Equation (131) is based on the assumption of no energy loss due to absorption by a gas medium between the two surfaces. However, this model provides for a fraction of the radiant energy to be absorbed in the adjoining vapor region. Also, the code allows the Surface 2 temperature to be either an actual surface temperature or a constant sink temperature. Because the radiation model is an approximation of the actual radiation heating, the following restriction exists; given radiation heat transfer from Surface 1 to some opposite Surface 2, CONTEMPT4/MOD3 accounts for the heat flow from Surface 1 and allows a specified fraction to be absorbed in the adjoining gas medium. However, no energy is transmitted to Surface 2 from specifying the radiation heating boundary condition on Surface 1. This restriction decouples the heat structures. Proper radiant heat transfer at Surface 2 can be obtained by specifying the radiation boundary condition for that surface on the appropriate control card.

Equations (132) and (133) are solved for radiation heating. The heat transfer is determined through use of

$$q_{ri} = h_{ri} A_i \left(T_i - T_s\right) \tag{132}$$

where

h_{ri} = heat transfer coefficient

A_i = surface area of Surface i

T_i = temperature of Surface i

T_s = temperature of opposite surface or of constant sink

q_{ri} = heat rate leaving Surface i.

The temperatures used to determine q_{ri} are end-of-time-step values. A fraction of heat, fq_{ri}, is absorbed in the medium adjoining Surface i. The f value is an input quantity.

The heat transfer coefficient, h_{ri}, is evaluated from

$$h_{ri} = \left| \frac{10^8 \, \sigma \, F_i \left[\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_s}{100}\right)^4 \right]}{T_i - T_s} \right| \tag{133}$$

where F_i is the input view factor.

Temperature values at the beginning of a time step are used to determine h_{ri}. For the initial steady-state calculation, T_s is an input value and T_i is a code-predicted number.

3.9.2 Compartment Energy Adjustment. The rate of heat transfer q_{HT} between one surface of a heat structure and an adjacent medium (either the vapor region or the pool region) is calculated by

$$q_{HT} = A \, h^b \, h \left(T_{wall} - T_b\right) \tag{134}$$

where

h = heat transfer coefficient

A = effective heat transfer surface area multiplier

h^b = geometry surface area adjustment factor.

The purpose of A in Equation (134) is to relate the heat transfer rates obtained from the solution of the one-dimensional heat conduction equation in the HEAT-1 subcode[11] to the heat transfer rates from the entire surface of the structure. The definition of h^b is such that the expression $[h^b h(T_{wall} - T_b)]$ represents the heat transfer rate across a unit surface in slab geometry (W/m^2), across a cylindrical surface of unit height in cylindrical geometry (W/m), and across a spherical shell in spherical geometry (W). The quantity h^b also accounts for the difference in the areas of the left and right surfaces of a cylindrical or spherical structure. Thus, the quantity A has the same value for either the left or right boundary, although its definition (and units) varies with the geometry of a structure. For example, in slab geometry, A is the cross-sectional area of the structure. Several identical structures can be described by one heat conduction equation by setting A equal to the sum of the cross-sectional areas of the structures. If a slab is symmetrical, only half of the slab need be described. One surface of the half slab would have symmetry conditions, and A would be doubled. In cylindrical geometry, A is usually the height of the cylinder (m) and Ah^b is the area of one of the curved surfaces of the cylindrical annulus. If the structure is not a complete cylinder (such as a cylindrical wall minus a door), the actual A used would be the original A multiplied by the ratio of one of the actual surfaces to the corresponding Ah^b of the entire cylindrical surface. In spherical geometry, A is the ratio of one of the surfaces of the structure to the corresponding surface of a spherical shell; that is, A is 0.5 for a hemisphere.

The program user specifies the compartment and its region to which the heat is transferred. If heat transfer is to a liquid region and no liquid pool exists in that compartment, the energy is transferred to the vapor region of the same compartment. No direct mass changes result from the heat structure calculations except for those calculations making use of the condensing superheated steam option.

A predictor-corrector scheme is employed to predict the energy transfer to heat structures. Preliminary compartment thermodynamic properties such as pressures and temperatures are estimated based on the effects of all problem features, except heat structures, prior to the heat structure calculations. Estimated (or predicted) compartment properties are used to determine structure heat transfer rates. Compartment properties are then recalculated based on the effect of all problem features, including heat structures.

3.10 Problem Editing and Time Step Control

This section describes the editing and time step control options available in CONTEMPT4/MOD3. The frequency and content of edits, as well as the selection of either manual or automatic time step size, are controlled by user input.

Time advancement from the present time to the next time occurs in an increment of one time step and is referred to as an iteration. Problem initiation may begin at time zero or some time later than zero.

CONTEMPT4/MOD3 provides major and minor editing of printed output at selected intervals during problem execution. The frequency of edits is based on specific time step (iteration) multiples. The content of major and minor edits is described in Sections 4.2.2.1 and 4.4.1. The output frequency for major edits may be specified differently than that for minor edits.

3.10.1 Time Step Control. Time step size may be entirely dictated by the user, entirely determined by the code, or based on a combination of user-dictated and code-determined values. After the program user has determined the problem time length, the entire problem time must then be divided into arbitrary time intervals, some of which may have time steps of fixed size, while other intervals may have time step sizes calculated by the code. User judgment and experience are the best guides for determining appropriate time step controls for a certain problem. Guidelines for choosing time step sizes and dividing the total problem time into discrete time intervals are discussed in Section 4.3.1.3. The two time step control options available, manual control and automatic control, are described below.

3.10.1.1 Manual Time Step Control—The manual time step control option allows the program user to input specific time step sizes for selected time intervals. No reduction or increase in time step size is performed by the code during time intervals when the manual option is in effect. This option assumes that the user has a priori judgment sufficient to estimate conservative values for time step size. This option also permits the user to avoid time step reduction for those time intervals where automatic time step control is undesired, for economic or other reasons.

3.10.1.2 Automatic Time Step Control—The automatic time step control option permits the code to determine time step size based on user input limits and compartment conditions. Although selection of the automatic control option for most analyses will result in longer (or nonoptimal) CPU running time, this may be preferable to making a series of runs with manual time step control to determine an optimal set of time step sizes. The user is cautioned that, for problems involving complex networks, the automatic time step control may not be suitable for certain time intervals, calculating either time step sizes too small (which unnecessarily increases CPU time) or time step sizes too large (which leads to unacceptable inaccuracy). The automatic control option is usually not suitable during periods of rapid blowdown or fluctuating junction flow rate. The guidelines in Section 4.3.1.3 may help to identify these inappropriate time intervals.

The operation of the automatic control option is constrained by maximum and minimum input values for time step size. Selection of these values is highly problem dependent; however, an understanding of how the time step control works may be helpful. For each time interval, the code uses the maximum time step size (variable DTA on Time Step and Edit Control Card 90II) for the first iteration. Realistic values for maximum and minimum time step sizes should be entered. The user should not depend totally on the code to seek a correct value. The smallest minimum time step size ever needed appears to be about 0.001 s for full-size containment analyses and 0.0001 s for experimental (scaled-down) containment analyses. In time intervals where rapid or critical changes in compartment conditions are not expected, the minimum time step size should be increased.

For each iteration, the automatic control logic calculates time step sizes based on compartment conditions.

3.10.1.3 Determination of Time Step Size—For the automatic time step control option, the checks performed on all compartments (except ice chests and outside atmosphere) and junctions to determine probable time step size are listed below. If time step reduction is warranted, the value dt_{auto} is used to calculate the new time step size dt_{new}.

$$dt_{auto} = C_1 \left| \frac{P}{\dot{P}} \right| \tag{135}$$

$$dt_{auto} = C_2 \left| \frac{m}{\dot{m}} \right| \tag{136}$$

$$dt_{auto} = C_3 \left| \frac{w}{\dot{w}} \right| \tag{137}$$

where

P = total compartment pressure

$\dot{P}$ = pressure rate change, dP/dt

m = total compartment mass

$\dot{m}$ = net compartment mass flux, dm/dt

w = junction mass flow

$\dot{w}$ = rate of change of junction flow, dw/dt

C_1 = constant = 0.010

C_2 = constant = 100.0

C_3 = constant = 0.0 for $\Delta T \leq 2.0$ K

= 20.0 for $2.0 \text{ K} < \Delta T < 10.0$ K

= 8.0 for $10.0 \text{ K} \leq \Delta T \leq 30.0$ K

= 2.0 for $30.0 \text{ K} < \Delta T \leq 60.0$ K

= 0.9 for $\Delta T > 60.0$ K

where ΔT is the differential vapor temperature across the junction.

The constants C_1, C_2, and C_3 were chosen such that, for the majority of problems, the calculated time step sizes would be underestimated.

If the values calculated for dt_{auto} are all larger than the present time step dt, the iteration is then completed with the present time step size, and in the following iteration, the time step size is increased by

$$dt = 1.10\ dt. \tag{138}$$

If any calculated value of dt_{auto} is less than dt, the iteration is then repeated using a new time step size, dt_{new}, calculated from

$$dt_{new} = \frac{dt}{C + 1} \tag{139}$$

where

C = dt/dt_{auto} truncated to the next lower integer. If C equals unity, no time step reduction will occur. If C is greater than three, the quantity (C + 1) is reduced by one in order to limit the effect of time step reduction.

In addition, compartment mass and energy inventories are checked to detect whenever total mass or energy voiding occurs in a compartment. If voiding occurs, the time step size is reduced by a factor of two and the iteration is repeated.

Subroutines involved in the automatic time step control logic include CHKFLO, CHKINV, and CHKCHG. Junction mass flow rate is monitored by subroutine CHKFLO. Compartment mass and energy inventories are monitored by subroutine CHKINV. Total pressure and compartment mass flux are monitored by subroutine CHKCHG. The calculations in these three routines are performed only once per time step.

Special logic is employed whenever the minimum time step size is chosen during an iteration. If compartment voiding is detected in CHKINV when the minimum time step is in use, a fatal error is generated.

Subroutine CHKCHG is not entered for those time steps where the minimum time step value was selected by either CHKFLO or CHKINV. If the minimum time step value is used for a given time step, then the following time step will also use the minimum value, and subroutines CHKCHG and CHKFLO will be bypassed for that iteration. Subsequent iterations will proceed normally until the minimum time step value is again selected.

3.10.2 Problem Termination. Normal problem termination occurs when either the iteration limit is exceeded or the problem end time is reached. Abnormal problem termination generally occurs whenever a fatal error is detected by the code. Compartment voiding may also cause abnormal termination. If voiding occurs when manual time step control is in effect, the problem will be stopped. If voiding occurs when automatic time step control is in effect and the time step size is the user input minimum time step size, the problem will also be stopped.

4. PROGRAM IMPLEMENTATION

This section discusses the use of the CONTEMPT4/MOD3 computer program in simulating the response of containment systems to postulated accident conditions. A general program description is followed by input data requirements and user guidelines.

4.1 Program Description

The CONTEMPT4/MOD3 computer program is written in FORTRAN IV and is operational on the CDC 7600 computer. To conserve computer storage, the program relies on both overlaying of program segments and dynamic allocation of variable storage requirements. Particular aspects of program organization, including a discussion of subroutine interfacing and sequencing, are presented in Appendix D.

CONTEMPT4/MOD3 problem execution consists of a series of stepwise time advancements of user-designated time step size. The program has an option to automatically calculate time step size.

The program uses one external source of data. The water and steam property tables are not contained within the computer until they are retrieved early in the calculation. These tables must be generated by the STH2O program described in Appendix B before a CONTEMPT4/MOD3 calculation is attempted. They need be generated and saved only once since CONTEMPT4/MOD3 uses the tables but does not modify them. For convenience in implementing CONTEMPT4/MOD3 these tables are contained as a separate file of the CONTEMPT4/MOD3 program and need not be generated by the program user.

In addition to the printed output, the program user may request plotted output. Plotting information is accumulated during time step processing and used by the PLOTCT4 plotting program (see Appendix F) to generate plots.

4.2 Input Data Requirements

All information needed by the program user to prepare a problem data card deck for use with CONTEMPT4/MOD3 is contained in this section. Additional input information can be found in Appendix E and may be helpful in obtaining correct interpretation of input card descriptions. However, the input data requirements and card descriptions found in this section are to be used when preparing a data card deck.

4.2.1 General Considerations. CONTEMPT4/MOD3 input data consist of a title card (optional), comment cards (optional), data cards, and a terminator card. A listing of the cards is printed at the beginning of each problem. The order of the title, data, and comment cards is unimportant. If duplicate title or data cards are encountered, the last title card and the last data card will be used. Data may be carried over to successive problems in a problem set. Thus, only the data that are changed must be entered for successive problems.

When a card format error is detected, a line is printed containing a dollar sign ($) located under the character causing the error and a comment giving the card column of the error. An error comment is produced such that input processing continues and a fatal or nonfatal error message is produced when the program attempts to process the erroneous data. A description of fatal and nonfatal error statements produced by CONTEMPT4/MOD3 is included in Appendix E. The CONTEMPT4/MOD3 problem is terminated at the end of input processing if fatal input errors are present.

4.2.1.1 Title Card—A title card is optional but recommended for each CONTEMPT4/MOD3 problem. A title card is identified by an equal sign (=) as the first nonblank character. The title is printed as the second line of every page.

4.2.1.2 Comment Cards—An asterisk (*) or a dollar sign ($) appearing as the first nonblank character identifies the card as a comment card. Any information may be entered on the remainder of the card. Blank cards are treated as comment cards. There is no processing of comment cards other than printing them. Comment cards may be placed anywhere in the input deck.

4.2.1.3 Data Cards—The data cards contain a varying number of fields which may be integer, floating point, or alphanumeric. Blanks preceding and following fields are ignored. The first field on a data card is a card number which must be an unsigned integer. If the first field has an error or is not an integer, an error flag is set. Consequently, data on the card are not used, and the card will be identified by the card sequence number in the list of unused data cards. After each card number and the accompanying data are converted, the card number is compared to previously entered card numbers. If a matching card number is found, the data entered on the previous card are replaced by the data of the current card. If the card being processed contains only a card number, the data entered on the previous card are deleted. If a card causes replacement or deletion of data, a statement is printed indicating that the card is a replacement card.

Comment information may be made to follow the data fields on any data card by initiating the comments with an asterisk or dollar sign.

A number field is started by either a digit (0 through 9), a sign (+ or -), or a decimal point (.). A comma or a blank (with one exception to be noted) terminates the number field. The number field has a number part and, optionally, an exponent part. A number field without a decimal point or an exponent is an integer field; a number field with a decimal point, an exponent, or both is a floating-point field. A floating-point field without a decimal point is assumed to have a decimal point immediately in front of the first digit. The exponent denotes the power of ten to be applied to the number part of the field. The exponent part is a sign, an E or D, and a sign followed by a number giving the power of ten. These rules for floating-point numbers are identical to those for entering data in FORTRAN E- or F-formatted fields except that no blanks (with one exception) are allowed between characters. Floating-point data punched by FORTRAN programs have a blank, treated as a plus sign, following an E or D denoting an exponent. Acceptable ways of entering floating-point numbers are illustrated by the following six fields, all containing the quantity 12.45:

12.45, +12.45, 1245E2 1.245+1, 1.245E1 1.245E+1.

A field starting with a letter is an alphanumeric field. The field is terminated by a single comma, one or more blanks, or the end of the card. All characters except commas and blanks are allowed.

A data card may be continued under the same card number by beginning each continuation card with a plus sign (+) instead of a card number. While this feature may be used, it is discouraged since it introduces order dependence into an otherwise order-independent set of cards. The CONTEMPT4/MOD3 card numbering system allows digits in the card numbers to be used for continuing card series that do not fit on one card.

4.2.1.4 Terminator Cards—The input data for CONTEMPT4/MOD3 problems are separated by slash cards; the final problem is terminated by a period card instead of a slash card. The period card also serves as the separator between problem sets. The slash and period cards have a (/) and (.), respectively, as the first nonblank character.

When a slash card is used as a problem terminator, the list of card numbers and associated data used in a problem is passed to the next problem. Cards entered for the next problem are added to the passed list or act as replacement cards, depending on the card number. The resulting input is the same as if all previous slash cards were removed from the input to the problem set.

When a period card is used as a terminator, input from all previous cards is erased before the input to the next problem is processed.

A final terminator is not necessary since the system senses the end of the input data file. Thus, single problems may be run without an explicit terminator if no plots are requested.

4.2.1.5 Internal/External Numbering—Frequently, the program user must change, add or delete data from the problem deck. In CONTEMPT4/MOD3 the effort required for such operations is minimized by providing a flexible system for numbering problem features. A problem feature is defined as either an analytical model description, such as the fan cooler model, or a program function, such as the generalized table logic discussed in the following section. Problem features other than heat structures may be numbered by the user in any arbitrary fashion without regard to sequencing; the only restraint is that an index number for a particular feature may be used only once. For example, there may be only one compartment numbered 9, although any other problem feature, such as a junction, may also be numbered 9.

The external numbering scheme adopted by the program user is converted by CONTEMPT4/MOD3 into an internal numbering system (for program use) which is sequential for each feature (beginning at one). Further information concerning internal/external numbering and the problem feature logic is contained in Appendix D.

As an example, standard compartments may be numbered 8, 9, 20, and 30, and ice compartments may be numbered 41, 42, 43, and 48. The data for any compartment may be removed without renumbering other compartments. Similarly, data for a new compartment may be freely inserted and assigned a new external number.

The heat structures are the only exception to the procedure above. Heat structures must be numbered sequentially, beginning at one. The internal and external numbers for this feature are the same. Index YY is reserved for numbering heat structures as a reminder of this numbering restraint.

4.2.1.6 Generalized Tables—CONTEMPT4/MOD3 contains the capability for processing and storing tables consisting of an arbitrary number of n-tuples, where $1 \leq n \leq 4$. Each of the n variables may have its own units. Furthermore, an optional title may accompany each table. Although these tables have diverse uses, all are processed and stored together. A description of generalized table format and input is presented in Appendix C.

4.2.1.7 Units Specification—All internal calculations in the CONTEMPT4/MOD3 program are performed using SI (Systeme Internationale d'Unites) metric units. Either SI or British units may be specified for CONTEMPT4/MOD3 output. However, units specification for input is flexible, allowing different input for model and problem features to be described in different units. Input data are converted into SI units for the code's internal use by a special subroutine. The actual unit specification must be in the form of those listed below.

1. Length: MM, CM, M, KM, IN, FT, YD

2. Area: MM2, CM2, M2, KM2, IN2, FT2, YD2

3. Volume: MM3, CM3, M3, LTR, IN3, FT3, YD3, GAL

4. Mass: GM, KG, LB

5. Time: SEC, MIN, HR

6. Energy: CAL, J, ERG, BTU, FT-LBF

7. Volume/time: M3/SEC, M3/MIN, M3/HR, LTR/SEC, LTR/MIN, LTR/HR, FT3/SEC, FT3/MIN, FT3/HR, GAL/SEC, GAL/MIN, GAL/HR

8. Mass/time: KG/SEC, KG/MIN, KG/HR, LB/SEC, LB/MIN, LB/HR

9. Power (energy/time): CAL/SEC, WATT, KW, MW, BTU/SEC, BTU/MIN, BTU/HR

10. Energy/mass: J/KG, BTU/LB, J/GM

11. Force: DYN, N, GMF, KGF, LBF, PNDL

12. Pressure: N/M2, DYN/CM2, BAR, KGF/M2, GMF/CM2, LBF/IN2, LBF/FT2, ATM, PNDL/FT2

13. Temperature: DEGK, DEGC, DEGF, DEGR

14. Reciprocal time: SEC-1, MIN-1, HR-1

15. Heat transfer coefficient: WATT/M2-DEGC, WATT/M2-DEGK, KW/M2-DEGC, KW/M2-DEGK, MW/M2-DEGC, MW/M2-DEGK, CAL/SEC-CM2-DEGC, BTU/SEC-FT2-DEGF, BTU/HR-FT2-DEGF

16. Thermal conductivity: WATT/M-DEGC, WATT/M-DEGK, CAL/SEC-CM-DEGC, BTU/SEC-FT-DEGF, BTU/HR-FT-DEGF

17. Heat capacity: J/KG-DEGC, J/KG-DEGK, CAL/GM-DEGC, BTU/LB-DEGF

18. Volumetric heat capacity: J/M3-DEGC, J/M3-DEGK, CAL/CM3-DEGC, BTU/FT3-DEGF

19. Density: KG/M3, GM/CM3, LB/FT3

20. Specific volume: M3/KG, CM3/GM, FT3/LB

21. Reciprocal length: MM-1, CM-1, M-1, KM-1, IN-1, FT-1, YD-1.

NOTE: For generalized tables only, NONE specifies a dimensionless quantity.

4.2.2 Data Card Summary. In the following description of the data cards, the data cards for a common feature (e.g., junction flow) are grouped together. For each data card, the card number is given along with the descriptive title for that card. Next, a detailed description of the variables required and the options available for that card is presented. The following conventions apply to all card numbers and descriptions:

1. The symbols I, J, II, and JJ mean that the corresponding digits in the card number are used to sequence cards in a card series. These sequence digits always start at one and form a sequence without skipping any numbers.

2. The symbols XX, XXX, and WW mean that the corresponding digits specify the number of the problem feature. Except where noted, these numbers need not be sequential.

3. The symbol YY is reserved for use in numbering heat structures. These digits must be sequential beginning at one. The heat structures are the only problem feature which must be numbered sequentially.

4. Fields on a data card are denoted by W1, W2, W3 ... and may not be omitted unless specifically noted. That is, where fields are optional, this will be noted; otherwise, each field must have an appropriate entry.

5. The type of data required for a field is denoted by A, R, or I for alphanumeric, real, or integer data, respectively.

The CONTEMPT4/MOD3 card series are listed in numerical order below. The data cards are grouped by function in a following listing.

Card	Card—Description[a]
=	Problem Title
100	*General Control
105	*Restart Control
1XX0	Single Transaction Title
1XX1	Single Transaction
2XX0	Double Transaction Title
2XX1	Double Transaction
6000	Ice Chest Drain Units and Initialization Limit
6XX1	Ice Chest Drain Description
6XX8	Additional Ice Chest Drain Inlet Compartment
7000	Drywell/Ice Chest Flow Units
8000	Junction Description Units
8XXX	Junction Description
9000	*Time Step and Edit Control
90II	*Time Step and Edit Control
91II	Minor Edit Variable Control
99II	Debug Control
40000	*Compartment Description Units
4XXX0	Compartment Title
4XXX1	*Compartment Description
4XXX2	Compartment Description and Initial Conditions Duplication
60000	Ice Initial Conditions Units
6XXX1	Ice Initial Conditions
6XXX2	Ice Initial Conditions Duplication
70000	Drywell/Ice Chest Junction
7JJII	Drywell/Ice Chest Flow Distribution
81000	Ice Chest Door Units
81XXX	Ice Chest Door Description
90000	Fan/Pump Units
90001	Source Table Units
90002	Freewheeling Fan/Pump Units
90XX1	Fan/Pump Description
90XX2	Fan/Pump Constant Speed or Flow Control
90XX4	Flow Rate Table Number
90XX5	Freewheeling Fan/Pump Description
90XX6	Source Table
91XXX	Fan Cooler Description
1XXXII	Ice Chest Door Generalized Table
1XXXII	Ice Performance Generalized Table
1XXXII	Outside Air Temperature Generalized Table

a. An asterisk (*) identifies a card required for all problems.

Card	Card—Description[a]
1XXXII	Single Transaction Generalized Table
1XXXII	Double Transaction Generalized Table
1XXXII	Fan Cooler Generalized Table
1XXXII	Debug On/Off Generalized Table
1XXXII	Ice Chest Drain Initialization Generalized Table
1XXXII	Heat Source Multiplier Generalized Table
1XXXII	Time-Dependent Heat Transfer Coefficient Generalized Table
1XXXII	Fan/Pump Flow Generalized Table
800000	Spray and Heat Exchanger Units
80XX00	Spray System Description
80XXII	Spray Table
8500WW	Heat Exchanger Description
85WWII	Heat Exchanger Energy Removal Rate Table
1000000	Common Data Units
1000001	Heat Structure Description Units
10001II	Material Properties
10002II	Miscellaneous Heat Transfer Coefficient
10003II	Time-Dependent Heat Transfer Coefficient
10004II	Temperature-Dependent Heat Transfer Coefficient
10005II	Tagami Boundary Conditions
1001100	General Bulk Temperature
1YY0000	Heat Structure Title
1YY0001	Heat Structure Control
1YY0002	Heat Structure Connection and Miscellaneous Data
1YY0200	Mesh Increment Format
1YY02II	Mesh Increment Description
1YY0300	Composition Overlay Repeat
1YY03II	Composition Overlay Description
1YY0400	Source Distribution Repeat
1YY04II	Source Distribution Description
1YY0600	Initial Temperature Estimate Repeat
1YY06II	Initial Temperature Estimate
1YY1100	Boundary Conditions
1YY1110	Steady-State Special Bulk Temperature.

Card	Problem Control Input Cards[a]
=	Problem Title
100	*General Control
105	*Restart Control
1XXXII	Outside Air Temperature Generalized Table
9000	*Time Step and Edit Control Units
90II	*Time Step and Edit Control
91II	Minor Edit Variable Control
99II	Debug Control
1XXXII	Debug On/Off Generalized Table

a. An asterisk (*) identifies a card required for all problems.

Card	Compartment Input Cards
40000	*Compartment Description Units
4XXX0	Compartment Title
4XXX1	*Compartment Description and Initial Conditions
4XXX2	Compartment Description and Initial Conditions Duplication

Card	Transaction Input Cards
1XX0	Single Compartment Title
1XX1	Single Transaction
1XXXII	Single Transaction Generalized Table
2XX0	Double Transaction Title
2XX1	Double Transaction
1XXXII	Double Transaction Generalized Table

Card	Intercompartment Junction Flow Input Cards
8000	Junction Description Units
8XXX	Junction Description

Card	Containment Cooling Spray Input Cards
800000	Spray and Heat Exchanger Units
80XX00	Spray System Description
80XXII	Spray Table
8500WW	Heat Exchanger Description
85WWII	Heat Exchanger Energy Removal Rate Table

Card	Containment Fan/Pump Input Cards
90000	Fan/Pump Units
90XX1	Fan/Pump Description
90001	Source Table Units
90XX6	Source Table
90XX2	Fan/Pump Constant Speed or Flow Control
90XX4	Flow Rate Table Number
1XXXII	Fan/Pump Flow Generalized Table
90002	Freewheeling Fan/Pump Units
90XX5	Freewheeling Fan/Pump Description

Card	Containment Fan Cooler Input Cards
91XXX	Fan Cooler Description
1XXXII	Fan Cooler Generalized Table

Card	Containment Sump Input Cards
6000	Sump Units and Initialization Limit
6XXI	Sump Description
6XX8	Additional Sump Inlet Compartment
1XXXII	Sump Initialization Generalized Table

Card	Ice Chest Input Cards
60000	Ice Initial Conditions Units
6XXX1	Ice Initial Condition
6XXX2	Ice Initial Conditions Duplication
1XXXII	Ice Performance Generalized Table

Card	Drywell/Ice Chest Flow Input Cards
7000	Drywell/Ice Chest Flow Units
70000	Drywell/Ice Chest Junction
7JJII	Drywell/Ice Chest Flow Distribution

Card	Ice Chest Door Input Cards
81000	Ice Chest Door Units
81XXX	Ice Chest Door Description
1XXXII	Ice Chest Door Generalized Table

Card	Individual Heat Structure Input Cards
1000001	Heat Structure Description Units
1YY0000	Heat Structure Title
1YY0001	Heat Structure Control
1YY0002	Heat Structure Connection and Miscellaneous Data
1YY0200	Mesh Increment Format
1YY02II	Mesh Increment Description
1YY0300	Composition Overlay Repeat
1YY03II	Composition Overlay Description
1YY0400	Source Distribution Repeat
1YY04II	Source Distribution Description
1YY0600	Initial Temperature Estimate Repeat
1YY06II	Initial Temperature Estimate
1YY1100	Boundary Conditions
1YY1110	Steady-State Special Bulk Temperature
1XXXII	Heat Source Multiplier Generalized Table
1XXXII	Time-Dependent Heat Transfer Coefficient Generalized Table

Card	Common Heat Structure Input Cards
1000000	Common Data Units
10001II	Material Properties
10002II	Miscellaneous Heat Transfer Coefficient
10003II	Time-Dependent Heat Transfer Coefficient
10004II	Temperature-Dependent Heat Transfer Coefficient
10005II	Tagami Boundary Conditions
1001100	General Bulk Temperature.

4.2.2.1 Problem Control Input—The card series in this group control the operation of CONTEMPT4/MOD3.

4.2.2.1.1 Problem Title Card—This optional card may be used to title the problem. The first nonblank character must be an equal sign (=); all following characters will be treated as the title.

4.2.2.1.2 General Control Card 100—This card is always required. Problem execution is normally terminated whenever TEND or ITLIM is reached.

W1-A		Time units for this card.
W2-R	TSRT	Starting time for the problem.

W3-R	TEND	Ending time for the problem.
W4-I	ITBOUT	= zero if there is not an outside air compartment or the outside air temperature does not change from its initial value. = number (XXX) of generalized table giving temperature of outside air compartment as a function of time. Outside Air Temperature Generalized Table IXXXII is required if this word is nonzero. If an entry is made for Word 5, this field must be present.
W5-A	IUNOUT	Enter BRT to obtain problem output in British units. Enter SI or zero, or leave this field blank to obtain output in SI units.
W6-I	ITLIM	Problem time step iteration limit. If ITLIM is negative, the problem will continue execution despite fatal input errors and fatal time step error; |ITLIM| will be used as the iteration limit. Only completed iterations are compared with ITLIM to limit problem execution. See Figure D-5 for a visual example of incomplete and complete iterations.

4.2.2.1.3 Restart Control Card 106—This card is always required.

W1-I	IRMI	Input Restart Mode Indicator. One of four values may be used:

IRMI	READ RESTART	WRITE RESTART
0	No	No
1	No	Yes
2	Yes	No
3	Yes	Yes

W2-I	IREST	A frequency indicator for restart data collection. Every IREST time steps the current restart file will be written onto TAPE7, a file specified by the CT4 program card. The user's job control language must contain directives to copy this data onto a permanent storage device following the end of CONTEMPT4/MOD3 execution.
W3-R	TAPTIM	The amount of CPU time specified for copying the restart file to permanent storage. During the execution of a restart-write problem the available CPU time (job control card specified value minus time used up to present) is monitored by the

REMTIM (XXX) function located in subroutine GO. Should this value be less than or equal to TAPTIM, execution of the problem terminates and job control passes to the directive following the execution statement. At this time, the contents of TAPE4 should be copied to permanent storage for use as restart read-in data on the subsequent problem.

4.2.2.1.4 Outside Air Temperature Generalized Table Card 1XXXII—This table must be presented when ITBOUT on Card 100 is nonzero. See note in Appendix C on generalized table numbering.

W1-A	Time units.
W2-A	Temperature units.
W3-I, W4-I	Always enter zero.
W5-R	Time.
W6-R	Temperature. These values may be less than 273.16 K.
...	An arbitrary number of pairs for time-temperature values may be entered. If the problem time is ever outside the range of this table, a non-fatal error will be printed and the extreme table value will be used. Note that the initial outside air temperature given on a Compartment Description Card 4XXX1 will be used for problem initialization, but this table can override that value for time step calculations.

4.2.2.1.5 Time Step and Edit Control Units Card 9000—This card is always required.

W1-A	Time units for Cards 90II.

4.2.2.1.6 Time Step and Edit Control Card 90II—This card is always required.

W1-R	TCE	Time at end of interval for which next six values apply. The values for TCE must be in increasing order and must not be greater than TEND on General Control Card 100.
W2-R	DTA	Time step length for this interval. See Sections 3.10.1.2 and 4.3.1.3 for guidelines. This value is used as the maximum time step size if automatic time step control is chosen for this time interval.
W3-R	DTMIN	Time step control option switch. = 0.0 for manual time step control. = minimum time step for automatic time step control. This value must be less than DTA assigned for this time interval.

W4-I	NMAJ	Major edit will be produced every NMAJ time steps. See Section 4.4.1 for a description of the output.
W5-I	NMIN	Minor edit will be produced every NMIN time steps, as specified on Cards 91II. See Section 4.4.1 for a description of the output.
W6-I	NRES	Restart information. Use zero.
W7-I	NPLT	Plot information will be saved every NPLT time-steps on TAPE1.

4.2.2.1.7 Minor Edit Variable Control Card 91II—All of the variables listed in a major edit are available through the minor edit option; these variables are listed by name and description below. The program user may select up to 14 pairs of these variables for editing every NMIN time steps, as specified on Card 90XX.

Name Variable	Variable
TMT	Total compartment mass
TMP	Total compartment pool mass
TMG	Total compartment atmosphere mass
WMT	Compartment water mass
WMP	Compartment pool water mass
WMG	Compartment atmosphere water mass
WMGL	Compartment atmosphere liquid water mass
WMGV	Compartment atmosphere vapor water mass
AMT	Total compartment air mass
UTT	Total compartment energy
UTP	Compartment pool energy
UTG	Total compartment atmosphere energy
UTGA	Compartment atmosphere air energy
TP	Pool temperature
TG	Atmosphere temperature
TPO	Last time step pool temperature
TGO	Last time step atmosphere temperature
PRT	Total compartment pressure
PRV	Water vapor partial pressure
PRA	Air partial pressure
VOLP	Compartment pool volume
VOLG	Compartment atmosphere volume
HUM	Relative humidity
XG	Atmosphere gas quality
DMT	Total mass flow rate into compartment
DMP	Total mass flow rate into compartment pool
DMG	Total mass flow rate into compartment atmosphere
DMPL	Liquid flow rate into compartment pool
DMPV	Vapor flow rate into compartment pool
DMPA	Air flow rate into compartment pool
DMGL	Liquid flow rate into compartment atmosphere
DMGV	Vapor flow rate into compartment atmosphere
DMGA	Air flow rate into compartment atmosphere
DMCE	Compartment condensation/evaporation mass flow rate

Name Variable	Variable
DMCW	Compartment wall condensation and fan cooler condensation rate
QT	Total energy addition
QP	Energy added to pool
QG	Energy added to atmosphere
QCE	Energy of condensation/evaporation
QCW	Energy of wall condensation and fan cooler condensation
DMST	Single transaction mass flow rate
DMSTI	Single transaction mass transferred
QST	Single transaction energy flow rate
QSTI	Single transaction energy transferred
DMDT	Double transaction mass flow rate
DMDTI	Double transaction mass transferred
QDT	Double transaction energy flow rate
QDTI	Double transaction energy transferred
GIJCNL	Junction left nozzle coefficient
GIJCNR	Junction right nozzle coefficient
FJCN	Junction form loss coefficient
DMJ	Total junction mass flow rate
DMJA	Junction air mass flow rate
DMJV	Junction vapor mass flow rate
DMJL	Junction liquid mass flow rate
QJ	Junction energy flow rate
AJNNEW	Junction flow area
THETA	Ice chest door opening angle
OMEGA	Ice chest door opening velocity
TII	Ice temperature
TMI	Ice mass
DMPI	Ice mass melt rate
QPI	Ice energy melt rate
SUMASS	Water mass in sump
SUH	Water energy in sump
SUDP	Sump driving pressure
SUWIN	Sump inlet mass flow rate
SUWEX	Sump drain mass flow rate
SUWOV	Sump overflow mass flow rate
SUQIN	Sump inlet energy flow rate
SUWX	Sump liquid height
SUPWX	Sump pipe liquid depth
SPEFF	Spray efficiency
SPDM	Spray mass flow rate
SPS1	Spray mass flow rate from Source 1
SPS2	Spray mass flow rate from Source 2
SPFV	Fraction of spray water to atmosphere
BTSL	Heat structure left temperature
BTSR	Heat structure right temperature
CHTSL	Heat structure left heat transfer coefficient
CHTSR	Heat structure right heat transfer coefficient
QHL	Heat structure left energy transfer rate
QHR	Heat structure right energy transfer rate
DMFP	Fan/pump mass flow rate
QFP	Fan/pump energy flow rate

Name Variable	Variable
TMESH	Heat structure mesh point temperature
DT	Time step size.

W1-A — Variable name selected for editing.

W2-I — Variable index (e.g., compartment external number). Use any positive integer as the variable index for editing time step size DT.

... — An arbitrary number of variable name and index pairs may be selected, up to a limit of 14 pairs.

4.2.2.1.8 Debug Control Card 99II—Each significant CONTEMPT4/MOD3 subroutine has a switch for controlling debug output. This card series allows these switches to be set either for the whole problem or according to a table of times. Table 6 gives the subroutine and system switch numbers used to control individual subroutines or sets of subroutines.

W1-I
... — Enter a list of positive integers and/or pairs consisting of a negative integer followed by a positive integer.

For single positive entries, the specified subroutine or calculation switches are turned on for the whole problem.

For a negative, positive pair, the absolute value of the first integer is the subroutine or calculation number under time control. The second entry in the pair is the Debug On/Off Generalized Table number (XXX); the next card must be used if this format is chosen.

4.2.2.1.9 Debug On/Off Generalized Table Card 1XXXII—This card is required if a generalized table was specified on Debug Control Card 99II.

W1-A — Time units.

W2-I, W3-I, W4-I — Always enter zero.

W5-I
... — Negative times or pair of positive times with absolute values in ascending order. For negative values, the output is turned on for only the first time step beginning at or after the absolute value of the time given. For pairs of positive values, the debug output is turned on for the first time step beginning at or after the first time, and remains on until the first time step beginning after the second time in the pair.

4.2.2.2 Compartment Input—In CONTEMPT4/MOD3 the primary coolant system, wetwell, drywell, standard or ice chest areas, and outside air are all called compartments. These card series give the compartment geometries and initial conditions.

Table 6. Subroutine index for debug control

Input Routines				Initialization Routines		Time Step Routines				Utility Routines	
Switch	Subroutines Controlled	Switch	Subroutines Controlled	Switch	Subroutines Controlled	Switch	Subroutines Controlled	Switch	Subroutines Controlled	Switch	Subroutines Controlled
1	CT4	21	GNTRAN	40	INISHL	45	GO	69	ICFLOW	95	CHRLD
2	INSEQ	22	HTBCIN	41	HTINTL	46	BDCOND	130	ICINRT	96	EER
3	CMPDUP	23	HTCN	42	INITLZ	122	BILTIN	70	JCNO	97	ERFIN
4	CMPLD	24	HTCOM	43	PLTHD	47	BULKT	127	MINOUT	98	FERR
5	COMPCD	25	HTIN	44	SMPNTL	94	CHKCHG	71	NOZL	99	IEXNUM
6	COMUN	133	HTTAG	121	SPRNTL	134	CHKFLO	72	ORIFIC	100	ILIQAT
7	DBCNCD	26	HT1UN			48	CHKINV	73	OUTTMP	101	INTNUM
8	DBOV	27	ICECD			49	COMPO	74	PLTTS	102	LDEXNM
124	DBTEM	128	ICEDIN			50	COMPU	75	PRDKTR	103	NEER
9	DBTB	28	ICELD			51	CONBR	76	RKGS	104	NFERR
131	FANCIN	29	JCNIN			52	CONT	77	SMPFCT	105	SETIND
10	DTLD	126	MINCD			53	DBCN	78	SMPFIL	106	SNAPCH
11	FANGEN	30	SPHXIN			54	DTRANO	79	SPHXO	107	SNAPCT
12	FANINP	31	SPCINP			132	FANCLR	80	SPRAY	108	SNAPDT
13	FANLD	32	STHIN			55	FANO	81	SPYD	109	SNAPGT
14	FCSINP	33	STLD			56	FANON	82	SPYINT	110	SNAPHT
15	FLODRI	34	SUMPIN			57	FANPMP	83	STATEC	111	SNAPIC
16	FLRINP	35	TIMIO			58	FANQ	84	STRANO	112	SNAPIS
17	FREINP	36	TRANCD			59	FRCT	85	SUMP	113	SNAPMB
18	FUNTIN	37	TRNREN			60	FREEW	86	SUMPO	114	SNAPMG
19	GNTBCD	38	TSTPIN			61	HEADO	87	SUPDR	115	SNAPSA
20	GNTBLD	39	UNITJH			62	HEATEX	88	TIMEO	116	SNAPSK
						63	HEATO	89	TIMSTP	117	SNAPST
						64	HTCOEF	90	TRNSXN	118	SNAPTI
						65	HT1GO	91	TSINTL	125	STH200
						66	HT1Q	92	TSINVN	119	TBLS
						129	ICEDOR	93	TSOUT	120	UNITSI
						67	ICECON	123	UCURV		
						68	ICEQ				

Debug Control for Systems

Switch	Subroutines Controlled	Description
1001	TRANCD STLD DTLD GNTBCD GNTRAN GNTBLD	Transaction input
1002	HTIN HT1UN HTCOM COMUN HTCN HTBCIN	Heat input
1003	FANINP FUNTIN FANGEN FALND FREINP SRCINP FLRINP FCSINP	Fan/pump input

Time Step Routine

Switch	Subroutines Controlled	Description
1004	SPYINT SPYD HEATEX SPRAY	Spray-heat exchanger
1005	FANPMP FANON FREEW UCURV BILTIN FANQ	Fan/pump
1006	SUPDR SMPFIL SUMP RKGS SMPFCT FRCT	Sumps
1007	PRDKTR HT1GO BDCOND BULKT HTCOEF HT1Q	Heat structures

4.2.2.2.1 Compartment Description Units Card 40000—This card is always required.

W1-A		Volume units for VOLT.
W2-A		Volume units for VOLP.
W3-A		Temperature units.
W4-A		Pressure units.
W5-A		Area units.
W6-A		Length units for ELB.
W7-A		Reciprocal time units for deentrainment rate.

4.2.2.2.2 Compartment Title Card 4XXX0—This card is optional and contains up to 64 columns of title information for Compartment XXX. The title must be enclosed in apostrophes (').

4.2.2.2.3 Compartment Description Card 4XXX1—This card is always required. Any number of standard (STD) or ice (ICE) compartments may be specified. Only one each of wetwell (POOL), drywell (DRY), primary coolant system (PRIM), and outside air (OUT) compartments may be selected. All compartment types except ice chests and outside air are treated as standard compartments for MOD3.

W1-A	CTYP	Compartment type, may be: PRIM—primary coolant system POOL—pressure suppression pool (wetwell) DRY—drywell STD—standard compartment ICE—ice compartment; additional cards must be input. See Section 4.2.2.9 for specific card series. OUT—outside air.
W2-R	VOLT	Total compartment volume (including ice volume if present).
W3-R	VOLP	Initial liquid region volume.
W4-R	TG	Initial temperature of atmosphere region ($\geq$273.16 K). A reasonable value must be entered even if this region is not present.
W5-R	TP	Initial temperature of liquid region ($\geq$273.16 K). A reasonable value must be entered even if this region is not present.
W6-R	PRT	Total compartment absolute pressure.

W7-R	HUM	Relative humidity of atmosphere region, $0.0 \le HUM \le 1.0$. A value of 1.0 must be entered for all ice chests.
W8-R	ALG	Surface area between pool and atmosphere. This value will be set to 0.00001 m^2 if zero is entered.
W9-R	CHTPGM	Film heat transfer coefficient multiplier for pool-atmosphere transfer. A value of 1.0 is recommended to agree with theory. This variable is C_1 in Equation (14).
W10-R	CMTPGM	Mass transfer multiplier for evaporation model. A value of 1.0 is recommended to agree with theory. This variable is C_2 in Equation (14).
W11-R	ELB	Elevation of compartment floor above arbitrary base. This value is not used in MOD3, but this field must be present. Use zero.
W12-R	DFAC	Deentrainment rate to specify the fraction of liquid water in atmosphere which drops to the pool per unit time. The fraction of liquid water in atmosphere which drops to the pool for the current time step is then equal to the variable, multiplied by the current time step size. No deentrainment will occur if zero is input. Defaults to total deentrainment (DFAC = 10^{12}) if no value is input.
W13-R	PFLASH	Optional. For dry compartment, if flashing model is turned on, then PFLASH = -1.0.
W14-R	FAC1	The fraction of the wall condensate that will be transferred to the pool region. $0.0 \le FAC1 \le 1.0$. Default to 1.0.

4.2.2.2.4 Compartment Description and Initial Conditions Duplication Card 4XXX2—Any number of compartments which have the same initial conditions as those previously entered for an identical compartment (using a 4XXX1 card) may be entered using this card instead of duplicating the Compartment Description and Initial Conditions Card 4XXX1.

W1-I		A list of negative integers and/or pairs of positive integers, with absolute values in increasing order. For a negative number, L, the description and initial conditions for Compartment XXX are applied to Compartment $\lvert L \rvert$. For pairs of positive numbers, M, N, the description and initial conditions for Compartment XXX are applied to the (N - M) + 1 compartments numbered M through N. In all cases, the compartment title is also duplicated. Compartments described by this card must not conflict with explicitly described compartments.

4.2.2.3 Transaction Input—It is possible to specify mass and/or energy transfer into or between compartments due to mechanisms not modeled explicitly by the code. Transfer rates are specified as a function of time. This capability will frequently be used to provide values for mass/energy transfer due to blowdown, decay power, metal-water reaction, and penetration leakage. Single transactions add mass and/or energy to a compartment region, whereas double transactions transfer mass and energy between two regions in two compartments. A generalized table is used to specify transaction rates. As many as 30 transactions may use the same table, but they must all be the same type, i.e., single or double, and if single, must all specify the same material. Refer to Section 3.2 for further clarification.

4.2.2.3.1 Single Transaction Title Card 1XX0—

W1-A		Up to 64 columns of title information for transaction XX, enclosed in apostrophes (').

4.2.2.3.2 Single Transaction Card 1XX1—For each single transaction card there must be a corresponding Single Transaction Generalized Table Card 1XXXII.

W1-I	IGSTTC	Number of compartment receiving additions.
W2-A		Region receiving additions; enter LIQ for pool region; enter ATM for vapor region.
W3-R	GSTV1M	Multiplier for mass flow.
W4-R	GSTV2M	Multiplier for energy flow.
W5-I	IGSTGT	Single transaction generalized table number.
W6-A	GSTMAT	Material transferred. Possible entries are:
		AIR—air is transferred
		LIQ—liquid water is transferred
		VAP—water vapor is transferred
		WAT—liquid, two-phase, or vapor water is transferred. If AIR or VAP is specified, or if WAT is specified and vapor is present, the receiving region must be ATM. See the Single Transaction Generalized Table Card 1XXXII for more information.

4.2.2.3.3 Single Transaction Generalized Table Card 1XXXII—The material specified by single transaction XXX is transferred between an infinite source/sink and the specified region.

W1-A		Time units.
W2-A		Mass flow rate or volumetric flow rate units.
W3-A		Energy flow rate, enthalpy, or temperature units.
W4-A		Enter 0 or pressure units.
W5-R		Time.

W6-R		Mass flow rate or volumetric flow rate.
W7-R		Energy flow rate, enthalpy, or temperature.
W8-R		Pressure or omitted field. See explanation below for correct format.
...		An arbitrary number of triplet or quadruple sets listing the data needed to perform the transaction. All allowed combinations of quantity types are listed in Table 7. In all cases the independent variable is time. Thus, Cases 1, 2, and 3 (if the material transferred is air) require entries in groups of three, while Cases 3 (if the material transferred is not air), 4, and 5 require entries in groups of four. If any different combination is entered, a nonfatal error will occur and the transaction will not be used. If problem time is outside the range of the table, no transfer will take place.

If pressure is present where not needed, there is a nonfatal error. A nonfatal error also occurs in Cases 3 to 5 if GSTMAT is LIQ or VAP and the values given are inconsistent with water in the specified state. If GSTMAT is WAT, only Case 4 may be used, and the code determines if liquid, two-phase, or vapor water is being transferred at each table time. If air, vapor, or two-phase water is transferred at any time, the receiving region must be ATM.

4.2.2.3.4 Double Transaction Title Card 2XX0—

W1-A		Up to 64 columns of title information for transaction XX, enclosed in apostrophes (').

4.2.2.3.5 Double Transaction Card 2XX1— For each double transaction there must be a corresponding Double Transaction Generalized Table Card 1XXXII.

W1-I	IGDTTC	Receiving compartment number.
W2-A		Region receiving flow, LIQ or ATM.
W3-I	IGDTFC	Number of compartment supplying flow.
W4-A		Region supplying flow, LIQ or ATM. Transfers from atmosphere region to liquid region are not allowed and will produce a nonfatal error.
W5-R	GDTV1M	Multiplier for mass flow.
W6-R	GDTV2M	Multiplier for energy flow.
W7-I	IGDTGT	Double transaction generalized table number.

4.2.2.3.6 Double Transaction Generalized Table Card 1XXXII— Material with the average energy and composition of the supplying region is transferred to the receiving region. All combinations are allowed except vapor region to pool region transfer (ATM to LIQ). In this table, either mass flow or energy flow is specified as a function of time. For each time step, the code will determine the associated energy flow or mass flow, and material composition according to the supplying region conditions.

W1-A		Time units.
W2-A		Mass flow or energy flow (power) units.
W3-I		Always enter zero.
W4-I		Always enter zero.
W5-R		Time.
W6-R		Mass flow rate or energy flow rate.
...		An arbitrary number of pairs of time and mass flow rate (or time and energy flow rate) listing the data needed to perform the transaction. If problem time is outside the range of the table, no transfer will take place.

4.2.2.4 Intercompartment Junction Flow Input—These cards describe flow junctions between compartments. Junctions may be either orifices or nozzles. There can be only one drywell-to-ice chest junction for each ice chest.

4.2.2.4.1 Junction Description Units Card 8000—

W1-A		Length units for elevation.
W2-A		Area units for throat area.
W3-A		Reciprocal length units for junction geometric inertia, (L/A). If this word is omitted, no junction inertance will be calculated.

4.2.2.4.2 Junction Description Card 8XXX—

W1-I	JCNLC	Left (normal inlet) compartment number.
W2-I	JCNRC	Right (normal outlet) compartment number.
W3-R	ELJN	Elevation of junction above left compartment floor. This value is not used in MOD3, but must be entered. Use zero.
W4-R	FJCNLR	Form loss coefficient or other multiplier for left-to-right flow.
W5-R	FJCNRL	Form loss coefficient or other multiplier for right-to-left flow.
W6-I	JCNFOP	Flow option: = 0 for two-phase slip flow. = 1 for single-phase flow. = 2 for two-phase homogeneous flow.

W7-R	AJN	Throat area, which is defined as the flow area at the most constricted part of a nozzle, or the flow area for an orifice.
W8-R	AJNL	The ratio of throat area to inlet area, where inlet area is the flow area at the extreme left of the junction. Enter 1.0 for orifices.
W9-R	AJNR	Same as AJNL except the ratio is throat area to outlet area where outlet area is the flow area at the extreme right of the junction. Enter 1.0 for orifices.
W10-R	GEOINT	Junction geometric inertia, (L/A). If this word is omitted, or units are unspecified on Word 3 of Card 8000, the value will be set to zero. Guidelines for selecting inertia values are given in Section 4.3.1.2.

Note that AJNL and AJNR are sufficient to describe all basic types of nozzles and orifices, as shown below:

Type	AJNL	AJNR
Converging nozzle	<1.0	1.0
Diverging nozzle	1.0	<1.0
Converging-diverging nozzle	<1.0	<1.0
Orifice	1.0	1.0

4.2.2.5 Containment Cooling Spray Input—The spray and heat exchanger model allows liquid to be pumped from up to two compartments and an outside source, passed through a heat exchanger, and sprayed into another compartment.

4.2.2.5.1 Spray and Heat Exchanger Units Card 800000—This card provides units for all spray and heat exchanger input. All words must be entered even if no heat exchanger is present.

W1-A	Pressure units.
W2-A	Time units.
W3-A	Mass/time units for mass flow rates.
W4-A	Temperature units.
W5-A	Area units.
W6-A	Heat transfer coefficient units.
W7-A	Power units for energy removal rates.

4.2.2.5.2 Spray System Description Card 80XX00—This card is required for all spray systems.

W1-I	NSPTOC	Number of compartment receiving flow.

W2-I	NSPFC1	Number of first donor compartment. A valid compartment number must be entered even if spray is entirely from an outside source.
W3-I	NSPFC2	Number of second donor compartment if there is one; otherwise enter zero.
W4-R	PRSPON	Pressure in NSPTOC above which spray is turned on.
W5-R	PRSPOF	Pressure in NSPTOC below which spray is turned off. PRSPOF must be less than or equal to PRSPON. If both PRSPON and PRSPOF are zero, the pressure switch is not used and spray calculations are controlled by table input.
W6-I	NSPHX	Heat exchanger number for this spray system. Zero may be entered if there is no heat exchanger.

4.2.2.5.3 Spray Table Card 80XXII—This card is required for all spray systems.

W1-R	TTB	Time.
W2-R	SPPM	Mass flow rate.
W3-R	SPEFF	Spray efficiency.
W4-R	SPSF1	Flow fraction from Compartment NSPFC1.
W5-R	SPSF2	Flow fraction from Compartment NSPFC2 if there is such a compartment; otherwise enter zero.
W6-R	SPDMP	Fraction of total flow dumped in the pool region of the compartment receiving flow. The remainder goes to the atmosphere region.
W7-R	SPOWT	Outside spray water temperature. = zero if no outside source is required, i.e., SPSF1 + SPSF2 = 1.0. = temperature of outside source used for spray water ($\geq$273.16 K). The fraction of spray water drawn from outside source at this temperature is 1.0 - SPSF1 - SPSF2.
...		An arbitrary number of sets of seven (Words 1 through 7) may be entered. The range of the table must include the times encountered in the problem.

4.2.2.5.4 Heat Exchanger Description Card 8500WW—This card is required only if a heat exchanger was specified on Card 80XX00; index WW refers to Word 6, NSPHX on Card 80XX00. A single heat exchanger description may apply to several spray systems. See Section 3.4 for a description of single and coupled heat exchanger types. The first five words apply to either a single heat exchanger or the first heat exchanger of a coupled system. Values must be input for the first five words even if they are not needed for the heat exchanger model chosen.

W1-I	IHX	Heat exchanger type option. = 1 for shell and tube heat exchanger. = 2 for cross-flow heat exchanger. = 3 for counter-flow heat exchanger. = 4 for parallel-flow heat exchanger. = 5 for time-dependent energy removal rate as described on Heat Exchanger Energy Removal Rate Table Card 85WWII.
W2-R	HYA	Heat transfer surface area of heat exchanger.
W3-R	HXTHTC	Overall heat transfer coefficient.
W4-R	HXTIN	Inlet temperature of heat exchanger coolant ($\geq$273.16 K).
W5-R	HXCDM	Flow rate of heat exchanger coolant.
W6 through W10		These five words are required to describe the second heat exchanger of a coupled system; they are left blank for a single heat exchanger. Words 6 through 10 are defined the same as Words 1 through 5, respectively, with the following exceptions: (a) a time-dependent energy removal rate table (Option 5) may not be used for Word 6, and (b) enter zero for Word 9. [If the inlet temperature of the second heat exchanger (Word 9) is known by the user in advance, then a single heat exchanger could be input.]

4.2.2.5.5 Heat Exchanger Energy Rate Table Card 85WWII—This card is required if IHX on the Heat Exchanger Description Card is 5; index WW refers to Word 6 on Card 80XX00.

W1-R	Time.
W2-R	Energy removal rate.
...	An arbitrary number of time/energy removal rate pairs may be entered. The range of the table must include the times encountered in the problem.

4.2.2.6 Containment Fan/Pump Input—The common fan/pump model transfers mass and energy between compartments, or from an external source into a compartment. The fan/pump Card 90000 and the fan/pump description Card 90XX1 are required for every fan or pump; other cards in this series depend on the options selected.

4.2.2.6.1 Fan/Pump Units Card 9000—This card is required if a fan or pump is modeled.

W1-A	Pressure and differential pressure units.
W2-A	Time units.
W3-A	Reciprocal time units for pump speed.
W4-A	Volumetric flow rate units.

W5-A		Temperature units.

4.2.2.6.2 Fan/Pump Description Card 90XX1—This card is required for all fan/pump models.

W1-A	IFAOP	Enter FAN or PUMP.	
W2-I	NT	Normal receiving compartment number.	
N3-I	NF	=	Normal donor compartment number, or
		=	-1 if an external source is used; Source Table Unit Card 90001 and Source Table Card 90XX6 are also required.
W4-I	ICURV	=	-1 if flow rate is input; flow rate Table Number Card 90XX4 is also required. The next word must be LOCKED if ICURV = -1.
		=	standard homologous curve number for fan/pump rotation option; fan/pump constant speed or Flow Control Card 90XX2, fan/pump units rotation option Card 90002, fan/pump Rated Variable Description Card 90XX5 are required. Currently, only one set of homologous curves are built-in. The program user may enter data which represent a specific characteristic curve using the open subroutine UCURV by specifying ICURV > 5.
W5-A	LOKFRE	=	LOCKED if fan/pump is in locked position after switch is turned off.
		=	FREE if fan/pump is allowed to freewheel after switch is turned off. Card 90XX2, Card 90XX5, Card 90002 are also required. This option is used only if ICURV = -1.

4.2.2.6.3 Source Table Units Card 90001—This card is required if NF on Card 90XX1 is negative.

W1-A	Density units.
W2-A	Energy/mass units for enthalpy.
W3-A	Pressure units.

4.2.2.6.4 Source Table Card 90XX6—This card is required if NF on Card 90XX1 is negative. This card describes a liquid source in the case of a pump, or a liquid-vapor-air source in the case of a fan. Card 90XX7 may be used as a continuation card.

W1-R	DENL	Liquid density.
W2-R	ENTL	Liquid specific enthalpy.
W3-R	SPRES	Source pressure.
W4-R	DENA	Air density (only entered for fan).

W5-R	ENTA	Air enthalpy (only entered for fan).
W6-R	DENV	Vapor density (only entered for fan).
W7-R	ENTV	Vapor enthalpy (only entered for fan).

4.2.2.6.5 Fan/Pump Constant Speed or Flow Control Card 90XX2—This card is required if ICURV on Card 90XX1 is positive or if IFLOW on Card 90XX4 is CON.

W1-A	ASORF	SPEED or FLOW.
W2-R	SORF	Speed or volumetric flow rate value.
W3-R	DPONOF	= Pressure difference between donor and receiver compartments, above which fan/pump is turned on = -1.0, this control is disabled.
W4-R	TIMON	Time for turning fan/pump on.
W5-R	TIMOFF	= Time for turning fan/pump off = -1.0, for no time switch; TIMON and TIMOFF are not used.
W6-R	PONOF	Absolute pressure above which the fan/pump is turned on.
W7-I	IPCOMP	= Number of compartment where pressure is obtained for PONOF control. = 0, for no pressure switch; PONOF is not used.
W8-R	TEMPF	Temperature above which the fan/pump is activated.
W9-I	ICTEMP	= Number of compartment where temperature is obtained for TEMPF control. = 0, for no temperature switch; TEMPF is not used.

4.2.2.6.6 Flow Rate Table Number Card 90XX4—This card is required if ICURV on Card 90XX1 is -1. This card specifies user-supplied flow rates.

W1-A	IFLOW	Type of flow rate specification: = CON for constant flow rate. Word 1 on Card must be FLOW. = DP for a table of volumetric flow rate versus pressure difference between donor and receiver compartment. Card 1XXXII is required. = AP for a table of volumetric flow rate versus pressure in a specified compartment. Card 1XXXII is required. = TIM for a table of volumetric flow rate versus time, Card 1XXXII is required.

W2-I	NFLOC	= 0, if IFLOW is CON. = Fan/pump Generalized Table Card Number 1XXXII, if IFLOW is not CON.
W3-I	IAPC	= Compartment number where the pressure is taken for IFLOW = AP option. = 0, if IFLOW is not AP.

4.2.2.6.7 Fan/Pump Flow Generalized Table Card 1XXXII—This card is required if IFLOW on Card 90XX4 is DP, AP, or TIM.

W1-A		= Pressure units for IFLOW = DP or AP on Card 90XX4. = Time units for IFLOW = TIM on Card 90XX4.
W2-A		Volumetric flow rate units.
W3-A, W4-A		Always enter zero.
W5-R		= Differential pressure for IFLOW = DP on Card 90XX4. = Pressure for IFLOW = AP on Card 90XX4. = Time for IFLOW = TIM on Card 90XX4.
W6-R		Volumetric flow rate value.
...		Any arbitrary number of pairs of values (Words 5 and 6) may be entered. The range of this table must include the range of values encountered in the problem.

4.2.2.6.8 Fan/Pump Rotation Option Units Card 90002—This card is required for ICURV > 0 on Card 90XX1 and ASORF = SPEED on Card 90XX2.

W1-A		Energy units for torque.
W2-A		Mass units.
W3-A		Area units. Words 2 and 3 are used to obtain moment-of-inertia units.
W4-A		Density units.

4.2.2.6.9 Fan/Pump Rated Variable Description Card 90XX5—This card is required for ICURVE > 0 on Card 90XX1 and ASORF = SPEED on Card 90XX2.

W1-R	RTORQ	Rated torque of the fan/pump.
W2-R	ENERT	Moment of inertia of the fan/pump rotor.
W3-R	RDEN	Rated flow density of the fan/pump.
W4-R	RFTORQ	Rated friction torque of the fan/pump.

W5-R	FTORQ	Constant frictional torque of the fan/pump.
W6-R	RSPEED	Rated rotational speed of the fan/pump.
W7-R	RVFT	Rated volumetric flow rate of the fan/pump.
W8-R	HEDR	Rated fan/pump head.

4.2.2.7 Containment Fan Cooler Input—Each compartment may contain only one fan cooler. Operation of the fan cooler is controlled by start and stop controls as a function of either temperature or time. A fan cooler generalized table is required for each fan cooler.

4.2.2.7.1 Fan Cooler Description Card 91XXX—This card is required for each fan cooler.

W1-R	TFCON	Either time or compartment vapor temperature at which fan cooler turns on.
W2-R	TFOFF	Either time (if Word 1 is time) or compartment vapor temperature (if Word 1 is temperature) at which fan cooler turns off.
W3-A	UNT	Units for Words 1 and 2, either time or temperature.
W4-R	FAC	Fraction of condensate formed on the cooling coils which drops to the pool region (0.0 ≤ FAC ≤ 1.0).
W5-I	IFCOMP	Compartment that contains the fan cooler.
W6-I	IACV	Number of fan cooler generalized table.

4.2.2.7.2 Fan Cooler Generalized Table Card 1XXXII—A table of compartment vapor temperature versus energy addition rate (negative rate implies energy removed from compartment) must accompany each fan cooler; the table number XXX is IACV on Card 91XXX.

W1-A	Temperature or time unit.
W2-A	Energy addition rate units.
W3-I, W4-I	Always enter zero.
W5-R	Temperature or time.
W6-R	Energy addition rate.
...	An arbitrary number of temperature/energy addition rate pairs may be entered. The range of temperature values must include the temperatures encountered in the problem.

4.2.2.8 Containment Ice Chest Drain Input—Water may drain from one or more compartments into a drain region from which it is distributed to other compartments through a drain pipe or overflow. Refer to Section 3.7 for clarification.

4.2.2.8.1 Ice Chest Drain Units and Initialization Limit Card 6000—

W1-A		Mass units.
W2-A		Energy units.
W3-A		Area units.
W4-A		Length units.
W5-I	NTSS	This optional field is used only if the problem start time, TSRT on the Problem Control Card 100, is greater than zero. The value entered is the number of time steps used in the ice chest drain initialization model for all drain regions. If TSRT is greater than zero and no value is entered, the default value of 100 will be used.

4.2.2.8.2 Ice Chest Drain Description Card 6XXI—

W1-I	NSUCIN	Inlet compartment number.
W2-I	NSUCEX	Exit compartment number.
W3-I	NSUCOV	Overflow compartment number.
W4-R	SUMASS	Initial mass of liquid, including liquid in pipe.
W5-R	SUH	Initial energy of liquid in drain region and drain pipe.
W6-R	SUA	Drain region cross-sectional area.
W7-R	SUPA	Drain pipe flow area.
W8-R	SUXMX	Height of overflow outlet above drain region floor.
W9-R	SUPXMX	Elevation difference between drain region floor and end of drain pipe.
W10-R	SUPLMX	Total drain pipe length.
W11-R	SUPKX	Absolute roughness of drain pipe. A typical value for steel pipe is 0.000046 m.
W12-R	SUFLOS	Total form loss coefficient for drain pipe, including pipe entrance and exit. If a negative value is entered, CONTEMPT4/MOD3 will use 1.0 + 0.45 [1 - (SUPA/SUA)].
W13-I	ISMPGT	Enter the number of the Ice Chest Drain Initialization Generalized Table Card for this drain if TSRT is greater than zero, and enter zero if TSRT

		is zero and W14 and W15 are entered. The word may be omitted if TSRT equals zero and the next two words are also omitted.
W14-R	SPEFFS	Drain spray efficiency. If this word and the following word are blank, drain outflow to the receiving compartment will not be treated as a spray source.
W15-R	SPDMPS	Fraction total drain outflow dumped into the pool region of the receiver compartment. The remainder goes to the atmosphere region.

4.2.2.8.3 Additional Ice Chest Drain Inlet Compartment Card 6XX8—This card must be present if more than one compartment drains into drain region XX. Card 6XX9 may be used for continuation.

W1-I ...	List the numbers of the compartments, besides the inlet compartment specified on the Ice Chest Drain Description Card 6XXI, which drain into drain region XX.

4.2.2.8.4 Ice Chest Drain Initialization Generalized Table Card 1XXXII—Index XXX for this table is ISMPGT on Card 6XXI. If the CONTEMPT4/MOD3 program has a starting time greater than zero (i.e., TSRT on General Control Card 100 is greater than zero), the ice chest drain initialization model is used to set the drain region level before time step calculations begin. This table specifies drain region mass and energy addition rates to be used during drain initialization. The range of the table must include zero and TSRT, the problem starting time.

W1-A	Time units.
W2-A	Mass flow units.
W3-A	Power units.
W4-A	Always enter zero.
W5-R	Time for which next two rates apply.
W6-R	Total mass flow rate into drain region.
W7-R	Total energy flow rate (power) into drain region.
...	An arbitrary number of sets (each consisting of time, mass flow rate, and energy flow rate) may be entered. The range of the table must extend up to time TSRT.

4.2.2.9 Ice Chest Input—For all ice chests specified ICE on Compartment Description Card 4XXX1, the following card series is required.

4.2.2.9.1 Ice Initial Conditions Units Card 60000—

W1-A	Temperature units.
W2-A	Mass units.

4.2.2.9.2 Ice Initial Conditions Card 6XXX1—Index XXX refers to the ice chest compartment external number on Card 4XXX1.

W1-R	TII	Ice initial temperature.
W2-R	TMI	Ice initial mass.
W3-I	ICEGT	Number of Ice Performance Generalized Table Card 1XXXII. Index XXX is the generalized table number and is not necessarily the same as the ice chest compartment number.

4.2.2.9.3 Ice Initial Conditions Duplication Card 6XXX2—When a number of ice chests have the same initial conditions, this card may be used instead of duplicate Ice Initial Condition Card 6XXX1.

W1-I ...	A list of negative integers and/or pairs of positive integers, with absolute values in increasing order. For a negative number, L, the initial conditions for ice chest XXX are applied to ice chest |L|. For pairs of positive numbers, M, N, the initial conditions for ice chest XXX are applied to the (M - N) + 1 ice chests numbered M through N. Initial conditions described by this card must not conflict with explicitly described conditions.

4.2.2.9.4 Ice Performance Generalized Table Card 1XXXII—Index XXX for this table is ICEGT on Card 6XXX1. This table specifies ice chest conditions as either a function of flow through a given ice chest junction or time. Saturation conditions are assumed.

For the case where quantities are specified as a function of mass flow rate, if there is a single drywell/ice chest junction with zero flow or flow into the ice chest, that junction is used. If there is no such junction the procedure is repeated for ice chest/ice chest and the ice chest/other junctions. If a junction cannot be selected unambiguously, there is a fatal error. Compartment conditions will be adjusted according to this table even if flow through the selected junction is zero.

W1-A	Mass flow units or time units.
W2-A	Melt water temperature units.
W3-A	Ice chest and exit vapor temperature units.
W4-A	Enter NONE, since exit quality is dimensionless.
W5-R	Mass flow rate or time.
W6-R	Melt water temperature ($\geq$273.16 K).
W7-R	Ice chest and exit vapor temperature ($\geq$273.16 K).
W8-R	Exit quality.
...	An arbitrary number of quadruplets may be entered. A nonfatal error will result if the actual junction mass flow rate or time exceeds the table upper value.

4.2.2.10 Drywell/Ice Chest Flow Input—The distribution of flow from the drywell to the ice chests is assumed to be known a priori. This card series is optional and may be used to specify the relative flow distribution as a function of time. Each drywell/ice chest junction receiving flow must be included.

4.2.2.10.1 Drywell/Ice Chest Time Units Card 7000—

W1-A	Units for time.

4.2.2.10.2 Drywell/Ice Chest Junction Card 70000—

W1-I ...	Enter the numbers of the junctions to which the flow distribution tables apply.

4.2.2.10.3 Drywell/Ice Chest Flow Distribution Card 7JJII—The index JJ is incremented for each time. Index JJ is sequential, without omissions beginning at 1. Index II is incremented if more than one card is required for a given time. This card has two formats. Regardless of which format is used, the sum of the flow fractions in effect for each time must equal 1.0000 ± 0.0001. If the time step midpoint is outside the range of the table, drywell/ice chest flow will be treated as normal junction flow instead of being distributed. Format 1 must be used for the 701II cards and may be used for any subsequent time. Format 2 may be used only for cards where JJ ≥ 2.

Format 1 is given below:

W1-R	Time.
W2-R ...	Fraction of total flow distributed to the first junction on the Drywell/Ice Chest Junction Card 70000. Repeat until a flow fraction has been given for each junction listed on the Drywell/Ice Chest Junction Card.

Format 2 may be used for Cards 7JJII where JJ ≥ 2 when it is desired to change only some flow fractions from the values used for the previous time. Format 2 is given below:

W1-R	Time.
W2-I	Junction number.
W3-R	Flow fraction.
...	Repeat Words 2 and 3 until as many pairs of junction numbers and flow fractions as desired have been listed.

4.2.2.11 Ice Chest Door Input—The ice chest door model approximates the operation of the ice chest door panels.

4.2.2.11.1 Ice Chest Door Units Card 81000—

W1-A	Units for product of moment arm times area.
W2-A	Mass units.
W3-A	Area units. Words 2 and 3 are used to obtain moment-of-inertia units.

W4-A		Pressure units.

4.2.2.11.2 Ice Chest Door Description Card 81XXX—The ice chest door number XXX must correspond to the junction number XXX where the door is located. The ice chest door is assumed to open in the direction of positive junction flow at that junction. An ice chest door generalized table must be entered. Only orifice junctions may be equipped with ice chest doors. Only one door per junction is allowed.

W1-I	LATCH	= zero means door has no latch and may open and close repeatedly. = greater than zero means door has a latch and will lock fully open after rotation of 90 degrees is achieved.
W2-R	ARM	Moment arm times area for door, $\int x dA$.
W3-R	DINRT	Moment of inertia for door, $\int x^2 dm$.
W4-R	PCV	Closure back pressure or force against door; zero is allowed.
W5-R	DAMP	Damping constant; zero is allowed.
W6-I	IACV	Number of Ice Chest Door Generalized Table XXX. One table may be referenced by several doors.

4.2.2.11.3 Ice Chest Door Generalized Table Card 1XXXII—A table of angle-versus-fractional area must accompany each ice door; the table number XXX is IACV on Card 81XXX. The angle of door opening must be in degrees and must range from 0 to 90. The fractional area available for flow may not be negative but may be greater than 1.0.

W1-A, W2-A	Always enter NONE.
W3-I, W4-I	Always enter zero.
W5-R	Angle of door opening (degrees).
W6-R	Fractional area (area available for flow divided by total door area).
...	An arbitrary number of angle and fractional area pairs may be entered.

4.2.2.12 Heat Structure Input for Each Structure—This card series describes the configuration of the heat structure and provides the boundary conditions and controls needed for the solution process. Heat structures may be attached to any compartment or pair of compartments. The term "mesh point" will be used in referring to one of the NCOL points in the calculational grid. The term "mesh space" refers to one of the (NCOL-1) spaces between mesh points. The numbering of mesh points and mesh spaces begins at the nominal left end of the heat structure.

Data common to all heat structures are entered using the card series following this series and also must be input whenever a heat structure is present.

NOTE: Although the index for all other code features may be numbered arbitrarily, heat structures must be numbered sequentially beginning with one. The symbol YY will be used instead of the usual XX as a reminder of this constraint.

4.2.2.12.1 Heat Structure Description Units Card 1000001—

W1-A		Length units for geometry data.
W2-A		Power units for heat source data.
W3-A		Temperature units.

4.2.2.12.2 Heat Structure Title Card 1YY0000— This optional card contains up to 64 columns of title information for heat structure, YY, enclosed in apostrophes (').

4.2.2.12.3 Heat Structure Control Card 1YY0001—

W1-I	NCOL	Number of mesh points (must be three or greater).
W2-I	IGEOM	Geometry type = 1 for rectangular. = 2 for cylindrical. = 3 for spherical.
W3-R	XO	Arbitrary coordinate for mesh point one (the nominal left boundary).
W4-R	FCTR	Heat source multiplier.
W5-I	MAXIT	Iteration limit for initial steady-state solution. A value of 100 is recommended.
W6-R	EPS	Convergence criterion on heat structure mesh temperatures. Always enter 0.01.
W7-R		Always enter zero.

4.2.2.12.4 Heat Structure Connection and Miscellaneous Data Card 1YY0002—

W1-I	ISTART	Control for activating heat structure. = 0 for activating structure after time DELAY is passed. = 1 for activating structure after time DELAY is passed and all ice in the (nominal left) ice compartment has melted. This option represents heat transfer to the uncovered ice support structure after total compartment ice melt has occurred. This option must be selected for heat structures inside or abutting ice chests.
W2-A		Time units for DELAY.
W3-R	DELAY	Time for activating heat structure; see ISTART above.

W4-A		Units for ARA. Enter area units, length units, or NONE for rectangular, cylindrical, or spherical geometry, respectively.
W5-R	ARA	Heat transfer surface multiplier for boundaries. The HEAT-1 subcode computes heat flux per unit area for rectangular geometry, heat flux per unit height for cylindrical geometry, and heat flux for the entire sphere for spherical geometry. The heat transfer from the subcode is then multiplied by ARA to obtain actual heat transfer. Thus, ARA may be slab surface area, cylinder height, or sphere fraction, and may be further modified to reflect incomplete surfaces; e.g., use height/2 for a half cylinder. See Section 3.9.2 for details.
W6-I	NCMPHL	Left compartment number.
W7-I	NCMPHR	Right compartment number.
W8-I	IPWRTB	If heat sources are time dependent, enter number of Heat Source Multiplier Generalized Table, Card 1XXXII; otherwise enter zero.

4.2.2.12.5 Mesh Increment Format Card 1YY0200—This card is required for each heat structure.

W1-I	If the mesh increment data from a previously described structure are being used, enter the number of that heat structure, YY. Otherwise, enter zero.
W2-I	If Word 1 is nonzero, omit this field and ignore the next card. If Word 1 is zero, enter the format (either 1 or 2, as described below) of the mesh increment.

4.2.2.12.6 Mesh Increment Description Card 1YY02II—This card is required only if Word 2 on Card 1YY0200 is 1 or 2. Use the format specified on Card 1YY0200. A mesh interval is a set of mesh spaces that are the same length.

Format 1:

W1-I	Number of mesh spaces in this mesh interval.
W2-R	Coordinate of the mesh point forming the nominal right boundary of this mesh interval with respect to coordinate X0 on Card 1YY0001.
...	An arbitrary number of pairs of mesh space number and mesh point coordinates may be entered until all the mesh spaces (NCOL-1 from Card 1YY0001) have been described.

Format 2:

W1-R	Length of each mesh space in this interval.
W2-I	Number of mesh spaces forming the nominal right boundary of this mesh interval.
...	An arbitrary number of pairs of mesh space length and mesh point number may be entered until all the mesh points (NCOL from Card 1YY0001) have been described.

4.2.2.12.7 Composition Overlay Description Card 1YY03II—Either this card or the following card is required for each heat structure. Composition numbers are keyed to the values on the Material Property Card 10001II; e.g., composition number 1 refers to the first pair of values on Card 10001II. Composition numbers apply to each mesh space in the region.

W1-I	Composition number.
W2-I	Mesh space number of the right-hand space in the region of composition listed for Word 1.
...	An arbitrary number of pairs of composition number and mesh space number may be entered until all mesh spaces (NCOL-1 from Card 1YY0001) have been described.

4.2.2.12.8 Composition Overlay Repeat Card 1440300—This card is required for each heat structure that does not use the previous card.

W1-I	Number of heat structure, YY, for which composition overlay was previously described. That structure must have the same mesh description as the present heat structure.

4.2.2.12.9 Source Distribution Description Card 1YY04II—Either this card or the following card is required for each heat structure. Heat source values apply to mesh spaces. A heat source value of zero means there are no heat sources present in the heat structure.

W1-R	Heat source value.
W2-I	Mesh space number of the rightmost space in region with source of Word 1.
...	An arbitrary number of pairs of heat source value and mesh space numbers may be entered until all mesh spaces (NCOL-1 from Card 1YY0001) have been described.

4.2.2.12.10 Source Distribution Repeat Card 1YY0400—This card is required for each heat structure that does not use the previous card.

W1-I	Number of heat structure for which source distribution was previously described. That structure must have the same mesh description as the present heat structure.

4.2.2.12.11 Initial Temperature Estimate Card 1YY06II—Either this card or the following card is required for each heat structure. An estimated initial temperature distribution must be supplied to begin the steady-state solution process. Temperature values apply to mesh points.

W1-R		Estimated initial temperature for mesh points in region described by Word 2 on this card.
W2-I		Mesh point number at nominal right boundary of region of constant estimated initial temperature.
...		An arbitrary number of pairs of initial temperature and mesh number may be entered until all mesh points (NCOL from Card 1YY0001) have been described.

4.2.2.12.12 Initial Temperature Estimate Repeat Card 1YY0600—This card is required for each heat structure that does not use the previous card.

W1-I		Number of heat structure for which initial temperature estimate was previously given. That structure must have the same mesh description as the present heat structure.

4.2.2.12.13 Heat Source Multiplier Generalized Table Card 1XXXII—This card is required if IPWRTB on Card 1YY0002 is not zero.

W1-A		Time units.
W2-A		Enter NONE.
W3-A, W4-A		Enter zero.
W5-R		Time.
W6-R		Heat source multiplier.
...		An arbitrary number of pairs of time and heat source multiplier may be entered. The range of this table must include the times encountered in the problem.

4.2.2.12.14 Boundary Conditions Card 1YY1100—This card is required for each heat structure. Each heat structure must be provided with a heat transfer coefficient option and a boundary temperature option for both the left and right boundaries. Additional cards may be needed, depending on the choice of options on this card. Table 4 summarizes the heat transfer coefficient options available.

W1-I	ISHL	Heat transfer coefficient control for nominal left boundary. = zero for heat transfer coefficient of 0.0 indicating a symmetrical or insulated condition. = 2 for heat transfer based on the mass ratio of steam to air (Uchida model). = 3 for heat transfer coefficient of 2.3 $W/m^2 \cdot K$ which is reasonable for transfer to the liquid region.

= 4 for heat transfer coefficient of 57,000 $W/m^2{\cdot}K$ which essentially sets the surface temperature to the bulk temperature.

= +5 for input time-dependent heat transfer coefficient. Time-Dependent Heat Transfer Coefficient Card 10003II is also required.

= -5 for same as +5 until a signal from code is received which converts ISHL to Option 2. MOD3 has no conditions that trigger this signal.

= 6 for input temperature-dependent heat transfer coefficient. Temperature-Dependent Heat Transfer Coefficient Card 10004II is also required.

= 7 through 26 for heat transfer coefficient of corresponding entry on Miscellaneous Heat Transfer Coefficient Card 10002II. For Options 7 through 15 only, a calculation of condensed steam due to wall condensation will be performed.

= 50 for use of turbulent natural convection correlation (for vapor vertical plane). If $T_{wall} - T_{vapor} \leq 0.5°F$, 1.08 $W/m^2{\cdot}K$ will be used.

= 51 for use of a direct radiation heating model. Additional input is required beginning with Word 5 on this card. Refer to Section 3.9.1.3 for a discussion of the limitations of the radiation heating model.

= 52 for heat transfer coefficient based on the sum of natural convection and radiation heating, i.e., Options 50 and 51 combined. Additional input is required beginning with Word 5 on this card.

= 53 for heat transfer coefficient based on the blowdown energy release (Tagami model). Additional model definition input is required following Word 4 of this card. Tagami Boundary Conditions Card 10005II is also required.

= +1XXX for input time-dependent heat transfer coefficient taken from Time-Dependent Heat Transfer Coefficient Generalized Table Number XXX.

= -1XXX for same as +1XXX until a signal from code is received which converts ISHL to Option 2. MOD3 has no conditions that trigger this signal.

W2-I ISTL Bulk temperature control for nominal left boundary.

= zero for constant input bulk temperature. General Bulk Temperature Card 1001100 is also required.

= 1 for use of temperature of outside air compartment.

= 2 for use of left compartment atmosphere temperature. This control must be chosen if mass transfer due to superheated steam condensation is desired.
= 3 for use of left compartment pool temperature. If no liquid pool is present, the atmosphere temperature is used.
= 4 or 5 for use of input bulk temperature. Steady-State Bulk Temperature Card 1YY1110 is also required.

W3-I	ISHR	Same choice as for Word 1, except the heat transfer coefficient applies to the nominal right boundary.
W4-I	ISTR	Same choice as for Word 2, except the bulk temperature control applies to the nominal right boundary.

If ISHL or ISHR is Option 51, 52, or 53, additional fields are required on this card. Note that Option 51 or 52 may not be specified for one boundary of a heat structure if Option 53 was specified for the other boundary. However, any other combination of heat transfer coefficient options is allowed. Words 6 through 9 apply to the first boundary, either left or right; and Words 10 through 13 apply to the second boundary. Words 5 through 13 serve a dual purpose, depending on whether Option 51, 52, or 53 was selected.

W5-A		For Options 51 and 52—temperature units for TQR. For Option 53—volume units for VTAG.
W6-I	NQR	For Options 51 and 52—±J, where J is the number of the heat structure facing or interacting with this structure. A minus indicates the left surface of J and a plus indicates the right. A value of zero causes the constant sink temperature TQR to be used in the heat flow determination. For Option 53—always enter zero.
W7-R	TQR	For Options 51 and 52— = constant sink temperature if NQR is zero. = temperature to be used in lieu of surface temperature of structure NQR for initial steady-state calculation if NQR is not zero.
	VTAG	For Option 53—volume term: either the free volume of the adjacent compartment, or the combined volume of the nodalized drywell.
W8-R	FQR	For Options 51 and 52—the fraction of radiated heat that is absorbed in the adjoining vapor medium ($0 \leq FQR \leq 1.0$). Note that no radiation heat is absorbed in structure NQR unless that structure also has a radiation heating boundary condition.
	ITGH	For Option 53—the heat transfer coefficient option for this boundary to be used after TPEAK.

		Any control option listed under Word 1 may be used except for Options 51, 52, or 53. Note: This word must be input in real format.
W9-R	VIEW	For Options 51 and 52—a view factor which is a multiplier on the radiation heat transfer.
	ITGT	For Option 53—the bulk temperature option for this boundary to be used after TPEAK. Any control option listed under Word 2 may be used. Note: This word must be input in real format.
W10 through W13		Same as Words 6 through 9 for a second radiation heating or Tagami boundary, as specified in Word 3.

4.2.2.12.15 Time-Dependent Heat Transfer Coefficient Generalized Table Card 1XXXII—This card is required if ISHL or ISHR on Card 1YY1100 is -1XXX or +1XXX. The index XXX for this table corresponds to the option index XXX.

W1-A	Enter time units.
W2-A	Enter heat transfer coefficient units.
W3-A, W4-A	Always enter zero.
W5-R	Time value.
W6-R	Heat transfer coefficient value.
...	An arbitrary number of pairs of time and heat transfer coefficients may be entered. The range of this table must include the times encountered in the problem.

4.2.2.12.16 Steady-State Special Bulk Temperature Card 1YY1110—This card is required if ISTL or ISTR on Card 1YY1100 is 4 or 5.

W1-A	Temperature units.
W2-R	Bulk temperature for first boundary using Option 4 or 5.
W3-R	Bulk temperature for second boundary using Option 4 or 5.

4.2.2.13 Common Heat Structure Input—This card series describes data that must be entered whenever a heat structure is present. Some of the cards in this series are required only when certain specified conditions are present.

4.2.2.13.1 Common Data Units Card 1000000—The first two fields on this card are always required. The last five fields are entered only as required. Enter a zero if needed as a space holder.

W1-A	Thermal conductivity units for material properties.

W2-A		Volumetric heat capacity units for material properties.
W3-A		Heat transfer coefficient units for Miscellaneous Heat Transfer Coefficient Card 10002II.
W4-A		Time units for Time-Dependent Heat Transfer Coefficient Card 10003II.
W5-A		Heat transfer coefficient units for Card 10003II.
W6-A		Temperature units for Temperature-Dependent Heat Transfer Coefficient Card 10004II.
W7-A		Heat transfer coefficient units for Card 10004II.

4.2.2.13.2 Material Properties Card 10001II—This card is required if any heat structure is present. These words are grouped in pairs, with each pair numbered sequentially from one, referring to the composition numbers on the Composition Overlay Description Card 1YY03II.

W1-R		Thermal conductivity for material one.
W2-R		Volumetric heat capacity for material one.
...		An arbitrary number of pairs of thermal conductivity and volumetric heat capacity may be entered until the different materials present in all heat structures have been entered.

4.2.2.13.3 Miscellaneous Heat Transfer Coefficient Card 10002II—This card is required if ISHL or ISHR on Card 1YY1100 is Options 7 through 26. Word 3 on Card 1000000 also must be entered.

W1-R	HTC	Heat transfer coefficient for Option 7.
...		An arbitrary number of additional values may be entered, up to a maximum of 20, with the second value representing Option 8, and so forth.

4.2.2.13.4 Time-Dependent Heat Transfer Coefficient Card 10003II—This card is required if ISHL or ISHR on Card 1YY1100 is Option +5 or -5. Words 4 and 5 on Card 1000000 also must be entered.

W1-R	HTCT(1)	Time.
W2-R	HTCT(2)	Heat transfer coefficient.
...		An arbitrary number of pairs of time and heat transfer coefficients may be entered on this card and additional cards, as needed.

4.2.2.13.5 Temperature-Dependent Heat Transfer Coefficient Card 10004II—This card is required if ISHL or ISHR on Card 1YY1100 is Option 6. Words 6 and 7 on Card 1000000 also must be entered.

W1-R	HTCTP(1)	Temperature of boundary region, either atmosphere or pool.

W2-R	HTCTP(2)	Heat transfer coefficient.
...		An arbitrary number of pairs of temperature and heat transfer coefficient may be entered on this card and additional cards, as needed. Temperatures must be in ascending order and include the range of temperatures encountered in the problem.

4.2.2.13.6 Tagami Boundary Conditions Card 10006II—This card is required if ISHL or ISHR on Card 1YY1100 is Option 53.

W1-A		Time units.
W2-R	TPEAK	Time interval from beginning of blowdown to initial pressure peak. This value is used to determine the total energy release due to blowdown of primary system (single transaction tables listed below). TPEAK must be within the range of times specified in the single transaction tables.
W3-I through W5-I		Single Transaction Table Number. The energy release used for the Tagami correlation is based on an integration of energy values over interval TPEAK in this table and the tables listed for the next two words. At least one of these three fields must be nonzero, and all three fields must be present. Zero may be used as a place holder.
W6-A		Heat transfer coefficient units used for display of maximum Tagami heat transfer coefficient during listing of input descriptions.

4.2.2.13.7 General Bulk Temperature Card 1001100—This card is required only if ISTL or ISTR on Card 1YY1100 is Option zero.

W1-A		Temperature units.
W2-R	TCONT	General bulk temperature.

4.3 User Guidelines

The purpose of this section is to provide the user with some generalized guidelines to help in preparing and successfully completing a system analysis using CONTEMPT4/MOD3. This section also may help to clarify some of the models and definitions used in the program.

4.3.1 Modeling Recommendations. The following recommendations are based on extensive use of CONTEMPT4/MOD3 and will permit the user to obtain accurate results with a minimum of inconvenience.

4.3.1.1 Compartments—Subdivision of containment volumes is usually not advantageous since the vapor region of a compartment is assumed to have a homogeneous composition. A separate compartment may describe the lower portion of the drywell which acts as a sump, but, in general, the drywell, wetwell, and primary coolant system compartments are each intended to be modeled by a single compartment. However, separate compartments can be used to isolate dead-ended volumes from the rest of the containment or to determine differential pressures and flows between compartment regions.

Analyses of ice chest performance could benefit from more detailed compartment nodalization schemes. For example, dividing the ice condenser into radial sections allows preferential ice melting patterns to be observed; representing each ice chest as a series of stacked ice chest compartments permits vertical ice depletion to be investigated.

4.3.1.2 Junction Input—The inclusion of junction inertness in the flow rate calculation can have a significant damp'ng effect (or none at all) depending on the inertia value chosen. An increase in junction geometric inertia allows a corresponding increase in time step size. However, unrealistic flow and pressure histories will result if abnormally high inertia values are input.

The junction geometric inertia term is a constant value specified by the user and input for every junction. Each junction may have a different inertia, or no inertia, if so desired. The junction inertia is directly related to the geometry of the junction. The following recommendations for the inertia term are made for some specific geometries.

The junction inertia for a simple stream tube configuration is

$$I = \frac{L_i}{2A_i} + \frac{L_j}{2A_j} \tag{140}$$

where

A = flow area

L = compartment flow length

i = the nominal donor compartment index

j = the nominal receiver compartment index.

This geometry generally is not encountered in containment descriptions.

When an abrupt area change occurs, such as illustrated in Figure 9, the streamlines will not conform to the boundaries of the area change and Equation (140) will not apply. The area change of the streamlines is somewhat less abrupt than the physical area change would indicate. This situation has been examined in Reference 15 and the following effective inertia given:

$$I = \frac{L_i}{2A_i} + \frac{L_j}{2KA_j} \tag{141}$$

where K is a positive-valued coefficient less than one. The value assigned to K is largely a matter of judgment. It is reasonable to assume that K would approach unity as L_j/A_j becomes large since the streamlines come into greater conformance with the area change as the flow length increases ($L_j/A_j > 4$ is an arbitrary limit which can be used to determine when K should be unity). Also, if $L_j/A_j < 1$, the total inertia can be set equal to L_j/A_j. These arbitrary guidelines give

$$K = 1.0 \qquad \text{if } \frac{L_j}{A_j} > 4 \tag{142}$$

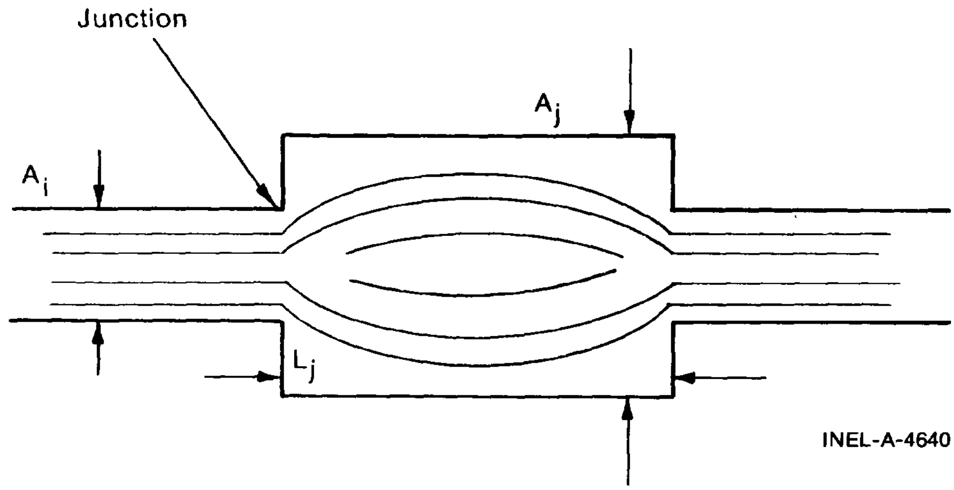

Figure 9. Streamlines during an abrupt area change.

$$K = \frac{A_i L_j}{A_j L_i} \quad \text{if } \frac{L_j}{A_j} < 1 \tag{143}$$

and, for ratios between 1 and 4, a linear interpolation could be used between unity and the value computed from Equation (142).[15]

The actual values of the geometric inertia to use for most long-term containment analyses are not crucial. CONTEMPT4/MOD3 containment transients are usually relatively long-lived, allowing the junction inertia term to act more as a damping constant than as a true inertness. For a realistic containment problem there is a range of geometric values that can be used for accurate and smooth containment analysis without substantially changing the results. The actual range of inertia values that can be used without appreciably affecting the results is unique to each problem (and junction). User experience and parametric studies on inertia values for a given geometry can be beneficial in achieving the best analysis efficiency for a particular problem.

4.3.1.3 Time Step Size—The successful selection of time step size is highly dependent on the problem. Experience is probably the most valuable asset in arriving at a reasonable set of time step values for a given problem.

The program user should first divide the total problem time into time intervals based on the anticipated rapidity of thermodynamic changes encountered in the problem. In general, the time interval beginning with initiation of break flow and continuing through the subcooled liquid portion of the blowdown should use time steps on the order of 0.01—0.001 s. The time interval characterized by the coastdown of the steam blowdown can use time step sizes on the order of 0.10—0.01 s. As the transient progresses, time step sizes can be increased. Gradual increases in time step size (by about a factor of two) are generally less likely to produce unwanted oscillations than are more abrupt time step size changes. Reduced time step sizes are needed, however, when situations arise which quickly alter thermodynamic conditions, such as activation of containment fan and spray systems. Time steps of about 1 s should be adequate near the end of the blowdown portion of the transient. When heat transfer between heat conducting structures and the atmosphere region is the predominate mechanism affecting compartment conditions, time step sizes greater than 1 min should be reasonable.

The automatic time step control is capable of modifying time step size in response to varying compartment conditions. In practice, the adequacy of time step size becomes evident only as the analysis proceeds.

In some instances, automatic time step control may be undesirable, leading to either unnecessary time step reduction without corresponding improvements in accuracy, or unwarranted increase in time step size with subsequent loss of accuracy. Those time intervals when junction mass flow rates undergo considerable changes in magnitude are best suited to manual time step control. The range of time step size for automatic time step control is limited by minimum and maximum values input by the user. It is imperative that the values set for both the upper and lower limits be used for some part of each time interval, thus maintaining the time step size within a reasonable range. It is recommended that the minimum and maximum time step size limits be within an order of magnitude of each other in order to preclude large fluctuations in actual time step size.

4.3.2 Resolving Computational Difficulties. In most cases, abnormal termination of a CONTEMPT4/MOD3 analysis is the result of an unrealistic situation which develops in a compartment and which cannot be reconciled by the code. While not all abnormal terminations can be anticipated and discussed here, this section does discuss in general some remedies for computational difficulties.

Each subroutine in CONTEMPT4/MOD3 and several of the HEAT-1 subcode subroutines generate error messages whenever trouble is detected. Each abnormal termination of an analysis will initiate at least one printed error message stating the cause of the termination and the probable location (subroutine) where the fatal error was found. A list of nonfatal and fatal error messages that may be encountered while using CONTEMPT4/MOD3 is compiled in Appendix E. Most computational difficulties can be identified readily by using the error messages and can be prevented by reviewing the logic that led to the error.

The most common computational difficulty leading to problem termination is a mass/energy balance failure. Such failure is generally caused by excessive time step size which leads to one of the following conditions: (a) unrealistic junction flow with resultant flow oscillations, (b) excessive heat transfer to a relatively small pool region, or (c) excessive heat transfer between heat structures and adjacent compartments. If manual time step control is used, subsequent problem runs should use time step sizes reduced by a factor of about four for the time immediately preceding the mass/energy balance failure. Automatic time step control seeks to avoid abnormal problem termination, but may be constrained by the user-input limits on time step size.

4.4 Output Description

4.4.1 Printed Output. The printed output for CONTEMPT4/MOD3, including major and minor edits, is divided into six sections:

1. The first section is an exact listing of the input data deck with a sequence number added to the left of each card number. Duplicate card numbers are flagged, and unacceptable numerical format is identified. See Section 4.2.1 for further details.

2. The second section is an intensive listing of the input data grouped according to feature type with descriptive headings to identify the data to the program user. Inconsistent combinations of data, missing data cards, and missing or extraneous fields on data cards are examples of fatal and nonfatal errors identified at this time. For many problem descriptions (e.g., compartments), the internal number assigned by the code is printed to the left of the user-assigned external number. A summary of memory allocation also is included in this section.

3. The third section is printed immediately after problem initialization and presents the initial compartment conditions prior to time step processing.

4. The fourth section is the printing of minor edit variables. Nearly all of the variables printed for a major edit are available for a minor edit. These variables are listed in Table 7. A minor edit printout consists of problem time followed by a heading of

Table 7. Single transaction variables

Case	First Dependent Variable	Second Dependent Variable	Third Dependent Variable
1	Mass flow rate	Energy flow rate	--
2	Mass flow rate	Specific enthalpy	--
3	Mass flow rate	Temperature	(pressure)--not used if GSTMAT is AIR
4	Volumetric flow rate	Specific enthalpy	Pressure
5	Volumetric flow rate	Temperature	Pressure

requested variable name, index, and units. Variable values are printed under their headings which are staggered to facilitate easier reading if all the minor edit variables cannot be placed in one horizontal row. The frequency of minor edits is user controlled.

5. The fifth section is the major time step edit. The frequency of major edits is also user controlled, but the content of a major edit is based on the number and variety of program features specified in the problem. Compartment conditions and intercompartment mass and energy transfer rates are printed for every problem. Values of parameters related in individual problem features are printed next only when the feature is used in the problem. The problem features edited are

   a. Single transactions
   b. Double transactions
   c. Junctions
   d. Ice chests
   e. Sumps
   f. Spray systems
   g. Heat structures
   h. Fans and pumps
   i. Ice chest doors
   j. Fan coolers.

6. The sixth section is the debug option which provides extensive monitoring of selected CONTEMPT4/MOD3 subroutines. The frequency of debug printing may be independent of both major and minor edits. Debug edits are intended for use by code developers and are not recommended for casual analysis purposes.

An example of the first five printed output sections described above is included with the sample problem results in Appendix G.

5. REFERENCES

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9. V. L. Streeter and E. B. Wylie, *Hydraulic Transients*, New York: McGraw-Hill Book Company Inc., 1967.

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13. D. C. Slaughterbeck, *Review of Heat Transfer Coefficients for Condensing Steam in a Containment Building Following a Loss-of-Coolant Accident*, IN-1388, September 1970.

14. M. Jakob, *Heat Transfer*, Vol. 1, New York: John Wiley and Sons, 1967.

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APPENDIX A

SUMMARY DESCRIPTION OF CONTAINMENT SYSTEMS

APPENDIX A

1. SUMMARY DESCRIPTION OF CONTAINMENT SYSTEMS

Several of the containment systems that can be modeled using the CONTEMPT4/MOD3 program are discussed briefly, and the major features of each system are described. Since CONTEMPT4/MOD3 is not presently designed to analyze BWR containment systems, those systems are not described.

1.1 PWR Dry Containment

Figure A-1 depicts a cross-sectional view of a typical pressurized water reactor (PWR) plant, showing the reactor vessel and containment volumes. The containment is tens of thousands of cubic metres in volume and is lined with steel and concrete. Figure A-2 depicts a simpler one-compartment representation of a dry containment. The reactor vessel and primary system are represented as a mass and energy source to the containment volume. The term drywell is commonly used to represent all chambers located within the inner steel liner of a containment building.

1.2 Dual or Annular Containment

A modification of the dry containment system is represented by the dual containment (also called annular containment) concept. Figure A-3 shows a cross-sectional view of a dual containment plant. Basically, this design separates the containment steel liner from the concrete shield wall. The annular space created between the steel and concrete walls (called the dual compartment) is maintained at a pressure below the pressures of both the drywell region and outside atmosphere. With the dual compartment operating at low pressure, any leakage flow would be into the annular region rather than into the environment.

The drywell compartment has basically the same safety features as a dry containment. The freestanding steel shell provides a low-leakage barrier to pressure and fission products. Cooling sprays and a fan cooling unit with cooling coils comprise the engineered safeguard system intended to reduce undesired high pressures and temperatures encountered in the drywell.

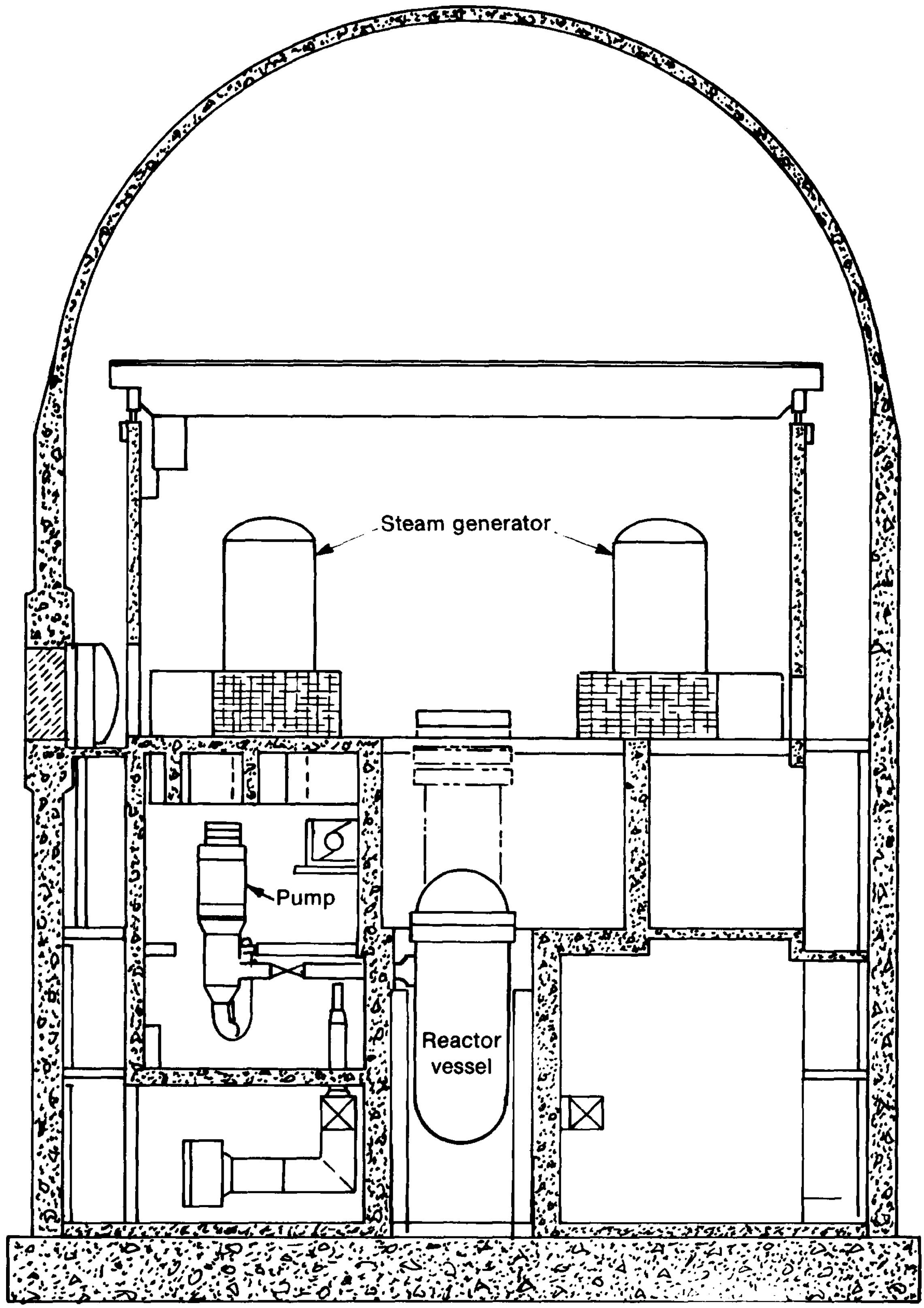

Figure A-1. Typical dry containment.

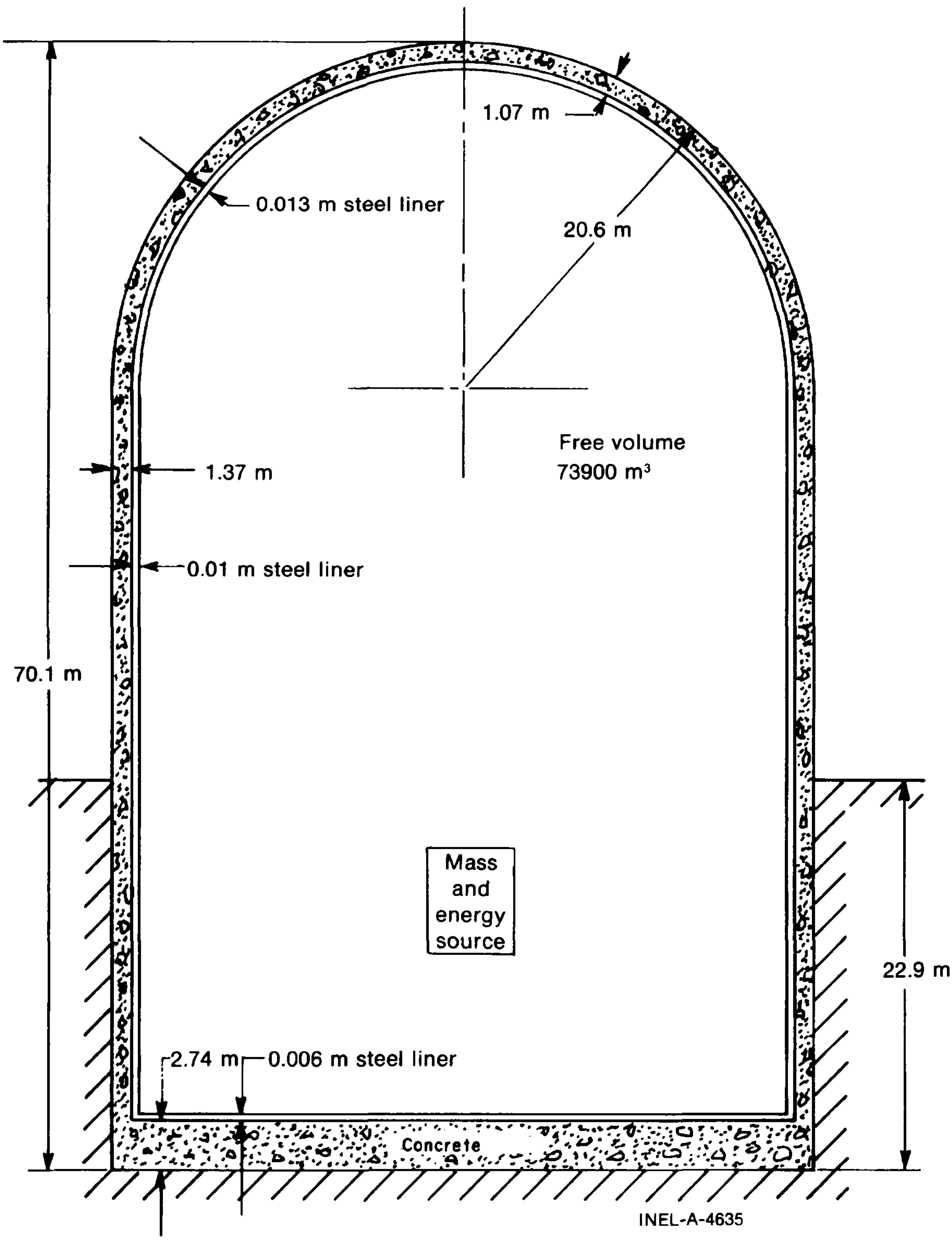

Figure A-2. One-compartment representation of a dry containment.

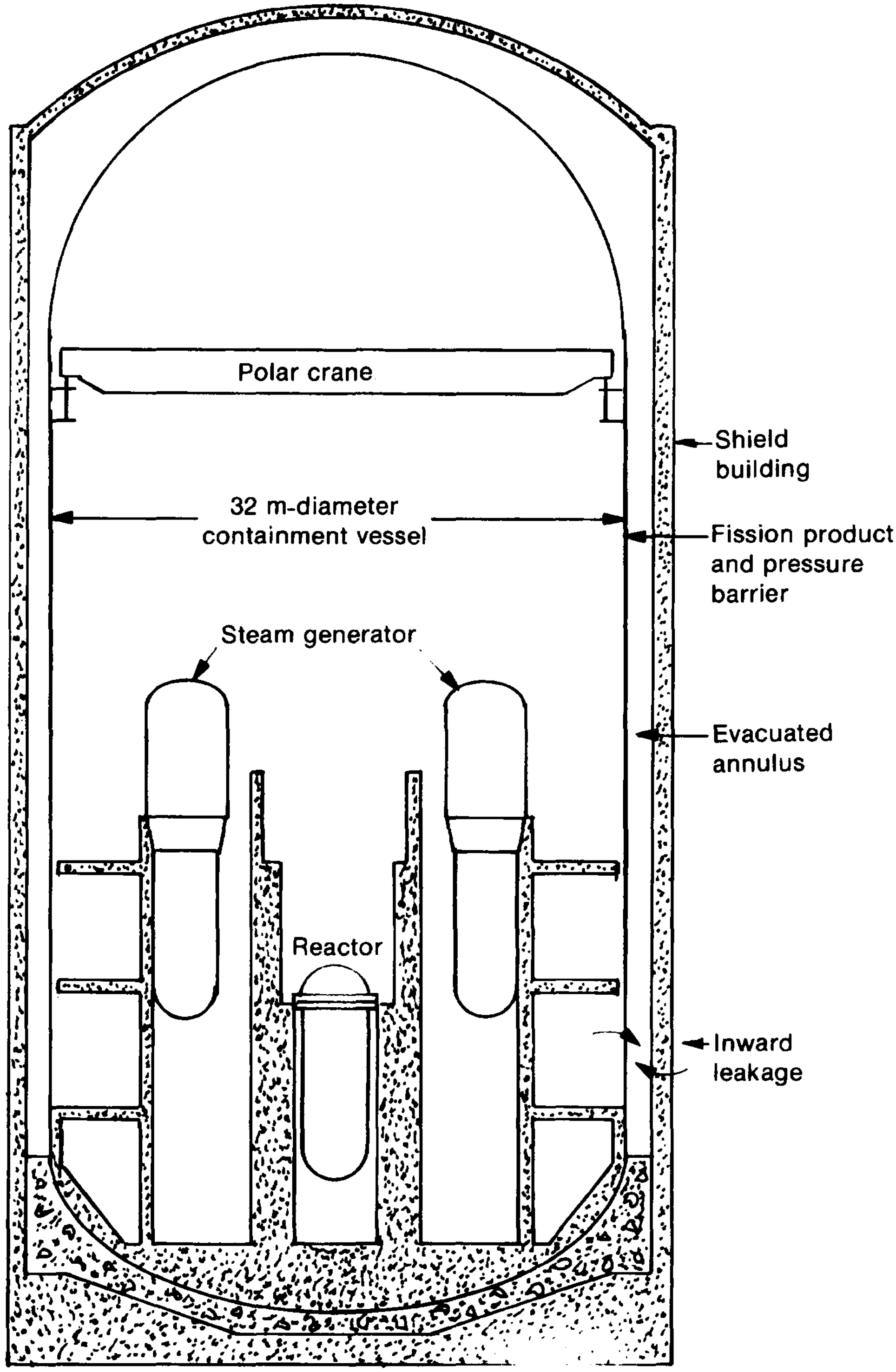

Figure A-3. Dual containment.

The dual compartment has an outer wall of thick reinforced concrete. The safety system associated with the dual compartment is a ventilation system.

1.3 Subatmospheric Containment

Subatmospheric containment is a concept wherein the reactor drywell pressure is maintained below atmospheric pressure during normal plant operation. A typical one-compartment dry containment is used, as shown in Figures A-1 and A-2.

1.4 Ice Condenser Containment

A cross-sectional view of a typical PWR plant with an ice condenser pressure suppression system is shown in Figure A-4. The containment is divided into three compartments: the lower compartment, the upper compartment, and the ice condenser compartment. The lower compartment completely encloses the reactor coolant system equipment and associated auxiliary systems equipment. The upper compartment contains the refueling canal, refueling equipment, and the overhead polar crane. The upper and lower compartments are separated by the operating deck which provides a low-leakage barrier between these two compartments. The ice condenser compartment is a completely enclosed and refrigerated annular compartment which is located radially between the upper and lower compartments and the outer wall of the containment. The ice compartment is generally above the operating deck in elevation.

In the event of a loss-of-coolant accident, door panels located below the operating deck at the bottom of the ice condenser would open quickly due to the pressure rise in the lower compartment caused by the release of reactor coolant. This would allow the steam to flow from the lower compartment into the ice condenser. In turn, door panels at the top of the ice condenser would open and allow some of the air from the lower compartment and the ice condenser compartment to flow into the upper compartment. The ice condenser would very quickly begin to condense the steam, thus limiting the peak pressure in the containment. Condensation of steam within the ice

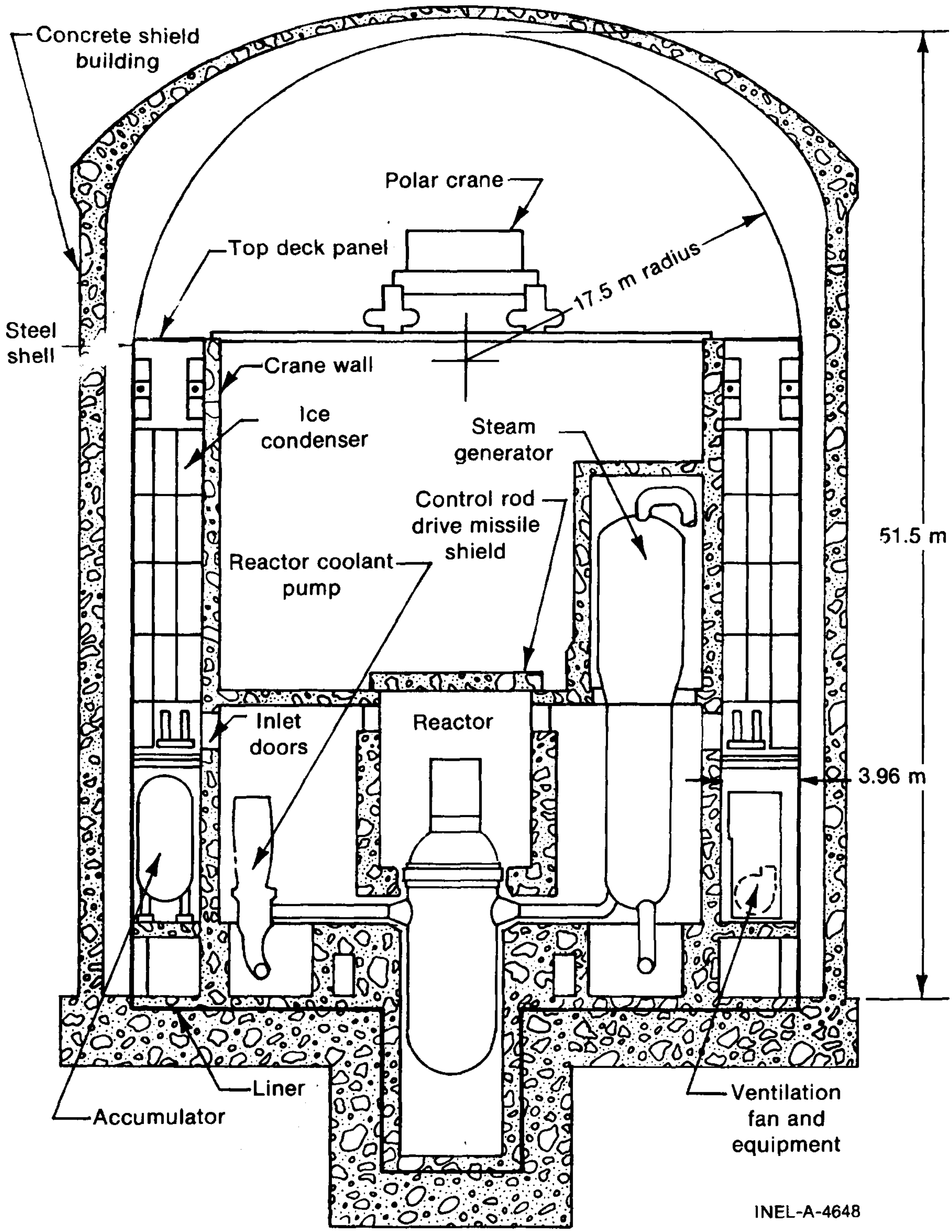

Figure A-4. Cross section of ice condenser containment.

condenser also promotes flow of steam from the lower compartment to the condensing surface of the ice, thus substantially reducing the time that the containment is at an elevated pressure.[A-1]

1.5 Reference

A-1. G. Masche, Systems Summary of a Westinghouse Pressurized Water Reactor Nuclear Power Plant, Westinghouse Electric Corporation, 1971, pp. 173-176.

APPENDIX B

STH2O PROGRAM

APPENDIX B

1. STH2O PROGRAM

The STH2O[a] water properties routines consist of a program to generate a file containing tables of thermodynamic properties of water and several subroutines that use the tables to calculate water property quantities. The production user of CONTEMPT4/MOD3 is normally not concerned with the water property file since the procedures used to access the program also provide access to the file. Transmittals of the CONTEMPT4/MOD3 program normally include the water property file.

1.1 STH2OG Program

The STH2OG program generates tables of thermodynamic properties of water using the 1967 International Formulation Committee (IFC) formulation of the properties of water as coded in the ASTEM package.[B-1] The tables are written to a file in a form convenient for reading into programs such as CONTEMPT4/MOD3. Properties stored in the tables as functions of pressure and temperature include specific volume, internal energy, coefficient of thermal expansion, isothermal compressibility, and the isopiestic heat capacity. The data spacing in the tables is variable, permitting the density to be greater where more accuracy is required.

Water properties in the data tables are in SI units. The nomenclature used in the following sections and the units of the properties are:

T	Temperature	Kelvin (K)
P	Pressure (absolute)	pascal (Pa) = newton/meter^2 (N/m^2) = joule/meter^3 (J/m^3)
v	Specific volume	meter^3/kilogram (m^3/kg)

a. The last character in STH2O is the letter O.

u	Specific internal energy	joule/kilogram (J/kg)
h	Specific enthalpy	joule/kilogram (J/kg)
$\beta = \frac{1}{v} \frac{\partial v}{\partial T}\Big\|_P$	Coefficient of thermal expansion	$kelvin^{-1}$ (K^{-1})
$\kappa = \frac{1}{v} \frac{\partial v}{\partial p}\Big\|_T$	Isothermal compressibility	$pascal^{-1}$ (Pa^{-1})
$c_p = \frac{\partial h}{\partial T}\Big\|_P$	Heat capacity at constant pressure	joule/kilogram-kelvin (J/kg-K)
f	Saturated liquid subscript	
g	Saturated vapor subscript	
sat	Saturated quantity subscript.	

The input data format is identical to the CONTEMPT4/MOD3 input format except that only one case is allowed. Entry on applicable cards is as follows:

1. Temperature and Pressure Count Card

Card	Data
1000	NT, NP where NT is the number of temperatures entered and NP is the number of pressures entered. Both quantities are in integer format.

2. Temperature Cards

Cards	Data
1001-1099	Temperatures for which water values are derived are entered in floating-point format in increasing order on cards with increasing card numbers. One or more temperatures can be entered on a card. Temperatures must be in the range 273.16 K $\leq$ T $\leq$ 1073.15 K. The card numbers need not be sequential. This facilitates the addition or deletion of temperatures.

3. Pressure Cards

Cards	Data
2001-2999	Pressures for which water values are desired are entered in floating-point format in increasing order on cards with increasing numbers. One or more pressures can be entered on a card. Pressures must be in the range 0 $\leq$ P $\leq$ 10^8 Pa. The card numbers need not be sequential.

Five tables are generated and packed into a single-dimensioned array. The first two tables are temperatures and pressures obtained from input data. The third table contains saturation properties as a function of the saturation temperatures in the temperature table. The fourth table is a separate saturation table as a function of the saturation pressures in the pressure table. The fifth table is a two-dimensional table containing the single-phase properties as a function of the temperatures and pressures in the first two tables. The tables are written on a data set for use by other modules utilizing the subroutines.

In the description of the tables, A is used for the array symbol; NT and NP are the number of temperatures and pressures entered as defined in the input description; NS is the number of input temperatures not above the critical temperature; and NS2 is the number of input pressures not above the critical pressure. The table storage is as follows:

1. The temperatures in increasing order, as obtained from the input data, are stored in A(1) through A(NT). The temperatures can be considered to be stored in an array dimensioned T(NT), where T(1) is equivalenced to A(1).

2. The pressures in increasing order, as obtained from the input data, are stored in A(NT + 1) through A(NT + NP). The pressures can be considered to be stored in an array dimensioned P(NP), where P(1) is equivalenced to A(NT + 1).

3. The saturation properties as a function of temperature are stored in A(NT + NP + 1) through A(NT + NP + NS*11). The saturation properties are stored as an array dimensioned B(11,NS), where B(1,1) is equivalenced to A(NT + NP + 1). The saturation values in B(N,I), with $1 \leq N \leq 11$, are a function of the temperature in T(I). The correspondence between the B array and the saturation properties is:

B(1,I)	P	B(6,I)	c_{pf}
B(2,I)	v_f	B(7,I)	v_g
B(3,I)	u_f	B(8,I)	u_g
B(4,I)	β_f	B(9,I)	β_g
B(5,I)	k_f	B(10,I)	κ_g
		B(11,I)	c_{pg}.

4. The saturation properties as a function of pressure are stored in A(NT + NP + NS*11 + 1) through A(NT + NP + NS*11 + NS2*11). The saturation properties are stored as an array dimensioned

C(11,NS2), where C(1,1) is equivalenced to A(NT + NP + NS*11 + 1). The saturation values in C(N,J), with $1 \leq N \leq 11$, are a function of the pressure in P(J). The correspondence between the C array and the saturation properties is the same as for the B array except that C(1,J) is the saturation temperature instead of the saturation pressure.

5. The single-phase properties as a function of temperature and pressure are stored in A(NT + NP + NS*11 + NS2*11 + 1) through A(NT + NP + NS*11 + NS2*11 + NT*NP*5). The single-phase properties are stored as an array dimensioned D(5,NT,NP), where D(1,1,1) is equivalenced to A(NT + NP + NS*11 + NS2*11 + 1). The values D(N,I,J), with $1 \leq N \leq 5$, are a function of the temperature in T(I) and the pressure in P(J). The correspondence between the D values and the properties is:

D(1,I,J)	v	D(3,I,J)	β
D(2,I,J)	u	D(4,I,J)	κ
		D(5,I,J)	c_p.

The tables generated by the module are written on a disk file of two records using FORTRAN sequential, nonformatted writes. The first record contains NT, NP, NS, and NS2. The second record contains the A array which has NTOT elements, where NTOT = NT + NP + NS*11 + NS2*11 + NT*NP*5.

The printed output includes the input data, values of NT, NP, NS, NS2, NTOT, and the generated table values.

The module uses the FTB package for dynamic storage allocation. The required region size depends on the input data. A region size of 200 K is sufficient for 45 single-phase temperatures, 29 single-phase pressures, 40 saturation temperatures, and 27 saturation pressures.

1.2 STH2OI: Initialization Subroutine

The STH2OI subroutine retrieves the tables needed by the other subroutines by reading the data set created by the STH2OG module and sets up a small common block named STH2OC. The subroutine must be called before a call is made to any of the other subroutines. The subroutine is called by CALL STH2OI (A, N, NUSE) where A is a 64-bit floating-point array of length NUSE available for storing the tables, and N is the unit number to be used to read the data set. On entry, NUSE must be greater than or equal to the length of the generated table (NTOT). On return, NUSE is set positive and contains the length of the tables, if the tables were successfully loaded into the A array. The values returned in NUSE are thus the number of words used in the A array. Words in the A array beyond A(NUSE) are available for other use. The subroutine will print an error message and return NUSE equal to -1, if the table cannot be retrieved. The subroutine can be placed in an overlay. The subroutine need be executed only once for each invoking of a module containing the STH2O subroutines unless the A array is destroyed.

1.3 Arguments Common to Remaining Subroutines

The A array is as defined in previous sections of this appendix and must be the array loaded by the call to STH2OI. The integer variable, IT, is set by the subroutines that can compute properties in the liquid, two-phase, and vapor states. It can be set to 1, 2, 3, or 4 as shown in Figure B-1 and is used to indicate whether a saturated pressure (or temperature) corresponding to an input temperature (or pressure) is available. Figure B-1 also indicates the value of quality returned for the various states and whether the fluid is considered liquid or vapor for interpolation procedures. Water above the critical pressure but below the critical temperature is considered to be in the liquid state.

S is an array of 23 floating-point words containing both input to and output from the subroutines. The assignment of properties to the S array is:

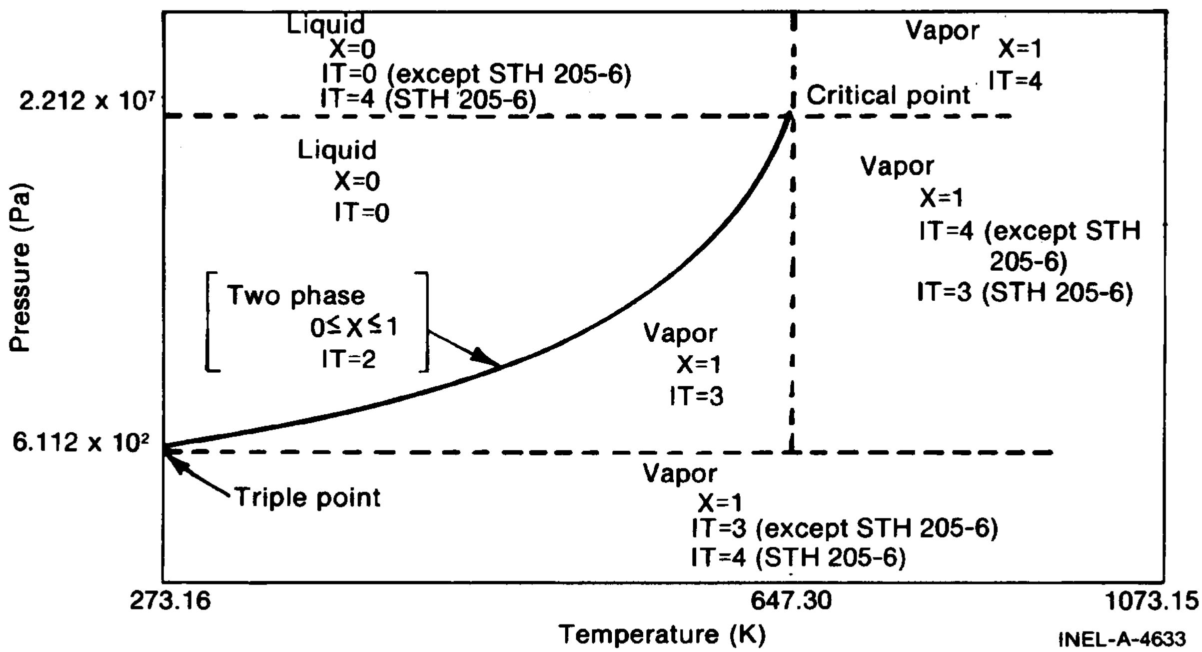

Figure B-1. Sketch definitions of state, quality, and IT.

S(1) T	S(8) c_p	S(16) h_g
S(2) P	S(9) X (quality)	S(17) β_f
S(3) v	S(10) P_{sat} or T_{sat}	S(18) β_g
S(4) u	S(11) v_f	S(19) κ_f
S(5) h	S(12) v_g	S(20) κ_g
S(6) β	S(13) u_f	S(21) c_{pf}
S(7) κ	S(14) u_g	S(22) c_{pg}
	S(15) h_f	S(23) indexes.

S(6) through S(8) are undefined for the two-phase state (IT is equal to 2). S(9) contains 0.0 for the liquid state (IT may be 1 or 4), contains the actual quality if in the two-phase state (IT is equal to 2), and contains 1.0 for the vapor state (IT may be 3 or 4). For all subroutines except

STH205, S(10) is the saturated pressure corresponding to the temperature in S(1) if IT is returned as 1 through 3, and is undefined if IT is returned as 4. For STH205, S(10) is the saturation temperature corresponding to the pressure in S(2) if IT is returned as 1 through 3, and is undefined if IT is returned as 4. S(11) through S(22) are undefined for single-phase states (IT is not equal to 2).

The S array is used for working storage, and undefined elements may be changed during subroutine execution. On entry, the indexes in S(23) are used to start the table search, if they are valid. On return, S(23) contains the indexes obtained by the table search. Execution time can be minimized if the table indexes are saved and used subsequently to start a table search. The subroutines do not fail when invalid indexes are entered in S(23) because the table search will then start at the beginning of the table.

An error flag, ERR, is returned FALSE if the input quantities are within the range of the tables and TRUE otherwise.

1.4 STH200: Saturation Pressure as a Function of Temperature

CALL STH200[a] (T, P, ERR) computes the saturation pressure, P, given the temperature, T, as input. The temperature must be in the range $273.16\ K \leq T \leq 647.30\ K$. This subroutine does not use the A array and can be called before STH2OI is called.

1.5 STH201: Saturated Properties as Functions of Temperature and Quality

CALL STH201 (A, S, ERR) computes the saturated water properties given temperature and quality as input. The temperature is entered in S(1) and must be greater than or equal to either T(1) or C(1,1) and less than or equal to either T(NS) or C(1,NS2). The arrays T and C are defined in Section 1 of this appendix. The quality, X, is entered in S(9) and must be in

a. The last character in STH200 is a zero.

the range $0.0 \le X \le 1.0$. S(3) through S(5) are return values for the two-phase mixture, and S(11) through S(22) are return values for saturated liquid and saturated vapor. S(2) and S(10) are returned equal. IT would always be set at 2 for this call and thus is not included in the argument list.

1.6 STH2O2: Saturated Properties as Functions of Pressure and Quality

CALL STH2O2 (A, S, ERR) computes saturated water properties given pressure and quality as input. The pressure is entered in S(2) and must be greater than or equal to the triple point pressure (611.2 Pa). The saturation temperature is returned in S(1), and the other elements of S are set as in STH2O1. STH2O2 is an entry point in the STH2O1 subroutine.

1.7 STH2O3: Single-Phase Properties as Functions of Temperature and Pressure

CALL STH2O3 (A, S, IT, ERR) computes single-phase water properties given temperature and pressure as input. The temperature, T, is entered in S(1) and must be within the range $T(1) \le T \le 500$ K. The pressure, P, is entered in S(2) and must be within the range $0 \le P \le P(NP)$ for the vapor state and $P(1) < P \le P(NP)$ for the liquid state. The arrays T and P are defined in Section 1 of this appendix. IT is never set to 2 because temperature and pressure cannot determine a two-phase condition. The single-phase quantities are returned in S(3) through S(8), and S(9) is set to either 0.0 of 1.0, corresponding to the liquid or vapor state, respectively.

1.8 STH2O4: Water Properties as Functions of Temperature and Specific Volume

CALL STH2O4 (A, S, IT, ERR) computes water properties given temperature and specific volume as input. The temperature, T, is entered in S(1) and must be within the range $T(1) \le T \le 500$ K. The range of specific volume depends on the state. If the temperature and specific volume indicate the liquid state, the resultant pressure, P, must be such that $P \geq P(1)$. The T and P arrays are defined in Section 1 of this appendix. The results are stored in the S array.

1.9 STH2O5: Water Properties as a Function of Pressure and Enthalpy

CALL STH2O5 (A, S, IT, ERR) computes water properties using pressure and enthalpy as input. The pressure is entered in S(2), and the enthalpy is entered in S(5). The range of pressure is identical to that for STH2O3, and the enthalpy must be in a range that would be returned by valid calls to STH2O3. The results are stored in the S array. S(10) is the saturation temperature corresponding to S(2) if IT $\neq$ 4.

1.10 Single-Phase Saturated Liquid Properties as Functions of Specific Energy of Specific Enthalpy

CALL STH2OU (A, S, ERR) [or CALL STH2OH (A, S, ERR)] computes single-phase saturated liquid water properties given specific energy (or specific enthalpy). The specific energy, u_w, is entered in S(4) [or specific enthalpy, h_w, is entered in S(5)] and must be within the saturation range of the tables. The single-phase quantities are returned in S(1) through S(5), S(9) is set to 0.0, and S(10) through S(23) are calculated. S(6) through S(8) are not calculated. STH2OH is an entry point in the STH2OU routine.

1.11 Reference

B-1. K. V. Moore, ASTEM--A Collection of FORTRAN Subroutines to Evaluate the 1967 ASME Equations of State for Water/Steam and Derivatives of These Equations, ANCR-1026, October 1971.

APPENDIX C

GENERALIZED TABLE DESCRIPTION AND INPUT

APPENDIX C

1. GENERALIZED TABLE DESCRIPTION AND INPUT

All tabular input data in CONTEMPT4/MOD3 are processed together and stored in a single dynamic storage block. This task is facilitated by requiring all input tables to follow the same format. The generalized tables in CONTEMPT4 process and store tables consisting of an arbitrary number of n-tuples, where $1 \leq n < 4$. The following card series use generalized tables:

Referencing Card Series	Table Use
100	Outside air temperature
1XX1	Single transaction
2XX1	Double transaction
6XXI	Sump initialization
99II	Debug control
6XXXI	Ice performance
81XXX	Ice chest door opening
90XX4	Fan/pump flow
91XXX	Fan cooler energy addition
1YY0002	Heat source multiplier
1YY1100	Time-dependent heat transfer coefficient.

This appendix does not provide specific input data requirements for the card series mentioned above. Such information for each of the cases above is contained in Section 4.2.2. This appendix does explain the input format common to all generalized tables.

All generalized tables, regardless of their function, belong to the same card series, namely 1XXXII (XXX is the table number and II is used for sequencing). It is incumbent on the program user to provide unique generalized table numbers. If this is not done, the replacement feature of the input processor will cause the last card with a given number to supercede previous cards with that number without any warning other than a printed message stating that a replacement has taken place. Where possible, the code checks to see if the table specified has the proper number of variables for the intended use. If a table is inadvertently replaced by another table with the same structure, however, the mistake may go undetected. Therefore, it is suggested that:

1. The user organize generalized table numbers into "subseries" with specific functions, e.g., 100-199 reserved for single transactions, 200-299 reserved for double transactions, 810-819 reserved for ice chest doors, etc.

2. The user check the replacement card messages in the edit of data cards to be sure no unintentional replacements have occurred.

The nonspecific format of generalized table data input is described below.

<u>1XXX00--Generalized Table Title Card</u>. This card is optional and is used to title generalized tables. Titles may be up to 64 characters enclosed with apostrophes ('). Apostrophes may be omitted if there are no character strings which could be interpreted as numbers and if compressed spacing is acceptable.

1XXXII <u>Generalized Table Card</u>.

W1-A Independent variable units.

W2-A First dependent variable units.

W3-A Second dependent variable units.

W4-A Third dependent variable units. If a dependent variable is dimensionless, NONE should be entered for units. If a dependent variable is not present, a zero should be entered for units. That is, if there is only one dependent variable, Words 3 and 4 should be zero.

W5-R . . . Table entries in sets of 1, 2, 3, or 4 items depending on whether Word 2, 3, or 4 is nonzero, respectively. The independent variable normally must be in ascending order. If it is not, a nonfatal error will occur during input processing; however, the problem will terminate if interpolation is attempted during time step processing.

APPENDIX D

PROGRAM ORGANIZATION

APPENDIX D

1. PROGRAM ORGANIZATION

This appendix discusses the internal organization of the CONTEMPT4/MOD3 program. Two techniques used to improve the utilization of core memory--overlays and dynamic storage--are discussed along with the program calling sequence and a description of the function of each subroutine. The code is structured according to top-down principles. Thus, at each level in the hierarchy, the operation of the code is understandable at that level of abstraction. This type of design leads to a modular, clear, and easily modified program structure.

1.1 Overlays

Overlaying, also called segmentation, is a technique for allowing sections of code to share computer core memory. This can be accomplished only when the code has distinct sections that are independent of each other.

The CONTEMPT4/MOD3 calculation can be divided into input, initialization, and time step phases. For each of these phases there is a separate overlay, as shown in Figure D-1. The origin of the memory pool is fixed by the longest overlay, the time step routines. None of the time step routines is mutually exclusive in a given problem, so it is not possible to overlay them further without swapping the code every time step. Such frequent swapping would gain relatively little memory but would result in large I/O charges, so this procedure is not used.

Another strategy is available for reducing the length of the time step routines. The origin of the memory pool is presently fixed by the coding needed for all the problem features. However, if it were known in advance that certain problem features would not be needed, a special version of CONTEMPT4/MOD3 could be created without the coding for those unneeded problem features. Because of dynamic storage, only coding requirements need be considered, and the savings would equal the size of the eliminated code. This procedure usually would not be justified economically, but could allow a given problem to run when field length would otherwise be limiting.

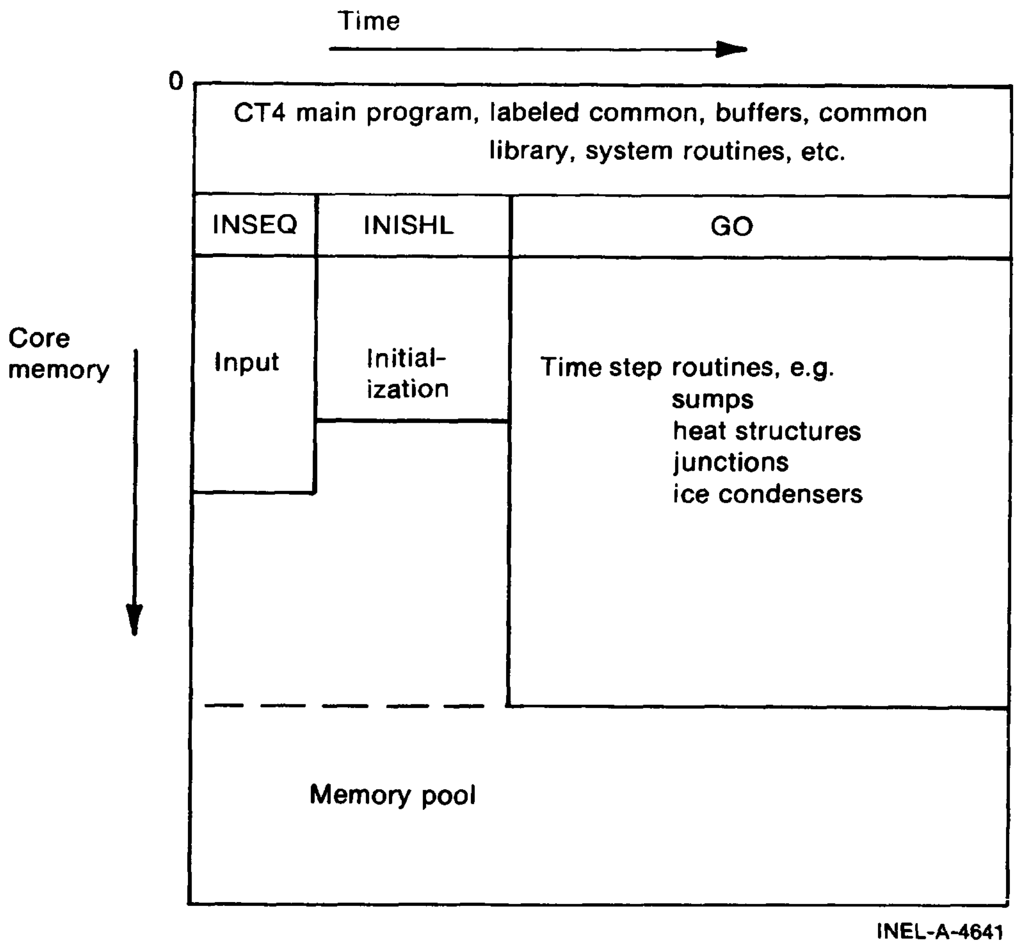

Figure D-1. CONTEMPT4/MOD3 overlays.

1.2 Dynamic Storage

Dynamic storage allocation (DSA) is a technique for making the most effective use of the computer's memory. In FORTRAN programming, working storage usually is allocated at compile time for the largest problem to be run by the program. For any smaller problem, there are unused areas of core, but the total field length required is the same as for the largest problem. It is anticipated that CONTEMPT4/MOD3 will be run with a highly variable mix of problem features and problem sizes. Dynamic storage allocation allows problems to be run using only the field length actually required for that particular problem. This provides economic and turnaround benefits, and allows the largest possible problem to be run if memory is limiting.

CONTEMPT4/MOD3 working storage is in a memory pool. This pool is organized into blocks which are either associated with some problem feature (e.g., the ice chest block), or some particular phase of the calculation. Memory management is the process by which the code reserves and releases blocks as needed.

1.2.1 Memory Organization

The memory pool resides in COMMON/FAST/ at the upper end of the job field length. It begins immediately after the last module of code in the largest overlay and ends at the end of the job field length. Consequently, the length and upper limit of the memory pool will change with the field length.

The memory pool is organized into blocks which are reserved as needed and are only as large as needed. They may reside anywhere in the memory pool. Table D-1 shows the blocks and their approximate sizes as a function of problem size.

Blocks themselves may have varying internal organization. Generally, the DSA implementation in CONTEMPT4/MOD3 is designed to allow dynamically stored variables to be referenced using meaningful variable names and relatively simple indexing. Even if the indexing is not understood, the source code is readable because dynamic variables are named just like normal FORTRAN variables. Block four, the main block, provides an illustration of the most common block organization. This block is always present and contains compartment quantities. It is called an array-structured block because it can be seen as a 79 x NC array, where NC is the number of compartments. Each row can be considered as a one-dimensional array containing a particular quantity and having a name (e.g., compartment pressure PRT).

While many blocks are array structured, others have more complex organization. Typically, such blocks are divided into subblocks, where each subblock has array-structured organization with different dimensionality.

TABLE D-1. CONTEMPT4/MOD3 DYNAMIC BLOCKS

Block Number	Block	Approximate Size	Reserving Routine
1.0	Water property table	Table size	STHIN
2.0	Input cards	Depends on number of input cards, released after input	INSEQ
3.0	Fan/pump	35 x NFP[a]	FANINP
4.0	Main (compartments)	80 x NC	COMPCD
5.0	Generalized tables	(12 x NGT) + (number of table entries)	GNTBCD
6.0	Single transactions	15 x NST	TRANCD
7.0	Double transactions	13 x NDT	TRANCD
8.0	Intercompartment flow junction	21 x NJN	JCNIN
9.0	Drywell/ice chest flow	MJN x NMF (MJN + 1)	FLODRI
10.0	Time control	7 x NTC	TSTPIN
11.0	Sprays and heat exchangers	(7 x NSPRY) + (6 x NHX) + (number of entries in spray and heat exchanger tables)	SPHXIN
12.0	Mk I/II PSS	(not used in MOD3)	--
13.0	Sumps	(22 x NSUMPS) + (number of additional compartments draining into sumps)	SUMPIN
14.0	Ice conditions	6 x NICE	ICECD
15.0	Mk III PSS	(not used in MOD3)	--
16.0	CONTEMPT heat	42 x NHS	HTIN
17.0	HEAT1 subcode	$<\sum[44 + (13 \times NCOLi)]$	HTIN
18.0	Temporary	(variable)	--
19.0	Temporary	(variable)	--

TABLE D-1. (continued)

Block Number	Block	Approximate Size	Reserving Routine
20.0	Internal/external number tables	12 + (number of items with external numbers)	LDEXNM
21.0	Ice chest doors	16 x NID	ICEDIN
22.0	Minor edit control	8 x NMIN	MINCD
23.0	Fan coolers	7 x NFC	FANCIN

a. Definitions of symbols:

NFP	Fans and pumps
NC	Compartments
NGT	Generalized tables
NST	Single transactions
NDT	Double transactions
NJN	Junctions
MJN	Junctions for drywell/ice chest flow
NMF	Mass flows for drywell/ice chest flow
NTC	Intervals for time control
NSPRY	Spray systems
NHX	Spray heat exchangers
NSUMPS	Sumps
NICE	Ice chests
NHS	Heat structures
NCOLi	Mesh points for heat structure i
NID	Ice chest doors
NMIN	Minor edits
NFC	Fan coolers.

1.2.2 Memory Management

Normally, the user need not be concerned with DSA. An understanding of DSA memory management may be necessary, however, if the problem is too large for the available memory.

Memory is managed by the FTB package from the INEL Environmental Subroutines. FTB maintains a record of which memory in the pool is not being used by reserved blocks. If more memory is requested than is available, the problem cannot continue, and the error message printed will include a display of how memory is allocated among the reserved blocks. The user may then determine how to change the problem to fit the core.

Blocks may be reserved for the length of a problem, or may be temporary, thus allowing the space they occupy to be used for different purposes during successive phases of the calculation. Memory use during a calculation proceeds as follows. First, INP reads the input cards, and they are stored in a block. Then, the water property tables are read and necessary space is reserved. A block is also reserved for the internal-external number table. The input processors are called to process the cards for each problem feature. If needed, each processor reserves a block for that problem feature. Temporary blocks also are made available to some processors for scratch use. At the conclusion of input, all permanent blocks have been reserved, the input cards are copied to disk, and their block is released. Also, the internal-external block is contracted to the size necessary. The maximum storage needed at any time is then determined, and the job field length can be reset. In the initialization and time step calculations, when a module needs temporary storage, it is reserved, then released when the module is finished. Working storage shares storage in a dynamic way the same as the code shares storage because of the overlay scheme.

1.2.3 Debugging

Dynamic storage makes it difficult to locate variables in a core dump. For the program user who wishes to debug effectively but does not desire to read dumps, a series of routines (SNAP subroutines) is included in the code which prints the contents of many blocks in a readable manner. These subroutines are activated by using the debug switches described in Section 4.2.2.1.

1.3 Logical Files

Logical files used by CONTEMPT4/MOD3 are listed below in the order they are declared on the program cards. File names may be substituted by placing a new file name in the proper position on a program execution control card.

For CONTEMPT4, the logical files are

1.	TAPE1	File for plot output, rewound before and after execution by CONTEMPT4/MOD3
2.	TAPE3	Water properties file, rewound before execution
3.	INPUT	File for input data
4.	OUTPUT	File for printed output
5.	TAPE2	Scratch file
6.	TAPE7	File on which the calculation results were written (for restart purpose)
7.	TAPE4	File from which restart data were extracted.

1.4 Internal/External Numbering

A flexible system of numbering data descriptions (e.g., compartment numbers) is incorporated into CONTEMPT4/MOD3, thus allowing the program user to add, change, or delete data from the problem deck with a minimum of effort. This is accomplished by maintaining an indexing scheme for the code (internal numbering) separate from that assigned by the user (external numbering). Input information that must be indexed, such as compartments that are identified by their index number, is divided into categories referred to as problem features. Table D-2 lists the problem features designated by the code. As a general example of external numbering, there may be only one compartment numbered 9, but any other problem feature, such as a junction, may also be numbered 9.

External numbers assigned by the program user in preparing problem data decks need not be sequential. Instead, the code will assign sequential internal numbering during input processing. Tables of external numbers for each of the 13 problem features are maintained as a dynamic block in

TABLE D-2. PROBLEM FEATURES

Problem Feature Number	Problem Feature
1	Compartments
2	Single transactions
3	Double transactions
4	Generalized tables
5	Sumps
6	Intercompartment junctions
7	Spray systems
8	Heat exchangers
9	Heat slabs
10	Ice compartments
11	Fan/pump models
12	Ice chest doors
13	Fan coolers

order to ensure correct sequencing of internal numbers and to detect duplicate external numbers. Major time step edits include both internal and external numbers for most problem features.

1.5 Subroutine Interfacing and Sequencing

The execution of a CONTEMPT4/MOD3 program uses the following sets of routines:

1. The 145 CONTEMPT4/MOD3 input, initialization, time step, and utility routines

2. The STH2O steam table routines

3. The HEAT-1 subcode

4. The INP input processing routine and the FTB dynamic storage allocation and scratch I/O package from the INEL environmental library.

The sequencing and relationship of the CONTEMPT4/MOD3 routines are shown in the following figures. All of these routines are described in the following section. In all cases, the utility routines are not shown. Figure D-2 shows the general program structure of the main program (CT4) and the three principal calculational phases (input, initialization, and time step processors). Figures D-3, D-4, and D-5 show the sequence and calling relationships of the three principal phases.

1.6 Subroutine Descriptions

This section contains a brief description of each CONTEMPT4/MOD3 routine. The routines are arranged alphabetically within each main classification, except for controlling routines which are listed first.

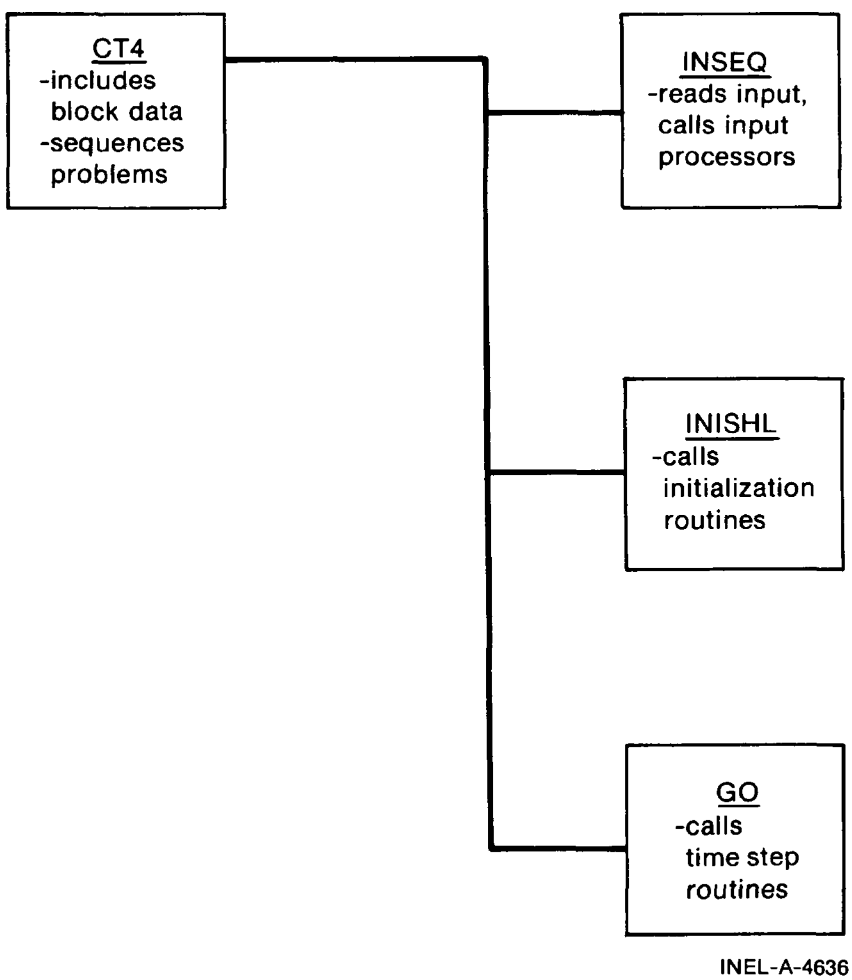

Figure D-2. CONTEMPT4/MOD3 general program structure.

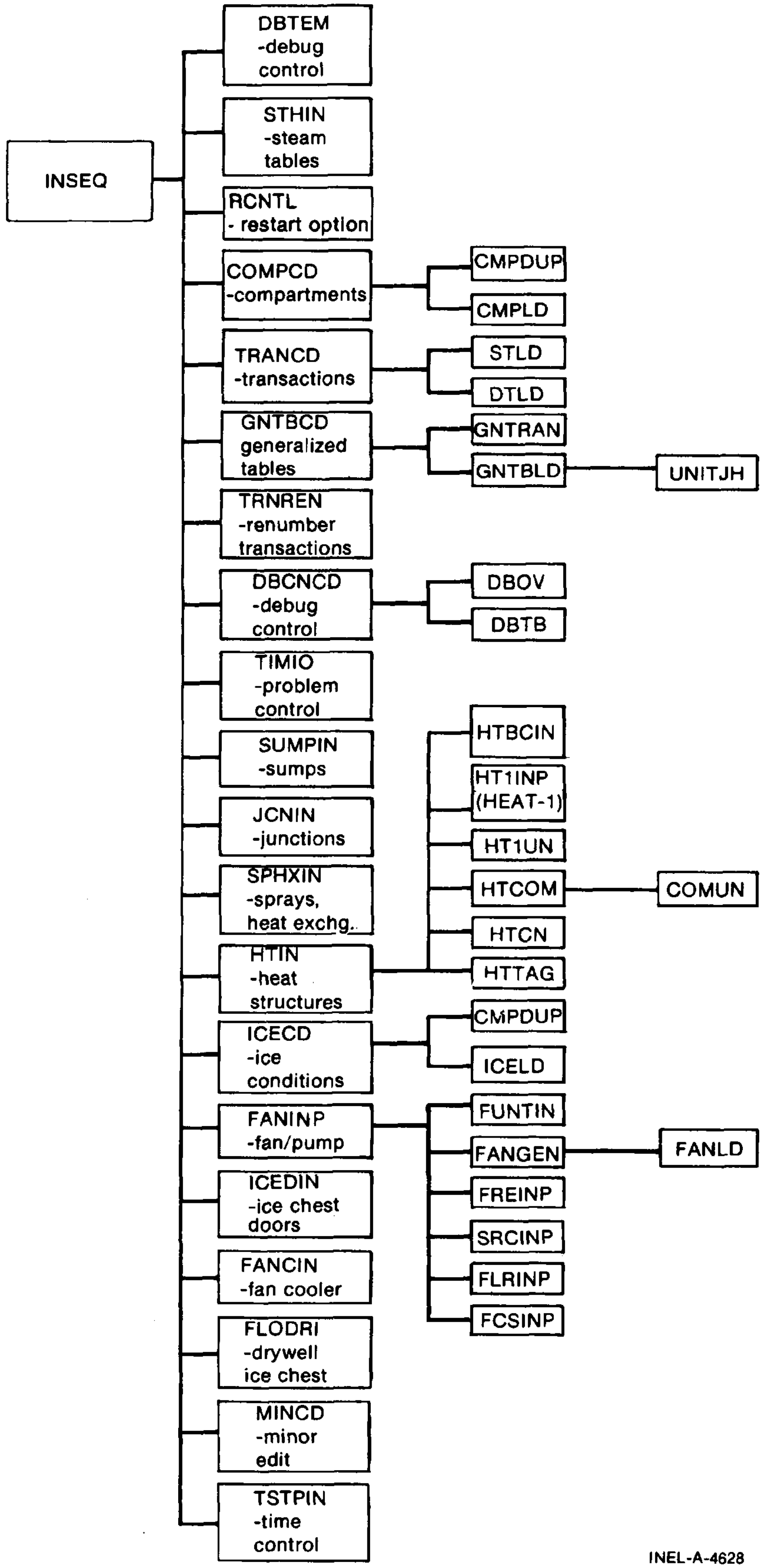

Figure D-3. CONTEMPT4/MOD3 input.

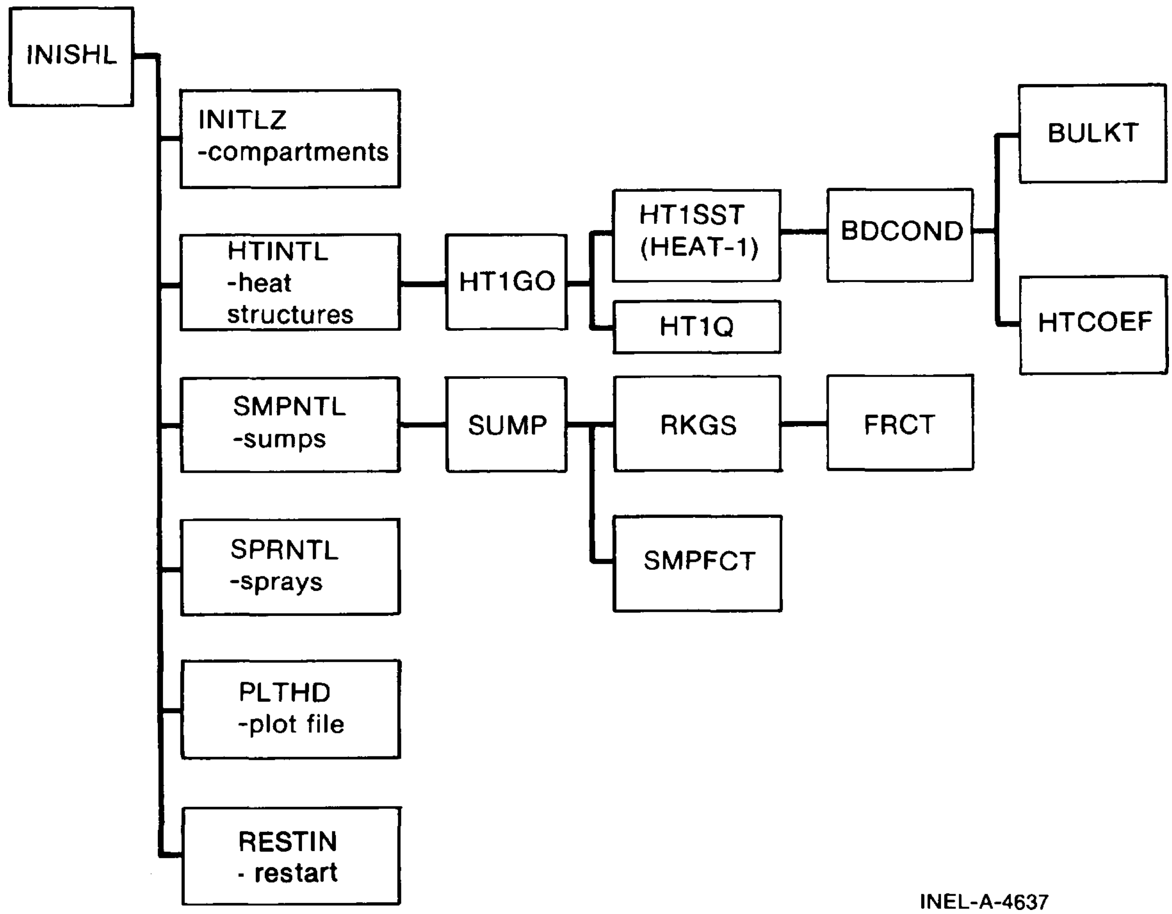

Figure D-4. CONTEMPT4/MOD3 initialization.

MAIN PROGRAM

CT4 Initiates each phase of the calculation

INPUT ROUTINES

INSEQ	Sequences input processing
CMPDUP	Processes compartment and ice initial condition duplication
CMPLD	Loads compartment data
COMPCD	Processes compartment descriptions
COMUN	Processes units card for common heat structure data
DBCNCD	Processes debug control information
DBOV	Removes time-independent switches from debug control array
DBTEM	Processes debug switches for input routines called before DBCNCD
DBTB	Loads debug control table

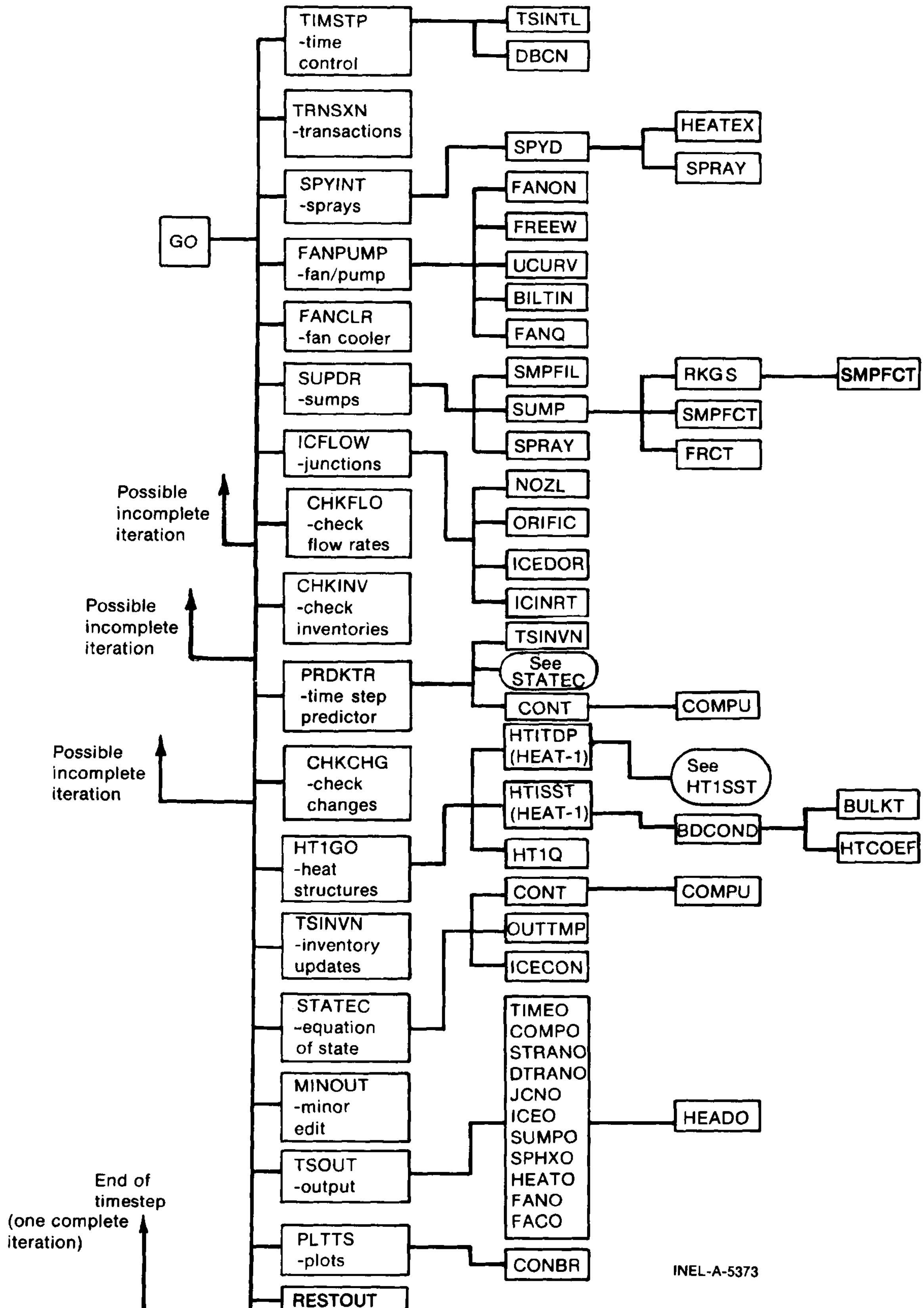

Figure D-5. CONTEMPT4/MOD3 time step sequencing.

DTLD	Loads double transactions
FANCIN	Processes fan cooler data
FANGEN	Processes fan/pump general descriptions
FANINP	Controls fan/pump input processing
FANLD	Loads fan/pump block
FCSINP	Processes fan/pump constant flow and speed control input
FLODRI	Processes drywell/ice chest flow distributions
FLRINP	Processes fan/pump flow rate table number cards
FREINP	Processes freewheeling fan/pump descriptions
FUNTIN	Processes fan/pump units cards
GNTBCD	Controls generalized table input processing
GNTBLD	Loads generalized table block
GNTRAN	Determines mass and energy rates for transaction specifications
HTBCIN	Processes heat structure boundary conditions
HTCN	Processes heat structure connection and miscellaneous data
HTCOM	Loads data common to all heat structures
HTIN	Controls heat structure input processing
HTTAG	Processes Tagami boundary conditions
HT1INP	Input for HEAT-1 subcode (not a CONTEMPT4 subroutine)
HT1UN	Reads units card and converts HEAT-1 block to SI units
ICECD	Processes ice initial conditions
ICEDIN	Processes ice chest door data
ICELD	Loads ice block
JCNIN	Processes intercompartment flow junction data
MINCD	Processes minor edit variables
RCNTL	Processes restart control card
SPHXIN	Processes spray system and heat exchanger input
SRCINP	Processes fan/pump source tables
STHIN	Reads and stores water property data
STLD	Loads single transaction block
SUMPIN	Processes sump data
TIMIO	Processes general control card
TRANCD	Controls transaction input processing
TRNREN	Renumbers transaction generalized tables using internal numbers
TSTPIN	Processes time step and edit control information
UNITJH	Processes units for generalized tables

INITIALIZATION ROUTINES

INISHL	Sequences problem initialization
HTINTL	Performs initial steady-state calculation for heat structures
HT1SST	HEAT-1 steady-state solver (not a CONTEMPT4 subroutine)
INITLZ	Solves equation of state to initialize compartment conditions
PLTHD	Writes header record on plot file
RESTIN	Reads restored data from TAPE4 file
SMPNTL	Initializes sumps using input flow history
SPRNTL	Initializes spray system control

TIME STEP ROUTINES

GO	Sequences time step calculation
BDCOND	Calculates heat structure boundary conditions
BILTIN	Calculates fan/pump flow from functional relations
BULKT	Determines bulk temperatures for BDCOND
CHKCHG	Checks compartment conditions to determine time step size
CHKFLO	Checks junction flow rates for time step reductions
CHKINV	Checks compartment inventories for time step reduction
COMPO	Prints compartment data
COMPU	Solves equation of state in compartments
CONBR	Converts plot information to British units
CONT	Performs compartment liquid-vapor interaction calculations
DBCN	Sets debug control switches each time step
DTRANO	Prints double transaction data
FANCLR	Performs fan cooler calculation
FACD	Prints fan cooler results
FANO	Prints fan/pump results
FANON	Turns fan/pump on or off
FANPMP	Controls fan/pump calculations
FANQ	Updates compartment mass and energy rates due to fan/pump
FRCT	Calculates friction factor for junction model
FREEW	Calculates speed for freewheeling fan/pump
HEADO	Prints heading for output edit
HEATEX	Calculates exit temperature for type one heat exchanger

HEATO	Prints results for heat structures
HTCOEFF	Determines heat transfer coefficients for BDCOND
HT1GO	Controls heat structure calculations
HT1Q	Updates mass and energy rates to include effect of heat transfer
HT1SST	HEAT-1 steady-state solver (not a CONTEMPT4 subroutine)
HT1TDP	HEAT-1 transient solver (not a CONTEMPT4 subroutine)
ICECON	Performs mass and energy balance for ice compartments
ICEDOR	Performs ice chest door calculation
ICEO	Output for ice condensers
ICFLOW	Performs intercompartment flow calculation
ICINRT	Calculates junction inertance
JCNO	Prints intercompartment flow results
MINOUT	Prints minor edits
NOZL	Calculates nozzle flow
ORIFIC	Calculates orifice flow
OUTTMP	Determines outside air temperature from a table
PLTTS	Writes values from this time step on plot file
PRDKTR	Predictor-corrector calculations for transfer due to heat structures
RESTOUT	Writes restart data onto the local file TAPE7
RKGS	Runge-Kutta solution for differential equation used in sump calculation
SMPFCT	Calculates derivatives for RKGS
SMPFIL	Sums mass and energy entering sumps
SPHXO	Prints spray and heat exchanger output
SPRAY	Calculates mass and energy transfer in each compartment region due to a spray system
SPYD	Performs spray calculation
SPYINT	Calls SPYD and updates compartment mass and energy rates
STATEC	Controls compartment equation-of-state calculation
STRANO	Prints single transaction output
SUMP	Calculates sump flow
SUMPO	Prints sump output
SUPDR	Controls the sump calculation
TIMEO	Prints time information
TIMSTP	Advances time each time step

TRNSXN	Updates mass and energy rates with changes due to transactions
TSINTL	Performs time step initialization
TSINVN	Updates compartment inventory
TSOUT	Sequences time step output routines
UCURV	User-supplied routine for specifying a pump curve

UTILITY ROUTINES

CHRLD	Expands and loads titles
ERR	Processes fatal time step errors, invoking recycling if necessary
ERFIN	Terminates problem processing if an error is detected
FERR	Processes fatal input errors
IEXNUM	Function returning external numbers
ILIQAT	Checks region designator
INTNUM	Function returning internal number
LDEXNUM	Loads and manages internal/external number table
NEER	Processes nonfatal time step error
NFEER	Processes nonfatal input error
SETIND	Initializes memory pool with minus indefinites

(SNAP routines below produce debug printing of specific areas.)

SNAPCH	CONTEMPT4/MOD3 heat block (16)
SNAPCT	Control common
SNAPDT	Double transactions block (7)
SNAPGT	Generalized tables block (5)
SNAPHT	HEAT-1 block (17)
SNAPIC	Ice block (14)
SNAPIS	Integers, skipping
SNAPMB	A main block array
SNAPMD	Matrix name and values in D format
SNAPMG	Main block (4)
SNAPSA	Eight-character alphanumeric data, skipping
SNAPSD	Scalars in double precision
SNAPSI	Scalars in integer format
SNAPSK	Reals, skipping

SNAPST	Single transactions block (6)
SNAPTI	Eight-word titles, skipping
SNAPVD	Vectors in D format
SNAPVI	Vectors in integer format

(End of SNAP routines.)

STH205	Special CONTEMPT4/MOD3 water property routine, returns water properties as a function of pressure and enthalpy
STH2OU	Special CONTEMPT4/MOD3 water property routine, returns saturated properties as a function of internal energy or enthalpy
TBLS	General linear interpolation routine
UNITSI	Processes unit specification and obtains conversion factor for SI.

APPENDIX E

ERROR MESSAGES

APPENDIX E

1. ERROR MESSAGES

This appendix contains a description of all error messages which might be encountered while using CONTEMPT4/MOD3. An error is produced whenever an unrealistic condition is detected either during input processing, initialization, or time step calculations. An error that allows problem execution to continue is referred to as a nonfatal error. An error that terminates problem execution is called a fatal error. As an option on General Control Card 100, the program user can specify that problem execution continue even after a fatal error is detected.

Each error-producing situation in CONTEMPT4/MOD3 is identified by a unique five-digit error number. The first three digits correspond to the Debug Control Subroutine Index listed in Table 6 and identify the subroutine in which the error was detected. The last two digits sequentially number the errors in each subroutine.

Listed in this appendix next to each error number is information about the nature of each error including, in some cases, applicable input description card numbers in parentheses. For example, error number 506 (actually 00506, but leading zeros are not printed) indicates that a negative value for deentrainment rate was incorrectly entered on the Compartment Description Card 4XXX1. The error was detected by Subroutine COMPCD (Debug Control Subroutine Index Number 5).

301	Compartment numbers must be in ascending order (4XXX2)
302	Zero cannot be used as a compartment number (4XXX2)
401	External number previously used for compartment
402	Wrong word for compartment type (4XXX1)
403	Primary compartment type previously used (4XXX1)
404	Drywell compartment type previously used (4XXX1)
405	Wetwell (pool) compartment type previously used (4XXX1)
406	Outside compartment type previously used (4XXX1)
407	Invalid humidity input; defaulted to 0.5 (4XXX1)
408	Pool surface area defaulted to 0.00005 m^{-1} (4XXX1)

409	Ice chest humidity should be 1.0 (4XXX1)
501	Format error (40000)
502	Units conversion error; incorrect units specified (40000)
503	Format error (4XXX0)
504	Format error (4XXX1)
505	Deentrainment rate not entered; defaulted to 1.E12 (4XXX1)
506	Negative dropout factor not allowed (4XXX1)
507	No units for dropout factor (40000)
508	Card 4XXX1 does not end with 1 (4XXX1)
509	Format error (4XXX2)
510	Block 4 reserved for dynamic storage exceeded
601	Format error (1000000)
602	through 608 Units conversion error; incorrect units (1000000)
701	Format error (99II)
722	Invalid debug control subroutine index number (99II)
901	Debug time control table is full (99II)
902	Invalid external number or problem feature (99II)
903	Format error for debug generalized table
904	Format error for debug generalized table
1001	Invalid internal number; check external number (2XX1)
1002	LIQ or ATM must be entered (2XX1)
1003	Invalid internal number; check external number (2XX1)
1004	LIQ or ATM must be entered (2XX1)
1005	Transfer from vapor to liquid region not allowed (2XX1)
1101	Card 90XX1 does not end in 1 (90XX1)
1102	Format error (90XX1)
1301	Invalid external number or problem feature for fan/pump
1302	Invalid external number or problem feature for fan/pump
1303	ICURV must be greater than 0 or equal to -1 (90XX1)
1304	Block 3 reserved for dynamic storage exceeded
1401	Format error (90XX2, 90XX3)
1402	Format error (90XX2, 90XX3)
1403	Invalid conversion factor; check units (90XX2, 90XX3)
1404	Format error (90XX2, 90XX3)
1405	Word one must be SPEED or FLOW (90XX2)
1406	Invalid external number or problem feature for fan/pump

1407	Invalid TIMON or TIMOFF (90XX2)
1408	Invalid external number or problem feature (90XX2)
1409	PONOF must be greater than or equal to 0 (90XX2)
1501	Format error (7000)
1502	Units conversion error; incorrect units specified (7000)
1503	Format error (70000)
1504	Invalid external number (70000)
1505	Format error (7JJII)
1506	Incorrect junction specified (70000, 7JJII)
1507	Invalid junction specified (70000, 7JJII)
1508	Sum of flow fractions must be 1.0 ± 0.0001 (7JJII)
1509	Block 9 reserved for dynamic storage exceeded
1601	Format error (90XX4)
1602	If IFLOW equal to CON, NFLOC must be 0 (90XX4)
1603	If NFLOC not equal to 0, IFLOW must not equal ICON (90XX4)
1604	Invalid external number or problem feature (90XX4)
1605	Invalid external number or problem feature for fan/pump
1606	Fan/pump flow rate table has incorrect dimension
1701	Word five must be either LOCKED or FREE (90XX1)
1702	Format error (90XX5)
1703	Invalid conversion factor; check units (90002)
1801	Format error (90000 - 90003)
1802	Format error (90000 - 90003)
1803	Units conversion error; incorrect units specified (90000 - 90003)
1901	Format error for generalized table
1902	Format error for generalized table
1903	A single and double transaction table both have same table number
1904	Single and double transaction tables must total less than 30
1905	Table missing; incorrect generalized table numbering
1906	Block 5 reserved for dynamic storage exceeded
2001	Format error in a generalized table units field
2002	Zero was not used to delete generalized table unit field
2003	Format error; incomplete unit found in generalized table
2004	Generalized table values must be in increasing value
2101	Error detected by subroutine UNITSI
2102	Error detected by subroutine UNITJH

2103 Error in units field for generalized table

2104 Error in units field for generalized table

2105 Error in units field for generalized table

2106 All calls to a single transaction table must specify same material

2107 If Word 6 is AIR or VAP, Word 2 must be ATM (1XX1)

2108 If material transferred is water, only Case 4 may be used (See Section 4.2.2.3)

2109 If material transferred is AIR, pressure is not used in Case 3 (See Section 4.2.2.3)

2110 Valid pressure not used for transaction Cases 4 and 5 (See Section 4.2.2.3)

2111 Material should be in either the liquid or vapor state

2112 Material should be in either the liquid or vapor state

2113 Units conversion error; incorrect units specified for generalized table

2114 Invalid units field for double transaction generalized table

2115 Atmosphere-to-liquid transfer not allowed for double transaction (2XX1)

2201 Units conversion or format error (1001100)

2202 Format error (1YY1100)

2203 Incorrect value for ISHL (1YY1100)

2204 Invalid Card 1001100 with Option 0 or improper bulk temperature option (1YY1100)

2205 Units conversion error; incorrect units specified (1YY1100)

2206 Format error (1YY1110)

2207 Units conversion error; incorrect units specified (1YY1110)

2208 Invalid external number for time-dependent heat transfer coefficient generalized table

2209 Time-dependent heat transfer coefficient generalized table data not multiple of two

2210 Heat transfer coefficient generalized table number outside range, $0 < XXX < 1000$ (1YY1100)

2211 Generalized table number XXX for option ±1XXX previously used (1YY1100)

2212 Incorrect format used in generalized table XXX (1YY1100)

2213 Tagami and radiation options cannot be used for same structure (1YY1100)

2214 Options 51, 52, and 53 cannot follow Tagami Option (1YY1100)

2215 Tagami volume term must be positive (1YY1100)

2216 Units conversion error for Word 5 (1YY1100)

2217 Incorrect Tagami correlation input (1YY1100, 10005II)

2301 Format error (1YY0000)

2302 Format error (1YY0002)

2303 ISTART must be either zero or one (1YY0002)

2304 Units conversion error; incorrect units specified (1YY0002)

2305 If IGEOM equals three, Word 4 on 1YY0002 must be NONE (1YY0001)

2306 Invalid left compartment number, NCMPHL (1YY0002)

2307 Invalid right compartment number, NCMPHR (1YY0002)

2308 Invalid heat source multiplier generalized table, IPWRTB (1YY0002)

2401 Format error (1000000)

2402 Format error (10001II)

2403 Values must be entered in pairs (10001II)

2404 Format error (10002II)

2405 Values must be entered in pairs (10003II)

2406 Values must be entered in pairs (10004II)

2501 Block 16 reserved for dynamic storage is exceeded

2502 Error detected by subroutine HT1INP

2601 Format error (1000001)

2602 Units conversion error; incorrect units specified (1000001)

2701 Format error (60000)

2702 Units conversion error; incorrect units specified (60000)

2703 Card 6XXX1 does not end with 1

2704 Format error on ice initial conditions card (6XXX1)

2705 Format error on ice duplication card (6XXX2)

2706 Ice compartment does not have initial conditions

2707 Ice performance table has incorrect table number

2708 Ice performance table has incorrect units specified

2801 Invalid external number or problem feature (6XXX1)

2802 Compartment XXX is not an ice chest (6XXX1)

2803 Invalid external number for ice performance generalized table

2804 Block 14 reserved for dynamic storage is exceeded

2901 Format error (8000)
2902 Units conversion error; incorrect units specified (8000)
2903 Format error (8XXX)
2904 Both Word 3 on Card 8000 and Word 10 on Card 8XXX must be entered
2905 Junction geometric inertia may not be negative (8XXX)
2906 Both Word 10 on Card 8XXX and Word 3 on Card 8000 must be entered
2907 Invalid left or right compartment number (8XXX)
2908 AJNL and AJNR must be less than or equal to one (8XXX)
2909 Block 8 reserved for dynamic storage is exceeded
2910 Block 8 reserved for dynamic storage is exceeded
3001 Format error (800000)
3002 Units conversion error; incorrect units specified (800000)
3003 Format error (80XX00)
3004 Incorrect number of entries (80XX00)
3005 Invalid external number or problem feature (80XX00)
3006 PRSPOF must be less than or equal to PRSPON (80XX00)
3007 Format error (80XXII)
3008 Incorrect number of entries (80XXII)
3009 First time-value must be zero (80XXII)
3010 Spray table has no spray system (80XXII, 80XX00)
3011 No spray table for spray system (80XXII, 80XX00)
3012 Format error (8500WW)
3013 Incorrect number of entries (8500WW)
3014 Type 5 is not allowed on coupled heat exchanger (8500WW)
3015 Format error (85WWII)
3016 No Type 5 heat exchanger for table (85WWII, 8500WW)
3017 No Type 5 heat exchanger specified for table (85WWII)
3018 Incorrect number of entries (85WWII)
3019 First time-value must be zero (85WWII)
3020 Invalid external number or problem feature (85WWII)
3021 No table for Type 5 heat exchanger (85WWII)
3022 Block 11 reserved for dynamic storage is exceeded
3101 Format error (90XX6)
3102 Format error (90XX7)
3103 Invalid conversion factor; incorrect units specified (90XX6)
3104 Must be either three or seven words per card (90XX6, 90XX7)

3105 If seven words on Card 90XX6, Word 1 must be FAN (90XX1)
3106 If three words on Card 90XX6, Word 1 must be PUMP (90XX1)
3201 Block 1 reserved for dynamic storage is exceeded
3301 Invalid external number or problem feature (1XX1)
3302 Word 2 must be ATM or LIQ (1XX1)
3303 Invalid entry made for GSTMAT (1XX1)
3401 Format error (6000)
3402 Units conversion error; incorrect units specified (6000)
3403 Format error (6XXI)
3404 Sump cross-sectional area must be greater than zero (6XXI)
3405 Invalid external number or problem feature on sump table
3406 Sump table values must be in multiples of three
3407 Invalid compartment number (6XXI, 6XX8)
3408 Both Word 14 and Word 15 must be entered (6XXI)
3409 Spray efficiency for sump not within correct limits (6XXI)
3410 No more than 30 drain compartments per sump (6XX8)
3411 Format error (6XX8)
3412 Invalid sump number XX (6XX8)
3413 Invalid compartment drains into sump (6XX8)
3414 Inlet compartment cannot be entered twice (6XXI, 6XX8)
3415 Block 13 reserved for dynamic storage is exceeded
3416 Dynamic storage exceeded; Block 13 deleted improperly
3501 Format error (100)
3502 Units conversion error; incorrect units specified (100)
3503 Outside air compartment missing or generalized table incorrect (100)
3601 Invalid card number or format error (1XX0, 1XX1)
3602 Format error (1XX1)
3603 Format error (1XX0, 1XX1)
3604 Block 6 or 7 reserved for dynamic storage is exceeded
3605 Cards must end with 1 (1XX1, 2XX1)
3701 External card numbers must be greater than zero
3702 External card numbers must be greater than zero
3801 Format error (9000)
3802 Units conversion error; incorrect units specified (9000)
3803 Format error (90II)
3804 Number of values must be a multiple of six (90II)

3805 NPLT may not be -1 for the first set (90II)

3806 Each value of TCE must be greater than the previous TCE (90II)

3807 Last value of TCE must be greater than TEND (100, 90II)

3808 Time step length must be greater than zero (90II)

3809 Block 10 reserved for dynamic storage is exceeded

3810 Time step control switch incorrectly set (90II)

4201 Ice volume exceeds compartment volume (4XXX1)

4202 Ice and liquid volume exceeds compartment volume (4XXX1)

4203 Liquid region volume may not be negative (4XXX1)

4204 Temperature not in saturated range (4XXX1)

4205 Temperature not in saturated range (4XXX1)

4206 Properties not in liquid or vapor state (4XXX1)

4207 Pressure not in saturated range (4XXX1)

4208 Pressure not in saturated range (4XXX1)

4401 Liquid volume may not exceed compartment volume

4402 Liquid volume may not exceed compartment volume

4403 Atmosphere volume may not be negative

4404 Atmosphere volume may not be negative

4501 Available scratch block too small for subroutine GO

4502 Iteration limit, ITLIM, must be greater than zero (100)

4503 Available scratch block too small for subroutine GO

4504 Minimum time step size for this interval is too large (90II)

4505 Time step size for this interval (90II)

5201 Error detected by TBLS; vapor temperature above 277°C

5202 Error detected by subroutine COMPU

5203 Specific energy not in saturated range

5204 Pressure not in saturated range

5205 Pressure not in saturated range

5206 Temperature not in saturated range

5701 Dependent variable outside FAN/PUMP generalized table range

6401 Error in Uchida table used in subroutine TCOEF

6402 Error in time versus heat transfer coefficient table (1003II)

6403 Error in bulk temperature versus heat transfer coefficient table (1004II)

6404 Error in time-dependent heat transfer coefficient table (10003II)

6501 Error in heat source multiplier table (1XXXII)

6502 ISTART must be either zero or one (1YY0002)

6503 Error detected by HT1SST

6504 Error detected by HT1TDP

6701 Same compartment specified for inlet and exit (8XXX)

6702 Error in ice performance generalized table

6703 Temperature not in the saturated range

6704 Same compartment specified for inlet and outlet (8XXX)

6705 Each junction must have left and right compartment (8XXX)

6706 Ice melt rate (DMFIS) negative

6707 Pool volume greater than total compartment volume (4XXX1)

6901 Compartment atmosphere volume must be greater than zero

6902 Convergent solution to nozzle flow rate not found

6903 Nozzle outlet pressure greater than inlet pressure

6904 Orifice flow rate not found due to inconsistent data

7301 Error in outside air temperature table

7401 Available scratch block too small for subroutine PLTTS

7501 Available scratch block too small for subroutine PRDKTR

7502 Error in subroutine CONT detected by subroutine PRDKTR

7801 Invalid inlet compartment number, NSUCIN (6XXI)

7802 Neither ALG nor SUA may be zero (4XXX1, 6XXI)

8101 Error in spray table (80XXII)

8102 Spray water temperature not in saturated range

8103 Incomplete blowdown--spraying water into primary system

8301 No ambiguous junction type selected (8XXX)

8302 Error in subroutine CONT detected by subroutine STATEC

8501 Sump mass flow rate from sump to pipe less than zero

8701 Sump driving pressure, SUDP, less than zero

8702 Specific enthalpy for sump water in saturated range

8703 Water mass in sump, SUMASS, less than zero

8901 Last value of TCE must be greater than TEND (90II)

9201 Total compartment mass, TMT, is less than zero

9202 Total compartment energy, UTT, is less than zero

9401 Excessive time step reductions

10201 Invalid problem feature

10202 Available scratch block too small

10203 External numbers of each problem feature must be in increasing order

12601 Format error (91II)

12602 Invalid variable selected for editing

12603 Invalid external number or problem feature (91II)

12604 Block 22 reserved for dynamic storage is exceeded

12801 Format error (81000)

12802 Format error (81XXX)

12803 Ice door is not orifice opening (81XXX, 8XXX)

12804 Ice performance generalized table has wrong number of variables

12805 Reserve storage Block 21 too small

12901 Error in ice chest door generalized table

13101 Format error (91XXX)

13102 Units conversion error; incorrect units specified (91XXX)

13103 ON must be less than TFCOFF (91XXX)

13104 TFCON must be less than TEND (91XXX)

13105 FAC must be between 0.0 and 1.0 inclusive (91XXX)

13106 Block 23 reserved for dynamic storage exceeded

13107 Invalid units for time or temperature (91XXX)

13201 Pressure not in the saturated range

13202 Atmosphere temperature of compartment outside fan cooler generalized table range

13203 Fan cooler compartment number must be greater than zero (91XXX)

13204 Fan cooler generalized table number must be greater than zero (91XXX)

13301 Format error (10005II)

13302 Invalid conversion factor; incorrect units specified (10005II)

13303 Time-to-pressure must be greater than zero (10005II)

13304 No single transaction tables specified by problem (10005II)

13305 Tagami time-to-pressure and blowdown table are inconsistent (10005II)

13306 Error message returned to subroutine HTTAG from table call.

APPENDIX F

PLOTCT4 PLOTTING PROGRAM

APPENDIX F

1. PLOTCT4 PLOTTING PROGRAM

This appendix discusses the implementation of the PLOTCT4 plotting program for plotting values of variables calculated by the CONTEMPT4/MOD3 computer program. PLOTCT4 program summary description, input requirements, and examples of plotted data are included in this appendix. This appendix provides the program user with sufficient information to correctly execute PLOTCT4.

1.1 PLOTCT4 Program Summary Description

PLOTCT4 is a digital computer program, written in FORTRAN IV, developed at the Idaho National Engineering Laboratory (INEL) to plot output variables from the CONTEMPT4/MOD3 multicompartment containment system analysis program. The PLOTCT4 program processes data from the CONTEMPT4/MOD3 plot tape in conjunction with user-specified plotting requests to produce graphs of selected variables. Options are available for the user to specify linear or logarithmic scales, axis labels, scale factors, range of variables, multiple ordinates, parameter-versus-time or parameter-versus-parameter plots, overlay plots, and difference plots. The program generates microfilm or Calcomp plots.

1.2 Input Data Requirements

All necessary information to prepare a plot request data deck for use with PLOTCT4 is contained in this section. The PLOTCT4 plot request cards normally follow the CONTEMPT4/MOD3 input data cards.

1.2.1 General Considerations

Two types of data are input into the PLOTCT4 program: data residing on magnetic tape, and card input data. The input data tape is the plot tape created by CONTEMPT4/MOD3. The order of the logical files used by PLOTCT4 is listed in Appendix D, Section 3.

PLOTCT4 has a highly user-oriented card input processing scheme. The data are input in free format with many entries having default values that make it as simple as putting three entries on a single card for each plot desired. Great flexibility is also provided to the user through many output options. Descriptions of the card input are given below.

1.2.2 Data Card Summary

PLOTCT4 card input consists of a title card (optional), comment cards (optional), plot request cards, and a terminator card. A listing of the cards is printed at the beginning of each problem. The order of the title, data, and comment cards is unimportant. If duplicate title or data cards are encountered, the last title card and the last data card will be used. Data may be carried over to successive problems in a problem set. Thus, only the data that are changed must be entered. When a card format error is detected, a line is printed containing a dollar sign ($) located under the character causing the error and a comment giving the card column of the error. An error comment is produced such that input processing continues when the program attempts to process the erroneous data. The PLOTCT4 program skips to the next plot request if input errors are encountered.

1.2.2.1 Title Card. A title card is optional for each PLOTCT4 data deck. A title card is identified by an equal sign (=) as the first nonblank character. The CONTEMPT4/MOD3 problem that generated the data supplies the title which appears on all plots. The PLOTCT4 title card is used only for user identification of the plot data deck.

1.2.2.2 Comment Cards. An asterisk (*) or a dollar sign ($) appearing as the first nonblank character identifies the card as a comment card. Any information may be entered on the remainder of the card. Blank cards are treated as comment cards. There is no processing of comment cards other than printing them. Comment cards may be placed anywhere in the input deck.

1.2.2.3 Terminator Card. The input data for PLOTCT4 problems are separated by slash cards; the final problem is terminated by a period card instead of a slash card. The period card also serves as the separator between problem sets. The slash and period cards have a (/) and (.), respectively, as the first nonblank characters.

When a slash card is used as a problem terminator, the list of card numbers and associated data used in the problem are passed to the next problem. Cards entered for the next problem are added to the passed list or act as replacement cards, depending on the card number. The resulting input is the same as if all previous slash cards were removed from the input to the problem set.

When a period card is used as a terminator, input from all previous cards is erased before the input to the next problem is processed. A final terminator is not necessary since the system senses the end of the input data file. Thus, single problems may be run without an explicit terminator.

1.2.2.4 General Considerations for Plot Request Cards. Plot request cards allow the program user to select the variables to be plotted and the plotting format. This section discusses, in general terms, the types of data acceptable for data cards, and the following section delineates the specific format of plot request cards.

The data cards contain a varying number of fields which may be integer, floating point, or alphanumeric. Blanks preceding and following fields are ignored. The first field on a data card is a card number which must be an unsigned integer. If the first field has an error or is not an integer, an error flag is set. Consequently, data on the card are not used, and the card will be identified by the card sequence number in the list of unused data cards. After each card number and the accompanying data are converted, the card number is compared to previously entered card numbers. If a matching card number is found, the data entered on the previous card are replaced by the data of the current card. If the card being processed contains only a card number, the data entered on the previous card are deleted. If a card causes replacement or deletion of data, a statement is printed indicating the card is a replacement card.

Comment information may be made to follow the data fields on any data card by initiating the comments with an asterisk or dollar sign.

A number field is started by a digit (0 through 9), a sign (+ or -), or a decimal point (.). A comma or a blank (with one exception to be noted) terminates the number field. The number field has a number part and, optionally, an exponent part. A number field without a decimal point or an exponent is an integer field; a number field with either a decimal point, an exponent, or both is a floating-point field. A floating-point field without a decimal is assumed to have a decimal point in front of the first digit. The exponent denotes the power of ten to be applied to the number part of the field. The exponent part is a sign, an E or D, and a sign followed by a number giving the power of ten. These rules for floating-point numbers are identical to those for entering data in FORTRAN E or F formatted fields except that no blanks (with one exception) are allowed between characters. Floating-point data punched by FORTRAN programs have a blank, treated as a plus sign, following an E or D denoting an exponent. Acceptable ways of entering floating-point numbers are illustrated by the following six fields, all containing the quantity 12.45:

12.45, +12.45, 1245E2 1.245+1, 1.245E1 1.245E+1

A field starting with a letter is an alphanumeric field. The field is terminated by a comma, a blank, or the end of the card. All characters except commas and blanks are allowed.

1.2.2.5 Plot Request Cards 900XXY. The eight fields, or words, on a plot request card control the variables plotted and the plotting format. The fields on a data card are denoted by W1, W2, W3 . . . and may not be omitted unless specifically noted or if default values are desired. The type of data required for each field is denoted by A, R, or I for alphanumeric, real, or integer, respectively. Blanks preceding and following fields are ignored. The various fields, or words, are independent of column number, but are ordered with respect to one another. The order of the fields on all plot request cards (from left to right on a card) is shown below:

W1-I	Sequence number
W2-A	Variable name
W3-I	Variable index
W4-A	Coordinate modification flag
W5-R	Scale factor
W6-R	Variable minimum
W7-R	Variable maximum
W8-A	Axis label.

The first three words (sequence number, variable name, and variable index) are required for each plot. The remaining five words have default values which will be discussed later and need not be entered. If any of the five optional words are set, every word preceding that word must be set also. The integer zero may be used to space over positions where the default values are desired. The content of each of the eight fields is discussed below.

1.2.2.5.1 Sequence Numbers--This word has no default value. The type of data required is integer. The sequence number is an integer of the form 900XXY. Index XX may be any integer from 1 to 99 inclusive. Index Y is always zero, except when used to indicate continuation of data from a previous card. Cards with the same sequence number are treated as replacement cards; the data on the previous cards with that number are replaced by the data on the current card. Plot request cards may be arranged in any order, with one exception: Data cards requesting overlay (multiparameter) plots must have sequence numbers in ascending order. The data cards are processed sequentially by PLOTCT4.

1.2.2.5.2 Variable Name--This field has no default value. The type of data required is alphanumeric. The variable name corresponds to the variable to be plotted. Table F-1 lists variables which may be plotted, and output units. Only those variables which appear in Table F-1 may be plotted.

1.2.2.5.3 Variable Index--This word has no default value. The type of data required is integer. This word corresponds to the external

TABLE F-1. LIST OF PLOTTED VARIABLES

Variable Name	Meaning	Units British	Units SI
The following variables pertain to individual compartments.			
TMT	Mass of air plus water	lb	kg
AMT	Mass of air	lb	kg
WMT	Mass of water	lb	kg
UTT	Energy of air plus water	Btu	J
The following variables pertain to the atmosphere region of individual compartments.			
TG	Temperature	°F	K
PRT	Total pressure	psia	Pa
PRA	Air partial pressure	psia	Pa
PRV	Water vapor partial pressure	psia	Pa
UTG	Total energy	Btu	J
TMG	Total mass	lb	kg
AMG	Mass of air	lb	kg
WMG	Mass of water	lb	kg
WMGV	Mass of water vapor	lb	kg
WMGL	Mass of liquid water	lb	kg
The following variables pertain to the pool region of individual compartments.			
TP	Temperature	°F	K
WMP	Mass of water	lb	kg
AMP	Mass of air	lb	kg
UTPA	Energy of air	Btu	J
UTP	Energy of water plus air	Btu	J
ELW	Surface elevation	ft	m
PRTP	Pressure at bottom floor of pool	psia	Pa
The following variables pertain to individual junctions.			
DMJ	Total mass flow rate	lb/hr	kg/s
DMJA	Air mass flow rate	lb/hr	kg/s
DMJV	Water mass flow rate	lb/hr	kg/s
QJ	Total energy flow rate	Btu/hr	W
DPJC	Pressure difference across junction	psi	Pa
The following variables pertain to individual ice chests.			
DMPI	Mass rate of ice melt	lb/hr	kg/s
QPI	Energy transfer rate due to ice melt	Btu/hr	W
TMI	Mass of ice	lb	kg

TABLE F-1. (continued)

Variable Name	Meaning	Units British	Units SI
The following variables pertain to all ice chests as a whole.			
TDMI	Mass rate of ice melt	lb/hr	kg/s
TQPI	Energy transfer rate due to ice melt	Btu/hr	W
TIMI	Mass of ice	lb	kg
The following variables pertain to individual heat structures.			
BTSL	Left side temperature	°F	K
BTSR	Right side temperature	°F	K
BTCL	Structure centerline temperature	°F	K
BTAV	Structure average temperature	°F	K
CHTL	Left side heat transfer coefficient	Btu/hr-ft^2-°F	W/m^2•K
CHTR	Right side heat transfer coefficient	Btu/hr-ft^2-°F	W/m^2•K
QHL	Left side energy transfer rate	Btu/hr	W
QHR	Right side energy transfer rate	Btu/hr	W
SQSL	Time-integrated heated transfer through left side	Btu	J
SQSR	Time-integrated heat transfer through right side	Btu	J
SUHS	Energy stored in structure (relative to start of problem)	Btu	J
The following variables pertain to individual BWR pressure suppression system vents.			
ELVA	Vent (or annulus) surface level	ft	m
VDMT	Vent total mass flow rate	lb/hr	kg/s
VDMA	Vent air mass flow rate	lb/hr	kg/s
VQT	Vent total energy flow rate	Btu/hr	W
The following variables pertain to the entire BWR pressure suppression system.			
DMTT	Total mass flow rate	lb/hr	kg/s
DMAT	Air mass flow rate	lb/hr	kg/s
DMWT	Water mass flow rate	lb/hr	kg/s
QTT	Total energy flow rate	Btu/hr	W
The following variables pertain to miscellaneous quantities.			
T	Time	s	s
DMST	Mass flow rate for each single transaction	lb/hr	kg/s
QST	Energy flow rate for each single transaction	Btu/hr	W
SUWX	Surface level of each sump	ft	m

TABLE F-1. (continued)

Variable Name	Meaning	Units British	Units SI
The following variables pertain to miscellaneous quantities (continued).			
DMFP	Mass flow rate for each fan or pump	lb/hr	kg/s
QFP	Energy flow rate for each fan or pump	Btu/hr	W
THET	Ice chest door opening angle	degrees	rad
AJNN	Ice chest door junction flow area	ft^2	m^2

number of the variable to be plotted. For a plot of pressure in Compartment 2, this index would equal 2. Zero is entered for the variable index when the variable name involves a collection, sum, or time. See Section 4.2.1.5 for further information about external numbering.

1.2.2.5.4 Coordinate Modification Flag--The default value for this entry provides linear scale plots with time as the x-axis variable and the selected variable as the y-axis variable. The type of data required is alphanumeric, and provides several variations to the default option. Each of the following paragraphs deals with one of the following functions of this field: logarithmic plotting, difference plotting, and parameter-versus-parameter plotting. The selection of more than one of these options for use on a single plot (e.g., log-log scaling of a parameter-versus-parameter plot) always necessitates the use of multiple cards. Refer to the sample problem for an example of how this field is used.

If the letter "L" is entered for this word, logarithmic scaling will be provided on the specified axis of the plot. Logarithmic plotting can be obtained on each axis by using multiple cards.

A difference plot may be generated by entering the letter "D" for this word. The difference between the dependent variable on this card (Word 2) and the dependent variable on the preceding card (next lowest sequence number) will be plotted. To use this feature, the user must provide an overlay option card (see paragraph 2.2.6.2) with the number of plots equal to two. PLOTCT4 performs no units compatibility check when preparing difference plots.

The default option for the x-axis plots time as the x-axis variable. Word 4 can be used to produce plots of one variable versus another, such as pressure versus temperature. This entry specifies which variable will be plotted on the x-axis. If the letter "X" is entered (Word 4), then the named variable (Word 2) is represented by the x-axis. In this case, the next four words on this card (Words 5 through 8) apply to the x-axis instead of the y-axis. The latest abscissa specification will be continued for subsequent plots (larger sequence numbers). That is, subsequent plots will be parameter-versus-parameter plots with the x-axis determined by the latest card that had "X" as Word 4. To revert the x-axis to the default time scale, the user must include a data request card with "T" for Word 2 and "X" for Word 4.

1.2.2.5.5 Scale Factor--The default value for this field is 1.0. The type of data required is real. The number entered for this word will be used as a multiplier for all the specified variable values on a plot, including variable minimum and maximum values. A zero entry in this field is treated as 1.0 and makes a convenient request for default. This factor applies to the y-axis unless the x-axis has been designated by the letter "X" in Word 4.

1.2.2.5.6 Variable Minimum--The default value for this word allows automatic scaling, and is the minimum value of the plotted variable. The type of data required is real. This word may be used to specify the axis minimum. Words 4 and 5 above determine whether the variable minimum applies to the x-axis or the y-axis.

1.2.2.5.7 Variable Maximum--The default value for this word allows automatic scaling, and is the maximum value of the plotted variable. The type of data required is real. This word may be used to specify the axis maximum. Words 4 and 5 above determine whether the variable maximum applies to the x-axis or the y-axis.

1.2.2.5.8 Axis Label--The default values for this word are the axis labels shown in Table F-2. The type of data required is alphanumeric.

TABLE F-2. LIST OF PLOTTED VARIABLE LABELS

Variable Name	Label
TMT	Mass of air + water--Compartment #I
AMT	Mass of air--Compartment #I
WMT	Mass of water--Compartment #I
UTT	Energy of air + water--Compartment #I
TG	Atmosphere temperature--Compartment #I
PRT	Atmosphere total pressure--Compartment #I
PRA	Air partial pressure--Compartment #I
PRV	Water vapor partial pressure--Compartment #I
UTG	Atmosphere total energy--Compartment #I
TMG	Atmosphere total mass--Compartment #I
AMG	Atmosphere air mass--Compartment #I
WMG	Atmosphere water mass--Compartment #I
WMGV	Atmosphere water vapor mass--Compartment #I
WMGL	Atmosphere liquid water mass--Compartment #I
TP	Pool temperature--Compartment #I
WMP	Pool water mass--Compartment #I
AMP	Pool air mass--Compartment #I
UTPA	Pool air energy--Compartment #I
UTP	Pool air + water energy--Compartment #I
ELW	Pool surface elevation--Compartment #I
PRTP	Pool surface pressure at bottom--Compartment #I
DMJ	Total mass flow rate--Junction #I
DMJA	Air mass flow rate--Junction #I
DMJV	Water mass flow rate--Junction #I
QJ	Energy flow rate--Junction #I
DPJC	Pressure difference across--Junction #I
DMPI	Mass rate ice melt--Chest #I
QPI	Energy transfer of ice melt--Chest #I
TMI	Ice mass--Chest #I
TDMI	Total mass rate ice melt
TQPI	Total energy transfer of ice melt
TIMI	Total ice mass
BTSL	Left side temperature--Structure #I
BTSR	Right side temperature--Structure #I
BTCL	Centerline temperature--Structure #I
BTAV	Average temperature--Structure #I
CHTL	Left side heat transfer coefficient--Structure #I
CHTR	Right side heat transfer coefficient--Structure #I
QHL	Left side energy transfer rate--Structure #I
QHR	Right side energy transfer rate--Structure #I
SQSL	Integrated heat transfer, left side--Structure #I
SQSR	Integrated heat transfer, right side--Structure #I

TABLE F-2. (continued)

Variable Name	Label
SUHS	Stored energy--Structure #I
T	Time
DMST	Mass flow rate--Transaction #I
QST	Energy flow rate--Transaction #I
SUWX	Surface level--Sump #I
DMFP	Mass flow rate--Fan/pump #I
QFP	Energy flow rate--Fan/pump #I
DMTT	PSS total mass flow rate
DMAT	PSS air mass flow rate
DMWT	PSS water mass flow rate
QTT	PSS total energy flow rate
ELVA	PSS vent/annulus surface level--Vent #I, or Annulus
VDMT	Total mass flow rate--Vent #I
VDMA	Air mass flow rate--Vent #I
VQT	Total energy flow rate--Vent #I
THET	Ice door opening--Junction #I
AJNN	Ice door area--Junction #I

A label supplied by the user should be enclosed by apostrophes (single quotation marks). Words 4 and 5 above determine whether the variable maximum applies to the x-axis or the y-axis.

1.2.2.6 Plot Control Cards. There are two special plot control cards that communicate control information to PLOTCT4. Both cards are optional.

1.2.2.6.1 Plot Type Indicator Card--This card determines whether the plots are microfilm, Calcomp, or both. The default, if this card is omitted, is microfilm.

The format of this card is similar to the plot request cards, but only the first three fields are used--sequence number, variable name, and variable index. The sequence number is defined above (see 2.2.5.1). The alphanumeric quantity "PL" is entered for the variable name. Three choices for variable index are allowed depending on the type of plots desired: (a) 0 for both microfilm and Calcomp, (b) 1 for microfilm only, and (c) 2 for Calcomp only.

1.2.2.6.2 Overlay Option Card--This card is used to obtain plots of more than one dependent variable against a given independent variable. The default, if this card is not used, is plots of one variable versus another (usually time).

The format of this card is similar to the plot request cards, but only the first three fields are used: sequence number, variable name, and variable index. The sequence number is defined above with the stipulation that data cards for overlaid plots have sequence numbers in ascending order. The alphanumeric quantity "OV" is entered for the variable name. The third field, variable index, is the number of plots to be overlaid on the y-axis.

1.2.2.7 Plot Debug Control Card. Each of the individual plotting routines in PLOTCT4 has a switch for controlling debug printout. This card provides debug output for selected plotting routines. If this card is omitted, no debug printout will occur. Plot debug edits are intended for use by code developers and are not recommended for casual analysis purposes.

The Plot Debug Control Card has a variable field format. The first word is always the sequence number 901000. The remaining fields are integer values of the system switch numbers for the plotting routines as listed in Table F-3. Any number of plotting routine debug switches may be set. A debug edit of all plotting routines will be performed if -1 is input following the sequence number.

1.3 PLOTCT4 Sample Problem

This section contains a PLOTCT4 sample problem which generated plots from data supplied by the CONTEMPT4/MOD3 containment analysis program. The correct format to use when creating a PLOTCT4 data deck and representative sample plots is shown in Figures F-1 through F-5.

The CONTEMPT4/MOD3 problem input used to generate the variable values stored on magnetic tape for use by PLOTCT4 is omitted. An input listing for the PLOTCT4 plotting requests is shown in Table F-4. The comment cards for the PLOTCT4 sample problem listing describe the options selected for the corresponding plots.

TABLE F-3. DEBUG CONTROL INDEX FOR PLOTCT4 ROUTINES

Switch	Routine Controlled	Function of Routine
1	PLOTCT4	Main driver
2	AXIS	Linear axis for Calcomp
3	BUFOUT	Duplicates IBM BUFIO routines (CDC only)
4	COUNT	Counts string length of titles
5	GRAFG	Sets limits and calls plot routines for microfilm
6	INTCON	Converts integers to EBCDIC (IBM only)
7	INTNUM	Returns problem internal number given external number
8	LAXIS	Log axis for Calcomp
9	PAGE	Prints page heading
10	PLOTMC	Calls the plot routines
11	PLOTR	Retrieves plot data from disk
12	PSCALE	Scales the plot data
13	REQST	Processes the plot requests
14	SETUP	Buffers in header record
15	SHFT	Left justifies titles
16	TAPER	Buffers in plot records and stores on disk files
17	XPLOT	Plots curves on Calcomp
18	XPLOTA	Writes out axis on Calcomp
-1	This switch provides debug printout of all PLOTCT4 routines.	

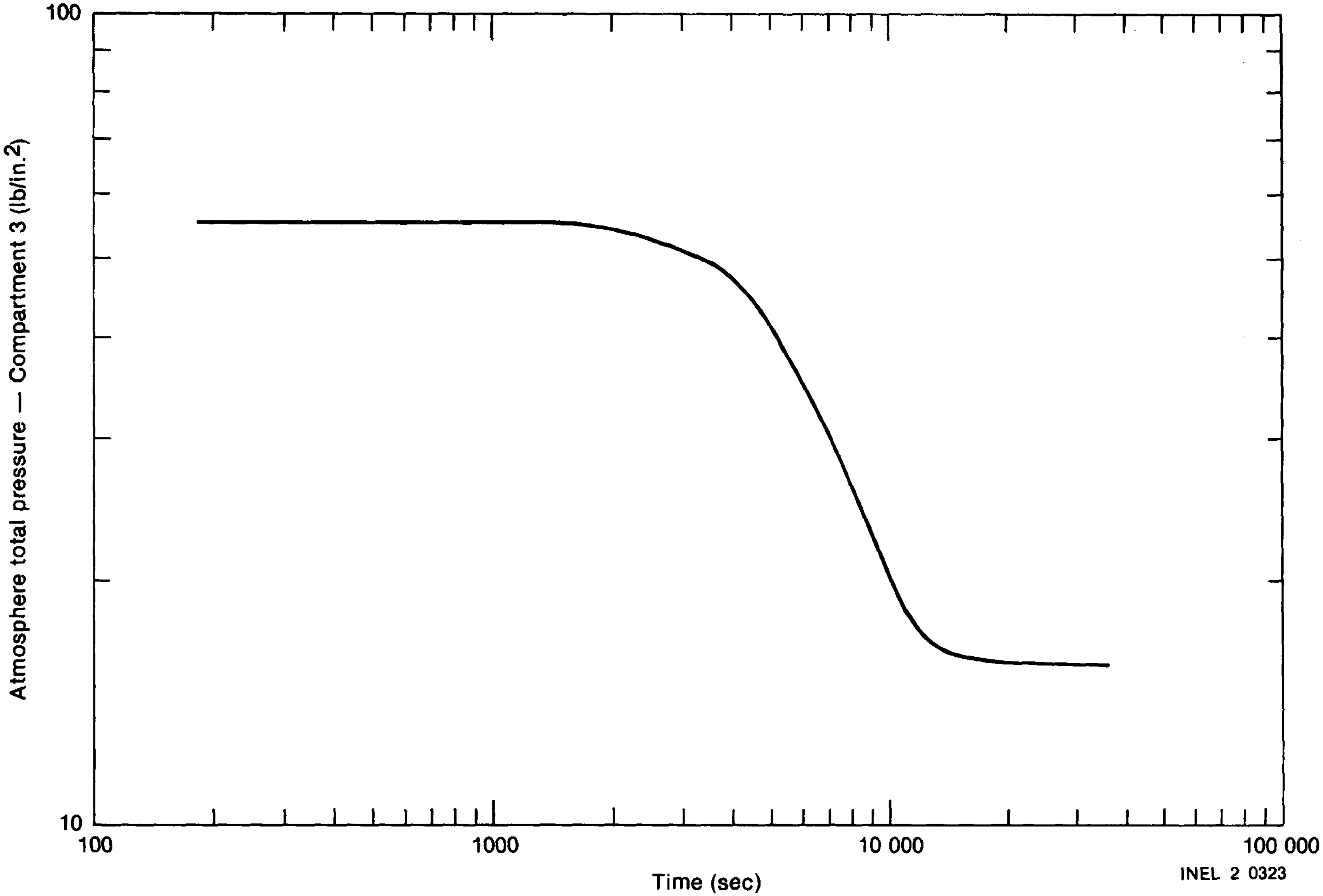

Figure F-1. Pressure vs. time on log-log scale.

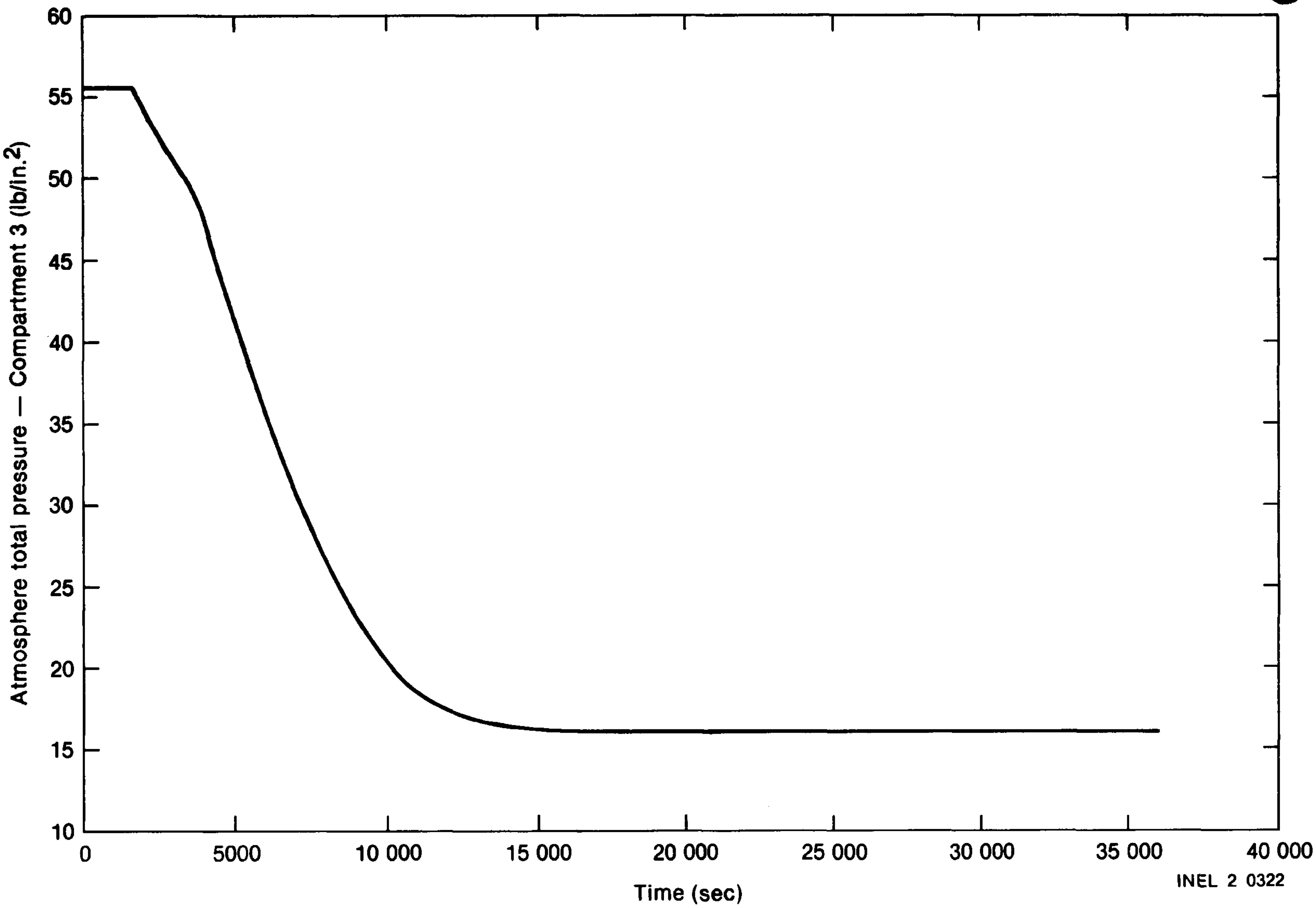

Figure F-2. Pressure vs. time on linear scale.

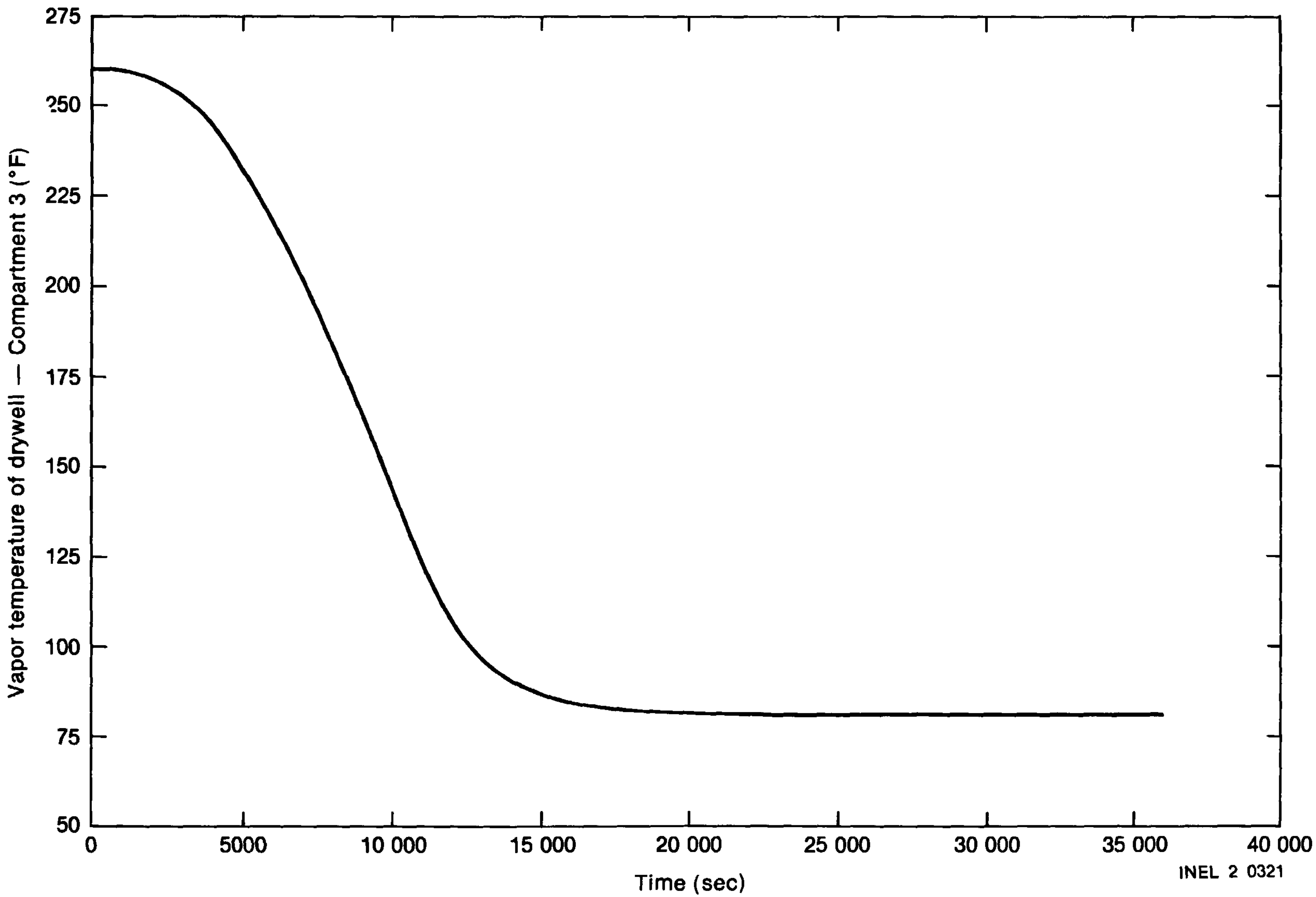

Figure F-3. Temperture vs. time on linear scale.

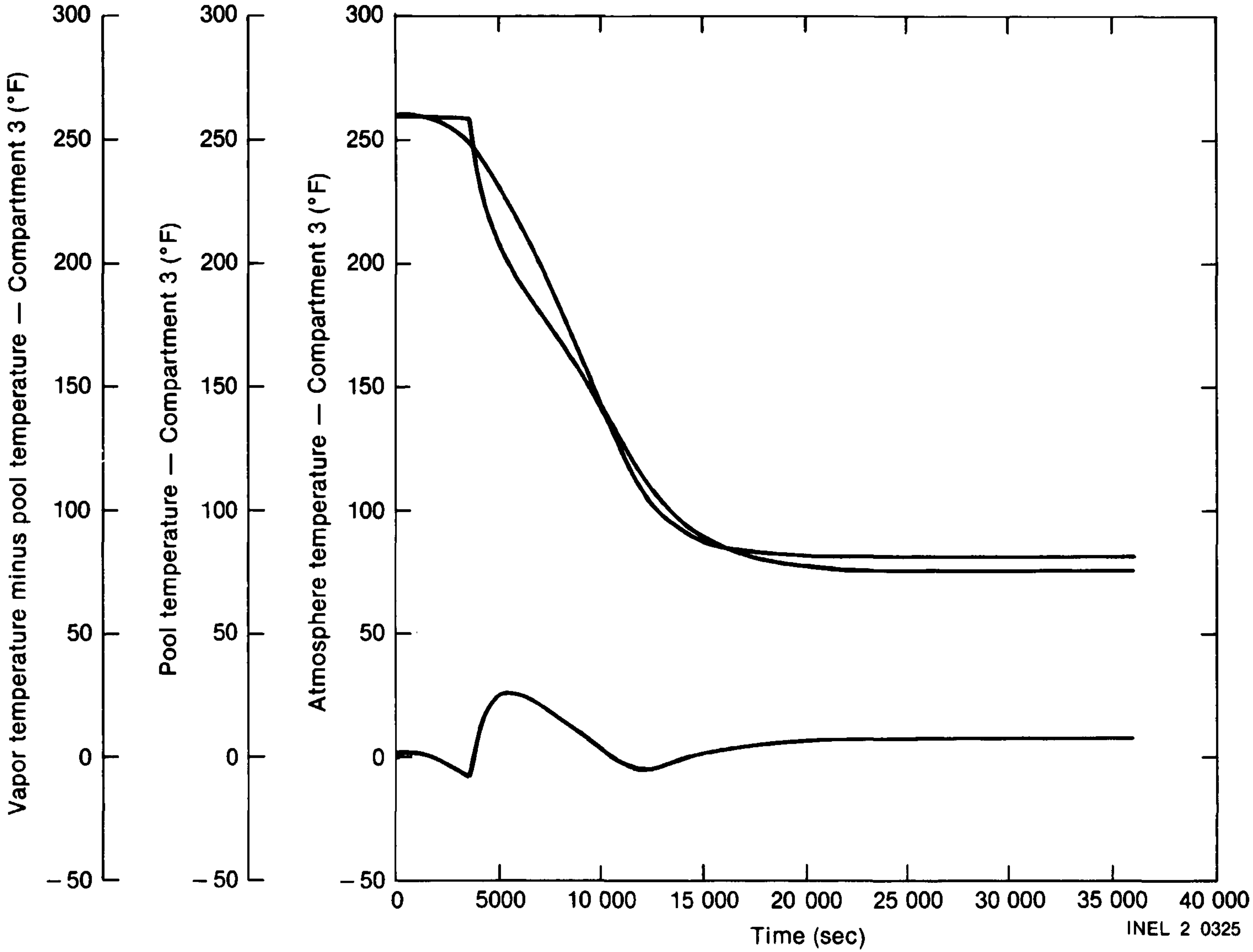

Figure F-4. Example of overlaid and difference plots.

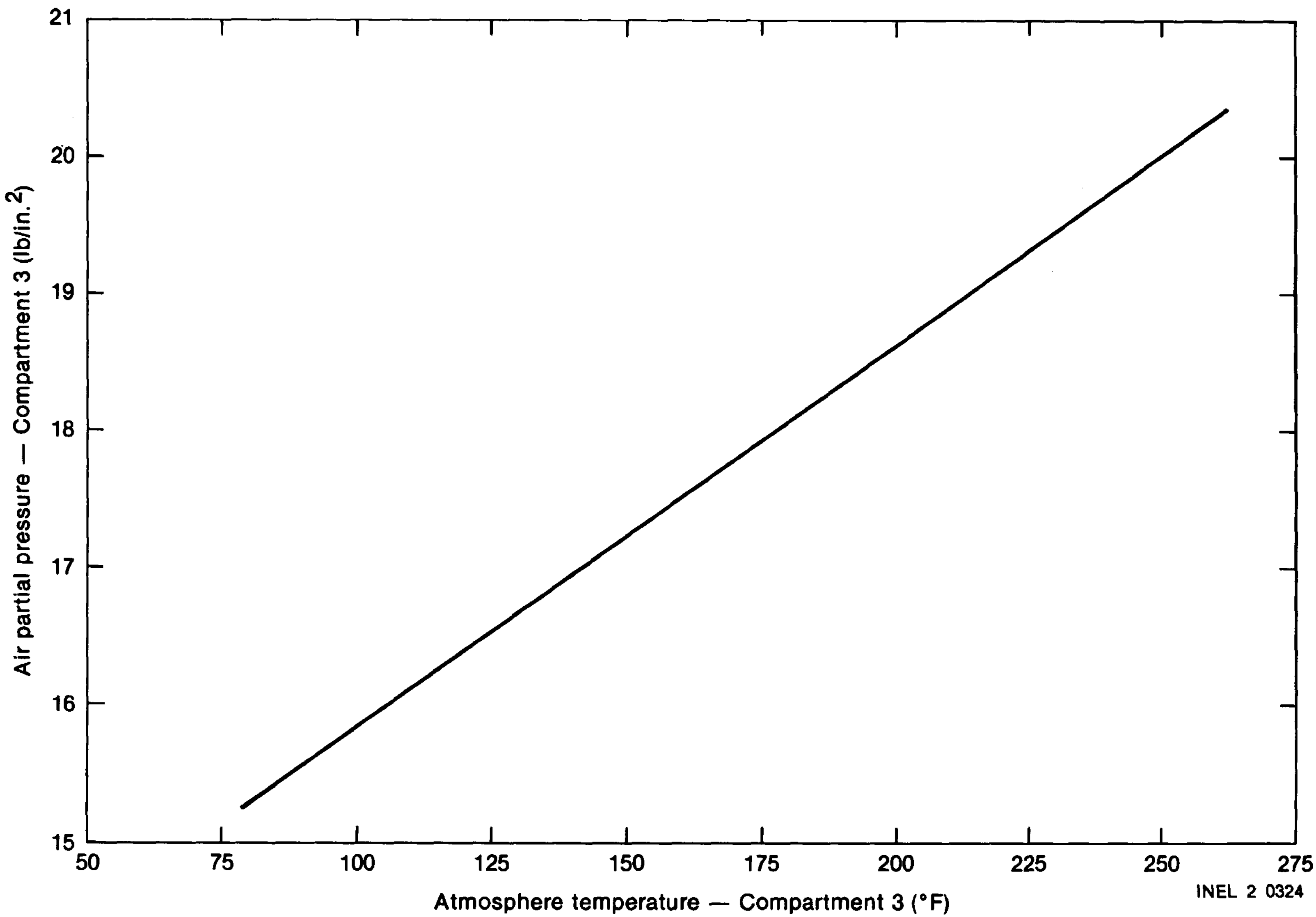

Figure F-5. Partial pressure vs. temperature on linear scale.

TABLE F-4. PLOTCT4 SAMPLE PROBLEM

LISTING OF INPUT DATA FOR CASE 1

```
* PLOTCT4 SAMPLE PROBLEM
*         SPECIFY MICROFILM PLOTS ONLY
900000    P1

* * * * * * * * * * * * * * * FIRST PLOT * * * * * * * * * * * * * * * *

*         COMP. 3 PRESSURE VS TIME - LOG-LOG PLOT
*         FORCE X-AXIS TO BE LOG SCALE FOR TIME
900100    T 0 L
*         PLOT COMP. 3 TOTAL PRESSURE - LOG SCALE ON Y-AXIS
900110    PRT 3 L

* * * * * * * * * * * * * * *SECOND PLOT * * * * * * * * * * * * * * * *

*         COMP. 3 PRESSURE VS TIME - LINEAR SCALE
*         RESET X-AXIS TO LINEAR TIME
900200    T 0 X
*         PLOT COMP. 3 TOTAL PRESSURE
900210    PRT 3

* * * * * * * * * * * * * * * THIRD PLOT * * * * * * * * * * * * * * * *

*         COMP. 3 VAPOR TEMPERATURE VS TIME - LINEAR PLOT
*         ASSIGN Y-AXIS TITLE
900250    TG 3 0 0 0 0 'VAPOR TEMPERATURE OF DRYWELL (DEG F)'

* * * * * * * * * * * * * * *FOURTH PLOT * * * * * * * * * * * * * * * *

*         THREE CURVES (POOL TEMP., VAPOR TEMP., DIFFERENCE IN TEMPS.) VS
*         TIME - LINEAR OVERLAYED PLOTS
*         OVERLAY 2 TEMPERATURES ON PLOT, THEN OVERLAY DIFFERENCE
900300    OV 4
900310    TG 3 0 0 -30. 270.
*         PLOT COMP. 3 POOL TEMPERATURE - ASSIGN SCALE
900320    TP 3 0 0 -30. 270.
*         PLOT DIFFERENCE OF ABOVE TWO TEMPERATURES - ASSIGN SCALE, TITLE
900330    TG 3 0 0 -30. 270.
*         PLOT COMP. 3 VAPOR TEMPERATURE - ASSIGN SCALE
900340    TP 3 D 0 -30. 270.
900341    'VAPOR TEMPERATURE MINUS POOL TEMPERATURE (DEG F)'

* * * * * * * * * * * * * * * FIFTH PLOT * * * * * * * * * * * * * * * *

*         COMP. 3 TEMPERATURE VS COMP. 3 PRESSURE - LINEAR SCALE
*         PLOT COMP. 3 VAPOR TEMPERATURE ON X-AXIS
900550    TG 3 X
*         PLOT COMP. 3 AIR PARTIAL PRESSURE ON Y-AXIS
900590    PRA 3
.         END OF PROBLEM
```

APPENDIX G

SAMPLE PROBLEMS

APPENDIX G

1. SAMPLE PROBLEMS

This appendix describes two CONTEMPT4/MOD3 sample problems. The first sample problem is the North Anna main steam-line break, the second is the Watts Bar ice containment analysis. The North Anna main steam-line break was previously modeled in CONTEMPT-LT, and the same input data used in the CONTEMPT-LT calculation were converted into input data suitable for a CONTEMPT4/MOD3 calculation. The Watts Bar ice containment analysis uses most of the significant features of CONTEMPT4/MOD3 to calculate the containment responses during a postulated LOCA condition. The results of the sample problems are provided along with the CONTEMPT4/MOD3 transmittal tape.

1.1 North Anna Main Steam-Line Break

The significant program features included in the analysis of the North Anna main steam-line break are: single transaction model, basic energy, mass balance models, and the heat structure model. The containment is modeled by a single dry compartment with a volume of 1.825×10^6 ft^3, at an initial temperature of 105°F, pressure of 14.7 psia, and relative humidity of 0.5.

Following the break, the containment atmosphere was allowed to return to ambient conditions without the use of active pressure reduction systems. The principal energy removal mechanism available in this problem was heat conduction into the containment structures, internal walls, and piping systems. Nine heat sinks were used to model the heat conduction process. The Uchida model was adopted for the heat transfer between the heat sinks and the compartment atmosphere.

The input listings of the CONTEMPT4/MOD3 calculation are shown in Table G-1. The results of the CONTEMPT4/MOD3 calculation, together with the CONTEMPT-LT calculation, are shown in Table G-2 and Figure G-1. The pressure and the temperature transients of this CONTEMPT4/MOD3 calculation are remarkably close to the pressure and the temperature transients of the CONTEMPT-LT calculation.

```
*NORTH ANNA MSLB 1 FT2 SPLIT SIMPLIFIED
100     HR  0.0  0.05  0  BRT  10000
105     1  10  12.0
9000    SEC
9001    20.0  0.01  0.0  20  200  0  10
9002    200.0  0.1  0.0  10  100  0  10
9003    590.0  1.0  0.0  5  10  0  5
9004    3600.0  5.0  0.0  50  100  0  50
40000   FT3  FT3  DEGF  LBF/IN2  FT2  FT  SEC-1
40031   DRY 1.825+6 0.0 105.0 120.0 9.6 0.5 0.0 0.0 1.0 0.0 0.0 -1.0
1010    *MAIN STEAM LINE BLOWDOWN*
1011    3  ATM  1.0  1.0  1  LIQ
100101 SEC    LB/SEC    BTU/LB  0
100102 0.0,  1491.0,  1190.0
100103 1.0,  1476.0,  1190.6
100104 2.0,  1455.0,  1191.2
100105 5.0,  1401.0,  1192.5
100106 10.0, 1341.0,  1194.0
100107 15.0, 1299.0,  1194.9
100108 25.0, 1263.0,  1195.9
100109 50.0, 1254.0,  1195.9
100110 100.0, 798.8,  1195.9
100111 1250.0, 194.37, 1195.9
1001100 DEGF  80.0
1000001 FT  BTU/SEC  DEGF
1010001 93  1  0.0  0.0  100  0.01  0.0
1010002 0  SEC  0.0  FT2  146272.0  3  3  0
1010200 0  1
1010201 2  0.0005
1010202 20  0.1007
1010203 30  0.3007
1010204 20  0.6007
1010205 20  3.0007
1010301 4  2,  3  22,  3  52,  3  72,  3  92
1010401 0.0  2,  0.0  22,  0.0  52,  0.0  72,  0.0  92
1010601 105.0  3, 105.0  23, 105.0  53, 105.0  73, 105.0  93
1011100 2  2  0  0
1000000 BTU/HR-FT-DEGF  BTU/FT3-DEGF
1000101  26.0               54.0
1000102   9.3               54.0
1000103   0.6               30.0
1000104   0.1               28.4
1000105   0.1               0.0135
1020000 'FLOOR ABOVE FOUNDATION MAT.'
1020001 101  1  0.0  0.0  100  0.01  0.0
1020002 0  SEC  0.0  FT2  11757.0  3  3  0
1020200 0  1
1020201 10  0.0104
1020202 20  0.1104
1020203 30  0.3104
1020204 20  0.6104
1020205 10  1.0104
1020206 10  2.0104
1020301 4  10,  3  30,  3  60,  3  80,  3  90,  3  100
1020401 0.0  10,  0.0  30,  0.0  60,  0.0  80,  0.0  90,  0.0  100
1020601 105.0 11, 105.0 31, 105.0 61, 105.0 81, 105.0 91, 105.0 101
1021100 2  2  0  0
1030000 'CONCRETE WALL TOP LINES CONTAINMENT CORE'
1030001 101  1  0.0  0.0  100  0.01  0
1030002 0  SEC  0.0  FT2  74412.0  3  3  0
1030200 0  1
1030201 2  0.0005
1030202 5  0.0322
1030203 2  0.0422
1030204 20 0.1422
1030205 30 0.3422
```

TABLE G-1. (continued)

```
1030206 20 0.6422
1030207 10 1.0422
1030208 11 4.5422
1030301 4  2,  1  7,  5  9,  3  29,  3  59,  3  79,  3  89,  3  100
1030401 0.0 2, 0.0 7, 0.0 9, 0.0 29, 0.0 59, 0.0 79, 0.0 89, 0.0 100
1030601 105.0 3, 105.0 8, 105.0 10, 105.0 30, 105.0 60
1030602 105.0 80, 105.0 90, 105.0 101
1031100 2  2  0  0
1040000 'MISC STAINLESS STEEL'
1040001 13  1  0.0  0.0  100  0.01  0.0
1040002 0  SEC  0.0  FT2  10220.0  3  3  0
1040200 0  1
1040201 2  0.0005
1040202 10  0.03442
1040301 4  2,  2  12
1040401 0.0  2,  0.0  12
1040601 105.0  3,  105.0  13
1041100 2  2  0  0
1050000 'MISC CARBON STEEL'
1050001 13  1  0.0  0.0  100  0.01  0
1050002 0  SEC  0.0  FT2  156246.0  3  3  0
1050200 0  1
1050201 2  0.0005
1050202 10 0.03867
1050301 4  2,  1  12
1050401 0.0  2,  0.0  12
1050601 105.0  3,  105.0  13
1051100 2  2  0  0
1060000 'MISC CARBO STEEL .25 IN THICK-SAMPLE CASE'
1060001 10  1  0.0  0.0  100  0.01  0
1060002 0  SEC  0.0  FT2  1.0  3  3  0
1060200 0  1
1060201 9  0.02
1060301 1  9
1060401 0.0  9
1060601 105.0  10
1061100 2  2  0  0
1070000 'MISC STEEL .375 IN THICK-SAMPLE CASE'
1070001 15  1  0.0  0.0  100  0.01  0
1070002 0  SEC  0.0  FT2  1.0  3  3  0
1070200 0  1
1070201 14  0.0313
1070301 1  14
1070401 0.0  14
1070601 105.0  15
1071100 2  2  0  0
1080000 'MISC STEEL .5 IN THICK-SAMPLE CASE'
1080001 20  1  0.0  0.0  100  0.01  0
1080002 0  SEC  0.0  FT2  1.0  3  3  0
1080200 0  1
1080201 19  0.04
1080301 1  19
1080401 0.0  19
1080601 105.0  20
1081100 2  2  0  0
1090000 'MISC STEEL .625 IN THICK -SAMPLE CASE'
1090001 25  1  0.0  0.0  100  0.01  0
1090002 0  SEC  0.0  FT2  1.0  3  3  0
1090200 0  1
1090201 24  0.0513
1090301 1  24
1090401 0.0  24
1090601 105.0  25
1091100 2  2  0  0
.END
```

TABLE G-2. PRESSURE AND TEMPERATURE TRANSIENTS (NORTH ANNA MSLB)

	CONTEMPT-LT (FAC = 0.92)			CONTEMPT4 (FAC = 0.92)		
Time (s)	Pressure (psia)	Atmospheric Temperature (°F)	Pool Temperature (°F)	Pressure (psia)	Atmospheric Temperature (°F)	Pool Temperature (°F)
0.0	9.6	105.0	105.0	9.6	105.0	105.0
1.0	10.1232	119.208	119.278	10.1234	119.332	119.332
2.0	10.6379	132.578	105.402	10.6380	132.629	105.405
4.0	11.6360	156.372	115.871	11.6361	156.421	115.877
6.0	12.5890	176.823	124.522	12.5892	176.871	124.529
8.0	13.5033	194.595	131.605	13.5035	194.640	131.612
10.0	14.3851	210.309	137.600	14.3854	210.352	137.607
15.0	16.4446	241.803	149.626	16.4469	241.842	149.632
20.0	18.3612	265.967	158.961	18.3663	266.184	158.980
30.0	21.7635	297.533	173.325	21.7711	297.684	173.365
40.0	24.8165	317.607	183.950	24.8171	317.484	183.997
50.0	27.5745	330.220	192.331	27.5755	330.084	192.381
60.0	29.9627	337.185	199.106	29.9735	337.284	199.157
70.0	31.9299	340.705	204.645	31.9453	340.884	204.698
80.0	33.4961	340.705	209.100	33.5130	340.884	209.156
90.0	34.8280	340.705	212.718	34.8280	340.884	212.776
100.0	35.8901	339.491	215.694	35.8830	339.084	215.746
120.0	37.8086	336.476	220.301	37.7746	235.484	220.347
140.0	39.8219	334.676	223.926	39.8810	335.484	223.971
160.0	41.9524	334.675	227.006	42.0167	335.484	227.054
180.0	44.2223	336.475	229.731	44.1886	335.484	229.771

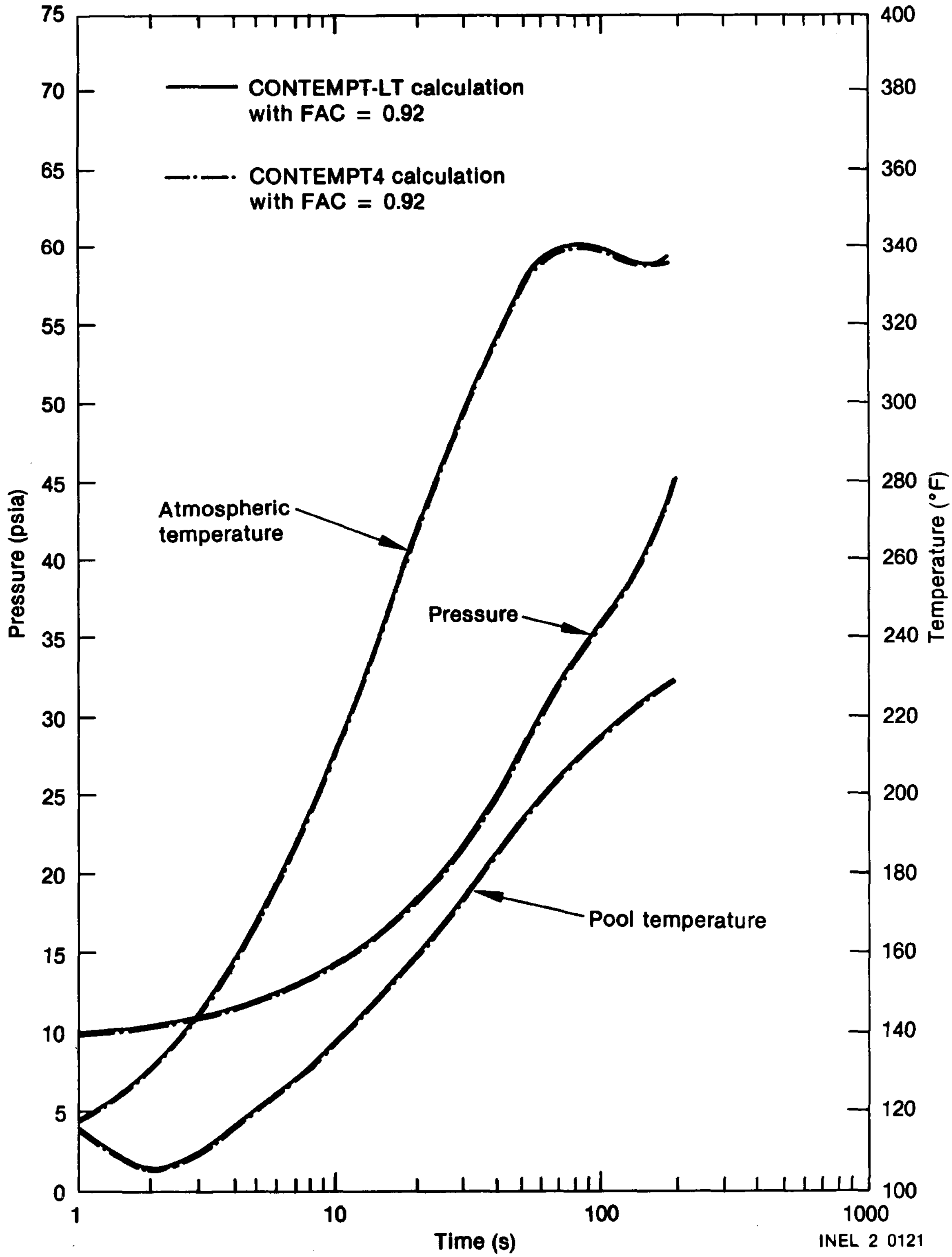

Figure G-1. North Anna MSLB pressure and temperature comparisons.

1.2 Watts Bar Ice Containment Analysis

The Watts Bar ice compartment system consists of a lower dry compartment which is connected to a dead-end compartment and the ice condenser. The ice condenser is connected to an upper compartment.

The initial pressure in all the compartments was 15 psia. The initial temperature in all standard compartments was 100°F except in the upper dead-end compartment, which was 80°F. All of the ice compartments had the same temperature, which was specified by the time-dependent input table. The initial temperature was 33°F.

The mass and energy flow rate of the blowdown was supplied by the time-dependent input table. Heat conduction through the containment structures was modeled by 23 heat slabs. Two cooling sprays were used as part of the pressure reduction system. They were activated at 45 s and 1 h after the initiation of the blowdown. The actual modeling and the input listings are shown in Figure G-2 and Table G-3, respectively.

The calculated pressure transients in different compartments are shown in Figures G-3 and G-4. The initial pressure oscillation, as shown in these figures, was caused by the relatively large time step (0.01 s) in the junction calculations. The oscillations were damped out after 20 s. In order to eliminate the pressure oscillations, a further reduction in time step was required. The maximum pressures in compartments 1, 2, 3, and 4 (refer to Figure G-2 for the compartment numbers) are 29.2, 32.2, 24.2, and 24.0 psia which occurred at 0.45, 1.2, 4.0, and 6.0 s, respectively. After passing the peaks, the pressure began to drop due to the pressure reduction mechanisms of the ice condenser, heat sinks, and decrease in the steam blowdown rate. Immediately after 45 s, pressures in all the compartments showed sharp reductions due to activation of the first cooling spray. Rapid reduction of the pressures at 200 s were again due to the sudden decrease in the steam blowdown rate and to the pressure reduction mechanisms.

The plot of temperature response in compartments 1 and 2 is shown in Figure G-5. The plot of temperature response in compartments 3 and 4 is

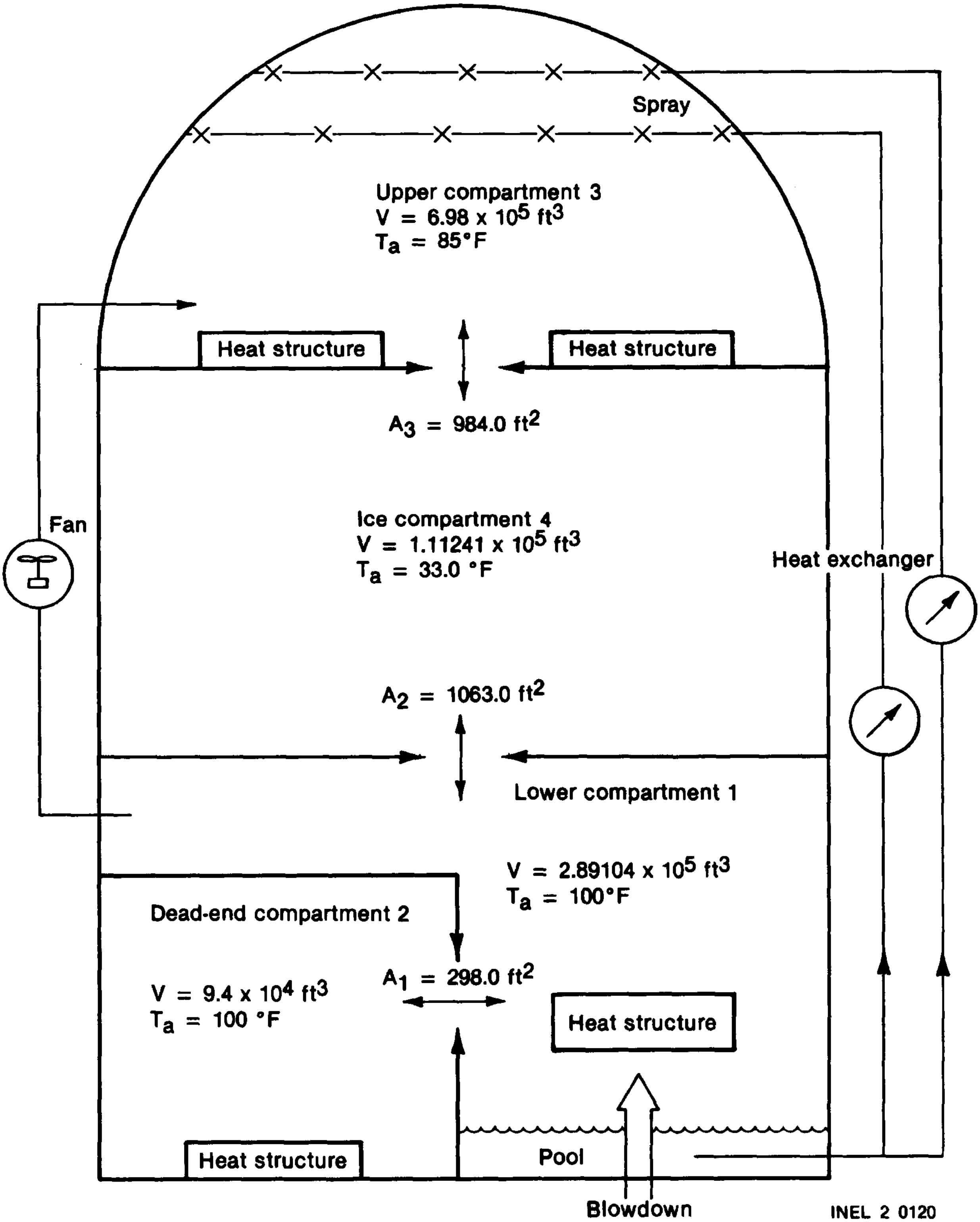

Figure G-2. Watts Bar ice containment modeling.

TABLE G-3. WATTS BAR ICE CONTAINMENT ANALYSIS--INPUT LISTING

```
LISTING OF INPUT DATA FOR CASE 4
      *       NRC ICE CONDENSER PROBLEM
      100     SEC 0.0  20.0  0  BRT  500000
      105     1  100  15.0
      9000    SEC
      9001    50.00       1.0      0.01   1     0  1  0
      9002    100.0       2.0      0.01   500    0  500  0
      9003    200.0       2.0      0.01   50(    0  500  0
      9004    500.0       2.0      0.01   500    0  500  0
      9005    1000.0     10.0      0.01    50    0  50   0
      9006    5000.0      2.0      0.001  100    0  100  0
      9007    1.0E4     200.0      1.0     50    0  50   0
      9008    5.0E4     1.0E3     10.0     50    0  50   0
      9009    1.0E5     2.0E3     10.0     50    0  50   0
      9010    5.0E5     1.0E4    100.0     50    0  50   0
      9011    1.0E6     2.0E4    100.0     50    0  50   0
      40000     FT3  FT3  DEGF  LBF/IN2  FT2  FT  SEC-1
      *        THERE WAS INSUFFICIENT DATA AVAILABLE TO ACCURATELY CALCULATE
      *        THE ATMOSPHERE/POOL INTERFACE AREA.  THE NUMBERS USED WERE
      *        COMPUTED ASSUMING THAT ALL VOLUMES WERE RECTANGULAR BOXES.
      40010     'LOWER COMPARTMENT'
      40020     'DEAD END VOLUME'
      40030     'UPPER COMPARTMENT'
      40040     'ICE COMPARTMENT NO. 4'
      *         ALL ICE CONDENSER SPECIFICATIONS ARE IDENTICAL
      *         EXCEPT COMPARTMENT COLUME
      40011   DRY 289014.0 0.0 100.0 100.0 15.0 0.1 8700.0  1.0 1.0 0 0.25 -1.0
      40021   STD  94000.0 0.0 100.0 100.0 15.0  0.1 4100.0  1.0 1.0 0 0.25
      40031   STD 698000.0 0.0  85.0  85.0 15.0  0.1 1.5E4   1.0 1.0 0 0.25
      40041   ICE 111241.0 0.0  33.0  33.0 15.0  1.0  60.0  1.0  1.0  0.0 0.25
      8000      FT   FT2  FT-1
      8002    1  2 0  4.20 4.20  0  298.0  1.0  1.0  2.1565
      8004    1  4 0  1.16 1.16  0 1063.0  1.0  1.0  0.2154
      8005    4  3 0  1.16 1.16  0  984.0  1.0  1.0  0.2517
      * DRAIN DESCRIPTION
      6000      LB  BTU  FT2  FT
      6041    4  1  2  0.0  0.0  1063.5  1063.5  120. 120. 120. 0.000046  -1.0
      6031    3  1  2  0.0  0.0  2003.1  2003.1   30.  30.  30. 0.000046  -1.0
      *         UNITS  FOR  ICE  INITIALIZATION
      * THE ICE PERFORMANCE TABLE USED IN THIS DATA SET IS THE SAME ONE
      * USED FOR THE WALTZ-MILL RUNS.  FURTHER INFORMATION FROM NRC SHOULD
      * PROVIDE A BETTER PERFORMANCE TABLE.
      60000     DEGF  LB
      60041     15.0  2.450006E6  7  * NOTE: DESIGN  SPEC USED FOR TEMP.
      100701    SEC   DEGF  DEGF  NONE
      100702     0.0      33.0      33.0      1.0
```

TABLE G-3. (continued)

```
100703     0.5     200.0      90.0      1.0
100704     1.0     210.0     147.0      1.0
100705     2.0     230.0     140.0      1.0
100706    10.0     175.0      75.0      1.0
100707   100.0     130.0      75.0      1.0
100708    1.E6     130.0      75.0      1.0
*    ICE CONDENSER PROBLEM BLOWDOWN TABLES
*    THE BLOWDOWN IS SEPARATED INTO  PARTS, THE VAPOR PORTION
*    AND THE LIQUID PORTIONS
1010      'VAPOR BLOWDOWN TABLE'
1011      1  ATM  1.0  1.0  1  VAP
100101    SEC   LB/SEC    BTU/SEC   0
100102    0.0            0.0          0.0
100103    1.00000E-8    2.61361E4    3.02913E7
100104    2.50331E-2    2.61361E4    3.02913E7
100105    1.25218E-1    3.05446E4    3.54006E7
100106    2.50276E-1    3.12901E4    3.62646E7
100107    3.50283E-1    3.04523E4    3.52936E7
100108    4.50334E-1    2.84610E4    3.29857E7
100109    5.75504E-1    2.77046E4    3.21091E7
100110    7.24750E-1    2.69557E4    3.12411E7
100111    8.75455E-1    2.61061E4    3.02564E7
100112    1.07552E+0    2.49137E4    2.88744E7
100113    1.35026E+0    2.35809E4    2.73297E7
100114    1.65024E+0    2.20030E4    2.55010E7
100115    1.90023E+0    2.04405E4    2.36902E7
100116    2.75014E+0    1.72135E4    1.99500E7
100117    4.25035E+0    1.44838E4    1.67865E7
100118    5.75034E+0    1.33139E4    1.54306E7
100119    7.25076E+0    1.46885E4    1.70237E7
100120    8.75090E+0    1.14149E4    1.32296E7
100121    1.02590E+1    1.04018E4    1.20555E7
100122    1.20026E+1    9.16474E3    1.06217E7
100123    1.37519E+1    7.86157E3    9.11140E6
100124    1.52506E+1    6.65855E3    7.71712E6
100125    1.67506E+1    5.33876E3    6.18752E6
100126    1.82507E+1    3.49836E3    4.05453E6
100127    1.97504E+1    2.12191E3    2.45925E6
100128    2.15006E+1    9.04012E2    1.04773E6
100129    2.32505E+1    2.52914E2    2.93123E5
100130    2.40056E+1    8.38995E0    9.72378E3
100131    2.40112E+1    0.00000E0    0.00000E0
100132    2.500E+1      4.45356E+2    5.77598E+5
100133    2.521E+1      2.36488E+2    3.06703E+5
100134    2.601E+1      3.60590E+2    4.67649E+5
100135    3.101E+1      9.72217E+2    1.25882E+6
100136    3.201E+1      1.05466E+3    1.36443E+6
```

TABLE G-3. (continued)

93	100137	3.201E+1	1.05792E+3	1.36853E+6
94	100138	3.601E+1	1.01941E+3	1.31538E+6
95	100139	4.701E+1	9.27829E+2	1.18826E+6
96	100140	5.000E+1	9.04452E+2	1.15593E+6
97	100141	5.400E+1	8.78376E+2	1.12005E+6
98	100142	6.401E+1	7.22574E+2	9.16259E+5
99	100143	6.401E+1	7.21867E+2	9.15343E+5
100	100144	7.401E+1	6.13547E+2	7.74924E+5
101	100145	8.401E+1	5.43446E+2	6.84181E+5
102	100146	1.000E+2	5.49086E+2	6.36380E+5
103	100147	1.440E+2	4.25076E+2	5.27367E+5
104	100148	1.949E+2	4.03635E+2	4.95865E+5
105	100149	1.950E+2	2.97000E+2	3.54000E+5
106	100150	2.000E+2	2.97000E+2	3.53000E+5
107	100151	3.000E+2	2.97000E+2	3.44000E+5
108	100152	3.050E+2	2.97000E+2	3.44000E+5
109	100153	3.100E+2	1.49000E+2	1.72000E+5
110	100154	4.000E+2	1.40000E+2	1.61000E+5
111	100155	5.000E+2	1.31000E+2	1.52000E+5
112	100156	6.000E+2	1.31000E+2	1.52000E+5
113	100157	7.000E+2	1.24000E+2	1.43000E+5
114	100158	8.000E+2	1.18000E+2	1.36000E+5
115	100159	9.000E+2	1.18000E+2	1.37000E+5
116	100160	1.000E+3	1.12000E+2	1.29000E+5
117	100161	1.200E+3	1.05000E+2	1.21000E+5
118	100162	1.400E+3	1.00000E+2	1.16000E+5
119	100163	1.600E+3	9.66000E+1	1.12000E+5
120	100164	1.765E+3	9.71000E+1	1.12000E+5
121	100165	2.000E+3	0.00000E+0	0.00000E+0
122	100166	1.000E+6	0.00000E+0	0.00000E+0
123	1020	'LIQUID BLOWDOWN TABLE'		
124	1021	1 ATM 1.0	1.0 2 LIQ	
125	100201	SEC LB/SEC	BTU/SEC 0	
126	100202	0.0	0.0	0.0
127	100203	1.00000E-8	4.39774E4	8.95713E6
128	100204	2.50331E-2	4.39774E4	8.95713E6
129	100205	1.25218E-1	3.95689E4	8.05924E6
130	100206	2.50276E-1	5.15058E4	1.04905E7
131	100207	3.50283E-1	4.92365E4	1.00283E7
132	100208	4.50334E-1	4.48718E4	9.13932E6
133	100209	5.75504E-1	4.25130E4	8.65887E6
134	100210	7.24750E-1	4.01771E4	8.18312E6
135	100211	8.75455E-1	3.80746E4	7.75489E6
136	100212	1.07552E+0	3.56756E4	7.26627E6
137	100213	1.35026E+0	3.30606E4	6.73366E6
138	100214	1.65024E+0	2.99505E4	6.10021E6
139	100215	1.90023E+0	2.71178E4	5.52324E6

TABLE G-3. (continued)

```
100216   2.75014E+0   2.14205E4   4.36285E6
100217   4.25035E+0   1.70920E4   3.48122E6
100218   5.75034E+0   1.55812E4   3.17351E6
100219   7.25076E+0   1.68873E4   3.43953E6
100220   8.75090E+0   1.16114E4   2.36496E6
100221   1.02590E+1   1.01436E4   2.06600E6
100222   1.20026E+1   8.48186E3   1.72755E6
100223   1.37519E+1   6.76563E3   1.37800E6
100224   1.52506E+1   5.78295E3   1.17785E6
100225   1.67060E+1   4.84854E3   9.87531E5
100226   1.82507E+1   3.78445E3   7.70802E5
100227   1.97504E+1   2.03756E3   4.05003E5
100228   2.15000E+1   1.36530E3   2.78078E5
100229   2.32505E+1   3.96102E2   8.06764E4
100230   2.40056E+1   8.53612E1   1.73860E4
100231   2.40112E+1   0.00000E0   0.00000E0
100232   2.500E+1     0.0         0.0
100233   8.401E+1     0.0         0.0
100234   1.000E+2     1.03471E1   2.17046E3
100235   1.400E2      0.0         0.0
100236   1.949E2      0.0         0.0
100237   1.950E2      3.70E2      7.29E4
100238   2.000E2      3.70E2      7.29E4
100239   3.000E2      3.71E2      7.30E4
100240   3.050E2      3.71E2      7.30E4
100241   3.100E2      5.19E2      1.02E5
100242   4.000E2      5.28E2      1.04E5
100243   5.000E2      5.36E2      1.06E5
100244   6.000E2      5.36E2      1.06E5
100245   7.000E2      5.43E2      1.07E5
100246   8.000E2      5.49E2      1.08E5
100247   9.000E2      5.49E2      1.08E5
100248   1.000E3      5.56E2      1.09E5
100249   1.200E3      5.63E2      1.11E5
100250   1.400E3      5.67E2      1.12E5
100251   1.600E3      5.71E2      1.12E5
100252   1.765E3      5.70E2      1.12E5
100253   2.000E3      0.0         0.0
100254   1.000E6      0.0         0.0
*          HEAT STRUCTURE INPUT DATA
*          DATA COMMON TO ALL HEAT STRUCTURES
*          MATERIAL PROPERTY DESCRIPTIONS
*          NEW MATERIAL PROTITIES
1000000    BTU/HR-FT-DEGF BTU/FT3-DEGF
1000001    FT BTU/HR DEGF
1000101    0.21,14.0  0.083,28.4 0.8,28.8 9.4,56.4 26.0,56.4
```

TABLE G-3. (continued)

```
*          ALL STRUCTURE INPUT WILL BE ORGANIZED INTO
*          BLOCKS BY TYPE OF INFORMATION
*          FIRST BLOCK:  COMPARTMENT TITLES
1010000    '1ST UPPER DECK CONCRETE'
1020000    '2ND UPPER DECK CONCRETE'
1030000    '3RD UPPER DECK CONCRETE'
1040000    'STEEL LINED UPPER DECK CONCRETE'
1050000    'UPPER DECK CARBON STEEL'
1060000    'CRAIN WALL CONCRETE'
1070000    '1ST LOWER DECK CONCRETE'
1080000    '2ND LOWER DECK CONCRETE'
1090000    'STEEL LINED LOWER CONCRETE'
1100000    'LOWER COMPARTMENT FLOOR CONCRETE'
1110000    'LOWER COMPARTMENT CARBON STEEL'
1120000    'ROOM 3 SHELL PANELS -- 1'
1130000    'ROOM 3 SHELL PANELS -- 2'
1140000    'ROOM 3 SHELL PANELS -- 3'
1150000    'ROOM 3 SHELL PANELS -- 4'
1160000    'ROOM 3 SHELL PANELS -- 5'
1170000    'ROOM 3 SHELL PANELS -- 6'
1180000    'ROOM 3 CRAIN WALL -- 1'
1190000    'ROOM 3 CRAIN WALL -- 2'
1200000    'ROOM 3 CRAIN WALL -- 3'
1210000    'ROOM 3 CRAIN WALL -- 4'
1220000    'ROOM 3 CRAIN WALL -- 5'
1230000    'ROOM 3 CRAIN WALL -- 6'
1010001    6  1  0.0  1.0  100  0.01  0
1020001    7  1  0.0  1.0  100  0.01  0
1030001    7  1  0.0  1.0  100  0.01  0
1040001    11  1  0.0  1.0  100  0.01  0
1050001    7  1  0.0  1.0  100  0.01  0
1060001    6  1  0.0  1.0  100  0.01  0
1070001    7  1  0.0  1.0  100  0.01  0
1080001    7  1  0.0  1.0  100  0.01  0
1090001    11  1  0.0  1.0  100  0.01  0
1100001    7  1  0.0  1.0  100  0.01  0
1110001    7  1  0.0  1.0  100  0.01  0
1120001    11  1  0.0  1.0  100  0.01  0
1130001    11  1  0.0  1.0  100  0.01  0
1140001    11  1  0.0  1.0  100  0.01  0
1150001    11  1  0.0  1.0  100  0.01  0
1160001    11  1  0.0  1.0  100  0.01  0
1170001    11  1  0.0  1.0  100  0.01  0
1180001    11  1  0.0  1.0  100  0.01  0
1190001    11  1  0.0  1.0  100  0.01  0
1200001    11  1  0.0  1.0  100  0.01  0
1210001    11  1  0.0  1.0  100  0.01  0
```

TABLE G-3. (continued)

```
1220001  11  1  0.0  1.0  100  0.01  0
1230001  11  1  0.0  1.0  100  0.01  0
*    DELAY SETTINGS AND SURFACE AREAS
1010002  0  SEC  0.0  FT2   4880.0  3  3  0
1020002  0  SEC  0.0  FT2  18280.0  3  3  0
1030002  0  SEC  0.0  FT2    760.0  3  3  0
1040002  0  SEC  0.0  FT2   3840.0  3  3  0
1050002  0  SEC  0.0  FT2  56331.0  3  3  0
1060002  0  SEC  0.0  FT2  31963.0  1  1  0
1070002  0  SEC  0.0  FT2   2830.0  1  1  0
1080002  0  SEC  0.0  FT2    760.0  1  1  0
1090002  0  SEC  0.0  FT2   2270.0  1  1  0
1100002  0  SEC  0.0  FT2  15921.0  1  1  0
1110002  0  SEC  0.0  FT2  28500.0  1  1  0
1120002  0  SEC  0.0  FT2    913.5  3  3  0
1130002  0  SEC  0.0  FT2    633.6  3  3  0
1140002  0  SEC  0.0  FT2    492.0  3  3  0
1150002  0  SEC  0.0  FT2    492.0  3  3  0
1160002  0  SEC  0.0  FT2    387.6  3  3  0
1170002  0  SEC  0.0  FT2    455.1  3  3  0
1180002  1  SEC  0.0  FT2    300.3  3  3  0
1190002  1  SEC  0.0  FT2    352.5  3  3  0
1200002  1  SEC  0.0  FT2    707.7  3  3  0
1210002  1  SEC  0.0  FT2    490.8  3  3  0
1220002  1  SEC  0.0  FT2    381.3  3  3  0
1230002  1  SEC  0.0  FT2    381.3  3  3  0
*MESH DESCRIPTIONS
1010200  0  1
1020200  0  1
1030200  0  1
1040200  0  1
1050200  0  1
1060200  0  1
1070200  0  1
1080200  0  1
1090200  0  1
1100200  0  1
1110200  0  1
1010201  5,1.1
1020201  1,0.0005   2,0.0015  3,1.4005
1030201  1,0.00125  2,0.00375 3,1.50125
1040201  5,0.0208   2,0.02912  3,1.52080
1050201  1,0.00063  2,0.00188 3,0.080625
1060201  5,1.43
1070201  1,0.00125  2,0.00375 3,1.00125
1080201  1,0.0005   2,0.0015  3,1.75050
1090201  5,0.021    2,0.2940   3,2.0210
```

TABLE G-3. (continued)

```
1100201  1,0.0005   2,0.0015   3,1.6005
1110201  1,0.00063  2,0.00188  3,0.066625
1120200  0  1
1120201  5,0.0625   2,0.0875   3,1.0625
1130200  12
1140200  12
1150200  12
1160200  12
1170200  12
1180200  0  1
1180201  5,1.0  5,2.0
1190200  18
1200200  18
1210200  18
1220200  18
1230200  18
* MATERIAL OVERLAY DESCRIPTION
1010301  3,5
1020301  2,1        3,3        3,6
1030301  2,1        3,3        3,6
1040301  4,5        3,7        3,10
1050301  1,1        5,3        5,6
1060301  3,5
1070301  2,1        3,3        3,6
1080301  2,1        3,3        3,6
1090301  4,5        3,7        3,10
1100301  2,1        3,3        3,6
1110301  1,1        5,3        5,6
1120301  1,5        5,7        5,10
1130300  12
1140300  12
1150300  12
1160300  12
1170300  12
1180301  1,5        3,10
1190300  18
1200300  18
1210300  18
1220300  18
1230300  18
* HEAT SOURCE DESCRIPTION
*          NEW  SOURCE  DISTRIBUTION
1010401    0.0,5
1020401    0.0,1        0.0,3        0.0,6
1030401    0.0,1        0.0,3        0.0,6
1040401    0.0,5        0.0,7        0.0,10
1050401    0.0,1        0.0,3        0.0,6
```

TABLE G-3. (continued)

```
1060401    0.0,5
1070401    0.0,1         0.0,3         0.0,6
1080401    0.0,1         0.0,3         0.0,6
1090401    0.0,5         0.0,7         0.0,10
1100401    0.0,1         0.0,3         0.0,6
1110401    0.0,1         0.0,3         0.0,6
1120401    0.0,5         0.0,7         0.0,10
1130400    12
1140400    12
1150400    12
1160400    12
1170400    12
1180401    0.0,5         0.0,10
1190400    18
1200400    18
1210400    18
1220400    18
1230400    18
* INITIAL TEMPERATURE DESCRIPTION
1010601    85.0,6
1020601    85.0,2         85.0,4         85.0,7
1030601    85.0,2         85.0,4         85.0,7
1040601    85.0,6         85.0,8         85.0,11
1050601    85.0,2         85.0,4         85.0,7
1060601   100.0,6
1070601   100.0,2        100.0,4        100.0,7
1080601   100.0,2        100.0,4        100.0,7
1090601   100.0,6        100.0,8        100.0,11
1100601   100.0,2        100.0,4        100.0,7
1110601   100.0,2        100.0,4        100.0,7
1120601   15.0,6         15.0,8         15.0,11
1130600   12
1140600   12
1150600   12
1160600   12
1170600   12
1180601   15.0,6         15.0,11
1190600   18
1200600   18
1210600   18
1220600   18
1230600   18
* BOUNDARY CONDITION DESCRIPTION
1011100    2   2   0   0
1021100    2   2   0   0
1031100    2   2   0   0
1041100    2   2   0   0
```

TABLE G-3. (continued)

```
1051100   2  2  0  0
1061100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1071100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1081100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1091100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1101100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1111100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1121100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1131100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1141100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1151100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1161100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1171100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1181100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1191100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1201100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1211100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1221100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1231100  53  2  0  0  FT3  0  383014.0    2.0  2.0
1090 'TRANSACTION TO REMOVE WATER FROM SUMP FOR CORE COOLING'
1091  1 LIQ  1.0  1.0  009  LIQ
100901   SEC   LB/SEC   BTU/LB  0
100902   0.0       0.0  0.0
100903   2025.0   0.0   0.0
100904   2025.0  -526.8   68.0
100905   3080.0  -526.8   68.0
100906   3600.0  -428.1   68.0
100907   1.E6    -428.1   68.0
* ADDITIONAL TAGAMI DESCRIPTION
1001100   DEGF, 100.0
1000501   SEC   100.0  1  2  0  BTU/HR-FT2-DEGF
*         CONTAINMENT SPRAY DATA AND  RHR DATA
* THE SPRAY EFFICIENCIES AND THE HEAT EXCHANGER FLOW RATES WERE
* NOT AVAILABLE IN THE NRC INSTRUCTIONS.  THOSE USED HERE ARE
* ARE GUESSES
800000    LBF/IN2  SEC  LB/SEC  DEGF  FT2  BTU/HR-FT2-DEGF BTU/HR
800100    3  1  0  0  0  1
800200    3  1  0  0  0  2
800101    0.0  0.0  0.7  0.0  0.0  0.95  85.0
800102    45.0  0.0  0.7  0.0  0.0  0.95  85.0
800103    45.0  555.73  0.7  0.0  0.0  0.95  85.0
800104    2980.0 555.73 0.7  0.0  0.0  0.95  85.0
800105    3000.0    0.0  0.7  0.0  0.0  0.95  85.0
800106    3080.0 555.73 0.7  1.0  0.0  0.95  0.0
800107    1E6  555.73 0.7  1.0  0.0  0.95  0.0
800201       0.0     0.0   0.7    1.0  0.0  0.95  0.0
800202    3600.0     0.0   0.7    1.0  0.0  0.95  0.0
```

TABLE G-3. (continued)

```
800203    3600.0  278.87  0.7    1.0  0.0  0.95  0.0
800204      1E6   278.87  0.7    1.0  0.0  0.95  0.0
*         HEAT EXCHANGER INPUT DATA
850001    1  3.1E6  1.0  85.0  1000.0
850002    1  1.6E6  1.0  85.0  1000.0
*         UPPER TO LOWER COMPARTMENT RETURN FAN
90000     LBF/IN2  SEC  SEC-1  FT3/MIN  DEGF
90011     FAN  1  3  -1  LOCKED
90012     FLOW  40000.0  -1.0  600.0  -1.0  14.7  0  100.0  3
90014     CON  0  0
. END OF NRC ICE CONDENSER PROBLEM
NRC ICE CONDENSER PROBLEM
```

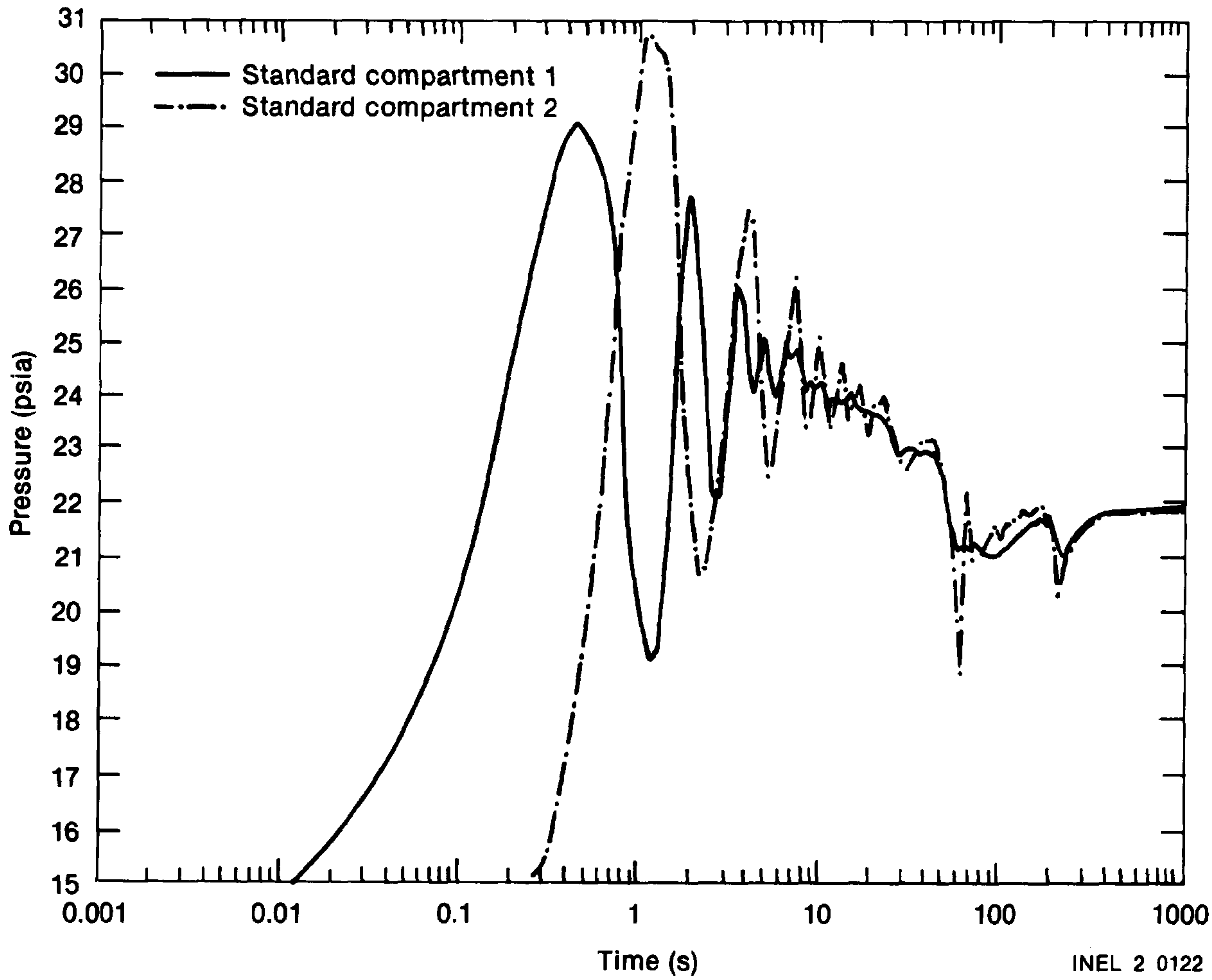

Figure G-3. Pressure transients in standard compartments 1 and 2.

shown in Figure G-6. The pool temperatures in compartments 1 and 2 increased slowly and finally reached the steady values of 230°F and 210°F, respectively. However, the atmospheric temperatures in compartments 1 and 2 showed a drastic increase at 30 s and a drastic decrease at 200 s. During the initial steam blowdown, which ended at 24 s, a large fraction of the atmospheric mass was driven out of compartments 1 and 2. The atmospheric temperature in these two compartments subsequently became very sensitive to the superheated-steam blowdown rate due to the relatively small atmospheric mass inventories left in the compartments. Thus, the second steam blowdown, which was initiated at 25 s, caused the atmospheric regions of compartments 1 and 2 to heat up rapidly. The sudden decrease of steam blowdown rate at 200 s, and the cooling mechanisms (ice condenser and spray) caused the atmospheric regions of compartments 1 and 2 to cool down to near-saturated temperatures of 235°F and 227°F, respectively.

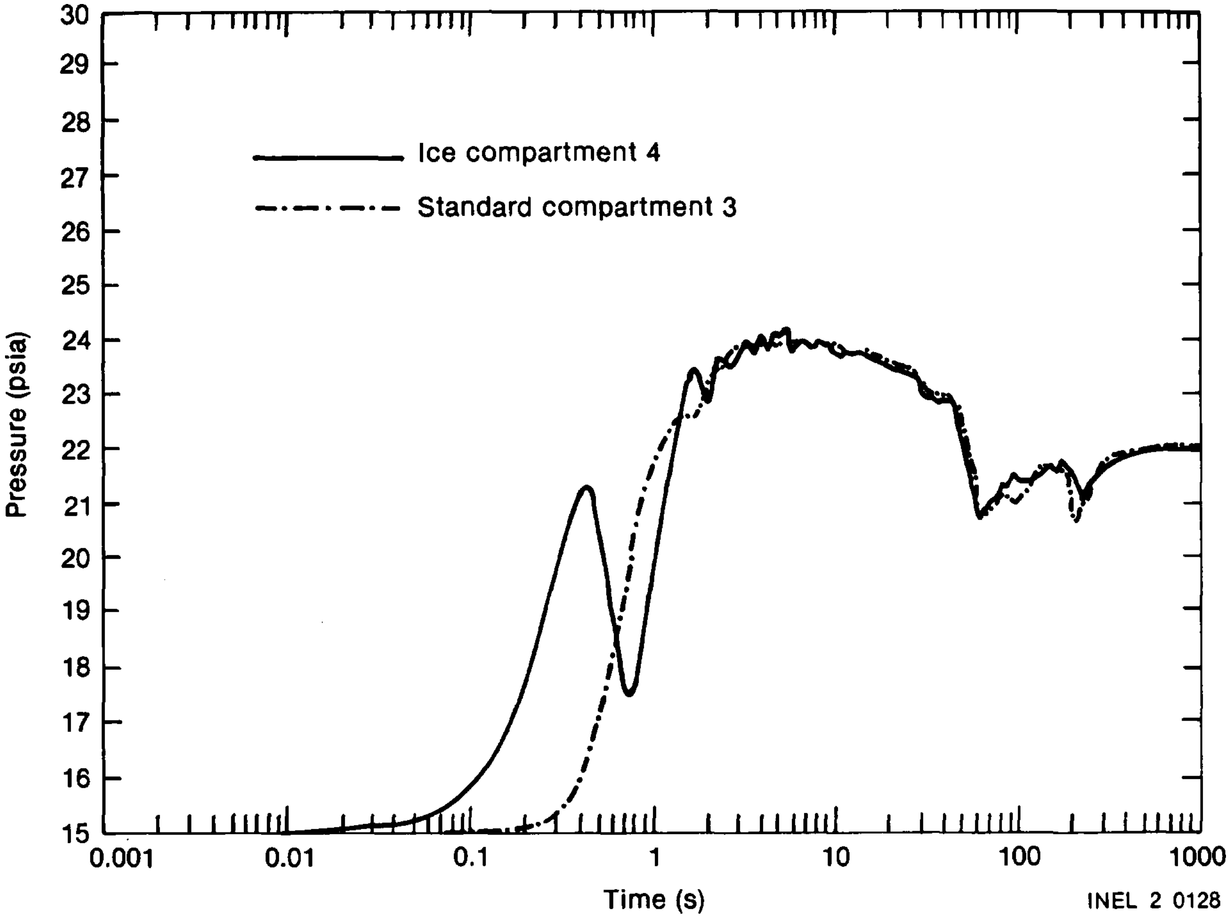

Figure G-4. Pressure transients in ice compartment 4 and standard compartment 3.

The atmospheric temperature in compartment 4 was prescribed based on the Watts Bar test data. The atmospheric temperature in compartment 3 reached 157°F at 3 s. The ice melt during the transient is presented in Figure G-7.

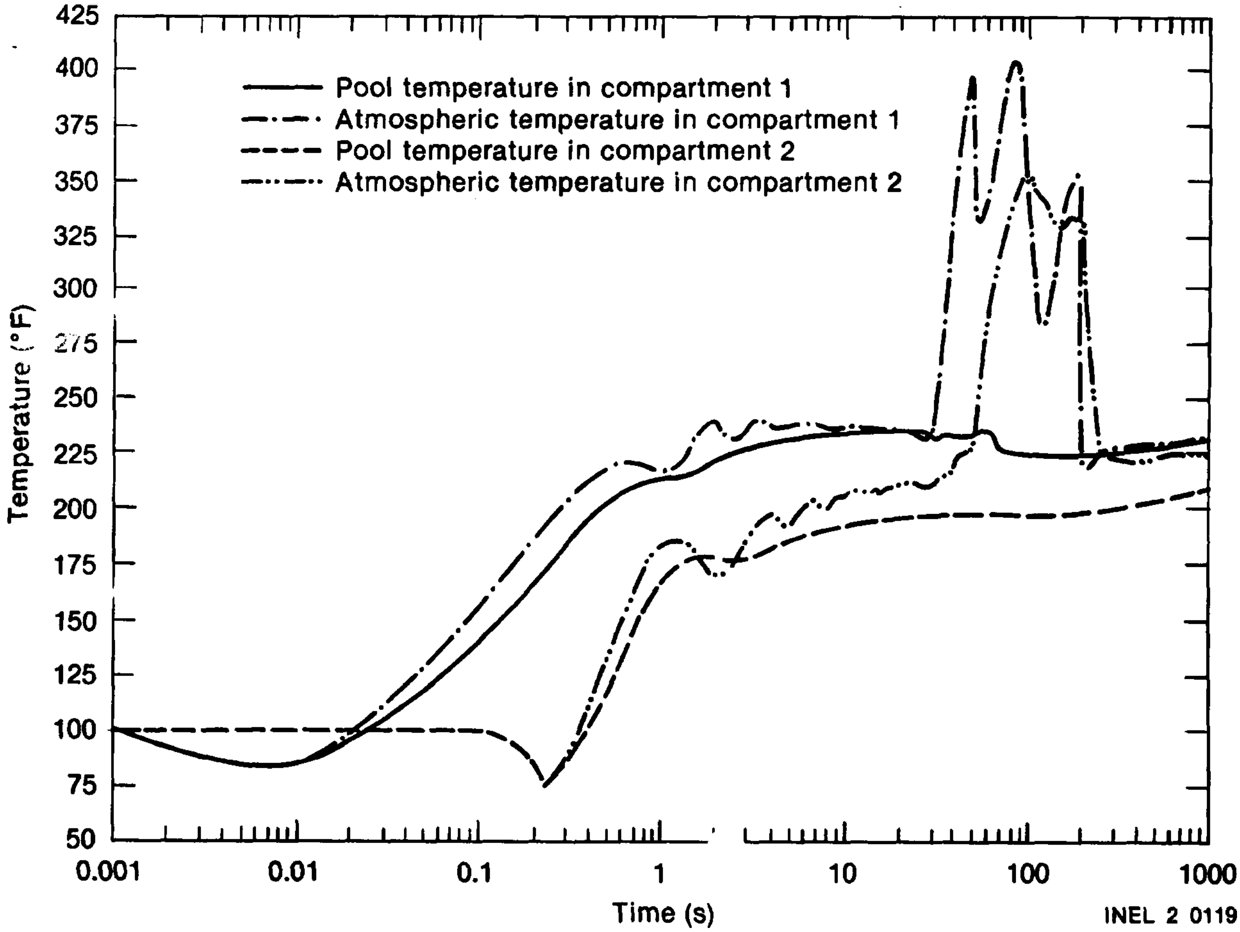

Figure G-5. Temperature transients in standard compartments 1 and 2.

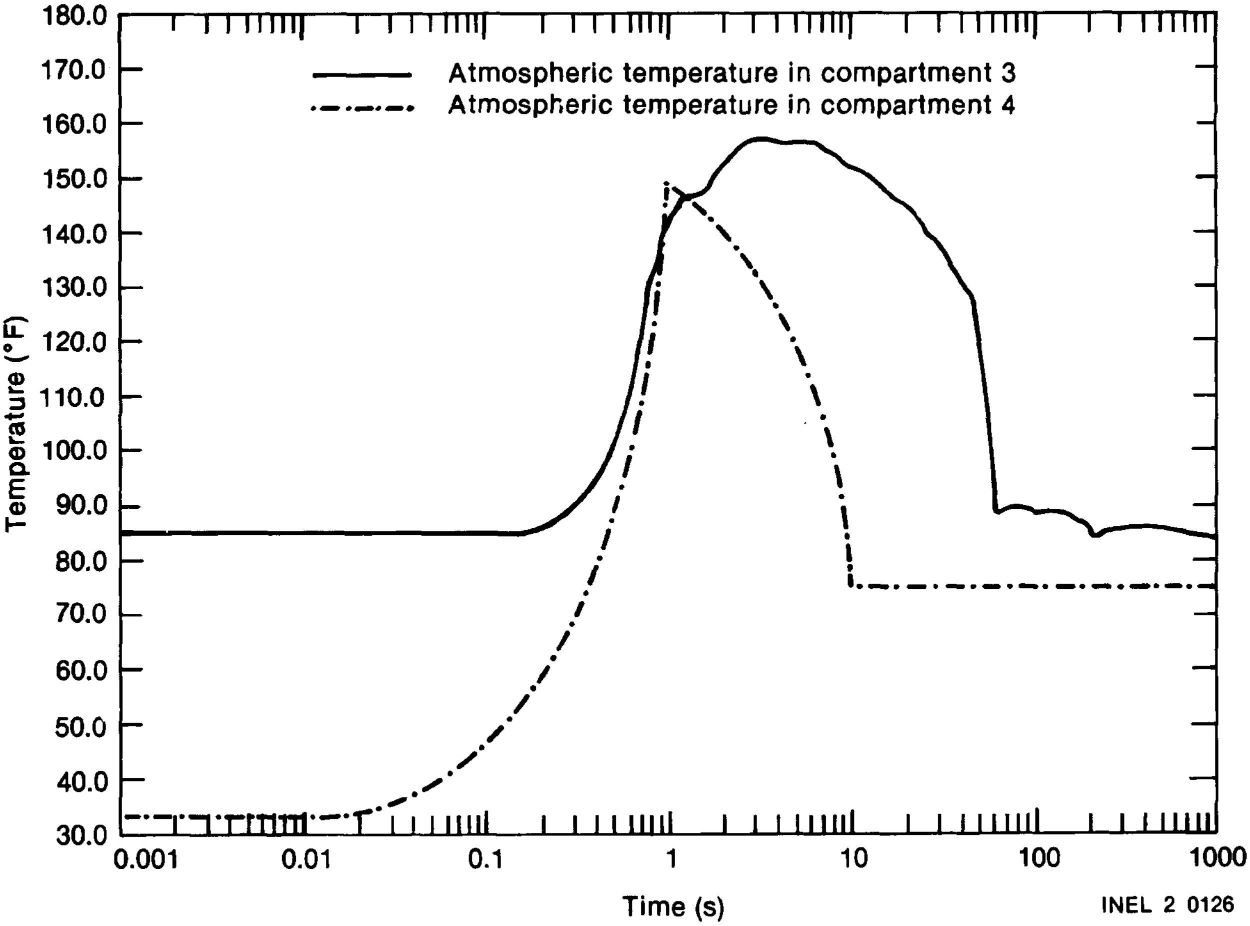

Figure G-6. Temperature transients in standard compartment 3 and ice compartment 4.

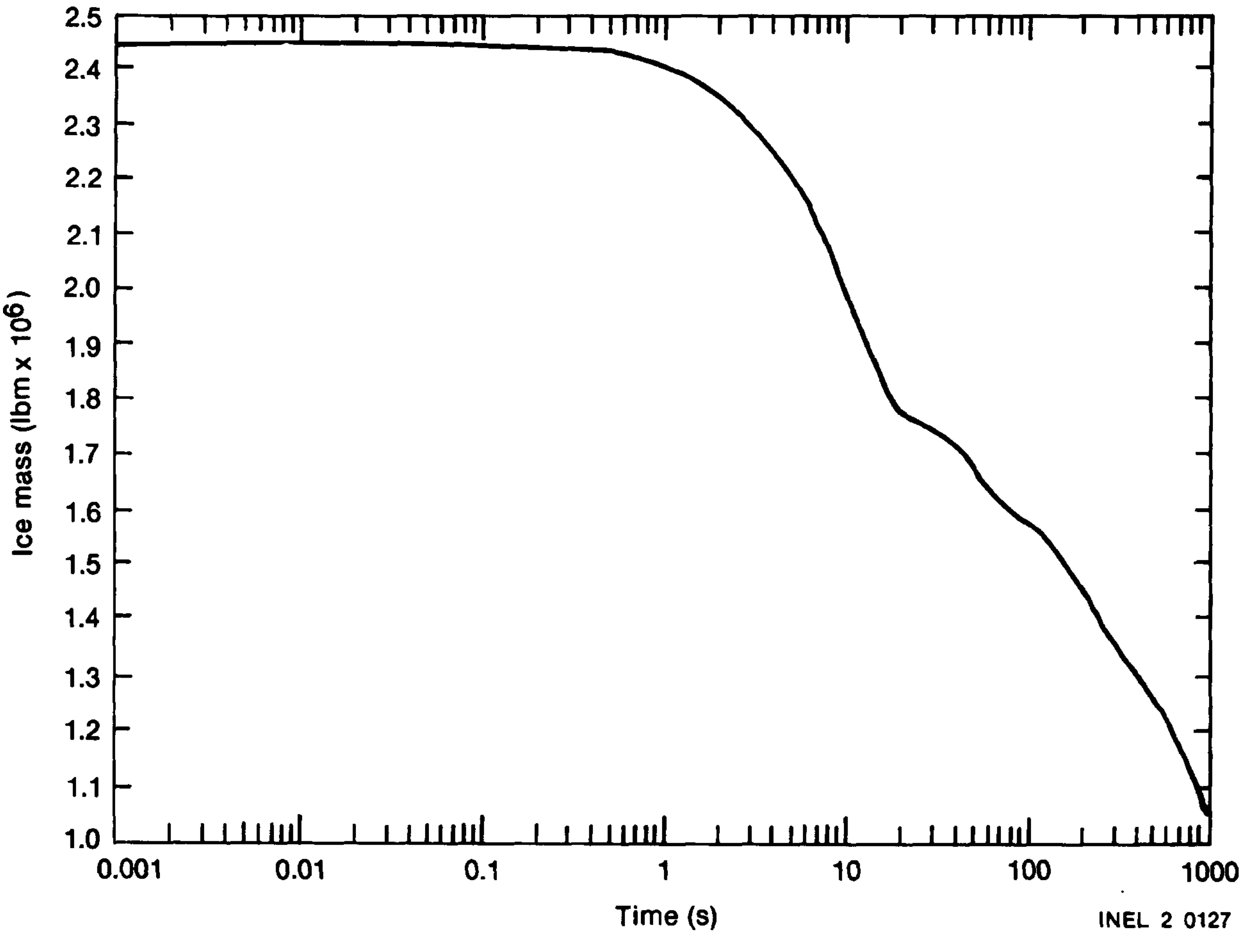

Figure G-7. Ice mass inventory in compartment 4 during the transient.