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CONTEMPT-LT/028-A COMPUTER PROGRAM FOR PREDICTING CONTAINMENT PRESSURE-TEMPERATURE RESPONSE TO A LOSS-OF-COOLANT ACCIDENT

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March 1979

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ABSTRACT

CONTEMPT-LT is a digital computer program, written in FORTRAN IV, developed to describe the long-term behavior of water-cooled nuclear reactor 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 energy exchange with adjacent compartments. The program is capable of describing the effects of leakage on containment response. Models are provided to describe fan cooler and cooling spray engineered safety systems. An annular fan model is also provided to model pressure control in the annular region of dual containment systems. Up to four compartments can be modeled with CONTEMPT-LT, and any compartment except the reactor system may have both a liquid pool region and an air-vapor atmosphere region above the pool. Each region is assumed to have a uniform temperature, but the temperatures of the two regions may be different. CONTEMPT-LT can be used to model all current boiling water reactor pressure suppression systems, including containments with either vertical or horizontal vent systems. CONTEMPT-LT can also be used to model pressurized water reactor dry containments, subatmospheric containments, and dual volume containments with an annulus region, and can be used to describe containment responses in experimental containment systems.

The program user defines which compartments are used, specifies input mass and energy additions, defines heat structure and leakage systems, and describes the time advancement and output control. CONTEMPT-LT source decks are available in double precision extended-binary-coded-decimal-interchange-code (EBCDIC) versions from the Argonne Code Center. Sample problems have been run on the CDC-7600 computer.

Version 024 of the CONTEMPT-LT computer program was released to the Argonne Code Center concurrent with publication of the original user's manual (ANCR-1219) in June 1975. Version 026 of the CONTEMPT-LT computer program was then developed and released to the Argonne Code Center in April 1976. No changes were made to ANCR-1219 at that time. This manual is a revision of the original ANCR-1219. It includes a discussion of all modifications, additions, and corrections to the CONTEMPT-LT computer program used in the latest Version, CONTEMPT-LT/028.

NOMENCLATURE AND UNITS

All calculations in the CONTEMPT-LT program are done using a standardized set of metric units, called SI (Systeme Internationale d'Unites) units. By user option, all program input and output may be in either SI or British units. This section describes the basic symbols used throughout the report, and both British and SI units are listed. All symbols, but not units, are defined in the report and therefore, some symbols are not repeated here. Rather a general symbol is described as representative of perhaps several symbols having different subscripts but the same base. Thus, M_X is a general mass symbol, and M_{WV}, $M_{W\ell}$, M_{Wt}, M_{WVV}, . . ., are used and defined throughout the report.

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

		Units	
Base Symbol	Description	SI	British
M_X,ΔM_X,m_X	mass	kg	lbm
V_X	volume	m^3	ft^3
T_X,u_X	absolute temperature	^oK	^oR
U_X	total energy	J	Btu
Δt,t	time	sec	hr
p_X	absolute pressure	Pa	$lbf/in.^2$
P_X	flow perimeter	m	ft
A_X,S_X	area	m^2	ft^2
ℓ,x,z,A	length or elevation	m	ft
W_X	mass flow rate	kg/sec	lbm/hr
G_X	mass flux	$kg/(sec\text{-}m^2)$	$lbm/(hr\text{-}ft^2)$
v	flow velocity	m/sec	ft/hr

Base Symbol	Description	Units	
		SI	British
v_x	specific volume	m^3/kg	ft^3/lbm
u_x	specific energy	J/kg	Btu/lbm
h_x, i_x	specific enthalpy	J/kg	Btu/lbm
c_x	specific heat	$J/(kg\text{-}^oK)$	$Btu/(lbm\text{-}^oR)$
x	quality and mole fraction	---	---
h,H	heat transfer coefficient	$J/(sec\text{-}m^2\text{-}^oK)$	$Btu/(hr\text{-}ft^2\text{-}^oF)$
q	heat transfer rate	W	Btu/hr
k	thermal conductivity	$W/(m\text{-}^oK)$	$Btu/(hr\text{-}ft\text{-}^oF)$
μ	viscosity	kg/(m-sec)	lbm/(ft-hr)
β	coefficient of thermal expansion	$1/^oK$	$1/^oF$
β	flow system area ratio	---	---
g	acceleration of gravity	m/sec^2	ft/hr^2
ρ	density	kg/m^3	lbm/ft^3
HUM_x	relative humidity	---	---
R_{HT}	heat structure energy transfer rate	W	Btu/hr
R_x	mass or energy addition rates from table input	kg/sec or W	lbm/hr or Btu/hr
R_a, R_w, R_m	gas constants	$Pa\text{-}m^3/(kg\text{-}^oK)$	$lbf\text{-}ft^3/(in.^2\text{-}lbm\text{-}^oR)$

Base Symbol	Description	Units	
		SI	British
$\dot{U}_F$	fan cooler heat removal rate	W	Btu/hr
K_L	normal leakage coefficient, including area	m^3/(Pa-sec)	ft^3-$in.^2$/(hr-lbf)
η_{hx}	heat exchanger efficiency	---	---
λ	primary decay energy release rate	[a]	[a]
E_{mw}	primary metal-water reaction energy release rate	[a]	[a]
$K_{\lambda 1}$,$K_{\lambda 2}$	primary and drywell multipliers of λ	[a]	[a]
K_{mw1},K_{mw2}	primary and drywell multipliers of E_{mw}	[a]	[a]
M_g	molecular weight of water	kg/kmol	lbm/lbmol
K_b	mass transfer coefficient	kmol/(sec-m^2)	lbmol/(hr-ft^2)
ϕ	surface heat flux	W/m^2	Btu/(hr-ft^2)

[a] Products of λ $K_{\lambda i}$ and E_{mw} K_{mwi} must have units of W or Btu/hr.

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CONTEMPT-LT/028 – A COMPUTER PROGRAM FOR PREDICTING CONTAINMENT PRESSURE-TEMPERATURE RESPONSE TO A LOSS-OF-COOLANT ACCIDENT

I. INTRODUCTION

CONTEMPT-LT[a] (CONtainment TEMperature Pressure Transient - Long Term) is a digital computer program, written in FORTRAN IV, developed to predict the long-term behavior of water-cooled nuclear reactor containment systems subjected to postulated loss-of-coolant accident (LOCA) conditions. The program can be used to describe containment responses in experimental containment systems.

CONTEMPT-LT calculates the time variation of compartment pressures, temperatures, mass and energy inventories, heat structure temperature distributions, and energy exchange with adjacent compartments. The program is capable of describing the effects of penetration and small crack leakage on containment response. Models are provided to describe fan cooler and cooling spray engineered safety systems. An annular fan model is provided for pressure control in the annular region of dual containment systems. CONTEMPT-LT can be used to model from one to four compartments, and any compartment except the primary compartment may have both a liquid pool region and a vapor atmosphere region above the pool. Each region is assumed to have a uniform temperature, but the temperatures of the two regions may be different. The program user defines which compartments are used, specifies input mass and energy additions, defines heat structure and leakage systems, and describes the time advancement and output control.

CONTEMPT-LT can be used to model all standard boiling water reactor (BWR) pressure suppression systems, including Mark I, Mark II, and Mark III systems. CONTEMPT-LT can also be used to model pressurized water reactor (PWR) dry containments, subatmospheric containments, and dual containments with an annular region, and can be used to describe containment responses in experimental containment systems.

The report is primarily a user's manual, and details of equation derivations are not normally presented. Important assumptions and approximations are stated without full justification. Some added equation detail is provided on the horizontal vent (Mark III) containment model. The following sections present a program summary description, compartment analytical model descriptions, compartment mass and energy transfer model descriptions, boiling water reactor pressure suppression system model discussions, and a complete program input and output description. These sections and their general content are:

(1) Section II, Program Summary Description: gives an overall summary of the CONTEMPT-LT program.

[a] CONTEMPT-LT/028 2/9/79 Configuration Control Number H00898IB.

(2) Section III, CONTEMPT-LT Compartment Analytical Models: describes the equations, assumptions, and options associated with a generalized compartment model; describes initialization of generalized compartment thermodynamic properties; and describes which program models are available for interaction with each of the four compartments.

(3) Section IV, Compartment Mass and Energy Transfer Models: describes the equations, assumptions, and options associated with models which describe mass and energy transfer processes between or with compartments. The models described are for fluid leakage; ECC and compartment cooling sprays, fans, and heat exchanger operation; tabular transfer processes; and heat structure energy storage and transfer.

(4) Section V, BWR Pressure Suppression System Models: describes the equations, assumptions, and options associated with BWR pressure suppression system models; including major sections on the vertical vent Mark I and Mark II designs, and on the newer horizontal vent Mark III design.

Appendix A briefly discusses the physical containment features of various reactor plants suitable for evaluation with CONTEMPT-LT. Appendix B provides a description of the vent flow control process. Appendix C presents the horizontal vent clearing model derivation and equations. Appendix D describes the computer program for generating tables of water properties that are used by CONTEMPT-LT. Appendix E describes the equations and options available to represent heat conducting structures, including details of three heat transfer coefficient correlations. Appendix F describes the vent flow equations and irreversible pressure loss models. Appendix G presents summary descriptions of each subroutine in CONTEMPT-LT and flow charts illustrating interaction among the various subroutines. Appendix H contains a complete input description in the exact form necessary for computer input. Appendix I provides additional descriptions for the various program output parameters. Appendix J presents a CONTEMPT-LT sample problem. The first public version of CONTEMPT-LT was labeled Version 024 and documented in ANCR-1219. Version 026 was then developed and released to the Argonne Code Center in April 1976. No changes were made to ANCR-1219 at that time. Appendix K describes in detail the model differences between the CONTEMPT-LT/026 code and the CONTEMPT-LT/028 code which is the current public version.

The CONTEMPT-LT computer program is being released as a current calculational method for estimating thermal and hydraulic transient phenomena in containment systems of light-water reactors and similar experimental facilities.

II. PROGRAM SUMMARY DESCRIPTION

CONTEMPT-LT is a computer program developed to describe the thermal-hydraulic behavior of reactor containment systems subjected to postulated accident conditions. CONTEMPT-LT provides a numerical method for analyzing the transient containment behavior of pressurized water reactors, boiling water reactors (Mark I, Mark II, or Mark III), and experimental water reactor simulators or related experiments. CONTEMPT-LT predicts the interrelated effects of reactor system blowdown, heat transfer, atmosphere leakage, safeguard system operation, pressure suppression system response, and miscellaneous mass and energy additions.

Compartments modeled with CONTEMPT-LT may contain two separated regions (vapor and liquid pool) at different temperatures. Models allow pool boiling or evaporation, and condensation from the vapor region is calculated. Up to four unique compartments may be modeled in the program. Various input tables control time-dependent mass and energy additions to the drywell compartment. Spray system operation, heat transfer, and leakage also modify mass and energy inventories of the various compartments.

Program input formats are defined in Appendix H, and the output symbols and results are described in Appendix I.

CONTEMPT-LT/028 is the most recent code in a series of computer programs[1,2,3] developed to describe the thermal-hydraulic conditions attendant to various postulated transients in the containments of light-water reactor systems. CONTEMPT-LT/028 incorporates the various improvements and modifications to CONTEMPT-LT since publication of the CONTEMPT-LT document[1]. The major modifications and improvements are:

(1) A drywell pressure flash model, added as a user option, for use in ECCS back pressure analysis

(2) A Tagami heat transfer correlation analytical model

(3) An annular fan analytical model to control the annular compartment pressure and to monitor the radionuclide release to the biota

(4) Several new heat structure modifications and options

(5) A maximum pressure stop switch to terminate the code if the pressure in any compartment (except the primary) exceeds the input switch value

(6) An expanded spray edit output

(7) A dial to specify the amount of the condensate formed in cooling coils and heat structures that will fall into the pool region

(8) Corrections to the pool evaporation/condensation models and the Uchida heat transfer models.

III. CONTEMPT-LT COMPARTMENT ANALYTICAL MODELS

The models used in CONTEMPT-LT to describe each compartment are presented in this section. Program evolvement has led to different features available in each compartment. This section first describes the models applicable to a basic or generalized compartment. The wetwell, drywell, and annular compartments are generalized compartments. Each generalized compartment model includes a vapor region and a liquid pool region. Evaporation, condensation, and pool boiling processes are modeled. The reactor primary system compartment is not considered to be a generalized compartment and is represented as a one-region model with boiling and water overflow processes calculated. Initialization of thermodynamic conditions in each generalized compartment is included in the basic compartment model discussion.

Following the descriptions of generalized compartment models and initialization, each of the four compartment models are individually discussed. The mass and energy transfer models applicable to each compartment are mentioned to further characterize the unique features of each compartment model. Extensive discussion of specific mass and energy transfer models is presented in Sections IV and V. Section IV describes models of fluid leakage; fan coolers, sprays, heat exchanger operation, and annular fan operation; heat structure energy storage and transfer; and tabular mass and energy transfer. Section V describes BWR pressure suppression system mass and energy transfer models. All of these models describe processes which alter the mass and energy within a containment compartment and therefore the compartment pressure and temperature. Compartment pressure and temperature are the main variables of interest in a containment analysis, and therefore great emphasis is placed on compartment models, with secondary interest directed toward the mass and energy transfer models.

CONTEMPT-LT assigns specific numbers to each compartment; namely, Compartment 1 is the reactor primary system, Compartment 2 is the wetwell, Compartment 3 is the drywell, and Compartment 4 is the dual or annular compartment.

Descriptions of various analytical models applicable for each generalized compartment are presented. The primary system compartment is not considered to be a generalized compartment. Each generalized compartment contains a vapor region and possibly a liquid pool region. Models for mass and energy transfer between the two regions are discussed.

1. DESCRIPTION OF GENERALIZED COMPARTMENT MODEL

Figure 1 depicts general compartment features. Each generalized compartment may contain a liquid pool region with a vapor region above the pool. The regions may have different temperatures and may experience heat and mass transfer as discussed in this section and in Sections IV and V. Leakage into or out of the vapor region is allowed. Also, heat transfer to, from, or through various structures is provided for each region. Mass and

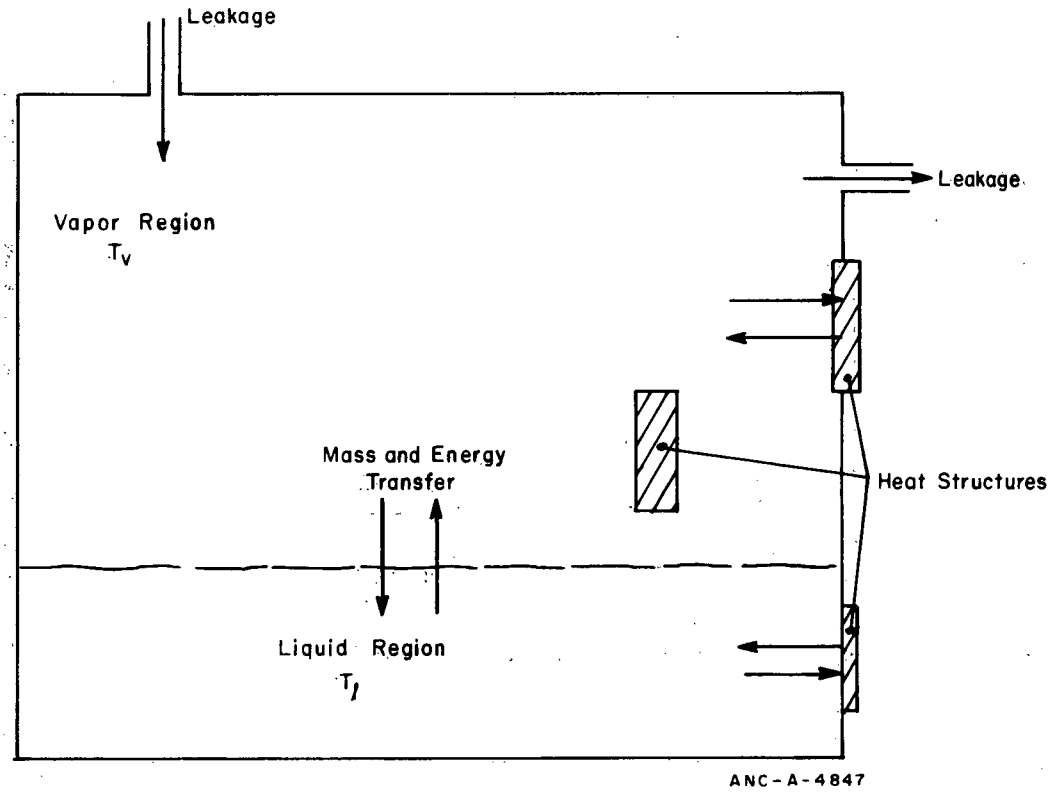

Fig. 1 General compartment features.

energy transfer by leakage and heat structures is discussed in Section IV. This section describes the analytical models representing a generalized compartment vapor region and boiling, evaporation, and condensation interactions between the vapor and pool regions. Initialization of compartment thermodynamic conditions is described.

1.1 Vapor Region

During a timestep, the mass and energy in a compartment vapor region may be modified by boiling, evaporation, or condensation interactions with the liquid pool; by heat transfer through structures; by wall leakage; by safeguard systems; possibly by pressure suppression systems; or by tabular additions which are input to the program. Given updated region masses of air and water, along with the total energy, iterations may be performed through use of the steam tables and trial temperature values, until a mass-energy balance is achieved.

The thermodynamic properties of water and steam required by the CONTEMPT-LT program must be computed external to the program and made available to the program as a data set. The STH20 program, which is described in Appendix D, generates the tables of water properties as a data set in the proper format for CONTEMPT-LT. Properties stored in the tables as functions of pressure and temperature include specific volume, specific internal energy, isobaric heat capacity, specific enthalpy, coefficient of thermal expansion, and isothermal compressibility. The data spacing in the tables is variable, permitting the density

to be greatest where the most accuracy is required. Subroutines are included in CONTEMPT-LT to compute the water properties in a given state from differing sets of input variables. The program conventionally uses temperature and specific volume which may be used for both single- and two-phase conditions.

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

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

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

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

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

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

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

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

where

c_v	=	constant volume heat capacity of air
M_a	=	mass of air
M_{wv}	=	mass of water
p	=	total pressure
p_{wv}	=	pressure of water
R_a	=	gas constant for air
T_v	=	temperature (absolute units)
U_v	=	total internal energy
u_w	=	specific internal energy of water
V_v	=	volume
x	=	quality of two-phase region

v_f = specific volume of saturated liquid

v_g = specific volume of saturated vapor

v_w = specific volume of water.

These equations are based on the assumptions of the Gibbs-Dalton law for vapors, that no vapor is dissolved in the liquid, that air is a perfect gas, and that all components are at the same temperature.

Equations (1) through (5) are solved iteratively. The quantities, V_v, U_v, M_{wv}, and M_a are given and T_v, p, and x are to be determined. The compartment equation of state iterative solution process is described in detail in Section 1 of Appendix B, with one exception. Appendix B discusses the solution for a vent pipe flow element and is based on enthalpy transport rather than internal energy. With this exception, the details are identical for compartment and vent flow element equation of state solutions, and, in both cases, subroutine COMPU is used to obtain that solution.

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

$$M_{wvv} = x\, M_{wv} \tag{6}$$

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

Disposition of the liquid ($M_{wv\ell}$) is discussed in Section III-1.3 as part of the pool-vapor region interactions.

1.2 Liquid Region

During a timestep, the mass and energy in a compartment pool, or liquid region, may be modified by interactions with the vapor region, by heat transfer through structures, possibly by safeguard systems or pressure suppression systems, or possibly by tabular additions which are input to the program. Given updated liquid region mass and energy, the temperature and specific thermodynamic properties are obtained. No requirement exists in CONTEMPT-LT that a liquid region exist within a generalized compartment.

The compartment liquid region, if it exists, is assumed to be a single-phase liquid (quality = 0) at saturation conditions. The pool specific energy for liquid ($u_{\ell p}$) is calculated from

$$u_{\ell p} = \frac{U_\ell}{M_{w\ell}} \tag{8}$$

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 STH20U routine (Appendix D). The liquid pool volume (V_ℓ) is determined by

$$V_\ell = M_{w\ell}\, v_{\ell p} \quad . \tag{9}$$

1.3 Liquid-Vapor Region Interactions

Except for the primary system (a single-region compartment) each compartment 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 interface.

The following two sections describe pool boiling, pool evaporation, vapor region condensation, and interface energy transfer.

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_{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:

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

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

1.3.2 Evaporation, Condensation, and Sensible Heat. If pool boiling occurs during a timestep, no evaporation or condensation is permitted during the same timestep. 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 movement changes.

Figure 2 depicts a simplified representation of a generalized compartment in CONTEMPT-LT. A pool with bulk temperature T_f is considered.

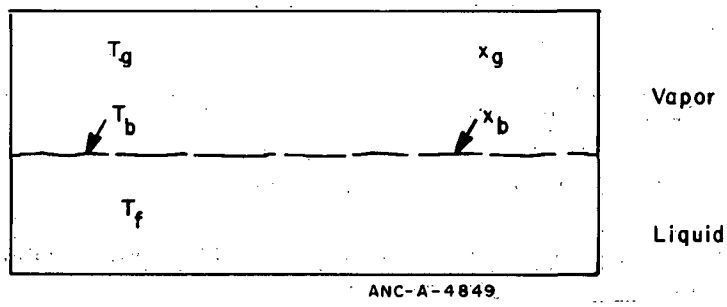

Fig. 2 Compartment containing liquid and vapor regions.

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[4].

$$\phi = C_1 h_b\, (T_g - T_b) + \left[C_2 K_b M_g (i_{fg} + i_f)(x_g - x_b) \right] / x_{am} \tag{14}$$

where

ϕ = surface heat flux

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

C_1 = input heat transfer multiplier constant

C_2 = input mass transfer multiplier constant

K_b = mass transfer coefficient

M_g = molecular weight of water

i_f = specific internal enthalpy of fluid transferred

i_{fg} = latent heat of vaporization

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 $C_1 = C_2 = 1$. CONTEMPT-LT will check and assure that the mass transferred within a given timestep does not exceed the total mass of water available in the region involved. For pressure suppression calculations, the user may also select an input option which affects only the drywell and, if selected, no evaporation or condensation effects are calculated in the drywell until both blowdown and vent flow have stopped. The sensible heat transfer term of Equation (14) is unaffected by this option; that is, it is always evaluated and applied.

The remainder of the present section describes how the terms in Equation (14) are evaluated for use in CONTEMPT-LT. 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[4]

$$x_{am} = \frac{x_{ab} - x_a}{\ln(x_{ab}/x_a)} \tag{15}$$

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 CONTEMPT-LT, 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[5,6]

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

$$\frac{h_b L}{k_b} = 0.14\ (Gr\ Pr)_b^{1/3} \tag{16}$$

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

$$\frac{h_b L}{k_b} = 0.54\ (Gr\ Pr)_b^{1/4} \tag{17}$$

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

$$\frac{h_b L}{k_b} = 0.27\ (Gr\ Pr)_b^{1/4} \tag{18}$$

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

$$Gr = \frac{\beta g \Delta T L^3 \rho^2}{\mu^2} \tag{19}$$

$$Pr = \frac{C_p \mu}{k} \tag{20}$$

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[5]

$$K_b = \frac{h_b}{C_{pg} M_g} \left(\frac{Pr}{Sc}\right)^{2/3} \tag{21}$$

where

C_{pg} = specific heat of vapor region

Sc = Schmidt number.

The Schmidt number is defined by

$$Sc = \frac{\mu}{\rho D_{AB}} \tag{22}$$

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[5]. The diffusivity D_{AB} can be estimated from[5]

$$D_{AB} = \frac{a}{p} \left(\frac{T}{\sqrt{T_{cA} T_{cB}}}\right)^b (p_{cA} p_{cB})^{1/3} (T_{cA} T_{cB})^{5/12} \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{1/2} \tag{23}$$

where

a = constant = 3.688×10^{-3} for water and air

b = constant = 2.334 for water and air

T = temperature of mixture

p = pressure of mixture

T_{cX} = critical temperature of component X

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 (23) reduces to

$$D_{AB} = \frac{4.40 \times 10^{-6} \, T^{2.334}}{p} \, . \tag{24}$$

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 (21) cannot be used to calculate K_b. In this case, K_b is calculated from[8]

$$K_b = \frac{\gamma p D_{AB}}{LRT} \left[\frac{L^3 g (\rho_o - \rho_b)}{\mu D_{AB}} \right]^{0.373} \quad (25)$$

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.

If the mass transfer rate is large, the sensible heat transfer rate h_b is no longer independent of mass transfer. The transfer rate will also include sensible heat transfer by the vapor molecules, in which case the sensible heat transfer coefficient h_b' with mass transfer is related to that without mass transfer by[5]

$$h_b' = \left[\frac{a}{e^a - 1} \right] h_b \quad (26)$$

where

$$a = \frac{K_b M_g C_{pg} (x_g - x_b)}{h_b x_{am}} \quad (27)$$

1.4 Initialization of Generalized Compartment Conditions

The problem input defines necessary compartment parameters at initial steady state conditions. Calls to the STH201 and STH203 steam table routines provide specific property values for the compartment regions. The water vapor partial pressure in each compartment vapor region is determined from

$$p_{wv} = p_s \, HUM \quad (28)$$

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

$$M_{wvv} = V_v \, HUM/v_g \tag{29}$$

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

$$M_a = \frac{V_v \, (p_t - p_{wv})}{T_v \, R_a} \tag{30}$$

where

p_t = total pressure in vapor region

T_v = absolute temperature of compartment vapor region

R_a = gas constant for air.

The intial energy associated with the air (U_a) is

$$U_a = M_a \, c_{va} \, T_v \tag{31}$$

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.

2. DUAL COMPARTMENT MODEL

The dual or annular compartment model available in CONTEMPT-LT has the features of a generalized compartment. A vapor region and a liquid pool region may exist in the compartment. The models available for mass and energy transfer with other compartments are restricted to leakage and heat structures and an annular fan. The annular fan model is provided for pressure control and may be used to determine the net radionuclidic release to the atmosphere.

3. DRYWELL COMPARTMENT MODEL

The drywell compartment model possesses all the features of a generalized compartment. In addition, all of the mass and energy transfer processes described in Section IV are available to the drywell model. If a BWR pressure suppression system (PSS) is being modeled, then the PSS mass and energy transfer features discussed in Section V are also available to the drywell model. Finally, in CONTEMPT-LT, there is a unique relation between the reactor primary compartment model and the drywell model, which is described in Section III-5.

The program user may select an option to prevent liquid condensation fallout from the drywell vapor region during blowdown of the primary system if a pressure suppression problem is being evaluated. When this option is specified, the condensation is bypassed until two conditions are satisfied: (1) blowdown of the primary system has stopped (defined to occur at last time entry on 3XX cards), and (2) PSS vent system flow has ceased. After these conditions are satisfied, the drywell condensation proceeds normally.

The program user may specify that a pressure flash model be used to calculate drywell thermodynamic conditions. This choice can result in slightly lower containment pressure during periods when the blowdown fluid is predominantly liquid. Contrary to the temperature flash method (described in Section III-1.1) which assumes that the entering blowdown fluid is instantaneously mixed with and reaches thermal equilibrium with the vapor region, the pressure flash model allows the blowdown fluid to flash into steam based on the total compartment pressure before fluid equilibrium has been reached. The equation used to determine the amount of blowdown liquid which has flashed is

$$M_{flash} = \frac{U_{liq} - M_{liq}\, h_{\ell b3}}{h_{gb3} - h_{\ell b3}} \tag{32}$$

where

M_{flash} = mass of blowdown liquid which flashes

U_{liq} = total step energy of blowdown fluid which enters drywell

M_{liq} = mass of blowdown fluid initially entering drywell atmosphere

$h_{\ell b3}$ = specific enthalpy of liquid at boiling based on total pressure

h_{gb3} = specific enthalpy of vapor at boiling based on total pressure.

Any remaining unflashed liquid (M_{left}) and its energy (U_{left}) is then transferred to the pool region.

$$M_{left} = M_{liq} - M_{flash} \tag{33}$$

$$U_{left} = M_{left}\, h_{\ell b3} \tag{34}$$

The procedure described in Section III-1.1 relating to the temperature flash method [Equations (1) through (7)] is then used to determine the final drywell thermodynamic conditions.

4. WETWELL COMPARTMENT MODEL

The wetwell compartment model possesses all features of a generalized compartment. In addition, cooling sprays and associated heat exchanger models are available to the wetwell compartment. If a BWR pressure suppression system is being evaluated, then the associated mass and energy transfer processes, discussed in Section V, are available to the wetwell compartment model.

5. REACTOR PRIMARY SYSTEM COMPARTMENT MODEL

The reactor primary system compartment model is not a generalized compartment model. The primary system (also called primary) compartment is modeled as a single region containing liquid water mass and energy. No evaporation or condensation processes are considered. Boiling and overflow of the liquid is modeled. If the primary system liquid boils, the boiled-off mass and energy are immediately transferred to the drywell vapor region. If the primary system overflows, perhaps from additions of emergency core coolant system (ECCS) water, the overflow water is immediately transferred to the drywell floor or pool region. No pressure dependent flow connections exist between the primary and any other compartment. Leakage is not allowed in the primary compartment model. Mass and energy transfer from ECCS spray operation and decay heat and metal-water reactions, represented by tabular input, are modeled after blowdown of the primary system has finished. Heat transfer through wall structures between the primary system and any other compartment is allowed at any time during a problem, except no energy changes are made to the primary system until blowdown has finished. As an example, a heat structure connecting the primary and drywell compartments is considered. During blowdown of the primary system, the drywell model will either receive energy from the primary system or lose energy into the heat structure. The drywell energy is adjusted accordingly. However, the primary system energy change is set to zero until blowdown has been completed. The equations solved in CONTEMPT-LT to evaluate primary compartment boiling and overflow are presented. A

specific relationship between the primary system and drywell compartment models exists. Boiling will occur if

$$\frac{U_{t1}}{M_{wt1}} > u_{\ell b3} \tag{35}$$

where

U_{t1} = primary system total energy

M_{wt1} = primary system total mass of water

$u_{\ell b3}$ = drywell specific energy of liquid at boiling, based on total pressure.

If boiling occurs, the mass of water boiled off is immediately transferred to the drywell vapor region. The transferred mass (m_{boil}) is

$$m_{boil} = \frac{U_{t1} - M_{wt1}\, u_{\ell b3}}{u_{gb3} - u_{\ell b3}} \tag{36}$$

where

u_{gb3} = drywell specific energy of vapor at boiling, based on total pressure.

The primary system and drywell masses and energies are adjusted as follows:

$$U_{v3} = U_{v3} + m_{boil}\, u_{gb3} \tag{37}$$

$$M_{wv3} = M_{wv3} + m_{boil} \tag{38}$$

$$M_{wt1} = M_{wt1} - m_{boil} \tag{39}$$

$$U_{t1} = u_{\ell b3}\, M_{wt1} \tag{40}$$

where

M_{wv3} = mass of water in drywell vapor region

U_{v3} = total energy of drywell vapor region.

After primary system boiling, if any, has been completed, a check is performed to determine whether excess water is present in the primary system which could spill over into the drywell liquid pool. Overflow will occur if

$$M_{wt1}\, v_{\ell b3} > V_1 \tag{41}$$

where

$v_{\ell b3}$ = drywell specific volume of liquid at boiling, based on total pressure

V_1 = primary system total volume.

If overflow does occur, the primary system and drywell pool masses and energies are modified as follows:

$$m_{spill} = \frac{M_{wt1}\, v_{\ell b3} - V_1}{v_{\ell b3}} \tag{42}$$

$$M_{wt1} = M_{wt1} - m_{spill1} \tag{43}$$

$$M_{w\ell 3} = M_{w\ell 3} + m_{spill1} \tag{44}$$

$$U_{t1} = U_{t1} - m_{spill1}\, h_{\ell p3} \tag{45}$$

$$U_{\ell 3} = U_{\ell 3} + m_{spill1}\, h_{\ell p3} \tag{46}$$

where

m_{spill} = mass of liquid water overflowing to the drywell floor

$M_{w\ell 3}$ = mass of liquid water in drywell pool region

$U_{\ell 3}$ = total energy in drywell pool region

$h_{\ell p3}$ = specific enthalpy of saturated liquid based on drywell pool region specific energy and zero quality.

After primary system boiling and overflow calculations have been completed, the primary system specific energy (U_{t1}/M_{wt1}) is determined and used as an entry to the steam tables (STH20U) to obtain the primary system temperature and pressure.

In CONTEMPT-LT, the end of blowdown is defined to occur at the time corresponding to the last time entry on the blowdown mass and energy addition table (3XX cards). This time is an important logic switch in the program, because primary compartment changes are not allowed until blowdown has been completed.

IV. COMPARTMENT MASS AND ENERGY TRANSFER MODELS

Specific models used in CONTEMPT-LT to transfer mass and energy between compartments are described in this section. Section III described the compartment models, with emphasis on mass and energy exchange processes which occur between the two compartment regions. Most processes which transfer mass and energy into or out of a compartment are discussed in this section. BWR pressure suppression system models transfer mass and energy between two specific compartments, and because those models are complicated and apply only in BWR calculations, they are described separately (in Section V).

This section first discusses the leakage models, which calculate vapor flow between the vapor regions of two compartments. The ECCS and cooling spray models are then described, along with the associated heat exchanger models. A model representing fan coolers is also described. Mass and energy tabular models are discussed next, and finally the heat conducting structure models are explained. Appendix E presents considerable detail on the equations and options of the heat structure models.

Models described in this section are used in a particular CONTEMPT-LT problem evaluation only if they have been selected by the program user. Leakage may be specified between any two compartments, or between any compartment and the outside atmosphere, except the primary system compartment may not be included in this model application. ECCS and cooling sprays may be modeled in all compartments except the dual compartment. The fan cooler model may be used only in the drywell. Tabular mass and energy additions are mainly restricted to modeling in the drywell, but decay heat and metal-water reaction energy transfer models can be specified in the primary system compartment. Energy transfer by heat conducting structures can be assigned to any compartment model, with limitations on the primary system compartment transfer prior to completion of the blowdown of the primary system.

1. COMPARTMENT LEAKAGE MODEL

CONTEMPT-LT allows two types of leakage calculations -- normal compartment leakage determined from tabular input and program calculations and penetration leakage determined from program calculations. Leakage models may be associated with all compartments except the primary system compartment.

1.1 Normal Leakage

For normal or small-crack leakage, the mass leakage rate (W_{LN}) is determined from

$$W_{LN} = K_L \rho (p_i - p_e) \tag{47}$$

where

K_L = input leakage coefficient, including an area factor

ρ = density of flowing vapor

p_i = pressure in inlet compartment

p_e = pressure in exit compartment.

Associated compartment mass and energy modifications resulting from normal leakage are described below in Section IV-1.3.

1.2 Penetration Leakage

For penetrations, the flow is assumed to be through one of three types of nozzles: a converging nozzle, a diverging nozzle, or a converging-diverging nozzle. In each case, the equation of the mass leakage rate (W_{LP}) is

$$W_{LP} = C_d A_* Z p_i \sqrt{\frac{2\gamma}{(\gamma-1) R_m T_i}} \sqrt{1 - Z^{\gamma-1}} \qquad (48)$$

where

C_d = an input constant, usually 1.0

A_* = nozzle throat area

p_i = pressure at inlet side

T_i = absolute temperature of flowing mixture

γ = ratio of C_p/C_v for air = 1.4

R_m = gas constant of the air and water vapor mixture

Z = function of pressure ratio as defined subsequently.

The mass averaged gas constant is determined from

$$R_m = \frac{M_a R_a + M_{wv} R_{wv}}{M_a + M_{wv}} \qquad (49)$$

where

M_a = mass of air in mixture

M_{wv} = mass of water vapor in mixture

R_a = gas constant for air

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

$$Z = \left(\frac{p_e}{p_i}\right)^{\frac{1}{\gamma}} \quad \text{for } \frac{p_e}{p_i} > \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} = 0.528 \tag{50}$$

or

$$Z = \left(0.528\right)^{\frac{1}{\gamma}} = \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \quad \text{for } \frac{p_e}{p_i} \leq 0.528. \tag{51}$$

The determination of Z for a converging-diverging nozzle is calculated from Equations (50) and (51) for sonic flow, and for subsonic flow the following equation is used:

$$Z = \left(\frac{p_*}{p_i}\right)^{\frac{1}{\gamma}} \tag{52}$$

where

p_* = pressure at the nozzle throat.

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

$$\frac{A_e}{A_*} = \frac{M_*}{M_e}\left[\frac{1 + \frac{\gamma-1}{2} M_e^2}{1 + \frac{\gamma-1}{2} M_*^2}\right]^{\frac{\gamma+1}{2(\gamma-1)}} \tag{53}$$

$$\left(\frac{p_i}{p_e}\right)_c = \left[1 + \frac{\gamma-1}{2} \left(M_{e_c}^2\right)\right]^{\frac{\gamma}{\gamma-1}} \tag{54}$$

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 (53) and solving the equation by using Newton's method. This value of M_{e_c} is used in Equation (54) 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 (50).

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 (55). The resulting value of M_e^2 is used in Equation (53) to calculate M_* by iteration, and Equation (56) is used to calculate (p_*/p_e). Equation (52) is then solved for Z.

$$M_e^2 = \frac{2}{\gamma-1}\left[\left(\frac{p_i}{p_e}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \tag{55}$$

$$\frac{P_*}{P_e} = \left[\frac{1 + \frac{\gamma-1}{2} M_e^2}{1 + \frac{\gamma-1}{2} M_*^2}\right]^{\frac{\gamma}{\gamma-1}} \tag{56}$$

Mass and energy transfer resulting from penetration leakage flow is discussed in the next section.

1.3 Mass and Energy Transfer

This section discusses compartment mass and energy transfer resulting from normal and penetration leakage. Donor compartment (inlet side of nozzle) mass and energy updates are performed according to the following equations. A positive leak rate represents mass leaving the donor compartment.

$$U_v = U_v - \overline{\Delta U_N} - \overline{\Delta U_P} \tag{57}$$

$$M_a = M_a - \overline{[r_a (W_{LN} + W_{LP}) \Delta t]} \tag{58}$$

$$U_a = M_a \cdot c_{pa} \cdot T_v \tag{59}$$

$$M_{wv} = M_{wv} - \overline{[r_w (W_{LN} + W_{LP}) \Delta t]} \tag{60}$$

where

U_v = total energy of vapor region of donor compartment

$\overline{\Delta U_N}$ = average energy removed from donor compartment due to normal leakage

$\overline{\Delta U_P}$ = average energy removed from donor compartment due to penetration leakage

M_a = total mass of air in donor compartment

U_a = total energy of air in donor compartment

c_{pa} = specific heat of air at constant pressure

T_v = absolute temperature of vapor region in donor compartment

M_{wv} = total mass of water in vapor region of donor compartment

r_a = mass fraction of air in nozzle flow

r_w = mass fraction of water vapor in nozzle flow

Δt = timestep length.

$\overline{\Delta U_N}$ and $\overline{\Delta U_P}$ are the averages of $\dot{U}_N$ and $\dot{U}_P$, averaged over two timesteps, multiplied by the timestep length, Δt. $\dot{U}_N$ and $\dot{U}_P$ are the rates of energy removal from the donor compartment due to normal and penetration leakage, respectively. The energy removal rates are determined from

$$\dot{U}_N = + r_a W_{LN} T_v c_{pa} + r_w W_{LN} h_g \tag{61}$$

$$\dot{U}_P = + r_a W_{Lp} T_v c_{pa} + r_w W_{LP} h_g \tag{62}$$

where

c_{pa} = specific heat of air at constant pressure

h_g = specific enthalpy of water vapor in donor compartment

and

$$r_a = M_a / (M_a + M_{wv}) \tag{63}$$

$$r_w = 1 - r_a \, . \tag{64}$$

The compartments receiving the leakage flow are permitted to be different for normal and penetration leakage. Subscript eN represents the compartment on the exit side of the leak for normal leakage, and eP represents the compartment on the exit side of the leak for penetration leakage. The normal leakage effects are determined by

$$U_{veN} = U_{veN} + \overline{\Delta U}_N \tag{65}$$

$$M_{aeN} = M_{aeN} + \overline{(r_a \; W_{LN} \; \Delta t)} \tag{66}$$

$$U_{aeN} = U_{aeN} + \overline{[c_{va} \; (r_a \; W_{LN} \; \Delta t) \; T_{vi}]} \tag{67}$$

$$M_{wveN} = M_{wveN} + \overline{(r_w \; W_{LN} \; \Delta t)} \tag{68}$$

where all symbols have been previously defined. Similarly, the penetration leakage inventory changes in compartment eP (exit side of penetration leak) are determined from Equations (65) through (68), with subscript eP substituted for eN, W_{LP} for W_{LN}, and ΔU_P for ΔU_N.

2. SAFETY SYSTEM MODELS

Safety systems modeled in CONTEMPT-LT include emergency core cooling systems (ECCS), compartment cooling sprays, and fan coolers. The ECCS and cooling sprays may interact with all compartments except the dual compartment. Fan coolers can be modeled only in the drywell compartment. Heat exchangers may be modeled with the spray system, and are discussed separately in Section IV-2.2.

2.1 ECCS and Cooling Sprays

The ECC and cooling spray systems are described by two tables and two control cards. The two tables are essentially identical and each allows specification of distribution and source mass flow rates as a function of time. CONTEMPT-LT allows spray system control with either a combination of time-dependent table input and drywell pressure switches or with just the table input alone. If the total pressure of the drywell vapor region exceeds the startup switch limit and also exceeds the shutoff switch limit, then the table input is used to describe the spray system. If both switch limits are zero, then control is entirely by table input. Features of the spray model are illustrated in Figure 3 where S_D, S_W, and S_{EX} represent source fractions of the spray water total flow rate (W_S) originating from the drywell pool, wetwell pool, and external sources, respectively. Water from the two pools can pass through a heat exchanger which may be used to modify the temperature of water pumped from the drywell or wetwell pools. D_{DV}, D_{WV}, D_P, D_{DL}, and D_{EX} represent the fraction distribution of W_S to the drywell vapor region, wetwell vapor region, primary system, drywell liquid pool, and loss from the containment system, respectively.

All source and distribution fractions are input quantities, as are W_S, the total spray system flow rate, and η_S, the spray heat transfer efficiency. This efficiency is used in both the drywell and the wetwell models and is defined as

$$\eta_S = \frac{h_{sf} - h_s}{h_e - h_s} \tag{69}$$

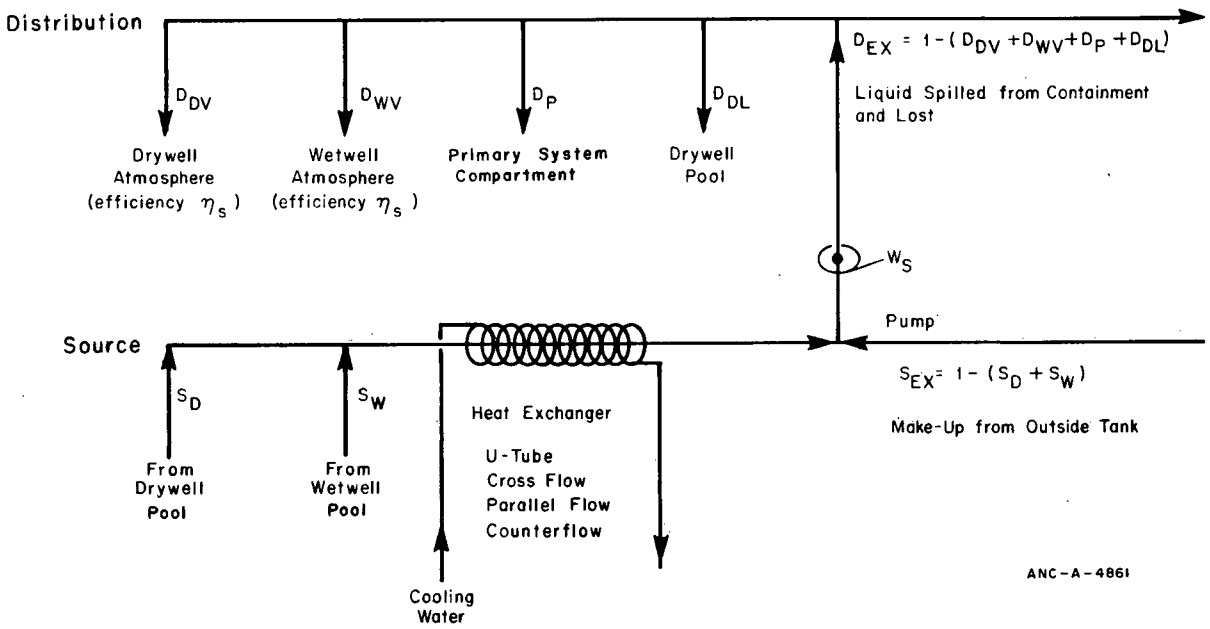

Fig. 3 ECC and cooling spray model.

where

h_s = specific enthalpy of spray droplets leaving spray nozzle

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

h_e = end point specific enthalpy of water in the vapor region prior to spray effects. If the vapor region is saturated, h_e equals the specific enthalpy of liquid in that region. If the region is superheated, h_e equals the specific enthalpy of water vapor for the region.

If a heat exchanger is specified to cool the spray source water, the specific enthalpy of the drywell and wetwell liquid leaving the heat exchanger is h_{hx} (described in the next subsection). If no heat exchanger is used, then a mass-averaged specific enthalpy (h_{av}) is used to represent the drywell and wetwell source water. The averaged specific enthalpy is

$$h_{av} = (S_D\, h_{\ell p3} + S_W\, h_{\ell p2})/(S_D + S_W) \tag{70}$$

where

$h_{\ell p3}$ = specific enthalpy of liquid water in the drywell pool region

$h_{\ell p2}$ = specific enthalpy of liquid water in the wetwell pool region.

If $S_D + S_W$ equals zero, then h_{av} is set to zero. Either S_D or S_W is set to zero if no pool of water exists in that particular compartment.

The final average specific enthalpy of the spray liquid (h_s) is determined from

$$h_s = [(S_D + S_W)\ h_{hx} + S_{EX}\ h_{ex}]/(S_D + S_W + S_{EX}) \tag{71}$$

where

h_{ex} = specific enthalpy of external source water.

If $S_D + S_W + S_{EX}$ equals zero, the spray system calculation is bypassed. If no heat exchanger is used, h_{av} replaces h_{hx} in Equation (71). For a superheated vapor region, Equation (69) may be solved for h_{sf}, including both phases if present, by using the input spray efficiency. The specific enthalpy h_{sf} and the compartment partial vapor pressure are then used to determine the final quality (x) of the spray water after the water has interacted with the vapor region. An efficiency modifier δ_s is defined such that for superheated regions the product $\eta_s\ \delta_s$ equals unity. For saturated vapor regions, δ_s equals unity and the quality x always equals zero.

Drywell, wetwell, and primary system inventories are then updated to account for the mass and energy changes, as follows:

$$\Delta M_s = \Delta t\ W_S\ (S_D + S_W + S_{EX}) \tag{72}$$

$$\Delta H_{sv3} = \delta_s\ \eta_s\ \Delta M_s\ D_{DV}\ \left[h_{\ell 3}\ (1-x) - h_s\right] \tag{73}$$

$$\Delta H_{sv2} = \delta_s\ \eta_s\ \Delta M_s\ D_{WV}\ \left[h_{\ell 2}\ (1-x) - h_s\right] \tag{74}$$

$$U_{v3} = U_{v3} - \Delta H_{sv3} \tag{75}$$

$$M_{w\ell 3} = M_{w\ell 3} - \Delta t\ W_s\ S_D + \Delta M_s \left[D_{DV}\ (1-x) + D_{DL}\right] \tag{76}$$

$$M_{wv3} = M_{wv3} + \Delta M_s\ D_{DV}\ x \tag{77}$$

$$U_{\ell 3} = U_{\ell 3} - \Delta t\ W_S\ S_D\ h_{\ell p3} + \Delta H_{sv3} + \Delta M_S\ (D_{DV} + D_{DL})\ h_s \tag{78}$$

$$W_{wt1} = M_{wt1} + \Delta M_S\ D_P \tag{79}$$

$$U_{t1} = U_{t1} + \Delta M_S\ D_P\ h_S \tag{80}$$

and if a wetwell exists,

$$U_{v2} = U_{v2} - \Delta H_{sv2} \tag{81}$$

$$M_{w\ell 2} = M_{w\ell 2} - \Delta t\ W_S\ S_W + \Delta M_S\ D_{WV}\ (1-x) \tag{82}$$

$$M_{wv2} = M_{wv2} + \Delta M_S\ D_{WV}\ x \tag{83}$$

$$U_{\ell 2} = U_{\ell 2} - \Delta t\ W_S\ S_W\ h_{\ell p2} + \Delta H_{sv2} + \Delta M_S\ D_{WV}\ h_s \tag{84}$$

where x, δ_s were defined previously and

Δt = timestep length

$h_{\ell 3}$ = specific enthalpy of liquid water in drywell vapor region

$h_{\ell 2}$ = specific enthalpy of liquid water in wetwell vapor region

U_{v3} = drywell vapor region total energy

U_{v2} = wetwell vapor region total energy

U_{t1} = primary system total energy

M_{wt1} = primary system total mass

$M_{w\ell 3}$ = drywell pool region mass of water

$M_{w\ell 2}$ = wetwell pool region mass of water

M_{wv2} = wetwell vapor region mass of water

M_{wv3} = drywell vapor region mass of water

$U_{\ell 3}$ = drywell pool region total energy

$U_{\ell 2}$ = wetwell pool region total energy

and $h_{\ell p2}$, $h_{\ell p3}$ were defined following Equation (70).

2.2 Heat Exchangers

One of four different types of heat exchangers can be selected by the input data. The efficiency (η_{hx}) of the heat exchanger is calculated by using equations from Kays and London[9] for steady state conditions. These equations are as follows.

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

$$\eta_{hx} = 2 \left\{ 1 + \frac{C_{min}}{C_{max}} + \left[1 + \left(\frac{C_{min}}{C_{max}} \right)^2 \right]^{1/2} \left[\frac{1 + e^{-\alpha}}{1 - e^{-\alpha}} \right] \right\}^{-1} \tag{85}$$

where

$$\alpha = N_{tu} \left[1 + \left(\frac{C_{min}}{C_{max}} \right)^2 \right]^{1/2} \tag{86}$$

$$N_{tu} = A_{hx} H_{hx} / C_{min} \quad . \tag{87}$$

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 $C_h W_{hx}$ and $C_c W_c$. W_c is the cold leg flow in the heat exchanger, and W_{hx} is the hot leg flow which is $W_S (S_D + S_W)$ in Figure 3. Also, C_c and C_h 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:

$$\eta_{hx} = 1 - e^{-\alpha} \tag{88}$$

$$\alpha = \frac{C_{max}}{C_{min}} \left[1 - \exp \left(-N_{tu} \frac{C_{min}}{C_{max}} \right) \right] \tag{89}$$

if

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

or

$$\eta_{hx} = \frac{C_{max}}{C_{min}} \left(1 - e^{-\alpha} \right) \tag{90}$$

$$\alpha = \frac{C_{min}}{C_{max}} \left(1 - e^{-N_{tu}} \right) \tag{91}$$

if

$$C_{min} = C_{unmixed} \text{ and } C_{max} = C_{mixed} \quad .$$

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:

$$\eta_{hx} = (1 - e^{-\alpha}) \left(1 - \frac{C_{min}}{C_{max}} e^{-\alpha}\right)^{-1} \tag{92}$$

$$\alpha = N_{tu} \left(1 - \frac{C_{min}}{C_{max}}\right) \tag{93}$$

or if

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

then

$$\eta_{hx} = \frac{N_{tu}}{1 + N_{tu}} \cdot \tag{94}$$

For the parallel-flow heat exchanger:

$$\eta_{hx} = (1 - e^{-\alpha}) \left(1 + \frac{C_{min}}{C_{max}}\right)^{-1} \tag{95}$$

$$\alpha = N_{tu} \left(1 + \frac{C_{min}}{C_{max}}\right) . \tag{96}$$

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

$$T_{hx} = T_h - \frac{C_{min}}{C} \eta_{hx} (T_h - T_c) \tag{97}$$

where

T_h = hot leg water temperature

T_c = cold leg water temperature

C = $C_c W_{hx}$ = total heat capacity.

For T_{hx}, a value of h_{hx} is obtained from the steam tables (STH201) and Equation (68) is solved to obtain the spray enthalpy.

2.3 Fan Coolers

Some containment systems contain fan cooler units to circulate the containment atmosphere past cooling coils and thereby remove energy from the atmosphere. CONTEMPT-LT models a fan cooler, in the drywell only, by a simple time-dependent input table of heat removal (or addition) rates.

Input start and stop times control use of the fan cooler. The drywell vapor region total energy (U_{v3}) is adjusted according to

$$U_{v3} = U_{v3} + \Delta t \, \dot{U}_F \tag{98}$$

where

Δt = timestep length

$\dot{U}_F$ = input fan cooler heat removal rate.

Whenever superheated vapor region conditions exist in the drywell, the rate at which condensate forms on the cooling coils ($\dot{m}$) and is transferred to the pool region is calculated from

$$\dot{m} = fq/(h_v - h_\ell) \tag{99}$$

where

q = heat transfer rate used to calculate condensate dropout rate

h_v = specific enthalpy of vapor region

h_ℓ = specific enthalpy of liquid in vapor region

f = user specified fraction of condensate formed on cooling coils which is dropped into the pool region.

The drywell pool region total energy ($U_{\ell 3}$) is adjusted to account for the condensate formed using

$$U_{\ell 3} = U_{\ell 3} + \dot{m} \, h_\ell . \tag{100}$$

2.4 Annular Fan

The annular fan model describes the performance of a containment fan transferring mass and energy between the vapor regions of the annular compartment (in a dual containment system) and the outside compartment. Flow through the fan is defined by a user-input table of volumentric flow as a function of differential pressure between the compartments.

The performance of the fan is controlled by user-input start and stop times and minimum and maximum differential pressures. After the start time has been reached, the fan will still remain off until the differential pressure between the two compartments drops below the minimum specified by the user. It will then remain on until the maximum user specified differential pressure is reached.

The compartment inventories are updated according to

$$\dot{m} = \pm Q\rho \tag{101}$$

$$\dot{q} = \pm Qh\rho \tag{102}$$

where

$\dot{m}$ = mass flow rate

$\dot{q}$ = energy flow rate

Q = volumetric flow rate

ρ = average vapor region density

h = average vapor region enthalpy.

3. MASS AND ENERGY ADDITION TABULAR MODELS

The program user has several input tables available to describe various time-dependent mass and energy additions to the drywell compartment. Water mass and energy additions include primary system blowdown, primary system decay heat and metal-water reaction energy, and direct additions to the vapor and pool regions. Air may be added to the drywell vapor region. Tables of decay heat and metal-water reaction energy additions to the primary system compartment may be specified.

Quantities obtained from each time-dependent table are calculated by a linear interpolation of the tables for the midpoint of the time interval $(t + \frac{\Delta t}{2})$. Step changes of these quantities are obtained by insertion of the value just before the step change and the value just after the step change, both for the same time value.

3.1 Blowdown

Blowdown mass and energy additions are input to CONTEMPT-LT as a table of time, mass addition rate, and enthalpy (3XX cards). All additions for blowdown are to the vapor region of the drywell compartment, according to the following equations:

$$M_{wv3} = M_{wv3} + \Delta t \; R_{w1} \tag{103}$$

$$U_{v3} = U_{v3} + \Delta t \; R_{w1} \; h_{w1} \tag{104}$$

where

M_{wv3}= mass of water (vapor plus liquid) in vapor region of drywell

R_{w1} = blowdown mass addition rate of water

Δt = timestep length

h_{w1} = specific enthalpy of blowdown mass

U_{v3} = total energy of drywell vapor region.

The specific enthalpy value should include the internal energy, the Pv work term, and the kinetic energy of the incoming fluid. Within CONTEMPT-LT, blowdown is defined as ending with the last time entry on the 3XX cards. Prior to that time, reflood may have occurred and break effluent from reflooding may be included in the blowdown table input.

3.2 Primary Decay Heat and Metal-Water Reaction

The program user may model the effects of reactor primary decay heat and metal-water reactions by specifying time-dependent input tables. The energy increment resulting from this addition is

$$\Delta U = \Delta t \; (\lambda \; K_{\lambda 1} + E_{mw} \; K_{mw1}) \tag{105}$$

where

Δt = timestep length

λ = input decay energy release rate in primary system (cards 1XX)

E_{mw} = input metal-water reaction energy release rate in primary system (cards 2XX)

$K_{\lambda 1}, K_{mw1}$ = decay energy and metal-water reaction multipliers (cards 4XX).

Units for the input parameters inside the parentheses of Equation (105) are arbitrary within the limit that the products of $\lambda K_{\lambda 1}$, and $E_{mw} K_{mw1}$ must be in units of W or Btu/hr.

If blowdown of the primary system has not finished, Equation (105) is ignored and no primary system heat exchange is allowed. After blowdown has been completed, ΔU is used in the following manner. If the primary system contains some water, ΔU is added to the

total energy of the primary system. Otherwise, ΔU is added to the energy of the drywell vapor region. If the energy addition is sufficient, boiling of the liquid can occur. Primary system boiling creates a direct mass and energy contribution to the drywell atmosphere; however, no direct mass additions are user specified.

3.3 Direct Additions

Other input tables are provided to allow direct mass and energy additions to the drywell vapor or liquid pool regions. Specifically, tables are provided for: (1) water additions to the drywell pool, (2) water additions to the drywell vapor region, (3) water mass and decay heat and metal-water reaction energy additions to the drywell vapor region, and (4) air mass additions to the drywell vapor region. No provision exists for time-dependent input additions to the wetwell or dual compartments.

Time-dependent mass and energy additions to the drywell liquid pool region are specified on the 6XX cards, which contain sets of time, water mass addition rate, and heat addition rate. The appropriate equations are:

$$M_{w\ell 3} = M_{w\ell 3} + \Delta t \; R_{w\ell} \tag{106}$$

$$U_{\ell 3} = U_{\ell 3} + \Delta t \; R_{e\ell} \tag{107}$$

where

$M_{w\ell 3}$ = mass of water in drywell pool region

$U_{\ell 3}$ = total energy of drywell pool region

$R_{w\ell}$ = mass addition rate

$R_{e\ell}$ = energy addition rate.

If $R_{e\ell}$ is input as zero, CONTEMPT-LT will calculate an energy addition rate as the product of mass addition and drywell pool specific energy for liquid ($u_{\ell p}$).

$$R_{e\ell} = R_{w\ell} \; u_{\ell p} \tag{108}$$

This option is convenient when water is being removed from the drywell pool and the water addition rate is negative.

Additions to the drywell vapor region may be input on the 5XX cards, which contain sets of time, water mass addition rate, and energy addition rate. Mass (M_{wv3}) and energy (U_{v3}) of the drywell vapor are modified each timestep by

$$M_{wv3} = M_{wv3} + \Delta t \; R_{w2} \tag{109}$$

$$U_{v3} = U_{v3} + \Delta t \; R_{e2} \tag{110}$$

where

R_{w2} = input mass addition rate

R_{e2} = input energy addition rate.

Time-dependent variables ($K_{\lambda 2}$, K_{mw2}) used in the calculation of reactor decay heat and metal-water reaction energy additions to the drywell vapor region are input on the 7XX card series, along with another water mass addition rate parameter (R_{w3}) for the drywell vapor region. The drywell vapor region energy is modified by

$$U_{v3} = U_{v3} + \Delta t \; (\lambda \; K_{\lambda 2} + E_{mw} \; K_{mw2}) \tag{111}$$

where λ, E_{mw} are primary system decay heat and metal-water reaction energy release rates described previously [Equation (105)] and are input on the 1XX and 2XX cards. $K_{\lambda 2}$, K_{mw2} are energy multipliers to provide for decay heat and metal-water reaction contributions to the drywell atmosphere. Units are the same as described previously for Equation (105). R_{w3} is applied according to

$$M_{wv3} = M_{wv3} + \Delta t \; R_{w3} \quad . \tag{112}$$

A time-dependent direct air addition to the drywell atmosphere is input on the 9XX cards. This contribution is calculated from

$$M_{a3} = M_{a3} + \Delta t \; R_a \tag{113}$$

$$U_{v3} = U_{v3} + \Delta t \; R_a \; C_{pa} \; T_a \tag{114}$$

where

M_{a3} = mass of air in drywell vapor region

R_a = air mass addition rate

C_{pa} = specific heat of air at constant pressure

T_a = absolute temperature of incoming air.

The user may also specify step mass and energy additions to the drywell vapor region at the start of the problem. These additions are input on Card 11001 and are included in the problem initialization calculations.

4. HEAT CONDUCTING STRUCTURE ANALYTICAL MODEL

CONTEMPT-LT provides up to 20 heat conducting structures which can transfer heat between any combination of compartments or between any compartment and the outside air. The user specifies the physical connections and also specifies boundary conditions consisting of heat transfer coefficients and bulk temperatures. The boundary conditions may be input values or determined from selected correlations. This section summarizes the basic heat transfer equations, and CONTEMPT-LT options available to describe program boundary conditions of bulk temperature and heat transfer coefficients. Equations are presented which describe the compartment energy changes resulting from the presence of heat structures. Appendix E presents considerable detail on the derivation of the numerical equations solved, and on the various available boundary conditions. Most of the heat structure analytical capability originated from the HEAT-1 program[10].

4.1 Temperature Distribution

The temperature distribution through each structure is determined by solving the one-dimensional multiregion heat-conduction equation by the method outlined in Appendix E. The partial differential equation for which a numerical approximation is derived is

$$g(x)\ \frac{\partial u(x,\ t)}{\partial t} = \nabla \cdot k(x)\ \nabla u(x,\ t) + S(x,\ t) \qquad (115)$$

where

u = temperature

x = space variable

t = time variable

g = volumetric heat capacity

k = thermal conductivity

S = source term per unit volume.

Numerical approximations to Equation (115) are derived in Appendix E for slab, cylindrical, and spherical geometries in one space dimension. Figure 4 illustrates the placement of mesh points at which the temperatures will be calculated.

Mesh points are placed such that they lie on the exterior boundaries of the problem, at the interfaces between materials, and at equal intervals between the interfaces or boundaries. Up to 101 mesh points for each structure are allowed by the code. A region is a segment of space which contains the same material throughout and has a constant spacing between mesh points. Up to twenty regions for each structure are allowed, and each may

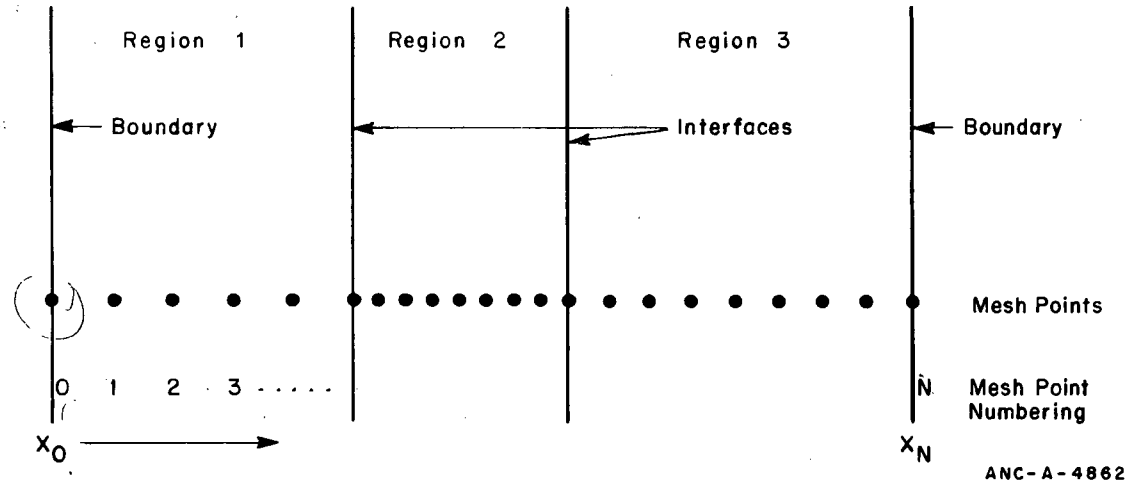

Fig. 4 Mesh point layout.

contain a different material. A new region is required whenever a material interface exists or a different mesh point spacing is desired. The recommendation is that no mesh spacing change occur at interfaces of significantly dissimilar materials, and also that a mesh spacing should not change by more than a factor of three within the same or similar materials.

4.2 Boundary Conditions and Options

The boundary conditions are of the general form

$$A(u, t)u + B(u, t) \frac{\partial u}{\partial \bar{n}} = D(u, t)\, C(t) \quad . \tag{116}$$

In the CONTEMPT-LT code, the boundary conditions are normally

$$- k \frac{\partial u}{\partial \bar{n}} = H(u, t) \left[u - u_B(t) \right] \tag{117}$$

where u is the surface temperature, $u_B(t)$ is the bulk temperature, $\bar{n}$ is a vector in the direction out of the heat-conducting structure, k is the thermal conductivity of the conducting material, and H(u,t) is the heat transfer coefficient. In Equations (116) and (117), A corresponds to H, B to u_B, and D to H. Specification of H(u,t) and u_B for each boundary is done in the input data. The difference approximation to Equation (116) is discussed in Appendix E.

As indicated in Equation (117), 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(u,t)] can be one of the following: zero, indicating a symmetry or insulated condition; a time-dependent value taken from Cards 4300XX; a condensing steam value[11] dependent

on the ratio of steam to air; a value of 0.4 (British units) for heat transfer to the liquid region; a value of 10^4 (British units) from a steam generating boundary condition; an outside air time-dependent value from Cards 10XX; a temperature-dependent value from Cards 4400XX; a value from a miscellaneous area set up by the input data; a turbulent natural convection correlation determination; a direct radiation model calculation; or a combination of the direct radiation and natural convection correlations.

The bulk temperature is selected by the input data and is one of the following: a constant value entered in the input, the time-dependent outside air temperature from Cards 10XX, a compartment vapor temperature, or a compartment liquid temperature.

The heat structure coding in CONTEMPT-LT contains logic which calculates the condensation of steam on heat structures. This condensing steam model is activated only when several conditions have been met. These conditions include:

(1) A heat structure must be present.

(2) The bulk temperature must be based on the vapor region temperature.

(3) The heat surface (wall) temperature must be less than the saturation temperature and the vapor region must be superheated. When the vapor region is saturated, the heat structure condensing steam model is not used because an implicit condensation calculation is performed by subroutine COMPU which determines saturated vapor region properties.

(4) Water vapor must be present.

(5) A heat transfer coefficient option must be chosen which, in fact, allows wall condensation.

(6) The bulk temperature must be based on the vapor region temperature.

If these conditions are met, wall condensate will enter the liquid region of a compartment at the saturation temperature based on the compartment water vapor partial pressure.

CONTEMPT-LT permits wall condensation to be included in the heat structure calculations for the following heat transfer coefficient options: 2, ±5, 7-15, and 53 [numbers refer to Words 1 and 3 on the boundary condition card (Card 1YY400)]. The code will set $T_{bulk} = T_{sat}$ for cases where the user specifies the bulk temperature as equal to the vapor temperature for options 2, ±5, 7-15, and 53 unless a change of heat transfer coefficient option has occurred. This modification overrides the bulk temperature option chosen by the user so that the bulk temperature always equal the vapor region temperature. For heat transfer coefficient options 2, ±5, 7-15, and 53, a heat transfer coefficient based on a turbulent natural convection correlation (Option 50) will be used whenever either (a) the heat structure (wall) temperature (T_{wall}) is greater than the vapor region temperature (T_v),

or (b) the heat structure (wall) temperature is greater than the saturation temperature (T_{sat}) and less than the vapor region temperature. If the heat structure (wall) temperature is less than both the saturation temperature and the vapor region temperature, then the maximum is used of either

$$q = h_u A(T_v - T_{wall}) \tag{118}$$

or

$$q = h_N A(T_{sat} - T_{wall}) \tag{119}$$

where

h_u = 114 J/(sec-m^2-^{o}K) (the lower bound for the Uchida option)

h_N = the user-chosen heat transfer coefficient

A = the effective heat transfer surface-area multiplier.

For user convenience in selecting proper heat transfer boundary conditions, Table I summarizes the principal features of the heat transfer coefficient options.

Several of the heat transfer coefficient boundary condition options are discussed further in Appendix E.

4.3 Compartment Energy Adjustment

The rate of heat transfer between one surface of a heat-conducting structure and an adjacent medium (R_{HT}) is calculated by

$$R_{HT} = A\, h^b H(u - u_B) \tag{120}$$

where H is the heat transfer coefficient, A is the effective heat transfer surface-area multiplier, h^b is a geometry surface area adjustment factor further defined in Appendix E, u is the surface temperature of the structure, and u_B is the temperature of the medium adjacent to the boundary.

User input specifies to what compartment and which region heat is transferred. If transfer is to a liquid region and no liquid exists in that region, then the energy is transferred to the vapor region of the same compartment. No direct mass changes result from the heat structure calculations, except from those calculations making use of the condensing steam option. Heat transfer is performed by using an average value of heat transfer rate:

$$\bar{R}_{HT} = \frac{R_{HT} + R_{HT}\ (old)}{2} \tag{121}$$

TABLE I

SUMMARY OF HEAT TRANSFER COEFFICIENT OPTIONS FOR HEAT CONDUCTING STRUCTURES[a]

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 J/(sec-m^2-^oK)	No	No
1	HTC from outside air table	No	No
2	Uchida correlation	Yes	Yes
3	HTC = 2.3 J/(sec-m^2-^oK)	No	No
4	HTC = 57 000 J/(sec-m^2-^oK)	No	No
±5	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	Tubulent natural convection correlation	No	No
51	Direct radiation correlation	No	No
52	Option 50 plus Option 51	No	No
53	Tagami correlation	Yes	[d]

[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.

TABLE I (continued)

[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

$$T_{wall} > T_{sat} + 1 \text{ K},$$

or

$$T_{wall} > T_v,$$

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

In addition, the bulk temperature must be selected as the vapor temperature (Option 2 for Word 2 on the boundary conditions card, Card 1YY400). 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 $T_{wall} \leq T_v$ 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 J/(sec-m^2-^{o}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, then the vapor temperature will be used.

TABLE I (continued)

[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.

where R_{HT} (old) is the previous timestep value of R_{HT}. If heat is transferred to a liquid region, then the total energy flow is

$$U_{H\ell i} = \Delta t \, \bar{R}_{HT} \tag{122}$$

where

Δt = timestep length

$U_{H\ell i}$ = timestep energy flow to liquid region of compartment i, from heat structure being considered.

For heat transfer to vapor region:

$$U_{Hvi} = \Delta t \, \bar{R}_{HT} \tag{123}$$

where

U_{Hvi} = timestep energy flow to vapor region of compartment i, from heat structure being considered.

Appropriate values of U_{Hvi} and $U_{H\ell i}$ are determined for each heat structure and summed to produce the total energy flow into each compartment, according to

$$U_{\ell i} = U_{\ell i} + \sum_j U_{H\ell ij} \tag{124}$$

$$U_{vi} = U_{vi} + \sum_j U_{Hvij} \tag{125}$$

$$U_{ti} = U_{ti} + \sum_j (U_{H\ell ij} + U_{Hvij}) \tag{126}$$

where the sum over j indicates contributions from all heat structures j exchanging energy with the appropriate region of compartment i.

V. BWR PRESSURE SUPPRESSION SYSTEM MODELS

Specific models used in CONTEMPT-LT to represent BWR pressure suppression systems (PSS) are described in this section. Most of the section discussion concerns two topics: (1) geometric modeling of PSS vent arrangements, and (2) analytical modeling of fluid movement through the vent arrangements. The PSS models in CONTEMPT-LT transfer mass and energy between the drywell and wetwell compartments. Section IV describes more generalized mass and energy transfer models for transfer between all compartments. Section III describes each compartment and the mass and energy exchange processes between the pool and vapor regions of a compartment.

CONTEMPT-LT can be used to model any current BWR pressure suppression system design. Current designs fall into two categories: those with vertical downcomers, or vents (Mark I and Mark II), and those with horizontal vents (Mark III). These two vent arrangements require different analytical models, which are discussed in the following section. For either system, analyses are divided into three time regimes:

(1) A transient regime termed the vent clearing transient, in which liquid water is expelled from the vent system under transient incompressible flow conditions.

(2) A regime in which quasi-steady compressible flow of a two-component, two-phase water-steam-air mixture is established within the vent system.

(3) A long-term regime in which compartment mass and energy changes occur due to engineered safety systems, leakage, heat transfer, or other mechanisms.

This section on BWR PSS models consists of three main subsections, and additional detail is provided in three appendixes. The first topic described is the vertical vent (Mark I and Mark II) PSS model. Considerable detail on the vent flow model is provided in Appendix F, with additional detail on the iterative flow solution process presented in Appendix B.

The second major topic is the horizontal vent (Mark III) PSS model. The vent flow equations described in Appendix F, and the flow iteration control presented in Appendix B, are referenced as is Appendix C which provides details of the Mark III vent clearing analytical model in CONTEMPT-LT. The third subsection describes the vacuum relief system model available for BWR PSS calculations.

1. VERTICAL VENT SYSTEM MODELS FOR MARK I AND MARK II CONTAINMENTS

The various CONTEMPT-LT models used to describe vertical vent system performance are presented. Appendixes A, B, and F are referenced for additional detail on the Mark I and Mark II systems and on analytical models. Section V-1.1 briefly describes the vertical vent (or downcomer) geometry model used in CONTEMPT-LT. Sections V-1.2 through -1.6 describe various analytical models and application of those models.

1.1 Geometry Model Considerations

The Mark I and Mark II reactor plant schematics are shown in Appendix A. The CONTEMPT-LT pressure-suppression model can simulate a vent system as shown in Figure 5, consisting of piping components that transport an air-water-steam mixture from the drywell to the wetwell. The vent system configuration accepted by the program consists of a series flow path that is constructed from a sequence of circular pipe elements as illustrated in Figure 6. The pipe elements may be either of two types: (a) straight, constant flow area lengths of circular pipe (Type 1) or (b) circular elbows, tees, or transition sections with or without changes of flow area (Type 2).

Parallel flow paths result if a vent system branches one or more times. The program approximates a parallel flow calculation by computing flow through a single typical path as shown in Figure 7. At a flow element representing a branch in the vent system, the outlet diameter of the element is specified as the pipe diameter of a path selected as the typical path. A pipe element branch fraction is specified as the ratio of the area of the typical outlet path to the total outlet area of a branch (Figure 7). Flow leaving a typical branch is computed as the product of the branch fraction and the flow entering the branch. Total flow through the vent system is the product of the flow leaving the last pipe element and the number of last elements, usually called downcomers.

The vent entrance is modeled as a special element which is used to allow determination of fluid conditions at the vent entrance, based on stagnation conditions in the drywell atmosphere. The calculation is always for a Type 2 element, and the vent entrance diameter and irreversible loss coefficient are user specified. The vent entrance diameter is assumed infinite, and downstream conditions are used to determine the pressure loss. In general, selection of proper loss coefficients depends on whether upstream or downstream conditions are used. The program uses upstream conditions if element subdivisions are used, uses conditions for the smaller cross-section area at abrupt area changes, and uses upstream conditions for the last element. An abrupt area change is a Type 2 element with zero length. Type 2 flow elements may be subdivided to provide improved numerical approximations of area change effects. However, no subdivisions are allowed in a Type 2 element with a nonzero energy loss coefficient and an abrupt area change. An abrupt area change is specified by inputting a zero flow element length for a Type 2 element. Vent exit loss coefficients are a function of the vent exit area and the wetwell surface area. All loss coefficient formulas are presented in Appendix F.

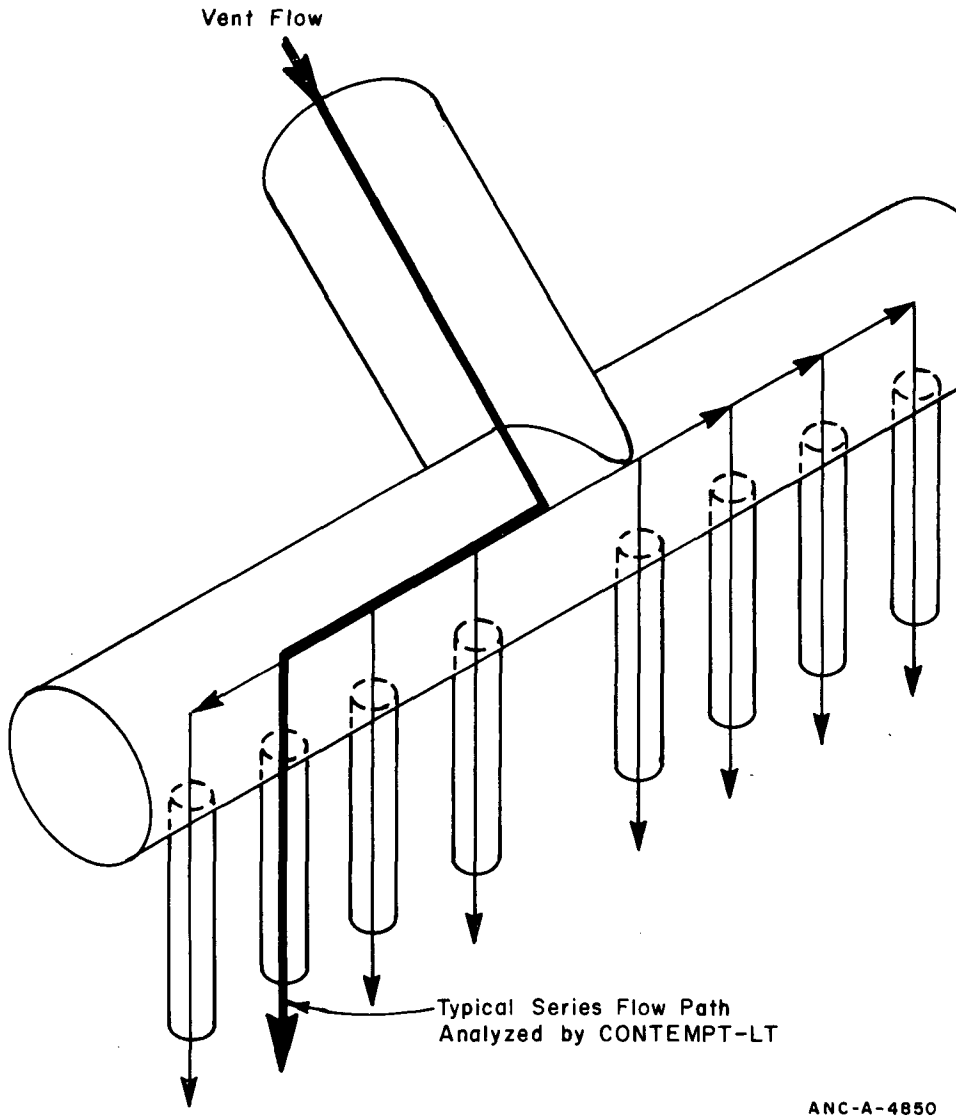

Fig. 5 Vent system flow path model.

1.2 Vent Clearing

The vent clearing phase is defined as that time when the liquid water initially in the vent pipes is being expelled due to a rapid drywell pressure increase. The liquid is assumed to be incompressible. The forces acting upon it are assumed to be the drywell pressure, the friction force due to the walls of the vent, the weight of the water slug, and the back pressure exerted by the liquid and vapor within the wetwell at the vent pipe exit plane.

After the vent pipe has initially been cleared of water, user controlled static pressure differences are used to cause the vent to be refilled and initiate reclearing again if needed. After the initial pressure peak, the vents are arbitrarily declared closed (no two-phase flow) if the pressure differential between the drywell and wetwell vapor regions is less than C_1 times the hydrostatic pressure associated with the vent submergence (ΔP_H)where C_1 (and later C_2) is an input constant. Likewise, the vent clearing process is initialized and restarted if the compartment pressure differential later exceeds $C_2\ \Delta P_H$. Vent reclearing is initialized

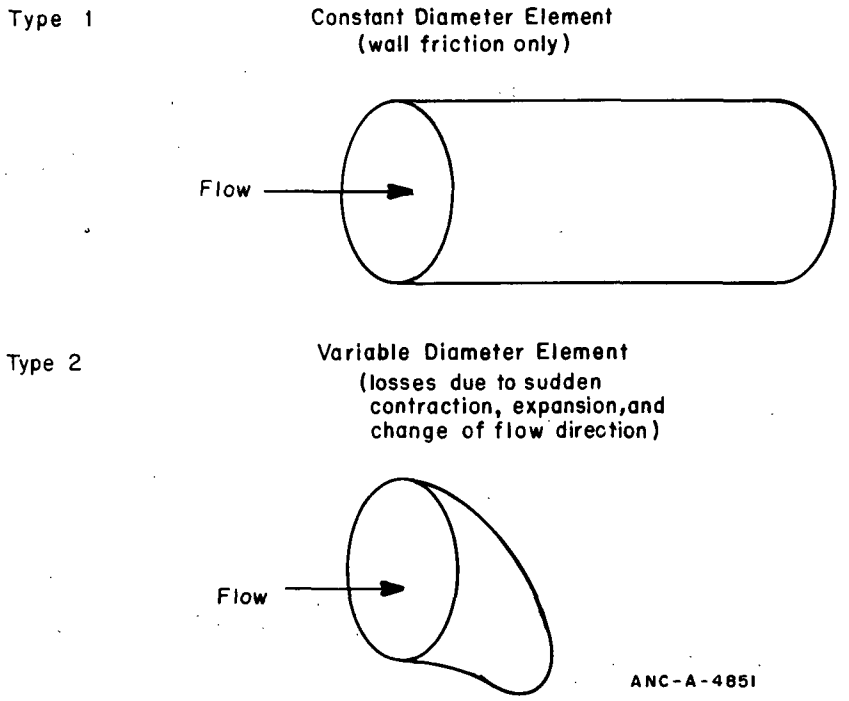

Fig. 6 Pipe elements used to describe vent system.

with the vent liquid displacement equal to the value determined from the hydrostatic conditions for the pressure difference given and with a velocity of zero. The normal vent clearing transient equations are evaluated until the vents have recleared. This procedure is a simplification of the actual dynamic vent opening-closing process.

The vent clearing transient is solved using the mechanical energy equation for incompressible liquid[5], coupled with a Runge-Kutta technique. The energy equation is

$$\frac{d}{dt}\left[K_{tot}(t) + \phi_{tot}(t)\right] = -W - E_i \qquad (127)$$

where

$K_{tot}(t)$ = total kinetic energy

$\phi_{tot}(t)$ = total potential energy

W = rate at which mechanical work is done on the surroundings by the system

E_i = rate at which mechanical energy is irreversibly converted to thermal energy (friction loss).

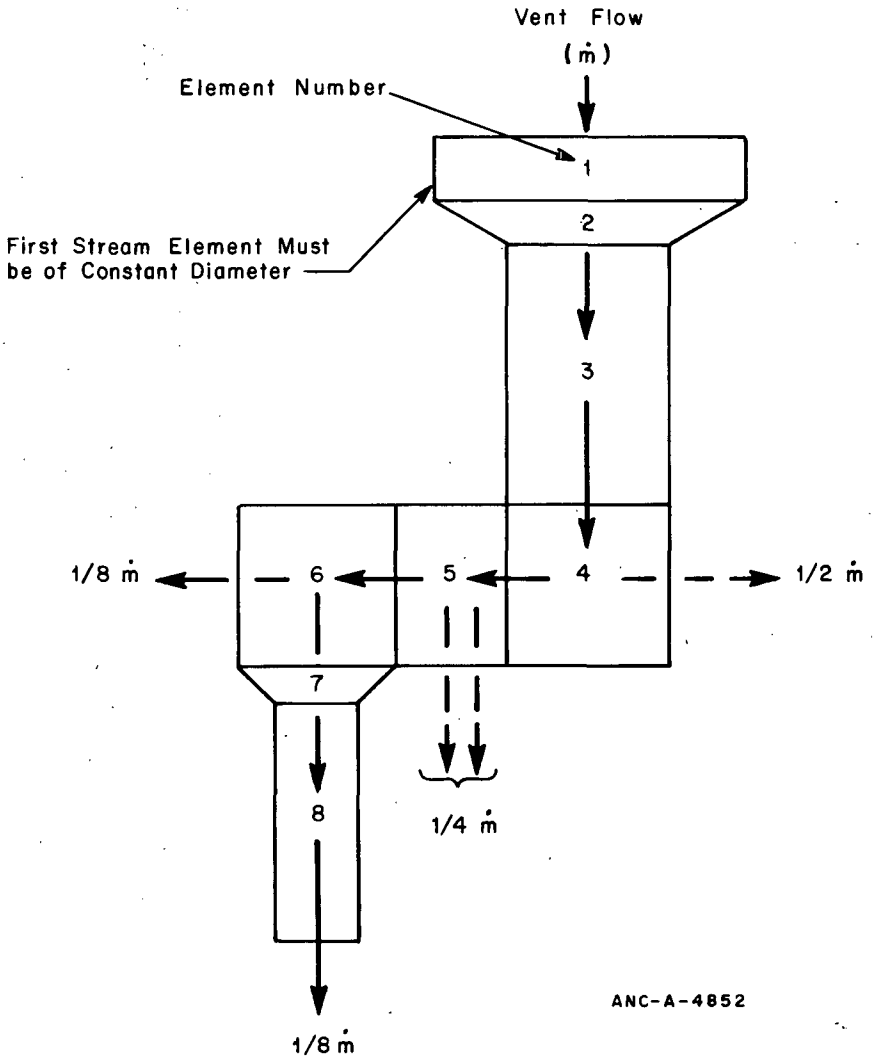

Fig. 7 Use of local flow rate multipliers to represent flow branches. (Represents the vent system of Figure 5.)

Figure 8 illustrates the vertical vent system and defines several variables used in the solution of the energy equation. The various symbols are:

S_V, S_W = surface areas of the vent outlet and wetwell, respectively

v_V, v_W = water surface velocity in vent and wetwell in directions indicated

p_V, p_W = total pressure of drywell and wetwell vapor regions, respectively

Z_V, Z_W = liquid displacements in directions indicated for vent and wetwell, respectively

L = initial vent submergence in wetwell pool

D_V = vent exit diameter.

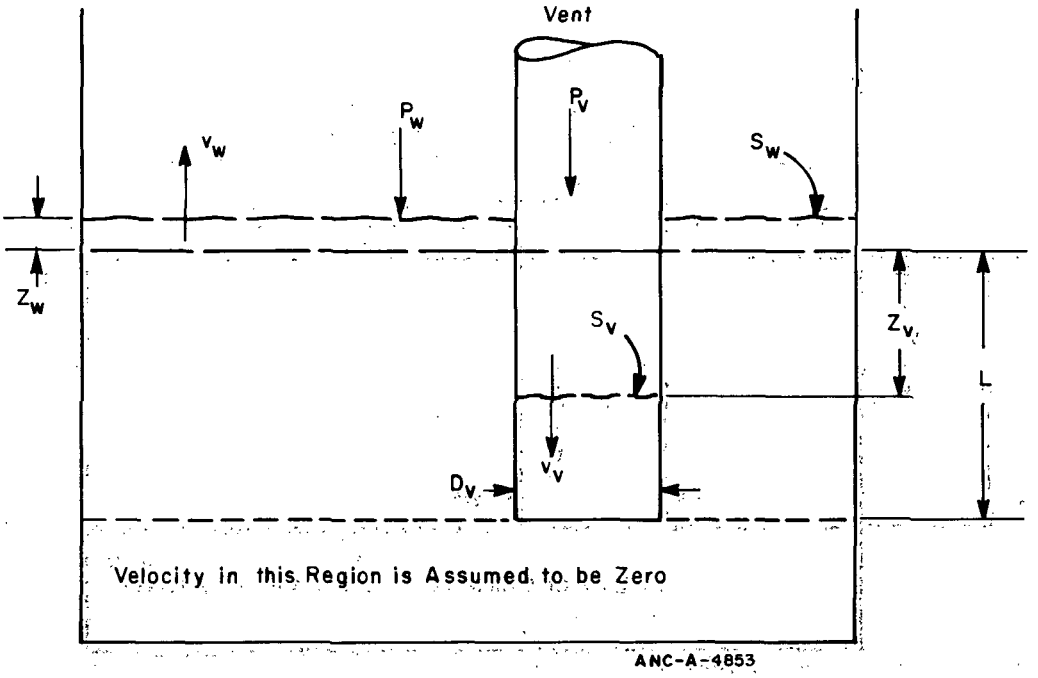

Fig. 8 Vent clearing schematic for vertical vents (Mark I, Mark II).

Also

β = ratio of total vent exit area to wetwell pool surface area

ρ = vent and wetwell liquid density

g = acceleration due to gravity.

When solutions are obtained for the various terms in the energy equation the vent clearing acceleration (a_v) is obtained:

$$a_v = \frac{(p_v - p_w)}{\rho(1+\beta)\left[L - (1-\beta)Z_v\right]} - \frac{gZ_v}{\left[L - (1-\beta)Z_v\right]} - \frac{f_m v_v |v_v|}{2 D_v (1+\beta)} \frac{(L - Z_v)}{\left[L - (1-\beta)Z_v\right]} + \frac{v_v^2}{2\left[L - (1-\beta)Z_v\right]} \left[\frac{1 - \delta(v_v) + \beta(2 - 2\beta^2 - \beta^3)}{(1+\beta)^3}\right] \quad (128)$$

where

f_m = Moody friction factor for vent walls

$\delta(v_v)$ = delta function for vent exit irreversible loss term: $\delta(v_v) = 1.0$ if $v_v > 0$, and $\delta(v_v) = 0$ if $v_v \leq 0$.

Vent clearing velocity and surface displacement can be obtained from

$$v_v = \int_t a_v \, dt = \int_t \frac{dv_v}{dt} \, dt \tag{129}$$

and

$$Z_v = \int_t v_v \, dt = \int_t \frac{dZ_v}{dt} \, dt \quad . \tag{130}$$

Equations (128), (129), and (130) are solved in CONTEMPT-LT with a five-step Runge-Kutta technique. The vent is defined to be cleared if

$$Z_v \geq L + \frac{D_v}{3} \tag{131}$$

that is, if the cleared length equals or exceeds the initial vent submergence plus one-third the pipe exit diameter. The latter term results from an assumption that a hemispherical bubble is formed at the vent exit as part of the vent clearing process. During the vent clearing transient regime, flow from the drywell to the wetwell is assumed to be zero except for the liquid water that is expelled from the vent pipe system. Since the boundary between the drywell and the wetwell is located at the initial water surface within the vent pipe, the water in the vent pipes should be included in the calculation of initial mass of liquid water in the wetwell. The change in drywell volume due to vent clearing and refilling is calculated and used.

1.3 Vent Flow

Quasi-steady flow of a two-component, two-phase steam-air-liquid water mixture is assumed to begin immediately after the vent clearing transient is completed. Solution of the conservation equations for vent flow is an iterative process in CONTEMPT-LT. On the basis of known conditions at the entrance of a given flow element, the exit conditions are calculated and become entrance conditions for the next element. Provisions are included for sonic or choked flow determination and preferential control of the mass fractions in the flowing mixture. The equations of change and the iteration control descriptions are provided in Appendix F.

Figure 9 illustrates a vent flow element and defines nomenclature used in the equations of change describing flow through the element. A_i and A_f are the flow element entrance and exit surface areas, respectively. The direction of flow is denoted by the vector $\vec{\ell}$, which is oriented at an angle α from the positive vertical direction. The force of gravity is

positive in a downward direction, and elevation is positive in an upward direction. z_i and z_f denote fixed elevations for the midpoint of each surface, whereas ℓ_i and ℓ_f are fixed end positions along the length direction of the element.

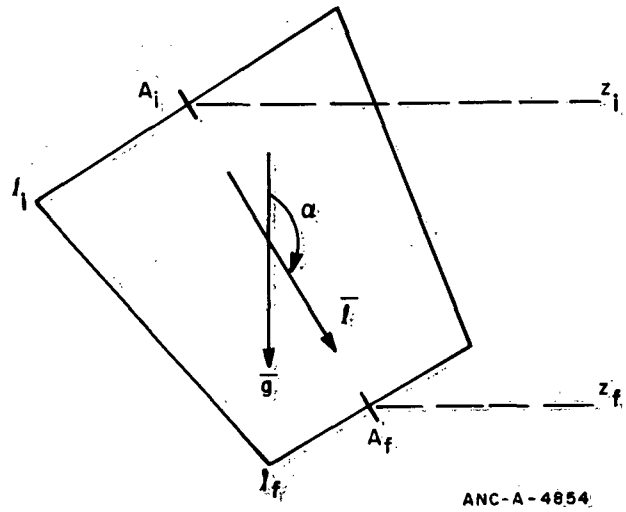

Fig. 9 Vent flow element illustration.

The integral forms of the equations of change, integrated from the flow element entrance (i) to exit (f), become

Continuity

$$(\rho\ v\ A)_i = (\rho\ v\ A)_f = W, \text{ a constant} \tag{132}$$

Energy

$$\frac{1}{2}(v_f^2 - v_i^2) + (h_f - h_i) + g(z_f - z_i) = 0 \tag{133}$$

Momentum

$$p_f = p_i - \Delta p_{IR} - \hat{\rho}\, g(z_f - z_i) - W\left(\frac{\hat{l}}{A}\right)(v_f - v_i) \tag{134}$$

where

ρ = fluid density

v = fluid velocity

A = flow area

W = flow rate

g = acceleration due to dravity

h = fluid specific enthalpy

z = elevation being considered

p = absolute total pressure

$\hat{\rho}$ = average fluid density in element

$(\frac{\hat{1}}{A})$ = averaged inverse flow area

Δp_{IR} = irreversible pressure loss due to wall friction and area or direction changes in element.

The energy equation, Equation (133), may be rearranged to solve for the element exit velocity:

$$v_f = \left\{ 2 \left[h_i - h_f - g(z_f - z_i) \right] + v_i^2 \right\}^{1/2} \qquad (135)$$

given elevations and entrance parameters.

To determine vent flow, the vent entrance conditions are determined, an estimated flow rate is assumed, and the equations of change are solved for each flow element sequentially. Details of the flow element and vent flow iteration processes are provided in Appendix B. Appendix F provides added detail on the equations of change used to obtain Equations (132) through (135), and discusses the determination of the vent entrance mixture composition and irreversible pressure losses.

1.4 Failed Vents

A failed vent is defined as a vent pipe that has broken in such a manner that the drywell atmosphere can be vented directly into the wetwell vapor region, bypassing steam condensation in the wetwell pool. Separate input entries describe the break location within the typical vent path and specify the number of failed vents. Mass fraction multipliers and a liquid carryover factor may be input for the failed vents. These parameters may differ from the normal unfailed vent values. The user may also specify an exit irreversible single-phase loss coefficient and pipe exit diameter or accept the normal vent parameters for the same flow element location. If values are input, then the element located at the break point must be a Type 2 flow element.

1.5 PSS Solution Sequence and Mass and Energy Changes

The first paragraph of this section briefly describes the sequence CONTEMPT-LT follows each timestep when a BWR vertical vent PSS is being evaluated. Subsequent paragraphs discuss the PSS mass and energy transfer between the drywell and wetwell.

If the vents have not yet been cleared, the sequence of pressure suppression operations for a given timestep starts with the vent clearing calculation. Compartment conditions at the beginning of the timestep are used in the equations. If the vents do no clear during the current timestep and no failed vents exist, then CONTEMPT-LT bypasses all remaining pressure suppression calculations. If failed vents are present, then the two-phase flow calculations are performed and compartment masses and energies updated. Failed vents do not require a vent clearing calculation. If the normal vents clear during a timestep or are open at the beginning of a timestep, then the two-phase flow equations are solved and compartment masses and energies are updated. The failed vent (if any) flow solution is then obtained and compartment inventories are again modified.

When normal or failed vent flow is established during a timestep, the drywell and wetwell compartment masses and energies must be modified to account for the flow. Failed vent modifications are described after the following discussion for a normal vent.

The total pressure suppression vent system mass flow through normal vents from the drywell into the wetwell (ΔM_{PS}) is

$$\Delta M_{PS} = W \, \Delta t \, N_{DC} \tag{136}$$

where

W = mass flow rate through a single vent or downcomer

Δt = timestep length

N_{DC} = number of downcomers or vents.

The total steam (or water vapor), air, and liquid fraction flows are:

$$\Delta M_s = r_s \, \Delta M_{PS} \tag{137}$$

$$\Delta M_a = r_a \, \Delta M_{PS} \tag{138}$$

$$\Delta M_\ell = r_\ell \, \Delta M_{PS} \tag{139}$$

where r_s, r_a, and r_ℓ are mass fractions of water vapor, air, and liquid, respectively, in the flow mixture.

The mass flows are checked to assure they do not exceed the available drywell inventory. If either the liquid or water vapor flow is greater than the current drywell inventory, CONTEMPT-LT will automatically reduce the timestep size, return to the start of the current timestep and proceed with the transient analysis. If ΔM_a exceeds the drywell air content, the program does not reduce the timestep, but merely resets ΔM_a to the mass of air in the drywell. This simplification would normally occur for only one timestep. Compartment inventory changes proceed as follows:

$$M_{wv3} = M_{wv3} - \Delta M_s - \Delta M_\ell \tag{140}$$

$$M_{a3} = M_{a3} - \Delta M_a \tag{141}$$

$$M_{a2} = M_{a2} + \Delta M_a \tag{142}$$

$$M_{w\ell 2} = M_{w\ell 2} + \Delta M_s + \Delta M_\ell \tag{143}$$

$$U_{v3} = U_{v3} - h_{g3}\,\Delta M_s - c_{pa}\Delta M_a T_{v3} - h_{\ell 3}\Delta M_\ell \tag{144}$$

$$U_{v2} = U_{v2} + \Delta M_a \left[c_{va} + f_1\,(c_{pa} - c_{va})\right]\left[T_{\ell 2} + f_2(T_{v3} - T_{\ell 2})\right] \tag{145}$$

$$U_{\ell 2} = U_{\ell 2} + \Delta M_a \left\{c_{pa}\,T_{v3} - \left[c_{va} + f_1\,(c_{pa} - c_{va})\right]\left[T_{\ell 2} + f_2(T_{v3} - T_{\ell 2})\right]\right\} + h_{\ell 3}\,\Delta M_\ell + h_{g3}\,\Delta M_s \tag{146}$$

where

M_{wv3} = mass of water in drywell vapor region

M_{a3} = mass of air in drywell

M_{a2} = mass of air in wetwell

$M_{w\ell 2}$ = mass of water in wetwell pool

U_{v3} = total energy in drywell vapor region

U_{v2} = total energy in wetwell vapor region

$U_{\ell 2}$ = total energy in wetwell liquid region

f_1, f_2 = input multipliers on air bubble energy transfer

h_{g3} = specific enthalpy of water vapor in drywell vapor region

$h_{\ell 3}$ = specific enthalpy of liquid water in drywell vapor region

c_{pa} = heat capacity of air at constant pressure

c_{va} = heat capacity of air at constant volume

T_{v3} = absolute temperature of drywell vapor region

$T_{\ell 2}$ = absolute temperature of wetwell liquid region.

The following comments apply if fluid flow has been calculated through failed vents. For flow from failed vents, Equations (136) through (139) are solved by using appropriate parameters for the failed vents. Also, Equations (140), (141), (142), and (144) apply, and Equations (143) and (146) are ignored. Equation (145) is replaced by

$$U_{v2} = U_{v2} + c_{pa}\,\Delta M_a\,T_{v3} + h_{g3}\,\Delta M_s + h_{\ell 3}\Delta M_\ell \quad . \tag{147}$$

The wetwell vapor region receives direct mass additions according to

$$M_{wv2} = M_{wv2} + \Delta M_s + \Delta M_\ell \quad . \tag{148}$$

1.6 Timestep Control

This section discusses a timestep reduction model associated with vent flow, with vent clearing, and with vent closing or refilling.

A timestep reduction is initiated if the calculated mass of water flow through the PSS vents exceeds the mass of water in the drywell vapor region. The masses of vapor and liquid water are checked individually. Timestep reductions may result from excessive flow through either normal or failed vents. A reduction caused by either vent system will be applied equally to both normal and failed vent flows. The reduced timestep will be used for all subsequent timesteps until the end of the original input timestep is reached. Then CONTEMPT-LT will continue with the original input timesteps. CONTEMPT-LT allows up to 50 reductions within an input timestep, and each reduction allows a reduction factor up to a maximum of 99. If either of the preceding criteria is violated, an error message will be printed and program execution will be stopped.

If the vents clear during a given timestep, the timestep size is reduced to the point of clearing, and all mass and energy updates are made. The time of vent clearing is determined from

$$t = t_{old} + \frac{-v_{old} + \sqrt{v_{old}^2 - 2a\,(X_{old} - L)}}{a} \tag{149}$$

where

a = vent liquid acceleration during the present timestep

L = the initial distance liquid must be displaced before the vents are considered cleared (vent submergence)

t = time of vent clearing

t_{old} = time at beginning of the present timestep

v_{old} = velocity at beginning of the present timestep

X_{old} = liquid displacement at beginning of the present timestep.

The next reduced timestep is selected to carry the calculation to the end of the original input timestep.

The timestep reduction mechanism associated with vent refilling or closing is based on the transient pressure derivatives in the drywell and the wetwell. An approximate time for vent refilling is given by

$$t = t_{old} + \frac{p_{v2} + C_1 \Delta p_h - p_{v3}}{\frac{\Delta p_{v3}}{\Delta t} - \frac{\Delta p_{v2}}{\Delta t}} \tag{150}$$

where

p_{v3} = pressure in the drywell vapor region

p_{v2} = pressure in the wetwell vapor region

t = approximate time of vent refilling

t_{old} = time at beginning of present timestep

C_1 = vent clearing multiplying factor (input)

Δp_h = hydrostatic pressure head at vent exit.

The wetwell pressure derivative is determined from the change in pressure over the previous timestep. Whereas the pressure derivative in the wetwell is relatively constant with time, the drywell pressure derivative fluctuates due to the changing drywell inventory. The vent flow and the mass addition due to blowdown are utilized to determine the drywell transient pressure derivative, defined as

$$\frac{\Delta p_{v3}}{\Delta t} = \frac{\Delta p_{v3}}{\Delta M_{v3}} \frac{\Delta M_{v3}}{\Delta t} \approx \frac{\Delta p_{v3}}{\Delta M_{v3}} W \qquad (151)$$

where

ΔM_{v3} = change in the mass of water in vapor region of drywell over the previous timestep

Δp_{v3} = change in drywell pressure over the previous timestep

t = time

W = rate of mass flow into the drywell due to vent flow and blowdown.

If the time of vent closing is successively underpredicted, then the timestep size will continually decrease during solution convergence. In that case, the vents are considered closed if the pressure difference between the drywell and wetwell is within 0.1 psi of the pressure difference specified by the input.

2. HORIZONTAL VENT SYSTEM MODEL FOR MARK III CONTAINMENT

CONTEMPT-LT analytical models developed to describe the performance of the Mark III horizontal vent pressure suppression system are discussed. Appendixes A, B, C, and F provide additional detail on the Mark III system and models. Section V-2.1 briefly discusses system and model geometry considerations. Sections V-2.2 through -2.4 describe the PSS analytical models and application of those models.

2.1 Geometry Model Considerations

The Mark III horizontal vent PSS concept and basic design are discussed in Appendix A. Figure 10 depicts a detailed view of a horizontal vent arrangement. CONTEMPT-LT models one azimuthal segment of the vent system and determines total mass flow as the product of the number of segments times the mass flow from one segment.

The vent clearing and vent two-phase flow models both allow the number of vents to vary from unity to ten. The nodes and equations used in the two models, however, are different. The vent clearing model assumes two nodes (one annulus and one vent) per vent, as shown in Figure 11, whereas the two-phase flow model allows a variable number of nodes, which are user specified. Figure 12 shows a sample two-phase flow nodalization. Although the number of nodes is versatile, the numbering sequence is rigid, and a maximum of 50 flow elements or nodes is allowed. Element 1 is a vent entrance element, providing a transition between the drywell and annulus. It is assumed to have zero length and an area contraction factor of ten. The bottom elevation of Element 1 should be the initial water

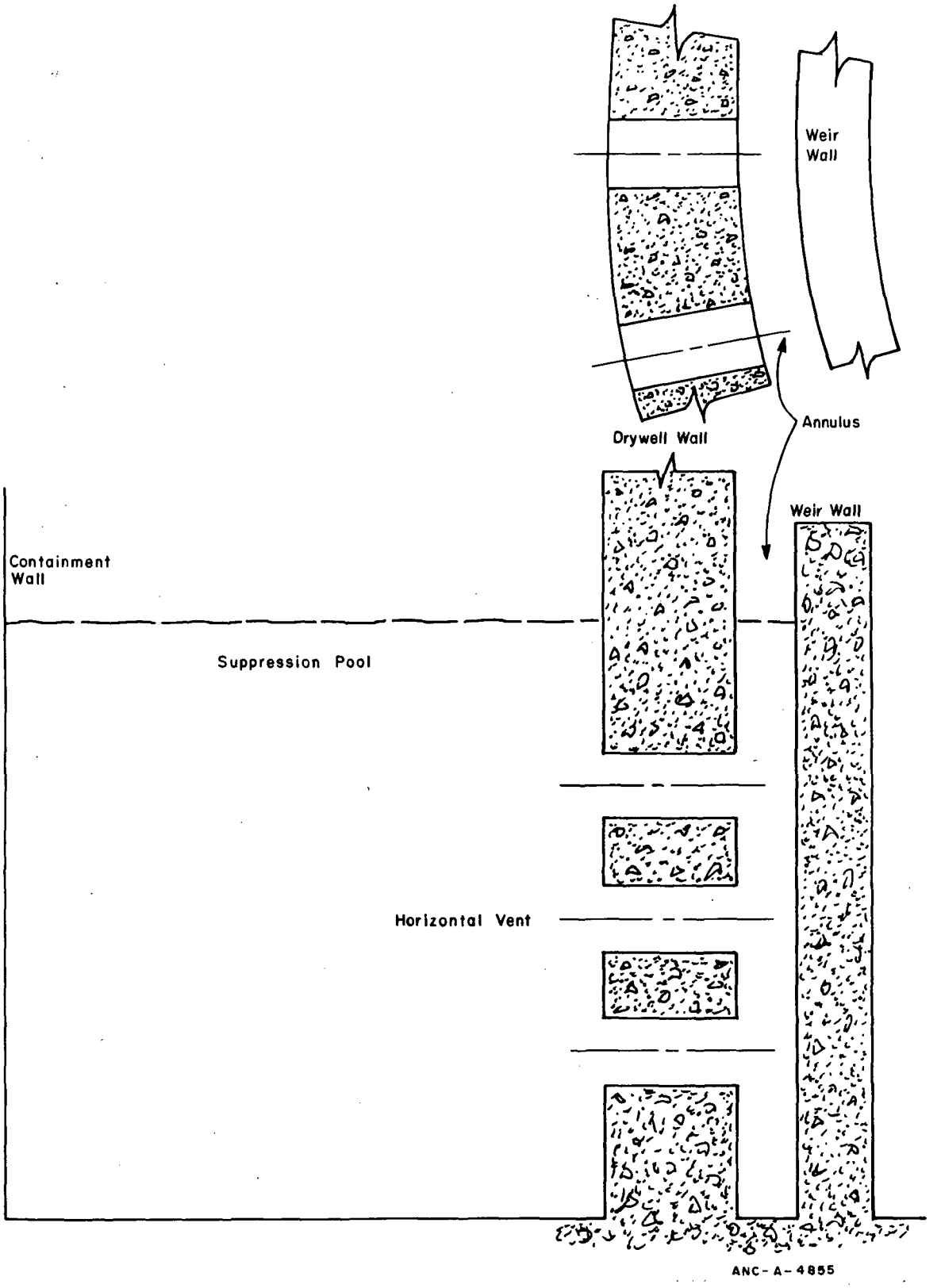

Fig. 10 Typical Mark III horizontal vent arrangement.

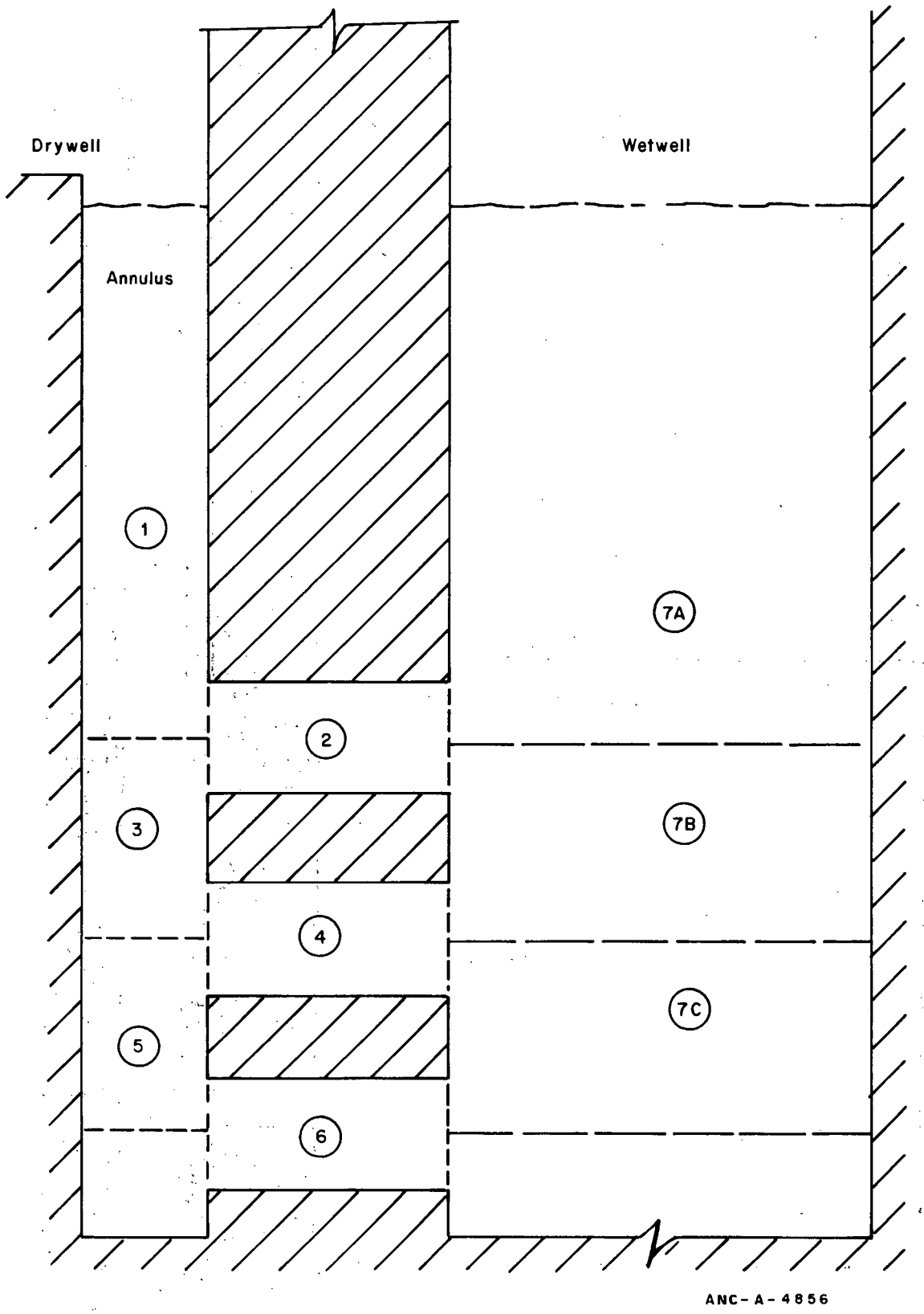

Fig. 11 Horizontal vent clearing model.

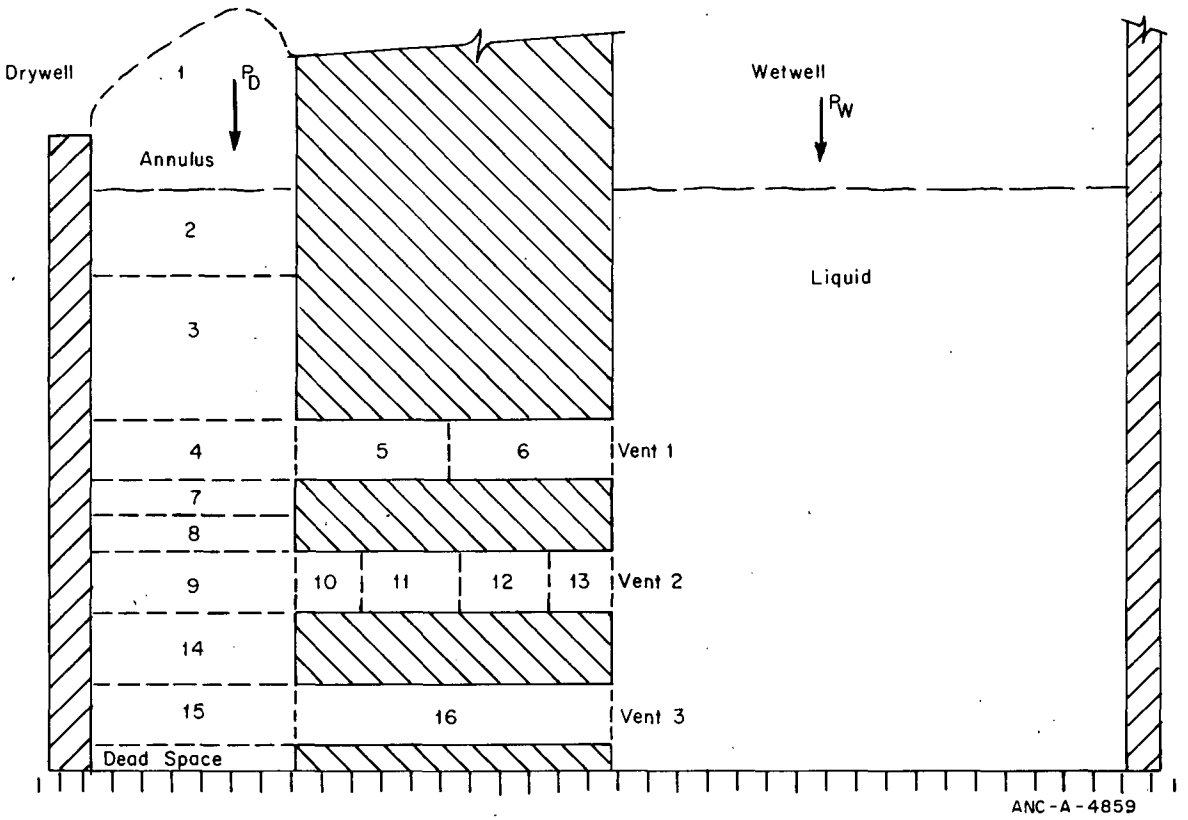

Fig. 12 Typical CONTEMPT-LT horizontal vent flow nodalization.

level in the annulus. Numbering increases along the first (top) vent loop "L", down the annulus, and out the vent. After the first vent is numbered, numbering resumes at the annulus location immediately below the first vent. Numbering is performed in an increasing order in each vent loop. Special significance is attached to vent entrace and exit flow elements (for example, numbers 4, 6, 9, 13, 15, and 16 of Figure 12), as these define the system geometry to the vent flow routine and thus enable program control of the vent iteration schemes. These elements also have form loss coefficients associated with them. Element 4, for example, is termed a "branch" element and is treated in a special manner. In CONTEMPT-LT, the branch element length (height) is assumed equal to the diameter of the associated vent.

The vertical vent pressure suppression model (Mark I and Mark II) assumes the vent system can be represented by a typical single exit vent flow path because all vent exits experience the same back pressure. In a multilevel horizontal vent system, however, the various vent levels have neither the same wetwell back pressure nor the same driving pressure. Therefore, each vent level flow must be determined and summed to obtain the total flow. Because of the multilevel vent arrangement, an additional level of iteration is required, compared to the vertical vent model. Since up to three (or in general $N \leqslant 10$) vents may be evaluated instead of one as in vertical vent pressure suppression models, the user should expect a horizontal vent problem to run longer than a vertical vent problem.

2.2 Vent Clearing

Although the vent clearing transient is a three-dimensional event, the model assumes one-dimensional flow. Multidimensional effects are approximated, however. For example, integration of the momentum balance in the downward direction over an annulus node volume retains a cross momentum flux term due to the presence of a vent, and the irreversible loss terms are based on real three-dimensional measurements. An illustrative vent arrangement with horizontal vent clearing is shown in Figure 13. Horizontal clearing, for purposes of this report, means that the water clears the vent as a plug.

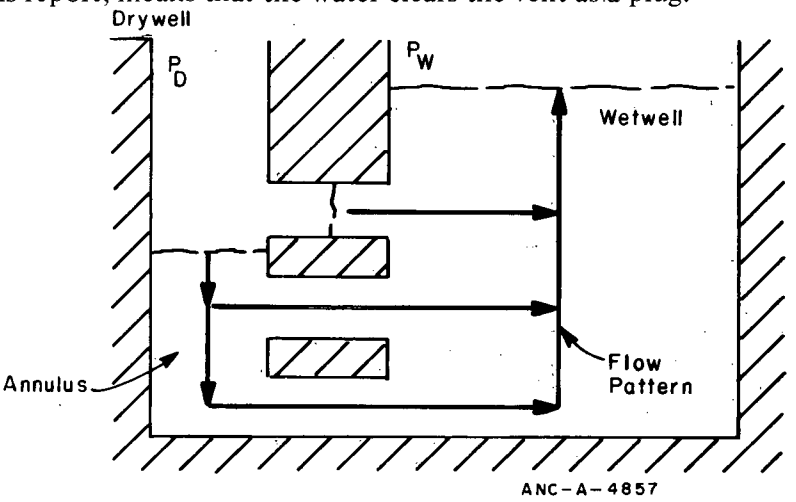

Fig. 13 Schematic of vents with horizontal vent clearing.

Modeling of the vent clearing action is based on a need for representing independent motion among the horizontal vents which lie in a vertical plane. The pressure drop across a vent is determined by a vent node and an annulus node; thus, a three-vent model contains three annulus nodes and three vent nodes. A seventh node is used to model dynamic behavior in the wetwell. Although the wetwell is represented by a single node, the boundaries of the node change with the vent under examination to describe the respective pressure drop within the wetwell.

The major assumptions used to develop the multinode model are:

(1) Incompressible transient flow of a pure liquid

(2) Adiabatic conditions

(3) One-dimensional macroscopic conservation equations for each node

(4) Vents clear as plugs

(5) Multidimensional effects can be represented by irreversible loss terms.

The detailed model equations, their derivation, and additional assumptions are presented in Appendix C.

The basic conservation equations for deriving the model are[5]

Continuity Balance

$$\frac{d}{dt} m_{tot} = -\Delta W \tag{152}$$

Momentum Balance

$$\frac{d}{dt} (\vec{mv})_{tot} = -\Delta(\vec{vW} + \vec{pA}) - \vec{F} + m_{tot} \vec{g} \tag{153}$$

where

t	=	time
m_{tot}	=	mass of fluid within a control volume
W	=	mass flow rate
$(\vec{mv})_{tot}$	=	total momentum of fluid within a control volume
$\vec{F}$	=	sum of pressure and viscous forces of fluid on solid surfaces of control volume
$\vec{v}$	=	velocity of fluid
p	=	pressure on surface area of fluid control volume
A	=	surface area of control volume
$\vec{g}$	=	acceleration of gravity.

Solution of the basic equations yields accelerations for each node, based on node velocities and pressures. For N vents, the model uses $2N + 1$ nodes requiring $2N + 2$ pressures and $2N + 2$ separate velocities. Three known boundary conditions (drywell and wetwell pressures, zero velocity at bottom of annulus) reduce the number of variables to $4N + 1$ unknowns, which are related in $N + 1$ significant mass equations and $3N$ momentum equations. When a vent is being cleared, another mass equation and another momentum equation are necessary.

From the basic equations of the vent clearing model, a set of equations involving only the velocities as variables can be developed. In the resulting set, the drywell and wetwell pressures are boundary conditions. No other pressures appear.

To solve the system of equations, a set of momentum and mass equations is first arranged to eliminate the internal pressures. In general, the vent and wetwell velocities can also be eliminated. The annulus, wetwell, and vent liquid displacements are obtained from the solution of the equation system. The resulting set of N equations is readily solved by a Runge-Kutta numerical technique.

The vent system water temperature is assumed to be equal to the wetwell pool temperature. Initially, the annulus and horizontal vents are not considered part of either the drywell or wetwell. Subsequent mass and associated energy exchanges between the vent system and the wetwell or drywell pools are accounted for, and the drywell vapor region volume is changed due to changing annulus and vent water contents.

The final vent clearing equations solved are dependent on the wetwell and drywell vapor region pressures. The drywell pressure provided to the vent clearing routines is the annulus pressure at the level of the lowest vent experiencing two-phase flow (that is, the pressure is adjusted for flow losses).

A program option allows partial vent opening to be simulated even though a plug clearing model is used. If used, the option selects a two-phase flow area directly proportional to the fraction of vent length cleared. For example, if 25% of the vent length is cleared, then the flow area would be 25% of the fully cleared vent area. Other input options allow the user to eliminate the cross-momentum flux term in the vent clearing expressions, or to adjust various loss coefficients.

2.3 Vent Flow

The Mark III model allows up to ten vents, and a variable number of vents may be cleared or partially cleared at a given timestep. If any vent is cleared (or partially cleared if the linear area fraction option is used), the flow control subroutine is called to determine the vent system two-phase flow.

A typical horizontal vent (Mark III) system flow nodalization was illustrated in Figure 12. Section V-1.3 discussed the basic quasi-steady state flow equations solved for each flow element in the PPS vent model. Appendix F describes the equations of change in more detail, along with determination of the vent entrance mixture composition and irreversible pressure loss calculations. Appendix B provides details of the iterative solution for flow through the PSS system.

Figure 14 depicts an enlarged view of a branch element. In general, flow will split at the branch with a portion entering the vent (Path 1) and the rest proceeding down the annulus to exit through lower vents (Path 2). The flow bypassing the vent (Path 2) is termed "bypass flow", and the user can specify bypass loss coefficients in addition to the vent entrance coefficients. Since the flow element depicted in Figure 9 is the basis for the CONTEMPT-LT flow equations, an assumption concerning the flow area division at a branch element is required. From mass continuity considerations, the incoming annulus flow must equal the sum of the vent flow and the flow bypassing the vent and going on down the annulus. CONTEMPT-LT solves branch element flow by treating a branch element as two elements; one representing the vent entrance (Path 1), and the second representing the bypass or annulus flow entrance (Path 2). Both branch element representations have upstream areas equal to the annulus area which is consistent with Idel'chik[12] loss coefficient data, which are based on the total annulus equivalent diameter and velocity. The true upstream velocity is used in determining Idel'chik loss coefficients. The actual element mass flux is used in the momentum equation and in the irreversible pressure loss term.

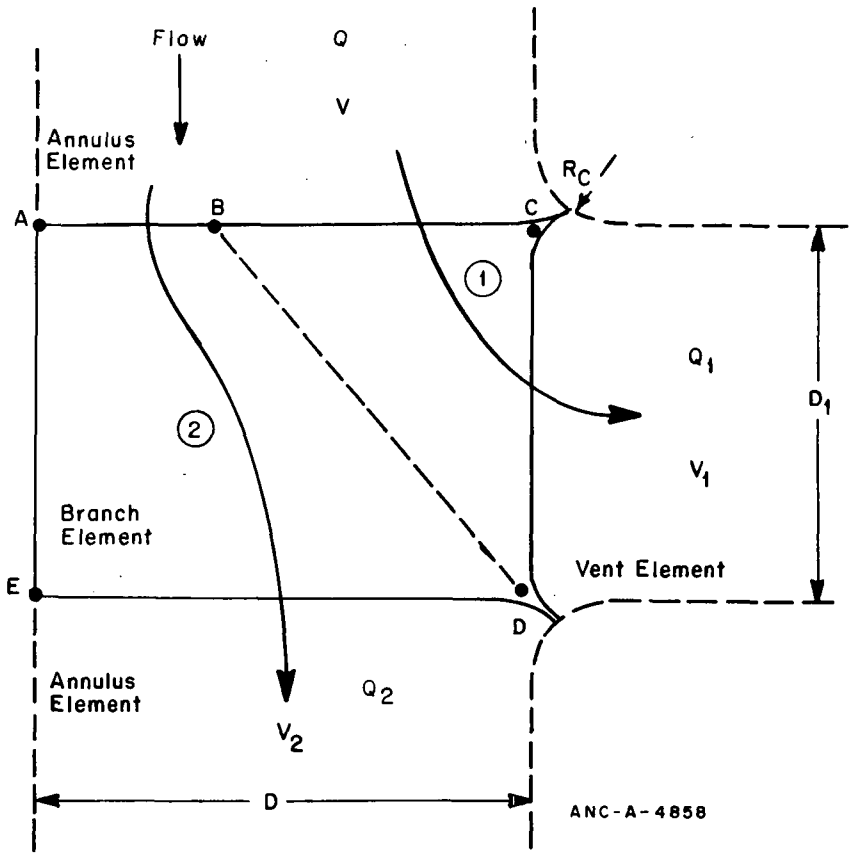

Fig. 14 Mark III branch flow element.

Each branch element and Element 1 may be subdivided by user input control. Element subdivision may be employed to reduce large area differences between the entrance and exit areas of a flow element calculation. Essentially each subdivision is treated as a separate "flow element", except irreversible loss terms are applied to only the last subdivision. Limited experience to date suggests one subdivision is adequate.

All wall friction and area or direction change losses described are adjusted by user input multiplier factors for each flow element. The multiplier is applied to both flow paths within a branch element. The velocity dependent Idel'chik data may be used for both flow path calculations in a branch element, or either constant or area-dependent loss coefficients can be selected. Use of constant coefficients for branch elements is not recommended if the vent flow area is specified to be proportional to the cleared length of the vent. Large changes in branch downstream flow areas can occur under such conditions. Also, if area-dependent loss coefficients are specified, downstream flow conditions (velocity, density) should be selected. The vent exit pressure loss calculation is based on exit upstream conditions, which are downstream conditions for the last vent flow element. Therefore, downstream conditions should be specified for the last flow element in a vent.

Options have been provided to allow use of four different flow conditions for calculating irreversible pressure losses in elements with area changes. This versatility was provided to allow user evaluation and comparison of CONTEMPT-LT pressure loss calculations with various appropriate experimental data. The four conditions available are:

(1) Maximum mass flux and associated conditions

(2) Minimum mass flux and associated conditions

(3) Upstream mass flux and associated conditions

(4) Downstream mass flux and associated conditions.

If downstream conditions have been selected, then the downstream mass flux would be used in the irreversible pressure loss term, Appendix F. Selection of downstream conditions is recommended for all flow elements. Idel'chik usage requires upstream conditions but CONTEMPT-LT overrides the input selection, in this one case only, and internally specifies the proper mass flux.

No failed vent model is used for the horizontal vent containment system. The penetration leakage model may be used to represent leakage paths between the drywell and wetwell vapor regions.

2.4 PSS Solution Sequence and Mass and Energy Changes

During a given timestep, the sequence of pressure suppression calculations starts with a vent clearing calculation. Any liquid mass exchange with the drywell or wetwell is accounted for during the solution operation. Annulus and wetwell liquid levels are adjusted as appropriate. If any vents are clear or partially clear, then a two-phase flow calculation is performed. If no vents are clear, CONTEMPT-LT bypasses all remaining pressure suppression calculations. For the situation for which some vents are cleared, the vent clearing routine determines the two-phase flow area and wetter perimeter for each vent. When a flow solution is obtained, the drywell and wetwell masses and energies are updated to account for the timestep vent flow.

Normal timestep control is specified by the user by means of input data. However, routines related to horizontal vent geometry may determine that the timestep size is too large for either vent clearing or two-phase flow calculations. Rather than terminate the computer run, CONTEMPT-LT will reduce the relevant timestep size and proceed with problem execution. An original timestep may be subdivided up to 50 times, with a maximum reduction factor at any subdivision time of 99. Exceeding these limits will cause problem termination. The original timestep size is reestablished as soon as the code specified subdivisions have been completed.

At the completion of the vent clearing and vent flow calculations, drywell and wetwell inventories are updated. First, vent clearing mass transfers are accounted for by the following equations:

$$M_{w\ell 2} = M_{w\ell 2} + \Delta M_{vw} \, N_{DC} \tag{154}$$

$$U_{\ell 2} = U_{\ell 2} + h_{\ell p 2} \, \Delta M_{vw} \, N_{DC} \tag{155}$$

$$V_{\ell 2} = V_{\ell 2} + \Delta M_{vw} N_{DC}/\rho_{\ell p2} \quad . \tag{156}$$

where

$M_{w\ell 2}$ = mass of liquid water in wetwell pool region

$U_{\ell 2}$ = total energy of wetwell pool region

$V_{\ell 2}$ = volume of wetwell pool region

ΔM_{vw} = mass of liquid water that flowed from one azimuthal segment of the vent system into wetwell pool

N_{DC} = number of azimuthal segments of vent system

$h_{\ell p2}$ = specific enthalpy of liquid water in wetwell pool region

$\rho_{\ell p2}$ = density of liquid water in wetwell pool region.

The value of ΔM_{vw} may be either positive or negative. The mass of liquid water that flows from one segment of the vent system over the weir wall into the drywell pool is ΔM_{vd} and similarly may be positive or negative. The magnitude of ΔM_{vd} need not equal that of ΔM_{vw}, and both may be nonzero if sufficient flow reversal occurs. If ΔM_{vd} is nonzero, drywell pool conditions are changed by

$$M_{w\ell 3} = M_{w\ell 3} + \Delta M_{vd} N_{DC} \tag{157}$$

$$U_{\ell 3} = U_{\ell 3} + h_{\ell p2} \Delta M_{vd} N_{DC} \tag{158}$$

$$V_{\ell 3} = V_{\ell 3} + \Delta M_{vd} N_{DC}/\rho_{\ell p2} \tag{159}$$

where the symbols have been defined previously except the subscript "3" which denotes drywell properties.

Vent two-phase flow masses are determined as follows:

$$\Delta M_{PS} = WT \Delta t N_{DC} \tag{160}$$

$$\Delta M_s = r_s \Delta M_{PS} \tag{161}$$

$$\Delta M_a = r_a \Delta M_{PS} \tag{162}$$

$$\Delta M_\ell = r_\ell \Delta M_{PS} \tag{163}$$

where

WT	=	total flow from one vent segment into wetwell pool
Δt	=	timestep size
r_s, r_a, r_ℓ	=	mass fractions of water vapor, air, and liquid, respectively, in vent flow
ΔM_{PS}	=	total mass flow through entire pressure suppression system
ΔM_s	=	total mass flow of water vapor
ΔM_a	=	total mass flow of air
ΔM_ℓ	=	total mass flow of liquid water.

If ΔM_a exceeds the current drywell air content, ΔM_a is reduced to the current content. If either ΔM_s or ΔM_ℓ exceeds the drywell vapor region content of water vapor or liquid, respectively, then the timestep size is reduced and the vent clearing and two-phase flow equations are recalculated. Water from the drywell pool is not allowed to flow through the vent system. Compartment mass and energy updates are performed to account for mass and energy changes.

$$U_{v3} = U_{v3} - h_{\ell 3}\,\Delta M_\ell - h_{g3}\,\Delta M_s - c_{pa}\,T_{v3}\,\Delta M_a \tag{164}$$

$$M_{wv3} = M_{wv3} - \Delta M_\ell - \Delta M_s \tag{165}$$

$$M_{a3} = M_{a3} - \Delta M_a \tag{166}$$

$$M_{a2} = M_{a2} + \Delta M_a \tag{167}$$

$$M_{w\ell 2} = M_{w\ell 2} + \Delta M_\ell + \Delta M_s \tag{168}$$

$$U_{\ell 2} = U_{\ell 2} + h_{\ell 3}\,\Delta M_\ell + h_{g3}\,\Delta M_s + \left\{c_{pa}\,T_{v3} - \left[c_{va} + f_1\,(c_{pa} - c_{va})\right]\left[T_{\ell 2} + f_2\,(T_{v3} - T_{\ell 2})\right]\right\}\Delta M_a \tag{169}$$

$$U_{v2} = U_{v2} + \Delta M_a\left[c_{va} + f_1\,(c_{pa} - c_{va})\right]\left[T_{\ell 2} + f_2\,(T_{v3} - T_{\ell 2})\right] \tag{170}$$

where

U_{v3} = drywell vapor region total energy

U_{v2} = wetwell vapor region total energy

M_{wv3} = mass of water in drywell vapor region

M_{a3} = mass of air in drywell

M_{a2} = mass of air in wetwell

$M_{w\ell 2}$ = mass of water in wetwell pool region

$U_{\ell 2}$ = wetwell pool region total energy

$h_{\ell 3}$ = specific enthalpy of liquid in drywell vapor region

h_{g3} = specific enthalpy of vapor in drywell vapor region

f_1, f_2 = input multipliers on air bubble energy transfer

c_{pa} = specific heat of air at constant pressure

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

T_{v3} = absolute temperature of drywell vapor region

$T_{\ell 2}$ = absolute temperature of wetwell pool region.

3. VACUUM RELIEF SYSTEM MODEL

All BWR pressure suppression system models in CONTEMPT-LT provide an option to model a vacuum breaker pressure relief system between the wetwell and drywell vapor regions. Only flow from the wetwell to the drywell is calculated; that is, flow is in one direction only. In addition, the model is activated only when the compartment differential pressure exceeds an input value. The model determines flow from the following equations:

$$\Delta p = k_{vr} \frac{G^2}{2\rho} \tag{171}$$

$$W_{VAC} = N_{vr} \sqrt{\frac{2 \rho A^2 \Delta p}{k_{vr}}} \tag{172}$$

where

Δp	=	wetwell pressure minus drywell pressure
G	=	flow rate per unit area
A	=	area of one vacuum relief breaker
W_{VAC}	=	flow rate through entire breaker system
N_{vr}	=	number of vacuum breakers in system
ρ	=	density of wetwell vapor region
k_{vr}	=	single-phase irreversible loss coefficient for a vacuum relief breaker.

Equation (171) is a simplified form of the integral momentum equation for steady state, compressible, single-phase flow with assumed restrictions of constant area, elevation, and velocity.

If vacuum relief system flow occurs during a timestep, compartment masses and energies are updated as follows:

$$\Delta M_w = \Delta t \; W_{VAC} \; \frac{M_{wv2}}{M_{wv2} + M_{a2}} \tag{173}$$

$$\Delta M_a = \Delta t \; W_{VAC} \; \frac{M_{a2}}{M_{wv2} + M_{a2}} \tag{174}$$

$$M_{wv3} = M_{wv3} + \Delta M_w \tag{175}$$

$$M_{wv2} = M_{wv2} - \Delta M_w \tag{176}$$

$$M_{a2} = M_{a2} - \Delta M_a \tag{177}$$

$$M_{a3} = M_{a3} + \Delta M_a \tag{178}$$

$$U_{v3} = U_{v3} + h_{g2} \; \Delta M_w + c_{pa} \; T_{v2} \; \Delta M_a \tag{179}$$

$$U_{v2} = U_{v2} - h_{g2} \; \Delta M_w - c_{pa} \; T_{v2} \; \Delta M_a \tag{180}$$

where

Δt = timestep length

ΔM_w = mass of water flow

ΔM_a = mass of air flow

M_{wv2} = mass of water in wetwell vapor region

M_{a2} = mass of air in wetwell vapor region

M_{a3} = mass of air in drywell vapor region

M_{wv3} = mass of water in drywell vapor region

U_{v3} = total energy in drywell vapor region

U_{v2} = total energy in wetwell vapor region

h_{g2} = specific enthalpy of water vapor in wetwell vapor region

c_{pa} = specific heat of air at constant pressure

T_{v2} = absolute temperature of wetwell vapor region.

No system checks exist to prevent excessive flow, from either large timesteps or unreasonable input parameters. Use of large timesteps during vacuum relief flow can result in unrealistic mass transfer and biased compartment pressures.

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APPENDIX A

SUMMARY DESCRIPTIONS OF CONTAINMENT SYSTEMS

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Several containment systems that can be modeled with CONTEMPT-LT are discussed briefly, and the major physical features of each system are described. Since CONTEMPT-LT is not presently designed to analyze an ice condenser containment system, that system is not described.

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 several million cubic feet 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.

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 lower pressure, any leakage flow would be into the annular region rather than into the environment.

The drywell compartment basically has the same safety features as a dry containment. The free standing 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 any undesired high pressures and temperatures encountered in the drywell.

The dual compartment has an outer wall of thick reinforced concrete. The safety system associated with the dual compartment is a ventilation system. CONTEMPT-LT does not presently have the capability for modeling the ventilation system.

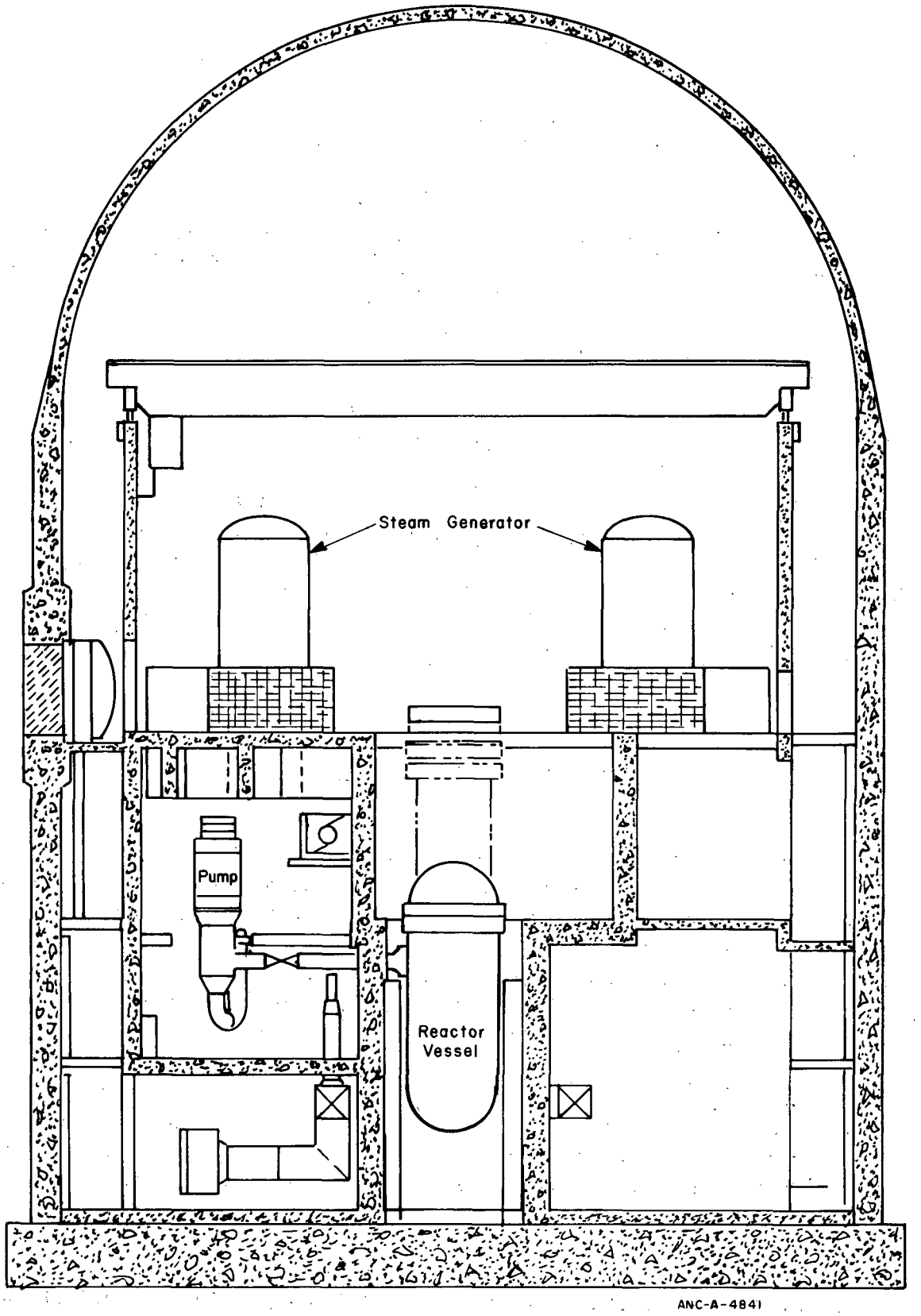

Fig. A-1 Typical dry containment.

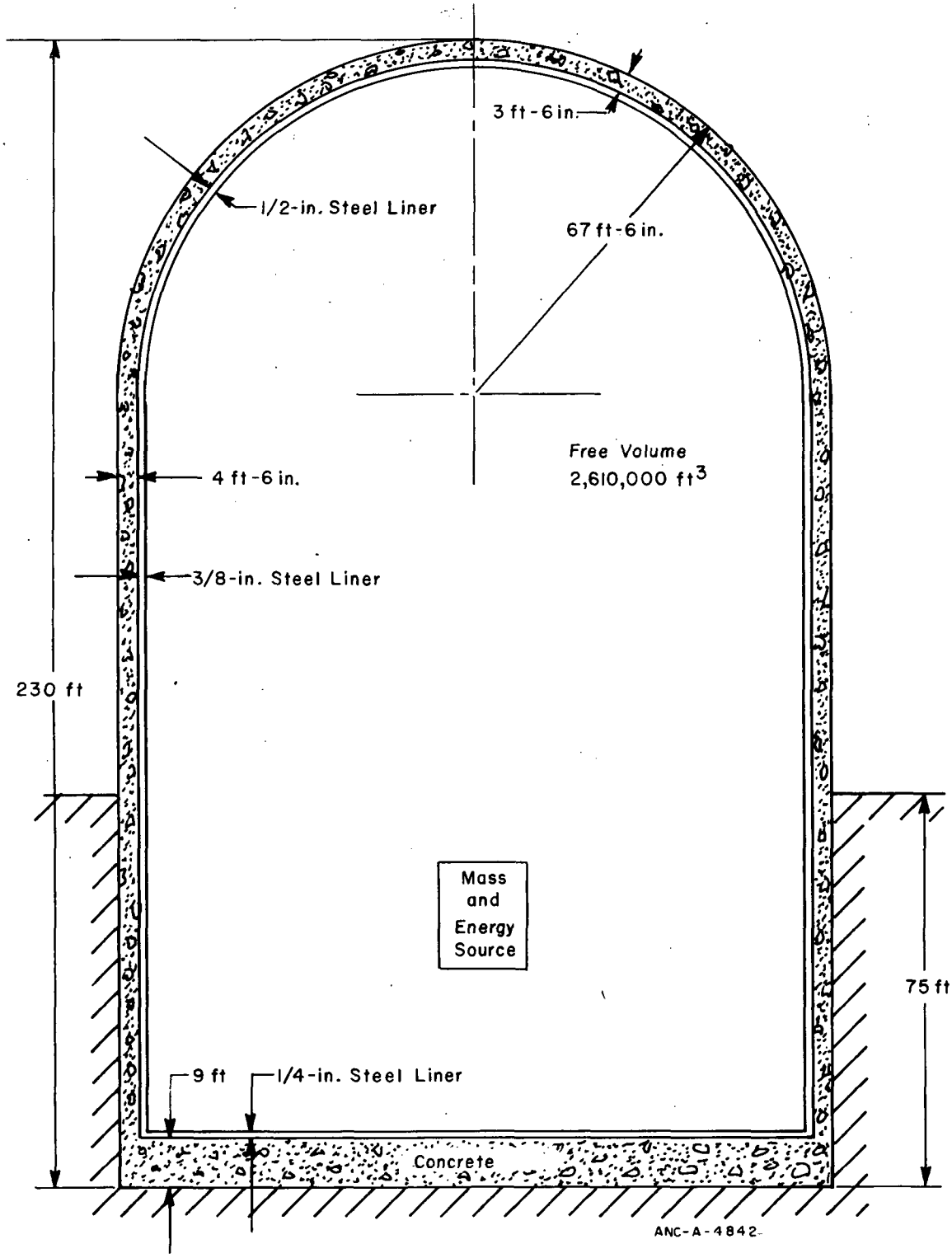

Fig. A-2 One-compartment representation of a dry containment.

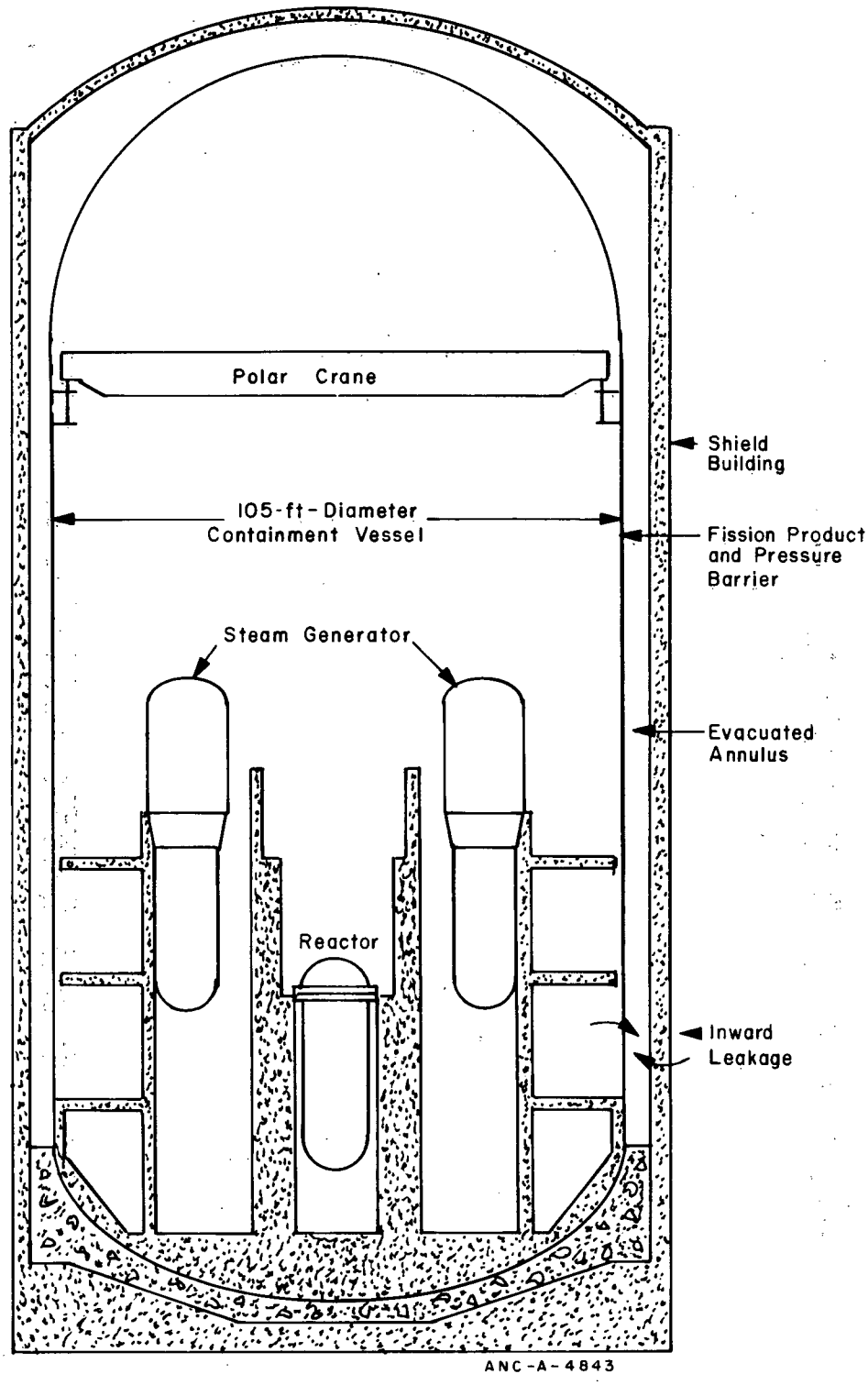

Fig. A-3 Dual containment.

3. SUBATMOSPHERIC CONTAINMENT

Subatmospheric containment is a concept whereby 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.

4. BWR MARK I PRESSURE SUPPRESSION CONTAINMENT

Figure A-4 is a schematic of a Mark I pressure suppression containment system for a boiling-water reactor (BWR). This containment concept, as all containment concepts for the BWR systems, features a relatively small steel drywell (dry containment chamber) connected by a system of vent pipes to another steel containment compartment commonly referred to as a wetwell. The vent pipes exit into a pool of water in the wetwell. In the event of an LOCA, the drywell pressure increases and the resulting high pressure forces a mixture of air, steam, and liquid through the vents into the wetwell. Since the vent pipe exits are located under water, the steam flowing into the wetwell is condensed in the wetwell liquid water pool. The pool acts as a large passive energy sink, thereby reducing the drywell and wetwell peak pressures and temperatures.

Atmosphere spray systems are located in both the drywell and wetwell compartments. Heat exchangers can be used to cool the spray water.

5. BWR MARK II PRESSURE SUPPRESSION CONTAINMENT

The BWR Mark II containment system functions basically the same as the Mark I system but the plant arrangement is considerably different.

The drywell is in the form of a truncated cone, and immediately below is the cylindrical pressure suppression chamber. These two units comprise a structurally integrated prestressed concrete pressure vessel lined with welded steel plate and provided with a steel pressure head for closure at the top of the drywell. The drywell and suppression chamber are separated by a reinforced concrete floor, as shown in Figure A-5, which serves to prevent flow of steam from the drywell into the suppression chamber except through the vents (downcomers) provided for this purpose. The vent system conducts flow from the drywell to the pressure suppression chamber, which condenses the steam portion and contains the noncondensable gases and fission products.

6. BWR MARK III PRESSURE SUPPRESSION CONTAINMENT

The Mark III containment system is conceptually similar to the earlier Mark I and Mark II systems. However, considerable differences exist in the physical layout,

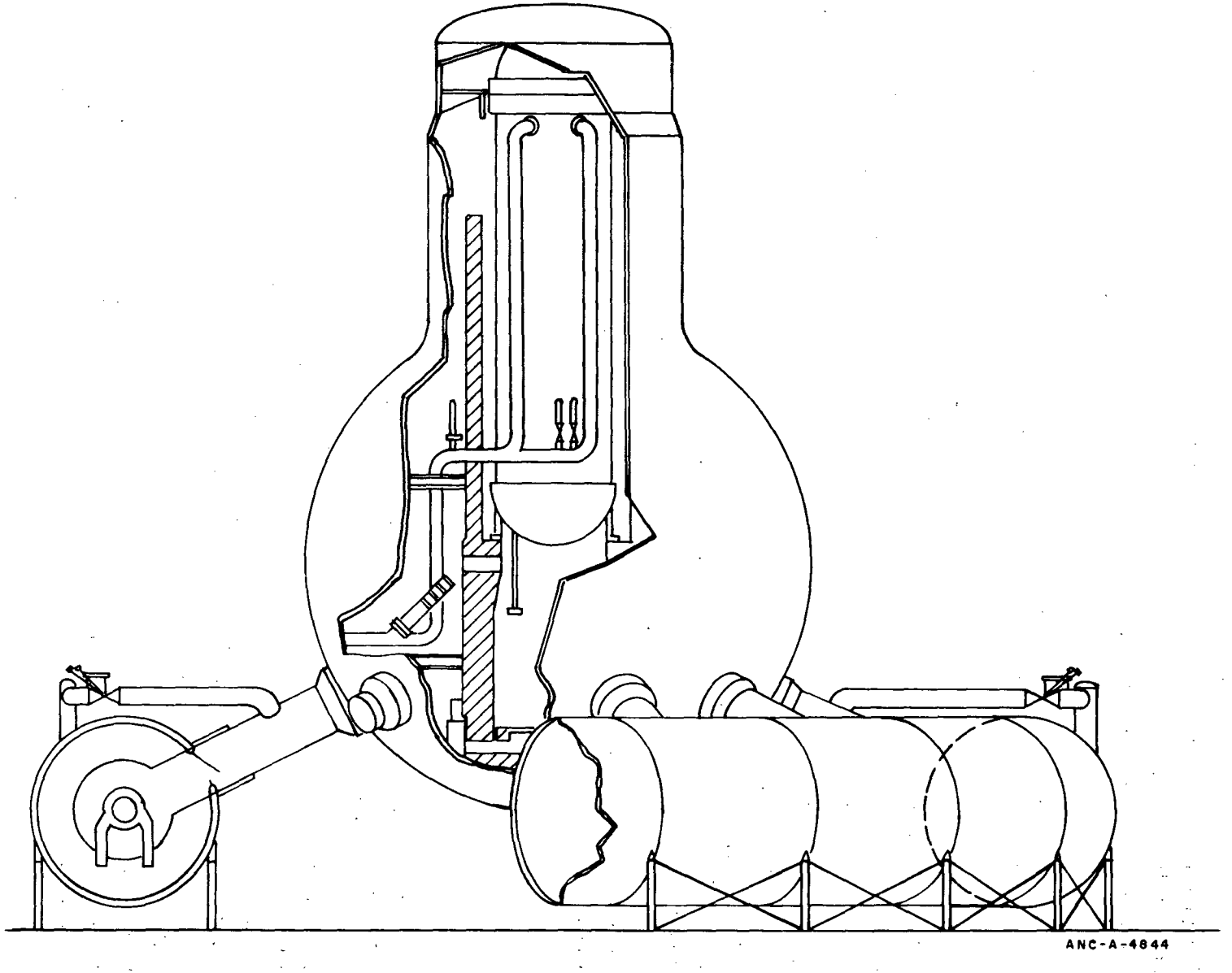

Fig. A-4 Pressure suppression containment system "light globe" drywell with "torus" wetwell design.

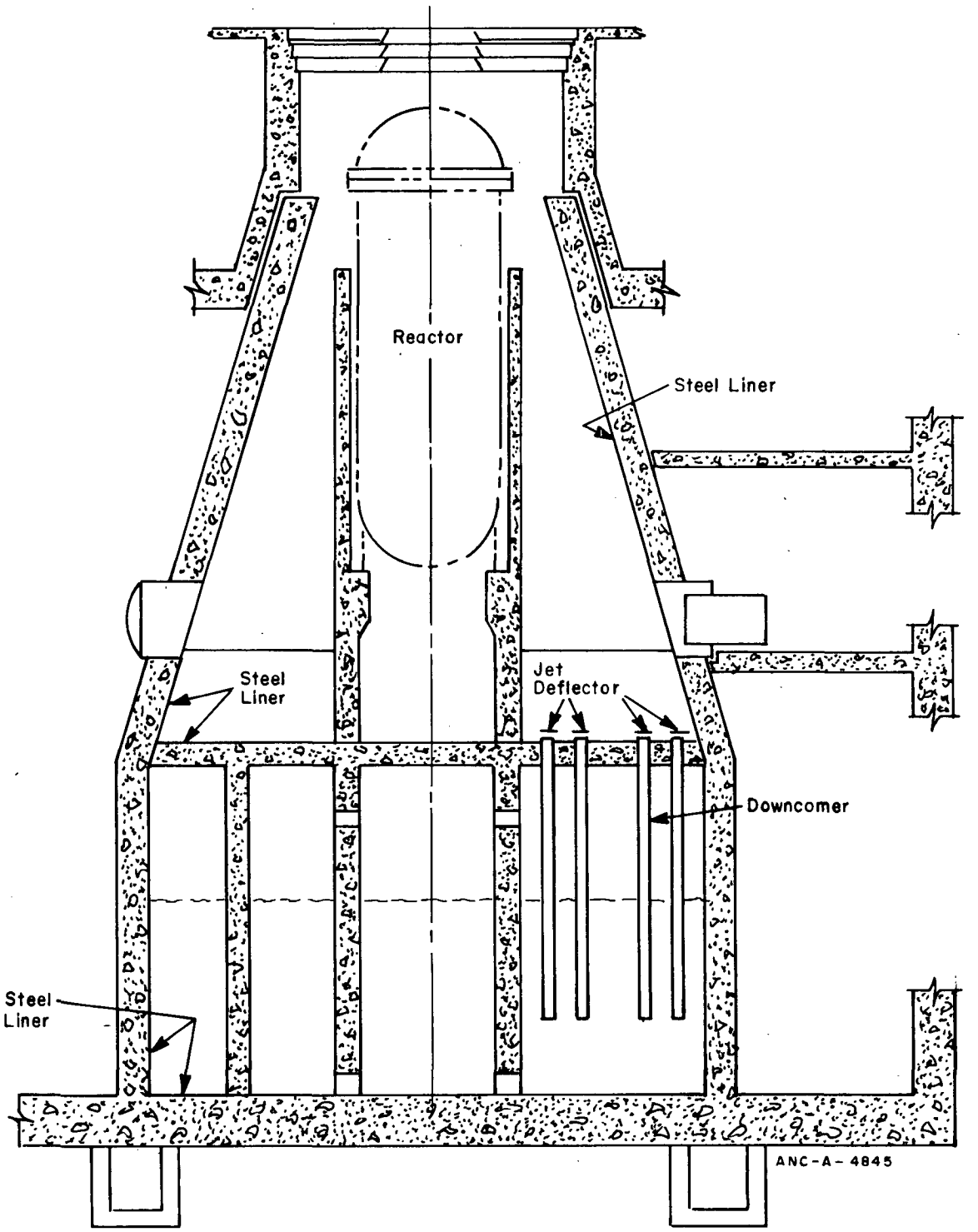

Fig. A-5 Mark II pressure suppression containment.

compartment volumes, and pressure suppression vent arrangement. The Mark III arrangement uses horizontal vents to conduct the steam from an LOCA into the suppression pool. Figure A-6 depicts a cross-sectional view of a Mark III containment showing the drywell, three horizontal vent levels, and the wetwell. The containment outer structure is a steel-lined concrete cylinder topped with a dome. The suppression pool totally encircles the drywell, with the weir wall inside the drywell providing the inner wall and the outer wetwell steel liner providing the outer wall.

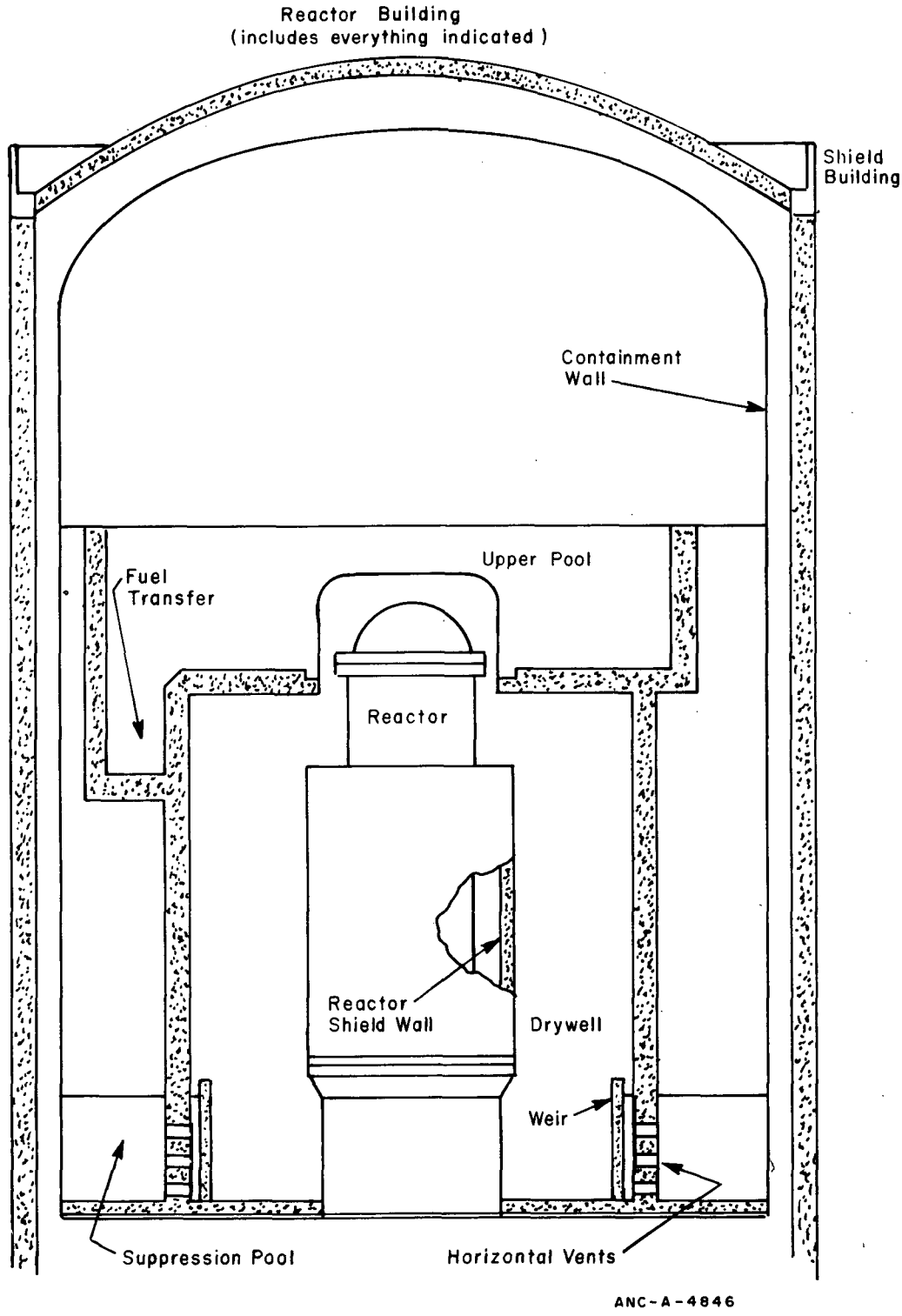

Fig. A-6 Mark III containment.

APPENDIX B

VENT FLOW CONTROL

APPENDIX B

VENT FLOW CONTROL

This appendix describes the numerical techniques used in CONTEMPT-LT for computing the vent flow from the drywell to the wetwell in pressure suppression containment systems. The flow through the vents consists of a two-component, two-phase mixture of water and air. The flow can be unchoked or choked, and depends upon the drywell conditions and the wetwell backpressure. The flow is computed using a three-level iterative process for the vertical vent (Mark I and Mark II) model and a four-level iteration for the horizontal vent (Mark III) model. The innermost level of iteration is used to evaluate the equation of state for each flow element. The second level of iteration is used to solve the conservation equations for a given flow element, or to determine whether the mass flow estimate is above the choked flow limit. The third level of iteration is used to adjust the mass flow in a vent until either a choked flow condition is determined or the outlet pressure at the vent exit equals the backpressure of the wetwell. For horizontal (Mark III) multilevel vent systems, an additional mass balance is required to assure agreement between the annulus incoming flow and the exit flow summed from all vents.

1. EQUATION OF STATE ITERATION PROCESS

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

$$h_{mix} = F_w\, h_w\,(T, v_w) + F_a\, c_p\, T \quad . \tag{B-1}$$

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

$$p = p_w\,(T, v_w) + \frac{F_a R_a T}{F_w v_g(T)} \tag{B-2}$$

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

$$p = p_w\,(T, v_w) + \frac{F_a R_a T}{x F_w v_g(T)} \tag{B-3}$$

$$v_w = (1-x)\, v_f(T) + x v_g(T) \tag{B-4}$$

where

c_p = heat capacity of air at constant pressure

F_a = air mass fraction

F_w = water mass fraction

p = total pressure

p_w = pressure of water

R_a = gas constant for air

T = temperature (absolute units)

h_{mix} = mixture specific enthalpy

h_w = specific enthalpy of water

x = quality of two-phase region

v_f = specific volume of saturated liquid

v_g = specific volume of saturated vapor

v_w = specific volume of water.

These equations are based on the assumptions of the Gibbs-Dalton law for vapors, that no vapor is dissolved in the liquid, that air is a perfect gas, and that all components are at the same temperature.

Equations (B-1) through (B-4) are solved iteratively, the quantities, h_{mix}, F_w, and F_a are given and T, p, and x are to be determined. Equation (B-1) is rewritten as

$$F(T) = h_{mix} - F_w h_w (T, v_w) - F_a c_p T \tag{B-5}$$

and T is adjusted through a process similar to Newton's method until F(T) is sufficiently near zero. The first trial temperature is the initial temperature or the result of the last time advancement. Through use of the trial temperature and v_w, the water properties h_w, p_w, and x are determined from the equation of state for water. Evaluation of water properties is based on table interpolation procedures. After the first evaluation of F(T), the trial temperature is changed by $0.5^{\circ}K$ in the direction indicated by the sign of F(T), and F(T) is reevaluated. Subsequent trial temperatures are determined from

$$T^{m+1} = T^m - \frac{F(T^m)}{\frac{F(T^m)-F(T^{m-1})}{T^m-T^{m-1}}} \tag{B-6}$$

where the superscript indicates the iteration number. Iterations are terminated when $\left|\frac{F(T^m)-F(T^{m-1})}{h_{mix}}\right| \leq 0.0005$ or the difference in the upper and lower temperature limits is less

than 0.005°K. Checks are incorporated into the iteration process to guarantee each iteration is an improvement over the previous iteration and that anomalies can be overcome.

Figure B-1 shows a possible iteration sequence. The first trial solution is marked "1", and the second trial solution 0.5°K greater and marked "2". The slope determined from Trials 1 and 2 is used to obtain the third trial temperature by extrapolation. The results from Trials 2 and 3 are used to obtain Trial Temperature 4 by interpolation and the resultant value of the function meets the convergence criteria. At the beginning of the iteration, the limits of the water property tables are set as the upper and lower limits for the trial temperature. As each trial temperature is evaluated, the appropriate limit is replaced by the trial temperature. In the example, the lower limit would be replaced successively by T_1, T_2, and T_4 and the upper limit would be replaced by T_3. After the next temperature is determined by extrapolation, the extrapolated temperature is compared to the appropriate limit. If the trial temperature exceeds the limit, the average of the limit and the last trial temperature is used as the next trial temperature. Because of the table lookup and interpolation procedures used for the water properties, an anomaly in F(T) such as that marked by "a" in Figure B-1 may be encountered. The iteration procedure just described could become "trapped" in the local maximum. This problem is resolved by setting the next trial function to the average of the appropriate limit and the last trial temperature whenever the derivative is greater than or equal to zero.

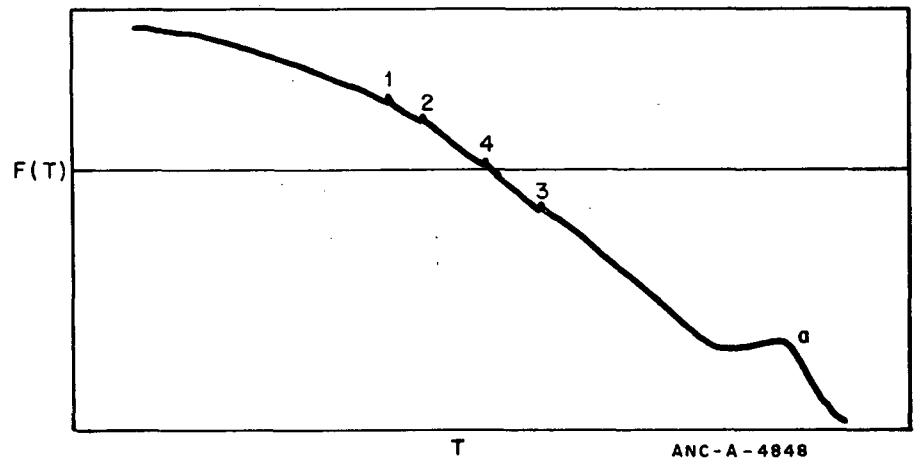

Fig. B-1 Sketch of balancing routine iteration.

Once the temperature is determined, the total pressure is calculated from Equation (B-2) or (B-3). Also, the mixture quality (x) is obtained from the solution process, and the mass fraction of steam (F_{wv}), and mass fraction of liquid water ($F_{w\ell}$) within the flow element are determined from

$$F_{wv} = x\ F_w \tag{B-7}$$

$$F_{w\ell} = (1-x)\ F_w \tag{B-8}$$

2. FLOW ELEMENT ITERATIVE PROCESS

Given a trial flow rate, W, from the Level 3 vent iteration, Level 2 iterations are used to solve the equations of change and the equation of state for each element. A solution is first obtained for the initial element and then successive elements in the direction of flow until either a solution is obtained for the last element or the equations for an element are determined as having no solution. A solution will not exist if the trial flow rate is greater than choked flow at the outer surface.

The solution of the element equations is reduced to an iteration on the outlet enthalpy. Given a trial exit enthalpy, the exit velocity is obtained from the energy equation. The equations of change for a flow element have been described in the body of the report. The flow density or specific volume can then be obtained from

$$v_{mix} = \frac{u}{W} A \tag{B-9}$$

where W = given trial flow rate

A = given flow element exit area

u = flow element exit velocity from energy equation

v_{mix} = specific volume of flow mixture.

The equation of state is iteratively solved (Level 1) using input values for enthalpy, specific volume, water mass fraction, and air mass fraction. The output consists of temperature, pressure (P_s), and specific water properties. Through use of the exit velocity, the momentum equation is also solved to obtain a flow element exit pressure (P_m). A solution is obtained when a trial enthalpy has been found such that $G(h) = P_m - P_s$ is sufficiently near zero.

Figure B-2 is a sketch of the behavior of G(h) versus enthalpy, and three cases of the flow, W, relative to the choked flow, W_c, are presented for clarification of the following discussion. For flow values, $W \leqslant W_c$, two solutions exist and the desired solution, based on empirical observation, is the root to the right of the maximum. No solution exists for $W > W_c$, and this condition is used to detect that the trial flow is greater than the choked flow. The $W = W_c$ condition is approached at the exit surface or an upstream surface with the smallest outlet area when the vent iteration (Level 3) converges on choked flow.

The Level 2 flow element iteration procedure is similar to that described for equation of state balancing but with the added complications of determining whether a solution exists, and if a solution exists, converging on the desired root.

The stagnation enthalpy (h_T) is an upper bound but not a realistic bound because that bound could lead to zero velocity and an attempted division by zero. At the start of a Level 2 iteration, an absolute upper bound is established as

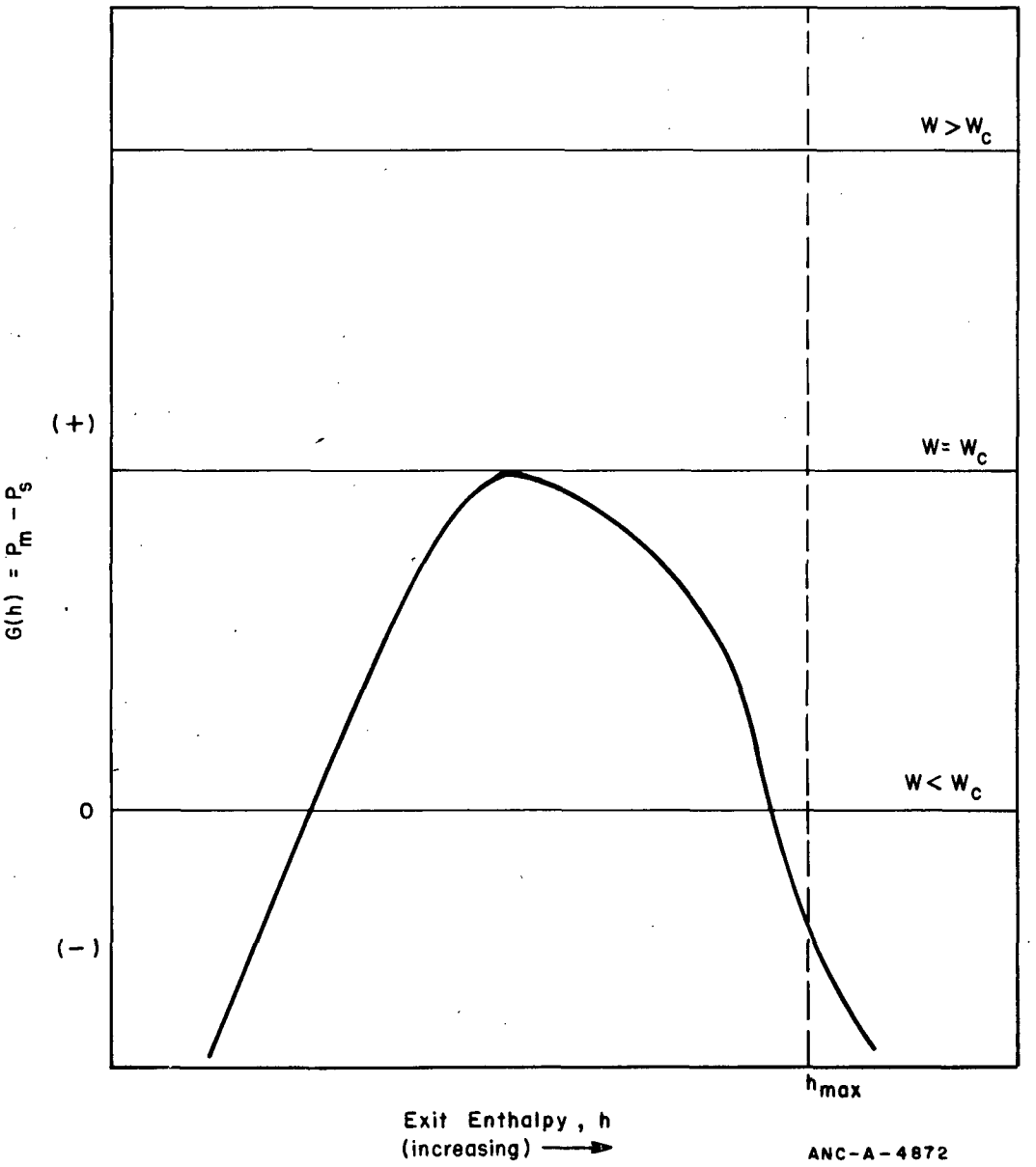

Fig. B-2 Level 2 iteration control scheme.

$$h_{max} = 0.99999\ (h_T - g\ \Delta z) \tag{B-10}$$

where

g	=	acceleration of gravity
Δz	=	elevation difference between flow element entrance and exit.

All trial enthalpies are compared to h_{max} and may not exceed h_{max}. If the solution exists between h_{max} and h_T, as can occur in the first few elements for low flow, the results for h_{max} are accepted as the solution.

Upper and lower limits are used in Level 2 iterations to prevent extrapolation outside the solution limits established by the previous trials in a similar fashion as in the balance iteration. However, the upper and lower limits are not set initially. A useful initial lower limit is not available, and the lower limit is set to each trial enthalpy that yields a positive G(h). The upper limit is set to each trial enthalpy that yields a negative G(h). A false upper limit can result whenever a trial function of the maximum of G(h) is used (Figure B-2). When a false upper limit is detected, the upper limit is reset to an unset state. When an extrapolation is indicated in a direction with an unset bound, the magnitude of the extrapolation is limited to 25 Btu/lb or to the distance to the absolute upper limit, h_{max}, which is always checked.

The first trial enthalpy, h^1, for a flow element iteration is the result from the previous iteration for this element (may be from the previous vent Level 3 iteration in the current timestep or the last vent iteration for the previous timestep) if $0.95\ h_{max} \leqslant h^1 \leqslant h_{max}$; otherwise h_{max} is used for the initial element, and then results from one element are used for the next element. The initial trial temperature for the equation of state iteration is taken from the same source as the trial enthalpy. The second trial enthalpy is obtained by changing the first trial enthalpy by the magnitude $0.005\ h^1$ and by taking the sign of $G(h^1)$.

By starting with the results of the second trial enthalpy, a slope can be determined from

$$\delta = \frac{G(h^m) - G(h^{m-1})}{h^m - h^{m-1}} \tag{B-11}$$

where m represents the iteration number. For negative slopes, extrapolation or interpolation as described for the equation of state balance routine occurs. A positive slope indicates one of the following: (1) a trial enthalpy to the left of the maximum has been used, a false upper limit has been set, and the iteration must be forced to the desired root; (2) no solution exists; (3) an anomaly has been encountered. An anomaly can be caused by the equation of state because that equation is solved only within iteration tolerance. If any one of the previous trial enthalpies resulted in a negative slope, an anomaly is assumed if both upper and lower bounds have been set, or identical results were returned from the equation

of state for the last two trial enthalpies; otherwise no solution is assumed to exist. The behavior of G(h) is such that the iteration procedure should converge to the desired root if such a root exists, once a negative slope has been obtained. If a positive slope is encountered before a negative slope, four additional attempts are made to select a trial enthalpy that yields a negative slope by testing enthalpies successively closer to h_{max}. If a negative slope cannot be obtained, no solution is assumed to exist.

A converged solution is reached when either

$$\left| \frac{G(h^m)}{P_s} \right| < 0.001$$

or the relative difference between the upper and lower bounds is less than 0.001.

3. VENT ITERATION PROCEDURES

The vent iteration (Level 3) adjusts the flow, W, until either the outlet pressure of the last element, P_e, equals the backpressure exerted by the wetwell, P_b, or the choked flow value, W_c, is determined. Figure B-3 is a sketch of the function $E(w) = P_e - P_b$. Flow values to the left of W_c are unchoked and depend on the pressure difference. When choked flow is indicated, the flow is no longer dependent on the backpressure.

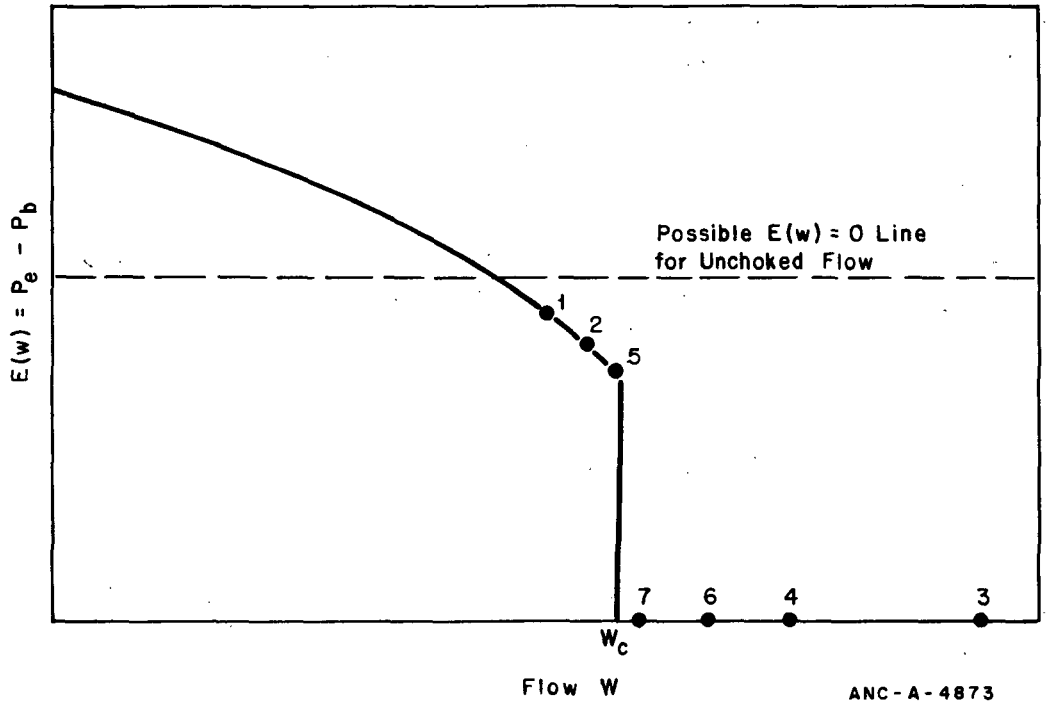

Fig. B-3 Sketch of vent iteration control.

The vent iteration proceeds as if the flow is unchoked, and the procedures are similar to that described for the balance and element iterations. If the flow from the previous timestep is zero or if the drywell pressure changes significantly, the initial trial flow is estimated; otherwise the flow from the previous timestep is used. No upper or lower bounds are set initially, but trial flows in the unchoked region are set into the appropriate bound, depending on the sign of E(w). If the first trial flow, w^1, is unchoked, the second trial flow is changed by 0.0125 w^1 in the direction indicated by the sign of $E(w^1)$. Once results from the two unchoked trial flows are available, interpolation or extrapolation of the last two unchoked results is attempted whenever an unchoked result is obtained. If no bound exists, extrapolation is limited to 0.10 W. If the bound is set and extrapolation is beyond the bound, the next trial flow is the average of the current flow and the bound.

A trial flow is above the choked flow when the flow equations for one of the elements have no solution. When no solution exists, the upper bound is set to the trial flow, and the next trial flow is the average of the current flow and the lower bound if that bound exists, or 0.90 W if the lower bound is not set.

A converged solution in the unchoked state is obtained when a trial flow below the choked value results in

$$\left| \frac{P_e - P_b}{P_b} \right| < \epsilon_3 \text{ where } \epsilon_3 \text{ is an input quantity.}$$

The printed output indicates "unchoked" for this case. The choked flow value is a unique value, and the iteration procedure computes only an approximate value. The computed value equals the choked value within the iteration tolerance but may be slightly above or below the actual choked flow. A converged solution in the choked state is obtained when a trial flow is above the choked value, an upper bound, b_u, and a lower bound, b_ℓ, are both set, and the bounds satisfy

$$\left| \frac{b_u - b_\ell}{b_\ell} \right| \leq \epsilon_3 .$$

The printed output indicates "choked A" (for Above choked flow) for this case. A choked flow solution is also assumed when a trial flow is below the choked value,

$$\left| \frac{P_e - P_b}{P_b} \right| < \epsilon_3$$

is not satisfied, and $\frac{b_u - b_\ell}{b_\ell} \leq \epsilon_3$ is satisfied. The printed output has "choked B" (for Below choked flow) for this case.

Figure B-3 shows a possible Level 3 iteration sequence for choked flow. Flows marked 1 and 2 indicate the first two trial flows which are below choked flow. Flow 3 is obtained by extrapolation and is above choked flow. Flow 4 is obtained by averaging the bounds set to Flows 2 and 3. Flow 4 is above choked flow, and Flow 5 is obtained by averaging the bounds now set to Flows 2 and 4. Flow 5 is below choked flow but extrapolation using the

results of the last two unchoked flows, Flows 2 and 5, is beyond the current upper bound of Flow 4, so Flow 6 is obtained by averaging Flows 4 and 5. Flow 6 is above choked flow, and Flow 7 is obtained by averaging Flows 5 and 6. Flow 7 is choked, but the bounds are within tolerance and the process has converged to the "choked A" state.

For the vertical vent (Mark I and Mark II) model a pressure suppression system flow solution is completed at the vent level of iteration. For the horizontal vent (Mark III) system an additional level is required to obtain a mass balance between the incoming annulus flow and the sum of the flow from all vents.

4. HORIZONTAL VENT SYSTEM (MARK III) ANNULUS AND VENT FLOW BALANCE

The horizontal vent (Mark III) system may have parallel flow paths, and the flow from all paths (vent level) must be summed and compared with the initial flow input to the annulus. After all vent flow solutions have been obtained,

$$D(W) = WT - WSUM \tag{B-12}$$

is determined where

WT = flow into annulus

WSUM = flow exiting from all vents.

Next a flow balance test is performed to determine whether

$$\left| \frac{WT - WSUM}{WT} \right| < \epsilon_4 \tag{B-13}$$

where ϵ_4 is an input convergence value. If the convergence is satisfied, WSUM is accepted as the total vent system flow solution. Otherwise, WT is modified and the entire four levels of iteration are repeated if a second convergence test is also exceeded. The Level 4 balance scheme assumes a convergence behavior similar to that shown in Figure B-4. During the first outer, or Level 4, iteration no flow limits are set. On subsequent iterations lower (WL_ℓ) and upper (WL_u) mass flow limits are set if, and only if, WSUM is (a) less than WL_u and greater than WL_ℓ, or (b) the appropriate limit is zero (unset).

A second convergence test is performed on the limits if both are nonzero. A solution is accepted if

$$\left| \frac{WL_\ell - WL_u}{WL_j} \right| < \epsilon_4 \tag{B-14}$$

where j represents either ℓ or u, the last limit set. Otherwise, WT is updated and the system reiterated (four levels).

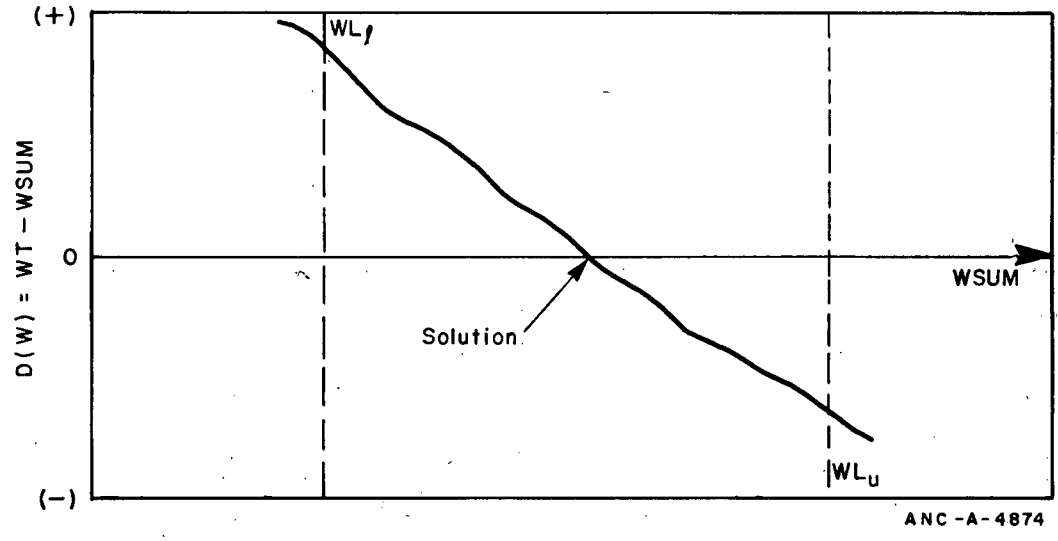

Fig. B-4 Sketch of Level 4 balance.

If both limits are nonzero, WSUM is tested to determine whether it is within the limits. If so, WT is updated to equal WSUM and the flow iterations are repeated. The first time WSUM is outside the limits, WT is set to the average of the limits and the iterations are repeated. For the second, third, and fourth times WSUM exceeds the limits, the appropriate limit is changed to equal WSUM, and WT is set to WSUM and all levels of iteration are completed. The fifth time WSUM exceeds the limits is treated as the first time because the counter index is reset. Iteration continues until either a solution is obtained or the maximum number of iterations has been completed.

APPENDIX C

HORIZONTAL VENT SYSTEM (MARK III) VENT CLEARING EQUATIONS

APPENDIX C

HORIZONTAL VENT SYSTEM (MARK III) VENT CLEARING EQUATIONS

The horizontal (Mark III) vent clearing model has been described in Section V-2 of the main report. Modeling of the vent clearing action is based on a need for representing independent action among the horizontal vents which lie in a vertical plane. The pressure drop across a vent is determined by a vent node and an annulus node; thus, a three-vent model contains three annulus nodes and three vent nodes. A seventh node is used to model dynamic behavior in the wetwell. Although the wetwell is represented by only a single node, the boundaries of the node change with the vent under examination, to describe the respective pressure drop within the wetwell. Seven nodes are considered the minimum number acceptable for representing dynamic behavior independently in each vent of a three-vent design.

1. ASSUMPTIONS

Although the vent clearing transient is a three-dimensional event, the model is based on one-dimensional flow. Multidimensional effects are approximated. Integration of the momentum balance in the downward direction over an annulus node volume retains a cross momentum flux term due to the presence of a vent, and the irreversible loss terms based on real three-dimensional measurements.

The analytical model is generalized to account for a vertical stacking of N vents. A diagram of the analytical model is shown in Figure C-1. Assumptions used in developing the mathematical model are:

(1) Number of nodes representing one vertical column of N vents is 2N+1.

(2) Vertical construction, that is, S_W, S_D, and L are invariant with height.

(3) Each vent has a constant cross section A_n and lies horizontally.

(4) Flow is an incompressible pure liquid.

(5) No heat is conducted into or out of the system.

(6) One-dimensional macroscopic mass and momentum equations apply to each node.

(7) Vent clears as a plug, that is, water surface in vent is perpendicular to vent axis.

(8) Pressure on entrance and exit surfaces of vent is the pressure at center of surface.

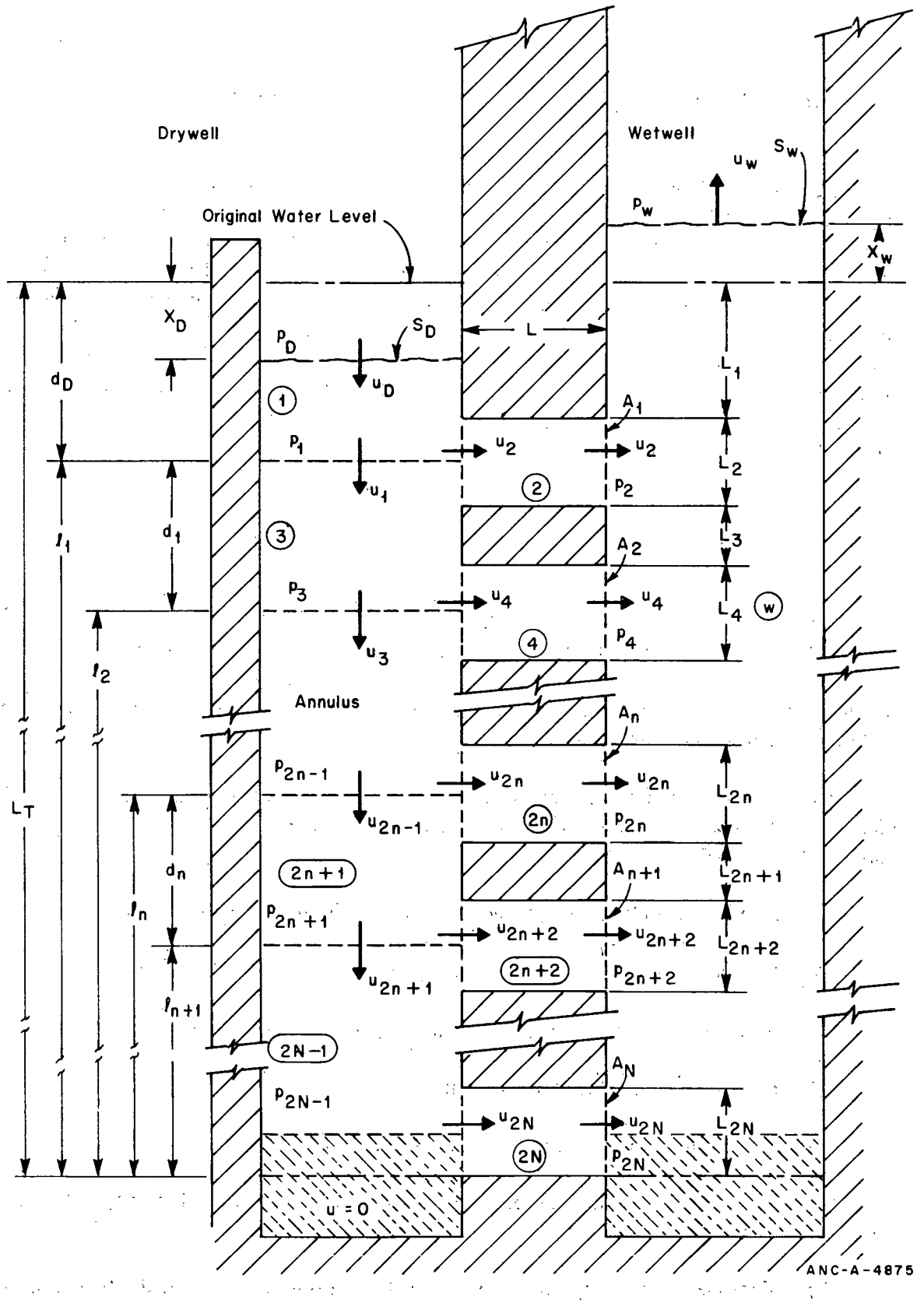

Fig. C-1 Horizontal (Mark III) vent model with node 1 clearing.

(9) Momentum in nodes on drywell side is a function of only the entrance velocity.

(10) Momentum in vent nodes is a function of only the exit velocity.

(11) Momentum in wetwell node is a multistep function of the vertical flow profile.

(12) Two-dimensional effects of sudden expansions or contractions and of elbows can be included in friction loss terms.

(13) Friction effects due to wall in wetwell are negligible.

(14) Liquid in annulus and wetwell below center of bottom vent are negligible, but liquid in vent is not negligible.

(15) Bubble formation at end of vent is insignificant.

The common symbols used in the equations are:

Symbol	Definition
L,ℓ,X,Y,d	Distance
A,S	Area
V	Volume
u	Velocity
$\dot{u}$	Acceleration
p	Pressure
ρ	Density
g	Acceleration of Gravity
f	Fanning Friction Factor
R	Hydraulic Radius = $\frac{\text{Cross Sectional Area}}{\text{Wetted Perimeter}}$

Other symbols are defined as they appear.

2. GENERAL EQUATIONS

The basic equations[C-1] used in derivation of the model are:

Macroscopic Mass Balance

$$\frac{d}{dt} m_{tot} = -\Delta W \qquad \text{(C-1)}$$

where

m_{tot} = $\int \rho dV$ = mass of fluid within the control volume

W = $\rho u S$ = mass rate of flow.

Macroscopic Momentum Balance

$$\frac{d}{dt} \vec{P}_{tot} = - \Delta(u\vec{w} + p\vec{S}) - \vec{F} + m_{tot} \vec{g} \qquad \text{(C-2)}$$

where

P_{tot} = $\int \rho \vec{u} dV$ = total momentum of fluid within the control volume

$\vec{F}$ = sum of pressure and viscous forces of fluid on solid surface of control volume.

The macroscopic mechanical energy equation could also be written but it is not necessary. A set consisting of either the mass and energy or the mass and momentum equations is sufficient, and the dynamic coupling of all pressures is preserved. Both sets will balance for the initial conditions, but the energy equations require the use of L'Hospital's rule whenever the average nodal velocity is zero. Since the momentum equations have no such restriction, they are employed in this model. (Figure C-1 and the previously listed symbol definitions may be referred to for added clarification of the following equations.)

Some useful geometrical relationships for the model are:

$$L_T = \sum_{i=1}^{2N} L_i \qquad \text{(C-3)}$$

$$\ell_n = \left(\sum_{i=2n}^{2N} L_i \right) - 1/2 \, L_{2n} \qquad \text{(C-4)}$$

$$d_n = L_{2n+1} + 1/2 \, (L_{2n} + L_{2n+2}) \, . \qquad \text{(C-5)}$$

From Equations (C-4) and (C-5):

$$d_n = \ell_n - \ell_{n+1} \, . \qquad \text{(C-6)}$$

The following definitions are used extensively in the analytical model:

$$\alpha_n = \frac{A_n}{S_D} \qquad \text{(C-7)}$$

$$\beta_n = \frac{A_n}{S_w} \, . \qquad \text{(C-8)}$$

Let

$$\beta = S_D/S_w \quad . \tag{C-9}$$

From Equations (C-7) through (C-9):

$$\beta = \frac{\beta_n}{\alpha_n} \quad . \tag{C-10}$$

When a vent is uncovered the geometry of the vent changes to that shown in Figure C-2, where

X_D = displacement of annulus water surface from its original level

Y_n = displacement of vent water surface from entrance of vent

d_D = vertical dimension of water in the annulus node being cleared.

Vent n (Vent Node 2n) starts to clear once annulus Node 2n-1 is completely cleared.

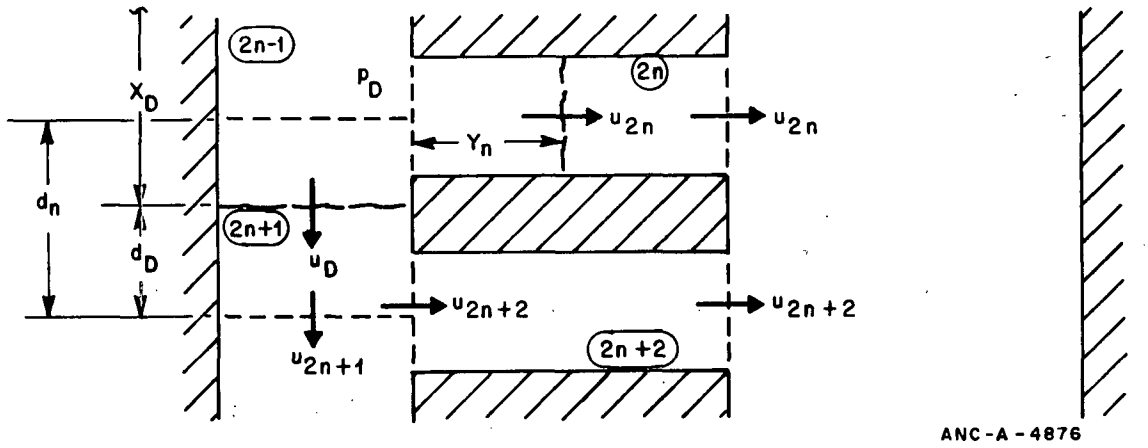

Fig. C-2 Uncovered vent model.

Formulas for irreversible losses in Equation (C-2) which are due to viscous forces are available in standard texts[C-1,C-2]. The Fanning friction factor f is defined by the following formulas. The Reynolds number is

$$\mathrm{Re} = \frac{Du\rho}{\mu} \tag{C-11}$$

where D is the pipe diameter and μ is the viscosity. For noncylindrical pipes, replace D by the hydraulic radius R in the formula

$$D = 4R = 4\left(\frac{\text{cross-sectional area}}{\text{wetted perimeter}}\right) \quad . \tag{C-12}$$

If Re $<$ 2,200, f is calculated by

$$f = \frac{16}{Re} \quad . \tag{C-13}$$

If Re $\geqslant$ 2,200, f is calculated by[C-2]

$$f = \left[2 \log_{10} \left(\frac{2.51}{Re\sqrt{f}} + \frac{0.271K}{D}\right)\right]^{-2} \tag{C-14}$$

where K is the wall surface absolute roughness. The relationship between the Fanning friction factor f and the Moody friction factor f_m is $f_m = 4f$.

3. ANNULUS NODES

Note 2n+1 - Not Clearing

Mass Balance: $\rho S_D u_{2n-1} - \rho S_D u_{2n+1} - \rho A_{n+1} u_{2n+2} = 0$

$$u_{2n-1} = u_{2n+1} + \alpha_{n+1} u_{2n+2} \quad . \tag{C-15}$$

Momentum Balance: $P_{tot} = \rho S_D d_n u_{2n-1}$

$$\frac{d}{dt} P_{tot} = \rho S_D d_n \dot{u}_{2n-1}$$

$$\Delta(uw + pS) = \rho S_D (u_{2n+1}^2 + 1/2\, u_{2n+2}\, u_{2n+1} - u_{2n-1}^2) + S_D (p_{2n+1} - p_{2n-1})$$

$$F = \rho |u_{2n-1}| S_D \frac{f u_{2n-1} d_n}{2R} + \frac{\rho}{2} K_{e_{n+1}} A_{n+1} |u_{2n+2}| u_{2n+2}$$

$$m_{tot}\, g = \rho g S_D d_n$$

$$\dot{u}_{2n-1} = \frac{u_{2n-1}^2 - 1/2\, u_{2n+2}\, u_{2n+1} - u_{2n+1}^2}{d_n} + \frac{p_{2n-1} - p_{2n+1}}{\rho d_n} + g - \frac{f |u_{2n-1}| u_{2n-1}}{2R} - \frac{K_{e_{n+1}} \alpha_{n+1} |u_{2n+2}| u_{2n+2}}{2d_n} \qquad n = 1, 2, 3, \ldots, N-2 \tag{C-16}$$

where $K_{e_{n+1}}$ is the elbow loss coefficient.

When Node 2n+1 is in the clearing phase, the clearing equations turn out to be just Equations (C-15) and (C-16) with the following substitutions (y $\rightarrow$ z means y is replaced by z):

$$u_{2n-1} \rightarrow u_D$$

$$p_{2n-1} \rightarrow p_D \qquad \text{(C-17)}$$

$$d_n \rightarrow d_D$$

where

$$d_D = L_T - \ell_{n+1} - X_D \cdot \qquad \text{(C-18)}$$

The bottom node, Node 2N-1, in the dry well is a special case of the 2n+1 node with n=N-1 and $u_{2N-1}=0$ in Equations (C-15) through (C-18).

4. VENT NODES

When the general even-numbered (2n) node, which is a vent node, is not clearing, the following balances apply:

Node 2n - Not Clearing

Mass Balance: $\rho A_n u_{2n_{in}} + \rho A_n u_{2n_{out}} = 0$ (C-19)

$$\therefore u_{2n_{in}} = u_{2n_{out}} = u_{2n} \cdot$$

Momentum Balance: $P_{tot} = \rho A_n L u_{2n}$

$$\frac{d}{dt} P_{tot} = \rho A_n L \dot{u}_{2n}$$

$$\Delta(uw + pS) = (p_{2n} - p_{2n-1}) A_n u_{2n}$$

$$F = \rho |u_{2n}| A_n \frac{f u_{2n} L}{2R} + 1/2 K_{sc_n} \rho u_{2n}^2 A_n (1-\alpha_n)$$

$$m_{tot} g = 0$$

$$\dot{u}_{2n} = \frac{p_{2n-1} - p_{2n}}{\rho L} - \frac{f|u_{2n}|u_{2n}}{2R} - \frac{1}{2L} K_{sc_n} (1 - \alpha_n)|u_{2n}|u_{2n} \qquad \text{(C-20)}$$

$$n = 1, 2, 3, \ldots, N$$

where K_{sc} is the sudden-contraction loss coefficient. For negative u_{2n}, α_n is replaced by β_n.

When a vent is clearing, the mass balance is no longer trivial, due to the loss of mass from the vent itself, as shown in Figure C-1. The balances are:

Node 2n - Clearing

Mass Balance: $\frac{d}{dt} m_{tot} = \frac{d}{dt} [\rho A_n (L-Y_n)] = - \rho A_n \frac{d}{dt} Y_n$

$$\Delta w = - \rho A_n u_{2n} \tag{C-21}$$

$$\frac{d}{dt} Y_n = u_{2n} \quad n = 1, 2, 3, \ldots, N.$$

Momentum Balance: $P_{tot} = \rho (L-Y_n) A_n u_{2n}$

$$\frac{d}{dt} P_{tot} = \rho (L-Y_n) A_n \dot{u}_{2n} - \rho A_n u_{2n}^2$$

$$\Delta(\dot{u}w + pS) = \rho A_n u_{2n}^2 + p_{2n} A_n - p_D A_n$$

$$F = \rho |u_{2n}| A_n \frac{f u_{2n} (L-Y_n)}{2R} + 1/2 K_{sc_n} \rho u_{2n} A_n (1-\alpha_n)$$

$$m_{tot} g = 0$$

$$\dot{u}_{2n} = \frac{p_D - p_{2n}}{\rho (L-Y_n)} - \frac{f |u_{2n}| u_{2n}}{2R} \quad n = 1, 2, 3, \ldots, N \tag{C-22}$$

which is the same as the momentum balance for a full vent [Equation (C-20)], with the following substitutions:

$$\begin{aligned} p_{2n-1} &\rightarrow p_D \\ L &\rightarrow L-Y_n \\ K_{sc} &\rightarrow 0 \ (u_{2n}>0) \ . \end{aligned} \tag{C-23}$$

5. WETWELL NODE

During vent clearing, the wetwell node (w) has N possible incoming flow paths, one for each vent. The mass balance in the wetwell node is first written in terms of the vent velocities, but by applying the continuity equations for the vent and annulus nodes, a direct relationship between the annulus and wetwell surface motion is obtained. Thus, if annulus Node 2M-1 is being cleared and the number of vents cleared is NC, some mass balances in the wetwell are:

Node w

$$\text{Mass Balance:} \quad \rho u_w S_w = \sum_{n=1}^{N} \rho u_{2n} A_n \tag{C-24}$$

$$u_w = \sum_{n=1}^{N} \beta_n u_{2n}$$

$$= \beta u_D + \sum_{n=NC+1}^{M-1} \beta_n u_{2n} \tag{C-25}$$

As shown in Figure C-3, momentum in the wetwell node is considered as a stepped function of elevation with discontinuities occurring at the vent centerline elevations. Subnode boundaries are also drawn at the centerline elevations so that a momentum equation can be written for the volume contained between the wetwell surface and any given vent level. For annulus Node 2M-1 clearing and NC vents fully cleared, the momentum balances are (superscript on P_{tot}^{n} refers to highest node for which it is valid):

Node w

Momentum Balance:

$$P_{tot}^{M-1} = \rho S_w [(L_T - \ell_{NC+1} + X_w) u_w + \sum_{i=NC+1}^{n-1} d_i (u_w - \sum_{j=NC+1}^{i} \beta_j u_{2j})]$$

$$n \leq M-1$$

$$P_{tot}^{M} = P_{tot}^{M-1} + \rho S_D \, d_{M-1} \, \beta u_D \qquad n=M$$

$$P_{tot}^{N} = P_{tot}^{M} + \rho S_D \sum_{i=M}^{n-1} d_i \beta u_{2i-1} \qquad M<n\leq N$$

$$\frac{d}{dt} P_{tot}^{N} = \rho S_w [(L_T - \ell_{NC+1} + X_w) \dot{u}_w$$

$$+ \sum_{i=NC+1}^{M-2} d_i (\dot{u}_w - \sum_{j=NC+1}^{i} \beta_j u_{2j}) + \beta \, d_{M-1} \, \dot{u}_D$$

$$+ \beta \sum_{i=M}^{N-1} d_i \dot{u}_{2i-1}] + \rho S_w u_w^2 \quad .$$

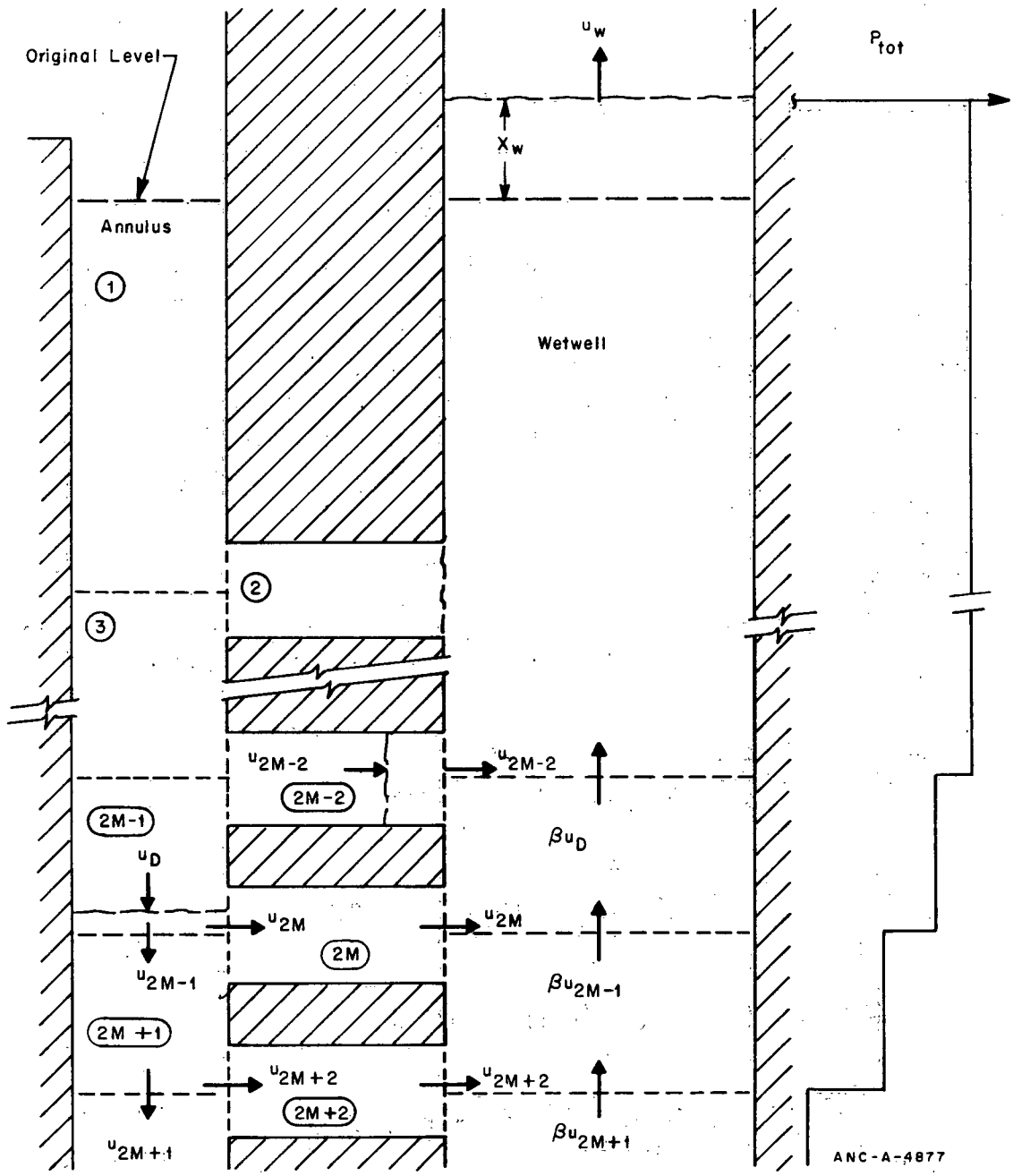

Fig. C-3 Wetwell model.

$$\Delta(uw + pS) = - \rho S_w u_s^2 + (p_w - p_{2n}) S_w$$

$$u_s = \begin{cases} u_w - \sum_{i=NC+1}^{n} \beta_i u_{2i} & 1 \leq n \leq N \\ \beta u_D & n = M-1 \\ \beta u_{2n-1} & n \geq M \end{cases}$$

$$m_{tot} g = - \rho S_w L_{wn} g$$

$$F = \frac{\rho}{2} \sum_{i=1}^{n} A_i u_{2i}^2 [K_{we_i} + (\beta_i - 1)^2 K_{se_i}] \qquad \text{(C-26)}$$

where K_{se} is the sudden-expansion loss term and K_{we} is the wetwell elbow loss term.

$$\dot{u}_w^{M-1} = \frac{1}{L_{wn}} \{u_s^2 - u_w^2 + \sum_{i=NC+1}^{n-1} (d_i \sum_{j=NC+1}^{i} \beta_j \dot{u}_{2j}) + \frac{p_{2n} - p_w}{\rho} - L_{wn} g$$

$$- \frac{1}{2} \sum_{i=1}^{n} \beta_i u_{2i}^2 [K_{we_i} + (\beta_i - 1)^2 K_{se_i}]\} \quad n \leq M-1 \qquad \text{(C-27)}$$

$$\dot{u}_w^M = \dot{u}_w^{M-1} - \frac{d_{M-1}}{L_{wn}} \beta \dot{u}_D \qquad n=M \qquad \text{(C-28)}$$

$$\dot{u}_w^N = \dot{u}_w^M - \frac{\beta}{L_{wn}} \sum_{i=M}^{n-1} d_i \dot{u}_{2i-1} \qquad M < n \leq N \qquad \text{(C-29)}$$

where

$$L_{wn} = L_T + X_w - \ell_n \quad . \qquad \text{(C-30)}$$

6. METHOD OF SOLUTION

The vent clearing model for N vents uses 2N+1 nodes requiring 2N+2 pressures and 2N+2 separate velocities. Three boundary conditions ($u_{2N-1} = 0$, p_D and p_w) reduce the number of variables to 4N+1 unknowns, which are related in N+1 mass equations and 3N momentum equation. When a vent is being cleared, another mass equation and another momentum equation are necessary.

From the basic equations of the model (or as derived previously), a set of equations involving only the velocities as variables can be developed. In the resulting set, the pressures p_D and p_w are boundary conditions. No other pressures appear.

To solve the system of equations, a set of momentum and mass equations is rearranged to eliminate the internal pressures. In general, the vent and wetwell velocities (u_{2n} and u_w, respectively) can be eliminated. The resulting set of N equations has the general form

$$\dot{u}_{2n-1} = f[u_D, u_{2i-1}, \ldots, \dot{u}_{2i-1}, \ldots (i \neq n), X_D, Y_i, \ldots, p_D, p_w] \tag{C-31}$$

$$\begin{cases} i = 1, 2, \ldots, N-1 \\ n = 0, 1, 2, \ldots, N-1 \end{cases}$$

where, for Node 2M-1 clearing

$$u_{2M-3} = u_D$$

$$u_{2n-1} = 0 \qquad n = 0, 1, 2, \ldots, M-2 \ .$$

The system of Equations (C-31) is solved by a Runge-Kutta numerical technique. The system of equations may also be extended to solve for X_D and Y_i by using the identities

$$\left.\begin{aligned} \dot{X}_D &= u_D \\ \dot{Y}_i &= u_{2i} \end{aligned}\right\} . \tag{C-32}$$

7. VENT SPILLING

Under certain conditions, a lower vent can be clearing while an upper vent is refilling. In those cases, *the flow in the bottom vent still has forward inertia but is beginning to slow down*. Before the clearing action has time to reverse and refill the bottom vent, the next upper vent may completely refill and spill over into the annulus. Because the bottom vent is only partially full, the spill water enters the bottom vent until it becomes full, then the annulus begins refilling.

Because the spill model is not employed during the crucial clearing phases when peak pressures may be reached, a simple model is used. Continuity of spill water is conserved but the momentum contribution of spill water is ignored and the time delay due to falling is also ignored. The equations for all vents except the bottom vent are unchanged by the addition of the spill model. The only operational difference is that the equations are still being used after the vent refills, although the mass within the vent is constant and the node vent entrance side boundary is held constant.

8. REFERENCES

C-1. R. B. Bird, W. E. Stewart, E. N. Lightfoot, *Transport Phenomena*, John Wiley and Sons, Inc., 1960.

C-2. T. Baumeister (ed.), *Mechanical Engineer's Handbook*, 6th ed. New York: McGraw-Hill Book Co., Inc., 1958.

APPENDIX D

STEAM TABLES -- STH20 PROGRAM

APPENDIX D

STEAM TABLES -- STH20 PROGRAM

The STH20 computer program generates tables of water properties and writes these tables on a data set in the proper format for CONTEMPT-LT or RELAP4[D-1]. CONTEMPT-LT no longer contains a built-in table of water properties, but instead requires an input water property file as generated by STH20. This appendix describes generation of such a file; and describes the subcodes which use that file. 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 greatest where the most accuracy is required.

Water properties in the data tables are in SI units. The nomenclature used in the following sections is:

T	Temperature
P	Pressure
v	Specific volume
u	Specific internal energy
h	Enthalpy
$\beta=\frac{1}{v}\left.\frac{\partial v}{\partial T}\right\|_P$	Coefficient of thermal expansion
$\kappa=\frac{1}{v}\left.\frac{\partial h}{\partial P}\right\|_T$	Isothermal compressibility
$c_p=\left.\frac{\partial h}{\partial T}\right\|_P$	Isopiestic heat capacity
f	Saturated liquid subscript
g	Saturated vapor subscript
sat	Saturated pressure subscript.

1. STH20G MODULE INPUT DATA

The STH20G module generates tables of thermodynamic properties of water using the 1967 International Formulation Committee (IFC) formulation for industrial use of the properties of steam[D-2,D-3] as coded in the ASTEM package[D-4]. The input data format is identical to the CONTEMPT-LT input format described in Appendix H except that only one case is allowed.

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 integer format.

Temperature Cards

Cards	Data
1001-1999	Temperature values 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 $273.16^{o}K \leq T \leq 1073.15^{o}K$. If temperatures above the critical point, $647.30^{o}K$, are entered, the critical temperature should be entered also to increase accuracy of data interpolation for locations above and near the critical point. The card numbers need not be sequential which facilitates the addition or deletion of temperatures.

Pressure Cards

Cards	Data
2001-2999	Pressure values 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 $0 < P \leq 10^{8}$ Pa. The card numbers need not be sequential.

2. STH20G MODULE TABLE FORMAT

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

presssure table; and 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. The tables are generated and stored using 64-bit words for floating-point quantities.

In the description of the tables, A is used for the array symbol, NT and NP are 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), $1 \leqslant N \leqslant 11$, are a function of the temperature in T(I). The correspondence between the B array and the saturation properties are:

B(1,I)	P	B(7,I)	v_g
B(2,I)	v_f	B(8,I)	u_g
B(3,I)	u_f	B(9,I)	β_g
B(4,I)	β_f	B(10,I)	κ_g
B(5,I)	κ_f	B(11,I)	c_{pg}.
B(6,I)	c_{pf}		

(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), $1 \leqslant N \leqslant 11$, 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), $1 \leqslant N \leqslant 5$, are a function of the temperature in T(I) and the pressure in P(J). The correspondence between the D values and the properties are:

D(1,I,J) v	D(4,I,J) κ
D(2,I,J) u	D(5,I,J) c_p
D(3,I,J) β	

3. STH20G MODULE OUTPUT

The tables generated by the module are written on a disk file of two records by using FORTRAN sequential, nonformatted statements. 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.

4. USE OF THE STH20G MODULE

The module uses the FTB package for dynamic storage allocation. The required region size depends on the input data. For example, a region size of 200K is sufficient for 45 single-phase temperatures, 29 single-phase pressures, 40 saturation temperatures, and 27 saturation pressures. The defaults for the required DD card are STH20101 for the disk file written on Unit 1, STH20501 for the input data read on Unit 5, and FT06F001 for the printed output written on Unit 6.

5. STH20I, INITIALIZATION SUBROUTINE

The STH20I subroutine retrieves the tables needed by the other subroutines by reading the data set created by the STH20G module and sets up a small common block named STH20C. This subroutine must be called before any of the other subroutines. The subroutine is called by CALL STH20I (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 value returned to NUSE is thus the number of 64-bit words used in the A array. Words in the A array beyond A(NUSE) are available for other use. The subroutine prints an error message and returns 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 STH20 subroutines unless the A array is destroyed.

6. ARGUMENTS COMMON TO THE REMAINING SUBROUTINES

The A array is as defined in Section 2 and must be the array loaded by the call to STH20I. The integer variable, IT, is set by the subroutines that can compute properties in the liquid, two-phase, and vapor states. IT is set to 1 for the liquid state, 2 for the two-phase state, 3 for the vapor state below the critical temperature, and 4 for the state above the critical temperature. Water at pressures above the critical pressure, but at temperatures below the critical temperature, is considered to be in the liquid state.

S is an array of twenty-three 64-bit floating-point words containing both input to and output from the subroutines. The assignment of properties to the S array is:

S(1) T	S(12) v_g
S(2) P	S(13) u_f
S(3) v	S(14) u_g
S(4) u	S(15) h_f
S(5) h	S(16) h_g
S(6) β	S(17) β_f
S(7) κ	S(18) β_g
S(8) c_p	S(19) κ_f
S(9) X(quality)	S(20) κ_g
S(10) P_{sat}	S(21) c_{pf}
S(11) v_f	S(22) c_{pg}
	S(23) indexes

S(6) through S(8) are undefined if IT is returned as 2 S(9) contains 0.0 if IT is returned as 1, contains the quality if IT is returned as 2, and contains 1.0 if IT is returned as 3 or 4. S(10) is the saturation 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. S(11) through S(22) are undefined if IT is not returned as 2. The S array is used for working storage and undefined elements may be changed during subroutine execution. On entry, S(23) contains the indexes obtained by the table search. Execution time can be minimized if the table indices returned 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.

A logical error flag, ERR, is set FALSE if the input quantities are within the range of the tables and TRUE otherwise.

7. SATURATION PRESSURE AS A FUNCTION OF TEMPERATURE

CALL STH200 (T, P, ERR) computes the saturation pressure P given the temperature T as input. The temperature must be in the range $273.16^{o}K \leqslant T \leqslant 647.30^{o}K$. This subroutine does not use the A array and can be called before STH20I is called. STH200 is an entry point in the STH201 subroutines.

8. 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 2. The quality, X, is entered in S(9) and must be in the range $0.0 \leqslant X \leqslant 1.0$. S(3) through S(5) return values for the two-phase mixture and S(11) through S(22) return values for saturated liquid and saturated vapor. S(2) and S(10) are returned equal. IT would always be 2 for this call and thus is not included in the argument list.

9. SATURATED PROPERTIES AS FUNCTIONS OF PRESSURE AND QUALITY

CALL STH202 (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 STH201. STH202 is an entry point in the STH201 subroutine.

10. SINGLE-PHASE PROPERTIES AS FUNCTIONS OF TEMPERATURE AND PRESSURE

CALL STH203 (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 $T(1) \leqslant T \leqslant T(NT)$. The pressure, P, is entered in S(2) and must be within the range $0 < P \leqslant P(NP)$ for the vapor state and $P(1) \leqslant P \leqslant P(NP)$ for the liquid state. The arrays T and P are defined in Section 2. 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 or 1.0 corresponding to the liquid or vapor state, respectively.

11. WATER PROPERTIES AS FUNCTIONS OF TEMPERATURE AND SPECIFIC VOLUME

CALL STH204 (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 $T(1) \leqslant T \leqslant T(NT)$. 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 within the range $P(1) \leqslant P \leqslant P(NP)$. If the temperature and specific volume indicate the superheated state, the resultant pressure must be less than P(NP). The T and P arrays are defined in Section 2. The results are stored in the S array as described in Section 6.

12. SINGLE-PHASE SATURATED LIQUID PROPERTIES AS FUNCTIONS OF SPECIFIC ENERGY OR SPECIFIC ENTHALPY

CALL STH20U (A, S, ERR) [or CALL STH20H (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. STH20H is an entry point in the STH20U routine.

13. REFERENCES

D-1. K. V. Moore and W. H. Rettig, *RELAP4 – A Computer Program for Transient Thermal Hydraulic Analysis,* ANCR-1127 (December 1973).

D-2. C. A. Mayer et al, *Thermodynamic and Transport Properties of Steam.* The American Society of Mechanical Engineers (1967).

D-3. E. Schmidt, *Properties of Water and Steam in SI Units,* Springer-Verlag New York, Inc., New York, New York (1969).

D-4. 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 E

HEAT CONDUCTING STRUCTURES: DIFFERENCE EQUATIONS AND SOLUTIONS

APPENDIX E

HEAT CONDUCTING STRUCTURES: DIFFERENCE EQUATIONS AND SOLUTIONS

Numerical approximations of the heat conduction equation and generalized boundary conditions, and solutions to these equations are discussed in this appendix. Several boundary condition options are also discussed. Much of the theory presented in this appendix has been documented[E-1].

1. NUMERICAL APPROXIMATION TO THE HEAT CONDUCTION EQUATION

The temperature distribution through each structure is determined by solving the one-dimensional multiregion heat-conduction equation by the method outlined in IDO-16867[E-1]. A summary of both the transient and the steady state solution of the heat-conduction equation is given below. The partial differential equation for which a numerical approximation is derived is

$$g(x) \frac{\partial}{\partial t} \left[u(x,t)\right] = \nabla \cdot k(x) \nabla u(x,t) + S(x,t) \qquad \text{(E-1)}$$

where

u = temperature

x = space variable

t = time variable

g = volumetric heat capacity

k = thermal conductivity

S = source term per unit volume.

Numerical approximations to Equation (E-1) are derived for slab, cylindrical, and spherical geometries in one space dimension.

Figure E-1 illustrates the placement of mesh points at which the temperature is calculated. Mesh points are placed such that they lie on the exterior boundaries of the problem, at the interfaces between materials, and at equal intervals between the interfaces and between the interfaces and the boundaries. Up to 101 mesh points for each structure are allowed by the code. A region is a segment of space which contains a single material and has a constant spacing between mesh points. Up to 20 regions for each structure are allowed, and each region may contain a different material. A new region is required

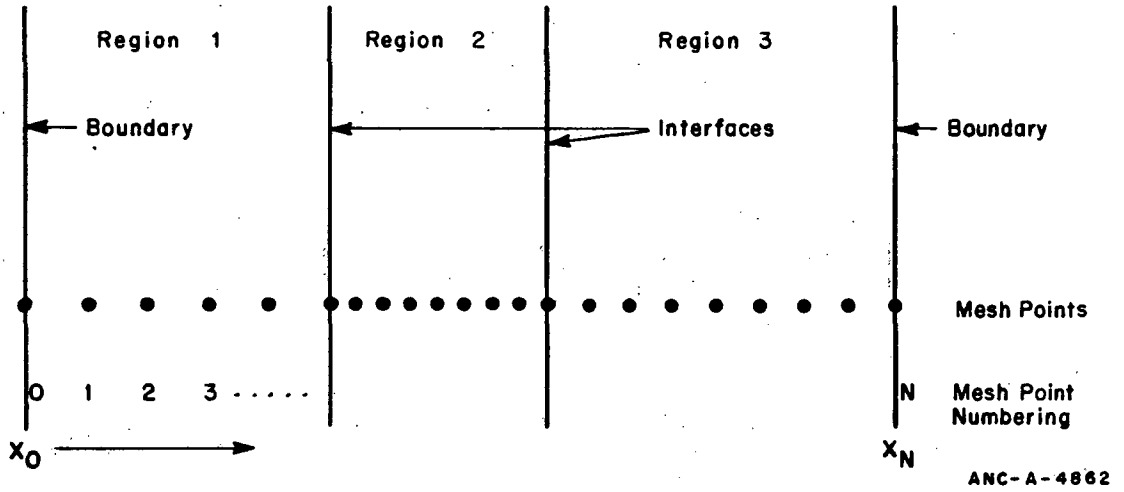

Fig. E-1 Mesh point layout.

whenever a material interface exists or a different mesh point spacing is desired. The mesh spacing should not change at interfaces of significantly dissimilar materials, and also a mesh spacing should not change by more than a factor of three within the same or similar materials.

Figure E-2 represents three typical mesh points. Subscripts ℓ and r designate quantities to the left and right, respectively, of the mesh point. The h's indicate the mesh point spacings, which are not necessarily equal. The quantities k, g, and S are assumed constant between mesh points, but $k_{\ell n}$ is not necessarily equal to k_{rn} and similarly for g and S.

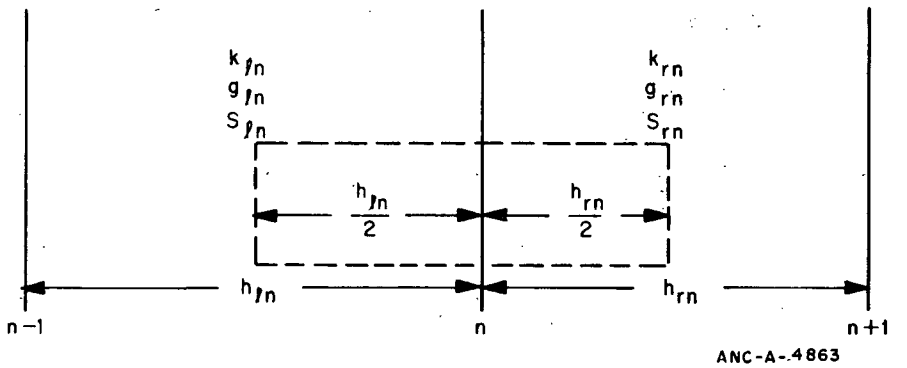

Fig. E-2 Typical mesh points.

To obtain the spatial difference approximation for the n^{th} mesh point, Equation (E-1) is integrated over an incremental volume, the volume being indicated by the dashed line in Figure E-2. Since the code is one-dimensional, the dimensions of the volume for other than the x dimension are set to unity. For slab geometry, the volume is a rectangular solid. For cylindrical geometry, the volume is a cylindrical annulus; and for spherical geometry, the volume is a spherical shell. For convenience, the following quantities are defined.

For slab geometry:

$$h^v_{\ell n} = \frac{h_{\ell n}}{2} \qquad h^v_{rn} = \frac{h_{rn}}{2}$$

$$h^s_{\ell n} = \frac{1}{h_{\ell n}} \qquad h^s_{rn} = \frac{1}{h_{rn}} \tag{E-2}$$

$$h^b_n = 1.$$

For cylindrical geometry:

$$h^v_{\ell n} = 2\pi \frac{h_{\ell n}}{2} \left(x_n - \frac{h_{\ell n}}{4}\right) \qquad h^v_{rn} = 2\pi \frac{h_{rn}}{2} \left(x_n + \frac{h_{rn}}{4}\right)$$

$$h^s_{\ell n} = \frac{2\pi}{h_{\ell n}} \left(x_n - \frac{h_{\ell n}}{2}\right) \qquad h^s_{rn} = \frac{2\pi}{h_{rn}} \left(x_n + \frac{h_{rn}}{2}\right) \tag{E-3}$$

$$h^b_n = 2\pi x_n .$$

For spherical geometry:

$$h^v_{\ell n} = \frac{4}{3\pi} \left[x_n^3 - \left(x_n - \frac{h_{\ell n}}{2}\right)^3\right] \qquad h^v_{rn} = \frac{4}{3\pi} \left[\left(x_n + \frac{h_{rn}}{2}\right)^3 - x_n^3\right]$$

$$h^s_{\ell n} = \frac{4\pi}{h_{\ell n}} \left(x_n - \frac{h_{\ell n}}{2}\right)^2 \qquad h^s_{rn} = \frac{4\pi}{h_{rn}} \left(x_n + \frac{h_{rn}}{2}\right)^2 \tag{E-4}$$

and for all geometries:

$$h^b_n = 4\pi x_n^2$$

$$D_n = g_{\ell n}\ h^v_{\ell n} + g_{rn}\ h^v_{rn} . \tag{E-5}$$

The superscripts, v and s, are not time superscripts but refer to volume and surface-gradient weights. The h^b_n is a surface weight used only at exterior boundaries.

The space dependence and the time dependence of the source term are assumed separable, that is:

$$S(x,t) = P_f\ P_t\lambda(t)\ Q(x) \tag{E-6}$$

where P_f is a power factor, $P_t\lambda(t)$ accounts for the time dependence, and $Q(x)$ accounts for the space dependence. The time-dependent part consists of two functions, P_t and $\lambda(t)$. The function P_t is defined by

$$P_t = 0 \text{ for } t < t_d$$

and

$$P_t = 1 \text{ for } t \geq t_d \tag{E-7}$$

where t_d is a delay time. The second function [$\lambda(t)$] is the decay power value taken from Cards 1XX. For the space-dependent part of Equation (E-6) [Q(x)] the subscripts ℓ and r are applied in the same manner as described previously.

When a finite difference approximation is applied to the integral form of Equation (E-1), the basic difference equation for the n^{th} mesh point is

$$\frac{\left(u_n^{m+1} - u_n^m\right) D_n}{\Delta t} = -\left(u_n - u_{n-1}\right) k_{\ell n} h_{\ell n}^s + \left(u_{n+1} - u_n\right) k_{rn} h_{rn}^s \tag{E-8}$$
$$+ \left(Q_{\ell n} h_{\ell n}^v + Q_{rn} h_{rn}^v\right) P_f P_t^{\lambda} \quad .$$

The symbol u_n^m indicates the temperature at x_n at time t_m, and the symbol u_n^{m+1} indicates the temperature at x_n at time t_{m+1}.

If the right-hand side of Equation (E-8) is given the symbol δ_n, Equation (E-9) can be written

$$\frac{\left(u_n^{m+1} - u_n^m\right) D_n}{\Delta t} = \delta_n \quad . \tag{E-9}$$

In the expression given thus far, the time superscript for δ_n has been omitted. For steady state:

$$\delta_n = 0 \tag{E-10}$$

and no time superscripts are needed. For the time-dependent case, the average of the value of δ_n at the beginning and the end of the time interval is used, and the implicit formula results:

$$\frac{\left(u_n^{m+1} - u_n^m\right) D_n}{\Delta t} = \frac{\delta_n^{m+1} + \delta_n^m}{2} \quad . \tag{E-11}$$

In Equation (E-11), the u^m symbols are known because they are either the results of the steady state calculation or the results of the last time advancement; but the determination of u^{m+1} requires the solution of simultaneous equations.

When Equation (E-11) is written out in full, the difference approximation for the nth interior mesh point for transient and steady state cases is

$$a_n u_{n-1}^{m+1} + b_n u_n^{m+1} + c_n u_{n+1}^{m+1} = d_n \tag{E-12}$$

where

$$a_n = -\frac{k_{\ell n}\, h^s_{\ell n}\Delta t}{2} \qquad c_n = -\frac{k_{rn}\, h^s_{rn}\Delta t}{2} \qquad b_n = \sigma D_n - a_n - c_n$$

$$d_n = -\sigma\, a_n\, u^m_{n-1} + \sigma\left(D_n + a_n + c_n\right)\, u^m_n - \sigma\, c_n\, u^m_{n+1}$$

$$+ \Delta t P_f P_t \left(\frac{\lambda^{m+1} + \sigma\lambda^m}{2}\right)\left(Q_{\ell n}\, h^v_{\ell n} + Q_{rn}\, h^v_{rn}\right)$$

and σ is unity for transient cases and zero for steady state cases.

2. DIFFERENCE APPROXIMATION TO BOUNDARY CONDITIONS

The boundary conditions are of the general form

$$A(u,t)u + B(u,t)\,\frac{\partial u}{\partial \bar{n}} = D(u,t)\; C(t). \tag{E-13}$$

In the CONTEMPT–LT code, the boundary conditions are normally

$$-k\,\frac{\partial u}{\partial \bar{n}} = H(u,t)\left[u - u_B(t)\right] \tag{E-14}$$

where u is the surface temperature, $u_B(t)$ is the bulk temperature, $\bar{n}$ is a vector in the direction out of the heat-conducting structure, k is the thermal conductivity of the conducting material, and H(u,t) is the heat transfer coefficient. In Equations (E-13) and (E-14), A corresponds to H, B to k, C to u_B, and D to H. Specification of H(u,t) and u_B for each boundary is done in the input data.

The method described is again used to obtain the difference approximation at the boundaries, but with the volume of integration as indicated in Figure E-3.

The complete equation for the mesh point at $x = x_o$ becomes

$$\left(\frac{u^{m+1}_o - u^m_o}{\Delta t}\right) g_{ro}\, h^v_{ro} = + k_{ro}\left(\frac{D_o\, C_o - A_o\, u_o}{B_o}\right) h^b_o + k_{ro}\left(u_1 - u_o\right) h^s_{ro} + S_{ro}\, h^v_{ro}\,. \tag{E-15}$$

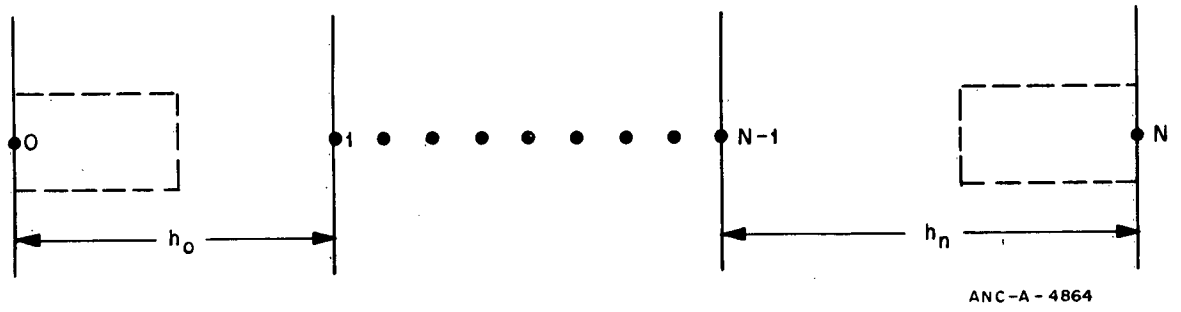

Fig. E-3 Boundary mesh points.

Approximations for the boundary $x = x_n$ are derived in a similar fashion. These equations for the boundary mesh points are converted to the implicit formula in the same manner as for the interior points. Thus, for $x = x_o$:

$$b_o\, u_o^{m+1} + c_o\, u_1^{m+1} = d_o \tag{E-16}$$

where

$$c_o = -\frac{k_{ro}\, h_{ro}^s\, \Delta t}{2}, \quad b_o = \sigma\, g_{ro}\, h_{ro}^v + \frac{k_{ro}\, A_o\, h_o^b \Delta t}{2B_o} - c_o$$

$$d_o = -\sigma\, c_o\, u_1^m + \sigma \left(g_{ro}\, h_{ro}^v + c_o - \frac{k_{ro}\, A_o\, h_o^b \Delta t}{2B_o} \right) u_o$$

$$+ \frac{k_{ro}\, h_o^b\, D_o\, \Delta t \left(C_o^{m+1} + \sigma\, C_o^m \right)}{2B_o} + \Delta t\, P_f\, P_t \left(\frac{\lambda^{m+1} + \sigma \lambda^m}{2} \right) Q_{ro}\, h_{ro}^v .$$

For $x = x_N$,

$$a_N\, u_{N-1}^{m+1} + b_N\, u_N^{m+1} = d_N \tag{E-17}$$

where

$$a_N = -\frac{k_{\ell N}\, h_{\ell N}^s\, \Delta t}{2}, \quad b_N = \sigma\, g_{\ell N}\, h_{\ell N}^v + \frac{k_{\ell N}\, A_N\, h_N^b\, \Delta t}{2B_N} - a_N,$$

$$d_N = -\sigma\, a_N\, u_{N-1}^m + \sigma \left(g_{\ell N}\, h_{\ell N}^v - \frac{k_{\ell N}\, A_N\, h_N^b\, \Delta t}{2B_N} + a_N \right) u_N^m$$

$$+ \frac{k_{\ell N}\, h_N^b\, D_N\, \Delta t \left(C_N^{m+1} + \sigma\, C_N^m \right)}{2B_N} + \Delta t P_f P_t \left(\frac{\lambda^{m+1} + \sigma \lambda^m}{2} \right) Q_{\ell N}\, h_{\ell N}^v .$$

3. EQUATION SOLUTION AND ENERGY EXCHANGE

The difference approximations for the mesh points, Equations (E-12), (E-16), and (E-17), lead to a tridiagonal set of N + 1 equations:

$$\begin{vmatrix} b_0 & c_0 & 0 & 0 & \cdot & 0 & 0 & 0 \\ a_1 & b_1 & c_1 & 0 & \cdot & 0 & 0 & 0 \\ 0 & a_2 & b_2 & c_2 & \cdot & 0 & 0 & 0 \\ 0 & 0 & a_3 & b_3 & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 0 & \cdot & a_{N-1} & b_{N-1} & c_{N-1} \\ 0 & 0 & 0 & 0 & \cdot & 0 & a_N & b_N \end{vmatrix} \begin{vmatrix} u_0^{m+1} \\ u_1^{m+1} \\ u_2^{m+1} \\ \cdot \\ \cdot \\ u_{N-1}^{m+1} \\ u_N^{m+1} \end{vmatrix} = \begin{vmatrix} d_0 \\ d_1 \\ d_2 \\ \cdot \\ \cdot \\ d_{N-1} \\ d_N \end{vmatrix} . \tag{E-18}$$

In the general boundary condition form of Equation (E-13), the coefficient matrix is nearly symmetric, with only the elements c_o and a_N possibly not symmetric. In the form of Equation (E-14), the matrix is always symmetric.

The solution to the preceding equations is obtained by applying the rules for Gaussian elimination, that is, by defining

$$(1) \quad E_o = \frac{c_o}{b_o} \quad \text{and} \quad F_o = \frac{d_o}{b_o} \tag{E-19}$$

$$(2) \quad E_j = \frac{c_j}{b_j - a_j E_{j-1}} \quad \text{and} \quad F_j = \frac{d_j - a_j F_{j-1}}{b_j - a_j E_{j-1}} \tag{E-20}$$

for j = 1, 2, ... , N-1

and

$$(3) \quad u_N^{m+1} = \frac{d_N - a_N F_{N-1}}{b_N - a_N E_{N-1}} \tag{E-21}$$

$$(4) \quad u_j^{m+1} = - E_j u_{j+1} + F_j \tag{E-22}$$

for j = N-1, N-2, . . . 2, 1, 0.

The rate of heat transfer between one surface of a heat-conducting structure and an adjacent medium is calculated by

$$R_{HT} = A\ h^b H(u - u_B) \qquad \text{(E-23)}$$

where H is the heat transfer coefficient; A is the effective heat transfer surface-area multiplier; h^b is defined in Equations (E-2), (E-3), and (E-4); u is the surface temperature of the structure; and u_B is the temperature of the medium adjacent to the boundary. The purpose of A in Equation (E-23) is to relate the heat-transfer rates obtained from the solution of the one-dimensional heat-conduction equation to the heat-transfer rates (Btu/hr) from the entire surface of the structure. The definition of h^b is such that the expression $[h^b H(u - u_B)]$ represents the heat-transfer rate across a unit surface in slab geometry $(\frac{Btu}{hr\text{-}ft^2})$, across a cylindrical surface of unit height in cylindrical geometry (Btu/hr-ft), and across a spherical shell in spherical geometry (Btu/hr). The quantity h^b also accounts for the difference in the areas of the left and the right surfaces of a cylindrical or spherical structure. Thus, the quantity A has the same value for either the left or the right boundary, although its definition (and units) varies with the geometry of a structure. For example, in slab geometry, A is just the cross-sectional area of the structure (ft^2). 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 symmetric, 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 (ft) and Ah^b is the area of one (depending on whether h^b_o or h^b_N is used) 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.

4. DETAILS OF BOUNDARY CONDITION OPTIONS

Available boundary condition options are discussed in the body of this report. Additional detail for several of these options is given here.

4.1 Condensing Steam Option (Uchida)

The Uchida condensing steam heat transfer coefficient, which is one boundary condition option in CONTEMPT-LT, is dependent on the adjoining compartment mass ratio of air to steam, as described in Table E-I. As stated previously, both sensible heat and mass transfer are associated with this option, for either saturated or superheated conditions. For superheated regions, for which the temperature of the compartment vapor region (T_V) is greater than the saturation temperature (T_S), based on the compartment pressure, and the

TABLE E-I

HEAT TRANSFER COEFFICIENT VERSUS MASS RATIO OF AIR TO STEAM[E-2]

Mass Ratio (air/steam)	Heat Transfer Coefficient, (Btu/hr-°F-ft^2)	Mass Ratio (air/steam)	Heat Transfer Coefficient, (Btu/hr-°F-ft^2)
$\geq$50	2	3.0	29
20	8	2.3	37
18	9	1.8	46
14	10	1.3	63
10	14	0.8	98
7	17	0.5	140
5	21	$\leq$0.1	280
4	24		

temperature of the wall (T_w) is less than T_s, then the heat transfer rate (q_u) is calculated from

$$q_u = h_u A (T_s - T_w) \tag{E-24}$$

or

$$q_u = 2A (T_v - T_w) \tag{E-25}$$

whichever is greater, where h_u is the standard Uchida condensing steam heat transfer coefficient, 2 is the lower limit value allowed (presented in British units), and A is the surface area associated with the heat transfer. The rate of mass transfer from the vapor region to the liquid region ($\dot{m}_u$) is then obtained from

$$\dot{m}_u = f q_u / (h_v - h_\ell) \tag{E-26}$$

where

h_v = specific enthalpy of vapor in vapor region

h_ℓ = specific enthalpy of liquid in vapor region

f = user-specified fraction of condensate which may potentially form on walls or cooling coils which is actually dropped into the pool.

For saturated atmosphere conditions, the standard Uchida heat transfer coefficient [h_u of Equation (E-24)] is used, and mass transfer is determined from Equation (E-26).

When the user has specified that the bulk temperature is equal to the vapor temperature, no steam is explicitly condensed when:

(1) The vapor is superheated and the wall surface temperature is greater than the saturation temperature

(2) The wall temperature is greater than the vapor temperature

(3) The wall temperature is less than the vapor temperature, but the bulk temperature is less than or equal to the saturation temperature.

4.2 Turbulent Natural Convection

A turbulent natural convection correlation is applicable when the product of Grashof and Prandtl[E-3] numbers is within the range

$$\sim 10^7 \leq (Gr\ Pr) \leq 10^{12} \ .$$

This correlation is given by[E-4]

$$h_c = 0.13 \left[\rho_f^2\ g\ \beta_f\ \Delta T\ C_{pf}\ k_f^2 / \mu_f \right]^{1/3} \qquad \text{(E-27)}$$

where

g = acceleration due to gravity

h_c = heat transfer coefficient

ρ_f = density of gas region, including air and water vapor

β_f = $1/T_f$ where T_f is absolute temperature of film (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,

$$(T_{wall} + T_{bulk})/2 \ .$$

In CONTEMPT-LT, appropriate variables in Equation (E-27) are tabulated for film temperatures between 100 and 400°F. 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 is used, and if ΔT is less than 1.0°F, a value of 0.19 Btu/hr-ft^2-°F is assigned to h_c.

4.3 Direct Radiation Model

A simplified direct radiation heating model may be specified at any heat structure boundary. The user may specify only radiation heat transfer at a boundary, or may specify combined radiation and natural convection heat transfer. A basic equation for direct radiation heat transfer from Surface 1 to Surface 2 is[E-4]

$$q_{r12} = \sigma A_1 F_{12} (T_1^4 - T_2^4) \qquad \text{(E-28)}$$

where

q_{r12} = energy absorbtion rate at Surface 2

σ = the Stefan-Boltzman 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 black-body radiation theory, the view factor, F_{12}, represents the fraction of radiation leaving Surface 1 that is absorbed by Surface 2. For nonblack-body theory, the surface emissivities may also be combined into the view factor.

Equation (E-28) is based on the assumption of no energy loss due to absorption by a gas medium between the two surfaces. However, the model used in CONTEMPT-LT provides for a fraction of the radiant energy to be absorbed in the adjoining vapor region. Also, CONTEMPT-LT allows the Surface 2 temperature to be either an actual surface temperature or a constant sink temperature. Because the CONTEMPT-LT radiation model is an approximation to the actual radiation heating, the following restriction exists: Given radiation heat transfer from Surface 1 to some opposite Surface 2, CONTEMPT-LT 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 (E-29) and (E-30) are the equations solved in CONTEMPT-LT for radiation heating. The heat transfer is determined through use of

$$q_{ri} = h_{ri} A_i (t_i - t_s) \qquad \text{(E-29)}$$

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-timestep 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

$$h_{ri} = \left| \frac{10^8 \sigma F_i \left[\left(\frac{T_i}{100} \right)^4 - \left(\frac{T_s}{100} \right)^4 \right]}{T_i - T_s} \right| \qquad \text{(E-30)}$$

where

F_i = input view factor

T_i = absolute temperature of surface i

T_s = absolute temperature of opposite surface or constant sink temperature.

Temperature values at the beginning of a timestep 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.

4.4 Forced Convection Condensing Steam Option (Tagami)

A transient period occurs during blowdown of the primary coolant when condensation on the structures is characterized by forced convection in the containment atmosphere. Tagami developed an empirical correlation, applicable during this forced convection period, which states that the maximum heat transfer coefficient depends on the

total energy released from the primary coolant system during the decompression, on the volume of the containment building, and on the time required for decompression[E-5]. This heat transfer correlation can be expressed as

$$h_{max} = C\left(\frac{Q}{Vt_p}\right)^{0.62} \qquad \text{(E-31)}$$

where

h_{max} = the maximum heat transfer coefficient during blowdown [W/m^3-^oK or $Btu(hr\text{-}ft^2\text{-}^oF)$]

C = a constant equal to 0.607 for SI units or 72.5 for British units

Q = the total energy released from the primary system during blowdown (J or Btu)

V = the free volume of the adjacent compartment (m^3 or ft^3)

t_p = the time interval until peak pressure (sec or hr).

5. REFERENCES

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E-4. W. McAdams, *Heat Transmission*, 3rd edition, New York: McGraw-Hill Book Co., 1954.

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APPENDIX F

VENT FLOW AND IRREVERSIBLE PRESSURE LOSSES

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VENT FLOW AND IRREVERSIBLE PRESSURE LOSSES

This appendix describes the equations of change used to calculate quasi-steady state two-phase, two-component flow through BWR pressure suppression system (PSS) vent pipes and irregular geometry vent arrangements. The models used in CONTEMPT-LT to determine vent entrance mixture composition are described. Both the vertical vent (Mark I and Mark II) and horizontal vent (Mark III) systems are modeled and discussed. Irreversible pressure loss models used to obtain the friction and form loss terms in the equations of change are presented for both straight, constant area flow elements and for flow elements with area or direction changes. Section V discusses PSS flow calculations in general terms in addition to other PSS models. This appendix provides additional detail on the vent flow models.

1. VENT FLOW ANALYTICAL MODEL

Quasi-steady flow of a two-component, two-phase steam-air-liquid water mixture is assumed to begin immediately after the vent clearing transient is completed. Solution of the conservation equations for vent flow is an iterative process in CONTEMPT-LT. On the basis of known conditions at the entrance of a given flow element, the exit conditions are calculated and become entrance conditions for the next element. Provisions are included for sonic or choked flow determination and preferential control of the mass fractions in the flowing mixture. The equations of change provided in Section 1.1 apply to both the vertical vent and the horizontal vent systems. Model differences do exist between the two systems and those are discussed in Sections 1.2 and 2 of this appendix. Section 1.2 discusses vent entrance mixture composition.

1.1 Equations of Change

To determine vent flow, the vent entrance conditions are determined, an estimated flow rate is assumed, and the equations of change are solved for each flow element sequentially. Details of the flow element and vent flow iteration processes are provided in Appendix B.

The basic assumptions associated with the vent flow analytical expressions are:

(1) compressible, steady state theory applicable for given timestep

(2) one-dimensional flow

(3) adiabatic flow

(4) homogeneous conditions

(5) two-component and two-phase flow

(6) spatially nonconstant flow element areas allowable, with average area approximation in momentum equations

(7) irreversible effects can be accounted for by wall friction and loss coefficients, with two-phase corrections

(8) average property values at a given cross section of a flow element are adequate.

The nomenclature used in the equations of change is clarified in Figure F-1. A_i and A_f are the flow element entrance and exit surface areas, respectively. The direction of flow is denoted by the vector $\overline{\ell}$, which is oriented at an angle α from the positive vertical direction. The force of gravity is positive in a downward direction, and elevation is positive in an upward direction. z_i and z_f denote fixed elevations for the midpoint of each surface, whereas ℓ_i and ℓ_f are fixed end positions along the length direction of the element.

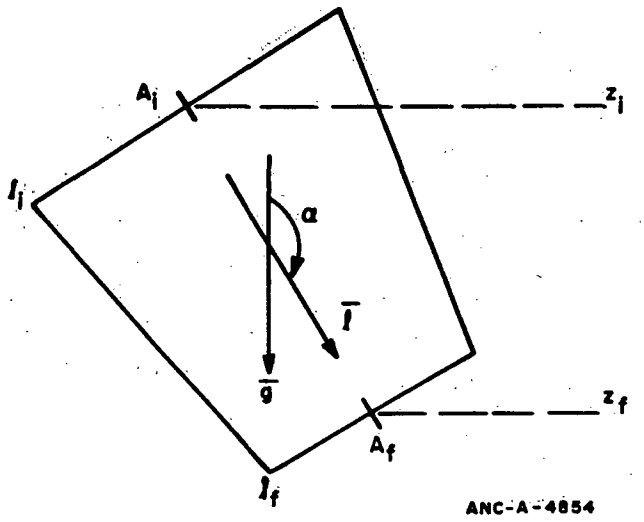

Fig. F-1 Vent flow element illustration.

Using the stated assumptions, with the direction of one-dimensional flow along $\overline{\ell}$, the conservation equations can be expressed in differential form as[F-1, F-2]

Continuity

$$\frac{d}{d\ell}(\rho \, v \, A) = \frac{dW}{d\ell} = 0 \tag{F-1}$$

Momentum

$$W \frac{dv}{d\ell} = -A \frac{dp}{d\ell} - P \tau_w - A\rho g \cos \alpha \tag{F-2}$$

Energy

$$-W \frac{d}{d\ell} \left(h + \frac{v^2}{2} + g\ z\right) = 0 \qquad \text{(F-3)}$$

where

ρ = fluid density

v = fluid velocity

A = flow area

W = flow rate

p = absolute total pressure

P = wetted perimeter of flow area

τ_w = average wall shear stress

g = acceleration due to gravity

h = fluid specific enthalpy

z = elevation being considered.

The integral forms of the preceding equations, integrated from the flow element entrance (i) to exit (f), become

Continuity

$$(\rho\ v\ A)_i = (\rho\ v\ A)_f = W, \text{ a constant} \qquad \text{(F-4)}$$

Energy

$$\frac{1}{2} (v_f^2 - v_i^2) + (h_f - h_i) + g(z_f - z_i) = 0 \qquad \text{(F-5)}$$

Momentum

$$p_f = p_i - \Delta p_{IR} - \hat{\rho}\ g(z_f - z_i) - W(\hat{\frac{1}{A}})\ (v_f - v_i) \qquad \text{(F-6)}$$

where

$\hat{\rho}$ = average fluid density in element

$(\frac{\hat{1}}{A})$ = average inverse flow area

Δp_{IR} = irreversible pressure loss due to wall friction and area or direction changes in element.

The average density

$$\hat{\rho} = \frac{\rho_i + \rho_f}{2} \tag{F-7}$$

is simply an arithmetic mean value for the element.

The average inverse flow area is obtained from

$$(\frac{\hat{1}}{A}) = \frac{1}{2} (\frac{1}{A_i} + \frac{1}{A_f}) \quad . \tag{F-8}$$

Section 2 of this appendix describes the various models used to obtain the irreversible pressure loss term, Δp_{IR}.

The energy equation, Equation (F-5), may be rearranged to solve for the element exit velocity,

$$v_f = \left\{ 2 \left[h_i - h_f - g(z_f - z_i) \right] + v_i^2 \right\}^{1/2} \tag{F-9}$$

given elevations and entrance parameters. This element exit velocity is then used in the momentum equation, Equation (F-6), to obtain the element exit pressure. The element exit pressure obtained from the momentum equation is compared to the equation of state pressure, and if agreement within a small percentage is not achieved, the fluid temperature is changed and the process reiterated until agreement is obtained. The exit conditions of one element become the entrance conditions for the next element, and solutions are obtained for each flow element. The vent exit pressure is compared to the static vent back pressure (wetwell water head plus wetwell vapor region pressure). If the two pressures disagree by more than an allowed percentage, the vent flow estimate is revised and the entire process is reiterated until agreement is achieved or choked flow is obtained. Appendix B provides added detail on the iterative flow contol process.

1.2 Vent Entrance Mixture Composition

CONTEMPT-LT provides the capability to allow a user to modify the mixture composition flowing through the PSS vents. A possible use is to force early air carryover through the vents. The mass fraction of air (r_a), water vapor (r_s), and liquid water (r_ℓ)

entering the pressure suppression vent system are computed from the drywell vapor region inventory and modified by program input parameters. The vertical vent and horizontal vent models agree except on the detail of input and application of the composition modifiers. This section describes the vent entrance specific volume and maximum specific enthalpy allowed within a flow element solution; then the composition modifiers are discussed.

The specific volume of fluid entering a vent [v(avg)] is a mass weighted average value obtained from

$$v(avg) = r_\ell \, v_\ell + (r_a + r_s) \frac{V_{vv}}{M_a + M_{wvv}} \tag{F-10}$$

where

v_ℓ = specific volume of liquid in the drywell vapor region

V_{vv} = volume of vapor in drywell vapor region (corrected for liquid content)

M_a = mass of air in drywell vapor region

M_{wvv} = mass of water vapor in drywell vapor region

r_ℓ, r_a, r_s = vent fluid mass fractions of liquid, air, and water vapor, respectively.

The maximum enthalpy (h_{max}) allowed within a flow element solution in CONTEMPT-LT is

$$h_{max} = 0.99999 \, [h_T - g(z_f - z_i)] \tag{F-11}$$

where

g = acceleration of gravity

z_i, z_f = element elevations, defined in Figure F-1

h_T = stagnation specific enthalpy of drywell vapor region.

The maximum enthalpy is kept below h_T to prevent a zero velocity flow solution. The stagnation enthalpy of the drywell vapor region is determined from

$$h_T = r_\ell \, h_\ell + r_s \, h_g + r_a \, c_{pa} \, T_{v3} \tag{F-12}$$

where

h_ℓ = specific enthalpy of liquid water in drywell vapor region

h_g = specific enthalpy of water vapor in drywell vapor region

c_{pa} = specific heat of air at constant pressure

T_{v3} = absolute temperature of drywell vapor region.

The values of r_ℓ, r_a, and r_s used in this section are determined as follows.

If D is greater than zero, the final vent entrance mass fractions are

$$r_a = r''_a/D \tag{F-13}$$

$$r_s = r''_s/D \tag{F-14}$$

$$r_\ell = r''_\ell/D \tag{F-15}$$

If D is zero, the modifier table is not used and values are obtained from Equations (F-20) through (F-22). The terms in Equations (F-13) through (F-15) are determined from

$$r'''_a = r'_a\, r_{av} \tag{F-16}$$

$$r'''_s = r'_s\, r_{sv} \tag{F-17}$$

$$r'''_\ell = r'_\ell\, r_{\ell v} \tag{F-18}$$

$$D = r'''_a + r''_s + r''_\ell \tag{F-19}$$

where r'_a, r'_s, and r'_ℓ are input vent flow mass fraction modifiers; and r_{av}, r_{sv}, and $r_{\ell v}$ are calculated from

$$r_{\ell v} = PCO \cdot \frac{M_{wv\ell}}{M_a + M_{wvv} + M_{wv\ell}} \tag{F-20}$$

$$r_{av} = (1 - r_{\ell v}) \frac{M_a}{M_a + M_{wvv}} \tag{F-21}$$

$$r_{sv} = 1 - r_{\ell v} - r_{av} \tag{F-22}$$

where

PCO = input liquid carryover factor to account for liquid separation resulting from baffles at vent entrance

$M_{wv\ell}$ = mass of liquid water in drywell vapor region

M_{wvv} = mass of water vapor in drywell vapor region

M_a = mass of air in drywell vapor region.

For the vertical vent PSS model, values of r'_a, r'_s, and r'_ℓ may be time dependent and are input on Cards 19XX. Use of the input values continues until D [Equation (F-19)] becomes equal to zero. After that time, Equations (F-20) through (F-22) are used to obtain r_ℓ, r_a, and r_s, respectively.

In the horizontal vent model, input modifiers r'_a, r'_s, and r'_ℓ are not time dependent but rather are used until a mass ratio criterion on either air or steam is satisfied. If the optional modifiers are used, they are input on Card 50001. The input mass ratio criterion is either an air or steam mass ratio lower limit for use of the mass fraction modifiers. A positive value means the modifiers are used until the vent entrance mass fraction of air to air plus steam is less than the input limit. A negative value allows use of the modifiers until the vent entrance mass fraction of steam to air plus steam is less than the absolute value of the input limit. After the lower limit is reached, the vent entrance mass fractions are determined from Equations (F-20) through (F-22).

2. IRREVERSIBLE PRESSURE LOSS ANALYTICAL MODELS

This section describes the models used to obtain irreversible pressure losses due to fluid flow through PSS vent flow elements. Figure F-2 shows the two types of flow elements considered: (a) straight, constant flow area lengths of circular pipe, or equivalent diameter noncircular pipe (Type 1) or (b) equivalent diameter or circular elbows, tees, or transition sections with or without changes of flow area or flow direction (Type 2).

Solution of the momentum equation for pressure suppression vent flow elements results in a pressure loss term representing frictional and other irreversible losses (Δp_{IR}). Different formulations of Δp_{IR} are appropriate for straight pipe sections and flow elements that contain area or directional changes. Section 2.1 describes the constant area models, and Section 2.2 describes the irreversible loss determinations for flow elements that have area or directional changes.

2.1 Flow Elements with Constant Area

For two-phase flow in a straight flow element with no changes in cross-sectional area or flow direction, a single-phase pressure drop is calculated and a modified Baroczy

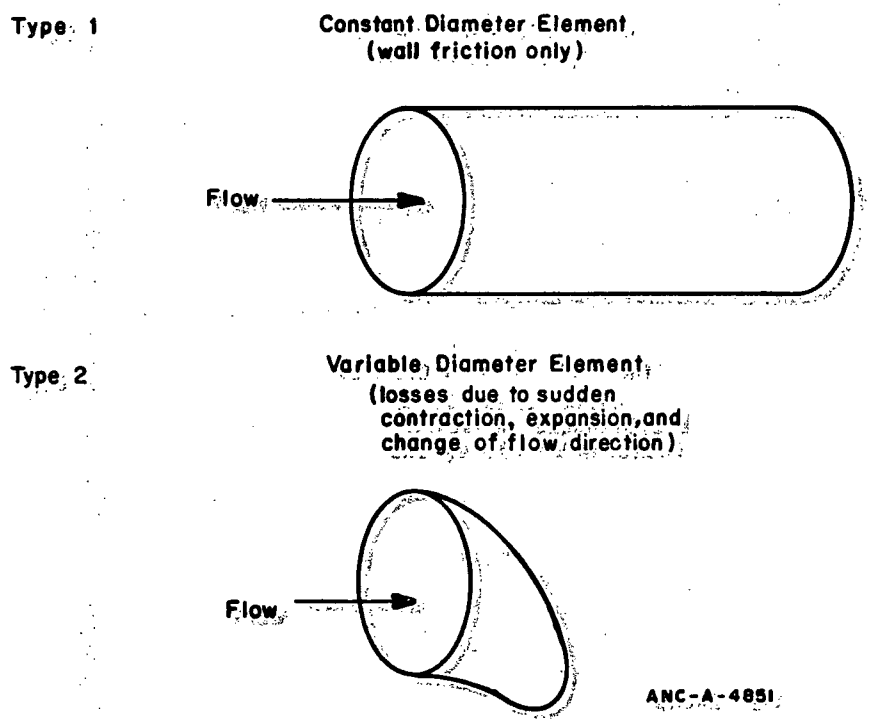

Fig. F-2 Flow elements used to describe vent system.

two-phase correction is applied[F-3]. If Δp_{LO} is the single-phase irreversible pressure loss for liquid only flow, then the two-phase pressure drop is

$$\Delta p_{IR} = \Delta p_{LO} \phi_m^2 \tag{F-23}$$

where ϕ_m^2 is the modified Baroczy two-phase correction factor. The ϕ_m^2 correction depends on quality, mass flux, and the flowing mixture property index (I_p). Quality and mass flux are readily available in CONTEMPT-LT. The property index is calculated and then program tables which contain ϕ_m^2 as a function of the three variables are interpolated to get the two-phase correction. I_p is defined as

$$I_p = (\rho_g/\rho_\ell)\ (\mu_\ell/\mu_g)^{0.2} \tag{F-24}$$

where

ρ_g = gas (vapor) density

ρ_ℓ = thermodynamic liquid water density (not the actual compartment liquid density)

μ_ℓ = liquid water dynamic viscosity based on compartment temperature

μ_g = gas viscosity as defined subsequently.

The values for ρ_g, ρ_ℓ, μ_ℓ, and μ_g are representative of the averaged single-phase properties at a given pressure and temperature rather than the specific mixture composition. For example, for air-steam-liquid water flow:

$$\rho_g = \frac{m_a + m_v}{V_v - m_\ell v_\ell} \tag{F-25}$$

where

m_a = mass of air in compartment

m_ℓ = mass of liquid in compartment vapor region

m_v = mass of water vapor in compartment

v_ℓ = thermodynamic specific volume of liquid

V_v = volume of compartment vapor region.

For single-component gas flow, the viscosity may be obtained from tabular data. However, if two gases are present, an average gas viscosity is more difficult to obtain. The equation used to calculate a water-vapor-air mixture gas viscosity is[F-1]

$$\mu_g = \frac{y_a}{y_a + y_v \phi_{av}} \mu_a + \frac{y_v}{y_v + y_a \phi_{va}} \mu_v \tag{F-26}$$

where subscripts a and v represent air and water vapor, respectively, and y_i = mole fraction of component i.

$$\phi_{ij} = \frac{1}{\sqrt{8}} \left(1 + \frac{M_i}{M_j}\right)^{-1/2} \left[1 + \left(\frac{\mu_i}{\mu_j}\right)^{1/2} \left(\frac{M_j}{M_i}\right)^{1/4}\right]^2 \tag{F-27}$$

where M_i = molecular weight of component i.

Appropriate values of ϕ_{ij} for an air-water vapor mixture are $\phi_{av} \sim 1.1$ and $\phi_{va} \sim 0.9$.

Δp_{LO} in Equation (F-23) is defined to be

$$\Delta p_{LO} = \left(\frac{\hat{l}}{A}\right) \hat{P} \tau_{wo} (\ell_f - \ell_i) \tag{F-28}$$

where

$$\tau_{w0} = f_{LO} \frac{G|G|}{2\rho_\ell} \tag{F-29}$$

$\hat{P}$ = average wetted perimeter of flow area

$(\frac{\hat{1}}{A})$ = average inverse flow area of element [Equation (F-8)]

$(\ell_f - \ell_i)$ = length of flow element

G = total downstream mass flow per unit area (air, water vapor, and liquid)

f_{LO} = liquid only single-phase friction factor (Fanning).

$\hat{P}$ is defined as

$$\hat{P} = \frac{2}{\left(\frac{1}{P_i} + \frac{1}{P_f}\right)} \tag{F-30}$$

where P_i, P_f are the flow element inlet and outlet wetted perimeters, respectively.

CONTEMPT-LT actually calculates Moody friction factors (f_m) rather than the Fanning value (f_{LO}). Since $f_m = 4f_{LO}$, the final equation used for straight flow elements becomes

$$\Delta p_{IR} = (\frac{\hat{1}}{A})\ \hat{P}\ \frac{f_m\ G|G|}{8\ \rho_\ell}\ (\ell_f - \ell_i)\ \phi_m^{\ 2} \ . \tag{F-31}$$

For laminar flow, for which the Reynolds number (Re) is less than 2,200, f_m is obtained from

$$f_m = 64/Re \ . \tag{F-32}$$

For turbulent flow, where $Re > 2{,}200$, f_m is obtained by an iterative solution[F-4]:

$$f_m = \left[-2\ \log_{10}\left(\frac{2.51}{Re\ \sqrt{f_{mp}}} + \frac{0.271\ k_x}{D}\right)\right]^{-2} \tag{F-33}$$

where

f_{mp} = preceding trial value of f_m

k_x = absolute roughness of wall surface.

If f_m and f_{mp} are equal (within a tolerance), the program accepts the value of f_m. If f_m and f_{mp} are not equal, f_{mp} is replaced by the previous value of f_m, and f_m is recalculated until the two values are nearly equal. When f_m is known, Equation (F-31) is solved for the irreversible pressure loss. To determine f_m for the two-phase flowing mixture, the mixture Reynolds number is obtained to determine if the flow is laminar or turbulent ($Re > 2{,}200$), which determines which equation is solved for f_m. The Reynolds number is defined by

$$Re = D|G|/\mu_x \tag{F-34}$$

where

D = equivalent diameter of flow area

G = total mass flux

μ_x = dynamic viscosity.

To determine whether the flow is laminar or turbulent, a mixture Reynolds number representing the total viscous and inertial forces is calculated from Equation (F-34), through use of a total mixture viscosity. Due to the significant differences between liquid water and water vapor or air densities, the following expression[F-2] is used to combine liquid and gas viscosities:

$$\frac{1}{\mu} = \frac{x}{\mu_g} + \frac{1-x}{\mu_\ell} \tag{F-35}$$

where

x = gas quality (air and vapor)

μ_ℓ = liquid water viscosity

μ_g = gas mixture viscosity [from Equation (F-26)]

μ = total mixture viscosity.

After the flow regime and therefore the equation needed to obtain the single-phase friction factor have been determined, the proper liquid-only, single-phase friction factor that will be modified by the Baroczy multipliers is calculated. A liquid-only friction factor is required since the Baroczy correlation is based on that assumption. First, Equation (F-34) is solved for a liquid-only Reynolds number through use of the total mass flux and the liquid viscosity, μ_ℓ. Then, through use of that Reynolds number, f_m is determined from either Equation (F-32) or Equation (F-33), as appropriate.

The preceding formulations are based on the assumption of two-phase flow. For single-phase conditions, the Baroczy correction is not applied, and Δp_{IR} is calcualted from

$$\Delta p_{IR} = \frac{f_{mi}}{4} \frac{G|G|}{2\rho_i} \tag{F-36}$$

where

G = total mass flux

i = subscript for liquid or gas

f_{mi} = Moody single-phase friction factor

ρ_i = actual component density.

The friction factor is obtained from Equations (F-32) through (F-34), except μ_i replaces μ_x. For single-phase liquid flow, ρ_i and μ_i are available and a solution can be obtained for the wall friction pressure loss. For single-phase gas flow, whether consisting of one or two components, the density is obtained from Equation (F-25) with m_ℓ equal to zero. The average gas viscosity is determined from Equations (F-26) and (F-27).

2.2 Flow Elements with Area or Direction Changes

For flow elements with area or direction changes such as the Mark III annulus or vent entrances, or for the vent exit area expansion, the two-phase pressure loss is determined from the following equation[F-3]:

$$\Delta p_{IR} = \gamma \frac{KG|G|}{2\rho_\ell} \tag{F-37}$$

where

K = liquid single-phase irreversible loss coefficient

ρ_ℓ = thermodynamic liquid density (based on temperature rather than composition of flowing mixture)

G = total mass flux for both phases (downstream or upstream depending on application of K)

γ = two-phase correction factor

and

$$\gamma = \frac{\rho_\ell}{\rho_g} \frac{x^2}{R_g} + \frac{(1 - x)^2}{R_\ell} \tag{F-38}$$

where

ρ_g = gas density based on thermodynamic temperature and pressure

R_g = volume fraction of gas in flow mixture

R_ℓ = volume fraction of liquid in flow mixture

x = quality of flow mixture.

Depending on the user specified model application, the loss coefficient (K) may be a program input constant or an area- or velocity-dependent property calculated by CONTEMPT-LT.

2.2.1 Area Dependent Losses. Area dependent loss coefficients are based on the following formulas[F-1]. For an area expansion with a downstream flow velocity, K is determined from

$$K = \left(\frac{1}{\beta} - 1\right)^2 \qquad \text{(F-39)}$$

where

β = area ratio = flow element small area divided by flow element large area ($\leq$1.0).

For an area expansion with zero downstream velocity, K takes the form

$$K = (\beta - 1)^2 \quad . \qquad \text{(F-40)}$$

The upstream flow velocity is used in Equation (F-36) in this case. The only application of Equation (F-40) is for the vent exit losses, for which β is defined as the vent exit flow area divided by the surface area of one segment of the wetwell pool.

If a flow area contraction is experienced, the loss coefficient becomes

$$K = 0.45\ (1 - \beta) \quad . \qquad \text{(F-41)}$$

The vertical vent entrance loss coefficient is input to the program. The Mark III weir annulus entrance is assumed to have an area contraction with a reduction factor of ten (β = 0.1) which is built into the code. A value of 1.90 is assigned to K for Mark III vent entrance right angle bends[F-1], which is added to the vent entrance K based on area expansion or contraction, as the situation may require.

2.2.2 Velocity Dependent Losses. Velocity dependent loss coefficients are used in the horizontal vent model but not in the vertical vent model.

The single-phase loss coefficient (K) of Equation (F-37) is interpolated from velocity dependent Idel'chik data[F-5] if user specified. Figure F-3 illustrates the model representation of a Mark III vent entrance or branch element. Loss coefficients for both the vent flow (K_1) and the bypass flow (K_2) are determined.

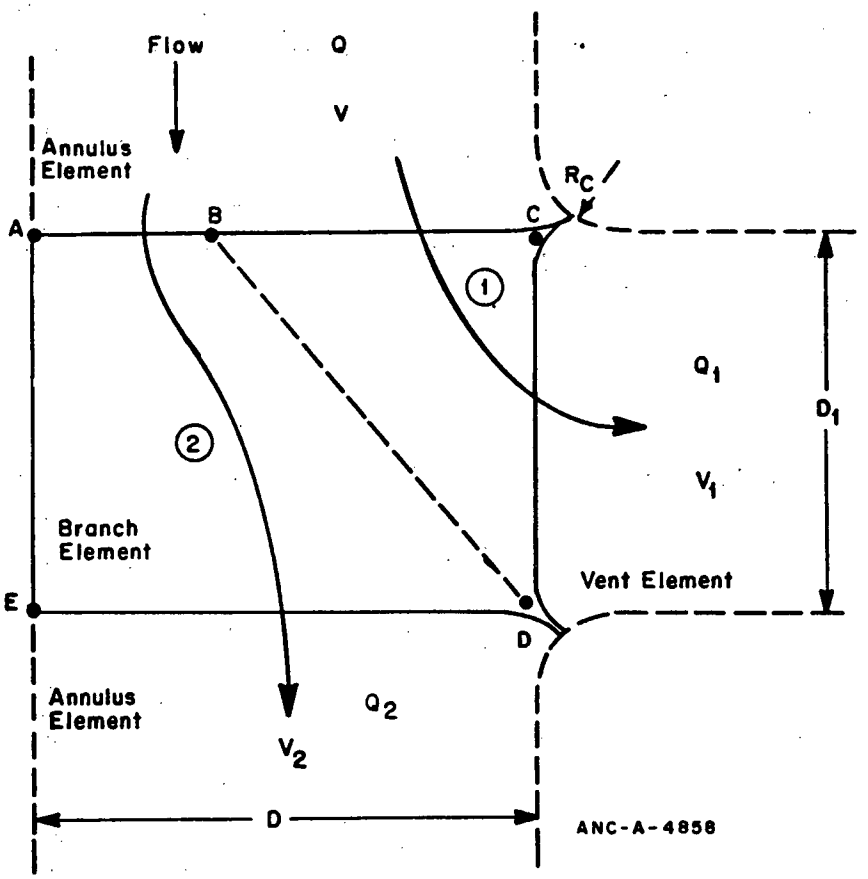

Fig. F-3 Mark III branch flow element.

(a) Vent Flow Path. If the vent flow path, Path 1 of Figure F-3, is assumed always to be perpendicular to the annulus, two classes of K_1 need to be considered -- those for sharp corners and those for rounded corners.

For sharp corners (R_c equals zero, Figure F-3):

$$K_1 = \begin{cases} C\left[1 - (v_1/v)^2\right] & \text{for } D_1/D \leq 2/3 \\ C\left[0.34 - (v_1/v)^2\right] & \text{for } D_1/D = 1 \end{cases} \qquad \text{(F-42)}$$

where v, v_1, D, D_1 are defined in Figure F-3, and

$$C = \begin{cases} 1.0 & v_1/v \leq 0.8 \\ 1.0 - \frac{1}{2}(v_1/v - 0.8) & 0.8 < v_1/v \leq 1.0. \\ 0.9 & v_1/v > 1.0 \end{cases} \qquad \text{(F-43)}$$

Since Idel'chik does not list a formula for the range of D_1/D between 2/3 and 1, linear interpolation between the two formulas in Equation (F-42) is used. Also, the same reference actually lists $C \approx 0.9$ for $v_1/v > 0.8$. An interpolation $0.8 < v_1/v \leq 1.0$ is provided in the code to prevent a possible instability from occurring due to a step change in K_1.

For rounded corners ($R_c/D_1 > 0.01$, Figure F-3), the data are not expressed by a formula but are presented in graphical and tabular forms[F-5]. The graphical form is reproduced here as Figure F-4. The tabular form is used in the code at 0.1 intervals of K_1 over the range of branch to mainstream volumetric flow ratios from 0 to 1.0. The graph in Figure F-4 is specifically for $R_c/D_1 = 0.1$ and 0.2 only. Linear interpolation of the tables and also of Equation (F-42) is used between these values. If $R_c/D_1 < 0.01$, the code treats the corner as sharp. If $R_c/D_1 > 0.2$, the code uses the data for $R_c/D_1 = 0.2$.

(b) Bypass Flow Path. For the bypass flow path, Path 2 of Figure F-3, the loss coefficient is

$$K_2 = 0.4\left[1.0 - (v_2/v)^2\right] \qquad \text{(F-44)}$$

where $v_2/v \leq 1.0$, and v_2 and v are defined in Figure F-3.

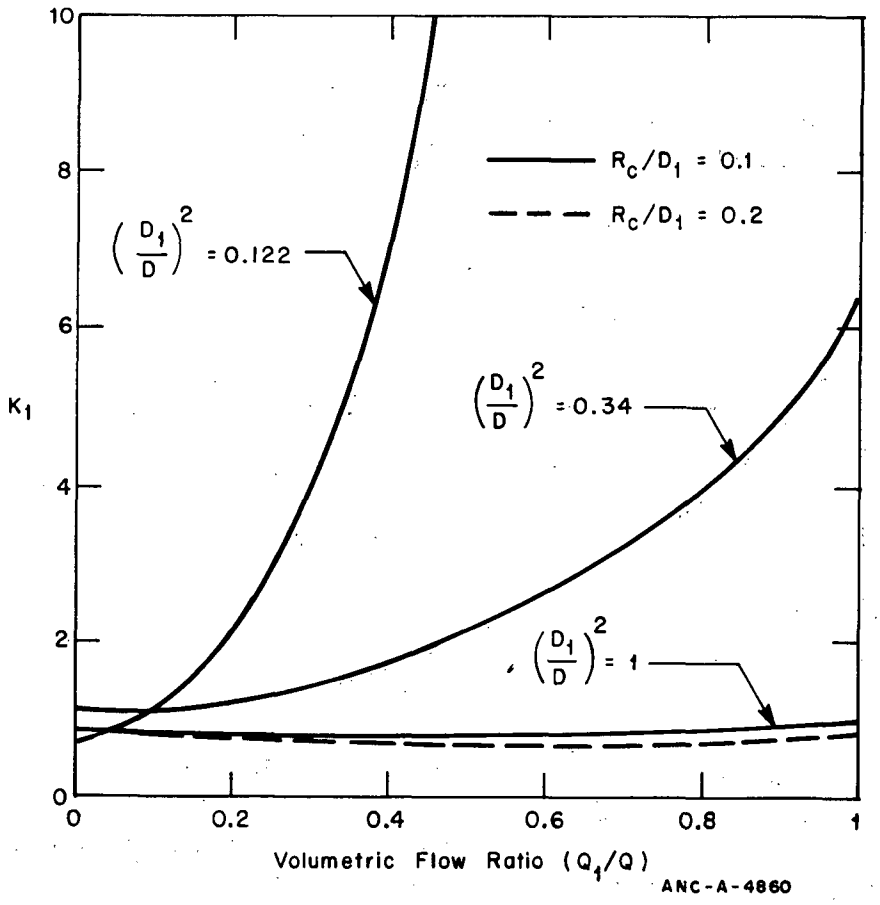

Fig. F-4 Idel'chik loss coefficients (K_1) for rounded corners.

3. REFERENCES

F-1. R. B. Bird, W. E. Stewart, E. N. Lightfoot, *Transport Phenomena,* New York: John Wiley & Sons, 1960.

F-2. G. B. Wallis, *One-Dimensional Two-Phase Flow,* New York: McGraw-Hill Book Company, Inc., 1969.

F-3. C. J. Baroczy, *A Systematic Correlation for Two-Phase Pressure Drop,* AIChE Preprint 37, presented at the Eighth National Heat Transfer Conference, AIChE-ASME (August 1965).

F-4. T. Baumeister (ed.), *Mechanical Engineers' Handbook,* 6th ed. New York: McGraw-Hill Book Company, 1958, pp 3-71.

F-5. I. E. Idel'chik, *Handbook of Hydraulic Resistance - Coefficients of Local Resistance and of Friction,* AEC-TR-6630, United States Clearinghouse for Federal Scientific and Technical Information (1966).

APPENDIX G

CONTEMPT-LT OPERATIONAL CONTROL

APPENDIX G

CONTEMPT-LT OPERATIONAL CONTROL

This appendix briefly describes the general subroutine structure used in CONTEMPT-LT. Program and coding details are omitted to maintain brevity, but enough information is provided to define the general purpose of each FORTRAN subroutine.

1. SUBROUTINE INTERFACING AND SEQUENCING

CONTEMPT-LT consists of 33 FORTRAN source subroutines, plus many system routines, programs contained in the INEL Environmental Subroutine Manual, and steam table programs (Appendix D). Figure G-1 illustrates the separation of operations in CONTEMPT-LT. All problem input is read and processed using INPUT and its associated subroutines. Limited dynamic core storage is also used in the input routines. Subroutine GO controls operations within a given timestep, and produces most of the printout. PLAS is a plot control routine which uses system programs to produce linear or semilogarithmic Calcomp and microfilm plots of drywell and wetwell temperature and pressure.

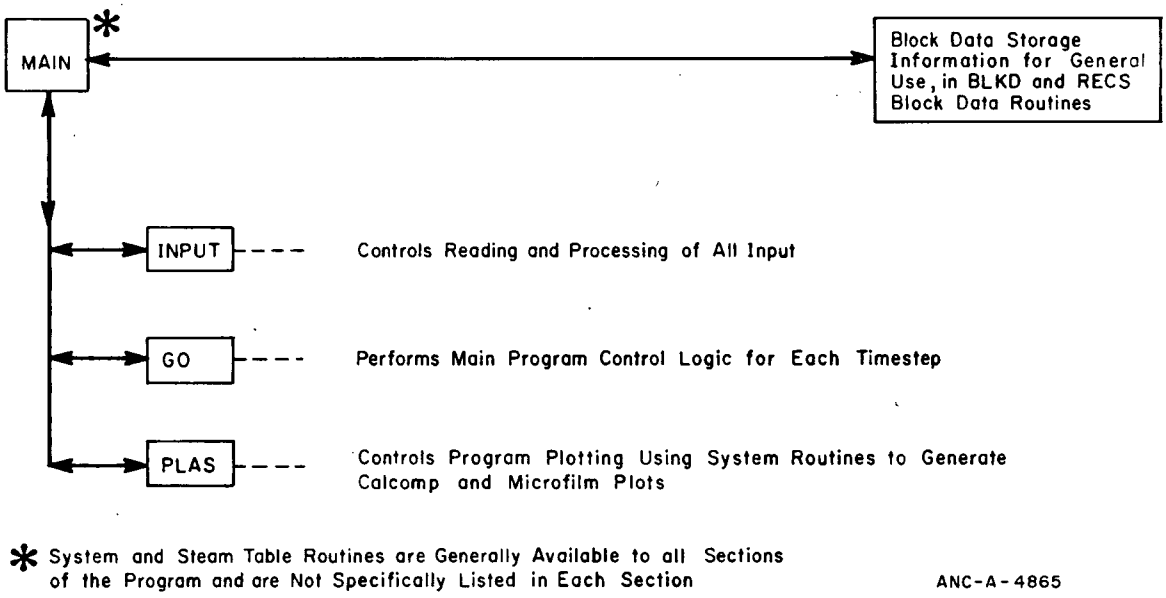

Fig. G-1 CONTEMPT-LT general program structure.

Figure G-2 shows the five program input processing routines and briefly explains the functions of each. INPUT reads all data into a storage array, and the other routines take selected input from that array, check input formats and number of entries, and write the information with explanatory comments and units. Then all data are converted to metric (SI) units if British units were used for problem input. INPRO1 processes general program input including timestep data, compartment conditions, mass and energy addition tables, and safeguard system information. INPRO2, INPS, and INMK are called only if certain data

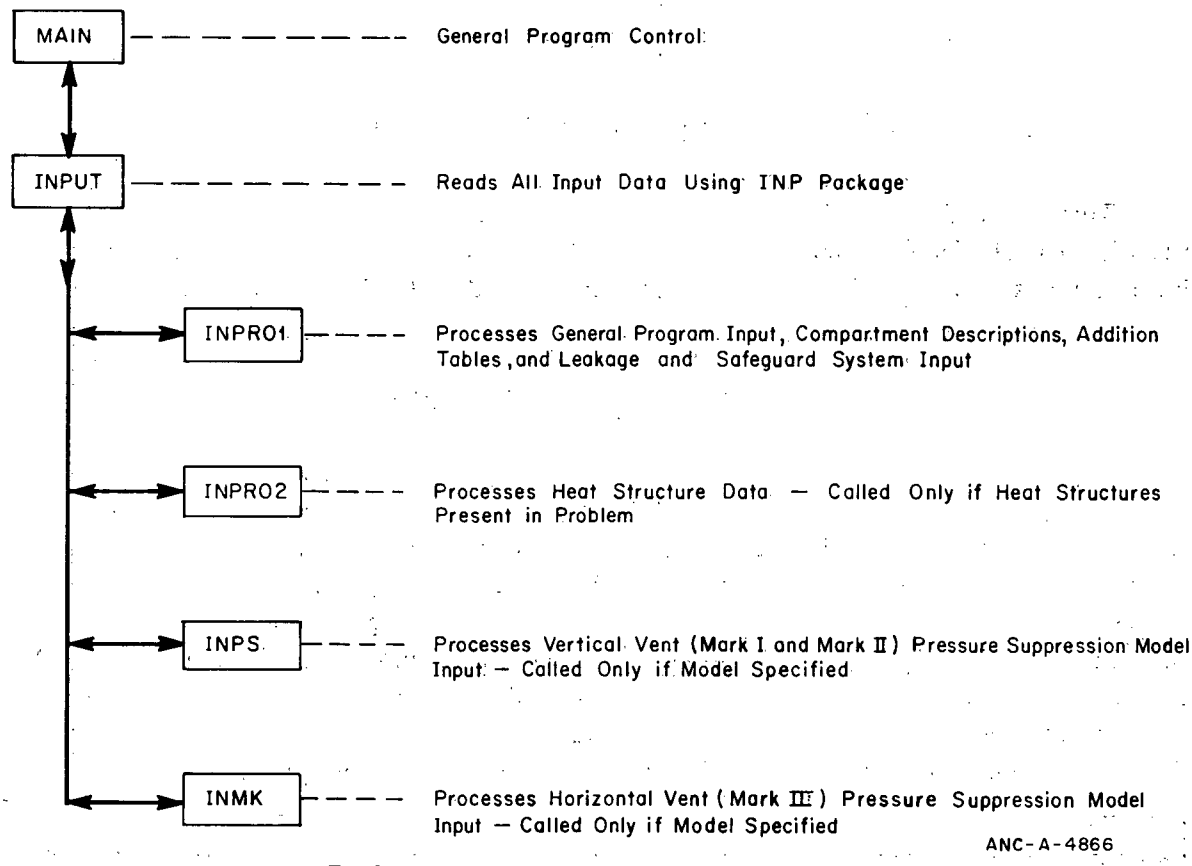

Fig. G-2 CONTEMPT-LT input processing subroutines.

are input, as specified on a general control card. INPRO2 processes all heat structure data. INPS processes all data for the vertical vent (Mark I and Mark II) pressure suppression model, and INMK performs a similar function for the horizontal vent (Mark III) pressure suppression model.

Figure G-3 lists the major subroutines available for use during each timestep. During the initial steady state calculation GO initializes compartment conditions, and also heat structure temperatures by means of calls to the TIMDP and HEAT programs. The sequence of operations within a timestep is generally from the top to the bottom of Figure G-3. If a BWR pressure suppression system is being modeled, then that calculation is performed first. Next is a series of possible mass and energy additions for which the SRCHF and TABLU subroutines are used to interpolate input table entries. If a cooling spray or ECCS is in service, subroutine SPRAY is called to calculate that effect.

The next block of subroutines is called as the first phase of a predictor-corrector calculation to account for leakage and heat transfer. Estimates for the effects of leakage and heat transfer are made for the timestep midpoint. Compartment inventories are temporarily updated and calls to CONT and COMPU provide predicted compartment pressures and temperatures. Using those values, TIMDP and HEAT provide current heat structure temperatures and the amount of heat exchange with adjoining compartments. The original

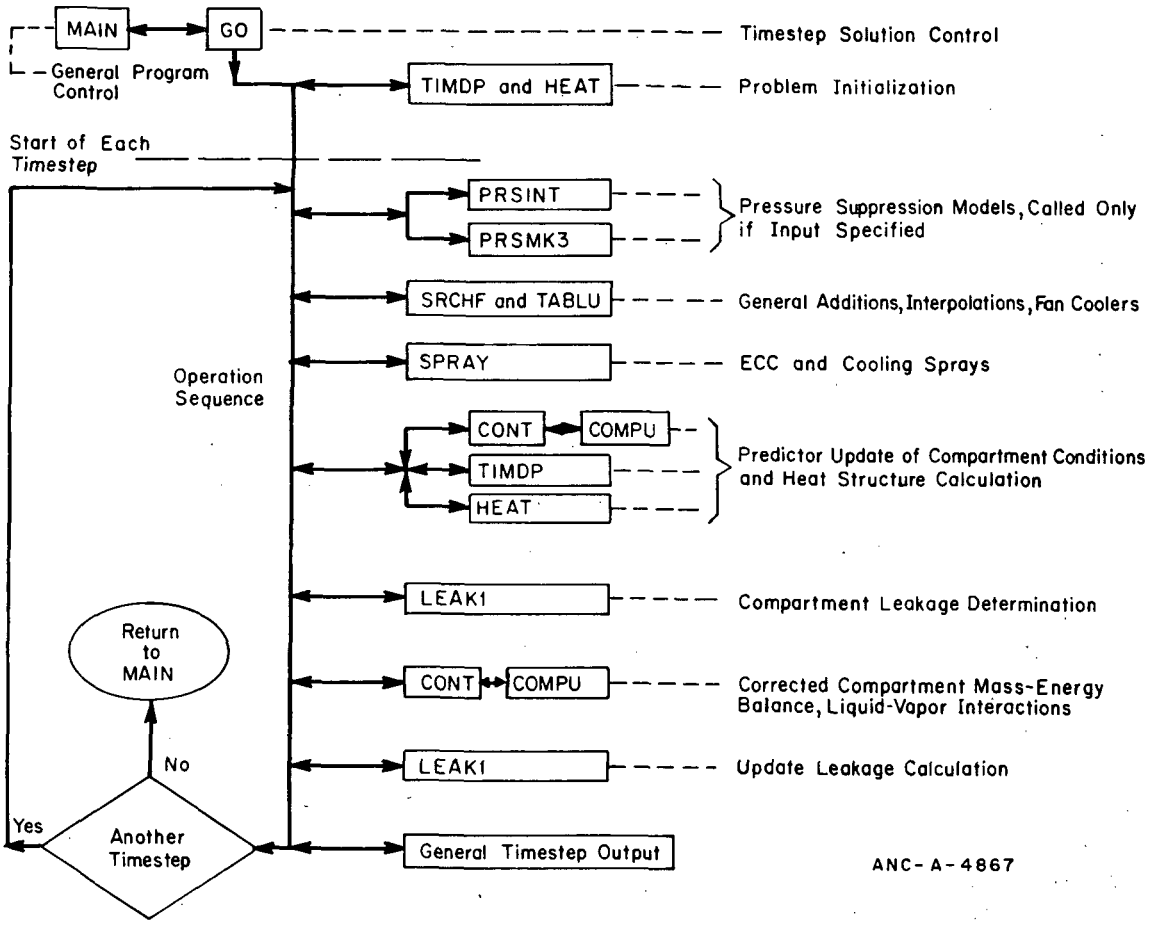

Fig. G-3 Timestep processing subroutines.

compartment inventories (not the temporary values) are updated to account for the heat transfer, and then LEAK1 is called to determine compartment leakage. Again, compartment inventories are adjusted to account for the leakage.

Finally, CONT and COMPU are called to obtain the timestep final equation of state solution. Compartment liquid-vapor region interactions are calculated prior to determining the pressures and temperatures. LEAK1 is then called to provide the best leakage information for the next timestep, but no inventory changes are made. General output is printed for the timestep and GO recycles for another timestep if the problem end time has not been reached.

Figure G-4 lists the subroutines called if a calculation is being performed in CONTEMPT-LT for a vertical vent (Mark I or Mark II) suppression system. First VACU is called if a vacuum breaker relief system has been specified. VACU determines vapor flow from the wetwell to the drywell vapor region. Next, PRSINT is used to calculate the pressure suppression system vent clearing transient and two-phase flow through the vents, if any. Equation of state solutions are obtained for each subdivision of each flow element, by means of COMPU. Two-phase pressure drop correction multipliers are obtained for straight pipes from the TPFM and POL2 subroutines. PRSINT modifies compartment inventories to reflect the vent flow.

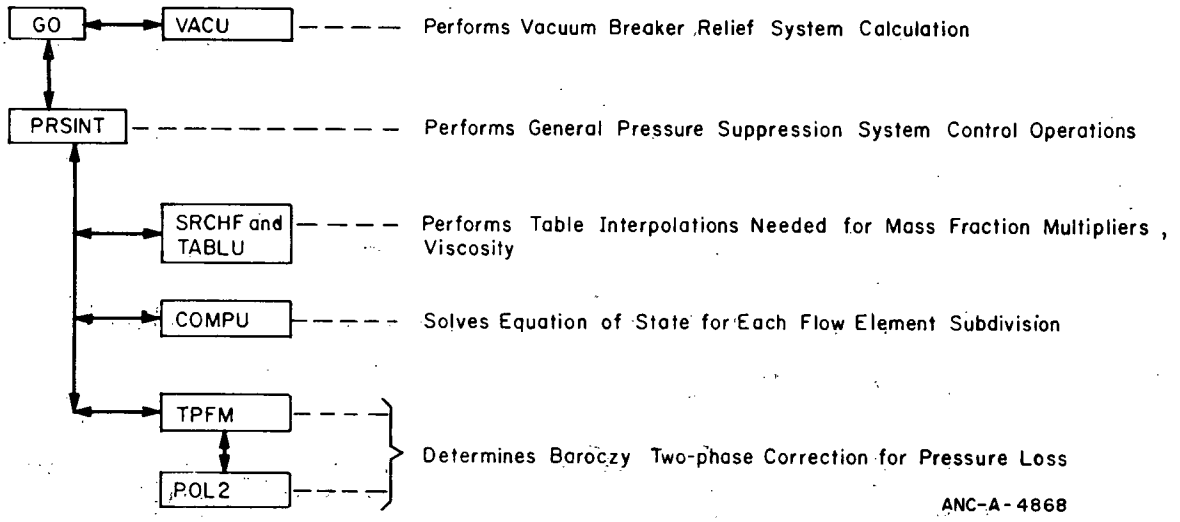

Fig. G-4 Vertical vent (Mark I and Mark II) pressure suppression subroutines.

Figures G-5, G-6, and G-7 list all program subroutines used in determining the vent clearing and two-phase flow solutions for a horizontal vent (Mark III) containment system. As in the vertical vent model, VACU is called to determine flow, if any, through the vacuum breaker relief valves. Following that, PRSMK3 is used to control the solution process and update compartment inventories after the solution has been obtained. First, the vent clearing determination is performed as indicated on Figure G-6. Subroutine VNTCLR controls the vent clearing solution, calling DRKGM3 which solves the system differential equations using a Runge-Kutta integration technique. Subroutine FCT provides the appropriate differential equations to DRKGM3, which depend on the water level position within the vent configuration. Function FRIC calculates the wall friction pressure drop associated with flow through any node.

As shown on Figure G-7, subroutine FLOCON controls the horizontal vent system two-component, two-phase flow solution. Subcode FLW2P3 and COMPU are called to determine flow element (or subdivision) exit conditions, given inlet conditions. Depending on the type of flow element and loss coefficient option specified, subroutines TPFM, POL2 or SIDLCK may be called to provide irreversible loss coefficients. FLOCON also determines some loss coefficients. Subcode EXITBL performs the vent (Level 3) flow iteration control and provides new vent flow estimates during the iteration process. FLOCON also controls the Level 4 outer mass balance.

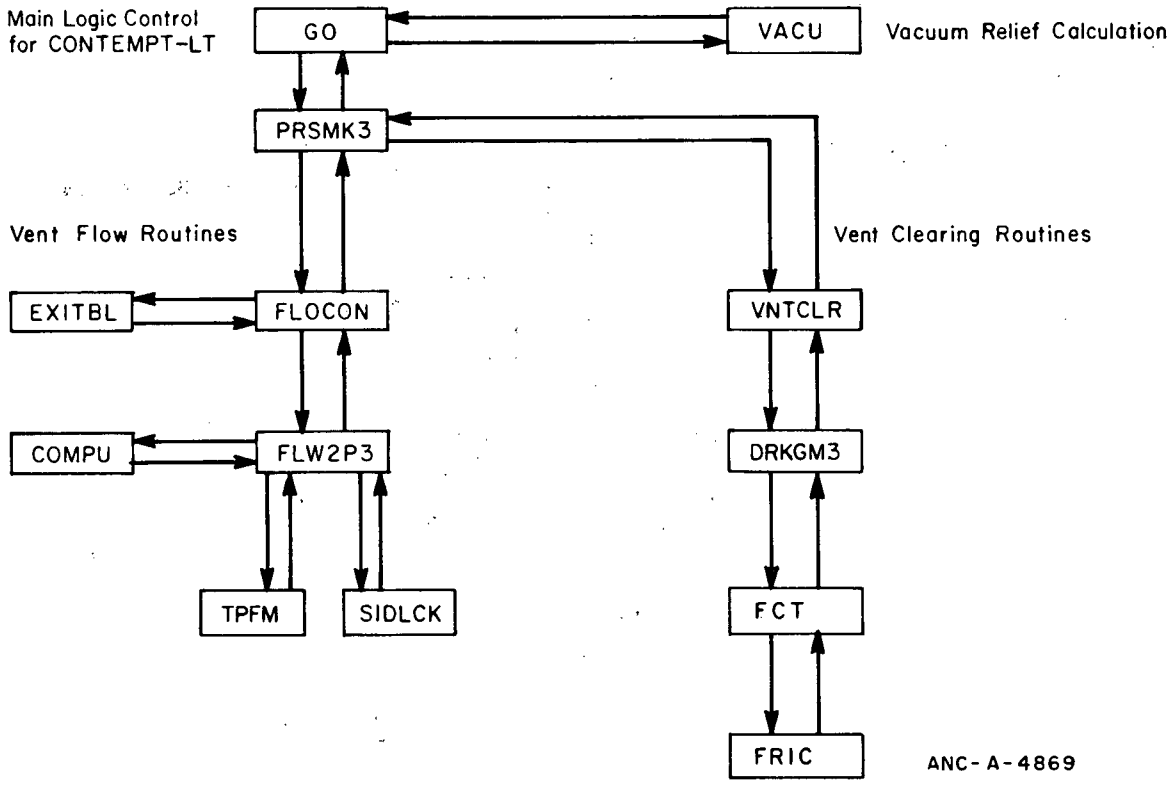

Fig. G-5 CONTEMPT-LT horizontal vent (Mark III) interfacing.

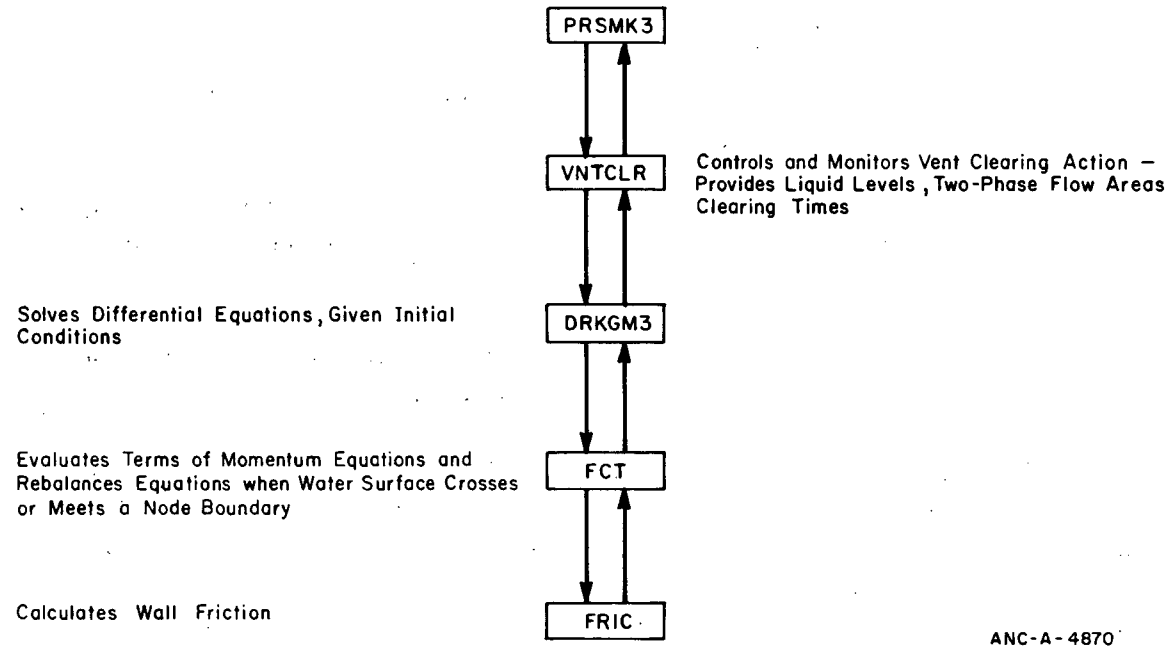

Fig. G-6 Horizontal vent (Mark III) vent clearing routines.

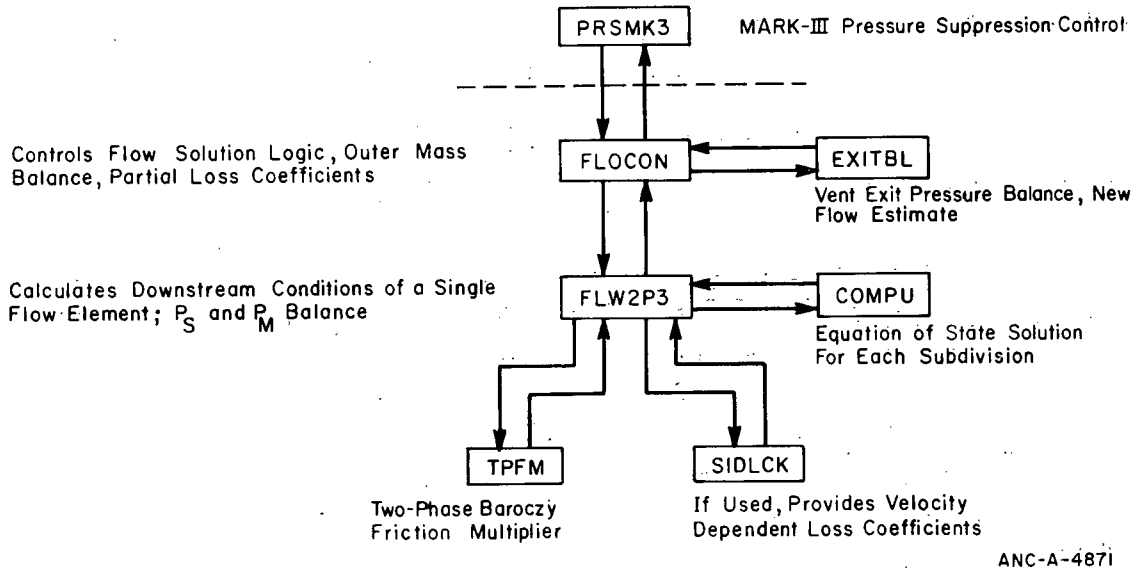

Fig. G-7 Horizontal vent (Mark III) vent flow routines.

2. SUMMARY DESCRIPTION OF EACH SUBROUTINE

In the following paragraphs each CONTEMPT-LT FORTRAN source program is briefly described.

BLKD - a block data program containing c_p, c_v, and R for air. Also contains temperature-dependent steam and liquid water viscosities and the Uchida heat transfer coefficients as a function of air-to-steam mass ratio.

COMPU - solves compartment vapor region or flow element equation of state including presence of air. Calls steam table subroutines.

CONT - performs compartment liquid-vapor interactions (boiling, evaporation, condensation), calls COMPU and updates pressures, temperatures, mass contents, and specific properties.

DRKGM3 - solves horizontal vent (Mark III) vent clearing system of first order differential equations, using a fourth order Runge-Kutta formula.

EXITBL - a subcode that controls the vent flow iteration (Level 3) process by using the vent exit pressure minus the vent back pressure difference as a function of vent flow. Provides new flow estimates and determines choking conditions.

FCT - determines the horizontal vent (Mark III) vent clearing differential equations for use in DRKGM3.

FLOCON - performs control of the two-phase flow solution in a horizontal vent (Mark III) multilevel vent arrangement. Determines certain irreversible loss coefficients. Calls FLW2P3 and EXITBL subcodes.

FLW2P3 - solves steady state equations of change for one-dimensional stream tube two-phase flow. Calculates exit conditions when given inlet conditions. Calls COMPU, TPFM, and SIDLCK subprograms.

FRIC - a function program that calculates irreversible pressure losses due to wall friction.

GO - the main logic control subroutine in CONTEMPT-LT that controls solution sequence in a timestep, updates compartment inventories, and outputs program results.

HEAT - calculates appropriate heat structure boundary conditions, temperature distribution in each structure, and energy transfer with adjacent compartments.

INMK - processes and edits input associated with the horizontal vent (Mark III) containment system.

INPS - processes and edits input associated with the vertical vent (Mark I and Mark II) containment model.

INPUT - Reads all problem input using INP package, eliminates some unnecessary storage using the FTB dynamic storage routines, and calls the INPRO1, INPRO2, INPS, and INMK input processing subroutines.

INPRO1 - processes and edits general program input, compartment descriptions, addition tables, timestep data, and safety system information.

INPRO2 - processes and edits input associated with heat structures.

LEAK1 - calculates both normal tabular small crack leakage and penetration leakage between two compartments. Provides mass and energy leaked into compartment.

MAIN - calls INPUT, GO, and PLAS routines. Determines problem running time.

PGCK - a minor subroutine which restores an output page if a specified amount of space is not available for a selected printout.

PLAS - controls plotting of drywell and wetwell pressure and temperatures. Calls computer system routines to plot Calcomp or microfilm plots.

PRSMK3 - General horizontal vent (Mark III) system control program. Calls VNTCLR and FLOCON routines, updates compartment masses and energies.

POL2 - a general routine that interpolates a function of two variables. Called by the TPFM routine

PRSINT - general vertical vent (Mark I and Mark II) pressure suppression system evaluation and control routine. Performs vent clearing, two-phase flow, and inventory updating calculations.

RECS - a data block program which contains the program name and descriptive heading printed at the top of each page.

SIDLCK - given flow velocity and geometry information, SIDLCK returns Idel'chik loss coefficients for a right angle wye.

SPRAY - calculates effects of safeguard system cooling sprays, utilizing four possible types of heat exchangers.

SRCHF - a linear interpolation routine that is used to obtain data from tables of pairs of independent and dependent parameters. Contains an entry point INTRP.

STH2OU - a steam table program to provide single-phase saturated liquid properties as a function of specific energy.

TABLU - a linear interpolation routine used to obtain data from tables having more than one dependent parameter for each independent parameter. Program contains an entry point TABLG.

TIMDP - performs linear interpolations on decay energy release rate table and outside air temperature and heat transfer coefficient.

TPFM - performs interpolation of modified Baroczy pressure loss multipliers for two-phase flow.

VACU - calculates simple incompressible flow through a vacuum breaker relief valve system.

VNTCLR - controls the horizontal vent (Mark III) clearing calculations. Provides system water levels and flow areas.

APPENDIX H

INPUT DATA REQUIREMENTS

APPENDIX H

INPUT DATA REQUIREMENTS

CONTEMPT-LT input data requirements are presented in this appendix. Requirements are discussed for the control cards for the INEL (Idaho National Engineering Laboratory) computer system, and problem input is arranged in logical sections. Depending on the model being evaluated and the choice of options selected, some entire sections of input may be omitted.

1. INEL JOB SUBMITTAL REQUIREMENTS

The CONTEMPT-LT program is operational at INEL on the CDC-7600 computer. A series of control cards containing accounting and computing information is required when a job is submitted for processing on the INEL computer system. Previous editions of this manual contained job control information although such information was of little value to code users outside INEL. Currently, job control information is available to INEL personnel through manuals which are maintained by computer systems personnel. For these reasons, the instructions pertaining to INEL computer job submittals have been deleted from this manual.

2. DATA DECK ORGANIZATION

A CONTEMPT-LT problem consists of a title card, 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.

When a card format error is detected, a line containing a dollar sign ($) located under the character causing the error and a comment giving the card column of the error is printed. An error comment is produced such that input processing continues, and usually another error comment is produced when the program attempts to process the erroneous data. The CONTEMPT-LT problem is terminated at the end of input processing.

2.1 Title Card

A title card should be entered for each CONTEMPT-LT problem. A title card has an equal sign (=) as the first nonblank character. The remainder of the title card is printed as the second line of every page. It is normally placed first in the problem.

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.

2.3 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 is replaced by the data of the current card. If the card being processed contains only a card number, the card number and 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 preceding 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 either 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, or 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 (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 1245+2 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.

2.4 Terminator Cards

The input data for CONTEMPT-LT 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. Comments may follow the slash and period on the slash and period cards; however, the /* combination is reserved for INEL system job terminator cards.

When a slash card is used as a problem terminator, the list of card numbers and associated data used in a 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.

3. DATA DECK SUMMARY

In the following description of the data cards, the card number is given along with a descriptive title of the data contained on the card. Next is given an explanation of any variable data (such as compartment number), which is included in the card number. Then the order of the data (W1, W2, . . .), the format (I, R, or A), the variable name, and the input data requirements are given where applicable. The format of the field, integer, real or floating, or alphanumeric, is indicated by I, R, or A, respectively.

3.1 Geometry, Control, and Addition Tables

This section describes the various general control cards, system geometry specification, and mass and energy addition tables.

3.1.1 Title Card. This card is optional, but recommended. Title card information will be printed as the heading on each output page and also as a title for plotted results. The first nonblank character must be an equal sign (=), and any characters may be in subsequent columns.

3.1.2 Card 11000. This card is optional, and British units are assumed if the card is missing.

W1-A	BRT	Enter either BRITISH or SI (alphanumeric). All program input and output must be in the stated units, with some exceptions. Certain input cards (as 3XX cards) have

additional versatility with respect to units flexibility, and debug type edits are normally in metric (SI) units. Where appropriate, units are indicated in this report by British or SI units.

3.1.3 General Control Card 11001. This card is required.

W1-R	TFNL	Problem end time at which calculations will cease (hr or sec).
W2-I	NSL	Number of heat conducting structures. Maximum of 20. If value is zero, no heat transfer calculations will be performed and no heat structure input data should be entered.
W3-I	NPSOPT	Option to select pressure suppression model. A 0 indicates no pressure suppression, 1 indicates the standard vertical (Mark I, II) vent system model, 2 indicates the horizontal (Mark III) vent model.
W4-R	TAIR	Initial outside air temperature (^{o}F or ^{o}K).
W5-R	PAIR	Initial outside air absolute pressure (psia or Pa).
W6-R	HUMO	Initial outside air relative humidity (0.0 to 1.0).
W7-R	TCONT	Constant temperature (^{o}F or ^{o}K) when type 0 is specified for heat structure bulk temperature control on 1YY400 cards.
W8-R	MWLV(3)	The amount of water (lbm or kg) introduced to the drywell compartment, as a step input, at the start of the problem run.
W9-R	UVWT(3)	Total internal energy (Btu or J) associated with the amount of water entered.
W10-R	MWT(1)	Amount of water (lbm or kg) left in primary system at end of blowdown.
W11-R	UTOT(1)	Total internal energy (Btu or J) associated with water left in primary system at end of blowdown.

W12-R	DAW2	Switch to select use of evaporation-condensation model in drywell prior to end of blowdown and cessation of vent flow (if vent system is modeled): 0.0 indicates use of model, 1.0 bypasses model.
W13-R	FAC	A dial to specify fraction (0.0 to 1.0) of wall or cooling coil condensate transferred from the superheated compartment atmosphere to the pool. (Used for both fan cooler and Uchida heat structure models.) Defaults to 1.0 if value is not entered or if supplied value is outside specified range.
W14-R	PSTOP	Maximum total absolute compartment pressure allowed (psia or Pa). Problem execution will stop if the pressure in any compartment exceeds this value. No pressure check is performed if this word is omitted or is 0.0.

3.1.4 Compartment Description Cards 10XX1. These cards contain initial condition information for each compartment XX, where XX = 01, 02, 03, 04. CONTEMPT-LT requires input data for XX = 01 and 03. Input data for the others are optional. Compartment 01 is the primary system, 02 is a wetwell, 03 is the standard drywell, and 04 is a dual containment compartment.

W1-R	VOL	Total compartment volume (ft^3 or m^3). If this item is zero, the compartment is assumed to be nonexistent (same as omitting card). The volume of the primary system should be input to be the volume below the elevation of the break.
W2-R	VOLL	Volume of liquid pool on floor (ft^3 or m^3); may be zero but must not exceed total volume.
W3-R	TV	Temperature of vapor region (^oF or ^oK). (>32 ^oF if Word 1 > 0.)
W4-R	TL	Temperature of liquid pool region (^oF or ^oK). (>32 ^oF if Word 1 > 0.)
W5-R	PRT	Total compartment absolute pressure (psia or Pa). (>1.0 psia if Word 1 >0.)
W6-R	HUM	Relative humidity of vapor region, limited to between 0.0 and 1.0.

W7-R	ASURF	Horizontal cross-sectional area of compartment, used for liquid pool surface area and needed in evaporation model (ft^2 or m^2).
W8-R	CHTC	A film heat transfer coefficient multiplier for sensible heat transfer between the liquid pool and vapor region (1.0 recommended).
W9-R	CMTC	A mass transfer multiplier for evaporation model (1.0 recommended). Use of large multipliers may produce unrealistic evaporation calculations in certain cases. For the primary system, values of Words 2,6,7,8, and 9 are not used and zero may be entered. If the primary system fills with water, any overflow is transferred to the drywell liquid pool region.
W10-R	PFLASH	For drywell only, switch to select drywell pressure flash option: 1.0 indicates use of pressure flash model, 0.0 or omission indicates the use of the temperature flash model.

3.1.5 Plot Control Card 10. This card is entered only if plots are desired. If entered, plots of drywell pressure, drywell atmosphere temperature, and drywell liquid temperature versus time are drawn. For pressure suppression problems, the wetwell pressure and temperature are also plotted. Plots can be generated on the Calcomp plotter, the microfilm plotter, or both.

W1-I	IPLCTO	1 for Calcomp plots, 2 for microfilm plots, 3 for both.
W2-I	IPLCT1	1 for linear plot only, 2 for semilog (time on log scale) plot only, 3 for both plots.
W3-A	IPLCT2	Enter HR, MIN, or SEC to select the units of the time axis to be hours, minutes, or seconds.
W4-R	PLXXX(1)	The specified minimum for time.
W5-R	PLXXX(2)	The specified maximum for time.
W6-R	PLXXX(3)	The specified minimum for pressure
W7-R	PLXXX(4)	The specified maximum for pressure
W8-R	PLXXX(5)	The specified minimum for temperature.
W9-R	PLXXX(6)	The specified maximum for temperature.

Words 4 through 9 determine plot scaling for the time, pressure, and temperature axes such that the axes can contain the minimum and maximum values. If the specified value is zero, the minimum or maximum value of the function is used. If the specified value is nonzero and the value does not bound the minimum or maximum value of the function, the minimum or maximum value is used. This allows a user to specify plot scales such that plots from different runs have identical scaling. However, the scaling supplied by the user is overridden if the function cannot fit on the graph.

3.1.6 Timestep Units Definition Card 9000. This card is optional, and time units of hours are assumed for 90XX cards if this card is missing (even if SI units are specified).

W1-A	UNITT	HR or SEC; the units for both time and timestep length on 90XX cards (alphanumeric).

3.1.7 Timestep and Print Control Cards 90XX. XX = 01, 02, ... These cards are required.

W1-R	TX(1)	Interval end of time (hr or sec, as per card 9000).
W2-R	TX(2)	Timestep length (hr or sec, as per card 9000).
W3-I	IT(1)	Printout frequency for heat-conducting structures.
W4-I	IT(2)	Printout frequency for pressures, temperatures, masses, ... An arbitrary number of additional sets may be entered on this card and additional cards as needed up to a maximum of 50 sets. A printout frequency of five means that quantities are printed every fifth timestep. If heat-conducting data are printed, pressure and temperature data also are printed. When a change in printout frequency is encountered, data for the next timestep are printed, and the new print frequency then becomes effective.

3.1.8 Outside Air Condition Cards 10XX. XX = 01, 02 ..., These cards are optional.

W1-R	OAT(1)	Time (hr or sec).
W2-R	OAT(2)	Outside air temperature (^{o}F or ^{o}K).
W3-R	OAT(3)	Heat transfer coefficient to outside air (Btu/ft^2-hr-^{o}F or W/m^2-^{o}K). An arbitrary number of additional sets may be entered on this card and additional cards as needed up

to a maximum of 25 sets. This table is a 24-hour cyclic table; that is, search in this table is for time modulus 24 hours. Thus, only time values to 24 hours are needed.

These cards are assumed to exist if: (a) any heat transfer structure uses the outside air as either a boundary control or heat transfer compartment, and (b) if any leakage to the outside atmosphere is specified.

3.1.9 Mass and Energy Addition Tables. The following section describes tables used for normal building leakage and various mass and energy input rates. With the exception of normal building leakage, each table has time as the first entry. The first value for time must be zero, and except for the blowdown table, the last value of time must equal or exceed the problem end time. Problem termination results when a table limit is exceeded. The first value of a set must be equal to or greater than the first value of a preceding set.

(1) Decay Power Table Cards 1XX.

XX = 01, 02, . . . These cards are optional.

W1-R	POP(1)	Time (hr or sec).
W2-R	POP(2)	Decay energy release rate in primary system or drywell or both. The units of the product of POP(2) and BWSA(2) must be Btu/hr or W. BWSA is input on Cards 4XX. An arbitrary number of additional pairs may be entered on this card and additional cards as needed up to a maximum of 50 pairs.

(2) Metal-Water Reaction Table Cards 2XX.

XX = 01, 02, . . . These cards are optional.

W1-R	MWREAC(1)	Time (hr or sec).
W2-R	MWREAC(2)	Energy release rate in primary system from metal-water reaction. The units of the product of MWREAC(2) and BWSA(3) must be Btu/hr or W. BWSA is input on Cards 4XX. An arbitrary number of additional pairs may be entered on this card and additional cards as needed up to a maximum of 50 pairs.

(3) Blowdown Table Units Definition Card 300. This card is optional; if missing, the blowdown mass and energy cards (Cards 3XX) entry units will be assumed to be hr, lbm/hr, and Btu/lbm for time, mass addition rate, and enthalpy, respectively (even if SI units are specified).

W1-A	UNITT	HR or SEC; input time unit.

W2-A	UNITM	LBM/HR, LBM/SEC, or KG/SEC; unit for input mass addition rate.
W3-A	UNITH	BTU/LBM or J/KG; unit for input enthalpy.

(4) Blowdown Mass and Energy Addition Table Cards 3XX.

XX = 01, 02, ... These cards are required.

W1-R	MADD(1)	Time (hr or sec, as per card 300).
W2-R	MADD(2)	Water addition rate (lbm/hr, lbm/sec, or kg/sec).
W3-R	MADD(3)	Enthalpy (Btu/lbm or J/kg) of water. This quantity should include the internal energy, the Pv work term, and the kinetic energy of the incoming fluid. An arbitrary number of additional sets may be entered on this card and additional cards up to a maximum of 50 sets.

The blowdown mass and energy addition table describes rates of water and energy addition to the drywell from blowdown of the primary system. The last time value in this table need not be equal to or greater than the problem end time. When the problem time exceeds the last time value in this table, blowdown is assumed to have ended. In pressure suppression problems, condensed liquid water in the drywell atmosphere, by option, will not fall to the drywell liquid region until the program time has exceeded the last time value of this table and vent flow has stopped.

(5) Primary System Energy Addition Table Cards 4XX.

XX = 01, 02, . . . These cards are optional. Zero values are used if cards are omitted.

W1-R	BWSA(1)	Time (hr or sec).
W2-R	BWSA(2)	Energy multiplier of decay power (primary).
W3-R	BWSA(3)	Energy multiplier of metal-water reaction (primary). Units comments on BWSA under descriptions for Cards 1XX and 2XX apply here. An arbitrary number of additional sets may be entered on this card and additional cards as needed up to a maximum of 50 sets.

The primary system energy addition table describes rates of energy addition to the primary system after blowdown ends. The initial amounts of water and energy in the

primary system are entered on Card 11001. The first time value in this table must be zero even though values from this table are not used until blowdown ends.

(6) Drywell Vapor Region Direct Heat and Water Addition Table Cards 5XX.

XX = 01, 02, . . . These cards are optional.

W1-R	DHA(1)	Time (hr or sec).
W2-R	DHA(2)	Water addition rate (lbm/hr or Kg/sec).
W3-R	DHA(3)	Energy addition rate (Btu/hr or W). An arbitrary number of additional sets may be entered on this card and additional cards as needed up to a maximum of 50 sets.

(7) Drywell Liquid Region Direct Heat and Water Addition Table Cards 6XX.

XX = 01, 02, . . . These cards are optional.

W1-R	DHL(1)	Time (hr or sec).
W2-R	DHL(2)	Water addition rate(lbm/hr or kg/sec).
W3-R	DHL(3)	Energy addition rate (Btu/hr or W). If this quantity is zero, the energy addition rate is given by the water addition rate times the current specific enthalpy of the drywell liquid. This option is normally used when water is being removed from the drywell liquid region and the water addition rate is negative. An arbitrary number of additional sets may be entered on this card and additional cards as needed up to a maximum of 50 sets.

(8) Drywell Decay Power and Metal-Water Reaction Multipliers and Water Addition Table Cards 7XX.

XX = 01, 02, . . . These cards are optional.

W1-R	SHA(1)	Time (hr or sec).
W2-R	SHA(2)	Energy multiplier of decay power (drywell).
W3-R	SHA(3)	Energy multiplier of metal-water reaction (drywell).

W4-R	SHA(4)	Water addition rate (lbm/hr or kg/sec).
		An arbitrary number of additional sets may be entered on this card and additional cards as needed up to a maximum of 50 sets. Units on SHA(2) and SHA(3) are the same as on BWSA, Cards 4XX.

(9) Drywell Air Addition Table Cards 9XX.

XX = 01, 02, . . . These cards are optional.

W1-R	AAA(1)	Time (hr or sec).
W2-R	AAA(2)	Air addition rate (lbm/hr or kg/sec).
W3-R	AAA(3)	Temperature of entering air (^{o}F or ^{o}K).
		An arbitrary number of additional sets may be entered on this card and additional cards as needed up to a maximum of 20 sets.

3.1.10 Heat Exchanger Description Cards 800 and 850. These two cards describe two heat exchangers associated with two ECC and building spray systems. Either card is optional, and zeroes will be entered by CONTEMPT-LT for all card values if the card is omitted.

W1-I	IHEX	Type of heat exchanger for ECC-spray system. Zero means no heat exchanger calculation is to be made. Types may be 1, 2, 3, or 4. If negative, a printout is made of heat exchanger results.
W2-R	HEX(1)	Heat exchanger surface area (ft^2 or m^2).
W3-R	HEX(2)	Overall heat exchanger heat transfer coefficient (Btu/hr-ft^2-^{o}F or W/m^2-^{o}K).
W4-R	HEX(3)	Heat exchanger coolant inlet temperature (^{o}F or ^{o}K).
W5-R	HEX(4)	Heat exchanger coolant flow rate (lbm/hr or kg/sec).
W6-R	HEX(5)	Drywell pressure at which spray system is activated (psia or Pa).

W7-R	HEX(6)	Drywell pressure at which spray system is shut off (psia or Pa). Spray system is also dependent on tabular data from Cards 8XX. If Words 6 and 7 are both zero, spray system is effectively controlled only by tabular data.

3.1.11 Heat Exchanger and Outside Flow Table Cards 8XX.

XX = 01, 02, 03, . . . , 49, XX = 51, 52, 53, . . . , 99

Cards starting with 801 describe the first system and cards starting with 851 describe the second system. Either set of cards is optional.

The heat exchanger and outside flow tables specify the flow of water for two independent cooling spray systems. Water can be obtained from the drywell and wetwell liquid regions and passed through a heat exchanger. Water leaving the heat exchanger can be mixed with outside water and the mixture directed to ECC, the drywell liquid region, the drywell spray system, and the wetwell spray system. The heat exchanger for the first system is described on Card 800 and the heat exchanger for the second system is described on Card 850.

W1-R	AWA(1)	Time (hr or sec).
W2-R	AWA(2)	Flow rate (lbm/hr or kg/sec). The fractions specified in Words 4 through 9 apply to this quantity.
W3-R	AWA(3)	Spray efficiency. Quantity is used for both drywell and wetwell.
W4-R	AWA(4)	Fraction of flow directed to drywell spray.
W5-R	AWA(5)	Fraction of flow directed to wetwell spray.
W6-R	AWA(6)	Fraction of flow directed to primary system (must = 0 until blowdown ends).
W7-R	AWA(7)	Fraction of flow directed to drywell liquid region.
W8-R	AWA(8)	Fraction of flow obtained from drywell liquid region.
W9-R	AWA(9)	Fraction of flow obtained from wetwell liquid region.

W10-R	AWA(10)	Temperature of outside water (^{O}F or ^{O}K).

The fraction of flow given by the difference between unity and the sum of Words 4 through 7 is lost to the containment system. The difference between unity and the sum of Words 8 and 9 is the fraction of outside water flow. Heat exchanger data must be furnished if flow is obtained from the drywell or the wetwell. An arbitrary number of additional sets may be entered on this card and additional cards as needed up to a maximum of 50 sets.

3.1.12 Fan Cooler System Control Card 2000. This card is optional.

W1-R	TFAN(1)	Starting time for fan cooler system (hr or sec).
W2-R	TFAN(2)	Ending time for fan cooler system (hr or sec).

3.1.13 Fan Cooler Table Cards 20XX.

XX = 01, 02, . . .

This table specifies the energy addition rate as a function of temperature. A positive energy addition value implies heat is added to the drywell containment. Temperatures must be entered in decreasing order. These cards are to be entered only if Card 2000 is entered.

W1-R	FNCL(1)	Temperature (^{O}F or ^{O}K).
W2-R	FNCL(2)	Energy addition rate (Btu/hr or W).

TEMP CORRESPONDS TO T_{SAT}, NOT T_{BULK}

An arbitrary number of pairs may be entered on this card and additional cards up to a maximum of 50 pairs.

3.1.14 Penetration Leakage Specification Cards 3XX00.

XX = 02, 03, 04

Any of these cards are optional, and if present, contain penetration leakage information for compartment XX. Leakage with the primary system should not be specified.

W1-I	LCMPP	Identification number of compartment that leakage is into (0, 2, 3, or 4).

W2-R	LK(1)	Area of throat for leakage calculation (ft^2 or m^2). If zero, corresponding leakage calculation will not be made.
W3-R	LK(2)	Ratio of throat area to exit area for leakage calculation.
W4-R	LK(3)	Ratio of throat area to inlet area for leakage calculation.
W5-R	LK(4)	Constant multiplier for leakage calculation.
W6-R through W9-R		Additional set of four values (Words 2 through 5) for second penetration leakage calculation [LK(7) through LK(10)].

3.1.15 Normal Leakage Specification Cards 3XXYY. This series of cards contains normal leakage tables and may be omitted if desired. The XX values are compartment numbers where the leakage is assumed to originate. The YY card sequence numbers must start with 01 and increase sequentially for a given compartment.

XX = 02, 03, 04

YY = 01, 02, . . . , 25

W1-I	LCMPN	Number of compartment that leakage is into (0, 2, 3, 4).
W2-R	LCOEF(1)	Pressure differential (psi or Pa).
W3-R	LCOEF(2)	Leakage coefficient (ft^3-$in.^2$/hr-lb_f or m^3/sec-Pa).
		An arbitrary number of additional pairs of pressure differential and leakage coefficient may be entered on this card and additional cards as needed up to a maximum of 25 pairs. Problem termination results if the actual pressure differential exceeds the table maximum value. Differential pressure values must be in increasing order.

3.1.16. Annular Fan Units Card 3000.

W1-A	Time units (hr or sec).
W2-A	Differential pressure units (psia or Pa).

W3-A		Volumetric flow units (m^3/sec or ft^3/min).
W4-R	TIMON	Time for turning fan on.
W5-R	TIMOF	Time for turning fan off.
W6-R	DPMAX	Differential pressure at which fan turns off and remains off until DPMIN is reached.
W7-R	DPMIN	Differential pressure at which fan turns on and remains on until DPMAX is reached.

3.1.17 Annular Fan Flow Control Card 30XX.

XX = 01, 02, . . .

W1-R	Differential pressure.
W2-R	Volumetric flow rate.
	Up to 49 additional pairs of differential pressure/ volumetric flow rate. Differential pressures must span those encountered in the problem.

The annular fan model transfers mass and energy between the annular region and the outside air when modeling a dual containment system. A positive volumetric flow rate implies that mass and energy is moved from the annular compartment. The differential pressure is defined as the difference between the atmospheric pressure and the annular pressure. It is defined as positive when the atmospheric pressure is greater than the annular pressure. Up to 50 pairs of pressures may be entered but they must be in increasing order.

3.2 Heat-Conducting Structures

The first part of this section describes input cards related to each heat structure, whereas the second part describes thermal conductivities, heat capacities, and film coefficients which may apply to several structures. Data specified in this section should be input only if heat-conducting structures exist in the CONTEMPT-LT problem, that is, if Word 2 on Card 11001 is nonzero. Further, some cards in this section are not to be input unless specifically required by other heat structure specification cards.

3.2.1 Specifications of Heat-Conducting Structures. One set of data as described in this section is required for each heat-conducting structure. For card numbers of these data, YY is 01 for the first heat-conducting structure, 02 for the second, and so forth. YY numbers must be sequential; that is, if 01 and 03 are used, then 02 must also be present.

(1) Heat Structure Title Card 1YY000. Any alphabetic, numeric, or special characters desired may be punched on this card to identify the structure. Apostrophes (') should enclose the entire title (TITPS).

(2) Heat Structure General Information Card 1YY001.

	W1-I	N	Total number of mesh points. This quantity is one larger than the number of intervals; must be less than 102.
	W2-I	L	Number of regions. Must be less than 21.
0	W3-I	IGEOM	Geometry type. 0 for slab geometry, 1 for cylindrical geometry, 2 for spherical geometry.
0	W4-R	XO	Coordinate of left boundary (ft or m).
0	W5-R	FF	Power factor, P_f.
0	W6-R	DELAY	Delay time until source is started (hr or sec).
Area	W7-R	ARA	Heat-transfer surface multiplier.
	W8-I	NCMPH(1)	Left side compartment number.
	W9-I	NCMPH(2)	Right side compartment number.

(3) Mesh Spacing Cards 1YY1XX.

XX = 01, 02, . . .

W1-I	NS	The number of intervals in the first region.
W2-R	UB	The value of the space coordinate on the right boundary of the first region (ft or m). For the remaining regions, pairs of numbers are entered on this card and additional cards as needed.

(4) Material Overlay Cards 1YY2XX.

XX = 01, 02, . . .

W1-I	ITS	Material number for Region 1. Additional values are given on this card and additional cards as needed for each of the remaining regions.

(5) Source Space - Dependence and Control Card 1YY300.

W1-I	N4	Source type control. If this quantity is zero, the source space dependence is constant over the entire structure and the next word is that value. If this quantity is unity, the space dependence is constant over a region but may be different in each region. If this quantity is two, the space dependence can differ in each interval. If the value is nonzero, additional cards (1YY3XX) are required.
W2-R	QS	The constant value of the space dependence of the source if the source type control is zero.

(6) Additional Source Space-Dependence Cards 1YY3XX.

XX = 01, 02, . . . These cards are required only if the source word in card 1YY300 is nonzero.

W1-R	QS	Source for Region or Interval 1. Additional values are given on this card and additional cards for each of the remaining regions or intervals.

(7) Boundary Condition Card 1YY400. This card specifies the left and right boundary conditions for both heat transfer coefficient and bulk temperature.

W1-I	BT0(1)	Heat-transfer coefficient control for left boundary. If this quantity is: 0, the heat-transfer coefficient is zero, indicating a symmetry or insulated condition. 1, the outside air table values of heat-transfer coefficient are used. 2, the heat-transfer coefficient is a condensing steam value dependent on the mass ratio of water vapor to air (Uchida) (this option causes condensed mass exchange also).

3, the heat-transfer coefficient is 0.4 (British units), usually used for the heat transfer to the liquid region.

4, the heat-transfer coefficient is 10^4 (British units), essentially setting the surface temperature to the bulk temperature.

±5, if positive or unsigned, the heat-transfer coefficient is taken from the table of time versus heat-transfer coefficient (4300XX cards). If negative, the heat-transfer coefficient is taken from the table of time versus heat-transfer coefficient until the first zero mass addition is encountered on the 3XX cards, then a condensing steam value (Uchida, Option 2) is used.

6, the heat-transfer coefficient is taken from a table of boundary temperature versus heat-transfer coefficient (4400XX cards).

7, 8, or greater (up to 26 maximum), the heat-transfer coefficient used is the heat-transfer coefficient of the same type number. These heat-transfer coefficients are entered on Cards 4200XX. For example, entering eight would cause the heat-transfer coefficient Type 8 entered on Word 2 of Card 420001 to be used. (For 7 through 15 only, a calculation of condensed steam due to wall condensation will be performed.)

50, a turbulent natural convection correlation (for vapor, vertical plane) is used to obtain the heat-transfer coefficient (a value of 0.19 Btu/hr-ft^2-^{o}F is used if $|T_{wall} - T_{vapor}| \leq 1.0^oF$).

51, a direct radiation heating model is used to obtain the heat-transfer coefficient. Additional model definition input is required following Word 4 of this card.

52, the heat-transfer will be the sum of natural convection and radiation heating; that is, Options 50 and 51 combined. Additional model definition input is required following Word 4 of this card.

		53, the heat-transfer coefficient is based on the Tagami heat-transfer correlation. Additional model definition input is required following Word 4 of this card.
W2-I	BTO(2)	Bulk temperature control for left boundary. If this quantity is: 0, the bulk temperature is the temperature entered on Card 11001. 1, the bulk temperature is the time-dependent value entered on the outside air conditions cards. 2, the bulk temperature is the left (right) compartment vapor temperature. 3, the bulk temperature is the left (right) compartment liquid temperature. If no liquid is present, the vapor temperature will be used. 4, the steady state left (right) side bulk temperature is entered on Card 1YY410. Option 4 reverts to Option 2 when the transient commences. 5, the steady state left (right) side bulk temperature is entered on card 1YY410. Option 5 reverts to Option 3 when the transient commences.
W3-I	BTN(1)	The same as Word 1 except for the right boundary.
W4-I	BTN(2)	The same as Word 2 except for the right boundary.
	Words 5-12	These words are needed only if Option 51, 52, or 53 has been specified on this card. Words 5 through 8 apply to the first boundary, and Words 9 through 12 apply to the second boundary, if Option 51, 52, or 53 was specified also for the second boundary.

W5-I	NQR(1)	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 designates the right surface. A value of zero causes a constant sink temperature to be used in the heat flow determination. For Option 53, always enter zero.
W6-R	TQR(1)	For Options 51 and 52, the constant sink temperature (^{o}F or ^{o}K); or if J is nonzero, this temperature will be used instead of the surface temperature of structure J for only the initial steady state calculation.
	TPEAK	For Option 53, time interval (hr or sec) to peak pressure. This value is used to determine the total energy release due to blowdown of primary system and maximum Tagami coefficient. TPEAK must be within the range of times used for the blowdown table (3XX cards).
W7-R	FQR(1)	For Options 51 and 52, the fraction of radiated heat which is absorbed in adjoining vapor medium ($0 \leqslant$ value $\leqslant 1.0$). (No radiation heat is absorbed in structure J unless that structure also utilizes a radiation heating boundary condition.)
	IBTQ2(1)	For Option 53, the heat transfer coefficient control for left 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.
W8-R	VIEWF(1)	Options 51 and 52, a view factor which is a direct multiplier on the radiation heat transfer.
	IBTQ2(2)	For Option 53, the bulk temperature control for left 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.
	Words 9-12	The same as Words 5 through 8 for a second radiation heating or Tagami correlation boundary, as specified in Word 3 [NQR(2), IBTN2(1), . . .].

(8) Steady State Special Bulk Temperature Card 1YY410. This card is entered only if Option 4 or 5 was selected for either Word 2 or Word 4 of Card 1YY400.

W1-R	TBI(1)	Bulk temperature for left surface initialization at steady state only, if Word 2 of Card 1YY400 was either 4 or 5. Otherwise, this entry should be the only one on card and is for right side initialization.
W2-R	TBI(2)	Bulk temperature for right surface initialization at steady state only. A value should be entered only if both Words 2 and 4 of Card 1YY400 were either 4 or 5.

3.2.2 Data Tables Common to All Heat-Conducting Structures. Data tables described in this section are common to all heat-conducting structures. Cards described in this section are not to be included if not needed. If they are included, time and temperature entries must cover the ranges of time and temperature anticipated in the problem; otherwise, an error condition and problem termination will occur when time or temperature exceed these ranges.

(1) Thermal Conductivity and Volumetric Heat Capacity Cards 4100XX.

XX = 01, 02, . . .

W1-R	TUCVHC(1)	Thermal conductivity for Material 1. (Btu/hr-ft-^{o}F or W/m-^{o}K).
W2-R	TUCVHC(2)	Volumetric heat capacity for Material 1 (Btu/ft^{3}-^{o}F or J/m^{3}-^{o}K). An arbitrary number of additional pairs may be entered on this and additional cards for Materials 2, 3, . . . up to a maximum of 20 materials. These cards must be present if heat-conducting structures are used.

(2) Miscellaneous Heat-Transfer Coefficient Cards 4200XX.

XX = 01, 02, . . . These cards are needed only if any heat-transfer coefficient Type 7 through 26 was specified on any 1YY400 card.

W1-R	HTC	Heat-transfer coefficient Type 7 (Btu/hr-ft^{2}-^{o}F or W/m^{2}-^{o}K). An arbitrary number of additional values may be entered on this and other cards as needed for Types 8, 9, . . . , up to a maximum of 20 values.

(3) Time-Dependent Heat-Transfer Coefficient Cards 4300XX.

XX = 01, 02, . . . These cards are needed only if heat transfer coefficient type ±5 was specified on any 1YY400 card.

W1-R	HTCT(1)	Time (hr or sec).
W2-R	HTCT(2)	Heat-transfer coefficient (Btu/hr-ft^{2}-^{o}F or W/m^{2}-^{o}K).
		An arbitrary number of additional pairs may be entered on this card and additional cards as needed up to a maximum of 25 pairs.

(4) Temperature-Dependent Heat-Transfer Coefficient Cards 4400XX.

XX = 01, 02, . . .

These cards are needed only if heat transfer coefficient Type 6 was specified on any 1YY400 card.

W1-R	HTCTP(1)	Temperature (^{o}F or ^{o}K) of boundary region.
W1-R	HTCTP(2)	Heat-transfer coefficient (Btu/hr-ft^{2}-^{o}F or W/m^{2}-^{o}K).
		An arbitrary number of additional pairs of values may be entered on this card and additional cards as needed up to a maximum of 25 pairs.

3.3 Vertical Vent (Mark I and Mark II) Pressure Suppression System

None of the cards specified in this section may be entered if Word 3 of Card 11001 is not equal to 1; and conversely, all cards except Card 1803 must be entered if Option 1 was specified.

3.3.1 Miscellaneous Control Cards.

(1) System Control Card 1801.

W1-I	NOL	Number of pipe elements in normal (unfailed) pressure suppression vent piping. The number of pipe elements is limited to 20.

W2-I	NTABL(1)	Number of quantities (not sets) entered in table of time, and vent mass fractions of air, steam, and water for use with normal vents.
W3-I	SELECT	Type of pressure suppression output information. The number -1 gives minimum output and should be used for production runs. Numbers 0 and 1 are used for diagnosing errors; 0 causes printing of iteration results for each pipe element, and 1 causes additional printing of inner iteration data for each pipe element.
W4-R	TSEP1	Time at which a detailed printout of vent flow iterations is desired (hr or sec). Detailed printout at this time is identical to that obtained when Word 3 is 1. At other times, printout is controlled by Word 3. This quantity is ignored if zero; zero should be entered for production runs.
W5-R	NUCSV(1)	Number of downcomers in normal vent system.
W6-R	PCO(1)	Ratio of fraction of liquid water entering normal vent system to fraction of liquid water in drywell atmosphere region.
W7-R	EPSEX	Convergence criterion for vent flow; 0.005 is recommended. Iterations to determine vent flow are made until relative difference between piping exit pressure and back pressure is less than this quantity. This quantity is used only for unchoked flow; criteria for terminating inner iterations and choked flow iterations are specified in the program and cannot be specified by input data.
W8-I	NOLS(2)	Number of pipe elements in failed vents. This number must be less than Word 1. If zero, no vents have failed. Failed vents are identical to normal vents up to pipe element specified by this number. If this quantity is missing, Words 9 through 11 must not be entered.
W9-I	NTABL(2)	Number of quantities (not sets) entered in table of time, and vent mass fractions of air, steam, and water for use with failed vents.

W10-R	NUCSV(2)	Number of failed vents.
W11-R	PCO(2)	Ratio of fraction of liquid water entering failed vents to fraction of liquid water in drywell atmosphere region.

(2) Miscellaneous Vent Data Card 1802.

W1-R	L1	Vent submergence at start of blowdown (ft or m).
W2-R	KXVCL	Absolute roughness of inside wall of vent exit pipe to be used during vent clearing calculation (ft or m).
W3-R	COF	Irreversible energy loss coefficient for incompressible single-phase flow to be used for entrance calculation from drywell to vent opening.
W4-R	DIAX(1)	Inside diameter of vent opening (ft or m).
W5-R	FAIL(1)	Energy loss coefficient for last pipe element of failed vent.
W6-R	FAIL(2)	Exit diameter of last pipe element of failed vent (ft or m). The element number of the last pipe element of the failed vent is entered in Word 8 of Card 1801. If Words 5 and 6 are zero, the exit diameter of the last pipe element of the failed vent is the same as that of the corresponding element in the normal vent and the irreversible loss calculation uses the irreversible loss entry for the normal vent and depends on the type of pipe element. Words 5 and 6 values (if nonzero) are used for the last element of the failed vent and the last element must be Type 2 if failed vents are present.
W7-I	IFSEL	0 selects standard calculation which computes a friction factor as a function of Reynolds number and uses a Baroczy two-phase multiplier. 1 specifies that friction factors are obtained from the 1200 series cards. Friction factors are fixed, but Baroczy two-phase multiplier is applied. 2

specifies the same as 1 except that two-phase multiplier is not applied. The mixture density is used in computing the friction loss.

W8-R VNTCLF(1) Multiplying factor for vent closing (0.0 to 1.0 values). Vents assumed closed if product of vent submergence hydrostatic pressure head and VNTCLF(1) $\geq$ (drywell pressure - wetwell pressure).

W9-R VNTCLF(2) Multiplying factor for initiation of vent reclearing [VNTCLF(1) to 1.0 values]. Vent clearing calculations resumed if (drywell pressure - wetwell pressure) $\geq$ VNTCLF(2) times the vent submergence hydrostatic pressure head.

W10-R DCAM(1) Multiplier on (C_p - C_v) difference term for air energy transport through the wetwell pool to atmosphere region (0.0 to 1.0, 0. = C_v, 1.0 = C_p, C_v used in previous versions of CONTEMPT-LT).

W11-R DCAM(2) Multiplier on (T_{v3} - $T_{\ell 2}$) difference term for air energy transport through the wetwell pool to atmosphere region [0.0 to 1.0, 0. = $T_{\ell 2}$(wetwell pool), 1.0 = T_{v3} (drywell vapor), $T_{\ell 2}$ used in previous version of CONTEMPT-LT].

(3) Vacuum Relief System Card 1803. This card is optional.

W1-R PRVALV(1) Pressure difference ($lb_f/in.^2$ or Pa) at which vacuum breakers between wetwell and drywell open. When pressure in wetwell exceeds drywell pressure by this amount, flow through the vacuum breakers is calculated.

W2-R — k_{vr}, single-phase irreversible loss coefficient for vacuum relief system. If this quantity is zero, no vacuum system calculations are performed and the other input quantities can be zero.

W3-R — A, flow area of one vacuum breaker (ft^2 or m^2).

W4-R — N_{vr}, number of vacuum breakers in system.

3.3.2 Pressure Suppression Vent Piping Data. These cards describe the vent piping leading from the drywell to the wetwell including the submerged portion of the pipe. The vent piping is divided into pipe elements, and one entry is required for each pipe element for each quantity described subsequently. The pipe elements are ordered from the pipe entrance to the exit in the wetwell liquid region. The number of pipe elements is given on Card 1801.

(1) Pipe Element Type Cards 11XX.

XX = 01, 02, . . .

W1-I	LEG	Type 1 or 2 for pipe Element 1. The remaining type numbers may be entered on this and additional cards as needed.

The type of pipe element is defined as follows:

Type 1: Pipe diameter is constant over the length of pipe element; wall friction calculation used for irreversible energy loss.

Type 2: Pipe diameter can change over the length of the pipe element; energy loss coefficient is used for irreversible energy loss; flow can be subdivided to obtain better accuracy in the numerical approximations for area change and large density change.

The entrance calculation, which is the calculation used to determine fluid conditions at the entrance from stagnation conditions in the drywell atmosphere, is always for a Type 2 element and its input data are specified on Card 1802. The first quantity on these cards specifies the type for the pipe element starting at the entrance.

(2) Pipe Element Irreversible Loss Data Cards 12XX.

XX = 01, 02, . . .

W1-R	COEF	Roughness factor or energy loss coefficient as described subsequently for Element 1.

Data for the remaining elements may be entered on this and additional cards as needed.

For a Type 1 pipe element, the quantity entered is the absolute roughness of the pipe inside wall (ft or m). For a Type 2 pipe element, the quantity entered is the irreversible energy loss coefficient for incompressible single-phase flow. If appreciable wall friction is present in a Type 2 element, it must be included in the energy loss coefficient. The energy loss coefficient for the entrance calculation is given on Card 1802 but is printed as the first value in the input edit of these quantities. The energy loss coefficients depend on whether upstream or downstream conditions are used. The program uses:

(1) Downstream conditions in the entrance calculation

(2) Upstream conditions if subdivisions are used

(3) Conditions for the smaller cross-sectional area at abrupt area changes

(4) Upstream conditions in the last element

An abrupt area change is a Type 2 element with zero length.

(3) Pipe Element Vertical Height Data Cards 13XX.

W1-R	DELHX	Elevation change between the inlet and outlet of pipe Element 1 (ft or m). The sign of this quantity is positive if the outlet is higher than the inlet; horizontal pipe elements have zero elevation change. Data for the remaining elements may be entered on this and additional cards as needed.

(4) Pipe Element Diameter Data Cards 14XX.

XX = 01, 02, . . .

W1-R	DIAX(2)	Inside diameter of the outlet of pipe Element 1 (ft or m). The diameter of the entrance, which is the inlet diameter for the first pipe element, is given on Card 1802 and the outlet diameter of an element is the inlet diameter for the next element. The outlet diameter must equal the inlet diameter for Type 1 elements. Diameter data for the remaining elements may be entered on this and additional cards as needed.

(5) Pipe Element Length Data Cards 15XX.

XX = 01, 02, . . .

W1-R	LX	Length of pipe Element 1 (ft or m). In Type 1 elements, this quantity is used in computing wall friction. In Type 2 elements, this quantity is tested only for zero or nonzero value. If zero, the element is assumed to have an abrupt area change. Length data for the remaining elements may be entered on this and additional cards as needed.

(6) Pipe Element Subdivision Data Cards 16XX.

XX = 01, 02, . . .

W1-I	NOS	Number of subdivisons for pipe Element 1. Only Type 2 elements may be subdivided, and any integer number (usually zero) may be entered for Type 1 elements. If the pipe element is not to be subdivided, 0 or 1 is entered. No subdivisions are allowed in a Type 2 element with a nonzero energy loss coefficient and an abrupt area change. Subdivision data for the remaining elements may be entered on this and additional cards as needed.

(7) Pipe Element Branch Fraction Data Cards 17XX.

W1-R	RWX	Branch fraction for pipe Element 1. The fraction must be 1.0 for Type 1 elements and Type 2 elements without flow branching. An example of a branch fraction, if a pipe branched into four equal flow paths, the branch fraction would be 0.25. Branch fraction data for the remaining elements may be entered on this card and additional cards as needed.

3.3.3 Vent Mass Fraction Tables. The mass fractions of air (r_a), water vapor (r_s), and liquid water (r_ℓ) entering the pressure suppression vent system are computed from the masses of these quantities in the drywell, and a liquid separation factor is entered on Card 1801. These mass fractions can be modified by factors, r'_a, r'_s, and r'_ℓ obtained as a function of time from an optional table. Separate tables can be entered for normal vents and failed vents. The number of quantities entered in each table is specified on Card 1801. A table is not used and must not be entered if the quantity on Card 1801 is zero or not specified on the card. The entries on Card 1801 specify the number of quantities and not the number of sets.

(1) Vent Mass Fraction Tables Cards 19XX.

XX = 01, 02, . . . , 49 (maximum) (normal vents)

XX = 51, 52, . . . , 99 (maximum) (failed vents)

For the normal vent flow calculations, for which XX = 01, 02, . . . up to a maximum of 49:

W1-R	TBLRA(1)	Time (hr or sec).
W2-R	TBLRA(2)	r'_a, air mass fraction modifier.
W3-R	TBLRA(3)	r'_s, water vapor mass fraction modifier.
W4-R	TBLRA(4)	r'_ℓ, liquid water mass fraction modifier. An arbitrary number of sets may be entered on this card and additional cards as needed until the number of quantities on Word 2 of Card 1801 have been entered.

Similar information is entered for the failed vent flow calculations, for which XX = 51, 52, . . . , up to a maximum of 99. An arbitrary number of sets may be entered on these cards as needed until the quantities on Word 9 of Card 1801 have been entered. TBLRB(i) replaces TBLRA(i) for the failed vent data.

3.4 Horizontal Vent (Mark III) Pressure Suppression System

Input cards described in this section may be entered only if the horizontal vent (Mark III) containment system has been specified on Card 11001, Word 3. All input must be in either British or metric (SI) units as previously defined.

3.4.1 General Description and Control Cards.

(1) General Specification Card 50000.

W1-I	NUCSV	Number of repeating azimuthal segments in entire annular system. The mass-energy interchange is calculated for one segment and multiplied by the total number of segments.
W2-I	NELMTS	Number of flow elements in one segment, including the vent pipes ($\leqslant$ 50). The annulus entrance is Element 1.

W3-I	NVENTS	Number of horizontal vents (or branches) in a segment ($1 \leqslant N \leqslant 10$).
W4-R	RABLK	A horizontal vent blockage factor, applied to all vents. Ratio of vent open flow area to flow area that would exist if no purge lines or obstructions existed (values from 0. to 1.0).
W5-R	PCO	A water carryover factor, used to account for liquid-vapor separation effects from drywell internal structures, baffles, and so forth (from 0.0 to 1.0). Ratio of fraction of liquid water entering vent system to fraction of liquid water in drywell vapor region.
W6-R	VAF	A vent clearing area factor which determines whether a vent two-phase flow area opens as a solid plug (either fully open or closed) or if flow area is proportional to the cleared length. For plug, 0.0 is used and if area is proportional to cleared length, 1.0 is used.
W7-I	MAXITR	The maximum number of trial iterations permitted during solution of the equations of change for a given flow element. A value of 30 is recommended.
W8-R	EPSMK(1)	The convergence criterion ratio of pressures [(equation of state - momentum equation solution)/ equation of state] for solution of a given flow element. Normal pressure operation will continue until the absolute value of this ratio is obtained or the iteration limit specified is reached. A value of 0.001 is recommended.
W9-I	MAXLP	The maximum number of trial iterations permitted during convergence calculations on the pressure balance for each vent. Normal program operation will continue until the absolute value of [(vent exit pressure - vent back pressure) / vent back pressure] is less than the convergence ratio input by means of Word 10 or the iteration limit is reached. A value of 30 is recommended.

W10-R	EPSMK(2)	The convergence criterion pressure ratio [(vent exit pressure - wetwell back pressure) / wetwell back pressure] as discussed previously. A value of 0.005 is recommended.
W11-I	MAXIW	The maximum number of trial iterations permitted during the vent system total mass flow balance. A value of 20 is recommended.
W12-R	EPSMK(3)	The convergence criterion on mass ratio [(total flow in - flow summed from all vents) / total flow in]. Normal pressure operation will continue until this value is obtained or the iteration limit is reached. A value of 0.005 is recommended.

(2) Vent Air and Steam Carryover and Wetwell Air Bubble Modifiers Card 50001. This card is optional, values of 1.0 will be assigned to the vent modifiers if the card is not input, and 0.0 will be assigned to the wetwell air bubble modifiers.

W1-R	RPRIME(1)	An air or steam mass ratio lower limit for use of the following mass fraction modifiers. A positive value means the modifiers are used until the vent entrance mass fraction of [air/(air + steam)] is less than the Word 1 value. A negative value allows use of the modifiers until the vent entrance mass fraction of [steam/(air + steam)] is less than the absolute value of Word 1. The vent entrance mass fractions are modified by the following three values, until the lower limit is reached.
W2-R	RPRIME(2)	The air mass fraction modifier (r'_a).
W3-R	RPRIME(3)	The steam mass fraction modifier (r'_s).
W4-R	RPRIME(4)	The liquid water mass fraction modifier (r'_ℓ).
W5-R	DCAM(1)	Multiplier on (C_p - C_v) air specific heat difference term for air energy transport through the wetwell pool to atmosphere region (0.0 to 1.0, 0.0 = C_v, 1.0 = C_p, specific heat of air at constant volume (C_v) used in previous versions of CONTEMPT-LT).
W6-R	DCAM(2)	Multiplier on (T_{v3} - $T_{\ell 2}$) temperature difference term for air energy transport through the wetwell pool to atmosphere region (0.0 to 1.0, 0.0 = $T_{\ell 2}$ (wetwell pool temperature), 1.0 = T_{v3} (drywell

vapor temperature), $T_{\ell 2}$ used in previous versions of CONTEMPT-LT).

(3) Annulus-Vent Description Card 50002.

W1-R	LVENT	Flow path length of typical horizontal vent through drywell wall (ft or m).
W2-R	ANND	Inner diameter of annulus (ft or m). This parameter, with annulus width and water depth, is used to calculate flow areas and water mass.
W3-R	ANNW	Width of annulus (ft or m).
W4-R	ZWI	Initial height of water in annulus, relative to a given floor level (ft or m). This initial value corresponds to the bottom elevation of flow Element 1.
W5-R	ZWEIR	Height of weir wall in drywell, relative to floor level used for ZWI (ft or m).
W6-R	ZWWI	Initial height of liquid water level in wetwell relative to floor level used for ZWI (ft or m).

(4) Vacuum Relief System Card 50003. This card is optional and may be omitted if no vacuum relief system is used.

W1-R	PRVALV(1)	Pressure difference (lbf/in.^{2} or Pa) at which vacuum breakers between wetwell and drywell open. When pressure in wetwell exceeds drywell pressure by this amount, flow through the vacuum breakers is calculated.
W2-R	—	Irreversible loss coefficient, k_{vr}, of vacuum relief system. If this quantity is zero, no vacuum system calculations are performed and the other input quantities can be zero.
W3-R	—	A, area of one vacuum relief breaker (ft^2 or m^2).
W4-R	—	N_{vr}, number of vacuum breakers in system.

(5) Table of Inner Iteration Printout Option Cards 5001X.

X = 0, 1, 2, . . . These cards may be omitted and Option 0 used.

This series of cards contains sets of problem time (in seconds) and vent system printout option. The first time should be greater than zero, but the last time does not have to exceed the problem termination time. Four levels of detail are available for output of vent clearing and vent flow calculations, intended primarily for special purpose code evaluation. All output resulting from use of Options 1 through 5 will be in SI units. For production runs, either Option 0 should be used, or the cards should be left out of the input deck.

W1-R	TIMEPT	Problem time (seconds) that user desires a detailed printout. Printout will occur at nearest timestep.
W2-I	IPRINT	Option on level of printout detail.

A maximum of 20 sets may be entered, as desired. The printout options are described as follows:

Option	Description
0 (or no Input Cards)	Minimum Detail: Standard timestep information on vent water level, vent flow, and containment system temperature, pressure, energies, and so forth.
1	In addition to the standard edit, printout includes all detailed information for each flow element iteration and details of the vent clearing process, including each Runge-Kutta iteration. This edit can produce considerable output and is intended for detailed code examinations by programmers.
2	In addition to the standard edit, printout includes all Level 2 iteration results for vent flows (that is, vent iteration values but no individual flow element results) and the vent clearing water levels, velocities, and accelerations for all subdivided timesteps rquired by the vent clearing model.
3	In addition to the standard edit, printout includes only limited vent flow information on the outer mass balance iteration and vent clearing water levels, velocities, and accelerations for user input timesteps.
4	Use of Options 2 and 3 combined.
5	Use of Options 1, 2, and 3 combined.

3.4.2 Flow Element Specifications. The cards listed in this subsection contain information applicable to all flow elements. Additional information for branch elements (vent entrance) is provided in the next subsection.

(1) Loss Coefficient Mulitplier Cards 501XX.

XX = 01, 02, . . . , up to 10

W1-R	XKMULT	$\pm C_1$. If minus C_1 is entered, all flow element loss coefficients will be multiplied by the absolute value of C_1, and no other data need be entered on this card. If a positive value is entered, then values must be entered on this card series for all flow elements ($\leq$ 50). The actual values entered, including sign, will multiply the loss coefficients. (The multiplier for branch elements is applied for both vent entrance and bypass calculations.)

(2) Flow Path Length of Flow Elements Cards 502XX.

XX = 01, 02, . . . , up to 10

W1-R	LX	The flow path length of flow Element 1 (ft or m). Additional values are entered on this card series for each flow element ($\leq$ 50). For branch elements (in annulus at entrance to a vent), elevation differences between top and bottom of element are entered. The value for Element 1 is set equal to zero in CONTEMPT-LT; any value may be entered.

(3) Flow Element Loss Coefficients Cards 503XX.

XX = 01, 02, . . . , up to 10

W1-R	COEF	The roughness factor or loss coefficient for pressure drop in flow Element 1. For constant area Type 1 elements, the quantity entered is the absolute roughness of the wall surface (ft or m). For Type 2 elements, the irreversible energy loss coefficient for incompressible single-phase flow is entered. Element 1 is a Type 2 element. If a negative value is entered for Element 1 or any other Type 2 element, then the input loss coefficient is ignored, for that element only, and a program-determined value based on area ratios is applied.

The calculated values are:

$K_c = 0.45\ (1 - \beta)$, contraction

$K_e = (\frac{1-\beta}{\beta})2$, expansion

$K_{RA} = 1.90$, sharp right angle turn

β = small area/large area.

For a branch element with flow into the vent, the loss coefficient used will be K_{RA} plus either K_c or K_e as appropriate.

Additional values are entered on this card series for each flow element ($\leqslant$ 50). (Use of velocity dependent data specified on Cards 515XX may override these options for Type 2 elements.)

(4) Loss Coefficient Model Option Cards 504XX.

XX = 01, 02, . . . , up to 10

W1-I NDPBSE Option to select model base for irreversible loss coefficient for flow Element 1.

(1) maximum mass flux and associated conditions

(2) minimum mass flux and associated conditions

(3) upstream mass flux and associated conditions

(4) downstream mass flux and associated conditions

Additional values are entered on this card series for each flow element ($\leqslant$ 50). Only Type 2 elements actually use these options; all Type 1 elements use downstream conditions and any option may be input. These options are provided as a user convenience, for example, to allow special comparisons with experimental data. Option 4 should be specified if area-dependent loss coefficients have been selected on cards 503XX or 516XX.

(5) Flow Element Subdivision Cards 505XX.

XX = 01, 02, . . . , up to 10

W1-I	NOSD	The number of subdivisions in flow Element 1. Only Type 2 elements may be subdivided, and integer 1 should be entered for Type 1 elements. Equations of change are solved for each subdivision including appropriate area differences. Normally one subdivision is adequate. Additional values are entered on this card series for each flow element ($\leqslant 50$).

3.4.3 Vent-Branch Description. The cards in this subsection describe the horizontal vents and identify the flow elements associated with each vent.

(1) Vent Elevation Cards 510XX.

XX = 01, 02, . . ., up to 10

W1-R	ZV	Centerline elevation (ft or m) of first vent (top vent) relative to same floor reference as used for 50002 card data. Additional vent centerline elevations are entered on this card series; each subsequent elevation must be lower than the previous entry (bottom vent entered last) ($\leqslant 10$).

(2) Vent Diameter Cards 511XX.

XX = 01, 02, . . ., up to 10

W1-R	DV	Inside diameter of first (top) horizontal vent (ft or m). Additional vent diameters are entered on this card series. Vent ordering must be same as used on 510XX cards ($\leqslant 10$).

(3) Branch Flow Element Identification Cards 512XX.

XX = 01, 02, . . ., up to 10

W1-I	NJNPTH	Branch flow element number for first (top) vent. Additional branch element numbers are entered for each vent. Ordering scheme as specified is used (maximum of 10 branch elements).

(4) End-of-Vent Identification Cards 513XX.

XX = 01, 02, . . ., up to 10

W1-I	NEND	Number of the flow element at the wetwell end of the first (top) vent pipe. Additional end-of-vent flow element numbers are entered on these cards, in the standard order of lower elevation vents (maximum of 10 vents).

(5) Branch Element Corner Radius Cards 514XX.

XX = 01, 02, . . ., up to 10

W1-R	RC	The corner radius (from annulus into vent) of the first (top) vent branch flow element (ft or m). Additional radii, in standard order of increasing vent number, are entered on this card series ($\leq$ 10). The radii are used only if velocity-dependent loss coefficients are specified. If velocity-dependent coefficients are not specified, 0.0 is entered.

(6) Branch Element Additional Irreversible Loss Coefficient Options for Two-Phase Flow Cards 515XX.

W1-I	NIDL	Additional option on irreversible loss coefficient for both bypass and vent entrance portions of first (top) branch flow element. 1 = use constant value or area-dependent value as input on Cards 503XX or 516XX. 2 = use Idel'chick data, based on upstream mass flux and conditions. Both types are modified by the multiplier input on cards 501XX. Input additional options for each branch element, in order of increasing vent number ($\leq$ 10).

(7) Branch Element Bypass Irreversible Loss Coefficients for Two-Phase Flow Cards 516XX.

XX = 01, 02, . . . , up to 10

W1-R	COEFCN	The irreversible loss coefficient for the bypass flow for the first (top) branch flow element. If a negative value is entered, the program calculates and uses an area expansion coefficient, $K_e = (\frac{1-\beta}{\beta})^2=0$, where β = small area/large area of flow element = 1.0. If Option 2 was specified on Card 51501, the input or area-dependent value will be used only as an initial estimate. Additional bypass coefficients are input for each branch element in order of increasing vent number ($\leqslant$ 10).

(8) Vent Clearing Loss Coefficients Cards 517XX.

XX = 01, 02, . . . , up to 10

W1-R	FVNT(1)	Multiplier on cross-momentum-flux term at Vent 1 entrance during vent clearing calculations (if 0.0, term is not used; if 1.0, term is fully applied).
W2-R	FVNT(2)	Absolute roughness of top vent (Vent 1) and associated annulus walls (ft or m).
W3-R	FVNT(3)	Vent entrance irreversible elbow loss coefficient for Vent 1.
W4-R	FVNT(4)	Vent exit irreversible elbow loss coefficient for Vent 1.
W5-R	FVNT(5)	Vent 1 entrance sudden contraction irreversible loss coefficient mulitplier.
W6-R	FVNT(6)	Vent 1 exit sudden expansion irreversible loss coefficient multiplier.
		(Words 5 and 6 are multipliers of 0.45 $(1-\beta)$ and $(1-\beta)^2$, respectively, where β equals the ratio of small to large flow areas being considered. Additional data are input, in sets of six words as just described, for each vent in increasing order ($\leqslant$ 10 sets).

APPENDIX I

CONTEMPT-LT OUTPUT DESCRIPTION

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CONTEMPT-LT OUTPUT DESCRIPTION

1. PRINTED OUTPUT

This appendix provides a description of the various variables that may be listed during a timestep edit of CONTEMPT-LT. Included are definitions of terms encountered in a problem utilizing pressure suppression, multiple heat structures, multiple compartment leakage, and the dual compartment option.

The explanation of specific output variables is divided into sections of (a) general compartment variables, (b) heat structures, (c) compartment leakage, and (d) pressure suppression. The sample problem of Appendix J may be referred to for added clarification. Either British or metric (SI) units are possible, depending on the input option used, and the appropriate units for each system are indicated in this appendix by British or SI; for example, X is distance (ft or m).

1.1 General Compartment Variables

The items listed subsequently apply to all compartments. Compartment numbers are defined in the initial program output.

1.1.1 Pressure.

TOTAL -- Vapor region total absolute pressure (psia or Pa) which acts on the compartment walls and liquid pool surface. Calculated at the end of a timestep.

STEAM -- End-of-timestep partial water vapor absolute pressure in the vapor region (psia or Pa), based on the vapor temperature.

1.1.2 Temperature.

ATMOS -- End-of-timestep vapor region temperature (^{O}F or ^{O}K), determined from the equation of state and saturated water properties.

POOL -- End-of-timestep temperature of the liquid pool of water, if water is present (^{O}F or ^{O}K).

1.1.3 Energy.

ATMOS -- End-of-timestep total energy of the compartment vapor region (Btu or J), due to the presence of air, liquid, and vapor water in the vapor region.

POOL -- Total energy associated with the pool mass of water (Btu or J), at the end of the timestep.

TOTAL -- This is the end of timestep total energy within the compartment, including air, water vapor, and liquid water (Btu or J).

1.1.4 Convergence DE/E. This is a unitless ratio indicating the convergence of the vapor region energy, due to the predictor-corrector philosophy used to account for timestep changes resulting from heat transfer. The purpose of this item is to provide information for the user. If this parameter exceeds about 10^{-3}, that indicates the timestep size is too large and should be reduced.

1.1.5 Air Mass. This is the end of timestep mass of all air in the compartment (lbm or kg). All air is assumed to be in the vapor region.

1.1.6 Water Mass.

VAPOR - ATMOS -- This is the end of timestep mass of water vapor contained within the compartment vapor region (lbm or kg).

ATMOS - LIQUID -- This is the end of the timestep mass of liquid water contained within the compartment vapor region (lbm or kg).

POOL -- Total mass of water in the liquid pool at the end of the timestep (lbm or kg).

TOTAL -- This is the end of timestep mass of all water (vapor and liquid) in the entire compartment (lbm or kg).

1.1.7 Humidity. This is the relative humidity determined at the end of the timestep.

1.1.8 Condensation. This parameter, if positive, is the mass rate that condensed liquid was removed from the vapor to the liquid pool region (lbm/sec or kg/sec). A negative value represents the mass rate that water evaporated from the pool to the vapor region.

1.1.9 Transfer Coefficients.

MASS - This parameter is the mass transfer coefficient determined by the evaporation/condensation model. It does not include the input multiplier (lbmol/hr-ft^2 or kmol/sec-m^2).

HEAT -- This parameter is the sensible heat transfer coefficient determined by the evaporation/condensation model. It does not include the input multiplier (Btu/sec-ft^2-^oR or J/sec-m^2-^oK).

1.1.10 Miscellaneous.

FAN COOLER RATE -- The energy addition rate (Btu/hr or W) that fan systems are adding heat to the drywell vapor region. A negative value indicates heat removal from the drywell. This value is merely the interpolated number from the 20XX input cards.

HEAT EXCHANGER INFORMATION -- Three items are listed if spray systems and heat exchangers are in operation. EFFIC is the heat exchanger efficiency as calculated for the type of exchanger specified in the input. SPRAY-ECC TEMP. is the spray water temperature (^{O}F or ^{O}K) as it leaves the spray head(s). HT. REM. RATE is the Btu/hr or W removed from the plant system by the cold side of the heat exchanger.

1.2 Heat Structure Output

Most output associated with the heat structures is self-explanatory; therefore, the following definitions tend to be brief. Until noted later in this section, all comments apply for a single given heat structure. The values are for temperatures or heat rates associated with the heat structure and do not necessarily mean the emitted heat is actually absorbed elsewhere (for example, radiation heating).

END STEP BTU/HR or END STEP WATTS -- The rate of heat leaving the indicated heat structure surface as calculated at the end of timestep. A negative value means heat is entering the heat structure.

STEP BTU or STEP J -- The calculated average heat leaving the indicated surface during a given timestep. The value is an average of the current and previous timestep heat rate values multiplied by the current timestep length. A value of zero will be indicated for symmetry boundary conditions, or for interchange with the primary system (only on primary side, however) if blowdown has not ended.

TOTAL NET BTU or TOTAL NET J -- A problem summation of the STEP BTU or STEP J values for the given heat structure.

H; K; BULK TEMP; MESH POINT TEMPERATURES -- These variables are self-explanatory and units are indicated on the output. The H and BULK TEMP are boundary conditions for an effective convective heat transfer solution of the type $Q = H A_s (T_{surface} - T_{bulk})$. The thermal conductivity is utilized in the solution for the structure temperatures.

SUMMARY OF HEAT TRANSFER -- The summary table provides a concise tabulation of the effects of all heat structures. This table lists heat transfer to compartments, not heat leaving heat structures. For radiation heating, most energy radiated from a structure will not ordinarily be deposited in the adjoining compartment region. If many structures transfer heat to or from a given compartment, this table will show the total effect of all such structures. The STEP-LIQUID and STEP-VAPOR values are averages of current and previous timestep calculations, identical to the STEP BTU or STEP J parameter

discussed. The LIQUID or VAPOR term indicates which portion of the compartment received the heat. NET values are merely problem summations of the STEP values.

1.3 Compartment Leakage Output

All output is labeled and is considered to be self-explanatory. Caution should be exercised to differentiate between "gain" and "loss" headings. All edited values are end-of-timestep results except NET items, which are problem summations of unedited step average values (average of current and previous timestep values).

LEAKRATE -- This is the total mass flow (lbm/hr or kg/sec) from the indicated compartment, including air and water vapor.

ENERGY GAIN -- The three items edited are the end-of-timestep total energy gain for the compartment, the normal leakage portion of that total, and the penetration portion (Btu or J).

STEP AND NET LOSSES – These values are mass (lbm or kg) losses from the compartment, for water vapor and air separately. Net values are simply time summations of the step values.

ATMOSPHERE LEAKAGE -- These values are air and water vapor mass losses to the outside atmosphere, from all leaks to the atmosphere, integrated over the problem time.

1.4 Pressure Suppression System Output

This section is divided into two parts, one for the vertical vent (Mark I and Mark II) containment systems, and the other for the horizontal vent (Mark III) system. All pressure suppression parameters are associated with beginning of timestep conditions before compartment conditions are updated for that step.

1.4.1 Vertical Vent (Mark I and Mark II) Systems.

DRYWELL PR.; WETWELL PR.; V; X -- These symbols will be printed prior to normal vent clearing if a vertical vent pressure suppression system is being evaluated. The DRYWELL PR. and WETWELL PR. values are simply the vapor region total absolute pressures (psia or Pa) of the two indicated compartments. V and X are the vent water clearing velocity (ft/sec or m/sec) and total displacement (ft or m).

RW, RA, RS, RG -- These symbols are listed either once or twice per timestep, after the vent system has been cleared and flow has been established. The first edit refers to unfailed vents and the second refers to failed vents (if any). All four items are mass fractions, defined as follows:

RW = The vent inlet liquid water mass fraction, which is: (drywell mass of liquid water in vapor region) (code input carryover fraction) / (sum of drywell masses of liquid water in vapor region, noncondensed vapor water, and air)

RA = The vent inlet air mass fraction which is: (1 - RW) (drywell mass of air) / (sum of drywell masses of air and noncondensed vapor water)

RS = 1 - RW - RA = vent inlet noncondensed water mass fraction

RG = RA + RS = 1 - RW = vent inlet vapor mass fraction.

Some differences may exist between unfailed and failed vent values (assuming input carryover fractions have been specified to be the same) because the unfailed vent flow is solved and drywell and wetwell masses and energies are updated before the failed vent calculation is performed, for each timestep.

WDOTT -- The total mass flow rate (lbm/hr or kg/sec) from all unfailed vents for the first printout, and for all failed vents for the second edit (if any). If failed vents are present, they do not have to be cleared, so initially the single edit of WDOTT would be for the failed vents.

PX, TX, VX, PPOOL, RS -- PX is usually exit total absolute pressure (psia or Pa) for either normal or failed vents, obtained from the equation-of-state solution. If a vent is choked at some point other than the exit, the PX is the last estimated pressure at the choking point rather than at the vent exit (and is only an estimate). TX is the temperature (^{o}F or ^{o}K) of the fluid leaving the vent (normally), based on the equation of state, including air if present. The temperature will correspond to the choking location if choking exists with limitations similar to those on the PX term. VX is the vent fluid exit velocity (ft/sec or m/sec), based on solution of the energy equation. Location and accuracy limitations for choked situations exist similar to those on PX and TX. PPOOL is just the wetwell backpressure (psia or Pa) at the vent exit. RS is the noncondensed water mass fraction previously determined from the equation of state for the vent exit conditions (or choking location, if choking occurs), rather than for vent inlet conditions.

1.4.2 Horizontal Vent (Mark III) System. The horizontal vent (Mark III) pressure suppression system output values are clearly defined on the computer printout. All debug type output is in SI units, regardless of what units have been specified for the problem. Summary descriptions for each output value are provided.

n VENTS CLEAR -- n is the number of vent levels that have some area open for two-phase flow.

ANN. WATER ELEV. -- The weir annulus water level determined after the vent clearing calculations have been performed (ft or m).

LIQ. MASS FLOW TO COMP. -- The mass of liquid water (lbm or kg) that has flowed during the timestep from the annulus and all vents to the wetwell (Compartment 2) or to the drywell (Compartment 3) if a pressure reversal occurs.

TOTAL SYSTEM TWO-PHASE FLOW -- The total mass flow (lbm or kg) of two-phase, two-component flow through all vents for the current timestep.

VENT ENTRANCE MASS FRACTIONS -- (LIQ., STEAM, AIR) - These are identical to RW, RS, and RA discussed previously for the vertical vent system.

VENT -- Vent level; Level 1 is on top; Level 2 is next lower; and so forth.

GAS AREA -- The single-vent, two-phase flow area as determined by the vent clearing routines, and modified by the input vent blockage factor and the input vent area fraction multiplier (ft^2 or m^2).

MASS FLOW -- The mass (lbm or kg) of two-phase mixture that has flowed during the timestep from the drywell to the wetwell, through the single specified vent.

STATUS -- Indicates whether the flow was choked (sonic) or unchoked.

Various levels of debug editing are available to the user but the symbols are not defined in this appendix. This edit is intended for detailed code examinations.

1.5 Spray System Output

All output is in sentence form and is considered to be self-explanatory. During the particular time step in which a spray system is activated or deactivated, a message is printed identifying the spray system (No. 1 or No. 2), its status (on or off), and the time elapsed since the problem began. As part of the major time step edit, the net heat removal rate from the atmosphere region (of the drywell and wetwell) is printed for active spray systems. This heat removal rate is an indication of the performance of the spray system.

1.6 Annular Fan

Annular fan information is printed only if annular fan modeling is chosen. During input processing, the time on, time off, DPMAX, DPMIN, and the input table of differential pressure as a function of volumetric flow rate will be printed. During the time step, the mass and energy removed from the annular compartment will be printed.

2. PLOTTED OUTPUT

Options are available for obtaining linear plots of pressure and temperature versus time, or semilogarithmic plots of the same variables versus time on a logarithmic axis, or

both types of plots. The user can also specify plots from a Calcomp plotter, from a microfilm plotter, or from both. The user may specify plot scaling for the time, pressure, and temperature axes such that the axes can contain the minimum and maximum values. If the specified value is zero, the minimum or maximum value of the function is used. If the specified value is nonzero and the value does not bound the minimum or maximum value of the function, the minimum or maximum value is used. This feature allows a user to specify plot scales such that plots from different runs have identical scaling. However, the scaling supplied by the user is overridden if the function cannot fit on the graph.

The pressure plot displays drywell vapor region total pressure, and wetwell vapor region total pressure if a wetwell exists in the problem, as a function of time. The drywell pressure is labeled P and the wetwell value is labeled PW. The temperature plot can contain three time-dependent variables. The drywell vapor region temperature is labeled TA, and TB represents the drywell liquid pool temperature if a pool exists. The wetwell vapor region temperature is identified by TW and is plotted if a wetwell exists in the problem.

APPENDIX J

SAMPLE PROBLEM

APPENDIX J

SAMPLE PROBLEM

Attached is a partial output listing of a CONTEMPT-LT sample problem. The problem is for a simplified representation of a horizontal vent (Mark III) containment with one heat structure and both normal and penetration leakage. Figure J-1 is a schematic representation of the sample problem, showing each compartment and interconnections. The initial output is a listing of the input deck exactly as it was entered. Next is a listing of most of the input with explanations of each item. Next the compartment initial steady state results are edited. The time printed each edited timestep is the end-of-timestep data. For the sake of brevity, output only through the first printed page is included here.

Four plots, Figures J-2 through J-5, obtained originally as microfilm plots from the sample problem, are presented. Similar plots may also be obtained from a Calcomp plotter.

The top (first) Mark III vent is starting to clear at 0.92 seconds and is fully clear at 1.01 seconds. Openings of Vents 2 and 3 occur at 1.18 and 1.46 seconds, respectively.

Complete results of the sample problem are provided along with the CONTEMPT-LT program source deck.

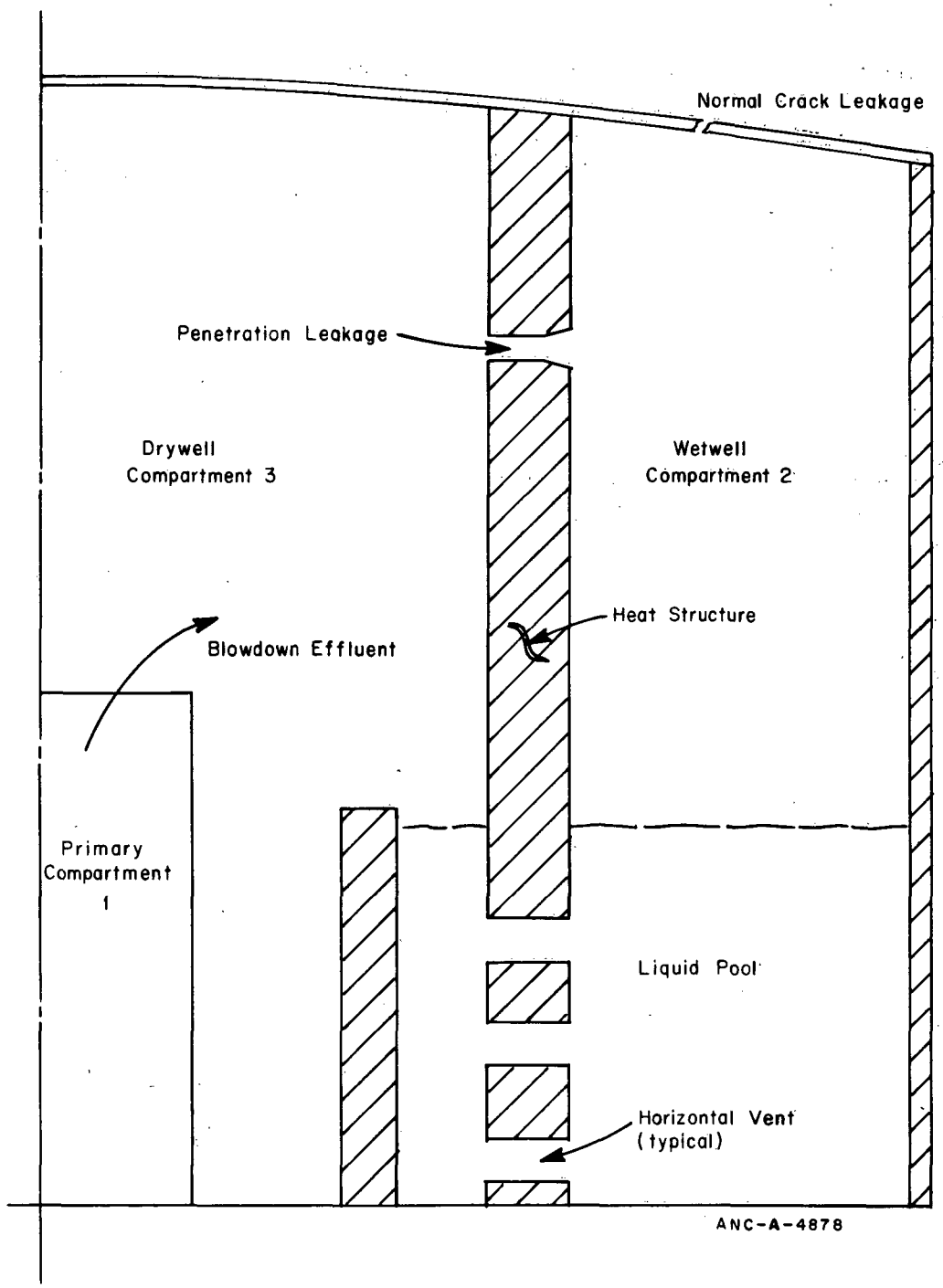

Fig. J-1 Sample Mark III system -- CONTEMPT-LT sample problem representation.

LISTING OF INPUT DATA FOR CASE 1

```
    1   = SAMPLE PROBLEM FOR CONTEMPT-LT USING MARK-III OPTION W/ PLUG OPENING
    2   *     USING LARGE TIMESTEPS IN SAMPLE PROBLEM
    3   *    INCLUDE LEAKAGE AND HEAT STRUCTURE
    4   11001  .01 1  2 80. 14.7 .5 0. 0. 0. 0. 0.  1.0              * GENERAL CONTROL
    5   10011  1+5 .0  500.  500.  2000. 1.0  .0 .0 .0               * PRIMARY SYSTEM
    6   10021  1.4+6  1.568+5  90. 90.  14.7 0.5  7327.10  1.0  1.0 * WETWELL
    7   10031  2.8+5  .0   135.  135.   14.7 0.2  1.0  1.0  1.0     * DRYWELL
    8   9000   SEC
    9   9001  0.81 0.10  5 1  2.00  .05 10 1  4.00 .10  10 1
   10   9002  10.0  0.50 10 1 15. .2 10 1 20. .25 10 1 40. .5 10 1
   11   300    SEC  LBM/SEC  BTU/LBM
   12   301 0.00  13400.     1190.0     0.19       13200.     1190.6
   13   302 0.191 9500.      1190.6     1.99       9200.      1191.5    * STEAM BLOWDOWN
   14   303 2.00  31983.     577.0      3.00       31745.     581.8
   15   304 4.20  31360.     587.1      5.0        27040.     590.1
   16   305   10.0  10000.  600.  20.0  0.0  600.
   17   30201  0 0.1 1.0 10.0 2.0 100.  2.0  * NORMAL LEAKAGE
   18   30300  2 1.0 0.9 1.0 1.0 0.  0.  0.  0.     *  PENETRATION LEAKAGE
   19   101000  'EXAMPLE OF HEAT STRUCTURE BETWEEN DRYWELL AND WETWELL '
   20   101001  5 1 0 60.,1.0,.0,1+4,3,2       * SLAB DESCRIPTION
   21   101101  4  61.
   22   101201  1
   23   101300  0  0.0
   24   101400  2 2 50 4   * OVERRIDE COMPARTMENT TEMP AT STEADY STATE
   25   101410  101.0   *  STEADY STATE VALUE ON RIGHT SIDE
   26   410001  29.   53.
   27   50000  45  10 3 1.0 1.0 0.0 50 .001 30 .005 30 .005          * PLUG CLEARING
   28   50002  5.0   68.0  2.50  21.3333  22.0 21.3333
   29   50101  -1.0
   30   50201  .0  9.83333 2.3333 5.0
   31   50202  1.83333 2.3333  5.0
   32   50203  1.83333 2.3333  5.0
   33   50301 -0.45 15-3 -1.9 15-3
   34   50302  15-3 -1.9 15-3
   35   50303  15-3 -1.9 15-3
   36   50401  4 4 4 4 4 4 4 4 4 4
   37   50501  1 1 1 1
   38   50502  1 1 1
   39   50503  1 1 1
   40   51001  10.33333 6.16667  2.00
   41   51101   2.33333  2.33333  2.33333
   42   51201  3 6 9
   43   51301  4 7 10
   44   51401  .0 .0 .0
   45   51501  2  2  2
   46   51601  -0.25  -0.25  -0.25
   47   51701  1.0  15-3  1.0  1.0  1.0   1.0
   48   51702  1.0  15-3  1.0  1.0  1.0   1.0
   49   51703  1.0  15-3  1.0  1.0  1.0   1.0
   50   10  3 3 SEC  0 0 0 0 0 0     *  PLOT CONTROL
   51   9002  10.0 0.50 10 1      100.  1.0  10  1      * TIMESTEP
        CARD ABOVE IS REPLACEMENT CARD.
   52   .  * END CARD
```

PROBLEM END TIME= 1.0000000D-02 HRS * NO. HEAT STRUCTURES= 1 PRESSURE SUPPRESSION OPT.= 2
OUTSIDE AIR TEMPERATURE = 8.0000000 01 F * PRESSURE = 1.4700000 01 PSIA * HUMIDITY = 5.0000000D-01
CONSTANT TEMP. FOR HEAT SLABS= 0.0 F STEP WATER TO DRY WELL = 0.0 LBM , WITH STEP ENERGY = 0.0 BTU
PRIMARY SYSTEM END-OF-BLOWDOWN WATER CONTENT = 0.0 LBM,WITH ENERGY = 0.0 BTU

SPRAY-ECC HEAT EXCHANGER, NO. 1
TYPE = 0 HEAT TRANSFER AREA = 0.0 OVERALL H.T. COEFF. = 0.0 COOLANT INLET TEMP.= 0.0
INLET MASS FLOW = 0.0
PRESSURE FOR SPRAY ON AND OFF = 0.0 , 0.0

SPRAY-ECC HEAT EXCHANGER, NO. 2
TYPE = 0 HEAT TRANSFER AREA = 0.0 OVERALL H.T. COEFF. = 0.0 COOLANT INLET TEMP.= 0.0
INLET MASS FLOW = 0.0
PRESSURE FOR SPRAY ON AND OFF = 0.0 , 0.0

COMP.= 1 VOL.= 1.0000000D 04 LIQ.VOL= 0.0 VAPOR VOL= 1.0000000D 04 HUMIDITY= 1.0000 TOTAL PRESSURE= 2.0000000 03
VAPOR TEMPERATURE= 5.0000000D 02 LIQ. TEMP.= 5.0000000D 02 SURF. AREA= 0.0
HEAT TRANS. MULT.= 0.0 MASS TRANS. MULT.= 0.0

COMP.= 2 VOL.= 1.4000000D 06 LIQ.VOL= 1.5680000D 05 VAPOR VOL= 1.2432000 06 HUMIDITY= 0.5000 TOTAL PRESSURE= 1.4700000 01
VAPOR TEMPERATURE= 9.0000000D 01 LIQ. TEMP.= 9.0000000D 01 SURF. AREA= 7.3271000 03
HEAT TRANS. MULT.= 1.0000000D 00 MASS TRANS. MULT.= 1.0000000D 00

COMP.= 3 VOL.= 2.8000000D 05 LIQ.VOL= 0.0 VAPOR VOL= 2.8000000D 05 HUMIDITY= 0.2000 TOTAL PRESSURE= 1.4700000 01
VAPOR TEMPERATURE= 1.3500000 02 LIQ. TEMP.= 1.3500000 02 SURF. AREA= 1.0000000D 00
HEAT TRANS. MULT.= 1.0000000D 00 MASS TRANS. MULT.= 1.0000000D 00

LEAKAGE PENETRATION NO. 1 FROM COMPARTMENT 3 TO 2 IS CONSIDERED TO BE A DIVERGING NOZZLE
THROAT AREA = 1.0000000D 00 THROAT/EXIT AREA RATIO = 9.0000000D-01
THROAT/INLET AREA RATIO = 1.0000000D 00 CONSTANT MULTIPLIER = 1.0000000D 00

NORMAL COMPARTMENT LEAKAGE TABLE OF DELTA-PRESSURE AND COEFFICIENT -- FROM COMPARTMENT 2 TO 0

1.0000000D-01	1.0000000D 00	1.0000000D 01	2.0000000D 00
1.0000000D 02	2.0000000D 00		

TABLE OF TIME, POWER DECAY

0.0	0.0	3.6000000D 09	0.0

TABLE OF TIME, METAL-WATER REACTION

0.0	0.0	3.6000000D 09	0.0

TABLE OF TIME(SEC) , WATER ADDITION RATE(LBM/SEC) , AND ENTHALPY(BTU/LBM)

0.0	1.3400000D 04	1.1900000D 03	1.9000000D-01	1.3200000D 04	1.1906000D 03
1.9100000D-01	9.5000000D 03	1.1906000D 03	1.9900000D 00	9.2000000D 03	1.1915000D 03
2.0000000D 00	3.1983000D 04	5.7700000D 02	3.0000000D 00	3.1745000D 04	5.8180000D 02
4.2000000D 00	3.1360000D 04	5.8710000D 02	5.0000000D 00	2.7040000D 04	5.9010000D 02
1.0000000D 01	1.0000000D 04	6.0000000D 02	2.0000000D 01	0.0	6.0000000D 02

PRIMARY VESSEL ENERGY INPUT, TIME, POWER MULT., M-W MULT.

0.0	0.0	0.0	3.6000000D 09	0.0	0.0

TOP REGION DIRECT ADDITION TABLE, TIME, WATER RATE, HEAT RATE

0.0	0.0	0.0	1.0000000D 06	0.0	0.0

LIQUID REGION DIRECT ADDITION TABLE, TIME, WATER RATE, HEAT RATE

0.0	0.0	0.0	1.0000000D 06	0.0	0.0

SUPER HEAT ADDITION TABLE, TIME, POW MULT., M-W MULT., FLOW RATE

0.0	0.0	0.0	0.0
1.0000000D 06	0.0	0.0	0.0

SPRAY-ECC SYSTEM, NO. 1

TIME	FLOW RATE	DR.W.EFF	PCT.DRY	PCT.WET	PCT.ECC	PCT.DWL	INP.DRY	INP.WET	OUT.TEMP.
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0000000D 06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SPRAY-ECC SYSTEM, NO. 2

TIME	FLOW RATE	DR.W.EFF	PCT.DRY	PCT.WET	PCT.ECC	PCT.DWL	INP.DRY	INP.WET	OUT.TEMP.
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0000000D 06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ARBITRARY AIR ADDITION TABLE, TIME, AIR ADDED, TEMP.

0.0	0.0	0.0	3.6000000D 09	0.0	0.0

OUTSIDE AIR CONDITIONS TABLE, TIME, TEMP., HEAT TRANSFER COEF. (24 HR. CYCLE)

0.0	0.0	0.0	2.4000000D 01	0.0	0.0

TABLE OF TIME, TIME STEP (BOTH IN SEC), SLAB PRINT FREQUENCY, AND CONTAINMENT DATA PRINT FREQUENCY

8.1000000D-01	1.0000000D-01	5	1	2.0000000D 00	5.0000000D-02	10	1
4.0000000D 00	1.0000000D-01	10	1	1.0000000D 01	5.0000000D-01	10	1
1.0000000D 02	1.0000000D 00	10	1				

* * * INPUT EDIT FOR MARK-III PRESSURE SUPPRESSION SYSTEM * * *

NUMBER OF AZIMUTHAL SEGMENTS = 45 NUMBER OF VENTS = 3 NUMBER OF FLOW ELEMENTS = 10 VENT BLOCKAGE FACTOR = 1.0000000D 00
LIQUID CARRYOVER FRACTION = 1.0000000D 00 FLOW ELEMENT ITERATION LIMIT = 50 AND CONVERGENCE = 1.0000000D-03
VENT BALANCE ITERATION LIMIT = 30 AND CONVERGENCE = 5.0000000D-03 OUTER ITERATION LIMIT = 30 AND CONVERGENCE = 5.0000000D-03
VENT CLEARING AREA FACTOR = 0.0

HORIZONTAL VENT LENGTH (FT)= 5.0000000D 00 ANNULUS INSIDE DIAMETER (FT)= 6.8000000D 01 AND ANNULUS WIDTH (FT)= 2.5000000D 00

ANNULUS INITIAL WATER HEIGHT (FT)= 2.1333300D 01 WEIR WALL HEIGHT (FT)= 2.2000000D 01 WET WELL INIT. WATER HT(FT)= 2.1333300D 01

TABLE OF FLOW ELEMENT NUMBER AND LOSS COEFFICIENT MULTIPLIER..

1	1.0000000D 00	2	1.0000000D 00	3	1.0000000D 00	4	1.0000000D 00	5	1.0000000D 00
6	1.0000000D 00	7	1.0000000D 00	8	1.0000000D 00	9	1.0000000D 00	10	1.0000000D 00

TABLE OF FLOW ELEMENT NUMBER AND LENGTH (FT) OF FLOW PATH

1	0.0	2	9.8333300D 00	3	2.3333000D 00	4	5.0000000D 00	5	1.8333300D 00
6	2.3333000D 00	7	5.0000000D 00	8	1.8333300D 00	9	2.3333000D 00	10	5.0000000D 00

TABLE OF FLOW ELEMENT NUMBER AND LOSS COEFFICIENT

1	-4.5000000D-01	2	1.5000000D-04	3	-1.9000000D 00	4	1.5000000D-04	5	1.5000000D-04
6	-1.9000000D 00	7	1.5000000D-04	8	1.5000000D-04	9	-1.9000000D 00	10	1.5000000D-04

TABLE OF FLOW ELEMENT NUMBER FOLLOWED BY OPTION ON BASE MODEL FOR 2-PHASE LOSS COEFFICIENTS

1	4	2	4	3	4	4	4	5	4	6	4	7	4	8	4
9	4	10	4												

TABLE OF FLOW ELEMENT NUMBER AND NUMBER OF REQUESTED SUBDIVISIONS -(ONLY TYPE 2 ELEMENTS WILL BE SUBDIVIDED)

1	1	2	1	3	1	4	1	5	1	6	1	7	1	8	1
9	1	10	1												

TABLE OF VENT NUMBER AND VENT CENTERLINE ELEVATIONS (FT)

1 1.033333D 01 2 6.166670D 00 3 2.000000D 00

TABLE OF VENT NUMBER AND VENT INSIDE DIAMETER (FT)
1 2.333330D 00 2 2.333330D 00 3 2.333330D 00

TABLE OF VENT NUMBER AND ASSOCIATED BRANCH ELEMENT NUMBER
1 3 2 6 3 9

TABLE OF VENT NUMBER AND END-OF-VENT FLOW ELEMENT NUMBER
1 4 2 7 3 10

TABLE OF VENT NUMBER AND CORNER RADIUS (FT) OF BRANCH ELEMENTS
1 0.0 2 0.0 3 0.0

TABLE OF VENT NUMBER AND OPTION ON BRANCH ELEMENT BYPASS LOSS COEFFICIENT
1 2 2 2 3 2

TABLE OF VENT NUMBER AND BRANCH ELEMENT BYPASS ENERGY LOSS COEFFICIENT
1 -2.5000000-01 2 -2.5000000-01 3 -2.5000000-01

VENT CLEARING LOSS COEFFICIENTS AND MOMENTUM FLUX MULTIPLIER

VENT	MOMENT. FLUX MULT	VENT ROUGHNESS(FT)	ENTRANCE ELBOW LOSS	EXIT ELBOW LOSS	CONTRACTION	EXPANSION
1	1.0000000D 00	1.5000000-04	1.0000000D 00	1.0000000D 00	1.0000000D 00	1.0000000D 00
2	1.0000000D 00	1.5000000-04	1.0000000D 00	1.0000000D 00	1.0000000D 00	1.0000000D 00
3	1.0000000D 00	1.5000000-04	1.0000000D 00	1.0000000D 00	1.0000000D 00	1.0000000D 00

HEAT STRUCTURE NO. 1 TRANSFER BETWEEN FOLLOWING COMPARTMENTS : LEFT = 3 RIGHT = 2
EXAMPLE OF HEAT STRUCTURE BETWEEN DRYWELL AND WETWELL

5 MESH POINTS 1 REGIONS RECTANGULAR GEOMETRY SOURCE FACTOR = 1.0000000D 00 SURFACE FACTOR = 1.0000000D 03
DELAY = 0.0

MESH POINT COORDINATES (* INDICATES REGION BOUNDARY)
6.0000000D 01 6.0250000D 01 6.0500000D 01 6.0750000D 01 6.1000000D 01*

COMPOSITION OVERLAY
1

SOURCE SPATIAL DEPENDENCE
0.0 0.0 0.0 0.0
INTEGRATED SPACIAL DEPENDENCE = 0.0

BOUNDARY CONDITION CONTROL OPTIONS = 2, 2,50, 4

THE INITIAL RIGHT SIDE BULK TEMPERATURE = 101.000

TABLES COMMON TO ALL HEAT SLABS

THERMAL CONDUCTIVITY AND VOLUMETRIC HEAT CAPACITY TABLE

COMPOSITION NO.,	THERMAL CONDUCTIVITY,	HEAT CAPACITY
1	2.9000000 01	5.3000000 01

```
CONTEMPT-LT/025,PV,06/30/75,AEROJET NUCLEAR CO. CONTAINMENT SYSTEM PRESSURE-TEMPERATURE HISTORY PROGRAM-DOUBLE PRECISION   PAGE 0008
  SAMPLE PROBLEM FOR CONTEMPT-LT USING MARK-III OPTION W/ PLUG OPENING                    06/03/75

 THE FOLLOWING DEFINITIONS WILL BE USED AT TIMES FOR COMPARTMENT IDENTIFICATION
  0 = OUTSIDE ATMOSPHERE
  1 = PRIMARY SYSTEM
  2 = WET WELL
  3 = DRY WELL
  4 = ANNULAR COMPARTMENT

HEAT STRUCTURE  1 EXAMPLE OF HEAT STRUCTURE BETWEEN DRYWELL AND WETWELL                          BETWEEN COMPARTMENTS  3 AND  2
TO LEFT COMP.  END STEP BTU/HR     STEP BTU  TOTAL NET BTU *** TO RIGHT COMP.   END STEP BTU/HR     STEP BTU  TOTAL NET BTU
    3 VAPOR      -2.024146D 04  0.0           0.0                  2 VAPOR      2.024146D 04  0.0           0.0
LEFT  FILM COEF.,H =  3.036837D 00 BTU/HR.FT2.F * FIRST MESH K =  2.900000D 01 BTU/HR.FT.F * BULK TEMP =  1.350000D 02 F
RIGHT FILM COEF.,H =  7.599086D-01 BTU/HR.FT2.F *  LAST MESH K =  2.900000D 01 BTU/HR.FT.F * BULK TEMP =  1.010000D 02 F
MESH POINT TEMPERATURES (F), LEFT TO RIGHT
  1.283347D 02  1.281602D 02  1.279857D 02  1.278112D 02  1.276367D 02


CONTEMPT-LT/025,PV,06/30/75,AEROJET NUCLEAR CO. CONTAINMENT SYSTEM PRESSURE-TEMPERATURE HISTORY PROGRAM-DOUBLE PRECISION   PAGE 0009
  SAMPLE PROBLEM FOR CONTEMPT-LT USING MARK-III OPTION W/ PLUG OPENING                    06/03/75

 * * * * * * * * * * * * * * * * TIME =  0.0          HR =  0.0          MIN =  0.0          SEC * * * * * * * * * * * * * * * *

COMP      P R E S S U R E  (PSIA)    T E M P E R A T U R E  (F)          E  N  E  R  G  Y    (BTU)                          CONVERGENCE
 NO.       TOTAL          STEAM          ATMOS          POOL          ATMOS          POOL          TOTAL                    DE/E
  1     2.000000D 03   0.0            5.000000D 02   5.000000D 02   0.0            0.0            0.0                     0.0
  2     1.470000D 01   3.49063D-01    9.000000D 01   9.000000D 01   9.626200D 06   5.650770D 08   5.747030D 08            0.0
  3     1.470000D 01   5.07493D-01    1.350000D 02   1.350000D 02   2.261520D 06   0.0            2.261520D 06            0.0
                                                                                                  TRANSFER COEFFICIENTS
         AIR MASS              W  A  T  E  R      M  A  S  S     ( LBM)          HUMIDITY     CONDENSATION     MASS          HEAT
          ( LBM)          VAPOR--ATMOS--LIQUID       POOL          TOTAL                        (LB/S)      (LB MOL/S FT2)(BTU/S FT2 R)
  1     0.0            0.0            0.0            0.0            0.0            1.000000D 00   0.0             0.0           0.0
  2     8.773410 04    1.32785D 03    0.0            9.740040 06    9.741370 06    5.000000-01    0.0             0.0           0.0
  3     1.806300 04    4.03047D 02    0.0            0.0            4.030470 02    2.000000-01    0.0             0.0           0.0
COMPARTMENT   2 LEAKRATE=  0.0          LBM/HR *ENERGY GAIN(BTU)=  0.0          (NORMAL=  0.0          PENETRATION=  0.0          )
STEP AND NET LOSSES(LBM): STEP STEAM=  0.0          STEP AIR=  0.0          NET STEAM=  0.0          NET AIR=  0.0
COMPARTMENT   3 LEAKRATE=  0.0          LBM/HR *ENERGY GAIN(BTU)=  0.0          (NORMAL=  0.0          PENETRATION=  0.0          )
STEP AND NET LOSSES(LBM): STEP STEAM=  0.0          STEP AIR=  0.0          NET STEAM=  0.0          NET AIR=  0.0


 * * * * * * * * * * * * * * * * TIME =  2.777778D-05 HR =  1.666667D-03 MIN =  1.000000D-01 SEC * * * * * * * * * * * * * * * *
   0 VENTS CLEAR *  ANN. WATER ELEV=  2.133330D 01(FT) LIQ.MASS FLOW LBM TO COMP 2=  0.0          TO COMP 3=  0.0
     VENT CLEARING LENGTHS (FT) ARE   0.0            0.0            0.0

COMP      P R E S S U R E  (PSIA)    T E M P E R A T U R E  (F)          E  N  E  R  G  Y    (BTU)                          CONVERGENCE
 NO.       TOTAL          STEAM          ATMOS          POOL          ATMOS          POOL          TOTAL                    DE/E
  1     2.000000D 03   0.0            5.000000D 02   5.000000D 02   0.0            0.0            0.0                     0.0
  2     1.470040 01    3.49379D-01    8.999320 01    9.000000 01    9.626690 06    5.650770 08    5.747040 08             3.33957D-05
  3     1.773310 01    2.37173D 00    1.840410 02    1.324680 02    3.849570 06    1.046540 00    3.849570 06            -1.29132D-04
                                                                                                  TRANSFER COEFFICIENTS
         AIR MASS              W  A  T  E  R      M  A  S  S     ( LBM)          HUMIDITY     CONDENSATION     MASS          HEAT
          ( LBM)          VAPOR--ATMOS--LIQUID       POOL          TOTAL                        (LB/S)      (LB MOL/S FT2)(BTU/S FT2 R)
  1     0.0            0.0            0.0            0.0            0.0            1.000000D 00   0.0             0.0           0.0
  2     8.773590 04    1.32803D 03    0.0            9.740040 06    9.741370 06    5.001670-01   -6.028830-04     1.876920-07   6.312910-07
  3     1.806120 04    1.73760D 03    0.0            1.042210-02    1.737610 03    2.867590-01    0.0             0.0           0.0
COMPARTMENT   2 LEAKRATE=  1.016657D 03 LBM/HR *ENERGY GAIN(BTU)= -4.123650D 00 (NORMAL= -4.123650D 00 PENETRATION=  0.0          )
STEP AND NET LOSSES(LBM): STEP STEAM=  4.210927D-04 STEP AIR=  2.781938D-02 NET STEAM=  0.0          NET AIR= -3.010218D-03
COMPARTMENT   3 LEAKRATE=  1.450012D 05 LBM/HR *ENERGY GAIN(BTU)= -9.698964D 02 (NORMAL=  0.0          PENETRATION= -9.698964D 02)
STEP AND NET LOSSES(LBM): STEP STEAM=  3.534922D-01 STEP AIR=  3.674319D 00 NET STEAM=  1.769906D-01 NET AIR=  1.839690D 00
```

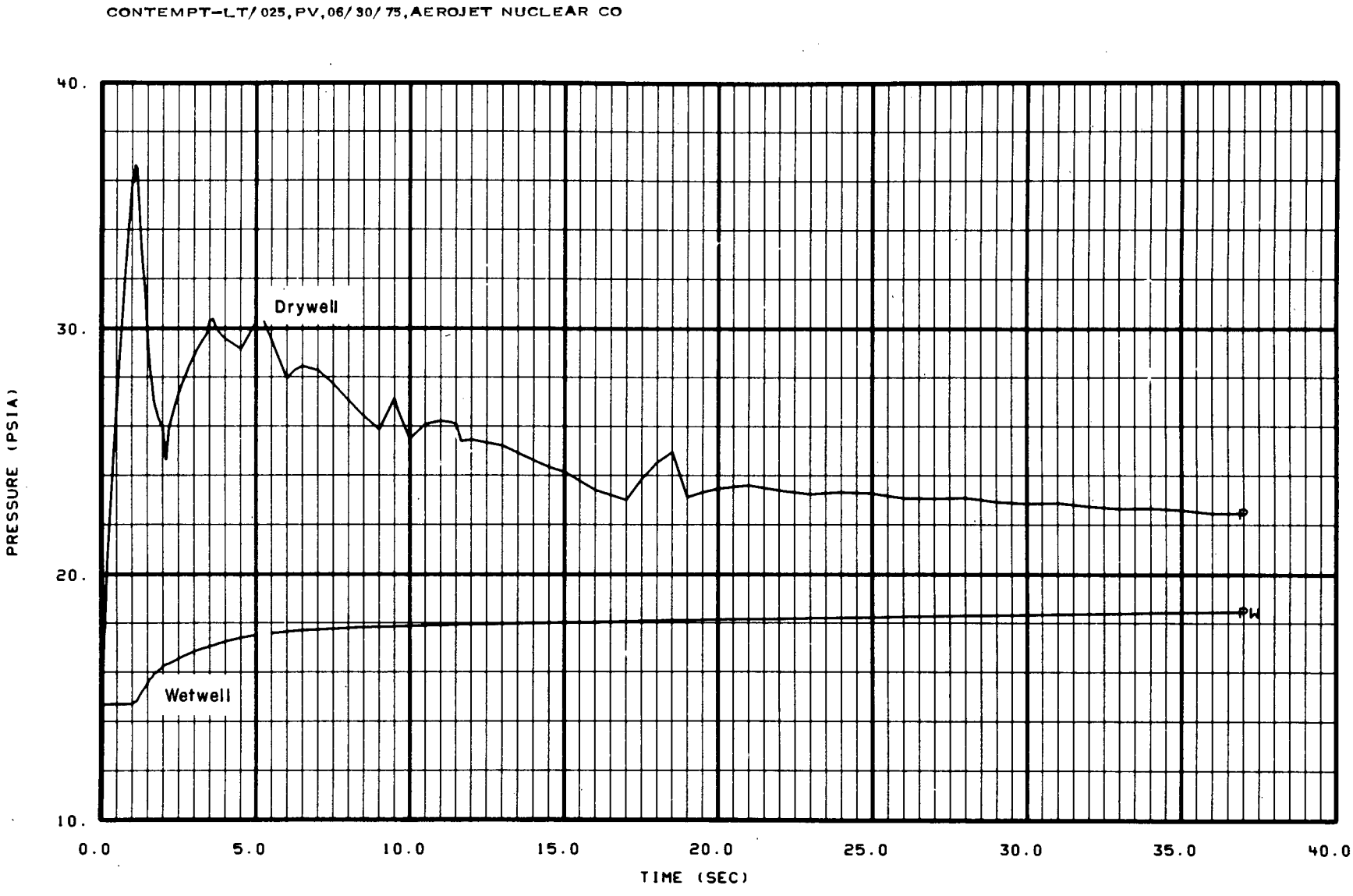

Fig. J-2 CONTEMPT-LT sample problem -- pressure versus time.

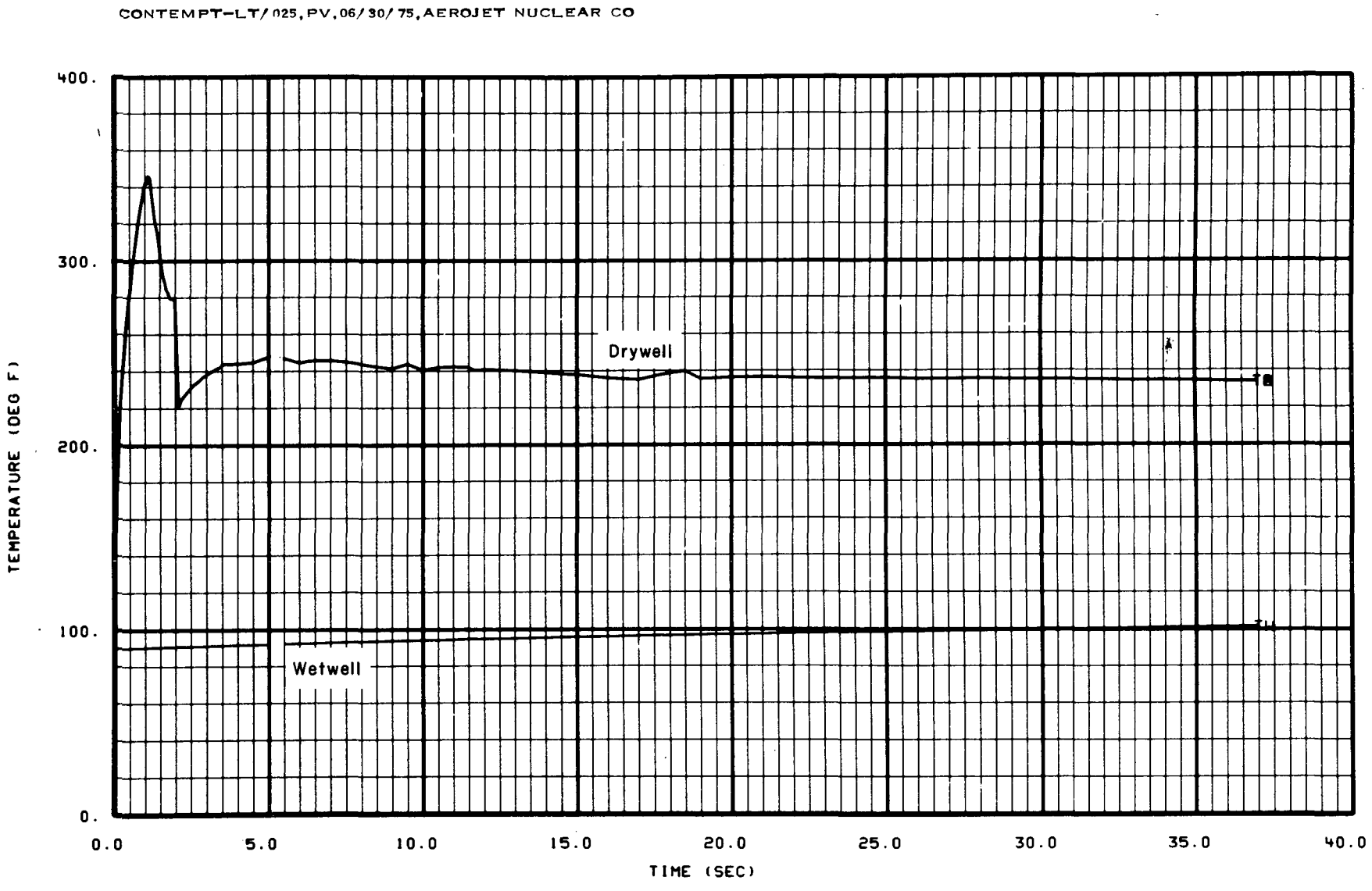

Fig. J-3 CONTEMPT-LT sample problem -- temperature versus time.

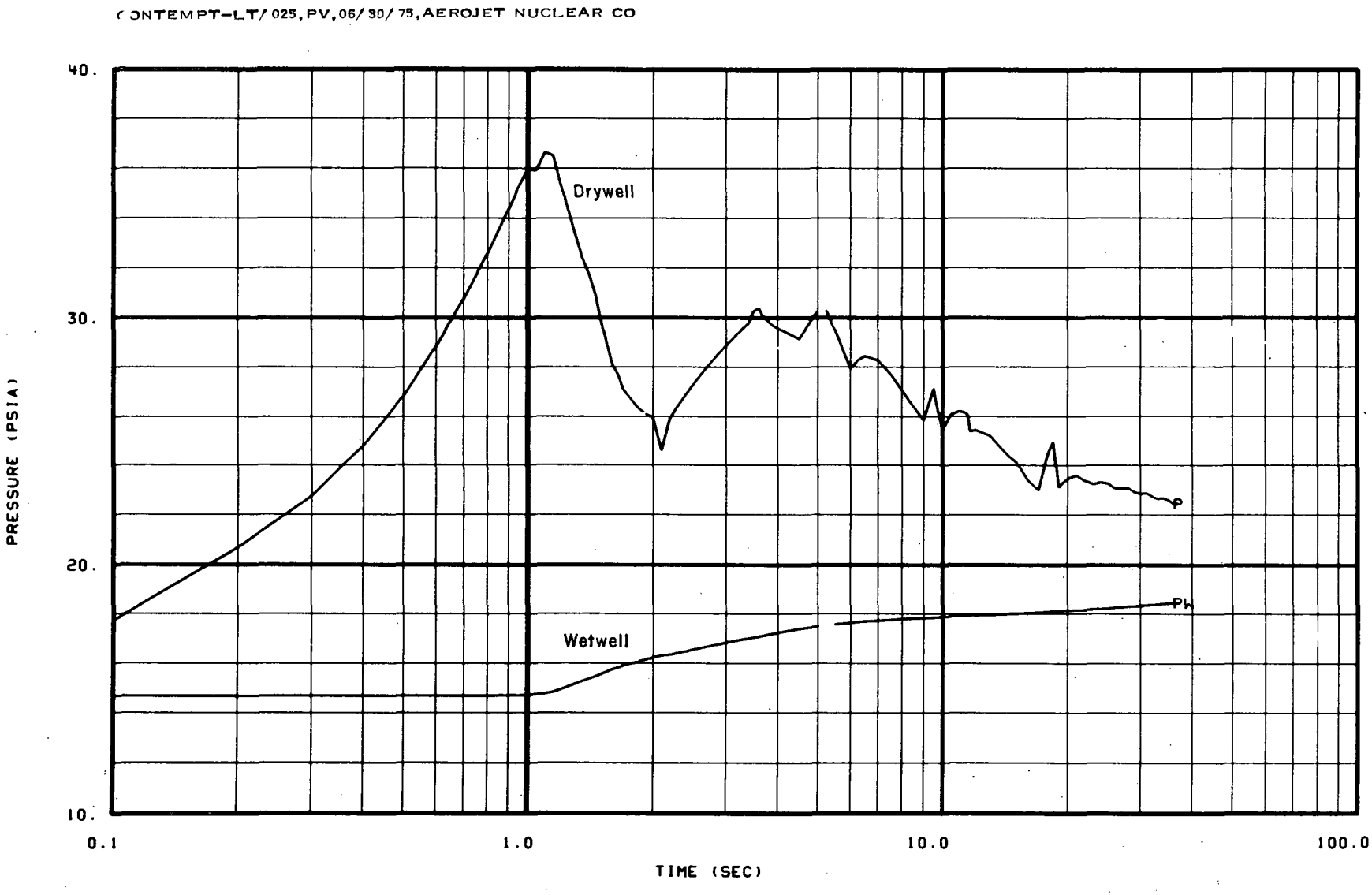

Fig. J-4 CONTEMPT-LT sample problem -- pressure versus time (semilogarithm plot).

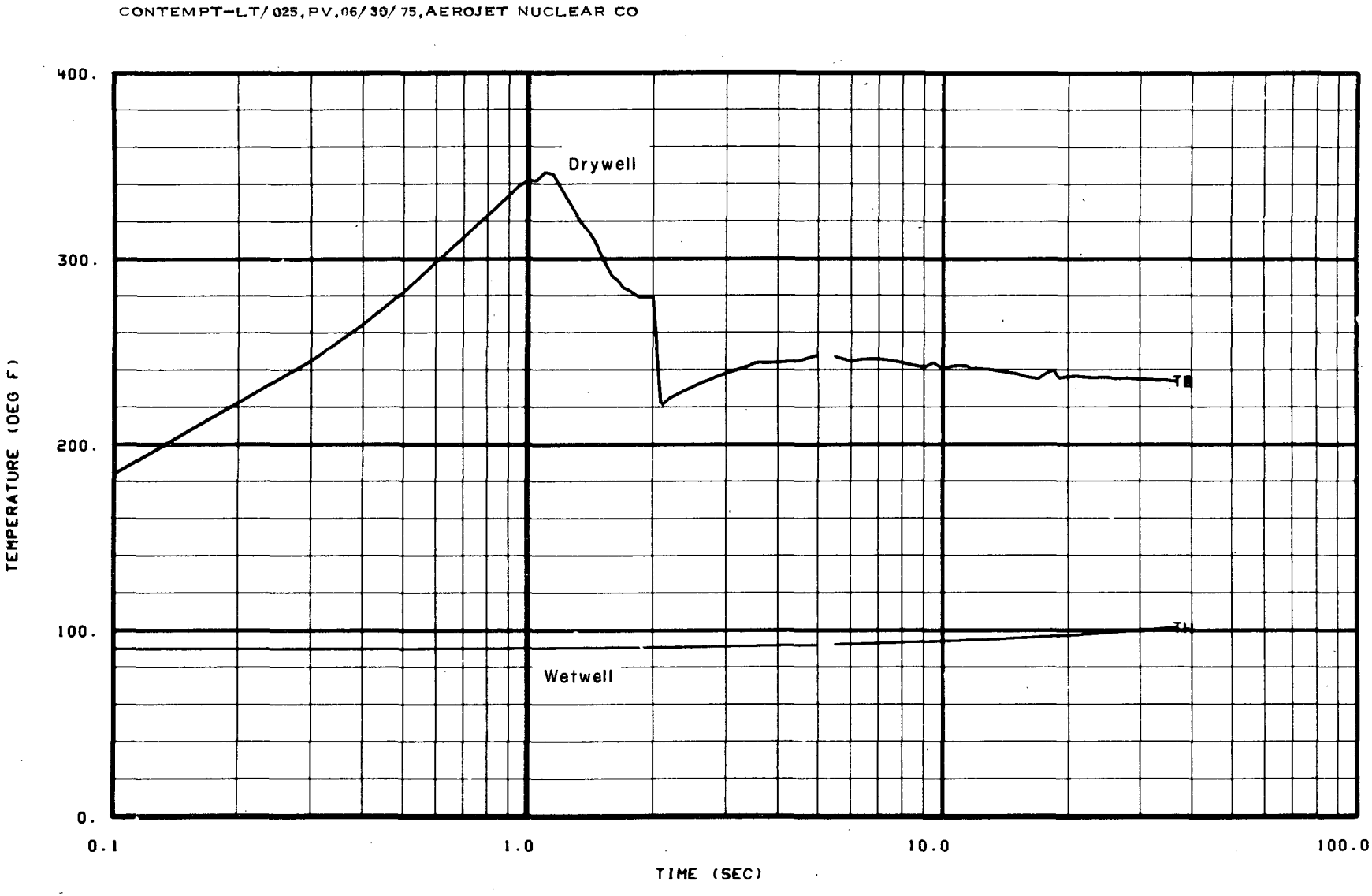

Fig. J-5 CONTEMPT-LT sample problem -- temperature versus time (semilogarithm plot).

APPENDIX K

DESCRIPTION OF NEW MODELS USED IN VERSION 028

APPENDIX K

DESCRIPTION OF NEW MODELS USED IN VERSION 028

1. MODEL DESCRIPTIONS

Several modifications and additions to the previous version of the CONTEMPT-LT computer code[K-1] have been included in this latest version designated CONTEMPT-LT/028.

The sample problems in this Appendix can be duplicated using the version of CONTEMPT-LT/028 retained at EG&G Idaho, Inc. under configuration control number 1111111.

Three new models were added to the CONTEMPT-LT/026 code. (a) A drywell pressure flash model was added which enables the program to calculate drywell thermodynamic conditions without assuming that the blowdown fluid reaches thermal equilibrium with the drywell atmosphere. This option normally results in lower pressures than the temperature flash (thermal-equilibrium) method previously available to calculate compartment thermodynamic conditions and is therefore recommended for the calculation of containment conditions used for ECCS analyses. (b) A forced-convection condensing-steam (Tagami) heat transfer correlation was added to the code as an option to be used for determining heat structure thermal behavior during the turbulent blowdown period. (c) An annular fan model also has been added to allow simulation of a PWR dual containment system which includes mass/energy transfer between the annular region and the outside air. This model can be used to determine the net volumetric release from the annular region to the atmosphere.

Modifications of the existing CONTEMPT-LT coding consisted of the following:

(1) The time step editing capability was expanded to include a more detailed description of spray conditions

(2) Changes to generalize the heat structure boundary conditions were made including an increase in the number of heat transfer coefficient options which allow condensing steam (wall) heat transfer

(3) A condensate dial was added which regulates the rate of wall condensation

(4) An option switch was added which stops program execution whenever a user-specified maximum pressure value has been exceeded

(5) Minor errors in the coding of the pool evaporation-condensation model were corrected.

Input changes needed to select the Version 028 modifications are presented in the following subsections, together with representative problem results obtained from testing the Version 028 changes.

1.1 Analytical Drywell Pressure Flash Model

At any time during a loss-of-coolant accident (LOCA), the postulated thermodynamic state of the liquid and vapor phases in the drywell is dependent on the assumptions made regarding the separation and distribution of mass and energy resulting from the blowdown of the reactor system. Previous versions of CONTEMPT-LT have used a thermal-equilibrium model (temperature flash) to determine the thermodynamic conditions of the gaseous region of a compartment. As a user option, a pressure flash model, which has different thermodynamic conditions than the temperature flash method, has been included in Version 028 for use with the drywell compartment model. The pressure flash method generally calculates lower drywell total pressures, and, consequently, is useful in determining back pressures for ECCS analyses. The temperature flash method and then the pressure flash method are described below.

In the temperature flash model it is assumed that the incremental mass and energy from the blowdown of the primary system enters the drywell and is uniformly and instantaneously mixed throughout the vapor region. During a given time step, the blowdown fluid actually enters the containment at very high velocities and tends to break up in small droplets. This dispersion allows for intimate contact between the blowdown mass and the drywell atmosphere, leading to the fundamental assumption of the temperature flash method: the air-steam mixture is forced into thermal equilibrium with the blowdown mass (water droplets) which is entrained in the atmosphere.

The pressure flash model is similar to the temperature flash method, but differs in the final thermodynamic states of the vapor and liquid regions at the end of the time step. The same processes apply, but the liquid droplets (or condensate) at the end of the time step are assumed to enter the liquid region at a temperature which corresponds to the total vapor-region pressure rather than the steam partial pressure. This process is analogous to the boiling of liquid blowdown mass entrained in the atmosphere based on the total drywell pressure.

The pressure flash model in CONTEMPT-LT determines the amount of blowdown liquid which flashes against the total compartment pressure by using the drywell thermodynamic conditions and the blowdown mass and energy addition rates as input on the 3XX cards. Since the thermodynamic state of the blowdown fluid is needed for a precise flashing calculation and the actual fluid state cannot always be determined using the present CONTEMPT-LT input data alone, it is necessary to make several simplifying assumptions. The only other alternative calculation method which would allow the fluid state to be determined, would be to require the program user to provide additional input data, such as the source system pressure or fluid quality, data which are not required for the temperature flash method and which may not be available to all users.

The thermodynamic conditions calculated by the pressure flash method can be varied by treating the drywell and blowdown fluid energies either as internal energies or as enthalpies. The form of the pressure flash method which yields the lowest drywell total pressure is that which treats the energies encountered in the pressure flash calculation as enthalpies. The lowest calculated drywell back pressure is useful in performing conservative analyses of ECCS performance.

The fluid state of the blowdown fluid must be determined before the pressure flash calculation begins. If blowdown fluid enters the drywell with a fluid enthalpy, h_{in}, which is less than the drywell specific enthalpy of saturated liquid based on total pressure, h_f, it is assumed the fluid drops directly to the pool region without flashing. Similarly, blowdown fluid which enters the drywell with a fluid enthalpy greater than the drywell specific enthalpy of saturated vapor based on total pressure, h_g, is assumed to flash entirely with no blowdown fluid entering the pool.

Blowdown fluid which enters the drywell with an intermediate enthalpy ($h_f < h_{in} < h_g$) is assumed to be composed entirely of liquid water. This assumption allows more flashing to occur than would occur if the vapor component of the blowdown fluid were known and isolated from the flashing calculation since the incoming vapor would increase the drywell pressure and the amount of liquid which would flash based on the total pressure. The mass of blowdown liquid with an intermediate enthalpy which flashes against the total drywell pressure is

$$M_{flash} = \frac{M_{in}\,[h_{in} - h_f]}{h_g - h_f} \qquad \text{(K-1)}$$

where

M_{flash} = mass of blowdown liquid which flashes

M_{in} = mass of blowdown fluid which enters the drywell

h_{in} = specific enthalpy of blowdown fluid which enters the drywell

h_f = specific enthalpy of fluid

h_g = specific enthalpy of vapor.

The atmosphere region inventories are then updated to reflect the vapor mass, M_{flash}, added with specific enthalpy h_g. Any unflashed liquid, ($M_{in} - M_{flash}$), is transferred to the pool region with specific enthalpy h_f. The atmosphere region is brought into thermal equilibrium using the temperature flash method and the pool region conditions are determined from a steam table search based on pool specific energy.

When the BWR models are selected, the pressure flash option will drop the unflashed blowdown liquid component to the pool even if the user selects the input option which allows no dropout.

The actual physical process would allow condensate (the liquid droplets which remained in the atmosphere after the compartment thermodynamic conditions are reached, and which subsequently deentrained to the pool) to enter the liquid region at a temperature between the temperatures predicted by the two methods. The pressure flash method postulates more mass and energy transfer to the pool region and usually calculates lower drywell pressures than the temperature flash method. The pressure flash method is recommended for calculating containment conditions which are in turn used for ECCS boundary conditions.

1.2 Tagami Heat Transfer Correlation Analytical Model

Heat transfer in a containment building following a loss-of-coolant accident can be divided into two time periods. The first is a transient period that occurs during blowdown of the primary coolant when condensation on the structures is characterized by forced convection in the containment atmosphere. A natural convection period follows in which condensation on the structures is not influenced by turbulent decompression of the primary coolant system. Uchida has shown that the heat transfer coefficient during the natural convection period depends on the weight ratio of air to steam in the containment[K-2]; these results are available as an option in CONTEMPT-LT.

Experiments have shown that during the transient or forced convection period, the heat transfer to vertical surfaces increases with time after a LOCA until a maximum coefficient is reached slightly before or near the end of blowdown. The heat transfer gradually decreases from this maximum and presumably approaches that of the natural convection heat transfer model. Tagami was able to correlate these experimental data for the maximum heat transfer coefficient on steel surfaces. The empirical correlation shows that the maximum heat transfer coefficient depends on the total energy released from the primary coolant system during the decompression per unit volume of the containment building, and also depends on the time required for decompression[K-3]. This heat transfer correlation can be expressed as

$$h_{max} = C\left(\frac{Q}{Vt_p}\right)^{0.62} \qquad \text{(K-2)}$$

where

h_{max} = the maximum heat transfer coefficient during blowdown ($W/m^3\text{-}^oK$)

C = a constant equal to 0.607 for SI units

Q = the total energy released from the primary system during blowdown (J)

V = the free volume of the adjacent compartment (m^3)

t_p = the time interval from the initiation of the break until the first peak pressure caused by blowdown (sec).

The Tagami heat transfer correlation, Equation (K-2), has been incorporated into CONTEMPT-LT as one of the Version 028 modifications to better describe the containment heat transfer during the forced convection portion of the blowdown.

It is significant how long and when the Tagami correlation is applicable. The time interval from the beginning of blowdown until the initial (but not necessarily the maximum) peak pressure caused by the blowdown, t_p, must be input by the user if the Tagami correlation is selected. This time interval is used to calculate the energy released by the primary system from the time of rupture until the time peak pressure occurs. The heat transfer coefficient is increased linearly to its maximum value depending on the actual problem time, t, using

$$h = h_{max} \frac{t}{t_p} . \qquad \text{(K-3)}$$

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.

1.3 Annular Fan Analytical Model

The annular fan model describes the performance of a containment fan transferring mass and energy between the vapor regions of the annular (or dual) compartment and the outside compartment. The volumetric flow rate (Q) is defined as positive for flow from the annular compartment to the outside compartment. The fan model determines the mass and energy transfer rates between the two compartments. The defining equations are

$$\dot{m}_{out} = Q\rho \qquad \text{(K-4)}$$

$$\dot{m}_{ann} = -Q\rho \qquad \text{(K-5)}$$

$$\dot{q}_{out} = Qh\rho \qquad \text{(K-6)}$$

$$\dot{q}_{ann} = -Qh\rho \qquad \text{(K-7)}$$

$$\rho = \rho_a + \rho_v + \rho_f \qquad \text{(K-8)}$$

$$h = \frac{h_a\rho_a + h_v\rho_v + h_f\rho_f}{\rho} \qquad \text{(K-9)}$$

where

Q	=	volumetric flow rate
$\dot{m}_{out}$	=	mass flow rate to outside
$\dot{m}_{ann}$	=	mass flow rate to annular compartment
$\dot{q}_{out}$	=	energy transfer rate to outside
$\dot{q}_{ann}$	=	energy transfer rate to annular compartment
ρ	=	average atmosphere region density
h	=	average atmosphere region specific enthalpy
a	=	subscript for air
v	=	subscript for vapor
f	=	subscript for fluid.

The user defines the volumetric flow rate Q as a function of the differential pressure between the compartments as an input table. A positive Δp is defined when the atmospheric pressure is larger than the annular pressure. This table defines the fan characteristics and should span the range of differential pressures encountered in the problem.

Control of the fan is user specified by defining on (t_{on}) and off (t_{off}) times for the fan and by defining a Δp_{max} and a Δp_{min} where

$$\Delta p \triangleq p_{out} - p_{ann} \qquad \text{(K-10)}$$

when Δp is greater than Δp_{max} the fan will turn off and will remain off until Δp is less than Δp_{min}. When Δp is less than Δp_{min}, the fan will turn on and will remain on until Δp is greater than Δp_{max}. The fan will be on for negative differential pressures when the annular pressure is greater than the outside compartment pressure. For times less than t_{on} the fan will be off and no pressure checking is done. Similarly, for times greater than t_{off}, the fan will be off the entire time. For times between t_{on} and t_{off}, the differential pressures will determine fan operation.

1.4 Heat Structure Modifications

Three major heat structure modifications were made to CONTEMPT-LT. These three changes are discussed below.

The first heat structure modification in CONTEMPT-LT entailed expanding the condensing steam calculation to include several other heat transfer coefficient option types. The heat structure coding in CONTEMPT-LT contains logic which calculates condensation of steam on heat structures. This condensing steam model is activated only when several conditions have been met. These conditions include:

(1) A heat structure must be present.

(2) The bulk temperature must be based on the vapor region temperature.

(3) The heat structure (wall) temperature must be less than the saturation temperature and the vapor region must be superheated. When the vapor region is saturated, the heat structure condensing steam model is not used because an implicit condensation calculation is performed by subroutine COMPU which determines saturated vapor region properties.

(4) Water vapor must be present.

(5) A heat transfer coefficient option must be chosen which, in fact, allows wall condensation.

(6) The bulk temperature must be based on the vapor region temperature.

Wall condensate immediately enters the liquid region of a compartment at the saturation temperature based on the compartment water vapor partial pressure.

In previous versions of CONTEMPT-LT, only the Uchida option allowed wall condensation. Version 028 permits wall condensation to be included in the heat structure calculations for the following heat transfer coefficient options: 2, ±5, 7-15, and 53 (numbers refer to Words 1 and 3 on Boundary Condition Card 1YY400).

A second modification to the heat structure logic in CONTEMPT-LT affects the determination of bulk temperature for cases where the user specifies the bulk temperature as equal to the vapor temperature for options 2, ±5, 7-15, and 53. The code will set $T_{bulk} = T_{sat}$ unless a change of heat transfer coefficient option has occurred as specified in modification three as explained below. This modification overrides the bulk temperature option chosen by the user so that the bulk temperature always equals the vapor region temperature.

A third heat structure modification requires a coefficient for heat transfer coefficient options 2, ±5, 7-15, and 53 based on a turbulent natural convection correlation (Option 50) will be used whenever either (a) the heat structure (wall) temperature is greater than the vapor region temperature, or (b) the heat structure (wall) temperature is greater than the saturation temperature and less than the vapor region temperature. If the heat structure

(wall) temperature is less than both the saturation temperature and the vapor region temperature, then the maximum is used of either

$$q = h_u A(T_v - T_{wall}) \quad \text{(K-11)}$$

or

$$q = h_N A(T_{sat} - T_{wall}) \quad \text{(K-12)}$$

where

h_u = 11.4 J/(sec-m^2-^{o}K) (the lower bound for the Uchida option)

h_N = user-chosen heat transfer coefficient.

For user convenience in selecting proper heat transfer boundary conditions, Table K-I summarizes the principal features of the heat transfer coefficient options.

1.5 Maximum Pressure Stop Switch

In some instances the user may wish to stop program execution if the total pressure computed in any compartment except the primary system exceeds a predetermined value. The excessive compartment pressure may be the result of an input error, in which case it would be economically desirable to stop the problem. As an option, the user may input a maximum value of compartment pressure; compartment pressures will then be checked, and problem execution stopped if the preset value is exceeded. This option normally allows the user to obtain plotted data, that is, problem termination due to the maximum pressure stop switch is treated by the program as a normal termination.

1.6 Spray Edits

The major edit capability of CONTEMPT-LT which prints out applicable problem variables and thermodynamic conditions at user controlled intervals, has been expanded to include a statement of the energy removal rate from the drywell atmosphere region and the wetwell atmosphere region for each spray system. These energy removal rates indicate the relative performance of the containment spray systems. In addition, messages will be printed whenever a spray system is activated or deactivated.

1.7 Condensate Dial

The heat structure and fan cooler models in CONTEMPT-LT are capable of calculating the amount of condensate formed on heat conducting structures and fan cooler coils during superheated conditions in a compartment. A dial (ranging from 0 to 100%) has been added to the condensate calculation so that the user can specify the fraction of condensed

TABLE K-I

SUMMARY OF HEAT TRANSFER COEFFICIENT OPTIONS FOR HEAT CONDUCTING STRUCTURES[a]

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 J/(sec-m^2-^oK)	No	No
1	HTC from outside air table	No	No
2	Uchida correlation	Yes	Yes
3	HTC = 2.3 J/(sec-m^2-^oK)	No	No
4	HTC = 57 000 J/(sec-m^2-^oK)	No	No
±5	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	Tubulent natural convection correlation	No	No
51	Direct radiation correlation	No	No
52	Option 50 plus Option 51	No	No
53	Tagami correlation	Yes	[d]

[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.

TABLE K-I (continued)

[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

$$T_{wall} > T_{sat} + 1 \text{ K},$$

$$T_{wall} > T_{v},$$

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 the boundary conditions card, Card 1YY400). 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 J/(sec-m^2-^{o}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, then the vapor temperature will be used.

TABLE K-I (continued)

[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.

superheated steam which forms on surfaces and be transferred to the pool region. Thus, the sensitivity of condensation processes in a given containment calculation can be determined using the condensate dial.

The modifications to both the fan cooler and the heat structure models were the same. The equation used to determine the amount of condensate transferred from the atmosphere to the pool was revised to include a factor representing the amount of condensate formed.

$$\dot{m} = \frac{f q_u}{(h_v - h_\ell)} \tag{K-13}$$

where

$\dot{m}$ = rate of mass transfer of condensate from vapor region to pool region

q_u = heat transfer rate used to calculate condensate dropout rate

h_v = specific enthalpy of vapor in vapor region

h_ℓ = specific enthalpy of liquid in vapor region

f = fraction of condensate which forms on walls or cooling coils which is actually dropped into the pool region.

1.8 Pool Evaporation/Condensation Model Corrections

Three coding corrections were made to the pool evaporation/condensation analytical model in CONTEMPT-LT. The effect of these corrections on problem results is negligible in most cases and significant only for problems which are observed for over several hours.

First, the analytical modeling in CONTEMPT-LT requires that the energy transferred to the pool region during the condensation process include both the energy of the liquid condensate and the latent heat of change of phase. Earlier versions of the code did not account for this transfer of latent heat during the condensation phase. This error appeared in Subroutine CONT.

Second, the atmospheric bulk molecular weight which appears in Equation (21) of Reference K-1 was calculated incorrectly; the molecular weights of air and steam were reversed in the coded equation. This error appeared in Subroutine CONT.

Finally, the dynamic viscosity of water as a function of temperature is stored in a table in subroutine BLKD. This table is used by the pool evaporation/condensation mode. The viscosity table was incorrectly coded as a function of degrees Celsius and did not include values below 250°C. All internal calculations in CONTEMPT-LT are performed in SI units, thus requiring the temperature in the viscosity table to be in Kelvins. A new viscosity table was incorporated into the code by assuming a constant pressure of one bar and covering a range from 273°K to 773°K.

1.9 Uchida Heat Transfer Correlation Correction

The Uchida heat transfer correlation specifies heat transfer coefficients as a function of compartment mass ratio of air to steam. The correlation is included in CONTEMPT-LT in the form of a data statement in Subroutine Block Data. The heat transfer coefficient for a mass ratio of 0.5 was erroneously entered as 738.174 J/(sec-m^2-°K); this value has been corrected to 794.95 J/(sec-m^2-°K). The effect of this correction is negligible.

2. INPUT DESCRIPTIONS

Several of the Version 028 modifications to CONTEMPT-LT require additional input data to be supplied by the program user. The input data and format necessary to select each of the following Version 028 features is discussed below:

(1) The drywell pressure flash option

(2) The Tagami heat transfer correlation

(3) The maximum pressure stop switch

(4) The condensate dial

(5) The annular fan analytical model.

Minor redefinition of temperature input for many of the heat transfer coefficient options was done, but no input changes are required in that regard.

2.1 Drywell Pressure Flash Input

A variable representing a switch to select the pressure flash analytical model for computing drywell thermodynamic conditions was added to the drywell description card, (Card 10031) as Word 10. The user may select the drywell pressure flash model by specifying 1.0 for Word 10; if this word is omitted or 0.0 is input, the temperature flash model is used for the drywell. Word 10 is ignored on compartment description cards (Cards 10011, 10021, and 10041) because only the temperature flash model is available for the primary, wetwell, and annulus compartments.

2.2 Tagami Heat Transfer Correlation Input

The existing format of the heat structure boundary condition card (Card 1YY400) was unchanged as a result of adding the Tagami correlation. Heat transfer coefficient Option 53 is used to specify the Tagami correlation for either or both the left and right structure boundaries as Words 1 and 3. If the Tagami correlation is selected, additional input following Word 4 on this card is required: a zero should be entered for Word 5. For the first Tagami boundary, the time to peak pressure at the end of the initial blowdown must be included as Word 6; the heat transfer coefficient control and bulk temperature control used after the time entered as Word 6 must be included as Words 7 and 8, respectively. For the second Tagami boundary (if two are specified) Words 10, 11, and 12 are used for the additional Tagami correlation information. A zero should be entered for Word 9. The time to peak pressure entered as either Word 6 or 10 must be the same for all Tagami descriptions; the code will select the last value read in for time-to-peak-pressure to use in the Tagami correlation. In addition, a valid blowdown table (3XX cards) must be input.

2.3 Maximum Pressure Stop Switch Input

A variable representing the maximum allowed total compartment pressure for any compartment has been added to the general control card (Card 11001) as Word 14. At user option, program execution will stop when the pressure in any compartment exceeds the value input for Word 14. If this word is omitted, or 0.0 is input, no compartment pressure check will be performed.

2.4 Condensate Dial Input

A variable representing the fraction of potential condensate dropout was added to the general control card (Card 11001) as Word 13. The range of this dial is from 0.0 to 1.0. If this word is omitted, or if a number outside this range is input, the value of the condensate fraction will default to 1.0. This value is used for both the fan cooler and heat structure models, whenever either or both are present.

2.5 Annular Fan Model Input

The 30XX series cards have been introduced to supply input for the annular fan model. The XX designates card continuation and must be sequential beginning at 01. The 3000 card supplies fan units and controls. Words 1, 2, and 3 are alpha fields indicating the units for time, differential pressure, and volumetric flow rate, respectively. Words 4 and 5 are time controls designating the time at which fan operation may begin and the time at which it must stop. Words 6 and 7 are the differential pressures DPMAX and DPMIN. For differential pressures greater than DPMAX, the fan is off and remains off until the differential pressure drops below DPMIN. The fan then remains on until DPMAX is again reached. On Cards 3001 through 30XX, up to 50 pairs of differential pressure/volumetric flow rate may be entered. The differential pressures must span those which might be encountered in the problem.

3. REFERENCES

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K-3. 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).

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