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FOR CONTAINMENT DESIGN
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Key Words: Blowdown, Reflood, Quench, LOCA, ECCS, Containment, Entrainment

ABSTRACT

This document provides the generic model for calculating mass and energy release rates following a loss-of-coolant accident. The model is developed in accordance with the requirements in Section 6.2.1.3 of the NRC Standard Review Plan. The mass and energy release rates are used as inputs to the containment analysis code to determine the maximum containment pressure.

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depressurization, the rate of steam generation in the CONTEMPT code is determined by decay heat, RCS metal heat, and sensible heat from the steam generators. Both the RCS metal and the steam generators are assumed to be cooled down to 212F within three hours after the accident.

CONTEMPT models the RCS as a vessel containing residual water. The properties of water in the vessel are based on the containment total pressure. ECC is injected into the vessel, and the spillage rate to the sump is calculated when the liquid volume in the vessel exceeds a fixed volume (the volume to reach break elevation). The spillage flow is assumed to have the same enthalpy as the ECC enthalpy (nonmixing model). However, for hot leg breaks the enthalpy of the spillage flow is calculated by the code since ECC injected into the RCS must pass through the core or steam generators before spilling to the containment (mixing model). All the decay heat, primary metal heat, and steam generator energy is used to generate steam. Saturated steam is assumed to be released to the containment atmosphere. Condensation of steam on ECC is not considered in this phase of the accident. When all of the stored energy (relative to 212F) in the steam generators and primary metal has been removed, the boiloff calculations continue into the decay heat phase, during which decay heat is used as the only energy source for boiling. During the recirculation phase, the enthalpy of the water injected into the vessel is based on the temperature of the sump. The temperature reduction due to the decay heat exchanger is conservatively neglected.

Decay heat generation up to 1000 seconds after the postulated break occurs is based on proposed standard ANS 5.1 as required for short-term analyses of LOCA by Appendix L of 10 CFR 50. Decay heat generation after 1000 seconds is based on Branch Technical Position APCSB 9-1 for determination of long-term cooling requirements.

The mass and energy release model used in the CONTEMPT code is described below. The mixing model was used for hot leg breaks, and the nonmixing model was used for cold leg breaks.

4.4.1. Reactor Vessel Injection Models

Two reactor injection models are available — one completely mixes the injected water with the residual water in the reactor vessel. In the second model the ECC water is injected into the reactor downcomer, pushing up the residual water to the top of the reactor vessel. Analyses of the two models follow:

4.4.2. Complete Mixing Model (for Hot Leg Break)

An option is provided for using part or all of the energy from the decay heat primary metal and steam generator to calculate boil-off rates. To accomplish this the following two equations are used. The first equation M_1 calculates steam generation from unheated water and the second equation M_2 calculates steam generation after water has been heated to a saturated condition.

$$M_1 = f(t) \times \Delta E/(h_g - u_{left})$$

$$M_2 = \{[1 - f(t)] \times \Delta E - W_{rv} \times C_{ex} \times \Delta t \times (T_{sat} - T_{hout}) - (M_{left} - M_1) \times (h_f - u_{left})\}/(h_g - h_f)$$ 1

then,

$$M_{boil} = M_1 + M_2$$

$$M_2 = 0 \text{ if } M_2 \leq 0$$

where f(t) is an energy multiplier and may be varied from 0 to 1.0. A value of 1.0 was used in the analysis to maximize the steam generation by M_1. This is conservative because no energy was used in the second equation M_2 for heating up the residual water and the injection water.

If $M_{boil} < 0$, no water is boiled and $M_{boil} = 0$. If $0 \leq M_{boil} < W_{rv}\Delta t + M_{left}$ and not all the water is boiled,

$$M'_{left} = M_{left} + W_{rv}\Delta t - M_{boil},$$

$$U'_{left} = U_{left} + \Delta E + W_{rv}C_{ex}\Delta t(t_{hout} - T_{ref}) - M_{boil}h_g,$$

$$u'_{left} = U'_{left}/M'_{left},$$

$$M'_{wtr} = M_{wtr} + M_{boil},$$

$$U'_{t} = U_{tot} + M_{boil}h_g.$$

If $M_{boil} \geq W_{rv}\Delta t + M_{left}$, all the water is boiled off: 1

$$M_{boil} = W_{rv}\Delta t + M_{left},$$

$$M'_{left} = 0,$$

$$U'_{left} = 0,$$

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$$u'_{left} = 0,$$

$$M'_{wtr} = M_{wtr} + M_{boil}.$$

The excessive decay heat can be kept in the reactor vessel or dumped into the containment atmosphere. In the former case,

$$U'_{tot} = U_{tot} + M_{boil}h_g.$$

If the excessive energy is dumped into the containment,

$$U'_{tot} = U_{tot} + \Delta E - M_{left}u_{left} + W_{rv}C_{ex}\Delta t(T_{hout} - T_{ref}).$$

If $M'_{left} > V_{left}/v_f$, the overflow spray water is drained into the containment sump:

$$M_{drain} = M'_{left} - V_{left}/v_f,$$

$$M''_{left} = V_{left}/v_f,$$

$$U''_{left} = M''_{left}u'_{left},$$

$$M'_{wtrb} = M_{wtrb} + M_{drain},$$

$$U'_{totb} = U_{totb} + M_{drain}u'_{left}.$$

If the spray water is taken from the containment sump, then

$$M'_{wtrb} = M_{wtrb} + M_{drain} - W_{rv}\Delta t,$$

$$U'_{totb} = U_{totb} + M_{drain}u'_{left} - W_{rv}C_{ex}\Delta t(T_b - T_{ref})$$

where

W_{rv} = spray flow rate injected into reactor vessel, lb/s,

T_{hout} = spray water temperature at spray nozzle, F,

h_f = saturated water enthalpy, Btu/lb,

h_g = saturated steam enthalpy, Btu/lb,

T_{sat} = saturation temperature, F

M_{left} = amount of residual water in reactor vessel, lb,

U_{left} = total energy associated with M_{left}, Btu,

u_{left} = specific energy associated with M_{left}, Btu/lb,

V_{left} = maximum reactor vessel volume that can hold residual water, ft^3,

T_b = containment liquid region temperature, F.

4.4.3. Completely Nonmixing Model (for Cold Leg Break)

The total energy contributed to the reactor vessel is assumed to boil the topmost part of the residual water. The steam generated is vented to the containment atmosphere. If the reactor vessel is full, the additional spray water spills to the containment sump. The computational procedure is as follows:

1. At each time step the volume-versus-density and the integral energy of the residual water in the reactor vessel are tabulated, i.e.,

   $$V_i \text{ Vs } \rho_i \text{ and } U_i, \; i = 1, 2, \ldots, N$$

   It should be noted that before the spray is started these values are

   $$V_1 = M_{left}/\rho_{left}, \; \rho_1 = \rho_{left}, \; u_1 = u_{left}, \text{ and } N = 1.$$

2. After the spray is started, the following set of values is added to the table

   $$V_{N+1} = W_{ex}\Delta t/\rho_{ex}, \; \rho_{N+1} = \rho_{ex}, \; u_{N+1} = h_{ex} - (P/J\rho_{ex})$$

   where J is the mechanical-to-thermal energy conversion factor.

3. The number L is detemined, so that

   $$\Delta E - \sum_{i=1}^{L} V_i\rho_i(h_g - h_i) > 0$$

   and

   $$\Delta E - \sum_{i=1}^{L} V_i\rho_i(h_g - h_i) \leq 0$$

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where $h_i = u_i + (P/J\rho_i)$,

h_g = saturated steam enthalpy corresponding to the containment total pressure.

To total amount of water boiled, M_{boil}, is

$$M_{boil} = \sum_{i=1}^{L-1} V_i \rho_i + M_{b,L}$$

where $M_{b,L}$ = the amount of water boiled from volume V_L,

$$M_{b,L} = \left[\Delta E - \sum_{i=1}^{L-1} V_i \rho_i (h_g - h_i)\right] \Big/ (h_g - h_L).$$

4. The amount of spray water spilled to the containment sump, M_{drain}, is

$$M_{drain} = \left[\sum_{i=L}^{N+1} V_i - \frac{M_{b,L}}{\rho_L} - V_{left}\right] \rho_{N+1}$$

where V_{left} = maximum reactor holding volume.

5. The table is reconstructed as follows:

$$N' = N + 2 - L$$

$$V_1' = V_L - M_{b,L}/\rho L$$

$$V_i' = V_{L+i-1},\ i = 2, 3, \ldots N' - 1$$

$$V_{N'}' = V_{N+1} - M_{drain}/\rho_{N+1}$$

$$\rho_i' = \rho_{L+i-1}\ i = 1, 2, \ldots N'$$

$$u_i' = u_{L+i-1}\ i = 1, 2, \ldots N'$$

6. The containment mass and energy are updates by

$$M_{wtr}' = M_{wtr} + M_{boil}$$

$$U_{tot} = U_{tot} + M_{boil} h_g$$

$$M_{wtrb}' = M_{wtrb} + M_{drain}$$

$$U_{totb}' = U_{totb} + M_{drain} h_{ex}$$

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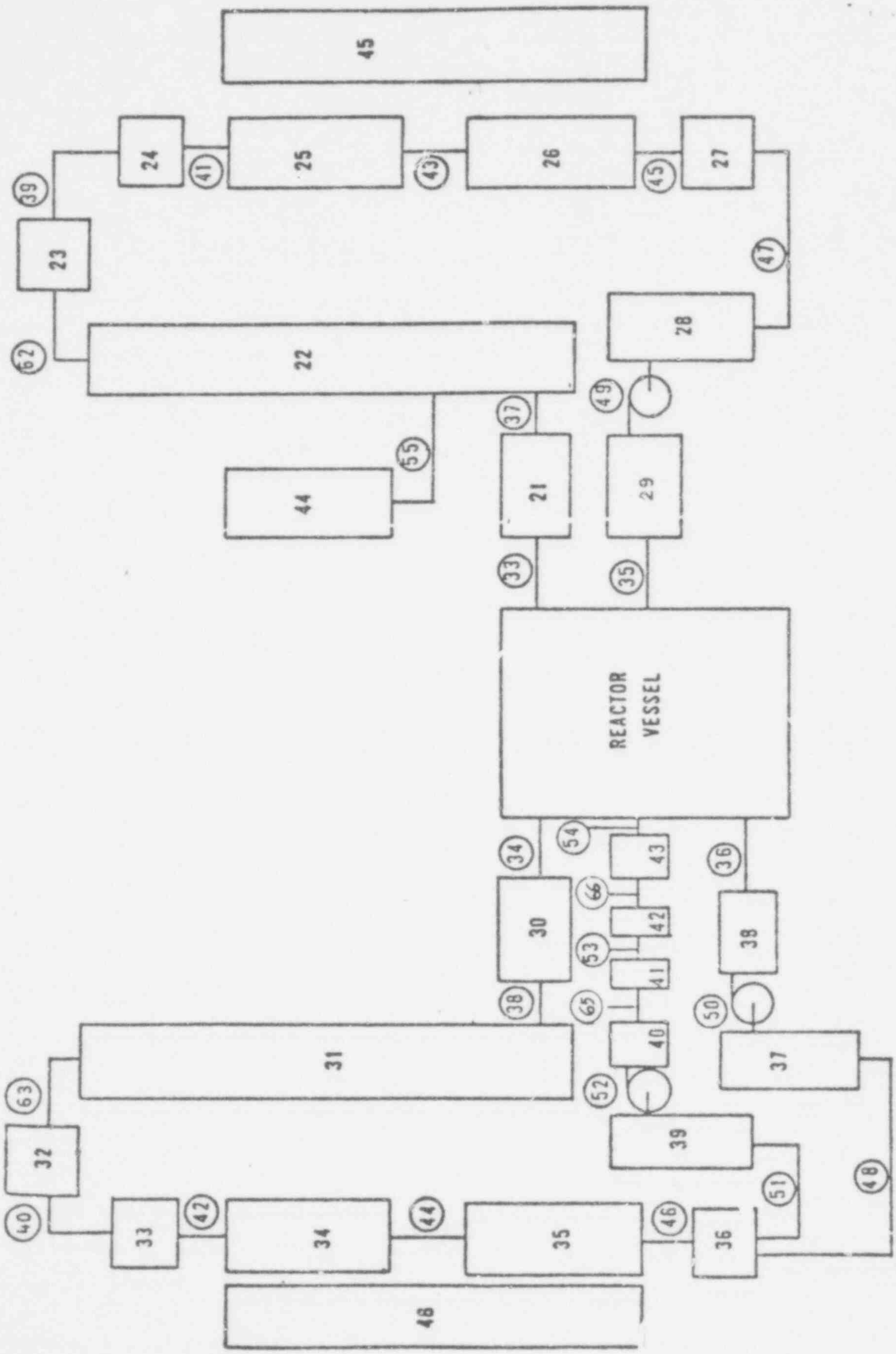

Figure 4-1. CRAFT Noding Diagram — Loop Noding