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DYNODE-P VERSION 2:

A NUCLEAR STEAM SUPPLY SYSTEM TRANSIENT SIMULATOR

FOR

PRESSURIZED WATER REACTORS -

.USER MANUAL

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2	March 15, 1977	a.	Page 2-15	Text revised; reference to TD deleted
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		c. Page 2-22; Figure revised to show inactive region
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5	April 19, 1978	a. Replace Page 2-6	Revised Text
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1.0 INTRODUCTION

DYNODE-P Version 2 (referenced as DYNODE-P/2) is a Fortran IV computer program which simulates the nuclear steam supply system (NSSS) of a pressurized water reactor (PWR) under transient conditions. DYNODE-P/2 was developed by Nuclear Associates International (NAI) and is an NAI proprietary program. DYNODE-P/2 is an extension of the DYNODE-P code (Reference 1).

DYNODE-P/2 includes a simulation of the components of a PWR NSSS which significantly influence the response of the system to transient conditions. Geometry options are provided to permit representation of any of the current PWR designs.

The major features of DYNODE-P/2 are:

- Point kinetics model for core power transients with major feedback mechanisms and decay heat represented.
- Power forced mode option for hot channel analyses.
- Multinode radial fuel rod and multinode axial coolant channel representations in the core.
- Conservation of mass, energy, volume, and boron concentration for the reactor coolant system. Conservation of momentum is optional. | 4
- Detailed pressurizer model including spray and heater systems and safety and relief valves.
- Explicit representation of the shell side of the steam generators including conservation of mass, energy, and volume.
- Explicit representation of the main steam system with isolation, check, dump, bypass, and turbine valves including conservation of mass, energy, momentum and volume.
- Representation of the reactor protective and high pressure safety injection systems.
- Representation of the major control systems.
- Provisions for simulating a variety of transients and accidents including a break in the main steam system.
- Self-initialization.
- Batch case input.

This report contains:

- Description of the models incorporated into DYNODE-P/2 (Section 2.0).
- Description of the input (Section 3.0).
- Description of the output (Section 4.0).
- A sample problem (Section 5.0).

2.0 MODEL DESCRIPTION

This section describes the theoretical basis for the DYNODE-P/2 computer program. The basic components are:

- The reactor core
- The reactor coolant system
- The steam generator
- The main steam system
- Safety systems
- Additional systems

2.1 System Overview

The general layout of the PWR-NSSS simulated by DYNODE-P/2 is shown in Figure 1. This schematic corresponds to one loop of a particular system design. DYNODE-P/2 provides the capability of full loop simulation for any of the current PWR designs. Models which describe unique features of each design are discussed in the appropriate sections below.

This schematic indicates the major components and systems which are simulated. In addition to the component hardware, controller and actuation system simulation is also provided.

2.2 Reactor Core

The reactor core model includes a transient simulation of the neutron power, the fuel and cladding temperatures at the average power, and the energy distribution within the average coolant channel. Each of these features of the DYNODE-P/2 program are discussed below.

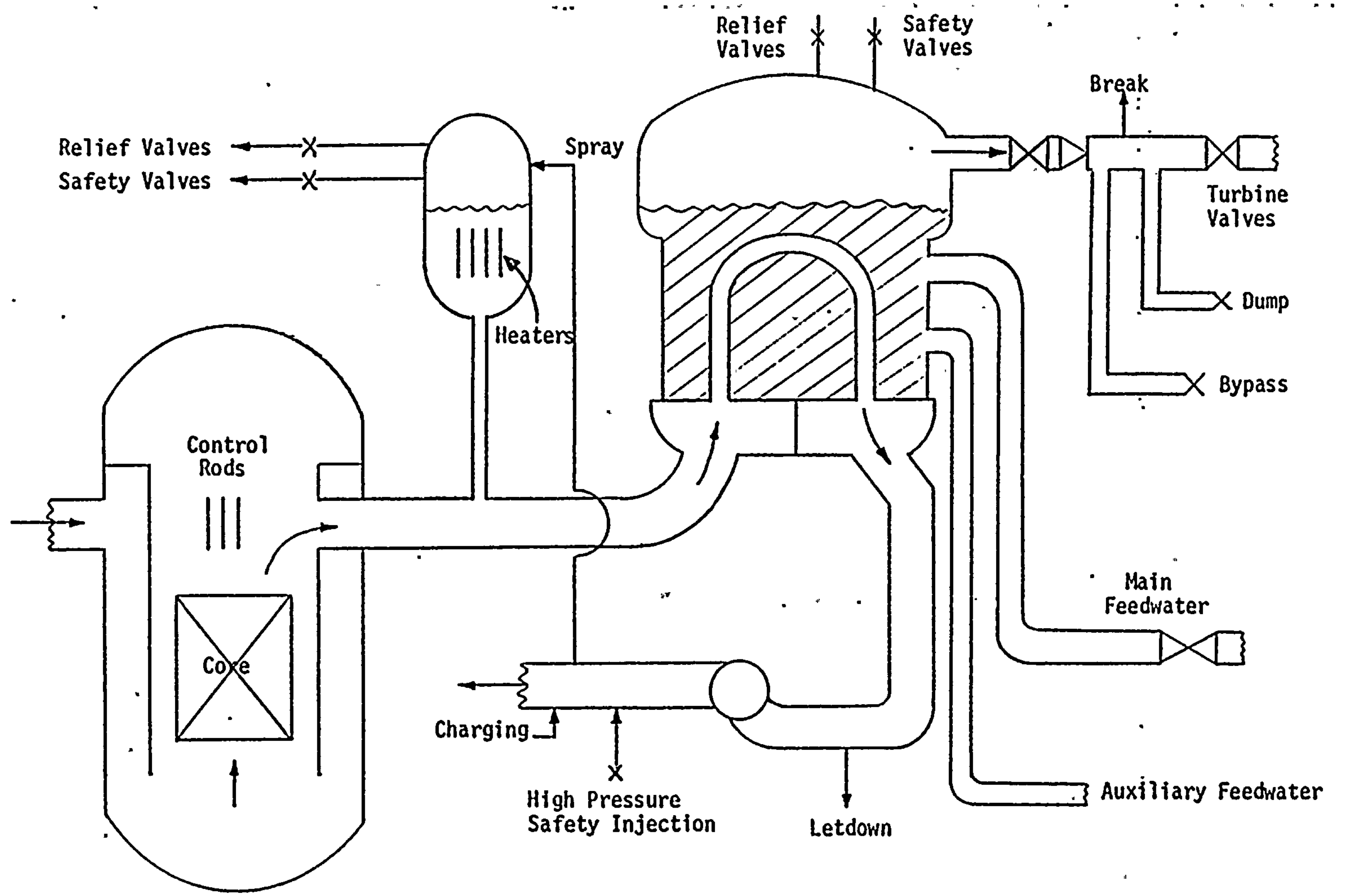

FIGURE 1 SCHEMATIC OF DYNODE-P/2 NSSS REPRESENTATION
(Only One Loop Shown)

2.2.1 Fuel Rod

The fuel rod representation at the average axial power location consists of a discrete radial nodalization within the oxide and cladding regions as shown in Figure 2. The oxide region is divided into M equal volume nodes, while the cladding is represented by two nodes. The temperature (T_n) is calculated at the average radius ($\bar{r}_n$) within each node (V_n) and is representative of the average temperature within that node. The fuel-cladding gap is not represented geometrical, but its effect on heat conductance is taken into account through the use of a heat transfer coefficient as discussed below.

Within the fuel rod, the radial heat conduction equation is:

$$\rho \; c \, \frac{\partial T(r,t)}{\partial t} = Q(r,t) + \frac{1}{r} \frac{\partial}{\partial r} \left[kr \, \frac{\partial T(r,t)}{\partial r} \right] \qquad (1)$$

The nomenclature is given in Appendix A. The total core power density is Z (see Section 2.2.3). The fraction r_f is assumed to be generated in the oxide. No heat generation is assumed in the cladding. The radial heat generation profile in the oxide is f(r). Thus

$$Q(r,t) = \begin{cases} Q_o \dfrac{Z(t)}{Z_o} f(r) r_f & ; \quad 0 < r < \text{RIN} \\ 0 & ; \quad r > \text{RIN} \end{cases} \qquad (2)$$

The heat capacity and conductivity of the oxide are temperature dependent and expressed as:

$$c_f = ACP + BCP(T) \qquad (3a)$$

$$k_f = \frac{A}{B + 273 + T} + C(T + 273)^3 \qquad (3b)$$

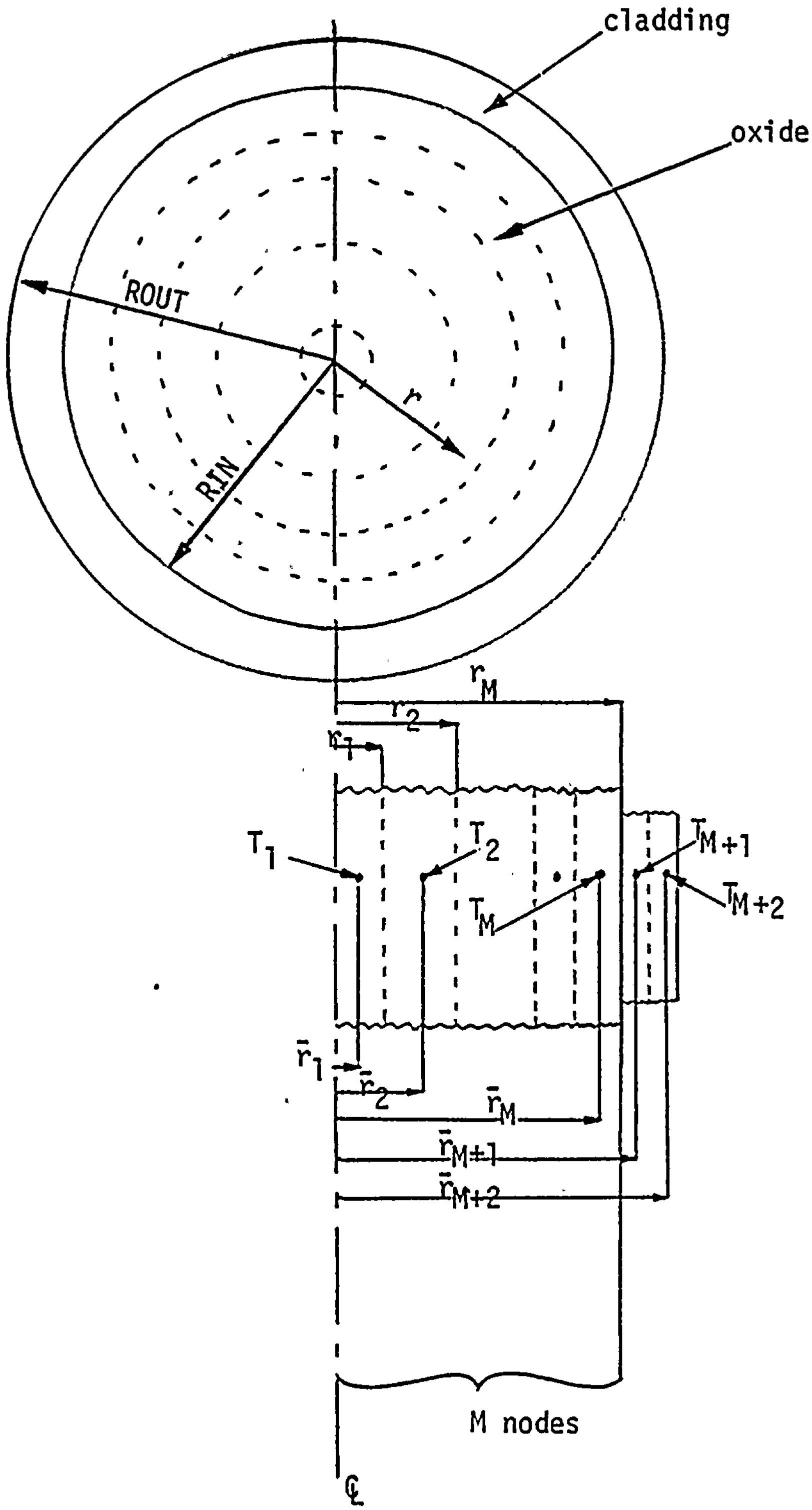

FIGURE 2 RADIAL FUEL ROD DESCRIPTION

where ACP, BCP, A, B, and C are user specified constants and T is the oxide temperature in ^{o}C. The cladding conductivity and heat capacity and the oxide and cladding densities are assumed constant and uniform.

The boundary conditions for the oxide region are:

$$\left.\frac{\partial T}{\partial r}\right|_{r\,=\,0} = 0 \qquad (4a)$$

$$-2\pi k_f \left.\left[r\frac{\partial T}{\partial r}\right]\right|_{r\,=\,RIN} = A_{gap}\,\emptyset_{gap} \qquad (4b)$$

The heat transfer area between the oxide and cladding A_{gap} is $2\pi RIN$.

The heat flux can be expressed in terms of the temperature difference between the last oxide and first cladding node as

$$\emptyset_{gap} = U_{gap}\left[T_M - T_{M+1}\right] \qquad (5a)$$

where the effective heat transfer coefficient is

$$U_{gap} = \frac{1}{\dfrac{(RIN - \bar{r}_M)}{k_{fM}} + \dfrac{1}{HG} + \dfrac{(\bar{r}_{M+1} - RIN)}{k_c}} \qquad (5b)$$

HG is the gap heat transfer coefficient which depends on the average fuel temperature through the relationship

$$HG = HG_o + AHG\,\frac{\langle \Delta T_f' \rangle}{\langle T_{f_o}' \rangle} + BHG\left(\frac{\langle \Delta T_f' \rangle}{\langle T_{f_o}' \rangle}\right)^{2} \qquad (5c)$$

where $\langle T_f' \rangle$ is the average fuel temperature in ^{o}K.

The boundary conditions for the cladding are:

$$-2\pi\ k_c \left[r \frac{\partial T}{\partial r} \right] \bigg|_{r\ =\ RIN} = A_{gap}\ \phi_{gap} \tag{6a}$$

and

$$-2\pi\ k_c \left[r \frac{\partial T}{\partial r} \right] \bigg|_{r\ =\ ROUT} = A_s\ \phi_s \tag{6b}$$

The surface heat transfer area A_s is 2π ROUT and the surface heat flux is given by

$$\phi_s = U_s\ (T_{M+2} - T_W) \tag{7a}$$

where the effective heat transfer coefficient is

$$U_s = \frac{1}{\frac{ROUT - \bar{r}_{M+2}}{k_c} + \frac{1}{HF}} \tag{7b}$$

HF is the surface heat transfer coefficient which is assumed to be proportional to the core flow rate raised to the 0.8 power with a minimum value of 5.0 Btu/hrft^2°F. The core average bulk coolant sink temperature, T_W, is computed from the core average coolant enthalpy and RCS pressure. 5

2.2.2 Coolant Channel

The axial coolant channel representation is shown schematically in Figure 3. The coupling between the fuel and coolant channel is shown in Figure 4. The nodal spacing is divided equally along the full length of the channel.

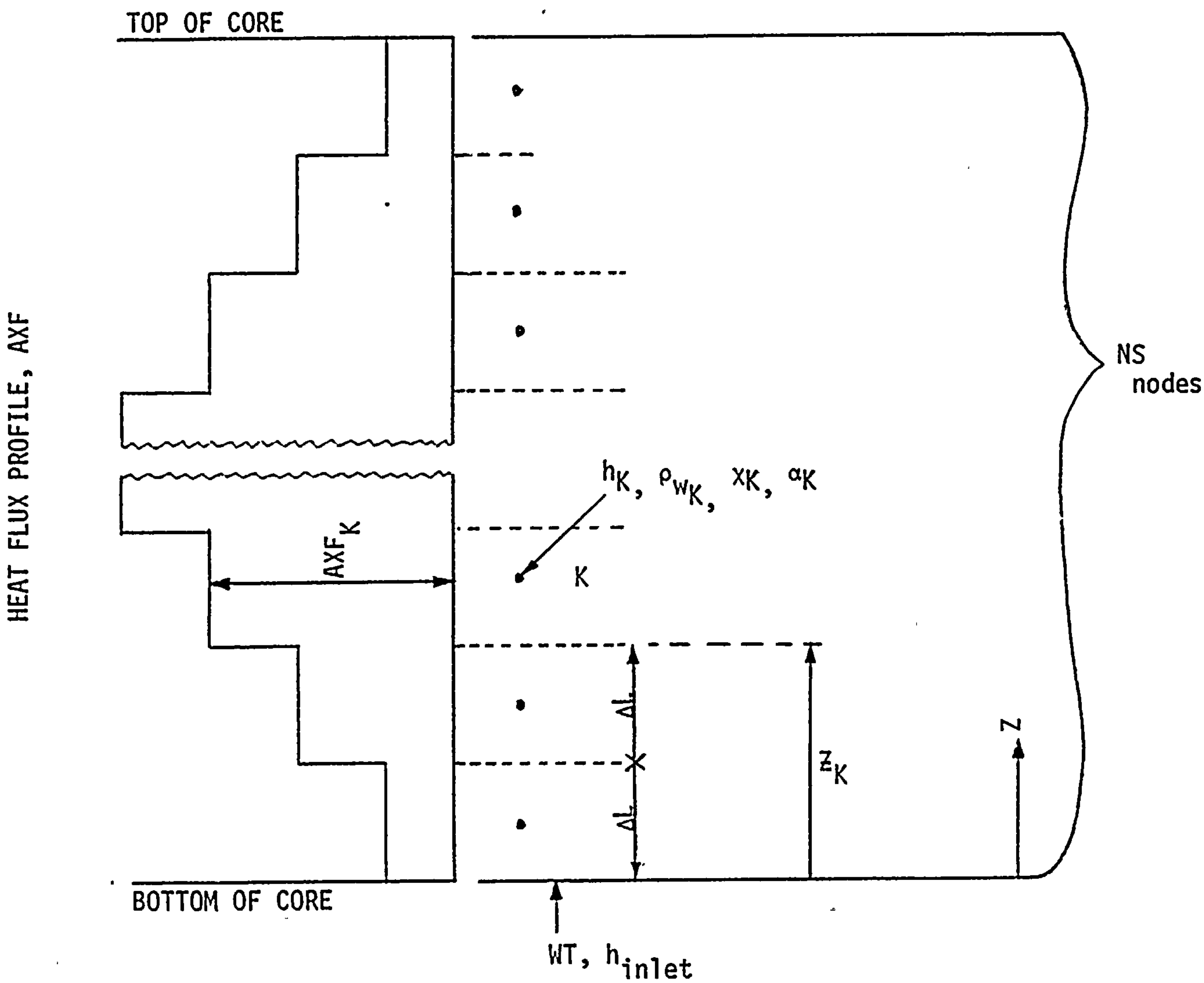

FIGURE 3 AXIAL COOLANT CHANNEL DESCRIPTION

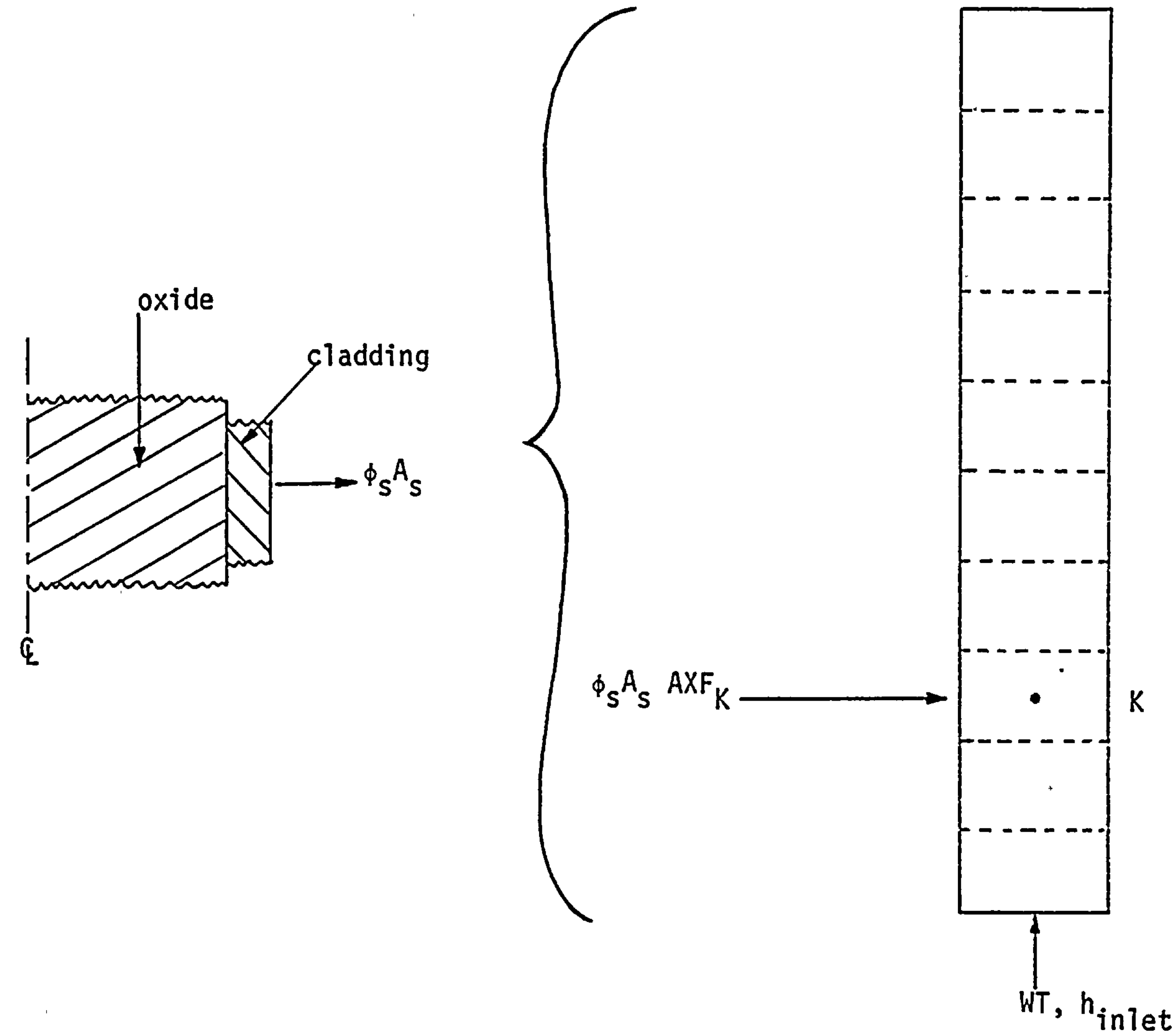

FIGURE 4 FUEL ROD - COOLANT CHANNEL COUPLING

The core average heat flux at the cladding surface is given by Equation (7a). The axial heat flux profile (AXF_K) is assumed to be constant, however the magnitude ($\emptyset_s$) will vary during the transient because of temperature variations. The axial profile is input into DYNODE-P/2 which is normalized internally in the program to an average of 1.0.

The heat balance equation in the coolant channel at an arbitrary point z is

$$\left(\rho_w \frac{\partial h}{\partial t}\right) = \frac{\phi_s A_s f(z)}{A_{flow}} - \frac{W}{A_{flow}} \frac{\partial h}{\partial z} + \frac{1}{J} \frac{dp}{dt} + r_w Zf(z) \times \frac{\pi (RIN)^2}{A_{flow}} \quad (8)$$

f(z) is the normalized axial heat flux profile. $r_w = (1 - r_f)$ is the fraction of the core power generated directly in the coolant. The coolant mass flow rate (W) is assumed to always be in the positive (upward) direction and is given by the sum of the loop flows (see Section 2.3.4).

The boundary condition at the core inlet is

$$h \Big|_{z = 0} = h_{inlet} \quad (9)$$

The coolant properties, which are based on the enthalpy and pressure, are evaluated from polynominal fits to the ASME 1967 Steam Tables below the critical pressure (Reference 2). The pressure used in these evaluations is obtained from the pressurizer model described in Section 2.3.3.

Equation 8 is integrated over a typical nodal volume. The resulting equation yields a coupled set of differential equations which are integrated simultaneously over each time step. Based on the new enthalpies and the pressure at the beginning of the time step, the specific volumes for each node are calculated from the above water properties. These specific volumes are used with the fixed nodal volumes to compute the new nodal masses. The differences between the new masses and those at the beginning of the time step form one component in the calculation of the mass transported between the RCS and pressurizer (surge line flow) over that time step (see Section 2.3.3).

The nodal quality is given by

$$x_K = (h_K - h_f)/(h_g - h_f) \tag{10a}$$

For saturated conditions, the local void fraction (α_k) is calculated with one of the following models depending on the user's option:

Variable Slip Model

$$\alpha_k = CC1 + CC2(x_k) + CC3(x_k^2) + CC4(x_k^3) \tag{10b}$$

Constant Slip Model

$$\alpha_k = 1/(1 + ((1-x_k)/x_k) \cdot \nu_f \cdot SLIP/\nu_g) \tag{10c}$$

where the constants CC1, CC2, CC3, CC4, and SLIP are input parameters.

DYNODE-P/2 considers departure from nucleate boiling (DNB) along the coolant channel. The W-3 correlation is the basis for this analysis. Non-uniform axial heat

flux effects are taken into account explicitly. The user has the option of considering cold wall effects on DNB. This correlation is given by.

$$\phi_{DNB} \times 10^{-6} = QDNB1 * QDNB2/FF \quad (11a)$$

QDNB1 is the basic W-3 correlation given by

$$\begin{aligned} QDNB1 = &\{(2.022 - 0.0004302\ p) \\ &+ (0.1722 - 0.0000984\ p) * \\ &\exp[(18.177 - 0.004129\ p)\ \chi]\} * \\ &\{(0.1484 - 1.596\ \chi + 0.1729\ \chi\ |\chi|) * G' \\ &+ 1.037\} * \\ &\{1.157 - 0.869\ \chi\} * \\ &\{0.2664 + 0.8357\ \exp[-3.151\ D_e]\} * \\ &\{0.8258 + 0.000794\ (h_f - h_{inlet})\} \end{aligned} \quad (11b)$$

QDNB2 is the optional cold wall factor (included only if the input value of DEH > 0) given by

$$\begin{aligned} QDNB2 = &[1.36 + 0.12\ \exp\ (9\chi)] * \\ &[1.2 - 1.6\ \exp\ (-1.92\ D_e)] * \\ &[1.33 - 0.237\ \exp\ (5.66\ \chi)] \end{aligned} \quad (11c)$$

DEH is the heated equivalent hydraulic diameter and is used to evaluate both QDNB1 and QDNB2 when an unheated surface is present in the channel (D_e=DEH>0). DE is the hydraulic diameter and is used in Eq (11b) (D_e=DE) when DEH $\leq$ 0.

The FF factor accounts for non-uniform axial effects and is given by

$$FF(z) = \begin{cases} \dfrac{CC \int_0^z \phi(z') e^{-CC[z - z']} dz'}{\phi(z) [1 - e^{-CC\, Z_{DNB,EU}}]} & ; \dfrac{\partial \phi}{\partial z} < 0 \\ 1.0 & ; \dfrac{\partial \phi}{\partial z} > 0 \end{cases} \quad (11d)$$

where

$$CC = 1.8 \, [(1 - \chi)^{4.31}/(G')^{0.475}] \ ft^{-1} \quad (11e)$$

The distance $Z_{DNB,EU}$ in (11d) is the equivalent uniform heat flux DNB length defined by

$$h_k - h_{inlet} = \frac{(\phi_s A_s \cdot AXF_k)}{WT} \int_0^{Z_{DNB,EU}} dz \quad (11f)$$

In the above expressions, the local quality is evaluated from Equation (10a) and

$$G' = \frac{WT}{A_{flow}} \times 10^{-6} \quad (11g)$$

If the heat flux at any location along the fuel rod equals or exceeds the DNB heat flux at that location divided by CHFFRC (a DNB margin factor as input by the user); i.e., $\phi_k \geq \phi_{DNB}/CHFFRC$, the heat flux at that location is set to zero. Rewetting (pre-DNB) is permitted if the calculated heat flux becomes less than $\phi_{DNB}/CHFFRC$.

The analysis of the core boron concentration is performed in the same manner as for the remainder of the reactor coolant system; i.e., only the average concentration is calculated (see Section 2.3.1).

2.2.3 Core Power Transient

In DYNODE-P/2, the core power can either be calculated directly from the point kinetics model or be input. These models are described below.

The initial power density, PO, and the radial pin power peaking factor, PRAD, are input into the program. The radial peaking factor is used to increase the input value of the power density, so that the initial power density used in the analysis is given by PO * PRAD.

2.2.3.1 Power Forced Mode

This option is exercised for cases in which the core average power transient is known.

The input power transient, P(t), is normalized to the initial core average power level, so that in Equation (2)

$$P(t) = \frac{Z(t)}{Z_0} \tag{12a}$$

When this option is used, all calculations associated with the point kinetics model are bypassed.

The power transient is input in the form of a table set as shown in Figure 5. The input values of time are measured from t = 0. Linear interpolations between table values are performed for TPDA(1) < t < TPDA(NTPOW). Outside this range,

$$P(t) = \begin{cases} 1.0 & t < TPDA(1) \\ POWER(NTPOW) & t \geq TPDA(NTPOW) \end{cases} \tag{12b}$$

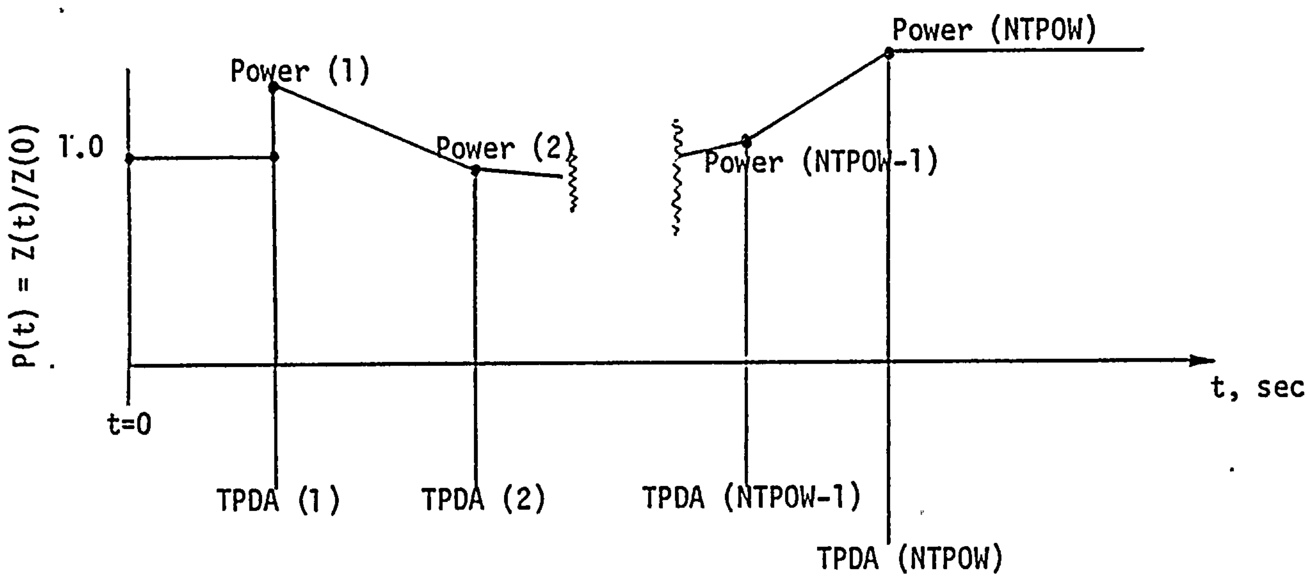

FIGURE 5 POWER FORCED MODE INPUT

The example shown in Figure 5 is not typical, since POWER(1) ≠ 1.0 and TPDA(1) ≠ 0.0, but is intended to indicate the general manner in which this table set is utilized in the program.

2.2.3.2 Point Kinetics Model

In the point kinetics model, the transient is assumed to begin at $t = 0$.

The point kinetics equations including decay heat are given by

$$\frac{\partial n}{\partial t} = \frac{n}{RL}\left[k_{eff}(1-\beta) - 1\right] + \frac{AA}{RL}\left(\frac{1}{1+\alpha}\right)\sum_{i=1}^{IT} C_i\lambda_i \quad (13a)$$

and

$$\frac{\partial C_i}{\partial t} = \nu\beta_i \frac{n}{AA} - C_i\lambda_i;\ i=1,\ldots,IT \quad (13b)$$

$$\alpha = \nu \frac{\sum_{i=1}^{IT} \beta_i}{\beta} - 1 \quad (13c)$$

$$\frac{\partial q_i}{\partial t} = \gamma_i n - \Lambda_i q_i \quad ; \quad i = 1, \ldots, IDH \quad (13d)$$

$$Z = (1 - \sum_{i=1}^{IDH} \gamma_i)n + \sum_{i=1}^{IDH} \Lambda_i q_i \quad (13e)$$

The major feedback mechanisms; Doppler, moderator temperature (enthalpy), and boron; are included in the evaluation of k_{eff}. In addition, reactivity insertions due to rod motion are taken into account. Thus

$$k_{eff} = 1 - \Delta k_{DOP} - \Delta k_{ENT} - \Delta k_{BORON} + \Delta k_{IN} + \Delta k_S(t) + \Delta k_{CRC} \quad (14a)$$

The Doppler reactivity is obtained from either

$$\Delta k_{DOP} = \{1 + DK1 \langle\alpha\rangle\} DK2 \quad \{\sqrt{\langle T'_f\rangle} - \sqrt{T'_c}\} DK3 \quad (14b)$$

or an interpolation/extrapolation in an input table of reactivity versus average fuel temperature. The moderator reactivity is obtained from either

$$\Delta k_{ENT} = \{ AK <h> + BK <h>^2 + CK\} \quad (14c)$$

or a table of reactivity versus normalized coolant density.

Here, $<\alpha>$ and $<h>$ are the core average void fraction and coolant enthalpy, respectively; $<T_f>$ is the volume average fuel temperature in ^oK; and T'_c is the bulk coolant (sink) temperature in ^oK.

The boron contribution depends on the total boron mass in the coolant and is given by

$$\Delta k_{BORON} = DKBC \times b_{CORE} \times (\rho_{CORE}/\rho_{CORE,0}) \quad (14d)$$

where DKBC is the reactivity coefficient corresponding to the initial core coolant density.

Δk_{IN} is the sum of the initial Doppler, enthalpy, and boron reactivities, and the reactivity insertion Δk_{RSI}. Δk_{RSI} is input as either a step change or a ramp change in reactivity as shown in Figure 6. These reactivity insertions begin at $t = 0$. The initial Doppler and enthalpy terms are included here to balance the reactivity at $t = 0$, so the core is just critical at that time.

$\Delta k_S(t)$ represents the scram reactivity and is input in table set form as shown in Figure 7. Note that the input values of time are measured with respect to TSCRAM, so that $\Delta k_S(t)=0$ for $t <$ TSCRAM. Linear interpolations between table values are performed for TDSA(1) $\leq t -$ TSCRAM $<$ TSDA(NTSCRAM). Outside this range,

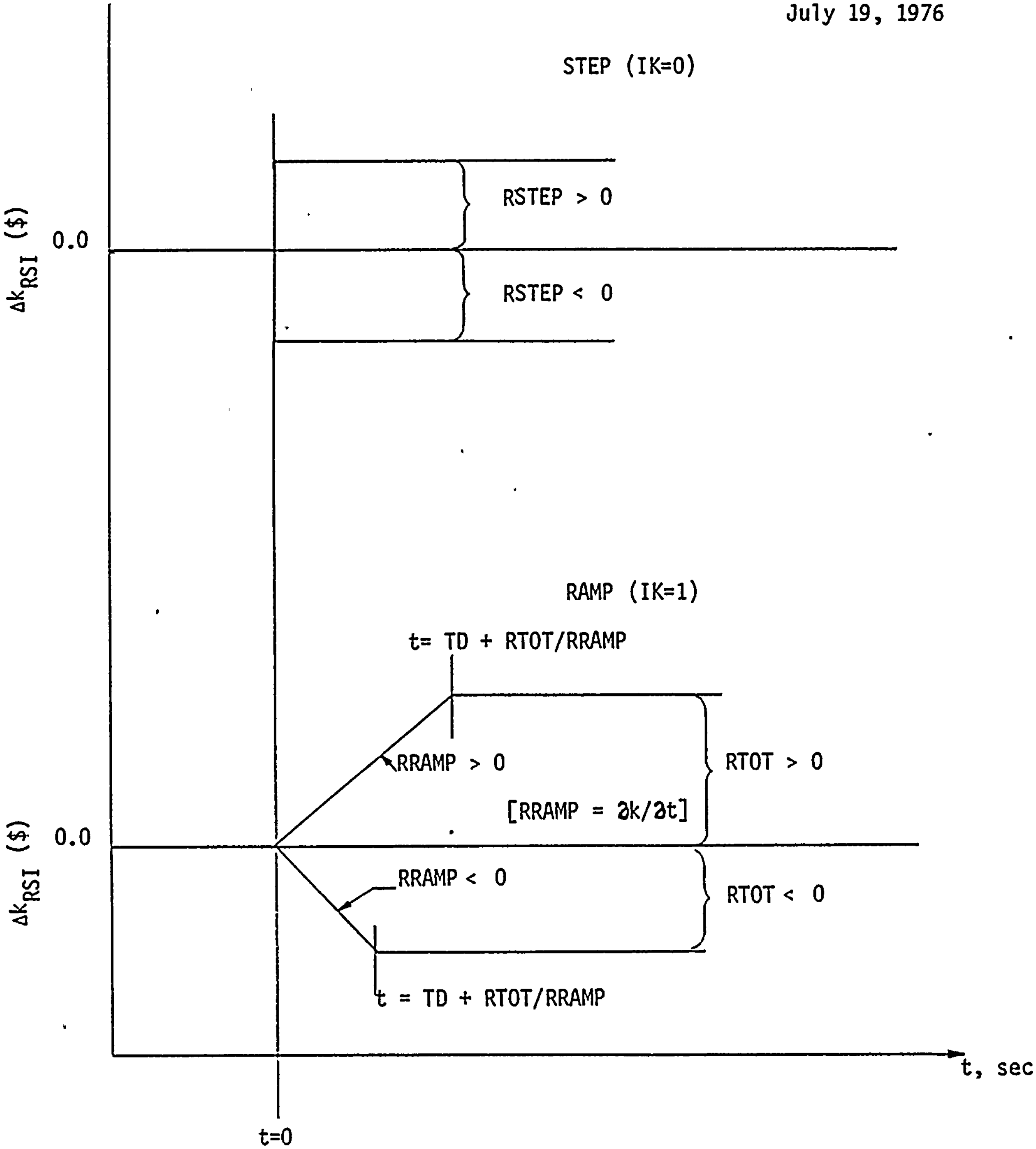

FIGURE 6 STEP OR RAMP REACTIVITY INPUT

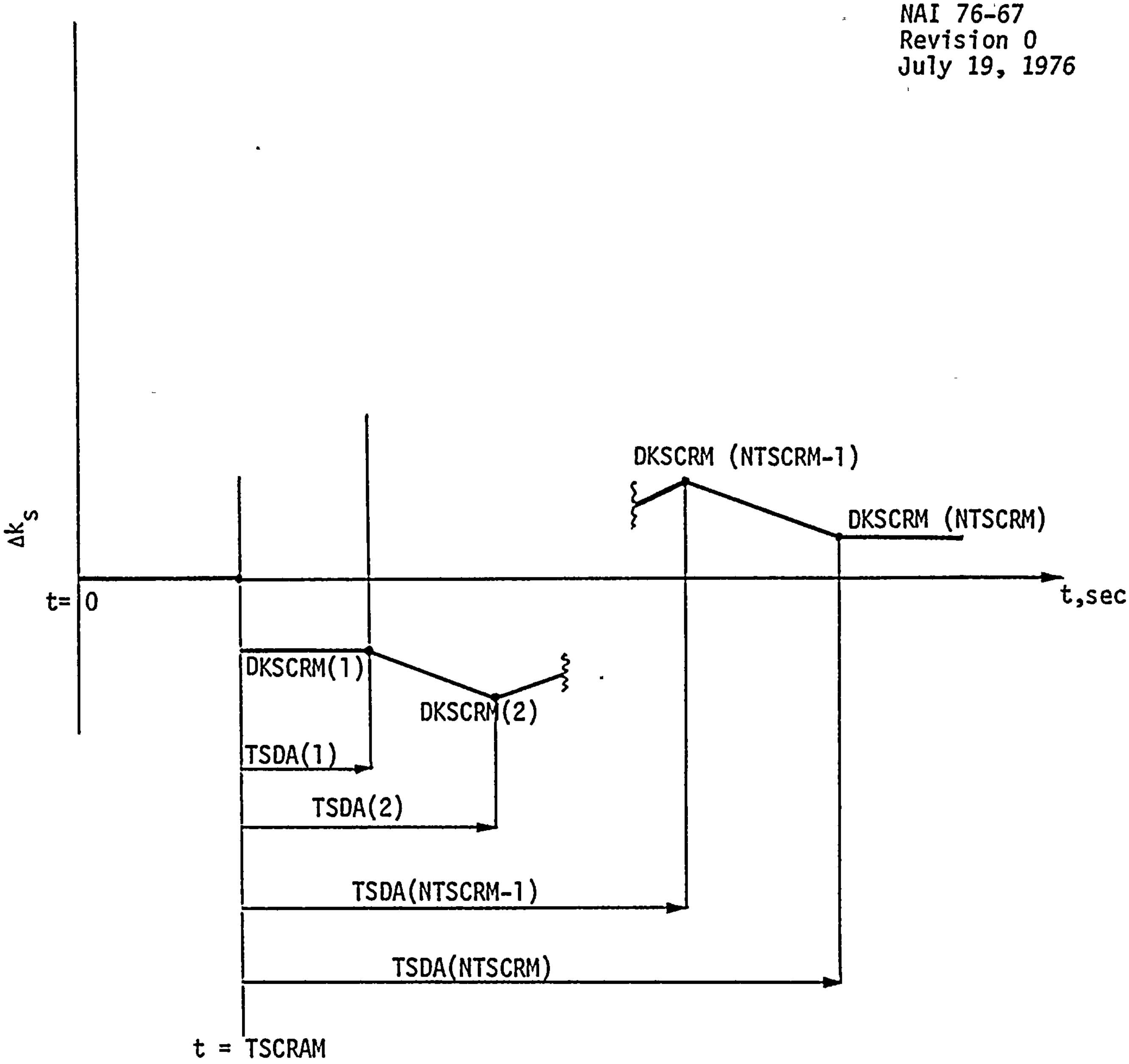

FIGURE 7 SCRAM REACTIVITY INPUT

$$\Delta k_S(t) = \begin{cases} DKSCRM(1) & t - TSCRAM < TSDA(1) \\ DKSCRM(NTSCRM) & t - TSCRAM \geq TSDA(NTSCRM) \end{cases} \quad (14e)$$

An option is provided to determine TSCRAM. If ISCRAM > 1, the input value for TSCRAM is used. If ISCRAM = 1, TSCRAM is based on the reactor protective system trips. In this case, TSCRAM is set equal to the time the trip setpoint is reached plus the corresponding trip delay time. The trips which are simulated in DYNODE-P/2 are discussed in Section 2.6.2.

Δk_{CRC} is the reactivity change due to control rod motion produced by the control rod controller (see Section 2.7.4.5).

2.3 Reactor Coolant System

This section describes the models used in DYNODE-P/2 to represent the regions of the reactor coolant system (RCS) excluding the core. Included are discussion of the conservation and state equations, geometry representations, the pressurizer model, and the system flow distribution.

2.3.1 Conservation Equations and Equation of State

The RCS (excluding the core and pressurizer) is divided into regions (control volumes) of constant volume (see Section 2.3.2). The conservation of mass and energy equations for volume i are based on the following differential equations.

$$\frac{d\rho}{dt} = - \frac{\partial}{\partial Z} \cdot \left(\frac{W}{A}\right) \quad (15)$$

$$\rho \frac{\partial h}{\partial t} = - \frac{W}{A} \frac{\partial h}{\partial Z} + \frac{1}{J} \frac{dp}{dt} - Q \qquad (16)$$

These equations are integrated over a fixed volume V_i to yield:

$$\frac{dh_i}{dt} = \frac{W_i(h_i^{in} - h_i^{out})}{m_i} + \frac{dp}{dt} v_i/J - \frac{Q_i}{m_i} + \frac{(h_{surge} - h_i)}{m_i} \frac{dm_i}{dt} \qquad (17)$$

The inlet and outlet enthalpies are based on the average control volume enthalpies, so that

$$h_i^{out} = h_i \qquad (18)$$

In the above equations, p is the RCS pressure obtained from the pressurizer model, and Q_i is the heat removal from sources external to the RCS.. The only external source considered in DYNODE-P/2 is the heat transfer between tube and shell sides of the steam generator (see Section 2.4). The last term on the right hand side of (17) is included to conserve energy as fluid is transported between the hot leg and the pressurizer (see Section 2.3.3).

The entire coupled set of Eqs (17) are integrated over a time step simultaneously assuming a fixed heat sink. Based on the new enthalpies and the pressure at the beginning of the time step, the specific volumes for each control volume are calculated from the water pro-

perties in Reference 2. These specific volumes in conjunction with the volumes are used to compute the new control volume masses. The differences between the new masses and those at the beginning of the time step form the remaining component in the calculation of the surge line flow for that time step (see Section 2.3.3).

For the cold leg, the mass and energy are adjusted for the charging, letdown, pressurizer spray, and high pressure safety injection flows. This adjustment is made prior to calculating the surge line flow. The representation for these systems are discussed later.

The conservation of boron equation for all regions in the RCS (excluding the pressurizer) are:

$$\frac{db_i}{dt} = \frac{W_i(b_i^{in} - b_i^{out})}{m_i} \tag{19a}$$

The inlet and outlet boron concentrations are given by the control volume averages, so that

$$b_i^{out} = b_i \tag{19b}$$

The boron concentrations in the cold and hot leg regions are adjusted for the charging, letdown, spray, safety injection, and surge line flow.

2.3.2 Control Volume Representations

The RC system is represented by control volumes as shown in Figures 8 and 9. Figure 8 corresponds to NSSS designs in which there are two cold legs per steam generator (LCE $\neq$ 0), and Figure 9, in which there is one cold leg per steam generator (LCE = 0).

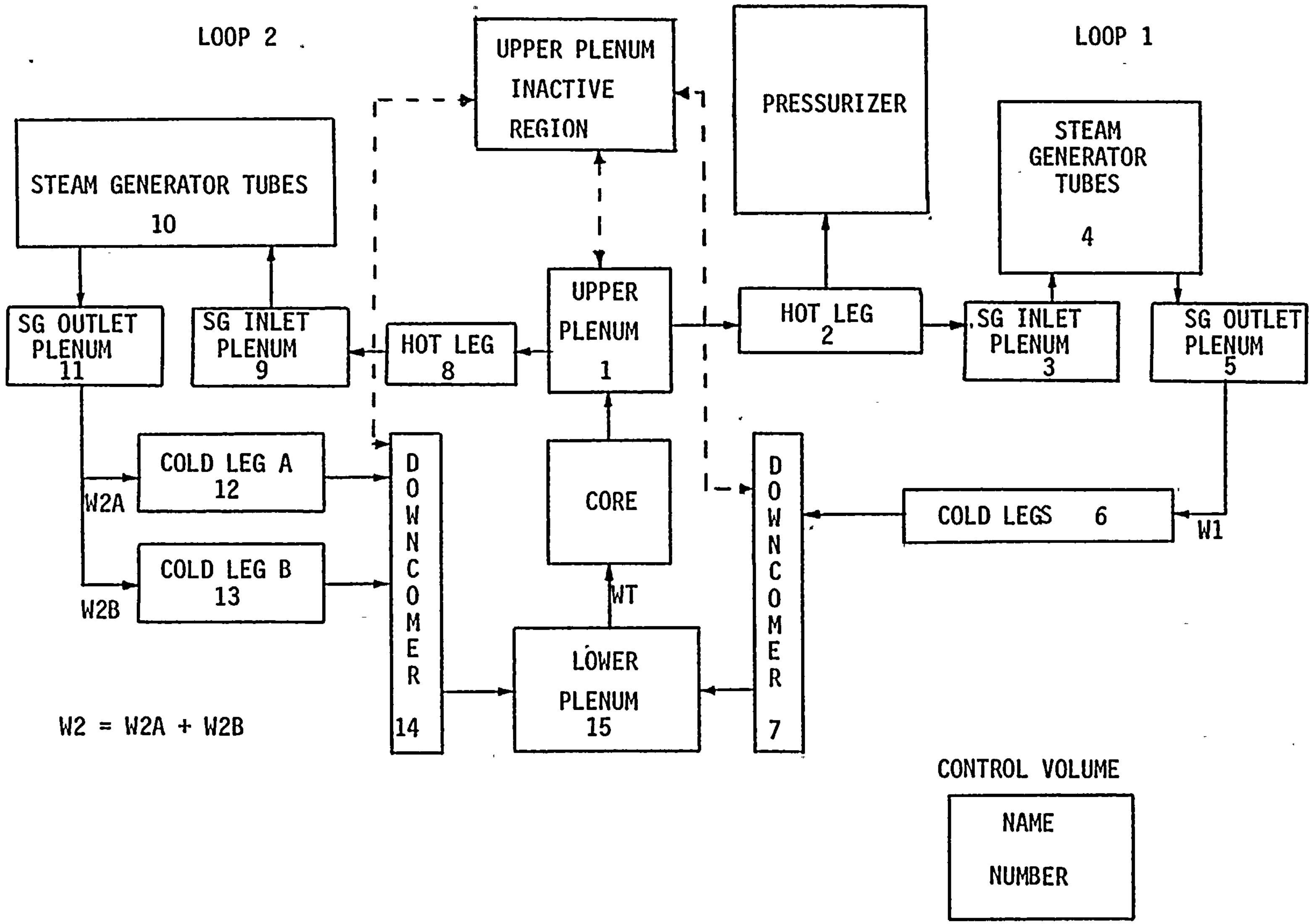

FIGURE 8 REPRESENTATION OF NSSS WITH TWO COLD LEGS PER STEAM GENERATOR

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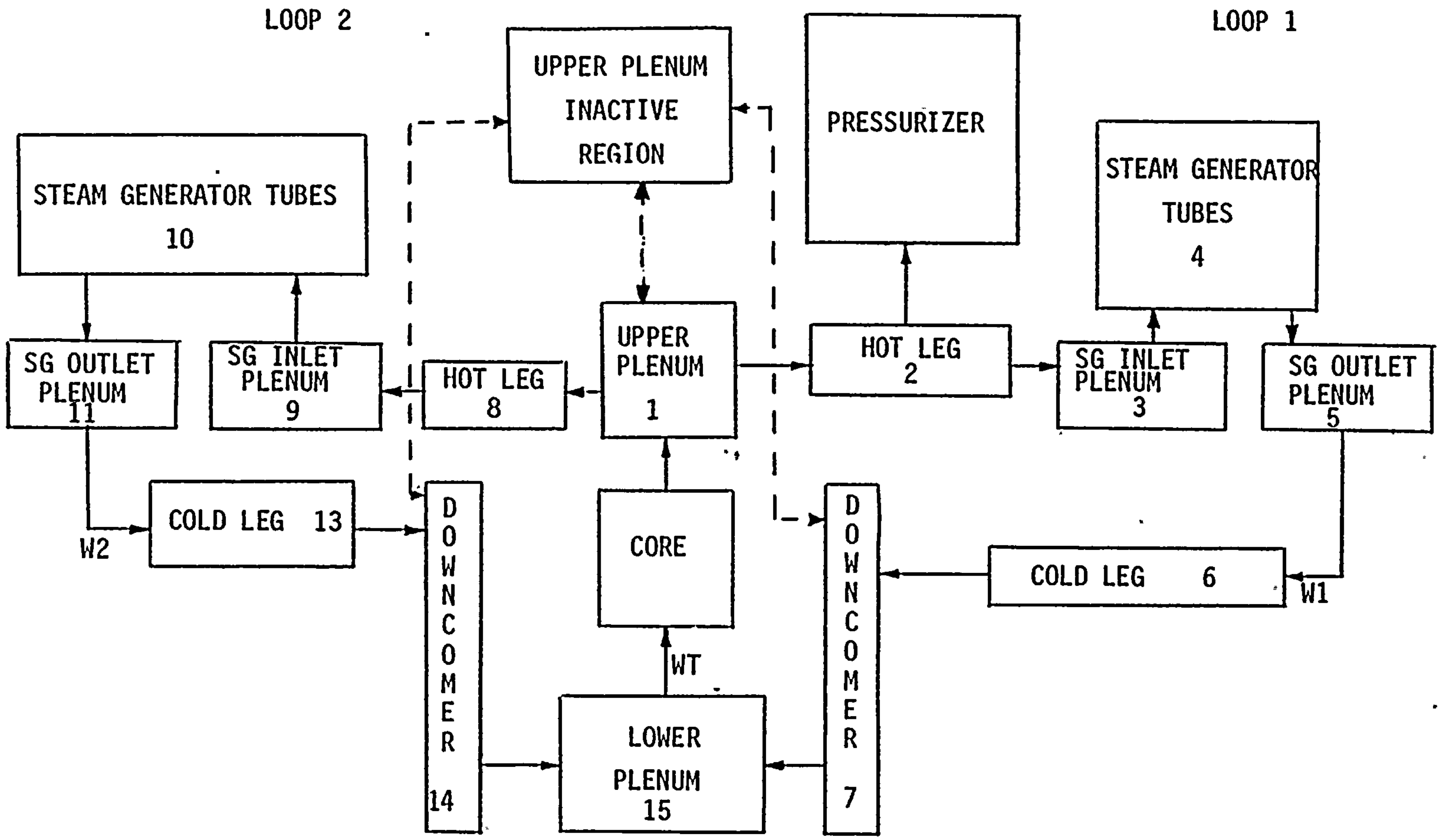

FIGURE 9 REPRESENTATION OF NSSS WITH ONE COLD LEG PER STEAM GENERATOR

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For simulation of plants with more than two loops, the loops which behave identically are grouped together to form an effective loop. For plants with two cold legs per steam generator, the cold legs in Loop 1 are combined as shown in Figure 8.

2.3.3 Pressurizer

The RC system pressure is taken as the pressurizer pressure as long as there is liquid in the pressurizer. The pressurizer model is identical to the TOPS model except that wall condensation is ignored (Reference 3) as long as steam and liquid are present. This is a non-equilibrium model in which the conservation of mass, energy, and volume are solved for the upper and lower regions simultaneously. These equations are:

$$\frac{d}{dt} U_w = W_{surge} h_{surge} + W_{spray} h_{spray} + W_{spray} \frac{(h_f - h_{spray})}{(h_G - h_f)} h_G - W_{ec} h_g - \frac{p}{J} \frac{dV_w}{dt} + Q_{wG} + Q_{heater} \tag{20a}$$

$$\frac{dm_w}{dt} = W_{surge} + W_{spray} + W_{spray} \frac{(h_f - h_{spray})}{(h_G - h_f)} - W_{ec} \tag{20b}$$

$$\frac{dV_w}{dt} = \nu_w \frac{dm_v}{dt} \tag{20c}$$

$$\frac{dU_G}{dt} = -\left(W_{SV} + W_{RV} + W_{spray} \frac{(h_f - h_{spray})}{(h_G - h_f)}\right) h_G + W_{ec} h_g - \frac{p}{J} \frac{dV_G}{dt} - Q_{wG} \tag{21a}$$

$$\frac{dm_G}{dt} = -(W_{SV} + W_{RV} + W_{spray} \frac{(h_f - h_{spray})}{(h_G - h_f)}) + W_{ec} \quad (21b)$$

$$\frac{dV_G}{dt} = -\frac{dV_W}{dt} \quad (21c)$$

The surge line flow is completely mixed with the lower region fluid and is based on the expansion or contraction of the fluid in the remainder of the RCS (see Sections 2.2.2 and 2.3.1). Thus, the surge flow is given by

$$W_{surge} = -\sum_i \frac{dm_i}{dt} \quad (20d)$$

where the sums are taken over all other fluid regions of the RCS. The surge enthalpy is taken as the hot leg enthalpy when flow is into the pressurizer and as the pressurizer liquid enthalpy when flow is out.

The evaporation-condensation flow is given by

$$W_{ec} = KA(p_{sat}(T_W) - p) \quad (22a)$$

where

$$K(lb/sec\text{-}ft^2\text{-}psi) = \begin{cases} 0.0425\sqrt{1096/(T_W+460)} & \text{for evaporation} \\ 0.0001 & \text{for condensation} \end{cases} \quad (22b)$$

The desuperheating heat transfer between the two regions is given by 5

$$Q_{WG} = U_{WG}A(T_G - T_W) \quad (23a)$$

where

$$U_{WG} = 9.0 \text{ Btu/sec ft}^2 \text{ }^oF \quad (23b)$$

and $Q_{WG} \geq 0.0$ (23c) 5

The pressurizer heater and spray representations are discussed in Section 2.7.2. The enthalpy of the spray flow is the cold leg enthalpy.

The steam flows through the safety and relief valves are based on the same model. For the relief valves, the steam flow is

$$W_{RV} = F_{RV} \left[\frac{2p}{\nu_G (K/A^2)_{RV}} \right]^{1/2} \quad (24a)$$

where

$$F_{RV} = (p - p_{RV1})/(p_{RV2} - p_{RV1}) \quad (24b)$$

$$0 \leq F_{RV} \leq 1.0 \quad (24c)$$

Similar expressions apply for the safety valves.

This set of equations is integrated to yield the mass, and internal energy of each region as a function of time. The pressure is calculated from an iteration procedure which considers both regions simultaneously at a common pressure. This procedure which is identical to TOPS forces the sum of the region volumes to coincide with the fixed total pressurizer volume.

DYNODE-P/2 calculates the boron concentration of the pressurizer liquid and takes into account the changes due to the surge and spray flows. The surge line boron concentration is that of the hot leg when the flow is into the pressurizer and the pressurizer liquid value when it is out of the pressurizer. The spray concentration is that of the cold leg. The boron is treated as being non-volatile, so that the boron remains in the lower region during evaporation.

If the pressurizer is full ($m_G = 0$), the liquid flow through the relief and safety values, W_{WR}, is computed from either Equations (24a) using ν_W in place of ν_G or from an interpolation/extrapolation in table input set for mass flow rate per unit area versus pressure at constant enthalpy. In this latter case, the effect of variations in the liquid enthalpy from the curve reference value is taken into account through use of an additional factor; namely $\{1 + \frac{\partial}{\partial h} (\frac{G}{G_{ref}}) \left[h_W - h_{ref}\right] \}$. In either case, Equation (24b) is replaced with

$$F_{RV} = (p - p_{RV1})/(0.1\ p_{RV1}) \qquad (24d)$$

i.e.; the valves are assumed to open linearly over a 10% range of the lift pressure. For a full pressurizer, Eqs (20) are replaced with

$$\frac{dU_W}{dt} = W_{surge}\, h_{surge} + W_{spray}\, h_{spray} - W_{WR} h_W + Q_{heater} \qquad (25a)$$

$$\frac{dm_W}{dt} = W_{surge} + W_{spray} - W_{WR} \qquad (25b)$$

and Equations (21) are ignored. The boron concentration is adjusted for the water relief.

Once the pressurizer empties (m_W=0), the RCS pressure is based on either the average fluid properties in the core and RCS loops or the fluid properties of the upper plenum inactive region for the remainder of the transient. This latter option is used if the inactive region is included (VUP>0.0) and ICIRCU=2 and is described in Section 2.3.5. For the first option, the effective volume for these pressure calculations is computed from the total internal energy and mass in

these regions at the time the pressurizer empties. This volume is very nearly equal to the actual total volume of these regions. If the fluid in these regions is contracting, no surge line flow is permitted, and the mass addition to the other regions is obtained from the upper plenum region. The upper plenum inactive region (See Figures 8 and 9) is used for this purpose if this volume is included (VUP >0.0); otherwise the upper plenum, Volume 1, is used. If the

fluid is expanding, the excess fluid is put into the pressurizer in the form of steam. The pressure is not allowed to drop below the saturation pressure corresponding to the maximum local enthalpy in these regions during this period.

2.3.4 RCS Flow Rates

The transient RCS flow rates may either be specified by the user (IPUMP = 0) or computed from the conservation of momentum (IPUMP ≠ 0). For the former cases in which the NSSS design has one cold leg per steam generator (see Figure 9), the flow rates in each loop (W1 and W2) are specified individually. For cases involving NSSS plants with two cold legs per steam generator (Figure 8), the individual loop flows and the flow in cold leg B of Loop 2 are specified. In all cases, the core flow (WT) is the sum of the loop flows (W1 and W2). The flow in Loop 1 is assumed to be always greater than zero. The flow in Loop 2 is arbitrary (positive or negative), but W1 + W2 > 0, otherwise WT < 0. All flows can be specified either by table sets or by equation fits of the following form. 4

The flow fit for Loop 1 is

$$W1 = W1_0 \{1 + WX1 \times t + WX2 [\exp(WX3 \times t)]\} / (1 + WX2) \qquad (26)$$

where t is measured with respect to 0. Similar expressions hold for the Loop 2 and Loop 2 Cold Leg B flows.

The flows may be specified in terms of mass or volumetric rates. If volumetric rates are specified, the mass flows in each loop are based on the corresponding cold leg specific volumes.

If the dynamic flow option is selected (IPUMP $\neq$ 0), the conservation of momentum equations for the RCS flow rates and the conservation of angular momentum for the RCS pumps are solved. Figures 9AA and 9BB show the schematical diagrams for the two types of loop configurations corresponding to Figures 8 and 9, respectively. Figures 9AA and 9BB also identify the pump numbering system and the loop fluid inertial factors, (L/A)'s, and pressure loss coefficients, K's. All pumps are assumed to have the same hydraulic characteristics and identical pump motors. 4

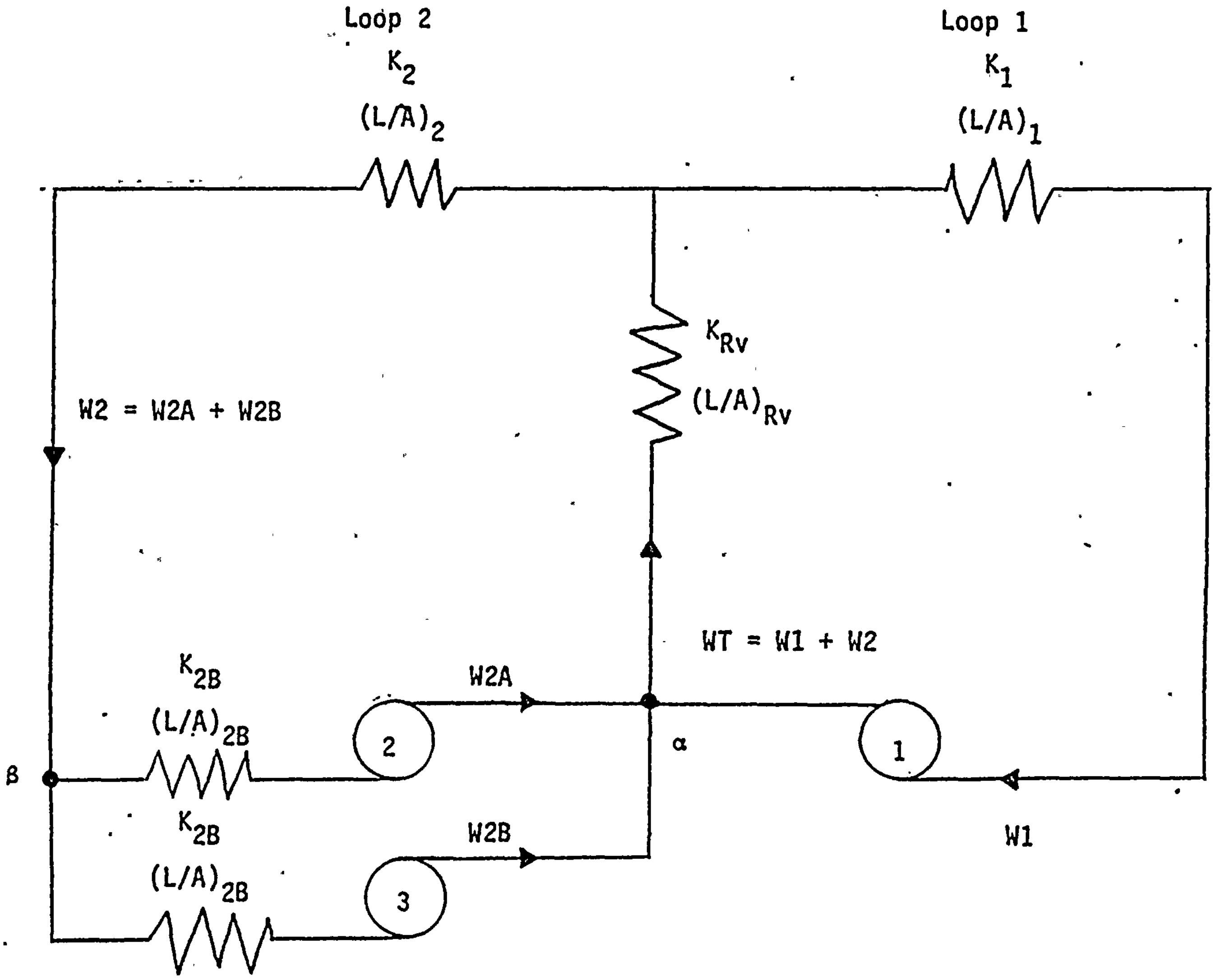

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Figure 9AA REPRESENTATION OF NSSS WITH TWO COLD LEGS PER STEAM GENERATOR FOR DYNAMIC FLOW CALCULATIONS

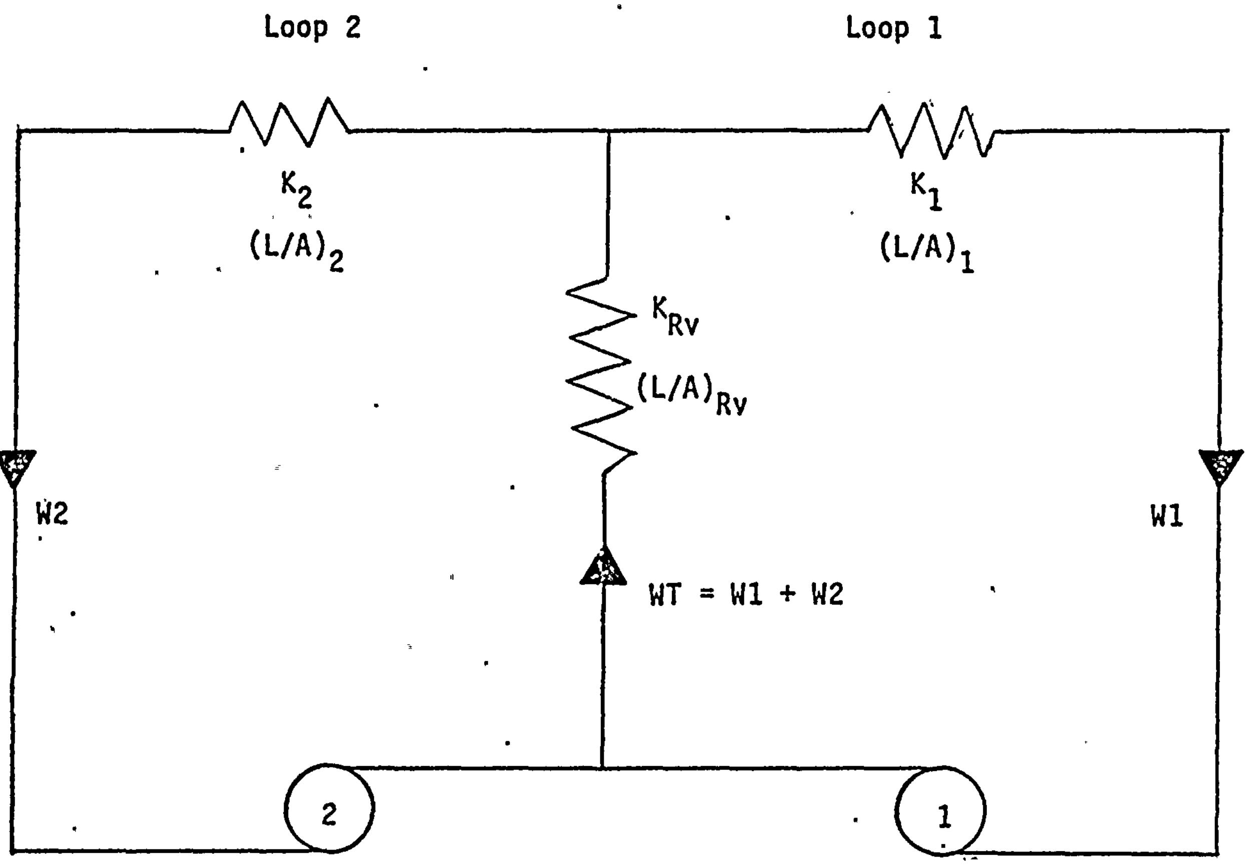

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Figure 9BB REPRESENTATION OF NSSS WITH ONE COLD LEG PER STEAM GENERATOR FOR DYNAMIC FLOW CALCULATIONS

For the loop configuration with two cold legs per steam generator, loop segments 2A and 2B are assumed to have the same fluid inertial factors, $(L/A)_{2B}$ and pressure loss coefficients, K_{2B}.

In general, the conservation of momentum equation for loop i is:

$$\left(\frac{L}{A}\right)_i^* \frac{dW_i}{dt} = \Delta p_i \qquad (26a)$$

where $(L/A)_i^*$ is the effective loop inertial factor which includes the core fluid and Δp_i is the total loop pressure rise. The corresponding conservation of angular momentum is

$$I_i \frac{d\omega_i}{dt} = T_i \qquad (26b)$$

where I_i is the total inertia of pump i and its motor and T_i is the corresponding total torque. 4

For the loop configuration with two colds per steam generator, the loop pressure rises are:

$$\Delta p_1 = \Delta p_{pump\ 1} - \Delta p_{RV} - \frac{K_1 W_1 |W_1|}{2\rho_1} \qquad (26c)$$

$$\Delta p_{2A} = \Delta p_{pump\ 2} - \frac{K_{2B} W_{2A} |W_{2A}|}{2\rho_{2A}} - \Delta p_{\alpha\beta} \qquad (26d)$$

$$\Delta p_{2B} = \Delta p_{pump\ 3} - \frac{K_{2B} W_{2B} |W_{2B}|}{2\rho_{2B}} - \Delta p_{\alpha\beta} \qquad (26e)$$

$$\Delta p_2 = -\Delta p_{RV} - \frac{K_2 W_2 |W_2|}{2\rho_2} + \Delta p_{\alpha\beta} \qquad (26f)$$

where

$$\Delta p_{RV} = \frac{K_{RV} W_T |W_T|}{2\rho_1} \tag{26g}$$

and $\Delta p_{\alpha\beta} = p_\alpha - p_\beta$ (Refer to Figure 9AA for locations α and β). Also, from continuity,

$$\frac{dW_2}{dt} = \frac{dW_{2A}}{dt} + \frac{dW_{2B}}{dt} \tag{26h}$$

Thus, the momentum equations governing the flow rates W_2, W_{2A}, and W_{2B} (Eqs (26a)) along with Eq. (26h) represent a set of four equations in four unknowns; namely, $\frac{dW_2}{dt}$, $\frac{dW_{2A}}{dt}$, $\frac{dW_{2B}}{dt}$, and $\Delta p_{\alpha\beta}$. This set can be reduced to two equations in terms of $\frac{dW_{2A}}{dt}$ and $\frac{dW_{2B}}{dt}$. 4

For the loop configuration with one cold leg per steam generator, the loop pressure pressure rises are:

$$\Delta p_i = \Delta p_{pump\ i} - \Delta p_{RV} - \frac{K_i W_i |W_i|}{2\rho_i} \tag{26i}$$

where Δp_{RV} is given by Eq (26g).

It should be noted that the gravity heads are neglected in the loop momentum equations, since they are small for practical transient analyses. Thus, conditions of natural circulation cannot be represented properly and should be avoided.

In general, the total (net) pump torque is given by:

$$T_i = T_{mi} - T_{hi} - T_{fi} - T_{wi} \tag{26j}$$

where the terms on the right hand side represent the contributions due to the motor, hydraulics, friction, and windage, respectively. The motor torque, which is a function of the motor speed when the power is on, is set to zero if the motor is off or if the pump shaft is assumed to be either locked or sheared. The hydraulic torque is discussed later. The friction and windage torques are given by

$$T_f = C_f \, |\omega/\omega_R|^{n_f} \qquad (26k)$$

and

$$T_w = C_w \, |\omega/\omega_R|^{n_w} \qquad (26l)$$

where ω_R is the rated pump speed.

Any pump motor may be either on or off initially, but at least one pump in the system must be on. However, for the loop configuration with two cold legs per SG, if only one pump is on initially in Loop 2, the Loop 2B 4
pump must be the one which is on.

Six types of pump transients are permitted; namely

- o Continuous steady-state operation (constant speed)
- o Pump motor trip
- o Pump shaft seizure (locking)
- o Pump shaft break (shearing)
- o Pump motor startup
- o Specified time-dependent speed.

Any pump may experience any of the above transients with individual specification for the time at which each pump begins its transient; however, all pumps experiencing the last type are assumed to have the same speed versus time behavior. When a pump shaft shears, the inertia I for that pump is changed to reflect the decoupling between the pump and the flywheel and motor, and the windage torque is set to zero.

The hydraulic characteristics of the pump are represented by the homologous relationships for centrifugal pumps (See Section V.5 of Reference 5). The homologous representation relates the dimensionless pump head, h, and dimensionless hydraulic torque, b, in terms of the dimensionless speed, α, and dimensionless volumetric flow, ν, which are developed from the pump four-quadrant curves. These relationships are shown in Figures 9CC and 9DD for single phase flow through the pump along with the four curve type identifications. These curves yield the pump characteristics for all possible values of pump speed and flow (including normal and reverse directions). Table 1A gives a clearer definition for each pump head curve type. The corresponding table for the torque curves is identical with b replacing h. The dimensionless parameters are given in terms of the rated values by:

$$\alpha = \omega/\omega_R$$
$$\nu = Q/Q_R$$
$$h = H/H_R \qquad (26m)$$
$$b = T/T_R$$

4

The pump head and hydraulic torque are thus found by: computing α and ν for the given conditions; finding either h/α^2 and b/α^2 (if $\alpha > \nu$) or h/ν^2 and b/ν^2 ($\nu > \alpha$); calculating h and b; and using these results in

$$H = h\ H_R \qquad (26n)$$

and

$$T_h = b\ T_R\ \rho/\rho_R \qquad (26o)$$

where ρ and ρ_R are the actual and rated fluid densities, respectively. The pump pressure rise is given by

$$\Delta p_{pump} = H\rho \qquad (26p)$$

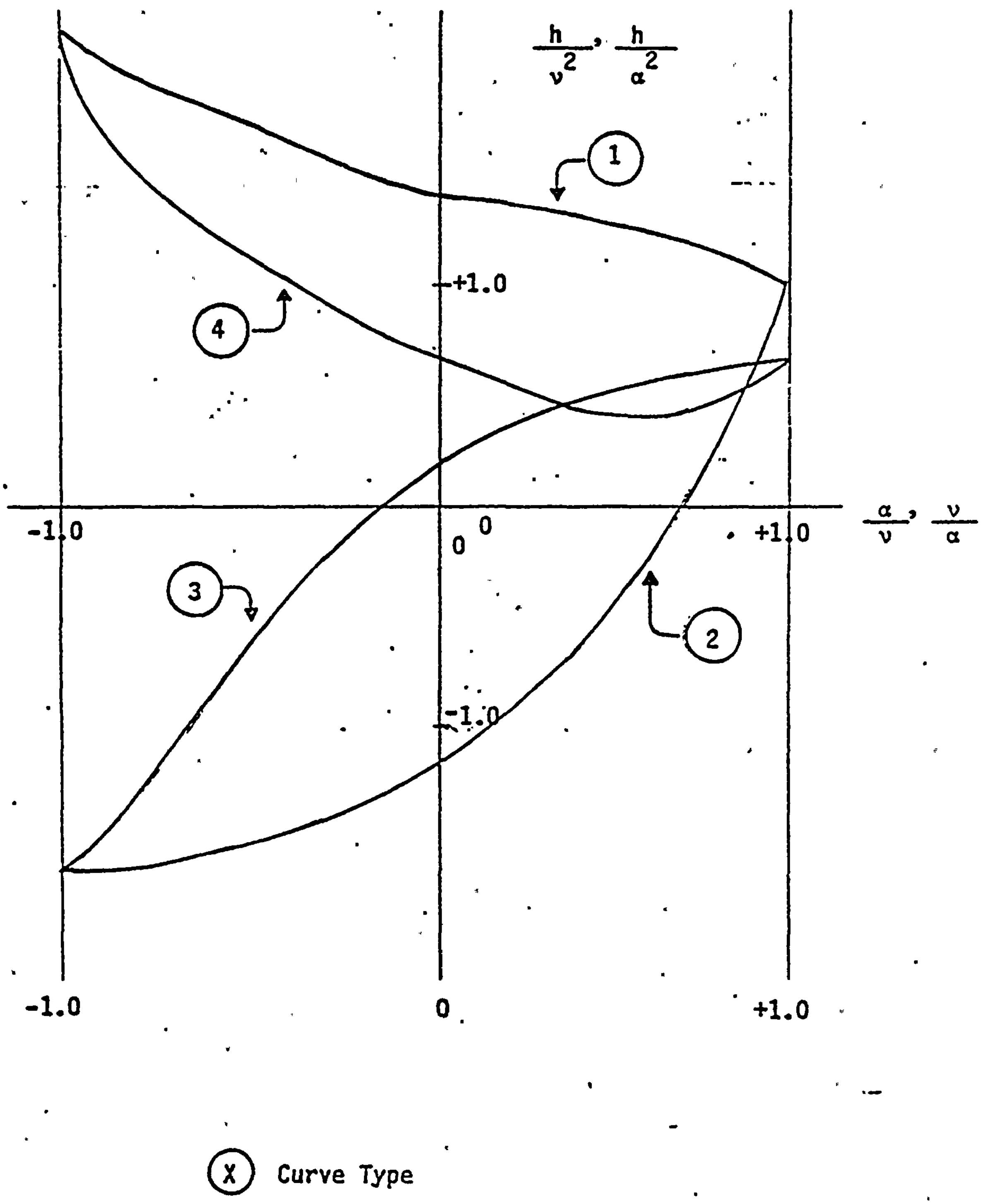

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Figure 9CC Homologous Pump Head Relationship

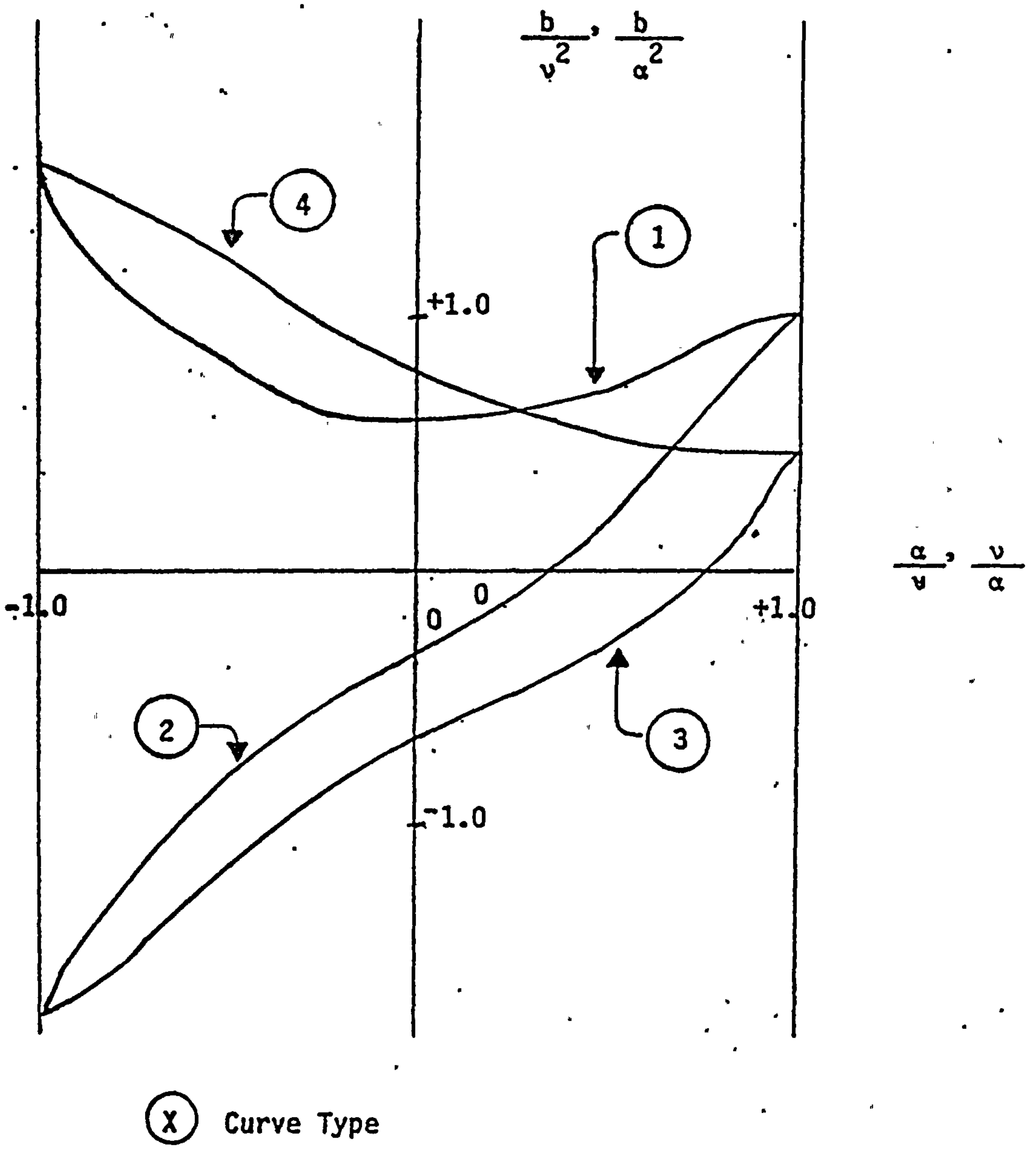

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Figure 9DD Homologous Hydraulic Torque Relationship

TABLE 1A

HOMOLOGOUS CURVE TYPE IDENTIFICATIONS

Curve Type	α	ν	Ratio Which is Between -1 and 1		Curve Name
1	>0	>0	ν/α	h/α^2	HAN
1	>0	<0	ν/α	h/α^2	HAD
2	>0	>0	α/ν	h/ν^2	HVN
2	<0	>0	α/ν	h/ν^2	HVR
3	<0	<0	ν/α	h/α^2	HAT
3	<0	>0	ν/α	h/α^2	HAR
4	<0	<0	α/ν	h/ν^2	HVT
4	>0	<0	α/ν	h/ν^2	HVD

4

Finally, an option is available which allows pumps to rotate backwards (reverse speed). Pumps with sheared shafts and pumps with specified time-dependent speeds are always allowed to rotate backwards. 4

2.3.5 Upper Plenum Inactive Region

The representation of the upper plenum inactive region (dead volume) as shown in Figures 9A and 9B is optional. This region is included, if the user specified volume, VUP, is greater than 0.0. Two options are available for representing the circulation flow between the downcomer, inactive region, and upper plenum. In either case, these circulation flows transport energy and boron with no net mass transport. Mass transport out of the inactive region is assumed to occur only after the pressurizer is emptied and the RCS fluid is contracting as described in Section 2.3.3 above.

For the first circulation flow option (ICIRCU=0 or 2), the circulation flow path as shown in Figure 9A is from the downcomer through the inactive region and into the upper plenum.

For the second option (ICIRCU=1), two independent path types are assumed as shown in Figure 9B; one between the downcomer regions and the inactive region, and one between the upper plenum and the inactive region.

If ICIRCU=2, the RCS pressure is based on the inactive region fluid properties after the pressurizer empties. For this case, the effective volume for this region is calculated from the internal energy and mass in this region at the time the pressurizer empties. This volume is very nearly equal to the actual inactive region volume. For this pressure calculation, the following two assumptions are made for the inactive region:

1. The process is constant specific volume.
2. The fraction FFUPIV of the pseudo-energy removal rate (the RCS mass contraction rate times the inactive region enthalpy) is removed.

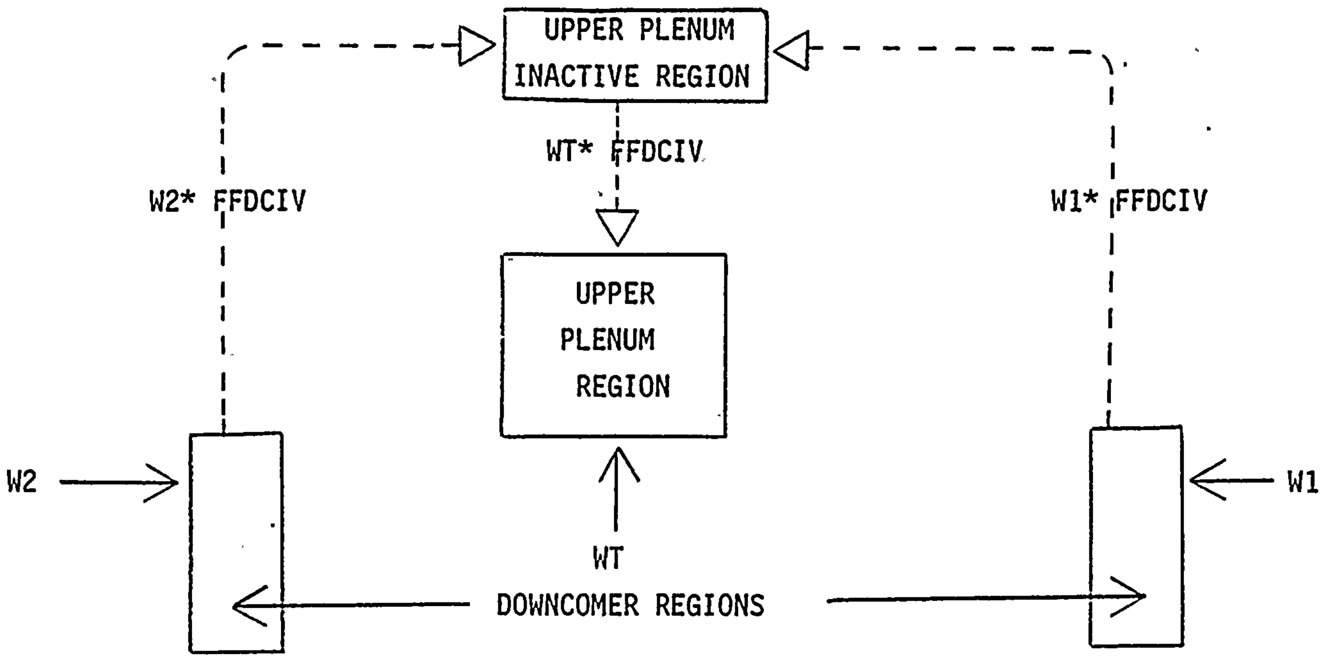

FIGURE 9A - UPPER PLENUM INACTIVE REGION REPRESENTATION (ICIRCU=0 or 2)

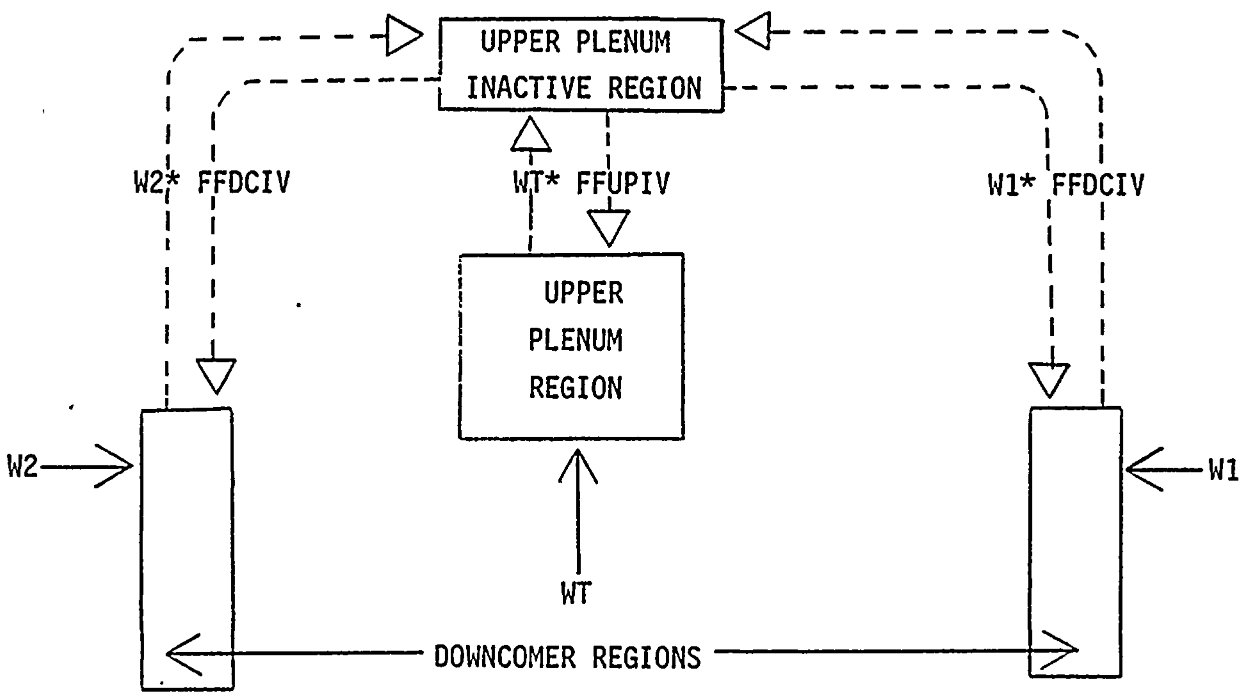

FIGURE 9B - UPPER PLENUM INACTIVE REGION REPRESENTATION (ICIRCU=1)

2.4 Steam Generators

This section describes the models provided in DYNODE-P/2 for simulation of both the U-Tube Steam Generator (UTSG) and Once-Through Steam Generator (OTSG) designs. For each design, the geometric representation, and the heat transfer and dynamic models are described.

2.4.1 U-Tube Steam Generator

2.4.1.1 Geometry

Figure 10 is a schematic of the geometry of a typical UTSG as modeled in DYNODE-P/2.

2.4.1.2 Heat Transfer

The heat transfer coefficient, U_{SG}, from the tube to shell side is based on:

- o RCS coolant to tube inside surface
  - Forced convection (Dittus-Boelter with a minimum valve of 5.0 Btu/hr ft^2 °F)
- o Tube inside to outside surface
  - Slab heat conduction
- o Tube outside surface to shell side water
  - Nucleate Boiling (Thom)
- o Fouling factor
  - User specified

These heat transfer correlations are evaluated from the local temperatures and properties.

The total steam generator heat transfer rate is given by

$$Q_i = U_{SG_i} \times SGA_i \times F_{SG_i} \times \Delta T_{\ell m} \quad (27a)$$

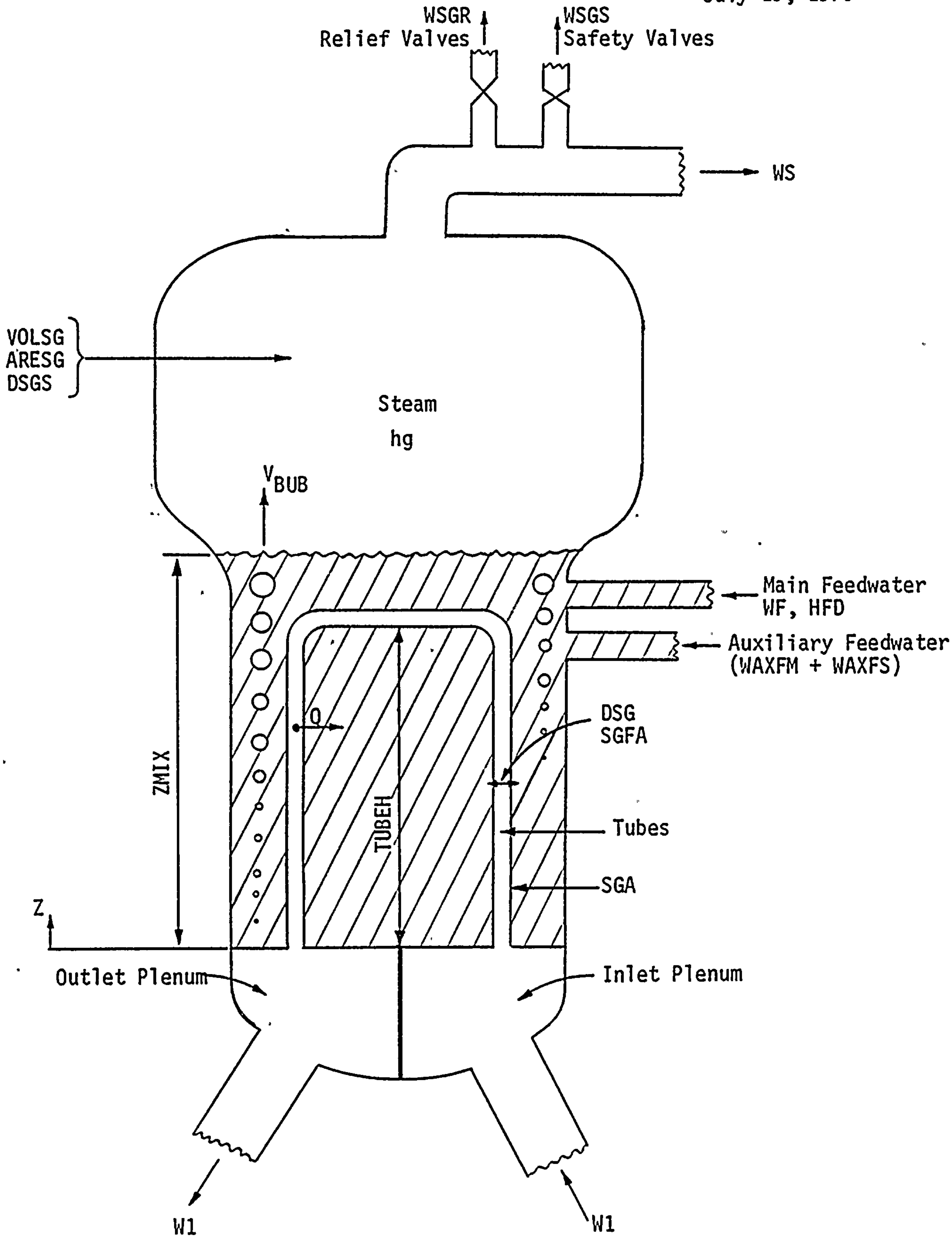

FIGURE 10 SCHEMATIC OF U-TUBE STEAM GENERATOR

where $\Delta T_{\ell m}$ is the log-mean temperature difference from tube to shell side. The factor F_{SG} is given by

$$F_{SG} = AR \times F_{TC} \tag{27b}$$

where AR is a constant factor calculated during initialization such that the steam generator heat load matches the core power at that time (see Section 2.8.3). F_{TC} accounts for changes in the heat transfer area as the tubes become uncovered during the transient and is proportional to the mixture level. The mixture level model is discussed in the following section.

An option has been provided (IFLGT) for determining the initial shell side temperature (and hence pressure). If the input temperature TS is used only as an initial guess, the above model is used to calculate U_{SG}. If the input value of TS is used to set the shell side pressure, then U_{SG} is based on forced convection from the RCS coolant to the tube inside surface plus an effective resistance from the tube inside surface to the shell side coolant. This latter resistance is calculated during initialization to match the steam generator heat load and the core power and is held constant during the transient. The fouling factor is ignored in this case.

If reverse heat transfer (shell to tube side) is calculated, the heat transfer rate as calculated from the above model is multiplied by the user specified reverse heat transfer factor.

2.4.1.3 Dynamic Model

The conservation of mass, energy, and volume are solved for the shell side of the steam generators. Under all conditions, the water and steam are assumed to be saturated

and in equilibrium. Figure 10 shows the mass flows and enthalpies which are considered in these conservation equations.

An option (ISGOPT) is provided for calculating the pressure and temperature responses of the shell side under transient conditions. When the temperature option is selected, the transient temperature is computed from the model discussed in Reference 4. When the enthalpy option is selected, the transient pressure is computed for the equilibrium state of the steam and water based on the specific volume and enthalpy. In either case, the saturated water properties are given in the form of table sets based on the ASME 1967 Steam Tables.

The steam which is generated on the shell side due to heat addition and flashing is assumed to be produced in the two-phase region as indicated in Figure 10. This steam is allowed to rise to the mixture level, ZMIX, where it is separated into the steam region. The mixture level representation in DYNODE-P/2 is the same as the bubble rise model in Reference 5 except that the Wilson correlation (Reference 6) is used to calculate the bubble rise velocity. In this representation, the mass of the steam entrapped in the mixture, m_{gb}, is calculated from integrating the following expression:

$$\frac{dm_{gb}}{dt} = \frac{dm_g}{dt} + W_{s_{tot}} - ARESG(v_{BUB}\rho_{gb})\Big|_{ZMIX} F_{BUB} \qquad (28a)$$

where $W_{s_{tot}}$ is the total out flow from the steam dome, m_g is the total steam mass, and F_{BUB} is a factor calculated during the initialization. m_{gb} is limited between 0.0 and m_g.

The bubble density is assumed to be distributed as

$$\rho_{gb}(z) = y \frac{z}{ZMIX} + x \tag{28b}$$

where

$$\left.\begin{aligned} y &= 2C_o \frac{m_{gb}}{V_m} \\ x &= (1 - C_o) \frac{m_{gb}}{V_m} \end{aligned}\right\} \; 0 \leq \alpha_m \leq ½ \tag{28c}$$

$$\left.\begin{aligned} y &= 2C_o(\rho_g - \frac{m_{gb}}{V_m}) \\ x &= (1 + C_o) \frac{m_{gb}}{V_m} - C_o\rho_g \end{aligned}\right\} \; ½ \leq \alpha_m \leq 1 \tag{28d}$$

where α_m is the average mixture void fraction, and C_o is the user specified bubble rise gradient parameter.

The Wilson correlation expresses the void fraction as a function of the bubble rise velocity as

$$\alpha = C_1\left(\frac{\rho_g}{\rho_f - \rho_g}\right)^{0.32}\left(\frac{\sqrt{\frac{\sigma}{(\rho_f - \rho_g)}}}{DSGS}\right)^{0.19}\left(\frac{V_{BUB}}{\left[g\sqrt{\frac{\sigma}{(\rho_f - \rho_g)}}\right]^{0.5}}\right)^{C_2} \tag{28e}$$

where

$$C_1 = 0.75,\ C_2 = 0.78;\ \frac{V_{BUB}}{\left[g\sqrt{\frac{\sigma}{(\rho_f - \rho_g)}}\right]^{0.5}} > 5.5 \tag{28f}$$

$$C_1 = 0.136,\ C_2 = 1.78;\ \frac{V_{BUB}}{\left[g\sqrt{\frac{\sigma}{(\rho_f - \rho_g)}}\right]^{0.5}} < 5.5 \tag{28g}$$

Eq (28e) is inverted to express V_{BUB} as a function of α.

The mixture level is obtained from

$$ZMIX = V_m/ARESG \tag{29a}$$

where

$$V_m = m_{gb}\nu_g + m_f\nu_f \tag{29b}$$

and the water level is

$$WTRLVL = m_f\nu_f/ARESG \tag{29c}$$

where m_f is the total liquid mass.

2.4.2 Once-Through Steam Generator

2.4.2.1 Geometry

Figure 11 is a schematic of the geometry of a typical OTSG as modeled in DYNODE-P/2.

2.4.2.2 Heat Transfer

The total heat transfer from tube to shell side is the sum of the heat transfer to the subcooled, saturated, and superheat regions on the shell side.

The heat transfer coefficient from the RCS coolant to the tube inside surface is calculated from the Dittus-Boelter forced convection correlation. Heat transfer through the tube walls is based on slab heat conduction. The shell side heat transfer correlations which are used are:

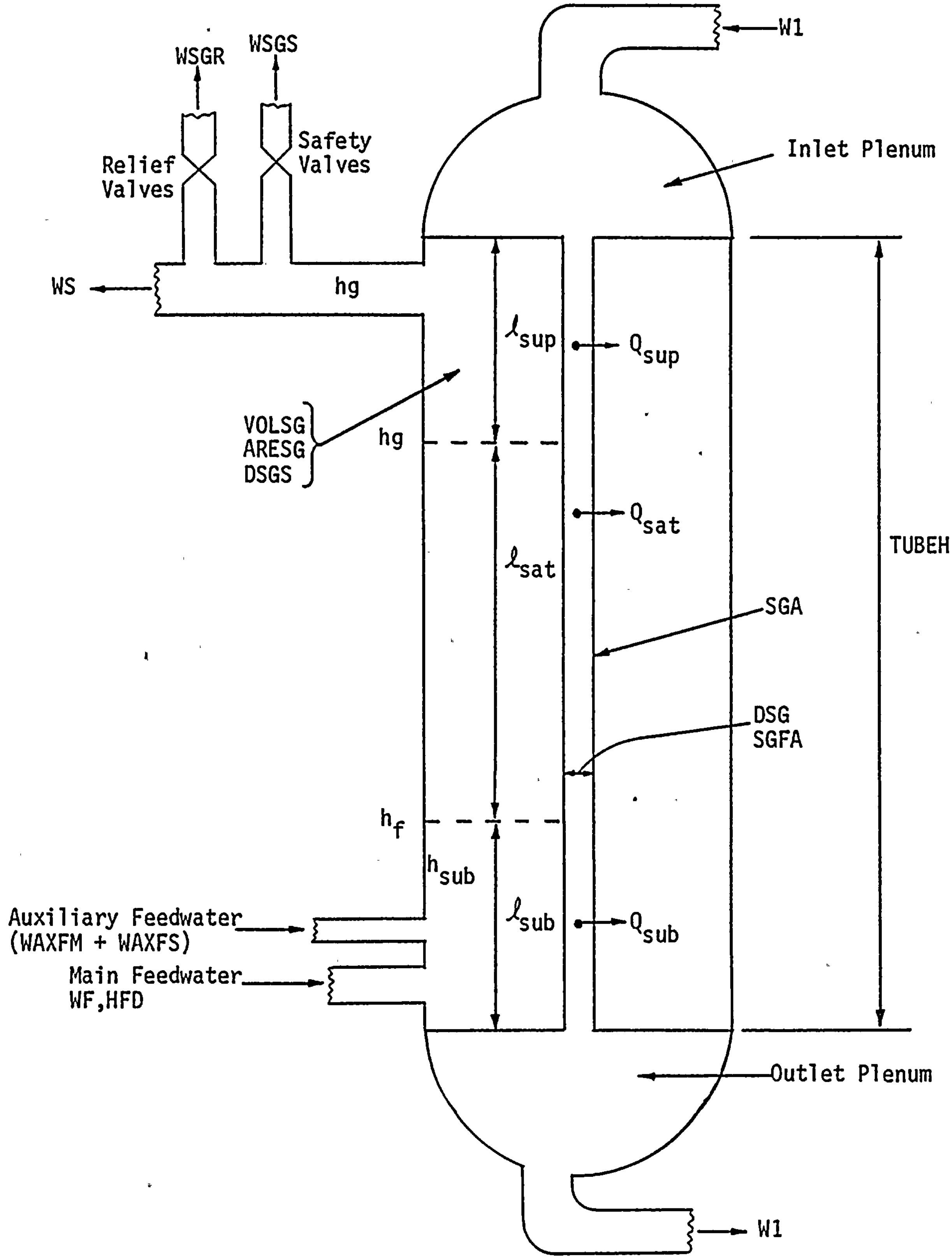

FIGURE 11 SCHEMATIC OF ONCE-THROUGH STEAM GENERATOR

- Subcooled
  - Forced convection (Dittus-Boelter with minimum of 5.0 Btu/hr ft^2 ^oF)
- Saturated
  - Nucleate Boiling (Thom)
- Superheated
  - Forced convection (Dittus-Boelter)

A single fouling factor is applied to each region. All heat transfer coefficients are evaluated from the local temperatures and properties.

The heat transfer to the subcooled region is given by

$$Q_{sub} = U_{sub} \times SGA \times \frac{\ell_{sub}}{TUBEH} \times AR_{sub} \times \Delta T_{sub} \qquad (30a)$$

where ΔT_{sub} is the difference between the tube side outlet and shell side subcooled temperatures. The constant factor AR_{sub} is calculated during initialization so that the steam generator heat load matches the core power at that time (see Section 2.8.3).

The heat transfer to the saturated and superheat regions are combined to yield

$$Q_{SS} = Q_{sat} + Q_{sup} = U_{SS} \times SGA \times \left[1 - \frac{\ell_{sub}}{TUBEH}\right] \times AR_{SS} \times \Delta T_{SS} \qquad (30b)$$

where ΔT_{SS} is the difference in the average tube-side and the saturated shell side temperatures. The constant factor AR_{SS} is calculated in the same manner as AR_{sub}.

For reverse heat transfer, the user supplied reverse heat transfer factor multiplies Eqs (30).

2.4.2.3 Dynamic Model

The conservation of mass, energy, and volume equations are solved for the shell side for the subcooled, saturated, and superheat regions. In this model, the saturated and superheat regions are treated as being saturated and in equilibrium; i.e., the superheat effect on the thermal dynamic model is neglected. The boundary between the subcooled and saturated regions is taken as the location where the fluid enthalpy reaches h_f; and the boundary between the saturated and superheat regions, where it reaches h_g.

For the subcooled region;

$$h_{sc} = \frac{1}{2} [h_{fw} + h_f] \tag{31a}$$

so that

$$\frac{dh_{sc}}{dt} = \frac{1}{2} \left[\frac{dh_{fw}}{dt} + \frac{\partial h_f}{\partial p} \frac{dp}{dt} \right] \tag{31b}$$

$$\frac{dm_{sc}}{dt} = \Big[(h_f - h_{fw}) W_{fw} - Q_{sub} + m_{sc} \left(\frac{dh_{sc}}{dt} - \frac{\nu_{sc}}{J} \frac{dp}{dt} \right) \Big] \Big/ (h_f - h_{sc}) \tag{31c}$$

and

$$\frac{dV_{sc}}{dt} = \nu_{sc} \frac{dm_{sc}}{dt} \qquad (31d)$$

W_{fw} and h_{fw} are total feedwater (main plus auxiliary) flow and corresponding average enthalpy.

For the combined saturated and superheat region, the equations for the steam and water phases are

$$\frac{dm_g}{dt} = W_{ev} - W_s \qquad (32a)$$

$$\frac{dm_f}{dt} = W_{fw} - \frac{dm_{sc}}{dt} - W_{ev} \qquad (32b)$$

$$\frac{dV_{ss}}{dt} = \frac{-dV_{sc}}{dt} \qquad (32c)$$

$$W_{ev} = [W_s \nu_g - W_{fw} \nu_f - (m_g \frac{\partial \nu_g}{\partial p} + m_f \frac{\partial \nu_f}{\partial p}) \frac{dp}{dt} + \frac{dm_{sc}}{dt} (\nu_f - \nu_{sc})]/(\nu_g - \nu_f) \qquad (32d)$$

$$\frac{dU_{fg}}{dt} = Q_{ss} + h_f W_{fw} - W_s h_g - \frac{dm_{sc}}{dt} h_f - \frac{p}{J} \frac{dV_{ss}}{dt} \qquad (32e)$$

In these expressions, W_{ev} represents the rate at which saturated liquid is evaporated, W_s is the total steam flow out of the generator, and U_{fg} is the total internal energy of the saturated liquid and steam.

The above set of equations is solved for dp/dt which is integrated to yield the transient shell side pressure. In addition, the mass and volume equations are integrated. The subcooled length is given by

$$\ell_{sub} = m_{sc}\, \nu_{sc}/ARESG \qquad (33)$$

The transient saturated length is computed from the total saturated liquid volume assuming that the enthalpy varies linearly from h_f to h_g over this region (uniform heat flux assumption).

The water level is computed as the total liquid (subcooled plus saturated) volume divided by ARESG.

The water property curve fits of Reference 2 are used on the secondary side of the OTSG model.

2.4.3 Main Feedwater System

The main feedwater system is treated identically for both the UTSG and OTSG. The initial feedwater inlet enthalpy is specified by the user, and the program computes the initial feedwater flow (and steam flow) based on the initial steam generator heat load.

For the transient conditions, changes in the feedwater flow and enthalpy can be specified individually for each steam generator by the user through input table sets of $\Delta(W_{fw}/W_{fw_o})$ and Δh_{fw} versus time.

Alternately, changes in the feedwater flow which reflect the feedwater controller action to match the water level and the power dependent level demand signal can be considered (see Section 2.7.4.1). In this case, the feedwater flow to each generator is controlled independently. The feedwater enthalpy is assumed constant.

The main feedwater to both SG's is isolated during a transient if a safety injection actuation signal is generated (see Section 2.6.1.2) or one of the following signals is actuated for either generator:

- Low steam generator pressure
- High steam generator water level
- Low core average temperature coincident with a reactor scram actuation signal

Following the isolation signal, the feedwater flow is ramped down to a minimum value WFDMIN over the time interval FWRMPT and feedwater controller action is not permitted. These quantities are user specified. Feedwater isolation is not considered, if the transient feedwater flow and enthalpy are specified for either steam generator.

The auxiliary feedwater systems are described in Section 2.7.1.

2.4.4 Main Steam System Relief and Safety Valves

Each SG has an identical set of relief and safety valves located before the steam line isolation valve (see Figures 10 and 11). The steam flow through each valve is based on the same model. For the relief valves in steam generator i,

$$WSGR_i = F_{SGRV_i} \left[\frac{2\rho_{SG_i}}{v_{g_i} (K/A^2)_{SGRV}} \right]^{1/2} \times N_{SG_i} \tag{34a}$$

where

$$F_{SGRV_i} = \frac{(p_{SG_i} - p_{SGRV_1})}{(p_{SGRV_2} - p_{SGRV_1})} \tag{34b}$$

$$0 \leq F_{SGRV_i} \leq 1.0 \tag{34c}$$

and N_{SG_i} is the total number of steam generators represented by loop i. Similar expressions apply to the safety valves.

2.5 Main Steam System

This section describes the models provided in DYNODE-P/2 for representing the main steam system. The geometric representations, the main steam line isolation and check valves, the steam dump and bypass valves, and the turbine valves are discussed. In addition, the dynamic pressure model, transient power demand simulation, and main steam system break model are covered.

An option has been provided, (ISTFLW), which allows the user to neglect the main steam system representation. When this option is exercised, the flow through the main steam line isolation valves is set equal to the total feedwater flow (main plus auxiliary). Also, if this option is used, the input temperatures for the steam generator shell sides are used to set the initial shell side pressures for U-tube steam generators (IFLGT = 1).

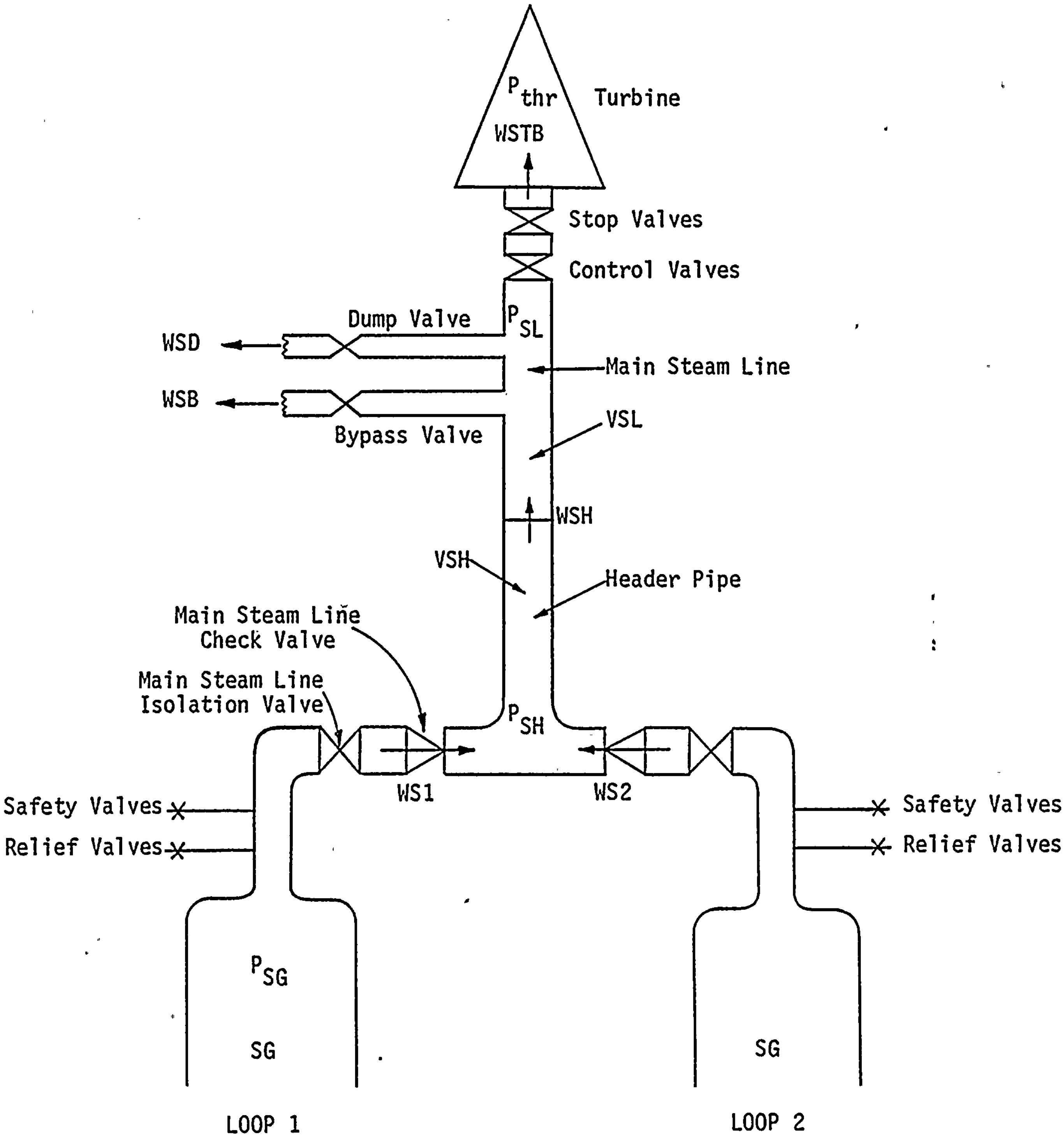

FIGURE 12 SCHEMATIC OF MAIN STEAM SYSTEM WITH ONE MAIN STEAM LINE TO TURBINE

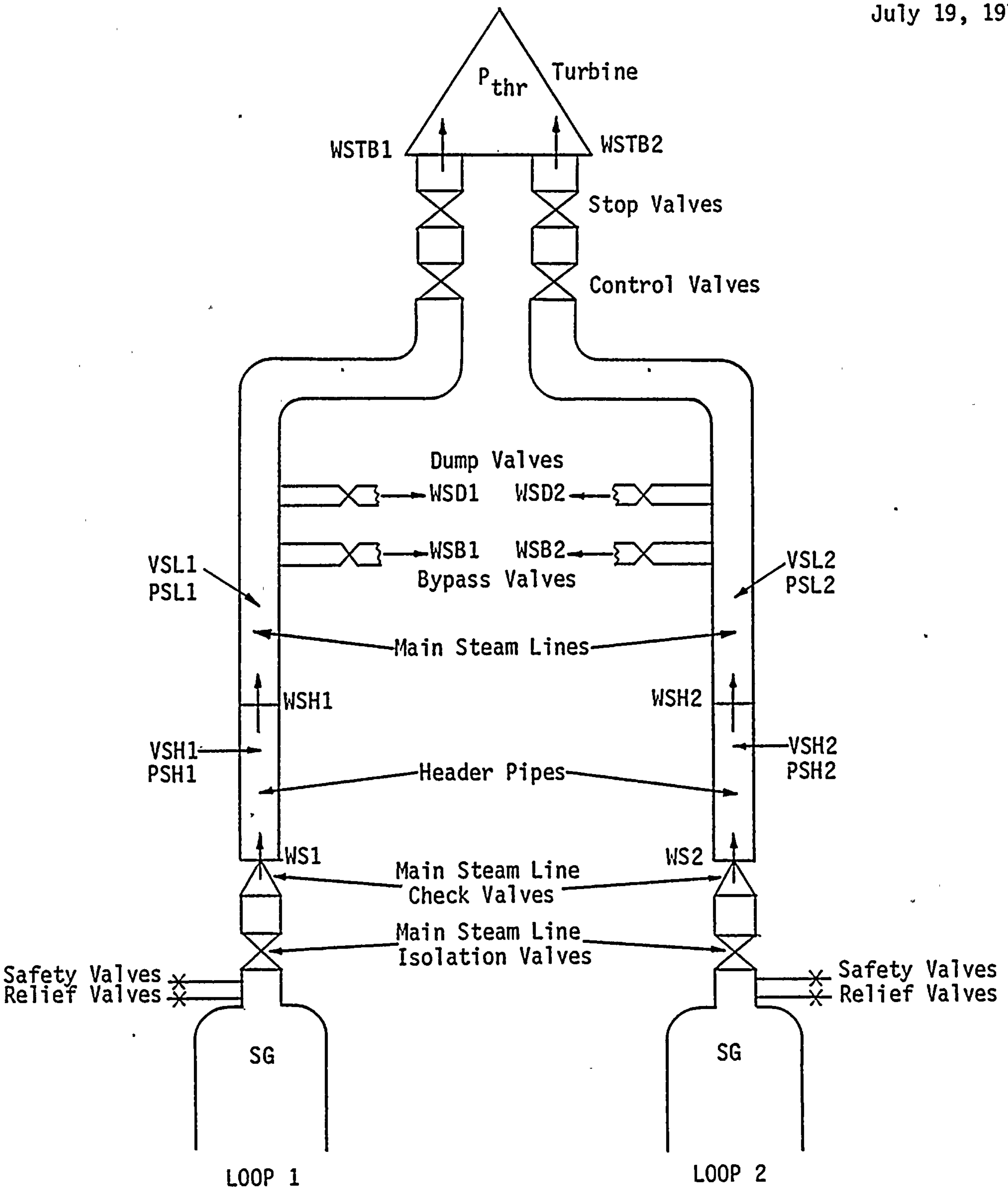

FIGURE 13 SCHEMATIC OF MAIN STEAM SYSTEM WITH TWO MAIN STEAM LINES TO TURBINE

2.5.1 Geometry

Two types of main steam system piping can be represented in DYNODE-P/2 as shown in Figures 12 and 13. The geometry selection is made by the user through the input parameter LSS.

2.5.2 Main Steam Line Isolation and Check Valves

The initial main steam line isolation valve positions are arbitrary (between full open and full closed) and specified by the user.

The actuation signal for main steam line isolation valve closure is optional based on user specification. The signal can be ignored or can be generated by one of the following two sets of conditions occurring in either generation:

- Either Hi-Hi steam line flow or Hi steam line flow and low core average temperature in coincidence with a safety injection actuation.
- Low steam generator pressure.

Closure of the isolation valves begins following the user specified delay time after the actuation signal and is linear with time. The time delays and closure rates can be different for the two valves.

The check valves are simulated by prohibiting back flow from the header pipes into the steam generator.

The flow through these valves is governed by the momentum equation

$$I_{SL} \frac{dWS}{dt} = (P_{SG} - P_{SH}) - \left(\frac{K}{A^2}\right)_{SL} \frac{WS|WS|\nu_{g_{SG}}}{2} \quad (35a)$$

The area in the inertia factor $I_{SL} = (L/A)_{SL}$ and the area A_{SL} are varied in direct proportion to the main steam line isolation valve area. The integration of Eq (35a) is carried out over a time step evaluating the flows on the right hand side at the end of the step.

The flow from the header pipe into the main steam line is obtained from a similar solution to

$$I_{SH} \frac{dWSH}{dt} = (P_{SH} - P_{SL}) - (\frac{K}{A^2})_{SH} \frac{WSH|WSH|\nu g_{SH}}{2} \qquad (35b)$$

Eqs (35a) and (35b) are not used, if either a turbine runback or a turbine power demand transient (see Section 2.5.5) are simulated. In these cases, WS and WSH are obtained from the product of the initial flows and the fractional turbine demand.

2.5.3 Steam Dump and Bypass Valves

The steam dump and bypass valves are represented individually for each steam line. These valves may be initially open. The user specifies these valve positions for each line. Each valve in each line is treated separately.

The dump and bypass valves are modeled in an identical manner, so that the following discussion which relates to the dump valves also applies to the bypass valves.

A dump valve area is automatically controlled in one of the following modes based on user specifications:

- Maximum of high steam line pressure and high core average temperature.
- High steam line pressure before scram actuation and maximum of high steam pressure and high core average temperature after scram.

When controlling on core average temperature, the highest auctioneered temperature is used. The options for selecting the temperature sensor locations in the RCS are described in Section 2.6.2.

Alternately, dump valve opening can be initiated following the user specified actuation signal and is linear with time.

The valve opening rates can be different for the valves in each line. In addition, the fraction of valve opening can be limited through user specifications.

The dump flow rates are given by

$$WSD = WSH_o \times F_D \times A_D \tag{36}$$

where WSH_o is the initial steam line flow rate, F_D is the total valve capacity, and A_D is the fractional open area of the valve.

2.5.4 Turbine Control and Stop Valves

The turbine control and stop valves are represented individually for each steam line and can all be treated separately. The initial turbine control valve positions for each line are specified by the user. The initial stop valve positions are assumed full open.

The control valve position during the transient can be adjusted to match the turbine power demand (see Section 2.5.5) or to simulate a turbine runback. In this latter case, the user specifies the time at which runback is initiated and runback level. For either case, the flow through the turbine valves is set equal to the product of the initial flow and the fractional turbine demand.

Stop valve closure (turbine trip) can be actuated by one of the following signals:

- Overspeed - Turbine power demand exceeds the specified setpoint. Note: This signal also generates a reactor scram actuation signal if the setpoint for Trip 7 > 0.0 (see Section 2.6.2.1).
- A reactor scram actuation.

The stop valves begin to close linearly with time following the specified time delay after the actuation signal.

The time delay, closure rate, and fraction of valve closure are specified independently for each steam line.

The steam flow to the turbine for each line is given by the solution to the momentum equation.

$$I_{TB} \frac{dWSTB}{dt} = (P_{SL} - p_{thr}) - \left(\frac{K}{A^2}\right)_{TB} \frac{WSTB|WSTB|v_{g_{SL}}}{2} \quad (37)$$

This equation is solved in the same manner as Eq. (33a).

A_{TB} is the fraction turbine flow area relative to the initial area (minimum of control and stop areas), and p_{thr} is the constant turbine throttle pressure (calculated from the initial flow conditions and valve positions). The inertia factor varies inversely with A_{TB}.

No back flow from the turbine into the steam line is permitted.

2.5.5 Power Demand

A turbine power demand transient can be simulated in DYNODE-P/2 through a user specified table of demand versus time. This table is input in the same manner as the core power forced table (see Section 2.2.3.1). If the table set is not entered, the power demand is held constant at the initial value.

This turbine power demand is used to control the main steam system flows, to set the core average temperature demand for the control rod controller (see Section 2.7.4), and to determine the actuation signal for turbine stop valve closure (overspeed trip).

2.5.6 Main Steam System Break

DYNODE-P/2 provides simulation of a break in the main steam system. The break can be placed in one of the following locations:

- In the steam line between the steam generator outlet and the steam line isolation valve.
- In the steam header pipe.
- In the main steam line.
- In the main feedwater pipe between the isolation valve and the steam generator inlet.

In any case, the break is on the Loop 2 side of the main steam system.

The user specifies the time the break is assumed to occur, the duration of the break opening, and the effective break area.

The break flow is given by

$$WBREAK = A_{Break}(t) \times G(h,p) \tag{38}$$

where $A_{Break}(t)$ is assumed to vary linearly with time, and $G(h,p)$ is the mass flow rate per unit area. G is evaluated from an interpolation/extrapolation in the Moody leak flow tables as programmed in RELAP4 (Reference 5) based on the enthalpy and pressure at the break location. For a break in the steam pipe, perfect moisture separation in the steam generator is assumed. The break flow is added to the other flows out of the region in which the break is located in considering the mass and energy balances.

2.5.7 Dynamic Pressure Model

The initial pressures in the main steam system are calculated by DYNODE-P/2 during the initialization segment (see Section 2.8.5) based on the initial flow conditions and valve positions by setting the time derivative to zero in the momentum equations.

The transient pressure responses of the steam line pipe regions are calculated from the conservation of mass, energy, and volume. The steam flow rates into and out of each region are calculated from the previous equations. For a typical region i,

$$\frac{dm_i}{dt} = \sum_j W_{ij} \qquad (39a)$$

$$\frac{dU_i}{dt} = \sum_j (hW)_{ij} \qquad (39b)$$

and the volume is constant. The sums are taken over all the flows entering (positive) and leaving (negative) the region.

The specific volume and internal energy are used to evaluate the region pressure based on the water properties of Reference 2.

The pressures in the main steam line regions are not allowed to drop below atmospheric pressure during depressurization accidents.

2.6 Safety Systems

This section describes the simulation of the high pressure safety injection system (HPSIS) and the reactor protective system (RPS) as simulated in DYNODE-P/2. For each, the components and the actuation systems are described. The remaining systems simulated are described in Section 2.7.

2.6.1 High Pressure Safety Injection System

The HPSIS delivers water to the RCS during accidents in which the RCS coolant volume is reduced.

2.6.1.1 Components

The HPSIS consists of a high head pump which delivers water to the cold legs of the RCS (see Figure 1) following an actuation signal. The delivery characteristics of the pump (head-capacity) are specified by a table set of flow rate versus RCS pressure.

Interpolation/extrapolation in the table set is performed based on the pressurizer pressure. Negative flows are not permitted.

If the delivery of more than one pump is desired, the head-capacity curve must include the total flow rate which is desired. The enthalpy and boron concentration of the safety injection water is specified by the user.

Provisions have been made in the model to allow the boron concentration in the safety injection line (between the concentrated borated water storage tank (BWST) and the RCS injection point) to initially have a different boron concentration relative to the BWST water. In this case, the user specifies the water mass and concentration in the line and this concentration is used until the water mass is swept out. This effect simulates transport delay between the BWST and the RCS.

2.6.1.2 Actuation Signal

The HPSIS actuation signal is generated automatically when 5
the pressurizer pressure and water level exceed their set-

points. The actuation logic is optionally either an or or an and, i.e. one of the following two conditions: 5

Low pressurizer pressure or low pressurizer water level

Low pressurizer pressure coincident with low pressurizer water level

The actuation signal can also be initiated by user specification.

The water delivery to the RCS begins after the specified delay time following the actuation signal.

2.6.2 Reactor Protective System

The RPS is designed to scram the reactor during transients and accidents to prevent or mitigate fuel damage. The use of the RPS is optional in DYNODE-P/2.

The set of trip functions which are simulated in DYNODE-P/2 are listed in Table 1. In addition, if the turbine trips on overspeed (see Section 2.5.4), a reactor trip is also actuated if it has not yet been generated by some other actuation signal and the setpoint for trip 7 > 0.0. Alternately, the user may specify the time at which scram actuation occurs. Trips relating to the steam generator secondary side are actuated if the setpoint is reached in either generator.

The control rod reactivity insertion begins after the appropriate time delay following the actuation signal. For a turbine overspeed trip, the trip delay time specified for Trip 7 in Table 1 is used.

The trip setpoints for the first ten trips in Table 1 are constants as specified by the user. The overpower and overtemperature trip setpoints are variables which depend on the core average temperature and pressure as described below.

Two options are available for simulating the overpower and overtemperature ΔT trips. The first option consists of using the steady-state lines as shown in Figures 14 and 15. In this case, the core average temperature, ΔT^{ave}_{core}, is used with Figure 14 to generate the Overpower ΔT trip setpoint for ΔT_{core}. When the sensed ΔT core exceeds the setpoint, a trip actuation occurs. Similarily, T^{ave}_{core} and the RCS pressure are used with Figure 15 to generate the Overtemperature ΔT trip setpoint for ΔT_{core}. This calculation is performed in the following manner. The user specifies the setpoint lines at various constant pressures. The setpoint on ΔT_{core} for a given T^{ave}_{core} is calculated as a function of pressure. An interpolation/extrapolation is performed to determine the trip setpoint corresponding to the current pressurizer pressure. When the sensed ΔT_{core} exceeds the setpoint, a trip signal is generated.

The second option consists of dynamic simulations of the setpoint generators. In this case, the time - dependent setpoints are calculated from the following expressions:

$$\Delta T^{\text{Setpoint}}_{\text{Overpower}}(s) = \Delta T^{op}_{o} \left\{ K_4 - K_5 \frac{\tau_3 s}{(1 + \tau_3 s)} T^{ave}_{core}(s) - K_6 \left(T^{ave}_{core}(s) - T^{op}_{o}\right) \right\} \quad (40a)$$

and

$$\Delta T^{\text{setpoint}}_{\text{overtemperature}}(s) = \Delta T^{oT}_{o} \left\{ K_1 - K_2 \frac{(1 + \tau_1 s)}{(1 + \tau_2 s)} \left(T^{ave}_{core}(s) - T^{oT}_{o}\right) + K_3 \left(p(s) - p_o\right) \right\} \quad (40b)$$

These equations express the setpoints as a function of the frequency domain variable s. The corresponding equations in the time domain are obtained by Laplace transform inversions which are the expressions programmed in DYNODE-P/2.

The gains K_1 through K_6 and time constants τ_1, and τ_3 are input parameters. The overpower ΔT setpoint is calculated assuming $K_6 = 0.0$ when $T_{core}^{ave} < T_o^{op}$ and the rate/lag term is not allowed to increase the setpoint.

In addition, options are available for selecting the temperature sensor locations and the trip logic as described below. T_{core}^{ave} and ΔT core are given by

$$T_{core}^{ave} = (T_{hot} + T_{cold}) / 2 \qquad (40c)$$

and

$$\Delta T_{core} = T_{hot} - T_{cold} \qquad (40d)$$

where T_{hot} and T_{cold} are the sensed temperatures which are based on 5
either the reactor vessel upper and lower plenum temperatures, the hot and cold leg temperatures, or the steam generator inlet and outlet plenum temperatures, respectively. When the latter two sets of sensor locations are selected, two sets of temperatures and corresponding trip set points are calculated, one for each of the two loops. For these cases, the user may opt for a trip signal generation either when either loop ΔT_{core} exceeds the corresponding setpoint or only when the Loop 1 ΔT_{core} exceeds the setpoints. This latter option is provided to simulate multi-trip logic circuits for plants with three or more loops. The calculated fluid temperatures corresponding to the sensor locations are delayed and then lagged to simulate 5
transport delay and sensor response times in computing the sensed hot and cold temperatures for use in Eqs (40).

It should be noted that the T_{core}^{ave} described above is also used as input to the steam dump and bypass valve controllers, the control rod controller, and the main feedwater and steam line isolation activation systems. In cases where the sensors are placed in the

loops, the highest auctioneered T_{core}^{ave} is used as input to these control systems.

In addition, auctioneering is used to select the highest sensed ΔT_{core} and the lowest $\Delta T_{core}^{setpoint}$ to test for the actuation of the control rod controller prohibit signal.

TABLE 1

RPS TRIP FUNCTIONS

TRIP NUMBER	TRIP FUNCTION
1	High neutron power
2	High pressurizer pressure
3	Low pressurizer pressure
4	High pressurizer level
5	Low pressurizer pressure
6	Low-Low steam generator water level
7	Turbine Trip - High steam generator level
8	Low reactor coolant flow
9	High power to flow ratio
10	High core outlet temperature
11	Overpower ΔT
12	Overtemperature ΔT

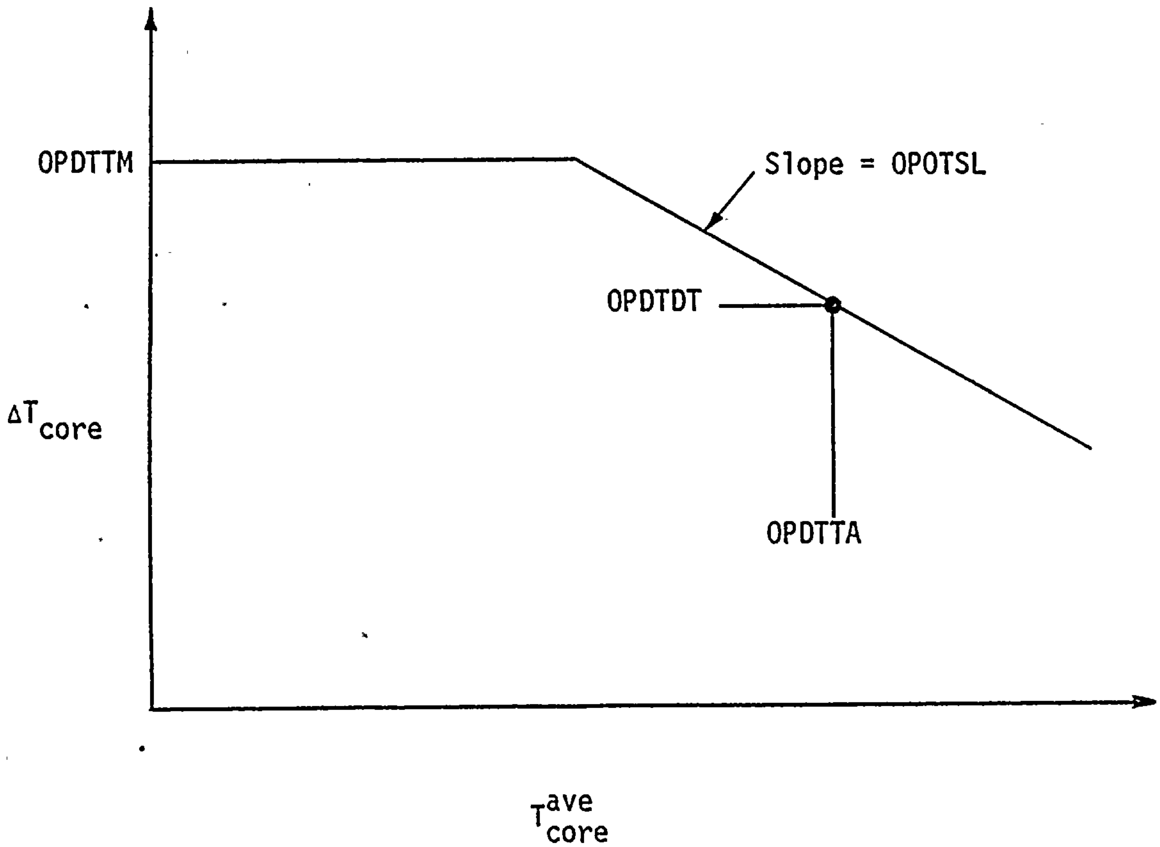

FIGURE 14 OVERPOWER ΔT TRIP

It should be noted that when the RPS is simulated, DYNODE-P/2 utilizes all the trips in Table 1. If the user desires to ignore any of these trips, the trip setpoints must be set at a level which is outside the range over which the corresponding parameter varies during the transient.

The program logic is structured so that the earliest scram time (time at which setpoint is reached plus delay time) is 5
used to begin the scram reactivity insertion.

2.7 Additional Systems

This section describes the remaining systems which are simulated in DYNODE-P/2. For each system, the component actuation, and controls are discussed.

2.7.1 Auxiliary Feedwater

The auxiliary feedwater system consists of a motor and a steam-turbine driven feedwater pump. Each type of pump is represented and treated separately.

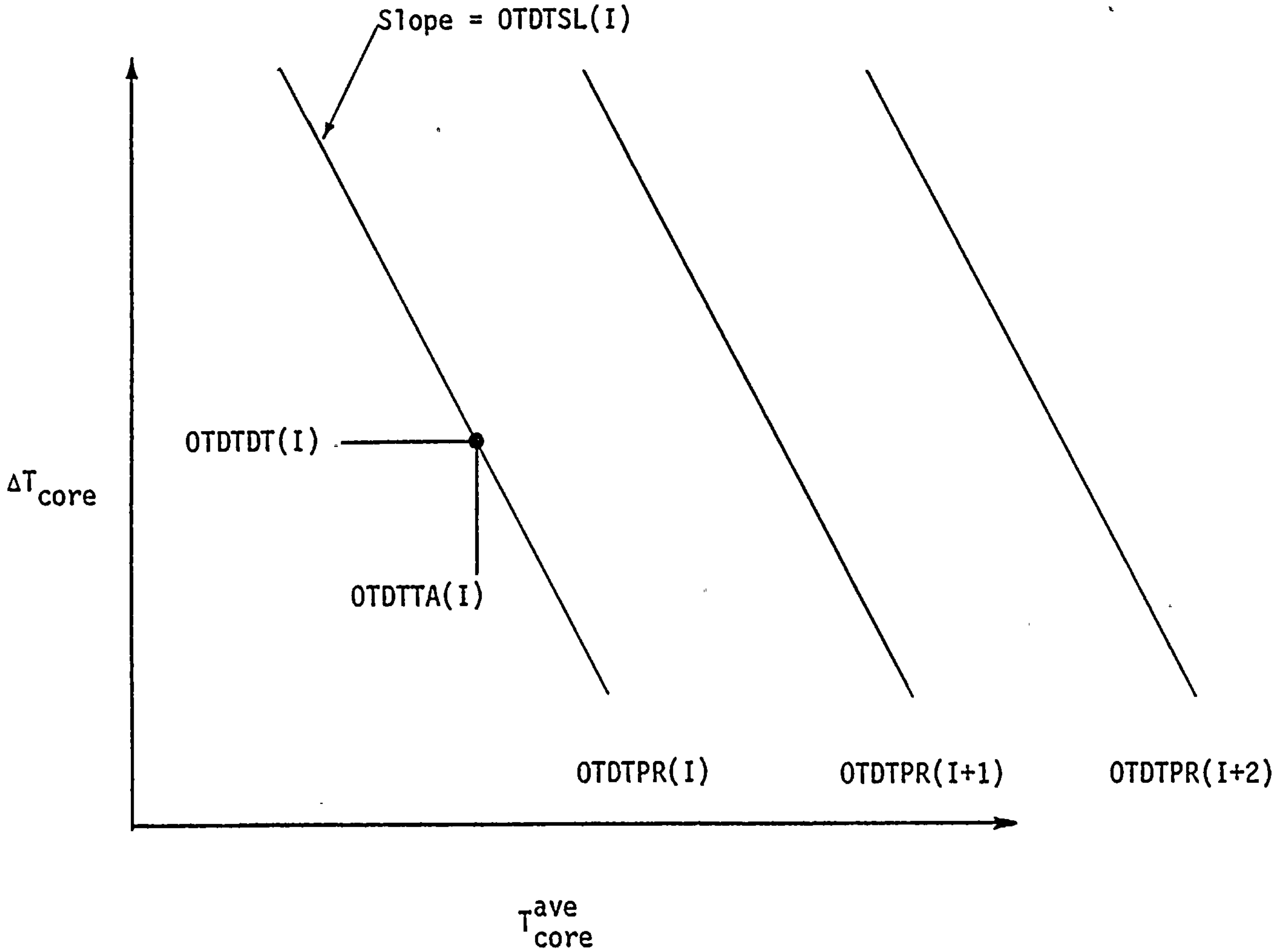

FIGURE 15 OVERTEMPERATURE ΔT TRIP

Each pump has its own head-capacity curve consisting of a user specified data set of flow versus steam generator pressure. These head-capacity curves are given in terms of the flow per steam generator and the flow is obtained by interpolation/extrapolation in these table sets. The enthalpy of the water from each pump is specified separately.

Automatic actuation of each auxiliary feedwater pump occurs under the following conditions:

- At the time of HPSIS actuation.
- At the time main feedwater is totally isolated in either steam generator (zero main feedwater flow).
- Low-Low steam generator water level (RPS Trip 6 setpoint) in either steam generator.

When this latter actuation signal is generated, auxiliary feedwater to the steam generator in which the actuation signal was generated is not permitted. Alternately, each auxiliary feedwater pump can be actuated at a pre-specified time which is input by the user.

Auxiliary feedwater delivery begins after the specified time delay following the actuation signal.

2.7.2 Pressurizer Heaters and Sprays

The pressurizer heater system contains a proportional and a back-up bank of heaters. The heater output is controlled by the pressurizer pressure and water level. The pressure control is shown in Figure 16.

The level control takes precedence over the pressure control when either the high or the low water level setpoint is reached. If the water level exceeds the high level

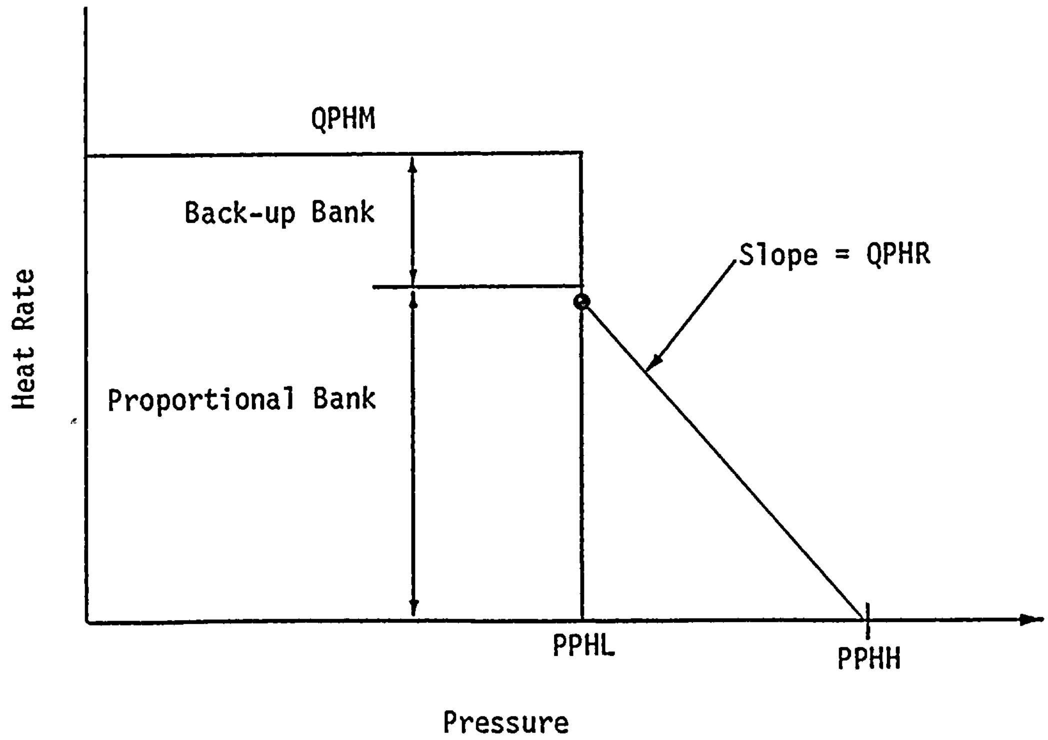

FIGURE 16 PRESSURIZER HEATER PRESSURE CONTROL

setpoint, all the heaters are turned on and the heat output is QPHM. If the water level drops below the low level setpoint, the heaters are turned off.

The pressurizer spray system allows water from the cold leg to flow into the pressurizer steam region (see Figure 1). The spray system is controlled by the pressurizer pressure as shown in Figure 17.

2.7.3 Charging and Letdown

The charging and letdown systems are connected to the cold leg as shown in Figure 1. These systems are controlled by the pressurizer water level.

The charging system is turned on when the level falls below the setpoint, and water is pumped at constant rate. The enthalpy and boron concentration of this water is specified by the user.

The letdown flow control is shown in Figure 18.

2.7.4 Control Systems

This section describes the main feedwater and control rod control systems.

2.7.4.1 Main Feedwater Controller

The main feedwater controller adjusts the feedwater flow to match the steam generator water level to the water level demand. The water level demand is based on the core power and is obtained from an interpolation/extrapolation the user specified table of water level demand versus power. Feedwater control for each steam generator is separate. This controller is bypassed if the feedwater flows and enthalpies are specified by the user for either steam generator.

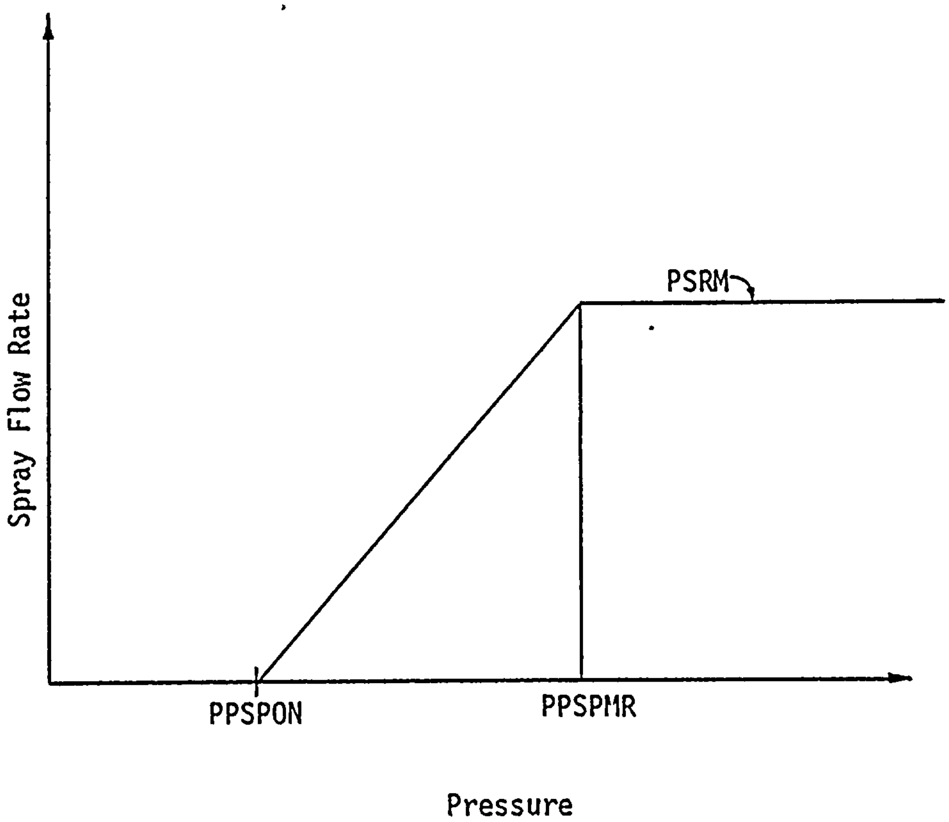

FIGURE 17 PRESSURIZER SPRAY PRESSURE CONTROL

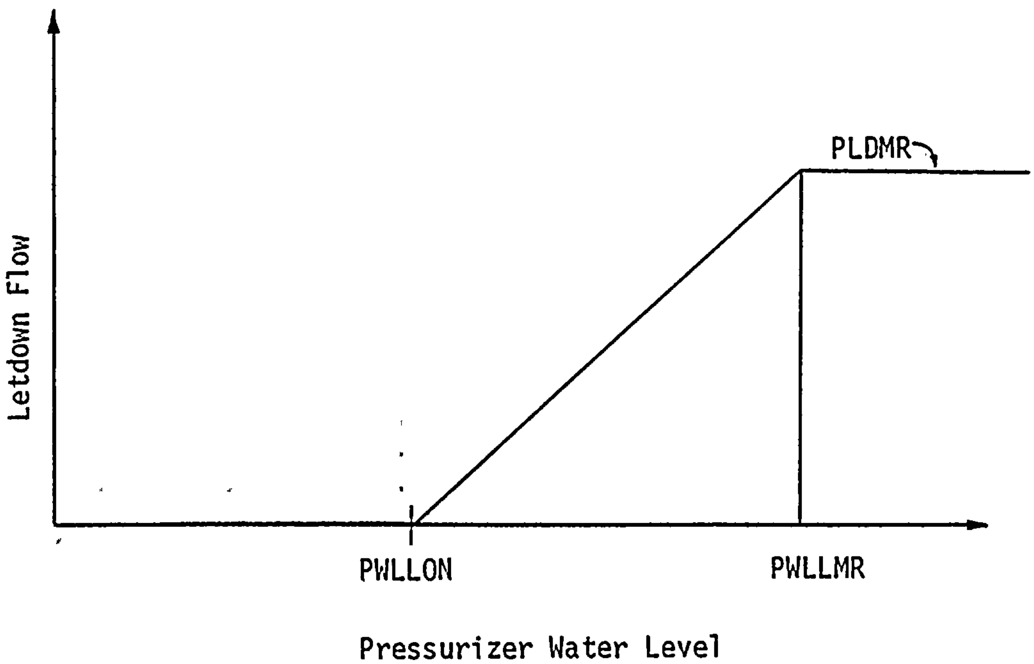

FIGURE 18 LETDOWN FLOW CONTROL

The difference between the water level and the demand is the error signal ε. The feedwater water flow is given by

$$WF(t) = WF_o + \int_o^t \frac{\partial}{\partial t'} [WF(t')]dt' \quad (41a)$$

where

$$\frac{\partial}{\partial t} WF = -WF_o \times C_{fw} \left\{ \frac{\tau_{fw1}}{\tau_{fw2}} \varepsilon(t) + \left(1 - \frac{\tau_{fw1}}{\tau_{fw2}}\right) e^{-t/\tau_{fw2}} \int_o^{t/\tau_{fw2}} e^y \dot{\varepsilon}(y) dy \right\} \quad (41b)$$

where C_{fw} is the controller constant, and τ_{fw1} and τ_{fw2} are the lead and lag time constants, respectively. No controller action is permitted if the error signal is within the controller deadband. The magnitude of the feedwater flow is limited to be less than the user specified maximum value.

Feedwater control is not permitted following a feedwater isolation actuation signal.

2.7.4.2 Control Rod Controller

In Eq (14a), Δk_{CRC} is the change in reactivity produced by the control rod controller. This controller adjusts the rod position to correct the input error signal to the controller. Control on either the core average temperature or the power level is permitted. In either case,

$$\Delta k_{CRC}(t) = \int_o^t dt' \frac{\partial}{\partial t'} [\Delta k_{CRC}] \quad (42a)$$

where

$$\frac{\partial}{\partial t}[\Delta k_{CRC}] = -C_{CRC}\left\{\varepsilon(t)\ \frac{\tau_{CRC1}}{\tau_{CRC2}} + \left(1 - \frac{\tau_{CRC1}}{\tau_{CRC2}}\right) e^{-t/\tau_{CRC2}} \int_0^{t/\tau CRC2} e^y \varepsilon(y)\, dy\right\} \tag{42b}$$

where ε is the error signal, τ_{CRC1} and τ_{CRC2} are the lead and lag time constants, and C_{CRC} is the controller constant. No controller action is taken if the error signal is within the deadband specified by the user.

Controller action is also prohibited under any of the following conditions:

- After a scram actuation signal.
- Low power level setpoint.
- Highest auctioneered sensed ΔT_{core} within a specified margin of the lowest auctioneered overpower trip setpoint.
- Highest auctioneered sensed ΔT_{core} within a specified margin of the lowest auctioneered overtemperature trip setpoint.

The last two prohibits are inoperative, if the RPS is not used. Also, a control rod withdrawal prohibit following a turbine runback can be optionally specified by the user.

2.8 Initialization

This section describes the initialization which is performed by DYNODE-P/2 for each of the model components and systems based on the specified initial conditions.

The initial conditions relating to plant operation which are specified for each case consist of: core power level and distribution; pressurizer pressure and water level; core inlet enthalpy; RCS loop flow rates; boron concentration; steam generator temperatures, feedwater enthalpies, and water levels; and main steam system valve positions.

2.8.1 Core

The initialization consists of solving the set of differential equations with all time derivatives set equal to zero. The variables which are initialized are the fuel rod temperatures, the axial coolant enthalpy and mass distribution, and the delay neutron and decay heat precursor concentrations. In the case of the fuel rod temperatures, an iteration procedure is required, since the oxide conductivity and heat capacity are temperature dependent. Convergence of this process is to a built-in criterion of 0.1°C for all oxide and cladding nodes.

k_{eff} is set to unity.

2.8.2 Reactor Coolant System

The enthalpy distribution for all regions of the RC system (excluding the core and pressurizer) is calculated from the initial core inlet and outlet enthalpies, and the initial loop flow rates and steam generator heat loads. The initial SG heat load split for the two loops is assumed to be proportional to the absolute value of the loop flow rates. The initial flow in Loop 1 must be greater than zero, while the Loop 2 flows can be either positive or negative. However, $W1 + W2 = WT > 0$.

The mass and temperature distributions are calculated from the enthalpy distribution and the initial pressurizer pressure.

The initial pressurizer water and steam are assumed to be saturated at the initial pressurizer pressure.

The initial boron concentration of the water in all regions of the RC system (including the core and pressurizer) is assumed to be uniform at the value specified by the user. The pressurizer steam is assumed to be boron free.

If the dynamic pump option is selected, the program will initialize the pump speeds and rated pump head, H_R, for the given initial flow and pump status conditions. This initialization consists of solving the loop momentum and pump speed equations given in Section 2.3.4 with all time derivatives set to zero. In performing this initialization, the input values for the loop flow rates are used for those loops in which the pumps are specified to be initially running. The 4
flows in idle loops are calculated from the conservation of momentum equations. It should be noted that at least one pump must be running initially. The rated pump head is determined from the condition that the pump pressure rise must balance the loop pressure losses. Similarly, the initial pump speeds are calculated by balancing the motor torque against the net losses (hydraulic, friction, and windage). Pumps which are initially idle have zero initial speeds.

2.8.3 Main Steam System

The initializations of the shell side of the steam generators and the main steam system are performed simultaneously. This is necessary, since these regions are thermal-hydraulically coupled. The initialization for both types of steam generators is similar. Thus, this procedure is described only for the UTSG design.

The procedure begins with the SG shell side. The heat load for each generator is set on the basis of the RCS loop flows as described in the previous section. The heat transfer coefficients are computed as described in

Section 2.4.1.2. $\Delta T_{\ell m}$ is calculated from Eq (27a) with AR = 1.0. Since the tube side temperature is known from the RC system initialization, this sets the shell side temperature and hence pressure along with the saturation properties.

From the heat load, feedwater enthalpy, and h_g, the initial steam flow is computed for each generator. The initial feedwater flow is set equal to the steam flow. The steam flow sets the pressure drop between each steam generator outlet and the corresponding steam line header pipe and hence the header pipe pressure.

If there is only one main steam line to the turbine (see Figure 12), the header pipe is a common pressure region as seen by both generators. Hence, the header pressures as computed for both generators must be equal. If these

pressures differ by more than 0.1%, the steam generator shell side pressures are adjusted to force the header pressures to be equal and the saturation properties are evaluated at the new pressures. With the new saturation temperatures, the effective UA of each generator is computed. The AR factors are then calculated from the ratio of the effective to the actual UA.

The above procedure is repeated until the two header pressures agree to within 0.1%.

If there are two main steam lines to the turbine (Figure 13), the common pressure region is the turbine throttle. Thus, for this case, the procedure is as described above except that the additional pressure drop from the header pipe to the turbine is also included in these considerations.

Once the region pressures have been computed, the masses and enthalpies are set based on the saturated properties and the initial water levels in the steam generators are obtained from the mixture heights and void fractions. The bubble rise factor, F_{BUB}, is calculated so that the time derivative of the bubble mass is zero.

It should be noted that the initial flow distribution within the main steam system takes into account the specified initial valve positions.

2.9 Integration

DYNODE-P/2 solves the core differential equations for the fuel rod temperatures, coolant channel enthalpies, and point kinetics simultaneously utilizing the Runge-Kutta-Merson method (References 7 and 8) with variable time steps. The time steps are selected automatically within the program based on the estimated truncation error. If the maximum relative truncation error exceeds the user supplied accuracy limit ACCURC, the time step is halved and the integration is repeated; if the

maximum error is less than ACCURC/32, the time step is doubled for the next integration. 2

The user specifies the minimum and maximum time step sizes allowed for each case as described below as well as the print interval size. 2

If the dynamic pump option is selected, the loop momentum and pump speed equations are integrated simultaneously using the Runge - Kutta - Merson integration method. These integrations are performed simultaneously with the RCS equations which describe the enthalpy distribution. In this manner, the loop flows are updated continuously for use in the RCS enthalpy transport equations. 4

This same integration method is employed to solve the set of simultaneous differential equations which describe the enthalpy and boron concentration distribution in the remainder of the RCS, excluding the pressurizer. All other differential equations are solved by explicit integration.

The core and the RCS differential equations are integrated over separate time step sizes. The program automatically selects the optimal time step for each set of equations. Figure 19 demonstrates the manner in which the variable minimum time step (DELIN) and the print interval (DELLP) are specified by the user. The set DELMX(I) specify the maximum RCS time step during the transient and are input in the same manner. The minimum time step for the core integration is obtained by dividing the minimum RCS value by the user specified integer NOKIN. The time step size for the main steam system equations is obtained by dividing the current RCS time step size by the user specified integer NOSTM(I). 2

The time step for the RCS integration is also utilized to solve all the remaining differential equations for the RCS. 2

For stability reasons, it is recommended that for transient calculations the maximum specified time step should satisfy the following relationship:

$$DELMX \leq \min \{\frac{m_i}{W_i}\} \qquad (43)$$ 2

where the set i includes all the RCS regions.

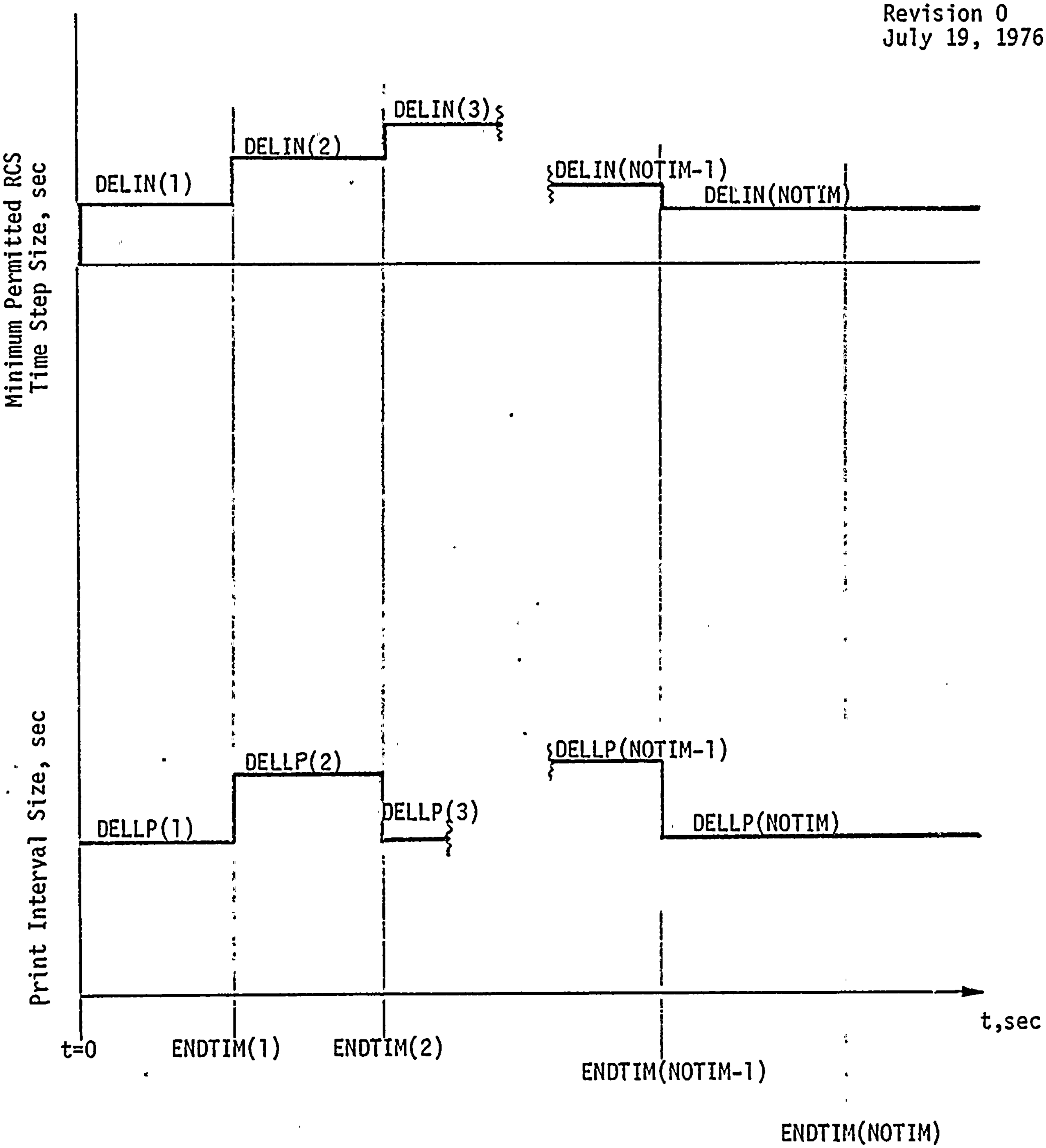

FIGURE 19 TIME STEP AND PRINT INTERVAL INPUT

3.0 INPUT DESCRIPTION

This section describes the input to DYNODE-P/2. All input formats are fixed and all integer data must be right adjusted. Columns 71-80 are available on all input cards for specification of arbitrary alphanumeric identification information. Program restrictions for integer variables are included. All cards must be input for each problem, except as noted below, even though the data may not be utilized in that problem. Problems may be batched simply by stacking data decks. The control cards and their use are described in Appendix B.

Card 1 - Title

Field	Format	Variable - Description (units)
1-80	10A8	Problem Title

Card 2 - Control Variables

Field	Format	Variable - Description (units)
1-5	I5	IK - Reactivity Insertion Type IK = 0 Step IK = 1 Ramp
6-10	I5	IT - Number of delayed neutron groups $1 \leq IT \leq 6$
11-15	I5	IDH - Number of decay heat precursor groups $0 \leq IDH \leq 12$
16-20	I5	IPLT - Plot Option IPLT = 0 No Plots IPLT = 1 Plots
21-25	I5	NOTIM - Number of time step and print interval data sets $1 \leq NOTIM \leq 20$
26-30	I5	NOKIN - Parameter used to set minimum core time step. If NOKIN $\leq$ 0, NOKIN set = 10.
31-40	E10.0	ACCURC - Accuracy limit for truncation error associated with Runge-Kutta-Merson integration. If ACCURC $\leq$0.0, default value is 1.0E-6.
41-50	E10.0	TT - Problem end time (seconds)

Card 3 - Plot Control Card

Omit if IPLT ≠ 1 on Card 2

Field	Format	Variable - Data (units)
1-5	I5	IPTC (1)
6-10	I5	IPTC (2)
⋮	⋮	⋮
51-55	I5	IPTC (11)

IPTC (I) = {0 — Variable I is not plotted
{1 — Variable I is plotted

I	Variable	Units
1	Relative Power	
2	RCS Pressure	psia
3	keff	
4	Core Average Heat Flux	Btu/hr-ft^2
5	Average Fuel Temperature	°F
6	Maximum Fuel Temperature	°F
7	Total SG Heat Load	(Btu/sec-pin)
8	Pressurizer Water Level	(feet)
9	Core Flow Rate	(lbm/hr-pin)
10	Core Inlet Enthalpy	(Btu/lbm)
11	Pressurizer Safety and Relief Flow	(lbm/sec-pin)

Card 4 - Time Step and Print Interval Sizes (see Figure 19)

1-10	E10.0	ENDTIM(I) - End time for current time step and print interval sizes (seconds)
11-20	E10.0	DELIN(I) - Minimum RCS time step size (seconds)

21-30	E10.0	DELLP(I)	- Print interval size (seconds)
31-40	E10.0	DELMX(I)	- Maximum RCS time step size (seconds) (If DELMX(I) $\leq$ 0.0, default to DELLP(I)/2)
41-45	I5	NØSTM(I)	- Number of main steam system time steps per RCS time step (If NØSTM(I) $\leq$ 0, default to NØSTM(I)=10). NOTE: If ISTFLW≠0(Card 20), NØPD≠0 (Card 75), or TRBT>0.0(Card 51), NOSTM(I) is defaulted to 1.

NOTE: Card Type 4 must be repeated NOTIM times.

Card 5 - Geometry Data

Field	Format	Variable - Data (units)
1-5	I5	M - Number of nodes in oxide region $3 \leq M \leq 8$
6-10	I5	NS - Number of axial nodes in coolant $3 \leq NS \leq 12$
11-20	E10.0	SEGL - Axial coolant node length (feet)
21-30	E10.0	RIN - Inner cladding radius (cm)
31-40	E10.0	ROUT - Outer cladding radius (cm)
41-50	E10.0	AF - Coolant flow area per fuel rod (ft^2)
51-60	E10.0	WP - Weight of fuel oxide per unit length (gm/cm)
61-70	E10.0	RHC - Cladding density (gm/cc)

Card 6 - Geometry Data Continued

1-10	E10.0	DE - Channel equivalent diameter for DNB calculations (feet)
11-20	E10.0	DEH - Channel heated equivalent diameter for DNB calculations (feet).

Note: In Equations (11b) and (11c),

$$D_e = \begin{cases} 12 \times DEH & DEH > 0.0 \\ 12 \times DE & DEH \leq 0.0 \end{cases}$$

and

$$QDNB2 = 1.0 \qquad DEH \leq 0.0$$

Card 7 - Heat Transfer Data

1-10	E10.0	ACP - Oxide Heat Capacity constant in Eq. (3a) (joules/gm-°C)
11-20	E10.0	BCP - Oxide Heat Capacity constant in Eq. (3a) (joules/gm-°C^2)
21-30	E10.0	A - Oxide Conductivity constant in Eq. (3b) (watts/cm)

Field	Format	Variable - Data (units)
31-40	E10.0	B - Oxide Conductivity constant in Eq. (3b) (°C)
41-50	E10.0	C - Oxide Conductivity constant in Eq. (3b) (watts/cm-°C-°K^3)
51-60	E10.0	CPC - Cladding heat capacity (joules/gm-°C)
61-70	E10.0	KC - Cladding conductivity (watts/cm-°C)

Card 8 - Heat Transfer Data - Continued

Field	Format	Variable - Data (units)
1-10	E10.0	HG_0 - Initial Fuel-Cladding gap heat transfer coefficient (watts/cm^2 - °C)
11-20	E10.0	AHG - Linear Temperature Coefficient of HG (watts/cm^2 - °C)
21-30	E10.0	BHG - Quadratic Temperature Coefficient of HG (watts/cm^2 - °C)
31-40	E10.0	HF - Initial Cladding surface heat transfer coefficient (watts/cm^2 - °C)
41-50	E10.0	CHFFR - DNB heat flux margin factor. If CHFFR $\leq$ 0.0, CHFFR set = 1.0

Card 9 - Void/Quality Data

Field	Format	Variable - Data (units)
1-5	I5	OPTSLP - Slip correlation option (see Section 2.2.2) OPTSLP = 0 Constant Slip Model OPTSLP = 1 Variable Slip Model
11-20	E10.0	SLIP - Constant slip.
21-30	E10.0	CC1 - Void/quality coefficient.
31-40	E10.0	CC2 - Void/quality coefficient.
41-50	E10.0	CC3 - Void/quality coefficient.
51-60	E10.0	CC4 - Void/quality coefficient.

Card 10 - Primary System Data

1-10	E10.0	ENI - If ENI > 0.0, initial coolant enthalpy at core inlet (BTU/Lbm) If ENI ≤ 0.0, core inlet temperature (°F). 5
11-20	E10.0	PRO - Initial Pressurizer pressure (psia)
21-30	E10.0	W1 - Initial Coolant flow in Loop 1 (units specified by LF on Card 57)
31-40	E10.0	W2 - Initial Coolant flow in Loop 2 (units specified by LF)
41-50	E10.0	W2CB - Initial Coolant flow in Loop 2B (units specified by LF) (W2CB set to W2, if LCE = 0 on card 57)
51-60	E10.0	BORCON - Initial Coolant Boron Concentration (PPM)

Card 11 - Power Level and Kinetics Parameters

1-10	E10.0	PO - Initial power level per unit volume of oxide (watts/cc)
11-20	E10.0	AA - Conversion factor in Eq (13a) (joules/fission)
21-30	E10.0	RL - Prompt neutron lifetime in Eq (13a) (seconds)
31-40	E10.0	BT - Effective total delay neutron fraction which equals β in Eq (13a)
41-50	E10.0	NU - Fast neutrons per fission which equals ν in Eq (13b)
51-60	E10.0	ALPHA - Equals α defined by Eq (13c)

Card 12 - Reactivity Coefficients

1-10	E10.0	AK - Enthalpy reactivity factor in Eq (14c) (lbm/Btu)
11-20	E10.0	BK - Enthalpy reactivity factor in Eq (14c) $(\text{lbm/Btu})^2$
21-30	E10.0	CK - Enthalpy reactivity factor in Eq (14c)

Field	Format	Variable - Data (units)
31-40	E10.0	DK1 - Doppler reactivity factor in Eq (14b)
41-50	E10.0	DK2 - Doppler reactivity factor in Eq (14b) $(1/\sqrt{^\circ K})$
51-60	E10.0	DK3 - Doppler reactivity factor in Eq (14b)
61-70	E10.0	DKBC - Boron reactivity Coefficient (1/PPM)

Note: AK, BK and CK are not used if NORO ≠ 0
DK1, DK2 and DK3 are not used if NOTF ≠ 0

Card 13 - Reactivity versus Coolant Density Option

1-5	I5	NORO - Number of points for the ΔReactivity vs coolant Density Table.

Card 14 - Reactivity versus Coolant Density Table

1-10	E10.0	ROTB(I) - Coolant density (normalized)
11-20	E10.0	DKRO(I) - ΔReactivity

Note: Card Type 14 is repeated NORO times and ROTB(I) < ROTB(I + 1)

Card 15 - Reactivity versus Average Fuel Temperature Option

1-5	I5	NOTF - Number of points for the ΔReactivity vs Fuel Temperature Table.

Card 16 - Reactivity versus Average Fuel Temperature Table

1-10	E10.0	TFTB(I) - Fuel Temperature (°C)
11-20	E10.0	DKTF(I) - ΔReactivity

Note: Card Type 16 is repeated NOTF times and TFTB(I) < TFTB(I + 1)

Card 17 - Reactor Coolant System Volume Data

1-10	E10.0	VL(1) - Upper Plenum (ft^3/pin)
11-20	E10.0	VL(2) - Loop 1 Hot Let (ft^3/pin)

Field	Format	Variable - Data (units)
21-30	E10.0	VL(3) - Steam Generator 1 Inlet Plenum (ft^3/pin)
31-40	E10.0	VL(4) - Steam Generator 1 Tubes (ft^3/pin)
41-50	E10.0	VL(5) - Steam Generator 1 Outlet Plenum (ft^3/pin)
51-60	E10.0	VL(6) - Loop 1 Cold Leg (ft^3/pin)

Card 18 - Reactor Coolant System Volume Data

1-10	E10.0	VL(7) - Loop 1 Downcomer (ft^3/pin)
11-20	E10.0	VL(8) - Loop 2 Hot Leg (ft^3/pin)
21-30	E10.0	VL(9) - Steam Generator 2 Inlet Plenum (ft^3/pin)
31-40	E10.0	VL(10) - Steam Generator 2 Tubes (ft^3/pin)
41-50	E10.0	VL(11) - Steam Generator 2 Outlet Plenum (ft^3/pin)
51-60	E10.0	VL(12) - Loop 2 Cold Leg A (ft^3/pin)

Note: Volume 12 neglected if LCE = 0 on Card 57.

Card 19 - Reactor Coolant System Volume Data

1-10	E10.0	VL(13) - Loop 2 Cold Leg B (ft^3/pin)
11-20	E10.0	VL(14) - Loop 2 Downcomer (ft^3/pin)
21-30	E10.0	VL(15) - Lower Plenum (ft^3/pin)
31-40	E10.0	VPLC - Core Volume (ft^3/pin)
41-50	E10.0	VUP - Upper Plenum Inactive Region Volume (ft^3/pin) NOTE: If VUP $\leq$ 0.0, this region is ignored

Card 19A - Upper Plenum Inactive Region Data (Omit if VUP $\leq$ 0.0)

1-10	E10.0	FFDCIV - Loop flow fraction which is circulated between downcomer and inactive region
11-20	E10.0	FFUPIV - RCS flow fraction which is circulated between upper plenum and inactive region
21-30	E10.0	HUP - Inactive region initial enthalpy (Btu/lbm) NOTE: If HUP = 0.0; HUP set equal to initial reactor vessel outlet enthalpy. If HUP <0.0; HUP set equal to initial reactor vessel inlet enthalpy

31-35	I5	ICIRCU - Inactive region circulation flow option ICIRCU = 0 or 2; circulation from downcomer to upper plenum ICIRCU = 1; circulation between downcomer and inactive region and between upper plenum and inactive region are independent NOTE: If ICIRCU=2, the RCS pressure is based on the inactive region fluid properties.

Card 20 - Steam Generator Options

1-5	I5	IFLGT(1) - Loop 1 Initialization Option for U-Tube Steam Generator Model
6-10	I5	IFLGT(2) - Loop 2 Initialization Option for U-Tube Steam Generator Model

IFLGT(I) =
- 0 Input Temperature TS(I) used for initial guess
- 1 Input Temperature TS(I) used to set initial secondary side side pressure.

If ISTFLW $\neq$ 0, IFLGT(I) is defaulted to 1.

Field	Format	Variable - Data (units)
11-15	I5	ISGOPT - U-Tube Steam Generator Model Option ISGOPT = 1 Temperature Integration ISGOPT = 2 Enthalpy Integration
16-20	I5	ISGUOT - UTSG/OTSG option ISGUOT = 0 For UTSG ISGUOT = 1 For OTSG
21-25	I5	ISTFLW - Main steam system representation option. If ISTFLW = 0, Main steam system is represented. If ISTFLW ≠ 0, Main steam system is not represented and the main steam line flow equals the total feedwater flow.

Card 21 - Steam Generator Data

1-10	E10.0	SGNUM(1) - Number of S.G. in Loop 1
11-20	E10.0	SGNUM(2) - Number of S.G. in Loop 2

Card 22 - Steam Generator Data

1-10	E10.0	VOLSG(I) - S.G. shell side volume (FT^3/pin)
11-20	E10.0	ARESG(I) - S.G. shell side flow area (FT^2/pin)
21-30	E10.0	SGA(I) - S.G. Heat Transfer Area (FT^2/PIN)
31-40	E10.0	SGFA(I) - S.G. tube side flow area (FT^2/PIN)
41-50	E10.0	ZMIX(I) - S.G. Initial Mixture Level for U-Tube S.G. only (feet)
51-60	E10.0	TS(I) - Initial shell side Temperature (°F)
61-70	E10.0	HFD(I) - S.G. Initial Feedwater Enthalpy (Btu/lbm)

Card 23 - Steam Generator Data

1-10	E10.0	SLKA2(I) - Steam Line K/A^2 with isolation valve full open from steam dome to header $[(PIN/FT^2)]^2$
11-20	E10.0	FIVO(I) - Initial Fraction Isolation Valve open

[illegible]

[illegible]

Field	Format	Variable - Data (units)
21-30	E10.0	SUBLEN(I) - Initial Subcooled Length for OTSG only (FT)
31-40	E10.0	SATLEN(I) - Initial Saturated Length for OTSG only (FT)
41-50	E10.0	AVSG(I) - Initial average SG void fraction for UTSG only.

Note: Cards 22 and 23 are repeated for each steam generator

Card 24 - Steam Generator Data

1-10	E10.0	DSG - Tube Side Hydraulic Diameter (FEET)
11-20	E10.0	TUBEH - Tube Height (FEET)
21-30	E10.0	TUBEDX - Tube Wall Thickness (FEET)
31-40	E10.0	RFOUL - Heat Transfer Fouling Factor
41-50	E10.0	REVERS - Reverse Heat Transfer Factor
51-60	E10.0	DSGS - Shell Side Hydraulic Diameter (FEET)
61-70	E10.0	CO - Bubble rise gradient parameter for UTSG only.

Card 25 - Steam Generator Relief Valve Data

1-10	E10.0	RKA2 - Relief valve K/Area^2 (PIN - SG/FT^2)^2
11-20	E10.0	PSGR1 - Shell side pressure at which relief valves begin to open (PSIA)
21-30	E10.0	PSGR2 - Shell side pressure at which relief valves are full open (PSIA)

Card 26 - Steam Generator Safety Valve Data

1-10	E10.0	SKA2 - Safety valve K/Area^2 (PIN - SG/FT^2)^2
11-20	E10.0	PSGS1 - Shell side pressure at which safety valves begin to open (PSIA)
21-30	E10.0	PSGS2 - Shell side pressure at which safety valves are full open (PSIA)

Card 27 - Steam Line Geometry Option and Inertia Factors

Field	Format	Variable - Data (units)
1-5	I5	LSS - Number of Main Steam Lines to Turbine (LSS = 1 or 2)
11-20	E10.0	XISL(1) - Inertia factor (L/A) from steam dome to header for steam generator 1 (PIN/FT)
21-30	E10.0	XISH(1) - Inertia factor (L/A) from header to main steam line for steam generator 1 (PIN/FT)
31-40	E10.0	XIST(1) - Inertia factor (L/A) from main steam line to turbine for steam generator 1 (PIN/FT)
41-50	E10.0	XISL(2) (PIN/FT)
51-60	E10.0	XISH(2) (PIN/FT)
61-70	E10.0	XIST(2) (PIN/FT)

Card 28 - Steam Line Geometry Data

1-10	E10.0	VSH(I) - Steam header line volume (FT^3/PIN)
11-20	E10.0	VSL(I) - Main Steam line volume (FT^3/PIN)
21-30	E10.0	SHKA2(I) - K/A^2 from header to main steam line $(PIN/FT^2)^2$
31-40	E10.0	STKA2(I) - K/A^2 from main steam line to turbine with turbine valves full open $(PIN/FT^2)^2$

Note: Card 28 is repeated LSS times.

Card 29 - Steam Line Bypass Valve Data

1-10	E10.0	SBPFR(I) - Bypass Capacity per main steam line (fraction of initial steam line flow)
11-20	E10.0	FRBPOP(I) - Initial fraction bypass valves open

Field	Format	Variable - Data (units)
21-30	E10.0	FRBPA(I) - Fraction of bypass valve which can be varied during the transient
31-40	E10.0	DABPDT(I) - Bypass valve opening rate for core average temperature control (1/°F)
41-50	E10.0	DABPDP(I) - Bypass valve opening rate for steam line pressure control (1/psi)
51-60	E10.0	STBP(I) - Bypass valve actuation time signal (sec)
61-70	E10.0	VORBP(I) - Bypass valve opening rate (1/sec)

Note: Card 29 is repeated LSS times.
In addition to the above implied limits, the fractional valve area is restricted between 0 and 1.

Card 30 - Steam Line Dump Valve Data

1-10	E10.0	SDPFR(I) - Dump capacity per main steam line (fraction of initial steam flow)
11-20	E10.0	FRDPOP(I) - Initial fraction dump open
21-30	E10.0	FRDPA(I) - Variable dump fraction
31-40	E10.0	DADPDT(I) - Dump valve opening rate for core average temperature control (1/°F)
41-50	E10.0	DADPDP(I) - Dump valve opening rate for steam line pressure control (1/psi)
51-60	E10.0	STDP(I) - Dump valve actuation time signal (sec)
61-70	E10.0	VORDP(I) - Dump valve opening rate (1/sec)

Note: Card 30 is repeated LSS times.
See note for Card 29 for area limits.

Card 31 - Turbine Control Valve Data

1-10	E10.0	FRCVC(I) - Initial fraction control valve closed
11-20	E10.0	FRCVA(I) - Variable control valve fraction
21-30	E10.0	VCRCV(I) - Control valve closure rate (1/sec)
31-40	E10.0	TDCV(I) - Control valve closure time delay following actuation signal (seconds)

Note: Card 31 is repeated LSS times.

Card 32 - Turbine Stop Valve Data

Field	Format	Variable - Data (units)
1-10	E10.0	VCRSV(I) - Stop valve closure rate (1/sec)
11-20	E10.0	FRSV(I) - Fraction of stop valve closure
21-30	E10.0	TDSV(I) - Stop valve closure time delay following actuation signal (sec)

Note: Card 32 is repeated LSS times.

Card 33 - Main Steam Line Isolation Valve Data

1-10	E10.0	VCRATE(I) - MSIV closure rate (1/sec)
11-20	E10.0	TDMSV(I) - MSIV closure time delay following actuation signal (sec)

Note: Card 33 is required for both steam generators.

Card 34 - Pressurizer Data

1-10	E10.0	VPSPR - Initial Pressurizer Steam Volume (FT^3/PIN)
11-20	E10.0	VPLPR - Initial Pressurizer Liquid Volume (FT^3/PIN)
21-30	E10.0	WTRLVL - Initial Pressurizer Water Level (FEET)

Card 35 - Pressurizer Relief Valve Data

1-10	E10.0	RVKA2 - Relief Valve K/A^2 $(PIN/FT^2)^2$
11-20	E10.0	PRELF1 - Reactor coolant system pressure at which relief valves begin to open (PSIA)
21-30	E10.0	PRELF2 - Full Open pressure (PSIA)

Card 36 - Pressurizer Safety Valve Data

1-10	E10.0	SVKA2 - Safety Valve K/A^2 $(PIN/FT^2)^2$

Field	Format	Variable - Data (units)
11-20	E10.0	PSAFT1 - Reactor coolant system pressure at which safety valves begin to open (PSIA)
21-30	E10.0	PSAFT2 - Full open pressure (PSIA)

Card 37 - Pressurizer Heater Data

1-10	E10.0	PPHH - Pressure at which heaters are turned on (PSIA)
11-20	E10.0	PPHL - Low end of proportional heater range (PSIA)
21-30	E10.0	PWLHON - High pressurizer water level setpoint - heaters on (FT)
31-40	E10.0	PWLHOF - Low Pressurizer water level setpoint - heaters off (FT)
41-50	E10.0	QPHR - Proportional heater ramp rate (BTU/SEC - PSIA-PIN)
51-60	E10.0	QPHM - Maximum heater heat rate (BTU/SEC-PIN)

Card 38 - Charging System Data

1-10	E10.0	PWLCON - Low Pressurizer level setpoint for RCS charging flow on (FEET)
11-20	E10.0	PCR - RCS charging flow rate (LBM/Sec-PIN)
21-30	E10.0	ENCHR - Enthalpy of Charging water (BTU/LBM)
31-40	E10.0	BNCHR - Boron concentration of charging water (PPM)

Card 39 - Letdown System Data

1-10	E10.0	PWLLON - High pressurizer level setpoint for beginning of letdown flow (FEET)
11-20	E10.0	PWLLMR - Pressurizer level for maximum letdown flow (FEET)
21-30	E10.0	PLDMR - Maximum letdown flow (LBM/SEC-PIN)

Card 40 - Pressurizer Spray Data

Field	Format	Variable - Data (units)
1-10	E10.0	PPSPON - High Pressurizer Pressure Set-point for Sprays ON (PSIA)
11-20	E10.0	PPSPMR - Pressurizer Pressure for maximum spray flow (PSIA)
21-30	E10.0	PSRM - Maximum spray flow (LBM/SEC-PIN)

Card 41 - Pressurizer Water Relief Data

Field	Format	Variable - Data (units)
1-5	I5	NOWTRR - Number of Data Pairs ($0 \leq$ NOWTRR ≤ 10) If NOWTRR = 0, water relief based on Eq (24a)
11-20	E10.0	ARELF - Relief Valve Area (FT^2/PIN)
21-30	E10.0	ASAFT - Safety Valve Area (FT^2/PIN)
31-40	E10.0	DISCCF - Discharge Coefficient
41-50	E10.0	HWTRRF - Curve reference water enthalpy (BTU/LBM)
51-60	E10.0	DGWRDH - Slope of mass flow vs. enthalpy (LBM/BTU)

Card 42 - Pressurizer Water Relief Table

Field	Format	Variable - Data (units)
1-10	E10.0	PGWTRR(2) - Pressure (PSIA)
11-20	E10.0	PGWTRR(1) - Water relief flow rate (LBM/FT^2-SEC)
21-30	E10.0	PGWTRR(4)
31-40	E10.0	PGWTRR(3)
⋮	⋮	⋮

Card set 42 is repeated until NOWTRR data pairs are entered. There are three data pairs per card.

Card 43 - Safety Injection Data

Field	Format	Variable - Data (units)
1-5	I5	NOSIN - Number of flow vs. pressure data points ($0 \leq$ NOSIN ≤ 25)
6-10	I5	IESFAS - Safety injection actuation logic option. If IESFAS = 0, exceeding pressurizer level <u>or</u> pressure setpoint will initiate signal. 5 If IESFAS $\neq$ 0 , exceeding both pressurizer level <u>and</u> pressure setpoints required to initiate signal.
11-20	E10.0	SILP - Low Pressure Actuation Setpoint (PSIA)
21-30	E10.0	SILL - Low Pressurizer Level Actuation Setpoint (FEET)
31-40	E10.0	SITIM - Input Actuation Time Signal. If SITIM $\leq$ 0.0, actuation is generated by either low pressure or low level signal. (sec)
41-50	E10.0	SITD - Time delay following actuation signal (SEC)
51-60	E10.0	ENSINJ - Enthalpy of safety injection water (BTU/LBM)
61-70	E10.0	BORSIN - Boron concentration of safety injection water (PPM) (See note on Card 44).

Card 44 - Safety Injection Line Data

1-10	E10.0	SILMAS - Coolant mass in safety injection line. (LBM/PIN).
11-20	E10.0	SILBRN - Initial boron concentration in safety injection line (PPM).

NOTE: The HPCI water injected into the RCS will have a boron concentration of SILBRN, until the total injected mass equals SILMAS. After this time, the concentration is taken as BORSIN.

Card 45 - Safety Injection Flow vs. Pressure Table

1-10	E10.0	PSINT(1) - RCS pressure (PSIA)
11-20	E10.0	WSINT(1) - Safety injection flow (LBM/SEC-PIN)
21-30	E10.0	PSINT(2)
31-40	E10.0	WSINT(2)
⋮	⋮	⋮

Field	Format	Variable - Data (units)

Note: PSINT(I) < PSINT(I+1)
Card Type 45 is repeated until NOSIN data pairs are entered with three pairs per card.

Card 46 - Motor Driven Auxiliary Feedwater Pump Data

Field	Format	Variable - Data (units)
1-5	I5	NOAXFM - Number of Flow vs. Pressure Data points ($0 \leq$ NOAXFM ≤ 25)
11-20	E10.0	TAXFWM - Actuation time signal. If TAXFWM ≤ 0.0, actuation signal is generated by safety injection signal, main feedwater isolation, or low steam generator level. (sec)
21-30	E10.0	TDAXFM - Time delay following actuation signal (SECS)
31-40	E10.0	HAXFM - Feedwater Enthalpy (BTU/LBM)
41-50	E10.0	FAXFW(1) - Auxiliary feedwater factor for SG1
51-60	E10.0	FAXFW(2)

Card 47 - Motor Driven Auxiliary Feedwater Table

Field	Format	Variable - Data (units)
1-10	E10.0	PAXFWM(I) - S.G. Shell Side Pressure (PSIA)
11-20	E10.0	WAXFWM(I) - Auxiliary Feedwater Flow (LBM/HR-PIN-SG)

Note: Card Type 47 is repeated NOAXFM times.
PAXFWM(I) < PAXFWM(I+1)

Card 48 - Steam Turbine Drive Auxiliary Feedwater Pump Data

Field	Format	Variable - Data (units)
1-5	I5	NOAXFS - Number of Flow vs Pressure Data Points ($0 \leq$ NOAXFS ≤ 25)
11-20	E10.0	TAXFWS - Actuation time signal (SECS) (see note for TAXFWM on Card 46) | 5
21-30	E10.0	TDAXFS - Time delay following actuation signal (SECS)
31-40	E10.0	HAXFS - Feedwater Enthalpy (BTU/LBM)

Field	Format	Variable - Data (units)

Card 49 - Steam Turbine Driven Auxiliary Feedwater Table

1-10	E10.0	PAXFWS(I) - S.G. Shell Side Pressure (PSIA)
11-20	E10.0	WAXFWS(I) - Auxiliary feedwater flow (LBM/HR-PIN-SG)

Note: Card Type 49 is repeated NOAXFS times.
$PAXFWS(I) \leq PAXFWS(I+1)$

Card 50 - Dump and Bypass Control System Data

Field	Format	Variable - Data (units)
1-5	I5	IDBOPT - Temperature - Pressure-Time control option IDPOPT < 0 actuation on time signal IDBOPT = 0 control on maximum of high TAV and high Psec IDBOPT > 0 control on high Psec before reactor trip and maximum of high TAV and high Psec after trip
11-20	E10.0	TARD - Dump control reference core average temperature (°F)
21-30	E10.0	PARD - Dump control reference steam line average pressure (PSIA)
31-40	E10.0	TARB - Bypass control reference core average temperature (°F)
41-50	E10.0	PARB - Bypass control reference steam line average pressure (PSIA)

Card 51 - Turbine Valve Controls

1-10	E10.0	PDOSPD - Stop Valve Overspeed Closure Setpoint (fraction of full power)
11-20	E10.0	TRBT - Turbine Runback Initiation Time. If TRBT ≤ 0.0, turbine runback ignored. (sec)
21-30	E10.0	TRBL - Turbine Runback Power Level Setpoint (Fraction of Initial Power) If TRBL ≤0, a control rod withdrawal prohibit is initiated following the turbine runback signal.

Field	Format	Variable - Data (units)
Card 52 - Main Steam Line and Main Feedwater Isolation Control		
1-5	I5	IOPSLI - Main steam line isolation signal option IOPSLI = 0 ignore IOPSLI = 1 Signal generated on either hi-hi steam flow or hi steam flow plus low core average temperature coincident with safety injection actuation IOPSLI = 2 Signal on low shell side pressure.
11-20	E10.0	HIHIWS - HI-HI Steam Flow Setpoint - (Fraction of Initial Flow)
21-30	E10.0	HIWS - HI Steam Flow Setpoint (Fraction of Initial Flow)
31-40	E10.0	TALO - Low Core Average Temperature Setpoint (°F)
41-50	E10.0	PSECLO - Low Shell Side Pressure Setpoint (PSIA)

Note: Only the last two setpoints are used for main feedwater isolation and are used irregardless of IOPSLI.

Field	Format	Variable - Data (units)
Card 53 - Feedwater Control System Data		
1-5	I5	NOLVSL - Number of S.G. Water Level vs. Power Level Data Pairs
11-20	E10.0	POPFFW - Ratio of Initial Power to Full Power
21-30	E10.0	WFDMIN - Minimum Feedwater Flow after trip (Fraction of Initial Flow)
31-40	E10.0	FWRMPT - Feedwater ramp down time (SECS)
41-50	E10.0	TDFWIS - Time Delay for Feedwater ramp down (SECS)
51-60	E10.0	WFDMAX - Maximum feedwater flow (Fraction of Initial Flow)

Field	Format	Variable - Data (units)
Card 54 - Feedwater Control System Data		
Omit if NOLVSL = 0		
1-10	E10.0	WTLDB - Water Level Controller Dead Band (FEET)
11-20	E10.0	CONLVL - Water Level Controller Constant (1/FT-SEC)
21-30	E10.0	TAULV2 - Water Level Lag Time Constant (SEC)
31-40	E10.0	TAULV1 - Water Level Lead Time Constant (SEC)
Card 55 - Water Level vs. Power Level Table		
1-10	E10.0	POWL(1) - Power Level (Fraction of Full Power)
11-20	E10.0	WTL(1) - S.G. Water Level (FEET)
21-30	E10.0	POWL(2)
31-40	E10.0	WTL(2)
⋮	⋮	⋮

Note: POWL(I) < POWL(I+1)

Card Type 55 is repeated until NOLVSL data pairs are entered with three pairs per card.

Field	Format	Variable - Data (units)
Card 56 - Control Rod Controller		
1-5	I5	IOPCRC - Controller Option IOPCRC = 0 ignore IOPCRC = 1, rod insertion to match core average temperature IOPCRC = 2, rod insertion to match power level demand
11-20	E10.0	TAVRFZ - Zero Power Core Reference Average Temperature (^{o}F)

Field	Format	Variable - Data (units)
21-30	E10.0	TAVRFF - Full Power Core Reference Average Temperature (°F)
31-40	E10.0	POPFCR - Ratio of Initial Power To Full Power
41-50	E10.0	PRSTOP - Low Power Level Rod Stop Signal Setpoint (Fraction of Full Power)
51-60	E10.0	DTMPOT - Margin Below the Overtemperature Trip Point at which Control Rod Motion is Stopped (°F)
61-70	E10.0	DTMPOP - Margin Below the Overpower Trip Point at which Control Rod Motion is Stopped (°F)

Card 57 - Control Rod Controller Data

Omit if IOPCRC = 0

Field	Format	Variable - Data (units)
1-10	E10.0	CRCDB - Controller Average Temperature Dead Band (°F)
11-20	E10.0	CONCRC - Controller Average Temperature Constant $(°F - SEC)^{-1}$
21-30	E10.0	TAUCR2 - Control Rod Lag Time Constant (SEC)
31-40	E10.0	TAUCR1 - Control Rod Lead Time Constant (SEC)
41-50	E10.0	CRCPDB - Controller Power Level Dead Band (Fraction of Full Power)
51-60	E10.0	CONCRP - Controller Power Level Constant (1/full power-sec)
61-70	E10.0	DKDTMX - Maximum controller reactivity insertion or withdrawal rate (1/sec). If DKDTMX $\leq$ 0.0; default is 1.0E+20.

Card 58 - Transient Flow Control Parameters

1-5	I5	NOTAB5 - Number of Loop 1 Flow vs. time data sets (Curve fit if 0) $0 \leq NOTAB5 \leq 50$
6-10	I5	NTB4 - Number of Loop 2 Flow vs. time data sets (Curve fit if 0) $0 \leq NTB4 \leq 50$

Field	Format	Variable - Data (units)
11-15	I5	NTB3 - Number of Loop 2 Cold Leg B Flow vs. time data sets (Curve fit if 0 and LCE = 1) 0 ≤ NTB3 ≤ 50
16-20	I5	LCE - RC system cold leg geometry option If LCE = 0, cold leg region 12 is ignored. If LCE ≠ 0, cold leg region 12 is included.
21-25	I5	LF- Flow rate units input option LF = 1 Mass flow input (Lbm/pin-hr) LF = 0 Volumetric flow input (Ft^3/pin-hr)
26-30	I5	NF1 - Number of Feedwater Flow and Enthalpy vs. Time data points for SG1. 0 ≤ NF1 ≤ 25
31-35	I5	NF2 - Number of Feedwater Flow and Enthalpy vs. Time data points for SG2 0 ≤ NF2 ≤ 25
36-40	I5	IPUMP If IPUMP = 0, RCS flow rates are specified and dynamic pump model is ignored. If IPUMP ≠ 0, dynamic pump model is included and RCS loop flows are calculated from momentum equations. 4

Card 59 - RCS Loop 1 Flow Transient Table

Omit if NOTAB5 = 0 or IPUMP ≠ 0 4

Field	Format	Variable - Data (units)
1-10	E10.0	TJ5(I) - Time point for coolant flow in Loop 1 measured from 0 (secs)
11-20	E10.0	WJ5(I) - Loop 1 coolant flow at TJ5 in units specified by LF
⋮	⋮	⋮

Card Type 59 is repeated until NOTAB5 data pairs are entered with three pairs per card.

Card 60 - RCS Loop 2 Flow Transient Table

Omit if NTB4 = 0 or IPUMP ≠ 0 | 4

1-10	E10.0	TJ4(I) - Time	see Card 59 comments
11-20	E10.0	WJ4(I) - Flow	
⋮	⋮	⋮	

Field	Format	Variable - Data (units)

Card 61 - RCS Loop 2 Cold Leg B Flow Transient Table | 4

Omit if NTB3 = 0, LCE = 0, or IPUMP ≠ 0

1-10	E10.0	TJ3(I)	see Card 59 comments
11-20	E10.0	WJ3(I)	
⋮	⋮	⋮	

Card 62 - RCS Loop 1 Flow Transient Curve | 4

Omit if NOTAB5 ≠ 0 or IPUMP ≠ 0

1-10	E10.0	WX1 Coefficient of linear term (Sec-1)
11-20	E10.0	WX2 Coefficient of exponential term
21-30	E10.0	EX3 Coefficient of exponent (Sec-1)

Card 63 - RCS Loop 2 Flow Transient Curve | 4

Omit if NTB4 ≠ 0 or IPUMP ≠ 0

1-10	E10.0	WY1	see Card 62 comments
11-20	E10.0	WY2	
21-30	E10.0	WY3	

Card 64 - RCS Loop 2 Cold Leg B Transient Curve | 4

Omit if LCE = 0, NTB3 ≠ 0, or IPUMP ≠ 0

1-10	E10.0	WZ1	see Card 62 comments
11-20	E10.0	WZ2	
21-30	E10.0	WZ3	

Card 64A* - Pump and Motor Data Input Options | 4

1-5	I5	NPPH(1) - Number of data entries for homologous pump head curve type 1. ≤21
6-10	I5	NPPH(2)
11-15	I5	NPPH(3)
16-20	I5	NPPH(4)
21-25	I5	NPPT(1) - Number of data entries for homologous pump hydraulic torque curve type 1. ≤21
26-30	I5	NPPT(2)
31-35	I5	NPPT(3)
36-40	I5	NPPT(4)

*Note: Cards 64A through 64L are omitted if IPUMP = 0.

Field		Format	Variable - Data (units)
41-45	I5	NPMT	- Number of data entries for pump motor torque curve. ≤ 20 If NPMT ≤ 0, this curve is zeroed out.
46-50	I5	IRP	- Reverse pump speed option. If IRP=0, reverse speed not permitted. If IRP≠0, reverse speed allowed.

Note: If NPPH or NPPT ≤0, this curve type is zeroed out.

Card 64B - Pump and Motor Data Options

1-5	I5	NPPL(1)	- Total number of pumps in Loop 1
6-10	I5	NPPL(2)	- Total number of pumps either Loop 2 (LCE=0) or Loop segment 2A(LCE≠0). 4
11-15	I5	NPPL(3)	- Total number of pumps in Loop segment 2B (LCE≠0)
16-20	I5	IPSTAT(1)	- Initial pump motor status for pumps in Loop 1. If IPSTAT=0, motor off If IPSTAT=1, motor on
21-25	I5	IPSTAT(2)	
26-30	I5	IPSTAT(3)	

Card 64C - Homologous Pump Head Data

1-10	E10.0	GH(1,1)- ν/α	First data pair
11-20	E10.0	HOG(1,1)- h/α^2	for Curve Type 1
21-30	E10.0	GH(1,2)- ν/α	Second data pair
31-40	E10.0	HOG(1,2)- h/α^2	for Curve Type 1
⋮	⋮	⋮	

Field	Format	Variable - Data (units)

Card 64C - Homologous Pump Head Data continued

Field	Format	Variable - Data (units)
	E10.0	GH(1,NPPH(1))- ν/α } Last data pair for
	E10.0	HOG(1,NPPH(1))-h/α^2 } Curve Type 1
1-10	E10.0	GH(2,1)- α/ν } First data pair for
11-20	E10.0	HOG(2,1)- h/ν^2 } Curve Type 2
⋮	⋮	⋮
	E10.0	GH(4,NPPH(4)) α/ν } Last data pair
	E10.0	HOG(4,NPPH(4)) h/ν^2 } for Curve Type 4

Notes: For each curve type I, GH(I,J)<GH(I,J+1). Each curve type begins on a new card. The data is entered with three pair per card. If NPPH(I)≤0, Curve Type I is omitted and the curve is zeroed out.

Card 64D - Homologous Pump Hydraulic Torque Data

Field	Format	Variable - Data (units)
1-10	E10.0	GZ(1,1)- ν/α } First data paid for
11-20	E10.0	TOG(1,1)- b/α^2 } Curve Type 1
⋮	⋮	⋮
	E10.0	GZ(4,NPPT(4)) α/ν } Last data pair
	E10.0	TOG(4,NPPT(4)) b/ν^2 } for Curve Type 4

4

Note: See notes for Card 64C.

Card 64E - Motor Torque Data

Field	Format	Variable - Data (units)
1-10	E10.0	AM(1) Relative motor speed (Fraction of rated pump speed)
	E10.0	TMOA(1) Relative motor torque (Fraction of rated pump hydraulic torque)
⋮	⋮	⋮
	E10.0	AM(NPMT)
	E10.0	TMOA(NPMT)

Note: If NPMT≤0, this data is omitted and the motor torque is zeroed out. The data is entered with three pairs per card.

Field	Format	Variable - Data (units)
Card 64F - Rated Pump Data		
1-10	E10.0	RATQ - Rated volumetric flow per pump (gpm/pin)
11-20	E10.0	RATT - Rated pump hydraulic torque (lbf-ft)
21-30	E10.0	RATS - Rated pump speed (rad/sec)
31-40	E10.0	RATD - Rated pump fluid density (lbm/ft^3)
Card 64G - Pump Inertia and Torque Data		
1-10	E10.0	PINERT - Pump inertia (lbm-ft^2)
11-20	E10.0	FINERT - Flywheel and motor inertia (lbm-ft^2)
21-30	E10.0	FRICC - Coefficient for friction torque losses=C_f (lbf-ft)
31-40	E10.0	FRICE - Exponential factor for friction losses = n_f.
41-50	E10.0	WINDC - Coefficient for windage torque losses = C_w (lbf-ft).
51-60	E10.0	WINDE - Exponential factor for windage losses = n_w.
Card 64H - Loop Fluid Inertia Factors		
1-10	E10.0	XINE1 - Loop 1 inertia factor, $(L/A)_1$ (pin/ft)
11-20	E10.0	XINE2 $(L/A)_2$ (pin/ft)
21-30	E10.0	XINE2B $(L/A)_{2B}$ (pin/ft)
31-40	E10.0	XINERV $(L/A)_{RV}$ (pin/ft)
Card 64I - Loop Pressure Loss Coefficients		
1-10	E10.0	PDC1 - Loop 1 loss coefficient K_1 (pin/ft^2)^2
11-20	E10.0	PDC2 - K_2 (pin/ft^2)^2
21-30	E10.0	PDC2B - K_{2B} (pin/ft^2)^2
31-40	E10.0	PDCRV - K_{RV} (pin/ft^2)^2

4

Field	Format	Variable - Data (units)

Card 64J - Pump Transient Specification

1-10	I10	IPTRCN(1) - Transient type for pump 1.
11-20	E10.0	TDPTR(1) - Time delay for pump transient to begin measured from t=0. (sec).
⋮	⋮	⋮
41-50	I10	IPTRCN(3)
51-60	E10.0	TDPTR (3)

Note:

IPTRCN	Transient Type
0	None (constant speed)
1	Pump motor trip
2	Pump shaft lock
3	Pump shaft shear
4	Pump motor startup
5	Time-dependent speed specified

4

Card 64K - Time Dependent Speed Paris

(Omit Card 64K if IPTRCN $\neq$ 5)

1-5	I5	NPSPVT - Number of time-dependent speed data pairs. $1 \leq NPSPVT \leq 25$

Card 64L - Time Dependent Speed Specification

(omit Card 64L if IPTRCN $\neq$ 5)

1-10	E10.0	TIMPSP(1) - Time measured from TDPTR (sec)
11-20	E10.0	PSPTIM(1) - Relative pump speed (Fraction of rated).
⋮	⋮	⋮
	E10.0	TIMPSP(NPSPVT) - Time measured from TDPTR (sec)
	E10.0	PSPTIM(NPSPVT) - Relative pump speed (Fraction of rated)

Note: There are three data pairs per card.

Field	Format	Variable - Data (units)
Card 65 - Steam Generator 1 Transient Feedwater Data		
1-10	E10.0	TFD1(I) - Time measured from 0 (SEC).
11-20	E10.0	WFW1(I) - Flow change from Initial Flow (Fraction of Initial Flow)
21-30	E10.0	HFW1(I) - Enthalpy Change from Initial value (BTU/LBM)

Card Type 65 is repeated NF1 times.

Field	Format	Variable - Data (units)
Card 66 - Steam Generator 2 Transient Feedwater Data		
1-10	E10.0	TFD2(I) - Time (SEC)
11-20	E10.0	WFW2(I) - Flow change (Fraction Initial)
21-30	E10.0	HFW2(I) - Enthalpy change (BTU/LBM)

Card Type 66 is repeated NF2 times.

Field	Format	Variable - Data (units)
Card 67 - Main Steam System Break Data		
1-5	I5	ISLBLC - Break Location ISLBLC = 0 Ignore ISLBLC < 0 The break is located in the main feedwater pipe of SG2 ISLBLC = 1 The break is located between SG outlet and the isolation valve in SG2 ISLBLC = 2 The break is located in the header pipe beyond the isolation valve ISLBLC = 3 The break is located in the main steam line section
11-20	E10.0	ASLB - Break Area (FT^2/PIN)
21-30	E10.0	BREAKT - Time at which break begins (SEC)
31-40	E10.0	BRKOPT - Time duration of break opening (SEC)
41-50	E10.0	BRAKHT - Feedwater pipe break elevation for UTSG only (FT)
Card 68 - Reactivity Transient Data		
1-10	E10.0	RSTEP - Step change in reactivity ($)
11-20	E10.0	RRAMP - Ramp Insertion rate ($/sec)
21-30	E10.0	RTOT - Total ramp insertion ($)
Card 69 - Scram Options		
1-5	I5	ISCRAM - Scram option ISCRAM = 0 No scram reactivity input ISCRAM = 1 Scram reactivity inserted following a trip signal ISCRAM > 1 Scram reactivity insertion signal at TSCRAM

Field	Format	Variable - Data (units)
6-10	I5	NTSCRM - Number of table sets of scram reactivity $1 \le NTSCRM \le 25$
11-20	E10.0	TSCRAM - Input time for scram insertion signal (SEC)
21-25	I5	ISENSR - Temperature sensor location option ISENSR = 0 Reactor vessel plenums = ± 1 Hot and cold legs = ± 2 Steam generator plenums For ISENSR >o, an overpower or overtemperature ΔT trip signal is generated when the setpoint is exceeded in either loop. For ISENSR <0, an overpower or overtemperature ΔT trip signal is generated only when the setpoint in Loop 1 is exceeded.
26-30	I5	ITRPTY - Overpower and overtemperature ΔT setpoint simulation option ITRPTY = 0, steady-state trip lines ITRPTY = 1, dynamic trip calculation.
31-40	E10.0	TDLYTH - Time delay for hot side temperature sensors (sec). If TDLYTH < 0.0, default is 0.0
41-50	E10.0	TDLYTC - Time delay for cold side temperature sensors (sec). If TDLYTC < 0.0, default is 0.0 5
51-60	E10.0	TLAGTH - Time constant for hot side temperature sensor lag (sec). If TLAGTH < 0.0, default is 0.0.
61-70	E10.0	TLAGTC - Time constant for cold side temperature sensor lag (sec). If TLAGTC < 0.0, default is 0.0.

Card 70 - Reactor Protective System Parameters

Omit if ISCRAM ≠ 1

1-10	E10.0	TRIP(I) - Trip I setpoint
11-20	E10.0	TDTRIP(I) - Time delay for scram insertion following Trip I (SEC)

I	Trip Function	Units
1	High neutron power	(Fraction of Initial Power)
2	High Pressurizer Pressure	(PSIA)
3	Low Pressurizer Pressure	(PSIA)
4	High Pressurizer Level	(FEET)
5	Low Pressurizer Level	(FEET)
6	Low-Low Steam Generator Level	(FEET)
7	Turbine Trip - HI S.G. Level	(FEET)

8	Low Reactor Coolant Flow	(Fraction of Initial Flow)
9	High Power to Flow ratio	(Fraction of Initial P/F ratio)
10	High Core Outlet Temperature	(°F)

Note: If TRIP(7) ≤ 0.0, reactor trip signal from turbine overspeed trip is ignored and this trip function is ignored.
Card 70 is repeated 10 times.

Card 71 - Overpower Delta T Trip Parameters

Omit if ISCRAM ≠ 1, or ITRPTY = 1

1-10	E10.0	OPDTTM - Maximum Delta T (°F)
11-20	E10.0	OPDTDT - Data Point Delta T (°F)
21-30	E10.0	OPDTTA - Data Point Average T (°F)
31-40	E10.0	OPDTSL - Slope of Delta T vs. Ave T
41-50	E10.0	TDTRIP(11) - Trip Time Delay (sec)

Card 71 A Overpower Delta T Trip Parameters

Omit if ISCRAM ≠ 1, or ITRPTY = 0

1-10	E10.0	OPDTO - Reference overpower ΔT (ΔT_0^{op} in Eq (40a)) (°F)
11-20	E10.0	OPDTAO - Reference overpower ΔT core average temperature (T_0^{op} in Eq (40a)) (°F)
21-30	E10.0	OPDTAU - Rate/lag time constant (τ_3 in EQ (40a)) (sec)
31-40	E10.0	OPDTK4 - Basic gain (K_4 in Eq (40a))
41-50	E10.0	OPDTK5 - Rate/lag gain (K_5 in Eq (40a)) (1/°F)
51-60	E10.0	OPDTK6 - Core average temperature gain (K_6 in Eq (40a)) (1/°F)

Card 71 B Overpower Delta T Trip Parameters

Omit if ISCRAM ≠ 1, or ITRPTY = 0

1-10	E10.0	TDTRIP (11) - Overpower ΔT trip time delay (sec)

Format	Variable - Data (units)

Overtemperature Delta T Trip Parameters

SCRAM ≠ 1, or ITRPTY = 1

I5	NPOTDT - Number of Constant Pressure Curves $0 \le NPOTDT \le 10$
E10.0	TDTRIP (12) - Trip Time Delay

Card 73 - Overtemperature Delta T Curves

Omit if ISCRAM ≠ 1, or ITRPTY = 1

1-10	E10.0	OTDTPR(I) - RC system pressure corresponding to curve I (PSIA)
11-20	E10.0	OTDTDT(I) - Delta T Data point on curve I (°F)
21-30	E10.0	OTDTTA(I) - Average T Data point on curve I (°F)
31-40	E10.0	OTDTSL(I) - Slope of Delta T vs. Average T for curve I.

Card Type 73 is repeated NPOTDT times.
Note that OTDTPR(I) < OTDTPR(I+1)

Card 73 A - Overtemperature Delta T Trip Parameters

Omit of ISCRAM ≠ 1, ITRPTY = 0

1-10	E10.0	OTDTO - Reference overtemperature ΔT (ΔT_0^{oT} in Eq (40b)) (^oF)
11-20	E10.0	OTDTAO - Reference overtemperature ΔT core average temperature (T_0^{oT} in EQ (40b)) (^oF)
21-30	E10.0	OTDTAU1 - Lead time constant (τ_1 in Eq (40b)) (sec)
31-40	E10.0	OTDTAU2 - Lag time constant (τ_2 in Eq (40b)) (sec)
41-50	E10.0	OTDTK1 - Basic gain (K_1 in Eq (40b))
51-60	E10.0	OTDTK2 - Core average timperature gain (K_2 in Eq (40b)) ($1/^oF$)

Card 73 B - Overtemperature Delta T Trip Parameters

Omit if ISCRAM $\neq$ 1, or ITRPTY = 0

1-10	E10.0	OTDTK3 - Pressure gain (K_3 in Eq (40b)) (1/psi)
11-20	E10.0	OTDTPO - Reference pressure (p_o in Eq (40b)) (psia)
21-30	E10.0	TDTRIP (12) - Overtemperature ΔT trip time delay (sec)

Card 74 - Scram Reactivity Table (See Figure 7)

Card 74 is included only when ISCRAM $\neq$ 0.

1-10	E10.0	TSDA(1) - Time point for scram reactivity measured from TSCRAM (seconds)
11-20	E10.0	DKSCRM(1) - Scram reactivity at time TSDA(1)
21-30	E10.0	TSDA(2)
31-40	E10.0	DKSCRM(2)
⋮	⋮	⋮

Card Type 74 is repeated until the NTSCRM Data pairs are entered with three data pairs per card.

Card 75 - Transient Power Demand Data

1-5	I5	NOPD - Number of Data Pairs $0 \leq NOPD \leq 25$
11-20	E10.0	POPF - Fraction of Initial to full power

Card 76 - Transient Power Demand Table

Field	Format	Variable - Data (units)
1-10	E10.0	TPOD(1) - Time into transient measured from zero (secs)
11-20	E10.0	POD(1) - Power demand (Fraction of Initial Power)
21-30	E10.0	TPOD(2)
31-40	E10.0	POD(2)
⋮	⋮	⋮

Card Type 76 is repeated until NOPD data pairs are entered with three pairs per card.

Card 77 - Power Forced Mode Option

1-5	I5	IPOW - Power forced mode option IPOW = 0 Kinetics calculated IPOW = 1 Power forced mode
6-10	I5	NTPOW - Number of table sets of power vs. time $1 \leq NTPOW \leq 25$

Card 78 - Power Transient Input (See Figure 5)

Card Type 78 is included only when IPOW = 1.

1-10	E10.0	TPDA(1) - Time point for relative power measured from t = 0 (Seconds)
11-20	E10.0	POWER(1) - Power level relative to initial value at time TPDA(1)
21-30	E10.0	TPDA(2)
31-40	E10.0	POWER(2)
⋮	⋮	⋮

Card Type 78 is repeated until the NTPOW data pairs are entered with three data pairs per card.

Card 79 - Radial Heat Generation Data

Field	Format	Variable - Data (units)
1-5	I5	IOPRAD - Input option for radial heat generation profile in fuel region IOPRAD = 0; No input and a uniform distribution is used. IOPRAD $\neq$ 0; input entire radial profile
11-20	E10.0	PRAD - Radial pin power peaking factor If PRAD $\leq$ 0.0, default = 1.0
21-30	E10.0	FW - Fraction of total core power generated directly in core coolant channel.

Card 80 - Axial Heat Flux Profile

1-10	E10.0	AXF(1) - Axial flux factor for node at the bottom of core
11-20	E10.0	AXF(2)
⋮	⋮	⋮
	E10.0	AXF(NS)

Card Type 80 is repeated until NS values of AXF have been entered with a maximum of six values per card.

Note: The Program normalizes the input values to an average of 1.0.

Card 81 - Radial Heat Generation Profile

Omit if IOPRAD = 0

1-10	E10.0	RAD(1) - Radial heat generation factor for central fuel node
11-20	E10.0	RAD(2)
⋮	⋮	⋮
	E10.0	RAD(M)

Note: The input values are normalized to an average value of 1.0 There are six entries per card.

Card 82 - Delay Neutrons Decay Constants

Field	Format	Variable - Data (units)
1-10	E10.0	AX(1) - Decay constant for first delay group which is equal to λ_1 in Eq (13b) (1/seconds)
11-20	E10.0	AX(2)
⋮	⋮	⋮
	E10.0	AX(IT)

Card 83 - Delay Neutron Fractions

1-10	E10.0	BX(1) - Fractional yield of first delay group neutrons per fission which equals β_1 in Eq (13b)
11-20	E10.0	BX(2)
⋮	⋮	⋮
	E10.0	BX(IT)

Card 84 - Decay Heat Decay Constants

Omit if IDH = 0

1-10	E10.0	ALQ(1) - Decay constant for first decay heat group which equals Λ_1 in Eq (13d) (1/SEC)
11-20	E10.0	ALQ(2)
⋮	⋮	⋮
	E10.0	ALQ(IDH)

There are six entries per card

Card 85 - Decay Heat Fractions

Omit if IDH = 0

1-10	E10.0	AAQ(1) - Energy fraction for first decay heat group which equals γ_1 in Eq (13d)
11-20	E10.0	AAQ(2)
⋮	⋮	⋮
	E10.0	AAQ(IDH)

There are six entries per card

4.0 OUTPUT DESCRIPTION

The printed output from DYNODE-P/2 is in the following format:

- o Version identification information
- o Input section
- o Transient output data
- o Summary output data

Descriptions of each segment are presented below. In addition, plots of the summary output can be requested through input specification and the control cards (see Appendix B).

4.1 Version Identification

This segment of output writes the following information:

1. Program name
2. Version identification
   - Number and date

4.2 Input

The input for the run is written in this segment. The input variables are grouped according to the input formats. Each variable is described along with its program symbol and appropriate units. Identification of option selections is also written.

4.3 Transient Output

For the initial time (t=0) and each time step at which the output is requested, the following data is written. The units of all variables are included in the output.

1. First data block
   a. Problem Title } Repeated on each page
   b. Time
   c. Pressurizer Pressure
   d. Core coolant flow rate
   e. Total core energy generated from t=0
   f. System time step number
   g. Current system time step size
   h. Total core power
   i. Relative neutron power

   If the kinetics option is selected, the following are included:

   j. Time derivative of the neutron power
   k. $\Delta k_{IN} + \Delta k_S$
   l. ΔK_{DOP}
   m. Δk_{ENT}
   n. Δk_{BORON}
   o. Δk_{CRC}
   p. k_{eff}
   q. Power Demand

   If decay heat generation is considered,

   r. Fission power
   s. Decay heat power

   This is followed by:

   t. The current core computational time step
   u. The core time step number
   v. The number of times the RCS and core time steps were halved and doubled from the last print. 5

2. Fuel Rod Temperature Block

   The temperature for each radial node in the oxide and cladding is printed. Average oxide and cladding temperatures are included. The temperatures in both °F and °C are included.

3. Axial Coolant Data Block

The coolant enthalpy, the heat flux, the DNB heat flux, the DNB ratio, and the coolant mass are printed for each axial coolant node. Numerical average values for the enthalpy and heat flux are also included.

4. Precursor Concentration Data Block

The delay neutron precursor concentrations are written for each delay neutron group when the kinetics option is selected.

5. Reactor Coolant System Data Block

The RCS (excluding core and pressurizer) mass, enthalpy, specific volume, boron concentration, and temperature distribution and the total enthalpy and mass are written.

In addition, the RCS loop flow distribution, the HPSIS, charging, letdown and main steam break flows are printed. If the dynamic flow model is used, the pump speeds, heads, and net torques are written. 4

6. Core Data Block

The core coolant total mass, flow rate, inlet and exit enthalpies, average density and enthalpy, core-to-coolant heat transfer, temperatures, trip set points, and average boron concentration, and integrated direct coolant energy deposition are written.

7. Pressurizer Data Block

The pressurizer masses, enthalpies, temperatures, volumes and internal energies for the upper and lower regions, the water level, surge line flow rate, relief and safety valve flow rates, heater and spray rates, integrated surge line flow and energy, and average liquid boron concentration are written. In addition, the saturation properties at the current pressure are printed.

8. Steam Generator Shell Side Data Block

The heat load, pressure, temperature, effective UA, feedwater

11. Additional Output Messages

Additional messages which provide warnings and other useful information to the user include:

a. Initialization - The number of iterations required to initialize the fuel and cladding temperatures and the

flow and enthalpy, flow rates for the steam line, relief and safety valves, water level, mixture level for UTSG, subcooled and saturated region lengths for OTSG, mass distribution, average void fraction, bubble rise velocity, total enthalpy, integrated heat transfer and net fluid flow energy out, volume errors associated with the pressure calculation which are greater than 0.001%, integrated net fluid flow, and fluid properties are printed for each steam generator.

9. Main Steam System Data Block

The pressure, mass, enthalpy, and flow distributions are written for all regions in the main steam system.

10. RCS Totals

The total fluid mass, energy, and enthalpy, and total boron mass in the RCS loops, the core, and the pressurizer are written along with the corresponding sums for the total RCS.

The integrals of the product of the flow and the enthalpy into and out of the RCS loops and the core are written. The integrated mass and energy additions and losses for the RCS from the pressurizer relief and safety valves, the pressurizer sprays and heaters, and the charging, letdown, and HPSI systems are printed.

The total energy deposition in the oxide region of the fuel rod is written along with the stored energy in the fuel and cladding. 5

The individual contributions from the core and the RCS loops to the surge line mass and energy transport are written. The values for the current contribution per system time step and the total integrals are given.

10a. Loop Flow and Pump Speed Parameters

If the dynamic flow model is used, loop pressure drops and pump torques and pressure rises are printed for each loop.

main steam system are printed along with the steam generator AR and F_{BUB} factors.

b. Occurrence of DNB - When DNB is calculated to occur at any axial coolant node, a message is written which identifies the axial location and time of occurrence.

c. Occurrence of Rewetting - When rewetting (pre-CHF) is calculated to occur, a message is written which identifies the location and time of occurrence.

d. Trip and Actuation Signals - Messages are written to inform the use of the times of occurrence for reactor trip, main feedwater isolation, safety injection actuation, auxiliary feedwater actuation, main steam line isolation, and turbine trip.

e. Pressure Non-Convergence - A message is written if the pressure calculation fails to converge within 50 iterations.

f. Effective RCS Volume - If the pressurizer empties, the effective RCS volume used for the pressure calculations after that time (see Section 2.3.3) is written.

4.4 Summary Output

After the entire transient output has been written, a summary output data block is printed. The summary data includes: time, relative neutron power, pressurizer pressure, k_{eff}, core average heat flux, average and maximum fuel temperatures, total steam generator heat load, core inlet flow and enthalpy, relief plus safety valve flow, and pressurizer water level. Each variable is listed corresponding to each time the transient output was written. In addition, the maximum transient relative power and pressurizer pressure and their corresponding times of occurrence are printed.

A summary table is provided which identifies all the trip signals (RPS, Main Feedwater Isolation, Safety Injection Actuation, Auxiliary Feedwater Actuation, Main Steam Line Isolation, and Turbine Trip) which occurred during the course of the transient and the time of occurrence of each.

5.0 SAMPLE PROBLEM

The input and output from a sample problem are given on the following pages. The first three pages are a listing of the input cards, and the remaining pages are select portions of the output. The fourth and fifth pages show the version identification segment. The next twelve pages are the input segment with the last of these containing the output of the initialization segment. The next four pages present the transient output segment for the initial time (t=0), and the next four, for t=1.0 seconds. The final two pages present the summary output block. 5

```
TEST C    FOR DYNODE-P/2 WITH DYNAMIC FLOW MODEL - STEADY STAT
     0     6    11     0     1    10                        1.0                 2
0.0         0.001      0.1          0.1          10                              4
     5    12         1.0      .47422      .53594     .001244     7.0634      6.5041    5
   .04497            0.0                                                          6
   0.24686           0.0       42.017      222.803.9635E-13    0.33012     0.17458    7
   0.62460           0.0         0.0    3.06621           1.0                      8
   0              1.6         0.0          0.0          0.0           0.0         9
.548.85           2250   2112.745  1056.367                         800.           10
   271.13632.393E-12  27.0E-060.00721               2.46          1.46             11
6.773     -50.0          0.0          0.0        1.08      -31.0        0.1163   -3   12
   0                                                                              13
   0                                                                              15
  .0485346.1446E-038.4489E-03    .042158.4489E-03    .02591                       17
   .016463.0723E-034.2244E-03   .0210754.2245E-03     0.0                         18
   .01295      .00823   .0263375     .01493                                       19
   1     1     1     0     0                                                      20
         2           1                                                            21
   .321963.3847E-03       2.77446.6688E-04      56.989      516.0       415.4     22-1
1.4551E 08           1.0         0.0       0.0       0.506                        23-1
   .160981.6924E-03       1.38723.3344E-04      56.989      516.0       415.4     22-2
5.8205E 08           1.0         0.0        0.0       0.506                       23-2
     .0646      31.2684.1667E-03                    0.10       0.1422        0.8   24
2.721 E+12        1050         1051                                               25
3.3104E 10        1100         1145                                               26
   1       6.648E 05 4.229E 05 2.578E 061.3296E 06              0.0         0.0   27
 8.318E-03 4.583E-022.6660E 074.3684E 07                                          28
   0.4203          0.0         1.0       .069        .005        0.0        0.0   29
0.0         0.0         0.0         0.0         0.0       0.0        0.0          30
0.0         1.0         0.0         0.0                                           31
1.0       +41.0         0.0                                                       32
0.2         0.0                                                                   33-1
0.2         0.0                                                                   33-2
  .0252644    .015325     12.8686                                                 34
1.1252E 13       2350        2351                                                 35
3.1595E 12       2500        2501                                                 36
      2230       2200 13.62277   7.0012      .00039466       .03848               37
  12.75     1.569E-04      479.50       800.0                                     38
13.0       13.038       1.942E-04                                                 39
      2275         23251.9670E-03                                                 40
    9        6.72   E-07 1.273E-06 0.855     736.       -0.008                    41
1750.       6552.      2000.      7241.      2567.      8000.                     42-1
2633.       10552.     3250.      15379.     4000.      21172.                    42-2
5000.       27034.     6000.      32414.     7000.      36483.                    42-3
   13       1730.      -5.584     0.0        15.0       100.       20000.         43
0.0         0.0                                                                   44
         0 3.747E-03          200 3.435E-03        390 3.122E-03                  45-1
       560 2.810E-03          715 2.498E-03        855 2.186E-03                  45-2
       975 1.873E-03         1075 1.561E-03       1160 1.249E-03                  45-3
      1235 9.367E-04         1283 6.245E-04       1330 3.122E-04                  45-4
      1360                0                                                       45-5
    0               0.0         0.0         0.0         2.0         1.0           46
    0       0.0         180.0       70.9                                          48
    1                547        1020        547        1020                       50
1.2         0.0        -0.75                                                      51
    0                                                                             52
    3               1.02        0.0        4.0        0.0        1.05             53
0.1        -0.2572     -1800.      200.                                           54
       0.024.2126             0.20    28.1526        1.50     28.1526             55
    1       551.0      578.29     1.0       0.15       5.0       5.0              56
0.75        0.126     -515.       40.       0.0        0.0                        57
    1    1          0    1    0    0    1                                         58
```

```
   13   11   12   14   17    9    9   10    6    0                          5
    2    1    0    1    1    0                                              64-B
 -1.0      3.55      -0.60      2.73      -0.32      2.20                   7-1A
 -0.18     2.00       0.0       1.73       0.20      1.50                   7-1B
  0.46     1.24       0.52      1.23       0.60      1.24                   7-1C
  0.66     1.24       0.80      1.17       0.90      1.10                   7-1D
  1.00     1.00                                                             7-1E
 -1.00     0.00      -0.01      0.00       0.00     -0.96                   7-2A
  0.10    -0.90       0.20     -0.81       0.30     -0.70                   7-2B
  0.40    -0.54       0.53     -0.30       0.65      0.00                   7-2C
  0.80     0.37       1.00      1.00                                        7-2D
 -1.00     0.00      -0.01      0.00       0.00     -0.16                   7-3A
  0.10    -0.12       0.20     -0.06       0.28      0.00                   7-3B
  0.40     0.09       0.60      0.31       0.70      0.42                   7-3C
  0.80     0.50       0.88      0.54       1.00      0.59                   7-3D
 -1.00     3.55      -0.89      3.20      -0.74      2.80                   7-4A
 -0.60     2.47      -0.46      2.20      -0.20      1.73                   7-4B
  0.00     1.40       0.37      0.80       0.43      0.74                   7-4C
  0.50     0.68       0.58      0.64       0.64      0.62                   7-4D
  0.70     0.61       1.00      0.59                                        7-4E
 -1.60     2.98      -0.82      2.40      -0.60      1.87                   8-1A
 -0.46     1.60      -0.34      1.40      -0.20      1.21                   8-1B
 -0.10     1.10       0.00      1.01       0.10      0.96                   8-1C
  0.20     0.92       0.30      0.90       0.40      0.89                   8-1D
  0.50     0.91       0.70      0.99       0.80      1.02                   8-1E
  0.90     1.02       1.00      1.00                                        8-1F
 -1.00     0.00      -0.01      0.00       0.00     -0.87                   8-2A
  0.10    -0.76       0.20     -0.63       0.30     -0.48                   8-2B
  0.40    -0.31       0.74      0.40       1.00      1.00                   8-2C
 -1.60     0.00      -0.01      0.00       0.00     -1.00                   8-3A
  0.25    -0.60       0.40     -0.37       0.50     -0.25                   8-3B
  0.60    -0.16       0.80     -0.01       1.00      0.11                   8-3C
 -1.00     2.98      -0.91      2.80      -0.80      2.60                   8-4A
 -0.70     2.42      -0.60      2.25      -0.42      2.00                   8-4B
  0.00     1.42       0.60      0.61       0.80      0.35                   8-4C
  1.00     0.11                                                             8-4D
 -100.     1.5       0.90       1.5       0.95       3.0                    9A
 1.05     -3.0       1.10      -1.5       100.      -1.5                    9B
 2.79      0.191    +5125.66    47.2                                        10
 0.5     +40.65    +50.1202  +42.0        0.0        1.0                    11
 0.9066 F+60.4533 E+60.4533 E+61.322  E+4                                   64-H
 0.640  E+82.560  E+82.560  E+81.324  E+7                                   64-I
           0   0.0                0   0.0                0   0.0
     0                                                                      67
 0.0      . 0.0        0.0                                                  68
     1   230.0           -2     1                                           69
        1.18          .5                                                    70-1
        2400         1.0                                                    70-2
        1700         1.0                                                    70-3
 19.913              1.0                                                    70-4
 5.584               1.0                                                    70-5
 12.389              1.0                                                    70-6
 36.639              1.0                                                    70-7
         .87          .6                                                    70-8
 1.      +200.0                                                             70-9
 1.      +200.0                                                             70-10
 55.9      578.0     10.0       1.11      0.02       0.00068                71-A
 2.3                                                                        71-B
 55.9      578.0     20.0       3.0       1.095      0.0107                 73-A
 0.000453  2250.0    2.3                                                    73-B
       0.1          0.0        0.2-0.0001770      0.3-0.0002655             74-1
       0.4-0.0003540           0.5-0.0005310      0.6-0.0007080             74-2
       0.7-0.0009735           0.8-0.0012390      0.9-0.0015930             74-3
```

1.0-0.0021240	1.1-0.002[illegible]550	1.2-0.0034515				74-4
1.3-0.0043365	1.4-0.005[illegible]985	1.5-0.0066375				74-5
1.6-0.0084060	1.7-0.0113280	1.8-0.0154875				74-6
1.9-0.0172575	2.0-0.0175230	2.1-0.0175230				74-7
2.2-0.0176115	2.3-0.0177000					74-8
0						75
0						77
0	1.0	0.026				79
.58	.92	1.07	1.17	1.22	1.23	80-1
1.22	1.17	1.10	.99	.84	.47	80-2
0.0124	0.0305	0.111	0.301	1.13	3.00	82
.00022	.00148	.00137	.00284	.00096	.00034	83
1.772	0.5774	6.743E-02	6.214E-03	4.739E-04	4.810E-05	84-1
5.344E-06	5.726E-07	1.036E-07	2.959E-08	7.585E-10		84-2
0.00299	0.00825	0.01550	0.01935	0.01165	0.00645	85-1
0.00231	0.00164	0.00085	0.00043	0.00057		85-2

UTILITIES SERVICE CENTER
6003 EXECUTIVE BOULEVARD
ROCKVILLE , MD.   20852
(301) 468-8010

```
XXXX       XXXX    XXXXXXXXX      XXXXXXXXXXX
XXXX       XXXX   XXXXXXXXXXX    XXXXXXXXXXXXX
XXXX       XXXX  XXXXXXXXXXXXX  XXXXXXXXXXXXXXX
XXXX       XXXX XXXX      XXXX XXXX      XXXX
XXXX       XXXX XXXX      XXXX XXXX      XXXX
XXXX       XXXX XXXX      XXXX XXXX      XXXX
XXXX       XXXX XXXX           XXXX
XXXX       XXXX XXXX           XXXX
XXXX       XXXX XXXX           XXXX
XXXX       XXXX XXXX           XXXX
XXXX       XXXX XXXXXXXXXXX    XXXX
XXXX       XXXX  XXXXXXXXXXX   XXXX
XXXX       XXXX   XXXXXXXXXXX  XXXX
XXXX       XXXX           XXXX XXXX
XXXX       XXXX           XXXX XXXX
XXXX       XXXX           XXXX XXXX
XXXX       XXXX           XXXX XXXX
XXXX       XXXX XXXX      XXXX XXXX      XXXX
XXXX       XXXX XXXX      XXXX XXXX      XXXX
XXXX       XXXX XXXX      XXXX XXXX      XXXX
XXXXXXXXXXXXXXX XXXXXXXXXXXXX  XXXXXXXXXXXXXXX
 XXXXXXXXXXXXX   XXXXXXXXXXX    XXXXXXXXXXXXX
  XXXXXXXXXXX     XXXXXXXXX      XXXXXXXXXXX
```

```
   CCCCCCC DDDDDDD
  C       C D       D
 C  CCCCCC DDDDDD  D
C  C             D  D
C  C             D  D
 C  CCCCCC DDDDDD  D
  C       C D       D
   CCCCCCC DDDDDDD    C O N T R O L   D A T A   C O R P O R A T I O N
```

```
******************************************
******************************************
**                                      **
**                                      **
**                                      **
**              DYNODEP 2               **
**                                      **
**                                      **
**                                      **
**           VERSION =  2.000           **
**                                      **
**                                      **
**                                      **
******************************************
******************************************
```

NUCLEAR ASSOCIATES DYNODE-I-P

VERSION 2 VERSION DATE (4-19-78)

TEST CASE FOR DYNODE-P/2 WITH DYNAMIC FLOW MODEL - STEADY STATE

DYNODE-I-P INPUT VALUES

I. CONTROL VARIABLES

NUMBER DECAY HEAT PRECURSR-IDH	11	
REACTIVITY INSERTION - IK	0	
NO. OF DELAYED NEUTRON GPS.-IT	6	
PLOT OPTION - IPLT	0	
NUMBER OF DEL AND LP DATA SETS-NOTIM	1	
NUMBER CORE CAL TIME STEPS/DELIN TS-NOKIN	10	
RKMERSON ACCURACY-ACCURC	.100000E-05	
TIME LIMIT FOR COMPLETE RUN-TT	1.0000	SEC

TIME STEP AND PRINT INTERVAL SETS

I	ENDTIM(I) SEC	DELIN(I) SEC	DELLP(I) SEC	DELMX(I) SEC	NOSTM(I) MSL STP
1	0.0000	.0010	.1000	.1000	10

II. GEOMETRY DESCRIPTION

NUMBER OF FUEL REGIONS - M	5	
NUMBER OF AXIAL SEGMENTS - NS	12	
LENGTH OF AXIAL SEGMENT - SEGL	1.0000	FT
INNER RADIUS OF FUEL CLAD-RIN	.4742	CM
OUTER RADIUS OF FUEL CLAD-ROUT	.5359	CM
FLOW AREA PER PIN - AF	.12440E-02	FT**2
WEIGHT OF FUEL PELLET - WP	7.0634	GM/CM OF LENGTH
DENSITY OF CLADDING - RHC	6.5041	GM/CC
CHANNEL EQUIVALENT DIAMETER-DE	.44970E-01	FT
HEATED EQUIVALENT DIAMETER-DEH	0.	FT

III. HEAT TRANSFER DATA

FUEL HEAT CAPACITY CURVE - ACP	.24686E+00	WT SEC/GM-C
FUEL HEAT CAPACITY CURVE - BCP	0.	WT SEC/GM-C**2
FUEL CONDUCTIVITY CONSTANTS-A	42.0170	WT/CM
FUEL CONDUCTIVITY CONSTANTS-B	222.8000	C
FUEL CONDUCTIVITY CONSTANTS-C	.39635E-12	WT/CM-C-K**3
CLAD HEAT CAPACITY - CPC	.3301	WT-SEC/GM-C
CLAD CONDUCTIVITY - KC	.1746	WT/CM-C
CONDUCTANCE OF UO2 CLAD GAP-HG	.6246	WT/CM**2-C
LINEAR TEMP COEFF OF HG - AHG	0.	WT/CM**2-C
QUADRC TEMP COEFF OF HG - BHG	0.	WT/CM**2-C
CLAD TO COOLANT CONDUCTANCE-HF	3.0662	WT/CM**2-C
CHF FACTOR - CHFFR	1.0000	

IV. SYSTEM DESCRIPTION

INIT CORE INLET ENTHALPY - ENI	548.8500	BTU/LBM
INITIAL LOOP 1 FLOWRATE - W1	2112.7450	LBM/PIN-HR
INITIAL LOOP 2 FLOWRATE - W2	1056.3670	LBM/PIN-HR

FOR LF = 1 THE FLOW RATE IS INPUT IN LBM/PIN-HR

SYSTEM PRESSURE - PRO	2250.0000	PSIA
INIT BORON CONCENTRTN-BORCON	800.0000	PPM

V. PHYSICAL CONSTANTS

POWER AT TIME ZERO - PO	271.1360	WT/CC
CONVERSION CONSTANT - AA	.32393E-10	WT-SEC/FISSION
PROMPT NEUTRON LIFETIME - RL	.27000E-04	SEC
EFF. DELAY NEUTRON FRACTION-BT	.72100E-02	
FAST NEUTRONS/FISSION - NU	2.4600	
TOT(BX(I)/BT)*NU-1,I=1, 6-ALPHA	1.4600	
ENTHALPY-REACTIVITY EQ. - AK	.67730E-04	LB/BTU
ENTHALPY-REACTIVITY EQ. - BK	0.	(LB/BTU)**2
ENTHALPY-REACTIVITY EQ. - CK	0.	
DOPPLER COEFFICIENT EQ. - DK1	0.	
DOPPLER COEFFICIENT EQ. - DK2	.10800E-02	
DOPPLER COEFFICIENT EQ. - DK3	.10000E+01	
BORON REACTIVITY COEFF -DKBC,	.11630E-03	1/PPM

VI. VOID/QUALITY CONSTANTS

SLIP CALCULATION OPTION-OPTSLP	0
CONSTANT SLIP VALUE - SLIP	1.6000
CONSTANT TERM - CC1	0.0000
LINEAR COEFFICIENT - CC2	0.0000
QUADRATIC COEFFICIENT - CC3	0.0000
CUBIC COEFFICIENT - CC4	0.0000

NUMBER OF ENTRIES IN REACTIVITY VS DENSITY TABLE (NCRO)= 0

NUMBER OF ENTRIES IN REACTIVITY VS FUEL TEMP TABLE (NOTF)= 0

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VII. PRIMARY COOLANT SYSTEM VOLUMES

VOLUME NO.	VOLUME NAME	VOLUME - FT**3/PIN
1	UPPR PLENM	.48534E-01
2	HOT LEG L1	.61446E-02
3	SG1 HOT PN	.84489E-02
4	STM GEN L1	.42150E-01
5	SG1 CLD PN	.84489E-02
6	CLD LEG L1	.25910E-01
7	DNCOMR L1	.16460E-01
8	HOT LEG L2	.30723E-02
9	SG2 HOT PN	.42244E-02
10	STM GEN L2	.21075E-01
11	SG2 CLD PN	.42245E-02
13	CLD LEG L2	.12950E-01
14	DNCOMR L2	.82300E-02
15	LOWR PLENM	.26338E-01
-	CORE	.14930E-01

SUMMARY OF RCS VOLUME INPUT DATA

RCS LOOPS	.2362101E+00	FT3/PIN
CORE	.1493000E-01	FT3/PIN
PRESS	.4058940E-01	FT3/PIN
TOTAL	.2917295E+00	FT3/PIN

PRESSURIZER DATA

PRESSURIZER STEAM VOL. - VPSPR	.0253	FT**3/PIN
PRESSURIZER LIQUID VOL.- VPLPR	.0153	FT**3/PIN
INITIAL PRESS WTR LEVEL-WTRLVL	12.8686	FEET
RELIEF VALVE K/A**2 - RVKA2	.11252E+14	(PIN/FT2)2
PRESS RELIEF VALVE OPEN-PRELF1	2350.0000	PSIA
RELIEF VALVE FULL OPEN -PRELF2	2351.0000	PSIA
SAFETY VALVE K/A**2 - SVKA2	.31595E+13	(PIN/FT2)2
PRESS SAFETY VALVE OPEN-PSAFT1	2500.0000	PSIA
SAFETY VALVE FULL OPEN -PSAFT2	2501.0000	PSIA
PRESS SETPOINT HEATERS ON-PPHH	2230.0000	PSIA
LOW PRESS PROP. HTR RANGE-PPHL	2200.0000	PSIA
LEVEL SETPOINT HTRS ON -PWLHON	13.6228	FEET
LEVEL SETPOINT HTRS OFF-PWLHOF	7.0012	FEET
PROPORT HEATER RAMP RATE -QPHR	.39466E-03	BTU/SEC-PSI-PIN
MAX. HEATER HEAT RATE - QPHM	.38480E-01	BTU/SEC-PIN
LOW PRESS LEVEL CHRG ON-PWLCON	12.7500	FEET
PRESS CHARGING RATE - PCR	.15690E-03	LB/SEC-PIN
CHARGING WATER ENTHALPY -ENCHR	.47950E+03	BTU/LB
CHARGING BORON CONCENT. -BNCHR	.80000E+03	PPM
HI PRESS LEVEL LETDN ON-PWLLON	13.0000	FEET
LEVEL FOR MAX LTDN RATE-PWLLMR	13.0380	FEET
MAX PRESS LETDOWN RATE - PLDMR	.19420E-03	LB/SEC-PIN
PRESS SETPOINT SPRAY ON-PPSPON	2275.0000	PSIA
PRESS FOR MAX SPRAY RATE-PPSPMR	2325.0000	PSIA
MAX PRESS SPRAY RATE - PSRM	.19670E-02	LB/SEC-PIN

PRESSURIZER WATER RELIEF TABLE INPUT
NUMBER OF DATA PAIRS - NOWTRR 9

```
RELIEF VALVE AREA - ARELF         .672000E-06 FT2/PIN
SAFE[illegible] VALVE AREA - ASAFT          .127300E-05 FT2/PIN
DISCHARGE COEFFICIENT - DISCCF    .855000E+00
CURVE REFERNCE ENTHALPY-HWTRRF    .736000E+03 BTU/LB
SLOPE FLOW VS ENTHALPY -DGWRDH -.800000E-02 1/(BTU/LB)
```

I	PRESSURE (PSIA)	MASS FLOW RATE (LB/FT2-SEC)
1	.1750000E+04	.6552000E+04
2	.2000000E+04	.7241000E+04
3	.2567000E+04	.8000000E+04
4	.2833000E+04	.1055200E+05
5	.3250000E+04	.1537900E+05
6	.4000000E+04	.2117200E+05
7	.5000000E+04	.2703400E+05
8	.6000000E+04	.3241400E+05
9	.7000000E+04	.3648300E+05

```
SAFETY INJECTION SYSTEM PARAMETERS
NUMBER OF DATA POINTS-PRESS,FLOW-NOSIN  13
LOW PRESS ACTUATION SIGNAL - SILP1730.00 PSIA
LOW LEVEL ACTUATION SIGNAL - SILL   5.58 FEET
ACTUATION TIME SIGNAL - SITIM  0.         SEC
ACTUATION TIME DELAY - SITD     .15000E+02 SEC
SAFETY INJECTION ENTHALPY-ENSINJ   .10000E+03 BTU/LB
SAFETY INJECTION BORON CN-BORSIN  .20000E+05 PPM
SAFETY INJECT. LINE WTR MASS-SILMAS  0.          LB/PIN
SAFETY INJECT. LINE BORON CONC.-SILBRN  0.           PPM

ESFAS OPTION - IESFAS = 0. SIGNAL ON EITHER PRESSURE OR LEVEL
```

I	PRESSURE(I) (PSIA)	FLOW(I) (LB/SEC-PIN)
1	0.000000	.374700E-02
2	200.000000	.343500E-02
3	390.000000	.312200E-02
4	560.000000	.281000E-02
5	715.000000	.249800E-02
6	855.000000	.218600E-02
7	975.000000	.187300E-02
8	1075.000000	.156100E-02
9	1160.000000	.124900E-02
10	1235.000000	.936700E-03
11	1283.000000	.624500E-03
12	1330.000000	.312200E-03
13	1360.000000	0.

STEAM GENERATOR DATA

```
U-TUBE STEAM GENERATORS - ISGUOT = 0
STEAM GENERATOR SECONDARY SIDE OPTION-ISGOPT  1
```

	STEAM GENERATOR 1	STEAM GENERATOR 2
INITIALIZATION OPTION-IFLGT	1	1
NUMBER OF SG IN LOOP-SGNUM	.2000000E+01	.1000000E+01
STM GEN SECND VOLUME-VOLSG	.3219600E+00	.1609800E+00 FT3/PIN
SECNDRY SIDE AREA - ARESG	.3384700E-02	.1692400E-02 FT2/PIN
HEAT TRANSFER AREA - SGA	.2774400E+01	.1387200E+01FT2/PIN
STM GEN TUBE FLOW AREASGF.	.6668800E-03	.3334400E-03FT2/PIN
INITIAL MIXTURE HGT - ZMIX	.5698900E+02	.5698900E+02 FEET

INITIAL SEC. SIDE TEMP-TS	.5160000E+03	.5160000E+03	F
INIT[illegible]FDWATER ENTHALPY-HFD	.4154000E+03	.41[illegible]0E+03	BTU/LB
STEA[illegible]LINE K/A**2 - SLKA2	.1455100E+09	.56[illegible]00E+09	(PIN/FT2)2
IN. FRAC ISOVALVE OPEN-FIV	.1000000E+01	.1000000E+01	
INITIAL SG AVE VOID - AVSG	.5060000E+00	.5060000E+00	

STEAM GENERATOR HEAT TRANSFER DATA.

HYDRAULIC DIAMETER - DSG	.64600E-01	FT
TUBE HEIGHT - TUBEH	.31266E+02	FT
TUBE THICKNESS - TUBEDX	.41667E-02	FT
FOULING FACTOR - RFOUL	-0.	
REVERSE HT TRAN FACTOR-REVERS	.10000E+00	
SEC SIDE HYDRAULIC DIAMTR-DSGS	.14220E+00	FT
BUBBLE RISE GRADIENT PARMTR-CO	.80000E+00	

RELIEF AND SAFETY VALVE DATA

	RELIEF VALVES	SAFETY VALVES	
K/AREA**2 - KA2	.2721000E+13	.3310400E+11	(PIN/FT2)2/SG
PRESS VALVES OPENING-PSG1	.1050000E+04	.1100000E+04	PSIA
PRESS VALVES FULLOPEN-PSG2	.1051000E+04	.1145000E+04	PSIA

MAIN STEAM SYSTEM DATA

NUMBER MAIN STEAM LINES TO TURBINE - LSS 1 STEAM GEN STEAM FLOW OPTION - ISTFLW 0

	LOOP 1	LOOP 2
INERTIA (L/A)SG OUT-HEADER- XISL(PIN/FT)	.66480E+06	.13296E+07
INERTIA (L/A)HEADER-MSL - XISH(PIN/FT)	.42290E+06	
INERTIA (L/A)MSL-TURBINE - XIST(PIN/FT)	.25780E+07	
STEAM HEADER LINE VOLUME -VSH (FT3/PIN)	.83180E-02	
MAIN STEAM LINE VOLUME - VSL (FT3/PIN)	.45830E-01	
STEAM HEADER K/A**2 - SHKA2 (PIN/FT2)2	.26660E+08	
MAIN STEAM LINE K/A**2-STKA2(PIN/FT2)2	.43684E+08	
BYPASS CAPACITY PER MAIN STM LINE-SBPFR	.42030E+00	
INITIAL FRACTION BYPASS OPEN - FRBPOP	0.	
VARIABLE BYPASS FRACTION - FRBPA	.10000E+01	
BYPASS FRACT AREA-TEMP RATE -DABPDT(1/F)	.69000E-01	
BYPASS FRAT AREA-PRES RATE-DABPDP(1/PSI)	.50000E-02	
BYPASS ACTUATION TIME SIGNAL - STBP(SEC)	0.	
BYPASS VALVE OPENING RATE -VORBP(1/SEC)	0.	
DUMP CAPACITY PER MAIN STM LINE-SDPFR	0.	
INITIAL FRACTION DUMP OPEN - FRDPOP	0.	
VARIABLE DUMP FRACTION - FRDPA	0.	
DUMP FRACT AREA-TEMP RATE - DADPDT (1/F)	0.	
DUMP FRACT AREA-PRES RATE -DADPDP(1/PSI)	0.	
DUMP ACTUATION TIME SIGNAL - STDP(SEC)	0.	
DUMP VALVE OPENING RATE - VORDP (1/SEC)	0.	
INITIAL FRACT CONTROL VALVES CLOSD-FRCVC	0.	
VARIABLE CONTROLVALVE FRACTION - FRCVA	.10000E+01	
CONTROL VALVE CLOSURE RATE-VCRCV(1/SEC)	0.	
CONTROL VALVE CLS TIME DELAY-TDCV(SEC)	0.	
STOP VALVE CLOSURE RATE-VCRSV (1/SEC)	.10000E+05	
FRACTION OF STOP VALVE CLOSURE - FRSV	.10000E+01	
STOP VALVE CLOSURE TIME DELAY-TDSV(SEC)	0.	
MSIV CLOSURE RATE - VCRATE (1/SEC)	.20000E+00	.20000E+00
MSIV CLOSURE TIME DELAY-TDMSV (SEC)	0.	0.

CONTROL SYSTEM DATA

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DUMP AND BYPASS CONTROLS
TEMP-PRESS CONTROL OPTION - IDPOPT                 1
REF AVE TEMP DUMP CONTROL  - TARD      .5470000E+03 F
REF STM PRESS DUMP CONTROL - PARD      .1020000E+04 PSIA
REF AVE TEMP BYPASS CONTROL - TARB     .5470000E+03 F
REF STM PRESS BYPASS CONTROL - PARB    .1020000E+04 PSIA

TURBINE VALVE CONTROLS
STOP VALVE OVERSPEED CLOSURE-PDOSPD  .1200000E+01 FRC FP
TURBINE RUNBACK INITIATIN TIME-TRBT 0.            SEC
TURBINE RUNBACK POWER LEVEL - TRBL    .7500000E+00 FRC IN
          STEAM LINE ISOLATION CONTROL
SIGNAL OPTION - IOPSLI   0
HI-HI STEAM FLOW - HIHIWS -0.             FRAC INITIAL
HI STEAM FLOW - HIWS       -0.             FRAC INITIAL
LOW CORE AVE TEMP - TALO  -0.             F
LOW SECONDARY SIDE PRESSURE-PSECLO        -0.0000 PSIA

FEEDWATER CONTROL
NUMBER OF WATER LEVEL VS POWER LEVEL DATA PAIRS - NOLVSL   3     RATIO INITIAL POWER TO FULL POWER - POPFFW   .102000E+01

MINIMUM FEEDWATER FLOW AFTER TRIP-WFDMIN 0.          FRAC IN
FEEDWATER RAMP DOWN TIME - FWRMPT   .400000E+01SEC
TIME DELAY FEEDWATER RAMP DOWN - TDFWIS 0.          SEC
MAXIMUM FEEDWATER FLOW - WFDMAX           .105000E+01 FRAC INIT FLOW
WATER LEVEL CONTROLLER DEAD BAND-WTLDB     .10 FEET
WATER LEVEL CONTROLLER CONSTANT-CONLVL -.257200E+00 1/FT-SEC
WATER LEVEL LAG TIME CONSTANT - TAULV2 -.180000E+04 SEC
WATER LEVEL LEAD TIME CONSTANT- TAULV1  .200000E+03 SEC
  I    POWER LEVEL      WATER LEVEL
     (FR. FULL POW)      (FEET)
  1   0.                .2421260E+02
  2    .2000000E+00     .2815260E+02
  3    .1500000E+01     .2815260E+02

CONTROL ROD CONTROLLER
CONTROL ROD CONTROLLER OPTION - IOPCRC             1
ZERO POWER REFERENCE CORE AVE TMP-TAVRFZ      551.0000 F
FULL POWER REFERENCE CORE AVE TMP-TAVRFF      578.2900 F
RATIO INITIAL POWER TO FULL POWER-POPFCR  .1000000E+01
LOW POWER LEVEL ROD STOP SIGNAL - PRSTOP  .1500000E+00 FRC FP
MARGIN OVERTMP TRIP FOR ROD STOP- DTMPOT        5.0000 F
MARGIN OVERPWR TRIP FOR ROD STOP- DTMPOP        5.0000 F
CONTROLLER AVE TEMP    DEAD BAND - CRCDB         .7500 F
CONTROLLER AVE TEMP    CONSTANT - CONCRC  .1260000E-05 1/F-SEC
CONTROL ROD LAG TIME CONSTANT - TAUCR2    .1500000E+02 SEC
CONTROL ROD LEAD TIME CONSTANT - TAUCR1   .4000000E+02 SEC
CONTROLLER POWER LEVEL DEAD BAND-CRCPDB  0.           FRC FP
CONTROLLER POWER LEVEL CONSTANT -CONCPP  0.           1/(FR FP-SEC)
MAXIMUM CONTROLLER REACTIVITY RATE - DKDTMX    .1000000E+21 1/SEC
***** ROD WITHDRAWL IS BLOCKED AFTER TURBINE RUNBACK
```

RCS LOOP FLOWS CALCULATED WITH HOMOLOGOUS PUMP MODEL

RCS COLD LEG GEOMETRY OPTION-LCE 0

PUMP OPTION PARAMETER - IPUMP 1

HOMOLOGOUS CURVES

PUMP HEAD CURVES

CURVE TYPE 1 CONTAINS 13 DATA PAIRS

J	GH(1,J)	HOG(1,J)
1	-.1000000E+01	.3550000E+01
2	-.6000000E+00	.2730000E+01
3	-.3200000E+00	.2200000E+01
4	-.1800000E+00	.2000000E+01
5	0.	.1730000E+01
6	.2000000E+00	.1500000E+01
7	.4600000E+00	.1240000E+01
8	.5200000E+00	.1230000E+01
9	.6000000E+00	.1240000E+01
10	.6600000E+00	.1240000E+01
11	.8000000E+00	.1170000E+01
12	.9000000E+00	.1100000E+01
13	.1000000E+01	.1000000E+01

CURVE TYPE 2 CONTAINS 11 DATA PAIRS

J	GH(2,J)	HOG(2,J)
1	-.1000000E+01	0.
2	-.1000000E-01	0.
3	0.	-.9600000E+00
4	.1000000E+00	-.9000000E+00
5	.2000000E+00	-.8100000E+00
6	.3000000E+00	-.7000000E+00
7	.4000000E+00	-.5400000E+00
8	.5300000E+00	-.3000000E+00
9	.6500000E+00	0.
10	.8000000E+00	.3700000E+00
11	.1000000E+01	.1000000E+01

CURVE TYPE 3 CONTAINS 12 DATA PAIRS

J	GH(3,J)	HOG(3,J)
1	-.1000000E+01	0.
2	-.1000000E-01	0.
3	0.	-.1600000E+00
4	.1000000E+00	-.1200000E+00
5	.2000000E+00	-.6000000E-01
6	.2800000E+00	0.
7	.4000000E+00	.9000000E-01
8	.6000000E+00	.3100000E+00
9	.7000000E+00	.4200000E+00
10	.8000000E+00	.5000000E+00
11	.8800000E+00	.5400000E+00
12	.1000000E+01	.5900000E+00

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CURVE TYPE 4 CONTAINS 14 DATA PAIRS

J	GH(4,J)	HOG(4,J)
1	-.1000000E+01	.3550000E+01
2	-.8900000E+00	.3200000E+01
3	-.7400000E+00	.2800000E+01
4	-.6000000E+00	.2470000E+01
5	-.4600000E+00	.2200000E+01
6	-.2000000E+00	.1730000E+01
7	0.	.1400000E+01
8	.3700000E+00	.8000000E+00
9	.4300000E+00	.7400000E+00
10	.5000000E+00	.6800000E+00
11	.5800000E+00	.6400000E+00
12	.6400000E+00	.6200000E+00
13	.7000000E+00	.6100000E+00
14	.1000000E+01	.5900000E+00

TORQUE CURVES

CURVE TYPE 1 CONTAINS 17 DATA PAIRS

J	GZ(1,J)	TOG(1,J)
1	-.1000000E+01	.2980000E+01
2	-.8200000E+00	.2400000E+01
3	-.6000000E+00	.1870000E+01
4	-.4600000E+00	.1600000E+01
5	-.3400000E+00	.1400000E+01
6	-.2000000E+00	.1210000E+01
7	-.1000000E+00	.1100000E+01
8	0.	.1010000E+01
9	.1000000E+00	.9600000E+00
10	.2000000E+00	.9200000E+00
11	.3000000E+00	.9000000E+00
12	.4000000E+00	.8900000E+00
13	.5000000E+00	.9100000E+00
14	.7000000E+00	.9900000E+00
15	.8000000E+00	.1020000E+01
16	.9000000E+00	.1020000E+01
17	.1000000E+01	.1000000E+01

CURVE TYPE 2 CONTAINS 9 DATA PAIRS

J	GZ(2,J)	TOG(2,J)
1	-.1000000E+01	0.
2	-.1000000E-01	0.
3	0.	-.8700000E+00
4	.1000000E+00	-.7600000E+00
5	.2000000E+00	-.6300000E+00
6	.3000000E+00	-.4800000E+00
7	.4000000E+00	-.3100000E+00
8	.7400000E+00	.4000000E+00
9	.1000000E+01	.1000000E+01

CURVE TYPE 3 CONTAINS 9 DATA PAIRS

J	GZ(3,J)	TOG(3,J)
1	-.1000000E+01	0.
2	-.1000000E-01	0.
3	0.	-.1000000E+01
4	.2500000E+00	-.6000000E+00
5	.4000000E+00	-.3700000E+00
6	.5000000E+00	-.2500000E+00
7	.6000000E+00	-.1600000E+00
8	.8000000E+00	-.1000000E-01
9	.1000000E+01	.1100000E+00

CURVE TYPE 4 CONTAINS 10 DATA PAIRS

J	G7(4,J)	TOG(4,J)
1	-.1000000E+01	.2980000E+01
2	-.9100000E+00	.2800000E+01
3	-.8000000E+00	.2600000E+01
4	-.7000000E+00	.2420000E+01
5	-.6000000E+00	.2250000E+01
6	-.4200000E+00	.2000000E+01
7	0.	.1420000E+01
8	.6000000E+00	.6100000E+00
9	.8000000E+00	.3500000E+00
10	.1000000E+01	.1100000E+00

MOTOR TORQUE CURVE
NUMBER OF DATA PAIRS-NPMT 6

J	AM(J)	TMOA(J)
1	-.1000000E+03	.1500000E+01
2	.9000000E+00	.1500000E+01
3	.9500000E+00	.3000000E+01
4	.1050000E+01	-.3000000E+01
5	.1100000E+01	-.1500000E+01
6	.1000000E+03	-.1500000E+01

REVERSE SPEED NOT PERMITTED (IRP EQ 0)

NUMBER OF PUMPS IN LOOPS AND INITIAL PUMP STATUSES

LOOP	NPPL	IPSTAT
1	2	1
2	1	1

RATED PUMP PARAMETERS FOR A SINGLE PUMP
RATED VOLUMETRIC FLOW - RATQ .2790000E+01 GPM/PIN
RATED PUMP TORQUE - RATT .1910000E+05 LBF-FT
RATED PUMP SPEED - RATS .1256600E+03 RAD/SEC
RATED PUMP FLUID DENSITY-RATD .4720000E+02 LBM/FT3

PUMP AND MOTOR INERTIAS AND TORQUE PARAMETERS
PUMP INERTIA - PINERT .5000000E+04 LBM-FT2
FLYWHEEL AND MOTOR INERTIA-FINERT .6500000E+05 LBM-FT2
FRICTION TORQUE COEFFICIENT-FRICC .1202000E+04 LBF-FT
FRICTION TORQUE EXPONENT - FRICE .2000000E+01
WINDAGE TORQUE COEFFICIENT-WINDC 0. LBF-FT
WINDAGE TORQUE EXPONENT - WINDE .1000000E+01

LOOP DATA

LOOP	INERTIA(XINE) (PIN/FT)	LOSS COEF(PDC) (PIN/FT2)**2
1	.9066000E+06	.6400000E+08
2	.4533000E+06	.2560000E+09
R VESSL	.1322000E+05	.1324000E+08

PUMP TRANSIENT SPECIFICATIONS

LOOP	TRANSIENT TYPE IPTRCN	TIME DELAY TDPTR (SEC)
1	6	0.

```
NO LOOP 1 TIME DEPENDENT FEEDWATER INPUT - NF1= 0

NO LOOP 2 TIME DEPENDENT FEEDWATER INPUT - NF2= 0
       REACTIVITY
  STEP INSERTION (IK=0) - RSTEP          0.0000 $
  RAMP INSERTION (IK=1) - RRAMP          0.0000 $/SEC
  TOTAL RAMP REACTIVITY - RTOT           0.0000 $


       SCRAM
 SCRAM OPTION - ISCRAM            1
 OPTION FOR LOOP SENSOR LOCATION-ISENSR      -2
 DELTA-T TRIP CALCULATION OPTION-ITRPTY       1
 HOT LEG TEMP - SENSOR DELAY TIME -TDLYTH-0.              SEC
 COLD LEG TEMP- SENSOR DELAY TIME -TDLYTC-0.              SEC
 HOT LEG TEMP-SENSOR LAG TIME CONS-TLAGTH-0.              SEC
 COLD LEG TMP-SENSOR LAG TIME CONS-TLAGTC-0.              SEC
 TIME DELAY FOR SCRAM - TSCRAM **********
 NUMBER OF DATA PAIRS - NTSCRM   23

 REACTOR PROTECTIVE SYSTEM PARAMETERS
  I    TRIP FUNCTION                          TRIP SET POINT  DELAY TIME(SEC)
  1  HIGH NEUTRON POWER (FRAC. INITIAL)**       .11800E+01      .50000E+00
  2  HIGH PRESSURIZER PRESSURE (PSIA)****       .24000E+04      .10000E+01
  3  LOW  PRESSURIZER PRESSURE (PSIA)****       .17000E+04      .10000E+01
  4  HIGH PRESSURIZER LEVEL (FEET)*******       .19913E+02      .10000E+01
  5  LOW  PRESSURIZER LEVEL (FEET)*******       .55840E+01      .10000E+01
  6  LOW-LOW STEAM GENERATOR LEVEL (FEET)       .12389E+02      .10000E+01
  7  TURBINE TRIP - HI S G LEVEL (FEET)**       .36639E+02      .10000E+01
  8  LOW REACTOR COOLANT FLOW (FRAC INIT)       .67000E+00      .60000E+00
  9  HIGH POWER/FLOW (FRAC. INITIAL)*****       .10000E+21     0.
 10  HIGH CORE OUTLET TEMPERATURE (F)****       .10000E+21     0.

 OVERPOWER DELTA-T TRIP PARAMETERS
 NOMINAL DELTA T - OPDT0                 55.9000 F
 NOMINAL T AVG - OPDTA0                 578.0000 F
 RATE/LAG TIME CONSTANT - OPDTAU         10.0000 SEC
 BASIC GAIN - OPDTK4                     1.11000
 RATE/LAG GAIN - OPDTK5                   .02000 /F
 TEMPERATURE GAIN - OPDTK6               .00068000 /F
 TRIP DELAY TIME - TDTRIP(11)             2.3000 SEC

 OVERTEMPERATURE DELTA-T TRIP PARAMETERS
 NOMINAL DELTA T - OTDT0               55.9000 F
 NOMINAL T AVG - OTDTA0               578.0000 F
 LEAD TIME CONSTANT - OTDTAU1          20.0000 SEC
 LAG TIME CONSTANT - OTDTAU2            3.0000 SEC
 BASIC GAIN - OTDTK1                   1.09500
 TEMPERATURE GAIN - OTDTK2             .01070000 /F
 PRESSURE GAIN - OTDTK3                .00045300 /PSI
 NOMINAL PRESS - OTDTP0             2250.0000 PSIA
 TRIP DELAY TIME - TDTRIP(12)           2.3000 SEC

 SCRAM REACTIVITY  VS  TIME TABLE

   TIME (SEC)         REACTIVITY
    .10000E+00        0.
    .20000E+00        -.17700E-03
    .30000E+00        -.26550E-03
```

[illegible]0000E+00	-.35400E-03
[illegible]0000E+00	-.53100E-03
.60000E+00	-.70800E-03
.70000E+00	-.97350E-03
.80000E+00	-.12390E-02
.90000E+00	-.15930E-02
.10000E+01	-.21240E-02
.11000E+01	-.26550E-02
.12000E+01	-.34515E-02
.13000E+01	-.43365E-02
.14000E+01	-.53985E-02
.15000E+01	-.66375E-02
.16000E+01	-.84960E-02
.17000E+01	-.11328E-01
.18000E+01	-.15468E-01
.19000E+01	-.17258E-01
.20000E+01	-.17523E-01
.21000E+01	-.17523E-01
.22000E+01	-.17612E-01
.23000E+01	-.17700E-01

KINETICS OPTION SELECTED - IPOW 0

INPUT ARRAYS

RADIAL PEAKING FACTOR - PRAD = 1.0000000

FRACTION POWER GENERATED IN COOLANT - FW .0260000

RELATIVE FLUX
(AXF(K),K=1,NS)

INPUT VALUES		NORMALIZED
1	.5800	.5810
2	.9200	.9215
3	1.0700	1.0718
4	1.1700	1.1720
5	1.2200	1.2220
6	1.2300	1.2321
7	1.2200	1.2220
8	1.1700	1.1720
9	1.1000	1.1018
10	.9900	.9917
11	.8400	.8414
12	.4700	.4708

RADIAL HEAT GENERATION PROFILE IN FUEL ROD

I	RAD(I)
1	1.000000
2	1.000000
3	1.000000
4	1.000000
5	1.000000

DELAY NEUTRON DATA

DECAY(1/SEC) (AX(I),I=1,IT)		FISSION YIELDS (BX(I),I=1,IT)	
1	.012400	1	.000220
2	.030500	2	.001480
3	.111000	3	.001370
4	.301000	4	.002840
5	1.130000	5	.000960
6	3.000000	6	.000340

DECAY HEAT PRECURSOR DATA

I	DECAY CONSTANT(1/SEC) ALO(I)	ENERGY FRACTION AAO(I)
1	.177200E+01	.299000E-02
2	.577400E+00	.825000E-02
3	.674300E-01	.155000E-01
4	.621400E-02	.193500E-01
5	.473900E-03	.116500E-01
6	.481000E-04	.645000E-02
7	.534400E-05	.231000E-02
8	.572600E-06	.164000E-02
9	.103600E-06	.850000E-03

10 .295900E-07 .430000E-03
11 .758500E-09 .570000E-03

END OF INPUT

****

PUMP INITIALIZATION PARAMETERS

RATED PUMP HEAD .2454522E+03 FEET

PUMP	SPEED (RAD/SEC)	VOLUMETRIC FLOW (GPM/PIN)	FLOW (LB/HR-PIN)
1	.1235469E+03	.2814421E+01	.2112745E+04
2	.1235469E+03	.2814407E+01	.1056367E+04

****

NUMBER OF ITERATIONS FOR INITIALIZATION OF FUEL AND CLAD TEMPS. 5

NUMBER OF ITERATIONS FOR INITIALIZATION OF FUEL AND CLAD TEMPS. 3

NUMBER OF ITERATIONS FOR INITIALIZATION OF PRIMARY AND SECONDARY SYSTEM VARIABLES 2

STEAM GENERATOR HEAT TRANSFER AREA FACTORS ****** AR1= 1.0000 AR2= 1.0000

U-TUBE SG BUBBLE RISE FACTORS ***** FRUB1= .23274E+01 FRUB2= .23273E+01

TEST CASE FOR DYNODE-P/2 WITH DYNAMIC FLOW MODEL - STEADY STATE

```
*****-   TIME=    0.000 SEC     PRESSURE= 2250.00 PSIA     FLOW= 3169.11 LB/HR-PIN    INTEGRATED ENERGY=  0.          WT-SEC/CC
*****-   TIME STEP NUMBER=        0      TIME STEP SIZE-DEL=   .10000E-02 SEC
POWER-   ABSOLUTE=   .27114E+03 WT/CC   RELATIVE=   .10000E+01      DERIVATIVE=  0.           WT/CC-SEC
REACTIVITY-   TIME INST=  .193169E+02 $  DOPPLER=  .901711E+00 $  ENTHALPY=  .551087E+01 $  BORON=  .129043E+02 $
              CONTROLLER= 0.          $  KEFFECTIVE= 1.0000000
              POWER DEMAND=  .100000E+01 FPC IN
              FISSION POWER=  .271136E+03 WT/CC     DECAY HEAT=  .189768E+02 WT/CC
              CORE COMPUTATION TIME STEP= 0.          SEC            AND NUMBER =          0
              RCS TIME STEP DOUBLED  FROM LAST PRINT =    0          RCS TIME STEP HALVED  FROM LAST PRINT =     0
              CORE TIME STEP DOUBLED FROM LAST PRINT =    0          CORE TIME STEP HALVED FROM LAST PRINT =     0
```

OXIDE AND CLADDING TEMPERATURES

	(F)	(C)
1	1450.9785	788.3214
2	1299.9305	704.4058
3	1153.6780	623.1545
4	1019.6022	548.6679
5	895.0302	479.4612
AVG	1163.8439	628.8022
1	639.3814	337.4341
2	620.6750	327.0417
AVG	630.0282	332.2379

	ENTHALPY(BTU/LB)		FLUX(BTU/HR-FT**2)		QDNBNU(BTU/HR-FT**2)		DNBR		MASS (LBM/PIN)
1	.550678E+03	1	.102199E+06	1	.100000E+07	1	0.	1	.581019E-01
2	.555405E+03	2	.162109E+06	2	.100000E+07	2	0.	2	.577894E-01
3	.561676E+03	3	.188540E+06	3	.100000E+07	3	0.	3	.573692E-01
4	.568735E+03	4	.206161E+06	4	.100000E+07	4	0.	4	.568886E-01
5	.576266E+03	5	.214971E+06	5	.100000E+07	5	0.	5	.563667E-01
6	.583987E+03	6	.216733E+06	6	.100000E+07	6	0.	6	.558218E-01
7	.591708E+03	7	.214971E+06	7	.100000E+07	7	0.	7	.552666E-01
8	.599239E+03	8	.206161E+06	8	.100000E+07	8	0.	8	.547151E-01
9	.606393E+03	9	.193826E+06	9	.100000E+07	9	0.	9	.541819E-01
10	.612979E+03	10	.174444E+06	10	.100000E+07	10	0.	10	.536830E-01
11	.618746E+03	11	.148013E+06	11	.100000E+07	11	0.	11	.532397E-01
12	.622874E+03	12	.828167E+05	12	.100000E+07	12	0.	12	.529187E-01
AVG	.587390E+03	AVG	.175912E+06					TOTAL	.666343E+00

PRECURSOR CONCENTRATION (1/CC)

1	.36532E+12
2	.99916E+12
3	.25414E+12
4	.19428E+12
5	.17493E+11
6	.23336E+10

NAI 76-67
Revision 5
April 19, 1978

TEST CASE FOR DYNODE-P/2 WITH DYNAMIC FLOW MODEL - STEADY STATE

****** TIME= 0.000 SEC

LOOP PARAMETERS

VOLUME		AVE ENTHALPY (BTU/LB)	MASS (LB/PIN)	SPEC VOLUME (FT3/LB)	BORON CNC (PPM)	TEMPERATURE (F)
1	UPPR PLENM	.6244E+03	.2060E+01	.2356E-01	.8000E+03	.6064E+03
2	HOT LEG L1	.6244E+03	.2608E+00	.2356E-01	.8000E+03	.6064E+03
3	SG1 HOT PN	.6244E+03	.3566E+00	.2356E-01	.8000E+03	.6064E+03
4	STM GEN L1	.5866E+03	.1866E+01	.2236E-01	.8000E+03	.5792E+03
5	SG1 CLD PN	.5489E+03	.3954E+00	.2137E-01	.8000E+03	.5502E+03
6	CLD LEG L1	.5489E+03	.1212E+01	.2137E-01	.8000E+03	.5502E+03
7	DNCOMP L1	.5489E+03	.7703E+00	.2137E-01	.8000E+03	.5502E+03
8	HOT LEG L2	.6244E+03	.1304E+00	.2356E-01	.8000E+03	.6064E+03
9	SG2 HOT PN	.6244E+03	.1793E+00	.2356E-01	.8000E+03	.6064E+03
10	STM GEN L2	.5866E+03	.9424E+00	.2236E-01	.8000E+03	.5792E+03
11	SG2 CLD PN	.5489E+03	.1977E+00	.2137E-01	.8000E+03	.5502E+03
13	CLD LG L2A	.5489E+03	.6060E+00	.2137E-01	.8000E+03	.5502E+03
14	DNCOMP L2	.5489E+03	.3851E+00	.2137E-01	.8000E+03	.5502E+03
15	LOWR PLENM	.5489E+03	.1232E+01	.2137E-01	.8000E+03	.5502E+03
	CORE	.5866E+03	.6663E+00	.2241E-01	.8000E+03	.5792E+03

LOOP FLOWS AND PUMP SPEEDS, HEADS, AND TORQUES

LOOP PUMP	FLOW (LB/HR-PIN)	SPEED (RAD/SEC)	HEAD (FEET)	NET TORQUE (LBF-FT)
1	.2112745E+04	.1235469E+03	.2298254E+03	-.3300478E+02
2	.1056367E+04	.1235469E+03	.2298270E+03	-.3304151E+02

SAFETY INJECTION FLOW= 0. LB/SEC-PIN
CHARGING FLOW= 0. LB/SEC-PIN LETDOWN FLOW= 0. LB/SEC-PIN

CORE VARIABLES
CORE MASS= .66634E+00 LB/PIN CORE FLOW= .31691E+04 LB/HR-PIN
CORE INLET ENTHALPY= .54885E+03 BTU/LB CORE OUTLET ENTHALPY= .62436E+03 BTU/LB
CORE AVE DENSITY= .44631E+02 LB/FT3 CORE AVE ENTHALPY= .58664E+03 BTU/LB CORE COOL HEAT TRANS 0. BTU/PIN
CORE INLET TEMP(F)= 550.21 CORE OUTLET TEMP(F)= 606.37 VESSEL AVE TEMP(F) = 578.29 VESSEL DELTA T(F) = 56.16

	ACTUAL DELTA-T(F)	OVERPOWER SETPOINT(F)	OVERTEMPERATURE SETPOINT(F)	SENSED AVE TEMP (F)
LOOP1	56.157	62.038	61.039	578.287
LOOP2	56.157	62.038	61.039	578.287

CORE AVE BORON CONCENTRATION= 800.0000 PPM COOLANT DIRECT ENERGY DEPOSITION= 0. BTU/PIN

PRESSURIZER VARIABLES
PRESS STEAM MASS= .160384E+00 LB/PIN PRESS LIQ MASS= .566932E+00 LB/PIN
STEAM ENTHALPY= .111781E+04 BTU/LB LIQUID ENTHALPY= .703446E+03 BTU/LB
STEAM VOLUME = .2526440E-01 FT3/PIN LIQUID VOLUME = .1532500E-01 FT3/PIN
STEAM INTERNAL ENERGY = .1687582E+03 BTU/PIN LIQUID INTERNAL ENERGY = .3924241E+03 BTU/PIN
PRESS LIQ LEVEL= .128686E+02 FEET SURGE LINE FLOW= 0. LB/SEC-PIN
RELIEF VALVE FLOW= 0. LB/SEC-PIN SAFETY VALVE FLOW= 0. LB/SEC-PIN
SPRAY FLOW= 0. LB/SEC-PIN HEATER RATE= 0. BTU/SEC-PIN
INTEGRATED SURGE LINE FLOW= 0. LB/PIN INTEGRATED SURGE LINE ENERGY= 0. BTU/PIN
STEAM TEMPERATURE= .656871E+03 F LIQUID TEMPERATURE= .656871E+03 F
PRESS LIQ. BORON CONCENTRATION= .8000E+03 PPM

SATURATION PROPERTIES
HG= 1117.814 HF= 703.446 VG= .1575243 VF= .0270314 TSAT= 656.8709

TEST CASE FOR DYNODE-P/2 WITH DYNAMIC FLOW MODEL - STEADY STATE

*****- TIME= 0.000 SEC

STEAM GENERATOR VARIABLES

	STEAM GENERATOR 1	STEAM GENERATOR 2
HEAT LOAD (BTU/SEC-PIN)	.4431266E+02	.2215591E+02
SECND SIDE PRESSURE(PSIA)	.7853931E+03	.7853933E+03
SECND SIDE TEMPERATURE(F)	.5160000E+03	.5160000E+03
UAAREA (BTU/HR-F-PIN)	.2759379E+04	.1379683E+04
FEEDWATER ENTHALPY(BTU/LB)	.4154000E+03	.4154000E+03
FEEDWATER FLOW (LB/HR-PIN)	.2033828E+03	.1016909E+03
AUX FDWTR FLOW (LB/HR-PIN)	0.	0.
STEAM LINE FLOW(LB/HR-PIN)	.2033828E+03	.1016909E+03
RELIEF VALVE FLOW(LB/HR-P)	0.	0.
SAFETY VALVE FLOW(LB/HR-P)	0.	C.
SECND SIDE WATER LEVEL(FT)	.2815257E+02	.2815257E+02
MIXTURE HEIGHT (FEET)	.5698900E+02	.5698900E+02
STEAM BUBBLE MASS(LBM/PIN)	.1678148E+00	.8390988E-01
AVE MIXTURE AVOID FRACTION	.5060000E+00	.5060000E+00
BUBBLE RISE VELOCITY(FT/S)	.4628443E+01	.4628442E+01
TOTL SAT LIQ MASS(LBM/PIN)	.4577642E+01	.2288889E+01
TOTAL STEAM MASS (LBM/PIN)	.3897322E+00	.1948638E+00
INT LOAD RCS-SG (BTU/PIN)	0.	0.
TOT ENTHALPY-HEGT(BTU/PIN)	.2789094E+04	.1394578E+04
INT LOAD SG-MSL (BTU/PIN)	0.	0.
INT MASS FLOW (LBM/PIN)	0.	0.
FLUID PROPERTIES		
SAT LIQ ENTHALPY (BTU/LB)	.5071415E+03	.5071416E+03
SAT LIQ SPEC VOL (FT3/LB)	.2081595E-01	.2081596E-01
SAT STM ENTHALPY (BTU/LB)	.1199751E+04	.1199751E+04
SAT STM SPEC VOL (FT3/LB)	.5816096E+00	.5816094E+00

MAIN STEAM SYSTEM VARIABLES

STEAM LINE HEADER PRESSURE-PSH(PSIA)	.75626582E+03
MAIN STEAM LINE PRESSURE-PSL (PSIA)	.74382037E+03
TURBINE THROTTLE PRESSURE-PTHR(PSIA)	.72307033E+03
STEAM LINE HEADER FLOW-WSH(LB/HR-PN)	.30507365E+03
STEAM TURBINE FLOW-WSTB (LB/HR-PIN)	.30507365E+03
STEAM BYPASS FLOW - WSB (LB/HR-PIN)	0.
STEAM DUMP FLOW - WSD (LB/HR-PIN)	0.
HEADER STEAM MASS - XMSH (LB/PIN)	.13798264E-01
MAIN STEAM LINE MASS-XMSL (LB/PIN)	.74715282E-01
HEADER ENTHALPY - HSH (BTU/LB)	.11999226E+04
MAIN STEAM LINE ENTHALPY-HSL(BTU/LB)	.12001554E+04

*****- TIME= 0.000 SEC

RCS TOTAL ENTHALPIES , ENERGIES , AND MASSES

	ENTHALPY (BTU/PIN)	ENERGY (BTU/PIN)	MASS (LBM/PIN)
LOOPS	.6158697E+04	.6060327E+04	.1061545E+02
CORE	.3909055E+03	.3846879E+03	.6663426E+00
PRESS	.5780859E+03	.5611873E+03	.7273165E+00
TOTAL	.7127688E+04	.7006197E+04	.1200911E+02

BORON MASS DISTRIBUTION AND TOTAL IN RCS (LBM/PIN)
LOOP TOTAL= .8492361E-02 CORE TOTAL= .5330741E-03 PRES TOTAL= .4535459E-03 RCS TOTAL= .9478981E-02

ENERGY INTO LOOPS = 0. ENERGY OUT OF LOOPS = 0.
ENERGY INTO CORE = 0. ENERGY OUT OF CORE = 0.

SURGE ENERGY AND MASS

CORE H,M =	0.	0.
LOOP H,M =	0.	0.
CORE INTGS	0.	0.
LOOP INTGS	0.	0.

INTEGRALS (MASS AND ENERGY) FOR RCS

	MASS (LBM/PIN)	ENERGY (BTU/PIN)
PRESS RELIEF VALVES	0.	0.
PRESS SAFETY VALVES	0.	0.
PRESS SPRAY SYSTEM	0.	0.
PRESS HEATERS		0.
RCS CHARGING SYSTEM	0.	0.
RCS LETDOWN SYSTEM	0.	0.
HPSI SYSTEM	0.	0.

ENERGY DEPOSITED IN OXIDE = 0. BTU/PIN TOTAL STORED ENERGY IN FUEL ROD = .4289191E+03 BTU/PIN
ENERGY STORED IN OXIDE = .3804372E+03 BTU/PIN ENERGY STORED IN CLAD = .4848190E+02 BTU/PIN

LOOP FLOW AND PUMP SPEED PARAMETERS

REACTOR VESSEL PRESSURE DROP .2366504E+02 PSI

LOOP	PRESSURE CHANGES (PSI) PUMP RISE	LOOP DROP	TORQUES (LBF-FT) MOTOR	HYDRAULIC	WINDAGE	FRICTION
1	.7468664E+02	.7450653E+02	.1927118E+05	-.1814227E+05	-0.	-.1161914E+04
2	.7468716E+02	.7450600E+02	.1927118E+05	-.1814231E+05	-0.	-.1161914E+04

TEST CASE FOR DYNODE-P/2 WITH DYNAMIC FLOW MODEL - STEADY STATE

```
*****-    TIME=    1.000 SEC      PRESSURE= 2249.99 PSIA      FLOW= 3171.22 LB/HR-PIN     INTEGRATED ENERGY=   .27112E+03 WT-SEC/CC
*****-    TIME STEP NUMBER=       25      TIME STEP SIZE-DEL=    .63000E-01 SEC
POWER-    ABSOLUTE=    .27110E+03 WT/CC    RELATIVE=    .99985E+00        DERIVATIVE=    .35359E-01 WT/CC-SEC
REACTIVITY-    TIME INST=  .193169E+02 $  DOPPLER=  .901686E+00 $  ENTHALPY=  .551068E+01 $  BORON=  .129046E+02 $
               CONTROLLER= 0.           $  KEFFECTIVE=  .9999991
               POWER DEMAND=  .100000E+01 FRC IN
               FISSION POWER=  .271096E+03 WT/CC      DECAY HEAT=  .189766E+02 WT/CC
               CORE COMPUTATION TIME STEP=  .107028E-01 SEC            AND NUMBER =            138
               RCS TIME STEP DOUBLED  FROM LAST PRINT =    1           RCS TIME STEP HALVED  FROM LAST PRINT =     0
               CORE TIME STEP DOUBLED FROM LAST PRINT =    7           CORE TIME STEP HALVED FROM LAST PRINT =     2
```

OXIDE AND CLADDING TEMPERATURES

	(F)	(C)
1	1450.9661	788.3145
2	1299.9153	704.3974
3	1153.6599	623.1444
4	1019.5813	548.6563
5	895.0071	479.4484
AVG	1163.8259	628.7922

1	639.3524	337.4180
2	620.6454	327.0252
AVG	629.9989	332.2216

	ENTHALPY(BTU/LB)		FLUX(BTU/HR-FT**2)		QDNBNU(BTU/HR-FT**2)		DNBR		MASS (LBM/PIN)
1	.550677E+03	1	.102203E+06	1	.176412E+07	1	.172606E+02	1	.581020E-01
2	.555401E+03	2	.162115E+06	2	.172574E+07	2	.106449E+02	2	.577896E-01
3	.561668E+03	3	.188547E+06	3	.167523E+07	3	.888474E+01	3	.573697E-01
4	.568723E+03	4	.206169E+06	4	.161893E+07	4	.785228E+01	4	.568894E-01
5	.576250E+03	5	.214979E+06	5	.155950E+07	5	.725405E+01	5	.563678E-01
6	.583967E+03	6	.216741E+06	6	.149928E+07	6	.691723E+01	6	.558232E-01
7	.591684E+03	7	.214979E+06	7	.143612E+07	7	.668011E+01	7	.552683E-01
8	.599212E+03	8	.206169E+06	8	.136318E+07	8	.661181E+01	8	.547171E-01
9	.606362E+03	9	.193834E+06	9	.129955E+07	9	.670429E+01	9	.541842E-01
10	.612946E+03	10	.174450E+06	10	.122887E+07	10	.704409E+01	10	.536855E-01
11	.618711E+03	11	.148018E+06	11	.115653E+07	11	.781323E+01	11	.532424E-01
12	.622839E+03	12	.828198E+05	12	.916065E+06	12	.110607E+02	12	.529215E-01
AVG	.587370E+03	AVG	.175919E+06					TOTAL	.666361E+00

PRECURSOR CONCENTRATION (1/CC)

1	.36532E+12
2	.99915E+12
3	.25414E+12
4	.19427E+12
5	.17492E+11
6	.23334E+10

TEST CASE FOR DYNODE-P/2 WITH DYNAMIC FLOW MODEL - STEADY STATE

*****- TIME= 1.000 SEC

LOOP PARAMETERS

VOLUME		AVE ENTHALPY (BTU/LB)	MASS (LB/PIN)	SPEC VOLUME (FT3/LB)	BORON CNC (PPM)	TEMPERATURE (F)
1	UPPR PLENM	.6243E+03	.2060E+01	.2356E-01	.8000E+03	.6064E+03
2	HOT LEG L1	.6244E+03	.2608E+00	.2356E-01	.8000E+03	.6064E+03
3	SG1 HOT PN	.6244E+03	.3586E+00	.2356E-01	.8000E+03	.6064E+03
4	STM GEN L1	.5866E+03	.1865E+01	.2236E-01	.8000E+03	.5792E+03
5	SG1 CLD PN	.5489E+03	.3954E+00	.2137E-01	.8000E+03	.5502E+03
6	CLD LEG L1	.5489E+03	.1212E+01	.2137E-01	.8000E+03	.5502E+03
7	DNCOMP L1	.5489E+03	.7703E+00	.2137E-01	.8000E+03	.5502E+03
8	HOT LEG L2	.6244E+03	.1304E+00	.2356E-01	.8000E+03	.6064E+03
9	SG2 HOT PN	.6244E+03	.1793E+00	.2356E-01	.8000E+03	.6064E+03
10	STM GEN L2	.5866E+03	.9424E+00	.2236E-01	.8000E+03	.5792E+03
11	SG2 CLD PN	.5489E+03	.1977E+00	.2137E-01	.8000E+03	.5502E+03
13	CLD LG L2B	.5489E+03	.6060E+00	.2137E-01	.8000E+03	.5502E+03
14	DNCOMP L2	.5489E+03	.3851E+00	.2137E-01	.8000E+03	.5502E+03
15	LOWR PLENM	.5489E+03	.1232E+01	.2137E-01	.8000E+03	.5502E+03
	CORE	.5866E+03	.6664E+00	.2241E-01	.8000E+03	.5792E+03

LOOP FLOWS AND PUMP SPEEDS,HEADS, AND TORQUES

LOOP PUMP	FLOW (LB/HR-PIN)	SPEED (RAD/SEC)	HEAD (FEET)	NET TORQUE (LBF-FT)
1	.2114067E+04	.1235469E+03	.2296323E+03	-.2852511E+02
2	.1057152E+04	.1235469E+03	.2295972E+03	-.2768511E+02

SAFETY INJECTION FLOW= 0. LB/SEC-PIN
CHARGING FLOW= 0. LB/SEC-PIN LETDOWN FLOW= 0. LB/SEC-PIN

CORE VARIABLES
CORE MASS= .66636E+00 LB/PIN CORE FLOW= .31712E+04 LB/HR-PIN
CORE INLET ENTHALPY= .54885E+03 BTU/LB CORE OUTLET ENTHALPY= .62432E+03 BTU/LB
CORE AVE DENSITY= .44632E+02 LB/FT3 CORE AVE ENTHALPY= .58662E+03 BTU/LB CORE COOL HEAT TRANS .647432E+02 BTU/PIN
CORE INLET TEMP(F)= 550.21 CORE OUTLET TEMP(F)= 606.36 VESSEL AVE TEMP(F) = 578.29 VESSEL DELTA T(F) = 56.15

	ACTUAL DELTA-T(F)	OVERPOWER SETPOINT(F)	OVERTEMPERATURE SETPOINT(F)	SENSED AVE TEMP (F)
LOOP1	56.148	62.034	61.025	578.291
LOOP2	56.144	62.031	61.016	578.293

CORE AVE BORON CONCENTRATION= 800.0000 PPM COOLANT DIRECT ENERGY DEPOSITION .172801E+01 BTU/PIN

PRESSURIZER VARIABLES
PRESS STEAM MASS= .160384E+00 LB/PIN PRESS LIQ MASS= .566923E+00 LB/PIN
STEAM ENTHALPY= .111781E+04 BTU/LB LIQUID ENTHALPY= .703446E+03 BTU/LB
STEAM VOLUME = .2526449E-01 FT3/PIN LIQUID VOLUME = .1532490E-01 FT3/PIN
STEAM INTERNAL ENERGY = .1687581E+03 BTU/PIN LIQUID INTERNAL ENERGY = .3924176E+03 BTU/PIN
PRESS LIQ LEVEL= .128685E+02 FEET SURGE LINE FLOW= -.230567E-04 LB/SEC-PIN
RELIEF VALVE FLOW= 0. LB/SEC-PIN SAFETY VALVE FLOW= 0. LB/SEC-PIN
SPRAY FLOW= 0. LB/SEC-PIN HEATER RATE= 0. BTU/SEC-PIN
INTEGRATED SURGE LINE FLOW= -.9364755E-05 LB/PIN INTEGRATED SURGE LINE ENERGY= -.661578E-02 BTU/PIN
STEAM TEMPERATURE= .656870E+03 F LIQUID TEMPERATURE= .656870E+03 F
PRESS LIQ. BORON CONCENTRATION= .8000E+03 PPM

SATURATION PROPERTIES
HG= 1117.815 HF= 703.445 VG= .1575254 VF= .0270314 TSAT= 656.8703

NAI 76-67
Revision 5
April 19, 1978

TEST CASE FOR DYNODE-P/2 WITH DYNAMIC FLOW MODEL - STEADY STATE

*****- TIME= 1.000 SEC

STEAM GENERATOR VARIABLES

	STEAM GENERATOR 1	STEAM GENERATOR 2
HEAT LOAD (BTU/SEC-PIN)	.4432030E+02	.2216137E+02
SECND SIDE PRESSURE(PSIA)	.7853906E+03	.7853928E+03
SECND SIDE TEMPERATURE(F)	.5159996E+03	.5159999E+03
U*AREA (BTU/HR-F-PIN)	.2759586E+04	.1379806E+04
FEEDWATER ENTHALPY(BTU/LB)	.4154000E+03	.4154000E+03
FEEDWATER FLOW (LB/HR-PIN)	.2033828E+03	.1016909E+03
AUX FDWTR FLOW (LB/HR-PIN)	0.	0.
STEAM LINE FLOW(LB/HR-PIN)	.2033966E+03	.1017011E+03
RELIEF VALVE FLOW(LB/HR-P)	0.	0.
SAFETY VALVE FLOW(LB/HR-P)	0.	0.
SECND SIDE WATER LEVEL(FT)	.2815250E+02	.2815250E+02
MIXTURE HEIGHT (FEET)	.5699059E+02	.5699083E+02
STEAM BUBBLE MASS(LBM/PIN)	.1678238E+00	.8391536E-01
AVE MIXTURE AVOID FRACTION	.5060149E+00	.5060171E+00
BUBBLE RISE VELOCITY(FT/S)	.4628471E+01	.4628466E+01
TOTL SAT LIQ MASS(LBM/PIN)	.4577633E+01	.2288883E+01
TOTAL STEAM MASS (LBM/PIN)	.3897312E+00	.1948638E+00
INT LOAD RCS-SG (BTU/PIN)	.4431649E+02	.2215962E+02
TOT ENTHALPY-HFGT(BTU/PIN)	.2789066E+04	.1394576E+04
INT LOAD SG-MSL (BTU/PIN)	.4432429E+02	.2216251E+02
INT MASS FLOW (LBM/PIN)	.1019449E-04	.5495203E-05
FLUID PROPERTIES		
SAT LIQ ENTHALPY (BTU/LB)	.5071411E+03	.5071415E+03
SAT LIQ SPEC VOL (FT3/LB)	.2081595E-01	.2081595E-01
SAT STM ENTHALPY (BTU/LB)	.1199751E+04	.1199751E+04
SAT STM SPEC VOL (FT3/LB)	.5816118E+00	.5816098E+00

MAIN STEAM SYSTEM VARIABLES

STEAM LINE HEADER PRESSURE-PSH(PSIA)	.75625844E+03
MAIN STEAM LINE PRESSURE-PSL (PSIA)	.74380881E+03
TURBINE THROTTLE PRESSURE-PTHR(PSIA)	.72307033E+03
STEAM LINE HEADER FLOW-WSH(LB/HR-PN)	.30510007E+03
STEAM TURBINE FLOW-WSTR (LB/HR-PIN)	.30503666E+03
STEAM BYPASS FLOW - WSB (LB/HR-PIN)	0.
STEAM DUMP FLOW - WSD (LB/HR-PIN)	0.
HEADER STEAM MASS - XMSH (LB/PIN)	.13801382E-01
MAIN STEAM LINE MASS-XMSL (LB/PIN)	.74741111E-01
HEADER ENTHALPY - HSH (BTU/LB)	.11997509E+04
MAIN STEAM LINE ENTHALPY-HSL(BTU/LB)	.11998925E+04

ooooo- TIME= 1.000 SEC

RCS TOTAL ENTHALPIES , ENERGIES , AND MASSES

	ENTHALPY (BTU/PIN)	ENERGY (BTU/PIN)	MASS (LBM/PIN)
LOOPS	.6158702E+04	.6060332E+04	.1061544E+02
CORE	.3909030E+03	.3846854E+03	.6663607E+00
PRESS	.5780792E+03	.5611757E+03	.7273072E+00
TOTAL	.7127685E+04	.7006194E+04	.1200911E+02

BORON MASS DISTRIBUTION AND TOTAL IN RCS (LBM/PIN)

LOOP TOTAL= .8492354E-02 CORE TOTAL= .5330886E-03 PRES TOTAL= .4535384E-03 RCS TOTAL= .9478981E-02

ENERGY INTO LOOPS = .5498862E+03 ENERGY OUT OF LOOPS = .4833992E+03

ENERGY INTO CORE = .4834007E+03 ENERGY OUT OF CORE = .5498878E+03

SURGE ENERGY AND MASS

CORE H,M =	-.5522997E-03	-.7851355E-06
LOOP H,M =	-.4695032E-03	-.6674341E-06
CORE INTGS	-.1254836E-01	-.1813335E-04
LOOP INTGS	.5932580E-02	.8768606E-05

INTEGRALS (MASS AND ENERGY) FOR RCS

	MASS (LBM/PIN)	ENERGY (BTU/PIN)
PRESS RELIEF VALVES	0.	0.
PRESS SAFETY VALVES	0.	0.
PRESS SPRAY SYSTEM	0.	0.
PRESS HEATERS		0.
RCS CHARGING SYSTEM	0.	0.
RCS LETDOWN SYSTEM	0.	0.
HPSI SYSTEM	0.	0.

ENERGY DEPOSITED IN OXIDE = .6473408E+02 BTU/PIN TOTAL STORED ENERGY IN FUEL ROD = .4289107E+03 BTU/PIN

ENERGY STORED IN OXIDE = .3804312E+03 BTU/PIN ENERGY STORED IN CLAD = .4847953E+02 BTU/PIN

LOOP FLOW AND PUMP SPEED PARAMETERS

REACTOR VESSEL PRESSURE DROP .2369658E+02 PSI

LOOP	PRESSURE CHANGES (PSI) PUMP RISE	LOOP DROP	TORQUES (LBF-FT) MOTOR	HYDRAULIC	WINDAGE	FRICTION
1	.7442373E+02	.7460182E+02	.1927118E+05	-.1813779E+05	-0.	-.1161914E+04
2	.7441215E+02	.7461335E+02	.1927118E+05	-.1813695E+05	-0.	-.1161914E+04

TIME([illegible]EC)	RELATIVE POWER	PRESS(PSIA)	KEFFECTIVE	AVE FL[illegible]X(B/HF2)	AVE FUEL(F)	MAX FUEL(F)	SG LOAD(B/S)
0.	.1000000E+01	.2250000E+04	.1000000E+01	.17[illegible]21E+06	.1163844E+04	.1450979E+04	.6646797E+02
.1000[illegible]E+00	.1000001E+01	.2250000E+04	.1000000E+01	.1759192E+06	.1163844E+04	.1450979E+04	.6647032E+02
.20000E+[illegible]	.1000000E+01	.2250000E+04	.1000000E+01	.1759197E+06	.1163844E+04	.1450979E+04	.6647238E+02
.30000E+00	.9999705E+00	.2250000E+04	.9999998E+00	.1759247E+06	.1163843E+04	.1450979E+04	.6647425E+02
.40000E+00	.9999637E+00	.2250000E+04	.9999998E+00	.1759217E+06	.1163841E+04	.1450978E+04	.6647584E+02
.50000E+00	.9999288E+00	.2249998E+04	.9999995E+00	.1759243E+06	.1163840E+04	.1450977E+04	.6647734E+02
.60000E+00	.9999198E+00	.2249998E+04	.9999995E+00	.1759217E+06	.1163837E+04	.1450976E+04	.6647853E+02
.70000E+00	.9998887E+00	.2249996E+04	.9999993E+00	.1759230E+06	.1163835E+04	.1450974E+04	.6647952E+02
.80000E+00	.9998808E+00	.2249994E+04	.9999992E+00	.1759205E+06	.1163832E+04	.1450972E+04	.6648037E+02
.90000E+00	.9998572E+00	.2249993E+04	.9999991E+00	.1759210E+06	.1163829E+04	.1450969E+04	.6648103E+02
.10000E+01	.9998513E+00	.2249991E+04	.9999991E+00	.1759187E+06	.1163826E+04	.1450966E+04	.6648167E+02

TIME (SEC)	CORE FLOW(L/H-P)	CORE IN H(B/L)	PLF+SFTY FLOW P	WTR LVL(FT)
0.	.3169112E+04	.5488500E+03	0.	.12[illegible]0E+02
.10000E+00	.3169861E+04	.5488500E+03	0.	.1286860E+02
.20000E+00	.3170297E+04	.5488500E+03	0.	.1286861E+02
.30000E+00	.3170571E+04	.5488500E+03	0.	.1286860E+02
.40000E+00	.3170757E+04	.5488500E+03	0.	.1286859E+02
.50000E+00	.3170890E+04	.5488500E+03	0.	.1286858E+02
.60000E+00	.3170991E+04	.5488500E+03	0.	.1286856E+02
.70000E+00	.3171068E+04	.5488500E+03	0.	.1286855E+02
.80000E+00	.3171130E+04	.5488500E+03	0.	.1286853E+02
.90000E+00	.3171180E+04	.5488500E+03	0.	.1286851E+02
.10000E+01	.3171219E+04	.5488500E+03	0.	.1286848E+02

MAXIMUM TRANSIENT POWER AND PRESSURE

RELATIVE POWER (FRACT. INITIAL)= .10000E+01 AT .11300E+00 SEC
PRESSURE (PSIA)= .22500E+04 AT 0. SEC

SUMMARY OF TRIP SIGNALS GENERATED DURING TRANSIENT

6.0 REFERENCES

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4. H. G. Hargrove, "MARVEL - A Digital Computer Code for Transient Analysis of a Multiloop PWR System," WCAP-7909, October 1972.

5. K. V. Moore and W. H. Rettig, "RELAP4 - A Computer Program for Transient Thermal-Hydraulic Analysis," ANCR-1127 Rev. 1, March 1975.

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8. H. R. Martens, "Comparative Study of Digital Integration Methods," Simulation, February 1969, pp 87-94.

APPENDIX A

NOMENCLATURE

Symbol	Description	
A	Heat transfer area	
A	Valve flow area	
A_{flow}	Coolant flow area	
AA	Conversion factor	
AR	Steam generator heat transfer factor	
ARESG	Cross sectional area of steam generator shell side	
AXF	Axial heat flux profile	
b	Boron concentration	
b	Homologous hydraulic pump torque	4
c	Heat capacity	
C	Delay neutron precursor density	
C	Controller constant	
C	Torque coefficient	4
C_o	Bubble rise gradient parameter	
D_e	Equivalent hydraulic diameter	
f(r)	Radial heat generation profile	
f(z)	Axial heat flux profile	
F	Fraction	
g	Conversion factor	
G	Mass flux	
h	Enthalpy	
h	Homologous pump head	4
H	Pump head	4
HF	Clad-coolant heat transfer coefficient	

Symbol	Description	
HG	Oxide-clad gap heat transfer coefficient	
I	Inertia	4
J	Conversion factor	
k	Conductivity	
k_{eff}	Effective multiplication factor	
Δk	Change in reactivity	
K	Pressure drop coefficient	
ℓ, L	Length	4
ΔL	Axial Coolant node length	
m	Coolant mass	
n	Fission power density	
n	Torque exponential factor	4
N	Number of steam generators	
N	Number of RCS pumps	4
p	Pressure	
p	Normalized core power density	
q	Decay heat precursor concentration	
Q	Heat generation or removal rate	
Q	Volumetric flow rate	4
r	Radial coordinate	
r	Heat generation fraction	
RL	Prompt neutron lifetime	
SGA	Steam generator heat transfer area	
t	Time	
T	Temperature	

Symbol	Description	
T	Torque	4
TSCRAM	Time at which scram rod motion begins	
TT	Problem end time	
$\Delta T_{\ell m}$	Log-mean temperature difference	
u	Internal energy	
U	Effective heat transfer coefficient	
U	Total integral energy	
v	Velocity	
V	Volume	
W	Mass flow rate	
WBREAK	Main steam system break flow	
WF	Feedwater flow	
W1	RCS Loop 1 flow rate	
W2	RCS Loop 2 flow rate	
W2B	Cold Leg B Loop 2 flow rate	
WS	Main steam line flow	
WSB	Bypass valve flow	
WSD	Dump valve flow	
WSGR	STeam generator relief valve flow	
WSH	Steam header pipe flow	
WSTB	Turbine steam flow	
WT	Core inlet flow rate	
x	intercept	
y	slope	
z	Axial coordinate in coolant channel	

Symbol	Description	
Z	Total core power density	
α	Void fraction	
α	Dimensionless pump speed	4
β	Effective delay neutron fraction	
γ	Decay heat fraction	
ΔX	Change in variable X	
ε	Error signal	
λ	Delay neutron decay constant	
Λ	Decay heat decay constant	
ν	Neutrons per fission	
ν	Specific volume	
ν	Dimensionless volumetric flow rate	4
ϕ	Heat flux	
ρ	Density	
σ	Surface tension of saturated water	
τ	Controller time constant	
χ	Quality	
ω	Pump speed	4

Subscripts

BORON	Boron
Break	Main steam system break
BUB	Bubble
c	Cladding
core	Core
C	Core
CRC	Control rod controller
D	Dump valve
DNB	Departure from nucleate boiling
DOP	Doppler
ec	Evaporation-condensation
ev	Evaporation
ENT	Enthalpy
EU	Equivalent uniform
exit	Exit conditions
f	Fuel
f	Saturated liquid
f	friction 4
fg	Saturated liquid and steam
fw	Feedwater
g	Saturated vapor
gap	Oxide-cladding gap
gb	Gas bubbles
G	Water vapor
h	hydraulic 4
heater	Pressurizer heaters
i	Delay neutron or decay heat precursor group
i	Coolant region
i	RCS loop index
inlet	Inlet conditions
IN	Initial Doppler, enthalpy and boron plus insertion
J	Cladding node
K	Coolant node
ℓ	Subcooled liquid
m	Mixture

Subscripts

m	motor	4
n	Oxide node	
o	Initial value	
P	Pressurizer	
pump	pump	4
ref	Reference value	
R	Rated	4
RSI	Ramp or step insertion	
RV	Pressurizer relief valves	
RV	Reactor Vessel	4
s	Fuel rod surface	
s	Steam	
sat	Saturated	
sc	Subcooled	
spray	Pressurizer spray	
ss	Saturated plus superheated	
sub	Subcooled	
sup	Superheated	
surge	Surge line	
S	Scram	
SG	Steam generator	
SH	Steam header	
SL	Steam line	
SV	Pressurizer safety valves	
thr	Turbine throttle	
tot	Total	
TB	Turbine	
TC	Steam generator tube covery	
UP	Upper plenum	
w	Coolant	
w	Water	
w	Windage	4
WG	Water-vapor	
WR	Water relief	

Subscripts

1	Lead
2	Lag
α	Steam Generator outlet plenum 4
β	Reactor Vessel inlet plenum

Superscripts

ave	Average
in	Inlet
out	Outlet
$'$	Absolute temperature

APPENDIX B

CONTROL CARDS AND THEIR USE

CONTROL CARDS AND THEIR USE

The following set of control cards is used to execute DYNODE-P Version 2 on the CYBERNET 7600. The XXXX items signify user supplied values. For the YYYY 5
items, contact NAI's Production Code Section.

```
XXX,TXXX,STMFZ.
ACCØUNT,XXXXXXX-XXX
STAGE(A,PRE,HY,VSN=YYYYY)
LABEL(A,R,L=YYYYYY)
COPYBF(A,DYNØD)                                  5
UNLØAD(A)
REWIND(DYNØD)
DYNØD.
EØR CARD
DATA CARDS
EØF CARD

EØR (The EØR card is a 7-8-9 punch in Column 1)
EØF (The EØF card is a 6-7-8-9 punch in Column 1)
```