7.0 INPUT AND OUTPUT FOR CENTS

The balance of plant and control system models including the associated user inputs are described in Chapter 6. This chapter describes inputs to the core power and kinetics model, fuel failure model, quench tank, and system malfunction models. It also summarizes the more useful output variables for characterizing the state of the PWR and its components. This chapter also describes the CENTS data dictionary and the CENTS standard output.

7.1 Core

This section describes the CENTS core model, representing the fuel rod bundle and its associated coolant channel. Variables for controlling the axial power shape, the power model, the point kinetics model, and the fuel failure model are described. Also, variables describing the state of these models as well as the core heat transfer model are described.

7.1.1 Core Power

CENTS provides two options for the core power: user input and a point kinetics model (Section 3.1.1). To access these options, see Table 7.2.

User Control The options for control of core power and the input variables controlling the options are summarized in Table 7.1. The detailed input variables are listed in Table 7.2. A list of output variables summarizing power production in the reactor is given in Table 7.3.

Use of Point Kinetics Model The input variables for the point kinetics model described in Section 3.1.1 are listed in Table 7.4. Separate control rod models are used to simulate insertion by scram, regulation by the control system, or a user-defined excursion. Note that if the moderator density feedback is used instead of the moderator temperature and boric acid concentration feedbacks, then the reactivity table as a function of moderator density must then be appropriate for the boric acid concentration in the core. The feedback reactivity output variables are listed in Table 7.5.

Initialization of Reactivity Model The reactivity feedbacks are based on change from an initial steady state value as explained in Section 3.1.1. The reference database for the CENTS code is initialized at steady state full power operation. Any change in fuel temperature, coolant temperature and coolant boric acid concentration (or moderator density if this option is used) from the reference conditions will produce a reactivity change which will change core power. The user may do one of the following to compensate for the changes:

1) Simulation of automatic reactivity compensation provides a reactivity equal to the perturbation, but of opposite sign, which exactly compensates for the perturbation. Use of this option overrides all feedbacks until the option is revoked; at which time a transient can be initiated from the just critical condition. (See Section 6.8 on the use of the CTL_CEA_PERFECT option.)

2) Re-initialization of the reference reactivity feedbacks for a different set of system conditions establishes a new steady state for the database. Establish user control of the power as explained in Table 7.1, change other system variables as needed, and run a transient to a new steady state. Obtain values of the Doppler and moderator feedback reactivities (Table 7.5). Compute the new reference (initial condition) reactivities as

$$\rho'_o = \rho_o + \Delta\rho$$

where

ρ_o = original reference reactivity, Table 7.4

$\Delta\rho$ = reactivity change due to change in system state, Table 7.5.

Enter the new initial condition reactivities in place of the original ones.

Point kinetics (Delayed and Fast Neutron Coefficients) The variables for these parameters are found in the POWER_COMMON partition POW_KIN_COMMON. The variables are defined in the CENTS variable dictionary. The user can input alternate values.

Switch to Decay Heat Curve CENTS computes the core power using the point kinetics model until core trip. At that time, it computes core power using both the point kinetics model (power stored in CTL_CORE_POWER_FRACTION) and the decay heat curve described in Table 7.2 multiplied by the decay heat multiplier POW_DKHT_DHCFCT (power stored in POW_USER_QCD_LOOKUP). CENTS normally switches from the point kinetics model to the decay heat curve when the core power drops below an input value. That is, after trip (CTL_CORE_TRIP = True), when

CTL_CORE_POWER_FRACTION ≤ POW_DKHT_DHCBEG

then a permanent switch is made to take the power from the decay heat curve in the database. This can produce a discontinuity in power if the power from the decay heat table differs from the power from the point kinetics model at the time of the switch.

Alternatively, a smooth transition can be achieved by comparing the power from the two models, using the following technique in a CENTS command file:

1. Set POW_DKHT_DHCBEG < 0.0
2. When CTL_CORE_TRIP is True, then:
    3. When POW_USER_QCD_LOOKUP ≥ CTL_CORE_POWER_FRACTION, then:
        4. Set POW_DKHT_DHCBEG > maximum decay heat power in table

This produces a smooth transition from the point kinetics power to the decay heat power.

Axial Power Shape The axial power shape is defined by the user using one of three options controlled by the variable AXPD_INPUT_OPT as described in Table 7.2 and the text below.

The AXPD_INPUT_OPT = 0 option supports an input shape with an average power for each fixed sized node (node-centered power) for any number of equally spaced axial nodes up to [ ] CENTS determines the number of non-zero values, normalizes the total power to 1.0 and maps the power shape to the CHT_NUM_NODE axial nodes used for the core heat transfer solution conserving total power. The user must set any unused elements of the input axial shape array to zero. The resulting shape is transferred to the array POW_USER_QAXL.

The AXPD_INPUT_OPT = 1 option supports input of pointwise power fractions (node-end-point power) for up to [ ] unevenly spaced axial nodes. If values are not entered for the 0.0 or 1.0 axial height fraction locations, CENTS extrapolates the input shape to find the pointwise power at these locations. The input axial power shape is integrated assuming that the average power in an interval is the average of the powers at the ends of the interval. The integral power for each axial node used in the core heat transfer solution axial nodalization is found by interpolation in this integrated power shape. Finally, the average power for each axial interval is found by subtracting the integral power at the bottom of the node from that at the top of the node. This axial power shape is normalized to conserve power and the resulting shape is transferred to the CHT_NUM_NODE axial nodes in the array POW_USER_QAXL.

The AXPD_INPUT_OPT = 2 option supports input of an axial shape with the same nodalization as the core heat transfer solution. This shape is transferred to the array POW_USER_QAXL without any processing.

7.1.2 *Core Heat Transfer*

The core heat transfer is modeled by an average power fuel rod in a closed channel. Details of the model are given in Section 3.3. The fuel rod is subdivided radially and axially as shown in Figure 7.1. Typically, there are [ ] An option to use the original model or an improved model to calculate enthalpy in the coolant channel (models described in Section 3.3.5) is selected by the following input variable:

CHT_USE_NEW_ENTHALPY_OPTION

= 0.0, use original model for coolant channel enthalpy calculation

= 1.0, use improved model for coolant channel enthalpy calculation

Figure 7.1 shows the CENTS variables, which describe the state of the fuel rod and coolant channel. The variables are defined in Table 7.6.

The heat transfer type, forced or natural convection, and the heat transfer regime on the boiling curve being used by CENTS are indicated by the variables CHT_BOILING and CHT_IHT, respectively, as shown in Table 7.7. The correlations being used are shown in Section 3.3.4.

7.1.3 *Fuel Failure*

CENTS does not have a mechanistic fuel failure model associated with its point kinetics model. However, the consequences of fuel failure are modeled. Fission product presence in the RCS, steam generator secondary side, main steamline header and quench tank, and fission product release from paths exiting these components are modeled.

The user simulates fuel failure by entering release rates for the various fission product groups at the time failure is to occur. As many as [ ] different fission product species or isotopes may be released in the core and tracked around the system. Of those, the core release rates for the following isotopes have specific variable names:

Cesium	Cs^{137}	CORE_PART_REL	(μC/sec)
Iodine	I^{131}	CORE_IOD_REL	(μC/sec)
Xenon	Xe^{133}	CORE_XEN_REL	(μC/sec).

Additional isotopes (e.g., Krypton) may be released via the array CORE_RELE_SOLU[ ] The structure of this array parallels that of the array of identifying pointers for all species, ID_TYPE_SPECIES(1:20), which is displayed in Table 7.14. The first five elements are reserved for the predefined species that are tracked by the solutes transport model (Section 4.15) – boron (release = 0.0), ^{16}N (production rate calculated by code), and the above three isotopes (input release rate). The last five elements are reserved for non-condensible gases (Section 4.12), of which hydrogen production in the core is calculated by the code. The remaining elements 6-15 are available for defining other species. The half-life of all species and isotopes being defined are input in the parallel array HALF_LIFE_SOLUTES(1:20). Their relative solubilities in liquid and steam (Section 4.15) are input in the parallel array CONC_RATIO_STM_LIQ(1:20).

Variables for fission product release by the primary and secondary systems are detailed in tables in later sections of this chapter. Note that the abbreviation PART for particulates replaces cesium in many variable names.

Fission product concentrations through the system are calculated on the basis of the various sources and sinks for these products, as described in Section 4.15. For the complete primary system represented by CENTS, the sources include:

a. release due to fuel failure
b. influx via the charging system (Section 6.2.6).

Table 7.1

User Control of Reactor Power

POW_USER_IFUPOW	Power and Reactivity Procedure
False (F)	CENTS calculates power based on reactivity feedbacks in Table 7.5. This includes the reactivity from the control rod regulating system computed according to the options described in Section 6.8.
True* (T)	The user controls power through the input of a power versus time table as described in Table 7.2. Reactivity varies because of feedbacks due to the power change. The control rod controller may be used to compensate these reactivity changes as described in Section 6.8 if this is appropriate.

* Must also set CTL_CORE_CONTROL_AUTO = F, Section 6.1.

Table 7.2
Core Power Inputs

User Defined Power Inputs

POW_USER_IFUPOW	User supplies power table if True (T) and CTL_CORE_CONTROL_AUTO is False (F)
POW_USER_NPOWT	Number of entries in power table
POW_USER_TPOWT	Time for power tables entries (sec)
POW_USER_POWT	User power table (fraction of rated power)
POW_USER_POWZ	Rated power (MWt)

Decay Heat

POW_DKHT_DHCFCT	Multiplier on decay heat curve
POW_DKHT_NDHC	Number of entries in decay heat table
POW_DKHT_TIMDHT	Time for decay heat table (sec)
POW_DKHT_ANSDHC	Decay heat table (frac of the power at trip)*
POW_DKHT_DHCBEG	Core power frac for switch to decay heat curve+

Zirconium-Water Reaction

POW_ZRH20_NYZIR	Flag to include Zr-$H_2$0 reaction, yes if True

* Must also set CTL_CORE_CONTROL_AUTO = F, Section 6.1.

*Current table in database is ANSI/ANS-5.1 - 1979 for nominal full power operation of a PWR (Reference 7.1).

+ Normally equal to the first entry of the decay heat table. Switch to decay heat occurs after scram when as described in Sections 3.1.2 and 7.1.1.

Table 7.2 (Continued)

Axial Power Shape

AXPD_INPUT_OPT = 0	Input shape as node average power for equally spaced nodes
KSHAPIN(J)	Node average power for fixed length nodes (J = 1,User Choice ≤ 50)
AXPD_PRINT_NORMALIZATION	Cue to edit normalization details (0/1 = not done/edit details)
AXPD_INPUT_OPT = 1	Input shape as node average power
AXPD_NUM_POINTS	Number of axial points
KSHAPIN(J)	Node average power (J = 1, AXPD_NUM_POINTS ≤ 50)
ZSHAPIN(J)	Fraction of core height (J = 1, AXPD_NUM_POINTS ≤ 50)
AXPD_PRINT_NORMALIZATION	Cue to edit normalization details (0/1 = not done/edit details)
AXPD_INPUT_OPT = 2	Input shape as node power fraction (Must sum to one)
KSHAPIN(J)	Normalized power fractions (J = 1,CHT_NUM_NODE ≤ 20)

Table 7.3

Core Power Outputs

Power

CTL_CORE_POWER_FRACTION	Fraction of rated power, actual
POW_EXCORE_POWER_AV	Fraction of rated power, from ex-core detectors
POW_CORE_TRIP_FRACTION	Fraction of rated power at trip
CFTH_RCSAXIAL_Q(J)*	Axial distribution of fuel heat generation rate (Btu/sec)
CTL_CORE_POWER	Core power (Btu/sec)
CTL_CORE_POWERA	Core power (MWt)
POW_USER_QAXL(J)*	Axial power shape (Normalized to 1.0)

Decay Heat

POW_DKHT_IFDHC	Flags switch to decay heat curve if true (T)
POW_DKHT_TIMDHC	Time of switch to decay heat (sec)
POW_USER_QCD_LOOKUP	Decay heat power from table (frac) (Table value * POW_DKHT_DHCFCT)
POW_USER_QCD	Final decay heat power (frac)

Zirconium-Water Reaction

POW_ZRH2O_H2M	Hydrogen generation (lbm/sec)
CHT_HT_GEN_ZR_WAT(J)*	Heat rate generated (Btu/sec)
POW_ZRH2O_QZRH2O(J)*	Heat flux generated (Btu/ft^2-sec)
POW_ZRH2O_PCZR(J)*	Percent zirconium reacted
POW_ZRH2O_ZX(J)*	Thickness of reacted cladding (ft)

* Defined for J=1,..., CHT_NUM_ROD (≤ 20) axial segments of fuel rod, Figure 7.1.

Table 7.4

Core Reactivity Inputs

Control Rod Scram

(CTL_CORE_TRIP = T and POW_KIN_SCRAM_ROD_OPTION = T)*

POW_KIN_NQDK	Number of entries in table (≤ 30)
POW_KIN_TQDK	Time for control rod reactivity table (sec)
POW_KIN_QDK	Reactivity+

User Specified Reactivity

POW_KIN_DK	User specified reactivity due to rod motion or other effects.** +

Doppler Reactivity (POW_KIN_DOPPLER_FB_OPTION = T)

POW_KIN_NDKTMP	Number of entries in table (≤ 30)
POW_KIN_TDKTMP	Fuel temperature for Doppler reactivity table (°F).
POW_KIN_DKTMP	Reactivity+
POW_KIN_DKTMPZ	Doppler reactivity for initial conditions+

Moderator Temperature (POW_KIN_MOD_TEMP_FB_OPTION = T)

POW_KIN_NDKCTM	Number of entries in table (≤ 30)
POW_KIN_TDKCTM	Moderator (coolant) temperature for table (°F)
POW_KIN_DKCTM	Reactivity+
POW_KIN_DKCTMZ	Moderator temperature reactivity for initial conditions+

Table 7.4 (Continued)

<u>Moderator Boric Acid Concentration</u> (POW_KIN_BORON_FB_OPTION = T)

POW_KIN_NDKCON	Number of entries in table (≤ 30)
POW_KIN_TDKCON	Moderator boric acid concentration for table (ppm)
POW_KIN_DKCON	Reactivity+
POW_KIN_DKCONZ	Moderator boric acid reactivity for initial conditions+

<u>Moderator Density</u> (POW_KIN_MOD_DENSITY_FB_OPTION = T)

POW_KIN_NDKDEN	Number of entries in table (≤ 30)
POW_KIN_TDKDEN	Moderator density for table (lbm/ft)
POW_KIN_DKDEN	Reactivity+
POW_KIN_DKDENZ	Moderator density reactivity for initial conditions+
POW_KIN_MOD_DENSITY_OPTION	
	= F, Use core bulk density, $\Sigma(V_i/v_i) / \Sigma(V_i)$ summed over the core axial sections
	= T, Use cold edge temperature (Appendix E) with the following parameters:
POW_KIN_EDGE_WEIGHT	Edge temp. geometric weight, frac
POW_KIN_DH_FACTOR	Core enthalpy rise, frac
POW_KIN_HERM_CREDIT_OPTION	
	= T, Use Hermite credit (Appendix E)
	= F, Do not use Hermite credit

(See Appendix E for the full set of input to support the Hermite ractivity credit CESEC emulation model.)

Table 7.4 (Continued)

Control Rod Regulating System (POW_KIN_REG_ROD_OPTION = T)

POW_KIN_NDKINS	Number of entries in table (≤ 100)
POW_KIN_TDKINS	Control rod position for table
POW_KIN_DKINS	Reactivity +
POW_KIN_DKINSZ	Control rod regulating system reactivity for initial rod position

Reactor Power Cutback System

(CTL_RPCS_TRIP = T and POW_KIN_CUT_ROD_OPTION = T)

POW_KIN_NCUTBACK	Number of entries in table (≤ 10)
POW_KIN_TCUTBACK	Time for RPCS reactivity table
POW_KIN_CUTBACK	Reactivity +

Fixed Neutron Source

POW_KIN_SOURCE	Kinetics source term (fraction of fission power)

* T means true, F means false.

**Use CEER's RAMP function to simulate variable insertion or withdrawal.

+ Reactivity units - δk/k

Table 7.5

Core Reactivity Outputs

Feedback Reactivity*

POW_KIN_OUT	Data Dictionary partition for the following parameters (see the CENTS variable dictionary)
POW_KIN_DKT	Total reactivity
POW_KIN_DK	User specified reactivity
POW_KIN_DKBOR	Moderator boric acid reactivity
POW_KIN_DKMOD	Moderator density reactivity
POW_KIN_DKDOP	Doppler effect reactivity
POW_KIN_DKTMD	Moderator temperature reactivity
POW_KIN_DKROD	Control rod regulating system reactivity
POW_KIN_DKSCRAM	Control rod reactivity (insertion, scram)
POW_KIN_DKCUT	Reactor power cutback rod reactivity
POW_KIN_DKHERMC	Hermite 3-D credit reactivity
POW_KIN_DK_INIT	Initial subcriticality reactivity

Independent Variable for Reactivity Feedback Interpolation**

POW_KIN_T	Average fuel temperature for Doppler (°F)
RCS_BORON_CORE	Boric acid concentration in core (ppm)
CHT_TCOOL_AV	Moderator temperature in core (°F)
POW_KIN_DENCOR	Moderator density in core (lbm/ft)

Other

SCRAM_DELAY	Total scram delay time after trip (sec)

* Reactivity units - δ k/k   **See section 3.1.1.

Table 7.6

Fuel Rod and Coolant Channel Variables

Fuel Rod Nodal Variables

CHT_HT_GEN_ZR_WAT(J)*	Zirconium-water reaction heat generation rate (Btu/sec)
CFTH_RCSAXIAL_Q(J)	Axial distribution of fuel heat generation rate (Btu/sec)
CHT_TEMP_ROD(I,J)**	Temperature distribution in fuel rod (°F)
CHT_TEMP_FUEL_AV	Average temperature of rod (°F)

Cladding Surface Variables

CHT_HT_FLUX(J)	Heat flux into coolant (Btu/ft²/sec)
CHT_TEMP_SURF(J)	Cladding surface temperature (°F)
CHT_BOILING	Flag for heat transfer mode, natural convection is True.
CHT_IHT (J)	Heat transfer regime (Table 7.7)

Coolant Channel Variables

CHT_ENTH_COOL(JJ)	Coolant enthalpy at bottom of section (Btu/lbm)
CHT_TEMP_COOL(JJ)	Coolant temperature at bottom of section (°F)

*Dimension of variable

I	= 1,..., CHT_NREGIONS_RAD	Number of radial regions in fuel rod (≤ 10)
J	= 1,..., CHT_NUM_NODE	Number of axial sections in fuel rod (≤ 20)
JJ	= 1,..., CHT_NUM_NODE + 1	No. of axial sect. in coolant channel (≤ 21)

Table 7.7

Core Heat Transfer State

Heat Transfer Type

CHT_BOILING*	TYPE
F	Forced convection
T	Natural circulation (pool boiling)

Heat Transfer Regime on Boiling Curve

CHT_IHT	REGIME
1	Subcooled
2	Nucleate boiling
4	Transition boiling
5	Stable film boiling
7	Steam
8	Supercritical steam

*F = false, T = true.

7.2 Primary System

As used here, primary system includes all of the major primary system components - reactor vessel, hot and cold legs, pressurizer, steam generators (primary side), pumps, and quench tank. The reactor core is discussed in Section 7.1.

The thermal-hydraulic equations for all of the primary system components except the quench tank are solved simultaneously as a single, coupled system. Consequently a single set of variables describes the primary system, with the exception of the quench tank which is discussed separately.

Additional variables providing more information about the primary system are listed in the CENTS variable dictionary and Appendix A.

7.2.1 Nodes

Typical CENTS nodal maps of the primary system for PWRs designed by Combustion Engineering and Westinghouse are shown in Figure 7.2. Diagrams for the original nodalization and a more detailed nodalization are shown. The more detailed nodalization for the primary side of the steam generator (SG) is provided as an option to support the enhanced SG heat transfer model described in Section 5.3. An option to use a more detailed nodalization in the reactor vessel downcomer improves simulation of asymmetric effects in the loops of the RCS. Table 7.8 describes the system component(s) represented by each node in Figure 7.2

Selected variables describing the thermal-hydraulic state of each node are listed in Table 7.9. The node numbers in Figure 7.2 and Table 7.8 correspond to the subscripts used for the variables in Table 7.9. The "overall node variables" describe the average state of a node at any time. When two-phase conditions occur in a node, details about the liquid and steam phases are provided by the "two-phase node variables" in Table 7.9.

7.2.2 *Flowpaths*

The momentum equation for flow between the primary system nodes is solved as part of the coupled system of equations. The internal flowpaths included in the simultaneous solution are referred to here as momentum flowpaths. Other flowpaths for which a simpler flow solution is performed, mostly used as sinks or sources of fluid external to the primary system, are referred to as non-momentum flowpaths.

The momentum flowpaths on the primary side are shown in Figure 7.2 and listed in Table 7.10. The non-momentum flowpaths are shown in Figure 7.3 and listed in Table 7.11. Table 7.29 summarizes the current states of valves and leaks for many of the non-momentum paths in the primary system. Variables giving the area and cross-references to a description of the appropriate system are also given.

Selected variables describing the state of the fluid in the momentum and non-momentum paths are listed in Table 7.12. Again the path numbers in Figures 7.2 and 7.3 and in Tables 7.10 and 7.11 correspond to the subscripts in Table 7.12.

Note that two numbering schemes are used for the non-momentum paths in Table 7.12. For the variables P_FLOW, P_ENTH and P_QUAL, the path numbers above 100 in Table 7.11 and Figure 7.3 refer to the non-momentum paths. The same information and additional variables are available for the non-momentum paths in Table 7.12. The non-momentum path numbers for these variables are numbered from 1 to 50 as described in Table 7.11. Here the Figure 7.3 path number for these variables must be reduced by 100 to obtain the proper subscript for the non-momentum path. For example,

P_FLOW(105) = RCS_P_FLOW_NONM(5).

7.2.3 Reactor Coolant Pumps

Table 7.12 also lists selected variables describing reactor coolant pump operation. The dimensioned pump variables refer to the reactor coolant pumps shown in Figure 7.2, with subscripts 1, ...,NUM_PUMPS (number of RCP). Additional pump variables may be found in the RCP_COMMON partition of the CENTS database. (See Section 7.6, the CENTS variable dictionary and Appendix A.)

Manual trip of any reactor coolant pump may be achieved by setting the pump voltage variable (Table 7.12) to zero. For example, RCPI_VOLT_FRAC(1) = 0.0 trips the pump in Loop 1.

7.2.4 Core Bypass

Core bypass is controlled by the variable RTRV_BYPASS, representing the fraction of total reactor vessel flow that bypasses the core. CENTS uses the reduced flow in computing forced-convection heat transfer coefficients, coolant heatup and certain frictional loss terms in the core.

7.2.5 Core-Exit Enthalpy Tilt

CENTS calculates the core-exit/hot-legs enthalpy tilt that results from non-symmetric operation of the steam generators, using a reactor vessel mixing model.

The code determines the liquid enthalpy difference being fed from the cold legs to the reactor vessel downcomer, with a proper accounting for abnormal conditions, such as uncovery of the reactor vessel inlet nozzles or back flow through one of the nozzles. The contribution of the fluid from each cold leg to the inlet enthalpy of each hot leg is given by a matrix of weighting factors. This downcomer enthalpy tilt is subjected to fluid mixing during flow through the downcomer, flow skirt and lower plenum, resulting in a lower, core-inlet enthalpy tilt. The mixing process is governed by a core-inlet mixing factor, F_i, and by the relative and absolute magnitudes of the cold-leg coolant flowrates. Coolant passing through the core is mixed further, with a flow-dependent mixing factor F_o. The resulting core-exit enthalpy tilt is then transmitted to the flow streams in the hot legs.

CENTS models core mixing using the following three input arrays:

RTRV_MIX_INLET(1:2), F_i

(1) inlet plenum mixing factor for low flowrate

(2) inlet plenum mixing factor for high flowrate

RTRV_MIX_OUTLET(1:2), F_o

(1) outlet plenum mixing factor for low flowrate

(2) outlet plenum mixing factor for high flowrate

RCS_KWEIGHT_HTILT(1:4,1:4)

(I,J): In the I'th hot leg, impact weight of the flow from the J'th cold leg.

Using these inputs, the hot leg enthalpy tilts, RCS_DELH_HLTILT(1:4), are calculated:

$$\text{RCS\_DELH\_HLTILT(I)} = \{H_{weighted}(I) - H_{average}\} * f_n(F_i) * g_n(F_o) * h_n(\text{flow imbalance among loops})$$

where

$H_{weighted}(I)$: enthalpy of hot leg I, calculated from weighted contributions from the cold legs, according to the weights array, RCS_KWEIGHT_HTILT.

$H_{average}$: flow-weighted average enthalpy of the hot legs

f_n, g_n, h_n : linear functions of the parameter.

Then for each hot leg path J, connected to hot leg node I, the path enthalpy is tilted:

P_ENTH(J) <= P_ENTH(J) + RCS_DELH_HLTILT(I)

The effect of the tilt on the hot legs can be observed through the path arrays P_ENTH (above), P_ENTH_LIQ and P_QUAL (Table 7.12), and the node arrays ENTH_TOT, ENTH_LIQ, TEMP_TOT and TEMP_LIQ (Table 7.9).

7.2.6 *Quench Tank*

The nodes and flowpaths used in the quench tank model are summarized in Figure 7.4 and Table 7.13. The state variables for the node are defined in Table 7.13. State variables for the rupture disk flowpath and a vent flowpath to the containment are also defined and solute information for the exit paths is provided. Variables for controlling opening of the exit paths are provided.

7.2.7 *Non-Condensibles and Solutes*

CENTS provides models for transporting non-condensibles (Section 4.12) and solutes (Section 4.15) throughout the primary system. The variables available to the code user for sources, transport, sinks and release of non-condensibles (NC) and solutes in the primary system are summarized in Tables 7.14 and 7.15. Inputs in the CENTS basedeck that define the characteristics of these species are required to use the non-condensible and solute models. The following species are supported:.

1. Non-condensible gases – hydrogen, nitrogen, air, and additional species defined via the CENTS basedeck.

2. Solutes – boron, ^{16}N, iodine, xenon, and particulates (usually cesium) , and additional species defined via the CENTS basedeck.

There are three sources of non-condensible (NC) gases:

1. Input of a gas (such as nitrogen) by the reactor operator. This is simulated by the CENTS gas system using the variables described in Table 7.14.

2. Input of gases (such as nitrogen) through the safety injection system. The variables described below are used by the system modeler or user to define the injection rates.

3. Production of hydrogen in the core by the zirconium-water reaction is described in Section 3.1.3 and Table 7.3.

There are three types of solutes with different sources:

1. Boron injection as boric acid from the CVCS and safety injection systems is modeled directly in CENTS.

2. ^{16}N production by neutron capture in the coolant is represented using the production constant listed below. This is the production rate at full power, which is multiplied in CENTS by the fraction of core power due to fission to find the ^{16}N production rate.

3. The fission product release rates from failed fuel – for iodine, xenon, particulates (usually cesium) and other isotopes and noble gases – are defined by the variables described in Tables 7.14 and 7.15.

Transport, partitioning, and release rates for these species are computed using the models described in Sections 4.12 and 4.15. The variables used to observe the movement and release of the non-condensibles and solutes are listed in Table 7.15. Assignment of the species is defined by the pointers listed in Table 7.14 that identify the position (value of second subscript K) for each specie in the arrays. Solute concentrations of the charging and auxiliary spray as well as the safety injection flows are set to the user input concentrations listed in Table 7.12.

Table 7.8A

<u>Typical Primary System Node Descriptions</u>

(C-E PWR)

1	Inner Vessel and Upper Plenum
2	Pressurizer
3	Reactor Vessel Annulus and Lower Plenum (Lower Plenum only)*
4	Reactor Vessel Upper Head
5	Hot Leg and Steam Generator Inlet Plenum (Loop 11)
6	Steam Generator Tube Bundle - Hot Side (Loop 11) (Upper Part of Active U-tubes)*
7	Steam Generator Tube Bundle - Cold Side (Loop 11) (Upper Part of Active U-tubes)*
8	Steam Generator Outlet Plenum and Loop Seal (Loop 11)
9	Cold Leg (Loop 11A)
10	Cold Leg (Loop 11B)
11	Hot leg and Steam Generator Inlet Plenum (Loop 12) (Upper Part of Active U-tubes)*
12	Steam Generator Tube Bundle - Hot Side (Loop 12) (Upper Part of Active U-tubes)*
13	Steam Generator Tube Bundle - Cold Side (Loop 12)
14	Steam Generator Outlet Plenum and Loop Seal (Loop 12)
15	Cold Leg (Loop 12A)
16	Cold Leg (Loop 12B)
17	Control Element Assembly (CEA) Guide Tubes

Table 7.8A (Continued)

Table 7.8B

Typical Primary System Node Descriptions

(Westinghouse 3-Loop PWR)

1	Inner Vessel and Upper Plenum
2	Reactor Vessel Upper Head
3	Reactor Vessel Annulus and Lower Plenum (Lower Plenum only)*
4	Pressurizer
5	Hot Leg and Steam Generator Inlet Plenum (Loop C)
6	" " " " " " (Loop A)
7	" " " " " " (Loop B)
8	Steam Generator Tube Bundle - Hot Side (Loop C) (Upper Part of Active U-tubes)*
9	" " " " " " (Loop A) (Upper Part of Active U-tubes)*
10	" " " " " " (Loop B) (Upper Part of Active U-tubes)*
11	" " " " - Cold Side (Loop C) (Upper Part of Active U-tubes)*
12	" " " " " " (Loop A) (Upper Part of Active U-tubes)*
13	" " " " " " (Loop B) (Upper Part of Active U-tubes)*
14	Steam Generator Outlet Plenum and Loop Seal (Loop C)
15	" " " " " " (Loop A)
16	" " " " " " (Loop B)
17	Cold Leg (Loop C)
18	" " (Loop A)
19	" " (Loop B)
20	Control Element Assembly (CEA) Guide Tubes

Table 7.8B (Continued)

Table 7.8C

Typical Primary System Node Descriptions

(Westinghouse 4-Loop PWR)

1	Inner Vessel and Upper Plenum		
2	Pressurizer		
3	Reactor Vessel Annulus and Lower Plenum		(Lower Plenum only)*
4	Reactor Vessel Upper Head		
5	Hot Leg and Steam Generator Inlet Plenum	(Loop 1)	
6	Steam Generator Tube Bundle - Hot Side	(Loop 1)	(Upper Part of Active U-tubes)*
7	" " " " - Cold Side	(Loop 1)	(Upper Part of Active U-tubes)*
8	Steam Generator Outlet Plenum and Loop Seal	(Loop 1)	
9	Cold Leg	(Loop 1)	
10	Hot Leg and Steam Generator Inlet Plenum	(Loop 2)	
11	Steam Generator Tube Bundle - Hot Side	(Loop 2)	(Upper Part of Active U-tubes)*
12	" " " " - Cold Side	(Loop 2)	(Upper Part of Active U-tubes)*
13	Steam Generator Outlet Plenum and Loop Seal	(Loop 2)	
14	Cold Leg	(Loop 2)	
15	Hot Leg and Steam Generator Inlet Plenum	(Loop 3)	
16	Steam Generator Tube Bundle - Hot Side	(Loop 3)	(Upper Part of Active U-tubes)*
17	" " " " - Cold Side	(Loop 3)	(Upper Part of Active U-tubes)*
18	Steam Generator Outlet Plenum and Loop Seal	(Loop 3)	
19	Cold Leg	(Loop 3)	
20	Hot Leg and Steam Generator Inlet Plenum	(Loop 4)	
21	Steam Generator Tube Bundle - Hot Side	(Loop 4)	(Upper Part of Active U-tubes)*
22	" " " " - Cold Side	(Loop 4)	(Upper Part of Active U-tubes)*
23	Steam Generator Outlet Plenum and Loop Seal	(Loop 4)	
24	Cold Leg	(Loop 4)	
25	Control Element Assembly (CEA) Guide Tubes		

Table 7.8C (Continued)

Table 7.9

Primary System Node Variables

Overall Node Variables

PRESS(N)*	Pressure (psia)
ENTH_TOT(N)	Average node enthalpy (Btu/lbm)
TEMP_TOT(N)	Average node temperature (°F)
TEMP_SAT(N)	Saturation temperature (°F)
MASS_TOT(N)	Total coolant mass (lbm)
LEVL_MIX(N)	Two-phase mixture level (feet)
LEVL_LIQ(N)**	Collapsed liquid level (feet)
NUM_NODES	Number of primary system nodes

Two-Phase Node Variables

Liquid Phase	Steam Phase	
ENTH_LIQ(N)	ENTH_STM(N)	Enthalpy (Btu/lbm)
ENTH_LIQ_SAT(N)	ENTH_STM_SAT(N)	Saturation enthalpy (Btu/lbm)
TEMP_LIQ(N)	TEMP_STM(N)	Temperature (°F)
MASS_LIQ(N)	MASS_STM(N)	Mass (lbm)
MASS_BUB(N)		Mass of entrained bubbles (lbm)

Solute Concentrations

RCS_CONC_BORON(N)	Node boron concentration (ppm)
RCS_CONC_IOD(N)	Node iodine concentration (μC/lbm)
RCS_CONC_PART(N)	Node particulates concentration (μC/lbm)
RCS_CONC_XEN(N)	Node xenon concentration (μC/lbm)
RCS_BORON_CORE	Average boron concentration in core (ppm)

* N = 1,..., NUM_NODE Refer to Figure 7.2 for particular node numbers.
** In the inner vessel (N = 1), LEVL_LIQ(1) is the subcooled liquid level

Table 7.10A

Typical Primary System Momentum Path Descriptions
(C-E PWR)

Number	Description

Table 7.10 A (Continued)

Number	Description

Table 7.10B

Typical Primary System Momentum Path Descriptions

(Westinghouse 3 Loop PWR)

Number	Description

Table 7.10 B (Continued)

Number	Description

Table 7.10 B (Continued)

Number	Description

Table 7.10C

Typical Primary System Momentum Path Descriptions
(Westinghouse 4 Loop PWR)

Number	Description

Table 7.10 C (Continued)

Number	Description

Table 7.10 C (Continued)

Paths Added for Expanded Nodalization

Table 7.11A

Typical Primary System Non-Momentum Path Descriptions
(C-E PWR)

Number*	Description+		Abbreviation	Non-Mom* Number
	External to Primary System			
101	Reactor Coolant Pump (RCP) Leak	(Loop 11A)	PSL	1
102	" " " " "	(Loop 11B)	"	2
103	" " " " "	(Loop 12A)	"	3
104	" " " " "	(Loop 12B)	"	4
105	Charging to Cold Leg	(Loop 11A)	CH	5
106	Charging to Cold Leg	(Loop 12B)	"	6
109	Letdown Outlet from Pump Discharge Leg	(Loop 12B)	LDNS	9
113	Hot Leg drain	(Loop 11)	RCW	13
114	Shutdown Cooling Outlet from Hot Leg	(Loop 12)	SDC	14
116	Emergency Core Cooling System Injection	(Loop 11A)	SIS	16
117	" " " " "	(Loop 11B)	"	17
118	" " " " "	(Loop 12A)	"	18
119	" " " " "	(Loop 12B)	"	19

Table 7.11 A (Continued)

Number*	Description+	Abbreviation	Non-Mom* Number
	Leaks for Component Breaks		
126	Steam Generator Tube Rupture (Loop 11 Hot Side)	SGTR	26
127	" " " " (Loop 11 Cold Side)	"	27
128	" " " " (Loop 12 Hot Side)	"	28
129	" " " " (Loop 12 Cold Side)	"	29
134	Discharge Cold Leg Small Break (Loop 11A)	SB	34
135	Suction Cold Leg Small Break (Loop 12)	SB	35
136	Hot Leg Small Break (Loop 12)	SB	36
137	Pressurizer Small Break	SB	37
138	Control Element Assembly (CEA) Ejection (Upper Head)	RODEJ	38
139	O-Ring Seal Leak	ATWS	39
	Internal to Primary System		
143	Main Spray to Pressurizer	SPR	43
144	Main Spray Source from Cold Leg (Loop 11A)		44
145	" " " " " (Loop 11B)		45
146	Pressurizer Relief (SV, PORV and vents combined)	SV, PORV	46
147	Upper Head Vent Valve	VENT	47

* The alternate path numbers are for non-momentum paths as a continuation of the momentum path arrays (101-150) or for the non-momentum paths numbered from 1-50. See the text for more information.

+ The non-momentum paths may be reconnected to different loops or nodes via the array P_NODE_INLET, or at different elevations via the array P_ELEV_INLET.

Table 7.11B

Typical Primary System Non-Momentum Path Descriptions
(Westinghouse 3 Loop PWR)

Number*	Description+		Abbreviation	Non-Mom* Number
	External to Primary System			
101	Reactor Coolant Pump (RCP) Leak	(Loop C)	PSL	1
102	" " " " " "	(Loop A)	"	2
103	" " " " " "	(Loop B)	"	3
105	Charging to Pump seal	(Loop C)	PS	5
106	Charging to Pump seal	(Loop A)	PS	6
107	Charging to Cold Leg and Pump Seal	(Loop B)	CH&PS	7
109	Letdown Outlet from Pump Discharge Leg	(Loop A)	LDNS	9
113	Hot Leg drain	(Loop C)	DRN	13
114	Shutdown Cooling Outlet from Hot Leg	(Loop A)	SHC	14
116	Emergency Core Cooling System Injection	(Loop C)	SIS	16
117	" " " " " " "	(Loop A)	"	17
118	" " " " " " "	(Loop B)	"	18

Table 7. 11 B (Continued)

Number*	Description+		Abbreviation	Non-Mom* Number
	Leaks for Component Breaks			
126	Steam Generator Tube Rupture (Loop C Hot Side)		SGTR	26
127	" " " "	(Loop C Cold Side)	"	27
128	" " " "	(Loop A Hot Side)	"	28
129	" " " "	(Loop A Cold Side)	"	29
130	" " " "	(Loop B Hot Side)	"	30
131	" " " "	(Loop B Cold Side)	"	31
134	Discharge Cold Leg Small Break	(Loop C)	SB	34
135	Suction Cold Leg Small Break	(Loop A)	SB	35
136	Hot Leg Small Break	(Loop A)	SB	36
137	Pressurizer Small Break		SB	37
138	Control Element Assembly (CEA) Ejection (Upper Head)		RODEJ	38
139	O-Ring Seal Leak		ATWS	39
	Internal to Primary System			
143	Main Spray to Pressurizer		SPR	43
144	Main Spray Source from Cold Leg	(Loop C)	"	44
145	" " " " "	(Loop A)	"	45
146	Pressurizer Relief (SV, PORV and vents combined)		SV, PORV	46
147	Upper Head Vent Valve		VENT	47

*The alternate path numbers are for non-momentum paths as a continuation of the momentum path arrays (101-150) or for the non-momentum paths numbered from 1-50. See the text for more information.

+The non-momentum paths may be reconnected to different loops or nodes via the array P_NODE_INLET, or at different elevations via the array P_ELEV_INLET.

Table 7.11C

Typical Primary System Non-Momentum Path Descriptions
(Westinghouse 4 Loop PWR)

Number*	Description+		Abbreviation	Non-Mom* Number
	External to Primary System			
101	Reactor Coolant Pump (RCP) Leak	(Loop 1)	PSL	1
102	" " " " "	(Loop 2)	PSL	2
103	" " " " "	(Loop 3)	PSL	3
104	" " " " "	(Loop 4)	PSL	4
105	Charging to Pump Seal	(Loop 1)	PS	5
106	Charging to Pump Seal	(Loop 2)	PS	6
107	Charging to Cold Leg and Pump Seal	(Loop 3)	CH&PS	7
108	Charging to Pump Seal	(Loop 4)	PS	8
109	Letdown Outlet from Pump Suction Leg	(Loop 3)	LDNS	9
110	Letdown Outlet from Pump Discharge Leg	(Loop 3)	LDNS	10
113	Hot Leg Drain	(Loop 1)	DRN	13
114	Shutdown Cooling Outlet from Hot Leg	(Loop 2)	SDC	14
116	Emergency Core Cooling System Injection	(Loop 1)	SIS	16
117	" " " " "	(Loop 2)	SIS	17
118	" " " " "	(Loop 3)	SIS	18
119	" " " " "	(Loop 4)	SIS	19
120	Safety Injection to Hot Leg	(Loop 1)	SIS	20
121	" " " "	(Loop 3)	SIS	21

Table 7. 11 C (Continued)

Number*	Description+		Abbreviation	Non-Mom* Number
	Leaks for Component Breaks			
126	Steam Generator Tube Rupture	(Loop 1 Hot Side)	SGTR	26
127	" " " "	(Loop 1 Cold Side)	"	27
128	" " " "	(Loop 2 Hot Side)	"	28
129	" " " "	(Loop 2 Cold Side)	"	29
130	" " " "	(Loop 3 Hot Side)	"	30
131	" " " "	(Loop 3 Cold Side)	"	31
132	" " " "	(Loop 4 Hot Side)	"	32
133	" " " "	(Loop 4 Cold Side)	"	33
134	Discharge Cold Leg Small Break	(Loop 3)	SB	34
135	Suction Cold Leg Small Break	(Loop 2)	SB	35
136	Hot Leg Small Break	(Loop 1)	SB	36
137	Pressurizer Small Break		SB	37
138	Control Element Assembly (CEA) Ejection (Upper Head)		RODEJ	38
139	O-Ring Seal Leak		ATWS	39
	Internal to Primary System			
143	Main Spray to Pressurizer		SPR	43
144	Main Spray Source from Cold Leg	(Loop 3)	"	44
145	" " " " "	(Loop 4)	"	45
146	Pressurizer Relief (SV, PORV and vents combined)		SV, PORV	46
147	Upper Head Vent Valve		VENT	47

*The alternate path numbers are for non-momentum paths as a continuation of the momentum path arrays (101-150) or for the non-momentum paths numbered from 1-50. See the text for more information. +The non-momentum paths may be reconnected to different loops or nodes via the array P_NODE_INLET, or at different elevations via the array P_ELEV_INLET.

Table 7.12

Primary System Path Variables

Path Types

1-100	Momentum
101-125	Non-momentum, sources or sinks external to primary system
126-142	Non-momentum, leaks
143-150	Non-momentum, sources or sinks internal to primary system

Path Variables

P_FLOW(J)*	Flowrate	(lbm/sec)
P_ENTH(J)	Enthalpy	(Btu/lbm)
P_ENTH_LIQ(M)	Liquid enthalpy	(Btu/lbm)
P_ENTH_STM(M)	Steam enthalpy	(Btu/lbm)
P_QUAL(J)	Quality	
DP_TOT(M)	Momentum Path pressure drop	(psid)
NUM_PATHS_MOM	Number of momentum paths (≤ 100)	
NUM_PATHS	Total of momentum and non-momentum paths (150)	

Non-Momentum Path Variables

RCS_P_FLOW_NONM(N)*	Flowrate	(lbm/sec)
RCS_P_ENTH_NONM(N)	Enthalpy	(Btu/lbm)
RCS_P_QUAL_NONM(N)	Quality	
RCS_P_BORON(N)	Boric acid concentration	(ppm)
RCS_P_IOD(N)	Iodine fission products	(μC/lbm)
RCS_P_PART(N)	Particulate " "	"
RCS_P_XEN(N)	Xenon " "	"
NUM_PATHS_NONM	Number of non-momentum paths (50)	

Table 7.12 (Continued)

Reactor Coolant Pump

SPEED_PUMP(I)*	Pump speed	(RPM)
DP_PUMP(I)	Pump head	(psid)
RCPI_VOLT_FRAC(I)	Pump voltage	(fraction of rated voltage)
RCP_HEAT(I)	Pump heat	(Btu/sec)
NUM_PUMPS	Number of reactor coolant pumps	(≤ 4)

Critical Flow Option for Liquid and Two-Phase

RCS_CRIT_MODEL = 0, Homogeneous Equilibrium model (HEM)

= 1, Henry-Fauske model (H-F)

See Section 4.7, CENTS variable dictionary and Appendix B.

Charging and Safety Injection System Solute Concentrations

CHGS_RCS_BORON	Charging system boron concentration	(ppm)
CHGS_RCS_HYD	Charging system hydrogen conc.	(lbm/lbm)
CHGS_RCS_IOD	Charging system iodine concentration	(μC/lbm)
CHGS_RCS_PART	Charging system particulates conc.	(μC/lbm)
CHGS_RCS_XEN	Charging system xenon concentration	(μC/lbm)
SIS_RCS_BORON	Safety injection system boron conc.	(ppm)

* See Figures 7.2 and 7.3 for particular path numbers.

I = 1,..., NUM_PUMPS

J = 1,..., NUM_PATHS

M = 1,..., NUM_PATHS_MOM

N = 1,..., NUM_PATHS_NONM

Table 7.13

Quench Tank Variables

Input

GWS_QT_FLOW	Gaseous waste system to quench tank flowrate.
QT_VENT_MULT	Adjustment multiplier on vent to containment flow
QT_RUPTURE_SPOINT	Rupture disk setpoint pressure
VLV_QT_GWS	Valve position of vent to gaseous waste system (GWS)
VLV_QT_CONT	Valve position of vent to containment

Output: Node

PRES_QT	Pressure	(psia)
TEMP_QT	Temperature	(°F)
ENTH_QT	Enthalpy	(Btu/lbm)
LEVL_QT	Level	(ft)
CONC_SOLU_QT(J)*	Solute concentrations	

Output: Rupture Disk Path

RUPTURE_QT	Disk ruptured when true	(T/F)
P_FLOW_DISK	Disk to containment flowrate	(lbm/sec)
ENTH_QT	Disk to containment enthalpy	(lbm/sec)

Output: Quench Tank to Containment Vent Path

P_FLOW_VENT_WAT	Vent water flowrate	(lbm/sec)
ENTH_QT	Vent enthalpy	(lbm/sec)

* See Table 7.9 for relationship of J to solute and units.

Table 7.14
Non-Condensible and Solute Inputs

Variable	Description	Units
	Input of Non-Condensibles Via Gas System	
GS_VES_NONC	Non-condensible inflow to vessel via Gas System	lbm/sec
GS_PRZR_NONC	Non-condensible inflow to przr via Gas System	lbm/sec
GS_SPECIES	Type of NC gas (see ID_TYPE_SPECIES)	Pointer
	Non-Condensibles from Safety Injection	
SIS1_RCS_NONC(5)	Non-condensible inflow via SI line, CL 1	lbm/sec
SIS2_RCS_NONC(5)	Non-condensible inflow via SI line, CL 2	lbm/sec
SIS3_RCS_NONC(5)	Non-condensible inflow via SI line, CL 3	lbm/sec
SIS4_RCS_NONC(5)	Non-condensible inflow via SI line, CL 4	lbm/sec
SIS5_RCS_NONC(5)	Non-condensible inflow via SI line, HL 1	lbm/sec
SIS6_RCS_NONC(5)	Non-condensible inflow via SI line, HL 2	lbm/sec
	Production of ^{16}N in Core	
CORE_N16_MULT	Production constant for ^{16}N, μC/power-fraction	Composite
	Fission Product Release from Fuel	
CORE_IOD_REL	Core iodine release	μC/lbm
CORE_PART_REL	Core particulate (typically cesium) release	μC/lbm
CORE_XEN_REL	Core xenon release	μC/lbm
CORE_RELE_SOLU(20)	Solute release rate in the core	Composite
	Definition of Species	
ID_TYPE_SPECIES(20)	Identifying pointers for all species	Partition
. ID_TYPE_SOLUTE(15)	Identifiers for the solute species	Pointer
.. ID_TYPE_BORON	Identifier for boron	Pointer
.. ID_TYPE_N16	Identifier for ^{16}N	Pointer
.. ID_TYPE_IODINE	Identifier for iodine	Pointer
.. ID_TYPE_XENON	Identifier for xenon	Pointer
.. ID_TYPE_PART	Identifier for particulates (typically cesium)	Pointer
. ID_TYPE_NONC(5)	Identifiers for the non-condensible species	Pointer
.. ID_TYPE_HYD	Identifier for hydrogen	Pointer
.. ID_TYPE_NIT	Identifier for nitrogen	Pointer
.. ID_TYPE_AIR	Identifier for air	Pointer
NUM_SOLUTES	Number of dissolved solutes (≤ 15)	Counts
NUM_NONC	Nnumber of non-condensible species (≤ 5)	Counts
HALF_LIFE_SOLUTES(20)	Decay half lives of dissolved species	Seconds
CONC_RATIO_STM_LIQ(20)	Relative solubilities in liquid and steam	Fraction

Table 7.15

Non-Condensible and Solute Outputs

RCS_CONC_SOLUTE(I,K)	Node concentrations of dissolved species*	
MASS_NONC_DIS(I,L)	Nodal mass of dissolved NC	(lbm)
MASS_NONC_SEP(I,L)	Nodal mass of separated NC	(lbm)
MASS_NONC_DIS_TOT(I)	Total mass of dissolved NC in node	(lbm)
MASS_NONC_SEP_TOT(I)	Total mass of separated NC in node	(lbm)
MASS_NONC_DIS_RCS	Total mass of dissolved NC in RCS	(lbm)
MASS_NONC_SEP_RCS	Total mass of separated NC in RCS	(lbm)
RCS_TOTAL_IODINE	Total iodine in RCS nodes	(Curies)
RCS_IOD_REL_TOT	Total iodine from core & ext. flows	(Curies)
P_CONC_SOLU(J,K)	Path concentrations of dissolved species*	
P_FLOW_NONC(J)	Path flow of all separated NC	(lbm)
P_FRAC_NONC(J,L)	Path concentrations of separated NC*	

I = 1, ... , NUM_NODES (≤ 50)

J = 1, ... , NUM_PATHS (≤ 150)
This includes NUM_PATHS_MOM momentum paths, and the non-momentum path types:

external	J = 101, ... , 100 + NUM_PATHS_EXT	(≤ 25),
leak	J = 126, ... , 125 + NUM_PATHS_LEAK	(≤ 17)
internal	J = 143, ... , 142 + NUM_PATHS_INT	(≤ 8)

K = 1, ..., 5 + NUM_NONC (≤ 20)

L = 1, ..., NUM_NONC (≤ 5)

* Species	Concentration Units
Non-condensibles	lbm/lbm fluid
Boron	ppm
Nitrogen-16	µC/lbm fluid
Fission products	µC/lbm fluid

7.3 Secondary System

The secondary system model includes the steam generator secondary (evaporator, downcomer and steam dome), main steamline header and related fluid sources and sinks as shown in Figure 7.5. The model also includes the steam generator tube heat transfer to the evaporator. Figure 7.6 gives a more detailed representation of the volume nodes and internal flowpaths for one steam generator, along with selected variables describing the state of the steam generator.

7.3.1 Steam Generator Nodalization

Table 7.17 defines the secondary node variables. Table 7.18 defines the secondary system internal flowpaths, i.e., paths between the secondary nodes. SGS_HLEVEL(I) represents the actual water level in the downcomer region of steam generator I. It normally equals SGS_HT3(I), the calculated level in the downcomer node, except when the can-deck/steam separators are flooded, i.e., exceeding the vertical limit of the downcomer node. SGS_HTI(I,J) represents the indicated water level (feet) in the downcomer region of steam generator I, as measured by its J'th reference leg (J: 1 = narrow range, 2 = wide range, 3 = unused spare).

CTL_SG_ILEVEL(I,J) exactly corresponds to SGS_HTI(I,J), but is measured as fraction of span. CTL_SG_ILEVEL is used in feedwater control. Note that SGS_HTI(I,J) may differ from SGS_HLEVEL(I) at off-calibration conditions.

7.3.2 Steam Generator Heat Transfer

An enhanced heat transfer model that provides more detailed temperature profiles for the primary coolant and the tubes in the steam generators (SG) has been added as described in Section 5.3 to support the expanded nodalization in the SG. It produces more realistic heat transfer coefficients on both the primary and secondary side of the

SG and a more accurate heat transfer rate. This allows use of more realistic values for the SG heat transfer tuning coefficients. It also gives more accurate flowrates and fluid temperatures in the RCS for natural circulation. Figure 7.7 shows the expanded nodalization in the SG and the enhanced heat transfer model.

7.3.3 *Main Steamline and Header*

The main steamline and steamline header model in CENTS has been upgraded as discussed in Section 5.6. The upgrade provides an option to model two mainline header nodes and to calculate the crossflow between them. It allows a main steamline break (MSLB) at any location along the steamline per the discussion for malfunctions on the secondary side of the NSSS in Section 7.5.2. It supports the capability to check for critical flow in any of the steamline flowpaths including the flowpath downstream of the steamline break location and the cross connect path (if the two node header model is used).

Table 7.16 lists the steamlines' valved flowpaths, whose controls are described in Section 6.6 as part of the control systems. Upstream and downstream connections for these paths are fixed by the array MSLH_VALVE_INLET(I) (steamline and header sources, see Figure 7.5) with the values for fluid sources defined as

Source No.	One steamline	Two steamlines	
	SL_1	SL_1	SL_2
SG_N	SG_N	$2 \cdot SG_N - 1$	$2 \cdot SG_N$
$MSLH_1$	$NUM\_SL \cdot NUM\_SG + 1$		
$MSLH_2$	$NUM\_SL \cdot NUM\_SG + 2$		

where

SG_N is the SG number (1, 2, etc.)

SL_1 and SL_2 are steamline 1 and 2 (if it exists)

$MSLH_1$ and $MSLH_2$ are the MSLH node number 1 and 2 (if it exists)

I = 1, ..., MSLH_VALVE_NUM ($\leq$ 50 - NUM_SL $\cdot$ NUM_SG – NUM_MSLH)

The array MSLH_VALVE_EXIT(I) defines the flow sinks (see nomenclature for Figure 7.5) as:

= 1, atmosphere

= 2, condenser,

= 3, containment, and

= 4, turbine

Table 7.17 lists the main steamline header and main steamline state variables.

Table 7.19 presents the variables describing the external sources and sinks of fluid for the secondary system. Included, via the SL_P_FLOW array, are the MSLH_VALVE_NUM valved flowpaths shown and numbered in Figure 7.5 and Table 7.16. SL_P_FLOW also includes, after MSLH_VALVE_NUM, one auxiliary steam path from each steamline (upstream of the MSIV) and one such path from each header node, each carrying a user-specified, constant steam flowrate (normally zero).

MSLH_FLOW_CHOKED is a flag that controls flow choking between the steamline header and the steamline break:

F = not choked

T = choked

7.3.4 *Feedwater System*

CENTS provides two options for representing the main feedwater and auxiliary (emergency) feedwater systems (FWS): a simplified model and a detailed model. For the simplified model, the control system built by the system modeler (Section 6.7) directly specifies the flowrate to each steam generator. For the more detailed model, the control system controls the feedwater pump speed and the flow control valves. The model to be used is selected by the value of

NUM_FWS_PUMPS	= 0, Use simplified system (Section 5.5.10),
	> 0, Use detailed system (Sections 5.5.1 - 5.5.9).

The detailed, discrete model for the main and auxiliary feedwater systems is derived from a set of models developed for the LTC code, Ref. 7.2. The improved model includes component models for control valves, recirculation control valves, isolation valves, condensate pumps, main feedwater pumps, heater drain pumps, auxiliary/emergency feedwater pumps, feedwater heaters, the condenser, heater drain tanks, and the feedwater piping including cross connects. Piping from the outlet of the condenser to the SG inlets is modeled (including heater drains) by means of a node flowpath network. The FWS model represents pumps with head-flow curves, provides line and valve losses, and responds to control systems built with the CENTS generic control system models. A typical system for a C-E PWR is shown in Figures 7.8 and 7.9. Tables 7.20 and 7.21 list the nodes and flowpaths for the system depicted in the figures.

Table 7.22 provides information about the input variables that are used to build a detailed feedwater system and define the performance of the system. It lists the partition in the data dictionary for each FWS component model, the maximum number of elements for each type of component, and selected input variables of interest to the code user. Table 7.23 lists variables used to observe the behavior of the detailed feedwater system. Interfaces to the component models driven by the control systems are provided by the variables listed below. The variables are defined in Tables 7.22 and 7.23 and in the CENTS variable dictionary.

FWS System Variable	Interface Variable	Units
FWS_SPDMD{NPMPMFW(L)} L = 1,..., NUM_FWS_PUMPS	= CTL_FWS_SPEED_SIG(L)	frac
FWS_SPDMD{NPMPEFW(L)} L = 1,..., NUM_FWS_PUMPS	= CTL_AFWS_SPEED_SIG(L)	frac
FWS_STROKE{NVMFV(N)} N = 1,..., NUM_SG	= CTL_FWS_SIG(N)	percent
If SG_ECONOMIZER = True FWS_STROKE{NVBFV(N)} N = 1,..., NUM_SG	= CTL_FWS_ECON_SIG(N)	percent
If SG_ECONOMIZER = False FWS_STROKE{NVBFV(N)} N = 1,..., NUM_SG	= CTL_FWS_BYP_SIG(N)	percent
FWS_STROKE{NVALRC(LL)} LL = 1,..., FWS_NRCIRC	= FWS_FWRCOUT(LL) · 100.	percent
FWS_POSISO(NP) NP = NPATH{NVMFV(N)} NP = NPATH{NVBFV(N)} N = 1,..., NUM_SG	= CTL_FWS_ISO_POS(N)	frac

7.3.5 *Solutes and Dose*

The CENTS solutes and non-condensibles models are described in Sections 4.12 and 4.15. CENTS tracks the solute species and non-condensible gases in the RCS as described in Section 7.2.7. The solutes in the RCS are used to provide a source or sink for the solutes in the SGS. CENTS tracks selected solutes (Table 7.24) in the SGS components (SG, steamline and MSLH). The iodine solute is used to find doses by means of the CENTS dose model described in Section 5.8.

Solutes can enter or exit the SG via feedwater, a SG tube rupture and SG steam flow. The concentration of solutes entering the SG for primary to secondary leaks such as a tube rupture is set to the concentration in the primary node where the leak occurs.

For secondary to primary leaks, the solute concentration entering the primary system is based on the concentration in the SG. If the evaporator level plus the elevation of the tubesheet is above the leak location, the solute concentration is set to the concentration in the liquid. Otherwise, it is set to the concentration in steam space. The concentration of hydrogen for secondary to primary leaks is zero. Variables for the concentration in the SG of the solutes that have specific variable names are listed in Table 7.24.

Solutes can also enter or exit the SG by means of the feedwater system. When flow is positive (to the SG), the solute concentrations are set to the values for the feedwater system in Table 7.24. When the flow is negative, which can only occur during a feedline break malfunction, the solute of the exiting fluid is set to the concentration of the SG node.

Iodine and gases leave the SG as part of the steam flow. For flow out of the SG, the concentration in the exiting steam is set to that in the steam space. For flow into the SG, the solute concentration is set to that of the steamline path MSLH_ISL(I). Iodine release to the atmosphere from all secondary systems paths includes four components that are combined to calculate the total iodine release RCS_DOSE_TOT_CURIE:

1. Direct release via secondary safety valves, ADVs, (possibly) bypass valves which discharge to the atmosphere as well as any contribution from a steamline break outside of the containment.
2. Release to atmosphere due to containment leakage.
3. Release to the atmosphere from the main steam system via the condenser with a decontamination term RCS_DOSE_COND_DF.
4. Release to the atmosphere from main steam system via the turbine with a decontamination term RCS_DOSE_COND_DF.

The variables used to specify key parameters for the iodine release model and to observe the iodine releases are listed in Table 7.24.

CENTS calculates doses due to iodine released from the SG using two models: a two (2) hour dose model and an eight (8) hour dose model. The variables used to calculate and observe these doses are listed in Table 7.24.

Table 7.16A

Steamline External Flowpaths:

Typical Numbering Scheme for Sources, Sinks and Paths

(C-E PWR)

No.	Steamline Sources
1.	Steamline 1, upstream of MSIV
2.	Steamline 2, upstream of MSIV
3.	Steamline header, downstream of MSIV

No.	Steamline Sinks
1.	Atmosphere
2.	Condenser
3.	Containment
4.	Turbine

No.	Steamline External Flowpaths	Source	Sink
1.	Atmospheric Dump Valve	1	1
2.	" " "	2	1
3.	Safety Valve	1	1
4.	" "	1	1
5.	" "	1	1
6.	" "	1	1
7.	" "	1	1
8.	" "	1	1
9.	" "	1	1
10.	" "	1	1

Table 7.16 A (Continued)

No.	Steamline External Flowpaths	Source	Sink
11.	Safety Valve	2	1
12.	" "	2	1
13.	" "	2	1
14.	" "	2	1
15.	" "	2	1
16.	" "	2	1
17.	" "	2	1
18.	" "	2	1
19.	Turbine Bypass Valves	3	2
20.	" " "	3	2
21.	" " "	3	2
22.	" " "	3	2
23.*	Turbine Admission Valves	3	4
24.	Constant Auxiliary Flow	1	
25.	" " "	2	
26.	" " "	3	
MSLB	Main Steamline Break	1	3
"	" " "	2	3
"	" " "	3	1

* MSLH_VALVE_NUM

Table 7.16B

Steamline External Flowpaths:

Typical Numbering Scheme for Sources, Sinks and Paths

(Westinghouse 3 Loop PWR)

No.	Steamline Sources
1.	Steamline 1, upstream of MSIV
2.	Steamline 2, upstream of MSIV
3.	Steamline 3, upstream of MSIV
4.	Steamline header, downstream of MSIV

No.	Steamline Sinks
1.	Atmosphere
2.	Condenser
3.	Containment
4.	Turbine

No.	Steamline External Flowpaths	Source	Sink
1.	Atmospheric Dump Valve	1	1
2.	" " "	2	1
3.	" " "	3	1
4.	Safety Valve	1	1
5.	" "	1	1
6.	" "	1	1
7.	" "	1	1
8.	" "	1	1

Table 7.16 B (Continued)

No.	Steamline External Flowpaths	Source	Sink
9.	Safety Valve	2	1
10.	" "	2	1
11.	" "	2	1
12.	" "	2	1
13.	" "	2	1
14.	Safety Valve	3	1
15.	" "	3	1
16.	" "	3	1
17.	" "	3	1
18.	" "	3	1
19.	Turbine Bypass Valves A + B	4	2
20.	" " " C + D	4	2
21.	" " " E + F	4	2
22.	" " " G + H	4	2
23.*	Turbine Admission Valves	4	4
24.	Constant Auxiliary Flow	1	
25.	" " "	2	
26.	" " "	3	
27.	" " "	4	
MSLB	Main Steamline Break	1	3
"	" " "	2	3
"	" " "	3	3
"	" " "	4	1

* MSLH_VALVE_NUM

Table 7.16C

Steamline External Flowpaths:

Typical Numbering Scheme for Sources, Sinks and Paths

(Westinghouse 4 Loop PWR)

No.	Steamline Sources
1.	Steamline 1, upstream of MSIV
2.	Steamline 2, upstream of MSIV
3.	Steamline 3, upstream of MSIV
4.	Steamline 4, upstream of MSIV
5.	Steamline header, downstream of MSIV

No.	Steamline Sinks
1.	Atmosphere
2.	Condenser
3.	Containment
4.	Turbine

No.	Steamline External Flowpaths	Source	Sink
1.	Atmospheric Dump Valve	1	1
2.	" " "	2	1
3.	" " "	3	1
4.	" " "	4	1
5.	Safety Valve	1	1
6.	" "	1	1
7.	" "	1	1
8.	" "	1	1
9.	" "	1	1

Table 7.16 C (Continued)

No.	Steamline External Flowpaths	Source	Sink
10.	Safety Valve	2	1
11.	" "	2	1
12.	" "	2	1
13.	" "	2	1
14.	" "	2	1
15.	Safety Valve	3	1
16.	" "	3	1
17.	" "	3	1
18.	" "	3	1
19.	" "	3	1
20.	Safety Valve	4	1
21.	" "	4	1
22.	" "	4	1
23.	" "	4	1
24.	" "	4	1
25.	Turbine Bypass Valves	5	2
26.	" " "	5	2
27.	" " "	5	2
28.	" " "	5	2
29.	" " "	5	2
30.	" " "	5	2
31.	" " "	5	2
32.*	Turbine Admission Valves	5	4
33.	Constant Auxiliary Flow	1	
34.	" " "	2	
35.	" " "	3	
36.	" " "	4	
37.	" " "	5	
MSLB	Main Steamline Break	1	3
"	" " "	2	3
"	" " "	3	3
"	" " "	4	3
"	" " "	5	1

* MSLH_VALVE_NUM

Table 7.17

Steam Generator Secondary Node Variables*

Steam Dome

SGS_P(I)*	Pressure	(psia)
SGS_ENTH1(I)	Average enthalpy	(Btu/lbm)
SGS_T1(I)	Temperature	(°F)
SGS_WF1(I)	Liquid mass	(lbm)
SGS_WG1(I)	Steam mass	(lbm)
SGS_M1(I)	Total fluid mass	(lbm)
SGS_CON_IO1(I)**	Iodine concentration	(μC/lbm)
SGS_HF(I)	Liquid saturation enthalpy	(Btu/lbm)
SGS_HG(I)	Steam saturation enthalpy	(Btu/lbm)

Evaporator

SGS_ENTH2(I)	Overall enthalpy	(Btu/lbm)
SGS_T2(I)	Temperature	(°F)
SGS_WF2(I)	Liquid mass	(lbm)
SGS_WG2(I)	Steam mass	(lbm)
SGS_M2(I)	Total fluid mass	(lbm)
SGS_CON_IO2(I)**	Iodine concentration for evaporator and downcomer	(μC/lbm)
SGS_HT2(I)	Level	(ft)

Table 7.17 (Continued)

Downcomer

SGS_ENTH3(I)	Overall enthalpy	(Btu/lbm)
SGS_T3(I)	Temperature	(°F)
SGS_WF3(I)	Liquid mass	(lbm)
SGS_WG3(I)	Steam mass	(lbm)
SGS_M3(I)	Total fluid mass	(lbm)
SGS_HT3(I)	Level	(ft)

Main Steamline Header Node 1

MSLH_STATE	Steamline header Node 1 variables	Partition
MSLH_P	Pressure	(psia)
MSLH_H	Average enthalpy	(Btu/lbm)
MSLH_T	Temperature	(°F)
MSLH_M	Total fluid mass	(lbm)
MSLH_CON_IO §	Iodine concentration	(μC/lbm)
MSLH_HF	Liquid saturation enthalpy	(Btu/lbm)
MSLH_HG	Steam saturation enthalpy	(Btu/lbm)

Main Steamline Header Node 2 (if used)

MSLH2_STATE	Steamline header Node 2 variables	Partition
MSLH2_P	Pressure	(psia)
MSLH2_H	Average enthalpy	(Btu/lbm)
MSLH2_T	Temperature	(°F)
MSLH2_M	Total fluid mass	(lbm)
MSLH2_CON_IO §	Iodine concentration	(μC/lbm)
MSLH2_HF	Liquid saturation enthalpy	(Btu/lbm)
MSLH2_HG	Steam saturation enthalpy	(Btu/lbm)
NUM_MSLH	Number of MSLH nodes (≤ 2)	(Counts)

Table 7.17 (Continued)

<u>Steamline</u>

NUM_SL	Number of steamlines per SG (≤ 2)	(Counts)
MSLH_PSL(II)	Pressure	(psia)
MSLH_TSL(II)	Temperature	(°F)
MSLH_HSL(II)	Average enthalpy	(Btu/lbm)

<u>Downcomer Water Level</u>$^{+}$

SGS_HLEVEL(I)	Downcomer water level, actual	(ft)
SGS_HTI(I,L)	Downcomer water level, measured by reference leg L	(ft)
CTL_SG_ILEVEL(I,L)	Downcomer water level, measured by reference leg L	(fraction)

<u>Steam Generator Nodalization (Input)</u>

NUM_SG	Number of steam generators ($N \leq 4$)	(Counts)
NUM_SG_NODES	Number of primary nodes in SG ($N \leq 16$) (NUM_SG_NODES / NUM_SG = 2 or 4)	(Counts)
NODE_SG(N)	Primary side node number in SG ($N \leq 16$)	(Counts)
NUM_SG_SECT(N)	Number of primary side sections in SG node requested in base deck ($N \leq 16$)	(Counts)
RCS_SG_NSECT(N)	Actual number of primary side sections used in SG node (dynamic) ($N \leq 16$)	(Counts)
RCS_SG_SECT_TOPT	Tube section primary side temp. model (0 = Exit, 1 = LMTD)	(Pointer)

Table 7.17 (Continued)

Steam Generator Tube Heat Transfer

SGS_NSECT(K)	No. of secondary side sections in SG {= Σ RCS_SG_NSECT(lower + upper)}	(Counts)
RCS_SG_SECT_TEMP(J,K)	Primary fluid temp.of tube sections	(°F)
RCS_SG_SECT_QP(J,K)	Primary heat rate of tube sections	(Btu/sec)
RCS_SG_SECT_QS(J,K)	Secondary heat rate of tube sections	(Btu/sec)
RCS_SG_SECT_TTUBE(J,K)	Tube temperatures of tube sections	(°F)
SGT_Q_MULT(I)[++]	Multiplier on heat transfer area	(fraction)
SGT_RCS_QCOLD(I)	RCS to cold side tubes	(Btu/sec)
SGT_RCS_QHOT(I)	RCS to hot side tubes	(Btu/sec)
SGT_SG_QCOLD(I)	Cold side tubes to secondary	(Btu/sec)
SGT_SG_QHOT(I)	Hot side tubes to secondary	(Btu/sec)
SGS_HEAT_LOAD	Total secondary heat load	(Btu/sec)

* Dimensions for subscripts

I = 1,..., NUM_SG (≤ 4)

II = 1,..., NUM_SL · NUM_SG (≤ 8)
{Order is SL_1 and SL_2 (if it exists) for SG_1, SL_1 and SL_2 (if exists) for SG_2, etc.}

J = 1,..., RCS_SG_NSECT(N) (≤ 20)
{Order is bottom to top of lower node, then bottom to top of upper node.}

K = 1,..., 2 · NUM_SG (≤ 8)
{Order is SG_1 hot side, SG_1 cold side, SG_2 hot side, etc.}

N = 1,..., NUM_SG_NODES (≤ 16)

** For solute species that have specific variable names, replace IO by BORON (boron), XE (xenon) or PT (particulates) concentrations.

§ For solute species that have specific variable names, replace IO by XE (xenon) or PT (particulates) concentrations.

\+ See text, Section 7.3.

++ This multiplier is user-input. It has the effect of simulating tube heat transfer area degradation due to tube plugging.

Table 7.18

Steam Generator Secondary Internal Flowpath Variables

SGS_W21(I)*	Evaporator to steam dome flowrate (Steam separation, Wilson model)	(lbm/sec)
SGS_W23(I)	Evaporator to downcomer flowrate (Recirculation flow)	(lbm/sec)
SGS_W32(I)	Downcomer to evaporator flowrate (Circular flow)	(lbm/sec)
SGS_W13(I)	Steam dome to downcomer flowrate (Steam condensation)	(lbm/sec)
SGS_W31(I)	Downcomer to steam dome flowrate (Boiling)	(lbm/sec)
SGS_WOUTSG(I)	Steam generator outlet nozzle flowrate	(lbm/sec)
MSLH_WIN(I)	Steam flow into MSLH	(lbm/sec)

*I = Steam generator number = 1,..., NUM_SG

Table 7.19

Secondary System External Flow Variables

	Flow In Steamline
SGS_WOUTSG(I)*	Flow at the steam nozzle
MSLH_WIN(I)	Flow to the steamline header
	Flow Out of Steamline
SL_P_FLOW(J)*	Flow through each of the valve paths off the steamlines: atmospheric dumps, steam bypass, safeties and turbine admission. (Figure 7.5 and Table 7.16)
SL_P_FLOW(NV + K)*	User-specified auxiliary steam outflow from steamline source K.
MSLH_WOUT	Partition of the following four arrays, which organize the above valve-path flows by source and sink (not including break flow and auxiliary flows).
MSLH_WOUT_ATM(K)*	Total flow from steamline source K* to atmosphere (safety and atmospheric dump valves)
MSLH_WOUT_COND(K)	Same as above, to condenser (turbine steam bypass)
MSLH_WOUT_CONT(K)	Same as above, to containment (none configured)
MSLH_WOUT_TURB(K)	Same as above, to turbine (turbine admission valve)

Table 7.19 (Continued)

MSLH_OUTFLOW(L,M)	Total exit flow quantities of species L to sinks M: L = 1 Total flow from all NUM_SG + 1 steamline sources, including break = 2 Average specific enthalpy (Btu/lbm) = 3,4,5 Average concentrations of iodine, particulates and xenon (μC/lbm) M = 1 To atmosphere = 2 To condenser = 3 To containment = 4 To turbine Each of these twenty elements may be referenced by an individual name. See CENTS variable dictionary, e.g., MSLH_FLOW_ATM is the total flowrate to atmosphere, via all ADVs and safety valves and a main steamline break at the header {equivalent to MSLH_OUTFLOW(1,1)}.
MSLH_VALVE_POS(J)	Open position of steamline valves, corresponding to SL_P_FLOW(J) (fraction).
	<u>Feedwater Systems</u>
FWS_FLOW(I)	Main feedwater flow to downcomer
FWS_ECON_FLOW(I)	Main feedwater flow to economizer
FWS_FLOW_TOT(I)	Total main feedwater flow
FWS_ENTH(I)	Specific enthalpy of above (Btu/lbm)
FWS_NOZ_FLOW(I)	Flow to downcomer through the main feed nozzle. Different from FWS_FLOW(I) only in case of feedline break

Table 7.19 (Continued)

FWS_NOZ_QUAL(I)	Quality at above (fraction)
FWS_ECON_NOZ_FLOW(I)	Flow to economizer through the main feed nozzle. Different from FWS_ECON_FLOW(I) only in case of feedline break
FWS_ECON_NOZ_QUAL(I)	Quality at above (fraction)
AFWS_FLOW(I)	Auxiliary feedwater flow
AFWS_ENTH(I)	Auxiliary feedwater enthalpy (Btu/lbm)

Steamline and Feedline Breaks

See Table 7.27.

Critical Flow Option
for Liquid and Two-Phase

SGS_CRIT_MODEL = 0, Homogeneous Equilibrium model (HEM)
= 1, Henry-Fauske model (H-F)
See Section 5.2.6, CENTS variable dictionary and Appendix B.

* I = 1,..., NUM_SG

J = 1,..., NV

K = 1,..., NUM_SG · NUM_SL: Steamline number upstream of MSIV
{order is SL_1 and SL_2 (if it exists) for SG_1, SL_1 and SL_2 (if it exists) for SG2, etc.}
= NUM_SG · NUM_SL + 1: Main steamline header(s) downstream of MSIV.

NV = MSLH_VALVE_NUM = Number of external valve paths

NUM_SG = Number of steam generators

NUM_SL = Number of steamlines per SG

Table 7.20

Typical Feedwater System Node Descriptions

Node or Junction	Description
"0"	Condenser
1	Condensate Pump Inlet Header
2	Condensate Pump Discharge Header
3	Low Pressure Heater Inlet / Condensate Pump Recirc. Line / S/U & B/D Demineralizer
4	Low Pressure Heater Discharge / Heater Drain Valve Discharge
5	Main Feed Pump Suction Header
6	Heater Drain Pump Discharge Header
7	Heater Drain Tank
8	Main Feed Pump #1 Discharge / MFP #1 Recirc. Line
9	Main Feed Pump #2 Discharge / MFP #2 Recirc. Line
10	Main Feed Pump Discharge Header
11	Feedwater Regulating Valve Header / Auxiliary Feedwater Discharge Line
12	Auxiliary & Emergency Feed Pump Suction Header
13	Emergency Feedwater Pump #1 Discharge Header
14	Emergency Feedwater Pump #2 Discharge Header
15	EFW Supply Header to Steam Generator A
16	EFW Supply Header to Steam Generator B
17	Auxiliary Feedwater Pump Discharge Header
18	EFW discharge to MFW Supply Line to Steam Generator A
19	EFW discharge to MFW Supply Line to Steam Generator B

Table 7.21

Typical Feedwater System Path Descriptions

Path	Description
1	Condenser to Condensate Pump Suction Header
2	Condensate Pump #1
3	Condensate Pump #2
4	Condensate Pump #3
5	Condensate Pump #4
6	Condensate Pump Discharge Header to Low Pressure Heater Suction
7	Condensate Pump Recirculation Line
8	Low Pressure Heaters
9	Low Pressure Heater Discharge Line to Main Feedwater Pump Suction Header
10	Heater Drain Pump Discharge Valve
11	Heater Drain Pump #1
12	Heater Drain Pump #2
13	Heater Drain Tank to Condenser (not shown in diagram)
14	Main Feedwater Pump #1
15	Main Feedwater Pump #1 Recirculation Line to Condenser
16	Main Feedwater Pump #1 Discharge Line to Header
17	Main Feedwater Pump #2
18	Main Feedwater Pump #2 Recirculation Line to Condenser
19	Main Feedwater Pump #2 Discharge Line to Header
20	Main Feedwater Pump Header to FRV Inlet Header
21	High Pressure Heater to SG A
22	High Pressure Heater to SG B
23	Line to S/U & B/D Demineralizer / Filter
24	Condensate Storage Tank to Auxiliary / Emergency Feedwater Pump Suction Header
25	Emergency Feedwater Pump #1
26	Emergency Feedwater Pump #2
27	Discharge Line from EFW Pump #1 to SG A

Table 7.21 (Continued)

28	Discharge Line from EFW Pump #1 to SG B
29	Discharge Line from EFW Pump #2 to SG B
30	Discharge Line from EFW Pump #2 to SG A
31	EFW Discharge Check Valve to MFW line to SG A
32	EFW Discharge Check Valve to MFW line to SG B
33	Auxiliary Feedwater Pump
34	Auxiliary Feedwater Pump Discharge Valve to EFW Header A
35	Auxiliary Feedwater Pump Discharge Valve to EFW Header B
36	Auxiliary Feedwater Pump Discharge Valve to FRV Inlet Header
37	MFW Supply Line to SG A
38	MFW Supply Line to SG B
39	Feedwater Line Break on MFW line to SG A
40	Feedwater Line Break on MFW line to SG B

Table 7.22

Feedwater System Inputs

FWS_FDPATH	FWS model flowpath partition	
FWS_NFLO	Number of flowpaths in feedwater system	(≤ 50)
FWS_HEXTN(J)*	FWS model external node enthalpy	(Btu/lbm)
FWS_PEXTN(J)*	FWS model external node leak back press.	(psia)
FWS_WEXTF(I)*	FWS model node external leak flow out	(lbm/sec)
FWS_HEXTF(I)*	FWS model node external leak enthalpy	(Btu/lbm)
FWS_AEXTF(I)*	FWS model node external leak flow area = 0, flow is input to FWS model > 0, flow is calculated by FWS model	(ft^2)
FWS_PEXTF(I)*	FWS model node external back pressure	(psia)
FWS_FDNODE	FWS model node partition	
FWS_NNOD	Number of internal nodes	(≤ 30)
FWS_NEXTN	Number of external nodes	(≤ 20)
FWS_FDVALV	FWS model valve partition	
FWS_NVAL	Number of control valves	(≤ 30)
FWS_NHDV	Number of drain tank flow control valves	(≤ 3)
FWS_NTABFV	Number of diff. types of control valve tables	(≤ 10)
FWS_FDPUMP	FWS model pump partition	
FWS_NPUM	Number of feedwater system pumps	(≤ 20)
FWS_NTABFP	Number of different feedwater pump tables	(≤ 10)
FWS_NMFWP	Number of main feedwater pumps	(≤ 4)
FWS_NEFWP	Number of emergency/aux. feedwater pumps	(≤ 4)
FWS_FDHEAT	FWS feedwater heater partition	
FWS_NHT	Number of feedwater heaters	(≤ 9)
FWS_HTRHMX	Feedwater heater maximum enthalpy	(Btu/lbm)
FWS_FDMODL	FWS model miscellaneous controls partition	
FWS_NRCIRC	Number of recirculation control valves	(≤ 20)
FWS_FWRCPB(LL)*	FWS recirc. pump control proportional band	(%)
FWS_FWRCRE(LL)*	FWS recirculation pump control reset	(sec)
FWS_FWRCSP(LL)*	FWS recirculation pump control setpoint	(gpm)
FWS_FWRCIR(LL)*	FWS recirc. pump control instr. range	(gal)

* Subscripts are defined at the end of Table 7.23.

Table 7.23

Feedwater System Outputs

FWS_HNODE(I)*	FWS model node enthalpy	(Btu/lbm)
FWS_P(I)	FWS model node pressure	(psia)
FWS_HEXT(K)*	FWS flowpath external node enthalpy	(Btu/lbm)
FWS_HPATH(K)	FWS model flowpath enthalpy	(Btu/lbm)
FWS_ICPUMP(K)	FWS model flowpath pump status	(flag)
FWS_KEY	FWS model any FW pumps on flag	(flag)
FWS_PEXT(K)	FWS model flowpath external pressure	(psia)
FWS_POSISO(K)	FWS model path isolation valve position	(fraction)
FWS_QCURR(K)	FWS model flowpath heat transfer	(Btu/sec)
FWS_W(K)	FWS model flowpath volumetric flowrate	(gpm)
FWS_WMAS(K)	FWS model flowpath mass flowrate	(lbm/sec)
FWS_SPDMD(L)*	FWS model pump speed demand	(fraction)
FWS_SPEED(L)	FWS model pump speed	(fraction)
FWS_STROKE(M)*	FWS model valve demand	(%)
FWS_POSIT(M)	FWS model valve position	(%)
FWS_TPWR	FWS model turbine power	(fraction)
FWS_FWRCOUT(LL)*	FWS recirculation pump control output	(fraction)
FWS_DCL_MASS(N)*	FWS model downcomer line mass	(lbm)
FWS_ECL_MASS(N)	FWS model economizer line mass	(lbm)
FWS_LINE_MASSES(N,2)	FWS steady state feedline mass (downcomer line, economizer line)	(lbm)
AFWS_FLOW(N)	Auxiliary feedwater flowrate	(lbm/sec)

Table 7.23 (Continued)

*	I	= 1,..., FWS_NNOD+	(≤ 30)
	J	= 1,..., FWS_NEXTN	(≤ 20)
	K	= 1,..., FWS_NFLO	(≤ 50)
	L	= 1,..., FWS_NPUM	(≤ 20)
	LL	= 1,..., FWS_NRCIRC	(≤ 20)
	M	= 1,..., FWS_NVAL	(≤ 30)
	N	= 1,..., FWS_NSG	(≤ 4)

+ Upper bound for arrays defined in Table 7.22.

Table 7.24

Steam Generator Dose and Solutes

With Specific Variable Names

Solute Concentrations in SG

Species	Steam Node	Evaporator and Downcomer Nodes	Units
Boron	SGS_CON_BORON1(I)	SGS_CON_BORON2(I)	ppm
Iodine	SGS_CON_IO1(I)	SGS_CON_IO2(I)	μC/lbm
Particulates	SGS_CON_PT1(I)	SGS_CON_PT2(I)	μC/lbm
Xenon	SGS_CON_XE1(I)	SGS_CON_XE2(I)	μC/lbm

Solute Concentrations in Feedwater and Steamlines

Species	Steamline	Header Node 1	Header Node 2	Feedwater	Units
Boron	0.0	0.0	0.0	0.0	ppm
Iodine	MSLH_ISL(K)	MSLH_CON_IO	MSLH2_CON_IO	FWS_CON_IO(I)	μC/lbm
Particulates	MSLH_CSL(K)	MSLH_CON_PT	MSLH2_CON_PT	FWS_CON_PT(I)	μC/lbm
Xenon	MSLH_XSL(K)	MSLH_CON_XE	MSLH2_CON_XE	FWS_CON_XE(I)	μC/lbm

Overall Iodine Concentrations in Flows to Steamline Exits

Destination	Value or Variable	Units
Atmosphere	MSLH_IO_ATM	μC/lbm
Condenser	MSLH_IO_COND	μC/lbm
Containment	MSLH_IO_CONT	μC/lbm
Turbine	MSLH_IO_TURB	μC/lbm

(continued...)

I = 1,..., NUM_SG
K = 1,..., NUM_SL · NUM_SG {order is SL_1 and SL_2 (if it exists) for SG_1, SL_1 and SL_2 (if it exists) for SG_2, etc.}

Table 7.24 (Continued)

Iodine Release to Atmosphere from Secondary Systems

MSLH_IO_INT_ATM	Integrated direct release to atmosphere (Curie)
MSLH_IO_INT_CONT	Integrated release rate from header to cont. (Curie)
RCS_DOSE_CONT_LEAK	Input containment leak rate (fraction/day)
MSLH_IO_CONT_LEAK	Iodine leak rate from cont. to atmosphere (μC/sec)
MSLH_IO_CONT_INT_LEAK	Integrated leakage from cont. to atmosphere (Curie)
MSLH_IO_INT_COND	Integrated release to condenser via bypass valves without decontamination (Curie)
MSLH_IO_INT_TURB	Integrated release from main steam system to turbine without decontamination (Curie)
RCS_DOSE_COND_DF	Iodine decontamination factor for condenser and turbine ($fraction^{-1}$)
RCS_DOSE_TOT_CURIE	Total release from all SG sources contributing to offsite dose (Curie)
SGS_TOTAL_IODINE	Total iodine in SG and header (Curie)

Iodine Dose

RCS_DOSE_CF	Input iodine dose conversion factor (REM/Curie)
RCS_DOSE_BF	Input effective breathing factor (ft^3/sec)
RCS_DOSE_XOQ2	Input 2 hour site dispersion factor for dose (sec/ft^3)
RCS_DOSE_XOQ8	Input 8 hour site dispersion factor for dose (sec/ft^3)
RCS_DOSE_2HR	Accumulated dose for 2 hour model (REM)
RCS_DOSE_8HR	Accumulated dose for 8 hour model (REM)

7.4 Wall Heat Transfer

CENTS calculates the thermal interactions of metal components ("wall heat") in the primary and secondary systems. The types of wall heat considered are

Wall heat transfer to liquid coolant
Wall heat transfer to steam coolant
Wall heat transfer to containment air.

Input variables to the wall heat model, that do not normally change, are found in the plant data segment of the CENTS database (Section 7.6). These include overall heat transfer coefficients and metal components' heat capacities.

Other input variables, such as various multipliers and containment temperatures, which may be used to tune the wall heat processes, are listed in Table 7.30. The table also lists output variables representing the various wall temperatures and heat transfer rates.

7.5 Malfunctions and Leaks

Simulation of the more common system malfunctions and fluid leaks is facilitated in CENTS by providing commands that initiate the desired behavior. This section provides details about the malfunctions, their initiating and output variables, and the systems affected.

Most of the malfunctions described are primary or secondary coolant system leaks. A practically unlimited variety of additional malfunctions can be generated by the user, through the combinations of the above malfunctions and manual control of the BOP and control systems described in Chapter 6.

7.5.1 *Primary System Malfunctions*

The primary system malfunctions directly involving coolant leakage are listed in Table 7.25. Small break (SB) loss of coolant accident (LOCA) leaks are provided in a pump-suction cold leg, pump-discharge cold leg, hot leg, pressurizer and upper head (CEA ejection). An anticipated transient without scram (ATWS) leak whose area depends on pressure is provided in the upper head as described in Section 4.14.4. Input variables for O-Ring seal leakage (ATWS) are given in Table 7.28.

Valve-leakage malfunctions are provided for the upper head vent valve, the pressurizer safety valves (SV) and power operated relief valves (PORV), and the pressurizer vents. Pump seal leakage, shaft break and rotor-lock are provided for each reactor coolant pump. In addition, rupture of steam generator tubes (SGTR) is modeled in the hot and cold sides of each steam generator tube bundle as described in Section 7.5.2.

The locations of system leaks are indicated in Figures 7.3 and 7.5 by the abbreviations used here. Node and flowpath designations are given in Table 7.25. The current state of the primary leak flow area is given by the variables in Table 7.29.

Each malfunction is initiated by setting the associated cue variable of Table 7.25 to an appropriate value. A valve malfunction or CEA ejection is specified as a fraction of the indicated area of a full-open valve or CEA. The fraction may exceed unity. A LOCA is specified by its break area. LOCA flowrates may depend on the containment pressure, CONT_PRES, which should be increased as the LOCA progresses to provide a proper back pressure. Multiple malfunctions are permitted. The normal value of an inactive malfunction variable is zero for the numeric variables, and false for the logical variables. Information about flowrate, enthalpy and solutes for the leaks may be obtained using the non-momentum path variables described in Table 7.12. Actual flow areas may be observed through the variables listed in Table 7.29.

Use of the CEA ejection malfunction should be combined with user input of an appropriate reactivity ramp using the variable POW_KIN_DK, Table 7.4. Despite having this capability, CENTS evaluations of regulatory compliance for the CEA ejection event are restricted as noted in footnote (6) to Table 7.25.

Likewise, the CENTS capability of modeling LOCA events is restricted as noted in footnote (7) to table 7.25.

CENTS provides an extended model for small break LOCA in a tributary or letdown line that supports specification of line pressure losses between the RCS piping and the break as described in Section 4.21. This includes friction, geometric and elevation pressure losses which are evaluated at the average of the upstream and downstream (break) properties. For a given flowrate the code iterates on the pressure losses until a pressure balance is obtained; then it iterates on the break flowrate until a flow balance is achieved in the line. For a letdown line break, the iteration process also considers the letdown flow contribution through the regenerative heat exchanger (RHX) without the break. Either a homogeneous equilibrium model (HEM) or Henry-Fauske (HF) model is available for the critical flow calculation per Section 4.7. The SBLOCA with line losses is invoked using the SBLOCA malfunction variable in Table 7.25. The variable used to invoke a letdown line break is listed in Table 7.25. Figure 4.12 shows the location of the letdown line breaks. The parameters used to find the letdown line losses and observe the results are listed in Table 7.27.

7.5.2 *Secondary System Malfunctions*

Several types of secondary system leaks are provided - steam generator tube rupture (SGTR, primary and secondary leak), steamline break upstream or downstream of the MSIV (MSLB), and main feedwater line break upstream or downstream of the feedline check valve (MFWLB). Details of each leak are provided in Table 7.26. The normal value of an inactive malfunction variable is zero. The actual leakage rate may depend on the containment pressure, CONT_PRES, which should be increased as the leakage increases for large, inside containment leaks. The physical locations of the leakage paths for the malfunctions are indicated in Figure 7.5

Additional losses of fluid due to normal or abnormal operation of secondary steam systems are described in Section 6.6. The user may define malfunctions for these systems by interfacing with their automatic control functions or by imposing direct manual control. These malfunctions may be defined separately, or combined with the above leaks and any of the primary system leaks and malfunctions (Section 7.5.1).

The CENTS model for steam generator tube rupture (SGTR) supports the two types of SGTR malfunctions described in Section 5.7 – a double-ended guillotine (DEG) or a slot break in a tube. It treats a DEG break as two breaks, each with a break area SG_TUBE_AREA · MAL_SGTR(J) · RCS_SGTR_FLOWMULT, separate sources for the fluid (hot side and cold side nodes), different loss terms from the source of the fluid to the break, and different exit enthalpies and flowrates. The SGTR guillotine break model is also used for a slot break in the SG tube with an outer iteration on pressure upstream of the slot to balance flows from each tube segment. Reverse flow through the SG tube break (DEG or slot) is allowed. Variables to define the break location, break area, loss terms and type of break are listed in Tables 7.26 and 7.27.

The CENTS model for main steamline break (MSLB) allows the break to occur at any location along the steamline. This requires specification of the flow resistance from the affected steam generator to the break location. The resulting flow resistance must be less than the total resistance from the SG to the main steamline header (MSLH) node. CENTS checks for critical flow in the steamline flowpaths, including in the flowpath downstream of the break location, and in the cross-connect line if two header nodes are used. The model supports representation of two possible flow restrictors:

1. A SG-side flow restrictor located between the SG steam nozzle and the MSIV (before the break if there is one).

2. A MSLH-side flow restrictor located after the MSIV (after the break if there is one) and before the header.

The location of the possible breaks, flow restrictors (possible choke points) and MSIV are shown in Figure 7.10 and described in Table 7.27. The location for break option zero (0) serves as the "intermediate" steamline location for atmospheric relief. The variables used to define the break location, minimum flow area, and flow resistance are listed in Table 7.27. The area of the unrestricted steamline is ASL_MAX. The break location is further positioned by the flow resistance coefficient MSLH_FKBRK. Some outputs from the MSLB are also listed in Table 7.27

Table 7.25

Primary System Coolant Leaks and Malfunctions [5]

Malfunction	Node [5]	Path [5]	Cue Variable	Function of Cue
SBLOCA [3]				
Discharge Leg [7]	17	134	MAL_SB_LOCA(1)	Break Area (ft^2)
Suction Leg [7]	15	135	MAL_SB_LOCA(2)	Break Area (ft^2)
Hot Leg [7]	6	136	MAL_SB_LOCA(3)	Break Area (ft^2)
Pressurizer RTD Well [7]	4	137	MAL_SB_LOCA(4)	Break Area (ft^2)
Letdown line break			MAL_LDN_BREAK	Break Area (ft^2)
			< 0, upstream of RHX; > 0, downstream of RHX	
Reactor Coolant Pumps				
RCP Seal Leak	14-16	101-103	RCP_SEALS_LEAK(J) [1]	gpm [4]
RCP Shaft Break		16-18	MAL_RCP_SHAFTBREAK(J)	True/False
RCP Locked Rotor		16-18	MAL_RCP_LOCKED(J)	True/False
Valves with Auto Controls [2]				
Pressurizer PORV	4	146	MAL_VLV_PRZR_PORV(K) [1]	Fraction
Pressurizer Safety Valve	4	146	MAL_VLV_PRZR_SAFETY(L) [1]	Fraction
Pressurizer Spray Bleed Valve	17-18	144-145	MAL_VLV_PRZR_MSPRAY(M) [1]	Fraction
Manually Controlled Valves [2,3]				
Upper Head Vent to Cont.	2	147	MAL_VLV_UHEAD_CONT	Fraction
Upper Head Vent to Quench	2	147	MAL_VLV_UHEAD_QT	Fraction
Pressurizer Vent to Containment	4	146	MAL_VLV_PRZR_CONT	Fraction
Pressurizer Vent to Quench	4	146	MAL_VLV_PRZR_QT	Fraction
Others				
UH Leak Due to CEA Ejection [6]	2	88	MAL_ROD_EJECT	Fraction

Table 7.25 (Continued)

Footnotes for table 7.25

(1)	J	= 1,..., NUM_PUMPS	(No. of RCPs)
	K	= 1,..., RCS_NUM_PORVS	(No. of pressurizer PORVs)
	L	= 1,..., RCS_NUM_SAFETYVLVS	(No. of pressurizer safety valves)
	M	= 1,..., RCS_NUM_MSPRAYVLVS	(No. of main spray bleed valves)

(2) Fail-open malfunctions. The valves will stick open at the fractional position indicated by the Cue, unless opened further by the automatic or manual controls described in Chapter 6. The indicated areas represent one open valve.

(3) Leak paths may be reconnected to other nodes and/or at other elevations.

(4) Liquid, at nominal pressure and temperature.

(5) Path and node numbers are examples for a typical 3 loop Westinghouse PWR nodalization.

(6) CENTS is not used for evaluations of regulatory compliance for the CEA (rod) ejection event which analyze for fuel failure using hot channel and DNBR calculations. However, CENTS can indeed be used for the pressure transient aspects of the rod ejection accident.

(7) CENTS is not used for LOCA calculations for the evaluation of regulatory compliance to 10CFR50.46 ECCS performance.

Table 7.26
Steam Generator Secondary System Leaks+

Malfunction	Location	Cue Variable	Function of Cue	Comments
Tube Rupture	Loop 1 Loop 2 Loop 3 Loop 4	MAL_SGTR(1) MAL_SGTR(2) MAL_SGTR(3) MAL_SGTR(4)	Number of tubes*	SG_1 SG_2 SG_3 SG_4
Steamline Break	Upstream of MSIV:			
	Steamline JJ*	MAL_MSLB_IN(JJ)	Location of break in steamline	See Table 7.27 and Figure 7.10
	Downstream of MSIV	MAL_MSLB_OUT	Flag (0/1=No/Yes)	
Feedwater Line Break	Upstream of check valve, Loop J*	MAL_FWLB_OUT(J) or MAL_FWLB_ECON_OUT(J)	Fraction of area	See Table 7.27 for associated flow variables
	Downstream of check valve, Loop J*	MAL_FWLB_IN(J) or MAL_FWLB_ECON_IN(J)		

* J = 1,..., NUM_SG
JJ = 1,..., NUM_SG • NUM_SL

Table 7.27

Variables for NSSS Breaks

	Critical Flow Model
RCS_CRIT_MODEL	Liquid and two-phase critical flow model 0 = HEM 1 = Henry-Fauske
	Letdown Line Break Input
LDN_PIPE_AREA(L)*	Letdown line flow area (ft^2)
LDN_PIPE_LOD(L)	Letdown line length/diameter for fric. loss
LDN_PIPE_KGEOM(L)	Letdown line geom. K-factor w/o entry loss
LDN_PIPE_KENT(LL)*	Letdown line entry loss K-factor
LDN_PIPE_DELTA_ELEV(L)	Letdown line elevation rise (ft)
	Letdown Line Break Output
CVCS_RHX_HLDN(LLL)*	Letdown enthalpy for RHX (Btu/lbm)
CVCS_RHX_HCH(LLL)	Charging enthalpy for RHX (Btu/lbm)
CVCS_RHX_WLDN	Total letdown mass flowrate including leak (lbm/sec)
CVCS_RHX_WCH	Charging mass flowrate (lbm/sec)
CVCS_RHX_HEAT	Regenerative heat exchanger heat load (Btu/sec)
	Input for SBLOCA in Tributary Line
SB_PIPE_AREA(I)*	SBLOCA pipe flow area (ft^2) (Set to zero for no line losses in SBLOCA)
SB_PIPE_LOD(I)	SBLOCA pipe length/diameter for fric.
SB_PIPE_KGEOM(I)	SB pipe geom. K-factor, w/o entrance loss
SB_PIPE_KENT(I)	SBLOCA pipe entrance loss K-factor
SB_DELTA_ELEV(I)	SB break elev. above RCS connection (ft)

Table 7.27 (Continued)

Steam Generator Tube Rupture

RCS_SGTR_PNODEIN(JJ)*	SGTR inlet node for fluid – 2 values/SG (Pointer)
RCS_SGTR_PELEVIN(JJ)	SGTR inlet elev. to tube – 2 values/SG (ft)
SGTR_TUBE_LENGTH(JJ)	SGTR tube length (friction loss) – 2 values/SG (ft)
SGTR_TUBE_ENTRANCE_K(JJ)	SGTR entrance K factor (use 0.5) – 2 values/SG
SGTR_BREAK_ELEV(J)*	SGTR elev. above top of tube sheet – 1 value/SG (ft)
RCS_SGTR_FLOWMULT	Flow mult. for rupture area. Set to 1.0 for DEG (frac)
SGTR_SLOT_BREAK_OPT(J)	SGTR Calculate slot break flow (True/False) False = Double-ended guillotine break True = Slot break
SGTR_SLOT_BREAK_AREA(J)	SGTR slot area per tube for slot break option (ft^2)
RCS_SGTR_FLOW(JJ)	SGTR flowrate (lbm/sec)
RCS_SGTR_ENTH(JJ)	SGTR enthalpy (Btu/lbm)

Steamline Break

Inside Containment (Upstream of MSIV)

MAL_MSLB_IN(JJ)	Location of steamline break (counts) = 0, No break = 1, Break before MSIV discharging to containment = 2, Break before MSIV discharging to atmosphere = 3, Break after MSIV discharging to atmosphere (between MSIV and MSLH flow restrictor)
MSLB_AREA	Break area for main steamline break (ft^2)
MSLH_AFRSL(JJ)	Minimum steamline flow area (flow restrictor) (ft^2)
MSLH_FKBRK(JJ)	Steamline K-factor from SG to break location
MSLB_IN_FLOW(JJ)	Flow rate for MSLB inside containment (lbm/sec) See steamline for flow properties, Table 7.17

Table 7.27 (Continued)

Outside Containment (Downstream of MSIV)

MAL_MSLB_OUT	Flag for MSLB outside containment (counts)
MSLB_OUT_FLOW	Flowrate for MSLB outside containment (lbm/sec) For flow properties, see header properties, Table 7.17

Main Feedwater Line Break

Downcomer Feedline	Economizer Feedline	
MAL_FWLB_OUT(J)	MAL_FWLB_ECON_OUT(J)	Fractional break area, upstream of check valve
MAL_FWLB_IN(J)	MAL_FWLB_ECON_IN(J)	Fractional break area, downstream of check valve
FWLB_FLOW(J)	FWLB_ECON_FLOW(J)	Break flowrate
FWLB_ENTH(J) **	FWLB_ECON_ENTH(J) **	Break flow enthalpy
FWS_FLOW(J)	FWS_ECON_FLOW(J)	Flow delivered by pumps
FWS_NOZ_FLOW(J)	FWS_ECON_NOZ_FLOW(J)	Flow at the feedwater nozzle
FWS_NOZ_QUAL(J)	FWS_ECON_NOZ_QUAL(J)	Flow quality at the nozzle

* I SBLOCA location. See subscripts for MAL_SB_LOCA in Table 7.25

J =1,..., NUM_SG

JJ =1,..., 2 · NUM_SG
(Order is SG_1 hot side, SG_1 cold side, SG_2 hot side, etc.)

L = 1, from RCS piping to RHX (before RHX)
= 2, from RHX to downstream break location (used for downstream break)

LL = 1, at entrance to letdown line from RCS piping
= 2, at entrance to RHX from letdown line (only used for downstream break)

LLL = 1, at RHX inlet
= 2, at RHX outlet

** Replace ENTH by IO, PT, XE to obtain solute concentrations of iodine, particulates or xenon (μC/lbm).

Table 7.28

O-Ring Seal Leakage (ATWS) Variables*

Variable	Definition	Unit
P_AREA_ATWS_MIN	A_{min} = minimum head seal leakage area	in^2
P_AREA_ATWS_MAX	A_{max} = maximum head seal leakage area	in^2
PRES_ATWS_MIN	P_{min} = minimum head seal leakage pressure	psia
PRES_ATWS_MAX	P_{max} = maximum head seal leakage pressure	psia
RCS_UHEAD_RING_SEAL_MULT	Multiplier on the head seal leakage area	

*See Section 4.14.4

Table 7.29

Primary System Valve and Leak Variables

Cue Type	Variable	Area Variable (ft²)	Ref Section
SG Tube Rupture	MAL_SGTR	P_AREA_LEAK(J), J = 1,..., 2 * NUM_SG	7.5.2
Small Break LOCA	MAL_SB_LOCA	P_AREA_LEAK(J) J = 9,..., 12	7.5.1
CEA Ejection	MAL_ROD_EJECT	P_AREA_LEAK(13)	"
O-Ring Seal (ATWS)		P_AREA_LEAK(14)	4.14.4
Pzr PORV "	VLV_PRZR_PORV	AREA_VALVE_PRZR(J) J = 1,..., 4*	6.4.1 "
Pzr Safety Valve "	VLV_PRZR_SAFETY	AREA_VALVE_PRZR(J) J = 5,..., 8*	6.4.2 "
Pzr PORV isolation "	VLV_PRZR_MOV	REA_VALVE_PRZR(J) J = 9,..., 12*	6.4.1
Pzr Vent to Containment	VLV_PRZR_CONT	AREA_VALVE_PRZR(13)	6.4.3
Pzr Vent to Q.T.	VLV_PRZR_QT	AREA_VALVE_PRZR(14)	"
"		AREA_VALVE_PRZR(15)	"
Upper Head Vent to Cont.	VLV_UHEAD_CONT	AREA_VALVE_UHEAD(1)	6.4.4
Upper Head Vent to Q.T	VLV_UHEAD_QT	AREA_VALVE_UHEAD(2)	"
"		AREA_VALVE_UHEAD(3)	"
Pzr Spray Lines	VLV_PRZR_MSPRAY	AREA_VALVE_SPRAY(1)	6.3.2
"		AREA_VALVE_SPRAY(2)	"

*For as many such valves that exist, up to 4.

Table 7.30

Wall Heat Variables

Read-Write Input*

RCS_PRZR_HLIQ_MULT	Multiplier on pressurizer wall-to-liquid heat transfer (frac)
RCS_PRZR_HWALLF_MULT	Multiplier on pressurizer wall condensation
RCS_PRZR_CONT_HEAT_MULT	Multiplier on pressurizer wall heat loss to containment (frac)
RCS_UHEAD_CONT_HEAT_MULT	Multiplier on upper-head wall heat loss to containment (frac)
RCS_CONT_HEAT_MULT	Multiplier on wall heat loss to containment from all primary system nodes (frac)
TEMP_CONT(N)	Cont.temperatures outside RCS nodes (°F)
CONT_SG_TEMP(J)	Containment temperature at steam generator (°F)

Output

HEAT_LIQ(N)	RCS node wall-to-liquid heat rates (Btu/sec)
HEAT_STM(N)	RCS node wall-to-steam heat rates (Btu/sec)
HEAT_WALL(N)	RCS node wall-to-coolant heat rates, Btu/sec)
HEAT_CONT(N)	RCS node cont.-to-wall heat rates (Btu/sec)
TEMP_WALL(N)	RCS node wall temperatures (°F)
MSLH_Q	Main steamline header coolant-to-wall heat rate (Btu/sec)
MSLH2_Q	Main steamline header 2 (if used) coolant-to-wall heat rate (Btu/sec)
MSLH_Q_ATM	Main steamline header wall-to-atmosphere heat rate (Btu/sec)
MSLH2_Q_ATM	Main steamline header 2 (if used) wall-to-atmosphere heat rate, (Btu/sec)
MSLH_TWALL	Main steamline header wall temperature (°F)
MSLH2_TWALL	Main steamline header 2 (if used) wall temperature (°F)

Table 7.30 (Continued)

SGS_Q_WALL1(J)	Steam generator steam dome coolant-to-wall heat rates (Btu/sec)
SGS_Q_WALL3(J)	Steam generator downcomer coolant-to-wall heat rates (Btu/sec)
SGS_Q_CONT(J)	Steam generator wall heat loss to cont. (Btu/sec)
SGS_TWALL(J)	Steam generator wall temperatures (°F)

* J = 1,..., NUM-SG (≤ 4)

N = 1,..., NUM_NODES (≤ 50)

7.6 CENTS Output

There are several methods available to observe output from CENTS. These include:

1. Standard CENTS Output – Section 7.6.1
2. CENTS Variable Dictionary – Section 7.6.2
3. Summary Output Variables – Section 7.6.3
4. Customized Edits from Executive Software
5. Graphical User Interface

These approaches are discussed in more detail in the following sections.

7.6.1 Standard CENTS Output

CENTS provides a standard, one-line, transient output, in addition to the data-dictionary accessing capabilities of the executive program. The standard and executive program outputs may be used simultaneously, if so desired. However, for ease of readability of output in long transient calculations, the executive program output may be directed to a file for later use.

User control of the standard output is achieved via the database variables described in Table 7.31. The choices of output information and formats are described in Table 7.32. Figure 7.11 shows examples of the two basic output choices. Note that the choices CTL_OUTPUT_OPTION = -1 and -2 are similar to choices 1 and 2, respectively, differing only in the definitions of the output for coolant levels in the pressurizer and steam generators, and the output for core power.

7.6.2 *Use of CENTS Variable Dictionary*

In addition to the variables described in Chapters 6 and 7, most of the CENTS variables are available for output. These variables are stored in a database on a disk file. Procedures for accessing these variables are available in the executive program. With these procedures, the user may assign values to variables, display their values or save them for later use (printing, plotting, manipulation, or as a snapshot for code restart or as an alternate initial state). These operations may be performed at any time during the transient.

The database variables are organized into the following model-specific COMMON blocks:

No.	Name	Description
0	CHR_COMMON	Database and controller names (character)
1	PLT_DATA	Nodalization and plant physical data
2	CHT_COMMON	Core heat transfer
3	POWER_COMMON	Core power calculations
4	RCS_COMMON	Primary system models
5	SGS_COMMON	Secondary system models
6	CONTROL_COMMON	Control and balance-of-plant systems
7	USER_COMMON	Miscellaneous models (used by modelers)
8	FWS_COMMON	Feedwater system models
9	NONCOND_COMMON	Noncondensible gas transport models

These segments are further subdivided into partitions representing various sub-models. Many of the variables are for specialized purposes and may not be useful for general PWR simulation.

The first block, CHR_COMMON, contains all character variables used for titles and labels of the controllers defined by the system modeler. The next block, PLT_DATA, contains information about the plant's physical systems and the node-flowpath scheme of Figures 7.2, 7.3 and 7.5. This information is never changed by the code and is rarely modified by the user. Normally there is only one version of this block for a plant. While the user may change the value of any variable, this change would be effective for the current transient calculation only, and would not be reflected in subsequent Restart calculations. A special procedure is required in order to effect a permanent change to the values of any PLT_DATA variables in the database.

The remaining blocks of the database represent the current plant state. Different versions of each are used to save different plant states. Many of the variables within these blocks are subject to dynamic changes in Global Common during a transient calculation, while others (setpoints, controls, etc.) may be changed by the user. The resulting modified state of the system may be saved, as a Snapshot file, for a later continuation of the transient, or as an alternate initial state.

The CENTS variable dictionary provides a list of the database variable names with dimensions (number of entries in a vector), definitions and units. An alphabetical list of the database variables appears with the variable dictionary. Appendix A lists the input variables needed for plant definition, state initialization, and control system definition (operator and controller actions).

7.6.3 Summary Output Variables

The organization of the variable dictionary in CENTS provides a convenient way to get a summary of the state of various systems, component models, etc. Examination of the CENTS variable dictionary shows that related variables (e.g., for a specific component model) are grouped sets in arrays called "Partition." Issuing a command to edit a partition produces an edit of the values for all variables that are part of that partition.

All the values of each array within the partition, even those that are not used, are edited. Table 7.33 illustrates this editing approach for the CTL_SUMMARY_DATA partition, which contains a number of variables that summarize the maxima, minima, times of occurrence of these maxima and minima, integrals of selected parameters and other key parameters during a transient. An additional partition that summarizes integrated iodine flow is also included in Table 7.33, as well as an additional partition (RCS_BALANCE) that facilitates performing a mass and energy balance for the RCS.

Title information describing the database files is also available as described in Table 7.33 to the user for the database file name, title, date and time stamp. The plant data and plant state (snapshot) portions of the database may be labeled separately.

7.6.4 Customized Edits

The customized edits are produced using the executive software, CEER, for CENTS. It has a command language that supports user interaction with the code at the beginning of and throughout the transient. The executive software allows the user to examine the values of a single scalar variable as well as one- and two-dimensional arrays at any time or when pre-selected states occur during the transient. It also supports design of a structured edit for a user selected set of output information – essentially a formatted page of output. Finally, it can produce files of selected variables for subsequent editing or plotting.

7.6.5 Graphical User Interface

The graphical user interface provides three forms of output. First is a command screen that displays the value of selected parameters using a tree of menus. Second is a graphical mimic that shows a subset of the plant's state. Third is an option to produce graphs of selected parameters in real time as the transient progresses.

Table 7.31

Standard Output Control Variables

Function	Variable	Description
Output frequency control	CTL_OUTPUT_INTERVAL	= N. Output is displayed every N time steps (1 step = 1 second for TIME_SCALE = .0) If = 0, no output.
Heading frequency control	CTL_OUTPUT_NTITLE	= M. Output heading is displayed at the start of output, and after every M output lines
Choice of output information and formats	CTL_OUTPUT_OPTION	= 1, 2, -1, -2. Indicates user's choice of one of four output variable lists. For a description, see the text, Table 7.32 and Figure 7.11.
Choice of coolant loops for output	CTL_OUTPUT_LOOP(2)	= L_1,L_2. Data for output items that are displayed for two loops (e.g., steam generator pressure) is obtained from loops L_1 and L_2.

Table 7.32

Description of Standard Output

ID*	CTL_ OUTPUT_ OPTION**	Database Variable ***	Description
A	All	TIME	Transient time (sec)
B	All	PRESS(NODE_PRZR)	Pressurizer pressure (psia)
C	1,2	LEVL_MIX(NODE_PRZR)	Height of coolant (water or two-phase) in the pressurizer (ft)
	-1, -2	CTL_PRZR_ILEVEL	Instrumentation indicated coolant height in the pressurizer (frac span)
D	All	LEVL_MIX(NODE_CORE)	Two-phase mixture height, inner vessel (ft)
E	All	TEMP_LIQ(N), N = NODE_CL(L_1)	Liquid^{+} temperature, loop L_1^{++} pump-discharge cold leg (°F)
F	All	TEMP_LIQ(N), N = NODE_CL(L_2)	Liquid^{+} temperature, loop L_2^{++} pump-discharge cold leg (°F)
G	All	TEMP_LIQ(N), N = RCS_NODE_HL(L_1)	Liquid^{+} temperature, loop L_1^{++} hot leg (°F)
H	All	TEMP_SAT(N), N = RCS_NODE_HL(L_1)	Saturation temperature, loop L_1^{++} hot leg (°F)
I	1,2	SGS_HLEVEL(L_1)	Liquid height, steam generator L_1^{++} downcomer (ft, above tubesheet)
	-1,-2	CTL_SGS_ILEVEL(L_1,1)	Measured liquid height, steam generator L_1^{++} downcomer (frac span, narrow range)

Table 7.32 (Continued)

ID*	CTL_ OUTPUT_ OPTION**	Database Variable ***	Description
J	1,2	SGS_HLEVEL(L_2)	Liquid height, steam generator L_2++ downcomer (ft, above tube sheet)
	-1,-2	CTL_SGS_ILEVEL(L_2,1)	Measured liquid height, steam generator L_2++ downcomer (frac span, narrow range)
K	All	SGS_P(L_1)	Pressure, steam generator L_1++ steam dome (ft)
L	All	SGS_P(L2)	Pressure, steam generator L_2++ steam dome (ft)
M	All	SGS_WOUTSG(L_1)	Steam flow, steam generator L_1++ outlet nozzle (lbm/sec)
N	All	SGS_WOUTSG(L_2)	Steam flow, steam generator L_2++ outlet nozzle (lbm/sec)
O	All	{CTL_CORE_TRIP}	Core trip signal; 0 = no trip (F), 1 = trip (T)
P	All	{CTL_TURB_TRIP}	Turbine trip signal; 0 = no trip (F), 1 = trip (T)
Q	All	{CTL_RPCS_TRIP}	Reactor Power Cutback Signal 0 = no signal (F), 1 = signal (T)
R	All	{CTL_MSIS_TRIP}	Main steam isolation signal; 0 = no signal (F), 1 = signal (T)
S	All	{CTL_SIAS_TRIP}	Safety injection actuation signal; 0 = no signal (F), 1 = signal (T)
T	All	{CTL_FWS_TRIP}	Main feedwater system trip signal; 0 = no trip (F), 1 = trip (T)

Table 7.32 (Continued)

ID*	CTL_ OUTPUT_ OPTION**	Database Variable ***	Description
U	All	{AFWS_FLOW}	Auxiliary feedwater: 0 = no feed, 1 = feed to any steam generator
V	All	{RCPI_VOLT_FRAC(1)}	Reactor coolant pump (RCP) 1; 1 = pump running; 0 = pump tripped
W	All	{RCPI_VOLT_FRAC(2)}	RCP 2, same as above
X	All	{RCPI_VOLT_FRAC(3)}	RCP 3, same as above
Y	All	{RCPI_VOLT_FRAC(4)}	RCP 4, (if exists), same as above
a	±1	{P_FLOW(146), P_FLOW(147)}	Primary system relief valves (pressurizer PORV, safety or vent, or upper head vent); 0 = valves closed, 1 = one or more valves open
b	±1	{MSLH_VALVE_POS}	Steam generator safety valves; 0 = valves closed, 1 = open valve
c	±1	{MSLH_VALVE_POS}	Turbine bypass; 0 = valves closed, 1 = open valve
d	±1	{MSLH_VALVE_POS}	Atmospheric dump valves; 0 = valves closed, 1 = open valve
e	±1	{VLV_PRZR_MSPRAY, CHGS_ASPRAY_FLOW}	Pressurizer spray (main and/or auxiliary); 0 = no spray beyond the continuous minimum, 1 = spray active

Table 7.32 (Continued)

ID*	CTL_ OUTPUT_ OPTION**	Database Variable ***	Description
f	±1	{SIS_RCS_FLOW - SI_TANK_FLOW}	High pressure safety injection (HPSI) or low pressure safety injection (LPSI); 0 = not injecting, 1 = injecting
g	±1	{SI_TANK_FLOW}	Safety injection tanks; 0 = not injecting, 1 = injecting
h	±1	{CTL_VOLT_PROP}	Pressurizer's proportional heaters; 0 = off, 1 = on at any level
i	±1	{CTL_VOLT_BACK}	Pressurizer's backup heaters; 0 = off, 1 = on
j	±1	CTL_CH_FLOW	Total charging flow delivery to RCS (lbm/sec)
k	±1	CTL_LDN_FLOW	Letdown flow (lbm/sec)
l	±1	FWS_FLOW(L_1) + AFWS_FLOW(L_1)	Feedwater flow (main and auxiliary) to steam generator L_1^{++} (lbm/sec)
m	±1	FWS_FLOW(L_2) + AFWS_FLOW(L_2)	Feedwater flow (main and auxiliary) to steam generator L_2^{++} (lbm/sec)
n	±1	P_FLOW(N), N = PATH_ANNUL_CORE .	Reactor vessel inlet flow (lbm/sec)

Table 7.32 (Continued)

ID*	CTL_ OUTPUT_ OPTION**	Database Variable ***	Description
p	±1	LEVL_MIX(NODE_UHEAD)	Two-phase mixture height, reactor vessel upper head (ft)
q	±1	CTL_CORE_POWER_FRACTION	Core power fraction, actual
	-1	POW_EXCORE_POWER_AV	Core power fraction, ex-core detectors

* See Figure 7.11 for ID definition

** "All" indicates that the item appears in all output formats (1, 2, -1, -2)

*** Brackets indicate the output item is a function of the variable, as explained, rather than the variable itself.

\+ If node quality exceeds 80%, steam temperature is displayed.

++ See CTL_OUTPUT_LOOP, Table 7.31, for definition of L_1 and L_2.

+++ Corresponding to Figure 7.2.

Table 7.33

Summary Output Data

Maxima, Minima, Integrals, etc.

Variable	Description	Units
CTL_SUMMARY_DATA(150)	**Case summary data**	**Partition**
CTL_MAX_POWER_FRAC	Maximum power fraction during run	frac
CTL_MAX_POWER_TIME	Time of maximum power during run	sec
CTL_MAX_HEAT_FLUX_FRAC	Maximum heat flux during run	frac
CTL_MAX_HEAT_FLUX_TIME	Time of maximum heat flux during run	sec
CTL_MAX_PRZR_PRESS	Maximum Pressurizer Pressure during run	psia
CTL_MAX_PRZR_PRESS_TIME	Time of maximum Przr Press during run	sec
CTL_MIN_PRZR_PRESS	Minimum Pressurizer Pressure during run	psia
CTL_MIN_PRZR_PRESS_TIME	Time of minimum Przr Press during run	sec
CTL_MAX_RCS_PRESS	Maximum RCS Pressure during run	psia
CTL_MAX_RCS_PRESS_TIME	Time of maximum RCS Press during run	sec
CTL_MIN_RCS_PRESS	Minimum RCS Pressure during run	psia
CTL_MIN_RCS_PRESS_TIME	Time of Minimum RCS Press during run	sec
CTL_MAX_SG_PRESS(K)	Maximum SG Pressure during run	psia
CTL_MAX_SG_PRESS_TIME(K)	Time of maximum SG Press during run	sec
CTL_MIN_SG_PRESS(K)	Minimum SG Pressure during run	psia
CTL_MIN_SG_PRESS_TIME(K)	Time of minimum SG Press during run	sec
CTL_INTEG_PFLOW_NONMOM(J)	Integrated flow thru all non-momentum paths	lbm
CTL_INTEG_SGS_VALVES(L)	Integrated flow though secondary paths	lbm
CTL_INTEG_MSLB_IN_FLOW(KK)	Integrated flow MSLB inside containment	lbm
CTL_INTEG_MSLB_OUT_FLOW	Integrated flow MSLB outside containment	lbm
CTL_INITIAL_CORE_FLOW	Initial core flow	lbm/sec
CTL_CORE_FLOW_FRAC	Normalized core flow - frac of initial	frac
CTL_HEAT_FLUX_FRAC	Core average heat flux fraction	frac
CTL_CETOP_MIN_DNBR	CETOP Minimum DNBR during run.	Fraction
CTL_CETOP_MIN_DNBR_TIME	Time of CETOP Minimum DNBR.	Seconds
MSLH_IO_INT_FLOW(10)	**Dose Model Integrated iodine flow**	**Partition**
MSLH_IO_INT_ATM	Integrated iodine flow to atmo	Curie
MSLH_IO_INT_COND	Integrated iodine flow to cond	Curie
MSLH_IO_INT_CONT	Integrated iodine flow to cont	Curie
MSLH_IO_INT_TURB	Integrated iodine flow to turb	Curie
MSLH_IO_CONT_LEAK	Iodine leak rate from containment	μC/sec
MSLH_IO_CONT_INT_LEAK	Integrated iodine leak from containment	Curie

Table 7.33 (Continued)

RCS Mass and Energy Balance

Variable	Description	Units
RCS_BALANCE(54)	RCS mass and energy balance	Partition
RCS_NODAL_EXT_FLOWS(I)	Sum of the external flows to each node	lbm/sec
RCS_NET_EXT_FLOW	Sum of all RCS flows - includes PRZR	lbm/sec
RCS_NET_HEAT_RATE	Sum of all heat flows to RCS	Btu/sec
RCS_TOTAL_MASS	Sum of all RCS nodal masses - inc PRZR	lbm
RCS_TOTAL_ENERGY	Sum of all RCS node total energy	Btu

Titles

Title Variable	String Length	Description
PLANT_DATA_FILE_NAME	70	Plant data file description
PLANT_DATA_TITLE	70	Plant data file title
PLANT_DATA_TIME	10	Plant data file time stamp
PLANT_DATA_DATE	10	Plant data file date stamp
SNAPSHOT_FILE_NAME	70	Snapshot file description
SNAPSHOT_TITLE	70	Snapshot file title
SNAPSHOT_TIME	10	Snapshot file time stamp
SNAPSHOT_DATE	10	Snapshot file date stamp
CTL_TITLE(M)	60	Titles of controllers

I = 1,..., NUM_NODES (≤ 50) Number of nodes

J = 1,..., 50 Number of non-momentum flowpaths

K = 1,..., NUM_SG (≤ 4) Number of steam generators

KK = 1,..., NUM_SG · NUM_SL (≤ 8) Number of steamlines

L = 1,..., MSLH_VALVE_NUM + NUM_SG · NUM_SL + NUM_MSLH (≤ 50)
Number of steamline external paths

M = 1,..., GROUPS (≤ 1000) Number of controllers

7.7 References

7.1 American Nuclear Society Standard, ANSI/ANS - 5.1 - 1979, "American National Standard for Decay Heat in Light Water Reactors", August 1979.

7.2 "Response of Combustion Engineering Nuclear Steam Supply System to Transients and Accidents", CEN-128, Vol. 1 (Non-Proprietary), April 1980.

FIGURE 7.1

FUEL ROD COOLANT CHANNEL VARIABLES

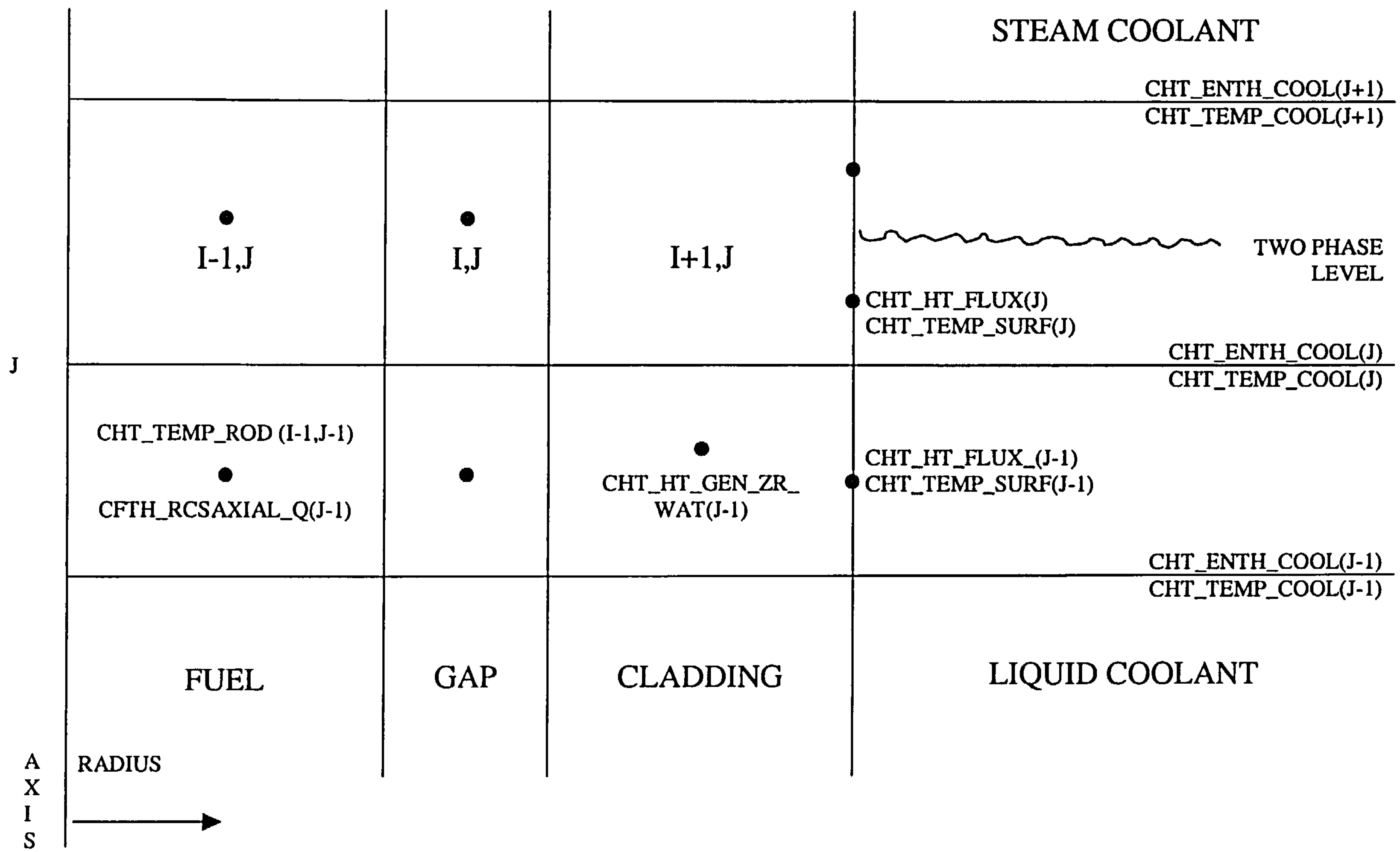

FIGURE 7.2A

TYPICAL PRIMARY SYSTEM NODE AND MOMENTUM FLOWPATH NUMBERS (CE PWR)

FIGURE 7.2B1

TYPICAL PRIMARY SYSTEM NODE AND MOMENTUM FLOWPATH NUMBERS (CE PWR WITH EXPANDED NODALIZATION)

FIGURE 7.2B2

PRESSURE VESSEL ANNULUS, SECTION VIEW
TYPICAL NODE AND MOMENTUM FLOWPATHS
(CE PWR WITH EXPANDED NODALIZATION)

FIGURE 7.2C

TYPICAL PRIMARY SYSTEM NODE AND MOMENTUM FLOWPATH NUMBERS (3-LOOP WESTINGHOUSE PWR)

FIGURE 7.2D1

TYPICAL PRIMARY SYSTEM NODE AND MOMENTUM FLOWPATH NUMBERS
(3-LOOP WESTINGHOUSE PWR WITH EXPANDED NODALIZATION)

FIGURE 7.2D2

PRESSURE VESSEL ANNULUS, SECTION VIEW
TYPICAL NODE AND MOMENTUM FLOWPATHS
(3 LOOP WESTINGHOUSE PWR WITH EXPANDED NODALIZATION)

FIGURE 7.2E

TYPICAL PRIMARY SYSTEM NODE AND MOMENTUM FLOWPATH NUMBERS (4-LOOP WESTINGHOUSE PWR)

FIGURE 7.2F1

TYPICAL PRIMARY SYSTEM NODE AND MOMENTUM FLOWPATH NUMBERS
(4-LOOP WESTINGHOUSE PWR WITH EXPANDED NODALIZATION)

FIGURE 7.2F2

PRESSURE VESSEL ANNULUS, SECTION VIEW
TYPICAL NODE AND MOMENTUM FLOWPATHS
(4 LOOP WESTINGHOUSE PWR WITH EXPANDED NODALIZATION)

FIGURE 7.3A
TYPICAL PRIMARY SYSTEM NON-MOMENTUM FLOWPATHS
(CE PWR WITH EXPANDED NODALIZATION)

FIGURE 7.3B
TYPICAL PRIMARY SYSTEM NON-MOMENTUM FLOWPATHS
(3-LOOP WESTINGHOUSE PWR WITH EXPANDED NODALIZATION)

FIGURE 7.3C
TYPICAL PRIMARY SYSTEM NON-MOMENTUM FLOWPATHS
(4-LOOP WESTINGHOUSE PWR WITH EXPANDED NODALIZATION)

FIGURE 7.4
QUENCH TANK VARIABLES

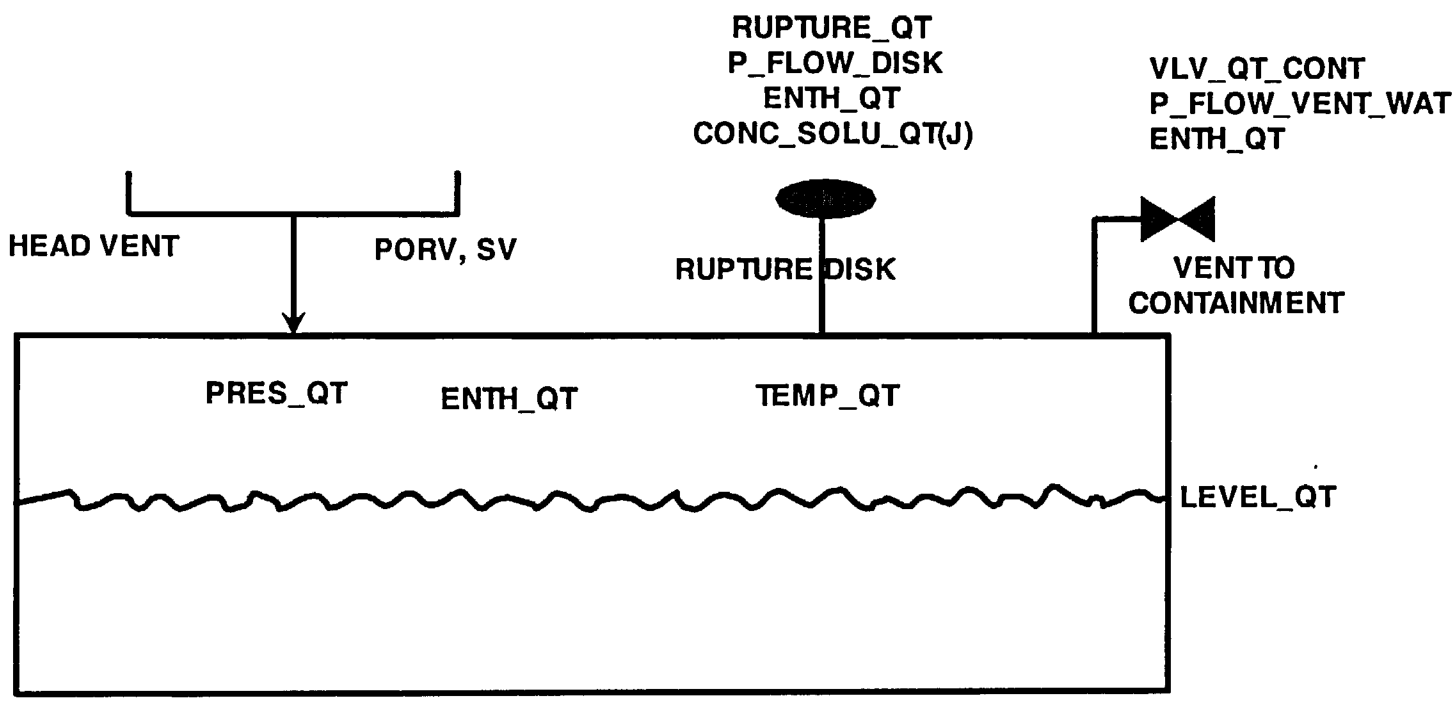

FIGURE 7.5A

TYPICAL SECONDARY SYSTEM NODES AND EXTERNAL FLOWPATHS (C-E PWR)

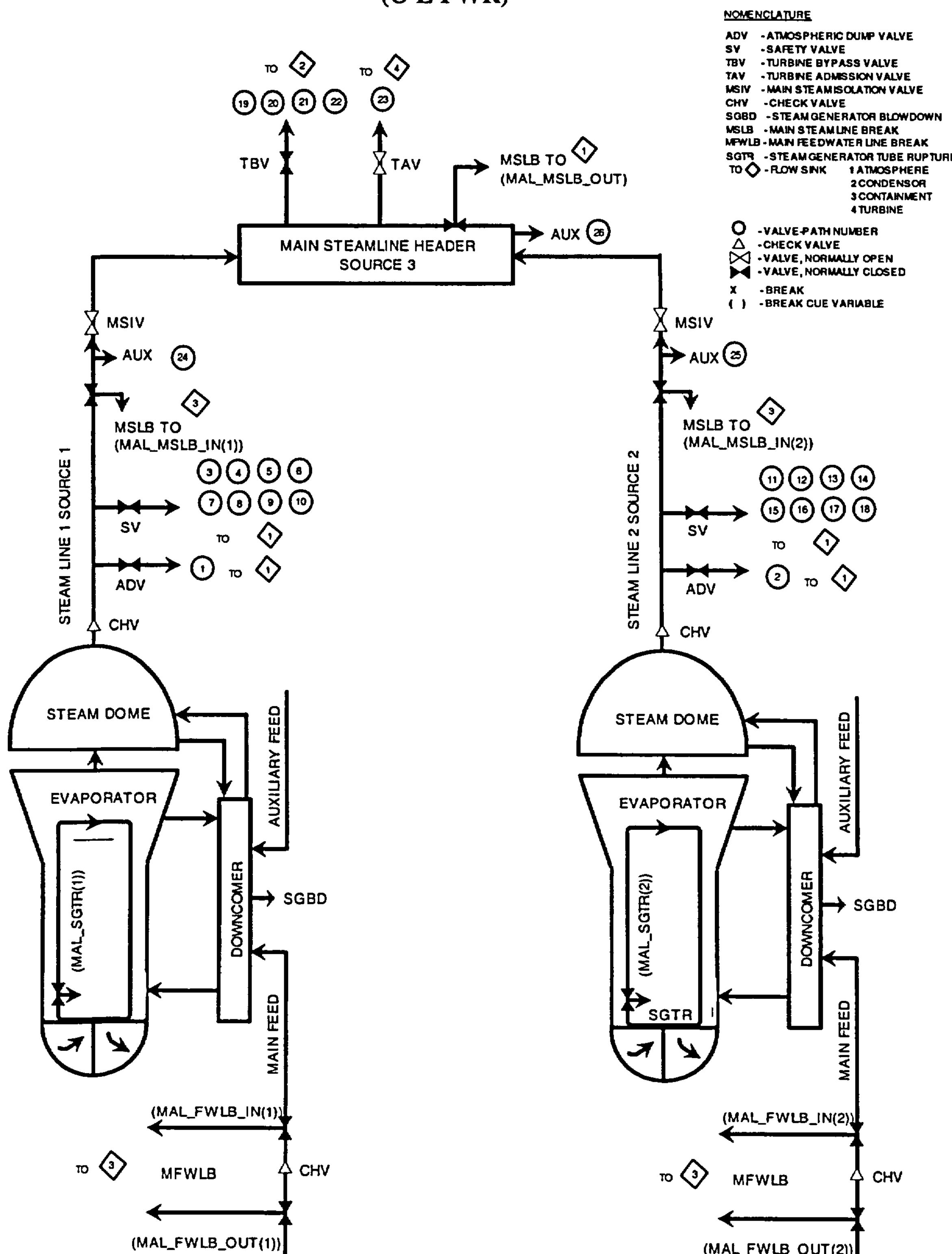

FIGURE 7.5B

TYPICAL SECONDARY SYSTEM NODES AND EXTERNAL FLOWPATHS (WESTINGHOUSE 3-LOOP PWR)

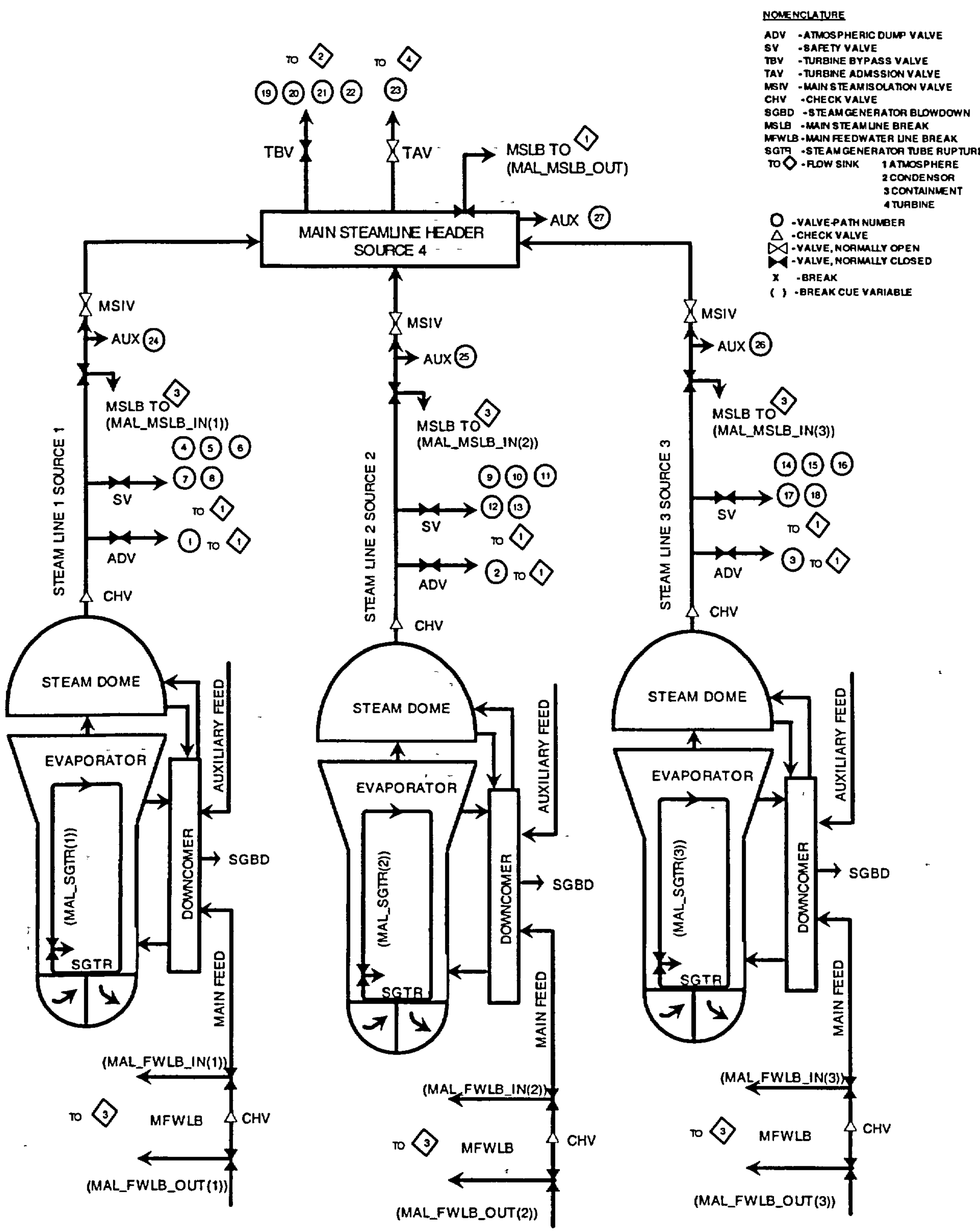

FIGURE 7.5C

TYPICAL SECONDARY SYSTEM NODES AND EXTERNAL FLOWPATHS (WESTINGHOUSE 4-LOOP PWR)

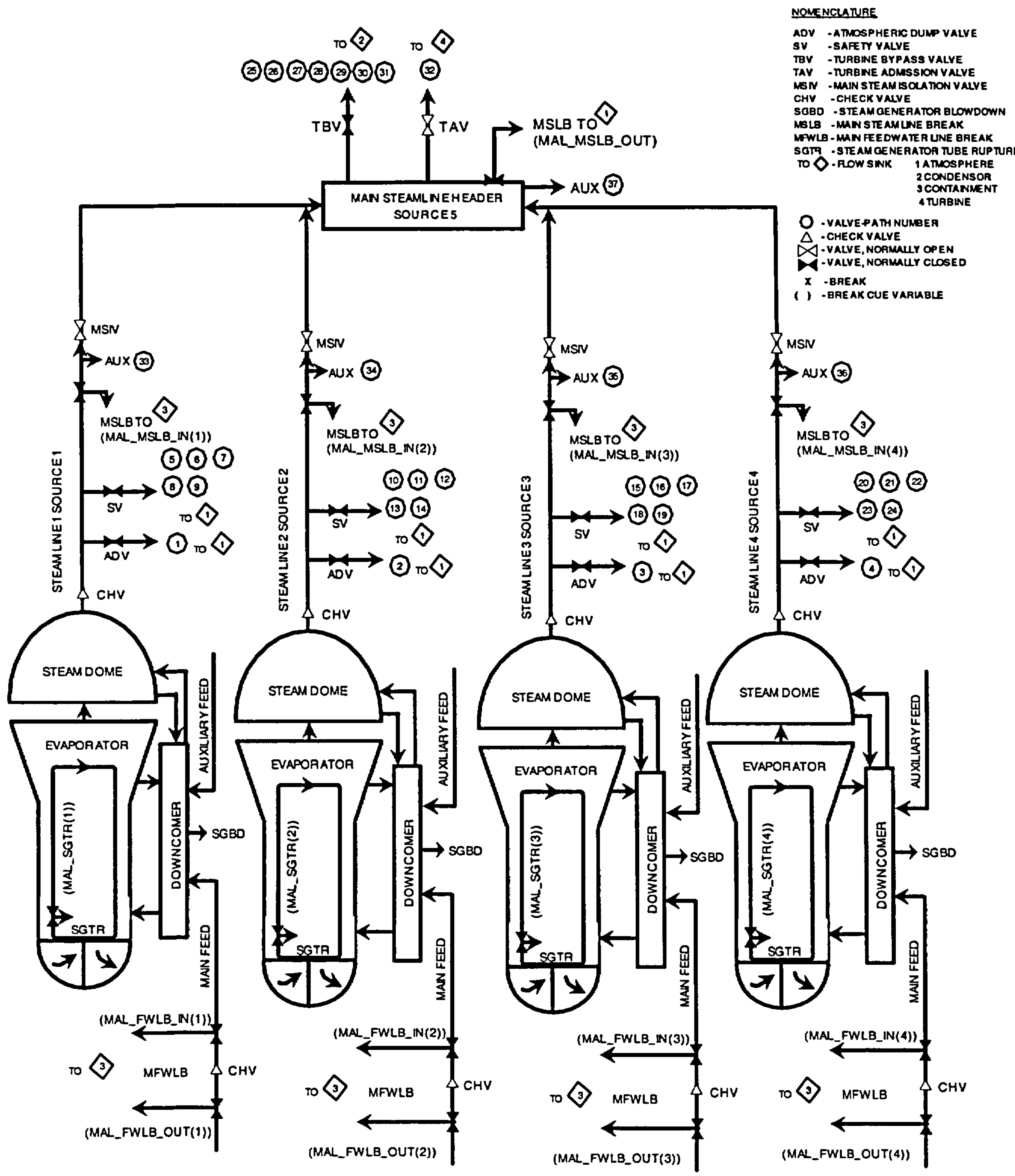

FIGURE 7.6

SECONDARY SYSTEM NODE AND INTERNAL FLOWPATH VARIABLES

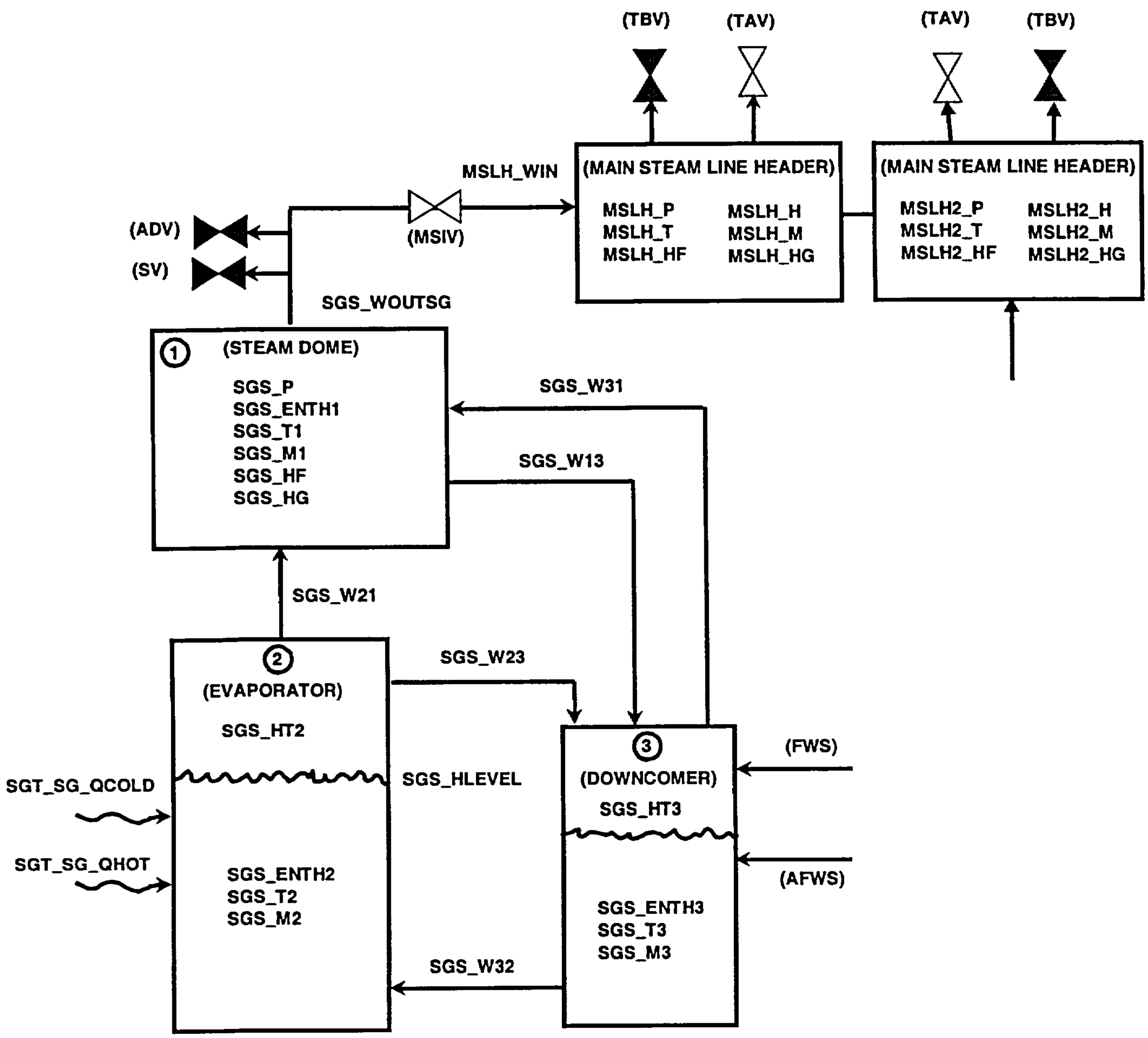

FIGURE 7.7
STEAM GENERATOR HEAT TRANSFER: TYPICAL NODALIZATION

FIGURE 7.8
TYPICAL FEEDWATER SYSTEM

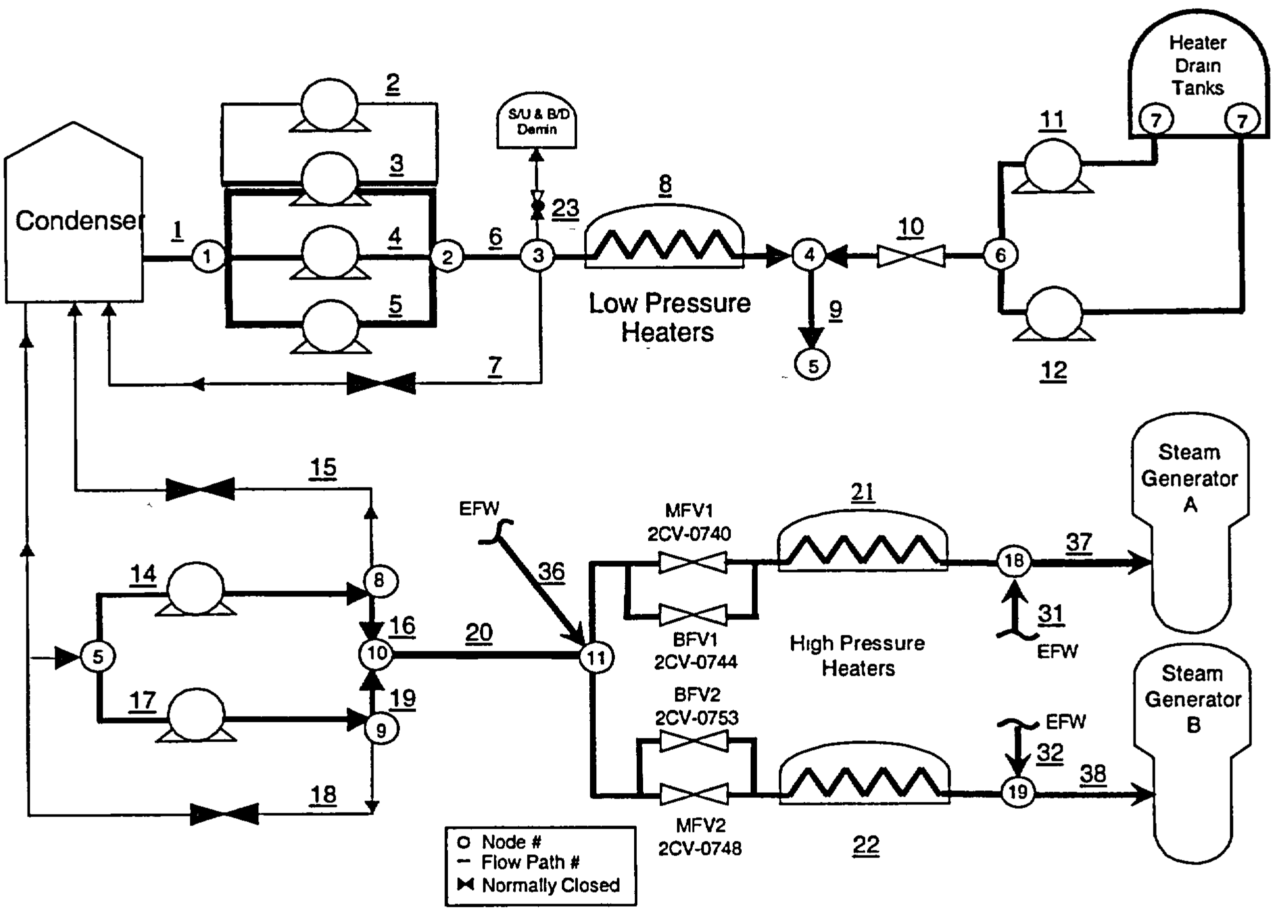

FIGURE 7.9
TYPICAL EMERGENCY FEEDWATER SYSTEM

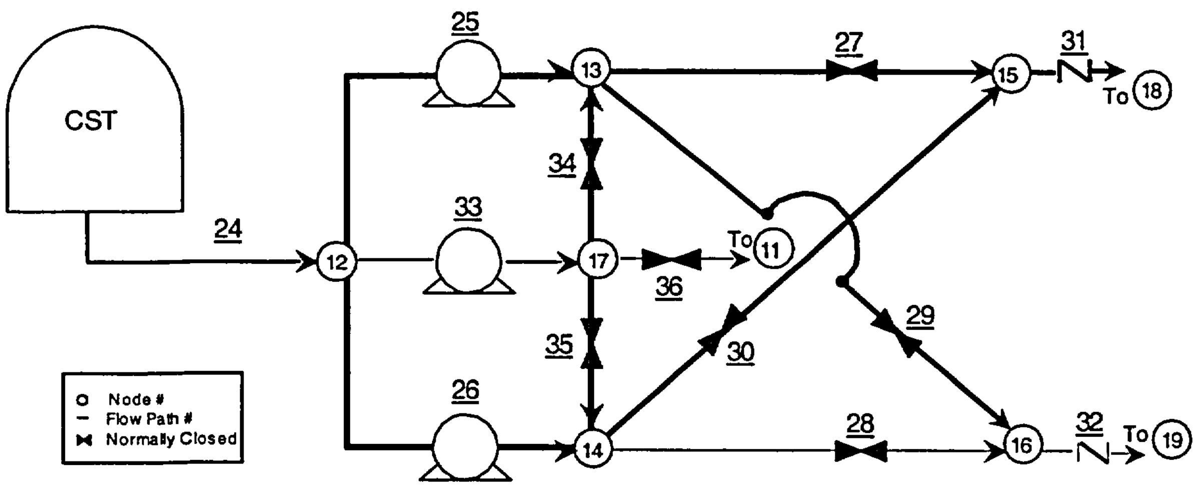

FIGURE 7.10

STEAMLINE BREAK LOCATIONS

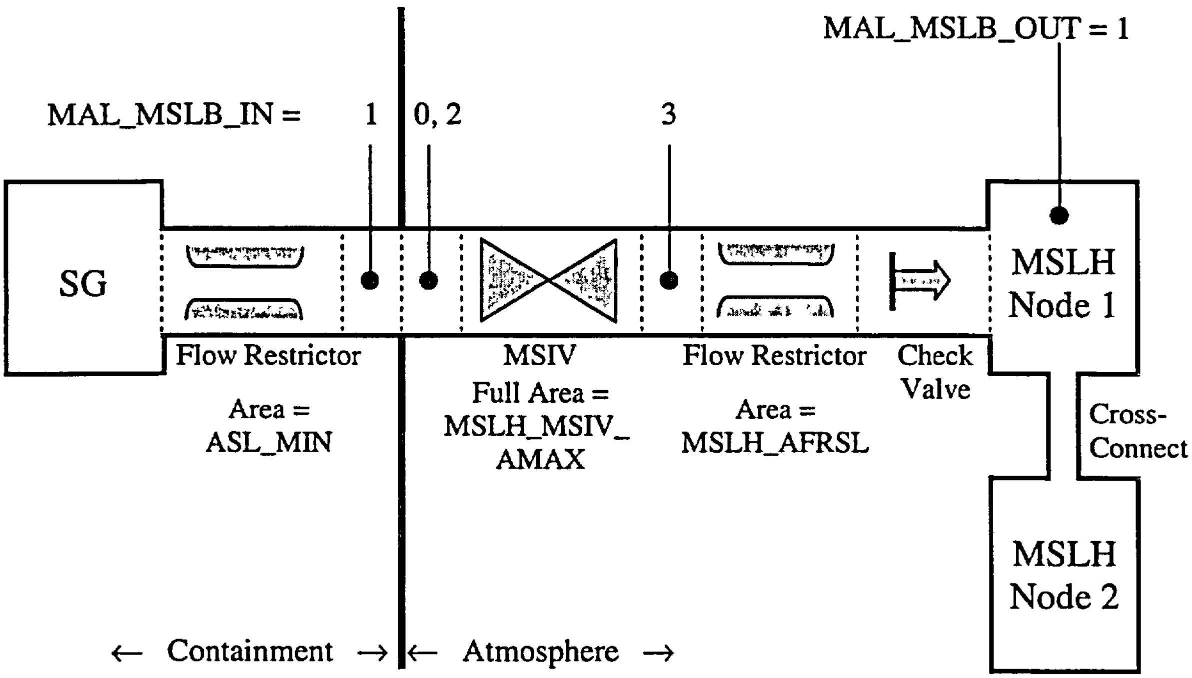

FIGURE 7.11
CENTS OUTPUT

```
? CTL_OUTPUT_INTERVAL = 2
? CTL_OUTPUT_OPTION = -1
? MAL_MSLB_IN(1) = 1
? GO 40

TRIPS: CORE,TURB,CSR,MSIS,SIAS,MFW,AFW(ON)                                                   VALVES: PRLF,SRLF,CDUMP,ADUMP,SPRAY
TIME  PRES   LEVELS       RCS TEMPS   SG LEVELS   SG PRES   ST FLOWS    TRIPS   RCPS VALVS SI  HT    CVCS    TOT FW    FLOW  UHLEV POWER
           PRZR  IV   1   3   1   1    1    2     1    2     1    2                                  CH  LDN   1    2

  A    B    C    D    E   F   G   H    I    J     K    L     M    N  OPQRSTU VWXY abcde fg hi    j    k    l    m     n     p    q

   0 2109 13.2 19.2 538 538 592 644 32.0 32.0   782  781   909  915 0000000 1111 00000 00 10  6.0  4.9  915  915 20063  9.4 0.9988
   2 2094 13.1 19.2 538 538 592 642 32.2 32.1   714  731  1687 1489 0000000 1111 00000 00 10  6.0  4.9 1140 1140 20023  9.4 0.9992
   4 2058 12.9 19.2 536 536 592 640 32.2 32.1   678  704  1419 1353 0000000 1111 00000 00 10  6.0  3.7 1140 1140 20023  9.4 0.9981
   6 2023 12.4 19.2 530 532 592 636 32.1 32.2   660  671  1455 1407 0000000 1111 00000 00 11 12.1  3.6 1140 1140 20053  9.4 0.9981
   8 2009 11.9 19.2 526 528 591 636 32.0 32.1   633  661  1515 1272 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20161  9.4 1.0056
  10 1994 11.3 19.2 523 527 589 635 31.7 32.2   626  637  1331 1421 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20230  9.4 1.0164
  12 1977 10.7 19.2 521 524 586 634 31.4 32.2   608  627  1435 1279 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20295  9.4 1.0240
  14 1962 10.2 19.2 518 521 584 633 31.2 32.1   595  617  1366 1283 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20370  9.4 1.0319
  16 1946  9.8 19.2 516 519 582 632 31.0 32.0   587  600  1331 1298 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20418  9.4 1.0352
  18 1932  9.3 19.2 514 516 580 631 30.9 31.9   576  593  1332 1256 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20486  9.4 1.0428
  20 1918  8.9 19.2 513 515 578 630 30.7 31.7   567  585  1314 1231 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20535  9.4 1.0494
  22 1905  8.6 19.2 510 513 576 629 30.6 31.5   558  574  1286 1238 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20580  9.4 1.0516
  24 1893  8.2 19.2 508 511 575 628 30.6 31.4   551  567  1274 1221 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20624  9.4 1.0581
  26 1882  7.9 19.2 507 509 573 628 30.5 31.2   544  561  1258 1192 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20679  9.4 1.0587
  28 1871  7.6 19.2 506 508 571 627 30.5 31.1   536  552  1244 1194 0000000 1111 00000 00 11 18.1  3.6 1140 1140 20698  9.4 1.0643
  30 1860  7.3 19.2 504 506 570 626 30.3 30.8   576  582   755  769 1100000 1111 00110 00 11 18.1  3.6 1090 1090 20822  9.4 0.5218
  32 1834  6.7 19.2 505 507 563 623 29.9 30.4   594  603   785  706 1100000 1111 00110 00 11 18.1  3.6  989  989 20853  9.4 0.2243
  34 1802  5.9 19.2 507 509 552 621 29.4 29.8   603  610   710  671 1100000 1111 00000 00 00 18.1  3.6  888  888 20826  9.4 0.1563
  36 1771  5.2 19.2 507 508 542 619 28.7 29.2   600  607   693  613 1100000 1111 00000 00 00 18.1  3.6  787  787 20814  9.4 0.1301
  38 1742  4.6 19.2 505 506 535 616 28.0 28.4   590  598   655  575 1100000 1111 00000 00 00 18.1  3.6  686  686 20803  9.4 0.1106
  40 1713  4.0 19.2 502 503 530 614 27.2 27.5   579  587   618  569 1100000 1111 00000 00 00 18.1  3.6  585  585 20844  9.4 0.0959
?
? CTL_OUTPUT_OPTION = -2
? GO TO 64
  42 1684  3.3 19.2 500 500 525 612 26.5 26.7   568  575   610  547 1100000 1111
  44 1654  2.7 19.2 497 497 520 609 25.8 26.1   554  563   591  525 1100000 1111
  46 1625  2.1 19.2 494 494 516 607 25.2 25.4   543  551   568  514 1100001 1111
  48 1597  2.0 19.2 491 492 512 605 24.6 24.8   531  539   554  496 1100001 1111
  50 1574  2.0 19.2 488 489 508 602 24.0 24.2   519  527   541  485 1100101 1111
  52 1538  1.9 19.2 486 486 506 599 23.4 23.7   508  515   527  478 1100101 1111
  54 1490  1.8 19.2 483 484 503 595 23.0 23.3   497  504   522  464 1100101 1111
  56 1434  1.7 19.2 481 481 500 590 22.6 23.0   486  493   517  449 1100101 1111
  58 1372  1.6 19.2 478 478 497 584 22.3 22.7   476  483   511  437 1100101 1111
  60 1377  1.6 19.2 476 476 489 586 22.2 22.5   440  511   954    0 1101111 1111
  62 1382  1.6 19.2 473 475 490 585 22.0 22.3   412  512   900    0 1101111 1111
  64 1370  1.6 19.2 465 476 486 585 21.7 22.2   391  521   845    0 1101111 1111
?
```