EPRI-CURL Dynamic Analysis of Loop Type LMFBRs

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Final Report
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Prepared by
Cornell University
Ithaca, New York

ELECTRIC POWER RESEARCH INSTITUTE

EPRI-CURL Dynamic Analysis of Loop Type LMFBRs

NP-1001
Research Project 352-1

Final Report, May 1979

Prepared by

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EPRI PERSPECTIVE

PROJECT DESCRIPTION

This final report describes a computer program, developed at Cornell University under Research Project 352 for the purpose of simulating transient behavior in a loop-type liquid metal-cooled fast breeder reactor (LMFBR) power plant. The mathematical models developed for the simulation are described and a user's guide is included. In addition, transient analysis studies for the purpose of program verification make up a significant portion of the report. From these studies it has been determined that the program is capable of simulating operational and accidental transients in an economical manner, when compared with similar simulation models, such as DEMO, BRENDA, and SSC-L. This is made possible by incorporating a numerical approximation technique that has not yet been completely verified with respect to accuracy. It does appear to be effective, however, when applied to a broad range of transient behavior in loop-type LMFBRs.

PROJECT OBJECTIVES

The overall objective of this project is to develop fast-running, yet accurate computer programs to analyze operational and accident transient behavior of both loop-type and pool-type LMFBR power plants. This objective has been achieved for loop-type plants; this report describes the resulting computer program. Development of a computer program that will be used for transient analysis of pool-type LMFBRs is currently in progress. Both programs incorporate numerical approximation techniques and simplified models that, when tied together to form the plant simulator, produce fast-running computer programs. To build confidence in and to verify these programs, extensive transient analysis is performed. Once verification has been achieved and some comparisons to the measured data (e.g., gathered in experimental LMFBRs) are made for code qualification purposes, the final products could then be used by utilities that may, someday, purchase LMFBR power plants.

PROJECT RESULTS

A computer program was developed, as stated above, for loop-type LMFBR power plant simulation. Incentive is equally strong to develop such a simulation model for pool-type LMFBR power plants. It is also important to establish a high degree of confidence in the mathematical models and numerical methods used to build the computer programs. A related project (RP1381) is now in progress at the University of Arizona to study the validity of the numerical methods used. The mathematical models used to simulate the control system, and the nuclear, thermal, and coolant dynamic behavior in the various system components must ultimately be validated by comparison with experiments. Unfortunately, a complete set of experiments is not available for validating all of the models used, necessitating the adoption of an indirect method for program qualification. That is, the relatively crude dynamic modeling of a plant system component that is programmed into the plant simulator is compared with a more comprehensive model of that same component; such models can be constructed in three-dimensional programs, e.g., COMMIX. The more comprehensive model is, in turn, validated by assessing its ability to predict a fairly realistic experiment, if such an experiment is available. Confidence is obtained when both the comprehensive model and the simplified model in the simulator both agree with the experiment. If no experiment is available, the comparison must be between the results of the system simulator and the more comprehensive model. In order to maximize comparison with experiment, it is recommended that a numerical-experimental comparison program be set up to validate LMFBR transient simulators. Existing relevant experimental data must be identified, and new experimental data must be obtained where needed.

In addition to program qualification by comparison with experiments, further confidence can be gained by numerical benchmarking; that is, transient simulation studies are carried out with several systems transient simulators, and the results are compared. Results of such comparisons are presented in the report. In general, very favorable agreement is obtained, allowing the conclusions that the approach taken in constructing the simulation model was valid, and that no gross coding errors exist.

Edward L. Fuller, Project Manager
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ABSTRACT

A computer-aided simulation is developed to analyze the transient behavior of loop type liquid metal-cooled fast breeder reactor plants. A set of nuclear, heat transfer, sodium dynamics, steam/water thermodynamics and control models for the multi-loop plant is developed to simulate operational, incident and accident transients.

The major important features of the model include:

1. a multi-loop simulation, consisting of a single loop and the remaining lumped loops,

2. a method to calculate the characteristic times for every differential equation, and apply the Runge-Kutta algorithm to variables with slow and moderate time responses as compared to the integration time step and evaluate the variables with fast responses from a prompt approximation to assure numerical stability and reduce the computation time; and

3. a pre-accident initialization method by forcing most variables into their prompt approximation.

The analytical submodels of the EPRI-CURL Code simulates: (a) the dynamics of sodium flows in the primary and secondary systems governed by forced and natural circulation, (b) reactor heat transfer, (c) neutron kinetics, reactivity feedbacks, and reactor power control, (d) intermediate heat exchanger heat transfer, (e) sodium transport delays in the primary and secondary systems, (f) steam/water thermodynamics, normal feed water flow and auxiliary feed water flow control, and (g) turbine header, throttle, steam bypass and relief flow control. There is a total of 489 first order ordinary differential equations modelling the entire plant.

The EPRI-CURL systems analysis computer code for loop-type liquid metal cooled fast breeder reactors is used to model the plant response of a typical LMFBR to several transient conditions.

The following transients are discussed:

1. a seismic-induced reactivity insertion;
2. a spurious pump trip; and
3. a complete loss of forced coolant circulation leading to buoyancy induced natural circulation.

The EPRI-CURL results are compared to parallel calculations using the FORE-II and DEMO simulation models where applicable.

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SUMMARY

A fast-running systems analysis code has been written to analyze the response to transients of loop-type Liquid Metal-cooled Fast Breeder Reactors. Among the transients which may be simulated are ramp changes in the demanded power, loss of power to any pump, step reactivity insertions (of less than one dollar), manual reactor trips, a turbine trip, a steam dump, or any combination of these.

Two heat transfer loops are modelled, one of which represents a single loop, and the other represents any number of remaining, equivalent loops. Each of these loops consists of a primary sodium loop, a secondary sodium loop, and a tertiary water/steam loop.

The mathematical model includes: point reactor kinetics, reactivity feedback, and reactor power control; primary, secondary, and tertiary thermal and coolant dynamics governed by forced and natural circulation; and plant protection and control systems.

A total of 489 differential equations model the entire plant. A method has been developed (using the diagonal elements of the Jacobian matrix) which separates these equations into two classes: those with a "fast" response time, and those with a "slow or moderate" response time, as compared to the chosen integration time step. The "moderate" response equations are integrated using a second order Runge-Kutta technique, and the "fast" response equations are evaluated using a prompt approximation technique. This assures numerical stability and allows significant reduction in computation time without much loss of accuracy.

The core neutron kinetics is calculated using two groups of delayed neutrons and three groups of fission products. Total reactor power is computed through a prompt approximation. Reactivity feedbacks due to the Doppler effect, sodium density, and core expansion are included. Two sets of independent control rod systems are provided for reactor shutdown. The primary control rod system also acts as the power controller.

The reactor heat transfer model divides the reactor core into eleven fueled regions, three in each of three flow channels, and one in each of two other flow channels. These can be used to simulate, for example, a central core region with lower and upper axial blankets in three channels, and an outer radial blanket in two other channels. A two zone mixing model of the reactor vessel upper plenum is included.

The primary system coolant dynamics model computes the flow distribution to each of the five fueled flow channels, as well as to an unheated bypass channel. This model also computes the flow in the two primary loops. Reynolds number dependent friction factors are used in all coolant dynamics calculations. In pipe rupture transients (where the pipe rupture occurs between the check valve and the reactor vessel in a single loop), this model also computes the flow rate out the pipe break. Coolant pumps with frequency controllers are also modelled.

All piping heat transport delays are included in the primary, secondary, and tertiary systems. Counterflow heat exchangers are modelled between the primary and secondary loops. Two evaporators and a superheater are modelled for heat transport from each secondary to each tertiary loop. Frequency controllers are also provided for the secondary sodium loops.

The tertiary system model includes a steam drum, fed by either a normal or an auxiliary feedwater supply system, and a steam header, which is fed by both tertiary system loops. Also modelled are the turbine throttle valve, the turbine bypass (dump) valve, and a safety relief valve.

All plant control systems are dependent on a supervisory controller which produces a demanded reactor and plant power. The controllers use this demanded power to compute setpoints for certain variables (such as reactor outlet temperatures, pump speeds, etc.) which are then compared to measured values of those variables and alter the controller output if the deviation is too large.

A plant protection system is also modelled, which compares the measured values of certain variables to reactor shutdown setpoints, and provides for automatic shutdown of the reactor if any setpoints are exceeded.

This report includes the basic modelling equations of each of these systems, as well as a user's guide which describes each individual subroutine and the required input. The system response to several transients has been calculated and compared to parallel calculations using the FORE-II and DEMO simulation models; these include: a seismic induced reactivity insertion, a spurious pump trip, and a complete loss-of-forced-cooling leading to buoyancy induced natural circulation.

The results show that: (1) knowledge of the diagonal entries in the Jacobian matrix of a large system of ordinary differential equations is a good estimate for identification of sources of stiffness, (2) judicious use of the quasi-static approximation reduces the need for either short timesteps or sophisticated implicit numerical-integration methods, (3) a multi-channel reactor heat transfer and sodium dynamics model is necessary for predicting thermohydraulic behavior correctly, especially the effect of reactor flow regimes and redistribution during natural convection cooling, (4) no sodium voiding was predicted for the above transients even with reactor scram time delays of the order of 1 second, and (5) there is general agreement between existing simulation models, but there is still a vital need for experimental and further theoretical verification.

Section 1

INTRODUCTION

The significance of the Liquid Metal-cooled Fast Breeder Reactor (LMFBR) was recognized very early in the development of nuclear energy. Fermi and his coworkers, concerned with the long-range availability of naturally-occurring fissionable fuel, in the spring of 1944, discussed the possibility of building a fast-neutron breeder reactor. Thirty-eight years of slow, but determined development of the fast breeder have laid the foundation for the present intensive effort. The rapid evolution of this type of reactor and the experimental and operational experience in this field requires the development of a theoretical means of simulation to improve the engineering design and better understanding of the safety problems associated with such systems.

Recent research in fast reactor technology has shown that there is a considerable potential for the development of more physically realistic and mathematically accurate models of simulation.

Accident risk assessment has evolved to the current Design Basis Accident (DBA) approach, which involves the determination of the capability of a given reactor design to deal with accidents of low probability and potentially high consequence. Standards are set to ensure high quality in design, construction, and operation of the plant so that the number and severity of events caused by a possible failure will be minimized (1).

In spite of these measures, it is assumed that operational upsets and accidents will occur and safeguards must be provided to cope with them.

High-probability, low consequence accidents are not normally considered to be serious, but it is important to understand their level of severity, and to predict the system response under these conditions. Therefore, analysis of the transients for a variety of abnormal or accident conditions is an important part of the overall safety evaluation.

Restricted analytical models and associated computer codes such as DEMO (2), NALAP (3), and BRENDA (4, 5) have been developed by other organizations to simulate the overall response of a fast reactor plant.

A number of simplifying assumptions and approximations are made in the above models which may be acceptable from the design point of view, but certainly unacceptable for a safety analysis. For example, the modeling of the entire reactor core by a single, average channel is highly questionable. The flow redistribution during the transients, enhanced by buoyancy in the reactor core is an important consideration. The temperature stratification in the reactor outlet plenum is also an important influence in the determination of the natural convection capability of the system.

It is essential that better solution techniques be developed, expecially determination of steady-state initial conditions, that at times could be tedious and expensive for systems of different design and geometric configurations. In order to meet this objective, Cornell University has developed an accurate, fast running systems dynamics code, EPRI-CURL that simulates the primary, secondary, and tertiary systems of a loop type LMFBR plant.

Section 2

SYSTEM DESCRIPTION AND SIMULATION MODEL

SYSTEM DESCRIPTION

This section provides an overall description of the EPRI-CURL code simulation model. A block diagram provides gross information on the model organization, features incorporated in the model, and some of the model inputs and outputs.

Figure 2-1 is a block diagram of the primary, secondary and tertiary systems. The heat transport loops of the plant are simulated by a two loop model; a single loop and the remaining lumped loops.

Each loop is positioned in an "elevated loop" arrangement to provide protection against loss of coolant in the unaffected loops in the event of failure of sodium piping in one of the loops. The relative elevations are arranged to promote natural circulation of the coolant in the primary, secondary and tertiary loops in the event of loss of all electrical power to the plant coolant pumps (station blackout) (6).

A primary pump is located on the hot leg piping of each loop. Sodium from the pump discharge is passed through the shell side of the Intermediate Heat Exchanger (IHX) in which heat is transferred to the secondary sodium. The sodium is then circulated in the cold leg piping through a check valve to the reactor vessel inlet nozzle, which is located near the lower end of the reactor vessel.

A secondary pump is located on the cold leg piping of each loop. Sodium from the pump discharge is passed through the tube side of the IHX in which the heat is transferred from the primary sodium. The sodium is then circulated through the Superheater (SH) and Evaporators (EV) of Steam Generation System (SGS) and back to the pump inlet nozzle.

The SGS consists of a feedwater pump, a steam drum, a recirculation line piping and two identical EV modules and a SH module from which the superheated steam is fed to a common steam header and then directed to the turbine through the throttle valves or bypassed to the condenser.

As an integral part of the plant control systems, the primary, secondary, and tertiary control systems provide the overall control of the plant for all normal and accident conditions. The automatic control system maintains the temperatures, flow rates, and the neutron flux according to a specified load demand (6, 7).

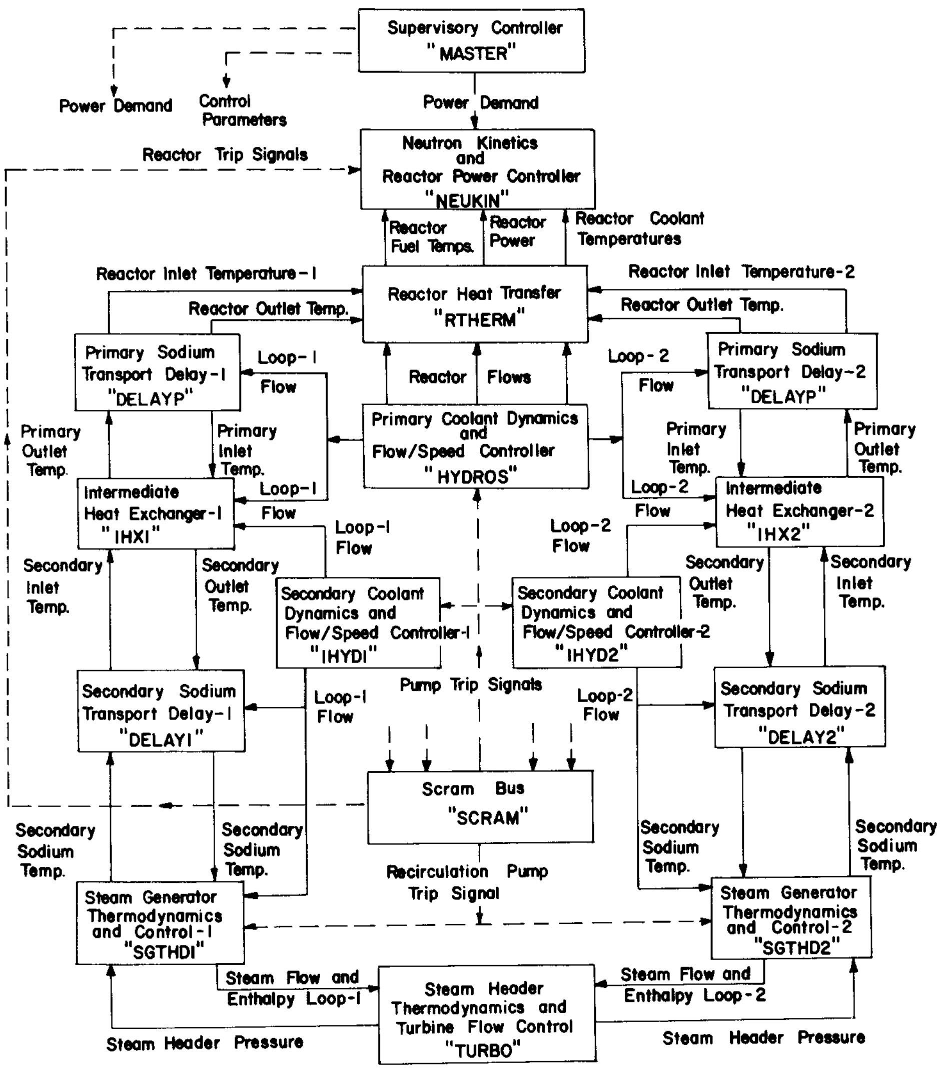


Figure 2-1. Block diagram of LMFBR system as modeled by EPRI-CURL

SIMULATION MODEL

The mathematical modeling for numerical simulation of a multiloop liquid-metal-cooled fast breeder reactor system has been developed by extending a modified version of the primary systems model originally developed by Pavlenco (7), as discussed in references (6, 8).

The core physics uses a two group point reactor kinetics and a three group fission product dynamics. The reactivity feedbacks, due to the nuclear Doppler effect, sodium density, core radial and axial expansion are included. Two sets of independent control rod systems are provided. The primary control rod system acts as the reactor power controller or a shutdown rod system, while the secondary rod system can only be used for the purpose of reactor shutdown.

The reactor heat transfer submodel divides the reactor into eleven fuel regions, three in each of the three central channels, and one in each of two other coolant channels. The bypass channel neglects the heat capacity of the structural material as well as the gamma ray heat effects. In this analysis the three central channels simulate the six average hot assemblies, the inner core region (102 assemblies), and the outer core region (90 assemblies), which include lower and upper axial blankets. The other two channels simulate the radial blanket and shields (474 assemblies), and the primary and secondary coolant rods (19 assemblies).

A two zone lower plenum model simulates the inlet plenum and the core inlet module regions, neglecting the heat capacity of the structural material.

The upper plenum model is based on Yang's (9) two zone mixing model for jets of negative buoyancy, also neglecting the structural material heat capacity effect.

The primary system coolant dynamics model includes the effects of friction, buoyancy, expansion, contraction and inertia. The model calculates the sodium flow rates in the two primary loops (neglecting the mass storage at the pump tanks), the five reactor channels, and the unheated bypass channel. The Reynolds number dependence of the friction factors inside the reactor channels is based on Novendstern's (10) turbulent flow model as discussed in reference (8). The piping friction factors are computed using the Blasius approximation for turbulent flow inside the round tubes as a function of flow Reynolds numbers (8). In a loss-of-piping integrity accident, this model also computes the flow rate out of the pipe break as discussed in references (7, 8).

The secondary loop coolant dynamics model calculates the sodium flow rate in the intermediate loop as governed by forced and natural convection effects (6, 8).

The coolant pump model includes the impeller dynamics, using the balance between the applied motor torque, fluid hydraulic torque and the frictional torque for primary, secondary and recirculation pumps of the tertiary system. The pump characteristics are represented using the homolgous theory (11) including the complete regimes of operation (12). The pump speed controller varies the motor generator set frequency (13), and hence the applied motor torque as governed by the flow-speed controller model for the sodium pumps. The recirculation pumps are constant speed, and uncontrolled.

The primary, secondary, and tertiary coolant transport delay model accounts for the turbulent mixing of the fluid, and the heat capacity of the pipe wall material (except for the tertiary system, where the pipes are assumed to be adiabatic). Counter flow heat exchangers are also modeled as discussed in references (7, 8).

The steam-water thermodynamics model, includes a compressible three region steam drum, fed by normal or auxiliary feed water through control valves, a downcomer, evaporators, a superheater, and a compressible steam header with its associated safety relief valve, throttle valve and the turbine bypass valve.

The hydrodynamics are based on the single mass-flow rate model with slip in the two-phase flow region. The slip model is based on the Armand semi-empirical slip flow correlation (14). The dryout in the evaporators is also predicted using the Bertoleti, et al. (15) method.

The thermodynamic properties of sodium and water are provided through curve fitted polynomials (6).

All plant control systems are dependent on a supervisory controller which produces a demanded reactor and plant power. The controllers use this demanded power to compute setpoints for certain variables (such as reactor outlet temperatures, pump speeds, etc.) which are then compared to measured values of those variables and alter the controller output if the deviation is too large.

A plant protection system is also modeled, which compares the measured values of certain variables to reactor shutdown setpoints, and provides for automatic shutdown of the reactor if any setpoints are exceeded.

A total of 489 differential equations model the entire plant. A method has been developed (using the diagonal elements of the Jacobian matrix) which separates these equations into two classes: those with a "fast" response time, and those with a "slow or moderate" response time, as compared to the chosen integration time step. The "moderate" response equations are integrated using a second order Runge-Kutta technique, and the "fast" response equations are evaluated using a prompt approximation technique. The prompt equations are also used to determine the pre-transient steady state conditions.

Section 3

MATHEMATICAL FORMULATION AND NUMERICAL METHODS

PROBLEM DESCRIPTION

The plant is modeled by a number of first-order differential equations of the form:

$$\frac{dX_i}{dt} = F_i(X_1, X_2, \ldots, X_n; t) \qquad (3\text{-}1)$$

$$i = 1, \ldots, n$$

where:

X_i = state variables,

F_i = differentiable functions, and

t = time, the independent variable.

The measure of stiffness of a system of equations is normally determined by the eigenvalues of the Jacobian matrix:

$$J\,(i,j) = \frac{d}{dX_i}\,F_j \qquad (3\text{-}2)$$

Unfortunately, the computation of the eigenvalues of a large (in this model, $n \cong 500$) system of equations is extremely time consuming, even for a computer.

ALTERNATIVE APPROACH TO STIFFNESS

To remedy this situation, it was decided to consider only the diagonal elements of the Jacobian matrix of Eq. 3-2.

The "characteristic time" for each of the state equations is defined as:

$$\tau_i = - \left(\frac{d}{dX_i} F_j\right)^{-1} \quad (3\text{-}3)$$

where:

τ_i = the "characteristic time" of state equation i (see Eq. 3-1).

The magnitude of each of these characteristic times is then compared to the integration time step, Δt, for the purpose of dividing them into two groups:

Class A variables -- those X_i whose state equations have a "characteristic time" greater than the time step; and

Class B variables -- all other X_i.

In practice it was found that best results were obtained if a slight weighting factor was applied; i.e.,

Class A variables = X_i when $\alpha \tau_i \geq \Delta t$

Class B variables = X_i when $\alpha \tau_i < \Delta t$

where:

α = weighting factor (generally chosen to be 0.7).

Because the "characteristic times" can generally be interpreted as the speed of response to a perturbation, the Class A variables may be interpreted as "slow or moderate" response variables, and the Class B variables as the "fast" response (i.e. "stiff") variables.

The Class A variables are integrated using a standard Runge-Kutta technique, and a quasi-static ("prompt jump" or "prompt approximation") technique is used on the Class B variables.

QUASI-STATIC APPROXIMATION

For the Class B variables, the differential equations for the state variables are replaced by algebraic equations of the form:

$$F_i \; (X_1, X_2, \ldots, X_n; t) = 0 \tag{3-4}$$

which is then solved for X_i. In order to provide consistency (and to preserve the Runge-Kutta feature that the order of integration does not affect the solution), the values used for the $X_j (j \neq i)$ in Eq. (3-4) are the values from the previous time step.

In some cases, the F_i are not linear in X_i, so that iterative numerical methods may need to be employed. And in the case of the primary flows, any Class B variables are solved simultaneously, in order to get the most accurate solutions for these extremely critical parameters.

PLANT INITIALIZATION

The initialization of plant conditions to their steady-state values is required before any transient calculation can take place. The inclusion of the prompt approximation equations greatly alleviates this problem.

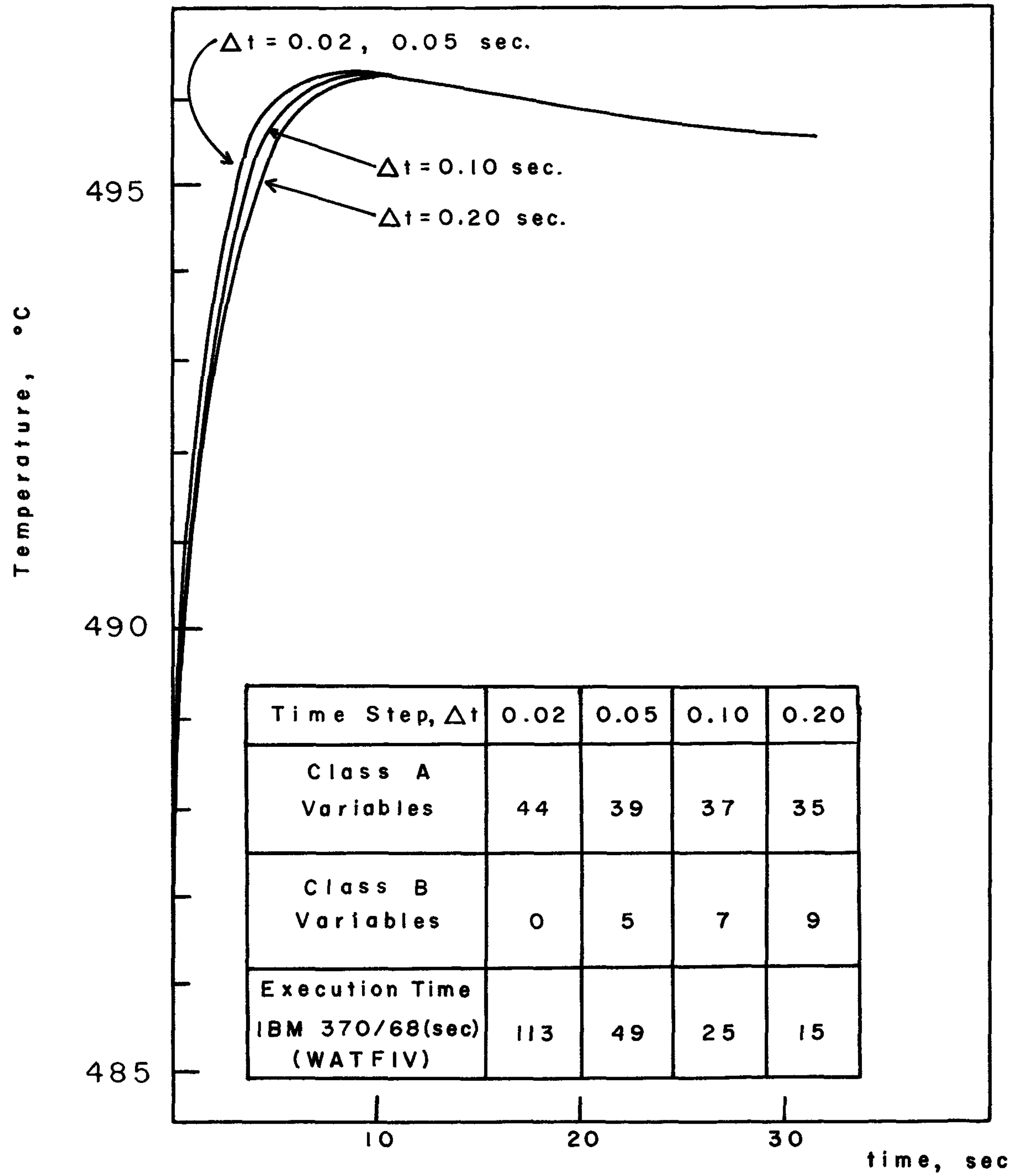
Those state variables that have prompt approximations are forced into the Class B status. Certain equations do not have prompt approximations (i.e. F_i is independent of X_i). For these equations, a "reasonable" time step (about 0.1 or 0.2 seconds) must be chosen to allow them to reach a steady state.

An example of this plant initialization technique is included as a sample problem in the appendices to this report.

A COMPARISON OF EXACT AND REDUCED SYSTEMS

A number of studies were made to determine the inaccuracies produced by the introduction of the quasi-static approximation. An example is included here as Figure 3-1. This example uses a single steam generator and header system decoupled from the rest of the plant (i.e., it represents only subroutine SGTHD1 and TURBO and their required ancillary programs).

It is observed that an increase in the time step greatly reduces computer execution time, while introducing very minor changes in the transient results. In the $\Delta t = 0.2$ case, all of the steam side superheater temperatures were Class B variables.



Time Step, Δt	0.02	0.05	0.10	0.20
Class A Variables	44	39	37	35
Class B Variables	0	5	7	9
Execution Time IBM 370/68(sec) (WATFIV)	113	49	25	15

Figure 3-1. Steam temperature at superheater outlet following a 11 °C increase in intermediate sodium inlet temperature, as computed by the EPRI-CURL code for various sizes of time steps.

Section 4

REACTOR POWER MODEL

The detailed description of the mathematical models and equations used in the EPRI-CURL Code is given in (6, 7).

The code model equations are given in this section to accompany the user guide description.

NEUTRON KINETICS

The point kinetics equations with a prompt jump approximation are used to simulate the nuclear power,

$$N(t) = \frac{\sum_{i=1}^{2} C_i(t)}{\beta-\rho} \tag{4-1}$$

$$\frac{dC_i(t)}{dt} = \lambda_i \, [\beta_i \, N(t) - C_i(t)], \; i = 1, 2, \tag{4-2}$$

where

$N(t)$ = total neutron power,

$C_i(t)$ = delayed neutron precursor power, group i,

ρ = total reactivity

β_i = delayed neutron fraction, group i,

$\beta = \sum_{i=1}^{2} \beta_i$, total delayed neutron fraction, and

λ_i = delayed neutron precursor decay constant, group i.

FISSION PRODUCT POWER

Three reduced groups of fission products are considered in determining the contributions of beta and gamma decay of the fission products to reactor power. The total fission product power may be written as,

$$F(t) = \sum_{i=1}^{3} F_i(t). \tag{4-3}$$

For each fission product group, the conservation of energy requires that,

$$\frac{dF_i(t)}{dt} = \lambda_i \, [\gamma_i \, P_T(t) - F_i(t)], \; i = 1, 2, 3, \tag{4-4}$$

where

$F_i(t)$ = fission product power, group i,

$F(t) = \sum_{i=1}^{3} F_i(t)$ = total fission product power,

λ_i = fission product decay constant, group i,

γ_i = fission product fraction group i, and

$P_T(t)$ = total reactor power given by Eq. 4-6.

For transients in which fission product densities have not reached their saturation values, the numerical values of the fission product fractions may be calculated from:

$$\beta_i = \beta_{si} \, [1 - \exp(-\lambda_i t_o)], \tag{4-5}$$

where

β_{si} = fission product fraction at saturation, group i, and

t_o = time during which the reactor has operated at power level P_T before the transient is initiated.

TOTAL REACTOR POWER

The total power of the fast reactor is obtained as the sum of contributions to power of neutrons and fission products; that is

$$P_T(t) = N(t) + F(t). \tag{4-6}$$

REACTIVITY FEEDBACKS

The temperature-dependence of the reactivity feedbacks has been included to simulate the eleven fuel regions and their respective sodium coolant regions with reactivities expressed in units of β.

$$P_{FB} = \sum_{i=1}^{11} \alpha_{Di} \ln[\bar{T}_{Fi}/T_{Fo}] + \sum_{i=1}^{11} \alpha_{Si} [\bar{T}_{ci}-T_{co}] \tag{4-7}$$

$$+ \alpha_R [T_c-T_{co}] + \sum_{i=1}^{11} \alpha_{Ai} [\bar{T}_{Fi}-F_{Fo}]$$

where:

ρ_{FB} = total feedback reactivity,
α_{Di} = nuclear doppler coefficient, fuel region i,
α_{Si} = sodium density coefficient, coolant region i,
α_R = radial core expansion coefficient,
α_{Ai} = axial core expansion coefficient, region i,
$\bar{T}_{Fi}$ = average fuel temperature, region i,
T_{Fo} = reference fuel temperature,
$\bar{T}_{ci}$ = average coolant temperature, region i,
T_{co} = reference coolant temperature,
T_c = average coolant inlet temperature,

and

i = 1 through 11 for the 11 fueled reactor regions (see Fig. 4-1).

PRIMARY AND SECONDARY CONTROL RODS; SCRAM OPERATION

The primary and secondary control rod systems are two completely independent systems for shutting down the reactor. In addition, the primary control rods are used for power control under normal operation.

Upon receipt of a primary or secondary scram signal, the affected rods begin to fall into the core. To account for scram assisting forces (scram spring in the primary system, hydraulic assist for the secondary rods) and drag forces, the rod

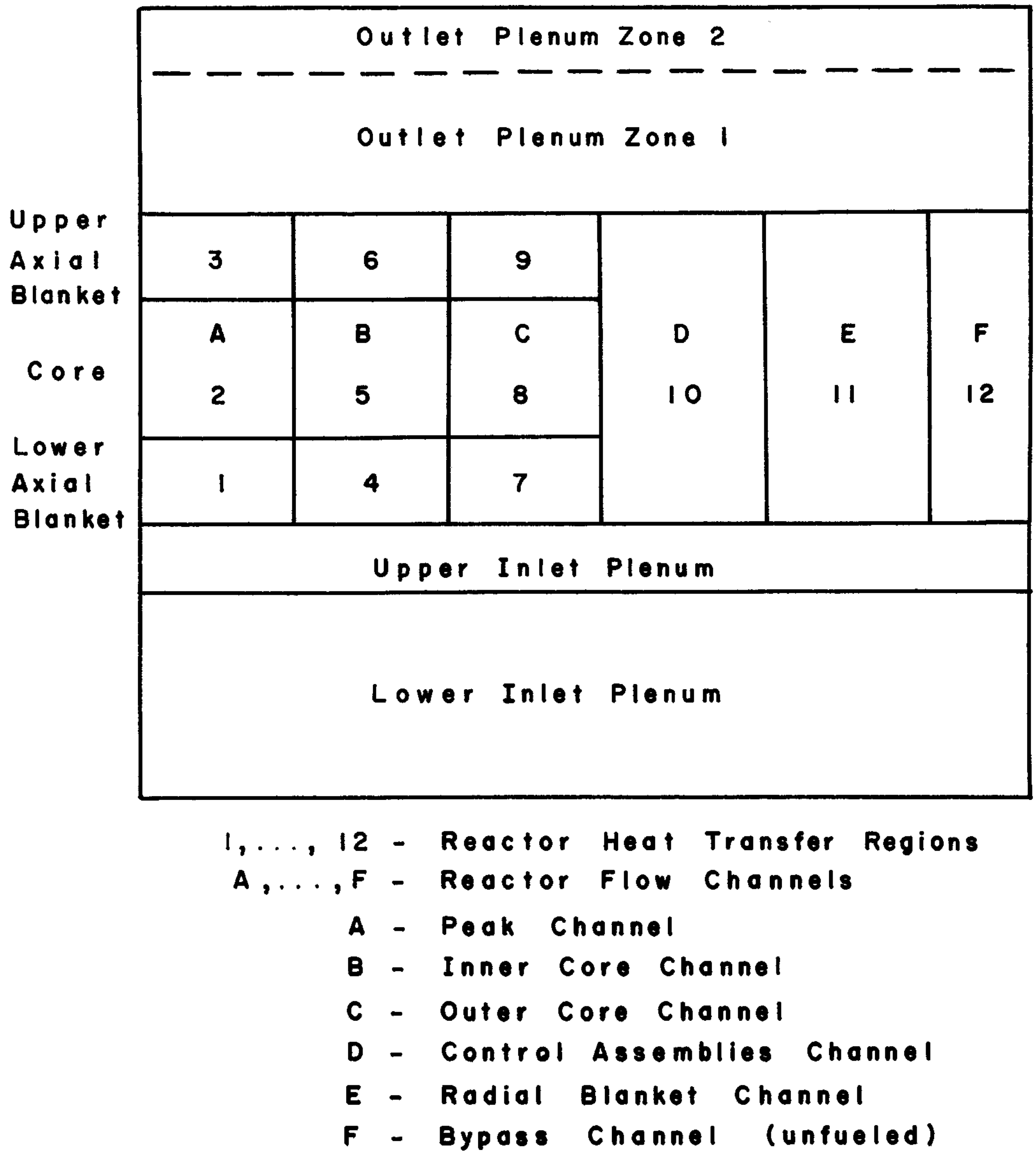


Figure 4-1. Reactor heat transfer regions and flow channels.

scram position is approximated by:

$$X = \frac{A \cdot t^2}{B \cdot t + 1} \quad ; \quad 0 \leq X \leq L, \tag{4-8}$$

where:

X = primary control rod scram position, (0 -- fully withdrawn, L -- fully inserted),
L = primary control rod stroke,
t = time after primary scram signal, and
A, B = input parameters chosen to fit insertion curve.

A similar equation exists for the secondary control rods.

The form of Eq. 4-8 was chosen in order to represent the initial rod insertion, where the relative reactivity change is important, as well as the central part of the curve, where the bulk of reactivity exists (see Fig. 4-2). Although the insertion of the last 20% of the rod is not as well represented, this is considered less important because over 95% of the control rod worth has already been inserted (see Eq. 4-9).

The scram reactivity of both the primary and secondary control rods is determined as a function of position using the "integral sine squared" control rod worth curve, i.e.:

$$\rho(x;t) = \rho_{max} \cdot \left(\frac{x}{L} - \frac{1}{2\pi} \sin \frac{2\pi x}{L}\right), \tag{4-9}$$

where:

$\rho(x;t)$ = reactivity worth of a control rod at position x,
ρ_{max} = total reactivity available for scram, and
L = maximum control rod stroke.

The reactivity available for scram in either system is defined as the total worth of rods withdrawn from the core less a stuck rod worth. Thus, in the primary system, the control rod reactivity in the core due to the power controller is as-

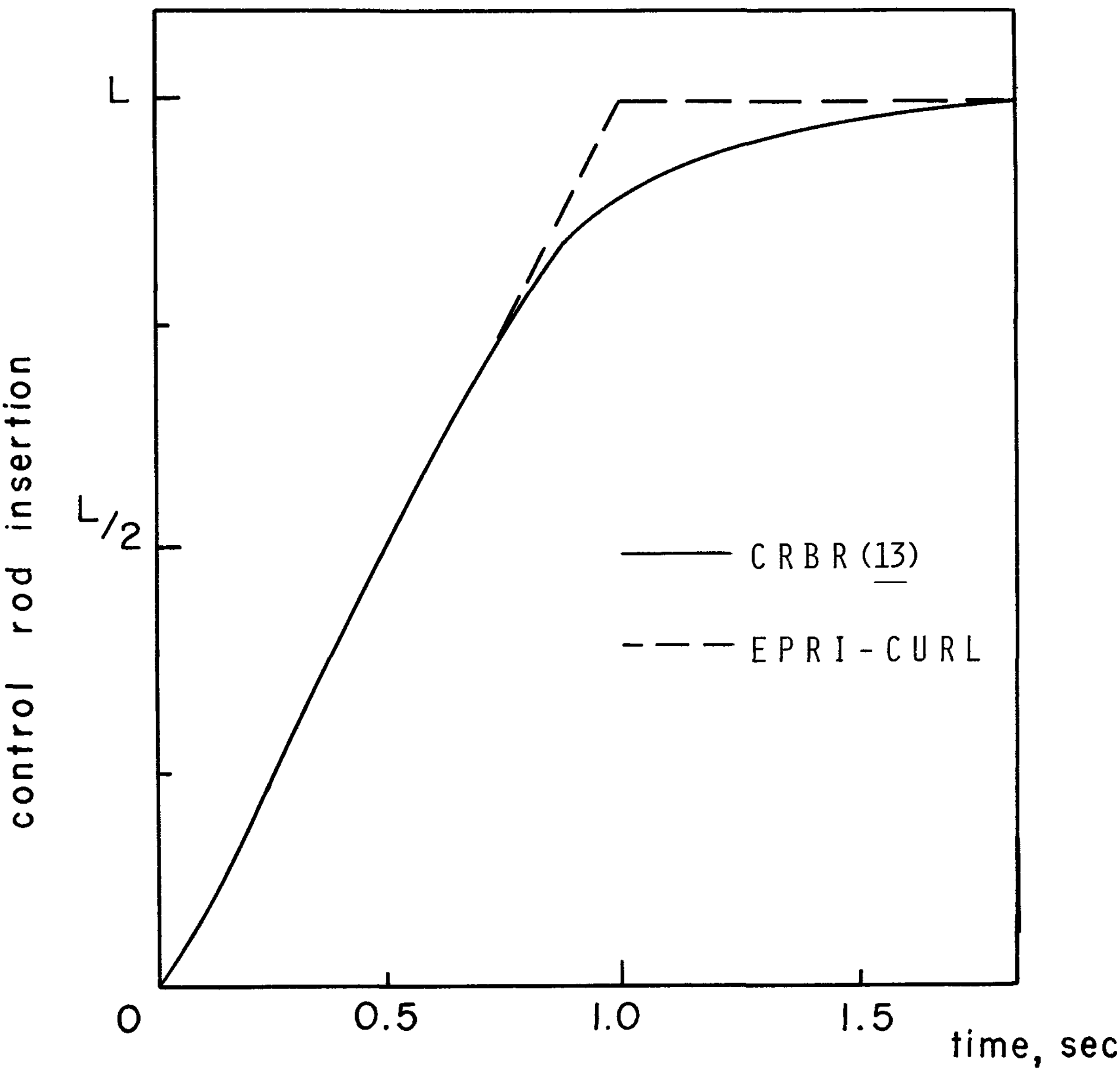


Figure 4-2. Comparison of control rod insertion rates between EPRI-CURL and the Clinch River Breeder Reactor. (Source: PSAR for CRBRP, Project Management Corp.)

sumed to be from fully inserted rods, and all other rods are fully withdrawn.

The equations that provide for reactor trip signals (and subsequent heat transfer system trip signals) are listed in Table 4-1 and 4-2.

REACTOR POWER CONTROLLER

The reactor power is controlled through the movement of the primary control rods. A proportional-integral (PI) control scheme was chosen, based on total primary rod reactivity.

The form of the control equation is as follows:

$$\frac{d\rho}{dt} = K \left(E_\phi + \frac{1}{\tau_I} \int_o^t E_\phi \, dt\right) \tag{4-10}$$

where:

ρ = control rod reactivity,

t = transient time,

E_ϕ = total flux deviation (see sec. 10, Fig. 10-1),

τ_I = integral time,

$$K = \frac{RMAX}{E_{\phi,max}\left(1 + \frac{t}{\tau_I}\right)}$$

RMAX = maximum allowed reactivity insertion rate, and

$E_{\phi,max}$ = saturation value of flux deviation.

The total worth inserted into the reactor is kept track of in order to know how much reactivity would be inserted for a primary scram signal.

Table 4-1

PRIMARY SYSTEM REACTOR TRIP EQUATIONS

Trip No.	Reason for Trip	Trip Equation
1	High Flux	$\phi \geq \phi$ max
2	Flux-Delayed Flux (RO>0)	$A_2 \cdot \int_{-\infty}^{t} \frac{e^{t/\tau}}{\tau} dt + B_2 \cdot \phi + C_2 \cdot \alpha_{ave} + D_2 \leq 0$
3	Flux-Delayed Flux (RO<0)	$A_3 \cdot \int_{-\infty}^{t} \frac{e^{t/\tau}}{\tau} dt + B_3 \cdot \phi + C_3 \cdot \alpha_{ave} + D_e \leq 0$
4	Flux - $\sqrt{\text{PRESSURE}}$	$A_4 \cdot \sqrt{P} + B_4 \cdot \phi + C_4 \leq 0$
5	Primary Pump Electrics	Loss of Power to Any Primary Pump
6	Primary-To-Intermediate Speed Ratio	$\left\|1 - \frac{\alpha_I}{\alpha_P} + \frac{C_6}{\alpha_P}\right\| - \frac{A_6}{\alpha_P} B_6 \geq 0$ in any loop
7	Reactor Vessel Level	$Z_{rv} < Z_L$
8	Steam-to-Feedwater Flow Ratio	$\left\|1 - \frac{W_{ST}}{W_{FW}}\right\| - A_8 \leq 0$ in any loop
9	IXH Primary Outlet Temperature	$T_{hx} \geq T_{shx}$ in any loop
10	Spare	

where A_i, B_i, C_i, D_i, ϕ max, τ, Z_L, T_{shx} are input parameters,

ϕ = normalized flux,
t = time,
α = normalized pump speed,
W = normalized flow rate,
P = normalized pressure at reactor inlet,
Z_{rv} = sodium level above reactor outlet nozzle,
T_{hx} = temperature at outlet of heat exchanger,

and subscripts:

ave = average of all primary,
I = intermediate,
ST = steam,
P = primary, and
FW = feedwater.

Table 4-2

SECONDARY SYSTEM REACTOR TRIP EQUATIONS

Trip No.	Reason for Trip	Trip Equation
11	Flux -- Total Flow	$A_{11} \cdot W_{TP} + B_{11} \cdot \phi + C_{11} \leq 0$
12	Primary-To-Intermediate Flow Ratio	$\left\lvert 1 - \frac{W_I}{W_P} + \frac{C_{12}}{W_P} \right\rvert - \frac{A_{12}}{W_P} - B_{12} \leq 0$ in any loop
13	Steam Drum Level	$\lvert 1 - H_D \rvert > H_{D,max}$
14	Evaporator Outlet Temperature	$T_{ev} \geq T_{sev}$ in any loop
15	Spare	

where A_i, B_i, C_i, T_{sev}, $H_{D,max}$ are input parameters,

ϕ = normalized flux,

W = normalized flow rate,

T_{ev} = temperature at outlet of evaporator,

H_D = normalized steam drum level,

and subscripts:

TP = total primary system,

P = primary, and

I = intermediate.

Section 5

REACTOR HEAT TRANSFER MODEL

The reactor heat transfer model consists of five radial core regions, an unheated core bypass region and two inlet plenum, and two outlet plenum regions.

The model calculates the transient sodium and fuel temperatures using a lumped parameter method.

The possibility of flow reversal in the above regions has also been included to insure accurate prediction of fuel and coolant temperatures during transient conditions (7).

Figure 5-1 shows an example of a core division, and Figure 5-2 describes the reactor coolant paths. Figure 4-1 shows the heat transfer regions.

REACTOR INLET PLENUM

Two constant volume, perfectly mixed zones of inlet plenum sodium temperatures are calculated neglecting the heat capacity of the plenum structural materials.

The lower zone consists of the main inlet plenum, and the upper zone contains the region from which the coolant is orificed into the reactor fuel assemblies.

The sodium temperature in the lower zone is calculated from:

$$\rho_A V_A C_A \frac{dT}{dt} A = W_1 \bar{C}_1 (T_1 - T_A) + NW_2 \bar{C}_2 (T_2 - T_A). \tag{5-1}$$

The upper zone sodium temperature is given by:

$$\rho_B V_B C_B \frac{dT}{dt} B = (W_1 + NW_2) \bar{C}_{AB} (T_A - T_B) - \sum_{i=1}^{6} W_{ci} C_{ci} T_{ci} \tag{5-2}$$

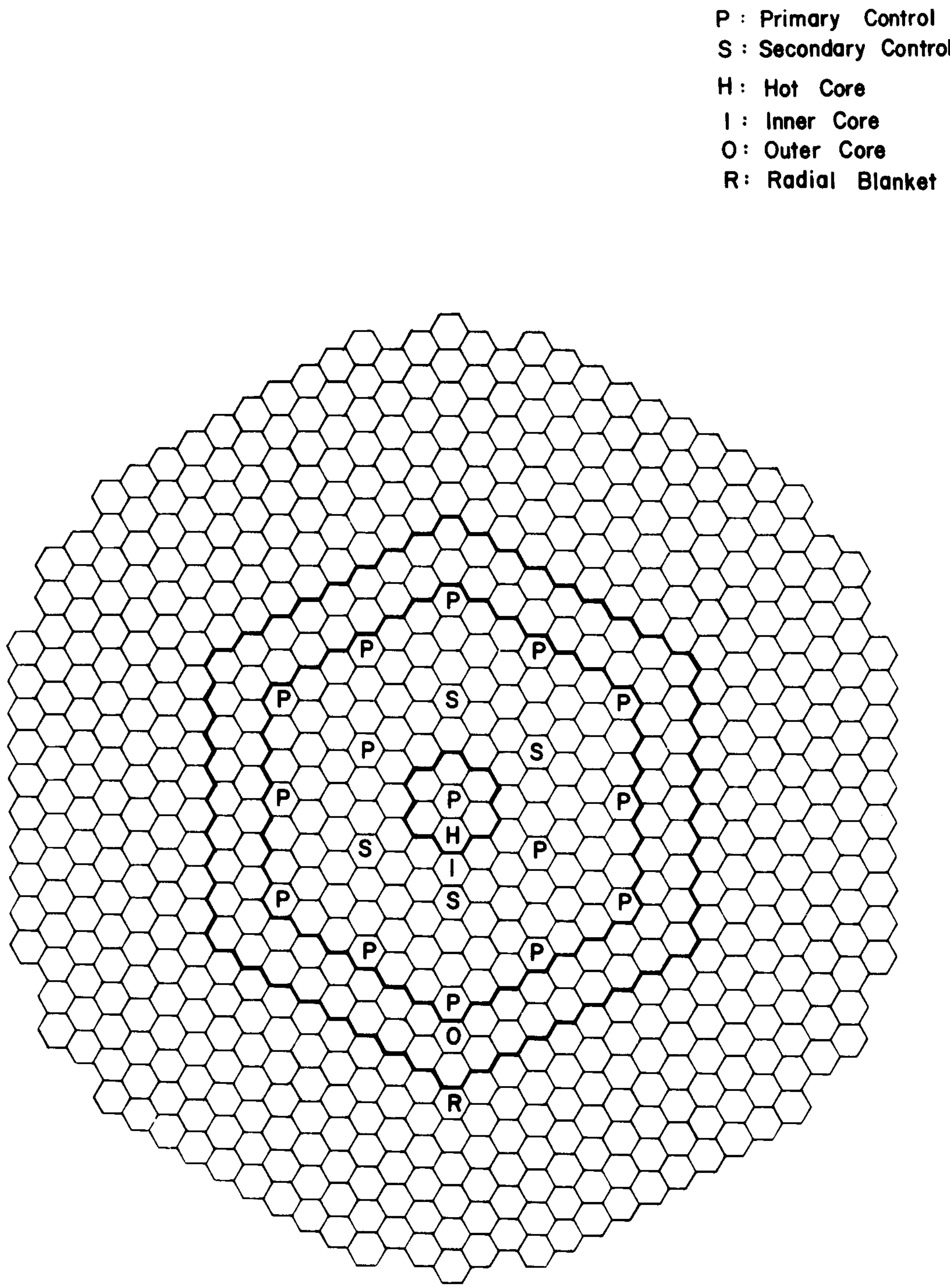


Figure 5-1. An Example of a Core Division

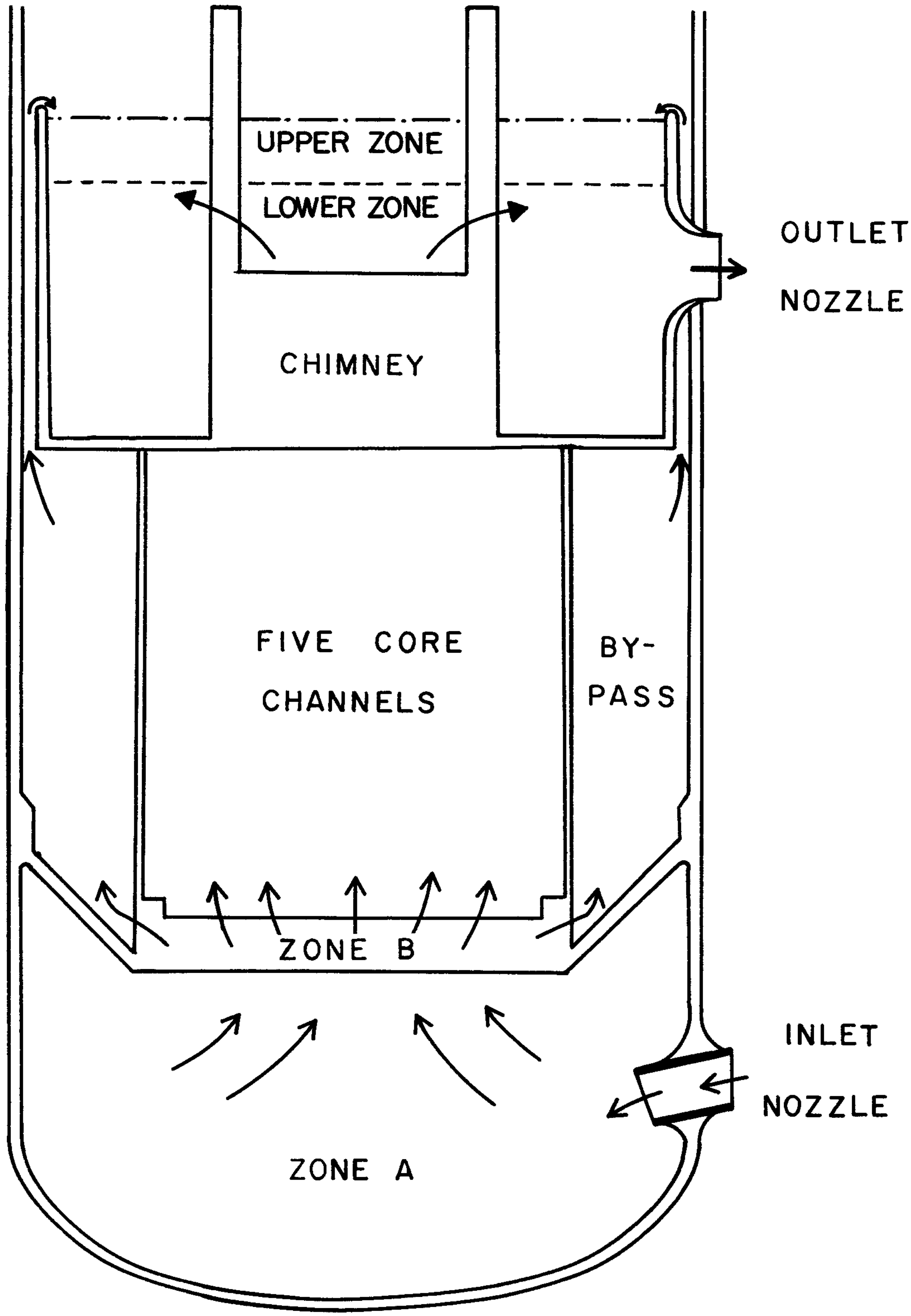


Figure 5-2. Reactor Enclosure and Coolant Paths

where

T = sodium temperature,

t = time,

C = heat capacity of sodium at constant pressure,

ρ = density of sodium,

V = sodium volume,

W_1 = sodium flow rate of the single loop,

W_2 = sodium flow rate of the lumped loop,

W_c = sodium flow rate of the core channel,

N = n-1, and

n = number of heat transport loops in the system;

subscripts:

A = lower plenum zone,

B = upper plenum zone,

ci = core i^{th} channel,

1 = single loop, and

2 = lumped loop.

REACTOR OUTLET PLENUM

A two zone mixing model based on the lumped-parameter approach (9) has been used to simulate the outlet plenum sodium temperatures neglecting the heat storage effect in the structural materials of the outlet reactor plenum.

The sodium temperature in the lower mixing zone is given by:

$$\rho_L V_L C_L \frac{dT_L(t)}{dt} = \sum_{i=1}^{5} W_{ci} C_{ci} \left[T_{ci} - T_L\right] + \beta_2 W_{BP} C_{L-u} (T_u - T_L) - hA(T_L - T_u) \qquad (5-3)$$

and, the upper zone sodium temperature is given by:

$$\rho_u V_u C_u \frac{dT_u(t)}{dt} = W_{BP} C_{BP-u} (T_{BP} - T_u) + \beta_1 [\sum_{i=1}^{5} W_{ci}] C_{L-u} (T_L - T_u) + hA(T_L - T_u) \quad (5\text{-}4)$$

where:

T = sodium temperature,

t = time,

C = heat capacity of sodium at constant pressure,

ρ = density of sodium

V = sodium volume

h = constant heat transfer coefficient between the outlet plenum zones,

A = cross-sectional area of outlet plenum,

W = sodium mass flow rate, and

β_1, β_2 = control integers (see the following discussion);

subscripts (two subscripts indicate that the physical property is taken at the average of the two zones):

L = lower zone of outlet plenum,

ci = core i^{th} channel,

BP = bypass channel, and

u = upper zone of outlet plenum.

The average jet penetration distance is given by (9):

$$Z_J = (1.0383\ Fr_o^{0.785}) r_o + Z_{ch}, \quad (5\text{-}5)$$

where:

Z_J = jet penetration distance in the outlet plenum,

Fr_o = densometric Froude number,

$$\equiv \left[\frac{W_c}{\pi r_o^2 \rho_c}\right]^2 \left[\frac{\rho_L}{g\, r_o (\rho_c - \rho_L)}\right]$$

r_o = radial coordinate of the jet flow,

Z_{ch} = chimney height,

$$W_c = \sum_{i=1}^{5} W_{ci},$$

ρ_c = average core sodium density, and

g = acceleration due to gravity.

The control integers β_1 and β_2 are defined as follows:

$$\left.\begin{aligned}\beta_1 &= 0\\ \beta_2 &= 1\end{aligned}\right\} \quad \text{For } Z_J \geq Z_{on} + 0.5\, D_{on},$$

$$\left.\begin{aligned}\beta_1 &= 0\\ \beta_2 &= 0\end{aligned}\right\} \quad \text{For } Z_{on} - 0.5\, D_{on} < Z_J < Z_{on} + 0.5\, D_{on},$$

$$\left.\begin{aligned}\beta_1 &= 1\\ \beta_2 &= 0\end{aligned}\right\} \quad \text{For } Z_J \leq Z_{on} - 0.5\, D_{on},$$

Z_{on} = reactor outlet nozzle height (lower edge), and

D_{on} = reactor outlet nozzle diameter.

REACTOR FUEL REGIONS

The reactor core is divided into five parallel channels consisting of:

1. peak channel,
2. inner core channel,
3. outer core channel,
4. control assemblies channel, and
5. radial shields and radial blanket channel.

There exists three axial fuel regions in the peak, inner and outer core channels consisting of lower axial blanket, reactor core and the upper axial blanket regions.

Figure 5-3 shows the schematics of the reactor fuel regions that are simulated by

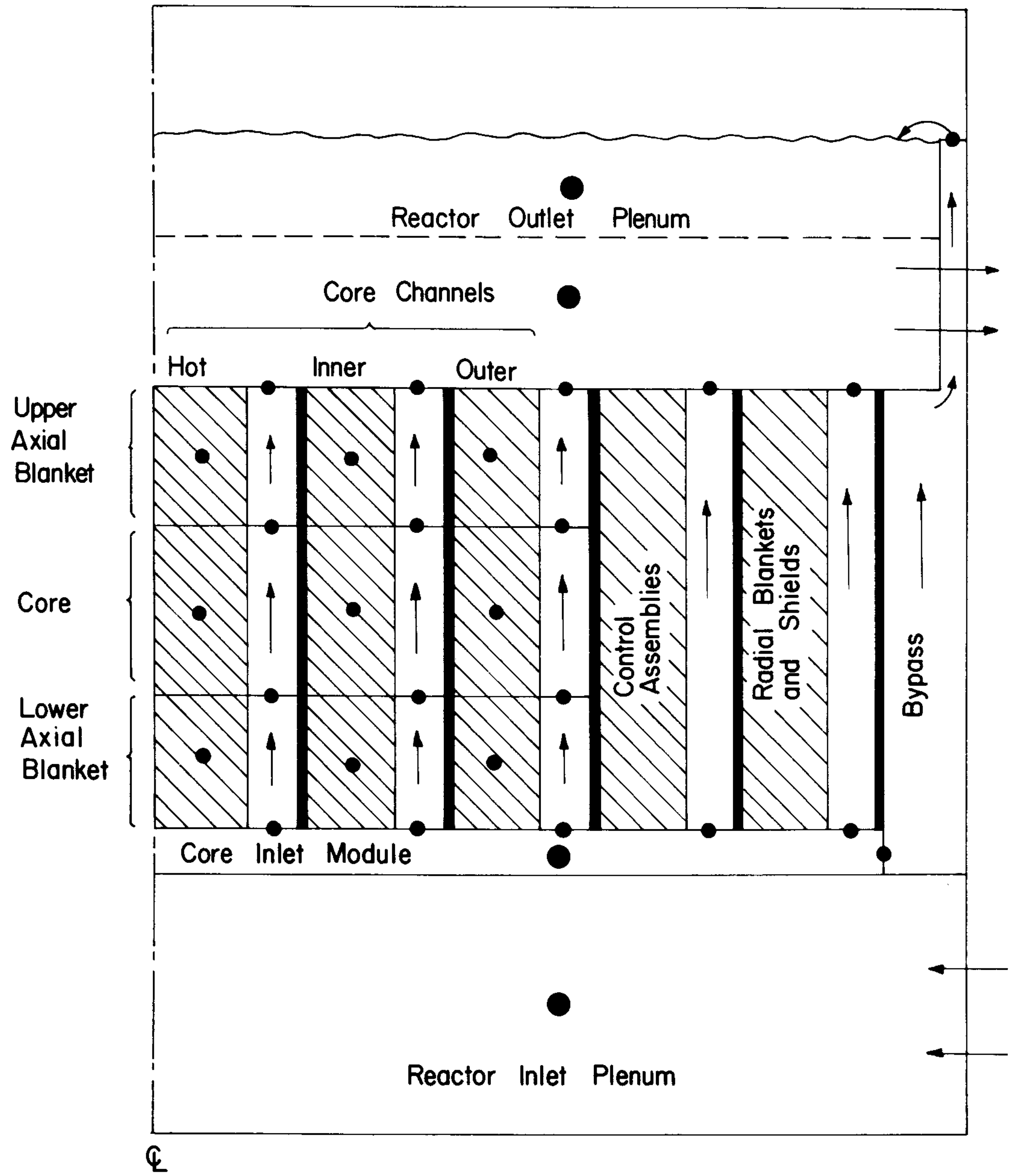


Figure 5-3. Reactor Heat Transfer Regions

the EPRI-CURL Code.

The following is the lumped parameter energy equation that simulates the above fuel temperatures in each region j (j = 1, 11) (see Fig. 4-1 for region numbers):

$$\rho_F V_F C_F \frac{dT_F}{dt} = Q_F''' V_F - U A [T_F - \bar{T}_C] \quad (5\text{-}6)$$

where:

ρ_F = fuel density,
V_F = fuel volume,
C_F = fuel specific heat,
T_F = fuel average temperature,
t = time,
Q_F''' = average heat density,
U = overall heat transfer coefficient (given by Eq. 5-11),
A = total heat transfer area,
$\bar{T}_C$ = average sodium temperature,
= $(Tc_{in} + Tc_o)/2.0$, and
Tc_{in} = sodium temperature at the inlet of region j,
Tc_o = sodium temperature at the outlet of region j.

REACTOR COOLANT REGIONS

The sodium temperature at the outlet of every control volume corresponding to the above mentioned fuel regions (j = 1, 11) and the bypass (j = 12) is given by:

$$\bar{\rho}_c V_c \bar{C}_c \frac{dT_{c_o}}{dt} = U A [T_F - \bar{T}_C] - W \bar{C} (T_{c_{in}} - T_{c_o}), \quad (5\text{-}7)$$

where

$\bar{\rho}_c$ = average sodium density,
V_c = volume of sodium,
$\bar{C}_c$ = average heat capacity of sodium, and
W = sodium mass flow rate.

The thermophysical properties of liquid sodium are calculated as a function of average sodium temperature in the region. Note that U = 0.0 for the bypass channel.

During flow reversal in any of the reactor channels, the equation form will remain the same except sodium inlet and outlet temperatures to the given region will switch.

HOT CHANNEL EQUATIONS

The reactor peak region transient temperatures are used to determine the hot channel conditions in the reactor.

The centerline temperature of a cylindrical fuel rod is calculated using:

$$T_o = T_F + \frac{Q''' R^2}{8k_f} , \tag{5-8}$$

where:

T_o = center-line fuel temperature,
T_F = average fuel temperature (given by Eq. 5-6),
Q''' = average fuel heat density,
R = fuel pellet radius, and
k_f = fuel pellet average thermal conductivity.

Two statistical hot channel temperatures of significance are calculated: the maximum core outlet coolant temperature and the maximum cladding temperature, as follows:

Maximum Core Outlet Sodium Temperature

$$T_{c,max} = T_{c_{in}} + \alpha_{c,hc} \cdot \overline{\Delta T}_{c_{hc}} \tag{5-9}$$

$$= (1-\alpha_{c,hc})\, T_{c_{in}} + \alpha_{c,hc}\, T_{c,\,core} ,$$

where:

$T_{c,\,max}$ = maximum outlet sodium temperature,

$T_{c,\ in}$ = peak region inlet sodium temperature,

$T_{c,\ core}$ = peak region core outlet sodium temperature,

$\alpha_{C,HC}$ = coolant hot channel factor,

$= \alpha_{\substack{flow \\ maldistribution}} \times \alpha_{radial} \times \alpha_{\substack{local \\ pin}} \times \alpha_{statistical}$, where:

$\left.\begin{array}{l} \alpha_{\substack{flow \\ distribution}} \\ \alpha_{radial} \\ \alpha_{\substack{local \\ pin}} \\ \alpha_{statistical} \end{array}\right\}$ Hot channel factors.

<u>Maximum Cladding Midwall Temperature</u>

$$T_{\substack{clad \\ max}} = T_{c,max} + \alpha_{film}\, \bar{\Delta}T_{film} + \alpha_{clad}\, \bar{\Delta}T_{clad} \tag{5-10}$$

where:

$T_{\substack{clad \\ max}}$ = maximum cladding midwall temperature,

$T_{c,max}$ = maximum coolant temperature (see Eq. 5-9),

$\bar{\Delta}T_{film}$ = average film temperature difference at the top of the reactor core in the peak region,

$\bar{\Delta}T_{clad}$ = average cladding temperature difference (between inner and outer surfaces) at the top of the reactor core in the peak region, and

$\left.\begin{array}{l} \alpha_{film} \\ \alpha_{clad} \end{array}\right\}$ hot channel factors.

OVERALL HEAT-TRANSFER COEFFICIENT FOR THE REACTOR ASSEMBLIES

Throughout the analysis the following modes of heat transfer were assumed:

1. conduction in the fuel material,

2. conduction in the gas filled gap, and

3. convection at the interface between cladding and coolant.

Therefore, the quasi-steady state approximation yields, for each region j (j = 1, 11):

$$U\,A = \left[\frac{\pi\ N\ L}{1/(8\ k_f) + \delta_g/(2K_g\ R) + 1/(2\ K_c)\ \ln\ (D/D-\delta_c) + 1/(h\ D)}\right], \qquad (5\text{-}11)$$

where:

U = overall heat transfer coefficient,

A = overall heat transfer area,

π = 3.1415,

N = total number of fuel pins under consideration,

L = effective length of fuel pin,

k_f = average thermal conductivity of fuel,

k_g = average thermal conductivity of gas filled gap,

k_c = average thermal conductivity of cladding,

D = pin outside diameter,

R = fuel radius,

δ_g = gas filled gap thickness,

δ_c = cladding thickness, and

h = convection heat-transfer coefficient.

Due to the triangular arrangement of the rod bundles, the flow area consists of a large number of parallel "tubes." Two different equivalent diameters have been calculated for each type of assembly: a hydraulic equivalent diameter, D_h, and a thermal equivalent diameter, D_t.

Thus

$$D_h = \frac{4 \cdot A_h}{P}, \qquad (5\text{-}12)$$

and

$$D_t = D\left[\frac{6\,(p/D)^2}{\pi\sqrt{3}} - 1\right], \qquad (5\text{-}13)$$

where:

A_h = total flow cross sectional area per assembly,
P = wetted perimeter per assembly,
D = rod outside diameter, and
p = pitch.

The following heat transfer coefficient correlations have been used:

a) Laminar Flow (16), $Re \leq 3000$

$$Nu = \frac{h D_t}{k} = 48/11 \simeq 4.36, \tag{5-14}$$

b) Turbulent Flow (17), $Re > 3000$

$$Nu = \frac{h D_t}{k} = 7. + 0.025 (\bar{\Psi} \ Pe)^{0.8}, \tag{5-15}$$

where:

$Re = \frac{\rho V D_h}{\mu}$ = Reynolds number ,

Nu = Nusselt number ,

$Pe = Re \cdot Pr$ = Peclet number ,

$Pr = \frac{\mu C_p}{k}$ = Prandtl number ,

$\bar{\Psi} = \frac{\varepsilon_H}{\varepsilon_M}$ = the average, effective value of the ratio of eddy diffusivity of heat transfer to that for momentum transfer = 1.0,

ρ = sodium density,
V = sodium velocity,
μ = sodium dynamic viscosity,
c_p = sodium heat capacity at constant pressure, and
k = sodium thermal conductivity.

Section 6

PRIMARY LOOP COOLANT DYNAMICS

GENERAL EQUATION OF MOTION

Transient sodium flow rates are calculated using the time-dependent equation of motion for an incompressible fluid.

Several simplifying assumptions are made in order to solve the problem while retaining the accuracy of the model:

1. a one-dimensional flow is considered,
2. the flow is incompressible,
3. fluid velocity is taken as an average over the pipe cross section, and
4. the macroscopic form of the basic equation of motion is used.

Based on these assumptions, the following equation is derived (6, 7):

$$a \frac{dW}{dt} = (P_1 - P_2) + g \bar{\bar{\rho}} (Z_1 - Z_2) + \frac{W^2}{2} \left(\frac{1}{A_1} + \frac{1}{A_2}\right) \left(\frac{1}{\rho_1 A_1} - \frac{1}{\rho_2 A_2}\right) - \frac{c}{\bar{\bar{\rho}}} W|W| \tag{6-1}$$

where:

a = inertial loss coefficient

$$\equiv \int_{x_1}^{x_2} \frac{dx}{A} \simeq \sum_{i=1}^{N} \frac{x_i}{A_i}$$

x = dimension in the direction of flow,

A = pipe cross-sectional area,

g = gravitational acceleration,

W = mass flow rate,

t = time,

P_1 = pressure at position x_1,

P_2 = pressure at position x_2,

$\bar{\bar{\rho}}$ = average density of the fluid

$= (\rho_1 + \rho_2)/2$,

ρ_1 = fluid density at position x_1,

ρ_2 = fluid density at position x_2,

Z_1 = relative elevation corresponding to x_1,

Z_2 = relative elevation corresponding to x_2,

c = frictional loss coefficient

$$\equiv \frac{1}{2}\int_{x_1}^{x_2} \frac{4f}{d_i A_i^2}\, dx \approx \frac{1}{2}\left[\sum_{i=1}^{N} \frac{4f_i \,\Delta x_i}{d_i \,A_i^2} + \sum_{i=1}^{M} \frac{K_i}{A_i^2}\right]$$

$4f$ = moody friction factor given below,

d_i = hydraulic diameter,

K = velocity head factor,

N = number of pipe sections of constant area,

M = number of pipe fittings,

A_1 = pipe cross sectional area corresponding to x_1, and

A_2 = pipe cross sectional area corresponding to x_2.

Normally A_1 and A_2 are equal as one applies equations 6-1 around a closed loop, and hence that term is normally neglected.

FRICTION FACTORS

Fluid friction correlations for the entire flow regime are required by the EPRI-CURL code. The following is a compilation of the friction factor correlations that have been selected.

Turbulent Regime Re > 3000

Wire-wrapped Fuel Rod Bundles. For the reactor wire-wrapped rod bundles, the following correlation for friction factor is used (10).

$$4f = \left[\frac{1.034}{(p/D)^{0.124}} + \frac{29.7\ (p/D)^{6.94}\ Re^{0.086}}{(L/D)^{2.239}}\right]^{0.885} 0.316\ Re^{-0.25} \qquad (6\text{-}2)$$

where:

$4f$ = moody friction factor,

p = pitch,

D = rod diameter,

L = spiral wire spacer lead, and

Re = reynolds number.

This equation is found to compare favorably with the FFTF experiments where $P/D > 1.08$.

Smooth Pipe. The following smooth pipe correlation is used in the EPRI-CURL Code (18):

$$4f = 0.0055 + 0.55\ (Re)^{-1/3} \tag{6-3}$$

Transition Regime $2000 \leq Re \leq 3000$

A linear extrapolation is used from the turbulent correlation (fuel bundle or smooth pipe) value at Re = 3000 to the laminar correlation value at Re = 2000.

Laminar Regime $Re < 2000$

The laminar flow friction factor is given by

$$4f = \frac{64}{Re} \tag{6-4}$$

The Reynolds number is calculated at the bulk temperature of the fluid in all of the thermal-hydraulics calculations.

PRIMARY FLOW MODEL

Six flows are simulated through the reactor. With the notation of Fig. 6-1 these flows are:

W_{HC} = total flow rate in the peak core assemblies,

W_{IC} = total flow rate in the inner core assemblies,

W_{OC} = total flow rate in the outer core assemblies,

W_{CA} = total flow rate in the primary control assemblies,

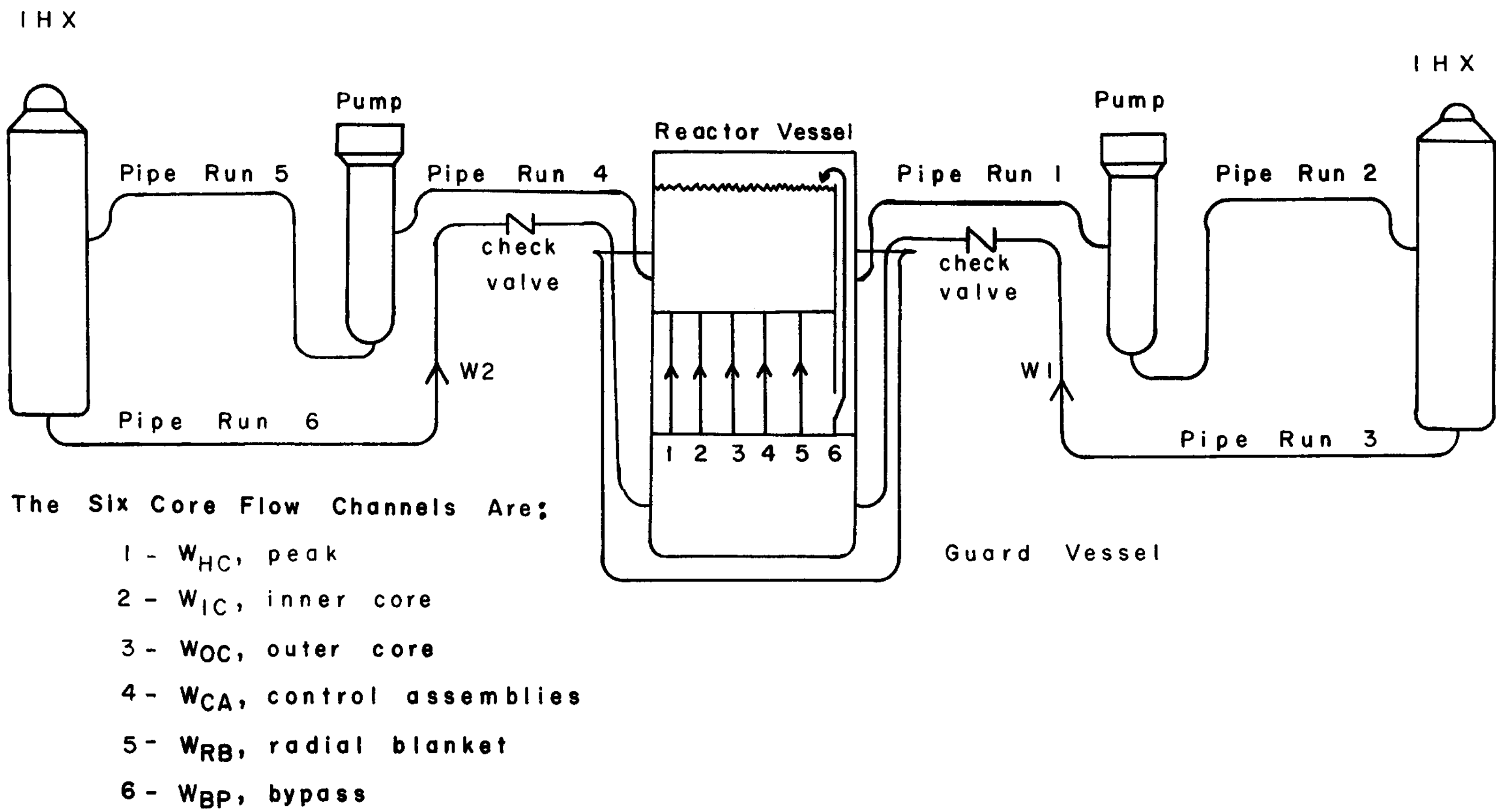


Figure 6-1. Primary System Flows and Piping Schematic

W_{RB} = total flow rate in the radial blanket assemblies, and

W_{BP} = total flow rate in the core bypass.

There are eight primary flow rates in the coolant dynamics model: six through the reactor and two in the heat transport system (HTS) loops. One loop flow, W_1, represents a single HTS loop, and the other, W_2, represents each of remaining identical loops.

Seven of the eight flow rates are determined by applying Eq. 6-1 successively around HTS loop 1 through each of the six reactor regions and once around HTS loop 2 through the inner core region, resulting in seven equations. The eighth flow rate, W_{IC}, is determined by assuming mass conservation in the system, i.e.:

$$W_{IC} = W_1 + (N-1) \cdot W_2 - W_{HC} - W_{OC} - W_{CA} - W_{RB} - W_{BP} \tag{6-5}$$

where

N = number of HTS loops in the system.

The other seven equations may be rewritten in the form:

$$\underline{A}\ \underline{X} = \underline{Y}, \tag{6-6}$$

where $\underline{A}$ is a 7 by 7 matrix of inertial loss coefficients (see Table 6-1),

$$\underline{X} = \begin{bmatrix} dW_1/dt \\ dW_2/dt \\ dW_{OC}/dt \\ dW_{HC}/dt \\ dW_{CA}/dt \\ dW_{RB}/dt \\ dW_{BP}/dt \end{bmatrix},$$

and $\underline{Y}$ is the flow dependent vector of the right hand side terms of Eq. 6-1 (7).

Because the inertial loss coefficients in the matrix $\underline{A}$ are constant during any

Table 6-1

MATRIX OF INERTIAL LOSS COEFFICIENTS,
NORMAL OPERATION

$$
\underline{A} = \begin{vmatrix}
a_1+a_P+a_{IC} & 2\cdot(a_P+a_{IC}) & -a_{IC} & -a_{IC} & -a_{IC} & -a_{IC} & -a_{IC} \\
a_1+a_P & 2\cdot a_P & a_{OC} & 0 & 0 & 0 & 0 \\
a_1+a_P & 2\cdot a_P & 0 & a_{HC} & 0 & 0 & 0 \\
a_1+a_P & 2\cdot a_P & 0 & 0 & a_{CA} & 0 & 0 \\
a_1+a_P & 2\cdot a_P & 0 & 0 & 0 & a_{RB} & 0 \\
a_1+a_P & 2\cdot a_P & 0 & 0 & 0 & 0 & a_{BP} \\
a_P+a_{IC} & a_2+2\cdot(a_P+a_{IC}) & -a_{IC} & -a_{IC} & -a_{IC} & -a_{IC} & -a_{IC}
\end{vmatrix}
$$

where:

a = inertial loss coefficient;

and subscripts:

IC, OC, HC, CA, RB, BP = six core flow channels (see Fig. 6-1),
P = inlet and outlet plena taken together,
1 = loop 1 piping, and
2 = loop 2 piping.

transient, Eq. 6-6 may be inverted to the form:

$$\underline{X} = \underline{A}^{-1}\,\underline{Y}, \tag{6-7}$$

which gives the derivative of each flow independently.

For the case of a pipe rupture in loop 1, another flow, W_{BRK} (between the break and the reactor vessel inlet nozzle), is required. An additional equation is obtained by applying Eq. 6-1 from the outlet nozzle to the rupture and into the guard vessel. The pressure at the outlet nozzle is obtained by considering the gravitational head up to the cover gas, where the pressure is known. This added equation depends only on one derivative, dW_1/dt, and is thus already independent of the other seven differential equations. Equations 6-6 and 6-7 are again used to solve for the seven flow derivatives, with $\underline{A}$ now as seen in Table 6-2, $\underline{Y}$ altered by replacing dW_1/dt by its analytical equivalent (from the added equation) (7), and

$$\underline{X} = \begin{bmatrix} dW_{BRK}/dt \\ dW_2/dt \\ dW_{OC}/dt \\ dW_{HC}/dt \\ dW_{CA}/dt \\ dW_{RB}/dt \\ dW_{BP}/dt \end{bmatrix}$$

The pressure drop out the break is determined using a rupture loss coefficient and gravity head consideration, i.e.

$$P_{BRK} = CD \cdot W_{out} \cdot |W_{out}| + \Delta P_G + P_V \tag{6-8}$$

where:

P_{BRK} = pressure of coolant inside of the break,

CD = rupture loss coefficient,

$W_{out} = W_1 - W_{BRK}$ = flow out the break,

ΔP_G = gravitational head built up in guard vessel (= 0 until guard vessel fills to the pipe rupture point), and

P_V = atmospheric pressure inside the guard vessel.

Table 6-2

MATRIX OF INERTIAL LOSS COEFFICIENTS,
PIPE RUPTURE

$$\underline{A} = \begin{vmatrix} a_B+a_P+a_{IC} & 2\cdot(a_P+a_{IC}) & -a_{IC} & -a_{IC} & -a_{IC} & -a_{IC} & -a_{IC} \\ a_B+a_{IC} & 2\cdot a_P & a_{OC} & 0 & 0 & 0 & 0 \\ a_B+a_{IC} & 2\cdot a_P & 0 & a_{HC} & 0 & 0 & 0 \\ a_B+a_{IC} & 2\cdot a_P & 0 & 0 & a_{CA} & 0 & 0 \\ a_B+a_{IC} & 2\cdot a_P & 0 & 0 & 0 & a_{RB} & 0 \\ a_B+a_{IC} & 2\cdot a_P & 0 & 0 & 0 & 0 & a_{BP} \\ a_{IP}+a_{IC} & a_2+2\cdot(a_P+a_{IC}) & -a_{IC} & -a_{IC} & -a_{IC} & -a_{IC} & -a_{IC} \end{vmatrix}$$

where:

a = inertial loss coefficient;

and subscripts:

IC, OC, HC, CA, RB, BP = six core flow channels (see Fig. 6-1),
P = inlet and outlet plena taken together,
IP = inlet plenum only,
1 = loop 1 piping,
2 = loop 2 piping, and
B = piping from break location to reactor inlet nozzle.

REACTOR COVER GAS

Since the primary pumps are located on the hot legs of the PHTS, the cover gas is kept at near atmospheric pressure. In the EPRI-CURL calculations, the cover gas pressure is calculated by applying a gravity head to the initial (input) value for the pressure at the reactor vessel outlet nozzle. At present, the cover gas pressure is held constant for the duration of the transient (7).

COOLANT PUMPS

The pumps are described by a so-called homologous model (19). The model gives relationships among the variable head (H), torque (T_P), flow rate (W), and rotational speed (ω). First these variables are normalized by dividing each one by its value at rated conditions. Thus the new variables are:

$\delta = H/H_D$ = normalized head = $f(\alpha,\nu)$

$\beta = T_P/T_{P,D}$ = normalized pump torque = $g(\alpha,\nu)$

$\alpha = \omega/\omega_D$ = normalized pump speed

$\nu = W/W_D$ = normalized mass flow rate

where:

H_D = design head

$T_{P,D}$ = design torque

ω_D = design speed

W_D = design flow

The following functional relationships appear to quite adequately fit the characteristics of centrifugal flow pumps (19).

$\left|\frac{\nu}{\alpha}\right| \leq 1;\ \alpha > 0$

$$\delta = \alpha^2 \left[A_1 + A_2 \left(\frac{\nu}{\alpha}\right) + A_3 \left(\frac{\nu}{\alpha}\right)^2 + A_4 \left(\frac{\nu}{\alpha}\right)^3\right] \qquad (6\text{-}9)$$

$$\beta = \alpha^2 \left[B_1 + B_2 \left(\frac{\nu}{\alpha}\right) + B_3 \left(\frac{\nu}{\alpha}\right)^2 + B_4 \left(\frac{\nu}{\alpha}\right)^3\right] \qquad (6\text{-}10)$$

$\left|\frac{\nu}{\alpha}\right| \leq 1;\ \alpha < o$

$$\delta = \alpha^2\ [A_5 + A_6 \left(\frac{\nu}{\alpha}\right) + A_7 \left(\frac{\nu}{\alpha}\right)^2 + A_8 \left(\frac{\nu}{\alpha}\right)^3] \qquad (6\text{-}11)$$

$$\beta = \alpha^2\ [B_5 + B_6 \left(\frac{\nu}{\alpha}\right) + B_7 \left(\frac{\nu}{\alpha}\right)^2 + B_8 \left(\frac{\nu}{\alpha}\right)^3] \qquad (6\text{-}12)$$

$\frac{\alpha}{\nu} < 1;\ \nu > o$

$$\delta = \nu^2\ [C_1 + C_2 \left(\frac{\alpha}{\nu}\right) + C_3 \left(\frac{\alpha}{\nu}\right)^2 + C_4 \left(\frac{\alpha}{\nu}\right)^3] \qquad (6\text{-}13)$$

$$\beta = \nu^2\ [D_1 + D_2 \left(\frac{\alpha}{\nu}\right) + D_3 \left(\frac{\alpha}{\nu}\right)^2 + D_4 \left(\frac{\alpha}{\nu}\right)^3] \qquad (6\text{-}14)$$

$\frac{\alpha}{\nu} < 1;\ \nu > o$

$$\delta = \nu^2\ [C_5 + C_6 \left(\frac{\alpha}{\nu}\right) + C_7 \left(\frac{\alpha}{\nu}\right)^2 + C_8 \left(\frac{\alpha}{\nu}\right)^3] \qquad (6\text{-}15)$$

$$\beta = \nu^2\ [D_5 + D_6 \left(\frac{\alpha}{\nu}\right) + D_7 \left(\frac{\alpha}{\nu}\right)^2 + D_8 \left(\frac{\alpha}{\nu}\right)^3] \qquad (6\text{-}16)$$

where the A_i, B_i, C_i, and D_i are input constants.

Figure 6-2 shows the complete operational regimes for which the above relationships can be applied.

COOLANT PUMP MOTORS

The following normalized torque characteristic is used to simulate the operation of the main motor (20).

$$T_{MM} = \frac{1}{[aS + b/S]} \qquad (6\text{-}17)$$

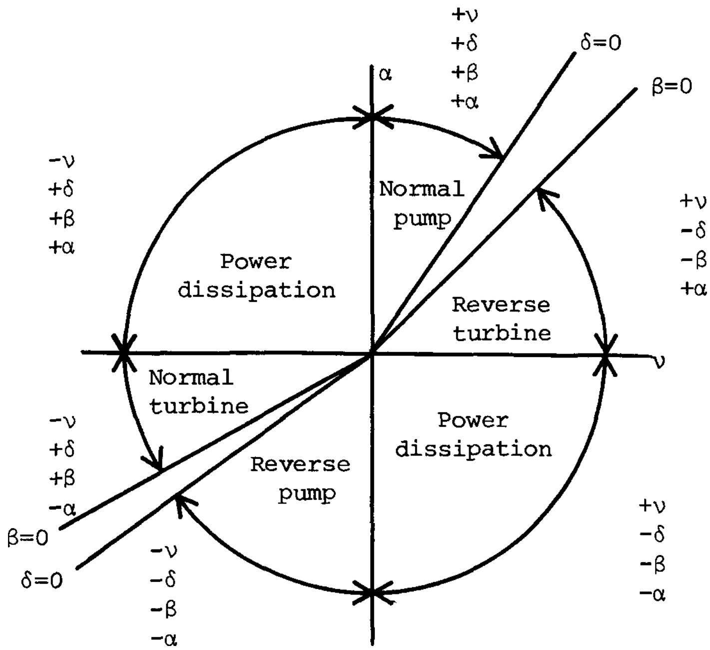


Figure 6-2. Pump Operational Regimes

where:

T_{MM} = normalized torque of the main motor,

S = main motor slip

$$= 1 - \frac{\omega_D}{\omega_S}\alpha$$

ω_D = design speed,

ω_S = synchronous speed,

$$= \frac{f}{P}$$

f = motor generator frequency,

P = number of pairs of poles,

α = normalized speed,

a = input constant, and

b = input constant.

Following the main motor trip, an automatic clutch connects the pony motor (via a reducing gear, 10:1 ratio) to the pump shaft when the pump speed decreases below 10% of the design speed, unless the option to exclude the pony motor is exercised, in which case the loop will undergo natural convection cooling.

The normalized torque of a squirrel cage type motor is used to simulate the operation of the pony motor:

$$T_{PM} = \frac{C}{[as + b/s]} \tag{6-18}$$

where:

T_{PM} = normalized torque of the pony motor

s = pony motor slip

$= 1 - \frac{\omega_D}{\omega_{sp}} \alpha$

ω_{sp} = pony motor synchronous speed

C = input constant

The torque due to motor windage, bearing and seal losses and the fluid friction on the pump shaft is calculated using:

$$T_{FR} = T_s \exp(-\alpha/\alpha_o) + T_R \alpha + T_{min} \tag{6-19}$$

where:

T_{FR} = normalized friction torque

T_s = normalized start-up torque

T_R = normalized rotating torque

T_{min} = minimum friction torque

α_o = input constant

It should be noted that the normalized friction torque at low pump speeds (<10%) used in the code is an important contribution to the conservatism of the calculations since the pump tailoff in speed significantly affects the total flow prior to the onset of thermally induced flow (natural circulation).

SPEED AND FREQUENCY CONTROLLER

The pump speed is obtained from a time-dependent torque balance equation:

$$\left(2\pi\ I\ \frac{\omega_D}{T_{P,D}}\right)\frac{d\alpha}{dt} = T_{\substack{Drive\\Motor}} - \beta - T_{FR} \qquad (6\text{-}20)$$

where:

I = moment of inertia of coupled motor-and pump-rotor,

ω_D = design pump speed,

$T_{P,D}$ = design pump torque,

t = time,

$T_{\substack{Drive\\Motor}} = K_{MM}T_{MM} + K_{PM}T_{PM}$,

T_{MM} = normalized main motor torque given by Eq. 6-17,

T_{PM} = normalized pony motor torque given by Eq. 6-18,

$K_{MM} = 1$, $K_{PM} = 0$ } main motor connected (normal operation),

$K_{MM} = 0$, $K_{PM} = 1$ } main motor disconnected and $\alpha \leq 0.1$,

$K_{MM} = 0$, $K_{PM} = 0$ } "station blackout," natural circulation, and

T_{FR} = normalized friction torque given by Eq. 6-19.

Variable pump speed is achieved by the main motor supplied with variable frequency power from a fluid coupled Motor Generator Set.

The following first order equation has been used to simulate the variable frequency:

$$\tau_{MGS}\frac{df}{dt} = K\ f_o\ E_\alpha \qquad (6\text{-}21)$$

where:

τ_{MGS} = motor generator set time constant,

t = time,

f = variable frequency,

f_o = rated frequency,

K = conversion gain, and

E_α = pump speed fractional deviation.

SODIUM TRANSPORT MODEL

The primary Heat Transport System (HTS) consists of three primary loops which transport the radioactive sodium coolant from the reactor vessel to the intermediate heat exchangers. The loops have a common flow passage through the reactor vessel between the inlet and outlet plena but are otherwise independent in operation.

The present model simulates only two primary loops of the HTS but is applicable to any system with two or more primary loops.

Thus, the two primary loops of the HTS have been divided into six pipe-runs (refer to Figure 6-1), three per loop as follows:

Loop 1: Run 1 -- reactor outlet nozzle to the primary sodium pump suction
Run 2 -- primary sodium pump discharge to the IHX inlet nozzle, and
Run 3 -- IHX outlet nozzle to the reactor inlet nozzle.

Loop 2: Run 4, 5, and 6 correspond symmetrically to runs 1, 2, and 3 of Loop 1.

The following is a description of the submodel of a pipe-run (7).

The sodium transport time along a pipe-section is given by the following equation:

$$\int_{t}^{t+\tau} \frac{W(t')}{\rho(t')}\, dt' = V \qquad (6\text{-}22)$$

where:

W = sodium mass flow rate,

ρ = average density of sodium,

V = volume of pipe section,

t = time,

τ = transport time,

t' = dummy variable of integration.

Application of heat-balance equation for the coolant over a pipe subsection gives:

$$(\rho V'C)_{C_J} \frac{dT_{C_J}}{dt} = (WC)_{C_J} (T_{C_{J-1}} - T_{C_J}) - (UA')_J \left(\frac{T_{C_J}+T_{C_{J-1}}}{2} - T_{M_J}\right) \qquad (6\text{-}23)$$

and for the metal:

$$(\rho V'C)_{M_J} \frac{dT_{M_J}}{dt} = (UA')_J \left(\frac{T_{C_J} + T_{C_{J-1}}}{2} - T_{M_J}\right) \qquad (6\text{-}24)$$

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

where:

T_{C_J} = coolant temperature at mesh point j,

T_{M_J} = metal temperature at node point j,

V' = metal or coolant volume per node,

A' = heat-transfer area per node,

W = coolant flow rate

C = coolant or metal specific heat

U = average overall heat-transfer coefficient based on inside diameter,

$= \left[\frac{1}{h_c} + \frac{d_i}{2K_m} \ln \left(1 + \frac{\delta}{d_i}\right)\right]^{-1}$

N = total number of pipe subsections,

h_c = convection heat-transfer coefficient,

K_M = thermal conductivity of the pipe wall,

d_i = inside diameter of the pipe,

δ = pipe wall thickness,

and subscripts:

C_J = coolant at mesh point J, and

M_J = metal at node point J.

Section 7

INTERMEDIATE HEAT EXCHANGER MODEL

The IHX is a counterflow shell and tube heat exchanger operating in the vertical position. The flowing directions of the two sodium flows are arranged to take benefit of the natural circulation effects. Thus, the primary sodium flows downward on the shell side and the secondary sodium flows upwards inside the tubes.

DESCRIPTION OF IHX THERMAL MODEL

The time-dependent heat-balance equations of the IHX thermal model are written as follows (Figure 7-1):

Primary inlet plenum:

$$(\rho VC)_{PIP} \frac{dT_{P_1}}{dt} = (1-\beta)\, C_{P_1} \left(T_{P_1} - T_{P_1}\right) \tag{7-1}$$

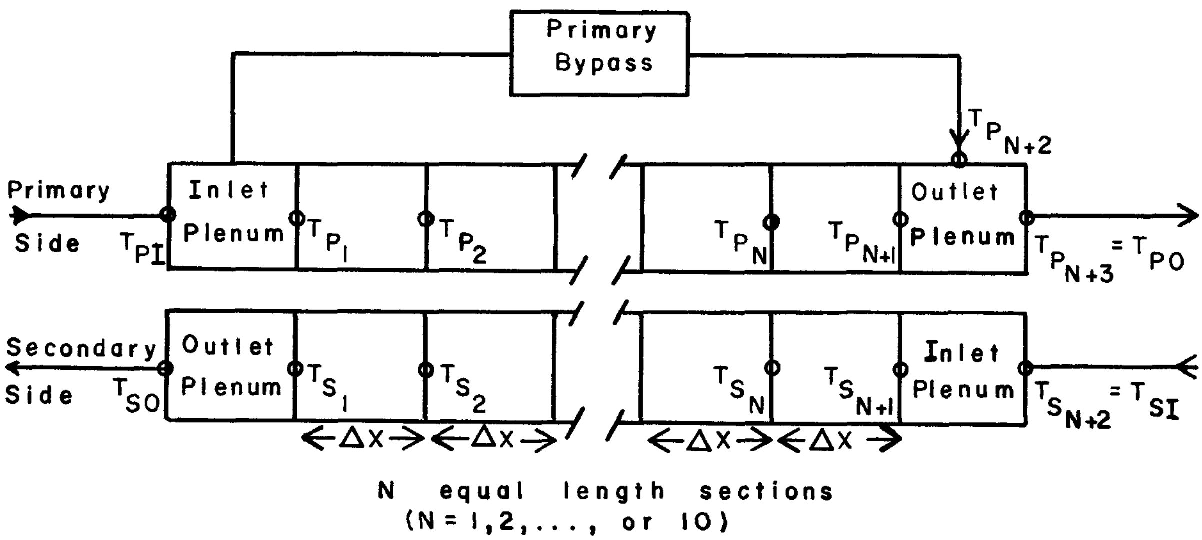


Figure 7-1. Intermediate Heat Exchanger Model

Primary bypass plenum:

$$(\rho VC)_{PB} \frac{dT_{PB}}{dt} = \beta \, W_P \, C_{PB} \, (T_{PI} - T_{PB}) \tag{7-2}$$

Primary outlet plenum:

$$(\rho VC)_{POP} \frac{dT_{POP}}{dt} = (1-\beta) \, W_P \, C_{PO} \, (T_{P_{N+1}} - T_{PO}) + \beta \, W_P \, C_{PO} \, (T_{PB} - T_{PO}) \tag{7-3}$$

Secondary inlet plenum:

$$(\rho VC)_{SIP} \frac{dT_{S_{N+1}}}{dt} = W_S \, C_{SIP} \, (T_{SI} - T_{S_{N+1}}) \tag{7-4}$$

Secondary outlet plenum:

$$(\rho VC)_{SO} \frac{dT_{SO}}{dt} = W_S \, C_{SO} \, (T_{S_1} - T_{SO}) \tag{7-5}$$

Primary sodium temperature at tube-bundle mesh-point (J+1):

$$\frac{1}{N} (\rho VC)_{P_{J,J+1}} \frac{dT_{P_{J+1}}}{dt} = [1-\beta] W_P \, C_{P_{J,J+1}} \, (T_{P_J} - T_{P_{J+1}}) - F_c \frac{U_{J,J+1} A}{N} \Delta T_{LM_{J,J+1}} \tag{7-6}$$

Secondary sodium temperature at tube-bundle mesh-point J:

$$\frac{1}{N}(\rho VC)_{S_{J,J+1}} \frac{dT_{S_J}}{dt} = W_S C_{S_{J,J+1}} (T_{S_{J+1}} - T_{S_J}) + F_c \frac{U_{J,J+1} A}{N} \Delta T_{LM_{J,J+1}} \qquad (7\text{-}7)$$

$$J = 1, 2, \ldots, N$$

where

W_P = primary sodium flow rate,

W_S = secondary sodium flow rate,

β = primary bypass flow fraction, percent of W_P,

T_{PI} = primary sodium inlet temperature,

T_{PO} = primary sodium outlet temperature,

T_{PB} = primary bypass sodium temperature,

T_{SI} = secondary sodium inlet temperature,

T_{SO} = secondary sodium outlet temperature,

T_{P_J} = primary sodium temperature at mesh-point J, J = 1, 2, ..., N+1,

ρ = density of sodium,

$C_{P_{J,J+1}}$ = average specific heat of primary sodium,

$C_{S_{J,J+1}}$ = same as $C_{P_{J,J+1}}$ but for secondary sodium,

A = total effective heat-transfer area based on O.D.,

$$U_{J,J+1} = \left[\frac{1}{\frac{de}{d_i}\left(\frac{1}{h}\right)_{s\ J,J+1} + \frac{de}{2K_T}\ln\left(\frac{de}{d_i}\right) + \left(\frac{1}{h}\right)_{p\ J,J+1}}\right],$$

$$\Delta T_{LM_{J,J+1}} = \left[\frac{(T_{P_{J+1}} - T_{S_{J+1}}) - (T_{P_J} - T_{S_J})}{\ln\left(\frac{T_{P_{J+1}} - T_{S_{J+1}}}{T_{P_J} - T_{S_J}}\right)}\right],$$

de = tube outside diameter,

d_i = tube inside diameter,

F_c = fouling correction factor for heat transfer,

K_T = thermal conductivity of tube material,

$(h_s)_{J,J+1}$ = tube-side convection heat transfer coefficient between mesh-point J and J+1 (secondary sodium) given by Eqs. 7-8 and 7-9, and

$(h_p)_{J,J+1}$ = shell-side convection heat-transfer coefficient between mesh points J and J+1 (primary sodium) given by Eqs. 5-14 and 5-15.

The shell side heat-transfer coefficients for laminar and turbulent flow used are as follows:

Laminar Flow (21) (Re $\leq$ 3000.)

$$Nu_{de} = \frac{h_p \cdot de}{K_c} = 7.15 \qquad (7\text{-}8)$$

Turbulent Flow (22) (Re > 3000.)

$$Nu_{de} = \frac{h_p \cdot de}{K_c} = a + b \; Pe^{\alpha} \qquad (7\text{-}9)$$

where:

$a = 6.66 + 3.126\,(p/de) + 1.184\,(p/de)^2$

$b = 0.0155$

$\alpha = 0.86$

K_c = thermal conductivity of coolant

p = pitch

Pe = Peclet number = RePr

Section 8

SECONDARY LOOP COOLANT DYNAMICS

SODIUM FLOW MODEL

Equation 6-1 has been applied to different pipe sections of figure 8-1 at the end of which the pressures are known, and then added to obtain the following equation which simulates the dynamics of sodium flow in the Intermediate Heat Transport System (IHTS):

$$a \frac{dW(t)}{dt} = \delta P_{SP} + \sum_{\substack{\text{around} \\ \text{loop}}} \left[\bar{\bar{\rho}}\, g\, \Delta Z + \frac{C}{\bar{\bar{\rho}}} W(t) \left| W(t) \right| \right] \qquad (8\text{-}1)$$

where:

a = total inertial loss coefficient for the secondary loop,
$W(t)$ = sodium flow rate in secondary loop,
t = time,
δP_{SP} = secondary loop pump pressure head,
g = acceleration due to gravity,
$\bar{\bar{\rho}}$ = average sodium density between inlet and outlet of pipe section,
ΔZ = change in relative elevation between end points of a pipe section, and
C = frictional loss coefficients.

The IHTS sodium flow is assumed to divide equally into the shell side of the evaporators and join together before the secondary loop pump, so the frictional loss coefficient is reduced by a factor of 4 in this region.

The intermediate loop pumps are exactly identical to those of the primary system.

SODIUM TRANSPORT MODEL

The intermediate Heat Transport System (IHTS) consists of sodium piping loops which transport non-radioactive sodium from the IHX to the Steam Generator System (SGS) and back to the IHX. Figure 8-1 shows the IHTS and the pipe-runs simulated.

Run 1 -- IHX outlet to SGS inlet

Run 2 -- SGS outlet to intermediate pump inlet header

Run 3 -- Pump inlet header to the intermediate pump inlet nozzle

Run 4 -- Intermediate pump outlet nozzle to the IHX inlet

Nodal energy balances have been performed for both pipe walls and the coolant as described in Section 6.

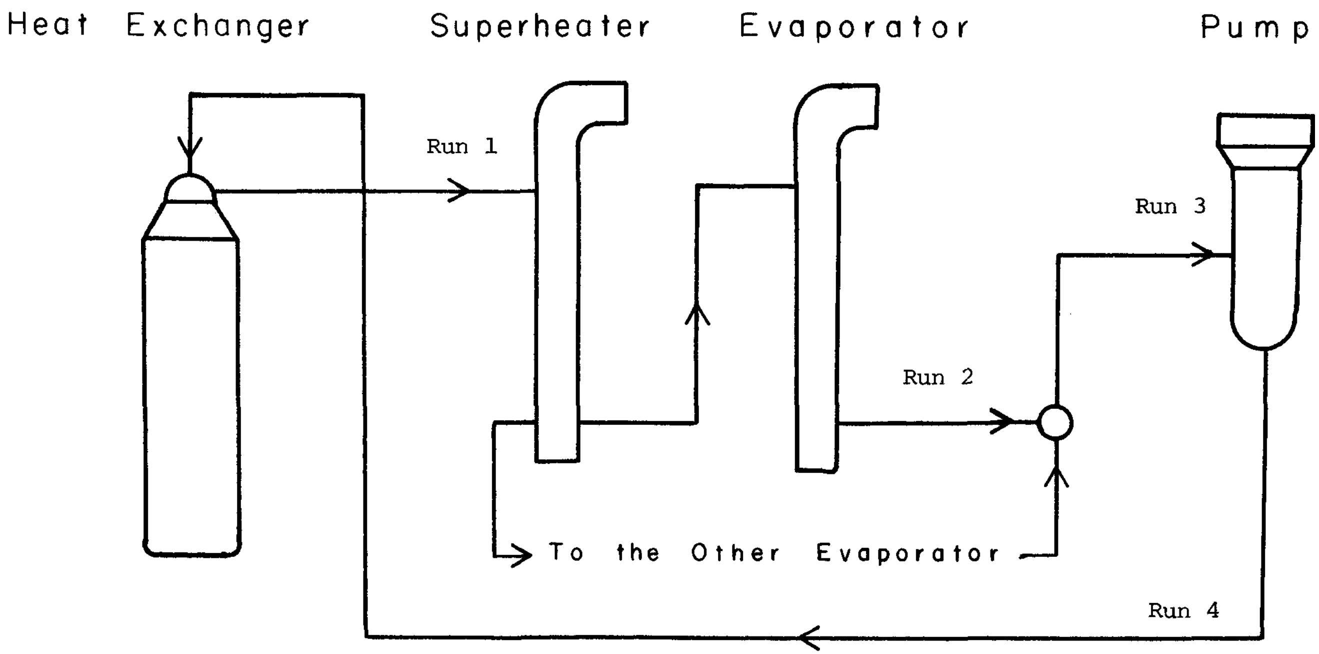


Figure 8-1. Intermediate Heat Transport Schematic

Section 9

TERTIARY LOOP MODEL

Transient sodium, water/steam enthalpies, pressures, temperatures, and flow rates have been simulated using a set of hydrodynamics and heat transfer models (6).

The steam generator system shown in Figure 9-1 is one of two loops modelled by the code (one for each of the two secondary sodium loops). Each loop consists of two evaporators, a steam drum, a recirculation pump, and a superheater module. The two steam generator loops are connected to a steam header through which the superheated steam drives the turbine.

HEAT TRANSFER MODEL

Shell Side Sodium

Transient sodium temperatures are calculated by performing an energy balance on each region in the evaporators and the superheater (6), that is,

$$(\rho VC)_{s_i} \frac{dT_{s_i}}{dt} = W_s C_{s_i} (T_{s_{i-1}} - T_{s_i}) - FQ_i \qquad (9\text{-}1)$$

where:

ρ = average sodium density,

V = volume of sodium in the region,

C = average heat capacity of sodium at constant pressure,

T_s = sodium temperature,

W_s = secondary side sodium mass flow rate,

F = fouling area correction factor for heat transfer,

Q = total amount of heat transferred,

= $UA\Delta T_{lm}$

U = overall heat transfer coefficient,

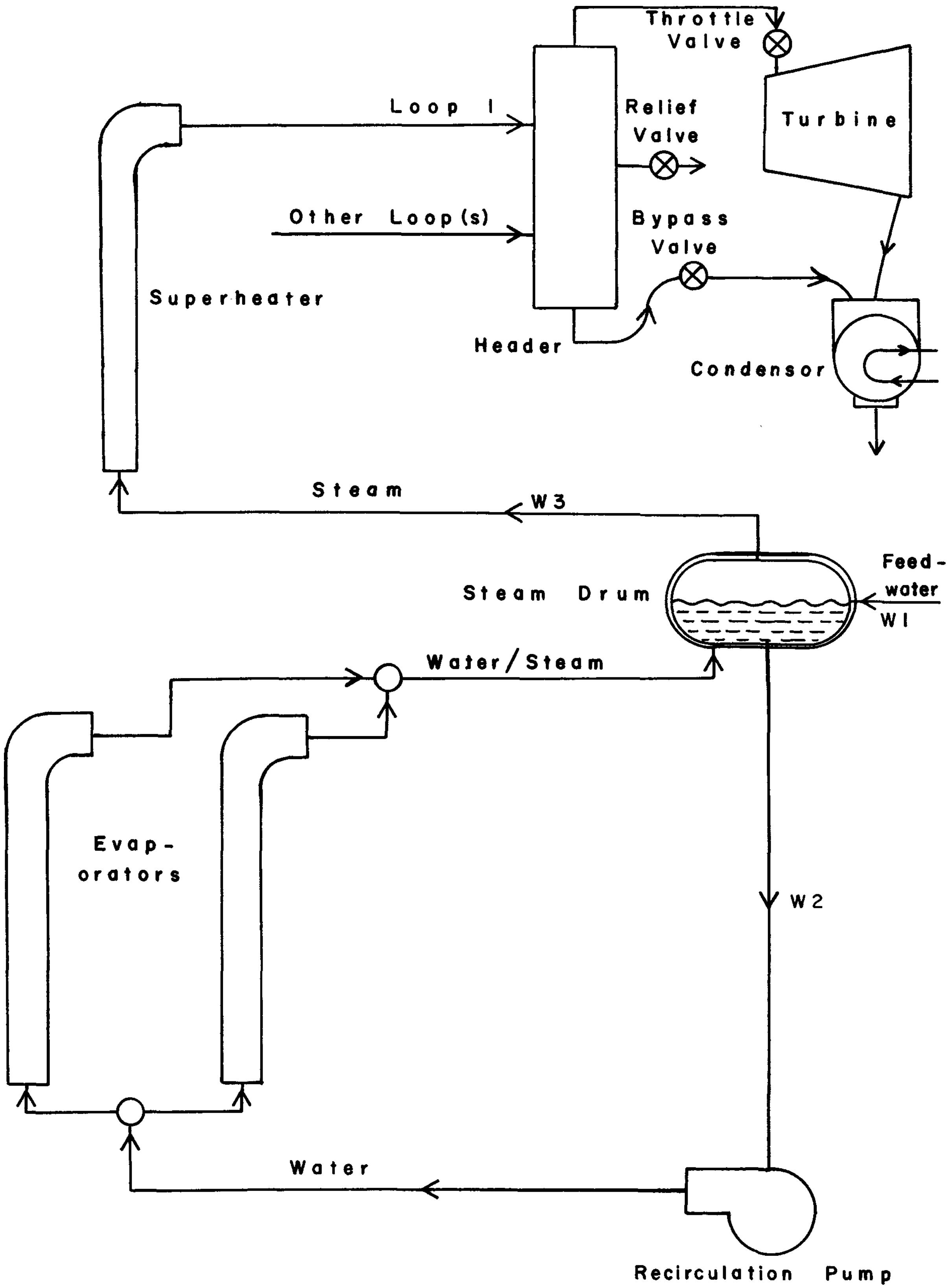


Figure 9-1. Steam Generator System Schematic

A = total heat transfer area, and

$\Delta\bar{T}_{lm}$ = average logarithmic temperature difference.

Subscripts:

s_i = node point at the region outlet, and

s_{i-1} = node point at the region inlet.

There are four equally divided heated regions in the superheater and two variable length heated regions in the evaporator modules.

The two evaporators are lumped together and assumed to behave symmetrically during all of the transients.

The pipes connecting the superheater to the evaporators has been modelled as five equally spaced subsections with no heat storage options in the walls.

Tube Side Water/Steam

The evaporators and superheater nodal enthalpies are simulated using the following energy equation (6):

$$\rho_J V_J \frac{dH_J}{dt} = W\ (H_{J-1} - H_J) + FQ_J \tag{9-2}$$

where

ρ = density of water, water/steam mixture, or superheated steam,

= function (T, P) water

= function (P, x) water/steam mixture,

= function (T, P) superheated steam,

T = temperature,

P = pressure,

x = steam quality (weight fraction),

H = specific enthalpy of water, water/steam mixture, or superheated steam,

W = mass flow rate of water, water/steam mixture, or superheated steam,

F = fouling area correction factor for heat transfer, and

Q = total amount of heat transferred;

Subscripts:

J = node point at the region outlet, and

J-1 = node point at the region inlet

There is one tube side equation for every corresponding heated shell side sodium equation. The connecting pipe runs have been simulated as a purely transport delay regions with no heat storage options in the pipe walls.

HYDRODYNAMICS

The water, water/steam and superheated steam flows and local pressures are calculated by solving the time-dependent incompressible flow equation of motion (Eq. 6-1) in the corresponding regions.

The model is divided into the following hydrodynamic regions:

1. a compressible steam drum,
2. incompressible single phase subcooled water in the downcomer of the recirculation line up to the saturation point in the evaporators,
3. two-phase water/steam mixture region in the evaporators up to the steam drum inlet nozzle.
4. single phase steam regions from the steam drum outlet nozzle through the superheater up to the steam header inlet nozzle, and
5. a compressible steam header model.

The recirculation pump is a constant speed centrifugal pump which is located between the drum and evaporators inlet.

Steam Drum

The energy and mass continuity are solved simultaneously to obtain the drum average pressure, and the steam water fractions in the drum using appropriate equations of state (6).

The drum, shown in Figure 9-2, is a horizontally mounted long cylinder with hemispherical heads. Most of the major appurtenances are located in a vertical plane through the drum centerline.

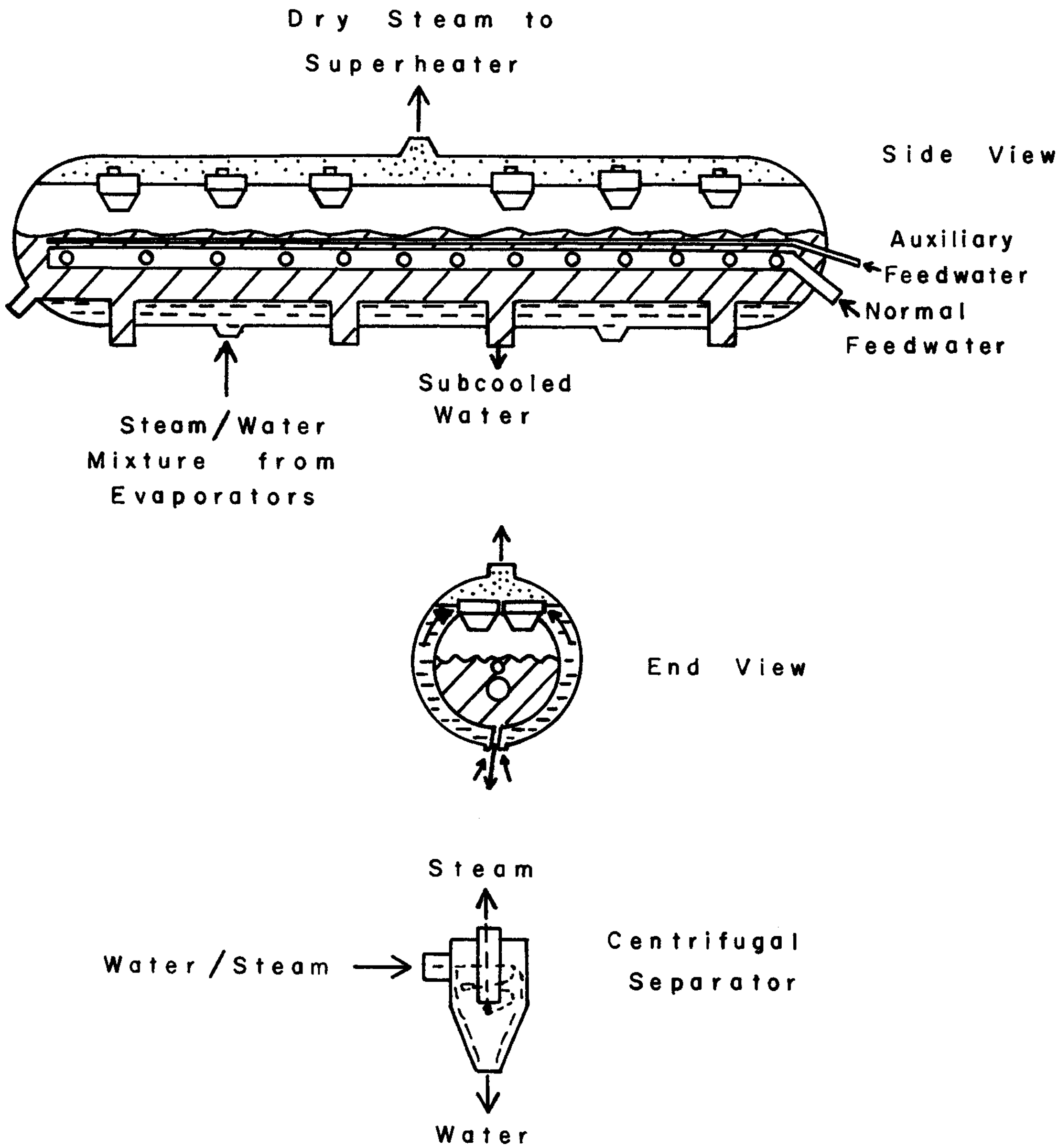


Figure 9-2. Steam Drum Schematics

Functionally, the drum receives saturated water/steam mixture from the evaporators and subcooled feedwater and produces saturated steam of low moisture content for the superheater, and subcooled water of low steam content for the recirculation pump.

Mass conservation requires that:

$$\frac{dM_D}{dt} = W_1 - W_3 \tag{9-3}$$

and, the total energy of the steam/water mixture in the drum is determined using:

$$\frac{dU_D}{dt} = W_1 H_1 + W_2 \ (H_m - H_s) - W_3 h_g \tag{9-4}$$

where:

M_D = total mass of steam/water in the drum,
t = time,
W_1 = feedwater mass flow rate,
W_2 = recirculation line mass flow rate,
W_3 = dry steam mass flow rate,
U_D = total internal energy of the steam/water in the drum,
H_1 = feedwater specific enthalpy,
H_m = steam/water mixture specific enthalpy from the evaporators,
H_s = subcooled water specific enthalpy at the drum outlet, and
h_g = dry steam specific enthalpy.

The specific internal energy is defined as:

$$\hat{u}_D \equiv \frac{U_D}{M_D} = (1-x) \ \hat{u}_f + x \ \hat{u}_g \tag{9-5}$$

where:

x = weight fraction of steam to the total mixture in the drum,
$\hat{u}_f$ = specific internal energy of saturated water,
$= h_f - P_D \hat{v}_f$

h_f = specific enthalpy of saturated water,

$\hat{v}_f$ = specific volume of saturated water,

P_D = drum average pressure,

$\hat{u}_g$ = specific internal energy of saturated steam,

$= h_g - P_D \hat{v}_g$

h_g = specific enthalpy of saturated steam, and

$\hat{v}_g$ = specific volume of saturated steam.

The average drum specific volume is defined as:

$$\hat{v}_D = \frac{V_D}{M_D} = (1-x)\ \hat{v}_f + x\ \hat{v}_g \qquad (9\text{-}6)$$

Therefore: the drum average pressure is calculated using the following iterative scheme:

$$P_D = P_{old} \left[\frac{\hat{v}_g\ (\hat{u}_D-\hat{u}_f) - \hat{v}_f\ (\hat{u}_d-\hat{u}_g)}{\hat{v}_D\ (\hat{u}_g-\hat{u}_f)} \right] \qquad (9\text{-}7)$$

where:

$$P_{old} = \begin{cases} P_D, & \text{initially} \\ \dfrac{P_D + P_{old}}{2} & \text{otherwise} \end{cases}$$

Note, during the iteration steps the right hand side of Eq. 9-7 is updated using the updated pressure and steam tables.

Single Phase Water Flow

Equation 6-1 is applied successively between the steam drum and the saturation point in the evaporators to obtain (6)

$$a_s \frac{dW_2}{dt} = (P_3 - P_9) + \delta P_{RP} + g\sum_{i=4}^{9} \bar{\bar{\rho}}_i \, (Z_{i-1} - Z_i) \tag{9-8}$$

$$+ \sum_{i=4}^{9} E_i \, W_2^2 + \left[\sum_{i=4}^{6} \frac{C_i}{\bar{\bar{\rho}}_i} + \frac{1}{4} \sum_{i=7}^{9} \frac{C_i}{\bar{\bar{\rho}}_i} \right] W_2 |W_2|$$

where:

a_s = total inertial loss coefficient for the subcooled region given by Equation 6-1,

P_3 = pressure at the drum outlet nozzle,

= P_D

P_9 = pressure at the saturation point in the evaporators,

δP_{RP} = pressure head of the pump,

= $\bar{\bar{\rho}}_{RP} H_{RP}$

H_{RP} = recirculation pump head,

$\bar{\bar{\rho}}_{RP}$ = average water density across the pump, and

$$\sum_{i=4}^{9} E_i = \frac{1}{2} \left[\sum_{i=4}^{6} \left(\frac{1}{A_{i-1}} + \frac{1}{A_i}\right) \left(\frac{1}{\rho_{i-1} A_{i-1}} - \frac{1}{\rho_i A_i}\right) \right.$$

$$\left. + \frac{1}{4} \sum_{i=7}^{9} \left(\frac{1}{A_{i-1}} + \frac{1}{A_i}\right) \left(\frac{1}{\rho_{i-1} A_i} - \frac{1}{\rho_i A_i}\right) \right]$$

Other variables have been defined by Eq. 6-1.

<u>Two-phase Water/Steam Flow</u>

Equation 6-1 is modified in the following way to account for the large frictional pressure losses associated with the two phase flows:

$$a \frac{dW}{dt} = (P_1 - P_2) + g \, \bar{\bar{\rho}}^* \, (Z_1 - Z_2) + \frac{W^2}{2} \left(\frac{1}{A_1} + \frac{1}{A_2}\right) \left(\frac{1}{\rho_1^* A_1} - \frac{1}{\rho_2^* A_2}\right) \tag{9-9}$$

$$- \phi_{TP} \left[\frac{C_f}{\bar{\rho}_f} \right] W|W|$$

where

ρ^* = two-phase flow mixture density,

$= \dfrac{1}{x\,\hat{v}_g + (1-x)\,\hat{v}_f}$,

$\bar{\bar{\rho}}^* = (\rho_1^* + \rho_2^*)/2$,

$\bar{\rho}_f$ = density of saturated water,

$= 1/\hat{v}_f$

c_f = frictional loss coefficient based on the liquid properties, and

ϕ_{TP} = two-phase flow frictional multiplier given by Eqs. 9-25 and 9-26. Subscripts 1 and 2 correspond to the positions x_1 and x_2 of Equation 6-1.

Applying Equation 9-9 successively between the saturation point and the drum inlet nozzle we get:

$$a_{TP}\frac{dW_2}{dt} = (P_9 - P_{13}) + g\sum_{i=10}^{13}\bar{\bar{\rho}}_i^*\,(Z_{i-1} - Z_i) \tag{9-10}$$

$$+ \frac{1}{2}\left[\sum_{i=10}^{12}\frac{1}{4}\left(\frac{1}{A_{i-1}} + \frac{1}{A_i}\right)\left(\frac{1}{\rho^* A_{i-1}} - \frac{1}{\rho_i^* A_i}\right) + \left(\frac{1}{A_{12}} - \frac{1}{A_{13}}\right)\left(\frac{1}{\rho_{12}^* A_{12}} - \frac{1}{\rho_{13}A_{13}}\right)\right] W_2^2$$

$$+ \left[\sum_{i=9}^{12}\phi_{TP_i}\frac{C_{fi}}{\rho_{fi}} + \frac{\phi_T P_{13}}{4}\,\frac{C_{f_{13}}}{\rho_{f_{13}}}\right] W_2|W_2|$$

where

a_{TP} = total inertial loss coefficient between 9 and 13

P_{13} = pressure at the drum inlet nozzle,

$= P_D$

Equations 9-8 and 9-10 are added to obtain an equation that uses the pump head as its only known boundary condition and is solved simultaneously with the energy equations of section 9 (Heat Transfer Model) to obtain the recirculation line mass flow rate.

Superheated Steam Flow

Equation 6-1 is applied successively between subsections joining the steam drum to the steam header to obtain the following equation for the superheated steam flow:

$$a_{SH} \frac{dW_3}{dt} = (P_D - P_{21}) + g \sum_{i=14}^{21} \bar{\rho}_i (Z_{i-1} - Z_i) + \sum_{i=14}^{21} E_i W_3^2 - \sum_{i=14}^{21} \frac{C_i}{\bar{\rho}_i} W_3 |W_3| \tag{9-11}$$

where

a_{SH} = total inertial loss coefficient for the superheated steam region,
W_3 = superheated steam mass flow rate,
P_D = drum pressure given by Eq. 9-7, and
P_{21} = pressure at the inlet of steam header,
= P_H given by equation 9-14.

Equation 9-11 is solved simultaneously with Eq. 9-2 and the steam tables for the superheated steam mass flow rate.

Steam Header

Two separate lines convey the superheated steam from the two steam generator loops to the main steam header (see Figure 9-1). Following temperature and pressure equalization in the header, the steam is carried to the turbine through the throttle valve(s) or bypassed (dumped) to the condenser via the dump valve. There are also a number of pressure relief valves provided to depressurize the system during off-normal conditions.

The steam header thermodynamics is based on conservation of mass and energy in the following manner:

Mass continuity requires

$$\frac{dM_H}{dt} = (W_3 + NW_{3L}) - (W_{TV} + W_{DV} + W_{RV}) \tag{9-12}$$

and, the total internal energy:

$$\frac{dU_H}{dt} = (W_3H_{21} + NW_{3L}H_{21L}) - (W_{TV} + W_{DV} + W_{RV})H \tag{9-13}$$

where:

M_H = superheated steam mass in the header,
U_H = superheated steam internal energy in the header,
W_3 = superheated steam mass flow rate from the single loop,
W_{3L} = superheated steam mass flow rate from the lumped loop,
W_{TV} = superheated steam mass flow rate through the throttle valve,
W_{DV} = superheated steam mass flow rate through the dump valve,
W_{RV} = superheated steam mass flow rate through the relief valves,
H_{21} = superheated steam specific enthalpy from the single loop,
H_{21L} = superheated steam specific enthalpy from the lumped loop,
H = steam header specific enthalpy, and
N = number of heat transport loops represented by lumped loop.

The header pressure, P_H, is calculated using:

(i) $\hat{u}_H = \frac{U_H}{M_H}$, $\hat{v}_H = \frac{V_H}{M_H}$

(ii) $H = \hat{u}_H + P_{old}$

(9-14)

(iii) T = function (H, P_{old})

(iv) P_H = function $(T, \hat{v}_H)$

where P_{old} is the header pressure based on the previous time step.

STEAM GENERATION SYSTEM VALVES

There is one feedwater control valve per loop, and a relief valve, a throttle valve and a dump (bypass) valve in the turbine header subsystem.

Feed Water Valve and Flow

The feedwater valve has been modeled as an equal percentage valve given by (1):

$$S_{FV} = S_{FV_{max}} \left[1 + \frac{\ln (W_F/W_{F,max})}{\ln (W_{F,max}/W_{F,min})} \right] \qquad (9\text{-}15)$$

where:

S_{FV} = feedwater valve opening (fraction of 1),

$S_{FV_{max}}$ = maximum opening of the F.W. valve

W_F = feedwater mass flow rate (noramlized),

$W_{F,max}$ = maximum feedwater normalized flow,

$W_{F,min}$ = minimum feedwater normalized flow.

Therefore the feedwater mass flow rate (normalized) is calculated using:

$$W_F = W_{F,max} \exp[\ln(W_{F,max}/W_{F,min}) \cdot (S_{FV}/S_{FV_{max}} - 1)] \qquad (9\text{-}16)$$

Throttle Valve and Flow

The throttle valve is also modeled as an equal percentage valve operating based on a constant pressure drop across the valve. The throttle valve flow is given by:

$$W_{TV} = W_{TVD} \sqrt{\frac{P_H - P_C}{(C_T + C_{TV})\ \alpha}} \qquad (9\text{-}17)$$

where:

W_{TV} = superheated steam flow through the throttle valve,

W_{TVD} = superheated steam flow through the throttle valve, at the rated condition,

P_H = steam header pressure given by Eq. 9-14,

P_C = condenser pressure,

C_T = frictional loss coefficient in the turbine and the stationary blades,

C_{TV} = frictional loss coefficient in the pipes,

$$\alpha = \frac{e^{-2aS_{TV}}}{W_{min}^2}$$

$$a = \ln \left(\frac{W_{max}}{W_{min}}\right)$$

W_{max} = maximum normalized steam flow rate,

W_{min} = minimum normalized steam flow rate, and

S_{TV} = throttle valve opening (fraction of 1), given by Equation 9-18.

The throttle valve position is given by:

$$\zeta_{TV} \frac{dS_{TV}}{dt} = K_{TV} E_{TV} \qquad (9\text{-}18)$$

where:

ζ_{TV} = controller time constant,

t = time,

K_{TV} = conversion gain factor,

E_{TV} = fractional header pressure deviation from the constant set point value.

Dump Valve and Flow

The dump (bypass) valve flow is calculated using:

$$W_{DV} = W_{DVD} S_{DV} \sqrt{\frac{P_H - P_C}{C_{DV}}} \qquad (9\text{-}19)$$

where:

W_{DV} = superheated steam flow through the dump valve,

W_{DVD} = superheated steam flow through the turbine at the rated condition,

S_{DV} = fractional opening of the dump valve, given by Eq. 9-20, and

C_{DV} = frictional loss coefficient.

The dump valve position is modeled as:

$$\zeta_{DV} \frac{dS_{DV}}{dt} = K_{DV} E_{DV} \qquad (9\text{-}20)$$

where:

ζ_{DV} = controller time constant,

K_{DV} = conversion gain factor, and

E_{DV} = fractional header pressure deviation from a constant set point value.

Relief Valve and Flow

The relief valves are modeled as burst type valves that open if the header pressure exceeds a specified set point limit.

The relief valve flow is calculated using:

$$W_{RV} = W_{TVD} C_{RV} (P_H - P_{SP}) \qquad (9\text{-}21)$$

where:

W_{RV} = superheated steam leaving the header through the relief valve,

W_{TVD} = superheated steam flow through the turbine throttle valve at the rated condition,

C_{RV} = inverse frictional loss coefficient, and

P_{SP} = relief valve set point pressure.

HEAT TRANSFER COEFFICIENTS

Shell Side Sodium

The shell side sodium heat transfer coefficients are calculated using Equations 5-14 and 5-15.

Tube Side Water/Steam

The subcooled water and superheated steam heat transfer coefficients are calculated using the Dittos-Boelter correlation:

$$Nu = \frac{hD}{k} = 0.023\ Re^{0.8}\ Pr^{0.4} \tag{9-22}$$

where:

h = heat transfer coefficient,
D = tube inside diameter,
k = water/steam average thermal conductivity,
Re = Reynolds number, and
Pr = Prandtl number.

The boiling region heat transfer coefficient is calculated using:

$$h = S \cdot h_{NB} + F \cdot h_c \tag{9-23}$$

where:

S = nucleate boiling suppression factor (23, 24)

$$= \begin{cases} 1.05 - 1.3x10^{-5}\ Re & Re \leq 2.5x10^4 \\ 0.83 - 4.3x10^{-6}\ Re & 2.5x10^4 < Re \leq 10^5 \\ 0.32\ \exp\ [-1.92x10^{-6}\ Re] & 10^5 < Re \leq 6x10^5 \\ 0.09 & Re > 6x10^5 \end{cases}$$

F = Reynolds number correction factor (23, 24)

$$= \begin{cases} 2.84\ \left(\frac{1}{x_{tt}}\right)^{0.45} & \frac{1}{x_{tt}} < 2 \\ 2.57 + 0.7643\ \left(\frac{1}{x_{tt}}\right) & \frac{1}{x_{tt}} \geq 2 \end{cases}$$

x_{tt} = Lokhart-Martinelli parameter given by:

$$\frac{1}{x_{tt}} = \left(\frac{x}{1-x}\right)^{0.09} \left(\frac{\hat{\nu}_g}{\hat{\nu}_f}\right)^{0.5} \left(\frac{\mu_g}{\mu_f}\right)^{0.1}$$

h_{NB} = nucleate boiling coefficient (23, 24, 31).

$= K \cdot T_x^2$

$$K = \frac{\mu_f \lambda_{fg}}{\sqrt{\sigma_f/(\rho_f-\rho_g)}} \left[\frac{C_{p_f}}{0.013 \lambda_{fg} Pr_f^{1.7}}\right]^3$$

μ_f = dynamic viscosity of saturated water,

λ_{fg} = latent heat of vaporization of water,

σ_f = surface tension of saturated water,

ρ_f = density of saturated water,

ρ_g = density of saturated steam,

h_c = convection heat transfer coefficient, given by:

$$\frac{h_c D}{k_f} = 0.023 \, Re_f^{0.8} \, Pr_f^{0.4}$$

C_{p_f} = heat capacity at constant pressure of saturated water,

Re_f = Reynolds number based on density and viscosity of saturated water,

Pr_f = Prandtl number of saturated water, and

k_f = thermal conductivity of saturated water.

The heat transfer after dryout is neglected, because this mode of heat transfer is usually not reached in the transients of interest.

DRYOUT PREDICTION

The following critical heat flux correlation (15) is used to predict the onset of dryout in the evaporators (note: correlation is unit-dependent):

$$\frac{q''_{CHF}}{\lambda_{fg} G} = \left(\frac{D}{4L}\right) \frac{1 - Pr}{\sqrt[3]{1.356G/10^6}} \; \frac{L}{L + 168 \, [(1/Pr) - 1]^{0.4} \, (G/10^6) \, D^{1.4}} \qquad (9\text{-}24)$$

where:

q''_{CHF} = critical heat flux, Btu/hr - ft^2 °F

λ_{fg} = latent heat of vaporization, Btu/lb$_m$,

G = water/steam mass flux, lb$_m$/hr - ft^2,

D = tube inside diameter, ft,

L = dryout length, ft,

Pr = reduced pressure = $\frac{P}{P_c}$

P_c = water critical pressure, and

P = evaporator system pressure.

TWO-PHASE FLOW FRICTION MULTIPLIER

The Armand's two-phase flow friction multiplier is used as (14)

$$\phi_{TP} = \frac{(1-x)^2}{(1-\alpha)^{1.42}} \qquad 0.39 < 1 - \alpha \leq 1.0 \tag{9-25}$$

$$\phi_{TP} = \frac{0.478\ (1-x)^2}{(1-\alpha)^{2.2}} \qquad 0 < 1 - \alpha \leq 0.39 \tag{9-26}$$

where:

α = modified Armand void fraction

$$= \frac{(0.833 + 0.167\ x)\ x\ \hat{v}_g}{x\ \hat{v}_g + (1-x)\ \hat{v}_f},$$

x = steam quality,

$\hat{v}_g$ = specific volume of saturated steam, and

$\hat{v}_f$ = specific volume of saturated water.

Section 10

CONTROL MODELS

The plant control system provides the necessary instrumentation and systems for the safe and reliable operation of the plant in all operating conditions.

Control is effected by coordinated feedforward and feedback loops which receive information from several measuring instruments and which adjust the appropriate parameters to match the required set point requirements.

The setpoints established by the plant supervisory controller and input to the second level controllers drive the system to its operating point. They characterize the feedforward action. The feedback consists of the difference between the "demanded" and the measured value of the process variables. Since feedback control requires that a deviation between the measured variable and its setpoint exists before control action can take place, the feedback controller changes its output until the deviation (error signal) between the two values is negligible or within a specified deadband (25).

Figure 10-1 describes the reactor power control model block diagram that is modeled in the EPRI-CURL Code.

The primary and secondary loops control models are shown in Figure 10-2 and 10-3.

The tertiary loops control model does not require any load dependent variables from the plant supervisory controller, and operates primarily based on near constant pressure in the turbine header. Figure 10-4 illustrates the control strategy and methods used in the EPRI-CURL Model.

All measured values used by the controllers and the plant protection system are determined from the following type of equation:

$$\zeta_m \frac{dX_m}{dt} = X - X_m \qquad (10\text{-}1)$$

where:

X = real value of the parameter to be measured,

X_m = measured value of the parameter, and

ζ_m = time constant of the relevant measuring device.

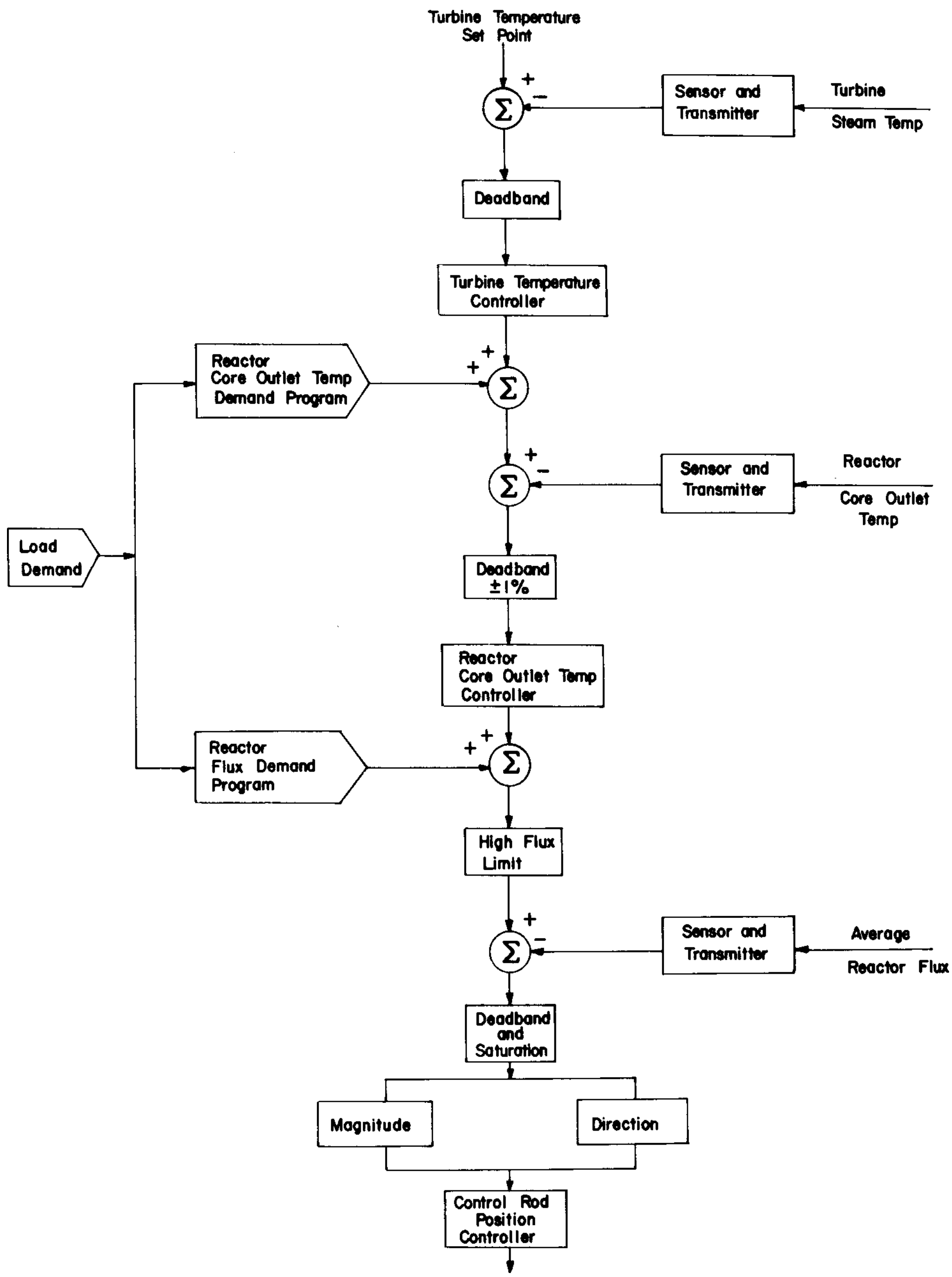


Figure 10-1. Reactor Power Controller Block Diagram

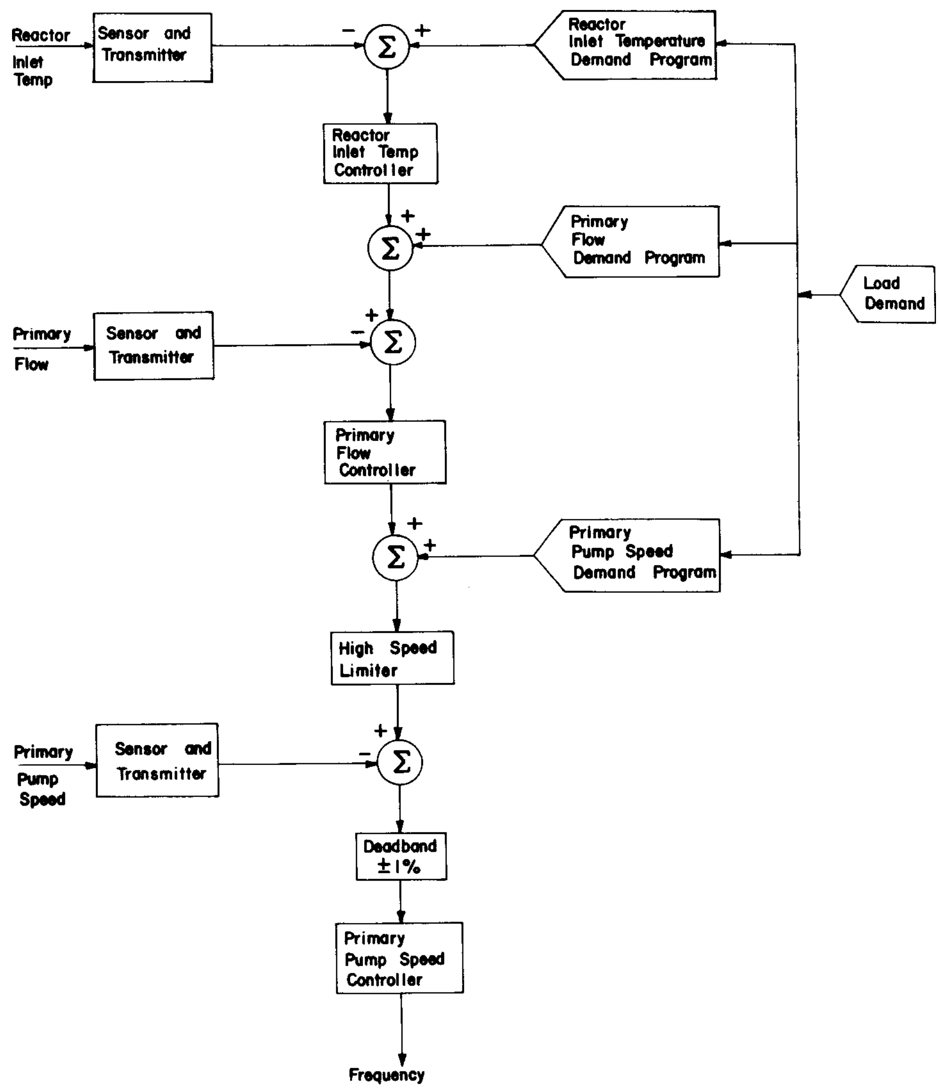


Figure 10-2. Primary Pump Controller Block Diagram

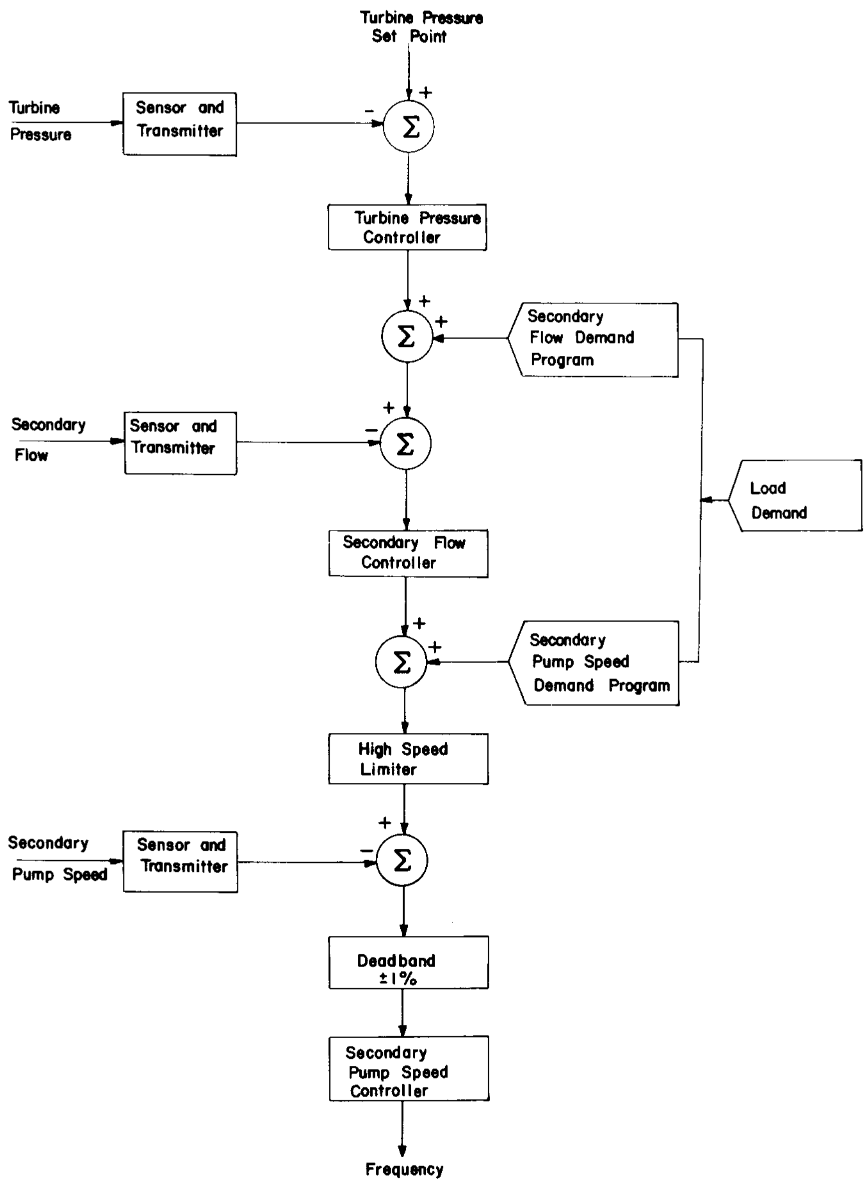


Figure 10-3. Secondary Pump Controller Block Diagram

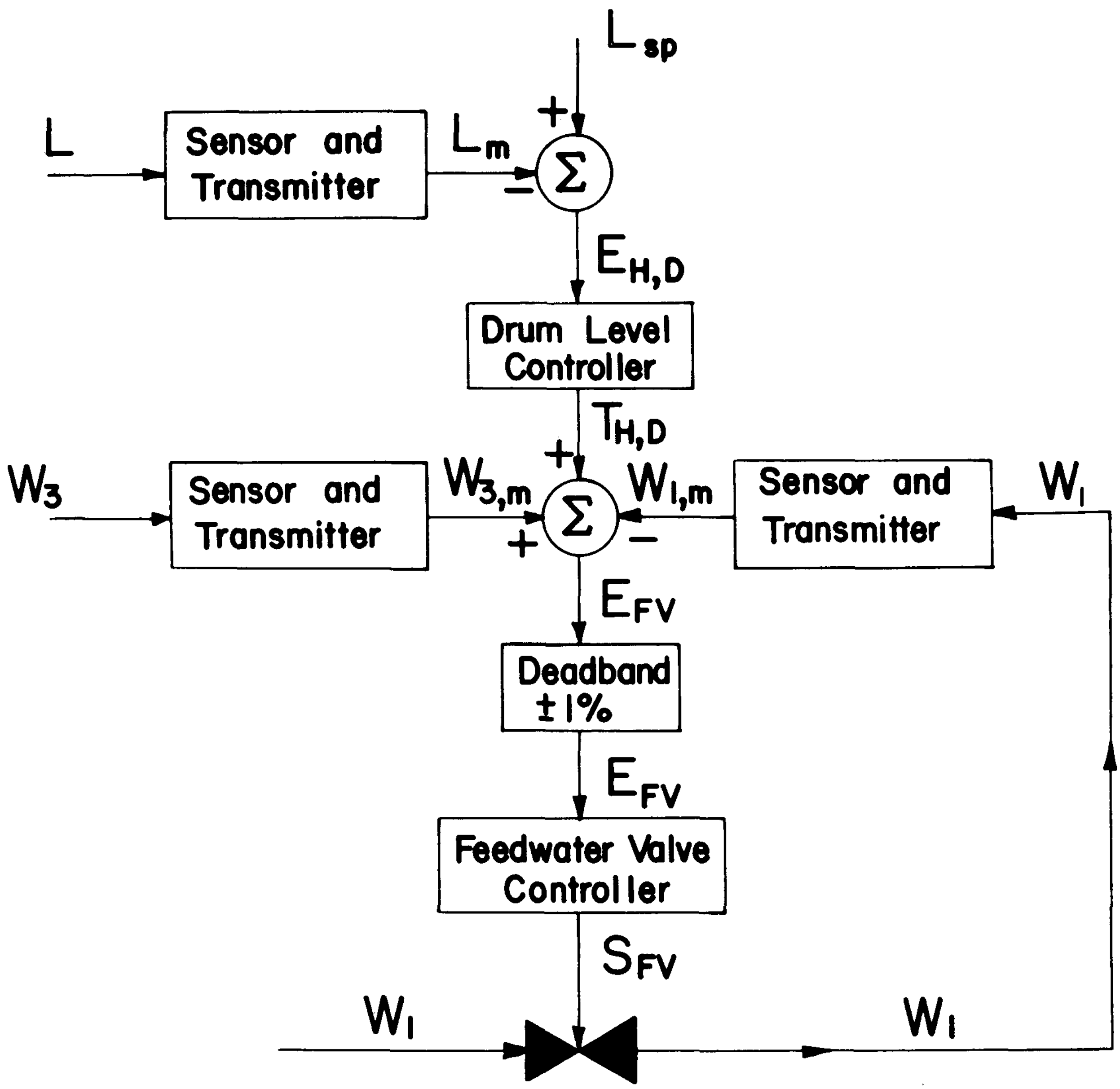


Figure 10-4. Tertiary Feedwater Valve Controller Block Diagram

Section 11

USER'S GUIDE TO EPRI-CURL

The EPRI-CURL Code User's Guide is intended to provide a complete description of the code input along with any other pertinent operating information needed to use the code effectively in performing LMFBR plant transient analyses. Other general information on the code is included for convenience; details of process variables, methods used are contained in this chapter. However, details of the equations used are not given here, but are instead cross-referenced to the preceding sections where appropriate.

Figure 11-1 shows the overall organization of the code, along with the number of differential equations formulated in the corresponding model subroutine (see also Figure 2-1).

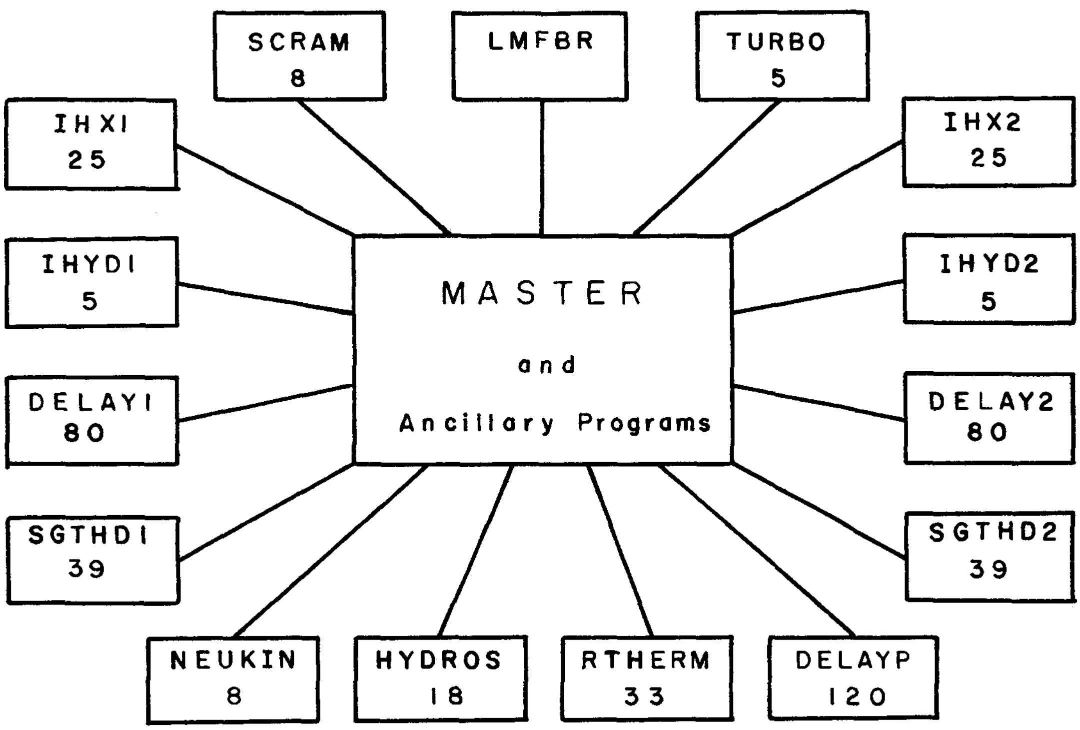


Figure 11-1. EPRI-CURL Code Organization

"Loop 1" in the code always refers to a single heat transport loop, while "loop 2" refers to the remaining, lumped loops (as defined by the input XLOOP in the master program).

Internally, all of the variables are calculated in British units. In order to allow EPRI-CURL to be more easily and universally applied, another subroutine, CONVRT, has been added as a pre-processor and a post-processor for the input and output data. As presently written, subroutine CONVRT allows the user to employ SI units, both in preparing the inputs and interpreting the outputs. Thus, the following units apply:

time - sec
power - MW_t
length - m
area - m^2
volume - m^3
frequency (angular speeds) - Hz (cps)
temperature - °C
reactivity - $
flow rate - kg/sec
density - kg/m^3
pressure - N/m^2
thermal conductivity - W/m °C
heat capacity - J/kg °C
moment of inertia - $kg\ m^2$
torque - N•m
inertial loss coefficient - m^{-1}
rupture loss coefficient - $\frac{1}{kg \cdot m}$
enthalpy - J/kg
heat transfer coefficient - w/m^2 °C

All temperature conversions are handled by subroutine TMPCON, so that, for example, degrees Kelvin (K) may be used instead of degrees Centrigrade (°C) by altering only this subroutine.

MASTER PROGRAM

Purpose and Scope

The master program performs the following important functions:

- It controls the flow of information to and from each subroutine;
- It takes as inputs the control variables which determine the type of transient to be simulated;
- It rearranges the components of the NULL vectors from each subroutine by bubbling out the zeros standing for the Class A variables to form an overall vector, NO, which is used by the RUNGE function to discriminate between Class A and Class B variables; Class A variables are those variables which have large characteristic times compared to the time step and are integrated by the RUNGE function; Class B variables have much shorter characteristic times and are evaluated from prompt approximation conditions using the new Class A variables (see section 3);
- It accepts the time step as an input, as well as values which may be used to alter the time step at various times throughout the calculation;
- It calls as needed the subroutines which model the primary, secondary, and tertiary systems, in which derivative values of Class A variables or the prompt approximation values of Class B variables are computed;
- It employs the RUNGE function to calculate new values of the Class A variables using a second-order Runge-Kutta algorithm (a fourth-order algorithm is also available);
- It controls the printing frequency of the transient results according to input values;
- It terminates the transient calculation when an input time limit is exceeded; and
- It has a mode whereby a plant initial steady state may be determined before proceeding to the transient calculation.

There are a total of 489 Class A or Class B variables which model the entire two-loop system.

Method

Extensive use of labelled COMMON statements is made in the master program to facilitate the exchange of information between the master program and each of the fourteen major subroutines (those with variables to be integrated).

Fourteen one-dimensional arrays are concatenated in a COMMON storage area called ALLR. An additional array, R(489), is constructed to overlap these arrays by means of an EQUIVALENCE statement. The concatenated arrays are used for easy cross-reference, and correspond to the integrated arrays in each major subroutine. The overall array, R, is used to hold and convey all the process variables to the RUNGE function.

The components of R are as follows:

R(1) = R1(1) . . . R(8) = R1(8)	Subroutine NEUKIN
R9() = R2(1) . . . R(26) = R2(18)	Subroutine HYDROS
R(27) = R3(1) . . . R(59) = R3(33)	Subroutine RTHERM
R(60) = R41(1) . . . R(84) = R41(25)	Subroutine IHX1
R(85) = R42(1) . . . R(109) = R42(25)	Subroutine IHX2
R(110) = R5(1) . . . R(229) = R5(120)	Subroutine DELAYP
R(230) = R61(1) . . . R(234) = R61(5)	Subroutine IHYD1

R(235)	=	R62(1)	Subroutine IHYD2
.		.	
.		.	
.		.	
R(239)	=	R62(5)	
R(240)	=	R71(1)	Subroutine DELAY1
.		.	
.		.	
.		.	
R(319)	=	R71(80)	
R(320)	=	R72(1)	Subroutine DELAY2
.		.	
.		.	
.		.	
R(399)	=	R72(80)	
R(400)	=	R81(1)	Subroutine SGTHD1
.		.	
.		.	
.		.	
R(438)	=	R81(39)	
R(439)	=	R82(1)	Subroutine SGTHD2
.		.	
.		.	
.		.	
R(477)	=	R82(39)	
R(478)	=	R9(1)	Subroutine TURBO
.		.	
.		.	
.		.	
R(482)	=	R9(5)	
R(483)	=	R10(1)	Subroutine SCRAM
.		.	
.		.	
.		.	
R(489)	=	R10(7)	

Two more COMMON storage areas, ALLF and ALLNUL, contain respectively the derivative values for each of the R-variables and the components of the local NULL vectors (vectors of Class B variables) for each subroutine.

Before entering the loop within which the time step procedure is carried out, the master program calls the plant initiation and physical properties model, LMFBR, and all the major subroutines to establish all the necessary initial conditions corresponding to the steady state at which the plant is assumed to have been operating prior to the initiation of the transient calculation.

In its present form, the master program can initiate a variety of transients involving various pump coastdowns, a turbine trip, a pipe rupture in the primary HTS, a reactivity insertion, a steam dump, and/or a change in power demand.

Another option is to have the master program institute a steady-state search given the plant parameters and an approximation of the plant steady state values at some chosen power. It must be noted that although a reasonable time step (~.2 sec) must be chosen in order to accommodate those few variables without Class B prompt approximations, the number of steps to reach steady-state is nearly independent of the size of the time increment. Steady-state conditions will be attained in a time much less than the time it would take a reactor to reach a steady-state given certain initial values. Its purpose is to determine the steady-state values for a particular reactor at a given power. Once the steady-state values are determined, a transient calculation may optionally begin.

The master program calls all the major subroutines and controls whether the subroutines should calculate the derivatives of the Class A variables or the values of the Class B variables.

The master program also calls the scram bus to determine whether the conditions in the reactor warrant a plan trip.

The step counter, ICOUNT, is incremented by 1 each time step, and selected results are printed if the new ICOUNT complies with the preset printing frequency.

Each major subroutine has a separate entry point which is called when the printout is required. The calculation is terminated in the master when the integration time exceeds the preset maximum.

Limitations

At present, the only output option included in the master program is to call on each subroutine in turn to produce its own output, which provides a fairly comprehensive listing of the variables pertinent to that subroutine.

However, the master program has access to all the process variables (see the description of the R-vector, above), as well as certain other parameters important to a transient analysis (such as hot spot temperatures), so that a selection of more limited output is certainly possible with only slight modifications to the master program.

<u>Input Data</u>

NAMELIST/MASA/MODE,IPRINT,IPK,SSEC,TMAXSC

where:

MODE = control integer for plant operation, where

$$= \begin{cases} 0, \text{ pre-accident initialization,} \\ 1, \text{ normal operation, and} \\ 2, \text{ pipe rupture in the primary HTS;} \end{cases}$$

IPRINT = initial value for printing frequency, IPRINT $\geq$ 1;

IPK = value for the printing frequency of the "characteristic times" of Section 3;

SSEC = initial value for the time step, sec; and

TMAXSC = maximum integration time for transient analysis, sec.

NAMELIST/MASB/P100,PD0,SLOPEP,PDEND,XLOOP

where:

P100 = 100% rated reactor power, MW_t;

PD0 = initial power demand, fractional power;

SLOPEP = rate at which demanded power is to change during the transient, fractional power/sec;

PDEND = final demanded reactor power, fractional power; and

XLOOP = number of loops to be represented by the lumped loop (i.e., one less than the total number of heat transfer loops in the primary system).

For example, to run a transient which represents a reactor that changes from 100% to 90% in 20 seconds, the following values would be used:

PD0 = 1.0

SLOPEP = -.005

PDEND = 0.9.

NAMELIST/MASC/TNEW,SNEW,IPNEW

where:

TNEW = vector of three times when the time step and/or the printing frequency may be altered,

SNEW = vector of three new time steps corresponding to TNEW, and

IPNEW = vector of three new printing frequencies corresponding to TNEW.

NAMELIST/MASD/TSCRM,TTRIP

where:

TSCRM = vector of two manual reactor scram times (primary and secondary system, respectively), and

TTRIP = vector of six manual pump trip times (two primary, two secondary, and two tertiary).

NAMELIST/MASE/NOPON,MTURB,MDUMP,RSTART,EPSILN

where:

NOPON = vector of four control integers to suppress pony motor operation,

NOPON(i) = { 0, pony motors operational, if required,
1, pony motors disconnected,

i = { 1, primary loop 1
2, primary loop 2
3, secondary loop 1,
4, secondary loop 2,

MTURB = control integer for turbine trip,

= { 0, normal operation,
1, turbine trip at time 0.0,

MDUMP = control integer for a steam dump,

= { 0, normal operation
1, uncontrolled opening of steam bypass valve at time 0.0,

RSTART = control integer for the option to start a transient calculation immediately following a pre-accident initialization (MODE = 0),

= { 0, no transient to follow a MODE = 0 run,
1, transient data will follow the MODE = 0 data and a transient begun.

EPSILN = convergence criterion (fractional change) required of each of the 489 process variables before a pre-accident initialization is considered accomplished.

If RSTART=1 for a MODE=0 calculation, a new set of master program data (MASA through MASG) will be required to define the circumstances of the transient calculation. If none is found (or if RSTART=0) the input data which defines the acquired steady state is printed and the calculation is terminated.

If RSTART=1 for a MODE≠0 calculation, the plant conditions are printed in input data form at the conclusion of the transient.

NAMELIST/MASF/RNSERT,TNSERT

where:

RNSERT = step reactivity insertion, $, and
TNSERT = time of reactivity insertion, sec.

NAMELIST/MASG/TNOFW1,TNOFW2,TAUX1,TAUX2

where:

TNOFW1 = time (from start of transient) when the main feedwater supply in the loop 1 steam generator system is to be manually disconnected;
TNOFW2 = the feedwater disconnection time for loop 2;
TAUX1 = time when the auxiliary feedwater is made available to loop 1; and
TAUX2 = time when the auxiliary feedwater is available to loop 2.

Initial Conditions

The initial conditions for the master program are set up by the program itself. These include initialization of the time at 0, and converting all times to hours which is the unit handled by the RUNGE function.

Input and Output Process Variables

The master program has access to all 489 of the class A and B process variables. Several of these variables, which may be considered to be output variables of the major subroutines, are required as inputs to other subroutines.

For example, the last temperature in the second pipe run of DELAYP, R5(20) (assuming 10 node pipes), is required as an input to the IHX1 subroutine, as the primary sodium inlet temperature to the heat exchanger, TPI1. Similarly, the primary sodium outlet temperature of the heat exchanger is required as the inlet to pipe run 3 in DELAYP.

The master program coordinates the entire flow of such information between the subroutines.

Other variables are generated inside the master program and supplied to other subprograms. For example, the time-dependent value of the power demand is calculated by the master program as a function of the input initial and final power level and the input slope.

The master program also controls the execution of the major subroutines by means of a COMMON statement:

```
COMMON/RUNGNO/K,KCALC
```

where:

K tells each subroutine what calculation phase to follow:

K =
- -1, read input data and initialize all process variables,
- 0, compute the value of Class B variables by the prompt approximation,
- 1, begin a new time step and compute the first set of derivatives of Class A variables,
- 2, compute a new set of derivatives for Class A variables, continuing in same time step,
- 3, same as 1, except characteristic times are evaluated and the local NULL vectors updated, and
- 4, re-initialize process variables for a transient calculation (used following a pre-accident initialization).

KCALC is a control integer which provides for the output of characteristic times when desired:

KCALC = 0, no output of characteristic times, and
1, output of the new characteristic times for each major subroutine.

One of the main functions of the master program is to channel all the newly calculated derivatives of Class A variables to the RUNGE function, which performs the actual integration.

The hot spot temperatures are made available to the master program in case the user wishes to provide his own (printed or plotted) version of output without needing to alter the other subroutines. The following COMMON statement is used:

```
COMMON/TMPMAX/TCMAX,TCLMAX,ZJET
```

where:

TCMAX = the hot spot coolant temperature;
TCLMAX = the hot spot (inner surface) cladding temperature, and
ZJET = the jet penetration distance in the outlet plenum (see Section 5, Eq. 5-5).

Required Suprograms

Functions:

- RUNGE -- carries out a second-order Runge-Kutta algorithm for integrating up to 489 first-order differential equations.

Subroutines:

- LMFBR -- carries out plant initialization and calculates physical properties for primary and secondary systems;
- NEUKIN,PUTNEU -- NEUKIN computes derivatives of 8 variables which model neutron kinetics and the reactor control system; PUTNEU controls this subroutine's output;
- HYDROS,PUTHYD -- HYDROS computes derivatives of up to 18 variables which describe the coolant dynamics, primary pumps, and the primary flow/speed controllers; PUTHYD controls the outputs;
- RTHERM,PUTRTH -- RTHERM computes derivatives for up to 33 reactor temperatures; PUTRTH controls the output;

- IHX1,PUTHX1 -- IHX1 computes derivatives for up to 25 primary and secondary sodium temperatures in the loop 1 heat exchanger; PUTHX1 controls its output;

- IHX2,PUTHX2 -- same as IHX1,PUTHX1, but for loop 2;

- DELAYP,PUTDEL -- DELAYP computes derivatives of up to 60 sodium and 60 wall temperatures in the primary piping; PUTDEL controls its output;

- IHYD1,PUTIH1 -- IHYD1 computes derivatives for up to 5 variables which describe the flow and flow/speed controllers in intermediate sodium loop 1; PUTIH1 controls its output;

- IHYD2,PUTIH2 -- same as IHYD1,PUTIH1, but for intermediate loop 2;

- DELAY1,PUTID1 -- calculates up to 40 sodium and 40 wall temperature derivatives for intermediate loop 1; PUTID1 controls its output;

- DELAY2,PUTID2 -- same as DELAY1,PUTID1, but for intermediate loop 2;

- SGTHD1,PUTSG1 -- SGTHD1 calculates the derivatives of the 39 variables which describe the loop 1 steam generation system enthalpies, temperatures, flows, and controllers; PUTSG1 regulates the output;

- SGTHD2,PUTSG2 -- same as SGTHD1,PUTSG1, but for loop 2;

- TURBO,PUTTUR -- TURBO calculates the derivatives of the 5 variables which model the thermodynamics of the steam header and the turbine bypass valve and throttle valve controllers; PUTTUR controls the output; and

- SCRAM, PUTSCR -- checks to see whether plant conditions warrant a reactor trip, and regulates the delay times for the plant and pump trips; PUTSCR controls the output of the seven plant parameters measured by this subroutine.

SUBROUTINE LMFBR(MODE, HOP, KX1, KX2, PD)

Purpose and Scope:

The subroutine LMFBR calculates 232 sodium average temperatures in the plant's primary and secondary loops and invokes subroutine PHYPRS to compute the thermophysical properties of liquid sodium, and uses them along with input flow, pressure, relative elevations to determine the gravitational pressure heads, the friction factors, velocity loss factors and the overall frictional loss coefficients.

The purpose of this subroutine has been to reduce the computational requirements of the code, by computing nearly all of the physical properties, average temperatures, mass fluxes, etc. at once and distributing them among the related subprograms.

The temperature, pressure and flow initialization is also performed by LMFBR using the input data.

Method:

Average sodium temperatures are calculated for every nodal region in the primary and secondary systems, along with the design related characteristic calculation (regional length, diameter, area, etc.).

The physical properties are calculated at the average sodium temperatures at every time step during the transient.

Input Data:

The following are the data that must be supplied to subroutine LMFBR through the appropriate NAMELIST statements.

```
NAMELIST/BR01/WI100,WI1,WI2,WIC,WOC,WHC,WCA,WRB,WBP,WS100,WS1,WS2,WBRK
```

where:

WI100 = primary sodium mass flow rate per loop at the rated condition (100% value)
WI1 = initial primary sodium flow in loop-1
WI2 = initial primary sodium flow in loop-2
WIC = initial sodium flow in the reactor inner core channel
WOC = initial sodium flow in the reactor outer core channel
WHC = initial sodium flow in the reactor peak core channel
WCA = initial sodium flow in the reactor control assemblies channel
WRB = initial sodium flow in the reactor radial blanket channel
WBP = initial sodium flow in the bypass channel,
WS100 = sodium flow in each secondary loop at 100% rated conditions,
WS1 = initial sodium flow in secondary loop 1,
WS2 = initial sodium flow in secondary loop 2, and
WBRK = initial sodium flow between the rupture and the reactor vessel in a pipe rupture calculation (usually = WI1).

NAMELIST/BRO2/TC,TIP1,TIP2,TOP1,TOP2,TM

where (refer to Fig. 4-1):

TC(i) = vector of initial coolant temperatures for each reactor region (i=1,12),

TIP1 = lower inlet plenum initial sodium temperature,

TIP2 = upper inlet plenum initial sodium temperature,

TOP1 = outlet plenum initial sodium temperature in zone 1,

TOP2 = outlet plenum initial sodium temperature in zone 2, and

TM(i) = vector of initial fuel temperatures for each reactor region (i=1,11, because no fuel in bypass channel).

NAMELIST/BRO3/K1,K2,NP,LP,N1,L1,N2,L2

where:

K1 = number of nodes in IHX-1,

K2 = number of nodes in IHX-2,

NP(i) = vector of number of subsections for each primary pipe run (i=1,6; see Fig. 6-1),

LP(i) = vector of control integers for the heat storage option in each primary pipe run (i=1,6)

$$= \begin{cases} 0, & \text{heat storage in pipe walls included in pipe run i,} \\ 1, & \text{heat storage neglected in pipe run i,} \end{cases}$$

N1(i) = number of subsections for secondary loop 1 pipe runs (i=1,4; see Fig. 8-1),

L1(i) = control integers for the heat storage option in secondary loop-1 (i=1,6),

N2(i) = same as N1(i) but for secondary loop 2, and

L2(i) = same as L1(i) but for secondary loop 2.

NAMELIST/BRO4/TP1,TS1

where (refer to Fig. 7-1):

TP1(i) = vector of initial IHX-1 primary side nodal temperatures (i=1,13); filled out with zeroes if K1 < 10, TS1(i) = vector of initial IHX-1 secondary side nodal temperatures (i=1,12); filled out with zeroes if K1 < 10.

In both the above temperature vectors, the order is as shown in Figure 7-1.

NAMELIST/BR05/TP2,TS2

where:

TP2(i) = same as TP1(i), but for IHX-2 (and K2), and

TS2(i) = same as TS1(i), but for IHX-2 (and K2).

NAMELIST/BR06/TCI1,TCI2,TCI3,TCI4,TCI5,TCI6

where:

TCIi = initial sodium temperature at inlet of primary pipe run i (i=1,6; see Fig. 6-1).

NAMELIST/BR07/TI11,TI12,TI13,TI14,TSI1,TSO1,TEI1

where:

TI1i = initial sodium temperature at inlet of pipe run i of secondary loop-1 (i=1,4),

TSI1 = initial sodium temperature at the inlet of the superheater in secondary loop-1,

TSO1 = initial sodium temperature at outlet of superheater in secondary loop-1, and

TEI1 = initial sodium temperature at inlet to evaporator in secondary loop-1.

NAMELIST/BR08/TI21,TI22,TI23,TI24,TSI2,TSO2,TEI2

where:

these correspond to the variables of NAMELIST/BR07/, but for secondary loop-2.

NAMELIST/BRO9/DH,AH,AIPT,AOPT

where:

DH(i) = vector of hydraulic equivalent diameters for the 12 reactor coolant regions of Fig. 4-1 (i=1,12),

AH(i) = vector of hydraulic areas for the 12 reactor coolant regions (i=1,12),

AIPT = hydraulic equivalent area of reactor inlet plenum, and

AOPT = hydraulic equivalent area of reactor outlet plenum.

NAMELIST/BR10/XL,P,WL,OD

where:

XL(i) = vector of lengths corresponding to the reactor coolant regions (i=1,12),

P(i) = vector of rod pitches corresponding to the reactor fuel regions (i=1,11, since no fuel in bypass),

WL(i) = vector of fuel rod wire leads for the reactor fuel regions (i=1,11), and

OD(i) = vector of the fuel rod outer diameters for the reactor fuel regions (i=1,11).

NAMELIST/BR11/DPX,APX,ODP,DELP,XLP,XL11,XL12,XL21,XL22

where:

DPX = hydraulic equivalent diameter for the primary side of the IHX,

APX = hydraulic area for primary side of the IHX,

ODP(i) = vector of outer diameters of primary pipe run i (i=1,3; it is assumed that the pipes in runs 4, 5, 6 are the same size as in 1, 2, and 3),

DELP(i) = vector of pipe wall thicknesses of primary pipe run i (i=1,3),

XLP(i) = vector of lengths of primary pipe run i (i=1,6),

XLP(7) = active length of tubes in IHX,

XL11 = length of IHX-1 primary side inlet plenum,

XL21 = length of IHX-2 primary side inlet plenum,

XL12 = length of IHX-1 primary side outlet plenum, and

XL22 = length of IHX-2 primary side outlet plenum.

NAMELIST/BR12/DSX,ASX,ODI,DELI,DSG,ASG,ODSE,DELSE,XLS

where:

DSX = hydraulic equivalent diameter for the secondary side of the IHX,

ASX = hydraulic area for the secondary side of the IHX,

ODI(i) = vector of outer diameters for secondary loop-1 pipe run i (i=1,4; assumed identical in loop-2),

DELI(i) = vector of pipe wall thicknesses for secondary loop-1 pipe run i (i=1,4; assumed identical in loop-2),

DSG = hydraulic equivalent diameter for secondary side of steam generator,

ASG = hydraulic area for secondary side of the steam generator,

ODSE = outer diameter of pipe connecting superheater to evaporator,

DELSE = pipe wall thickness of pipe connecting superheater to evaporator,

XLS(i) = { length of secondary loop-1 pipe run i (i=1,4), length of secondary loop-2 pipe run i-4 (i=5,8),

XLS(9) = flow path length of tubes in secondary side of IHX,

XLS(10) = flow path length of tubes in secondary side of superheater,

XLS(11) = length of pipe connecting the superheater to the evaporator (see Fig. 8-1), and

XLS(12) = flow path length of tubes in secondary side of evaporator.

NAMELIST/BR13/ZIN1,ZIN2,ZON,ZP1,ZP2,ZOPLEV

where:

ZIN1 = elevation of the reactor vessel inlet nozzles,

ZIN2 = elevation of the reactor subassembly inlet nozzles,

ZON = elevation of the reactor vessel outlet nozzles,

ZP1 = elevation of the primary pump 1 outlet nozzle,

ZP2 = elevation of the primary pump 2 outlet nozzle, and

ZOPLEV = elevation of initial operating sodium level in reactor vessel. (Note: The level chosen as zero elevation is arbitrary, as long as it remains consistent throughout the plant.)

NAMELIST/BR14/Z1,Z2,Z3

where:

Z1(i) = elevations of the NP(1) subsections of primary pipe run 1 (filled out with zeroes if NP(1) < 10),

Z2(i) = same as Z1(i), but for primary pipe run 2 (and NP(2)), and

Z3(i) = same as Z1(i), but for primary pipe run 3 (and NP(3)).

NAMELIST/BR15/Z4,Z5,Z6

where:

Z4(i) = same as Z1(i), but for primary pipe run 4 (and NP(4)),

Z5(i) = same as Z1(i), but for primary pipe run 5 (and NP(5)), and

Z6(i) = same as Z1(i), but for primary pipe run 6 (and NP(6)).

NAMELIST/BR16,ZX1,ZX2

where:

ZX1 = vector of 13 elevations of IHX-1 nodes; first is inlet plenum, then K1 nodes, then bypass, then outlet plenum (filled with zeroes for K1 < 10), and

ZX2 = same as ZX1, but for IHX-2 (and K2).

NAMELIST/BR17/P1,P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12

where:

Pi are primary system initial pressures (see Fig. 11-2).

NAMELIST/BR18/DSS,XKSS,CSS

where:

DSS = density of pipe wall material (all primary and secondary piping),

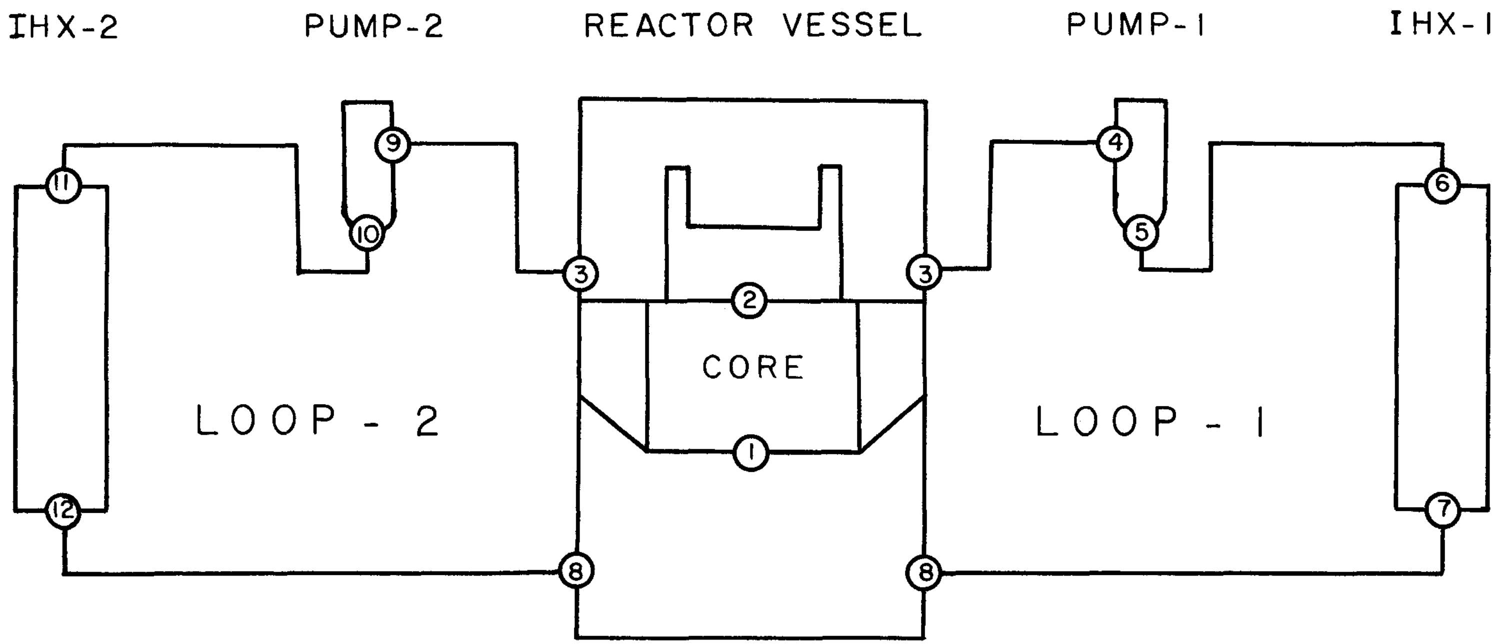


Figure 11-2. Primary System Pressure Locations

XKSS = thermal conductivity of pipe walls (primary and secondary), and
CSS = heat capacity of pipe walls (primary and secondary).

NAMELIST/BR19/PS1,PS2,PS3,PS4,PS5,PS6,PS7,PS8,PS9

where:

PSi are secondary loop-1 initial pressures (see Fig. 11-3).

NAMELIST/BR20/PI1,PI2,PI3,PI4,PI5,PI6,PI7,PI8,PI9

where:

PIi corresponds to PSi, but for secondary loop-2 (see Fig. 11-3).

NAMELIST/BR21/ZS1,ZS2,ZS3,ZS4

where:

ZSi(j) = vector of nodal elevations for secondary loop-1 piping (j=1,10), filled out with zeroes if N1(i) < 10.

NAMELIST/BR22/ZS5,ZS6,ZS7,ZS8

where:

ZS5, ..., ZS8 correspond to ZS1, ..., ZS4, but for secondary loop-2 (and N2(i)).

NAMELIST/BR23/ZHX1,ZHX2,ZSH1,ZSH2,ZEVI1,ZEVI2,ZEVO1,ZEVO2,ZSP1,ZSP2

where:

ZHX1 = elevation at outlet of secondary side of IHX-1,
ZHX2 = same as ZHX1, but for IHX-2,
ZSH1 = elevation at inlet of secondary side of superheater-1,
ZSH2 = same as ZSH1, but for superheater in loop 2,
ZEVI1 = elevation of inlet of secondary side of evaporators in loop 1,
ZEVI2 = same as ZEVI1, but for loop 2,

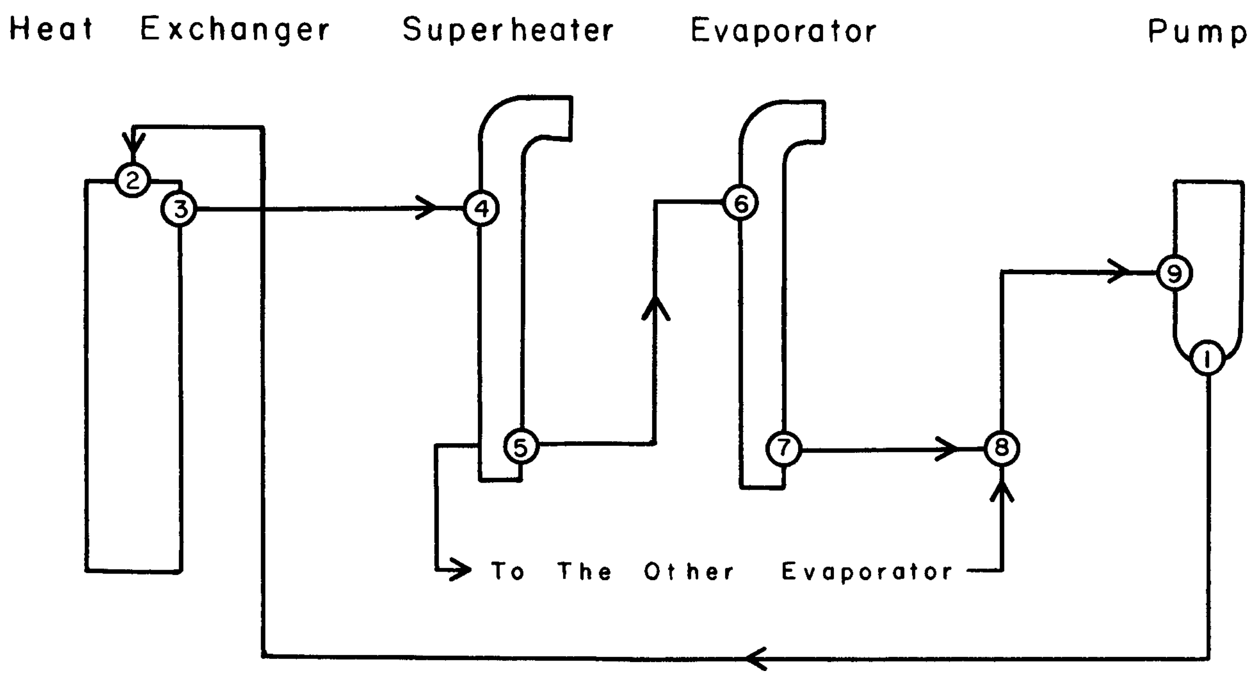


Figure 11-3. Intermediate System Pressure Locations

ZEVO1 = elevation of outlet of secondary side of evaporators in loop 1,

ZEVO2 = same as ZEVO1, but for loop 2,

ZSP1 = elevation at outlet nozzle of pump in secondary loop 1, and

ZSP2 = same as ZSP1, but for loop 2.

NAMELIST/BR24/PBRK,ZBRK,XBRK,PGV

where these are used only in pipe rupture transients (break after check valve in pipe run 3):

PBRK = pressure of coolant at break location before break,

ZBRK = elevation of break location,

XBRK = length of pipe from break to reactor inlet nozzle, and

PGV = pressure inside guard vessel before break.

NAMELIST/BR25/AA,BB,CC,DD

where these are the parameters in the pump head and torque relationships (eq. 6-9 through 6-16):

AA,BB,CC,DD are eight element vectors corresponding to A_i, B_i, C_i, and D_i.

Output Variables

The output variables of subroutine LMFBR are average temperatures, gravitational pressure heads, and frictional loss coefficients, all for the primary and secondary loops.

The three output variables which appear in the subroutine arguments are:

HOP = initial height of sodium in each reactor outlet plenum from core outlet to cover gas,

KX1 = K1 = number of nodes in IHX-1, and

KX2 = K2 = number of nodes in IHX-2.

Other output variables (temperatures, heads, etc.) are distributed through COMMON statements, and are described in the subroutines in which they appear.

Figure 11-4 pictures the inputs and outputs of subroutine LMFBR.

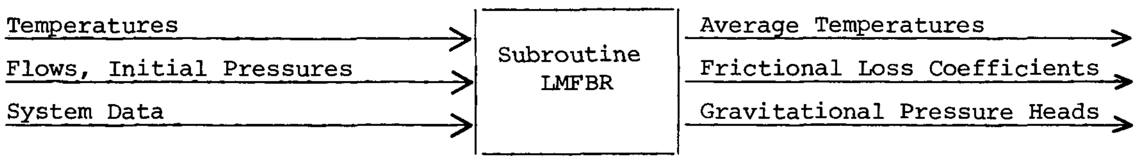


Figure 11-4. Inputs and Outputs of Subroutine LMFBR

Required Subprograms

Functions:

- o FRFAC = computes the Moody friction factor for laminar, transition, and turbulent regimes; and
- o DENSOD = computes sodium density as a function of temperature.

Subprograms:

- o PHYPRS = computes the physical properties of liquid sodium (density, dynamic viscosity, thermal conductivity, and heat capacity), and also the Reynolds number;
- o GHEAD = computes the total gravitational pressure heads, overall frictional loss coefficients, and velocity loss factors (due to bends, etc.) in a coolant region or a pipe with several subsections;
- o CONVRT = converts all input data into the proper units for the subroutine, and initializes all the conversion factors used by the other subroutines; and
- o RSTCON = a separate entry to subroutine CONVRT which converts to the input data units for the display of the restart data.

SUBROUTINE NEUKIN (MSCRAM,PTOT,PD)

Purpose and Scope

Subroutine NEUKIN computes the total reactor power as the sum of the power produced by neutron fission and by the decay of fission products in the reactor. Two groups of delayed neutrons and three groups of fission products are considered. Total reactor power can be computed for two distinct cases:

1. changes in power level governed by the reactor controller, and
2. changes in power level due to a primary and/or a secondary scram.

The power controller is a proportional-integral controller, based on reactor power demand and the measured reactor core outlet and measured steam temperatures, which alters the reactivity of the primary control rod limited by a maximum reactivity insertion rate. The reactor core outlet temperature is the flow weighted average of the peak channel, inner core, and outer core outlet temperatures as determined by subroutine RTHERM.

The reactivity feedbacks considered are assumed to be caused by:

1. sodium expansion effects in 11 reactor regions,
2. the nuclear Doppler effect in 11 reactor regions,
3. core axial expansion in 11 reactor regions, and
4. core radial expansion.

The reactor is assumed to be at steady-state initially, so the initial reactivity of the primary control rod is assumed to precisely counteract the feedback effects and the cold shutdown margin of reactivity.

Two independent control rod systems are simulated for shutting down the reactor. In addition, the primary control rods act as the power controller.

Method

A more detailed description of the equations and models used is given in Section 4 of this report.

There are eight first-order ordinary differential equations which simulate the neutron kinetics and the reactor control processes. To achieve the coupling of all physical processes involved, all equations are integrated simultaneously by the RUNGE function as called in the master program.

The eight variables with differential equations are supplied to the master through a dummy vector, R(8), which is defined as follows:

R(1) = P(1) = group 1 delay neutron power,
R(2) = P(2) = group 2 delay neutron power,
R(3) = P(3) = group 1 fission product power,
R(4) = P(4) = group 2 fission product power,

R(5) = P(5) = group 3 fission product power,

R(6) = TSTM = measured steam temperature at the turbine throttle valve,

R(7) = TROM = measured sodium temperature at the reactor core outlet, and

R(8) = ROCR1 = primary control rod reactivity.

Total neutron power is determined algebraically by means of a prompt jump approximation using the known values of the delayed neutron power contributions.

For a reactor scram shutdown (primary or secondary scram), the control rod position is determined by Eq. 4-8, and its reactivity contribution by Eq. 4-9.

Limitations

Due to the prompt jump approximation, subroutine NEUKIN cannot handle positive reactivity insertions close to or in excess of one dollar. Smaller positive insertions are allowed.

Input Data

NAMELIST/KINA/LAM,B

where:

LAM(i) = vector of decay constants for delayed neutron precursors (i=1,2) and fission products (i=3,5), and

B(i) = vector of delayed neutrons fractions (i=1,2) and fission product fractions (i=3,5).

NAMELIST/KINB/XO,ROMAX,ROSTUK,RINMAX,ROSUBC,TRESET,XKT

where:

XO(i) = length of control rod strokes, primary (i=1) and secondary (i=2),

ROMAX(i) = total control rod reactivities, primary (i=1) and secondary (i=2),

ROSTUK(i) = worth of stuck rods, primary (i=1) and secondary (i=2),

RINMAX = maximum reactivity insertion rate for the reactor power controller,

ROSUBC = cold reactor shutdown margin of reactivity,

TRESET = integral reset time for the reactor controller (see Eq. 4-10), and

XKT = steam temperature-to-reactor outlet temperature conversion gain in reactor power controller.

NAMELIST/KINC/TROM,TSTM,TSTSP,TAURO,TAUST

where:

TROM = initial value of measured reactor core outlet temperature,

TSTM = initial value of measured steam temperature (at the turbine),

TSTSP = load-independent steam set-point temperature,

TAURO = time constant for the measurement of the reactor core outlet temperature (see Eq. 10-1), and

TAUST = time constant for the measurement of the turbine steam temperature.

NAMELIST/KIND/TFREF,TCREF,ASOD,ADOP,ACAE,ACRE

where:

TFREF = reference fuel temperature (see Eq. 4-7),

TCREF = reference coolant temperature,

ASOD(i) = vector of sodium density reactivity coefficients (i=1,11 for the fueled regions of Fig. 4-1),

ADOP(i) = vector of nuclear doppler coefficients (i=1,11),

ACAE(i) = vector of core axial expansion coefficients (i=1,11), and

ACRE = core radial expansion coefficient.

NAMELIST/KINE/PRIMA,PRIMB,SECA,SECB

where:

PRIMA,PRIMB = parameters to represent primary rod insertion rate during a scram, corresponding to A,B of Eq. 4-8, and

SECA,SECB = similar parameters for secondary rod insertion rate during a scram.

NAMELIST/KINF/AT

where:

these are the parameters for the reactor outlet temperature setpoint, governed by the following equation:

$$TROSP = AT(1)\ PD^2 + AT(2)\ PD + AT(3)$$

where:

TROSP = reactor core outlet temperature setpoint, and
PD = demanded power (normalized).

Some other input data are provided by the master program through a common statement from the master program:

```
COMMON/REACT/P100,RNSERT,TNSERT
```

where:

P100 = rated reactor power,
RNSERT = size of step reactivity insertion, and
TNSERT = time of reactivity insertion.

Initial Conditions

Subroutine NEUKIN calculates the initial conditions of all its process variables. Various power fractions are calculated by use of the initial power, PTOT, as supplied in the argument list. Similarly, the initial values of the reactivity feedbacks, which determine the initial primary control rod reactivity, are determined within NEUKIN using the initial fuel and coolant temperatures.

Input Process Variables

The input process variables that are supplied by the list of arguments of NEUKIN are:

MSCRAM = control integer for reactor scrams,

$$= \begin{cases} \text{0, normal operation, power controller operational,} \\ \text{1, primary scram, power controller shut off,} \\ \text{2, secondary scram, power controller shut off, and} \\ \text{3, both primary and secondary scrams, controller shut off; and} \end{cases}$$

PD = demanded reactor power.

Other input process variables are provided through labelled common statements. These include:

COMMON/FBR1/TC(12), TIP1,TIP2,TCI(6),TOP1,TOP2,TON,TM(11)

These are the reactor fuel and coolant temperatures used for reactivity feedback calculations. The core outlet temperature, TRO, is obtained from a flow weighted average of the inner core, outer core, and peak channel outlet temperatures. The flow rates are obtained from another common:

COMMON/GET1/...,WIC,WOC,WHC,...

Other parameters obtained through COMMON statements are

COMMON/MISC/...,T,...,...

where:

T = transient time.

COMMON/RUNGNO/KRUNG,KCALC

where:

KRUNG is a control integer to determine what part of the subprogram is being called; and

KCALC is a control integer to determine when characteristic times are printed.

COMMON/PHDR/...,TST

where:

TST = steam temperature at the turbine throttle valve.

Output Process Variables

The main output process variable of the subroutine NEUKIN is the total reactor power, PTOT, which is contained in its list of arguments.

Certain information is also transferred to the subroutine SCRAM by means of a

COMMON statement.

```
COMMON/SCRP/PTOTN,RO
```

where:

PTOTN = normalized reactor power, and

RO = total reactor reactivity.

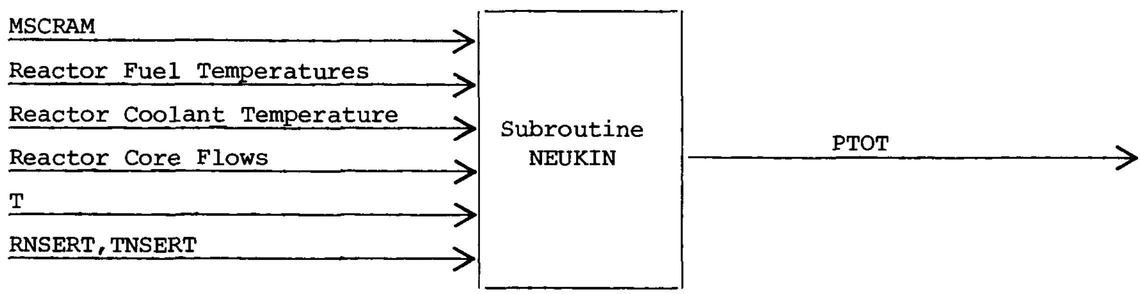


Figure 11-5. Input and Output Variables of Subroutine NEUKIN

Required Subprograms

Functions:

RVOTSP = computes the reactor core outlet temperature setpoint as a function of power demand.

Subroutines:

TMPCON = converts temperatures from °C to °F and vice versa.

Additional Comments

Subroutine NEUKIN has a secondary entry point, PUTNEU, which is accessed from the master program for the purpose of printing the latest results computed by NEUKIN.

In addition to the aforementioned variables, NEUKIN also uses a number of internal variables which do not need to be specifically defined in order to use subroutine NEUKIN.

SUBROUTINE HYDROS (MODE,KMM1,KMM2,PD,HOP)

Purpose and Scope

The subroutine HYDROS computes the sodium flow rates in the two primary loops and the six reactor vessel flow paths as governed by forced and natural circulation effects. During normal operation, the sodium flow rates in each primary loop are subject to the action of the two primary flow/speed controllers, one for each loop. Each controller has a feedforward action with feedbacks of primary pump speed and sodium flow rate (see Fig. 10-2).

The primary system is simulated with two primary loops, one of which is a single loop and the other represents each of the remaining, equivalent loops. A variable sodium level is allowed only in the reactor vessel and only for the case of a pipe rupture. The sodium flow rates in the primary loops is the same both before and after the primary pumps because the sodium level in the pump barrel is assumed to remain constant. The primary pumps are located on the hot legs of the loops.

Subroutine HYDROS can also handle the case of a major primary pipe rupture in the single loop. Both the sodium level in the reactor vessel and in the relevant guard vessel are computed during the transient. Following the primary pipe break, two distinct sodium flow rates are calculated in the single primary loop, before and after the break. A rupture loss coefficient may be provided as input to allow for various sizes of breaks.

In addition to the loss of coolant transient, subroutine HYDROS can be used to analyze changes in demanded power transients and sodium flow coastdown transients associated with a loss of power to any or all of the primary pumps.

Method

Detailed descriptions of the equations and models used in this subroutine are given in Section 6.

There are 18 first-order ordinary differential equations which simulate the primary coolant dynamics of the plant. One of these is used only in a pipe rupture transient, and the other 17 are used in all transients. All equations are integrated simultaneously within the function RUNGE (provided they are classified as Class A variables, see Section 3), in order to provide for the coupling of all the physical properties involved.

The 18 variables are defined both as components of a vector R (to be available to the master program for the RUNGE function) and as local variables for use within HYDROS. These variables are (see also Fig. 6-1):

R(1) = W(1) = W1 = sodium flow rate in loop 1 (before the break in pipe rupture transients),

R(2) = W(2) = W2 = sodium flow rate in loop 2,

R(3) = W(3) = WOC = sodium flow rate in reactor outer core region,

R(4) = W(4) = WHC = sodium flow rate in reactor peak core region,

R(5) = W(5) = WCA = sodium flow rate in reactor control assembly region,

R(6) = W(6) = WRB = sodium flow rate in reactor radial blanket region,

R(7) = W(7) = WBP = sodium flow rate in reactor bypass region,

R(8) = AL1 = primary pump speed in loop-1, normalized to 1,

R(9) = FREQ1 = primary pump controller frequency in loop-1,

R(10) = TRIM1 = measured reactor inlet temperature for loop-1,

R(11) = NEWM1 = measured sodium flow rate in loop, normalized to 1,

R(12) = ALM1 = measured primary pump speed rate in loop-1, normalized to 1,

R(13) = AL2 = primary pump speed to loop-2, normalized to 1,

R(14) = FREQ2 = primary pump controller frequency in loop-2,

R(15) = TRIM2 = measured reactor inlet nozzle temperature, loop-2,

R(16) = NEWM2 = measured sodium flow rate in loop-2, normalized to 1,

R(17) = ALM2 = measured primary pump speed in loop-2, normalized to 1,

R(18) = W(8) = sodium flow rate after the break in loop-1 (LOCA only).

The reactor inner core region flow rate, WIC, is determined algebraically from the other flow rates using mass conservation.

The primary pump characteristics are programmed separately in two additional subroutines, PHEAD and PTORQ, which compute the normalized pump head and the normalized pump torque, respectively, as functions of the normalized speed and flow rate.

The present coolant dynamics model of the primary system has the primary pumps located on the hot legs of the piping. For cases where the primary pumps are located on the cold legs of the primary loops, the inertial loss coefficients and reactor pressures (input to subroutine LMFBR) must be changed to reflect alterations in the geometry of the primary piping. The pressure of the cover gas in the reactor vessel must also be increased to account for increased pressure losses in the piping before the primary pump.

Limitations

The primary loop check valves are simulated only as local dynamic resistances, reflected through the frictional loss coefficients calculated from the initial system pressures. No inertia to retard the opening or closing of a check valve was considered. For any reverse pressure differential across a check valve, the flow through is assumed to be zero.

Because the sodium level in the primary pump barrels is assumed constant, the present model does not allow for a mismatch of the flow rates before and after a pump.

As presently modeled, the pipe rupture is assumed to occur between the check valve and the reactor inlet nozzle of pipe run 3.

Input Data

NAMELIST/HYDA/AX

where AX(i) is an 18 element vector of inertial loss coefficients, and

i=1 for pipe run 1,
i=2 for primary pump 1,
i=3 for pipe run 2,
i=4 for IHX-1,
i=5 for pipe run 3,
i=6 for inlet plenum,
i=7,...,11 correspond to i=1,...,5, but for primary loop 2,
i=12 for outlet plenum,
i=13 for inner core flow channel (see Fig. 4-1),
i=14 for outer core flow channel,
i=15 for peak core flow channel,
i=16 for control assembly flow channel,
i=17 for radial blanket flow channel, and
i=18 for bypass flow channel.

NAMELIST/HYDB/CA,CB,CE,MINERT,TMMD,DSPEED,POLES,PMSSP

where:

CA,CB,CE = are the coefficients in the torque equations (6-17 and 6-18)
MINERT = primary pump moment of inertia,
TMMD = main motor design torque,
DSPEED = primary pump design speed,
POLES = number of pairs of poles in the primary pumps, and
PMSSP = pony motor synchronous speed.

NAMELIST/HYDC/CDBRK,AX5BB,AXAB,VOLGV,SGVMID,SGVTOP,ZGVMID,ZGVTOP

where:

CDBRK = rupture loss coefficient of Eq. 6-8,
AX5BB = inertial loss coefficient in pipe run 3 before the break,
AXAB = inertial loss coefficient in pipe run 3 after the break,
VOLGV = total volume of the guard vessel,
SGVMID = constant cross-sectional area of the guard vessel from the break location to a given reference location (see ZGVMID, below),
SGVTOP = constant cross-sectional area of guard vessel above the reference point,
ZGVMID = elevation of reference location where the guard vessel may change cross-sectional area, and
ZGVTOP = elevation of top edge of guard vessel.

NAMELIST/HYDD/CONVG,FREQ0,XKA,TK,TS,TR,TMIN,AL0

where:

CONVG = conversion gain in the pump frequency controller equation (Eq. 6-21),
FREQ0 = steady-state 100% rated frequency of the motor generator,
XKA = flow-to-speed conversion gain in primary flow controller (see Fig. 10-2),
TK = motor generator set time constant (see Eq. 6-21),
TS = normalized startup friction torque (see Eq. 6-19),
TR = normalized rotating torque (see Eq. 6-19),
TMIN = minimum friction torque (see Eq. 6-19), and
AL0 = constant of Eq. 6-19.

NAMELIST/HYDE/FREQ1,FREQ2,AL1,AL2

where:

FREQi = initial value for frequency of pump motor in loop-i, and
ALi = initial value for pump speed in loop-i.

NAMELIST/HYDF/TAUWM,TAUAM,TAUTM,TRISPN

where:

TAUWM = time constant for measurement of flow rates,
TAUAM = time constant for measurement of pump speeds,
TAUTM = time constant for measurement of reactor inlet nozzle temperatures, and
TRISPN = reactor inlet nozzle temperature setpoint.

Initial Conditions

Some initial conditions data are provided through labeled COMMON statements, as follows:

COMMON/HYD2/NODB,PBRK,ZBRK,XLBRK,...

where:

NODB = node of pipe run 3 where pipe rupture occurs,
PBRK = coolant pressure at break location before rupture,
ZBRK = elevation of break location, and
XLBRK = pipe length from break location to reactor inlet.

COMMON/HYD3/ZOPNOM,DZCON,PCG,PGV,PINLET,AOP

where:

ZOPNOM = normal sodium level above reactor vessel outlet nozzle,
DZCON = elevation change from core outlet to reactor vessel outlet nozzle,
PCG = constant cover gas pressure,
PGV = constant guard vessel pressure,
PINLET = initial coolant pressure at reactor vessel inlet nozzle, and

AOP = cross-sectional area of outlet plenum.

COMMON/GET1/W100,W1,W2,WIC,WOC,WHC,WCA,WRB,WBP,...,WBRK

where these are the primary system flow rates (see NAMELIST/BR01/).

COMMON/NATCON/NOPON1,NOPON2

where these are NOPON(1) and NOPON(2) of NAMELIST/MASE/.

All other variables are initialized using input data (e.g., NAMELIST/HYDE/ above) or within the subroutine itself.

Input Process Variables

The input process variables which must be supplied with the list of arguments are:

MODE = control integer for transient selection (see NAMELIST/MASA/),

KMM1 = control integer for the main motor of primary pump 1 (see Eq. 6-20),

$= \begin{cases} 0, \text{ main motor disconnected,} \\ 1, \text{ normal operation,} \end{cases}$

KMM2 = same as KMM1, but for primary pump 2, and

PD = normalized power demand.

Other input process variables are made available to subroutine HYDROS through common statements:

COMMON/HYD1/TRI1,TRI2,CRIP

where:

TRI1 = reactor inlet nozzle temperature for loop 1,

TRI2 = reactor inlet nozzle temperature for loop 2, and

CRIP = total frictional loss coefficient for inlet plenum.

COMMON/FRICTS/CRLP1,CRLP2,CRPLEN,CRC(6),...

where:

CRLP1 = total frictional loss coefficient for loop 1,

CRLP2 = total frictional loss coefficient for loop 2,

CRPLEN = total frictional loss coefficient for both inlet and outlet plena, and

CRC(i) = total frictional loss coefficients for the six reactor flow regions: IC,OC,HC,CA,RB,BP.

COMMON/HEADS/GHEAD1,GHEAD2,GHPLEN,GH(6),...

where these are gravitational heads corresponding to the same regions as the total frictional loss coefficients of COMMON/FRICTS/.

COMMON/PHY4/...,DENOP,...,DPUMP1,...,DPUMP2,...

where:

DENOP = density of sodium at the outlet nozzle,

DPUMP1 = density of sodium in primary pump 1, and

DPUMP2 = density of sodium in primary pump 2.

COMMON/HYD2/...,CROBB,CROAB,HEADBB,HEADAB,DENAB

where:

CROBB = total frictional loss coefficient before the break in pipe run 3,

CROAB = total frictional loss coefficient between the break and the reactor inlet in pipe run 3,

HEADBB,

HEADAB = gravitational heads for the same regions as CROBB,CROAB, and

DENAB = density of coolant at break location.

Output Process Variables

Various primary sodium flow rates are the major output process variables of subroutine HYDROS. These flow rates are returned to the master in the R-vector previously defined.

One other output process variable (for pipe rupture transients) is transferred through the subroutine arguments:

HOP = sodium level above the core outlet.

Certain variables are transferred to the subroutine SCRAM for use in the plant trip equations. These are:

COMMON/SCRH/ALM1,ALM2,PRSNRM,NEWM1,NEWM2,ZOPTOT

where:

ALM1 = measured normalized pump speed in loop 1,
ALM2 = measured normalized pump speed in loop 2,
PRSNRM = normalized pressure at reactor inlet,
NEWM1 = measured normalized flow rate in loop 1,
NEWM2 = measured normalized flow rate in loop 2, and
ZOPTOT = sodium level above the RV outlet nozzle.

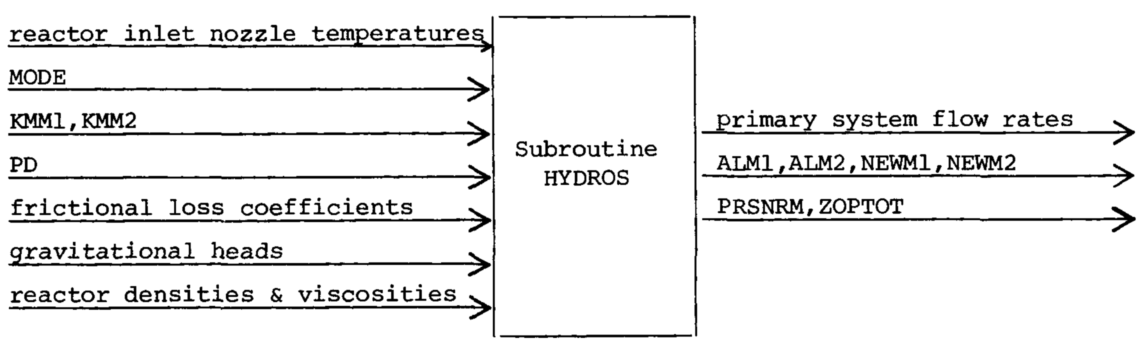


Figure 11-6. Inputs and Outputs of Subroutine HYDROS

Required Subprograms

Functions

- SOLVE = inverts the matrix of inertial loss coefficients and uses the inverted matrix to compute the derivatives of the sodium flow rates;
- RVOTSP = calculates the core outlet temperature setpoint as a function of power demand;
- PDERIV = calculates the derivative of PHEAD with respect to flow-rate; and
- FRFAC = calculates the 4f factor based on a correlation with Reynolds numbers.

Subroutines

- GHEAD = calculates gravitational heads and frictional loss coefficients;
- PTIME = calculates the derivative of PTORQ with respect to pump speed;
- PHEAD = computes the normalized pump head as a function of normalized pump speed and flow rate;
- PTORQ = computes the normalized pump torque as a function of normalized pump speed and flow rate;
- SYSTEM = solves a system of N ($N \leq 8$) equations using a Gauss-Jordan elimination technique;
- ALPHP = computes the pump speed under prompt approximation conditions;
- TFRIC = computes the normalized pump friction torque; and
- TMPCON = converts temperatures from °C to °F and vice versa.

Additional Comments:

Subroutine HYDROS has a secondary entry point, PUTHYD, which is used to print the latest results from subroutine HYDROS.

In addition to the aforementioned variables, subroutine HYDROS also employs a number of internal variables which need not be defined explicitly in order to use the subroutine.

SUBROUTINE RTHERM (MODE, PTMW, HOP, TI1, TI2)

Purpose and Scope:

Subroutine RTHERM computes the reactor temperatures in 33 separate regions and nodes. The model is divided into two reactor inlet plena, two reactor outlet plenum zones and six sodium flow path channels, consisting of: peak core channel, inner core channel, outer core channel, control assemblies channel, radial blanket and shield assemblies channel, and an unheated bypass channel.

Figure 11-7 depicts the eleven fuel regions of uniform heat generation that are simulated in the EPRI-CURL Code. The cladding and fuel centerline temperatures are also simulated using a pseudo-steady state approximation. Hot channel factors are applied to the average temperatures in the peak region to determine the maximum fuel and cladding temperatures in the reactor.

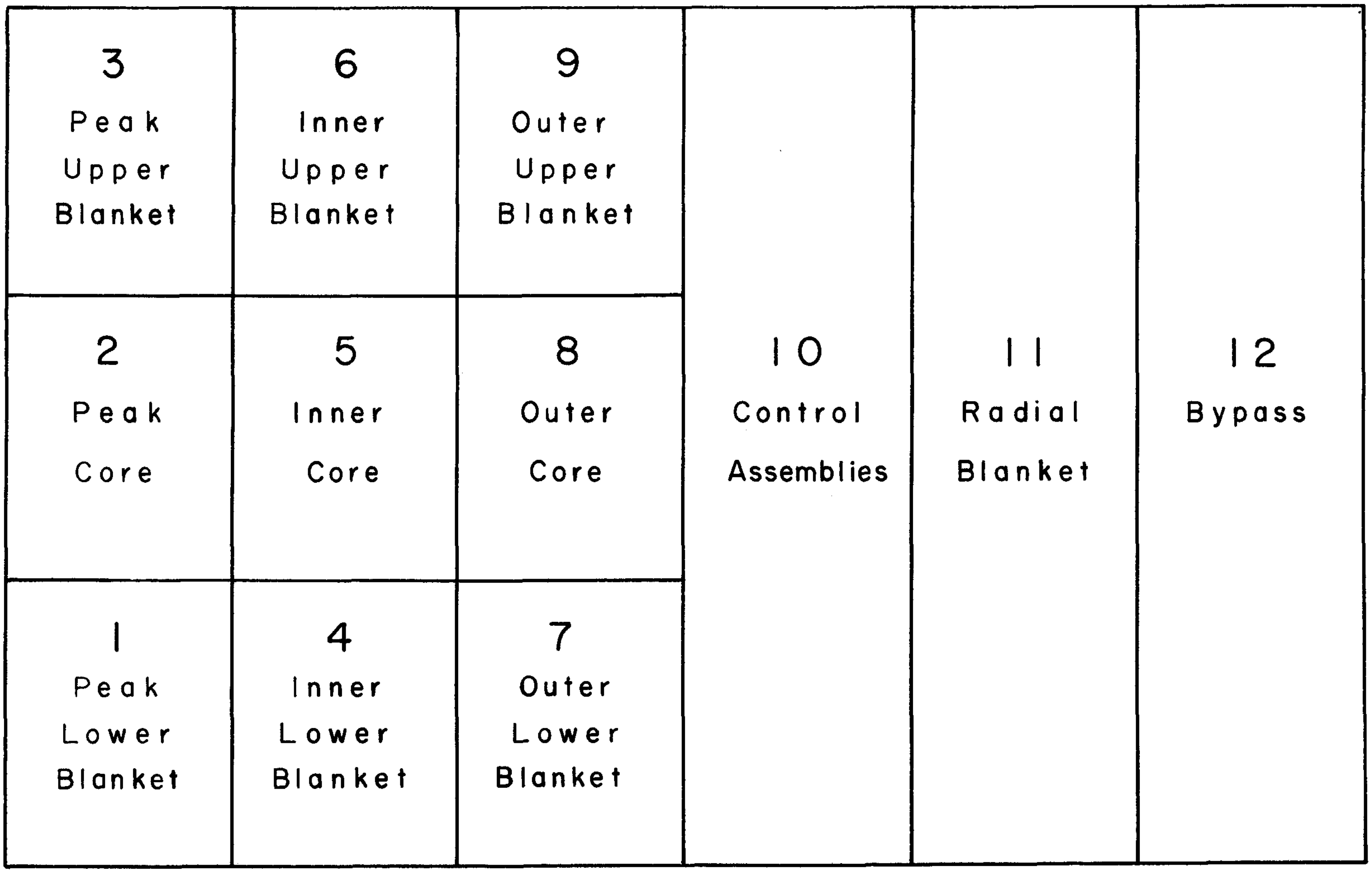


Figure 11-7. Reactor Heat Transfer Region Numbers

The model also permits flow reversal in any number of the six reactor sodium flow paths.

Method:

Detailed description of the equations used in RTHERM is given in Section 5 of this report.

The vector of process variables R3(33) is locally labelled Y(33), and is defined as follows:

Y(i)	= TM(i)	= reactor fuel region temperatures, i=1,11;
Y(12)	= TIP1	= average temperature of the lower region of the inlet plenum;
Y(13)	= TIP2	= average temperature of the upper region of the inlet plenum;
Y(i)	= TC(i-13)	= reactor coolant region temperatures, i=14,25;
Y(26)	= TOP1	= reactor outlet plenum temperature, lower zone;
Y(27)	= TOP2	= reactor outlet plenum temperature, upper zone; and
Y(i)	= TCI(i-27)	= temperature at junction between upper inlet plenum and the six core channels, i=28-33 (used only for cases of reversed flow).

Limitations:

The model assumes the liquid sodium is in the subcooled thermodynamic state, although some minor localized saturation may be tolerated. The model also assumes the core geometry is fully intact. The thermophysical properties of fuel, gas filled gap, cladding and other structural materials are temperature independent input parameters.

Input Data:

The following are lists of the input data required for subroutine RTHERM.

NAMELIST/RTH1/PF

where:

PF(i) = fraction of power generated in region i (see Fig. 11-7), (i=1,11 because the bypass region is assumed to generate no power).

NAMELIST/RTH2/VX,DT,VIP1,VIP2

where:

VX(i) = sodium volume in region i (i=1,12),

DT(i) = thermal equivalent diameter for fuel region i (i=1,11),

VIP1 = sodium volume in the lower inlet plenum, and

VIP2 = sodium volume in the upper inlet plenum.

NAMELIST/RTH3/DF,CF,XKF,DG,XKG,DC,XKCL

where:

DF(i) = fuel density in region i (i=1,11) (see Fig. 11-7),

CF(i) = fuel heat capacity in region i (i=1,11),

XKF(i) = reactor fuel thermal conductivity in region i (i=1,11),

DG(i) = fuel pin gas filled gap thickness in region i (i=1,11),

DC(i) = fuel pin cladding thickness in region i (i=1,11),

XKG = gas thermal conductivity in pin gap, and

XKCL = thermal conductivity of pin cladding.

NAMELIST/RTH4/VF,XL,R,XN

where:

VF(i) = fuel volume in region i (i=1,11)

XL(i) = active length for heat transfer in region i (i=1,11),

R(i) = fuel pellet radius in region i (i=1,11), and

XN(i) = total number of fuel pins in region i (i=1,11).

NAMELIST/RTH5/RO,ZCH,DON,HIF

where:

RO = radial coordinate of jet flow (see Eq. 5-5),

ZCH = height of reactor chimney,

DON = diameter of reactor outlet nozzle, and

HIF = heat transfer coefficient between two upper plenum regions.

NAMELIST/RTH6/HCFAC,FLFAC,CLFAC

where:

HCFAC = coolant hot channel factor (see Eq. 5-9),

FLFAC = film correction factor (see Eq. 5-10), and

CLFAC = clad correction factor (see Eq. 5-10).

Initial Conditions

The initial reactor temperatures are inputs to subroutine LMFBR (through NAMELIST/BRO2), and are transferred through:

COMMON/FBR1/TC(12),TIP1,TIP2,TCI(6),TOP1,TOP2,TON,TM(11)

These are the 33 variables to be integrated (see Y-vector, above) and are transferred to the MASTER program to a vector R3(33).

Input Process Variables

The five input variables which enter through the subroutine arguments are:

MODE = control integer for transient selection (see NAMELIST/MASA/),

PTMW = total reactor power,

HOP = height of sodium above core outlet,

TI1 = reactor inlet nozzle sodium temperature, loop-1, and

TI2 = reactor inlet nozzle sodium temperature, loop-2.

Other input process variables include:

COMMON/GET1/, which are the flow rates output by subroutine HYDROS,

COMMON/PHY1/, the first 33 elements of which are average region (as opposed to nodal) temperatures used to calculate physical properties, and

COMMONS/PHY4,PHY5,PHY6,PHY7/, which are the sodium densities, viscosities, specific heats, and thermal conductivities, respectively, at the temperatures of PHY1, above.

The Reynolds number is also inputed through the following:

COMMON/PHY8/RE(12), ...

During transients, the listed input process variables vary because they are output variables of other models.

Output Process Variables

The average sodium temperature at the reactor outlet nozzle, TON is an output process variable needed in subroutine DELAYP.

The average fuel and coolant temperatures in the reactor are also used to compute the feedback reactivities in NEUKIN subroutine.

The turbulent jet penetration distance in the outlet plenum is also an internal process variable which is needed in subroutine PLENO1. The following COMMON statement contains six sodium specific heats at the outlet of reactor coolant regions:

COMMON/PLNO/CHC,CIC,COC,CCA,CRB,CBP

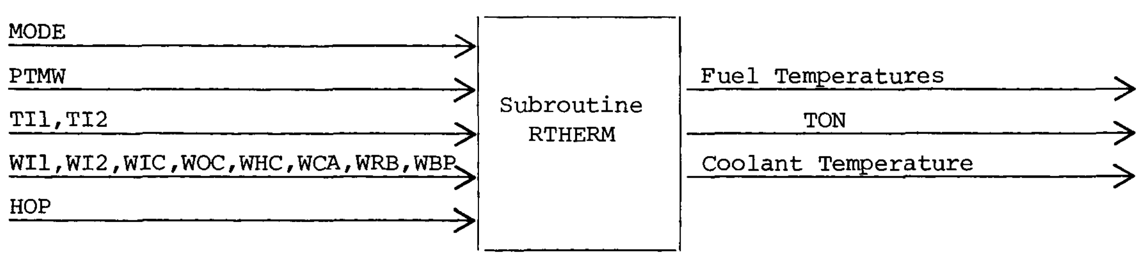


Figure 11-8. Input and Output Process Variables of Subroutine RTHERM

Required Subprograms

Functions:

o SPHSOD = computes sodium specific heat as a function of temperature,

- DENSOD = computes sodium density as a function of temperature, and
- HCORE = computes the convection heat transfer coefficient for sodium flowing along a bundle of cylindrical rods.

Subroutines:

- JET = computes the turbulent jet penetration distance in the outlet nozzle of the reactor as a function of average core flow rate and sodium density,
- UATOT = computes the overall heat transfer coefficient for sodium flowing along a bundle of cylindrical rods, as well as the fuel centerline, clad and film temperatures in prompt approximation,
- TIMECF = computes the fuel region characteristic times,
- TIMECC = computes the coolant region characteristic times,
- DFUEL = computes the fuel temperature time derivative in the reactor,
- DCOOL = computes the coolant temperature time derivatives in the reactor,
- TFUEL = computes the fuel temperature in prompt approximation,
- TCOOL = computes the coolant temperature in prompt approximation,
- PLENI1 = computes the coolant temperature of inlet plenum -1 in prompt approximation,
- PLENI2 = computes the coolant temperature of inlet plenum -2 in prompt approximation,
- PLENO1 = computes the coolant temperature of outlet plenum -1 in prompt approximation, and
- TMPCON = converts temperatures from °C to °F and vice versa.

Additional Comments

Subroutine RTHERM has one secondary entry, PUTRTH, which is used to print the latest results computed by RTHERM.

In addition to the aforementioned variables, subroutine RTHERM employs a number of internal variables which, however, do not need to be specified in order to use RTHERM.

SUBROUTINE DELAYP(W1,W2,MODE)

Purpose and Scope

Subroutine DELAYP computes the sodium temperatures in the primary piping system which connects the major components of the primary heat transport system. Six pipe runs are modeled, three in each of two primary loops (see Fig. 6-1). Given the inlet sodium temperature for each pipe run, subroutine DELAYP computes the sodium temperatures at each of N subsequent nodes, where N is the number of equal length subsections into which the pipe run is divided ($1 \leq N \leq 10$). These calculations are made in order to account for sodium transport delays around each loop as a function of flow rate.

Heat storage in pipe walls is included as an option for the evaluation of the transient sodium temperatures along the pipes. The sodium temperature at the exit of each pipe run is delivered as an output of DELAYP to the next heat transport system component downstream.

Method

Detailed descriptions of the model and the equations used are found in Section 6 of this report. Transient sodium temperatures and (optionally) transient wall temperatures are calculated by means of energy balances in each subsection of a pipe run. Sodium flow is based on single-phase, incompressible liquid sodium conditions.

The number of pipe subsections, N, is preset numerically for each of the six pipe runs, and can take on different values in each pipe run. Similarly, heat storage in the walls can be considered in any, all, or none of the six pipe runs.

The vector of process variables, R5(120), is labelled locally as Y(120), the first 60 of which are the nodal coolant temperatures (ten locations allocated for each pipe run, whether all are used or not), and the next 60 are the corresponding wall temperatures (ten locations allocated for each pipe run, whether heat storage is considered in that pipe run or not).

Limitations

The model does not accommodate reverse flows. It is assumed that check valves prevent the flow from reversing.

In the case of a pipe rupture transient, calculations are carried out in a normal manner. It is assumed that the rupture takes place near the reactor vessel so that the majority of the calculations along the pipe are still valid.

Input Data

All of the input data for subroutine DELAYP comes in from subroutine LMFBR through labeled COMMON statements.

```
COMMON/FBR14/...,ODP(3),DELP(3),XL(6),...
```

where:

ODP(i) = outer diameter of pipes in pipe run i (i=1,3); note: it is assumed that pipe runs 4,5,6 have the same dimensions as pipe runs 1,2,3 respectively

DELP(i) = pipe wall thickness for pipe run i (i=1,3; see note above), and

XL(i) = length of pipe run i (i=1,6).

```
COMMON/FBR10/N(6),L(6)
```

where:

N(i) = number of nodal subsections in pipe run i (i=1,6), and

L(i) = control integers for heat storage option, pipe run i (i=1,6) (see NAMELIST/BRO3/).

```
COMMON/FBR15/DSS,CSS,XKSS
```

where:

DSS = density of pipe wall material,

CSS = specific heat of pipe wall material, and

XKSS = thermal conductivity of pipe wall material.

Initial Conditions

The initial conditions are brought in through a COMMON statement from subroutine LMFBR:

```
COMMON/FBR5/TM1(10),TM2(10),TM3(10),TM4(10),TM5(10),TM6(10)
```

where:

TMi(j) = vector of initial coolant temperatures for pipe run i (j=1,N(i), filled out with zeroes if N(i) < 10).

The plant is assumed to be at steady state initially, so the wall temperature in each subsection is equivalent to the coolant temperature in that subsection at the beginning of the transient calculation.

Input Process Variables

The input process variables which must be supplied with the argument list are as follows:

W1 = sodium flow rate in primary loop-1,
W2 = sodium flow rate in primary loop-2, and
MODE = control integer for transient selection (see NAMELIST/MASA/).

The inlet temperatures of each pipe run are brought into the subroutine through a COMMON statement:

```
COMMON/FBR4/TCI1,TCI2,TCI3,TCI4,TCI5,TCI6
```

where:

TCIi = inlet temperature to pipe run i (i=1,6).

COMMONS/PHY4,PHY5,PHY6,PHY7,PHY8 bring in the sodium properties for each pipe subsection (densities, viscosities, specific heats, thermal conductivities, and Reynolds numbers, respectively).

Output Process Variables

The output process variables are the sodium outlet temperatures at the exit of each of the six pipe runs:

TC1(N1),...,TC6(N6)

where Ni refers to the number of subsections in pipe run i (i=1,6).

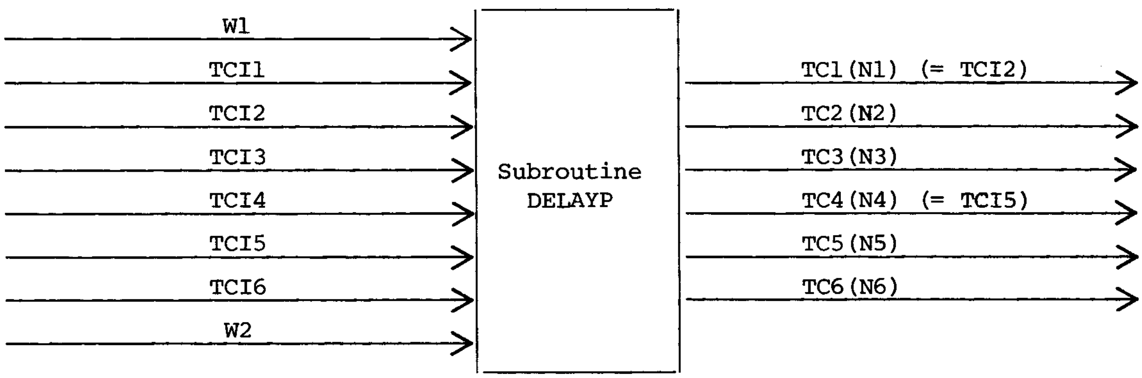


Figure 11-9. Inputs and Outputs of Subroutine DELAYP

Required Subprograms

Functions:

- o None.

Subroutines:

- o PIPE = calculates the transient temperatures of sodium and the pipe wall for N equal length subsections of a pipe run; the wall temperature may be neglected, and
- o TMPCON = converts temperatures from °C to °F and vice versa.

Additional Comments

At present, no temperature increase is assumed to occur in the primary pumps due to compression work, and all temperature delays through the pumps are neglected. Therefore, the outlet temperatures of pipe runs 1 and 4 are used as the inlet temperatures to pipe runs 2 and 5.

The coolant temperature arrays, TC1 to TC6, and the wall temperature arrays, TW1 to TW6, are concatenated in that order in a 120 element vector called Y, for transfer to the master program and the RUNGE function.

Subroutine DELAYP does not at present employ a prompt approximation for cases when time constants of the temperatures are small relative to the time step. For the pre-accident steady-state calculation, the inlet temperature of each pipe run is immediately propogated through the pipe and becomes the corresponding outlet temperature. This is done so that piping delays get neglected in the steady state search.

Subroutine DELAYP has an additional entry point, PUTDEL, which is used to print the latest results of the temperature calculations.

In addition to the aforementioned variables, subroutine DELAYP employs a number of internal variables which need not be explicitly defined in order to use the subroutine.

SUBROUTINE IHX1(MODE,WP,WS,TPI,TSI,N)

Purpose and Scope

The subroutine IHX1 computes the sodium temperatures at 2N+5 locations of the intermediate heat exchanger in loop 1, where N is the number of equal length subsections into which the active heat-transfer length is divided ($1 \leq N \leq 10$).

This variable mesh point feature has been incorporated in this subroutine to allow for more flexibility in determining the optimum compromise between computation time and accuracy of transient results. Primary and secondary inlet and outlet plena are simulated, as well as a primary bypass flow region. The other 2N temperatures calculated represent the temperatures in each primary or secondary heat transfer region.

No solid regions (shell, shrouds, tubes, etc.) are simulated in this model. This simplification was adopted after analyzing the transient results obtained from an earlier model of the IHX which incorporated solid region nodes. It was concluded that negligible errors are made by neglecting the heat storage in shells and tubes (7).

Method

Detailed descriptions of the equations and models used are given in Section 7 of this report. Transient IHX temperatures are calculated by means of an energy balance on each node of the system. Heat transferred between primary and secondary sodium flows is calculated to account for sodium film conductivity (as a function of flow and temperature) on both the shell and tube sides, and for the tube metal wall conductivity. Sodium flows are based on single-phase liquid sodium conditions with a constant bypass flow fraction.

The amount of heat exchanged between the primary and secondary systems is calculated by means of a logarithmic mean temperature difference (LMTD) in each heat-transfer subsection. It was found that the use of the LMTD resulted in better temperature profiles along the tube bundle than those obtained by other techniques such as backward-, forward-, and central-difference.

Calculation of the LMTD is performed by a separate subroutine LMTDIF, which is invoked recurrently by subroutine IHX1 for each heat-transfer region.

The vector of process variables, R41(25), is labelled locally as Y, and consists of:

Y(i) = TP(i) = coolant temperatures at the primary nodes (i=1,13) (refer to Fig. 7-1); and

Y(i) = TS(i-13) = coolant temperatures at the secondary nodes (i=14,25) (see Fig. 7-1).

Limitations

The model does not accommodate flow reversal. Check valves in the primary and secondary loops prevent the flows from reversing.

Input Data

```
NAMELIST/HX1A/DEXT,PITCH,XKSS,NT,BP,ACF
```

where:

DEXT = tube external diameter,
PITCH = triangular array tube pitch,
XKSS = thermal conductivity of tubes,
NT = number of tubes,
BP = bypass flow fraction, and
ACF = heat-transfer area correction factor (due to fouling, flow maldistribution, etc.).

NAMELIST/HX2A/VIP,VOP,VBP,VIS,VOS

where:

VIP = primary sodium inlet plenum volume,

VOP = primary sodium outlet plenum volume,

VBP = primary sodium bypass region volume,

VIS = secondary sodium inlet plenum volume, and

VOS = secondary sodium outlet plenum volume.

Other input data is obtained through a COMMON statement:

COMMON/FBR14/DEQUIP,STOTP,...,XLTOT,...,DINT,STOTS,...

where:

DEQUIP = shell side equivalent hydraulic diameter,

STOTP = shell side (primary) free flow area,

XLTOT = total tube bundle length,

DINT = tube side inner diameter, and

STOTS = tube side (secondary) free flow area.

The number of heat transfer regions, N, is input through the list of arguments to the subroutine.

Initial Conditions

The initial conditions for subroutine IHX1 are provided through a common statement from subroutine LMFBR:

COMMON/FBR2/TP(13),TS(12)

where:

TP = primary side sodium temperatures, and

TS = secondary side temperatures.

These initial temperatures are input to subroutine LMFBR through NAMELIST/BRO4/ (see Section 10.2).

Input Process Variables

The input process variables which are supplied through the list of arguments are:

MODE = control integer for transient operation,

$= \begin{cases} 0, \text{ pre-accident steady state initialization,} \\ 1, \text{ normal operation,} \end{cases}$

WP = primary sodium flow rate entering heat exchanger,

WS = secondary sodium flow rate entering heat exchanger,

TPI = primary sodium inlet nozzle temperature, and

TSI = secondary sodium inlet nozzle temperature.

Physical properties are brought into the subroutine through several COMMON statements:

sodium densities:	COMMON/PHY4/...,DP(13),...,DSDUM(12),...
sodium viscosities:	COMMON/PHY5/...,AVP(10),...,AVSDUM(10),...
sodium specific heats:	COMMON/PHY6/...,CP(13),...,CSDUM(12),...
sodium thermal conductivities:	COMMON/PHY7/...,XKP(13),...,XKSDUM(12),...
flow Reynolds numbers:	COMMON/PHY8/...,REP(10),...,RESDUM(10),...

All the secondary side parameters (those with names ending -DUM), need to be reversed within subroutine IHX1 because they are ordered in the direction of flow and the subroutine does its calculation in the direction of decreasing temperature.

Output Process Variables

The output process variables of subroutine IHX1 are the outlet nozzle temperatures on the primary and secondary sides, that is, TP(N+3) and TS(N+2) respectively.

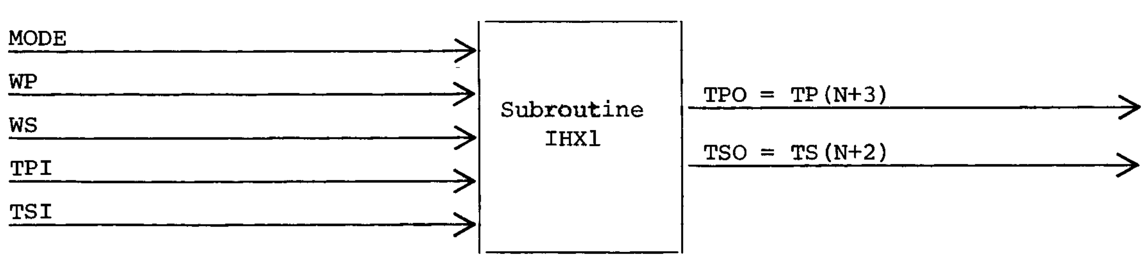


Figure 11-10. Input and Output Process Variables of Subroutine IHX1

Required Subprograms

Functions:

- None.

Subroutines:

- LMTDIF = computes the logarithmic mean temperature difference between primary and secondary flow regions,
- PROMTP = computes the prompt approximation values of primary side sodium temperatures for pre-accident initialization cases or cases in which the characteristic time is relatively short compared with the time step;
- PROMTS = equivalent to PROMTP, but for the secondary side temperatures; and
- TMPCON = converts temperatures from °C to °F and vice versa.

Additional Comments

Subroutine IHX1 has a secondary entry point, PUTHX1, which is used to print the latest results calculated by subroutine IHX1.

In addition to the aforementioned variables, this subroutine employs a number of internal variables which need not be understood in order to use the subroutine.

SUBROUTINE IHX2 (MODE,WP,WS,TPI,TSI,N)

Subroutine IHX2 is identical in most respects to subroutine IHX1, and is used to compute the transient behavior of the intermediate heat exchanger of loop 2. The two subroutines are completely distinct, so some associated parameters (number of nodes, area correction factor, etc.) need not be the same in each loop.

The input data to subroutine IHX2 is of the same form, but the NAMELIST names have changed to HX2A and HX2B.

The initial conditions come through a COMMON labelled FBR3, having been input to subroutine LMFBR through NAMELIST/BR05/.

The basic heat exchanger dimensions (flow areas, inner diameters, and heat transfer length) are identical in IHX1 and IHX2 because both subroutines use the same COMMON/FBR14/statement.

The vector of process variables is passed to the master program as R42(25).

SUBROUTINE IHYD1 (PD, PTM, KMM, MODE)

Purpose and Scope

The subroutine IHYD1 computes the sodium flow rate in the secondary loop as governed by forced and natural circulation effects. During normal operational transients, the sodium flow rate in the secondary loop is subject to the action of the secondary flow/speed controller. The secondary loop flow/speed controller is based on feed-forward with feedback strategy.

The sodium flow rate in the loop is assumed to be the same both before and after the secondary pump because the sodium level in the pump barrel is assumed to remain constant.

Subroutine IHYD1 can be used to analyze change of power and many sodium flow transients such as secondary pump coastdown.

Method

Detailed descriptions of the model and methods used are given in Section 8 of this report.

There are five first-order ordinary differential equations which simulate the secondary loop sodium dynamics. The vector of process variables R61(5), is locally labelled Y(5), and is defined as follows:

Y(1) = WI = sodium flow rate in the secondary loop,
Y(2) = ALFA = secondary pump speed (normalized),
Y(3) = WIM = measured sodium flow rate in the secondary loop (normalized),
Y(4) = ALFM = measured secondary pump speed (normalized), and
Y(5) = GF = frequency of motor generator-set.

The Reynolds number dependence of the frictional loss coefficients is considered, as well as the gravitational pressure heads developed by the density variations from the IHX to the steam generator system.

Limitations

The secondary loop sodium dynamics model assumes the sodium flow rates in the secondary sides of evaporators to be equally divided.

At present the model does not permit any secondary pipe ruptures. Provision for such an accident can be made by modeling an additional differential equation.

Input Data

The following are the required input data for subroutine IHYD1:

NAMELIST/IHA1/DSPEED,TMMD,MINERT,PMSSP

where:

DSPEED = secondary pump design speed,
TMMD = secondary pump main motor design torque,
MINERT = secondary pump moment of inertia, and
PMSSP = secondary pump pony motor synchronous speed.

NAMELIST/IHA2/PTSP,KFT,KST,KSF,TAUS

where:

PTSP = turbine header pressure set point,
KFT = pump flow trim conversion gain,
KST = pump speed trim conversion gain,
KSF = pump speed controller conversion gain,
TAUS(1) = secondary flow meter time constant,
TAUS(2) = secondary tachometer time constant, and
TAUS(3) = secondary motor generator-set time constant.

NAMELIST/IHA3/A1,A2,A3,AZ,TS,TR,TMIN,GFI,XNP,ALFA,GF

where:

A1 = constant used in the motor torque slip relationship (a in Eq. 6-17),
A2 = constant used in the motor torque slip relationship (b in Eq. 6-17),
A3 = constant used in the pony motor torque slip relationship (C in Eq. 6-18),
AZ = constant used in the friction torque equation (Eq. 6-19),
TS = pump start-up torque,
TR = pump rotating torque,
TMIN = minimum friction torque,

GFI = steady-state 100% rated frequency of Motor Generator Set,

XNP = number of pairs of poles,

ALFA = initial secondary pump speed, and

GF = initial frequency of pump motor generator.

Initial Conditions

Subroutine IHYD1 requires five initial conditions of which frequency and speed are input through NAMELIST/IHA3/ and the flow is made available through the following:

```
COMMON/GET1/ ..., WI100, WI, ...
```

The measured secondary loop flow and pump speed are initially set equal to their actual values in the subroutine, that is:

WIM = WI = measured sodium flow rate, and

ALFM = ALFA = normalized measured pump speed.

Input Process Variables

The input process variables which must be supplied with the list of arguments of subroutine IHYD1 are the following:

PD = normalized power demand,

PTM = measured turbine header pressure,

KMM = control parameter for the main motor of secondary pump,

KMM = 1.0 -- main motor connected (normal operation),

KMM = 0.0 -- main motor disconnected,

MODE = control parameter for transient selection,

MODE = 0 preaccident steady state initialization,

MODE = 1 normal operation, and

MODE = 3 natural circulation (pony motors not available).

Other required variables for subroutine IHYD1 are made available through the following COMMON statements:

```
COMMON/MISC/T,TSEC,ICOUNT,S,SSEC, ..., ...
```

where:

T = time in hours,
TSEC = time in seconds,
ICOUNT = step counter,
S = time step in hours, and
SSEC = time step in seconds.

COMMON/FBR14/ ..., XL3, XL7, XL8, XL1, ..., XL2, XL4, XL5, XL6, ...

where the secondary loop pipe lengths are:

XL1 = length of the pipe connecting the secondary pump to IHX,
XL2 = length of the tubes in IHX,
XL3 = length of the pipe connecting IHX to the superheater,
XL4 = length of the tubes in superheater,
XL5 = length of the pipe connecting superheater to the evaporator,
XL6 = length of the tubes in evaporator,
XL7 = length of the pipe connecting the evaporator to the connecting T, and
XL8 = length of the pipe connecting the T to the pump.

COMMON/FBR16/ ..., AS2, AS3, ..., AS4, AS5, AS6, AS7, ..., AS8, AS1, ...

are the flow areas in the secondary loops that correspond to the above mentioned lengths calculated in subroutine LMFBR.

COMMON/HEADS/ ..., DPBST, ...

where:

DPBST = total gravitational pressure head in secondary loop-1,

COMMON/FRICTS..., CCST, ...

where:

CCST = total frictional loss coefficient in secondary loop-1.

Output Process Variables

Secondary sodium flow rate is the only output process variable of subroutine IHYD1. The flow rate is WI.

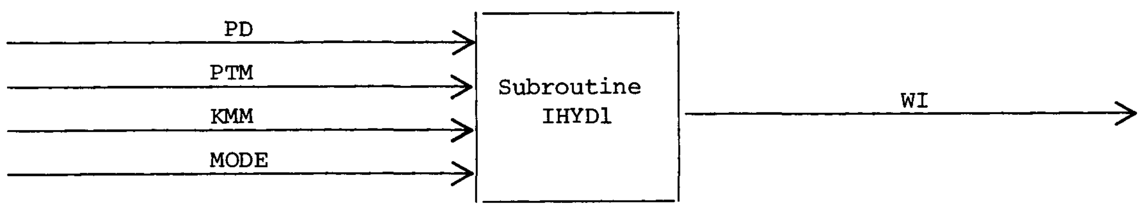


Figure 11-11. Input and Output Variables of Subroutine IHYD1

Required Subprograms

Functions

- o None.

Subroutines

- o PTIME = computes the derivatives of pump torque and friction torque with respect to pump speed as a function of normalized pump flow and speed,
- o PHEAD = computes the normalized pump head as a function of the normalized pump speed and flow rate,
- o PTORQ = computes the normalized pump torque as a function of the normalized pump speed and flow rate,
- o ALPHA = computes the pump speed from the prompt approximation conditions, and
- o TFRIC = computes the normalized pump friction torque.

Additional Comments

The subroutine IHYD1 has one secondary entry, PUTIH1, which is accessed from the master program for the purpose of printing the latest results computed by IHYD1.

In addition to the aforementioned variables, subroutine IHYD1 also employs a number of internal variables that need not be defined explicitly in order to use IHYD1.

SUBROUTINE IHYD2(PD,PTM,KMM,MODE)

Subroutine IHYD2 is identical in most respects to subroutine IHYD1 and is used to compute the transient behavior of the secondary loop-2 sodium flow dynamics. In order to preserve the laws of conservation of energy, mass, and momentum when simulating the response of a lumped loop, this loop is exactly identical to that of loop-1 (single loop).

Each of the two subroutines, IHYD1 and IHYD2, is allocated in a separate storage area and, thus, the values of the variables within each model are preserved and processed independently without any possibility of error.

Subroutine IHYD2 has only two NAMELIST data statements (as opposed to three in IHYD1), since the sodium pump characteristics for the two loops are identical and are made available to IHYD2 through the COMMON storage area ALPB from IHYD1. The input data are:

NAMELIST/IHB1/TMMD,MINERT,GFI,ALFA,GF

NAMELIST/IHB2/PTSP,KFT,KST,KSF,TAUS

where the descriptions of these variables are found under the NAMELIST statements of subroutine IHYD1.

The vector of process variables for subroutine IHYD2 is R62(5), labelled locally as Y(5).

SUBROUTINE DELAY1 (W1, MODE)

<u>Purpose and Scope</u>

Subroutine DELAY1 computes the sodium temperatures in the secondary piping system of loop-1 which connects the major components of the Intermediate Heat Transport System (IHTS). Four pipe runs are modeled for the secondary loop. Given the sodium temperature at the inlet of each pipe run, subroutine DELAY1 computes sodium temperatures at N subsequent locations, where N is the number of equal-length subsections into which the pipe run is divided; it can be set equal to any value between 1 and 10. These calculations are necessary in order to account for the sodium transport delays around the secondary loop as function of the sodium flow rate.

Heat storage in pipe walls is included as an option for the evaluation of the transient sodium temperatures along the pipes. The sodium temperature calculated at each pipe exit is delivered as an output of subroutine DELAY1 to be used as input temperature to the next major HTS component downstream.

Method

The equations used are of the same form as those in subroutine DELAYP. Transient sodium temperatures and, optionally, transient wall temperatures are calculated by means of energy balances on each subsection of a pipe run. Sodium flow is based on single-phase liquid sodium conditions with the same mass flow rate throughout the secondary loop. When heat storage in the pipe wall is considered, the amount of heat exchange within a pipe between the sodium and the wall is calculated as being directly proportional to the difference between the average wall temperature and the average inlet-outlet sodium temperature.

The number of pipe subsections, N, is preset numerically for each pipe run of the loop; it can take different values for different pipes. In order to estimate the effect of heat storage in the pipe walls on the sodium transient temperatures, the option of considering the heat stored in the walls can be applied to all pipe runs, to several selected pipe runs, or to none.

The vector of process variables, R71(80), is labelled locally as Y(80), the first 40 locations of which are the nodal coolant temperatures in each of the four pipe runs, and the last 40 are reserved for the corresponding wall temperatures (used if heat storage is considered).

Subroutine PIPE is invoked for each of the four pipe runs to compute the transient sodium temperature at each node, with or without heat storage.

Limitations

The model does not accommodate reverse flows. It is assumed that check valves will keep the flow from reversing.

At present, the number of nodes per pipe run is limited to 10.

Input Data

All of the required input data come in from subroutine LMFBR through labelled COMMON statements:

COMMON/FBR11/N(4),L(4)

where:

N(i) = number of pipe subsections in pipe run i (i=1,4), and

L(i) = control integer for heat storage option in pipe run i (i=1,4) (see NAMELIST/BRO3/).

COMMON/FBR14/...,XL(4),...,ODI(4),DELI(4)

where:

XL(i) = length of pipe run i (i=1,4),

ODI(i) = outer diameter of pipe in pipe run i (i=1,4), and

DELI(i) = pipe wall thickness in pipe run i (i=1,4).

Initial Conditions

The initial sodium temperatures are made available through a COMMON statement with LMFBR:

COMMON/FBR7/TM1(10),TM2(10),TM3(10),TM4(10)

where:

TMi(j) = sodium temperatures in pipe run i (j=1,N(i), filled out with zeroes if N(i) < 10), (i=1,4).

Initially, the pipe walls are assumed to be in thermal equilibrium with the coolant at each node.

Input Process Variables

The variables which must be supplied through the argument list are:

MODE = control integer for transient selection,

$$MODE = \begin{cases} 0, & \text{pre-accident steady state initialization, and} \\ 1, & \text{normal operation,} \end{cases}$$

W1 = flow rate in the loop.

Other input process variables are provided through COMMON statements:

COMMON/FBR6/TCI1,TCI2,TCI3,TCI4,...

where:

TCIi = Inlet sodium temperature to pipe run i.

COMMONS/PHY4,PHY5,PHY6,PHY7,PHY8/

provide the sodium physical properties (densities, viscosities, heat capacities, thermal conductivities, and Reynolds numbers, respectively) at each node of each pipe run.

Output Process Variables

The output process variables of subroutine DELAY1 are the sodium temperatures at the exit of the four pipe runs.

These output process variables are further used as input process variables for other components of the system.

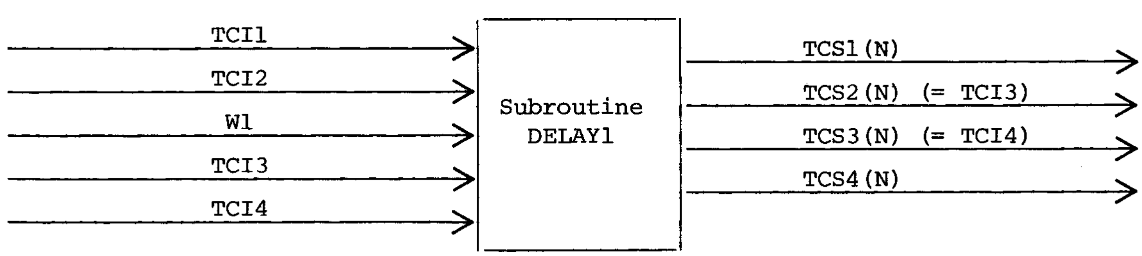


Figure 11-12. Input and Output Process Variables of Subroutine DELAY1

Required Subprograms

Functions:

- None.

Subroutines:

- PIPE = computes the transient temperatures of sodium and of the pipe wall in N equal-length subsections of a pipe run; heat storage in pipe walls is optional, and
- TMPCON = converts temperatures from °C to °F and vice versa.

Additional Comments

No temperature increase due to compression in the pumps is considered at present.

Subroutine DELAY1 does not employ a prompt approximation at present for cases where the length of a pipe subsection is so short as to make the "characteristic time" shorter than the time step increment. Care should be taken to avoid this situation.

Subroutine DELAY1 has an additional entry point, PUTID1 for the purpose of printing the results of the sodium transport delay calculations in secondary loop-1 whenever required by the master program. A number of internal variables are also employed which need not be known in order to use DELAY1.

SUBROUTINE DELAY2(W1, MODE)

Subroutine DELAY2 is exactly identical to subroutine DELAY1 and is used to compute the sodium and pipe wall temperatures in the Intermediate Heat Transport Systems (IHTS) of loop-2.

Each of the two subroutines, DELAY1 and DELAY2, is allocated in a separate storage area and, thus, the values of the variables within each model are preserved and processed independently without any possibility of error.

The vector of process variable for subroutine DELAY2 is R72(80), labelled locally as Y(80).

SUBROUTINE SGTHD1 (TISH, KMM, MODE)

Purpose and Scope

Subroutine SGTHD1 computes steam/water enthalpies, temperatures, pressures and flows as well as the steam generator secondary shell side sodium temperatures for loop-1 of the plant. It models 39 differential equations and solves them simultaneously either using the Runge-Kutta algorithm or the prompt approximation method.

Figure 11-13 shows the regions of simulation for this subroutine.

Method

Detailed descriptions of the equations used are given in Section 9 of this report. The model simulates the water/steam enthalpies flow rates and pressures and calls the appropriate equations of states (polynomial approximations to 1967 steam tables) to determine water/steam temperatures and thermodynamic properties.

The vector of process variables, R81(39), is labelled locally as Y(39), and is defined as follows:

Y(i)	= TCS(19-i)	= secondary system nodal sodium temperatures (see Fig. 11-13 for node definitions), i=1,11,
Y(i)	= H(i-9)	= tertiary system nodal enthalpies (see Fig. 11-13 for node definitions), i=12,30,
Y(31)	= ALFA	= normalized recirculation pump speed,
Y(32)	= W2	= recirculation line water/steam flow,
Y(33)	= W3	= steam flow through superheater,
Y(34)	= MT(2)	= mass of steam/water mixture in the steam drum,
Y(35)	= UI(2)	= total internal energy of the steam drum,
Y(36)	= HDM	= measured value of the steam drum level (normalized),
Y(37)	= WM3	= measured value of normalized steam flow,
Y(38)	= WM1	= measured value of normalized feedwater flow, and
Y(39)	= CVP	= position of the feedwater control valve.

Due to nonlinearity of the energy equations along the heat transfer regions (evaporators and superheaters), iterative schemes are developed that determine the tertiary side enthalpies and secondary side sodium temperatures when in prompt approximation.

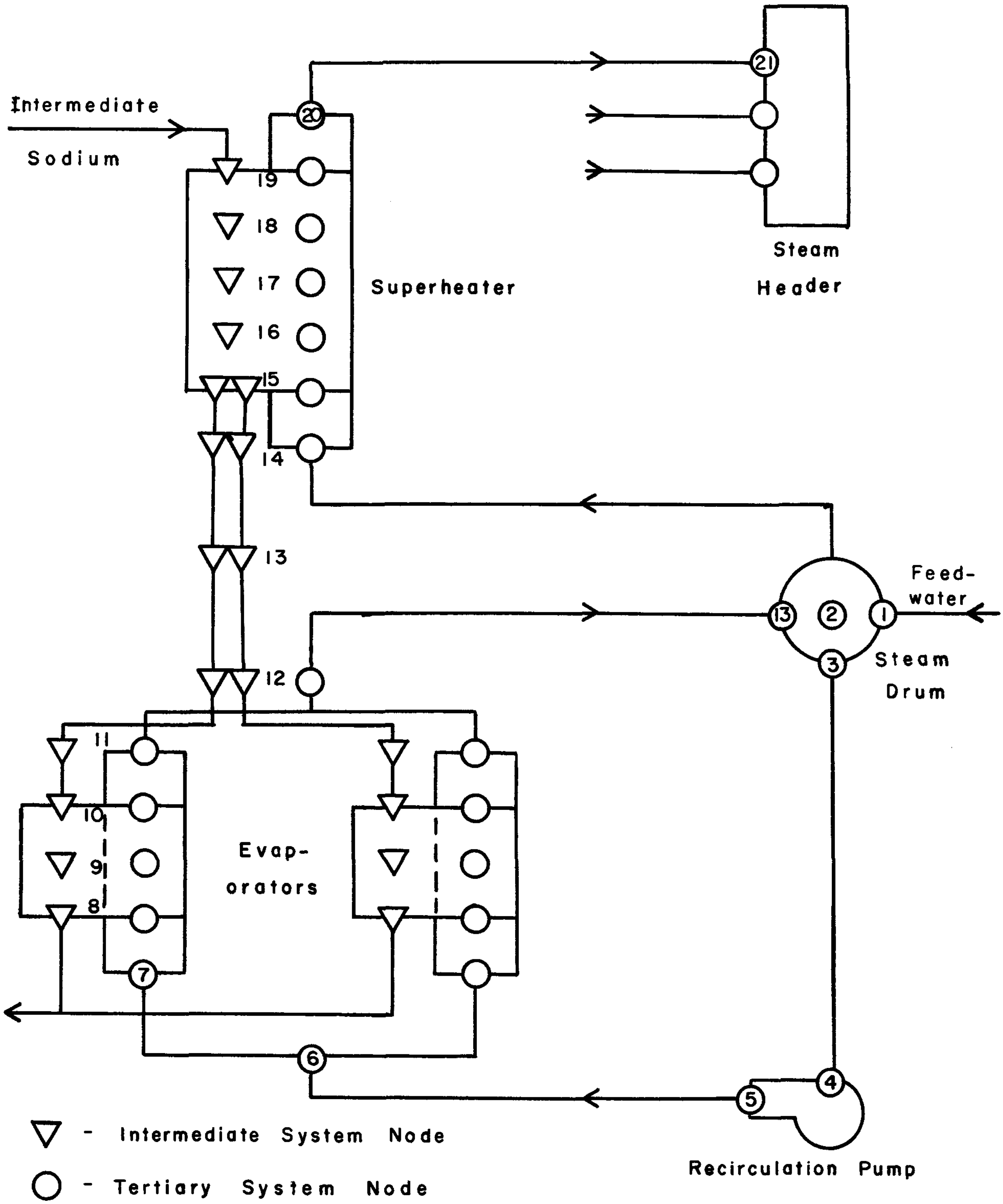


Figure 11-13. Nodal Definitions for Subroutine SGTHD1

Limitations

The model assumes symmetric evaporator modules and hence lumps the two together. The model does not handle flow reversal and steam generator blow-down accidents. The heat transfer modes in evaporators are limited to subcooled and saturated boiling and effect of film boiling after the dry out is neglected.

Input Data

The following 13 NAMELIST statements are used to input the required data for SGTHD1:

NAMELIST/SGA01/EPSI,P

where:

EPSI = accuracy criteria for drum pressure iteration (units of pressure), and

P(i) = vector of 21 tertiary system nodal pressures (see Figure 11-13 for node definitions).

NAMELIST/SGA02/H

where:

H(i) = vector of 21 tertiary system initial nodal enthalpies.

NAMELIST/SGA03/TCS

where:

TCS(i) = initial sodium temperature at secondary system node i (i=1,19; note that the first 7 are dummies and may be set to zero).

NAMELIST/SGA04/XLT,XL,ACF,TKON

where:

XLT = total effective tube length in an evaporator module, XL(i) = length of pipe (or region) from tertiary system node i-1 to node i (i=1,21);

NOTES:

XL(1) and XL(3) are not used by the code (may be set to zero),

XL(2) = total effective length of steam drum,

XL(9) and XL(10) are calculated internally by the code (using XLT and the calculated boiling lengths), and thus may be input as zero;

ACF = fouling area correction factor for heat transfer in the superheater, and

TKON = thermal conductivity of the superheater and evaporator tubes.

NAMELIST/SGA05/Z

where:

Z(i) = elevation of the tertiary system node i (i=1,21; NOTE: Z(9) may be input as zero).

NAMELIST/SGA06/XLS

where:

XLS(i) = length of pipe (or region) from secondary system node i-1 to node i (i=1,19);

NOTES:

XLS(1) → XLS(8) are dummies and should be set to zero,

XLS(9) and XLS(10) are determined by the code and may be set to zero.

NAMELIST/SGA07/PITCH,D

where:

PITCH = evaporator and superheater tube pitch, and

D(i) = vector of inner diameters of tertiary system pipes of NAMELIST/SGA04/ (i=1,21).

NAMELIST/SGA08/DS,DEL,XN

where:

DS(i) = vector of inner diameters of shrouds (in evaporators and superheater) and piping in the secondary system, corresponding to the pipes of NAMELIST/SGA06/ (i=1,19),

DEL(i) = vector of tube wall thicknesses (in evaporators and superheater) and pipe wall thicknesses, corresponding to the tertiary side piping (i=1,21), and

XN(i) = vector of the number of tubes or pipes corresponding to the tertiary pipes (or regions) of NAMELIST/SGA04/, note that the split of piping between nodes 6 and 12 is internally represented. For example, to model a system where the piping from the evaporators to the steam drum remains separate, XN should be as follows:

XN(8) → XN(11) = number of tubes in each evaporator,

XN(13) = 2.,

XN(15)→ XN(20) = number of tubes in the superheater,

all other XN = 1.

NOTE: DS(i) may be set to zero for i=1,7; the proper values must be included for i=8,9 in this case.

NAMELIST/SGA09/A1,A2,AZ,TS,TR,TMIN,DSPEED,SSPEED,TMD,MINERT

where:

A1,A2 correspond to a,b of the tertiary system version of Eq. 6-17,

AZ,TS,TR,TMIN correspond to α_o, T_S, T_R, T_{min} of the tertiary system version of Eq. 6-19,

DSPEED = recirculation pump design speed,

SSPEED = recirculation pump synchronous speed (constant),

TMD = recirculation pump design torque, and

MINERT = pump moment of inertia (see Eq. 6-20).

NAMELIST/SGA10/KFW,KCV,HDSP

where:

KFW = feedwater flow trim conversion gain,

KCV = feedwater valve controller conversion gain, and

HDSP = normalized steam drum setpoint water level.

NAMELIST/SGA11/W1100,W2100,W1,W2,W3,CVP,ALFA

where:

W1100 = 100% rated value of feedwater flow,

W2100 = 100% rated value of recirculation line flow,

W1 = initial feedwater flow,

W2 = initial recirculation line water/steam flow,

W3 = initial steam flow,

CVP = initial feedwater valve opening (normalized), and

ALFA = initial value of recirculation pump speed (normalized).

NAMELIST/SGA12/TAUS

where:

TAUS(1) = time constant of device measuring drum level,

TAUS(2) = time constant of device measuring steam flow,

TAUS(3) = time constant of device measuring feedwater flow, and

TAUS(4) = time constant of feedwater valve controller.

NAMELIST/SGA13/WFMIN,WFMAX,CVMAX,WAUXM,HAUW,HDAUX,HDMAX

where:

WFMIN,WFMAX,CVMAX correspond to $W_{F,min}$, $W_{F,max}$, $S_{FV_{max}}$ of Eq. 9-15,

WAUXM = maximum auxiliary water mass flow rate,

HAUW = auxiliary water enthalpy,

HDAUX = minimum normalized drum level under auxiliary feedwater flow (any less forces full opening of auxiliary feedwater valve), and

HDMAX = maximum normalized drum level under auxiliary feedwater flow (any more forces full closing of auxiliary valve).

Initial Conditions

The initial conditions to the 39 differential equations are supplied through NAMELIST/SGA02, SGA03, SGA11/ and the rest are calculated by the model as necessary.

Input Process Variables

There are three input process variables that must be supplied through the argument of SGTHD1;

TISH = superheater inlet sodium temperature, loop-1,

KMM = control integer for the recirculation pump operation

KMM = 1.0 -- normal operation

KMM = 0.0 -- pump trip

MODE = control integer for transient selection

MODE = 0 -- preaccident steady state initialization

MODE = 1 -- normal operation

The secondary loop sodium flow is supplied through:

```
COMMON/GET1/...,WI100,WI,...,...
```

where:

WI100 = 100% rated value of sodium flow and

WI = sodium flow rate in secondary loop-1.

The steam header pressure is available through:

```
COMMON/PHDR/PH, ...
```

where:

PH = steam header pressure.

Output Process Variables

The output process variables of subroutine SGTHD1 are the secondary sodium outlet temperature from the evaporators, the superheated steam enthalpy and flow rate from the superheater outlet steam line (at the inlet of the main steam header inlet nozzle).

The sodium outlet temperature is used in subroutine DELAY1, and the superheater enthalpy and flow are the required inputs to subroutine TURBO.

Figure 11-14 describes the input and output process variables of subroutine SGTHD1.

The steam drum measured water level is also an output that is required by subroutine SCRAM during the transients.

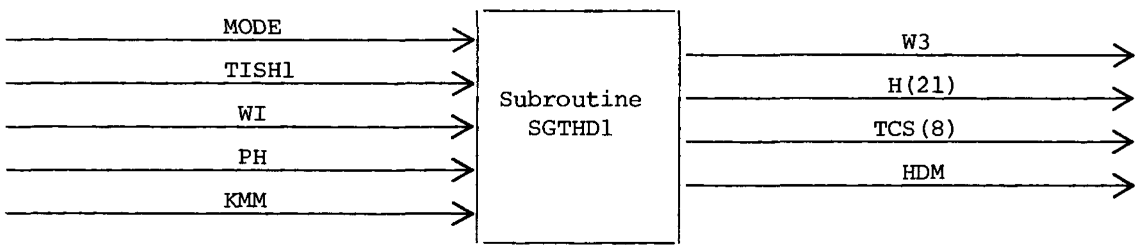


Figure 11-14. Input and Output Variables of Subroutine SGTHD1

Required Subprograms

Functions:

- DENSOD = computes density of subcooled liquid sodium as function of temperature,
- SPHSOD = computes heat capacity of liquid sodium at constant pressure as a function of temperature,
- VISSOD = computes the dynamic viscosity of liquid sodium as a function of temperature,
- THCSOD = computes the thermal conductivity of liquid sodium as a function of temperature,
- SURFTN = computes the surface tension of water as a function of temperature and specific volume,
- PSAT = computes the saturation pressure of water as a function of temperature,
- TCOND1 = computes the thermal conductivity of water as a function of pressure and temperature,
- TCOND2 = computes the thermal conductivity of steam as a function of temperature and specific volume,
- DVISC1 = computes the dynamic viscosity of water as a function of pressure and temperature,
- DVISC2 = computes the dynamic viscosity of steam as a function of temperature and specific volume,

- SHEAT1 = computes the heat capacity at constant pressure for water as a function of pressure and temperature,

- SHEAT2 = computes the heat capacity at constant pressure for steam as a function of pressure and temperature,

- SPVOL2 = computes the specific volume of steam as a function of temperature and pressure,

- TSTEAM = computes the temperature of superheated steam as a function of enthalpy and pressure,

- TMETAL = computes the tube wall to bulk temperature drop in the evaporating region,

- DPMOM = computes the momentum term coefficient in the equation of motion, and

- USTG = computes the overall heat transfer coefficient based on the steam generator tube outside diameter for the evaporator and superheater modules.

Subroutines:

- SWATER = computes the thermodynamic properties of saturated water and saturated steam as a function of pressure,

- WATER = computes the thermodynamic properties of subcooled water as a function of pressure and enthalpy,

- ENTH = computes the enthalpy of superheated steam in the superheater iteratively using the prompt approximation condition,

- PROMTT = computes the secondary side sodium temperature by Newton-Raphson's Method using the prompt approximation conditions,

- DRUM = computes the drum pressure as a function of specific internal energy and specific volume iteratively using a thermodynamic equilibrium model,

- LMTDIF = computes the logarithmic mean temperature difference,

- BRHTC = computes the heat transfer coefficient for the boiling portion of the evaporator,

- CHFLX = computes the distance at which the dryout occurs from the saturation point using a critical heat flux correlation,

- ARMAND = computes the two-phase flow frictional multiplier using the Armands Method,

- PTIME = computes the partial derivatives with respect to speed of pump hydraulic and friction torques,

- RPSPD = computes the recirculation pump speed in prompt approximation,

- o PHEAD = computes the recirculation pump head as a function of speed and flow,
- o PTORQ = computes the recirculation pump torque as a function of speed and flow, and
- o TFRIC = computes the pump frictional torque.

Additional Comments:

Subroutine SGTHD1 has an additional entry, PUTSG1, which is used to print the latest results computed by SGTHD1.

In addition to the aforementioned variables, subroutine SGTHD1 employs a number of internal variables which, however, do not need to be specified in order to use SGTHD1.

SUBROUTINE SGTHD2(TISH,KMM,MODE)

Subroutine SGTHD2 is identical to subroutine SGTHD1 and is used to compute the transient behavior of the Steam Generator System of loop-2.

The recirculation pump characteristics are exactly identical to those of loop 1 and are made available to SGTHD2 through COMMON storage location ARPP.

Each of the two subroutines, SGTHD1 and SGTHD2, is allocated in a separate storage area and, thus, the values of the variables associated with each subroutine are preserved and processed independently without any possibility of error.

The input data to SGTHD2 corresponds, with one exception, to the input data of subroutine SGTHD1, except that the NAMELIST names all begin SGB (instead of SGA). The lone exception is in:

    NAMELIST/SGB09/TMD,MINERT

because the other pump characteristics are identical to loop-1.

SUBROUTINE TURBO (MODE, W31, W32, H211, H212)

Purpose and Scope:

Subroutine TURBO simulates the main steam header, the turbine throttle valve, the turbine bypass (dump) valve and the header relief valves. The steam header pressure, temperature and enthalpy are calculated using conservation of mass and energy along with appropriate equations of state (steam tables and/or a corrected ideal gas model for water vapor).

Method:

The detailed descriptions of the equations used are given in Section 9 of this report. There are five differential equations in the submodel which simulate the following variables:

Y(1) = MH = mass of superheated steam inside the header,
Y(2) = IE = total internal energy of the superheated steam,
Y(3) = PM = measured header pressure at the guage,
Y(4) = TVP = fraction of the throttle valve opening, and
Y(5) = DVP = fraction of the dump (bypass) valve opening.

These variables are passed to the master program as R9(5).

The turbine throttle, bypass and header relief valves operate to keep the steam header pressure near constant.

Limitation:

The model does not calculate choked flow conditions at the valves, and hence there is no limitation on the steam flow rate through throttle, dump and relief valves.

The concept of acoustic wave phenomena has not been included, although acoustic waves may be of some importance during the turbine trip accident.

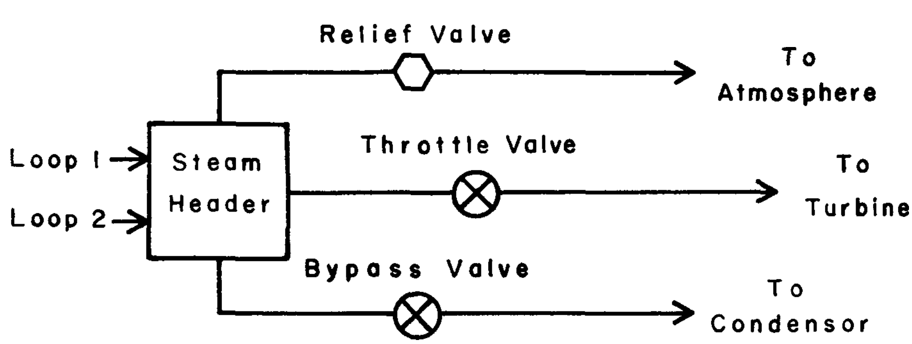


Figure 11-15. Main Steam Header and Turbine Flow Control

Input Data

The required data for subroutine TURBO are inputed via the following two NAMELIST statements.

NAMELIST/SHD1/VH,KTV,KDV,TVP,DVP,TAU,PSPTV,PSPDV,PSPRV

where:

VH = total volume of the main steam header,
KTV = throttle valve controller conversion gain,
KDV = dump valve controller conversion gain,
TVP = fractional opening of the throttle valve (initially),
DVP = fractional opening of the dump valve (initially),
TAU = time constant for the pressure gauge at the header,
PSPTV = throttle valve set point pressure,
PSPDV = dump valve set point pressure, and
PSPRV = relief valve set point pressure.

NAMELIST/SHD2/WT100,WNMAX,WNMIN,PH,PC,CT,CTV,CDV,CRV

where:

WT100 = 100% rated value of the turbine flow,
WNMAX = maximum fractional flow through the throttle valve,
WNMIN = minimum fractional flow through the throttle valve,
PH = main steam header initial pressure,
PC = condenser pressure,
CT = frictional loss in the turbine and stationary valve (in units of pressure),
CTV = frictional loss in the pipe and throttle valve (in units of pressure),
CDV = frictional loss in the bypass valve and piping (in units of pressure), and
CRV = inverse of frictional loss in the relief valve (in units of inverse pressure).

Initial Conditions:

The following initial conditions were inputed through the input data, Y(4) = TVP

Y(5) = DVP

and the other three initial conditions are calculated by subroutine TURBO.

Input Process Variables:

There are five input variables that come to TURBO through the subroutine argument. They are:

MODE = control integer for transient selection,

MODE = 0 -- preaccident steady state initialization,

MODE = 1 -- normal operation,

MODE = 4 -- turbine trip,

MODE = 5 -- uncontrolled opening of the dump (bypass) valve,

W31 = superheated steam mass flow rate from loop-1,

W32 = superheated steam mass flow rate from loop-2,

H211 = superheated steam enthalpy from loop-1, and,

H212 = superheated steam enthalpy from loop-2.

Output Process Variables:

The only output process variables from subroutine TURBO are the main steam header pressure PH, and the steam temperature TMH.

Figure 11-16 shows the input and output process variables of subroutine TURBO.

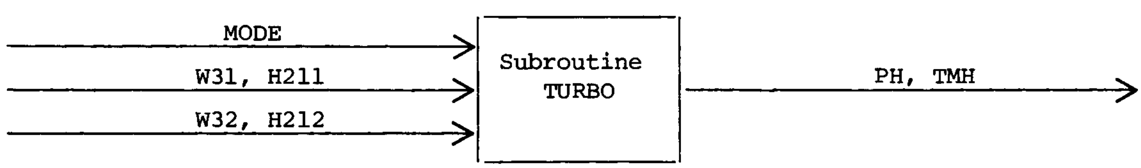


Figure 11-16. Input and Output Process Variables of Subroutine TURBO

Required Subprograms:

Functions

- TSTEAM = computes the steam temperature as a function of steam enthalpy and pressure,
- SPVOL2 = computes the specific volume of steam as a function of steam temperature and pressure.

Subroutines

- o HEADER = computes the steam pressure in the main steam header as a function of total specific internal energy and specific volume.

Additional Comments:

Subroutine TURBO has one secondary entry, PUTTUR, which is used to print the latest results computed by TURBO.

SUBROUTINE SCRAM(MSCRAM,KMM1,KMM2,KMS1,KMS2,KPM1,KPM2)

Purpose and Scope

Subroutine SCRAM compares various parameters (as sensed through measuring devices with known time constants) with reactor trip equations to determine whether a reactor shutdown is warranted.

Presently, the subroutine includes 9 possible trip equations for a primary control rod scram, and 4 equations for a secondary scram. Room has been left in the subroutine for the easy addition of 2 more trip equations, one primary and one secondary.

The actual plant trip may be delayed from the time of the trip signal by means of input, constant delay times. Separate delays are provided for control rod insertion, primary pump trip, secondary pump trip, and tertiary recirculation pump trip.

In addition, any pump or either control rod system may be tripped manually at any given time (see master program, NAMELIST/MASD/). These manual trips are overridden by any automatic trip which may occur at an earlier time in the transient.

Any trip equation may be neglected if desired, as provided in the input data set.

Method

Most of the variables used in the trip equations have already undergone measurement delays because they are used in the reactor power and flow/speed controllers.

Certain variables, however, do not have measured values, so these must be determined within subroutine SCRAM. To accomplish this, a vector is set up for integration within function RUNGE. This vector has 7 variables and is set up as follows:

R(1) = PRESM = measured normalized pressure at the reactor vessel inlet,

R(2) = ZRVOPM = measured sodium level above reactor vessel outlet nozzle, R(3) = PNRMM = measured normalized reactor power (flux),

R(4) = TIHX1M = measured IHX primary sodium outlet temperature in loop-1,

R(5) = TIHX2M = measured IHX primary sodium outlet temperature in loop-2,

R(6) = TVAP1M = measured evaporator outlet sodium temperature in loop-1, and

R(7) = TVAP2M = measured evaporator outlet sodium temperature in loop-2.

This vector is passed to the master program as R10(7).

It is assumed that the determination of whether power is increasing or decreasing (i.e. whether the total reactivity RO is positive or negative) is instantaneous.

As soon as a primary trip is initiated, no further calculation of the primary trip levels is done. The same is true for the secondary trips. The pump trips will occur due to the earliest of the control rod trips.

Limitations

At present, the same delay is used for a control rod trip in either the primary or the secondary scrams.

Input Data

NAMELIST/SCR1/NOSCRAM,DELAY,PMPDEL

where:

NOSCRM = vector of 15 integers which consists of the plant trips that are to be neglected, filled out with zeroes (e.g., to allow only primary system scrams, the value of NOSCRAM should be:

NOSCRAM = 11,12,13,14,15,0,0,0,0,0,0,0,0,0,0;

Note that the neglected scrams must appear in increasing order);

DELAY = delay time between trip signal and control rod drop, and

PMPDEL = vector of 6 delay times between trip signal and pump shut-off: 2 primary, 2 secondary, and 2 tertiary.

NAMELIST/SCR2/PLIM,TCON,A2,B2,C2,D2,A3,B3,C3,D3,A4,B4,C4,A6,B6,C6,A8,ZLEVEL,
THXSCR

These are the parameters in the primary trip equations of Table 4-1 where:

PLIM = ϕ max in #1 trip,

$$\left.\begin{array}{l} \text{TCON} = \tau \\ \text{A2} = A_2 \\ \text{B2} = B_2 \\ \text{C2} = C_2 \\ \text{D2} = D_2 \end{array}\right\} \text{ in \#2 trip,}$$

$$\left.\begin{array}{l} \text{A3} = A_3 \\ \text{B3} = B_3 \\ \text{C3} = C_3 \\ \text{D3} = D_3 \end{array}\right\} \text{ in \#3 trip,}$$

$$\left.\begin{array}{l} \text{A4} = A_4 \\ \text{B4} = B_4 \\ \text{C4} = C_4 \end{array}\right\} \text{ in \#4 trip,}$$

$$\left.\begin{array}{l} \text{A6} = A_6 \\ \text{B6} = B_6 \\ \text{C6} = C_6 \end{array}\right\} \text{ in \#6 trip,}$$

A8 = A_8 in #8 trip,

ZLEVEL = Z_L in #7 trip, and

THXSCR = T_{shx} in #9 trip.

NAMELIST/SCR3/A11,B11,C11,A12,B12,C12,DRUMAX,TVAPSC

These are the parameters in the secondary trip equations of Table 4-2, where:

$$\left.\begin{array}{l} \text{A11} = A_{11} \\ \text{B11} = B_{11} \\ \text{C11} = C_{11} \end{array}\right\} \text{ in \#11 trip,}$$

$$\left.\begin{array}{l} \text{A12} = A_{12} \\ \text{B12} = B_{12} \\ \text{C12} = C_{12} \end{array}\right\} \text{ in \#12 trip,}$$

DRUMAX = $H_{D,max}$ in #13 trip, and

TVAPSC = T_{sev} in #14 trip.

NAMELIST/SCR4/TAU

where TAU is a 7 element vector of measurement time constants for the following:

TAU(1) = time constant for reactor vessel inlet pressure measurement,
TAU(2) = time constant for sodium level measurement,
TAU(3) = time constant for reactor power measurement,
TAU(4) = time constant for IHX-1 outlet temperature measurement,
TAU(5) = time constant for IHX-2 outlet temperature measurement,
TAU(6) = time constant for evaporator outlet temperature measurement in loop 1, and
TAU(7) = time constant for evaporator outlet temperature measurement in loop 2.

Initial Conditions

All initial conditions are set up within the subroutine scram itself. The initial conditions of all the measured quantities are set to the initial values of the quantities themselves, because the reactor is assumed to be at steady state initially.

Input Process Variables

All the input process variables are supplied to subroutine SCRAM by means of COMMON statements.

```
COMMON/SCRH/ALM1,ALM2,PRES,WM1,WM2,ZRVOP
```

where:

ALM1 = measured value of the normalized pump speed in primary loop-1,
ALM2 = measured value of the normalized pump speed in primary loop-2,
PRES = normalized reactor inlet pressure,
WM1 = measured value of the normalized flow rate in primary loop-1,
WM2 = measured value of the normalized flow rate in primary loop-2, and
ZRVOP = sodium level in the reactor vessel above the outlet nozzle.

```
COMMON/SCRM/ALIM1,ALIM2,WIM1,WIM2,TIHX1,TIHX2
```

where:

ALIM1 = measured value of the normalized pump speed in intermediate loop-1,
ALIM2 = measured value of the normalized pump speed in intermediate loop-2,
WIM1 = measured value of the normalized flow rate in intermediate loop-2,
WIM2 = measured value of the normalized flow rate in intermediate loop-2,

TIHX1 = primary side outlet sodium temperature of heat exchanger in loop-1, and
TIHX2 = primary side outlet sodium temperature of heat exchanger in loop-2.

```
COMMON/SCRP/PNRM,RO
```

where:

PNRM = normalized reactor power, and
RO = total reactor reactivity.

```
COMMON/SCRT/HDM1,HDM2,TEVAP2,WSTM1,WSTM2,WFWM1,WFWM2
```

where:

HDM1 = measured value of normalized steam drum level in loop-1,
HDM2 = measured value of normalized steam drum level in loop-2,
TEVAP1 = evaporator outlet sodium temperature in loop-1,
TEVAP2 = evaporator outlet sodium temperature in loop-2,
WSTM1 = measured value of normalized steam flow rate in loop-1,
WSTM2 = measured value of normalized steam flow rate in loop-2,
WFWM1 = measured value of normalized feed-water flow rate in loop-1, and
WFWM2 = measured value of normalized feed-water flow rate in loop-2.

Output Process Variables

All of the output process variables of subroutine SCRAM are transferred through the subroutine arguments. These are:

MSCRAM = control integer for reactor scrams,

$$\text{MSCRAM} = \begin{cases} 0, & \text{normal operation,} \\ 1, & \text{primary system scram,} \\ 2, & \text{secondary system scram, and} \\ 3, & \text{both primary and secondary reactor scrams;} \end{cases}$$

KMM1 = control integer for primary pump 1

$$\text{KMM1} = \begin{cases} 1.0, & \text{pump operational, and} \\ 0.0, & \text{pump motor shut off;} \end{cases}$$

KMM2 = same as KMM1, but for primary pump 2,
KMS1 = same as KMM1, but for intermediate pump 1,
KMS2 = same as KMM1, but for intermediate pump 2,

KMG1 = same as KMM1, but for recirculation pump 1, and

KMG2 = same as KMM1, but for recirculation pump 2.

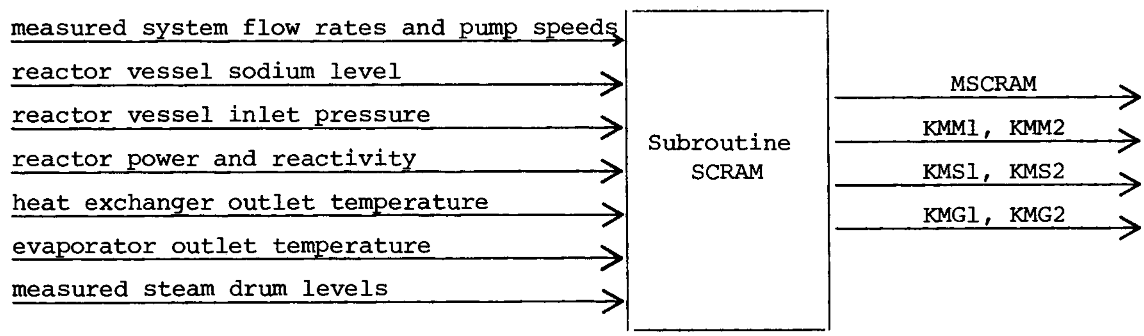


Figure 11-17. Inputs and Outputs of Subroutine SCRAM

Required Subprograms

None.

Additional Comments

In addition to the previously mentioned variables, subroutine SCRAM contains several internal variables which need not be defined in order to use the subroutine.

Subroutine SCRAM has one secondary entry, PUTSCR, which is used to print the latest values for the variables measured in SCRAM.

ANCILLARY PROGRAMS

There are 59 ancillary subprograms which are required by the major subroutines discussed in the previous sections.

These subprograms (functions and subroutines) are mostly general, and include the thermophysical properties of liquid sodium, water and steam, and may be replaced by other more up-to-date correlations and data as they become available.

They also include some of the more specific aspects of the plant modeling such as the reactor fuel energy equations and the compressible flow models of the steam drum and steam header. These models can be altered as needed by the user and will not create any major difficulty in the overall model.

Because all variables are internally represented in English units, these subprograms must accept input and provide output in English units. To avoid confusion, in case one wishes to alter a particular correlation, the required units are listed in this section.

FUNCTION VISSOD(X)

The VISSOD function computes the dynamic viscosity of liquid sodium as a function of its temperature measured in °F. The dynamic viscosity is first computed in units of poises, using an analytical expression and then converted into units of lb/ft - hr (17).

The input process variable is:

X = sodium temperature, °F.

The output process variable is:

VISSOD = dynamic viscosity of sodium, lb/ft - hr.

FUNCTION SPHSOD(X)

SPHSOD function computes the heat capacity of sodium as a function of its temperature °F. The heat capacity is computed in Btu/lb_m - °F using an analytical expression (17).

The input process variable is:

X = sodium temperature, °F.

The output process variable is:

SPHSOD = liquid sodium heat capacity, Btu/lb_m °F.

FUNCTION THCSOD(X)

THCSOD computes the thermal conductivity of liquid sodium as a function of its temperature in °F. An analytical expression is used to obtain the liquid sodium thermal conductivity in Btu/ft - hr - °F (17).

The input process variable is:

X = sodium temperature, °F.

The output process variable is:

THCSOD = liquid sodium thermal conductivity, Btu/ft - hr - °F.

FUNCTION DENSOD(X)

The DENSOD function computes the density of liquid sodium as a function of its temperature measured in °F. The sodium density is computed in lb_m/ft^3 using an analytical expression (17).

The input process variable is:

X = sodium temperature, °F.

The output process variable is:

DENSOD = liquid sodium density, lb_m/ft^3.

SUBROUTINE PHYPRS(N)

Subroutine PHYPRS computes the physical properties of liquid sodium as well as the flow Reynolds Number. The liquid sodium density, viscosity, specific heat, and thermal conductivity as well as the Reynolds Number are calculated in N different nodes.

The input process variables are:

N = total number of nodes/regions for which physical properties and Reynolds number needs to be calculated

COMMON/PHY1/TCAV(232)

TCAV(232) = vector of 232 sodium average temperatures, °F

COMMON/PHY2/G(232)

G(232) = vector of 232 sodium mass fluxes, lb_m/ft^2 - hr

COMMON/PHY3/DH(232)

DH(232) = vector of 232 hydraulic equivalent diameters, ft

The output process variables are:

COMMON/PHY4/DEN(232)

DEN(232) = vector of 232 sodium densities, lb_m/ft^3

COMMON/PHY5/VIS(232)

VIS(232) = vector of 232 sodium dynamic viscosities, lb/ft - hr

COMMON/PHY6/CPS(232)

CPS(232) = vector of 232 sodium heat capacities, Btu/lb_m - °F

COMMON/PHY7/XKS(232)

XKS(232) = vector of 232 sodium thermal conductivities, Btu/hr - ft °F

COMMON/PHY8/RES(232)

RES(232) = vector of 232 sodium Reynolds numbers

The following subprograms are required:

Functions

- o DENSOD = computes the density of liquid sodium,
- o VISSOD = computes the viscosity of liquid sodium,
- o SPHSOD = computes the specific heat of liquid sodium, and
- o THCSOD = computes the thermal conductivity of liquid sodium.

Subroutines

- o None.

FUNCTION FRFAC(RE,P,D,WL,M)

The FRFAC function calculates the moody friction coefficient in the reactor fuel rod bundle or inside a smooth pipe for the complete flow spectrum. The function uses analytical relationships described in Section 6 of this report, to calculate the 4f factor.

The required input process variables of the FRFAC function are:

RE = flow Reynolds number

P = rod pitch, ft

D = rod outside diameter, ft

WL = spiral wire spacer lead, ft

M = control integer

M = 0 -- for a pipe

M = 1 -- for reactor fuel rod bundles

Note: when FRFAC is used for a pipe, P, D, and WL should be specified as some dummies since Re and M are the only required inputs.

The output process variable is:

FRFAC = moody friction factor.

SUBROUTINE GHEAD(N,GC,ZO,Z,DO,DC,W,P1,P2,F,A,DE,XL,DPG,FT,XKT)

Subroutine GHEAD calculates the overall contributions to the flow due to bouyancy effects, the total sum of moody friction factors and a velocity head loss factor for a pipe run or a reactor coolant region of N subsections.

Subroutine GHEAD uses the sodium densities, relative elevations, flows, and initial pressure along with the moody friction factor to calculate:

$$\bar{\rho}_i = \frac{\rho_{i-1} + \rho_i}{2}$$

$$DPG = \frac{g}{g_c} \sum_{i=1}^{N} \bar{\rho}_i \, (Z_{i-1} - Z_i)$$

$$FT = \frac{1}{2g_c} \sum_{i=1}^{N} \frac{4f_i \, L_i}{\bar{\rho}_i \, d_i \, A_i^2}$$

and only once initially:

$$CT = \frac{144 \, (P_1 - P_2) + DPG}{W^2}$$

$$XKT = CT - FT$$

The following input process variables are made available to subroutine GHEAD via the arguments (see also Fig. 11-18):

N = number of coolant regions or pipe subsections in series,

GC = conversion factor of 4.17×10^8 lb_m - ft/lb_f - hr^2,

ZO = relative elevation at the region or pipe inlet, ft

Z = relative elevations at the N nodes or subsections, ft,

DO = coolant density at the pipe inlet, lb_m/ft^3,

DC = coolant density at the N nodes or subsections, lb_m/ft^3,

W = coolant mass flow rate in the pipe or region, lb_m/hr,

P1 = pipe or region inlet pressure, lb_f/in^2,

P2 = pipe or region outlet pressure, lb_f/in^2,

F = moody friction factor at N locations,

A = flow cross-sectional area, ft^2,

DE = hydraulic equivalent diameter, ft, and

XL = length of N subsections, ft.

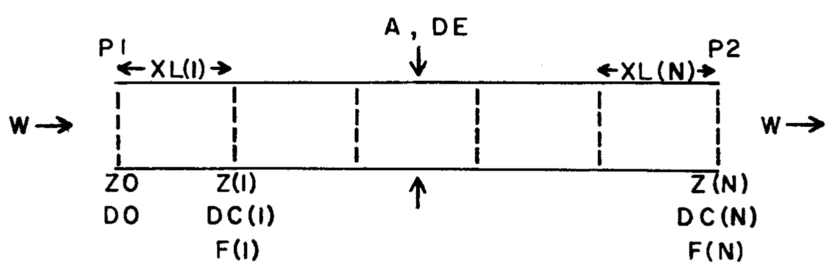


Figure 11-18. Pictorial Description of Arguments of Subroutine GHEAD

The following are the output process variables of subroutine GHEAD:

DPG = total sum of the gravitational pressure gradients, lb_f/ft^2,

FT = total sum of the friction factors, and

XKT = total velocity loss factor.

FUNCTION HCORE(RE,PE,DEQT,XK)

The HCORE function computes the convection heat-transfer coefficient for liquid sodium flowing along a bundle of circular rods, as functions of flow Reynolds and Peclet numbers.

Two different correlations are used depending upon the flow regimes: laminar (Equation 5-14), and turbulent (Equation 5-15).

The input process variables are:

RE = Reynolds number,

PE = Peclet number,

DEXT = thermal equivalent diameter of sodium flow cell area, ft, and

XK = thermal conductivity of liquid sodium, Btu/hr - ft - °F.

The output process variable is:

HCORE = convection heat-transfer coefficient, Btu/hr - ft^2 - °F.

SUBROUTINE UATOT(L,N,KM,KG,KC,DG,DC,H,D,R,Q,UA,TM,TSOD,TMAX,TCLAD,TFILM)

Subroutine UATOT computes the overall heat-transfer coefficient, UA, of a reactor assembly. Using a quasi-steady state approximation it also computes the average centerline temperature of the heat generating material, TMAX; the inner face temperature of the cladding, TCLAD; and the film temperature, TFILM.

The overall heat-transfer coefficient is computed by means of thermal resistances taken in series using the condition that the thermal-heat flux must be the same through all layers. The thermal resistances are considered from the equivalent radius of the heat-generating material to the point of average coolant temperature. The centerline temperature, as well as other temperatures at several intermediate locations, are computed with knowledge of partial thermal resistances (see Equations 5-8 and 5-11).

The input process variables are:

L = total effective heat transfer length, ft,

N = total number of pins of one kind,

KM = thermal conductivity of heat generating material, Btu/hr - ft °F,

KG = thermal conductivity of the gas filled gap, Btu/hr - ft - °F,

KC = thermal conductivity of the cladding, Btu/hr - ft - °F,

DG = gas filled gap thickness, ft,

DC = cladding thickness, ft,

H = convection heat transfer coefficient, Btu/hr - ft^2 - °F

D = pin external diameter, ft,

R = radius of heat generating pellet, ft,

Q = volumetric heat rate, Btu/hr - ft^3,

TM = average temperature of heat generating material, °F, and

TSOD = average temperature of sodium, °F.

The output process variables are:

UA = overall heat transfer coefficient times area, Btu/hr - °F

TMAX = average centerline temperature of heat generating material, °F

TCLAD = average cladding temperature at the inner face, °F, and

TFILM = average cladding temperature at the outer face, °F.

SUBROUTINE JET(ZCH,RO,WC,DB,DC,ZJET)

Subroutine JET calculates the average jet penetration distance in the reactor outlet plenum. Detailed description of the method used is given in Section 5 of this report.

The input process variables are:

ZCH = chimney height, ft,

RO = radial coordinate of the jet flow, ft,

WC = average reactor core flow, lb_m/hr,

DB = average sodium density in the lower zone of outlet plenum, lb_m/ft^3, and

DC = average sodium density in the core, lb_m/ft^3.

The outlet process variable is:

ZJET = jet penetration distance in the reactor outlet plenum, ft.

SUBROUTINE DFUEL(DF,VF,CF,QFV,UA,TF,TCIN,TCOUT,DTF)

Subroutine DFUEL calculates the time rate of change of reactor fuel average temperatures as function of nuclear heat generated and the heat transferred to the coolant. Detailed description is given in Section 4 of this report.

The input process variables are:

DF = fuel average density, lb_m/ft^3,

VF = fuel region volume, ft^3,

CF = fuel average heat capacity, Btu/lb_m °F

QFV = volumetric heat rate generated in the fuel, Btu/hr - ft^3

UA = overall heat transfer rate per degrees, Btu/hr - °F (UA -- heat transfer coefficient x heat transfer area)

TF = fuel region average temperature, °F,

TCIN = coolant temperature at the inlet of the region, °F, and

TCOUT = coolant temperature at the outlet of the region, °F.

The output process variable is:

DTF = time rate of change of reactor fuel region temperature, °F/hr.

SUBROUTINE DCOOL(DC,VC,CC,UA,TF,TCIN,TCOUT,DTC)

Subroutine DCOOL computes the time rate of change of reactor coolant region temperature, as function of total heat transferred from the fuel and the heat carried out due to the motion of fluid. Detailed description is discussed in Section 5 of this report.

The input process variables are:

DC = coolant region average density, lb_m/ft^3,

VC = coolant region volume, ft^3,

CC = coolant region average heat capacity, Btu/lb_m - °F,

UA = heat transfer rate per degrees, Btu/hr - °F (overall heat transfer coefficient times the heat transfer area of fuel),

TF = fuel region average temperature, °F,

TCIN = coolant region inlet sodium temperature, °F, and

TCOUT = coolant region outlet sodium temperature, °F.

The output process variable is:

DTC = time rate of change of coolant region average sodium temperature, °F/hr.

SUBROUTINE TIMECF(D,V,C,UA,TAU)

Subroutine TIMECF computes the fuel region characteristic time.

The input process variables are:

D = fuel region average density, lb_m/ft^3,

V = fuel region volume, ft^3,

C = fuel region average heat capacity, Btu/lb_m - °F, and

UA = rate of heat transfer per degrees, Btu/hr - °F.

The output process variable is:

TAU = fuel region characteristic time, hr.

SUBROUTINE TIMECC(D,V,C,UA,W,TAU)

Subroutine TIMECC computes the coolant region characteristic time in the reactor.

The input process variables are:

D = coolant region average density, lb_m/ft^3,

V = coolant region volume, ft^3,

C = coolant region average heat capacity, Btu/lb_m - °F,

UA = rate of heat transfer per degree, Btu/hr - °F, and

W = coolant mass flow rate, lb_m/hr.

The output process variable is:

TAU = coolant region characteristic time, hr.

SUBROUTINE TFUEL(QFV,VF,UA,TCAV,TF)

Subroutine TFUEL computes the fuel region average temperature in prompt approximation. The time independent form of equation 5-6 is solved for T_F.

The input process variables are:

QFV = volumetric heat generation rate, Btu/hr - ft^3,

FV = fuel region volume, ft^3,

UA = heat transfer rate per degree, Btu/hr - °F, and

TCAV = coolant region average temperature, °F.

The outlet process variable is:

TF = fuel region average temperature, °F.

SUBROUTINE TCOOL (CC,UA,W,TF,TCIN,TCOUT)

Subroutine TCOOL computes the coolant region outlet temperature in prompt approximation. The time independent form of equation 5-7 is solved for T_{c_o}.

The input process variables are:

CC = coolant region average heat capacity, Btu/lb_m - °F,
UA = heat transfer rate per degree, Btu/hr - °F,
W = coolant mass flow rate, lb_m/hr,
TF = fuel region average temperature, °F, and
TCIN = coolant region inlet sodium temperature, °F.

The output process variable is:

TCOUT = coolant region outlet sodium temperature, °F.

SUBROUTINE PLENI1(WI1,WI2,TI1,TI2,TIP2,TIP1,CPI1,CPI2)

Subroutine PLENI1 computes the sodium temperature in the reactor lower inlet plenum in prompt approximation. The time independent form of Equation 5-1 is solved for T_A.

The input process variables are:

WI1 = sodium mass flow rate, loop-1, lb_m/hr,
WI2 = sodium mass flow rate, loop-2, lb_m/hr,
TI1 = sodium temperature at the reactor inlet nozzle of loop-1, °F,
TI2 = sodium temperature at the reactor inlet nozzle of loop-2, °F,
TIP2 = sodium temperature in the upper inlet plenum, °F,
CPI1 = average sodium heat capacity at TI1, Btu/lb_m - °F, and
CPI2 = average sodium heat capacity at TI2, Btu/lb_m - °F.

The output process variable is:

TIP1 = sodium temperature in the reactor lower inlet plenum, °F.

SUBROUTINE PLENI2(MODE,CPIA,TPI1,TPI2)

Subroutine PLENI2 computes the sodium temperature in the reactor upper inlet plenum using prompt approximation. The time independent form of equation 5-2 is solved for T_B.

The input process variables are:

MODE = control integer for the transient selection,

MODE = 1 -- normal operation,

MODE = 2 -- pipe rupture accident,

CPIA = average heat capacity of sodium in the lower inlet plenum, Btu/lb_m - °F, and

TPI1 = sodium temperature in the lower inlet plenum.

The following COMMON storage areas contain the remainder of input process variables:

```
COMMON/GET1/...,WLP1,WI2,WIC,WOC,WHC,WCA,WRB,WBP,...
```

where:

WLP1 = sodium flow rate at the reactor inlet nozzle loop-1, lb_m/hr,
WI2 = sodium flow rate at the reactor inlet nozzle loop-2, lb_m/hr,
WIC = sodium flow rate at the reactor inner core region, lb_m/hr,
WOC = sodium flow rate at the reactor outer core region, lb_m/hr,
WHC = sodium flow rate at the reactor peak core region, lb_m/hr,
WCA = sodium flow rate at the reactor control assemblies region, lb_m/hr,
WRB = sodium flow rate at the reactor radial blanket region, lb_m/hr,
WBP = sodium flow rate at the reactor bypass region, lb_m/hr;

```
COMMON/FBR1/...,TC1,TC2,TC3,TC4,TC5,TC6, ...
```

where:

TC1 = sodium temperature at the inlet of reactor peak core region, °F,
TC2 = sodium temperature at the inlet of reactor inner core region, °F,
TC3 = sodium temperature at the inlet of reactor outer core region, °F,
TC4 = sodium temperature at the inlet of reactor control assemblies region, °F,
TC5 = sodium temperature at the inlet of reactor radial blanket region, °F,
TC6 = sodium temperature at the inlet of reactor bypass region, °F; and

```
COMMON/PHY6/...,CP1,CP2,CP3,CP4,CP5,CP6,...
```

where:

CP1 through CP6 are sodium heat capacities corresponding to TC1 through TC6, Btu/lb_m - °F.

The output process variable is:

TPI2 = sodium temperature in the upper zone of reactor inlet plenum, °F.

SUBROUTINE PLENO1(BETA2,HOP,ZJET,AOPT,HIF,TA,TB)

Subroutine PLENO1 computes sodium temperature in the lower zone of reactor outlet plenum using prompt approximation. The time independent form of Equation 5-3 is solved for T_L.

The input process variables are:

BETA2 = control constant (see Eq. 5-3),
HOP = height sodium in the reactor outlet plenum, ft,
ZJET = jet penetration distance in the outlet plenum, ft,
AOPT = cross sectional area of outlet plenum, ft^2,
HIF = constant heat transfer coefficient between the two upper plenum zones, Btu/hr - ft^2 - °F, and
TA = sodium temperature in the upper zone of outlet plenum, °F.

COMMON/FBR1/...,THC,...,TIC,...,TOC,...,TCA,...,TRB,TBP,...

where:

THC = sodium temperature at the outlet of peak core region, °F,
TIC = sodium temperature at the outlet of inner core region, °F,
TOC = sodium temperature at the outlet of outer core region, °F,
TCA = sodium temperature at the outlet of control assemblies region, °F,
TRB = sodium temperature at the outlet of radial blanket region, °F, and
TBP = sodium temperature at the outlet of bypass region, °F.

COMMON/GET1/...,WLP1,WI2,WIC,WOC,WHC,WCA,WRB,WBP,...

where:

WLP1 = sodium mass flow rate in loop-1, lb_m/hr,
WI2 = sodium mass flow rate in loop-2, lb_m/hr,
WIC = sodium mass flow rate in the inner core region, lb_m/hr,

WOC = sodium mass flow rate in the outer core region, lb_m/hr,

WHC = sodium mass flow rate in peak core region, lb_m/hr,

WCA = sodium mass flow rate in control assemblies region, lb_m/hr,

WRB = sodium mass flow rate in the radial blanket region, lb_m/hr, and

WBP = sodium mass flow rate in the bypass region, lb_m/hr.

COMMON/PLNO/CHC,CIC,COC,CCA,CRB,CBP

where:

CHC = sodium heat capacity corresponding to THC, Btu/lb_m - °F,

CIC = sodium heat capacity corresponding to TIC, Btu/lb_m - °F,

COC = sodium heat capacity corresponding to TOC, Btu/lb_m - °F,

CCA = sodium heat capacity corresponding to TCA, Btu/lb_m - °F,

CRB = sodium heat capacity corresponding to TRB, Btu/lb_m - °F, and

CBP = sodium heat capacity corresponding to TBP, Btu/lb_m - °F.

The output process variable is:

TB = sodium temperature in the lower zone of reactor outlet plenum, °F.

FUNCTION RUNGE(N,Y,F,X,H,NO)

The RUNGE function integrates up to 489 first-order ordinary differential equations using a second-order RUNGE-KUTTA algorithm. This algorithm can be applied, however, only to a selected class of variables from the total of 489. This selection is made depending upon the components of an auxiliary vector, NO, which consists of the numbers of the variables to which the RUNGE-KUTTA algorithm is not applied. A description of the basic method used is given in reference (26). Function RUNGE was adapted from this reference and then modified to accommodate the NO vector.

The input process variables are:

N = number of first-order ordinary differential equations to be integrated,

Y = vector of old values of dependent variables,

F = vector of new derivative values of dependent variables,

X = old value of the independent variable (i.e., time),

H = step increment (i.e., time step),

NO = vector of control integers to identify the differential equations not to be integrated.

The output process variables are:

RUNGE = integer used to signal when the integration is terminated

$$RUNGE = \begin{cases} 0, \text{ integration completed} \\ 1, \text{ integration initialized for this time step} \\ 2, \text{ integration continuing in same time step} \end{cases}$$

Y = new values of the dependent variables, and

X = new value of the independent variable.

SUBROUTINE PTORQ(A,V,BP)

Subroutine PTORQ computes the normalized primary, secondary, and recirculation pump torque, BP, as a function of normalized pump speed, A, and flow rate, V. Detailed descriptions of the analytical expressions used are given in Section 6 (Coolant Pumps).

The input process variables are:

A = normalized pump speed, and

V = normalized pump flow rate.

```
COMMON/PTRQ/BB(8),DD(8)
```

where:

BB and DD are the constants B_i and D_i of Eqs. 6-10, 6-12, 6-14, and 6-16.

The output process variable is:

BP = normalized pump torque.

SUBROUTINE PHEAD(A,V,HEAD)

Subroutine PHEAD computes the normalized pump head, HEAD, as a function of the normalized pump speed, A, and normalized pump flow, V. The descriptions of the analytical expressions used are given in Section 6 (Coolant Pumps).

The input process variables are:

A = normalized pump speed, and

V = normalized pump flow.

```
COMMON/PHED/AA(8),CC(8)
```

where:

AA and CC are the constants A_i and C_i of Eqs. 6-9, 6-11, 6-13, and 6-15.

The output process variable is:

HEAD = normalized pump head.

<u>SUBROUTINE TFRIC(A,AZ,TS,TR,TMIN,TFR)</u>

Subroutine TFRIC computes the frictional torque in the pumps, using Eq. 6-19.

The input process variables are:

A = normalized pump speed,
AZ = α_o of Eq. 6-19,
TS = T_s of Eq. 6-19,
TR = T_R of Eq. 6-19, and
TMIN = T_{min} of Eq. 6-19.

The output process variable is:

TFR = normalized frictional torque.

<u>SUBROUTINE ALPHP(A,V,GF,KMM,KPM,TMM,TDM,BP,TFR,SLIP)</u>

Subroutine ALPHP computes the normalized primary pump speed in prompt approximation. The time independent form of Equation 6-20 is solved iteratively using the Newton-Raphson Method for non-linear equations.

The input process variables are:

A = normalized old value of pump speed,
V = normalized pump flow rate,
GF = motor generator set variable frequency, cycles/sec,
KMM = main motor control constant,
  KMM = 1.0 -- main motor connected,
  KMM = 0.0 -- main motor disconnected,

KPM = pony motor control constant,

KPM = 0. -- normal operation (pony motor disconnected), and

KPM = 1. -- pony motor operational.

COMMON/ALPA/PMSSP,DSPEED,XNP,A1,A2,A3,AZ,TS,TR,TM

where:

PMSSP = pony motor synchronous speed, rpm,

DSPEED = pump design speed, rpm,

XNP = number of pairs of poles,

A1 = pump constant = a (see Equation 6-17 and 6-18),

A2 = pump constant = b

A3 = pump constant = c

AZ = friction torque equation constant = α_o (see Equation 6-19),

TS = normalized start-up torque = T_s,

TR = normalized rotating torque = T_R, and

TM = minimum friction torque = T_{min}.

The output process variables are:

TMM = main motor normalized torque,

TDM = drive motor normalized torque,

BP = normalized pump torque,

TFR = normalized friction torque,

SLIP = normalized slip, and

A = normalized new value of pump speed.

The following subprograms are required:

Subroutines

- PTORQ = computes the normalized pump torque as a function of normalized pump speed and flow rate,
- PTIME = computes the partial derivative values of the hydraulic and friction torques with respect to the pump speed, as a function of normalized speed and flow, and
- TFRIC = computes the pump frictional torque.

SUBROUTINE ALPHA(A,V,GF,KMM,KPM,TMM,TDM,BP,TFR,SLIP)

Subroutine ALPHA is exactly identical to subroutine ALPHP except it calculates the pump speed in prompt approximation for the secondary pumps.

SUBROUTINE RPSPD(A,V,KMM,TDM,TRP,TFR,SLIP)

Subroutine RPSPD computes the normalized recirculation pump speed using prompt approximation. The time independent form of Equation 6-20 is solved for normalized pump speed iteratively using the Newton-Raphson method for non-linear equations.

The input process variables are:

A = normalized old value of the recirculation pump speed,
V = normalized recirculation pump flow rate,
KMM = motor control constant
KMM = 1.0 -- normal operation,
KMM = 0.0 -- recirculation pump disconnected.

COMMON/ARPP/DSPEED,SSPEED,A1,A2,AZ,TS,TR,TM

where:

DSPEED = recirculation pump design speed, rpm,
SSPEED = recirculation pump synchronous speed, rpm,
A1 = pump constant = a (see Equation 6-17),
A2 = pump constant = b,
AZ = friction torque equation constant = α_o (see Equation 6-19),
TS = normalized start-up torque = T_S,
TR = normalized rotating torque = T_R, and
TM = normalized firction torque = T_{min}.

The output process variables are:

TDM = normalized drive motor torque,
TRP = normalized recirculation pump torque,
TFR = normalized friction torque,
SLIP = normalized slip, and
A = normalized new value of the recirculation pump speed.

The following subprograms are required:

Subroutines

- PTORQ = computes the normalized pump torque as a function of normalized recirculation pump speed and flow rate,
- PTIME = computes the partial derivative values of the hydraulic and friction torque with respect to the recirculation pump speed as a function of normalized recirculation pump speed and flow, and
- TFRIC = computes the pump friction torque.

SUBROUTINE PTIME (A,V,AZ,TS,TR,DTP,DTF)

Subroutine PTIME computes the partial derivatives of pump and friction torques with respect to pump speed. This is necessary to calculate both the pump time constant and pump speed when time constant is short compared to time step. Partial derivatives with respect to speed are evaluated using analytical expressions for the pump torque, and the friction torques of Section 6 (Coolant Pumps).

The input process variables are:

A = normalized pump speed,
V = normalized pump flow rate,
AZ = constant in friction torque equation (Eq. 6-19),
TS = normalized start-up torque, T_S, and
TR = normalized rotating torque, T_R.

The output process variables are:

DTP = normalized partial derivative of pump torque, and
DTF = normalized partial derivative of pump friction torque.

SUBROUTINE PIPE(N,L,K,W,TCI,TC,TW,FC,FW,DI,DEL,STOT,ATOT,VCTOT,XKSS,ROVCW,VCPRIM, CC,DC,VIS,XK,REC,U,UAPR,TAUC,TAUW)

Subroutine PIPE computes coolant exit temperatures and, optionally, average wall temperatures for up to ten equal length subsections of a pipe run of constant diameter. Two time-dependent heat balance equations are used for each pipe subsection, one for the sodium exit temperature and the other for the average pipe wall temperature. The latter is not computed if heat storage in pipe walls is neglected.

The input process variables are:

- N = number of equal-length pipe subsections (N = 1, 2, ..., 10)
- L = control integer for wall heat storage option,
  - L = 0 -- heat storage considered
  - L = 1 -- heat storage neglected
- K = control integer for characteristic time calculation with integration,
  - K = 3 -- characteristic times to be calculated
- W = sodium mass flow rate inside the pipe, lb_m/hr,
- TCI = sodium temperature at the pipe run inlet, °F,
- TC = vector of coolant temperatures (old values), °F,
- TW = vector of wall temperatures (old values), °F,
- DI = pipe inside diameter, in,
- DEL = pipe wall thickness, in,
- STOT = total pipe wall cross-sectional area, ft^2,
- VCTOT = total coolant volume per pipe run, ft^3,
- XKSS = thermal conductivity of pipe wall material, Btu/hr - ft - °F,
- ROVCW = pipe wall density times volume times heat capacity, Btu/°F,
- VCPRIM = coolant volume per section, ft^3,
- CC = vector of coolant average heat capacities, Btu/lb_m - °F,
- DC = vector of coolant average densities, lb_m/ft^3,
- VIS = vector of coolant average viscosities, lb/ft - hr,
- XK = vector of coolant average thermal conductivities Btu/hr - ft - °F, and
- REC = vector of Reynolds numbers.

The output process variables are:

- U = vector of overall heat transfer coefficient, Btu/hr - ft^2 - °F,
- UAPR = vector of rate of heat transfer per degree per subsection, Btu/hr - °F,
- TAUC = vector of coolant characteristic times, hr,
- TAUW = vector of wall characteristic times, hr,
- FC = vector of derivative values for the pipe coolant temperatures, °F/hr, and,
- FW = vector of derivative values of pipe wall temperatures (computed if heat storage is considered), °F/hr.

FUNCTION DPMOM(A1,A2,D1,D2,GC)

The DPMOM function computes the area change coefficient of the pressure change due to fluid momentum in Equation 6-1. The DPMOM function uses the cross sectional areas A1, A2 and the coolant density D1, and D2 to calculate:

$$DPMOM = \frac{1}{2GC} \left(\frac{1}{A1} + \frac{1}{A2}\right) \left(\frac{1}{D1A1} - \frac{1}{D2A2}\right)$$

The input process variables are:

A1 = flow cross-sectional area at location 1, ft^2,

A2 = flow cross-sectional area at location 2, ft^2,

D1 = flow average density at location 1, lb_m/ft^3,

D2 = flow average density at location 2, lb_m/ft^3, and

GC = conversion factor = 4.17×10^8 lb_m - ft /lb_f - hr^2,

The output process variable is:

DPMOM = area charge coefficient, lb_f - hr^2/lb_m^2 - ft^2.

FUNCTION TMETAL(C,HS,HW,DTTOT)

The TMETAL function computes the average temperature drop from the evaporator tube surface to the boiling water bulk temperature. The nucleate boiling coefficient discussed in Section 9 (Heat Transfer Coefficients) cannot be computed unless tube wall to bulk temperature drop T_X is available. Assuming the quasi-static approximation (neglecting tube wall heat capacity), conservation of energy requires:

$$\frac{K}{h_s} T_X^3 + \left(\frac{h_c}{h_s} + 1\right) T_X - \Delta T_T = 0$$

where:

$$K = \frac{\mu_f \lambda_{fg}}{\sqrt{\sigma_f/(\rho_f - \rho_g)}} \left[\frac{C_{p_f}}{0.013 \lambda_{fg} (C_{p_f} \mu_f/k_f)^{1.7}}\right]^3 \qquad \text{(see Section 9)}$$

h_s = secondary sodium side heat transfer coefficient, Btu/hr - ft^2 - °F,

h_c = tertiary water side convection coefficient, Btu/hr - ft^2 - °F,

ΔT_T = total average temperature drop from sodium side to water side, °F, and

= $\Delta\bar{T}_{lm}$ = average logarithmic temperature difference, °F.

The above equation is solved for T_X iteratively, using Newton-Raphson's Method for nonlinear equations.

The input process variables are:

$C = K$ = pressure dependent constant (see above),

$HS = h_s$ = sodium side heat transfer coefficient, Btu/hr - ft^2 - °F,

$HW = h_c$ = water side heat transfer coefficient, Btu/hr - ft^2 - °F, and

$DTTOT = \Delta T_T$ = average logarithmic temperature difference, °F.

The output process variable is:

$TMETAL = T_x$ = average temperature drop, metal to bulk water °F.

FUNCTION USTG(HO,HI,XID,OD,TK)

The USTG function calculates the overall heat transfer coefficient in a shell and tube heat exchanger (in this case evaporators and superheater), based on tube outside diameter. The overall heat transfer coefficient is calculated based on the assumption that the quasi-static approximation is valid.

The input process variables are:

HO = heat transfer coefficient on the shell side, Btu/hr - ft^2 - °F,

HI = heat transfer coefficient inside the tubes, Btu/hr - ft^2 - °F,

XID = tube inside diameter, ft,

OD = tube outside diameter, ft, and

TK = tube metal thermal conductivity, Btu/hr - ft - °F.

The output process variable is:

USTG = overall heat-transfer coefficient, Btu/hr - ft^2 - °F.

SUBROUTINE ARMAND(X,VF,VG,VOID,PHI)

Subroutine ARMAND computes the two-phase flow frictional multiplier. The description of Armand's method is given in Section 9. The modified Armand void fraction, and the two-phase flow frictional multiplier is calculated as function of steam quality, saturated water specific volume, and saturated steam specific volume.

The input process variables are:

X = steam quality (weight fraction),

VF = specific volume of saturated water, ft^3/lb_m, and

VG = specific volume of saturated steam, ft^3/lb_m.

The output process variables are:

VOID = armand modified void fraction (volume fraction), and

PHI = armand two-phase flow frictional multiplier.

SUBROUTINE CHFLX(HFLUX,P,G,D,HFG,XLC)

Subroutine CHFLX computes the length from saturation point of water at which dryout might occur. The method is based on the semi-empirical correlation discussed in Section 9 (Dryout Prediction).

The average heat flux in the boiling section of the evaporator is used to determine the dryout length. If the dryout length is less than the physical length of the boiling regions then dryout has occurred.

The input process variables are:

HFLUX = average boiling region heat flux, Btu/hr - ft^2,

P = local system pressure, lb_f/in^2,

G = water/steam mixture mass flux, lb_m/hr - ft^2,

D = hydraulic equivalent diameter, ft, and

HFG = latent heat of vaporization of saturated water, Btu/lb_m.

The output process variable is:

XLC = length from saturation point at which dryout occurs, ft.

SUBROUTINE BRHTC(G,D,DT,ST,VISF,VISG,DF,DG,CF,CG,XKF,XKG,HFG,TDLOG,HS,X,RE,PR,HC,HPB)

Subroutine BRHTC computes the heat transfer coefficient for the boiling region of the evaporators as a linear combination of nucleate boiling and convection coefficients. Detailed description of the method used is given in Section 9 of this report.

The input process variables are:

G = water/steam mass flux, lb_m/hr - ft^2,

D = hydraulic equivalent diameter, ft,

DT = thermal equivalent diameter, ft,

ST = surface tension, lb_f/ft,

VISF = viscosity of saturated water, lb/ft - hr,

VISG = viscosity of saturated steam, lb/ft - hr,

DF = density of saturated water, lb_m/ft^3,

DG = density of saturated steam, lb_m/ft^3,

CF = heat capacity of saturated water, Btu/lb_m - °F,

CG = heat capacity of saturated steam, Btu/lb_m - °F,

XKF = thermal conductivity of saturated water, Btu/hr - ft - °F,

XKG = thermal conductivity of saturated steam, Btu/hr - ft - °F,

HFG = latent heat of vaporization of saturated water, Btu/lb_m,

TDLOG = average logarithmic temperature difference, °F,

HS = secondary side sodium heat transfer coefficient, Btu/hr - ft^2 - °F, and

X = steam quality (weight fraction).

The output process variables are:

RE = flow Reynolds number,

PR = flow Prandtl number,

HC = boiling region heat transfer coefficient, Btu/hr - ft^2 - °F, and

HPB = nucleate boiling coefficient, Btu/hr - ft^2 - °F.

The following subprogram is required:

Function

- TMETAL = computes the tube wall to bulk water temperature drop.

SUBROUTINE LMTDIF(TA,TB,TC,TD,TDLOG)

Subroutine LMTDIF computes the average logarithmic temperature difference in a counter-current heat exchanger.

All possible combinations of the four temperature are considered. Since some of these combinations do not allow for the average temperature difference to be computed with the classical log-mean temperature difference equation, several appropriate approximations were made for such cases.

The temperatures involved are defined in Figure 11-19.

The input process variables are:

TA = hot fluid inlet temperature, °F,

TB = hot fluid outlet temperature, °F,

TC = cold fluid inlet temperature, °F, and

TD = cold fluid outlet temperature, °F.

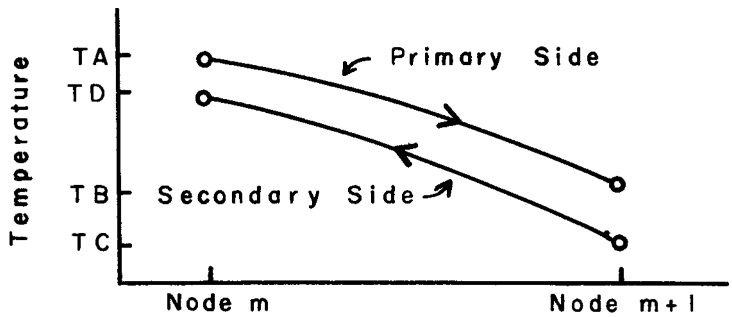


Figure 11-19. Definition of Temperatures in Subroutine LMTDIF

The output process variable is:

TDLOG = average logarithmic temperature difference, °F.

FUNCTION RVOTSP(PD)

The RVOTSP function computes the reactor core coolant outlet temperature set point as a function of power demand.

The following approximation is assumed:

$$T_{sp} = a_1 P_D^2 + a_2 P_D + a_3$$

where a_1, a_2, a_3 are input constants, and P_D is power demand.

The input process variables are:

PD = normalized reactor power demand

COMMON/RTSETP/AT1,AT2,AT3

where AT1, AT2, and AT3 correspond to a_1, a_2, and a_3.

The output process variable is:

RVOTSP = reactor core coolant outlet temperature set point, °F.

SUBROUTINE SYSTEM(A,X,M,N)

Subroutine SYSTEM is used to solve a system of M algebraic equations with M unknowns. It is invoked by subroutine HYDROS to compute the partial derivative values of the steady state sodium flow dynamics equations for the reactor vessel flows. These partial derivative values are necessary in the Newton-Raphson iteration method.

A Guass-Jordan reduction method is used to solve the system of M equations (note at present M can take up to 8 equations, but it could be increased by changing the dimension statements in SYSTEM).

The input process variables are:

A = an 8x9 augmented matrix of coefficients (filled out with zeroes if M<8),
M = number of equations, and
N = M+1.

The output process variable is:

X = solution vector of 8 partial derivative values (filled out with zeros if M<8).

FUNCTION SOLVE(A,X,INDEX,EPS)

The SOLVE function computes the derivative values of the sodium flow rates as invoked by subroutine HYDROS.

If INDEX is zero, SOLVE computes the solutions, X(I), of a system of linear equations with the augmented matrix of coefficients, A, and in addition, computes the inverse of the coefficient matrix in place. Subroutine HYDROS employs an INDEX = 0, only once, before the first time step of a given transient to compute the inverse matrix of inertial loss coefficients; this remains constant throughout the transient.

If INDEX is positive, the solutions, X(I), are computed by multiplying the inverse matrix (obtained for INDEX = 0) by the last column of A, which always holds the right hand members of the system of linear equations.

The value of the determinant is returned as the value of the function (SOLVE) when INDEX is zero, and as 1 when INDEX is positive.

Should the potential pivot of largest magnitude be smaller in magnitude than EPS, then the matrix is considered to be singular and a true zero is returned as the value of the function.

The input process variables are:

A = augmented matrix of coefficients (7x8),
INDEX = control integer (explained above), and
EPS = small number for convergence criterion.

The output process variable is:

X = solution vector of seven time-derivative values of sodium flows.

FUNCTION PDERIV(A,V,DESHD,DENS)

The PDERIV function computes the derivative with respect to flow of the pressure increase across a primary pump. This is necessary for calculating the loop flow time constants and the loop flow for the short time constant case. Partial derivatives of the pump head equations of Section 6 are taken with respect to the normalized flow rate.

The input process variables are:

A = normalized pump speed,
V = normalized flow rate,
DESHD = pump design head, ft, and
DENS = sodium density in the pump, lb_m/ft^3.

The output process variable is:

PDERIV = partial derivative of the pressure increase across a primary pump with respect to normalized flow rate, lb_f/ft^2.

SUBROUTINE DRUM(POLD,UT,VT,EPSI,XMT,XMG,XMF,PNEW)

Subroutine DRUM computes steam drum average pressure as a function of total internal energy and average specific volume.

The compressible thermodynamic equilibrium model used is described in Section 9 (Hydrodynamics).

Steam drum pressure is determined iteratively using conservation of mass and energy and steam tables.

The input process variables are:

POLD = old value of the drum pressure (first guess), lb_f/in^2,
UT = total average internal energy of the drum, Btu,
VT = total drum volume (constant), ft^3,
EPSI = constant small value for convergence criterion, lb_f/in^2, and
XMT = total average mass of steam/water mixture, lb_m.

The output process variables are:

XMG = mass of steam in the drum, lb_m,
XMF = mass of water in the drum, lb_m, and
PNEW = new value of the drum pressure, lb_f/in^2.

The following subprogram is required:

Subroutine

- SWATER = computes the thermodynamic properties of saturated water and saturated steam as function of pressure.

SUBROUTINE HEADER(POLD,SU,SV,H,T,PNEW)

Subroutine HEADER computes the steam pressure inside the main steam header in the tertiary system. The steam pressure is calculated using the definition of enthalpy, steam specific internal energy, average specific volume and steam tables along with a corrected ideal gas law, which relates the steam pressure to its temperature and specific volume, as described in Section 9.

The input process variables are:

POLD = steam header pressure (old value), lb_f/in^2,
SU = specific internal energy, Btu/lb_m, and
SV = specific volume, ft^3/lb_m.

The output process variables are:

H = steam header specific enthalpy, Btu/lb_m,
T = steam header temperature, °F, and
PNEW = steam header pressure (new value), lb_f/in^2.

The following subprogram is required:

Function

- TSTEAM = computes superheated steam temperature in °F as function of enthalpy and pressure.

SUBROUTINE PROMTP(W,C,TP1,TP2,TS2,TS1,U,A,SN)

Subroutine PROMTP computes sodium temperature of the primary side of IHX using a prompt approximation. The time independent form of Equation 7-6 is solved for $T_{P_{J+1}}$ using an iterative scheme. It is invoked in subroutines IHX1 and IHX2 when the characteristic time is short compared to the integration time step.

The input process variables are:

W = primary side sodium mass flow rate, lb_m/hr,
C = average specific heat of sodium, Btu/lb_m - °F,
TP1 = primary side sodium temperature at the inlet, °F,
TP2 = primary side sodium temperature at the outlet (old value), °F,
TS2 = secondary side sodium temperature at the inlet, °F,
TS1 = secondary side sodium temperature at the outlet, °F,
U = overall heat-transfer coefficient, Btu/hr - ft^2 - °F,
A = overall heat-transfer area, ft^2, and
XN = total number of equal-length subsections.

The output process variable is:

TP2 = primary side sodium temperature at the outlet (new value), °F.

The following subprogram is required:

Subroutine

- o LMTDIF = computes the average logarithmic temperature difference, °F.

SUBROUTINE PROMTS(W,C,TP1,TP2,TS2,TS1,U,A,XN)

Subroutine PROMTS computes sodium temperature of the secondary side of IHX using a prompt approximation. The time independent form of Equation 7-7 is solved for T_{S_J} using an iterative scheme. Subroutine PROMTS is invoked in subroutines IHX1 and IHX2 when the characteristic time is short compared to the integration time step.

The input process variables are:

W = secondary side sodium mass flow rate, lb_m/hr,
C = average specific heat of sodium, Btu/lb_m - °F,
TP1 = primary side sodium temperature at the inlet, °F,
TP2 = primary side sodium temperature at the outlet, °F,
TS1 = secondary side sodium temperature at the inlet, °F,
TS2 = secondary side sodium temperature at the outlet (old value), °F,
U = overall heat transfer coefficient, Btu/hr - ft^2 - °F,
A = overall heat transfer area, ft^2, and
XN = total number of equal-length subsections.

The output process variable is:

TS2 = secondary side sodium temperature at the outlet (new value), °F.

The following subprogram is required:

Subroutine

- o LMTDIF = computes the average logarithmic temperature difference, °F.

SUBROUTINE ENTH(HIN,WS,TA,TB,TC,TD,TDLOG,U,A,ACF,POUT,HOUT)

Subroutine ENTH computes steam enthalpy in a superheater using a prompt approximation. The time independent form of Equation 9-2 is solved for H_J using Newton-

Raphson Method of iteration (along with steam tables) when the characteristic time is short compared to the integration time step.

The input process variables are:

HIN = steam enthalpy at the inlet, Btu/lb_m,
WS = steam mass flow rate, lb_m/hr,
TA = secondary sodium temperature at the inlet, °F,
TB = secondary sodium temperature at the outlet, °F,
TC = steam temperature at the inlet, °F,
TD = steam temperature at the outlet (old value), °F,
TDLOG = average logarithmic temperature difference, °F,
U = overall heat transfer coefficient, Btu/hr - ft^2 - °F,
A = overall heat transfer area, ft^2,
ACF = fouling area correction factor,
POUT = steam pressure corresponding to TD, lb_f/in^2, and
HOUT = steam enthalpy at the outlet (old value), Btu/lb_m.

The output process variable is:

HOUT = steam enthalpy at the outlet (new value), Btu/lb_m.

The following subprograms are required:

Functions

- TSTEAM = computes the steam temperature as a function of enthalpy and pressure, °F, and
- HSTEAM = computes the steam enthalpy as a function of temperature and pressure, Btu/lb_m.

Subroutine

- LMTDIF = computes average logarithmic temperature difference, °F.

SUBROUTINE PROMTT(WI,C,TA,TB,TC,TD,U,A,ACFI)

Subroutine PROMTT computes sodium temperature of the secondary side of a steam generator (superheater and evaporator) using a prompt approximation. The time independent form of Equation 9-1 is solved for T_{si} using Newton-Raphson Method of iteration, when the characteristic time is short when compared with the integration time step.

The input process variables are:

WI = secondary sodium mass flow rate, lb_m/hr,
C = average specific heat of sodium, °F,
TA = secondary sodium temperature at the inlet, °F,
TB = secondary sodium temperature at the outlet (old value), °F,
TC = water/steam side temperature at the inlet, °F,
TD = water/steam side temperature at the outlet, °F,
U = overall heat-transfer coefficient, $Btu/hr - ft^2 - °F$,
A = heat transfer area of the region, ft^2, and
ACFI = inverse of fouling area correction factor.

The output process variable is:

TB = secondary sodium temperature at the outlet, °F.

The following subprogram is required:

Subroutine

- LMTDIF = computes average logarithmic temperature difference, °F.

SUBROUTINE WATER(P,H,T,D)

Subroutine WATER calculates temperature and density of subcooled water as a function of pressure and specific enthalpy.

The thermodynamic properties of subcooled water are calculated using polynomial fits by W.B. Jordan (27).

The fits are valid from atmospheric pressure to critical pressure, and from freezing to boiling.

The input process variables are:

P = pressure, lb_f/in^2, and
H = specific enthalpy, Btu/lb_m.

The output process variables are:

T = temperature, °F, and
D = density, lb_m/ft^3.

SUBROUTINE SWATER(P,T,HF,HG,HFG,DF,DG,SVF,SVG)

Subroutine SWATER computes the thermodynamic properties of saturated water and saturated steam as a function of pressure. The analytical functions by W.B. Jordan (27) have been used to calculate the thermodynamic state variables of saturated water and steam.

The input process variable is:

P = pressure, lb_f/in^2.

The output process variables are:

T = temperature, °F,
HF = enthalpy of saturated water, Btu/lb_m,
HG = enthalpy of saturated steam, Btu/lb_m,
HFG = latent heat of vaporization of saturated water, Btu/lb_m,
DF = density of saturated water, lb_m/ft^3,
DG = density of saturated steam, lb_m/ft^3,
SVF = specific volume of saturated water, ft^3/lb_m, and
SVG = specific volume of saturated steam, ft^3/lb_m.

The following subprogram is required:

Subroutine

- o WATER = computes the thermodynamic properties of subcooled water.

FUNCTION SURFTN(TF,VF)

The SURFTN function computes the surface tension of water as function of temperature and specific volume. An analytical fit of the surface tension as a function of water temperature and specific volume is used to calculate the surface tension in lb_f/ft.

The input process variables are:

TF = water temperature, °F, and

VF = water specific volume, ft^3/lb_m.

The output process variable is:

SURFTN = water surface tension, lb_f/ft.

FUNCTION PSAT(T)

The PSAT function computes the saturation pressure of water as a function of temperature. The analytical expression given in the 1967 steam tables (28) has been used, to calculate the saturation pressure in lb_f/in^2 as a function of temperature in °F.

The input process variable is:

T = temperature, °F.

The output process variable is:

PSAT = saturation pressure, lb_f/in^2.

FUNCTION TCOND1(P,TF)

The TCOND1 function computes thermal conductivity of water in Btu/hr - ft - °F. The analytical expression has been adapted from the 1967 Steam Tables (28).

The input process variables are:

P = pressure, lb_f/in^2, and

TF = temperature, °F.

The output process variable is:

TCOND1 = thermal conductivity of water, Btu/hr - ft - °F.

The following subprogram is required:

Function

o PSAT = computes the saturation pressure of water, lb_f/in^2.

FUNCTION TCOND2(T,V)

The TCOND2 function computes thermal conductivity of steam in Btu/hr - ft - °F. The analytical expression has been adapted from the 1967 Steam Tables (28).

The input process variables are:

T = temperature, °F, and
V = specific volume of steam, ft^3/lb_m.

The output process variable is:

TCOND2 = thermal conductivity of steam, Btu/hr - ft - °F.

FUNCTION DVISC1(P,TF)

The DVISC1 function computes dynamic viscosity of water in lb/ft - hr. The analytical expression has been adapted from the 1967 Steam Tables (28).

The input process variables are:

P = pressure, lb_f/in^2, and
TF = temperature, °F.

The output process variable is:

DVISC1 = dynamic viscosity of water, lb/ft - hr.

The following subprogram is required:

Function

o PSAT = computes the saturation pressure of water, lb_f/in^2.

FUNCTION DVISC2(TF,V)

The DVISC2 function computes dynamic viscosity of steam in lb/ft - hr. The analytical expression has been adapted from the 1967 Steam Tables (28).

The input process variables are:

TF = temperature, °F, and
V = specific volume of steam, ft^3/lb_m.

The output process variable is:

DVISC2 = dynamic viscosity of steam, lb/ft - hr.

FUNCTION TSTEAM(H,P)

The TSTEAM function computes temperature of the superheated steam in °F. The polynomial expression has been adapted from reference (18), which gives a polynomial fit valid from saturation to critical point of water.

The input process variables are:

H = specific enthalpy of steam, Btu/lb_m, and
P = pressure, lb_f/in^2.

The output process variable is:

TSTEAM = superheated steam temperature, °F.

The following subprogram is required:

Subroutine

- SWATER = computes the thermodynamic properties of saturated water and steam.

FUNCTION SHEAT1(P,T)

The SHEAT1 function computes the heat capacity of water at constant pressure as a function of pressure and temperature in Btu/lb_m - °F. The specific heat capacity at constant pressure has been determined using the following definition:

$$C_P \equiv \left(\frac{\partial H}{\partial T}\right)_P$$

where H is the specific enthalpy of water.

The input process variables are:

P = pressure, lb_f/in^2, and
T = temperature, °F.

The output process variable is:

SHEAT1 = specific heat capacity of water at constant pressure, Btu/lb_m - °F.

FUNCTION SHEAT2(P,T)

The SHEAT2 function is conceptually the same as SHEAT1 function except it calculates the specific heat capacity at constant pressure for steam in Btu/lb_n - °F.

FUNCTION SPVOL2(T,P)

The SPVOL2 function computes the specific volume of steam in ft^3/lb_m. The analytical expression used is based on a corrected ideal gas law equation, that calculates the specific volume as a function of pressure and temperature.

The input process variables are:

P = pressure, lb_f/in^2, and
T = temperature, °F.

The output process variable is:

SPVOL2 = specific volume of steam, ft^3/lb_m.

SUBROUTINE CONVRT

Subroutine CONVRT sets up the conversion factors for input and output processing.

As written, subroutine CONVRT converts all input data from SI units into the working units of the code (essentially British units). This subroutine also converts into SI units all printed output.

As well as setting up the conversion factors, subroutine CONVRT actually performs the conversion of the plant data input to subroutine LMFBR.

Subroutine CONVRT has a secondary entry, ENTRY RSTCON, for converting the plant data back to SI for printing under restart conditions.

Because of the structure of this subroutine, a user may define any consistent set of units he desires for input and output, merely by altering the conversion factors set up by this subroutine.

The following subprogram is required:

Subroutine

- TMPCON = converts temperatures from °C to °F and vice versa.

SUBROUTINE TMPCON(M,N,T)

Subroutine TMPCON performs temperature conversions from °C to °F and vice versa, depending on the control integer, M.

The input process variables are:

M = control integer,

$= \begin{cases} 0, \text{ conversion from °C to °F,} \\ 1, \text{ conversion from °F to °C,} \end{cases}$

N = the number of elements in the vector T, and

T = vector of temperatures to be converted.

The new temperatures are returned in the place of the old T(N) vector.

FUNCTION HSTEAM(T,P)

The HSTEAM function computes the enthalpy of superheated steam in Btu/lb_m. The correlation was obtained by rearranging the correlation of reference (18) that was used in the function TSTEAM.

The input process variables are:

T = temperature of steam, °F, and

P = pressure, lb_f/in^2.

The output process variable is:

HSTEAM = superheated steam enthalpy, Btu/lb_m.

INPUT DATA

The input data consists of 91 NAMELIST data cards arranged in a designated order. Each data card may be up to 80 columns, with column 1 always left blank.

The first card of a given NAMELIST must begin with the & character in column 2 followed by the name of that NAMELIST and a blank space. Following the last variable of a given NAMELIST should be at least one blank space followed by '&END', to indicate the end of that NAMELIST.

For example, the subroutine HYDROS contains the following NAMELIST:

```
NAMELIST/HYDF/TAUWM,TAUAM,TAUTM,TRISPN
```

The corresponding data card may be written as follows (2, 8, and 77 indicate column numbers);

```
2     8                                                            77
&HYDF TAUWM = 0.5, TAUAM = .02, TAUTM = 5., TRISPN = 3.8778E2        &END
```

Note that any format style is allowed. Sample input for the entire system is shown in Table 11-1. All input data should be in real number form except for the following integer-valued data:

MODE, IPRINT, IPK from &MASA,
IPNEW from &MASC,
NOPON, MTURB, MDUMP, RSTART from &MASE,
K1,K2,NP,LP,N1,L1,N2,L2 from &BRO3, and
NOSCRM from &SCR1.

The 91 input data cards must be arranged in the order seen in table 11-1 (i.e., in the order presented in this section).

OUTPUT FORMAT

An example of the output provided by the EPRI-CURL code may be found in the sample problem included as an appendix to this document. The units of the output variables

Table 11-1

SAMPLE INPUT DATA

```
NUMBER          PRINT   --  LISTING OF INPUT DATA SET  --

&MASA   MODE=0,IPRINT=50,IPK=10,SSEC=.2,TMAXSC=19.9                              &END
&MASB   P100=975.,PD0=1.,SLOPEP=0.,PDEND=1.,XLOOP=2.,                            &END
&MASC   TNEW=19.,2*50.,SNEW=3*0.2,IPNEW=1,5,1,                                   &END
&MASD   TSCRM=2*50.,TTRIP=6*50.,                                                 &END
&MASE NOPON=0,0,0,0,MTURB=0,MDUMP=0,RSTART=1,EPSILN=1.E-4                        &END
&MASF   RNSERT=.1,TNSERT=50.,                                                    &END
&MASG   TNOFW1=50.,TNOFW2=50.,TAUX1=50.,TAUX2=50.,                               &END
&BR01   WI100=1740.7,WI1=1740.7,WI2=1740.7,WIC=2153.08,WOC=1885.18,
  W4C=139.431,WCA=81.4652,WRB=745.716,WBP=217.225,WS100=1610.25,
  WS1=1610.25,WS2=1610.25,WBRK=1740.7,                                           &END
&BR02   TC=393.49,590.13,592.39,392.52,566.67,568.53,392.46,542.19,544.02,
  444.56,460.74,387.97,TIP1=387.97,TIP2=387.97,TOP1=535.17,TOP2=535.17,
  TM=460.61,1876.58,619.27,442.62,1595.16,588.56,441.42,1420.47,563.60,492.48,
  550.19,                                                                        &END
&BR03   K1=8,K2=8,NP=10,10,10,10,10,10,LP=0,0,0,0,0,0,N1=10,1,2,10,
  L1=0,0,0,0,N2=10,1,2,10,L2=0,0,0,0,                                            &END
&BR04   TP1=535.17,517.84,500.08,481.84,463.13,443.94,424.28,404.13,383.49,
  535.17,387.97,2*0.,TS1=502.14,484.02,465.46,446.42,426.88,406.87,386.36,
  365.37,343.89,502.14,2*0.,                                                     &END
&BR05   TP2=535.17,517.84,500.08,481.84,463.13,443.94,424.28,404.13,383.49,
  535.17,387.97,2*0.,TS2=502.14,484.02,465.46,446.42,426.88,406.87,386.36,
  365.37,343.89,502.14,2*0.,                                                     &END
&BR06   TCI1=535.17,TCI2=535.17,TCI3=387.97,TCI4=535.17,TCI5=535.17,
  TCI6=387.97,                                                                   &END
&BR07   TI11=502.14,TI12=343.89,TI13=343.89,TI14=343.89,TSI1=502.14,
  TS01=457.54,TEI1=457.54                                                        &END
&BR08   TI21=502.14,TI22=343.89,TI23=343.89,TI24=343.89,TSI2=502.14,
  TS02=457.54,TEI2=457.54                                                        &END
&BR09   DH=9*4.2977E-3,3.5966E-3,3.7186E-3,.3237,AH=3*.01858,3*.3205,3*.2824,
  .007153,.09857,.09222,AIPT=27.87,AOPT=27.87,                                   &END
&BR10   XL=.3557,.9144,1.6407,.3557,.9144,1.6407,.3557,.9144,1.6407,2.9108,
 2.9108,9.3113,P=9*.0073152,.016154,.014326,WL=9*.30236,.1524,.1015,
  OD=9*.0058522,.015545,.013106,                                                 &END
&BR11   DPX=.032918,APX=1.9361,ODP=.9144,.6096,.6096,DELP=3*.0127,XLP=37.454,
  32.748,52.715,37.454,32.748,52.715,7.3792,XL11=2.310,XL12=2.658,
  XL21=2.310,XL22=2.658,                                                         &END
&BR12   DSX=.01994,ASX=.89,ODI=.6096,.4572,.6096,.6096,DELI=4*.0127,DSG=.05166,
  ASG=.52523,ODSE=.4572,DELSE=.0127,XLS=150.,9.144,25.908,60.637,248.68,
  9.144,25.908,110.92,7.62,14.02,37.795,14.02,                                   &END
&BR13   ZIN1=-19.179,ZIN2=-16.183,ZON=-11.434,ZP1=-15.798,ZP2=-15.798,
  ZOPLEV=-6.8717,                                                                &END
&BR14   Z1=-11.43,-7.498,-7.498,-5.791,-5.791,-5.791,-8.23,-10.67,-13.26,-13.26,
  Z2=-17.07,-14.02,-10.67,-7.5,-7.5,-7.5,-7.5,-7.5,-7.5,-9.51,
  Z3=-16.46,-11.06,-5.64,-5.64,-5.94,-6.55,-7.19,-10.21,-15.61,-19.18,           &END
&BR15   Z4=-11.43,-7.498,-7.498,-5.791,-5.791,-5.791,-8.23,-10.67,-13.26,-13.26,
  Z5=-17.07,-14.02,-10.67,-7.5,-7.5,-7.5,-7.5,-7.5,-7.5,-9.51,
  Z6=-16.46,-11.06,-5.64,-5.64,-5.94,-6.55,-7.19,-10.21,-15.61,-19.18,           &END
&BR16   ZX1=-7.19,-8.02,-8.845,-9.67,-10.50,-11.32,-12.15,-12.975,-13.80,
  -16.465,-16.465,0.,0.,
        ZX2=-7.19,-8.02,-8.845,-9.67,-10.50,-11.32,-12.15,-12.975,-13.80,
  -16.465,-16.465,0.,0.,                                                         &END
&BR17   P1=8.459E5,P2=2.530E5,P3=2.199E5,P4=3.654E4,P5=1.140E6,P6=1.034E6,
  P7=9.389E5,P8=9.396E5,P9=3.654E4,P10=1.140E6,P11=1.034E6,P12=9.389E5,          &END
&BR18   DSS=8000.,XKSS=16.747,CSS=502.4,                                         &END
&BR19   PS1=1.568E6,PS2=2.530E5,PS3=2.199E5,PS4=1.089E6,PS5=8.135E5,
```

```
NUMBER          PRINT   --  LISTING OF INPUT DATA SET  --

   PS6=7.376E5,PS7=7.514E5,PS8=7.549E5,PS9=6.825E5,                        &END
 &BR20  PI1=1.568E6,PI2=2.530E5,PI3=2.199E5,PI4=1.089E6,PI5=8.135E5,
   PI6=7.376E5,PI7=7.514E5,PI8=7.549E5,PI9=6.825E5,                        &END
 &BR21  ZS1=-4.75,-4.75,-10.36,-13.50,-14.02,-14.17,-14.33,-14.48,-14.63,.10,
   ZS2=-12.47,9*0.,ZS3=-6.19,.10,8*0.,ZS4=-7.53,-10.97,-10.61,-3.41,-3.26,
   -3.26,-3.05,-2.93,-2.80,-2.68,                                          &END
 &BR22  ZS5=-4.75,-12.68,-13.01,-13.20,-13.49,-13.78,-14.06,-14.36,-14.63,
      .10,ZS6=-12.47,9*0.,ZS7=-6.19,.10,8*0.,ZS8=-10.97,-10.55,-10.13,-10.13,
   -10.12,-10.12,-3.41,-3.17,-2.93,-2.68,                                  &END
 &BR23  ZHX1=-5.88,ZHX2=-5.88,ZSH1=-12.01,ZSH2=-12.01,ZEVI1=.10,ZEVI2=.10,
   ZEVO1=-12.01,ZEVO2=-12.01,ZSP1=-3.10,ZSP2=-3.10,                        &END
 &BR24  PBRK=9.519E5,ZBRK=-19.05,XBRK=1.,PGV=1.02E5,                       &END
 &BR25  AA=2.65,-2.1.0.85,-0.4,-2.6,3.95,-0.3,-0.85,BB=2.25,-1.75,0.75,-0.25,
   -2.6,2.6,0.0,-0.2,CC=-0.9,1.85,-1.6,1.65,1.45,-2.5,1.65,-0.4,DD=-0.75,
   1.75,-1.25,1.25,1.3,-2.0,1.1,-0.6,                                      &END
 &KINA LAM=0.1993,0.02075,0.0833,0.0075,1.37E-4,B=0.0029925,0.0005075,0.0284,
   0.021,0.033                                                             &END
 &KINB  X0=2*.94,ROMAX=31.,8.4,ROSTUK=2.75,2.1,RINMAX=.024,ROSURC=-18.0,
   TRESET=60.,XKT=1.0                                                      &END
 &KINC  TROM=558.3,TSTM=482.2,TSTSP=482.2,TAURO=2.,TAUST=2.,               &END
 &KIND  TFREF=176.7,TCREF=176.7,ASOD=-0.83E-6,0.864E-5,-0.83E-6,-1.44E-5,
   1.469E-4,-1.44E-5,-1.25E-5,-0.94E-4,-1.25E-5,0.,-3.89E-5,ADOP=-3.572E-3,
   -.0437,-7.55E-4,-6.191E-2,-.7438,-.01309,-.05358,-.245,-.01133,0.,-.2518,
   ACAE=4*0.,-.000128,6*0.,ACRE=-.00167,                                   &END
 &KINE  PRIMA=11.68,PRIMB=10.33,SECA=8.962,SECB=7.1667,                    &END
 &KINF  AT=27.8,2.8,527.7,                                                 &END
 &HYDA  AX=57.94,21.26,131.23,32.80,131.23,8.20,57.94,21.26,131.23,32.80,
   131.23,8.20,4.59,12.15,655.70,78.39,7.13,67.23,                         &END
 &HYDB  CA=1.04,CB=.064904,CF=.0135,MINERT=1071.2,TMMD=25496.,DSPEED=18.6,
   POLES=3.0,PMSSP=2.0,                                                    &END
 &HYDC  CDBRK=.0081,AX5BB=129.92,AXAB=1.31,VOLGV=81.3,SGVMID=4.1,SGVTOP=4.6,
   ZGVMID=-11.4,ZGVTOP=-7.6,                                               &END
 &HYDD  CONVG=.5,FREQ0=60.,XKA=.5,TK=.4,TS=.105,TR=.023,TMIN=.012,AL0=.01, &END
 &HYDE  FREQ1=60.,FREQ2=60.,AL1=1.0,AL2=1.0,                               &END
 &HYDF  TAUWM=0.5,TAUAM=0.02,TAUTM=5.0,TRISPN=387.78,                      &END
 &RTH1  PF=.001011,.035521,.000405,.012879,.486385,.005152,.011110,.366694,
   .004443,.005500,.070600,                                                &END
 &RTH2  VX=.00651,.0170,.0306,.114,.293,.526,.101,.258,.463,.0209,.277,.798,
   DT=9*.00411,.00338,.00466,VIP1=81.167,VIP2=9.018,                       &END
 &RTH3  DF=9*11000.,2450.8,11000.,CF=9*326.57,1297.9,326.57,XKF=3.768,3.534,
   3.768,3.768,3.334,3.768,3.768,3.534,3.768,10.385,3.768,DG=10*1.652E-4,
   1.905E-4,XKG=.3081,DC=9*3.81E-5,1.626E-3,3.81E-5,XKCL=16.747,           &END
 &RTH4  VF=.008212,.0211,.008212,.1395,.3586,.1395,.1231,.3164,.1231,.1559,
   1.701,XL=.5078,.9144,.5078,.5078,.9144,.5078,.5078,.9144,.5078,1.981,1.625,
   R=9*.002375,.005967,.006035,XN=3*1302.,3*22134.,3*19530.,703.,9150.,    &END
 &RTH5  RO=.6431,ZCH=3.41,DON=.9144,HIF=559.88,                            &END
 &RTH6  HCFAC=1.54,FLFAC=3.49,CLFAC=1.192,                                 &END
 &HX1A  DEXT=.02222,PITCH=.0254,XKSS=16.747,NT=2850.,BP=.03,ACF=0.8,       &END
 &HX1B  VIP=8.362,VOP=1.996,VBP=5.692,VIS=7.122,VOS=9.492                  &END
 &HX2A  DEXT=.02222,PITCH=.0254,XKSS=16.747,NT=2850.,BP=.03,ACF=0.8,       &END
 &HX2B  VIP=8.362,VOP=1.996,VBP=5.692,VIS=7.122,VOS=9.492                  &END
 &IHA1  DSPEED=18.6,TMMD=25496.,MINERT=1071.2,PMSSP=2.,                    &END
 &IHA2  PTSP=9.996E6,KFT=.5,KST=.5,KSF=.5,TAUS=.5,.02,4.,                  &END
 &IHA3  A1=1.04,A2=.064904,A3=.0135,AZ=.01,TS=.105,TR=.023,TMIN=.012,GFI=60.,
   XNP=3.0,ALFA=1.0,GF=60.,                                                &END
```

Table 11-1 (cont.)

```
NUMBER          PRINT   --  LISTING OF INPUT DATA SET  --

&IHB1   TMMD=25496.,MINERT=1071.2,GFI=60.,ALFA=1.0,GF=60.,                      &END
&IHB2   PTSP=9.996E6,KFT=.5,KST=.5,KSF=.5,TAUS=.5,.02,4.,                       &END
&SGA01  EPSI=345.,P=3*1.215E7,1.219E7,1.319E7,1.318E7,1.317E7,1.313E7,
  1.289E7,1.243E7,1.233E7,1.220E7,1.215E7,1.208E7,1.197E7,1.161E7,1.124E7,
  1.088E7,1.051E7,1.041E7,9.996E6,                                             &END
&SGA02  H=1.003E6,1.614E6,6*1.250E6,1.527E6,4*2.0875E6,2*2.681E6,3.000E6,
  3.178E6,3.2775E6,3*3.331E6,                                                  &END
&SGA03  TCS=7*0.,343.89,381.24,6*457.54,479.39,491.65,498.47,502.14,           &END
&SGA04  XLT=14.02,XL=0.,9.144,0.,36.576,1.524,10.24,72.146,2.623,0.,0.,7.055,
  35.357,6.096,45.72,2.623,4*3.505,7.055,106.68,ACF=.65,TKON=37.73,            &END
&SGA05  Z=3.81,4.267,4.267,-15.063,-13.411,-14.935,-17.983,-15.360,0.,-1.340,
  2.705,9.754,4.267,-17.983,-15.360,-11.855,-8.35,-4.845,-1.340,2*2.705,       &END
&SGA06  XLS=10*0.,5*7.437,4*3.505,                                             &END
&SGA07  PITCH=.0310, D=.2286,1.829,2*.432,2*.381,.2286,4*.0103,.381,.330,
  .279,6*.0103,.432,                                                           &END
&SGA08  DS=7*0.,3*.927,5*.432,4*.927,DEL=7*.0254,4*.002769,3*.0254,6*.002769,
  .0254,XN=7*1.,4*757.,1.,2.,1.,6*757.,1.,                                     &END
&SGA09  A1=1.04,A2=.064904,AZ=.01,TS=.105,TR=.023,TMIN=.012,DSPEED=18.6,
  SSPEED=20.,TMD=25496.,MINFRT=1071.2,                                         &END
&SGA10  KFW=.005,KCV=.5,HDSP=1.0,                                              &END
&SGA11  W1100=139.85,W2100=279.7,W1=139.85,W2=279.7,W3=139.85,CVP=.9201,
  ALFA=1.0,                                                                    &END
&SGA12  TAUS=1.,2.,2.,2.,                                                      &END
&SGA13  WFMIN=.2,WFMAX=1.15,CVMAX=1.,WAUXM=34.927,HAUW=1.558E5,HDAUX=1.,
  HDMAX=1.5,                                                                   &END
&SGB01  EPSI=345.,P=3*1.215E7,1.219E7,1.319E7,1.318E7,1.317E7,1.313E7,
  1.289E7,1.243E7,1.233E7,1.220E7,1.215E7,1.208E7,1.197E7,1.161E7,1.124E7,
  1.088E7,1.051E7,1.041E7,9.996E6,                                             &END
&SGB02  H=1.003E6,1.614E6,6*1.250E6,1.527E6,4*2.0875E6,2*2.681E6,3.000E6,
  3.178E6,3.2775E6,3*3.331E6,                                                  &END
&SGB03  TCS=7*0.,343.89,381.24,6*457.54,479.39,491.65,498.47,502.14,           &END
&SGB04  XLT=14.02,XL=0.,9.144,0.,36.576,1.524,10.24,72.146,2.623,0.,0.,7.055,
  35.357,6.096,45.72,2.623,4*3.505,7.055,106.68,ACF=.65,TKON=37.73,            &END
&SGB05  Z=3.81,4.267,4.267,-15.063,-13.411,-14.935,-17.983,-15.360,0.,-1.340,
  2.705,9.754,4.267,-17.983,-15.360,-11.855,-8.35,-4.845,-1.340,2*2.7 5,       &END
&SGB06  XLS=10*0.,5*7.437,4*3.505,                                             &END
&SGB07  PITCH=.0310, D=.2286,1.829,2*.432,2*.381,.2286,4*.0103,.381,.330,
  .279,6*.0103,.432,                                                           &END
&SGB08  DS=7*0.,3*.927,5*.432,4*.927,DEL=7*.0254,4*.002769,3*.0254,6*.002769,
  .0254,XN=7*1.,4*757.,1.,2.,1.,6*757.,1.,                                     &END
&SGB09  TMD=25496.,MINERT=1071.2,                                              &END
&SGB10  KFW=.005,KCV=.5,HDSP=1.0,                                              &END
&SGB11  W1100=139.85,W2100=279.7,W1=139.85,W2=279.7,W3=139.85,CVP=.9201,
  ALFA=1.0,                                                                    &END
&SGB12  TAUS=1.,2.,2.,2.,                                                      &END
&SGB13  WFMIN=.2,WFMAX=1.15,CVMAX=1.,WAUXM=34.927,HAUW=1.558E5,HDAUX=1.,
  HDMAX=1.5,                                                                   &END
&SHD1  VH=38.511,KTV=0.3,KDV=5.0,TVP=1.0,DVP=0.0,TAU=0.15,PSPTV=9.996E6,
  PSPDV=1.010E7,PSPRV=1.103E7,                                                 &END
&SHD2  WT100=419.55,WNMAX=1.,WNMIN=.02,PH=9.996E6,PC=0.,CT=9.307E6,
  CTV=6.894E5,CDV=1.578E7,CRV=1.451E-6,                                        &END
&SCR1  NOSCRM=5,11,12,13,14,15,0,0,0,0,0,0,0,0,0,DELAY=.69,PMPDEL=6*.69,       &END
&SCR2  PLIM=1.15,TCON=28.,A2=1.01,B2=-.99,C2=.1706,D2=.0364,A3=-1.01,B3=1.01,
  C3=.1969,D3=.0416,A4=1.318,B4=-1.,C4=.0425,A6=.0598,B6=.145,C6=-.0025,A8=.3,
  ZLEVEL=4.2,THXSCR=443.,                                                      &END
```

Table 11-1 (cont.)

```
NUMBER          PRINT   --  LISTING OF INPUT DATA SET  --

  166           &SCR3  A11=1.2,B11=-.99,C11=.087,A12=.0493,B12=.145,C12=-.0025,DRUMAX=.22,
  167             TVAPSC=400.,                                                           &END
  168           &SCR4  TAU=.15,.5,.1,4*5.0,                                              &END
  169           &MASA  MODE=0,IPRINT=50,IPK=10,SSEC=.2,TMAXSC=19.9                       &END
  170           &MASB  P100=975.,PD0=.9,SLOPEP=0.,PDEND=.9,XLOOP=2.,                     &END
  171           &MASC  TNEW=19.,2*50.,SNEW=3*0.2,IPNEW=1,5,5,                            &END
  172           &MASD  TSCRM=2*50.,TTRIP=6*50.,                                          &END
  173           &MASE NOPON=0,0,0,0,MTURB=0,MDUMP=0,RSTART=1,EPSILN=1.E-4                &END
  174           &MASF  RNSERT=.1,TNSERT=50.,                                             &END
  175           &MASG  TNOFW1=50.,TNOFW2=50.,TAUX1=50.,TAUX2=50.,                        &END
  176           &MASA  MODE=1,IPRINT=20,IPK=100,SSEC=.1,TMAXSC=49.9                      &END
  177           &MASB  P100=975.,PD0=.9,SLOPEP=0.,PDEND=.9,XLOOP=2.,                     &END
  178           &MASC  TNEW=1.99,9.99,39.99,SNEW=.2,.2,.4,IPNEW=10,50,10,                &END
  179           &MASD  TSCRM=200.,9.99,TTRIP=6*0.,                                       &END
  180           &MASE NOPON=0,0,0,0,MTURB=1,MDUMP=0,RSTART=0,EPSILN=1.E-4                &END
  181           &MASF  RNSERT=.5,TNSERT=0.49,                                            &END
  182           &MASG  TNOFW1=0.,TNOFW2=0.,TAUX1=29.9996,TAUX2=29.9996,                  &END
```

are the same as the units of the input variables (see page 11-2 for the units to be used with the CONVRT and TMPCON subroutines as supplied with the code).

A brief description of the output follows:

All input data is printed as it is received by each subroutine. Immediately after the data for subroutine HYDROS (HYDA,...,HYDF), are certain parameters related to the primary plant hydraulics. This includes the matrix of inertial loss coefficients (see Table 6-1), its inverse, the design pump head in the primary system as calculated by the code (in units of length), the pressure of the reactor vessel cover gas (as calculated by the code), and, in the case of a pipe rupture transient, the guard vessel volume below the break.

After the input data has been read and printed, the transient calculation begins. The time step printing frequency is a user input, as well as the frequency of including the "characteristic times" (see section 3) with the rest of the output.

A time = 0.0 output is automatically printed, in order to show the initial conditions for the entire plant. The format for a time step is as follows. Items marked "x" are printed only as indicated. Other items are printed at every print step (for variable units, see page 11-2).

	STEP #	=	integration step counter,
x	T	=	time since beginning of transient (not in pre-accident initialization),
x	S	=	current value of time step (not in pre-accident initialization),
	VECTOR OF CONTROL INTEGERS	=	listing of all class B variables (see section 3) in the master R-vector (see page 11-4,5).

***** NEUTRON KINETICS CALCULATIONS *****
(none of which are printed in a pre-accident initialization)

PTOT	=	total reactor power,
PN	=	total neutron power,
PFP	=	total fission product power,
PDN:	=	delayed neutron power (each of two groups),
PFP:	=	fission product power (each of three groups),
ROTOT	=	total core reactivity,

ROCR1 = reactivity due to primary control rod,

ROCR2 = reactivity due to secondary control rod,

ROFDBK = total temperature feedback reactivity,

RODOP = total Doppler feedback reactivity,

ROSOD = total sodium density effect reactivity,

ROCRE = reactivity due to core radial expansion,

ROCAE = total reactivity due to core axial expansion,

TRO = average reactor core outlet temperature,

TROM = measured value of TRO,

TSTM = measured value of steam temperature at turbine throttle valve,

PD = normalized demanded power,

ETST = deviation from setpoint of measured steam temperature,

ETRO = deviation from setpoint of measured core outlet temperature,

EF = fractional deviation from setpoint of flux,

DELRO = value of integral in the P-I reactor power controller,

PTOTNORM = normalized power,

PNNORM = neutron power (normalized to total rated power),

PFPNORM = fission product power (normalized to total rated power),

SCRAM RODS = position of both primary and secondary scram rods, % (0% = fully withdrawn, 100% = fully inserted), and

x TAU 1→8 = characteristic times for each of the 8 process variables of subroutine NEUKIN (printed only in those steps when requested).

***** PRIMARY COOLANT DYNAMICS *****

FZ1NRM = normalized flow in the inner core region (algebraically determined from other flows using mass continuity),

FZ2NRM = normalized flow in outer core region,

FZ3NRM = normalized flow in peak core region,

CANRM = normalized flow in control assembly channel,

RBNRM = normalized flow in radical blanket region,

BPNRM = normalized flow in bypass region,

FLOWS: = values for each of the process flows (W(1)-W(7)),

AL1 = normalized pump speed in primary loop 1,

NEW1 = normalized flow in primary loop 1,

BP1 = normalized pump (output) torque in loop 1,

TMOTN1 = normalized motor (input) torque in loop 1,

HP1 = normalized pump head in loop 1,

FREQ1 = motor generator controller frequency in loop 1, sec^{-1}, AL2,NEW2,BP2, TMOTN2,HP2,FREQ2 = correspond to above variables, but for loop 2,

PD = normalized power demand,

TRISP = reactor inlet nozzle setpoint temperature,

NEWSP = setpoint for normalized loop flow,

ASP = setpoint for normalized pump speed,

XKW = conversion gain for temperature-to-flow deviation in pump speed controller,

EPS = convergence criterion for the flow rates evaluated simultaneously in the prompt approximation,

N = number of iterations to convergence of the prompt flows,

TRIM = measured reactor inlet nozzle temperature (one in each loop),

NEWM = measured normalized flow rates (one in each loop),

ALM = measured normalized pump speeds (one in each loop),

INLET PRSNRM = normalized reactor inlet nozzle pressure,

ET = deviation of inlet nozzle temperatures from setpoint (one in each loop),

EW = deviation of normalized flow rates from setpoint (one in each loop),

EA = deviation of normalized pump speeds from setpoint (one in each loop),

x G1NORM = normalized flow between pipe break and reactor vessel (printed only in pipe rupture transients),

x VOL. LOSS = total sodium volume which has escaped through the break (printed only in pipe rupture transients),

x ZOPTOT = height of sodium in reactor vessel above break elevation (printed only in pipe rupture transients),

x GVLEV = height of sodium in reactor guard vessel above break elevation (printed only in pipe rupture transients), and

x TAU 1-18 = characteristic times of each of the 18 process variables of subroutine HYDROS (printed only when requested).

***** REACTOR HEAT TRANSFER *****

x TAU 1-33 = characteristic times of each of the 33 process variables of subroutine RTHERM (printed only when requested),

CORE HOT SPOT:

MAX. COOLANT TEMP. = coolant hot spot temperature at top of core region, based on input 3σ factors, MAX. CLAD TEMP. = corresponding maximum clad temperature,

PEAK CORE AVERAGE TEMPERATURES:

FUEL CENTERLINE = average temperature of fuel centerline in peak core region,

CLAD INNER = average temperature of clad inner surface in peak core region,

CLAD OUTER = average temperature of clad outer surface in peak core region,

TM 1-11 = temperatures of 11 material (fuel or control assembly) regions in the reactor --

1-3 are lower blanket, core, and upper blanket for peak core region,

4-6 are lower blanket, core and upper blanket for inner core region,

7-9 are lower blanket, core and upper blanket for outer core region,

10 is control assembly average temperature,

11 is radial blanket average temperature,

TC 1-12 = coolant temperatures at outlet of 12 reactor regions, 1-11 as listed above, and 12 being the bypass channel,

TCI1-TCI6 = inlet temperatures to each of the six core flow regions, peak core, inner core, outer core, control assembly, radial blanket, and bypass,

LOWER PLENUM:

TOP ZONE TEMP. = average temperature of inlet plenum upper zone,

BOTTOM ZONE TEMP. = average temperature of inlet plenum lower zone,

UPPER PLENUM:

ZJET = penetration distance of core coolant jet above core outlet,

TOP ZONE TEMP. = average temperature of outlet plenum upper zone,

BOTTOM ZONE TEMP. = average temperature of outlet plenum lower zone, and

NOZZLE TEMP. = temperature at reactor vessel outlet nozzle.

***** IHX-1 THERMAL CALCULATIONS *****

x PR. SOD. CONVECTION HEAT-TRANS. COEFF. VALUES = primary sodium heat transfer coefficient at each heat transfer node (printed at time = 0.0 only),

x SEC. SOD. CONVECTION HEAT-TRANS. COEFF. VALUES = same as above, but for secondary sodium, x OVERALL HEAT TRANSFER COEFF. VALUES = total heat transfer coefficient at each IHX node (printed at time = 0.0 only),

x LOG-MEAN-TEMP.-DIF. VALUES = logarithmic mean temperature difference values for each node in the IHX (printed at time = 0.0 only),

x TAUP = N+3 characteristic times for IHX primary side (inlet plenum, each of N nodes, bypass, and outlet plenum) (printed only when requested),

x TAUS = N+2 characteristic times for IHX secondary side (each of N nodes, inlet plenum, and outlet plenum),

TP = N+3 IHX primary sodium temperatures, and

TS = N+2 IHX secondary sodium temperatures.

***** IHX-2 THERMAL CALCULATIONS *****

(corresponds exactly to IHX-1).

***** PRIMARY SODIUM TRANSPORT CALCULATIONS *****

x TAUC1 = characteristic times of coolant temperatures at each node in pipe run 1 (printed when requested),

x TAUW1 = characteristic times of wall temperatures at each node in pipe run 1 (printed when requested if heat storage is considered),

x TAUC2, TAUW2 = same as above, but for pipe run 2,

x TAUC3, TAUW3 = same as above, but for pipe run 3,

x TAUC4, TAUW4 = same as above, but for pipe run 4,

x TAUC5, TAUW5 = same as above, but for pipe run 5,

x TAUC6, TAUW6 = same as above, but for pipe run 6,

TC1 = coolant temperatures at each node at pipe run 1,

x TW1 = pipe wall temperatures at each node of pipe run 1 (printed if heat storage is considered),

TC2,TW2 = same as above, but for pipe run 2,

TC3,TW3 = same as above, but for pipe run 3,

TC4,TW4 = same as above, but for pipe run 4,

TC5,TW5 = same as above, but for pipe run 5, and

TC6,TW6 = same as above, but for pipe run 6.

***** INTERMEDIATE LOOP-1: COOLANT DYNAMICS *****

x TAU = characteristic times of the 5 process variables of subroutine IHYD1 (printed when requested), SODIUM FLOW RATE = normalized sodium flow in loop 1,

PUMP SPEED = normalized pump speed in loop 1,

PUMP HEAD = normalized pump head in loop 1,

MOTOR GEN. SET. FREQ. = motor generation set frequency for controller of intermediate pump in loop 1,

MAIN MOTOR TORQUE = normalized main motor torque of pump in loop 1,

DRIVE MOTOR TORQUE = normalized drive motor torque of pump in loop 1,

PUMP TORQUE = normalized (output) pump torque of pump in loop 1, and

FRICTION TORQUE = normalized friction torque of pump in loop 1.

***** INTERMEDIATE LOOP-2: COOLANT DYNAMICS *****

(corresponds exactly to LOOP-1 output)

***** INTERMEDIATE LOOP-1: SODIUM TRANSPORT *****

x TAUC1 = characteristic times of the coolant temperatures at each node of intermediate pipe run 1 (printed only when requested),

x TAUW1 = characteristic times of the wall temperatures at each node of intermediate pipe run 1 (printed when requested only if heat storage is considered),

x TAUC2,TAUW2 = same as above, but for intermediate pipe run 2,

x TAUC3,TAUW3 = same as above, but for intermediate pipe run 3,

x TAUC4,TAUW4 = same as above, but for intermediate pipe run 4,

TCS1 = coolant temperatures at each node of intermediate pipe run 1,

x TWS1 = pipe wall temperatures at each node of intermediate pipe run 1 (printed only if heat storage is considered),

TCS2,TWS2 = same as above, but for intermediate pipe run 2,

TCS3,TWS3 = same as above, but for intermediate pipe run 3, and

TCS4,TWS4 = same as above, but for intermediate pipe run 4.

***** INTERMEDIATE LOOP-2: SODIUM TRANSPORT *****

(corresponds to LOOP-1 output)

***** STEAM GENERATION LOOP-1 *****

x TAU = characteristic times of each of the 39 process variables of subroutine SGTHD1 (printed only when requested),

FEEDWATER FLOW = normalized feedwater flow to steam drum,

WATER/STEAM FLOW = normalized flow into drum from evaporators,

STEAM FLOW = normalized flow through superheater, INT. SODIUM FLOW = normalized sodium flow rate in intermediate loop 1,

x -- a message is printed at this point if the auxiliary feedwater has come on line, stating when it was first available, its enthalpy, and its normalized flow rate,

P = local pressures at 21 steam/water nodes in the tertiary loop (see Fig. 11-13),

H = local specific enthalpies at 21 steam/water nodes in the tertiary loop,

TM = steam/water temperatures calculated from steam tables at 21 nodes corresponding to the above H and P's,

TCS = secondary sodium temperatures corresponding to the nodes of Fig. 11-13,

TDLOG = logarithmic mean temperature difference,

9 -- evaporator non-boiling zone,

10 -- evaporator boiling zone,

16-19 -- superheater subsections,

U = overall heat-transfer coefficients, corresponding to the above TDLOG's,

HEAT FLUX = average heat flux in the boiling zone of the evaporator,

OUTLET STEAM QUALITY = steam quality at the evaporator tubes outlet,

NON-BOILING LENGTH = non-boiling length in the evaporators,

BOILING LENGTH = boiling length in the evaporators,

DRUM INT. ENERGY = total average steam drum internal energy,

DRUM LEVEL = water level in the steam drum (normalized with 1:center line, 0:empty, 2:full),

CVP = feedwater control valve position (fractional opening),

ALFA = recirculation pump speed (fractional speed), and

DPRP = pressure drop across the recirculation pump.

***** STEAM GENERATOR LOOP-2 *****

(corresponds to LOOP-1 output)

***** STEAM HEADER THERMODYNAMICS *****

x TIME CONSTANT OF HEADER PRESSURE GAUGE = steam header pressure gauge characteristic time, THROTTLE VALVE POSITION = fractional opening of the turbine throttle valve (1: fully open),

THROTTLE VALVE FLOW = fraction of flow through the turbine throttle valve (1: 100%),

DUMP (BYPASS) VALVE POSITION = fractional opening of the turbine bypass valve (1: fully open),

DUMP (BYPASS) VALVE FLOW = fraction of flow through the turbine bypass valve to the condenser,

RELIEF VALVE FLOW = fraction of flow through the header pressure relief valve to the atmosphere,

HEADER PRESSURE = steam header steam pressure,

TEMPERATURE = steam header steam temperature, and

SPECIFIC ENTHALPY = steam header steam specific enthalpy.

x ***** MEASURED VALUES FOR PPS *****

(these are not printed in a pre-accident initialization)

x TAU: = characteristic times for the seven variables measured in subroutine SCRAM (printed when requested),

PRESNORM = measured value for the normalized reactor inlet nozzle temperature,

VESSEL LEVEL = measured value for the reactor vessel sodium level (height above reactor vessel outlet nozzle),

PTOTNORM = measured value of normalized reactor power,

TIHX1 = measured IHX-1 outlet temperature,

TIHX2 = measured IHX-2 outlet temperature,

TEVAP1 = measured outlet temperature of loop-1 evaporator, and

TEVAP2 = measured outlet temperature of loop-2 evaporator.

In addition to the above output, certain other messages are printed between time steps. These include reactor scram signals, pump trips, pump cavitation in the recirculation pumps, dryout in the evaporators, etc., and are self-explanatory when they appear.

PROGRAMMING LANGUAGE AND COMPUTER REQUIREMENTS

These programs are coded using the FORTRAN IV language. The WATFIV compiler was used for debugging and testing the individual subroutines. The WATFIV compiler gives detailed error messages and executes the compliation step much faster than the IBM FORTRAN (G and H) compilers. However, execution under WATFIV is considerably slower than the IBM compilers.

All source programs have been compiled separately and the resultant object modules formed using the FORTRAN IV-G processor. Subsequently, only the linkage and execution steps need to be carried out with the appropriate input data. The core region required for each of these steps on an IBM 370/168 is about 306 K.

Typical computer run times for linkage and execution steps on an IBM 370/168 are listed in Table 11-2.

Table 11-2

EXAMPLES OF COMPUTER RUN TIMES ON AN IBM 370/168

Total Simulated Transient Time	Number of Time Steps	Linkage Time	Execution Time
20. sec	125	3.72 sec	24.87 sec
30. sec	175	3.62 sec	34.87 sec
50. sec	275	3.86 sec	51.12 sec
60. sec	325	3.60 sec	58.19 sec
100. sec	510	3.78 sec	109.21 sec

GENERAL HINTS

In general, it is usually good practice to have around 10-20% of the process variables in their prompt approximation (Class B) state. This can greatly reduce computation time.

When performing a steady-state initialization at a power other than 100%, the steady state at 100% should be found first in order to set up the proper rated conditions which are used to normalize the flows, reactor inlet pressure, etc.

The code calculates frictional loss coefficients based on the initial flows and pressures. Therefore it is important that the input flows and pressures correspond to a true reactor state in order to get correct results.

There has been some discussion as to whether the bypass flow channel in the reactor vessel can reverse (due to leakage in the upper reactor internals). Presently, CURL-L prohibits bypass flow reversal through a statement in subroutine HYDROS:

```
DATA NOBPRV/1/.
```

If bypass flow reversal is allowed, the 1 in the above statement should be changed to a 0.

Because the pipe subroutines (DELAYP, DELAY1, DELAY2) do not employ prompt approximations, care should be taken so that a short pipe run is not divided into too many nodes. The "characteristic time" of the coolant temperature (assuming equilibrium with the pipe wall) is defined as

$$\tau = \frac{\rho V}{W}$$

where:

τ = "characteristic time" of coolant,

ρ = coolant density,

W = coolant mass flow rate,

V = volume of coolant node,

$= \frac{A\ XL}{N}$

A = cross sectional areas of pipe,

XL = total length of pipe run, and

N = number of nodes the pipe run is divided into.

If τ at any node becomes smaller than the selected time step, problems could result in the integration, so N should be restricted accordingly.

In a steady-state calculation, a message may be printed which indicates which variable in the master R-vector has changed by the greatest amount in the current iteration. The printing frequency of this statement is determined by IPNEW (3).

The secondary control rod reactivity is <u>not</u> included in the cold shutdown margin of reactivity in this model. Thus, while a primary scram insertion causes the primary control rod reactivity to decrease toward zero, a secondary scram insertion starts at zero reactivity and adds "negative reactivity" as the secondary rods fall.

Section 12

TRANSIENT ANALYSIS AND VERIFICATION

INTRODUCTION

The classification of accidents in nuclear power plants is based on the frequency of the events and their damage severity levels.

The level of severity of the damage on the system falls rapidly as the probability of occurrence of the event increases, that is, the potential magnitude of injury or damage should be considerably less for accidents that are highly probable rather than for those that have a low probability of occurrence. It is convenient to define departures from normal operations that differ from level to level in the probability of their occurrence (29).

Level I includes conditions that occur frequently or regularly in the course of normal operation: refueling, or maintenance; e.g., load changes, approach to criticality, etc.

Level II includes all faults that are not expected during normal plant operation but can reasonably be expected during the life of a particular plant. Examples are loss of electrical power to the plant components (e.g., pumps) or control system, loss of feedwater, inadvertent rod withdrawal, etc. The conditions of this level correspond to those for which the "maximum safety settings" prevent the "safety limits" from being reached.

Level III is comprised of departures from nominal conditions that are not expected to occur in the lifetime of any particular plant, but may be expected to occur a few times in the nuclear power industry over a long time period. This includes accidents such as a large system rupture, or loss of offsite and onsite power supplies. The worst of these credible accident situations is chosen as the plant design basis accident (DBA). Its consequences form the upper limit of damage in the gross damage range.

The model is designed to predict the overall plant response to the perturbations that are classified by the given severity levels except for the following limitations:

1. Accidents leading to initiation of major sodium boiling can not be analyzed; however, small, localized saturation conditions might be tolerated.
2. Sodium fires and steam generator leaks are not considered.
3. Steam generator blow-down can not be analyzed.
4. No core disruptive accident (CDA) can be analyzed.

To test the overall model of the LMFBR plant system the transient results are analyzed and a comparison is made with the available literature on similar transients for the following perturbations:

1. Seismic induced reactivity insertion.
2. Spurious pump trip.
3. Complete loss-of-forced cooling leading to buoyancy induced natural circulation.

Causes and assumptions are identified, and transient results are discussed and comparisons are made to verify the model behaviors.

Table 12-1 shows the plant protection system shutdown functions.

SEISMIC INDUCED REACTIVITY INSERTION

Identification of Causes and Assumptions

It is assumed that an earthquake produces a loss of off-site electrical power to the plant causing a resultant loss of power to the coolant pumps and consequent decay of the primary, secondary and tertiary flows. The acceleration forces of the earthquake can cause compaction of the reactor core due to closing of radial gaps between the assemblies. This can result in a net positive step reactivity insertion to the core. When the control rods are scrammed, the rate of inward motion is decreased from the normal rate. This is due to a retarding force resulting from seismic induced impacts of the control rod assembly duct and driveline affecting the surrounding guide structure.

To simulate these conditions the following perturbation and assumptions are considered:

1. The turbine and all primary, secondary and tertiary pumps trip at time zero of the transient.
2. Failure to scram by the primary pump electric signal.

Table 12-1

PLANT PROTECTION SYSTEM

PRIMARY SHUTDOWN SYSTEM
1. High Flux
2. Flux-Delayed Flux
3. Flux - $\sqrt{\text{Pressure}}$
4. Primary Pump Electrics
5. Primary to Intermediate Speed Ratio
6. Reactor Vessel Level
7. Steam to Feedwater Flow Ratio
8. IHX Primary Outlet Temperature
SECONDARY SHUTDOWN SYSTEM
1. Flux-Total Flow
2. Primary to Intermediate Flow Ratio
3. Steam Drum Level
4. Evaporator Outlet Sodium Temperature

3. There is a 60¢ step insertion of reactivity 0.5 seconds after the transient initiation.
4. A 200 msec scram delay after the scram signal.
5. There is a Doppler coefficeient of -0.005.
6. Maximum fission product decay heat exists.
7. The reactor is operating at 100% rated power prior to perturbation.

Perturbation Results

Figure 12-1 shows the primary and secondary-loop sodium flow rates following the transient initiation. The decrease in the flow rates is caused by disconnecting the main motors causing the simultaneous tripping of the pumps. The primary system flow rates in the single (loop-1) and lumped (loop-2) loops are virtually identical, while the decay rate in the secondary loops vary due to the difference in the sodium inertia of the loops.

The decrease in heat removal rate caused by the decay of the coolant flow rate along with constant nuclear energy production causes a temperature rise in the reactor fuel and coolant. This is further increased at 0.5 seconds when the reactivity insertion takes place, producing the prompt increase in reactor power and the power to flow ratio in the reactor as shown in Figure 12-2.

The decrease in reactor coolant mass flow rate accompanied by constant high nuclear power at the beginning of the transient causes a slight increase in the reactor temperatures. The temperatures further increase at 500 milliseconds when the reactivity insertion occurs, causing a sharp increase in reactor power and, hence, a large increase in the power to flow ratio as shown in Figure 12-2.

Figure 12-3 shows total reactivity as a function of time. The reactivity stays constant until 0.5 seconds when the step increase of 60¢ is inserted causing a prompt increase in the power and, therefore, a sharp increase in the reactor fuel temperatures (see Figure 12-4). This increase causes Doppler broadening of resonances and, hence, an increase in neutron capture causing a slight decrease in reactivity.

The reactor scram signal is generated at 0.5 seconds resulting from 115% overpower (high flux) caused by the jump in the power. The control rods start to move in at 0.70 seconds causing a further decrease in reactivity and power. The total reactivity reaches a minimum at 1.7 seconds and then increases to stabilize at

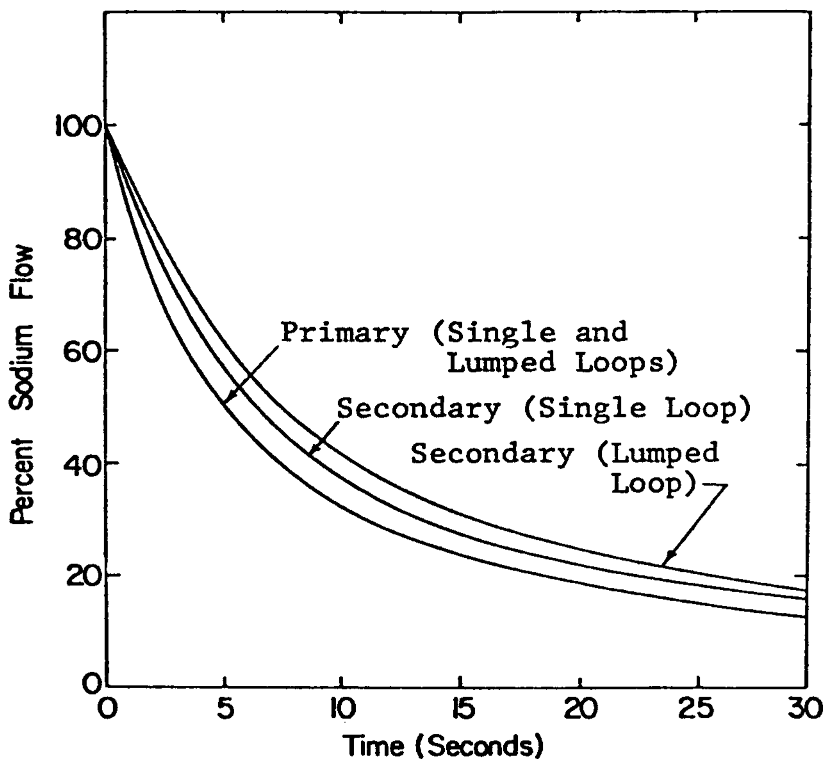


Figure 12-1 Seismic Perturbation - primary and secondary sodium mass flow rates

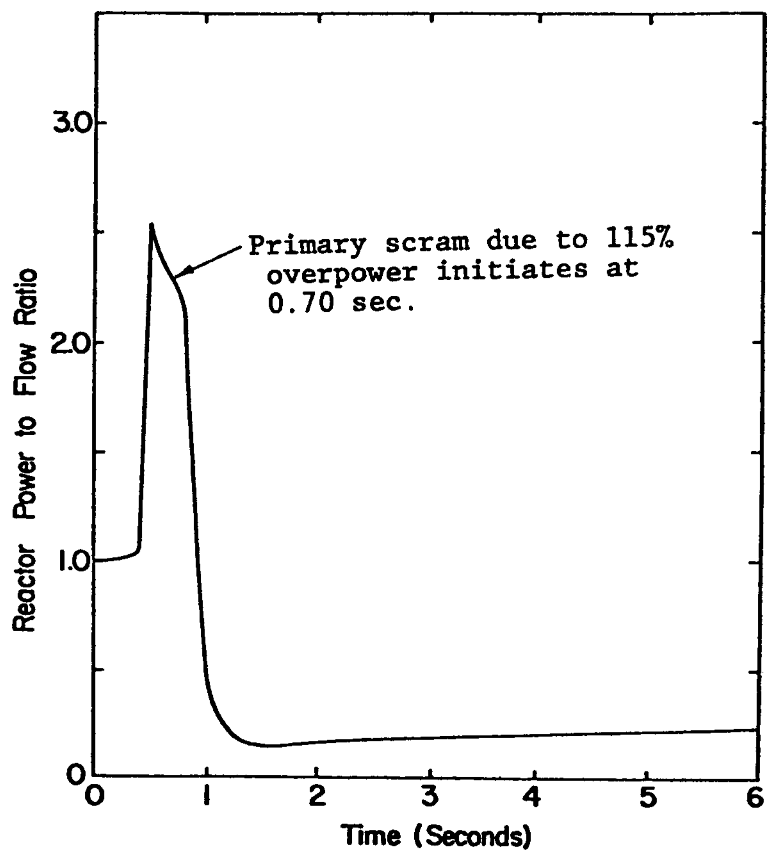


Figure 12-2 Seismic Perturbation - reactor power to flow ratio

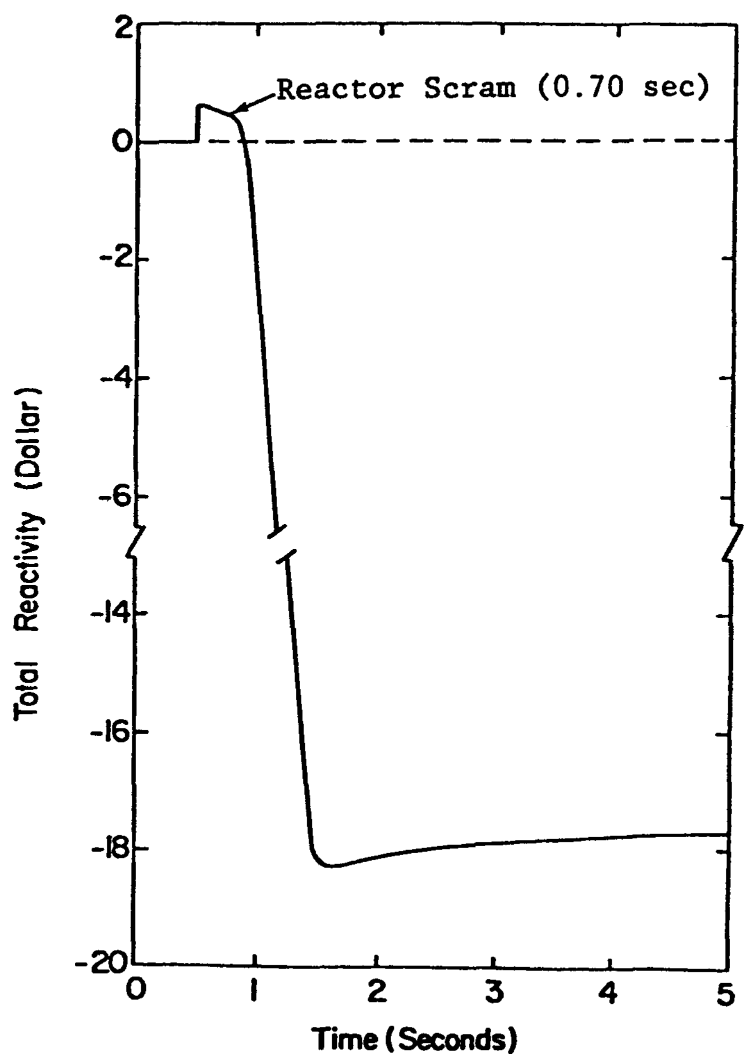


Figure 12-3 Seismic Perturbation - total reactivity

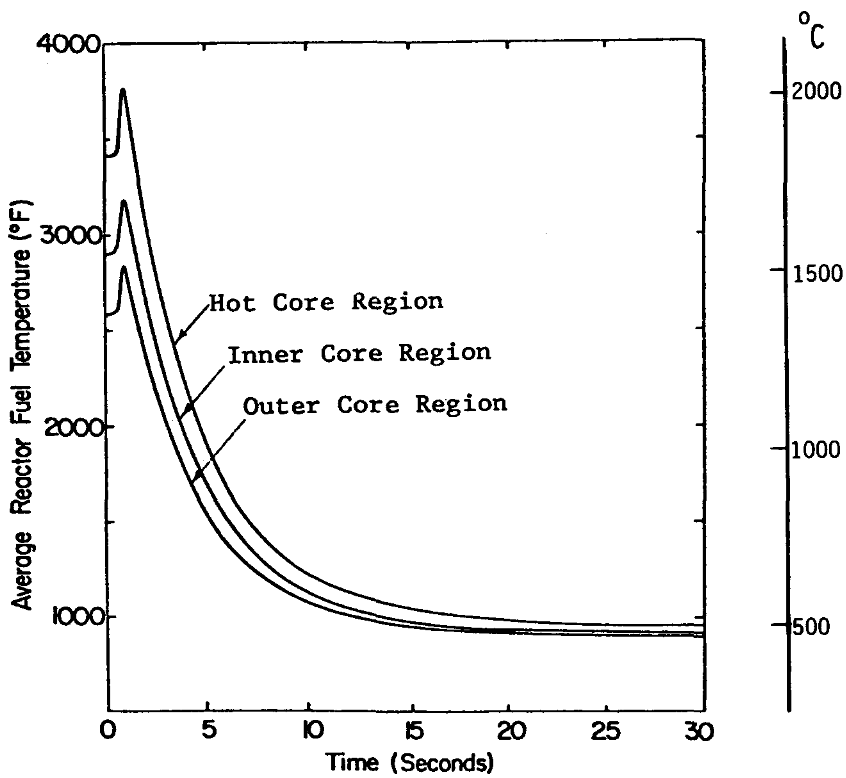


Figure 12-4 Seismic Perturbation - reactor average fuel temperature.

about -18$ due to rapid decrease in fuel and coolant temperatures caused by reactor scram as shown by Figures 12-4, 12-5, 12-7, and 12-8.

The increase in reactor power to flow ratio at about two seconds as shown by Figure 12-2, is due to the nearly constant reactor power caused by slow decay of the fission products and the continuous decrease in the flow rates. This increase will continue until the sodium flows stabilize at the pony motor driven values of about 10%; then, the power decreases slightly due to the continuous decay of short-lived fission products, causing, in turn a continuous decrease in the power to flow ratio starting at about 35 seconds.

It is observed from Figure 12-5 that the average hot channel reactor core fuel temperature increases sharply along with the power to flow ratio and reaches a maximum of 2650°C(4800°F) (just below the fuel melting temperature of 2760°C(5000°F) before dropping to lower temperatures, due to the reactor scram at 0.7 seconds.

Verification and Comparisons

Utilization of the Prompt Jump Approximation for the calculation of neutron flux amplitude along with two groups of delayed neutrons causes a prompt increase in the reactor power following the step reactivity insertion.

Figure 12-6 shows the reactor power as calculated by the present model and a similar analysis using the FORE-II model (13). It is observed that in the FORE-II analysis the power does not peak at the same time as the present model predicts. It is evident that the FORE-II analysis integrates the neutron flux amplitude equation using a more exact method than the Prompt Jump Approximation. Also the two group model used in the present work matches the transfer functions for the far field behavior to the six-group model and, hence, cannot accurately predict the behavior at small time intervals after the transient. However, the two models behave identically after about 0.8 seconds, as shown by Figure 12-6.

The hotspot midwall clad temperature in the hot channel, as computed by the two models, is shown in Figure 12-7. The reduction in the heat removal rate caused by the pump trip causes an increase in the cladding temperature, as predicted by the present model, although it is not clear why in the FORE-II model this temperature increase is not shown until the reactivity insertion time at 0.5 seconds. The rate at which the cladding temperature increases is greater in this model than

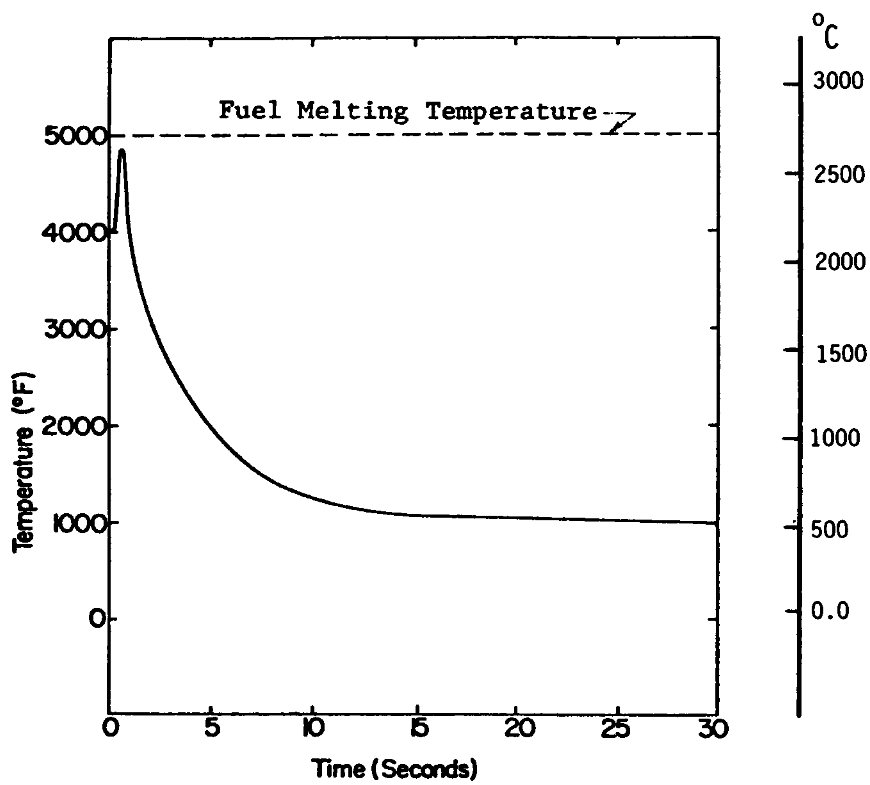


Figure 12-5 Seismic Perturbation - average fuel centerline temperature in the hot core region.

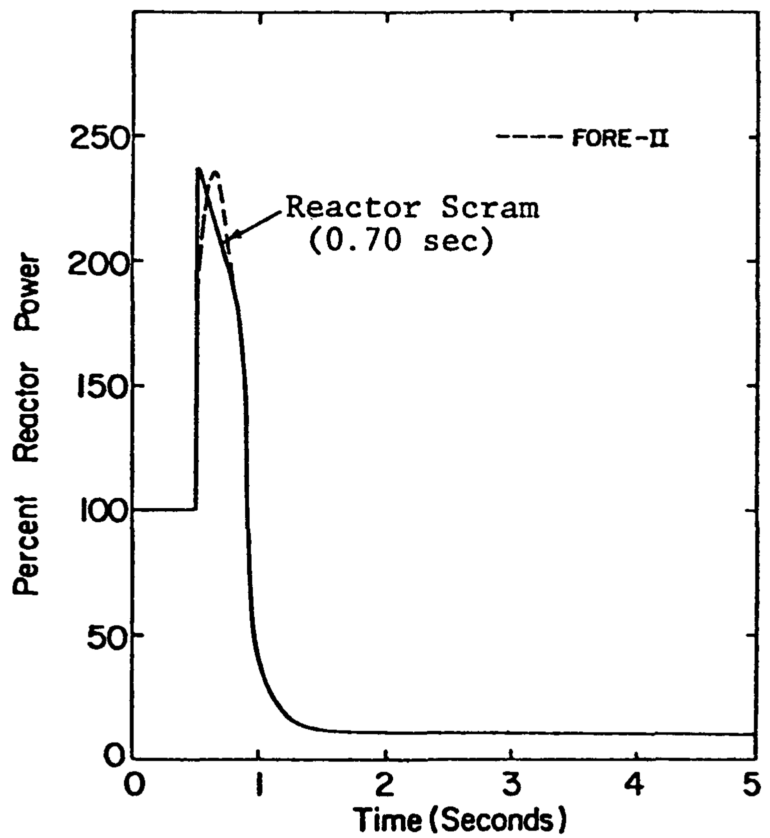


Figure 12-6 Seismic Perturbation - total reactor power.

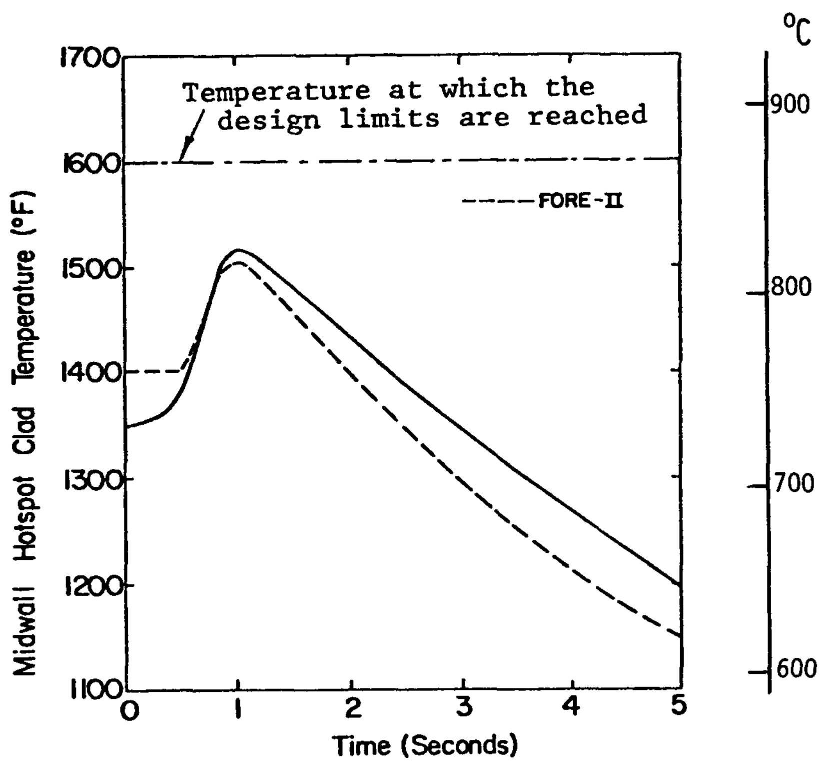


Figure 12-7 Seismic Perturbation - midwall hotspot clad temperature in the hot core region.

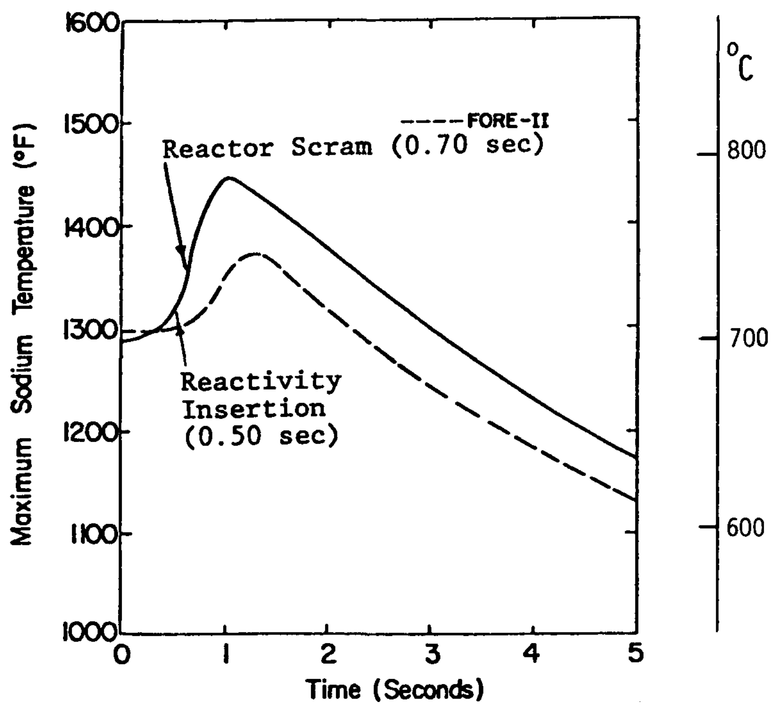


Figure 12-8 Seismic Perturbation - maximum sodium temperature at the hot core channel

in the FORE-II model. In the former case this is attributed to an instantaneous jump in reactor power as caused by the Prompt Jump Approximation.

It is important to note that the cladding temperature calculated by the FORE-II model corresponds to the cladding inner surface under the wire wrap, which is normally about 8-10°C higher than the midwall temperature that is calculated by the present model. However, the midwall temperature peaked at a higher temperature as predicted by this model. This discrepancy might be due in part to the possible differences in the magnitudes of the hotspot factors, and also to the sodium flow coastdown characteristics of the models.

The variation of the maximum hot-channel sodium temperature of the fuel assemblies is shown in Figure 12-8.

The maximum sodium temperature occurs at the top of the reactor core just below the upper axial blanket in the vicinity of the hottest cladding temperature.

Similar effects are predicted, as described for the cladding midwall temperature. The decrease in sodium flow rate, and the sharp rise in the energy production caused by reactivity insertion, increases the power to flow ratio that produces an increase in the hot channel coolant temperature in the reactor. This temperature increase is quite rapid and reaches a maximum at one second. It then begins to drop caused by the reactor scram.

Again two major differences are apparent. First the model predicts an increase in temperature prior to the reactivity insertion, while the FORE-II analysis does not show such a variation. Second, there is a sharper increase in the sodium temperature as compared to the FORE-II analysis.

It is believed that the difference in the magnitudes of the coolant temperature is due partially to the difference in the hot channel factors. But a much larger effect would be due to the fact that the coolant temperature reported does not correspond to the top of the core but rather corresponds to the temperature at the channel outlet at the top of the upper axial blanket.

It can be concluded that, there is a general agreement between the two models, and the discrepancies fall within the expected limits.

SPURIOUS PUMP TRIP

Identification of Causes and Assumptions

The determination of the response characteristics of the system to postulated undercooling events is important for the safe operation of fast breeder reactors.

A spurious trip of the sodium pumps may occur. This could be caused by an A.C. bus fault in which both the primary-loop sodium pump and the secondary-loop sodium pump on the same loop are tripped simultaneously. The consequences of such an incident are increased by failure to scram on a primary pump electric signal, thus leading to a more severe transient event.

To simulate these conditions the following perturbation and assumptions are imposed:

1. Primary and secondary pumps on the same loop (loop-1) are tripped simultaneously.
2. There is a failure to scram on the primary pump electric signal.
3. A 200 msec scram delay occurs after the scram signal.
4. A 500 msec pump trip delay occurs after the trip signal.
5. There is a Doppler coefficient of -0.005.
6. The maximum fission product decay heat is assumed.
7. The reactor is operating at 100% rated power prior to perturbation.

Perturbation Results

Figure 12-9 shows the primary and secondary loop sodium flow rates. Following the A.C. bus fault the sodium flow rate in loop-1 of the primary and secondary systems start decaying. It is observed that the sodium flow rate in the lumped loops (loop-2) of the primary system start increasing due to reduction in the pressure losses in the reactor caused by reduced flow.

The variation in the flow decay rates of the primary and secondary loops (loop-1) caused by the difference in the sodium inertial and frictional losses in the two systems generates a secondary reactor scram signal at 2.3 seconds after the transient initiation. The scram signal also produces trip signals for the unaffected primary and secondary pumps and the recirculation pumps of the tertiary system (in order to protect the reactor and system components from rapid cooling caused by a low power to flow ratio in the absence of forced pump trips). The pump trips are initiated after a half second delay following the reactor scram

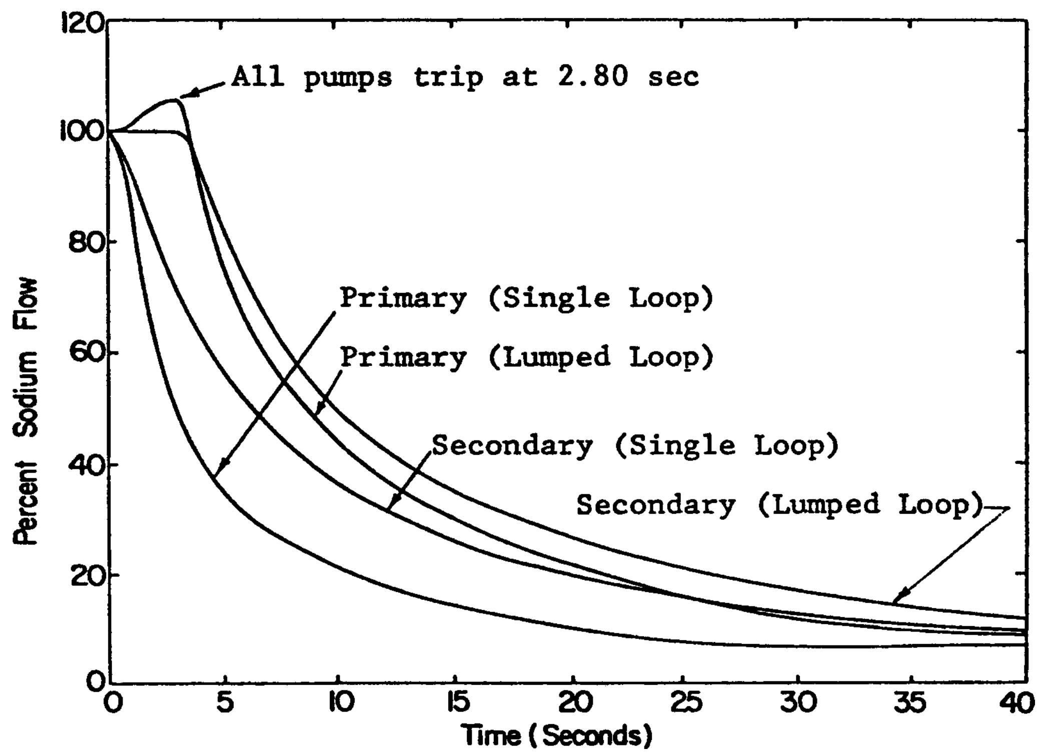


Figure 12-9 Spurious Pump Trip - primary and secondary sodium mass flow rates.

signal. The pump trips cause immediate coastdown of the sodium flow rates in the unaffected primary and secondary loops (loop-2).

As the pump speeds reduce and approach 10% of rated speed the auxiliary pony motor generators come on line to provide low flow capabilities for the decay heat removal in the primary and secondary loops, thus, preventing the flows from decreasing below approximately 7%.

Figure 12-10 represents the total reactor power and reactivity as calculated. Following the bus fault event the reactor fuel and coolant temperatures start increasing, producing a negative reactivity effect, and causing a very small decrease in the power.

At 2.3 seconds following the transient initiation, the primary to secondary flow ratio generates a secondary scram signal. The secondary control rods start moving after a 200 msec delay following the scram signal. This causes a decrease in the reactivity, which in turn, decreases the neutron density, and subsequently the total reactor power.

The reactivity reaches a minimum at about 3.5 seconds. It then begins increasing and levels off at about 30 seconds.

The reactor power to flow ratio increases following the bus fault initiation as the flow rate through the reactor core decreases (Figure 12-11). It reaches a maximum of 1.3 at 2.5 seconds, causing an increase in the reactor fuel (Figure 12-12) and coolant (Figure 12-13) temperatures. Following the reactor scram the power to flow ratio drops very rapidly and reaches a minimum at 3.5 seconds. It starts increasing again as the pump trips begin decreasing the sodium flow rates, and increases continuously and starts to stabilize as the pony motors begin operating effectively.

The variations in the reactor fuel and coolant temperatures follow the power to flow ratio except for the thermal lag associated with the heat capacity of the fuel and coolant.

Figure 12-13 also shows the sodium temperature at the reactor outlet nozzle. It is observed that the variations in outlet nozzle temperature are very small for the

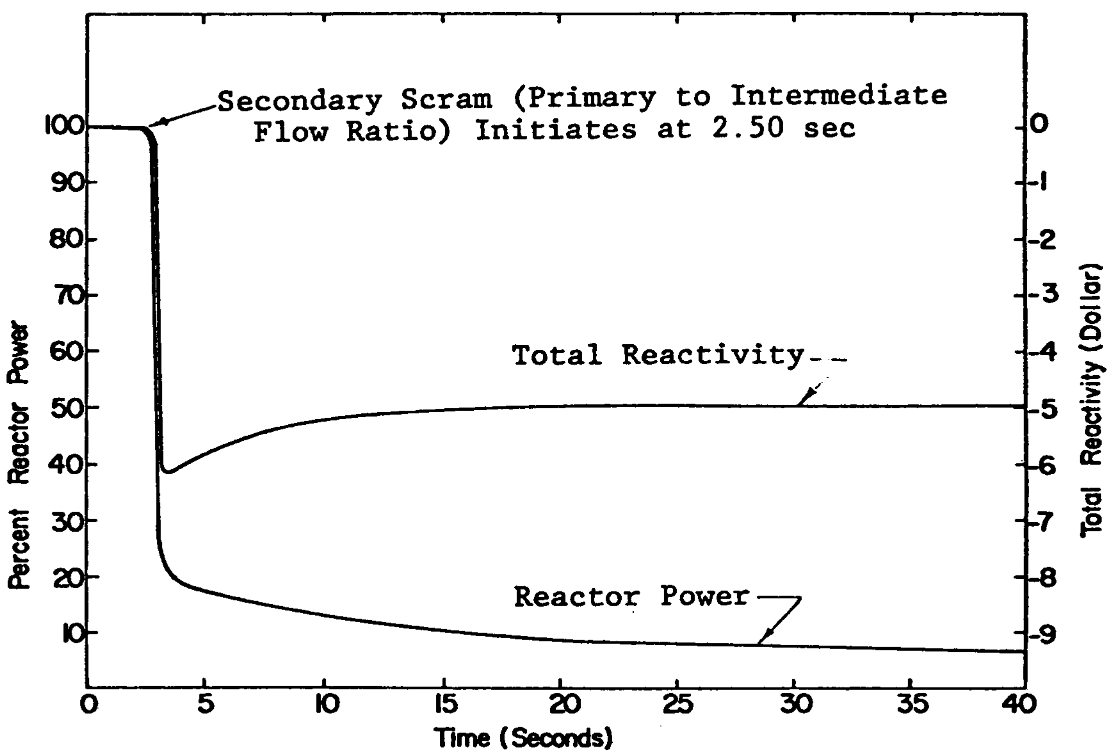


Figure 12-10 Spurious Pump Trip - total reactivity and reactor

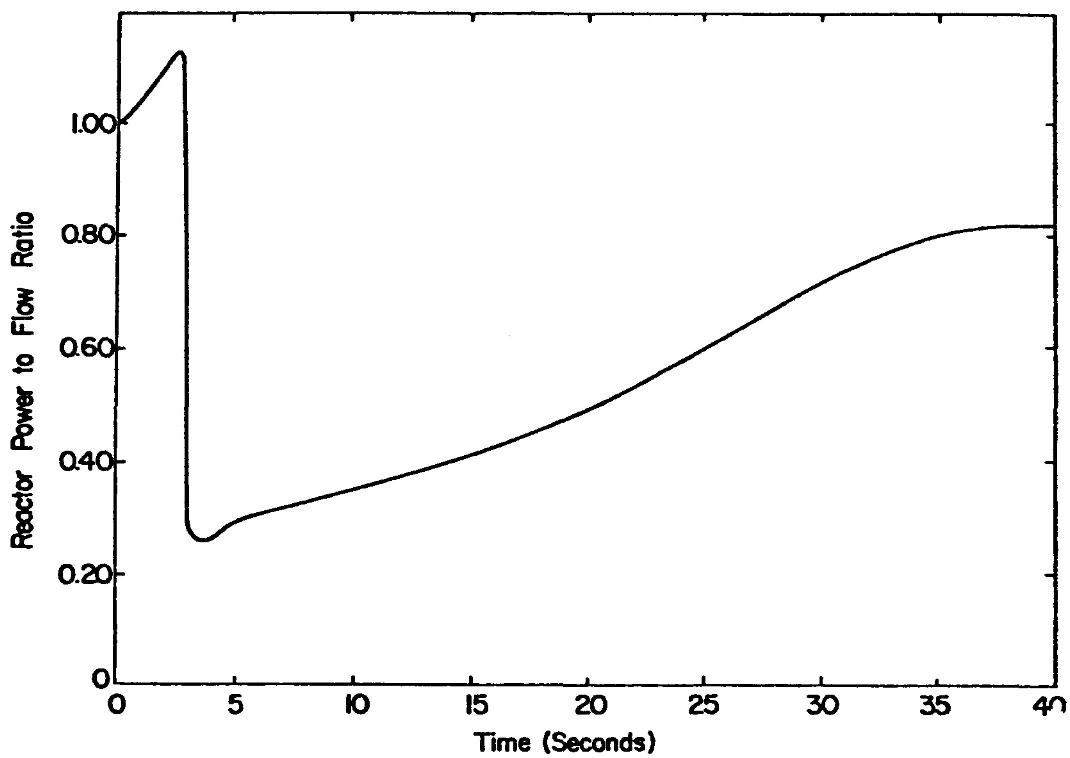


Figure 12-11 Spurious Pump Trip - reactor power to flow ratio

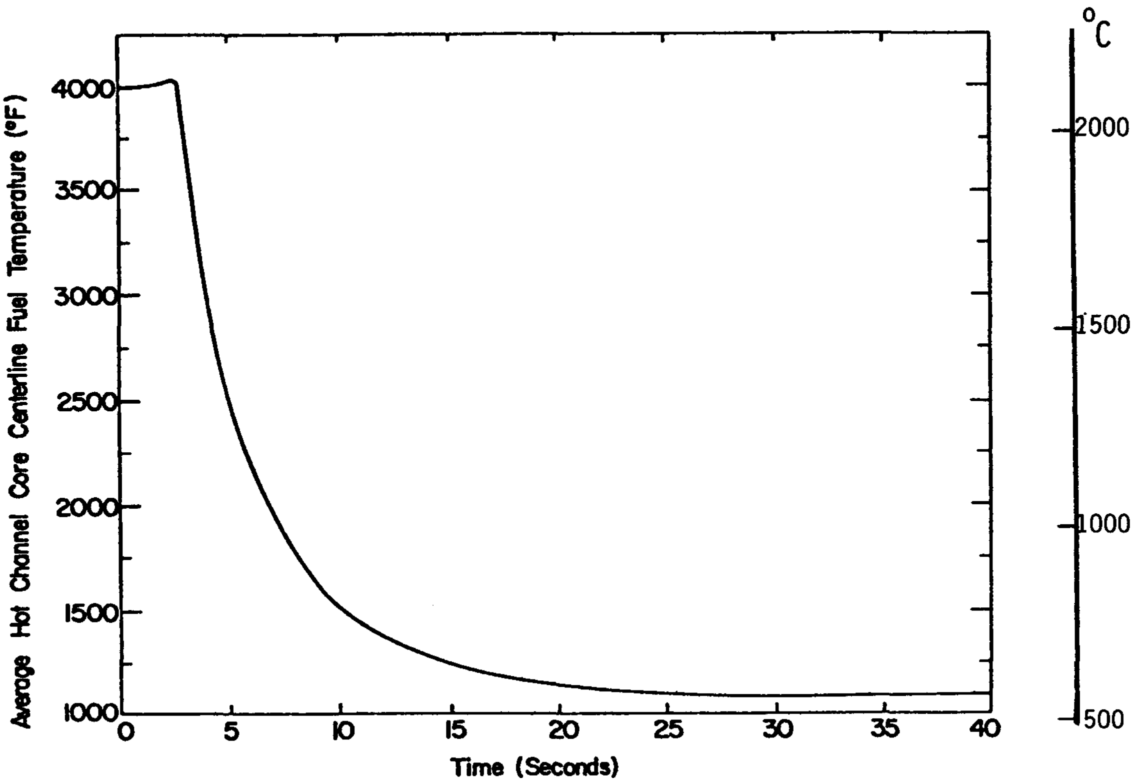


Figure 12-12 Spurious Pump Trip - average fuel centerline temperature in the hot core region

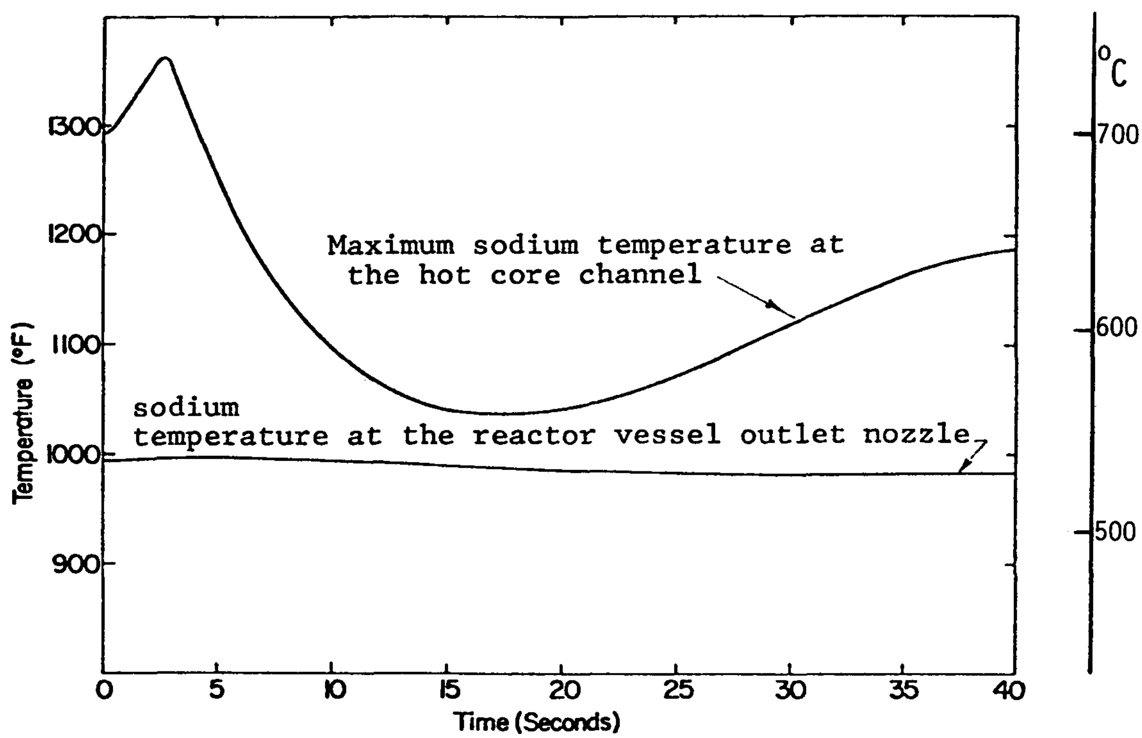


Figure 12-13 Spurious Pump Trip - maximum sodium temperature at the hot core channel and reactor vessel outlet nozzle sodium temperature

first 40 seconds of the transient due to the large heat capacity associated with the liquid sodium in the reactor outlet plenum.

The effects of the transient on the steam generation part of the plant are shown in Figures 12-14, 12-15, and 12-16.

Following the bus fault initiation the sodium flow rate in the secondary loop-1 starts decaying, leading to decreased heat transfer to the water-steam in the superheater and evaporator modules of the loop, and, therefore, a small decrease in the steam quality at the evaporator outlet, as shown in Figure 12-15.

At 2.8 seconds when all of the unaffected pumps in the plant are tripped (except for the feedwater pumps), the water-steam mixture mass flow rates in the recirculation line and evaporator modules begin to decrease, causing an immediate increase in the steam quality at the exit of the evaporators. Dryout at the extreme top of the evaporator modules was reached at 3.1 seconds in loop-2 and at 4 seconds in loop-1. The steam quality in both loops increases at approximately the same rate. At about 14 seconds, when the sodium temperature drop (Figure 12-14) at the inlet of the evaporators of loop-1 becomes appreciable the steam quality in that loop decreases at a fast rate. A similar effect is observed for loop-2 at about 20 seconds.

The recirculation line flow rates in loop-1 and loop-2 are almost identical except for a small variation caused by the difference in the pressures in the two loops (Figure 12-14). This increases the two-phase pressure drops for the loop with the lower pressure. This difference is also increased by a small difference in the recirculation pump speeds in the two loops.

As the steam quality increases at the inlet to the steam drum the saturated steam at the drum starts condensating leading to a decrease in the average drum pressure and, hence, a decrease in the pressure differential between the drum and the header, this in turn decreases the superheated steam mass flow rate as shown by Figure 12-16. This decrease is further effected by the action of the turbine control valve which closes to prevent the header pressure from decreasing.

The feedwater control valve shuts in order to match the feedwater flow rate and superheated steam and keep the water level in the drum at a near constant centerline. Figure 12-16 shows that the feedwater flow rates behave almost identically

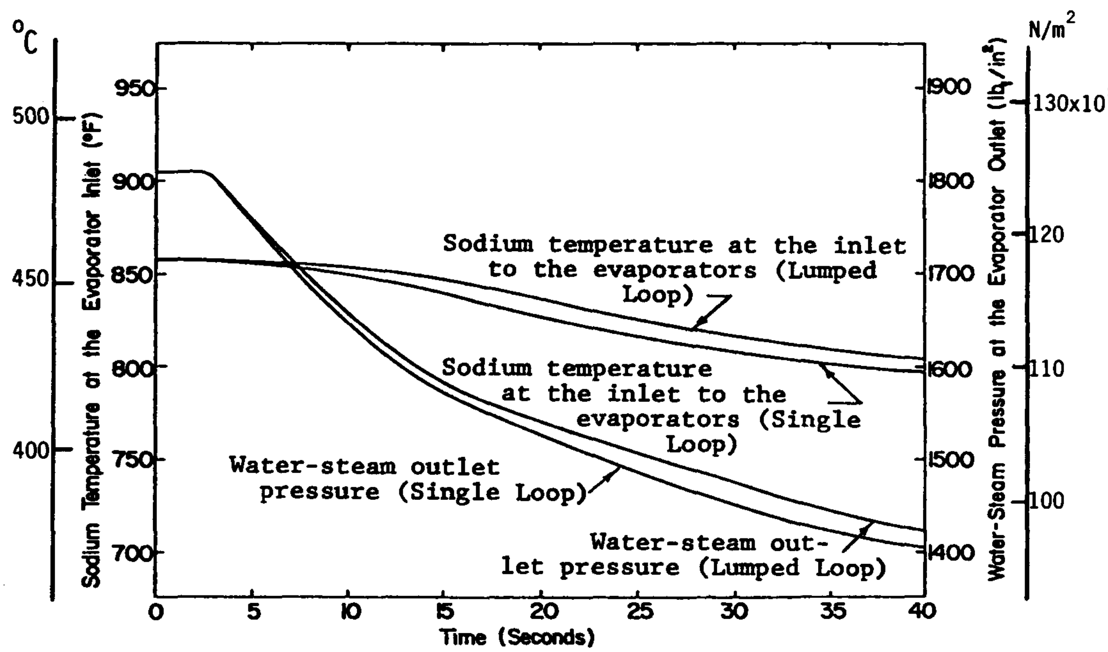


Figure 12-14 Spurious Pump Trip - sodium temperatures at the inlet of the evaporators and water/steam pressures at the outlet of the evaporators.

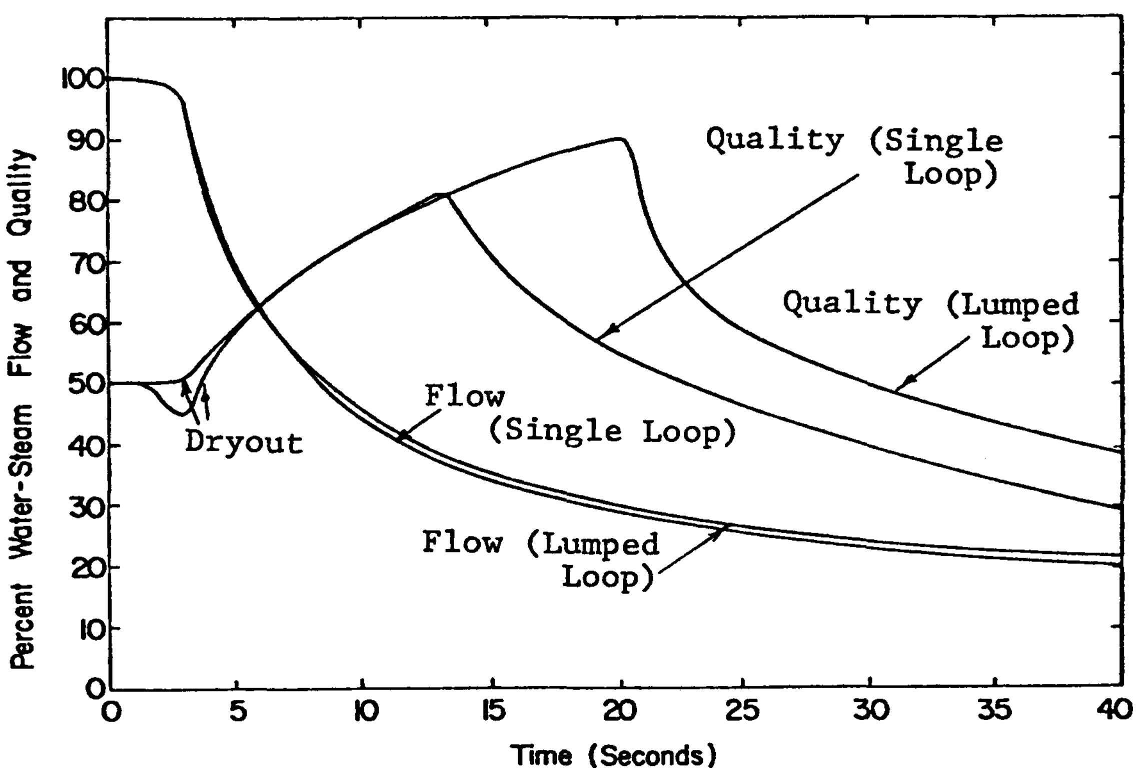


Figure 12-15 Spurious Pump Trip - recirculation line water-steam mass flow rate and steam quality at the evaporator exit

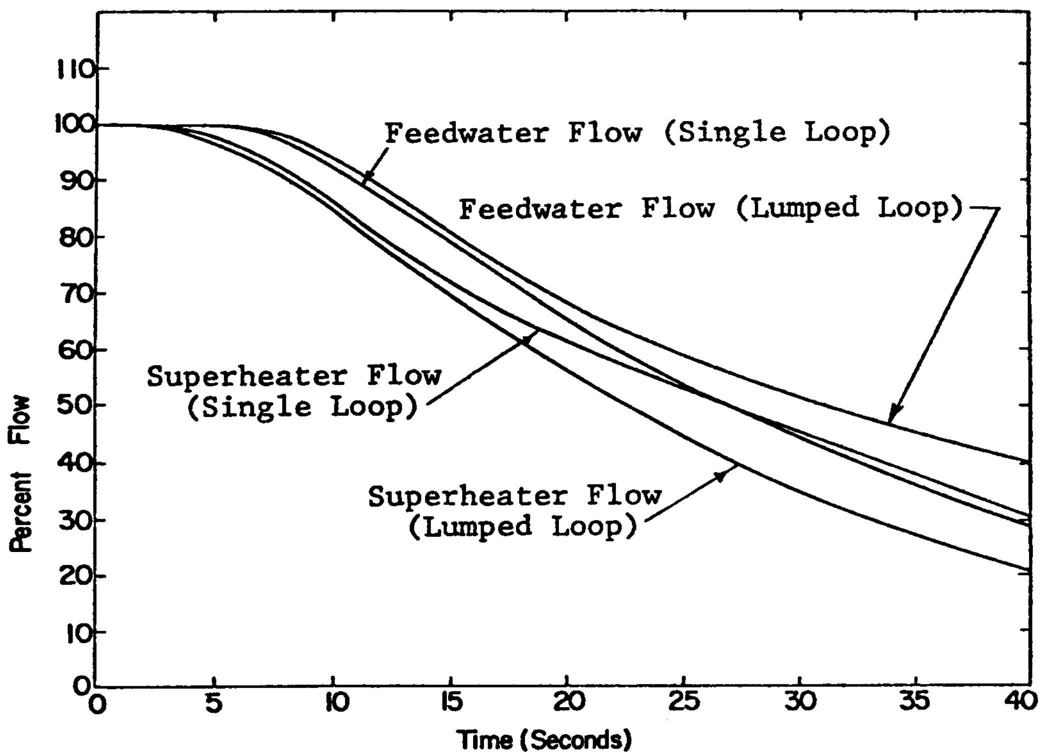


Figure 12-16 Spurious Pump Trip - superheated steam and feedwater line mass flow rates

to the steam flow rates except for a time lag associated with the controller deadbands and time constants.

Verification and Comparisons

The maximum clad midwall temperature in the hot channel is shown in Figure 12-17 as predicted by this model and DEMO (13).

Prior to the reactor scram the temperatures as calculated by the two models, behave almost identically. The initial temperature for the clad in the DEMO analysis was higher than the midwall temperature in the present model by 8°C(15°F); hence, the results predicted by DEMO consistently seem to be higher than this model until the time of scram.

In the DEMO analysis the primary to secondary flow ratio generated the secondary scram signal at two seconds. The scram signal was not generated until 2.3 seconds in this analysis. This leads to an eventual reactor scram initiation at 2.5 seconds, compared to the 2.2 seconds predicted by DEMO.

In the present model all of the unaffected pumps were simultaneously tripped at a half second following the scram signal, hence, causing a slow cooling in the reactor. This effect is observed in the midwall clad temperature, which drops rather fast at first. But as the pump coastdowns become effective this rate is reduced considerably.

The same analysis is performed by DEMO, shows a more rapid decrease in the clad temperature following the reactor scram, which leads one to believe that in the DEMO analysis the unaffected pumps were left operational, for at least the first few seconds following the reactor scram.

The results show a very close agreement for the first three seconds of the transient, but differ considerably later, due to minor differences in the transients. In both analyses the clad hotspot midwall temperature reached a maximum of 777°C(1430°F) at about 2.8 seconds, well below the design limit of 870°C(1600°F).

COMPLETE LOSS-OF-FORCED COOLING LEADING TO BUOYANCY INDUCED NATURAL CIRCULATION

Identification of Causes and Assumptions

The sequence of failures leading the plant into a natural circulation decay-heat removal mode for this analysis is loss of A.C. power to all of the plant coolant

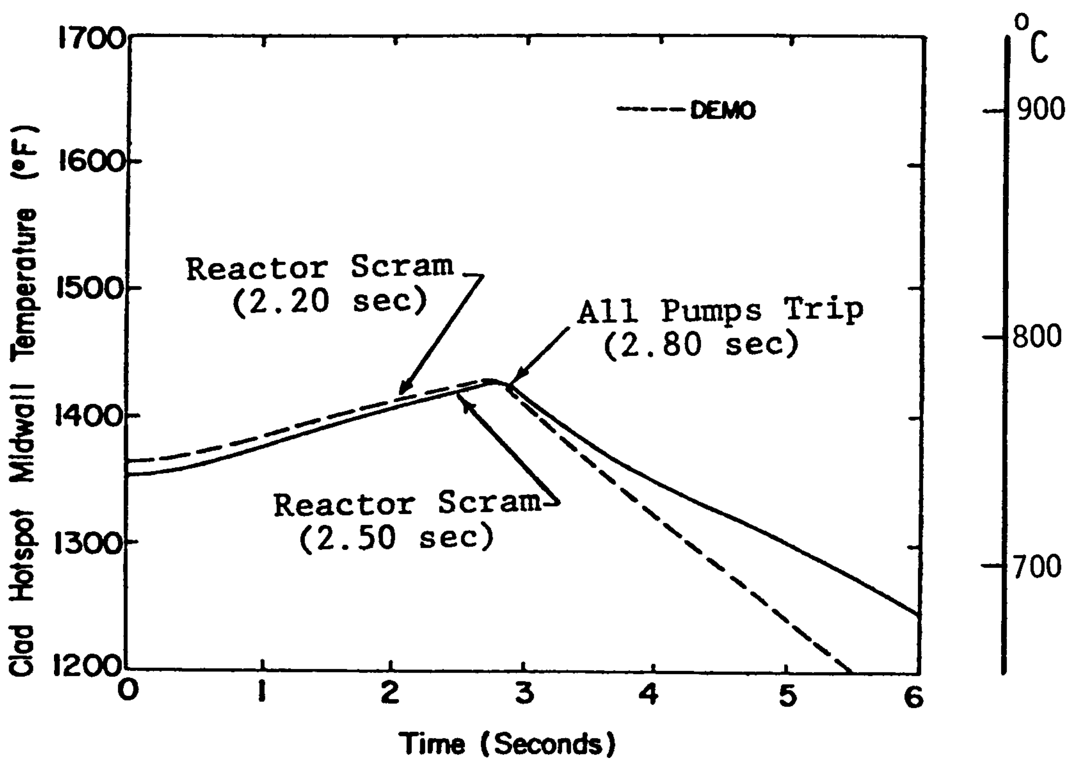


Figure 12-17 Spurious Pump Trip - clad hotspot midwall temperature in the hot core region

pumps, "station blackout", and failure of the auxiliary diesel generators to come on line for pony motor operations.

To simulate a full plant loss of A.C. power, the following sets of events must be assumed:

1. Primary, secondary, and tertiary pumps are tripped simultaneously at time zero.
2. The turbine is tripped at time zero.
3. Normal feedwater is unavailable.
4. There is a failure to start the auxiliary diesel generators.
5. Minimum primary, secondary, and tertiary pump inertia exists (I = 1073 kg-m^2(25420 lb$_m$-ft^2), T_D = 25490 N-m(18805 lb$_f$-ft), ω_D = 18.6 cps(1116 rpm)).
6. There is a maximum fission product decay heat.
7. The safety relief valve pressure setpoint is at 11.03x10^6 N/m^2(1600 lb$_f$/in^2).
8. The dump (bypass) valve pressure setpoint is at 10.10x10^6 N/m^2(1465 lb$_f$/in^2).
9. Steam generator auxiliary feedwater is available at 30 seconds following the transient initiation with 35 kg/sec(77 lb$_m$/sec) maximum flow rate per loop, and at 1.56x10^5 J/kg(67 Btu/lb$_m$) enthalpy.
10. A 700 msec scram delay follows the scram signal, on the primary control rods insertion.
11. Manual secondary scram is initiated at 1.4 seconds.
12. There is a Doppler coefficient of -0.005.
13. The heat capacity of the pipe walls in the PHTS and IHTS sodium transport models are considered.
14. The reactor is operating at 100% rated thermal-hydraulics conditions, prior to the transient.

Perturbation Results

Following the complete loss of A.C. power to the plant's coolant pumps, all of the plant's primary, secondary and tertiary loops start to coast down. The Plant Protection System (PPS) generates a primary scram signal caused by the primary pump electrics at time zero (see Table 12-1). The primary control rods start to move in at 700 msec; the manual scram at 1.4 seconds initiates movement of the secondary control rods.

Figure 12-18 shows the total reactor power. It is observed that the power remains constant until 0.7 seconds, when it starts to drop quite rapidly, due to the action

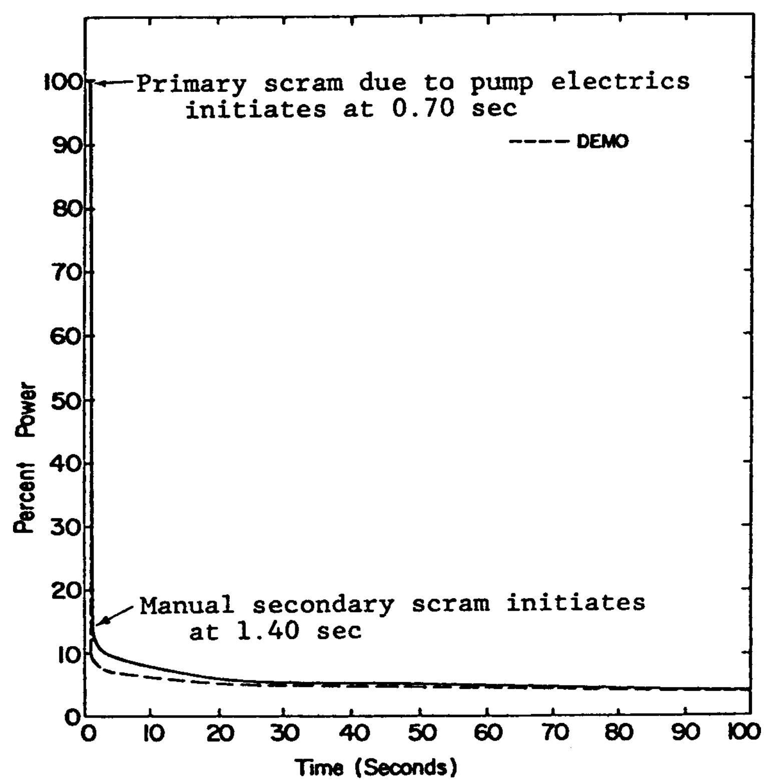


Figure 12-18 Natural Circulation - reactor power

of the primary control rods. Introduction of more negative reactivity at 1.4 seconds accelerates the continuous decrease. The power levels off to the fission products decay heat at about 60 seconds and continues to decrease at a very slow rate thereafter.

Figure 12-19 shows the primary pump speed in the single loop (loop-1), which starts to decrease at time zero due to the loss of A.C. power. At about 50 seconds the speed starts to decrease at a faster rate, caused by frictional losses in the motor windings, bearing and seal losses, and fluid friction on the pump shaft, as shown in Figure 12-20. The pump comes to a complete halt at approximately 54 seconds after the initiation of the transient, and remains locked for the duration of the transient. The pump speed in the lumped loops (loop-2) behaves almost identically to loop-1.

The sodium flow rate in the loop-1 of the PHTS starts decreasing almost immediately after the A.C. power loss. Figure 12-21 shows the sodium flow rate in loop-1 of the primary system. The flow begins decreasing at time zero and reaches the buoyancy-driven, natural circulation condition of 2% at approximately 65 seconds.

The total reactor power to flow ratio is shown in Figure 12-11. The power to flow ratio initially increases because of a decrease in the total reactor coolant flow rate, but at 0.7 seconds, as the reactor power starts decreasing (Figure 12-18), the power to flow also follows, since the reduction rate in the prompt neutron power is by far greater than the reduction rate in the sodium flow rate. At approximately two seconds the reactor power has almost reached a constant level, while the reactor sodium flow rate continues to drop, causing an increase in the power to flow ratio. This increase is further enhanced at 55 seconds as the reactor coolant flow reaches a minimum caused by the complete shutdown of the coolant pumps.

The buoyancy effects become more important at about 60 seconds, and the natural circulation is finally established at 65 seconds when the power to flow ratio starts decreasing from its maximum value of about two, and begins to level off at approximately 100 seconds after the transient initiation.

The average reactor fuel temperature are shown in Figure 12-23. The fuel temperatures are initially increased as the heat transfer rate decreases due to the decrease in reactor coolant flow rates. The largest temperature increase is observed in the

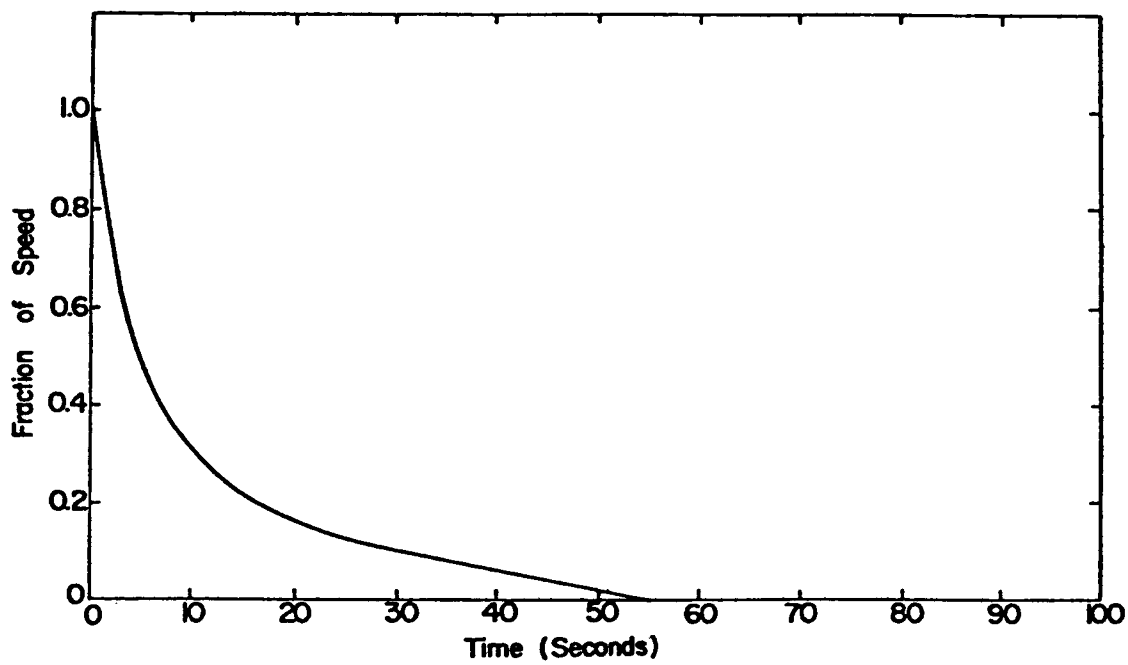


Figure 12-19 Natural Circulation - Primary pump speed in the single loop

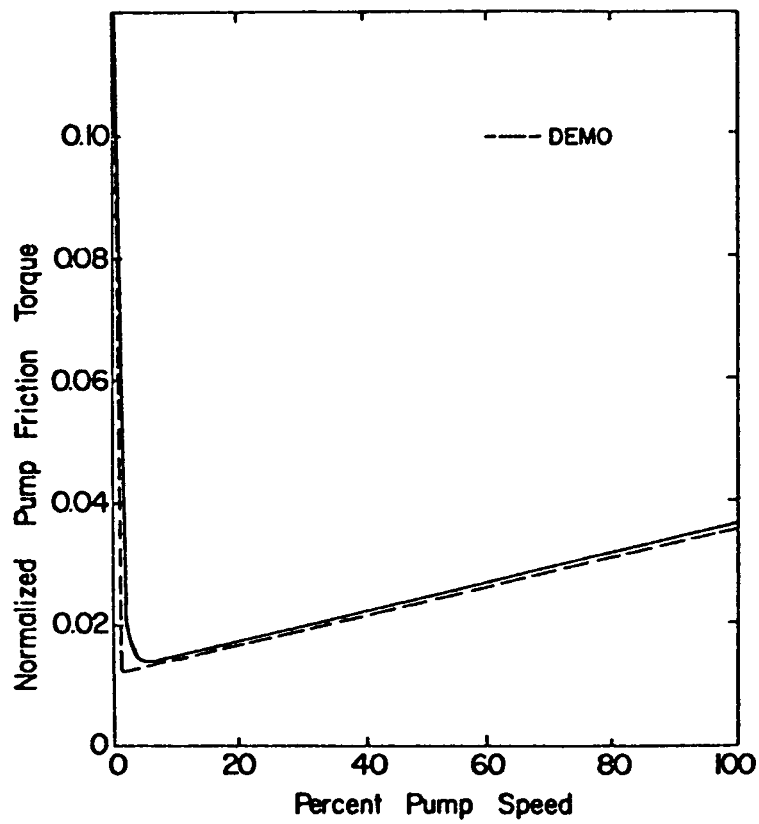


Figure 12-20 Friction torque as a function of pump speed

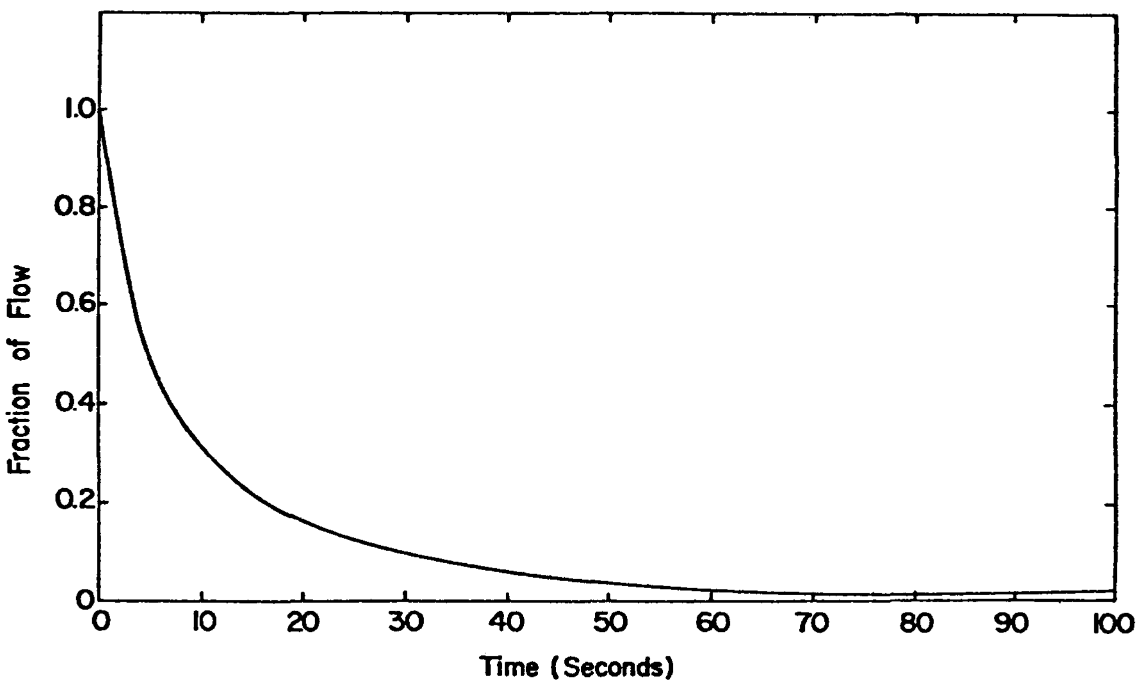


Figure 12-21 Natural Circulation - sodium mass flow rate in the single loop of the primary system

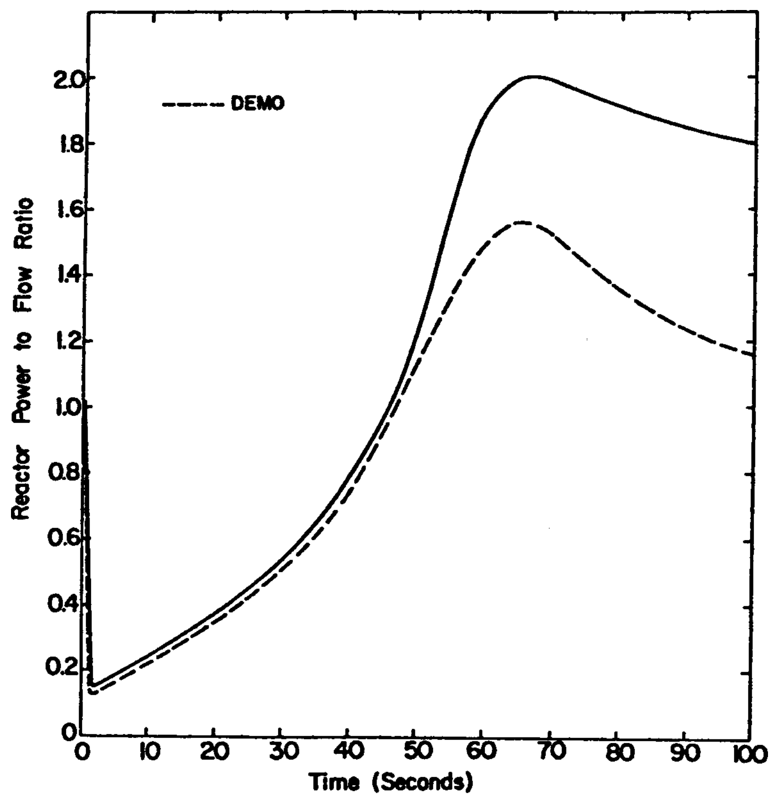


Figure 12-22 Natural Circulation - reactor power to flow ratio

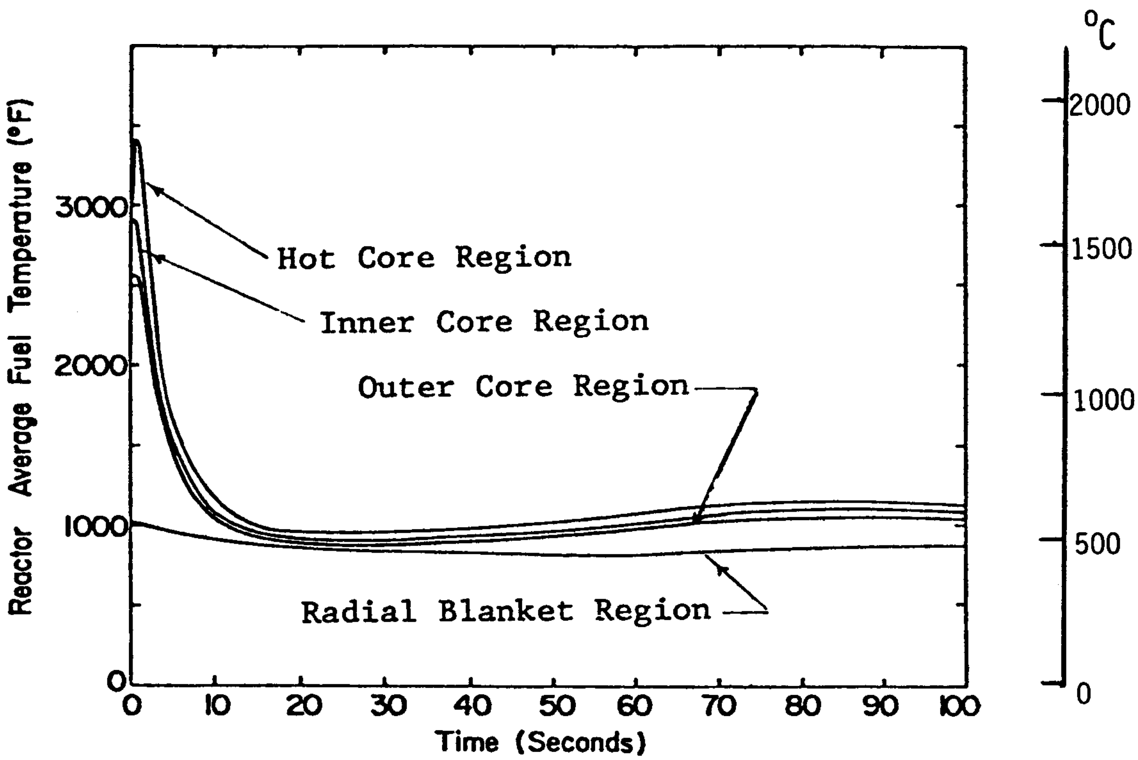


Figure 12-23 Natural Circulation - reactor average fuel temperatures

hot subassemblies in the center of the reactor core, since the neutron flux and importance are the greatest in this region. The next largest temperature increases are in the inner and outer core. The fuel temperatures start decreasing immediately after the reactor scram at 0.7 seconds; reach a minimum at 25 seconds, and then increase and stabilize as the natural convection is established at about 85 seconds. The fuel temperature in the radial blanket region does not increase as fast as the temperatures in the core. This is due to the large heat capacity of the radial blanket fuel region. However, the slow time response coupled with the large stored energy in the radial blankets causes the fuel temperature to reach a maximum value of 493°C(920°F) in approximately ten seconds.

Since the changes in temperature of the reactor control assemblies were quite small, they are not presented in Figure 12-23.

Figure 12-24 shows the average temperature of sodium at the outlet of the reactor channels. The channel exit temperatures for the hot, inner, and outer core assemblies behave very similar. The initial peak is caused by a decrease in the sodium flow rates in their respective channels. As the reactor power is reduced, the fuel temperatures start to decrease (Figure 12-23), therefore, reducing the heat transfer rate, and causing a drop in the coolant temperatures. It is observed that the response of the coolant temperatures are delayed, due to the thermal lag caused by the heat capacity of the liquid sodium.

The sodium temperatures reach a minimum in approximately 20 seconds, but then start to increase again because of the increase in the reactor power to flow ratio (Figure 12-22). They reach a second peak at approximately 95 seconds, when the bouyancy effects are high, and natural circulation is fully established.

The sodium temperature at the outlet of the radial blanket channel increases very slowly, and exceeds the average outlet temperatures of the sodium of the normally hotter core channels for approximately 35 seconds. This is caused by the large amount of stored energy inside the radial blanket fuel, and the slow response of the radial blanket coolant due to its large heat capacity. The radial blanket coolant temperature also reaches a minimum, but it is delayed considerably, and goes back up to stabilize as the natural circulation is established.

A similar response is observed for the control assemblies channel, but with much less variations, as expected.

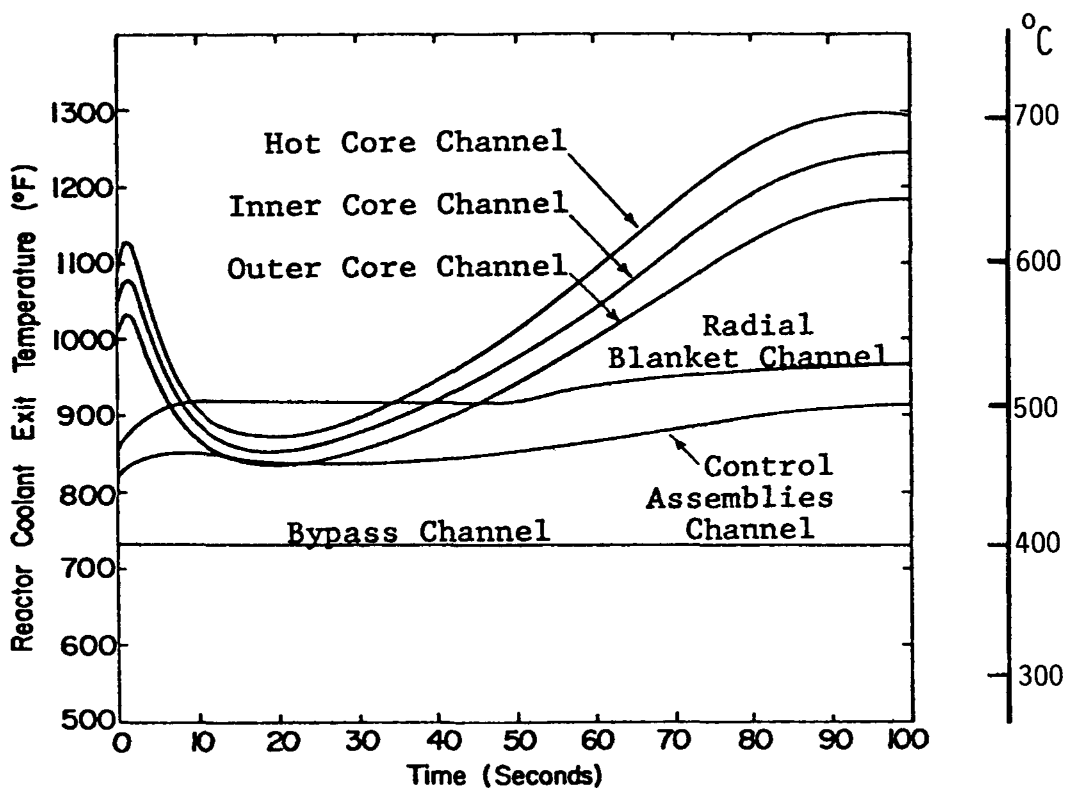


Figure 12-24 Natural Circulation - sodium average temperature at the exit of reactor channels

The unheated bypass channel sodium exit temperature decreases by a fraction of a degree, due to a slight decrease in the sodium temperature at the reactor inlet module, and then stays constant as the bypass channel sodium flow rate goes to zero at 55 seconds (note, due to the small decrease in temperature the figure indicates essentially no variations).

Figure 12-25 shows the sodium temperature at the reactor vessel outlet nozzle. This temperature behaves in the same manner as the coolant temperature at the outlet of the reactor channels (Figure 12-24) except for the difference in the magnitude and rate of variations. This is caused by the slower response in the reactor outlet plenum due to the large sodium heat capacity in this region. The temperature peaks at approximately three seconds to 536°C(996°F) and starts going down and reaches a minimum of 521°C(969.5°F) at about 55 seconds; thereafter, it starts increasing again.

Due to high temperature of the sodium at the outlet of the reactor channels the sodium is completely mixed and the jet penetration distance in the upper plenum is infinite; it is believed that the jet penetration distance will be reduced eventually as the reactor cools off, and the top mixing zone in the upper plenum will be formed at a later time in the natural circulation transient.

Figure 12-26 shows the redistribution of the sodium flows among the reactor channels, which are in fractions of the total reactor flow. It is interesting to note that the reactor coolant flow rates are decreasing even though the fractions normally increase in the more heated channels (core channels), and decrease in the cooler channels (bypass and control channels).

As the primary loop flows coastdown the buoyancy effects become increasingly more important; hence, the less dense sodium which is caused by more heat transfer in the hotter channels enhances the flow of the coolant. These effects are quite pronounced in Figure 12-26, which shows that the flow fractions in the hot, inner and outer core channels increase very slowly, but the radial blanket, control assemblies, and bypass channel flow fractions start decreasing immediately.

The flow in the bypass channel starts dropping at a faster rate at approximately 40 seconds and goes to zero at about 55 seconds, and is prevented from reversal. Hence it remains stagnant for the duration of the transient.

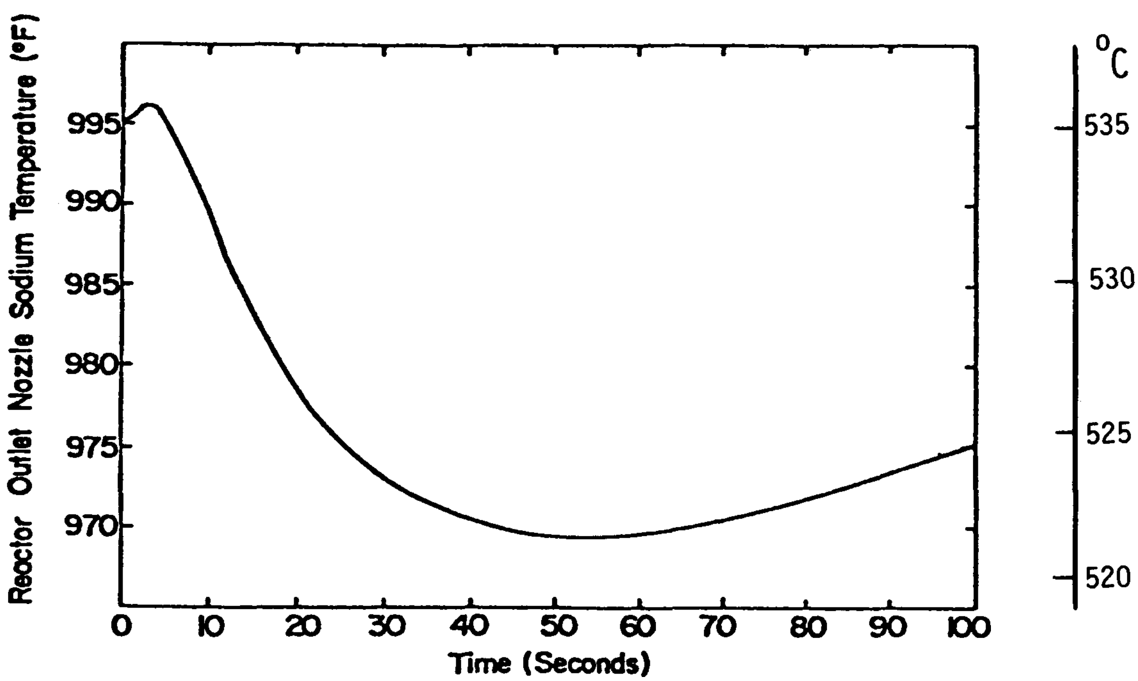


Figure 12-25 Natural Circulation - sodium temperature at the reactor vessel outlet nozzle

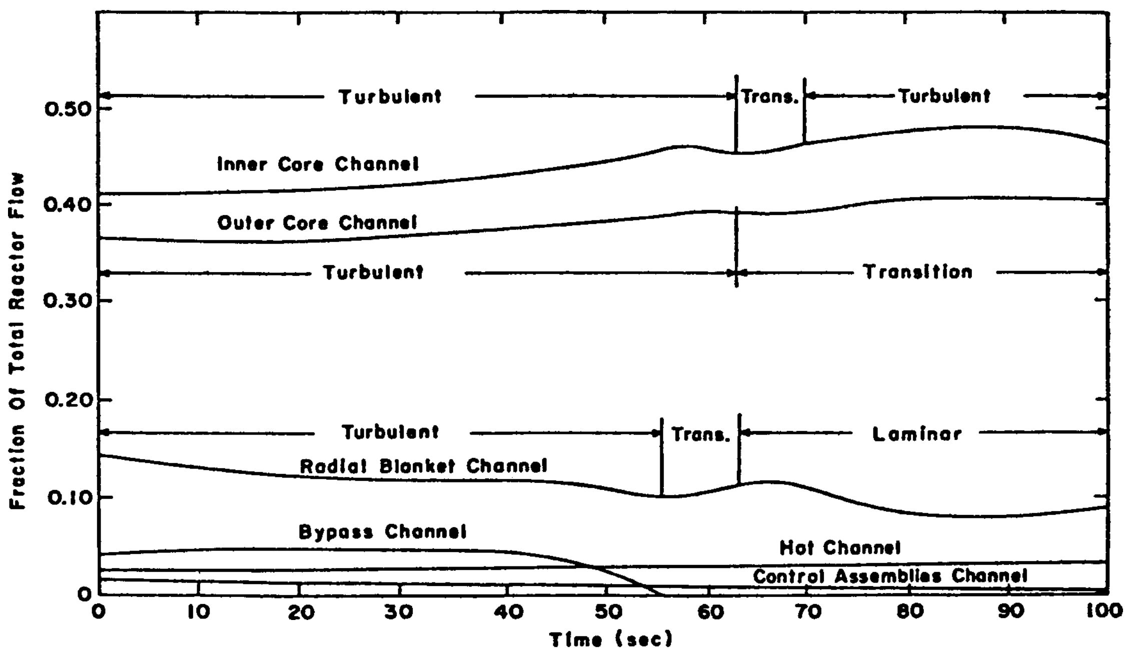


Figure 12-26 Natural Circulation - sodium flow redistribution inside the reactor vessel

As the flow rate in the radial blanket channel decreases, the flow changes from turbulent to transition and eventually to laminar regimes. These variations are observed due to the small increase in the radial blanket flow fraction at 55 seconds, which peaks at approximately 65 seconds when it goes into the laminar flow regime, therefore increasing the friction factors and causing a decrease in flow.

The slight decrease in the flow fractions in the inner and outer core channels at 55 seconds is caused by an increase in the flow fraction in the radial blanket channel. Hence there is a change in the flow pattern into the transition regime in both channels at about 65 seconds. The flows start to increase again and the move the inner core flow back into the turbulent regime at 70 seconds, while the outer core remains in the transition regime thereafter.

The sodium flow fraction in the hot channel remains in the turbulent regime throughout this transient.

Figure 12-27 shows the pump speed and sodium flow rate for the secondary loops of the plant. Following the loss of A.C. power both pumps start coasting down, hence decreasing the head across the pumps and the sodium flow rates. In this transient loop-1 (single loop) has the smallest inertia of all three loops (shorter pipe lengths), therefore the sodium flow and pump speed are decreasing slightly faster than the lumped loops. The pump speed in the single loop goes to zero at approximately 58 seconds, but the pump speeds in the lumped loops go to zero at about 60 seconds. The pump remains locked for the remainder of the transient.

The sodium flow rates in the loops coastdown, and reach the natural circulation driven conditions at about 90 seconds with approximately 2.5% sodium flow in each loop.

Figure 12-28 shows the recirculation line steam-water mixture mass flow rate. Following the pump trip, the flow rate starts decreasing. At approximately seven seconds after the transient initiation the saturated water reaches the recirculation pump causing immediate cavitation of the pump. This effect is observed by a sharp change in the flow rate reduction. The flow decreases to about 7% and is prevented from any further drop by the high buoyancy effects in the loop. As the auxiliary feedwater is made available at 30 seconds, it causes a slight subcooling of the water leaving the steam drum and, hence the recirculation pump comes out of

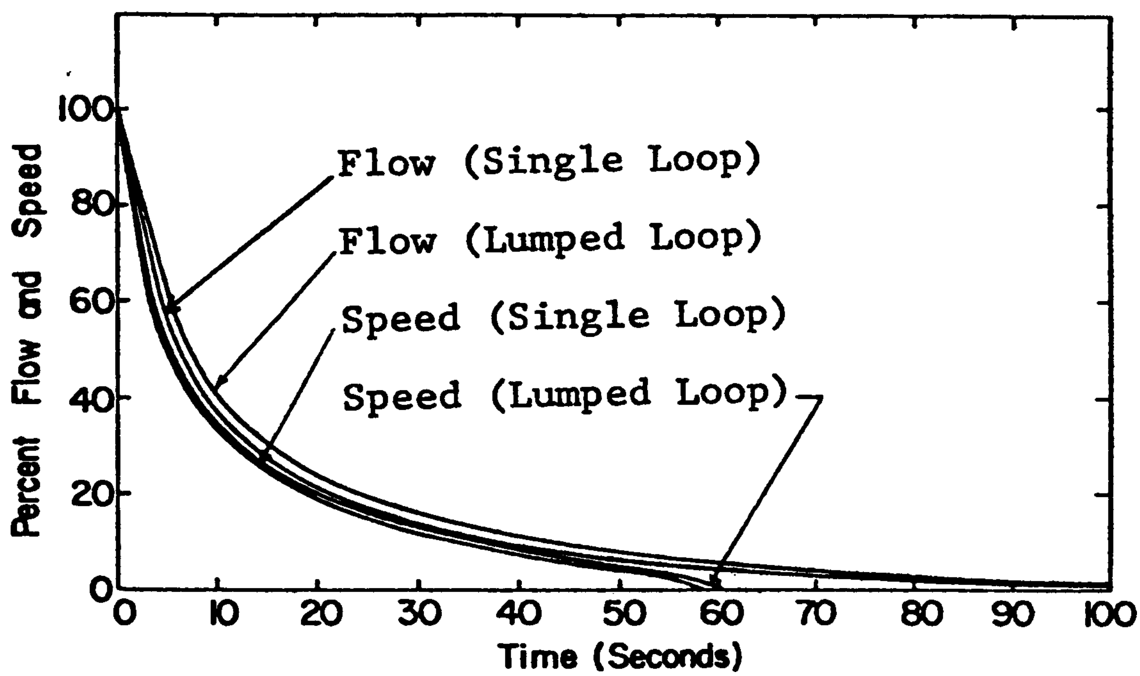


Figure 12-27 Natural Circulation - sodium mass flow rates and pump speeds in the secondary loops

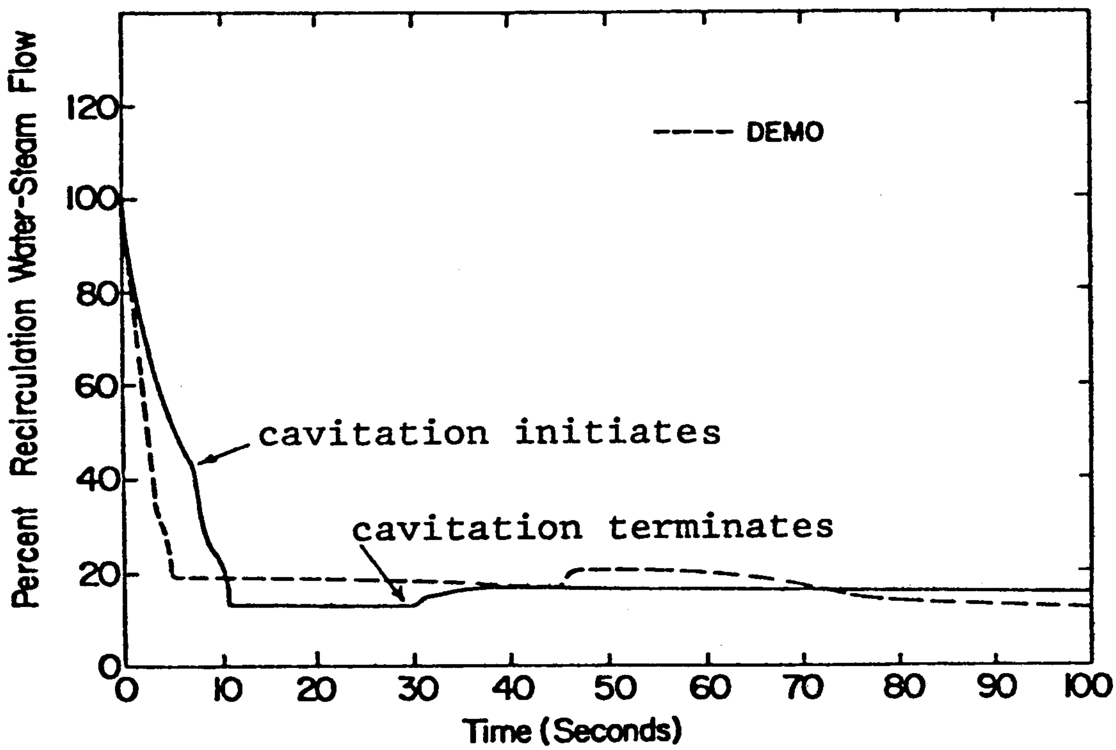


Figure 12-28 Natural Circulation - water and two-phase mixture mass flow rate in the recirculation line and evaporators

cavitation at 31 seconds causing a small jump in the flow rate. The flow rate of the steam-water reaches a complete natural circulation at approximately 45 seconds after the transient initiation, and stays at approximately 16% flow for the remainder of the transient.

Figure 12-29 shows the average pressures in the main steam header and the steam drum. Following the loss of the A.C. power supply to the plant, the steam turbine is tripped by a rapid closure of the turbine stop valves, causing immediate pressurization of the main steam header.

As the header pressure increases beyond 11.03×10^6 N/m^2 (1600 psi, the setpoint for safety relief valves), the safety relief valves open and relieve some of the pressure by discharging the steam to the atmosphere (Figure 12-30). The slow opening of the steam dump (bypass) valves, has a considerably smaller effect for the first few seconds, but after approximately seven seconds the dump valve is fully opened. This causes a further decrease in the header pressure. As the header pressure decreases below 10.10×10^6 N/m^2 (1465 psi, the setpoint for the dump valve) the valve starts to close again and decreases the steam flow rate going to the condenser through the valve and hence, increasing the pressure at about 11 seconds. This process is continued until the steam pressure in the main steam header stabilizes, at about the setpoint pressure of the dump valve, in approximately 50 seconds.

The average pressure inside the steam drums (one per loop) follows the steam header pressure except with a response which is considerably slower as is shown in Figure 12-29. The header pressure fluctuations are fed back into the steam drums through their respective superheated steam mass flow rates in each steam generator loop.

Figure 12-31 shows the superheated steam flow rate in the superheater and the connecting transport systems for loop-1 of the steam generator system. It is observed that the steam flow rate follows the pressure differential between the main steam header and the steam drum. The initial decrease is caused by a drop in the pressure difference due to the header pressurization after the turbine trip. The pressure fluctuations continue as the valve position varies to adjust the header pressure. It finally stabilizes at about 50 seconds to approximately 37% steam flow when the pressure differential has reached a constant value.

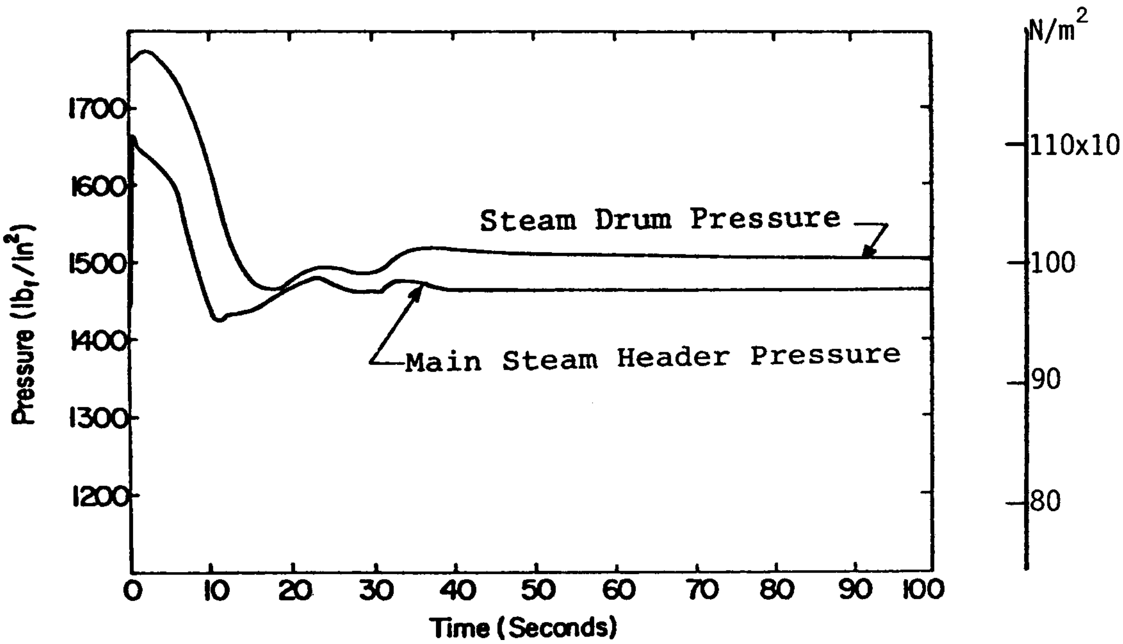


Figure 12-29 Natural Circulation - average pressure inside the steam drum and the main steam header

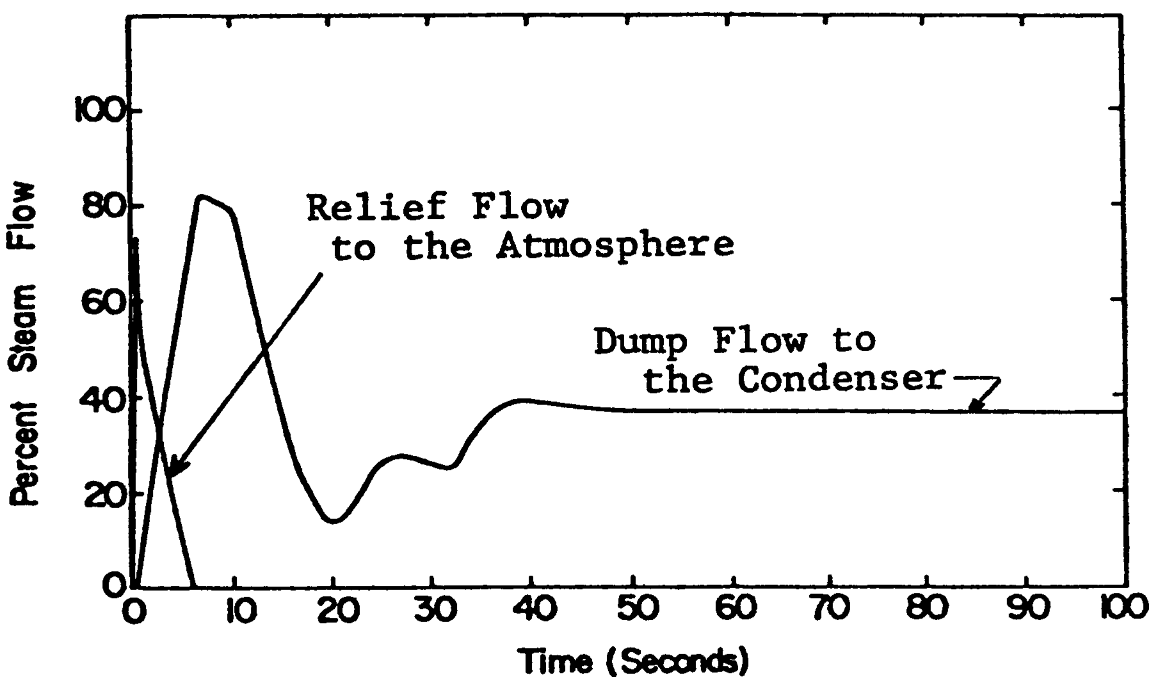


Figure 12-30 Natural Circulation - steam mass flow rate to the atmosphere and the condenser

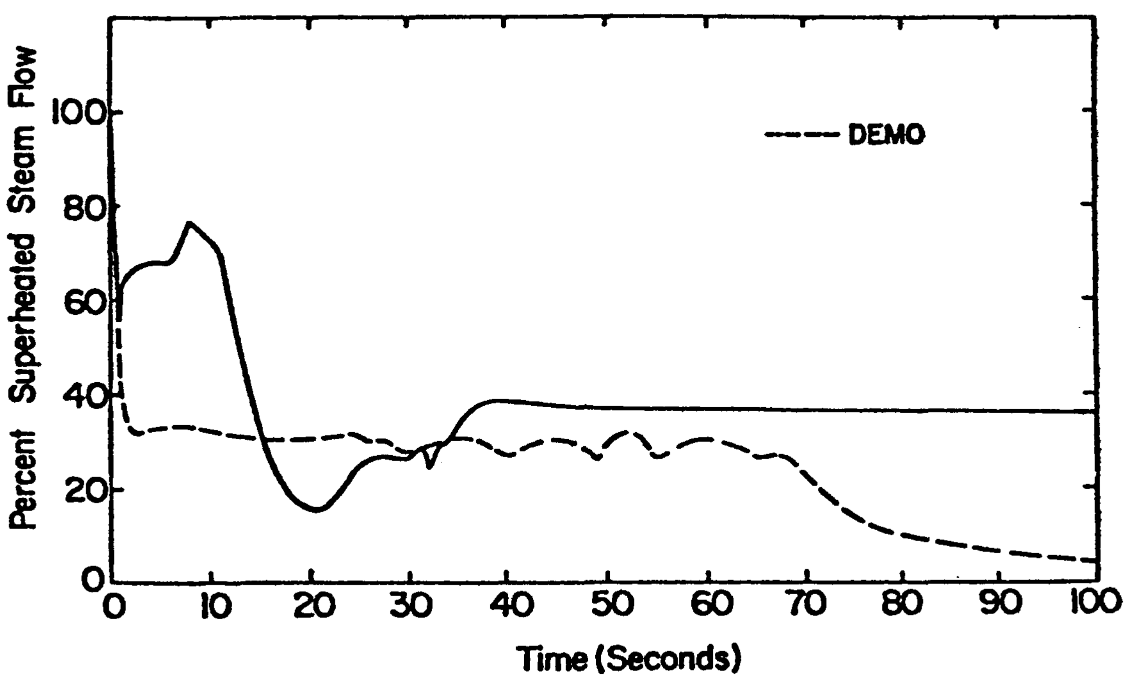


Figure 12-31 Natural Circulation - superheater steam mass flow rate in the single loop

Figure 12-32 shows the fraction of drum water level from the drum centerline.

The normal feedwater supply was stopped completely at the transient initiation, causing an immediate decrease in the water level. The level continues to drop rapidly until at 30 seconds the auxiliary feedwater valve opens, and starts supplying subcooled water at 35 kg/sec(77 lb_m/sec) to the steam drum. The effect of the addition of the auxiliary water supply is observed at 30 seconds by a small variation in the reduction rate.

The water level continues to decrease as the mismatch between the auxiliary feedwater entering the drum, and the saturated dry steam leaving reaches a constant rate or 18 kg/sec(40 lb_m/sec) reduction in the total mass of the water-steam mixture in the drum. The water level in the steam drum is expected to be restored later in the transient as the steam quality at the drum inlet is reduced, due to the decrease in heat transfer in the evaporator modules.

Figure 12-33 shows the superheated steam temperature at the outlet of the superheater module in loop-1. Generally speaking, the steam temperature is inversely proportional to the steam mass flow rate (Figure 12-31), that is; as the steam flow rate decreases the temperature increases, and vice versa. At about 50 seconds when the steam flow rate reaches a constant value of 37%, the temperature continues to go down, since the secondary sodium mass flow rate is continuously dropping. The high steam to sodium mass flow rate ratio causes a sharp decrease in the steam temperature even after both the sodium and steam flows have stabilized.

Verification and Comparison

The response of the reactor to the development of natural circulation can best be described in terms of clad hot spot midwall temperature, and the maxiuum hot channel sodium exit temperature.

Figure 12-34 shows the clad hotspot midwall temperature in the reactor core hot channel. Following the loss of the A.C. power supply to the pumps, the reactor coolant flow begins to decrease, while the reactor power remains constant at 100% value. These account for the high power to flow ratio (Figure 12-22). A decrease in the heat removal rate causes a sharp increase in the cladding temperature.

Following the scram initiation at 0.7 seconds, the reactor power is reduced considerably (Figure 12-18), at a rate faster than the coolant coastdown rate. The heat removal rate, and therefore the cladding temperature increase at 1.1 seconds.

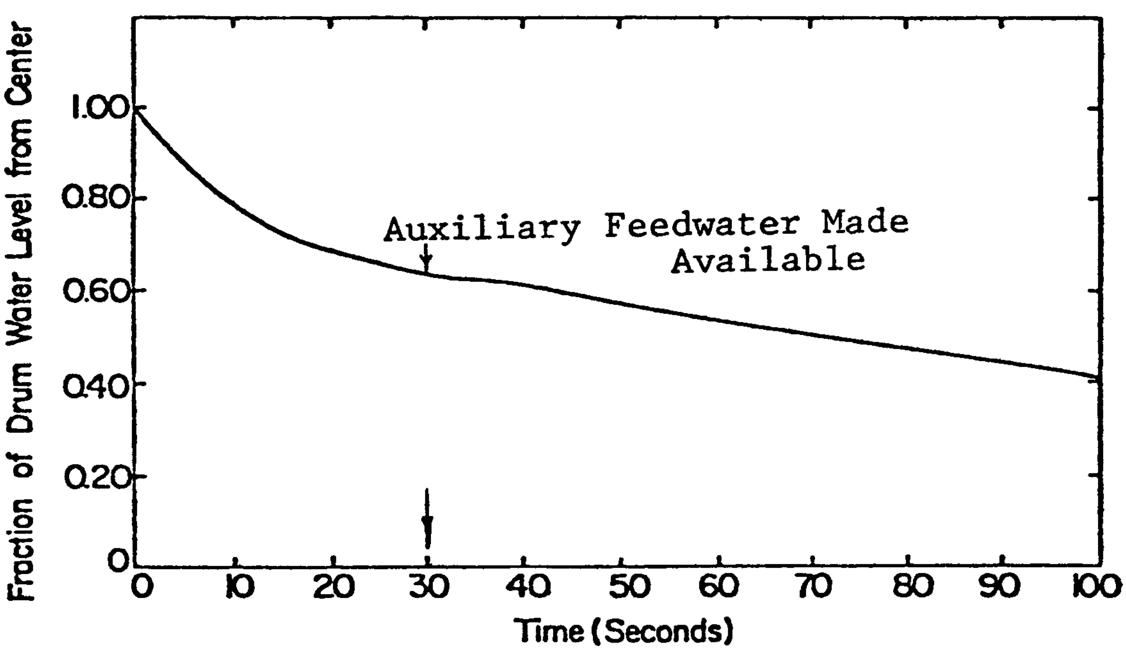


Figure 12-32 Natural Circulation - water level inside the steam drum of the single loop

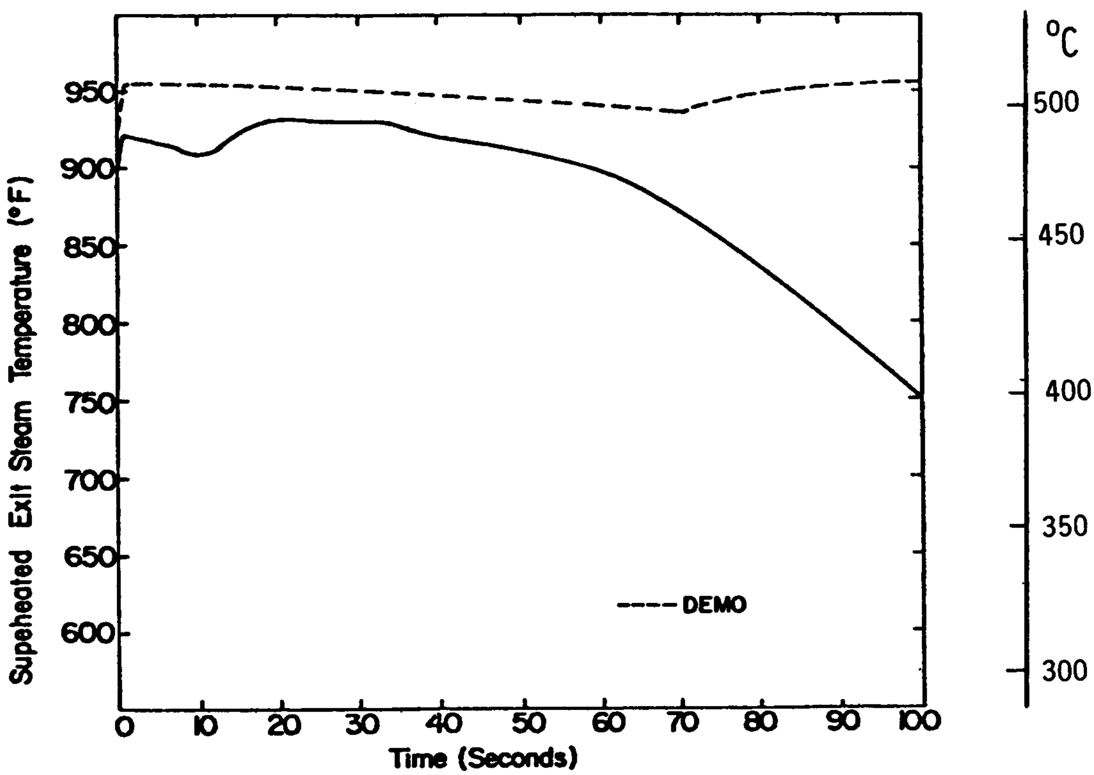


Figure 12-33 Natural Circulation - superheater exit steam temperature in the single loop

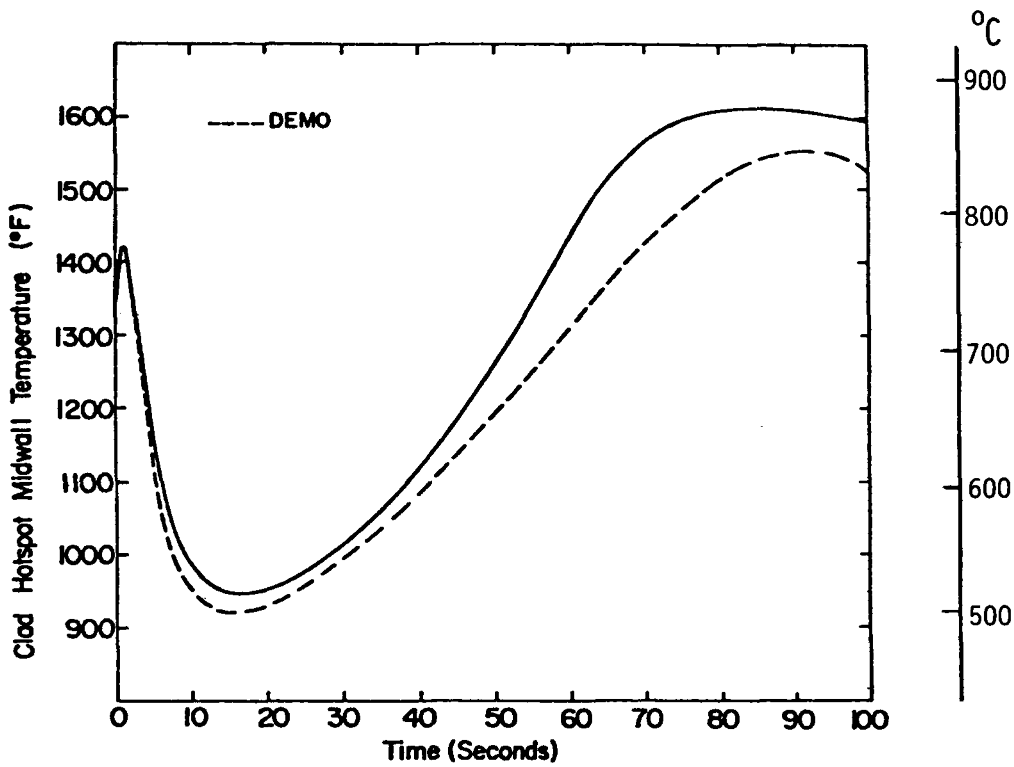


Figure 12-34 Natural Circulation - clad hotspot midwall temperature

At approximately 15 seconds after the transient, the clad temperature reaches a minimum of 510°C(950°F), and then starts increasing again. This increase is further enhanced by an increase in the power to flow ratio, due to the decrease in the sodium flow rate at 55 seconds (time at which the primary pumps come to a complete halt). The cladding temperature levels off at about 80 seconds. This indicates the development of buoyancy induced natural circulation that will start to cool the reactor thereafter.

Figure 12-34 also shows a similar transient using the DEMO code (30). It is observed that the two models behave almost identically for the first five seconds of the transient, but the differences are more significant thereafter.

Generally speaking, the total reactor power to flow ratio (Figure 12-22), drives the transients in the reactor as indicated by Figure 12-22, the model predicts a higher power to flow ratio than the DEMO analysis. Two factors contribute to this variation. First, the total reactor power (Figure 12-18) at the time following the scram is slightly higher than the one predicted by DEMO, because the present model considers slightly more power to be generated by the decay of the fission products. Second, the total reactor flow in the model is slightly lower than the one predicted by DEMO, since the pumps stop a second or two faster than they do in the DEMO model (30), due to the slightly higher friction included in this model (Figure 12-20). The flow redistribution in the reactor has been fully accounted for in this model, that is, the buoyancy effects cause an increase in sodium flow in the warmer channels, while DEMO assumes a constant flow fraction throughout the reactor channel. Therefore, the bypass flow will never become stagnant, and there would be a slightly smaller flow in other regions of the reactor indicating a slightly higher temperature. But this effect is offset by the larger difference in the power.

Figure 12-35 illustrates the transient behavior of the maximum sodium temperature in the hot channel. The maximum sodium temperature occurs in the hot channel, near the top of the active core, just below the upper axial blanket region.

This temperature also follows the reactor power to flow ratio behavior, as for the hotspot cladding temperature (Figure 12-34). The first peak occurs at about 1.2 seconds. At 740.5°C(1365°F) the sodium temperature starts to fall and reaches a mimimum at 15 seconds, it then starts to increase again, peaks at 85 seconds, and begins to stabilize as natural circulation becomes fully established.

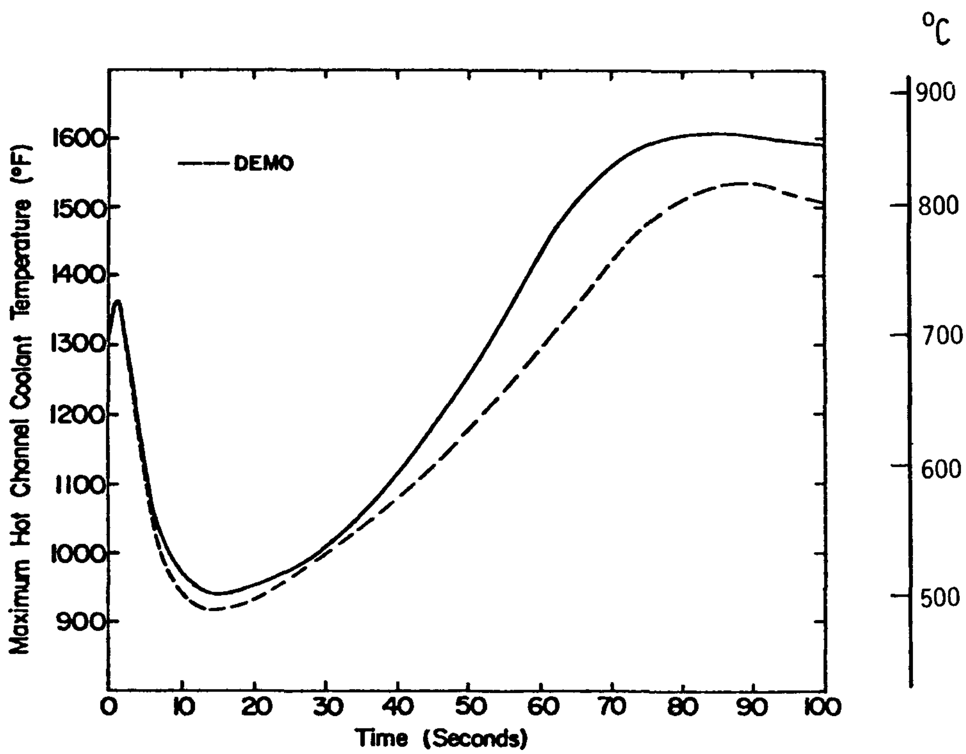


Figure 12-35 Natural Circulation - maximum hot channel sodium temperature

Again, the agreement between the two models is fairly good, and the difference in the magnitude of the temperature difference is caused by higher fission product decay heat rate and lower flow rates.

Figures 12-18 through 12-33 also show similar calculations using DEMO. The dashed lines represents the results as predicted by DEMO (30). Some of the figures show only the results of this model, meaning that the results are almost identical, or the results for similar variables do not exist.

It is important to note that the comparisons in the steam-water part of the plant are not very similar. This is because the transient results for the controlled bypass of the steam to the condenser depend strongly on the controller mechanism, the valve model, and important control parameters such as proportionality gain factors and the controller time constant. But as is indicated by Figure 12-28 the recirculation line water-steam flow rates are in generally good agreement, and the variations are basically due to the difference in the empirical correlations used, and the fact that DEMO (2) neglected the transport delays between the drum outlet nozzle and evaporator inlet nozzle, causing a faster response in the results.

Figure 12-31 shows the transient superheated steam flow rates as calculated by the two models. It is observed that the flow rate after an initial sharp drop caused by the turbine trip stays at about 30% and starts falling again at approximately 70 seconds (30). The model assumes that the steam drum pressure can only be relieved through the safety relief valves in the header, and does not switch to the closed-loop heat removal mode, as it is assumed by DEMO. Therefore, the steam flow rate remains high causing a decrease in the drum level.

It can be concluded that the two models are in close agreement and the establishment of the buoyancy induced natural circulation is predicted to occur at approximately the same period. They predict a coolant flow sufficient to remove the decay heat generated by the fission product following the scram assuring a safe shutdown.

Section 13

CONCLUSIONS

CONCLUSIONS

The purpose of this work was to develop a set of nuclear, thermal, coolant dynamics and control models capable of predicting the response of a loop-type, liquid metal-cooled fast breeder reactor to a number of postulated and actual accident events.

A number of numerical methods were proposed and tested to improve the accuracy of the model and reduce the overall computational requirements.

Finally, the models were assembled into a set of computer submodels that together were used to simulate three postulated events. Comparisons were made with existing simulation models, and the discrepancies were identified.

Several conclusions resulting from the analysis of the numerical studies can be drawn:

1. Knowledge of the diagonal entries in the Jacobian matrix of a large system of ordinary differential equations with varying relaxation times is sufficient for identification of the sources of stiffness generally encountered in the class of problems investigated.
2. Judicious use of the quasistatic approximation reduces the need for short time steps or sophisticated, implicit numerical-integration methods.
3. Formulation of quasistatic equations for most of the process variables provides the best means for the determination of pre-accident initial conditions.
4. A multi-channel reactor heat transfer and sodium dynamics model is necessary for predicting thermo-hydraulic responses correctly, especially during low-flow conditions.
5. From the comparisons with FORE-II, it can be concluded that it is sufficient to include two group delayed neutrons in the point kinetics equations for most transient cases, except for the short-term behavior of large reactivity insertions.
6. The choice of controllers is an important factor in determination of transient response of steam generator systems.

7. Neglecting the coolant transport delays does not necessarily lead to a conservative analysis.
8. Knowledge of flow regimes in the reactor is an important consideration during the low-flow conditions.
9. General agreement exists between the models, but there is still a vital need for further experimental and theoretical verification.
10. No sodium voiding was observed for the transients analyzed, and small delays in the reactor scram can very well be tolerated without voiding initiation.

Section 14

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APPENDIX A

EPRI-CURL PROGRAM LISTING

This section consists of a listing of the EPRI-CURL simulation code in its present state.

The subroutines are generally listed in the same order as they were presented in the User's Guide (Section 11 of this report).

```
C         ************************************************
C         *                                              *
C         *           CURL  -  LOOP VERSION              *
C         *                                              *
C         *                                              *
C         *              MASTER PROGRAM                  *
C         *                                              *
C         *               TO SIMULATE                    *
C         *                                              *
C         *                    A                         *
C         *                                              *
C         *        LIQUID - METAL - COOLED               *
C         *                                              *
C         *          FAST BREEDER REACTOR                *
C         *                                              *
C         *                                              *
C         *        CORNELL UNIVERSITY  1978              *
C         *                                              *
C         ************************************************
C
      INTEGER RUNGF,RSTART
      REAL KMM1,KMM2,KMS1,KMS2,KMG1,KMG2,NEWIM1,NEWIM2
      DIMENSION NO(489),R(489),RSAVE(489)
      DIMENSION TNEW(3),SNEW(3),IFNEW(3)
      DIMENSION NOPON(4)
      COMMON/ALLR/R1(8),R2(18),R3(33),R41(25),R42(25),R5(120),
     1  R61(5),R62(5),R71(80),R72(80),R81(39),R82(39),R9(5),R10(7)
      COMMON/ALLF/F(489)
      COMMON/ALLNUL/NULL(489)
      COMMON/RUNGNO/K,KCALC
      COMMON/GET1/W100,W1,W2,WIC,WOC,WHC,WCA,WRB,WBP,WS100,WS1,WS2,
     1WBRK
      COMMON/PHY4/DENS(232)
      COMMON/FBR1/TC(12),TIP1,TIP2,TCI(6),TOP1,TOP2,TON,TM(11)
      COMMON/FBR4/TCI1,TCI2,TCI3,TCI4,TCI5,TCI6
      COMMON/FBR6/TI11,TI12,TI13,TI14,TISH1,TSO1,TEI1
      COMMON/FBR8/TI21,TI22,TI23,TI24,TISH2,TSO2,TEI2
      COMMON/FBR10/NP(6),LP(6)
      COMMON/FBR11/N1(4),L1(4)
      COMMON/FBR12/N2(4),L2(4)
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/NATCON/NOPON1,NOPON2
      COMMON/REACT/P100,RNSERT,TNSERT
      COMMON/HYD1/T1,T2,CCCC
      COMMON/HYD3/ADUM(4),PIN,AOP
      COMMON/NORMS/WP100(8),WI100(2),WT100(2),PIN100
      COMMON/SCRM/ALIM1,ALIM2,NEWIM1,NEWIM2,TIHX1,TIHX2
      COMMON/SCRT/DRUM1,DRUM2,TEVAP1,TEVAP2.STFLW1,STFLW2.FWFLW1,FWFLW2
      COMMON/LOOP/XLOOP
      COMMON/FACT/XFAC,AFAC,VFAC.WFAC,PFAC,DFAC,CFAC,XKFAC.TFAC,XMFAC,
     1     IQFAC.SPFAC,XILFAC,XHFAC,ENTFAC,GC
      COMMON/TMPMAX/TCMAX,TCLMAX,ZJET
      COMMON/TRIPS/TSCRM(2),TTRIP(6)
      COMMON/SGEN1/TNOFW1,TAUX1
      COMMON/SGEN2/TNOFW2.TAUX2
C
      EQUIVALENCE (R(1),R1(1))
      NAMELIST/MASA/MODE,IPRINT,IPK,SSEC,TMAXSC
      NAMELIST/MASB/P100,PDO,SLOPEP,PDEND,XLOOP
      NAMELIST/MASC/TNEW,SNEW,IPNEW
      NAMELIST/MASD/TSCRM,TTRIP
```

```
      NAMELIST/MASE/NOPON,MTURB,MDUMP,RSTART,EPSILN
      NAMELIST/MASF/RNSERT,TNSERT
      NAMELIST/MASG/TNOFW1,TNOFW2,TAUX1,TAUX2
      DATA EPS,EPS2/1.E-10,1.E-5/
      DATA KMM1,KMM2,KMS1,KMS2,KMG1,KMG2/6*1./
      DATA NSTART/0/
      DATA NMOD/0/
C
      WRITE(6,900)
C          READ INPUT DATA
 8000 READ(5,MASA,END=9020)
      READ(5,MASB)
      READ(5,MASC)
      READ(5,MASD)
      READ(5,MASE)
      READ(5,MASF)
      READ(5,MASG)
      IF(MODE.NE.0) WRITE(6,901) PD0
      IF(NSTART.EQ.0.OR.MODE.EQ.0) GO TO 8001
      DIVI=ABS(1.-PD/PD0)
      IF(DIVI.LE.EPS2) GO TO 8001
      WRITE(6,911)
      GO TO 9
 8001 IF(MODE.EQ.1) WRITE(6,902)
      IF(MODE.EQ.2) WRITE(6,903)
      IF(MODE.EQ.0) WRITE(6,904)
      WRITE(6,914)
      WRITE(6,MASA)
      WRITE(6,MASB)
      WRITE(6,MASC)
      WRITE(6,MASD)
      WRITE(6,MASE)
      WRITE(6,MASF)
      WRITE(6,MASG)
      DO 1 I=1,489
      NULL(I)=0
    1 F(I)=0.
      IF(NSTART.EQ.1) GO TO 2
      DO 3 I=1,489
    3 R(I)=0.
    2 T=0.
      TMAX=TMAXSC/3600.
      TSEC=0.
      ICOUNT=0
      ISSP=IPNEW(3)
      PD=PD0
      PTOT=P100*PD
      ISPACE=0
      IKCAL=0
      S=SSEC/3600.
      MODE1=MODE
      MODE2=MODE
      MODET=MODE
      NOPON1=NOPON(1)
      NOPON2=NOPON(2)
      IF(NOPON(3).EQ.1) MODE1=3
      IF(NOPON(4).EQ.1) MODE2=3
      IF(MTURB.EQ.1) MODET=4
      IF(MDUMP.EQ.1) MODET=5
      MSCRAM=0
      IF(TSCRM(1).LE.0.) MSCRAM=MSCRAM+1
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      IF(TSCRM(2).LE.0.) MSCRAM=MSCRAM+2
      IF(TTRIP(1).LE.0.) KMM1=0
      IF(TTRIP(2).LE.0.) KMM2=0
      IF(TTRIP(3).LE.0.) KMS1=0
      IF(TTRIP(4).LE.0.) KMS2=0
      IF(TTRIP(5).LE.0.) KMG1=0
      IF(TTRIP(6).LE.0.) KMG2=0
      IF(MODE.EQ.0.AND.PD.EQ.1.) NMOD=1
C         INITIALIZE ALL STARTING (STEADY-STATE) VALUES OF THE SUBMODELS
    9 K=-1
      IF(T.NE.0.) K=4
      IF(NSTART.EQ.1) K=4
      IF(K.EQ.4) CALL RSTFBR(MODE,HPOT,NIHX1,NIHX2,PD)
      IF(K.NE.4) CALL LMFBR(MODE,HPOT,NIHX1,NIHX2,PD)
      IF(NMOD.EQ.1) PIN100=PIN
      N10N2=10+NP(2)
      N20N3=20+NP(3)
      N40N5=40+NP(5)
      N50N6=50+NP(6)
      NSI1=30+N1(4)
      NSI2=30+N2(4)
      NXIT1=2*NIHX1+5
      NXIT2=2*NIHX2+5
      NISH1=N1(1)
      NISH2=N2(1)
      T1=TCI3
      T2=TCI6
      TPI1=TON
      TPI2=TON
      WP1=W1
      WP2=W2
      TSI1=TI14
      TSI2=TI24
      CALL NEUKIN(MSCRAM,PTOT,PD)
      CALL HYDROS(MODE,KMM1,KMM2,PD,HPOT)
      CALL RTHERM(MODE,PTOT,HPOT,T1,T2)
      CALL IHX1(MODE,WP1,WS1,TPI1,TSI1,NIHX1)
      CALL IHX2(MODE,WP2,WS2,TPI2,TSI2,NIHX2)
      CALL DELAYP(WP1,WP2,MODE)
      CALL IHYD1(PD,PTM,KMS1,MODE1)
      CALL IHYD2(PD,PTM,KMS2,MODE2)
      CALL DELAY1(WS1,MODE1)
      CALL DELAY2(WS2,MODE2)
      CALL SGTHD1(TISH1,KMG1,MODE1,PD)
      CALL SGTHD2(TISH2,KMG2,MODE2,PD)
      W31=R81(33)
      W32=R82(33)
      H211=R81(30)
      H212=R82(30)
      CALL TURBO(MODET,W31,W32,H211,H212,PD)
      ALIM1=R61(4)
      ALIM2=R62(4)
      NEWIM1=R61(3)
      NEWIM2=R62(3)
      TIHX1=TCI3
      TIHX2=TCI6
      DRUM1=R81(36)
      DRUM2=R82(36)
      TEVAP1=TI12
      TEVAP2=TI22
      STFLW1=R81(37)
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      STFLW2=R82(37)
      FWFLW1=R81(38)
      FWFLW2=R82(38)
      CALL SCRAM(MSCRAM,KMM1,KMM2,KMS1,KMS2,KMG1,KMG2)
      IF(T.NE.0.) GO TO 9999
C         AT THIS POINT ALL SUBROUTINES ARE READY TO ACCEPT CALLS TO
C         COMPUTE DERIVATIVE VALUES.    ONLY THE TOTAL NUMBER OF PROCESS
C         VARIABLES, JOY, NEEDS TO BE INITIALIZED BEFORE THE TRANSIENT
C         CALCULATION BEGINS.
      JOY=489
      IF(MODE.NE.0) GO TO 100
      DO 10 I=1,8
   10 NULL(I)=I
      DO 20 I=1,120
   20 NULL(I+109)=I
      DO 30 I=1,80
      NULL(239+I)=I
   30 NULL(319+I)=I
      DO 40 I=1,7
   40 NULL(482+I)=I
  100 JMIDLE=1
      KCALC=1
      IF(K.NE.4) GO TO 1000
      K=1
      GO TO 2001
 1000 IF(ICOUNT.LE.1) KCALC=1
 1001 IF(JMIDLE.GE.4) GO TO 1100
      IF(TSEC.LT.TNEW(JMIDLE)) GO TO 1100
      SSEC=SNEW(JMIDLE)
      IPRINT=IPNEW(JMIDLE)
      ISPACE=ICOUNT
      S=SSEC/3600.
      KCALC=1
      JMIDLE=JMIDLE+1
      GO TO 1001
 1100 IF(ICOUNT.NE.0) CALL LMFBR(MODE,HPOT,NIHX1,NIHX2,PD)
 2000 K=RUNGE(JOY,R,F,T,S,NO)
 2001 IF(K.EQ.1) K=3
      KCALC=1
C         WHEN K=0,   COMPUTE PROMPT APPROXIMATION VARIABLES;
C         WHEN K=1,   BEGIN TIME STEP & COMPUTE VALUES OF DERIVATIVES;
C         WHEN K=2,   CONTINUE TIME STEP, COMPUTING NEW DERIVATIVE VALUES;
C         WHEN K=3,   BEGIN TIME STEP, COMPUTE NEW TIME CONSTANTS, AND
C                         COMPUTE THE DERIVATIVES.
      TSEC=T*3600.
      IF(R2(1).LT.EPS) R2(1)=EPS
      IF(R2(2).LT.EPS) R2(2)=EPS
      IF(R2(7).LT.EPS) R2(7)=EPS
      IF(R2(8).LE.0.0) R2(8)=0.0
      IF(R2(13).LE.0.0) R2(13)=0.0
      IF(R61(1).LE.EPS) R61(1)=EPS
      IF(R62(1).LE.EPS) R62(1)=EPS
      IF(R61(2).LE.0.0) R61(2)=0.0
      IF(R62(2).LE.0.0) R62(2)=0.0
      IF(R81(31).LE.0.0) R81(31)=0.0
      IF(R82(31).LE.0.0) R82(31)=0.0
      IF(R81(32).LE.EPS) R81(32)=EPS
      IF(R82(32).LE.EPS) R82(32)=EPS
      IF(R81(33).LE.EPS2) R81(33)=EPS2
      IF(R82(33).LE.EPS2) R82(33)=EPS2
      W1=R2(1)
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      W2=R2(2)
      WOC=R2(3)
      WHC=R2(4)
      WCA=R2(5)
      WRB=R2(6)
      WBP=R2(7)
      WIC=W1+XLOOP*W2-WOC-WHC-WCA-WRB-WBP
      IF(MODE.EQ.2) W1=R2(18)
      IF(MODE.EQ.2) WBRK=R2(1)
      WP1=W1
      WP2=W2
      WS1=R61(1)
      WS2=R62(1)
      T1=R5(N20N3)
      T2=R5(N50N6)
      TCI1=TON
      TCI2=R5(NP(1))
      TCI3=R41(NIHX1+3)
      TCI4=TON
      TCI5=R5(30+NP(4))
      TCI6=R42(NIHX2+3)
      TPI1=R5(N10N2)
      TPI2=R5(N40N5)
      TSI1=R71(NSI1)
      TSI2=R72(NSI2)
      TI11=R41(NXIT1)
      TI12=R81(11)
      TI13=R71(10+N1(2))
      TI14=R71(20+N1(3))
      TISH1=R71(NISH1)
      TSO1=R81(4)
      TEI1=R81(9)
      TI21=R42(NXIT2)
      TI22=R82(11)
      TI23=R72(10+N2(2))
      TI24=R72(20+N2(3))
      TISH2=R72(NISH2)
      TSO2=R82(4)
      TEI2=R82(9)
      W31=R81(33)
      W32=R82(33)
      H211=R81(30)
      H212=R82(30)
      PTM=R9(3)
      IF(MODE.NE.0) GO TO 2080
      T1=TCI3
      T2=TCI6
      TSI1=TI14
      TSI2=TI24
 2080 CONTINUE
      IF(SLOPEP.EQ.0.) GO TO 2100
      PD=PD0+SLOPEP*TSEC
      IF(SLOPEP.LT.0..AND.PD.LT.PDEND) GO TO 2090
      IF(SLOPEP.GT.0..AND.PD.GT.PDEND) GO TO 2090
      GO TO 2100
 2090 SLOPEP=0.
      PD=PDEND
 2100 IF(MODE.NE.0) CALL NEUKIN(MSCRAM,PTOT,PD)
      IF(MODE.EQ.0) PTOT=P100*PD
      CALL HYDROS(MODE,KMM1,KMM2,PD,HPOT)
      CALL RTHERM(MODE,PTOT,HPOT,T1,T2)
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```
      IF(MODE.EQ.0) TPI1=TON
      IF(MODE.EQ.0) TPI2=TON
      CALL IHX1(MODE,WP1,WS1,TPI1,TSI1,NIHX1)
      CALL IHX2(MODE,WP2,WS2,TPI2,TSI2,NIHX2)
      CALL DELAYP(WP1,WP2,MODE)
      CALL IHYD1(PD,PTM,KMS1,MODE1)
      CALL IHYD2(PD,PTM,KMS2,MODE2)
      CALL DELAY1(WS1,MODE1)
      CALL DELAY2(WS2,MODE2)
      IF(MODE.EQ.0) TISH1=R41(NXIT1)
      IF(MODE.EQ.0) TISH2=R42(NXIT2)
      CALL SGTHD1(TISH1,KMG1,MODE1,PD)
      CALL SGTHD2(TISH2,KMG2,MODE2,PD)
      CALL TURBO(MODET,W31,W32,H211,H212,PD)
      ALIM1=R61(4)
      ALIM2=R62(4)
      NEWIM1=R61(3)
      NEWIM2=R62(3)
      TIHX1=TCI3
      TIHX2=TCI6
      DRUM1=R81(36)
      DRUM2=R82(36)
      TEVAP1=TI12
      TEVAP2=TI22
      STFLW1=R81(37)
      STFLW2=R82(37)
      FWFLW1=R81(38)
      FWFLW2=R82(38)
      IF(MODE.NE.0) CALL SCRAM(MSCRAM,KMM1,KMM2,KMS1,KMS2,KMG1,KMG2)
      IF(K.NE.0) GO TO 3000
      ICOUNT=ICOUNT+1
      GO TO 1000
 3000 IF(K.EQ.1) GO TO 4000
      IF(K.EQ.2) GO TO 2000
C         REARRANGE NULL VECTOR TO FORM VECTOR NO (CONTROL INTEGERS)
      I=1
      DO 2900 J=1,489
      JCOUNT=0
      IF(J.GT.8) JCOUNT=8
      IF(J.GT.26) JCOUNT=26
      IF(J.GT.59) JCOUNT=59
      IF(J.GT.84) JCOUNT=84
      IF(J.GT.109) JCOUNT=109
      IF(J.GT.229) JCOUNT=229
      IF(J.GT.234) JCOUNT=234
      IF(J.GT.239) JCOUNT=239
      IF(J.GT.319) JCOUNT=319
      IF(J.GT.399) JCOUNT=399
      IF(J.GT.438) JCOUNT=438
      IF(J.GT.477) JCOUNT=477
      IF(J.GT.482) JCOUNT=482
      IF(NULL(J).EQ.0) GO TO 2900
      NO(I)=NULL(J)+JCOUNT
      I=I+1
 2900 CONTINUE
      DO 2905 J=I,JOY
 2905 NO(J)=0
 4000 IF(ICOUNT.EQ.ISPACE) GO TO 5500
      GO TO 9000
 5500 ISPACE=ICOUNT+IPRINT
      IF(MODE.NE.0) WRITE(6,905) ICOUNT,TSEC,SSEC
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      IF(MODE.EQ.0) WRITE(6,907) ICOUNT,PTOT
      IF(KCALC.EQ.1) WRITE(6,906) (NO(I),I=1,JOY)
      IF(IKCAL.LE.ICOUNT) GO TO 6000
      KCALC=0
      GO TO 6500
 6000 IKCAL=ICOUNT+IPK
 6500 CONTINUE
      IF(MODE.NE.0) CALL PUTNEU
      CALL PUTHYD
      CALL PUTRTH
      CALL PUTHX1
      CALL PUTHX2
      IF(MODE.NE.0) CALL PUTDEL
      CALL PUTIH1
      CALL PUTIH2
      IF(MODE.NE.0) CALL PUTID1
      IF(MODE.NE.0) CALL PUTID2
      CALL PUTSG1
      CALL PUTSG2
      CALL PUTTUR
      IF(MODE.NE.0) CALL PUTSCR
      KCALC=0
 9000 IF(MODE.NE.0) GO TO 9005
      IF(ICOUNT.EQ.0) GO TO 9002
      NDIV=0
      BIGDIV=0.
      DO 9001 I=1,JOY
      IF(R(I).EQ.0.) R(I)=EPS
      DIV=ABS((R(I)-RSAVE(I))/R(I))
      IF(DIV.GT.EPSILN.AND.ICOUNT.NE.ISSP) GO TO 9002
      IF(DIV.LE.BIGDIV) GO TO 9001
      BIGDIV=DIV
      NDIV=I
 9001 CONTINUE
      IF(BIGDIV.LE.EPSILN) GO TO 9010
      WRITE(6,912) ICOUNT,NDIV,BIGDIV
      ISSP=ICOUNT+IPNEW(3)
 9002 DO 9003 I=1,JOY
      IF(R(I).EQ.0.) R(I)=EPS
 9003 RSAVE(I)=R(I)
 9005 IF(T.LT.TMAX) GO TO 2000
      IF(ISPACE.NE.(ICOUNT+IPRINT)) GO TO 5500
      IF(MODE.NE.0) GO TO 9008
      WRITE(6,908)
      GO TO 9
 9008 IF(RSTART.NE.1) GO TO 9999
      WRITE(6,913)
      WRITE(6,914)
      GO TO 9
 9010 WRITE(6,909) ICOUNT
      NSTART=1
      NMOD=0
      IF(PD.NE.1.) GO TO 9014
      DO 9012 I=1,7
 9012 WP100(I)=R2(I)
      WP100(8)=R2(18)
      WI100(1)=R61(1)
      WI100(2)=R62(1)
      WT100(1)=R81(32)
      WT100(2)=R82(32)
      R2(8)=1.
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      R2(13)=1.
      R61(2)=1.
      R62(2)=1.
      R81(31)=1.
      R82(31)=1.
      NMOD=1
 9014 IF(RSTART.EQ.1) GO TO 8000
 9015 MODE=1
      IPRINT=0
      TMAXSC=0.
      RSTART=0
      WRITE(6,914)
      GO TO 2
 9020 WRITE(6,910)
      IF(NSTART.EQ.1) GO TO 9015
 9999 STOP
C
C         FORMAT STATEMENTS
  900 FORMAT('1',T34,63('*'),/T34,'*',61X,'*'/T34,'*',19X,'C U R L - ',
     1  'LOOP VERSION',20X,'*',/T34,'*',61X,'*'/T34,'*',61X,'*'/T34,'*',
     2  9X,'DYNAMIC SIMULATION OF A LIQUID-METAL-COOLED',9X,'*'/T34,'*',
     3  61X,'*'/T34,'*',20X,'FAST BREEDER REACTOR',21X,'*'/T34,'*',61X,
     4  '*'/T34,'*',61X,'*'/T34,'*',18X,'CORNELL UNIVERSITY  1978',19X,
     5  '*'/T34,'*',61X,'*'/T34,63('*')///)
  901 FORMAT(//15X,30('*'),5X,'TRANSIENT CALCULATION BEGINS',5X,30('*'),
     1   //3X,'REACTOR INITIALLY AT STEADY - STATE, OPERATING AT',
     2  2PF6.1,' % OF FULL POWER'//)
  902 FORMAT(3X,'PIPING INTEGRITY MAINTAINED'///)
  903 FORMAT(3X,'PIPE RUPTURE ACCIDENT'///)
  904 FORMAT(3X,'DETERMINATION OF STEADY STATE VALUES'///)
  905 FORMAT('1',5X,'STEP #',I6,3X,'TIME =',F11.5,' SEC',3X,'S =',F9.5,
     1  ' SEC')
  906 FORMAT(/T49,'TOTAL VECTOR OF CONTROL INTEGERS'/25(I5))
  907 FORMAT('1',5X,'STEP #',I6,23X,'S T E A D Y   S T A T E   C A L C',
     1  ' U L A T I O N'/47X,'POWER HELD CONSTANT AT',F8.2,' MWT'//)
  908 FORMAT('1',///10X,75('*'),/10X,'*',73X,'*',/10X,'*',14X,
     1  'NO CONVERGENCE FOUND IN ALLOTTED TIME PERIOD',15X,'*',
     2  /10X,'*',73X,'*',/10X,75('*')////)
  909 FORMAT('1',///29X,15('*'),5X,'CONVERGENCE IN',I5,' ITERATIONS',5X,
     1  15('*')///)
  910 FORMAT ('1',10X,10('*'),5X,'REQUIRED INPUT DATA FOR MASTER',
     1  ' PROGRAM NOT FOUND',5X,10('*'),///)
  911 FORMAT(//15X,16('*'),5X,'INITIAL STATE NOT AT SAME POWER AS ',
     1  'CALCULATED STEADY STATE',5X,16('*'),/T54,'TRANSIENT ABORTED'//)
  912 FORMAT(//19X,5('*'),5X,'NO CONVERGENCE IN',I5,' STEPS.    ',
     1  'VARIABLE #',I4,' CHANGED BY',2PF9.5,' %',5X,5('*'))
  913 FORMAT('1',25X,15('*'),5X,'END OF CALCULATION',5X,15('*')////)
  914 FORMAT(///20X,30('*'),5X,'I N P U T   D A T A',5X,30('*'),///)
      END
      SUBROUTINE LMFBR(MODE, HOP, KX1, KX2, PD)
      DIMENSION DBP(2),DIP(3),DIS(4),AP(3),AS(4)
      DIMENSION ZH(3),ZI(3),ZO(3),ZC(1),ZR(1),ZB(2)
      DIMENSION XL1(10),XL2(10),XL3(10),XL4(10),XL5(10)
      DIMENSION XL6(10),XLX1(13),XLX2(13),XLH(3),XLI(3),XLO(3),XLC(1)
      DIMENSION XLR(1),XLB(2),FH(3),FI(3),FO(3),FC(1),FR(1),FB(2),FP(4)
      DIMENSION F1(10),F2(10),F3(10),F4(10),F5(10),F6(10)
      DIMENSION FX1(13),FX2(13)
      DIMENSION XLS1(10),XLS2(10),XLS3(10),XLS4(10),XLS5(10),XLS6(10),
     1 XLS7(10),XLS8(10)
      DIMENSION FS1(10),FS2(10),FS3(10),FS4(10),FS5(10),FS6(10),FS7(10),
     1FS8(10),W(232),DPG(36)
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      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/LOOP/XLOOP
      COMMON/GET1/WI100,WI1,WI2,WIC,WOC,WHC,WCA,WRB,WBP,WS100,WS1,WS2,
     1WBRK
      COMMON/FBR1/TC(12),TIP1,TIP2,TCI(6),TOP1,TOP2,TON,TM(11)
      COMMON/FBR2/TP1(13),TS1(12)
      COMMON/FBR3/TP2(13),TS2(12)
      COMMON/FBR4/TCI1,TCI2,TCI3,TCI4,TCI5,TCI6
      COMMON/FBR5/TC1(10),TC2(10),TC3(10),TC4(10),TC5(10),TC6(10)
      COMMON/FBR6/TI11,TI12,TI13,TI14,TSI1,TSO1,TEI1
      COMMON/FBR7/TM1(10),TM2(10),TM3(10),TM4(10)
      COMMON/FBR8/TI21,TI22,TI23,TI24,TSI2,TSO2,TEI2
      COMMON/FBR9/TM5(10),TM6(10),TM7(10),TM8(10)
      COMMON/FBR10/NP(6),LP(6)
      COMMON/FBR11/N1(4),L1(4)
      COMMON/FBR12/N2(4),L2(4)
      COMMON/FBR13/DH(12),AH(12),AIPT,AOPT,OD(11)
      COMMON/FBR14/DPX,APX,ODP(3),DELP(3),XLP(7),XL11,XL12,XL21,
     1     XL22,DSX,ASX,XLS(12),ODI(4),DELI(4)
      COMMON/FBR15/DSS,CSS,XKSS
      COMMON/FBR16/AHY(232)
      COMMON/HEADS/DHG(11)
      COMMON/FRICTS/C(11)
      COMMON/PHY1/TCAV(232)
      COMMON/PHY2/G(232)
      COMMON/PHY3/DHY(232)
      COMMON/PHY4/DEH(3),DEI(3),DEO(3),DEC(1),DER(1),DEB(1),DIP1(2),
     1 DEIP1,DEIP2,DEOP1,DIP2(6),DOP1(5),DOP2(1),DON12(1),DE1(10),DP1(1)
     2 ,DE2(10),DX1(13),DE3(10),DE4(10),DP2(1),DE5(10),DX2(13),DE6(10),
     3 DUM1(11),DSX1,DES1(10),DSH1,DEVI1,DEVO1,DES2(10),DEST1,DES3(10),
     4 DESP1,DES4(10),DUM2(11),DSX2,DES5(10),DSH2,DEVI2,DEVO2,DES6(10),
     5 DEST2,DES7(10),DESP2,DES8(10)
      COMMON/PHY8/RE(232)
      COMMON/HYD1/TRI1,TRI2,CRIP
      COMMON/HYD2/NDB,PBRK,ZBRK,XLBRK,CROBB,CROAB,HEADBB,HEADAB,DENAB
      COMMON/HYD3/ZOPNOM,DZCON,PCG,PGV,PINLET,AOUTPL
      COMMON/PHED/AA(8),CC(8)
      COMMON/PTRQ/BB(8),DD(8)
      COMMON/CNV1/XL(12),P(11),WL(11),DSG,ASG,ODSE,DELSE
      COMMON/CNV2/ZIN1,ZIN2,ZON,ZP1,ZP2,ZOPLEV
      COMMON/CNV3/Z1(10),Z2(10),Z3(10),Z4(10),Z5(10),Z6(10)
      COMMON/CNV4/ZX1(13),ZX2(13)
      COMMON/CNV5/ZS1(10),ZS2(10),ZS3(10),ZS4(10),ZS5(10),ZS6(10),
     1 ZS7(10),ZS8(10)
      COMMON/CNV6/ZHX1,ZHX2,ZSH1,ZSH2,ZEVI1,ZEVI2,ZEVO1,ZEVO2,ZSP1,ZSP2
      COMMON/CNV7/P1,P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12
      COMMON/CNV8/PS1,PS2,PS3,PS4,PS5,PS6,PS7,PS8,PS9
      COMMON/CNV9/PI1,PI2,PI3,PI4,PI5,PI6,PI7,PI8,PI9
      COMMON/FACT/XFAC,FDUM1(3),PFAC,FDUM2(10),GCP
      NAMELIST/BRO1/WI100,WI1,WI2,WIC,WOC,WHC,WCA,WRB,WBP,WS100,WS1,WS2,
     1WBRK
      NAMELIST/BRO2/TC,TIP1,TIP2,TOP1,TOP2,TM
      NAMELIST/BRO3/K1,K2,NP,LP,N1,L1,N2,L2
      NAMELIST/BRO4/TP1,TS1
      NAMELIST/BRO5/TP2,TS2
      NAMELIST/BRO6/TCI1,TCI2,TCI3,TCI4,TCI5,TCI6
      NAMELIST/BRO7/TI11,TI12,TI13,TI14,TSI1,TSO1,TEI1
      NAMELIST/BRO8/TI21,TI22,TI23,TI24,TSI2,TSO2,TEI2
      NAMELIST/BRO9/DH,AH,AIPT,AOPT
      NAMELIST/BR10/XL,P,WL,OD
      NAMELIST/BR11/DPX,APX,ODP,DELP,XLP,XL11,XL12,XL21,XL22
```

```
      NAMELIST/BR12/DSX,ASX,ODI,DELI,DSG,ASG,ODSE,DELSE,XLS
      NAMELIST/BR13/ZIN1,ZIN2,ZON,ZP1,ZP2,ZOPLEV
      NAMELIST/BR14/Z1,Z2,Z3
      NAMELIST/BR15/Z4,Z5,Z6
      NAMELIST/BR16/ZX1,ZX2
      NAMELIST/BR17/P1,P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12
      NAMELIST/BR18/DSS,CSS,XKSS
      NAMELIST/BR19/PS1,PS2,PS3,PS4,PS5,PS6,PS7,PS8,PS9
      NAMELIST/BR20/PI1,PI2,PI3,PI4,PI5,PI6,PI7,PI8,PI9
      NAMELIST/BR21/ZS1,ZS2,ZS3,ZS4
      NAMELIST/BR22/ZS5,ZS6,ZS7,ZS8
      NAMELIST/BR23/ZHX1,ZHX2,ZSH1,ZSH2,ZEVI1,ZEVI2,ZEVO1,ZEVO2,ZSP1,ZSP
     12
      NAMELIST/BR24/PBRK,ZBRK,XBRK,PGV
      NAMELIST/BR25/AA,BB,CC,DD
      DATA PI/3.141593/
      IF(ICOUNT.NE.0) GO TO 15
      READ(5, BR01)
      READ(5, BR02)
      READ(5, BR03)
      READ(5, BR04)
      READ(5, BR05)
      READ(5, BR06)
      READ(5, BR07)
      READ(5, BR08)
      READ(5, BR09)
      READ(5, BR10)
      READ(5, BR11)
      READ(5, BR12)
      READ(5, BR13)
      READ(5, BR14)
      READ(5, BR15)
      READ(5, BR16)
      READ(5, BR17)
      READ(5, BR18)
      READ(5, BR19)
      READ(5, BR20)
      READ(5, BR21)
      READ(5, BR22)
      READ(5, BR23)
      READ(5, BR24)
      READ(5, BR25)
C
C          PRINT INPUT DATA
  998 WRITE(6, BR01)
      WRITE(6, BR02)
      WRITE(6, BR03)
      WRITE(6, BR04)
      WRITE(6, BR05)
      WRITE(6, BR06)
      WRITE(6, BR07)
      WRITE(6, BR08)
      WRITE(6, BR09)
      WRITE(6, BR10)
      WRITE(6, BR11)
      WRITE(6, BR12)
      WRITE(6, BR13)
      WRITE(6, BR14)
      WRITE(6, BR15)
      WRITE(6, BR16)
      WRITE(6, BR17)
```

```
      WRITE(6, BR18)
      WRITE(6, BR19)
      WRITE(6, BR20)
      WRITE(6, BR21)
      WRITE(6, BR22)
      WRITE(6, BR23)
      WRITE(6, BR24)
      WRITE(6, BR25)
C         CALL SUBROUTINE CONVRT TO CHANGE TO PROPER UNITS AND
C              INITIALIZE ALL THE CONVERSION FACTORS FOR THE
C              OTHER SUBROUTINES
C
      CALL CONVRT
      PBRK=PBRK/PFAC
      PGV=PGV/PFAC
      ZBRK=ZBRK/XFAC
      XBRK=XBRK/XFAC
C
      AOUTPL=AOPT
      ZH(1)=ZIN2+XL(1)
      ZI(1)=ZIN2+XL(4)
      ZO(1)=ZIN2+XL(7)
      DO 999 I=2,3
      IM=I-1
      ZH(I)=ZH(IM)+XL(I)
      ZI(I)=ZI(IM)+XL(I+3)
  999 ZO(I)=ZO(IM)+XL(I+6)
      ZC(1)=ZIN2+XL(10)
      ZR(1)=ZIN2+XL(11)
      ZB(1)=ZIN2+XL(12)
      ZB(2)=ZH(3)
      HOP=ZOPLEV-ZH(3)
      KX1=K1
      KX2=K2
      DO 1000 I=1,3
      DIP(I)=ODP(I)-2.*DELP(I)
 1000 AP(I)=PI/4.*DIP(I)**2/144.
      DO 1001 I=1,4
      DIS(I)=ODI(I)-2.*DELI(I)
 1001 AS(I)=PI/4.*DIS(I)**2/144.
      DISSE=ODSE-2.*DELSE
      ASSE=PI/4.*DISSE**2/144.
      NP1=NP(1)
      NP2=NP(2)
      NP3=NP(3)
      NP4=NP(4)
      NP5=NP(5)
      NP6=NP(6)
      N11=N1(1)
      N12=N1(2)
      N13=N1(3)
      N14=N1(4)
      N21=N2(1)
      N22=N2(2)
      N23=N2(3)
      N24=N2(4)
      XNP1=NP1
      XNP2=NP2
      XNP3=NP3
      XNP4=NP4
      XNP5=NP5
```

```
      XNP6=NP6
      XK1=K1
      XK2=K2
      GC=GCP*(3600.**2)
      K11=K1+1
      K21=K2+1
      K12=K1+2
      K22=K2+2
      XLX1(1)=XL11
      DO 301 I=2, K11
  301 XLX1(I)=XLP(7)/XK1
      XLX1(K12)=0.
      XLX1(K12+1)=XL12
      XLX2(1)=XL21
      DO 302 I=2, K21
  302 XLX2(I)=XLP(7)/XK2
      XLX2(K22)=0.
      XLX2(K22+1)=XL22
      DO 101 I=1, NP1
  101 XL1(I)=XLP(1)/XNP1
      DO 102 I=1, NP2
  102 XL2(I)=XLP(2)/XNP2
      DO 103 I=1, NP3
  103 XL3(I)=XLP(3)/XNP3
      DO 104 I=1, NP4
  104 XL4(I)=XLP(4)/XNP4
      DO 105 I=1, NP5
  105 XL5(I)=XLP(5)/XNP5
      DO 106 I=1, NP6
  106 XL6(I)=XLP(6)/XNP6
      XLIN=0.
      XLOUT=0.
      DO 303 I=1, 3
      XLH(I)=XL(I)
      XLI(I)=XL(I+3)
  303 XLO(I)=XL(I+6)
      XLC(1)=XL(10)
      XLR(1)=XL(11)
      XLB(1)=XL(12)
      XLB(2)=0.
C       INTERMEDIATE LOOPS
      XN11=N11
      XN12=N12
      XN13=N13
      XN14=N14
      XN21=N21
      XN22=N22
      XN23=N23
      XN24=N24
      DO 304 I=1, N11
  304 XLS1(I)=XLS(1)/XN11
      DO 305 I=1, N12
  305 XLS2(I)=XLS(2)/XN12
      DO 306 I=1, N13
  306 XLS3(I)=XLS(3)/XN13
      DO 307 I=1, N14
  307 XLS4(I)=XLS(4)/XN14
      DO 308 I=1, N21
  308 XLS5(I)=XLS(5)/XN21
      DO 309 I=1, N22
  309 XLS6(I)=XLS(6)/XN22
```

```
      DO 310 I=1, N23
  310 XLS7(I)=XLS(7)/XN23
      DO 311 I=1, N24
  311 XLS8(I)=XLS(8)/XN24
C      DEFINE THE DUMMY DHY FOR DIAMETER AND AHY FOR AREA OF FLOW
      DO 107 I=1, 12
      DHY(I)=DH(I)
  107 AHY(I)=AH(I)
      DIPT=SQRT(AIPT*4./PI)
      DOPT=SQRT(AOPT*4./PI)
      DO 300 I=13, 16
      DHY(I)=DIPT
  300 AHY(I)=AIPT
      DHY(17)=DOPT
      AHY(17)=AOPT
      DO 108 I=18, 29
      DHY(I)=DOPT
  108 AHY(I)=AOPT
      DO 109 I=30, 40
      DHY(I)=DIP(1)/12.0
  109 AHY(I)=AP(1)
      DO 110 I=41, 51
      DHY(I)=DIP(2)/12.
  110 AHY(I)=AP(2)
      DO 111 I=52, 64
      DHY(I)=DPX
  111 AHY(I)=APX
      DO 112 I=65, 74
      DHY(I)=DIP(3)/12.0
  112 AHY(I)=AP(3)
      DO 113 I=75, 84
      DHY(I)=DIP(1)/12.0
  113 AHY(I)=AP(1)
      DO 114 I=85, 95
      DHY(I)=DIP(2)/12.
  114 AHY(I)=AP(2)
      DO 115 I=96, 108
      DHY(I)=DPX
  115 AHY(I)=APX
      DO 116 I=109, 118
      DHY(I)=DIP(3)/12.
  116 AHY(I)=AP(3)
C      INTERMEDIATE LOOPS
C              LOOP 1:
      DO 117 I=119, 130
      DHY(I)=DSX
  117 AHY(I)=ASX
      DO 118 I=131, 140
      DHY(I)=DIS(1)/12.
  118 AHY(I)=AS(1)
      DHY(141)=DSG
      AHY(141)=ASG
      DHY(142)=DISSE/12.0
      AHY(142)=ASSE
      DHY(143)=DSG
      AHY(143)=ASG
      DO 119 I=144, 153
      DHY(I)=DIS(2)/12.
  119 AHY(I)=AS(2)
      DO 120 I=154, 164
      DHY(I)=DIS(3)/12.
```

```
      DHY(I+11)=DIS(4)/12.
      AHY(I)=AS(3)
  120 AHY(I+11)=AS(4)
C              LOOP 2:
      DO 121 I=176, 187
      DHY(I)=DSX
  121 AHY(I)=ASX
      DO 122 I=188, 197
      DHY(I)=DIS(1)/12.0
  122 AHY(I)=AS(1)
      DHY(198)=DSG
      AHY(198)=ASG
      DHY(199)=DISSE/12.0
      AHY(199)=ASSE
      DHY(200)=DSG
      AHY(200)=ASG
      DO 123 I=201, 210
      DHY(I)=DIS(2)/12.0
  123 AHY(I)=AS(2)
      DO 124 I=211, 221
      DHY(I)=DIS(3)/12.
      DHY(I+11)=DIS(4)/12.
      AHY(I)=AS(3)
  124 AHY(I+11)=AS(4)
      DZCON=ZON-ZH(3)
      ZOPNOM=HOP-DZCON
      PINLET=P8
      DENP=DENSOD(TOP1)
      PCG=P3-ZOPNOM*DENP/144.
      NODEB=1.+(XLP(3)-XBRK)/XLP(3)*NP3
      NDB=0
      XLBRK=XBRK-(NP3-NODEB)*XL3(1)
C       PIPE RUN INITIALIZATION
      DO 1 I=1, 10
    1 TC1(I)=TCI1
      DO 2 I=1, 10
    2 TC2(I)=TCI2
      DO 3 I=1, 10
    3 TC3(I)=TCI3
      DO 4 I=1, 10
    4 TC4(I)=TCI4
      DO 5 I=1, 10
    5 TC5(I)=TCI5
      DO 6 I=1, 10
    6 TC6(I)=TCI6
      DO 7 I=1, 10
    7 TM1(I)=TI11
      DO 8 I=1, 10
    8 TM2(I)=TI12
      DO 9 I=1, 10
    9 TM3(I)=TI13
      DO 10 I=1,10
   10 TM4(I)=TI14
      DO 11 I=1,10
   11 TM5(I)=TI21
      DO 12 I=1,10
   12 TM6(I)=TI22
      DO 13 I=1,10
   13 TM7(I)=TI23
      DO 14 I=1,10
   14 TM8(I)=TI24
```

```
   15 CONTINUE
C       CALCULATE AVERAGE COOLANT TEMPERATURES IN THE PRIMARY AND INTERMEDIATE
C                                SODIUM LOOPS
C       REACTOR
      TCAV(1)=(TCI(1)+TC(1))/2.0
      DO 16 I=2, 3
      TCAV(I)=(TC(I-1)+TC(I))/2.0
      TCAV(I+3)=(TC(I+2)+TC(I+3))/2.0
   16 TCAV(I+6)=(TC(I+5)+TC(I+6))/2.0
      TCAV(4)=(TCI(2)+TC(4))/2.0
      TCAV(7)=(TCI(3)+TC(7))/2.0
      TCAV(10)=(TCI(4)+TC(10))/2.0
      TCAV(11)=(TCI(5)+TC(11))/2.0
      TCAV(12)=(TCI(6)+TC(12))/2.0
      TCAV(13)=(TC3(NP3)+TIP1)/2.0
      TCAV(14)=(TC6(NP6)+TIP1)/2.0
      TCAV(15)=TIP1
      TCAV(16)=TIP2
      TCAV(17)=TOP1
      DO 17 I=1, 6
   17 TCAV(I+17)=(TCI(I)+TIP2)/2.0
      DO 18 I=1, 5
      IF(I.EQ.1) L=3
      IF(I.EQ.2) L=6
      IF(I.GT.2) L=I+6
   18 TCAV(I+23)=(TC(L)+TOP1)/2.0
      TCAV(29)=(TC(12)+TOP2)/2.0
      TCAV(30)=TCI1
C       PRIMARY HEAT TRANSPORT SYSTEM
      TCAV(31)=(TCI1+TC1(1))/2.0
      DO 19 I=2, 10
   19 TCAV(I+30)=(TC1(I-1)+TC1(I))/2.0
C     PUMP 1
      TCAV(41)=(TC1(NP1)+TCI2)/2.0
C
      TCAV(42)=(TCI2+TC2(1))/2.0
      DO 20 I=2, 10
   20 TCAV(I+41)=(TC2(I-1)+TC2(I))/2.0
C       IHX-1
      TCAV(52)=(TC2(NP2)+TP1(1))/2.0
      DO 21 I=2, 13
   21 TCAV(I+51)=(TP1(I-1)+TP1(I))/2.0
      TCAV(K1+53)=(TC2(NP2)+TP1(K12))/2.0
      TCAV(K1+54)=TP1(K12+1)
C
      TCAV(65)=(TCI3+TC3(1))/2.0
      DO 22 I=2, 10
   22 TCAV(I+64)=(TC3(I-1)+TC3(I))/2.0
C       LOOP 2:
      TCAV(75)=(TCI4+TC4(1))/2.0
      DO 23 I=2, 10
   23 TCAV(I+74)=(TC4(I-1)+TC4(I))/2.0
C       PUMP2
      TCAV(85)=(TC4(NP4)+TCI5)/2.0
      TCAV(86)=(TCI5+TC5(1))/2.0
      DO 24 I=2, 10
   24 TCAV(I+85)=(TC5(I-1)+TC5(I))/2.0
C       IHX-2
      TCAV(96)=(TC5(NP5)+TP2(1))/2.0
      DO 25 I=2, 13
   25 TCAV(I+95)=(TP2(I-1)+TP2(I))/2.0
```

```
      TCAV(K2+97)=(TC5(NP5)+TP2(K2+2))/2.0
      TCAV(K2+98)=TP2(K2+3)
C
      TCAV(109)=(TCI6+TC6(1))/2.0
      DO 26 I=2, 10
   26 TCAV(I+108)=(TC6(I-1)+TC6(I))/2.0
C      INTERMEDIATE LOOPS:
C
      TCAV(119)=(TM4(N14)+TS1(K1+1))/2.0
C      FIRST, ASSUME A DUMMY AVERAGE TEMPERATURE FOR THE MAXIMUM NO. OF NODES
      IF(ICOUNT.NE.0) GO TO 361
      DO 360 I=1, 11
  360 TCAV(119+I)=TCAV(119)
  361 CONTINUE
      DO 36 I=1, K1
   36 TCAV(119+I)=(TS1(K12-I)+TS1(K11-I))/2.0
      TCAV(120+K1)=(TS1(K12)+TS1(1))/2.0
      TCAV(131)=(TI11+TM1(1))/2.0
      DO 37 I=2, 10
   37 TCAV(I+130)=(TM1(I-1)+TM1(I))/2.0
      TCAV(141)=TSO1
      TCAV(142)=TEI1
      TCAV(143)=TI12
      TCAV(144)=(TI12+TM2(1))/2.0
      DO 38 I=2, 10
   38 TCAV(I+143)=(TM2(I-1)+TM2(I))/2.0
      TCAV(154)=TI13
      TCAV(155)=(TI13+TM3(1))/2.0
      DO 39 I=2, 10
   39 TCAV(I+154)=(TM3(I-1)+TM3(I))/2.0
      TCAV(165)=TI14
      TCAV(166)=(TI14+TM4(1))/2.0
      DO 40 I=2, 10
   40 TCAV(165+I)=(TM4(I-1)+TM4(I))/2.0
C      INTERMEDIATE LOOP 2:
      TCAV(176)=(TM8(N24)+TS2(K2+1))/2.0
C      FIRST, ASSUME A DUMMY AVERAGE TEMPERATURE FOR THE MAXIMUM NO. OF NODES
      IF(ICOUNT.NE.0) GO TO 411
      DO 410 I=1, 11
  410 TCAV(176+I)=TCAV(176)
  411 CONTINUE
      DO 41 I=1, K2
   41 TCAV(176+I)=(TS2(K22-I)+TS2(K21-I))/2.0
      TCAV(177+K2)=(TS2(K2+2)+TS2(1))/2.0
      TCAV(188)=(TI21+TM5(1))/2.0
      DO 42 I=2, 10
   42 TCAV(I+187)=(TM5(I-1)+TM5(I))/2.0
      TCAV(198)=TSO2
      TCAV(199)=TEI2
      TCAV(200)=TI22
      TCAV(201)=(TI22+TM6(1))/2.0
      DO 43 I=2, 10
   43 TCAV(I+200)=(TM6(I-1)+TM6(I))/2.0
      TCAV(211)=TI23
      TCAV(212)=(TI23+TM7(1))/2.0
      DO 44 I=2, 10
   44 TCAV(I+211)=(TM7(I-1)+TM7(I))/2.0
      TCAV(222)=TI24
      TCAV(223)=(TI24+TM8(1))/2.0
      DO 45 I=2, 10
   45 TCAV(I+222)=(TM8(I-1)+TM8(I))/2.0
```

```
C
C       DEFINE DUMMY VECTOR OF MASS FLOW RATE, "W" LBM/HRS
      DO 200 I=1, 3
      W(I)=WHC
      W(I+3)=WIC
      W(I+6)=WOC
  200 CONTINUE
      W(10)=WCA
      W(11)=WRB
      W(12)=WBP
      DO 201 I=13, 29
  201 W(I)=WI1+XLOOP*WI2
      DO 202 I=30, 74
  202 W(I)=WI1
      DO 203 I=75, 118
  203 W(I)=WI2
      DO 204 I=119, 141
  204 W(I)=WS1
      DO 205 I=142, 153
  205 W(I)=WS1/2.0
      DO 206 I=154, 175
  206 W(I)=WS1
      DO 207 I=176, 197
  207 W(I)=WS2
      DO 208 I=198, 210
  208 W(I)=WS2/2.0
      DO 209 I=211, 232
  209 W(I)=WS2
C       CALCULATE MASS FLUX OF SODUIM  LBM/HRS-SQ. FT
      DO 210 I=1, 232
  210 G(I)=W(I)/AHY(I)
C
C       NOW, WE ARE READY TO CALL THE PHYSICAL PROPERTIES SUBPROGRAM
      CALL PHYPRS(232)
      DENAB=DE3(NODEB)
C       CALCULATE THE COEFFICIENT OF FRICTION
C
C       1. REACTOR FLOWS
      DO 211 I=1, 3
      FH(I)=FRFAC(RE(I), P(I), OD(I), WL(I), 1)
      FI(I)=FRFAC(RE(I+3), P(I+3), OD(I+3), WL(I+3), 1)
  211 FO(I)=FRFAC(RE(I+6), P(I+6), OD(I+6), WL(I+6), 1)
      FC(1)=FRFAC(RE(10),P(10),OD(10),WL(10),1)
      FR(1)=FRFAC(RE(11),P(11),OD(11),WL(11),1)
      FB(1)=FRFAC(RE(12),0.,0.,0.,0)
      FB(2)=0.
      DO 212 I=1, 4
  212 FP(I)=0.0
      DO 213 I=1, NP1
  213 F1(I)=FRFAC(RE(I+30),0.,0.,0.,0)
      DO 214 I=1, NP2
  214 F2(I)=FRFAC(RE(I+41),0.,0.,0.,0)
      DO 215 I=1, NP3
  215 F3(I)=FRFAC(RE(I+64),0.,0.,0.,0)
      DO 216 I=1, NP4
  216 F4(I)=FRFAC(RE(I+74),0.,0.,0.,0)
      DO 217 I=1, NP5
  217 F5(I)=FRFAC(RE(I+85),0.,0.,0.,0)
      DO 218 I=1, NP6
  218 F6(I)=FRFAC(RE(I+108),0.,0.,0.,0)
      KP1=K1+3
```

```
      KP2=K2+3
      DO 219 I=1, KP1
  219 FX1(I)=FRFAC(RE(I+51),0.,0.,0.,0)
      DO 220 I=1, KP2
  220 FX2(I)=FRFAC(RE(I+95),0.,0.,0.,0)
C      2. INTERMEDIATE LOOPS
      FHX1=FRFAC(RE(130),0.,0.,0.,0)
      FHX2=FRFAC(RE(187),0.,0.,0.,0)
      FSH1=FRFAC(RE(141),0.,0.,0.,0)
      FSH2=FRFAC(RE(198),0.,0.,0.,0)
      FSE1=FRFAC(RE(142),0.,0.,0.,0)
      FSE2=FRFAC(RE(199),0.,0.,0.,0)
      FEV1=FRFAC(RE(143),0.,0.,0.,0)
      FEV2=FRFAC(RE(200),0.,0.,0.,0)
C      PIPE RUNS
      DO 221 I=1, N11
  221 FS1(I)=FRFAC(RE(130+I),0.,0.,0.,0)
      DO 222 I=1, N12
  222 FS2(I)=FRFAC(RE(143+I),0.,0.,0.,0)
      DO 223 I=1, N13
  223 FS3(I)=FRFAC(RE(154+I),0.,0.,0.,0)
      DO 224 I=1, N14
  224 FS4(I)=FRFAC(RE(165+I),0.,0.,0.,0)
      DO 225 I=1, N21
  225 FS5(I)=FRFAC(RE(187+I),0.,0.,0.,0)
      DO 226 I=1, N22
  226 FS6(I)=FRFAC(RE(200+I),0.,0.,0.,0)
      DO 227 I=1, N23
  227 FS7(I)=FRFAC(RE(211+I),0.,0.,0.,0)
      DO 228 I=1, N24
  228 FS8(I)=FRFAC(RE(222+I),0.,0.,0.,0)
C      CALCULATE THE BOUYANCY INDUCED PRESSEURE GRADIENTS AS WELL AS
C      THE FRICTIONAL COEFFICIENTS FOR THAT REGION AND ITS VELOCITY
C      HEAD FACTOR "K" (ONLY ONCE AT THE STEADY STATE CONDITIONS)
      CALL GHEAD(3,GC,ZIN2,ZH,DEIP1,DEH,W(1),P1,P2,FH,AHY(1),DHY(1),XLH,
     1 DPG(1),FTH,XKH)
      CALL GHEAD(3,GC,ZIN2,ZI,DEIP1,DEI,W(4),P1,P2,FI,AHY(4),DHY(4),XLI,
     1 DPG(2),FTI,XKI)
      CALL GHEAD(3,GC,ZIN2,ZO,DEIP1,DEO,W(7),P1,P2,FO,AHY(7),DHY(7),XLO,
     1 DPG(3),FTO,XKO)
      CALL GHEAD(1,GC,ZIN2,ZC,DEIP1,DEC,W(10),P1,P2,FC,AHY(10),DHY(10),
     1 XLC,DPG(4),FTC,XKC)
      CALL GHEAD(1,GC,ZIN2,ZR,DEIP1,DER,W(11),P1,P2,FR,AHY(11),DHY(11),
     1 XLR,DPG(5),FTR,XKR)
      DBP(1)=DEB(1)
      DBP(2)=DON12(1)
      CALL GHEAD(2,GC,ZIN2,ZB,DEIP1,DBP,W(12),P1,P2,FB,AHY(12),DHY(12),
     1 XLB,DPG(6),FTB,XKB)
C      PRIMARY HEAT TRANSPORT SYSTEM
      CALL GHEAD(NP1,GC,ZON,Z1,DON12(1),DE1,WI1,P3,P4,F1,AHY(30),DHY(30)
     1 ,XL1,DPG(7),FT1,XK1)
C      PUMP 1
      ROWP1=(DE1(NP1)+DP1(1))/2.0
      DPG(8)=ROWP1*(Z1(NP1)-ZP1)
      CALL GHEAD(NP2,GC,ZP1,Z2,DP1(1),DE2,WI1,P5,P6,F2,AHY(40),DHY(40),
     1 XL2,DPG(9),FT2,XK2)
      CALL GHEAD(KP1,GC,Z2(NP2),ZX1,DE2(NP2),DX1,WI1,P6,P7,FX1,AHY(52),
     1 DHY(52),XLX1,DPG(10),FTX1,XKX1)
      IF(MODE.EQ.2) NDB=NODEB
      CALL GHEAD(NP3,GC,ZX1(KP1),Z3,DX1(KP1),DE3,WI1,P7,P8,F3,AHY(64),
     1 DHY(64),XL3,DPG(11),FT3,XK3)
```

```
      NDB=0
      CALL GHEAD(NP4,GC,ZON,Z4,DON12(1),DE4,WI2,P3,P9,F4,AHY(74),DHY(74)
     1 ,XL4,DPG(12),FT4,XK4)
C       PUMP 2
      ROWP2=(DE4(NP4)+DP2(1))/2.0
      DPG(13)=ROWP2*(Z4(NP4)-ZP2)
      CALL GHEAD(NP5,GC,ZP2,Z5,DP2(1),DE5,WI2,P10,P11,F5,AHY(85),DHY(85)
     1 ,XL5,DPG(14),FT5,XK5)
      CALL GHEAD(KP2,GC,Z5(NP5),ZX2,DE5(NP5),DX2,WI2,P11,P12,FX2,AHY(96)
     1 ,DHY(96),XLX2,DPG(15),FTX2,XKX2)
      CALL GHEAD(NP6,GC,ZX2(KP2),Z6,DX2(KP2),DE6,WI2,P12,P8,F6,AHY(108),
     1 DHY(108),XL6,DPG(16),FT6,XK6)
C       INLET PLENUM
      CALL GHEAD(1,GC,ZIN1,ZIN2,DEIP1,DEIP2,W(15),P8,P1,FP(1),AHY(15),
     1 DHY(15),XLIN,DPG(17),FTIP1,XKIP1)
C       OUTLET PLENUM
      CALL GHEAD(1,GC,ZH(3),ZON,DEOP1,DON12(1),W(27),P2,P3,FP(2),
     1 AHY(16),DHY(16),XLOUT,DPG(18),FTOP,XKOP)
C       INTERMEDIATE LOOPS
      CALL GHEAD(1,GC,ZS4(N14),ZHX1,DES4(N14),DSX1,WS1,PS2,PS3,FHX1,
     1 AHY(130),DHY(130),XLS(9),DPG(19),FTHX1,XKHX1)
      CALL GHEAD(1,GC,ZS8(N24),ZHX2,DES8(N24),DSX2,WS2,PI2,PI3,FHX2,
     1 AHY(187),DHY(187),XLS(9),DPG(20),FTHX2,XKHX2)
      CALL GHEAD(1,GC,ZS1(N11),ZSH1,DES1(N11),DSH1,WS1,PS4,PS5,FSH1,
     1 AHY(141),DHY(141),XLS(10),DPG(21),FTSH1,XKSH1)
      CALL GHEAD(1,GC,ZS5(N21),ZSH2,DES5(N21),DSH2,WS2,PI4,PI5,FSH2,
     1 AHY(198),DHY(198),XLS(10),DPG(22),FTSH2,XKSH2)
      CALL GHEAD(1,GC,ZSH1,ZEVI1,DSH1,DEVI1,W(142),PS5,PS6,FSE1,AHY(142)
     1 ,DHY(142),XLS(11),DPG(23),FTSE1,XKSE1)
      CALL GHEAD(1,GC,ZSH2,ZEVI2,DSH2,DEVI2,W(199),PI5,PI6,FSE2,AHY(199)
     1 ,DHY(199),XLS(11),DPG(24),FTSE2,XKSE2)
      CALL GHEAD(1,GC,ZEVI1,ZEVO1,DEVI1,DEVO1,W(143),PS6,PS7,FEV1,
     1 AHY(143),DHY(143),XLS(12),DPG(25),FTEV1,XKEV1)
      CALL GHEAD(1,GC,ZEVI2,ZEVO2,DEVI2,DEVO2,W(200),PI6,PI7,FEV2,
     1 AHY(200),DHY(200),XLS(12),DPG(26),FTEV2,XKEV2)
C       INTERMEDIATE PIPE RUNS
      CALL CHEAD(N11,GC,ZHX1,ZS1,DSX1,DES1,WS1,PS3,PS4,FS1,AHY(140),
     1 DHY(140),XLS1,DPG(27),FTS1,XKS1)
      CALL GHEAD(N12,GC,ZEVO1,ZS2,DEVO1,DES2,W(153),PS7,PS8,FS2,AHY(153)
     1 ,DHY(153),XLS2,DPG(28),FTS2,XKS2)
      CALL GHEAD(N13,GC,ZS2(N12),ZS3,DES2(N12),DES3,W(164),PS8,PS9,FS3,
     1 AHY(164),DHY(164),XLS3,DPG(29),FTS3,XKS3)
      DPG(30)=DES3(N13)*(ZS3(N13)-ZSP1)
      CALL GHEAD(N14,GC,ZSP1,ZS4,DES3(N13),DES4,WS1,PS1,PS2,FS4,AHY(175)
     1 ,DHY(175),XLS4,DPG(31),FTS4,XKS4)
C      LOOP 2
      CALL GHEAD(N21,GC,ZHX2,ZS5,DSX2,DES5,WS2,PI3,PI4,FS5,AHY(197),
     1 DHY(197),XLS5,DPG(32),FTS5,XKS5)
      CALL GHEAD(N22,GC,ZEVO2,ZS6,DEVO2,DES6,W(210),PI7,PI8,FS6,AHY(210)
     1 ,DHY(210),XLS6,DPG(33),FTS6,XKS6)
      CALL GHEAD(N23,GC,ZS6(N22),ZS7,DES6(N22),DES7,WS2,PI8,PI9,FS7,
     1 AHY(221),DHY(221),XLS7,DPG(34),FTS7,XKS7)
      DPG(35)=DES7(N23)*(ZS7(N23)-ZSP2)
      CALL GHEAD(N24,GC,ZSP2,ZS8,DES7(N23),DES8,WS2,PI1,PI2,FS8,AHY(232)
     1 ,DHY(232),XLS8,DPG(36),FTS8,XKS8)
C
C       DETERMINE THE TOTAL PRESSURE GRADIENTS DUE TO GRAVITY
      DHG(1)=DPG(7)+DPG(8)+DPG(9)+DPG(10)+DPG(11)
      DHG(2)=DPG(12)+DPG(13)+DPG(14)+DPG(15)+DPG(16)
      DHG(3)=DPG(17)+DPG(18)
      DHG(4)=DPG(2)
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      DHG(5)=DPG(3)
      DHG(6)=DPG(1)
      DO 400 I=4, 6
  400 DHG(I+3)=DPG(I)
      DHG(10)=DPG(19)+DPG(21)+DPG(23)+DPG(25)+DPG(27)+DPG(28)+DPG(29)+
     1 DPG(30)+DPG(31)
      DHG(11)=DPG(20)+DPG(22)+DPG(24)+DPG(26)+DPG(32)+DPG(33)+DPG(34)+
     1 DPG(35)+DPG(36)
C
C       CALCULATE THE OVERALL FRICTIONAL LOSS COEFFICIENTS
C
      CROBB=FT1+FT2+FTX1+XK1+XK2+XKX1+CROBB
      HEADBB=DPG(7)+DPG(8)+DPG(9)+DPG(10)+HEADBB
      C(1)=FT1+FT2+FT3+FTX1+XK1+XK2+XK3+XKX1
      C(2)=FT4+FT5+FT6+FTX2+XK4+XK5+XK6+XKX2
      C(3)=FTIP1+FTOP+XKIP1+XKOP
      C(4)=FTI+XKI
      C(5)=FTO+XKO
      C(6)=FTH+XKH
      C(7)=FTC+XKC
      C(8)=FTR+XKR
      C(9)=FTB+XKB
      C(10)=FTHX1+XKHX1+FTSH1+XKSH1+((FTSE1+XKSE1+FTEV1+XKEV1+FTS2+XKS2)
     1 /4.0)+FTS1+XKS1+FTS3+XKS3+FTS4+XKS4
      C(11)=FTHX2+XKHX2+FTSH2+XKSH2+((FTSE2+XKSE2+FTEV2+XKEV2+FTS6+XKS6)
     1 /4.0)+FTS5+XKS5+FTS7+XKS7+FTS8+XKS8
      TRI1=TC3(NP3)
      TRI2=TC6(NP6)
      CRIP=FTIP1+XKIP1
      RETURN
      ENTRY RSTFBR(MODE, HOP, KX1, KX2, PD)
C          CALCULATE THE PRIMARY AND SECONDARY SYSTEM PRESSURES FOR RESTART
C
C          PRIMARY LOOPS
      P3=PCG+ZOPNOM*DON12(1)/144.
      P4=P3-((XK1+FT1)*WI1**2-DPG(7))/144.
      P2=P3+((XKOP+FTOP)*W(27)**2-DPG(18))/144.
      P1=P2+((XKR+FTR)*W(11)**2-DPG(5))/144.
      P8=P1+((XKIP1+FTIP1)*W(15)**2-DPG(17))/144.
      P7=P8+((XK3+FT3)*WI1**2-DPG(11))/144.
      P6=P7+((XKX1+FTX1)*WI1**2-DPG(10))/144.
      P5=P6+((XK2+FT2)*WI1**2-DPG(9))/144.
      P12=P8+((XK6+FT6)*WI2**2-DPG(16))/144.
      P11=P12+((XKX2+FTX2)*WI2**2-DPG(15))/144.
      P10=P11+((XK5+FT5)*WI2**2-DPG(14))/144.
      P9=P3-((XK4+FT4)*WI2**2-DPG(12))/144.
C          INTERMEDIATE LOOP 1
      PS8=PS9+((XKS3+FTS3)*W(164)**2-DPG(29))/144.
      PS7=PS8+((XKS2+FTS2)*W(153)**2-DPG(28))/144.
      PS6=PS7+((XKEV1+FTEV1)*W(143)**2-DPG(25))/144.
      PS5=PS6+((XKSE1+FTSE1)*W(142)**2-DPG(23))/144.
      PS4=PS5+((XKSH1+FTSH1)*WS1**2-DPG(21))/144.
      PS3=PS4+((XKS1+FTS1)*WS1**2-DPG(27))/144.
      PS2=PS3+((XKHX1+FTHX1)*WS1**2-DPG(19))/144.
      PS1=PS2+((XKS4+FTS4)*WS1**2-DPG(31))/144.
C          INTERMEDIATE LOOP 2
      PI8=PI9+((XKS7+FTS7)*WS2**2-DPG(34))/144.
      PI7=PI8+((XKS6+FTS6)*W(210)**2-DPG(33))/144.
      PI6=PI7+((XKEV2+FTEV2)*W(200)**2-DPG(26))/144.
      PI5=PI6+((XKSE2+FTSE2)*W(199)**2-DPG(24))/144.
      PI4=PI5+((XKSH2+FTSH2)*WS2**2-DPG(22))/144.
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      PI3=PI4+((XKS5+FTS5)*WS2**2-DPG(32))/144.
      PI2=PI3+((XKHX2+FTHX2)*WS2**2-DPG(20))/144.
      PI1=PI2+((XKS8+FTS8)*WS2**2-DPG(36))/144.
C
      IF(PD.EQ.1.) WI100=WI1
      IF(PD.EQ.1.) WS100=WS1
      CALL RSTCON
      PBRK=PBRK*PFAC
      PGV=PGV*PFAC
      ZBRK=ZBRK*XFAC
      XBRK=XBRK*XFAC
      GO TO 998
      END
```

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DATA SET UTILITY - GENERATE

IEB352I WARNING : OUTPUT RECFM/LRECL/BLKSIZE COPIED FROM INPUT

PROCESSING ENDED AT EOD
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```
      SUBROUTINE NEUKIN(MSCRAM,PTOT,PD)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C              NEUTRON KINETICS SIMULATION                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL LAM
      DIMENSION LAM(5),P(5),B(5),TAU(8)
      DIMENSION ROMAX(2),ROSTUK(2),XO(2)
      DIMENSION ASOD(11),ADOP(11),ACAE(11),TSOD(11),TCENT(3),TDUM(3)
      EQUIVALENCE (R(1),P(1)),(R(6),TSTM),(R(7),TROM),(R(8),ROCR1)
      EQUIVALENCE (TDUM(1),TFREF),(TDUM(2),TCREF),(TDUM(3),TSTSP)
      COMMON/SCRP/PTOTN,RO
      COMMON/PHDR/PH,TST
      COMMON/REACT/P100,RNSERT,TNSERT
      COMMON/MISC/THOUR,T,ICOUNT,SHOUR,S,IPRINT,TMAXSC
      COMMON/FBR1/TC(12),TIP1,TIP2,TCI(6),TOP1,TOP2,TON,TM(11)
      COMMON/GET1/WDUM1(3),WIC,WOC,WHC,WDUM2(7)
      COMMON/PHY6/CDUM1(23),CPO(5),CDUM2(204)
      COMMON/RTSETP/AT(3)
      COMMON/ALLR/R(8),DUM11(481)
      COMMON/ALLF/F(8),DUF11(481)
      COMMON/ALLNUL/NULL(8),DUN11(481)
      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/FACT/FDUM1(8),TFAC,FDUM2(7)
      NAMELIST/KINA/LAM,B
      NAMELIST/KINB/XO,ROMAX,ROSTUK,RINMAX,ROSUBC,TRESET,XKT
      NAMELIST/KINC/TROM,TSTM,TSTSP,TAURO,TAUST
      NAMELIST/KIND/TFREF,TCREF,ASOD,ADOP,ACAE,ACRE
      NAMELIST/KINE/PRIMA,PRIMB,SECA,SECB
      NAMELIST/KINF/AT
      DATA PI,TKEL/3.141593,459.67/
      DATA KSCRM1,KSCRM2,KNSERT/3*0/
      M=KRUNG+2
      GO TO ( 999,3000,2000,2100,1040,996),M
C          THIS STATEMENT IS OF THE FORM  GO TO (A,B,C,D,E,F) ,  WHERE:
C             A IS INITIALIZATION OF ALL RUN DATA; B IS PROMPT APPROXIMATION
C             CALCULATION; C IS INITIALIZE NEW TIME STEP VALUES AND COMPUTE
C             DERIVATIVES; D IS COMPUTE DERIVATIVES;  E IS COMPUTE NEW
C             TIME CONSTANTS; AND F IS INITIALIZE WITHOUT INPUT (RESTART).
C
  996 DO 997 I=1,11
      ASOD(I)=ASOD(I)*TFAC
  997 ACAE(I)=ACAE(I)*TFAC
      ACRE=ACRE*TFAC
      CALL TMPCON(1,3,AT)
      CALL TMPCON(1,3,TDUM)
      CALL TMPCON(1,1,TROM)
      CALL TMPCON(1,1,TSTM)
      GO TO 998
  999 READ(5,KINA)
      READ(5,KINB)
      READ(5,KINC)
      READ(5,KIND)
      READ(5,KINE)
      READ(5,KINF)
  998 WRITE(6,KINA)
      WRITE(6,KINB)
      WRITE(6,KINC)
      WRITE(6,KIND)
      WRITE(6,KINE)
      WRITE(6,KINF)
C
```

```
C         CONVERT INPUT TO PROPER UNITS
      DO 1001 I=1,11
      ASOD(I)=ASOD(I)/TFAC
 1001 ACAE(I)=ACAE(I)/TFAC
      ACRE=ACRE/TFAC
      CALL TMPCON(0,3,AT)
      CALL TMPCON(0,1,TROM)
      CALL TMPCON(0,1,TSTM)
      CALL TMPCON(0,3,TDUM)
C        COMPUTE INITIAL CONDITIONS OF POWER DENSITIES
      BDN=B(1)+B(2)
      BFP=B(3)+B(4)+B(5)
      DO 1000 I=3,5
 1000 P(I)=B(I)*PTOT
      PFP=P(3)+P(4)+P(5)
      PN=PTOT-PFP
      P(1)=B(1)*PN
      P(2)=B(2)*PN
      DELRO=0.
      X1=0.
      X2=0.
      PTOTN=PD
C         COMPUTE REACTIVITY FEEDBACKS
      RODOP=0.
      ROSOD=0.
      ROCAE=0.
      TSOD(1)=(TCI(1)+TC(1))/2.0
      TSOD(4)=(TCI(2)+TC(4))/2.0
      TSOD(7)=(TCI(3)+TC(7))/2.0
      TSOD(10)=(TCI(4)+TC(10))/2.0
      TSOD(11)=(TCI(5)+TC(11))/2.0
      DO 1 I=2, 3
      TSOD(I)=(TC(I-1)+TC(I))/2.0
      TSOD(I+3)=(TC(I+2)+TC(I+3))/2.0
      TSOD(I+6)=(TC(I+5)+TC(I+6))/2.0
    1 CONTINUE
      ROCRE=ACRE*(TIP2-TCREF)
      DO 2 I=1, 11
      RODOP=RODOP+ADOP(I)*ALOG((TM(I)+TKEL)/(TFREF+TKEL))
      ROSOD=ROSOD+ASOD(I)*(TSOD(I)-TCREF)
      ROCAE=ROCAE+ACAE(I)*(TM(I)-TFREF)
    2 CONTINUE
      ROFDBK=RODOP+ROSOD+ROCRE+ROCAE
      ROCR1=-(ROFDBK+ROSUBC)
      ROCR2=0.
      RO=ROCR1+ROFDBK+ROSUBC+ROCR2
      TOLD=T
      DROMAX=RINMAX*S
      RETURN
 1040 DO 1050 I=1,5
      TAU(I)=1./LAM(I)
 1050 CONTINUE
      TAU(6)=TAUST
      TAU(7)=TAURO
      TAU(8)=TRESET
      J=1
      DO 1060 I=1,8
      IF((TAU(I)*0.7).GE.S) GO TO 1060
      NULL(J)=I
      J=J+1
 1060 CONTINUE
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 2000 IF(T.LT.TNSERT) GO TO 2100
      IF(KNSERT.NE.0) GO TO 2100
      ROCR1=ROCR1+RNSERT
      KNSERT=1
      WRITE(6,390) RNSERT,T
 2100 IF(ROCR1.GT.ROMAX(1)) ROCR1=ROMAX(1)
      IF(MSCRAM.EQ.0) GO TO 2500
      IF(MSCRAM.EQ.2) GO TO 2300
C         CONTROL ROD REACTIVITY FOLLOWING A PRIMARY SCRAM
      IF(KSCRM1.NE.0) GO TO 2200
      KSCRM1=1
      TSCRM1=T
      WRITE(6,340) TSCRM1
      RO100=ROCR1-ROSTUK(1)
      XKG=0.
 2200 X1=PRIMA*(T-TSCRM1)**2/(1.+PRIMB*(T-TSCRM1))
      IF(X1.GT.X0(1)) X1=X0(1)
      ROCR1=RO100*(1.-X1/X0(1)+1./(2.*PI)*SIN(2.*PI*X1/X0(1)))+ROSTUK(1)
      IF(MSCRAM.EQ.1) GO TO 2800
C         CONTROL ROD REACTIVITY FOLLOWING A SECONDARY SCRAM
 2300 IF(KSCRM2.NE.0) GO TO 2400
      KSCRM2=1
      TSCRM2=T
      WRITE(6,350) TSCRM2
      RO200=ROMAX(2)-ROSTUK(2)
 2400 X2=SECA*(T-TSCRM2)**2/(1.+SECB*(T-TSCRM2))
      IF(X2.GT.X0(2)) X2=X0(2)
      ROCR2=-RO200*(X2/X0(2)-1./(2.*PI)*SIN(2.*PI*X2/X0(2)))
      GO TO 2800
C         CONTROL ROD REACTIVITY DURING NORMAL OPERATION
 2500 TROSP=RVOTSP(PD)
      FRSP=PD
      FR=PTOT/P100
      XKF=1./(2.*AT(1)*FRSP+AT(2))
      ETST=TSTSP-TSTM
      IF(ABS(ETST).LE.2.) ETST=0.
      ETROT=XKT*ETST
      TROSPT=TROSP+ETROT
      ETRO=TROSPT-TROM
      IF(ABS(ETRO).LE.2.) ETRO=0.
      EFTT=XKF*ETRO
      FRSPTT=FRSP+EFTT
      IF(FRSPTT.GT.1.0) FRSPTT=1.
      EF=FRSPTT-FR
      IF(ABS(EF).LE.0.01) EF=0.
      IF(EF.GE.0.05) EF=0.05
      IF(EF.LE.(-0.05)) EF=-0.05
      DELRO=DELRO+(T-TOLD)/TRESET*EF
      TOLD=T
      XKG=RINMAX/(.05*(1.+T/TRESET))
 2800 RODOP=0.
      ROSOD=0.
      ROCAE=0.
      TSOD(1)=(TCI(1)+TC(1))/2.0
      TSOD(4)=(TCI(2)+TC(4))/2.0
      TSOD(7)=(TCI(3)+TC(7))/2.0
      TSOD(10)=(TCI(4)+TC(10))/2.0
      TSOD(11)=(TCI(5)+TC(11))/2.0
      DO 3 I=2, 3
      TSOD(I)=(TC(I-1)+TC(I))/2.0
      TSOD(I+3)=(TC(I+2)+TC(I+3))/2.0
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      TSOD(I+6)=(TC(I+5)+TC(I+6))/2.0
    3 CONTINUE
      ROCRE=ACRE*(TIP2-TCREF)
      DO 4 I=1, 11
      RODOP=RODOP+ADOP(I)*ALOG((TM(I)+TKEL)/(TFREF+TKEL))
      ROSOD=ROSOD+ASOD(I)*(TSOD(I)-TCREF)
      ROCAE=ROCAE+ACAE(I)*(TM(I)-TFREF)
    4 CONTINUE
      ROFDBK=RODOP+ROSOD+ROCRE+ROCAE
      RO=ROCR1+ROCR2+ROFDBK+ROSUBC
C          COMPUTE CURRENT VALUES OF PN, PFP, AND PTOT
      PN=(P(1)+P(2))/(1.-RO)/BDN
      PFP=P(3)+P(4)+P(5)
      PTOT=PN+PFP
      J=1
      DO 2870 I=1,2
      IF(NULL(J).EQ.I) GO TO 2865
      F(I)=LAM(I)*(B(I)*PN-P(I))*3600.
      GO TO 2870
 2865 J=J+1
 2870 CONTINUE
      DO 2890 I=3,5
      IF(NULL(J).EQ.I) GO TO 2885
      F(I)=LAM(I)*(B(I)*PTOT-P(I))*3600.
      GO TO 2890
 2885 J=J+1
 2890 CONTINUE
      IF(NULL(J).EQ.6) GO TO 2892
      F(6)=(TST-TSTM)/TAU(6)*3600.
      GO TO 2893
 2892 J=J+1
 2893 IF(NULL(J).EQ.7) GO TO 2894
      TRO=(WHC*CPO(1)*TC(3)+WIC*CPO(2)*TC(6)+WOC*CPO(3)*TC(9))/
     1    (WHC*CPO(1)+WIC*CPO(2)+WOC*CPO(3))
      F(7)=(TRO-TROM)/TAU(7)*3600.
      GO TO 2895
 2894 J=J+1
 2895 IF(NULL(J).EQ.8) GO TO 2896
      F(8)=XKG*(EF+DELRO)*3600.
 2896 RETURN
 3000 RODOP=0.
      ROSOD=0.
      ROCAE=0.
      TSOD(1)=(TCI(1)+TC(1))/2.0
      TSOD(4)=(TCI(2)+TC(4))/2.0
      TSOD(7)=(TCI(3)+TC(7))/2.0
      TSOD(10)=(TCI(4)+TC(10))/2.0
      TSOD(11)=(TCI(5)+TC(11))/2.0
      DO 5 I=2, 3
      TSOD(I)=(TC(I-1)+TC(I))/2.0
      TSOD(I+3)=(TC(I+2)+TC(I+3))/2.0
      TSOD(I+6)=(TC(I+5)+TC(I+6))/2.0
    5 CONTINUE
      ROCRE=ACRE*(TIP2-TCREF)
      DO 6 I=1, 11
      RODOP=RODOP+ADOP(I)*ALOG((TM(I)+TKEL)/(TFREF+TKEL))
      ROSOD=ROSOD+ASOD(I)*(TSOD(I)-TCREF)
      ROCAE=ROCAE+ACAE(I)*(TM(I)-TFREF)
    6 CONTINUE
      ROFDBK=RODOP+ROSOD+ROCRE+ROCAE
      IF(ROCR1.GT.ROMAX(1)) ROCR1=ROMAX(1)
```

```
      RO=ROCR1+ROCR2+ROFDBK+ROSUBC
      PN=(P(1)+P(2))/(1.-RO)/BDN
      PFP=P(3)+P(4)+P(5)
      PTOT=PN+PFP
      IF(NULL(1).EQ.0) RETURN
      J=1
      DO 3020 I=1,2
      IF(NULL(J).NE.I) GO TO 3020
      P(I)=B(I)*PN
      J=J+1
 3020 CONTINUE
      DO 3050 I=3,5
      IF(NULL(J).NE.I) GO TO 3050
      P(I)=B(I)*PTOT
      J=J+1
 3050 CONTINUE
      IF(NULL(J).NE.6) GO TO 3060
      TSTM=TST
      J=J+1
 3060 IF(NULL(J).NE.7) GO TO 3070
      TRO=(WHC*CPO(1)*TC(3)+WIC*CPO(2)*TC(6)+WOC*CPO(3)*TC(9))/
     1    (WHC*CPO(1)+WIC*CPO(2)+WOC*CPO(3))
      TROM=TRO
      J=J+1
 3070 IF(NULL(J).NE.8) GO TO 3080
      CR1OLD=ROCR1
      IF(MSCRAM.EQ.0) ROCR1=-(ROCR2+ROFDBK+ROSUBC)
      IF(ROCR1.GT.ROMAX(1)) ROCR1=ROMAX(1)
      DRO=ROCR1-CR1OLD
      IF(DRO.GT.DROMAX) ROCR1=CR1OLD+DROMAX
      IF(DRO.LT.-DROMAX) ROCR1=CR1OLD-DROMAX
 3080 RO=ROCR1+ROCR2+ROFDBK+ROSUBC
      PN=(P(1)+P(2))/(1.-RO)/BDN
      PFP=P(3)+P(4)+P(5)
      PTOT=PN+PFP
      RETURN
      ENTRY PUTNEU
      WRITE(6,360)
      WRITE(6,310) PTOT,PN,PFP
      WRITE(6,320) (I,P(I),I=1,5)
      WRITE(6,330) RO,ROCR1,ROCR2,ROFDBK,RODOP,ROSOD,ROCRE,ROCAE
      TCENT(1)=TRO
      TCENT(2)=TROM
      TCENT(3)=TSTM
      CALL TMPCON(1,3,TCENT)
      WRITE(6,370) TCENT
      PTOTN=PTOT/P100
      PNN=PN/P100
      PFPN=PFP/P100
      POS1=X1/X0(1)*100.
      POS2=X2/X0(2)*100.
      WRITE(6,375) PD,ETST,ETRO,EF,DELRO
      WRITE(6,380) PTOTN,PNN,PFPN,POS1,POS2
      IF(KCALC.EQ.1) WRITE(6,300) (I,TAU(I),I=1,8)
      RETURN
  300 FORMAT(4(3X,'TAU',I2,' =',F10.4,8X))
  310 FORMAT(3X,'PTOT =',F13.3,' MWT',5X,'PN =',F13.3,' MWT',5X,
     1 'PFP =',F13.3,' MWT')
  320 FORMAT(3X,'PDN :',2(I5,F9.3,' MWT'),5X,'PFP :',3(I5,F9.3,' MWT'))
  330 FORMAT(3X,'ROTOT =',F14.6,' $',5X,'ROCR1 =',F14.6,' $',5X,
     1 'ROCR2 =',F14.6,' $',5X,'ROFDBK =',F14.6,' $'/3X,'RODOP =',
```

```
     2  F14.6,' $'.,5X,'ROSOD =',F14.6,' $',5X,'ROCRE =',F14.6,' $',
     3  5X,'ROCAE  =',F14.6,' $')
  340 FORMAT(/10X,'**** PRIMARY SCRAM INITIATED AT TIME =',F8.3,
     1  ' SEC ****'/)
  350 FORMAT(/10X,'**** SECONDARY SCRAM INITIATED AT TIME =',F8.3,
     1  ' SEC ****'/)
  360 FORMAT(/,2X,26('*'),5X,'N E U T R O N     K I N E T I C S     ',
     1  'C A L C U L A T I O N S',5X,26('*')/)
  370 FORMAT(3X,'TRO    =',F11.3,11X,'TROM   =',F11.3,11X,
     1  'TSIM  =',F11.3)
  375 FORMAT(3X,'PD =',F15.4,9X,'ETST  =',F14.6,7X,'ETRO  =',F14.6,3X,
     1  'EF =',F13.6,3X,'DELRO =',F13.6)
  380 FORMAT(3X,'PTOTNORM =',F9.4,9X,'PNNORM =',F11.4,9X,'PFPNORM =',
     1  F10.4,5X,'SCRAM RODS:   PRIM =',F8.3,' %',3X,'SEC =',F8.3,' %')
  390 FORMAT(/10X,'**** REACTIVITY INSERTION OF $',F6.3,' AT',F7.4,
     1  ' SEC ****'/)
      END
      SUBROUTINE HYDROS (MODE,KMM1,KMM2,PD,HOP)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C          PRIMARY COOLANT DYNAMICS SIMULATION                       C
C                 WITH FLOW CONTROLLERS                              C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL NEW1,NEW2,KMM1,KMM2,KPM1,KPM2,MINERT,NEWM1,NEWM2,NEWSP
      REAL NWSPT1,NWSPT2
      DIMENSION W(8),XF(7),AX(18),A(7,8),TAU(18),ROW(2)
      DIMENSION DWY(8,8),RHS(8),TRIX(8,9),DW(8),WNRM(8)
      DIMENSION WPRT(7),TPRT(3)
      COMMON/GET1/W100,W1,W2,WIC,WOC,WHC,WCA,WRB,WBP,WS100,
     1   WS1,WS2,WBRK
      COMMON/LOOP/XLOOP
      COMMON/SCRH/ALM1,ALM2,PRSNRM,NEWM1,NEWM2,ZOPTOT
      COMMON/HYD1/TRI1,TRI2,CRIP
      COMMON/HYD2/NODB,PBRK,ZBRK,XLBRK,CROBB,CROAB,HEADBB,HEADAB,DENAB
      COMMON/HYD3/ZOPNOM,DZCON,PCG,PGV,PINLET,AOP
      COMMON/PHY4/DDM1(29),DENOP,DDM2(10),DPUMP1,DDM3(23),DEN3(10),
     1   DDM4(10),DPUMP2,DDM5(147)
      COMMON/ALFA/PMSSP,DSPEED,POLES,CA,CB,CE,ALO,TS,TR,TMIN
      COMMON/NATCON/NOPON1,NOPON2
      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/HEADS/GHEAD1,GHEAD2,GHPLEN,GH(6),GDUM(2)
      COMMON/FRICTS/CRLP1,CRLP2,CRPLEN,CRC(6),CRDUM(2)
      COMMON/ALLR/DUM21(8),R(18),DUM22(463)
      COMMON/ALLF/DUF21(8),F(18),DUF22(463)
      COMMON/ALLNUL/DUN21(8),NULL(18),DUN22(463)
      COMMON/MISC/THOUR,T,ICOUNT,SHOUR,S,IPRINT,TMAXSC
      COMMON/FACT/XFAC,AFAC,VFAC,WFAC,PFAC,DFAC,FDUM1(3),XMFAC,TQFAC,
     1   SPFAC,XILFAC,FDUM2(2),GC
      COMMON/NORMS/WP100(8),WDUM(4),PR100
      NAMELIST/HYDA/AX
      NAMELIST/HYDB/CA,CB,CE,MINERT,TMMD,DSPEED,POLES,PMSSP
      NAMELIST/HYDC/CDBRK,AX5BB,AXAB,VOLGV,SGVMID,SGVTOP,ZGVMID,ZGVTOP
      NAMELIST/HYDD/CONVG,FREQ0,XKA,TK,TS,TR,TMIN,ALO
      NAMELIST/HYDE/FREQ1,FREQ2,AL1,AL2
      NAMELIST/HYDF/TAUWM,TAUAM,TAUTM,TRISPN
      DATA KTRIP1,KTRIP2/2*0/
      DATA NOBPRV/1/
      DATA DWY/64*0./,DW/8*0./
      DATA EPS,EPS1,EPS2/1.0E-5,1.E-15,1.0E-10/
      M=KRUNG+2
      IF(T.NE.0.) QKMM1=KMM1+FRICK*KMM1
      IF(T.NE.0.) QKMM2=KMM2+FRICK*KMM2
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      GO TO (999,3000,1390,2000,1390,995),M
C        THIS STATEMENT IS OF THE FORM  GO TO (A,B,C,D,E,F) ,  WHERE:
C         A IS INITIALIZATION OF ALL RUN DATA; B IS PROMPT APPROXIMATION
C         CALCULATION; C IS INITIALIZE NEW TIME STEP VALUES AND COMPUTE
C         DERIVATIVES; D IS COMPUTE DERIVATIVES;  E IS COMPUTE NEW
C         TIME CONSTANTS AND BEGIN NEW TIME STEP; AND F IS THE RESTART OPTION.
C
C         RESTART OPTION
  995 MINERT=MINERT*XMFAC
      TMMD=TMMD*TQFAC
      DSPEED=DSPEED*SPFAC
      PMSSP=PMSSP*SPFAC
      CALL TMPCON(1,1,TRISPN)
      CDBRK=CDBRK*XILFAC*DFAC*VFAC
      VOLGV=VOLGV*VFAC
      SGVMID=SGVMID*AFAC
      SGVTOP=SGVTOP*AFAC
      ZGVMID=ZGVMID*XFAC
      ZGVTOP=ZGVTOP*XFAC
      AXAB=AXAB*XILFAC
      DO 996 I=1,18
  996 AX(I)=AX(I)*XILFAC
      AL1=R(8)
      AL2=R(13)
      IF(AL1.EQ.1.) FREQ1=FREQ0
      IF(AL2.EQ.1.) FREQ2=FREQ0
      IF(PD.NE.1.) GO TO 997
      AL1=1.
      AL2=1.
      FREQ1=FREQ0
      FREQ2=FREQ0
      GO TO 997
C         READ INPUT DATA
  999 READ(5,HYDA)
      READ(5,HYDB)
      READ(5,HYDC)
      READ(5,HYDD)
      READ(5,HYDE)
      READ(5,HYDF)
C         PRINT INPUT DATA
  997 WRITE(6,HYDA)
      WRITE(6,HYDB)
      WRITE(6,HYDC)
      WRITE(6,HYDD)
      WRITE(6,HYDE)
      WRITE(6,HYDF)
C         CONVERT INPUT INTO PROPER UNITS
      MINERT=MINERT/XMFAC
      TMMD=TMMD/TQFAC
      DSPEED=DSPEED/SPFAC
      PMSSP=PMSSP/SPFAC
      CALL TMPCON(0,1,TRISPN)
      CDBRK=CDBRK/XILFAC/(DFAC*VFAC)
      VOLGV=VOLGV/VFAC
      SGVMID=SGVMID/AFAC
      SGVTOP=SGVTOP/AFAC
      ZGVMID=ZGVMID/XFAC
      ZGVTOP=ZGVTOP/XFAC
      W(1)=W1
      W(2)=W2
      W(3)=WOC
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      W(4)=WHC
      W(5)=WCA
      W(6)=WRB
      W(7)=W1+XLOOP*W2-WIC-WOC-WHC-WCA-WRB
      W(8)=W1
      WFZ1=WIC
      IF(PD.NE.1.) GO TO 9977
      DO 9976 I=1,8
9976  WP100(I)=W(I)
      WCORE=XLOOP*W(2)+W(1)
      YLP1=CRPLEN*WCORE*ABS(WCORE)+CRLP1*W(1)*ABS(W(1))-GHEAD1-GHPLEN
      HP100=(YLP1+CRC(2)*W(3)*ABS(W(3))-GH(3))/DPUMP1
      GO TO 9979
9977  IF(MODE.NE.0) GO TO 9979
      W1=W100*PD
      W2=W100*PD
      FREQ1=PD*FREQ0
      FREQ2=FREQ1
      AL1=PD
      AL2=PD
      DO 9978 I=1,8
9978  W(I)=PD*WP100(I)
      WFZ1=PD*WFZ100
9979  DO 998 I=1,8
 998  WNRM(I)=W(I)/WP100(I)
      WFZ100=WP100(1)+XLOOP*WP100(2)-WP100(3)-WP100(4)-WP100(5)-WP100(6)
     1      -WP100(7)
      WFZ1N=WFZ1/WFZ100
      IF(MODE.EQ.2) W(1)=WBRK
      ZOPTOT=ZOPNOM
      GVMAX=ZGVTOP-ZBRK
      GVINT=ZGVMID-ZBRK
      VGVINT=GVINT*SGVMID
      VGVMIN=VOLGV-VGVINT-(ZGVTOP-ZGVMID)*SGVTOP
      WCORE=XLOOP*W(2)+W(1)
      W2OLD=W2
      CALL TFRIC(1.,ALO,TS,TR,TMIN,FRICK)
      QKMM1=FRICK*KMM1+KMM1
      QKMM2=FRICK*KMM2+KMM2
      SSPED1=60.*FREQ1/POLES
      SLIP1=1.-DSPEED*AL1/SSPED1
      KPM1=0.
      TPM1=0.
      TMM1=SLIP1/(CA*SLIP1**2+CB)
      IF(AL1.GE.0.1.OR.NOPON1.EQ.1) GO TO 9985
      KPM1=1.
      SLPON1=1.-DSPEED*AL1/PMSSP
      TPM1=CE*SLPON1/(CA*SLPON1**2+CB)
9985  TDM1=QKMM1*TMM1+KPM1*TPM1
      SSPED2=60.*FREQ2/POLES
      SLIP2=1.-DSPEED*AL2/SSPED2
      KPM2=0.
      TPM2=0.
      TMM2=SLIP2/(CA*SLIP2**2+CB)
      IF(AL2.GE.0.1.OR.NOPON2.EQ.1) GO TO 9986
      KPM2=1.
      SLPON2=1.-DSPEED*AL2/PMSSP
      TPM2=CE*SLPON2/(CA*SLPON2**2+CB)
9986  TDM2=QKMM2*TMM2+KPM2*TPM2
      W1100=WP100(1)
      W2100=WP100(2)
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      NEW1=W1/W1100
      NEW2=W2/W2100
      CALL PHEAD(AL1,NEW1,HP1)
      CALL PHEAD(AL2,NEW2,HP2)
      CALL PTORQ(AL1,NEW1,BP1)
      CALL PTORQ(AL2,NEW2,BP2)
      CONST=3.141593*MINERT*DSPEED/(30.*GC*TMMD)
      TRIM1=TRI1
      TRIM2=TRI2
      ALM1=AL1
      ALM2=AL2
      NEWM1=NEW1
      NEWM2=NEW2
      ALOOP1=0.
      ALOOP2=0.
      DO 1000 I=1,5
      ALOOP1=ALOOP1+AX(I)
 1000 ALOOP2=ALOOP2+AX(I+6)
      AXBB=ALOOP1-AX(5)+AX5BB
      APLEN=AX(6)+AX(12)
      DO 1025 I=1,7
      DO 1025 J=1,8
 1025 A(I,J)=0.
      IF(MODE.NE.2) GO TO 1050
      AFLO=AX(12)+AXBB
      A(1,1)=AX(13)+AXAB+AX(6)
      A(2,1)=AX(6)+AXAB
      A(7,1)=AX(6)+AX(13)
      GO TO 1060
 1050 A(1,1)=ALOOP1+APLEN+AX(13)
      A(2,1)=ALOOP1+APLEN
      A(7,1)=APLEN+AX(13)
 1060 A(2,2)=XLOOP*APLEN
      DO 1100 I=3,6
      A(I,1)=A(2,1)
 1100 A(I,2)=A(2,2)
      A(1,2)=XLOOP*(APLEN+AX(13))
      A(7,2)=A(1,2)+ALOOP2
      DO 1200 I=3,7
      A(1,I)=-AX(13)
      A(7,I)=-AX(13)
 1200 A(I-1,I)=AX(11+I)
      WRITE(6,9901)
      WRITE(6,9902) ((I,J,A(I,J),J=1,7),I=1,7)
      DETER=SOLVE(A,XF,0,EPS1)
      WRITE(6,9903) DETER
      WRITE(6,9904)
      WRITE(6,9902) ((I,J,A(I,J),J=1,7),I=1,7)
C         CONVERT INERTIAL LOSS COEFFICIENTS INTO PROPER UNITS
      DO 1250 I=1,7
      DO 1250 J=1,7
 1250 A(I,J)=A(I,J)*XILFAC
      DO 1275 I=1,18
 1275 AX(I)=AX(I)/XILFAC
      APLEN=APLEN/XILFAC
      AFLO=AFLO/XILFAC
      AXAB=AXAB/XILFAC
      AXBB=AXBB/XILFAC
      ALOOP1=ALOOP1/XILFAC
      ALOOP2=ALOOP2/XILFAC
C
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      IF(MODE.NE.2) GO TO 1299
      CHECK=AXAB/SQRT((PBRK-PGV)*CDBRK)*3600.
      IF(S.GE.CHECK) WRITE (6,9918) CHECK
 1299 DO 1300 I=1,2
      ROW(I)=0.
      DO 1300 J=1,7
 1300 ROW(I)=ROW(I)+A(I,J)
C                 SET UP DUMMY VECTOR R
      DO 1350 I=1,7
 1350 R(I)=W(I)
      R(8)=AL1
      R(9)=FREQ1
      R(10)=TRIM1
      R(11)=NEWM1
      R(12)=ALM1
      R(13)=AL2
      R(14)=FREQ2
      R(15)=TRIM2
      R(16)=NEWM2
      R(17)=ALM2
      R(18)=W(8)
      TOLD=0.
      FLLEAK=0.
      YBRK=0.
      HPPRNT=HP100*XFAC
      PCGPRT=PCG*PFAC
      CDPRT=CDBRK/XILFAC/(DFAC*VFAC)
      VGVPRT=VGVMIN*VFAC
      WRITE(6,9917) HPPRNT,PCGPRT
      IF(MODE.EQ.2) WRITE(6,9920) CDPRT,VGVPRT
      DELPP2=HP100*DPUMP2*HP2
      PRSURE=PCG+(DELPP2+ZOPTOT*DENOP+GHEAD2-CRLP2*W2*ABS(W2))/144.
      IF(PD.EQ.1.) PR100=PINLET
      PRSNRM=PRSURE/PR100
      LPDUM=0
      RETURN
 1390 IF(KRUNG.NE.3.AND.MODE.NE.2) GO TO 1800
 1400 DP1DW1=PDERIV(AL1,NEW1,HP100,DPUMP1)/W1100
      DP2DW2=PDERIV(AL2,NEW2,HP100,DPUMP2)/W2100
      WCORE=W(1)+XLOOP*W(2)
      WFZ1=WCORE-W(3)-W(4)-W(5)-W(6)-W(7)
      CRWFZ1=2.*ABS(WFZ1)*CRC(1)
      IF(MODE.NE.2) GO TO 1450
      CROP=CRPLEN-CRIP
      WOUT=XLOOP*W(2)+W(8)
      IF(KRUNG.NE.3) GO TO 1800
      CRLOST=2.*CDBRK*ABS(W(8)-W(1))
      TAU(1)=3600./(ROW(1)*2.*CRIP*ABS(WCORE)+(ROW(1)-A(1,7))*
     1  (2.*CROAB*ABS(W(1))+CRLOST*AFLO/AXBB)+(A(1,1)+A(1,7))*CRWFZ1+
     2  A(1,7)*AX(12)/AXBB*CRLOST)
      TAU(2)=3600./(ROW(2)*2.*XLOOP*(CRIP*ABS(WCORE)+CROP*ABS(WOUT))+
     1  A(2,7)*(2.*CRLP2*ABS(W(2))-DP2DW2)+(A(2,1)+A(2,7))*XLOOP*CRWFZ1)
      TAU(18)=3600.*AXBB/(2.*CROBB*ABS(W(8))+CRLOST-DP1DW1)
      GO TO 1460
 1450 TAU(18)=0.
      TAU(1)=-3600./((ROW(1)-A(1,7))*(DP1DW1-2.*CRLP1*ABS(W(1)))-
     1  ROW(1)*2.*CRPLEN*WCORE-(A(1,1)+A(1,7))*CRWFZ1)
      TAU(2)=-3600./(A(2,7)*(DP2DW2-2.*CRLP2*ABS(W(2)))-
     1  ROW(2)*2.*XLOOP*CRPLEN*WCORE-(A(2,1)+A(2,7))*2.*CRWFZ1)
 1460 DO 1500 I=3,7
      TAU(I)=-3600./((A(I,1)+A(I,7))*CRWFZ1-A(I,I-1)*2.*CRC(I-1)*
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    1  ABS(W(I)))
1500 CONTINUE
     SSPED1=60.*FREQ1/POLES
     SSPED2=60.*FREQ2/POLES
     SLIP1=1.-AL1*DSPEED/SSPED1
     SLIP2=1.-AL2*DSPEED/SSPED2
     DTM1=(CA*SLIP1**2-CB)/(CA*SLIP1**2+CB)**2*DSPEED/SSPED1*QKMM1
     DTM2=(CA*SLIP2**2-CB)/(CA*SLIP2**2+CB)**2*DSPEED/SSPED2*QKMM2
     CALL PTIME(AL1,NEW1,AL0,TS,TR,DTP1,DTF1)
     CALL PTIME(AL2,NEW2,AL0,TS,TR,DTP2,DTF2)
     TAU(8)=-CONST/(DTM1-DTP1-DTF1)
     TAU(13)=-CONST/(DTM2-DTP2-DTF2)
     TAU(9)=9999.99999
     TAU(10)=TAUTM
     TAU(11)=TAUWM
     TAU(12)=TAUAM
     TAU(14)=9999.99999
     TAU(15)=TAUTM
     TAU(16)=TAUWM
     TAU(17)=TAUAM
     NULL18=0
     J=1
     IF(MODE.NE.0) GO TO 1600
     DO 1550 I=1, 18
     IF(I.EQ.9.OR.I.EQ.14) GO TO 1550
     NULL(J)=I
     J=J+1
1550 CONTINUE
     GO TO 1800
1600 DO 1700 I=1,18
     NULL(I)=0
     IF((ABS(TAU(I))*0.7).GE.S) GO TO 1700
     NULL(J)=I
     J=J+1
     IF(I.EQ.18.AND.MODE.EQ.2) NULL18=1
1700 CONTINUE
1800 IF(KMM1.NE.0..AND.KMM2.NE.0.) GO TO 2000
     IF(KTRIP1.NE.0.OR.KMM1.NE.0.) GO TO 1945
     KTRIP1=1
     TTRIP=T
     WRITE(6,9905) KTRIP1,TTRIP
     TTRIP1=THOUR
     AL10=AL1
1945 IF(KTRIP2.NE.0.OR.KMM2.NE.0.) GO TO 2000
     KTRIP2=2
     TTRIP=T
     WRITE(6,9905) KTRIP2,TTRIP
     TTRIP2=THOUR
     AL20=AL2
2000 WCORE=R(1)+XLOOP*R(2)
     WFZ1=WCORE-R(3)-R(4)-R(5)-R(6)-R(7)
     NEW1=R(1)/W1100
     NEW2=R(2)/W2100
     IF(MODE.EQ.2) NEW1=R(18)/W100
C                COMPUTE RHS OF FLOW EQUATIONS
     CALL PHEAD(R(8),NEW1,HP1)
     CALL PHEAD(R(13),NEW2,HP2)
     DELPP1=HP100*DPUMP1*HP1
     DELPP2=HP100*DPUMP2*HP2
     COMHED=DELPP1-CRLP1*R(1)*ABS(R(1))-CRPLEN*WCORE**2+GHEAD1+GHPLEN
     IF(MODE.NE.2) GO TO 2050
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      FLLEAK=FLLEAK+(R(18)-R(1))*(THOUR-TOLD)
      TOLD=THOUR
      FLSURP=FLLEAK/DENAB-VGVMIN
      IF(FLSURP.LT.0.) FLSURP=0.
      FLSINT=FLSURP-VGVINT
      IF(FLSINT.GE.0.) GO TO 2030
      GVLEV=FLSURP/SGVMID
      GO TO 2039
 2030 GVLEV=GVINT+FLSINT/SGVTOP
 2039 IF(GVLEV.GT.GVMAX) GVLEV=GVMAX
      POUT=GVLEV*DENAB+PGV*144.
 2040 ZOPTOT=ZOPNOM-FLLEAK/AOP/DENAB
      HOP=ZOPTOT+DZCON
      WOUT=XLOOP*R(2)+R(18)
      YBRK=DELPP1-POUT+DENOP*ZOPTOT+HEADBB+PCG*144.-CROBB*R(18)*
     1   ABS(R(18))-CDBRK*(R(18)-R(1))*ABS(R(18)-R(1))
      YLP1=CROP*WOUT*ABS(WOUT)+CRIP*WCORE*ABS(WCORE)+CROBB*R(18)*
     1   ABS(R(18))+CROAB*R(1)*ABS(R(1))-GHEAD1-GHPLEN
      COMHED=DELPP1-YLP1-YBRK*AFLO/AXBB
 2050 CONTINUE
      A(1,8)=COMHED-CRC(1)*WFZ1*ABS(WFZ1)+GH(1)
      DO 2100 I=2,6
 2100 A(I,8)=COMHED-CRC(I)*R(I+1)*ABS(R(I+1))+GH(I)
      A(7,8)=DELPP2-CRLP2*R(2)*ABS(R(2))-CRPLEN*WCORE**2+GHEAD2+GHPLEN+
     1  GH(1)-CRC(1)*WFZ1*ABS(WFZ1)
      IF(MODE.EQ.2) A(7,8)=A(7,8)+CROP*(WCORE*ABS(WCORE)-WOUT*ABS(WOUT))
     1   -YBRK*AX(12)/AXBB
C        CALL ON THE FUNCTION SOLVE TO GET THE DERIVATIVES OF THE FLOWS
      DETER=SOLVE(A,XF,1,EPS1)
      J=1
      DO 2200 I=1,7
      F(I)=XF(I)
      IF(NULL(J).NE.I) GO TO 2200
      J=J+1
      F(I)=0.
 2200 CONTINUE
      XKW=1./(100.*PD+5.)/8
      NEWSP=PD
      ASP=PD
   80 IF(NULL(J).NE.8) GO TO 81
      J=J+1
      GO TO 90
   81 SSPED1=60.*R(9)/POLES
      SLIP1=1.-DSPEED*R(8)/SSPED1
      KPM1=0.
      TPM1=0.
      TMM1=SLIP1/(CA*SLIP1**2+CB)
      IF(R(8).GE.0.1.OR.NOPON1.EQ.1) GO TO 85
      KPM1=1.
      SLPON1=1.-DSPEED*R(8)/PMSSP
      TPM1=CE*SLPON1/(CA*SLPON1**2+CB)
   85 TDM1=QKMM1*TMM1+KPM1*TPM1
      CALL PTORQ(R(8),NEW1,BP1)
      CALL TFRIC(R(8),ALO,TS,TR,TMIN,TF1)
      F(8)=3600.*(TDM1-BP1-TF1)/CONST
   90 IF(NULL(J).NE.9) GO TO 91
      J=J+1
      GO TO 100
   91 ET1=TRISPN-R(10)
      IF(ABS(ET1).LT.2.) ET1=0.
      EWT1=XKW*ET1
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      NWSPT1=NEWSP+EWT1
      EW1=NWSPT1-R(11)
      EATW1=XKA*EW1
      ASPTW1=ASP+EATW1
      IF(ASPTW1.GT.1.1) ASPTW1=1.1
      EA1=ASPTW1-R(12)
      IF(ABS(EA1).LE.0.01) EA1=0.
      F(9)=3600.*CONVG*FREQ0*EA1/TK
  100 IF(NULL(J).NE.10) GO TO 101
      J=J+1
      GO TO 110
  101 F(10)=(TRI1-R(10))/TAU(10)*3600.
  110 IF(NULL(J).NE.11) GO TO 111
      J=J+1
      GO TO 120
  111 F(11)=(NEW1-R(11))/TAU(11)*3600.
  120 IF(NULL(J).NE.12) GO TO 121
      J=J+1
      GO TO 130
  121 F(12)=(R(8)-R(12))/TAU(12)*3600.
  130 IF(NULL(J).NE.13) GO TO 131
      J=J+1
      GO TO 140
  131 SSPED2=60.*R(14)/POLES
      SLIP2=1.-DSPEED*R(13)/SSPED2
      KPM2=0.
      TPM2=0.
      TMM2=SLIP2/(CA*SLIP2**2+CB)
      IF(R(13).GE.0.1.OR.NOPON2.EQ.1) GO TO 135
      KPM2=1.
      SLPON2=1.-DSPEED*R(13)/PMSSP
      TPM2=CE*SLPON2/(CA*SLPON2**2+CB)
  135 TDM2=QKMM2*TMM2+KPM2*TPM2
      CALL PTORQ(R(13),NEW2,BP2)
      CALL TFRIC(R(13),ALO,TS,TR,TMIN,TF2)
      F(13)=3600.*(TDM2-BP2-TF2)/CONST
  140 IF(NULL(J).NE.14) GO TO 141
      J=J+1
      GO TO 150
  141 ET2=TRISPN-R(15)
      IF(ABS(ET2).LT.2.) ET2=0.
      EWT2=XKW*ET2
      NWSPT2=NEWSP+EWT2
      EW2=NWSPT2-R(16)
      EATW2=XKA*EW2
      ASPTW2=ASP+EATW2
      IF(ASPTW2.GT.1.1) ASPTW2=1.1
      EA2=ASPTW2-R(17)
      IF(ABS(EA2).LE.0.01) EA2=0.
      F(14)=3600.*CONVG*FPEQ0*EA2/TK
  150 IF(NULL(J).NE.15) GO TO 151
      J=J+1
      GO TO 160
  151 F(15)=(TRI2-R(15))/TAU(15)*3600.
  160 IF(NULL(J).NE.16) GO TO 161
      J=J+1
      GO TO 170
  161 F(16)=(NEW2-R(16))/TAU(16)*3600.
  170 IF(NULL(J).NE.17) GO TO 171
      J=J+1
      GO TO 180
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 171 F(17)=(R(13)-R(17))/TAU(17)*3600.
 180 IF(NULL(J).NE.18) GO TO 181
     RETURN
 181 F(18)=YBRK/AXBB
     RETURN
3000 AL1=R(8)
     FREQ1=R(9)
     TRIM1=R(10)
     NEWM1=R(11)
     ALM1=R(12)
     AL2=R(13)
     FREQ2=R(14)
     TRIM2=R(15)
     NEWM2=R(16)
     ALM2=R(17)
     ERLAST=1.E20
     NCOUNT=0
     NOBYP=0
     IF(R(7).LT.EPS2.AND.NOBPRV.EQ.1) R(7)=EPS2
     XDIV=1.
     DO 3002 I=1,7
3002 DW(I)=0.
3001 DO 3090 LPDUM=1,15
     NEW1=R(1)/W1100
     IF(MODE.EQ.2) NEW1=R(18)/W1100
     NEW2=R(2)/W2100
     WCORE=XLOOP*R(2)+R(1)
     WFZ1=WCORE-R(3)-R(4)-R(5)-R(6)-R(7)
     IF(NULL(1).EQ.0) GO TO 8180
     IF(MODE.NE.2.AND.NULL(1).GT.7) GO TO 8080
     IF(NULL(1).GT.7.AND.NULL18.EQ.0) GO TO 8080
     CALL PHEAD(AL1,NEW1,HP1)
     CALL PHEAD(AL2,NEW2,HP2)
     DELPP1=HP100*DPUMP1*HP1
     DELPP2=HP100*DPUMP2*HP2
     ZETA=2.*CRC(1)*ABS(WFZ1)
     IF(MODE.NE.2) GO TO 3005
     WOUT=R(18)+XLOOP*R(2)
     YBRK=DELPP1-POUT+DENOP*ZOPTOT+HEADBB+PCG*144.-CROBB*R(18)*
    1   ABS(R(18))-CDBRK*(R(18)-R(1))*ABS(R(18)-R(1))
     YLP1=CROP*WOUT*ABS(WOUT)+CRIP*WCORE*ABS(WCORE)+CROBB*R(18)*
    1   ABS(R(18))+CROAB*R(1)*ABS(R(1))-GHEAD1-GHPLEN
     COMHED=DELPP1-YLP1-YBRK*AFLO/AXBB
     GO TO 3006
3005 COMHED=DELPP1-CRLP1*R(1)*ABS(R(1))-CRPLEN*WCORE*ABS(WCORE)+GHEAD1+
    1   GHPLEN
3006 J=1
     NX=0
3010 ND=NULL(J)
     IF(ND.GT.7.OR.ND.EQ.0) GO TO 3050
     GO TO (8010,8020,8030,8030,8030,8030,8030),ND
8010 IF(MODE.NE.2) DWY(1,2)=PDERIV(AL1,NEW1,HP100,DPUMP1)/W1100-2.*
    1   CRPLEN*ABS(WCORE)-2.*CRLP1*ABS(R(1))
     IF(MODE.EQ.2) DWY(1,2)=-2.*CRIP*ABS(WCORE)-2.*CROAB*ABS(R(1))-
    1   2.*CDBRK*ABS(R(18)-R(1))*AFLO/AXBB
     DWY(1,1)=DWY(1,2)-ZETA
     DO 8011 I=3,6
8011 DWY(1,I)=DWY(1,2)
     IF(MODE.NE.2) DWY(1,7)=-2.*CRPLEN*ABS(WCORE)-ZETA
     IF(MODE.EQ.2) DWY(1,7)=-2.*CRIP*ABS(WCORE)-ZETA-AX(12)/AXBB*2.*
    1   CDBRK*ABS(R(18)-R(1))
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      IF(MODE.EQ.2) DWY(1,8)=2.*CDBRK*ABS(R(18)-R(1))/AXBB
      NX=NX+1
      J=J+1
      GO TO 3010
8020  IF(MODE.NE.2) DWY(2,2)=-2.*XLOOP*CRPLEN*ABS(WCORE)
      IF(MODE.EQ.2) DWY(2,2)=-2.*XLOOP*(CRIP*ABS(WCORE)+CROP*ABS(WOUT))
      DWY(2,1)=DWY(2,2)-XLOOP*ZETA
      DO 8021 I=3,6
8021  DWY(2,I)=DWY(2,2)
      DWY(2,7)=PDERIV(AL2,NEW2,HP100,DPUMP2)/W2100-2.*
     1  CRLP2*ABS(R(2))+DWY(2,1)
      NX=NX+1
      J=J+1
      GO TO 3010
8030  IF(NOBYP.EQ.1.AND.ND.EQ.7) GO TO 8040
      DWY(ND,1)=ZETA
      DWY(ND,ND-1)=-2.*CRC(ND-1)*ABS(R(ND))
      DWY(ND,7)=ZETA
      NX=NX+1
8040  J=J+1
      GO TO 3010
3050  IF(MODE.NE.2.OR.NULL18.EQ.0) GO TO 3054
      DWY(8,8)=(-2.*CROBB*ABS(R(18))-2.*CDBRK*ABS(R(18)-R(1))
     1  +PDERIV(AL1,NEW1,HP100,DPUMP1)/W1100)/AXBB
      DWY(8,1)=-2.*CROP*ABS(WOUT)-2.*CROBB*ABS(R(18))-AFLO*DWY(8,8)
      DO 3051 I=2,6
3051  DWY(8,I)=DWY(8,1)
      DWY(8,7)=-2.*CROP*ABS(WOUT)-AX(12)*DWY(8,8)
      NX=NX+1
3054  RHS(1)=COMHED-CRC(1)*WFZ1*ABS(WFZ1)+GH(1)
      DO 3055 I=2,6
3055  RHS(I)=COMHED-CRC(I)*R(I+1)*ABS(R(I+1))+GH(I)
      RHS(7)=DELPP2-CRLP2*R(2)*ABS(R(2))-CRPLEN*WCORE*ABS(WCORE)+GHEAD2+
     1   GHPLEN-CRC(1)*WFZ1*ABS(WFZ1)+GH(1)
      IF(MODE.EQ.2) RHS(7)=RHS(7)+CROP*(WCORE*ABS(WCORE)-WOUT*ABS(WOUT))
     1   -YBRK*AX(12)/AXBB
      NX1=NX+1
      DO 3060 I1=1,NX
      DO 3060 I2=1,NX1
      TRIX(I1,I2)=0.
      NSAV1=NULL(I1)
      NSAV2=NULL(I2)
      IF(I2.EQ.NX.AND.NULL18.NE.0) NSAV2=8
      IF(I1.NE.NX.OR.NULL18.EQ.0) GO TO 3059
      IF(I2.NE.NX1) TRIX(NX,I2)=DWY(NSAV2,8)
      IF(I2.EQ.NX1) TRIX(NX,NX1)=-YBRK/AXBB
      GO TO 3060
3059  DO 3061 K=1,7
      IF(I2.NE.NX1)TRIX(I1,I2)=TRIX(I1,I2)+A(NSAV1,K)*DWY(NSAV2,K)
      IF(I2.EQ.NX1)TRIX(I1,I2)=TRIX(I1,I2)-A(NSAV1,K)*RHS(K)
3061  CONTINUE
3060  CONTINUE
      CALL SYSTEM(TRIX,DW,NX,NX1)
      ERRTOT=0.
      EPS=1.E-5
      DO 3070 I=1,NX
      NSAV=NULL(I)
      IF(I.EQ.NX.AND.NULL18.NE.0) NSAV=18
      R(NSAV)=R(NSAV)+DW(I)/XDIV
      NSAV2=NSAV
      IF(NSAV.EQ.18) NSAV2=8
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      IF((R(NSAV)/WP100(NSAV2)).LT.0.1) EPS=1.E-3
3070  ERRTOT=ERRTOT+ABS(DW(I)/R(NSAV))
      ERRMAX=NX*EPS
      IF(ERRTOT.LT.ERRMAX) GO TO 3095
      IF(ERRTOT.LT.ERLAST) GO TO 3088
      IF(NCOUNT.EQ.1) GO TO 3085
      NCOUNT=1
      GO TO 3089
3085  XDIV=XDIV+1.
      WRITE(6,9919) XDIV
3088  NCOUNT=0
3089  ERLAST=ERRTOT
3090  CONTINUE
      IF(NULL18.EQ.0) GO TO 3094
      NXM1=NX-1
      KABC=18
      WRITE(6,9906) (NULL(I),I=1,NXM1),KABC
      GO TO 3095
3094  WRITE(6,9906) (NULL(I),I=1,NX)
3095  IF(R(1).LT.EPS2.AND.MODE.NE.2) R(1)=EPS2
      IF(R(2).LT.EPS2) R(2)=EPS2
      NEW1=R(1)/W1100
      IF(MODE.EQ.2) NEW1=R(18)/W1100
      NEW2=R(2)/W2100
      IF(R(7).GE.EPS2.OR.NOBPRV.NE.1) GO TO 8080
      R(7)=EPS2
      NOBYP=1
      ERLAST=0.
      GO TO 3001
8080  IF(NULL(J).NE.8) GO TO 8090
      KPM1=0.
      IF(AL1.LE.0.1.AND.NOPON1.EQ.0) KPM1=1.
      CALL ALPHP(R(8),NEW1,FREQ1,QKMM1,KPM1,TMM1,TDM1,BP1,TF1,SLIP1)
      J=J+1
8090  IF(NULL(J).NE.9) GO TO 8100
      J=J+1
8100  IF(NULL(J).NE.10) GO TO 8110
      R(10)=TRI1
      J=J+1
8110  IF(NULL(J).NE.11) GO TO 8120
      R(11)=NEW1
      J=J+1
8120  IF(NULL(J).NE.12) GO TO 8130
      R(12)=AL1
      J=J+1
8130  IF(NULL(J).NE.13) GO TO 8140
      KPM2=0.
      IF(AL2.LE.0.1.AND.NOPON2.EQ.0) KPM2=1.
      CALL ALPHP(R(13),NEW2,FREQ2,QKMM2,KPM2,TMM2,TDM2,BP2,TF2,SLIP2)
      J=J+1
8140  IF(NULL(J).NE.14) GO TO 8150
      J=J+1
8150  IF(NULL(J).NE.15) GO TO 8160
      R(15)=TRI2
      J=J+1
8160  IF(NULL(J).NE.16) GO TO 8170
      R(16)=NEW2
      J=J+1
8170  IF(NULL(J).NE.17) GO TO 8180
      R(17)=AL2
      J=J+1
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8180 DO 3100 I=1,7
     W(I)=R(I)
3100 WNRM(I)=W(I)/WP100(I)
     WCORE=XLOOP*W(2)+W(1)
     WFZ1=WCORE-W(3)-W(4)-W(5)-W(6)-W(7)
     WFZ1N=WFZ1/WFZ100
     IF(MODE.EQ.2) W(8)=R(18)
     AL1=R(8)
     FREQ1=R(9)
     TRIM1=R(10)
     NEWM1=R(11)
     ALM1=R(12)
     AL2=R(13)
     FREQ2=R(14)
     TRIM2=R(15)
     NEWM2=R(16)
     ALM2=R(17)
     DF2DT=(W(2)-W2OLD)/SHOUR
     W2OLD=W(2)
     PRSURE=PCG+(DELPP2+ZOPTOT*DENOP+GHEAD2-CRLP2*W(2)*ABS(W(2))-
    1   ALOOP2*DF2DT)/144.
     PRSNRM=PRSURE/PR100
     RETURN
     ENTRY PUTHYD
     WRITE(6,9907)
     WRITE(6,9908) WFZ1N,(WNRM(I),I=3,7)
     DO 9000 I=1,7
9000 WPRT(I)=W(I)*WFAC
     WRITE(6,9909) (I,WPRT(I),I=1,7)
     TPRT(1)=TRIM1
     TPRT(2)=TRIM2
     TPRT(3)=TRISPN
     CALL TMPCON(1,3,TPRT)
     WRITE(6,9910) AL1,NEW1,BP1,TDM1,HP1,FREQ1
     WRITE(6,9911) AL2,NEW2,BP2,TDM2,HP2,FREQ2
     WRITE(6,9912) PD,TPRT(3),NEWSP,ASP,XKW,EPS,LPDUM
     WRITE(6,9913) TPRT(1),TPRT(2),NEWM1,NEWM2,ALM1,ALM2,PRSNRM
     WRITE(6,9914) ET1,ET2,EW1,EW2,EA1,EA2
     IF(MODE.EQ.2) FLPRNT=FLLEAK/DENAB*VFAC
     IF(MODE.EQ.2) WRITE(6,9916) WNRM(1),FLPRNT,ZOPTOT,GVLEV
     IF(KCALC.EQ.1) WRITE(6,9915) (I,TAU(I),I=1,18)
     RETURN
9901 FORMAT (20X,'MATRIX OF INERTIAL LOSS COEFFICIENTS'/)
9902 FORMAT (7(3X,'A',I1,I1,' =',1PE10.3))
9903 FORMAT(/20X,'VALUE OF DETERMINANT IS ',1PE10.3/)
9904 FORMAT(/20X,'INVERSE MATRIX OF INERTIAL LOSS COEFFICIENTS'/)
9905 FORMAT(/20X,'**** PRIMARY PUMP #',I1,' TRIP AT',F8.4,' SEC ****'/)
9906 FORMAT(/20X,'***** CONVERGENCE NOT FOUND FOR PROMPT FLOWS:',
    1  8(3X,I2),'*****',/)
9907 FORMAT (/,2X,32('*'),5X,'P R I M A R Y',5X,'C O O L A N T',5X,
    1  'D Y N A M I C S',5X,32('*')/)
9908 FORMAT(3X,'FZ1NRM =',F7.4,26X,'FZ2NRM =',F7.4,2X,'FZ3NRM =',F7.4,
    1  2X,'CANRM =',F7.4,3X,'RBNRM =',F7.4,3X,'BPNRM =',F7.4)
9909 FORMAT(3X,'FLOWS: ',7(I1,2X,1PE11.4,3X))
9910 FORMAT(3X,'AL1=',F9.4,3X,'NEW1=',F9.4,3X,'BP1=',F9.4,3X,
    1  'TMOTN1=',F9.4,3X,'HP1=',F9.4,3X,'FREQ1=',F9.3)
9911 FORMAT(3X,'AL2=',F9.4,3X,'NEW2=',F9.4,3X,'BP2=',F9.4,3X,
    1  'TMOTN2=',F9.4,3X,'HP2=',F9.4,3X,'FREQ2=',F9.3)
9912 FORMAT(3X,'PD =',F9.4,3X,'TRISP =',F9.3,3X,'NEWSP =',F9.4,3X,
    1  'ASP =',F9.4,3X,'XKW =',1PE10.3,3X,'EPS =',E10.3,3X,'N =',I3)
9913 FORMAT(3X,'TRIM: ',2F11.3,6X,'NEWM: ',2F11.4,6X,'ALM: ',2F11.4,
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     1  6X,'INLET PRSNRM =',F7.4)
 9914 FORMAT (3X,'ET: ',2(1PE15.4),6X,'EW: ',2E15.4,6X,'EA: ',2E15.4)
 9915 FORMAT (6(3X,'TAU',I2,' =',F10.5))
 9916 FORMAT (3X,'G1NORM =',F10.4,3X,'VOL. LOSS =',1PE10.3,3X,'ZOPTOT ='
     1,0PF9.4,3X,'GVLEV =',F9.4)
 9917 FORMAT(//9X,'DESIGN PUMP HEAD IS',F13.5,/9X,'COVER GAS PRESSURE',
     1  ' IS',1PE11.4)
 9918 FORMAT(///3X,20('*'),5X,'INITIAL TIME STEP FOR THIS PIPE RUPTURE',
     1  ' ANALYSIS MUST BE LESS THAN',F8.5,' SEC',5X,20('*')//)
 9919 FORMAT (//10X,5('*'),5X,'CONVERGENCE PROBLEMS FOR PROMPT PRIMARY',
     1  ' FLOWS:   XDIV=',F8.4,5X,5('*'))
 9920 FORMAT (/9X,'RUPTURE LOSS COEFFICIENT (CDC) =',1PE11.4,/9X,
     1  'GUARD VESSEL VOL. BELOW BREAK =',0PF8.4)
      END
      SUBROUTINE RTHERM(MODE,PTMW,HOP,TI1,TI2)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                    REACTOR HEAT TRANSFER                         C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION TCLINE(11),TFILM(11),TCLAD(11),TAU(33),TAUS(33)
      DIMENSION W(12),PR(11),PE(11),H(11),UA(11)
      DIMENSION PF(11),CF(11),XKF(11),DF(11),VF(11),Q(11)
      DIMENSION XL(11),DT(11),R(11),DG(11),DC(11),XN(11),VX(12)
      DIMENSION TPRT(10)
      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/ALLR/DUR31(26),Y(33),DUR32(430)
      COMMON/ALLF/DUF31(26),F(33),DUF32(430)
      COMMON/ALLNUL/DUN31(26),NULL(33),DUN32(430)
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/LOOP/XLOOP
      COMMON/GET1/WI100,WLP1,WI2,WIC,WOC,WHC,WCA,WRB,WBP,WS100,WS1,WS2,
     1WBRK
      COMMON/FBR1/TC(12),TIP1,TIP2,TCI(6),TOP1,TOP2,TON,TM(11)
      COMMON/FBR13/DH(12),AH(12),AIPT,AOPT,OD(11)
      COMMON/PHY1/TCAV(12),TPI11,TPI12,TDUM1(3),TPI2(6),TPO1(5),TPO2(1),
     1 TDUM2(203)
      COMMON/PHY4/D(12),DPI11,DPI12,DPIA1,DPIA2,DPOA1,DPI2(6),DPO1(5),
     1 DPO2(1),DDUM(203)
      COMMON/PHY5/VS(12),DUVS(220)
      COMMON/PHY6/C(12),CPI11,CPI12,CPIA1,CPIA2,CPOA1,CPI2(6),CPO1(5),
     1 CPO2(1),CDUM(203)
      COMMON/PHY7/XK(12),DUK(220)
      COMMON/PHY8/RE(12),DRE(220)
      COMMON/PLNO/CHC,CIC,COC,CCA,CRB,CBP
      COMMON/TMPMAX/TCMAX,TCLMAX,ZJET
      COMMON/HYD3/DUH1,ZON,DUH2(4)
      COMMON/FACT/XFAC,AFAC,VFAC,FDUM1(2),DFAC,CFAC,XKFAC,FDUM2(7),GC
      NAMELIST/RTH1/PF
      NAMELIST/RTH2/VX,DT,VIP1,VIP2
      NAMELIST/RTH3/DF,CF,XKF,DG,XKG,DC,XKCL
      NAMELIST/RTH4/VF,XL,R,XN
      NAMELIST/RTH5/RO,ZCH,DON,HIF
      NAMELIST/RTH6/HCFAC,FLFAC,CLFAC
      DATA P1,P2/2*1./
      DATA CONFAC/3.4127E6/
      WI1=WLP1
      IF(MODE.EQ.2) WI1=WBRK
      VOPT=AOPT*HOP
      M=KRUNG+2
      GO TO (1000,2100,1100,2000,1100,996),M
C        RESTART OPTION
  996 DO 997 I=1,11
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      VX(I)=VX(I)*VFAC
      DT(I)=DT(I)*XFAC
      DF(I)=DF(I)*DFAC
      CF(I)=CF(I)*CFAC
      XKF(I)=XKF(I)*XKFAC
      DG(I)=DG(I)*XFAC
      DC(I)=DC(I)*XFAC
      VF(I)=VF(I)*VFAC
      XL(I)=XL(I)*XFAC
      R(I)=R(I)*XFAC
  997 CONTINUE
      VX(12)=VX(12)*VFAC
      VIP1=VIP1*VFAC
      VIP2=VIP2*VFAC
      XKG=XKG*XKFAC
      XKCL=XKCL*XKFAC
      RO=RO*XFAC
      ZCH=ZCH*XFAC
      DON=DON*XFAC
      HIF=HIF*XKFAC/XFAC
      GO TO 998
C
C         READ INPUT DATA
 1000 READ(5,RTH1)
      READ(5,RTH2)
      READ(5,RTH3)
      READ(5,RTH4)
      READ(5,RTH5)
      READ(5,RTH6)
C
C         PRINT INPUT DATA
  998 WRITE(6,RTH1)
      WRITE(6,RTH2)
      WRITE(6,RTH3)
      WRITE(6,RTH4)
      WRITE(6,RTH5)
      WRITE(6,RTH6)
C          CONVERT INPUT INTO PROPER UNITS
      DO 1010 I=1,11
      VX(I)=VX(I)/VFAC
      DT(I)=DT(I)/XFAC
      DF(I)=DF(I)/DFAC
      CF(I)=CF(I)/CFAC
      XKF(I)=XKF(I)/XKFAC
      DG(I)=DG(I)/XFAC
      DC(I)=DC(I)/XFAC
      VF(I)=VF(I)/VFAC
      XL(I)=XL(I)/XFAC
      R(I)=R(I)/XFAC
 1010 CONTINUE
      VX(12)=VX(12)/VFAC
      VIP1=VIP1/VFAC
      VIP2=VIP2/VFAC
      XKG=XKG/XKFAC
      XKCL=XKCL/XKFAC
      RO=RO/XFAC
      ZCH=ZCH/XFAC
      DON=DON/XFAC
      HIF=HIF/(XKFAC/XFAC)
      RON=0.5*DON
      AONT=3.14159*DON*DON/4.0
```

```
      Z1=ZON+0.5*DON
      Z2=ZON-0.5*DON
      RETURN
 1100 TOP12=(TOP1+TOP2)/2.0
      CPO12=SPHSOD(TOP12)
      CPOA2=SPHSOD(TOP2)
      DPOA2=DENSOD(TOP2)
C
C       CALCULATE THE HEAT CAPACITIES AT THE OUTLET OF CHANNELS
      CHC=SPHSOD(TC(3))
      CIC=SPHSOD(TC(6))
      COC=SPHSOD(TC(9))
      CCA=SPHSOD(TC(10))
      CRB=SPHSOD(TC(11))
      CBP=SPHSOD(TC(12))
C
C         CALCULATE VOLUMETRIC HEAT DENSITY OF THE REACTOR FUEL
      QBTU=PTMW*CONFAC
      DO 15 J=1, 11
   15 Q(J)=PF(J)*QBTU/VF(J)
      IF(WHC.GT.0.0) A1=1.0
      IF(WIC.GT.0.0) A2=1.0
      IF(WOC.GT.0.0) A3=1.0
      IF(WCA.GT.0.0) A4=1.0
      IF(WRB.GT.0.0) A5=1.0
      IF(WBP.GT.0.0) A6=1.0
C
C       DETERMINE THE JET PENETRATION DISTANCE IN THE UPPER PLENUM
C
      WCORE=WHC+WIC+WOC+WCA+WRB
      TCORE=(WHC*CPO1(1)*TC(3)+WIC*CPO1(2)*TC(6)+WOC*CPO1(3)*TC(9)+WCA*
     1CPO1(4)*TC(10)+WRB*CPO1(5)*TC(11))/(WHC*CPO1(1)+WIC*CPO1(2)+WOC*
     2CPO1(3)+WCA*CPO1(4)+WRB*CPO1(5))
      DCORE=DENSOD(TCORE)
      CALL JET(ZCH,RO,WCORE,DPOA1,DCORE,ZJET)
      IF(ZJET.GT.HOP) ZJET=HOP
      ZDIF=ZJET-HOP
      IF(ZDIF.LE.0.5) ZJET=HOP
      IF(ZJET.GE.Z1) GO TO 21
      IF(ZJET.LE.Z2) GO TO 22
      BETA1=0.0
      BETA2=0.0
      GO TO 23
   21 BETA1=0.0
      BETA2=1.0
      GO TO 23
   22 BETA1=1.0
      BETA2=0.0
   23 CONTINUE
      VPO1=AOPT*ZJET
      VPO2=VOPT-VPO1
C         DEFINE THE DUMMY VECTOR OF MASS FLOW RATE "W(I)"
      DO 30 I=1, 3
      W(I)=WHC
      W(I+3)=WIC
      W(I+6)=WOC
   30 CONTINUE
      W(10)=WCA
      W(11)=WRB
      W(12)=WBP
C         CALCULATE  TRANSPORT NUMBERS
```

```
      DO 40 I=1, 11
      PR(I)=C(I)*VS(I)/XK(I)
      PE(I)=RE(I)*PR(I)
      H(I)=HCORE(RE(I),PE(I),DT(I),XK(I))
      CALL UATOT(XL(I),XN(I),XKF(I),XKG,XKCL,DG(I),DC(I),H(I),OD(I),R(I)
     1,Q(I),UA(I),TM(I),TCAV(I),TCLINE(I),TCLAD(I),TFILM(I))
   40 CONTINUE
C
C       CALCULATE THE HOT SPOT TEMPERATURES
C
C     1. MAXIMUM CORE OUTLET SODIUM TEMPERATURE
      TCMAX=(1.-HCFAC)*TCI(1)+HCFAC*TC(2)
C     2. MAXIMUM CLADDING TEMPERATURE
      DTFILM=TFILM(2)-((TC(1)+TC(2))/2.0)
      DTCLAD=TCLAD(2)-TFILM(2)
      TCLMAX=TCMAX+(FLFAC*DTFILM+CLFAC*DTCLAD)
C
C         DEFINE THE DUMMY VECTOR OF VARIABLES "Y(I)"
      DO 50 I=1,11
   50 Y(I)=TM(I)
      Y(12)=TIP1
      Y(13)=TIP2
      DO 60 I=14, 25
   60 Y(I)=TC(I-13)
      Y(26)=TOP1
      Y(27)=TOP2
      DO 65 I=28, 33
   65 Y(I)=TCI(I-27)
      IF(KPUNG.NE.3) GO TO 2000
C
C         CALCULATE THE PROCESS TIME CONSTANTS FOR:
C         A. REACTOR FUEL REGIONS
      DO 70 I=1, 11
   70 CALL TIMECF(DF(I),VF(I),CF(I),UA(I),TAU(I))
C         B. REACTOR COOLANT REGIONS
      IF(WI1.LT.0.) P1=0.0
      IF(WI2 LT.0.) P2=0.0
      IF(P1.EQ.0..AND.P2.EQ.0.) GO TO 71
      TAU(12)=(DPIA1*VIP1*CPIA1)/(P1*WI1*CPI11+P2*XLOOP*WI2*CPI12)
      GO TO 72
   71 TAU(12)=1.E6
   72 IF(WHC.LT.0.0) A1=0.0
      IF(WIC.LT.0.0) A2=0.0
      IF(WOC.LT.0.0) A3=0.0
      IF(WCA.LT.0.0) A4=0.0
      IF(WRB.LT.0.0) A5=0.0
      IF(WBP.LT.0.0) A6=0.0
      IF(A1.EQ.0..AND.A2.EQ.0..AND.A3.EQ.0..AND.A4.EQ.0..AND.A5.EQ.0..
     1AND.A6.EQ.0.) GO TO 73
      TAU(13)=(DPIA2*VIP2*CPIA2)/(A1*WHC*CPI2(1)+A2*WIC*CPI2(2)+A3*WOC*
     1CPI2(3)+A4*WCA*CPI2(4)+A5*WRB*CPI2(5)+A6*WBP*CPI2(6))
      GO TO 74
   73 TAU(13)=1.E6
   74 CONTINUE
      DO 75 I=1. 11
   75 CALL TIMECC(D(I),VX(I),C(I),UA(I),W(I),TAU(I+13))
      IF(WBP.LE.0.) GO TO 76
      TAU(25)=(D(12)*VX(12))/WBP
      GO TO 77
   76 TAU(25)=1.E6
   77 IF(A1.EQ.0..AND.A2.EQ.0..AND.A3.EQ.0..AND.A4.EQ.0..AND.A5.EQ.0..
```

```
     1AND.A6.EQ.0..AND.BETA2.EQ.0.) GO TO 78
      TAU(26)=(DPOA1*VPO1*CPOA1)/(A1*WHC*CPO1(1)+A2*WIC*CPO1(2)+A3*WOC*
     1CPO1(3)+A4*WCA*CPO1(4)+A5*WRB*CPO1(5)+BETA2*A6*WBP*CPO12+HIF*AOPT)
      GO TO 79
   78 TAU(26)=1.E6
   79 IF(A6.EQ.0..AND.BETA1.EQ.0.) GO TO 791
      TAU(27)=(DPOA2*VPO2*CPOA2)/(A6*WBP*CPO2(1)+BETA2*(A1*WHC+A2*WIC+A3
     1*WOC+A4*WCA+A5*WRB)*CPO12+HIF*AOPT)
      GO TO 792
  791 TAU(27)=1.E6
  792 CONTINUE
      TAU(28)=ABS(TAU(14))
      TAU(29)=ABS(TAU(17))
      TAU(30)=ABS(TAU(20))
      TAU(31)=ABS(TAU(23))
      TAU(32)=ABS(TAU(24))
      TAU(33)=ABS(TAU(25))
C
C          COMPARE THE TIME CONSTANTS WITH THE INTEGRATION TIME STEP
      DO 80 I=1, 33
   80 NULL(I)=0
      J=1
      DO 85 I=1, 33
      IF((TAU(I)*0.75).GE.S) GO TO 85
      NULL(J)=I
      J=J+1
   85 CONTINUE
      DO 850 I=1, 33
  850 TAUS(I)=TAU(I)*3600.0
      IF(MODE.NE.0) GO TO 2000
      J=1
      DO 851 I=1, 33
      NULL(I)=J
      J=J+1
  851 CONTINUE
 2000 J=1
      DO 101 I=1, 11
      IF(I.EQ.3.AND.WHC.LT.0.) Y(16)=Y(26)
      IF(I.EQ.6.AND.WIC.LT.0.) Y(19)=Y(26)
      IF(I.EQ.9.AND.WOC.LT.0.) Y(22)=Y(26)
      IF(I.EQ.10.AND.WCA.LT.0.) Y(23)=Y(26)
      IF(I.EQ.11.AND.WRB.LT.0.) Y(24)=Y(26)
      IF(NULL(J).NE.I) GO TO 100
      J=J+1
      GO TO 101
  100 L=I+12
      IF(I.EQ.1) L=28
      IF(I.EQ.4)L=29
      IF(I.EQ.7)L=30
      IF(I.EQ.10.OR.I.EQ.11) L=I+21
      CALL DFUEL(DF(I),VF(I),CF(I),Q(I),UA(I),Y(I),Y(L),Y(I+13),F(I))
  101 CONTINUE
      IF(NULL(J).NE.12) GO TO 102
      J=J+1
      GO TO 103
  102 IF(WI1.LT.0.) TI1=Y(12)
      IF(WI2.LT.0.) TI2=Y(12)
      F(12)=(WI1*CPI11*(TI1-Y(12))+XLOOP*WI2*CPI12*(TI2-Y(12)))/(DPIA1*
     1VIP1*CPIA1)
  103 IF(NULL(J).NE.13) GO TO 104
      J=J+1
```

```
      GO TO 105
  104 IF(WHC.GE.0.) Y(28)=Y(13)
      IF(WIC.GE.0.) Y(29)=Y(13)
      IF(WOC.GE.0.) Y(30)=Y(13)
      IF(WCA.GE.0.) Y(31)=Y(13)
      IF(WRB.GE.0.) Y(32)=Y(13)
      IF(WBP.GE.0.) Y(33)=Y(13)
      F(13)=((WI1+XLOOP*WI2)*CPIA1*Y(12)-CPI2(1)*WHC*Y(28)-CPI2(2)*WIC*
     1Y(29)-CPI2(3)*WOC*Y(30)-CPI2(4)*WCA*Y(31)-CPI2(5)*WRB*Y(32)-
     2 CPI2(6)*WBP*Y(33))/(DPIA2*VIP2*CPIA2)
  105 DO 110 I=14, 24
      IF(NULL(J).NE.I) GO TO 106
      J=J+1
      GO TO 110
  106 IF(W(I-13).LT.0.) GO TO 108
      L=I-1
      IF(I.EQ.14) L=28
      IF(I.EQ.17) L=29
      IF(I.EQ.20) L=30
      IF(I.EQ.23.OR.I.EQ.24) L=I+8
      CALL DCOOL(D(I-13),VX(I-13),C(I-13),UA(I-13),Y(I-13),Y(L),Y(I),
     1W(I-13),F(I))
      GO TO 110
  108 IF(I.EQ.16.OR.I.EQ.19.OR.I.EQ.22.OR.I.EQ.23.OR.I.EQ.24) GO TO 109
      CALL DCOOL(D(I-12),VX(I-12),C(I-12),UA(I-12),Y(I-12),Y(I),Y(I+1),
     1W(I-12),F(I))
      GO TO 110
  109 Y(I)=Y(26)
      F(I)=0.0
  110 CONTINUE
      IF(NULL(J).NE.25) GO TO 111
      J=J+1
      GO TO 113
  111 IF(WBP.LT.0.) GO TO 112
      F(25)=WBP*(Y(13)-Y(25))/(D(12)*VX(12))
      GO TO 113
  112 Y(25)=Y(27)
      F(25)=0.0
  113 IF(NULL(J).NE.26) GO TO 114
      J=J+1
      GO TO 115
  114 IF(WHC.LT.0.) Y(16)=Y(26)
      IF(WIC.LT.0.) Y(19)=Y(26)
      IF(WOC.LT.0.) Y(22)=Y(26)
      IF(WCA.LT.0.) Y(23)=Y(26)
      IF(WRB.LT.0.) Y(24)=Y(26)
      TBPE=Y(25)
      IF(WBP.LT.0..AND.ZJET.GE.HOP) TBPE=Y(26)
      IF(ZJET.LT.HOP) TBPE=Y(27)
      IF(WHC.LT.0.) A1=0.0
      IF(WIC.LT.0.) A2=0.0
      IF(WOC.LT.0.) A3=0.0
      IF(WCA.LT.0.) A4=0.0
      IF(WRB.LT.0.) A5=0.0
      IF(WBP.LT.0.) A6=0.0
      F(26)=(WHC*CHC*(Y(16)-A1*Y(26))+WIC*CIC*(Y(19)-A2*Y(26))+WOC*COC*
     1(Y(22)-A3*Y(26))+WCA*CCA*(Y(23)-A4*Y(26))+WRB*CRB*(Y(24)-A5*Y(26))
     2+BETA2*WBP*CPO12*(TBPE-A6*Y(26))-HIF*AOPT*(Y(26)-Y(27)))/(DPOA1*
     3VPO1*CPOA1)
  115 IF(NULL(J).NE.27) GO TO 116
      J=J+1
```

```
      GO TO 117
  116 IF(WBP.LT.0.) Y(25)=Y(27)
      IF(WBP.LT.0.) A6=0.0
      IF(ZJET.GE.HOP) GO TO 1160
      F(27)=(WBP*CPO2(1)*(Y(25)-A6*Y(27))+BETA1*(WHC+WIC+WOC+WCA+WRB)*
     1CPO12*(Y(26)-Y(27))+HIF*AOPT*(Y(26)-Y(27)))/(DPOA2*VPO2*CPOA2)
      GO TO 117
 1160 Y(27)=Y(26)
      F(27)=F(26)
  117 L=1
      DO 120 I=28, 32
      IF(I.GT.28.AND.I.LE.31) L=L+3
      IF(I.EQ.32) L=11
      LK=L+13
      IF(NULL(J).NE.I) GO TO 118
      J=J+1
      GO TO 120
  118 IF(W(L).GE.0.) GO TO 119
      CALL DCOOL(D(L),VX(L),C(L),UA(L),Y(L),Y(I),Y(LK),W(L),F(I))
      GO TO 120
  119 F(I)=F(13)
  120 CONTINUE
      IF(NULL(J).NE.33) GO TO 121
      RETURN
  121 IF(WBP.GE.0.) GO TO 122
      F(33)=WBP*(Y(33)-Y(25))/(D(12)*VX(12))
      GO TO 123
  122 F(33)=F(13)
  123 CONTINUE
      RETURN
C
C           PROMPT APPROXIMATION EQUATIONS
 2100 DO 16 I=1, 11
   16 TM(I)=Y(I)
      TIP1=Y(12)
      TIP2=Y(13)
      DO 17 I=14, 25
   17 TC(I-13)=Y(I)
      TOP1=Y(26)
      TOP2=Y(27)
      DO 18 I=28, 33
   18 TCI(I-27)=Y(I)
      J=1
      DO 125 I=1, 11
      IF(NULL(J).EQ.I) GO TO 124
      GO TO 125
  124 CALL TFUEL(Q(I),VF(I),UA(I),TCAV(I),Y(I))
      J=J+1
  125 CONTINUE
      IF(NULL(J).EQ.12) GO TO 126
      GO TO 127
  126 CALL PLENI1(WI1,WI2,TI1,TI2,TIP2,Y(12),CPI11,CPI12)
      J=J+1
      IF(MODE.EQ.0) TIP1=Y(12)
  127 IF(NULL(J).EQ.13) GO TO 128
      GO TO 129
  128 CALL PLENI2(MODE,CPIA1,TIP1,Y(13))
      J=J+1
      IF(MODE.NE.0) GO TO 129
      TCI(1)=Y(13)
      TCI(2)=Y(13)
```

```
      TCI(3)=Y(13)
      TCI(4)=Y(13)
      TCI(5)=Y(13)
      TCI(6)=Y(13)
  129 DO 133 I=14, 24
      IF(NULL(J).EQ.I) GO TO 130
      GO TO 133
  130 IF(W(I-13).LT.0.) GO TO 131
      IF(I.EQ.14) GO TO 1130
      TCINT=TC(I-14)
 1130 IF(I.EQ.14) TCINT=TCI(1)
      IF(I.EQ.17)TCINT=TCI(2)
      IF(I.EQ.20)TCINT=TCI(3)
      IF(I.GE.23) TCINT=TCI(I-19)
      CALL TCOOL(C(I-13),UA(I-13),W(I-13),TM(I-13),TCINT,Y(I))
      J=J+1
      GO TO 133
  131 IF(I.GE.22.OR.I.EQ.16.OR.I.EQ.19) GO TO 132
      CALL TCOOL(C(I-12),UA(I-12),W(I-12),TM(I-12),TC(I-12),Y(I))
      J=J+1
      GO TO 133
  132 Y(I)=TOP1
      J=J+1
  133 CONTINUE
      IF(MODE.EQ.0) TIP2=Y(13)
      IF(NULL(J).EQ.25) GO TO 134
      GO TO 136
  134 IF(WBP.LT.0.) GO TO 135
      Y(25)=TIP2
      J=J+1
      GO TO 136
  135 Y(25)=TOP2
      J=J+1
  136 IF(NULL(J).EQ.26) GO TO 137
      GO TO 138
  137 CALL PLENO1(BETA2,HOP,ZJET,AOPT,HIF,TOP2,Y(26))
      J=J+1
  138 IF(NULL(J).EQ.27) GO TO 139
      GO TO 141
  139 IF(ZJET.GE.HOP) GO TO 140
      Y(27)=(WBP*CPO2(1)*TC(12)+BETA1*(WHC+WIC+WOC+WCA+WRB)*CPO12*TOP1+
     1HIF*AOPT*TOP1)/(WBP*CPO2(1)+BETA1*(WHC+WIC+WOC+WCA+WRB)+HIF*AOPT)
      J=J+1
      GO TO 141
  140 Y(27)=Y(26)
      J=J+1
  141 L=1
      DO 144 I=28, 32
      IF(I.GT.28.AND.I.LE.31) L=L+3
      IF(I.EQ.32) L=11
      IF(NULL(J).EQ.I) GO TO 142
      GO TO 144
  142 IF(W(L).GE.0.) GO TO 143
      CALL TCOOL(C(L),UA(L),W(L),TM(L),TC(L),Y(I))
      J=J+1
      GO TO 144
  143 Y(I)=TIP2
      J=J+1
  144 CONTINUE
      IF(NULL(J).EQ.33) GO TO 145
      GO TO 2200
```

```
  145 IF(WBP.GE.0.) GO TO 146
      Y(33)=TC(12)
      GO TO 2200
  146 Y(33)=TIP2
 2200 DO 147 I=1, 11
  147 TM(I)=Y(I)
      TIP1=Y(12)
      TIP2=Y(13)
      DO 148 I=14, 25
  148 TC(I-13)=Y(I)
      TOP1=Y(26)
      TOP2=Y(27)
      DO 149 I=28, 33
  149 TCI(I-27)=Y(I)
      IF(ZJET.GE.Z1) GO TO 150
      IF(ZJET.LE.Z2) GO TO 151
      ZA=ZJET-Z2
      ARG1=(ARSIN((ZA-RON)/RON)+1.5708)*RON*RON
      ARG2=(ZA-RON)*((2.*RON*ZA-ZA*ZA)**0.5)
      AON1=ARG1+ARG2
      GO TO 152
  150 AON1=AONT
      GO TO 152
  151 AON1=0.0
  152 AON2=AONT-AON1
C
C      DETERMINE THE REACTOR OUTLET NOZZLE SODIUM TEMPERATURE
C
      ROCPA1=DPOA1*CPOA1*AON1
      ROCPA2=DPOA2*CPOA2*AON2
      TON=(ROCPA1*TOP1+ROCPA2*TOP2)/(ROCPA1+ROCPA2)
      RETURN
      ENTRY PUTRTH
      WRITE(6, 3000)
      IF(KCALC.EQ.1) WRITE(6, 3025) (I, TAUS(I), I=1, 33)
      TPRT(1)=TCMAX
      TPRT(2)=TCLMAX
      TPRT(3)=TCLINE(2)
      TPRT(4)=TCLAD(2)
      TPRT(5)=TFILM(2)
      TPRT(6)=TIP2
      TPRT(7)=TIP1
      TPRT(8)=TOP2
      TPRT(9)=TOP1
      TPRT(10)=TON
      CALL TMPCON(1,10,TPRT)
      CALL TMPCON(1,11,TM)
      CALL TMPCON(1,12,TC)
      CALL TMPCON(1,6,TCI)
      ZJETP=ZJET*XFAC
      WRITE(6, 3050) TPRT(1),TPRT(2)
      WRITE(6, 3060) (TPRT(I),I=3,5)
      WRITE(6, 3100) (I, TM(I), I=1, 11)
      WRITE(6, 3200) (I, TC(I), I=1, 12)
      WRITE(6, 3500) (I, TCI(I), I=1, 6)
      WRITE(6, 3400) TPRT(6),TPRT(7)
      WRITE(6, 3300) ZJETP,(TPRT(I),I=8,10)
      CALL TMPCON(0,11,TM)
      CALL TMPCON(0,12,TC)
      CALL TMPCON(0,6,TCI)
 3000 FORMAT(/,2X,30('*'),5X,'R E A C T O R',5X,'H E A T',5X,
```

```
     1    'T R A N S F E R',5X,30('*')/)
3025 FORMAT(5(3X,'TAU',I2,' =',F10.4,' SEC'))
3050 FORMAT(5X,'CORE HOT SPOT:         MAX. COOLANT TEMP. =',F10.3,
     1 8X,'MAX. CLAD TEMP. =',F10.3)
3060 FORMAT(3X,'PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =',
     1F10.3,3X,'CLAD INNER =',F10.3,3X,'CLAD OUTER =',F10.3)
3100 FORMAT(6(3X,'TM',I2,' =',F10.3))
3200 FORMAT(6(3X,'TC',I2,' =',F10.3))
3300 FORMAT(3X,'UPPER PLENUM:  ZJET =',F10.3,3X,'TOP ZONE TEMP. =',
     1  F10.3,3X,'BOTTOM ZONE TEMP. =',F10.3,3X,'NOZZLE TEMP. =',F10.3)
3400 FORMAT(3X,'LOWER PLENUM:',24X,'TOP ZONE TEMP. =',
     1    F10.3,3X,'BOTTOM ZONE TEMP. =',F10.3)
3500 FORMAT(6(3X,'TCI',I1,' =',F10.3))
     RETURN
     END
```

DATA SET UTILITY - GENERATE

IEB352I WARNING : OUTPUT RECFM/LRECL/BLKSIZE COPIED FROM INPUT

PROCESSING ENDED AT EOD

```
      SUBROUTINE DELAYP(W1, W2, MODE)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     PRIMARY LOOPS SODIUM TRANSPORT DELAY SIMULATION           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION TC1(10),TC2(10),TC3(10),TC4(10),TC5(10),TC6(10)
      DIMENSION TW1(10),TW2(10),TW3(10),TW4(10),TW5(10),TW6(10)
      DIMENSION FC1(10),FC2(10),FC3(10),FC4(10),FC5(10),FC6(10)
      DIMENSION FW1(10),FW2(10),FW3(10),FW4(10),FW5(10),FW6(10)
      DIMENSION VCTOT(6),VWTOT(6),ATOT(6),ROVCW(6),VCPRIM(6)
      DIMENSION TAUC1(10),TAUC2(10),TAUC3(10),TAUC4(10),TAUC5(10),
     1  TAUC6(10),TAUW1(10),TAUW2(10),TAUW3(10),TAUW4(10),TAUW5(10),
     2  TAUW6(10),U1(10),U2(10),U3(10),U4(10),U5(10),U6(10),UPR1(10),
     3  UPR2(10),UPR3(10),UPR4(10),UPR5(10),UPR6(10)
      EQUIVALENCE (Y(1),TC1(1)),(Y(11),TC2(1)),(Y(21),TC3(1)),(Y(31),
     1 TC4(1)),(Y(41),TC5(1)),(Y(51),TC6(1)),(Y(61),TW1(1)),(Y(71),
     2 TW2(1)),(Y(81),TW3(1)),(Y(91),TW4(1)),(Y(101),TW5(1)),(Y(111),
     3 TW6(1))
      EQUIVALENCE (F(1),FC1(1)),(F(11),FC2(1)),(F(21),FC3(1)),(F(31),
     1 FC4(1)),(F(41),FC5(1)),(F(51),FC6(1)),(F(61),FW1(1)),(F(71),
     2 FW2(1)),(F(81),FW3(1)),(F(91),FW4(1)),(F(101),FW5(1)),(F(111),
     3 FW6(1))
      COMMON/FBR4/TCI1,TCI2,TCI3,TCI4,TCI5,TCI6
      COMMON/FBR5/TM1(10),TM2(10),TM3(10),TM4(10),TM5(10),TM6(10)
      COMMON/FBR10/N(6),L(6)
      COMMON/FBR14/DPX,APX,ODP(3),DELP(3),XL(7),XL11,
     1   XL12,XL21,XL22,DSX,ASX,XLS(12),ODI(4),DELI(4)
      COMMON/FBR15/DSS,CSS,XKSS
      COMMON/PHY4/DUMA(30),DC1(10),DUMB.DC2(10),DUMC(13),DC3(10),
     1  DC4(10),DUMD,DC5(10),DUME(13),DC6(10),DUMF(114)
      COMMON/PHY5/VDA(30),VS1(10),VDB,VS2(10),VDC(13),VS3(10),VS4(10),
     1  VDD,VS5(10),VDE(13),VS6(10).VDF(114)
      COMMON/PHY6/CDA(30),CC1(10),CDB,CC2(10),CDC(13),CC3(10),CC4(10),
     1   CDD,CC5(10),CDE(13),CC6(10),CDF(114)
      COMMON/PHY7/XDA(30),XK1(10),XDB,XK2(10),XDC(13),XK3(10),XK4(10),
     1   XDD.XK5(10),XDE(13),XK6(10),XDF(114)
      COMMON/PHY8/RDA(30),RE1(10),RDB,RE2(10),RDC(13),RE3(10),RE4(10),
     1   RDD,RE5(10),RDE(13),REC(10),RDF(114)
      COMMON/ALLR/DUM51(109),Y(120),DUM52(260)
      COMMON/ALLF/DUF51(109),F(120),DUF52(260)
      COMMON/ALLNUL/DUN51(109),NULL(120),DUN52(260)
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/RUNGNO/KRUNG,KCALC
      DATA PI/3.141593/
      MGO=KRUNG+2
      GO TO (1000,2100,2000,2000,2000,1000),MGO
C        FIX UP THE COMPONENTS OF THE NULL VECTOR AS FUNCTIONS OF N AND L
C        FIRST FOR THE COOLANT TEMP'S
 1000 DO 1020 I=1,6
      J2=10*I
      J1=J2-9
      DO 1020 J=J1,J2
      IF((J+10-J2).LE.N(I)) GO TO 1010
      NULL(J)=J
      GO TO 1020
 1010 NULL(J)=0
 1020 CONTINUE
C        AND NOW, FOR THE PIPE WALL TEMP'S
      DO 1050 I=1,6
      J2=60+10*I
      J1=J2-9
      DO 1050 J=J1,J2
```

```
      IF(L(I).NE.1) GO TO 1030
      NULL(J)=J
      GO TO 1050
 1030 IF((J+10-J2).LE.N(I)) GO TO 1040
      NULL(J)=J
      GO TO 1050
 1040 NULL(J)=0
 1050 CONTINUE
      I=1
      DO 1055 J=1,120
      IF(NULL(J).EQ.0) GO TO 1055
      NULL(I)=NULL(J)
      I=I+1
 1055 CONTINUE
      DO 1056 J=I,120
      NULL(J)=0
 1056 CONTINUE
      N1=N(1)
      N2=N(2)
      N3=N(3)
      N4=N(4)
      N5=N(5)
      N6=N(6)
C         INITIALIZE ALL COOLANT AND WALL TEMPERATURES
      DO 1057 I=1,10
      TC1(I)=TM1(I)
      TW1(I)=TM1(I)
      TC2(I)=TM2(I)
      TW2(I)=TM2(I)
      TC3(I)=TM3(I)
      TW3(I)=TM3(I)
      TC4(I)=TM4(I)
      TW4(I)=TM4(I)
      TC5(I)=TM5(I)
      TW5(I)=TM5(I)
      TC6(I)=TM6(I)
 1057 TW6(I)=TM6(I)
C        COMPUTE QUANTITIES RELATED TO THE PIPE RUNS
      DIR1=ODP(1)-2.*DELP(1)
      DIR2=ODP(2)-2.*DELP(2)
      DIR3=ODP(3)-2.*DELP(3)
      STOTR1=PI/4.*DIR1**2/144.
      STOTR2=PI/4.*DIR2**2/144.
      STOTR3=PI/4.*DIR3**2/144.
      XCIRR1=PI*DIR1/12.
      XCIRR2=PI*DIR2/12.
      XCIRR3=PI*DIR3/12.
      XSECR1=PI*(DIR1+DELP(1))*DELP(1)/144.
      XSECR2=PI*(DIR2+DELP(2))*DELP(2)/144.
      XSECR3=PI*(DIR3+DELP(3))*DELP(3)/144.
      VCTOT(1)=STOTR1*XL(1)
      VCTOT(2)=STOTR2*XL(2)
      VCTOT(3)=STOTR3*XL(3)
      VCTOT(4)=VCTOT(1)
      VCTOT(5)=VCTOT(2)
      VCTOT(6)=VCTOT(3)
      VWTOT(1)=XSECR1*XL(1)
      VWTOT(2)=XSECR2*XL(2)
      VWTOT(3)=XSECR3*XL(3)
      VWTOT(4)=VWTOT(1)
      VWTOT(5)=VWTOT(2)
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      VWTOT(6)=VWTOT(3)
      ATOT(1)=XCIRR1*XL(1)
      ATOT(2)=XCIRR2*XL(2)
      ATOT(3)=XCIRR3*XL(3)
      ATOT(4)=ATOT(1)
      ATOT(5)=ATOT(2)
      ATOT(6)=ATOT(3)
      DO 1058 I=1,6
      VCPRIM(I)=VCTOT(I)/N(I)
      VWPRIM=VWTOT(I)/N(I)
 1058 ROVCW(I)=VWPRIM*DSS*CSS
      RETURN
 2000 IF(MODE.EQ.0) RETURN
C          START CALLING ON THE SUBROUTINE PIPE TO GET THE TEMP DERIVATIVES
C            PIPE 1
      CALL PIPE (N(1),L(1),KRUNG,W1,TCI1,TC1,TW1,FC1,FW1,DIR1,DELP(1),
     1  STOTR1,ATOT(1),VCTOT(1),XKSS,ROVCW(1),
     2  VCPRIM(1),CC1,DC1,VS1,XK1,RE1,U1,UPR1,TAUC1,TAUW1)
C            PIPE 2
      CALL PIPE (N(2),L(2),KRUNG,W1,TCI2,TC2,TW2,FC2,FW2,DIR2,DELP(2),
     1  STOTR2,ATOT(2),VCTOT(2),XKSS,ROVCW(2),
     2  VCPRIM(2),CC2,DC2,VS2,XK2,RE2,U2,UPR2,TAUC2,TAUW2)
C            PIPE 3
      CALL PIPE (N(3),L(3),KRUNG,W1,TCI3,TC3,TW3,FC3,FW3,DIR3,DELP(3),
     1  STOTR3,ATOT(3),VCTOT(3),XKSS,ROVCW(3),
     2  VCPRIM(3),CC3,DC3,VS3,XK3,RE3,U3;UPR3,TAUC3,TAUW3)
C            PIPE 4
      CALL PIPE (N(4),L(4),KRUNG,W1,TCI4,TC4,TW4,FC4,FW4,DIR1,DELP(1),
     1  STOTR1,ATOT(4),VCTOT(4),XKSS,ROVCW(4),
     2  VCPRIM(4),CC4,DC4,VS4,XK4,RE4,U4,UPR4,TAUC4,TAUW4)
C            PIPE 5
      CALL PIPE (N(5),L(5),KRUNG,W1,TCI5,TC5,TW5,FC5,FW5,DIR2,DELP(2),
     1  STOTR2,ATOT(5),VCTOT(5),XKSS,ROVCW(5),
     2  VCPRIM(5),CC5,DC5,VS5,XK5,RE5,U5,UPR5,TAUC5,TAUW5)
C            PIPE 6
      CALL PIPE (N(6),L(6),KRUNG,W1,TCI6,TC6,TW6,FC6,FW6,DIR3,DELP(3),
     1  STOTR3,ATOT(6),VCTOT(6),XKSS,ROVCW(6),
     2  VCPRIM(6),CC6,DC6,VS6,XK6,RE6,U6,UPR6,TAUC6,TAUW6)
      RETURN
 2100 IF(MODE.NE.0) GO TO 2200
      DO 2150 I=1,.10
      TC1(I)=TCI1
      TC2(I)=TCI2
      TC3(I)=TCI3
      TC4(I)=TCI4
      TC5(I)=TCI5
 2150 TC6(I)=TCI6
 2200 DO 2300 I=1,10
      TM1(I)=TC1(I)
      TM2(I)=TC2(I)
      TM3(I)=TC3(I)
      TM4(I)=TC4(I)
      TM5(I)=TC5(I)
 2300 TM6(I)=TC6(I)
      RETURN
      ENTRY PUTDEL
      WRITE(6,196)
      CALL TMPCON(1,120,Y)
      IF(KCALC.NE.1) GO TO 3600
      J=1
      WRITE(6,300) J,(I,TAUC1(I),I=1,N1)
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      IF(L(1).EQ.0) WRITE(6,301) J,(I,TAUW1(I),I=1,N1)
      J=2
      WRITE(6,300) J,(I,TAUC2(I),I=1,N2)
      IF(L(2).EQ.0) WRITE(6,301) J,(I,TAUW2(I),I=1,N2)
      J=3
      WRITE(6,300) J,(I,TAUC3(I),I=1,N3)
      IF(L(3).EQ.0) WRITE(6,301) J,(I,TAUW3(I),I=1,N3)
      J=4
      WRITE(6,300) J,(I,TAUC4(I),I=1,N4)
      IF(L(4).EQ.0) WRITE(6,301) J,(I,TAUW4(I),I=1,N4)
      J=5
      WRITE(6,300) J,(I,TAUC5(I),I=1,N5)
      IF(L(5).EQ.0) WRITE(6,301) J,(I,TAUW5(I),I=1,N5)
      J=6
      WRITE(6,300) J,(I,TAUC6(I),I=1,N6)
      IF(L(6).EQ.0) WRITE(6,301) J,(I,TAUW6(I),I=1,N6)
 3600 J=1
      WRITE(6,140) J,(I,TC1(I),I=1,N1)
      IF(L(1).EQ.0) WRITE(6,145) J,(I,TW1(I),I=1,N1)
      J=2
      WRITE(6,140) J,(I,TC2(I),I=1,N2)
      IF(L(2).EQ.0) WRITE(6,145) J,(I,TW2(I),I=1,N2)
      J=3
      WRITE(6,140) J,(I,TC3(I),I=1,N3)
      IF(L(3).EQ.0) WRITE(6,145) J,(I,TW3(I),I=1,N3)
      J=4
      WRITE(6,140) J,(I,TC4(I),I=1,N4)
      IF(L(4).EQ.0) WRITE(6,145) J,(I,TW4(I),I=1,N4)
      J=5
      WRITE(6,140) J,(I,TC5(I),I=1,N5)
      IF(L(5).EQ.0) WRITE(6,145) J,(I,TW5(I),I=1,N5)
      J=6
      WRITE(6,140) J,(I,TC6(I),I=1,N6)
      IF(L(6).EQ.0) WRITE(6,145) J,(I,TW6(I),I=1,N6)
      CALL TMPCON(0,120,Y)
      RETURN
  140 FORMAT (2X,'TC',I1,':',10(I3,F9.3))
  145 FORMAT (2X,'TW',I1,':',10(I3,F9.3))
  196 FORMAT(/2X,15('*'),5X,'P R I M A R Y',5X,'S O D I U M',5X,
     1  'T R A N S P O R T',5X,'C A L C U L A T I O N S',5X,15('*')/)
  300 FORMAT (3X,'TAUC',I1,':',10(I3,F9.5))
  301 FORMAT (3X,'TAUW',I1,':',10(I3,F9.5))
      END
      SUBROUTINE IHX1(MODE,WP,WS,TPI,TSI,N)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     INTERMEDIATE HEAT EXCHANGER THERMAL MODEL (LOOP 1)      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL NT,NUSSP,NUSSS
      DIMENSION NUSSP(10),NUSSS(10),PRP(10),PRS(10),PEP(10),PES(10)
      DIMENSION HP(10),HS(10),U(10),TDLOG(10),HEAT(10)
      DIMENSION CS(12),DS(12),XKS(12),AVS(10),RES(10)
      DIMENSION TAUP(13),TAUS(25)
      COMMON/FBR2/TP(13),TS(12)
      COMMON/FBR4/TCI1,TCI2,TCI3,TCI4,TCI5,TCI6
      COMMON/FBR14/DEQUIP,STOTP,DUMA(12),XLTOT,DUMB(4),DINT,STOTS,
     1  DUMC(20)
      COMMON/PHY4/DUD1(51),DP(13),DUD2(54),DSDUM(12),DUD3(102)
      COMMON/PHY5/DUV1(52),AVP(10),DUV2(57),AVSDUM(10),DUV3(103)
      COMMON/PHY6/DUC1(51),CP(13),DUC2(54),CSDUM(12),DUC3(102)
      COMMON/PHY7/DUK1(51),XKP(13),DUK2(54),XKSDUM(12),DUK3(102)
      COMMON/PHY8/DUR1(52),REP(10),DUR2(57),RESDUM(10),DUR3(103)
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      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/ALLR/DUM411(59),Y(25),DUM412(405)
      COMMON/ALLF/DUF411(59),F(25),DUF412(405)
      COMMON/ALLNUL/DUN411(59),NULL(25),DUN412(405)
      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/FACT/XFAC,AFAC,VFAC,FDUM1(4),XKFAC,TFAC,FDUM2(4),XHFAC,
     1  FDUM3(2)
      NAMELIST/HX1A/DEXT,PITCH,XKSS,NT,BP,ACF
      NAMELIST/HX1B/VIP,VOP,VBP,VIS,VOS
      M=KRUNG+2
      GO TO (1004,3000,1000,2600,1000,998),M
C         THIS STATEMENT IS OF THE FORM  GO TO (A,B,C,D,E,F) ,  WHERE:
C            A IS INITIALIZATION OF ALL RUN DATA; B IS PROMPT APPROXIMATION
C            CALCULATION; C IS INITIALIZE NEW TIME STEP VALUES AND COMPUTE
C            DERIVATIVES; D IS COMPUTE DERIVATIVES;  E IS COMPUTE NEW
C            TIME CONSTANTS; AND F IS THE RESTART OPTION.
C
C         RESTART OPTION
  998 DEXT=DEXT*XFAC
      PITCH=PITCH*XFAC
      XKSS=XKSS*XKFAC
      VIP=VIP*VFAC
      VOP=VOP*VFAC
      VBP=VBP*VFAC
      VIS=VIS*VFAC
      VOS=VOS*VFAC
      GO TO 999
C
C         READ INPUT DATA
 1004 READ(5,HX1A)
      READ(5, HX1B)
C         PRINT INPUT DATA
  999 WRITE(6,HX1A)
      WRITE(6,HX1B)
C          CONVERT TO PROPER UNITS
      DEXT=DEXT/XFAC
      PITCH=PITCH/XFAC
      XKSS=XKSS/XKFAC
      VIP=VIP/VFAC
      VOP=VOP/VFAC
      VBP=VBP/VFAC
      VIS=VIS/VFAC
      VOS=VOS/VFAC
      N1=N+1
      N2=N+2
      N3=N+3
      N4=N+4
      NTOT=2*N+5
      NEND1=NTOT-1
      NEND2=NTOT-2
      XN=N
      NTOTP1=NTOT+1
      PD=PITCH/DEXT
      ALPHA=6.66+(3.126+1.184*PD)*PD
      DEDI=DEXT/DINT
      RTUBE=ALOG(DEDI)*DEXT/(2.*XKSS)
      VBUNDL=STOTP*XLTOT
      WPSTAR=(1.-BP)*WP
      ATOT=NT*XLTOT*3.141593*DEXT*ACF
      VTUBE=STOTS*XLTOT
C          INITIALIZE COMPONENTS OF THE DUMMY Y VECTOR
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      DO 1002 I=1,N3
      Y(I)=TP(I)
      IF(I.NE.N3) Y(I+N3)=TS(I)
 1002 CONTINUE
      RETURN
 1000 WPSTAR=(1.-BP)*WP
      DO 1099 I=1,N2
      CS(I)=CSDUM(N3-I)
      DS(I)=DSDUM(N3-I)
      XKS(I)=XKSDUM(N3-I)
      IF(I.GT.N) GO TO 1099
      AVS(I)=AVSDUM(N1-I)
      RES(I)=RESDUM(N1-I)
 1099 CONTINUE
      DO 1100 I=1,N
      CALL LMTDIF(Y(I),Y(I+1),Y(I+N4),Y(I+N3),TDLOG(I))
 1100 CONTINUE
C        SHELL-SIDE (PRI.SOD.) CONVECTION HEAT-TRANSFER COEFFICIENT
      DO 1500 I=1,N
      IF(REP(I).GT.3000.) GO TO 1200
      NUSSP(I)=7.15
      GO TO 1400
 1200 PRP(I)=CP(I+1)*AVP(I)/XKP(I)
      PEP(I)=REP(I)*PRP(I)
      NUSSP(I)=ALPHA+0.0155*PEP(I)**0.86
 1400 HP(I)=XKP(I)*NUSSP(I)/DEQUIP
 1500 CONTINUE
C        TUBE-SIDE (SEC.SOD) CONVECTION HEAT-TRANSFER COEFFICIENT
      DO 1900 I=1,N
      IF(RES(I).GT.3000.) GO TO 1600
      NUSSS(I)=4.363636
      GO TO 1800
 1600 PRS(I)=CS(I+1)*AVS(I)/XKS(I)
      PES(I)=RES(I)*PRS(I)
      NUSSS(I)=7.+.025*PES(I)**0.8
 1800 HS(I)=XKS(I)*NUSSS(I)/DINT
 1900 CONTINUE
C        OVERALL HEAT/TRANSFER COEFFICIENT
      DO 2000 I=1,N
      U(I)=1./(DEDI/HS(I)+RTUBE+1./HP(I))
 2000 CONTINUE
      IF(M.EQ.3) GO TO 2630
C        COMPUTE THE TIME CONSTANTS OF SODIUM TEMPERATURES
      TAUP(1)=3600.*DP(1)*VIP/WPSTAR
      DTMIN=TP(1)-TS(1)
      DO 2300 I=2,N1
      DTMAX=TP(I)-TS(I)
      DRATIO=DTMAX/DTMIN
      IF(DTMAX.NE.DTMIN) GO TO 2100
      DTMDTP=1.
      DTMDTS=1.
      GO TO 2200
 2100 IF(DRATIO.LE.0.) GO TO 2105
      XLOG=ALOG(DRATIO)
      DTMDTP=(1.-(1.-DTMIN/DTMAX)/XLOG)/XLOG
      DTMDTS=-(1.+(1.-DTMAX/DTMIN)/XLOG)/XLOG
      GO TO 2200
 2105 DTMDTP=0.0
      DTMDTS=0.0
 2200 TAUP(I)=3600.*DP(I)*VBUNDL*CP(I)/(XN*WPSTAR*CP(I)+U(I-1)*ATOT*
     1 DTMDTP)
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      ILESS1=I+N2
      TAUS(ILESS1)=3600.*DS(I)*VTUBE*CS(I)/(XN*WS*CS(I)+U(I-1)*ATOT*
     1 DTMDTS)
      DTMIN=DTMAX
 2300 CONTINUE
      TAUP(N2)=3600.*DP(N2)*VBP/(BP*WP)
      TAUP(N3)=3600.*DP(N3)*VOP*CP(N3)/(WPSTAR*CP(N3)+BP*WP*CP(N2))
      TAUS(NEND1)=3600.*DS(N1)*VIS/WS
      TAUS(NTOT)= 3600.*DS(N2)*VOS/WS
      J=1
      DO 2301 I=1, N3
      IF((TAUP(I)*0.7).GE.SSEC.AND.MODE.NE.0) GO TO 2301
      NULL(J)=I
      J=J+1
 2301 CONTINUE
      DO 2302 I=N4, NTOT
      IF((TAUS(I)*0.7).GE.SSEC.AND.MODE.NE.0) GO TO 2302
      NULL(J)=I
      J=J+1
 2302 CONTINUE
      IF(NTOTP1.GT.25) GO TO 2304
      DO 2303 I=NTOTP1, 25
      NULL(J)=I
      J=J+1
 2303 CONTINUE
 2304 GO TO 2630
 2600 DO 2610 I=1,N
      CALL LMTDIF(Y(I),Y(I+1),Y(I+N4),Y(I+N3),TDLOG(I))
 2610 CONTINUE
 2630 WPSTAR=(1.-BP)*WP
      J=1
      IF(NULL(J).NE.1) GO TO 2631
      J=J+1
      GO TO 2632
 2631 F(1)=WPSTAR*(TPI-Y(1))/(DP(1)*VIP)
 2632 DO 2700 I=1, N
 2700 HEAT(I)=U(I)*(ATOT/XN)*TDLOG(I)
      DO 2800 I=2,N1
      IF(NULL(J).NE.I) GO TO 2801
      J=J+1
      GO TO 2800
 2801 F(I)=(WPSTAR*CP(I)*(Y(I-1)-Y(I))-HEAT(I-1))/(DP(I)*(VBUNDL/XN)*
     1 CP(I))
 2800 CONTINUE
      IF(NULL(J).NE.N2) GO TO 2802
      J=J+1
      GO TO 2803
 2802 F(N2)=BP*WP*(TPI-Y(N2))/(DP(N2)*VBP)
 2803 IF(NULL(J).NE.N3) GO TO 2804
      J=J+1
      GO TO 2805
 2804 F(N3)=(WPSTAR*CP(N3)*(Y(N1)-Y(N3))+BP*WP*CP(N2)*(Y(N2)-Y(N3)))
     1 /(DP(N3)*VOP*CP(N3))
      TCI3=Y(N3)
 2805 CONTINUE
      DO 2900 I=N4,NEND2
      I1=I-N3
      I2=I-N2
      IF(NULL(J).NE.I) GO TO 2901
      J=J+1
      GO TO 2900
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2901 F(I)=(HEAT(I1)-WS*CS(I2)*(Y(I)-Y(I+1)))/(DS(I2)*(VTUBE/XN)*CS(I2))
2900 CONTINUE
     IF(NULL(J).NE.NEND1) GO TO 2902
     J=J+1
     GO TO 2903
2902 F(NEND1)=WS*(TSI-Y(NEND1))/(DS(N1)*VIS)
2903 IF(NULL(J).NE.NTOT) GO TO 2904
     GO TO 2950
2904 F(NTOT)=WS*(Y(N4)-Y(NTOT))/(DS(N2)*VOS)
2950 DO 2960 I=1,N3
     TP(I)=Y(I)
     IF(I.NE.N3) TS(I)=Y(N3+I)
2960 CONTINUE
     RETURN
3000 J=1
     IF(NULL(J).EQ.1) GO TO 3001
     GO TO 4001
3001 Y(1)=TPI
     J=J+1
4001 DO 4010 I=2, N1
     IF(NULL(J).EQ.I) GO TO 3002
     GO TO 4010
3002 CALL PROMTP(WPSTAR,CP(I),TP(I-1),Y(I),TS(I),TS(I-1),U(I-1),ATOT,
    1XN)
     J=J+1
4010 CONTINUE
     IF(NULL(J).EQ.N2) GO TO 3003
     GO TO 4011
3003 Y(N2)=TPI
     J=J+1
4011 IF(NULL(J).EQ.N3) GO TO 3004
     GO TO 4012
3004 ALF1=WPSTAR*CP(N3)/(BP*WP*CP(N2))
     IF(MODE.EQ.0) TP(N1)=Y(N1)
     IF(MODE.EQ.0) TP(N2)=Y(N2)
     Y(N3)=(ALF1*TP(N1)+TP(N2))/(ALF1+1.)
     TCI3=Y(N3)
     J=J+1
4012 DO 4020 I=N4, NEND2
     I1=I-N3
     I2=I-N2
     IF(NULL(J).EQ.I) GO TO 3005
     GO TO 4020
3005 CALL PROMTS(WS,CS(I2),TP(I1),TP(I2),TS(I2),Y(I),U(I1),ATOT,XN)
     J=J+1
4020 CONTINUE
     IF(NULL(J).EQ.NEND1) GO TO 3006
     GO TO 4021
3006 Y(NEND1)=TSI
     J=J+1
4021 IF(NULL(J).EQ.NTOT) GO TO 3007
     GO TO 4022
3007 Y(NTOT)=Y(N4)
4022 DO 3100 I=1, N3
3100 TP(I)=Y(I)
     DO 3200 I=1,N2
3200 TS(I)=Y(N3+I)
     MGO=1
     RETURN
     ENTRY PUTHX1
     WRITE(6,341)
```

```
      IF(ICOUNT.NE.0) GO TO 3350
      DO 3300 I=1,N
      HP(I)=HP(I)*XHFAC
      HS(I)=HS(I)*XHFAC
      U(I)=U(I)*XHFAC
 3300 CONTINUE
      DO 3301 I=1,10
 3301 TDLOG(I)=TDLOG(I)*TFAC
      WRITE(6,180) N,(I,HP(I),I=1,N)
      WRITE(6,190) N,(I,HS(I),I=1,N)
      WRITE(6,200) N,(I,U(I),I=1,N)
      WRITE(6,210) N,(I,TDLOG(I),I=1,N)
      DO 3349 I=1,N
 3349 U(I)=U(I)/XHFAC
 3350 IF(KCALC.NE.1) GO TO 3360
      WRITE(6,330) (I,TAUP(I),I=1,N3)
      WRITE(6,340) (I,TAUS(I),I=N4,NTOT)
 3360 CALL TMPCON(1,13,TP)
      CALL TMPCON(1,12,TS)
      WRITE(6,310) (I,TP(I),I=1,N3)
      WRITE(6,320) (I,TS(I),I=1,N2)
      CALL TMPCON(0,13,TP)
      CALL TMPCON(0,12,TS)
  180 FORMAT (/5X,'PRI. SOD.',I3,' CONVECTION HEAT-TRANS. COEF. VALUES'
     1 /5X,7(I3,1PE14.4))
  190 FORMAT (/5X,'SEC. SOD.',I3,' CONVECTION HEAT-TRANS. COEF. VALUES'
     1 /5X,7(I3,1PE14.4))
  200 FORMAT (/5X,I3,' OVERALL HEAT-TRANSF. COEF. VALUES'
     1 /5X,7(I3,1PE14.4))
  210 FORMAT (/5X,I3,' LOG-MEAN-TEMP-DIF. VALUES'
     1 /5X,7(I3,1PE14.4))
  310 FORMAT (2X,'TP:',10(I3,F9.3))
  320 FORMAT (2X,'TS:',10(I3,F9.3))
  330 FORMAT (2X,'TAUP:',10(I3,F9.4))
  340 FORMAT (2X,'TAUS:',10(I3,F9.4))
  341 FORMAT (/2X,25('*'),5X,'I H X - 1',5X,'T H E R M A L',5X,
     1 'C A L C U L A T I O N S',5X,25('*')/)
      RETURN
      END
      SUBROUTINE IHX2(MODE,WP,WS,TPI,TSI,N)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     INTERMEDIATE HEAT EXCHANGER THERMAL MODEL (LOOP 2)           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL NT,NUSSP,NUSSS
      DIMENSION NUSSP(10),NUSSS(10),PRP(10),PRS(10),PEP(10),PES(10)
      DIMENSION HP(10),HS(10),U(10),TDLOG(10),HEAT(10)
      DIMENSION CS(12),DS(12),XKS(12),AVS(10),RES(10)
      DIMENSION TAUP(13),TAUS(25)
      COMMON/FBR3/TP(13),TS(12)
      COMMON/FBR4/TCI4,TCI5,TCI6,TCI1,TCI2,TCI3
      COMMON/FBR14/DEQUIP,STOTP,DUMA(12),XLTOT,DUMB(4),DINT,STOTS,
     1  DUMC(20)
      COMMON/PHY4/DUD1(95),DP(13),DUD2(67),DSDUM(12),DUD3(45)
      COMMON/PHY5/DUV1(96),AVP(10),DUV2(70),AVSDUM(10),DUV3(46)
      COMMON/PHY6/DUC1(95),CP(13),DUC2(67),CSDUM(12),DUC3(45)
      COMMON/PHY7/DUK1(95),XKP(13),DUK2(67),XKSDUM(12),DUK3(45)
      COMMON/PHY8/DUR1(96),REP(10),DUR2(70),RESDUM(10),DUR3(46)
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/ALLR/DUM421(84),Y(25),DUM422(380)
      COMMON/ALLF/DUF421(84),F(25),DUF422(380)
      COMMON/ALLNUL/DUN421(84),NULL(25),DUN422(380)
```

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      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/FACT/XFAC,AFAC,VFAC,FDUM1(4),XKFAC,TFAC,FDUM2(4),XHFAC,
     1  FDUM3(2)
      NAMELIST/HX2A/DEXT,PITCH,XKSS,NT,BP,ACF
      NAMELIST/HX2B/VIP,VOP,VBP,VIS,VOS
      M=KRUNG+2
      GO TO (1004,3000,1000,2600,1000,998),M
C        THIS STATEMENT IS OF THE FORM  GO TO (A,B,C,D,E,F) ,  WHERE:
C           A IS INITIALIZATION OF ALL RUN DATA; B IS PROMPT APPROXIMATION
C           CALCULATION; C IS INITIALIZE NEW TIME STEP VALUES AND COMPUTE
C           DERIVATIVES; D IS COMPUTE DERIVATIVES;  E IS COMPUTE NEW
C           TIME CONSTANTS; AND F IS THE RESTART OPTION.
C
C        RESTART OPTION
  998 DEXT=DEXT*XFAC
      PITCH=PITCH*XFAC
      XKSS=XKSS*XKFAC
      VIP=VIP*VFAC
      VOP=VOP*VFAC
      VBP=VBP*VFAC
      VIS=VIS*VFAC
      VOS=VOS*VFAC
      GO TO 999
C
C        READ INPUT DATA
 1004 READ(5,HX2A)
      READ(5, HX2B)
C        PRINT INPUT DATA
  999 WRITE(6,HX2A)
      WRITE(6,HX2B)
C         CONVERT TO PROPER UNITS
      DEXT=DEXT/XFAC
      PITCH=PITCH/XFAC
      XKSS=XKSS/XKFAC
      VIP=VIP/VFAC
      VOP=VOP/VFAC
      VBP=VBP/VFAC
      VIS=VIS/VFAC
      VOS=VOS/VFAC
      N1=N+1
      N2=N+2
      N3=N+3
      N4=N+4
      NTOT=2*N+5
      NEND1=NTOT-1
      NEND2=NTOT-2
      XN=N
      NTOTP1=NTOT+1
      PD=PITCH/DEXT
      ALPHA=6.66+(3.126+1.184*PD)*PD
      DEDI=DEXT/DINT
      RTUBE=ALOG(DEDI)*DEXT/(2.*XKSS)
      VBUNDL=STOTP*XLTOT
      WPSTAR=(1.-BP)*WP
      ATOT=NT*XLTOT*3.141593*DEXT*ACF
      VTUBE=STOTS*XLTOT
C         INITIALIZE COMPONENTS OF THE DUMMY Y VECTOR
      DO 1002 I=1,N3
      Y(I)=TP(I)
      IF(I.NE.N3) Y(I+N3)=TS(I)
 1002 CONTINUE
```

```
      RETURN
 1000 WPSTAR=(1.-BP)*WP
      DO 1099 I=1,N2
      CS(I)=CSDUM(N3-I)
      DS(I)=DSDUM(N3-I)
      XKS(I)=XKSDUM(N3-I)
      IF(I.GT.N) GO TO 1099
      AVS(I)=AVSDUM(N1-I)
      RES(I)=RESDUM(N1-I)
 1099 CONTINUE
      DO 1100 I=1,N
      CALL LMTDIF(Y(I),Y(I+1),Y(I+N4),Y(I+N3),TDLOG(I))
 1100 CONTINUE
C        SHELL-SIDE (PRI.SOD.) CONVECTION HEAT-TRANSFER COEFFICIENT
      DO 1500 I=1,N
      IF(REP(I).GT.3000.) GO TO 1200
      NUSSP(I)=7.15
      GO TO 1400
 1200 PRP(I)=CP(I+1)*AVP(I)/XKP(I)
      PEP(I)=REP(I)*PRP(I)
      NUSSP(I)=ALPHA+0.0155*PEP(I)**0.86
 1400 HP(I)=XKP(I)*NUSSP(I)/DEQUIP
 1500 CONTINUE
C        TUBE-SIDE (SEC.SOD) CONVECTION HEAT-TRANSFER COEFFICIENT
      DO 1900 I=1,N
      IF(RES(I).GT.3000.) GO TO 1600
      NUSSS(I)=4.363636
      GO TO 1800
 1600 PRS(I)=CS(I+1)*AVS(I)/XKS(I)
      PES(I)=RES(I)*PRS(I)
      NUSSS(I)=7.+.025*PES(I)**0.8
 1800 HS(I)=XKS(I)*NUSSS(I)/DINT
 1900 CONTINUE
C        OVERALL HEAT/TRANSFER COEFFICIENT
      DO 2000 I=1,N
      U(I)=1./(DEDI/HS(I)+RTUBE+1./HP(I))
 2000 CONTINUE
      IF(M.EQ.3) GO TO 2630
C        COMPUTE THE TIME CONSTANTS OF SODIUM TEMPERATURES
      TAUP(1)=3600.*DP(1)*VIP/WPSTAR
      DTMIN=TP(1)-TS(1)
      DO 2300 I=2,N1
      DTMAX=TP(I)-TS(I)
      DRATIO=DTMAX/DTMIN
      IF(DTMAX.NE.DTMIN) GO TO 2100
      DTMDTP=1.
      DTMDTS=1.
      GO TO 2200
 2100 IF(DRATIO.LE.0.) GO TO 2105
      XLOG=ALOG(DRATIO)
      DTMDTP=(1.-(1.-DTMIN/DTMAX)/XLOG)/XLOG
      DTMDTS=-(1.+(1.-DTMAX/DTMIN)/XLOG)/XLOG
      GO TO 2200
 2105 DTMDTP=0.0
      DTMDTS=0.0
 2200 TAUP(I)=3600.*DP(I)*VBUNDL*CP(I)/(XN*WPSTAR*CP(I)+U(I-1)*ATOT*
     1 DTMDTP)
      ILESS1=I+N2
      TAUS(ILESS1)=3600.*DS(I)*VTUBE*CS(I)/(XN*WS*CS(I)+U(I-1)*ATOT*
     1 DTMDTS)
      DTMIN=DTMAX
```

```
2300 CONTINUE
     TAUP(N2)=3600.*DP(N2)*VBP/(BP*WP)
     TAUP(N3)=3600.*DP(N3)*VOP*CP(N3)/(WPSTAR*CP(N3)+BP*WP*CP(N2))
     TAUS(NEND1)=3600.*DS(N1)*VIS/WS
     TAUS(NTOT)= 3600.*DS(N2)*VOS/WS
     J=1
     DO 2301 I=1, N3
     IF((TAUP(I)*0.7).GE.SSEC.AND.MODE.NE.0) GO TO 2301
     NULL(J)=I
     J=J+1
2301 CONTINUE
     DO 2302 I=N4, NTOT
     IF((TAUS(I)*0.7).GE.SSEC.AND.MODE.NE.0) GO TO 2302
     NULL(J)=I
     J=J+1
2302 CONTINUE
     IF(NTOTP1.GT.25) GO TO 2304
     DO 2303 I=NTOTP1, 25
     NULL(J)=I
     J=J+1
2303 CONTINUE
2304 GO TO 2630
2600 DO 2610 I=1,N
     CALL LMTDIF(Y(I),Y(I+1),Y(I+N4),Y(I+N3),TDLOG(I))
2610 CONTINUE
2630 WPSTAR=(1.-BP)*WP
     J=1
     IF(NULL(J).NE.1) GO TO 2631
     J=J+1
     GO TO 2632
2631 F(1)=WPSTAR*(TPI-Y(1))/(DP(1)*VIP)
2632 DO 2700 I=1, N
2700 HEAT(I)=U(I)*(ATOT/XN)*TDLOG(I)
     DO 2800 I=2,N1
     IF(NULL(J).NE.I) GO TO 2801
     J=J+1
     GO TO 2800
2801 F(I)=(WPSTAR*CP(I)*(Y(I-1)-Y(I))-HEAT(I-1))/(DP(I)*(VBUNDL/XN)*
    1 CP(I))
2800 CONTINUE
     IF(NULL(J).NE.N2) GO TO 2802
     J=J+1
     GO TO 2803
2802 F(N2)=BP*WP*(TPI-Y(N2))/(DP(N2)*VBP)
2803 IF(NULL(J).NE.N3) GO TO 2804
     J=J+1
     GO TO 2805
2804 F(N3)=(WPSTAR*CP(N3)*(Y(N1)-Y(N3))+BP*WP*CP(N2)*(Y(N2)-Y(N3)))
    1 /(DP(N3)*VOP*CP(N3))
     TCI3=Y(N3)
2805 CONTINUE
     DO 2900 I=N4,NEND2
     I1=I-N3
     I2=I-N2
     IF(NULL(J).NE.I) GO TO 2901
     J=J+1
     GO TO 2900
2901 F(I)=(HEAT(I1)-WS*CS(I2)*(Y(I)-Y(I+1)))/(DS(I2)*(VTUBE/XN)*CS(I2))
2900 CONTINUE
     IF(NULL(J).NE.NEND1) GO TO 2902
     J=J+1
```

```
      GO TO 2903
2902  F(NEND1)=WS*(TSI-Y(NEND1))/(DS(N1)*VIS)
2903  IF(NULL(J).NE.NTOT) GO TO 2904
      GO TO 2950
2904  F(NTOT)=WS*(Y(N4)-Y(NTOT))/(DS(N2)*VOS)
2950  DO 2960 I=1,N3
      TP(I)=Y(I)
      IF(I.NE.N3) TS(I)=Y(N3+I)
2960  CONTINUE
      RETURN
3000  J=1
      IF(NULL(J).EQ.1) GO TO 3001
      GO TO 4001
3001  Y(1)=TPI
      J=J+1
4001  DO 4010 I=2, N1
      IF(NULL(J).EQ.I) GO TO 3002
      GO TO 4010
3002  CALL PROMTP(WPSTAR,CP(I),TP(I-1),Y(I),TS(I),TS(I-1),U(I-1),ATOT,
     1XN)
      J=J+1
4010  CONTINUE
      IF(NULL(J).EQ.N2) GO TO 3003
      GO TO 4011
3003  Y(N2)=TPI
      J=J+1
4011  IF(NULL(J).EQ.N3) GO TO 3004
      GO TO 4012
3004  ALF1=WPSTAR*CP(N3)/(BP*WP*CP(N2))
      IF(MODE.EQ.0) TP(N1)=Y(N1)
      IF(MODE.EQ.0) TP(N2)=Y(N2)
      Y(N3)=(ALF1*TP(N1)+TP(N2))/(ALF1+1.)
      TCI3=Y(N3)
      J=J+1
4012  DO 4020 I=N4, NEND2
      I1=I-N3
      I2=I-N2
      IF(NULL(J).EQ.I) GO TO 3005
      GO TO 4020
3005  CALL PROMTS(WS,CS(I2),TP(I1),TP(I2),TS(I2),Y(I),U(I1),ATOT,XN)
      J=J+1
4020  CONTINUE
      IF(NULL(J).EQ.NEND1) GO TO 3006
      GO TO 4021
3006  Y(NEND1)=TSI
      J=J+1
4021  IF(NULL(J).EQ.NTOT) GO TO 3007
      GO TO 4022
3007  Y(NTOT)=Y(N4)
4022  DO 3100 I=1, N3
3100  TP(I)=Y(I)
      DO 3200 I=1,N2
3200  TS(I)=Y(N3+I)
      MGO=1
      RETURN
      ENTRY PUTHX2
      WRITE(6,341)
      IF(ICOUNT.NE.0) GO TO 3350
      DO 3300 I=1,N
      HP(I)=HP(I)*XHFAC
      HS(I)=HS(I)*XHFAC
```

```
      U(I)=U(I)*XHFAC
 3300 CONTINUE
      DO 3301 I=1,10
 3301 TDLOG(I)=TDLOG(I)*TFAC
      WRITE(6,180) N,(I,HP(I),I=1,N)
      WRITE(6,190) N,(I,HS(I),I=1,N)
      WRITE(6,200) N,(I,U(I),I=1,N)
      WRITE(6,210) N,(I,TDLOG(I),I=1,N)
      DO 3349 I=1,N
 3349 U(I)=U(I)/XHFAC
 3350 IF(KCALC.NE.1) GO TO 3360
      WRITE(6,330) (I,TAUP(I),I=1,N3)
      WRITE(6,340) (I,TAUS(I),I=N4,NTOT)
 3360 CALL TMPCON(1,13,TP)
      CALL TMPCON(1,12,TS)
      WRITE(6,310) (I,TP(I),I=1,N3)
      WRITE(6,320) (I,TS(I),I=1,N2)
      CALL TMPCON(0,13,TP)
      CALL TMPCON(0,12,TS)
  180 FORMAT (/5X,'PRI. SOD.',I3,' CONVECTION HEAT-TRANS. COEF. VALUES'
     1 /5X,7(I3,1PE14.4))
  190 FORMAT (/5X,'SEC. SOD.',I3,' CONVECTION HEAT-TRANS. COEF. VALUES'
     1 /5X,7(I3,1PE14.4))
  200 FORMAT (/5X,I3,' OVERALL HEAT-TRANSF. COEF. VALUES'
     1 /5X,7(I3,1PE14.4))
  210 FORMAT (/5X,I3,' LOG-MEAN-TEMP-DIF. VALUES'
     1 /5X,7(I3,1PE14.4))
  310 FORMAT (2X,'TP:',10(I3,F9.3))
  320 FORMAT (2X,'TS:',10(I3,F9.3))
  330 FORMAT (2X,'TAUP:',10(I3,F9.4))
  340 FORMAT (2X,'TAUS:',10(I3,F9.4))
  341 FORMAT (/2X,25('*'),5X,'I H X - 2',5X,'T H E R M A L',5X,
     1  'C A L C U L A T I O N S',5X,25('*')/)
      RETURN
      END
      SUBROUTINE IHYD1(PD, PTM, KMM, MODE)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     INTERMEDIATE LOOP-1: COOLANT DYNAMICS SIMULATION       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL KMM,KPM,KFT,KST,KSF,MINERT
      DIMENSION TAU(5),TCM(5),TAUS(3)
      COMMON/ALPB/PMSSP,DSPEED,XNP,A1,A2,A3,AZ,TS,TR,TMIN
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/ALLR/DUR611(229),Y(5),DUR612(255)
      COMMON/ALLF/DUF611(229),F(5),DUF612(255)
      COMMON/ALLNUL/DUN611(229),NULL(5),DUN612(255)
      COMMON/GET1/WDUM(9),WI100,WI,WS2,WBRK
      COMMON/FBR14/XDM1(21),XL3,XL7,XL8,XL1,XDM2(4),XL2,XL4,XL5,XL6,
     1 XDM3(8)
      COMMON/FBR16/ADM1(129),AS2,AS3,ADM2(9),AS4,AS5,AS6,AS7,ADM3(9),AS8
     1,AS1,ADM4(77)
      COMMON/HEADS/DHG(9),DPBST,DPBS2
      COMMON/NORMS/ADUM(8),WS100,BDUM(4)
      COMMON/FRICTS/C(9),CCST,CCST2
      COMMON/FACT/FDUM1(4),PFAC,FDUM2(4),XMFAC,TQFAC,SPFAC,FDUM3(3),GCP
      NAMELIST/IHA1/DSPEED,TMMD,MINERT,PMSSP
      NAMELIST/IHA2/PTSP,KFT,KST,KSF,TAUS
      NAMELIST/IHA3/A1,A2,A3,AZ,TS,TR,TMIN,GFI,XNP,ALFA,GF
      DATA PI/3.141593/
      M=KRUNG+2
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      IF(TSEC.NE.0.) QKMM=KMM+FRICK*KMM
      GO TO (1000,6000,3000,5000,2000,998),M
C
C        RESTART OPTION
  998 DSPEED=DSPEED*SPFAC
      TMMD=TMMD*TQFAC
      MINERT=MINERT*XMFAC
      PMSSP=PMSSP*SPFAC
      PTSP=PTSP*PFAC
      ALFA=Y(2)
      IF(PD.EQ.1.) ALFA=1.
      IF(ALFA.EQ.1.) GF=GFI
      GO TO 1001
C      READ INPUT DATA
 1000 READ(5, IHA1)
      READ(5, IHA2)
      READ(5, IHA3)
C      PRINT INPUT DATA
 1001 WRITE(6, IHA1)
      WRITE(6, IHA2)
      WRITE(6, IHA3)
C         CONVERT TO PROPER UNITS
      DSPEED=DSPEED/SPFAC
      TMMD=TMMD/TQFAC
      MINERT=MINERT/XMFAC
      PMSSP=PMSSP/SPFAC
      PTSP=PTSP/PFAC
      GC=GCP*(3600.**2)
      IF(M.EQ.1) WS100=WI100
      WIM=WI/WS100
      ALFM=ALFA
      L=0
      IF(MODE.NE.0.OR.PD.EQ.1.) DHEAD=(CCST*WI*WI-DPBST)
C
C      CALCULATE THE OVERALL INERTIAL LOSS COEFFICIENT FOR THE ENTIRE LOOP
C
      ALST=((XL1/AS1)+(XL2/AS2)+(XL3/AS3)+(XL4/AS4)+(((XL5/AS5)+(XL6/AS6
     1)+(XL7/AS7))/2.0)+(XL8/AS8))/GC
      PCON1=120.*PI*MINERT/GC
      PCON2=PCON1*DSPEED/TMMD
      IF(MODE.NE.0.OR.PD.EQ.1.) GO TO 1002
      WI=WS100*PD
      GF=GFI*PD
      ALFA=PD
C
C      CALCULATE THE INTERMEDIATE PUMP DESIGN HEAD
C
 1002 WIN=WI/WS100
      CALL PHEAD(ALFA,WIN,PHN)
      CALL TFRIC(1.,AZ,TS,TR,TMIN,FRICK)
      QKMM=KMM+FRICK*KMM
      KPM=0.0
      SPEED=ALFA*DSPEED
      SSPEED=60.*GF/XNP
      SLIP=1.0-(SPEED/SSPEED)
      SLPM=1.0-(SPEED/PMSSP)
      TMM=SLIP/(A1*SLIP*SLIP+A2)
      TPM=A3*SLPM/(A1*SLPM*SLPM+A2)
      IF(ALFA.LE.0.1.AND.MODE.NE.3) KPM=1.0
      TDMN=QKMM*TMM+KPM*TPM
      CALL PTORQ(ALFA,WIN,BTORQ)
```

```
      CALL TFRIC(ALFA,AZ,TS,TR,TMIN,TFR)
      Y(1)=WI
      Y(2)=ALFA
      Y(3)=WIM
      Y(4)=ALFM
      Y(5)=GF
      RETURN
 2000 WIN=WI/WS100
      SSPEED=60.*GF/XNP
      SLIP=1.0-(ALFA*DSPEED/SSPEED)
      DTMD=-QKMM*DSPEED/SSPEED*((A2-A1*(SLIP**2))/((A1*(SLIP**2)+A2)**2
     1))
      CALL PTIME(ALFA,WIN,AZ,TS,TR,DTPD,DTFD)
      TAU(1)=ALST/(2.*CCST*WI)
      TAU(2)=PCON2/(DTFD+DTPD-DTMD)
      TAU(3)=TAUS(1)/3600.0
      TAU(4)=TAUS(2)/3600.0
      TAU(5)=TAUS(3)/3600.0
      DO 6 I=1, 5
      TCM(I)=TAU(I)*3600.0
    6 CONTINUE
      DO 7 I=1, 5
    7 NULL(I)=0
      J=1
      DO 8 I=1, 5
      IF(0.7*ABS(TAU(I)).GE.S) GO TO 8
      NULL(J)=I
      J=J+1
    8 CONTINUE
      IF(MODE.NE.0) GO TO 10
      J=1
      DO 9 I=1, 4
      NULL(I)=J
      J=J+1
    9 CONTINUE
   10 CONTINUE
 3000 IF(KMM.NE.0.0) GO TO 11
      IF(L.GT.0) GO TO 11
      L=1
      TTRIP=T
      TTRIPS=TTRIP*3600.0
      AZERO=ALFA
      WRITE(6, 9950) TTRIPS
   11 CONTINUE
C
C        COMPUTE THE DEMANDED QUANTITIES
      FLSP=PD
      ASP=PD
 5000 J=1
      ETP=(PTSP-PTM)/PTSP
      TFLT=KFT*ETP
      FLSPA=TFLT+FLSP
      EWI=FLSPA-Y(3)
      TFLF=KST*EWI
      ASPA=TFLF+ASP
      IF(ASPA.GT.1.) ASPA=1.0
      EPS=ASPA-Y(4)
      IF(ABS(EPS).LE.0.01) EPS=0.0
      IF(NULL(J).NE.1) GO TO 100
      J=J+1
      GO TO 101
```

```
 100 WIN=Y(1)/WS100
     CALL PHEAD(Y(2), WIN, PHN)
     DPIP=PHN*DHEAD
     F(1)=(DPIP+DPBST-CCST*Y(1)*ABS(Y(1)))/ALST
 101 IF(NULL(J).NE.2) GO TO 200
     J=J+1
     GO TO 201
 200 SPEED=Y(2)*DSPEED
     SSPEED=60.*Y(5)/XNP
     SLIP=1.0-(SPEED/SSPEED)
     SLPM=1.0-(SPEED/PMSSP)
     TMM=SLIP/(A1*SLIP*SLIP+A2)
     TPM=A3*SLPM/(A1*SLPM*SLPM+A2)
     KPM=0.
     IF(Y(2).LE.0.1.AND.MODE.NE.3) KPM=1.0
     TDMN=QKMM*TMM+KPM*TPM
     WIN=Y(1)/WS100
     CALL PTORQ(Y(2),WIN,BTORQ)
     CALL TFRIC(Y(2),AZ,TS,TR,TMIN,TFR)
     F(2)=(TDMN-BTORQ-TFR)/PCON2
 201 IF(NULL(J).NE.3) GO TO 300
     J=J+1
     GO TO 301
 300 F(3)=((Y(1)/WS100)-Y(3))/TAU(3)
 301 IF(NULL(J).NE.4) GO TO 400
     J=J+1
     GO TO 401
 400 F(4)=(Y(2)-Y(4))/TAU(4)
 401 IF(NULL(J).NE.5) GO TO 500
     RETURN
 500 F(5)=KSF*GFI*EPS/TAU(5)
     RETURN
6000 WI=Y(1)
     ALFA=Y(2)
     WIM=Y(3)
     ALFM=Y(4)
     GF=Y(5)
     WIN=WI/WS100
     J=1
     IF(NULL(J).EQ.1) GO TO 6100
     GO TO 6110
6100 CALL PHEAD(ALFA,WIN,PHN)
     DPIP=PHN*DHEAD
     Y(1)=((ABS(DPIP+DPBST))/CCST)**0.5
     IF((DPIP+DPBST).LT.0.0) Y(1)=-Y(1)
     J=J+1
6110 IF(NULL(J).EQ.2) GO TO 6200
     GO TO 6210
6200 KPM=0.
     IF(ALFA.LE.0.1.AND.MODE.NE.3) KPM=1.0
     CALL ALPHA(Y(2),WIN,GF,QKMM,KPM,TMM,TDMN,BTORQ,TFR,SLIP)
     J=J+1
6210 IF(NULL(J).EQ.3) GO TO 6300
     GO TO 6310
6300 Y(3)=WIN
     J=J+1
6310 IF(NULL(J).EQ.4) GO TO 6400
     GO TO 6410
6400 Y(4)=ALFA
     J=J+1
6410 IF(NULL(J).EQ.5) GO TO 6500
```

```
      GO TO 6510
 6500 Y(5)=GF
 6510 CONTINUE
      WI=Y(1)
      ALFA=Y(2)
      WIM=Y(3)
      ALFM=Y(4)
      GF=Y(5)
      WIN=WI/WS100
      RETURN
      ENTRY PUTIH1
      WRITE(6, 9935)
      IF(KCALC.EQ.1) WRITE(6, 9955) (I, TCM(I), I=1, 5)
      WRITE(6, 9940) WIN, ALFA, PHN, GF
      WRITE(6, 9945) TMM, TDMN, BTORQ, TFR
 9935 FORMAT(/,2X,'************************   I N T E R M E D I A T E
     1L O O P - 1:   C O O L A N T   D Y N A M I C S  *****************
     2*******'/)
 9940 FORMAT(3X,'SODIUM FLOW RATE =',F8.4,3X,'PUMP SPEED =',F8.4,3X,'PUM
     1P HEAD =',F8.4,3X,'MOTOR GEN. SET FREQ. =',F10.3,' CYCLES/SEC')
 9945 FORMAT(3X,'MAIN MOTOR TORQUE =',F8.4,3X,'DRIVE MOTOR TORQUE =',F8.
     14,3X,'PUMP TORQUE =',F8.4,3X,'FRICTION TORQUE =',F8.4)
 9950 FORMAT(/20X,'**** INTERMEDIATE PUMP #1 TRIP AT',F8.4,' SEC ****'/)
 9955 FORMAT(3X,'TAU:',5(I3, F12.6))
      RETURN
      END
      SUBROUTINE IHYD2(PD, PTM, KMM, MODE)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     INTERMEDIATE LOOP-2: COOLANT DYNAMICS SIMULATION     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL KMM,KPM,KFT,KST,KSF,MINERT
      DIMENSION TAU(5),TCM(5),TAUS(3)
      COMMON/ALPB/PMSSP,DSPEED,XNP,A1,A2,A3,AZ,TS,TR,TMIN
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/ALLR/DUR621(234),Y(5),DUR622(250)
      COMMON/ALLF/DUF621(234),F(5),DUF622(250)
      COMMON/ALLNUL/DUN621(234),NULL(5),DUN622(250)
      COMMON/GET1/WDUM(9),WI100,WS1,WI,WBRK
      COMMON/FBR14/XDM1(25),XL3,XL7,XL8,XL1,XL2,XL4,XL5,XL6,XDM3(8)
      COMMON/FBR16/ADM1(118),AS2,ADM2(11),AS3,ADM3(9),AS4,AS5,AS6,AS7,
     1 ADM4(9),AS8,AS1,ADM5(77)
      COMMON/HEADS/DHG(10),DPBST
      COMMON/FRICTS/C(10),CCST
      COMMON/NORMS/ADUM(9),WS100,BDUM(3)
      COMMON/FACT/FDUM1(4),PFAC,FDUM2(4),XMFAC,TQFAC,SPFAC,FDUM3(3),GCP
      NAMELIST/IHB1/TMMD,MINERT,GFI,ALFA,GF
      NAMELIST/IHB2/PTSP,KFT,KST,KSF,TAUS
      DATA PI/3.141593/
      M=KRUNG+2
      IF(TSEC.NE.0.) QKMM=KMM+FRICK*KMM
      GO TO (1000,6000,3000,5000,2000,998),M
C
C        RESTART OPTION
  998 TMMD=TMMD*TQFAC
      MINERT=MINERT*XMFAC
      PTSP=PTSP*PFAC
      ALFA=Y(2)
      IF(PD.EQ.1.) ALFA=1.
      IF(ALFA.EQ.1.) GF=GFI
      GO TO 1001
```

```
C       READ INPUT DATA
 1000 READ(5, IHB1)
      READ(5, IHB2)
C       PRINT INPUT DATA
 1001 WRITE(6, IHB1)
      WRITE(6, IHB2)
C          CONVERT TO PROPER UNITS
      TMMD=TMMD/TQFAC
      MINERT=MINERT/XMFAC
      PTSP=PTSP/PFAC
      IF(M.EQ.1) WS100=WI100
      GC=GCP*(3600.**2)
      WIM=WI/WS100
      ALFM=ALFA
      L=0
      IF(MODE.NE.0.OR.PD.EQ.1.) DHEAD=(CCST*WI*WI-DPBST)
C
C       CALCULATE THE OVERALL INERTIAL LOSS COEFFICIENT FOR THE ENTIRE LOOP
C
      ALST=((XL1/AS1)+(XL2/AS2)+(XL3/AS3)+(XL4/AS4)+(((XL5/AS5)+(XL6/AS6
     1)+(XL7/AS7))/2.0)+(XL8/AS8))/GC
      PCON1=120.*PI*MINERT/GC
      PCON2=PCON1*DSPEED/TMMD
      IF(MODE.NE.0.OR.PD.EQ.1.) GO TO 1002
      WI=WS100*PD
      GF=GFI*PD
      ALFA=PD
C
C       CALCULATE THE INTERMEDIATE PUMP DESIGN HEAD
C
 1002 WIN=WI/WS100
      CALL PHEAD(ALFA,WIN,PHN)
      CALL TFRIC(1.,AZ,TS,TR,TMIN,FRICK)
      QKMM=KMM+FRICK*KMM
      KPM=0.0
      SPEED=ALFA*DSPEED
      SSPEED=60.*GF/XNP
      SLIP=1.0-(SPEED/SSPEED)
      SLPM=1.0-(SPEED/PMSSP)
      TMM=SLIP/(A1*SLIP*SLIP+A2)
      TPM=A3*SLPM/(A1*SLPM*SLPM+A2)
      IF(ALFA.LE.0.1.AND.MODE.NE.3) KPM=1.0
      TDMN=QKMM*TMM+KPM*TPM
      CALL PTORQ(ALFA,WIN,BTORQ)
      CALL TFRIC(ALFA,AZ,TS,TR,TMIN,TFR)
      Y(1)=WI
      Y(2)=ALFA
      Y(3)=WIM
      Y(4)=ALFM
      Y(5)=GF
      RETURN
 2000 WIN=WI/WS100
      SSPEED=60.*GF/XNP
      SLIP=1.0-(ALFA*DSPEED/SSPEED)
      DTMD=-QKMM*DSPEED/SSPEED*((A2-A1*(SLIP**2))/((A1*(SLIP**2)+A2)**2
     1))
      CALL PTIME(ALFA,WIN,AZ,TS,TR,DTPD,DTFD)
      TAU(1)=ALST/(2.*CCST*WI)
      TAU(2)=PCON2/(DTFD+DTPD-DTMD)
      TAU(3)=TAUS(1)/3600.0
      TAU(4)=TAUS(2)/3600.0
```

```
      TAU(5)=TAUS(3)/3600.0
      DO 6 I=1, 5
      TCM(I)=TAU(I)*3600.0
    6 CONTINUE
      DO 7 I=1, 5
    7 NULL(I)=0
      J=1
      DO 8 I=1, 5
      IF(0.7*ABS(TAU(I)).GE.S) GO TO 8
      NULL(J)=I
      J=J+1
    8 CONTINUE
      IF(MODE.NE.0) GO TO 10
      J=1
      DO 9 I=1, 4
      NULL(I)=J
      J=J+1
    9 CONTINUE
   10 CONTINUE
 3000 IF(KMM.NE.0.0) GO TO 11
      IF(L.GT.0) GO TO 11
      L=1
      TTRIP=T
      TTRIPS=TTRIP*3600.0
      AZERO=ALFA
      WRITE(6, 9950) TTRIPS
   11 CONTINUE
C
C          COMPUTE THE DEMANDED QUANTITIES
      FLSP=PD
      ASP=PD
 5000 J=1
      ETP=(PTSP-PTM)/PTSP
      TFLT=KFT*ETP
      FLSPA=TFLT+FLSP
      EWI=FLSPA-Y(3)
      TFLF=KST*EWI
      ASPA=TFLF+ASP
      IF(ASPA.GT.1.) ASPA=1.0
      EPS=ASPA-Y(4)
      IF(ABS(EPS).LE.0.01) EPS=0.0
      IF(NULL(J).NE.1) GO TO 100
      J=J+1
      GO TO 101
  100 WIN=Y(1)/WS100
      CALL PHEAD(Y(2), WIN, PHN)
      DPIP=PHN*DHEAD
      F(1)=(DPIP+DPBST-CCST*Y(1)*ABS(Y(1)))/ALST
  101 IF(NULL(J).NE.2) GO TO 200
      J=J+1
      GO TO 201
  200 SPEED=Y(2)*DSPEED
      SSPEED=60.*Y(5)/XNP
      SLIP=1.0-(SPEED/SSPEED)
      SLPM=1.0-(SPEED/PMSSP)
      TMM=SLIP/(A1*SLIP*SLIP+A2)
      TPM=A3*SLPM/(A1*SLPM*SLPM+A2)
      KPM=0.
      IF(Y(2).LE.0.1.AND.MODE.NE.3) KPM=1.0
      TDMN=QKMM*TMM+KPM*TPM
      WIN=Y(1)/WS100
```

```
      CALL PTORQ(Y(2),WIN,BTORQ)
      CALL TFRIC(Y(2),AZ,TS,TR,TMIN,TFR)
      F(2)=(TDMN-BTORQ-TFR)/PCON2
  201 IF(NULL(J).NE.3) GO TO 300
      J=J+1
      GO TO 301
  300 F(3)=((Y(1)/WS100)-Y(3))/TAU(3)
  301 IF(NULL(J).NE.4) GO TO 400
      J=J+1
      GO TO 401
  400 F(4)=(Y(2)-Y(4))/TAU(4)
  401 IF(NULL(J).NE.5) GO TO 500
      RETURN
  500 F(5)=KSF*GFI*EPS/TAU(5)
      RETURN
 6000 WI=Y(1)
      ALFA=Y(2)
      WIM=Y(3)
      ALFM=Y(4)
      GF=Y(5)
      WIN=WI/WS100
      J=1
      IF(NULL(J).EQ.1) GO TO 6100
      GO TO 6110
 6100 CALL PHEAD(ALFA,WIN,PHN)
      DPIP=PHN*DHEAD
      Y(1)=((ABS(DPIP+DPBST))/CCST)**0.5
      IF((DPIP+DPBST).LT.0.0) Y(1)=-Y(1)
      J=J+1
 6110 IF(NULL(J).EQ.2) GO TO 6200
      GO TO 6210
 6200 KPM=0.
      IF(ALFA.LE.0.1.AND.MODE.NE.3) KPM=1.0
      CALL ALPHA(Y(2),WIN,GF,QKMM,KPM,TMM,TDMN,BTORQ,TFR,SLIP)
      J=J+1
 6210 IF(NULL(J).EQ.3) GO TO 6300
      GO TO 6310
 6300 Y(3)=WIN
      J=J+1
 6310 IF(NULL(J).EQ.4) GO TO 6400
      GO TO 6410
 6400 Y(4)=ALFA
      J=J+1
 6410 IF(NULL(J).EQ.5) GO TO 6500
      GO TO 6510
 6500 Y(5)=GF
 6510 CONTINUE
      WI=Y(1)
      ALFA=Y(2)
      WIM=Y(3)
      ALFM=Y(4)
      GF=Y(5)
      WIN=WI/WS100
      RETURN
      ENTRY PUTIH2
      WRITE(6, 9935)
      IF(KCALC.EQ.1) WRITE(6, 9955) (I, TCM(I), I=1, 5)
      WRITE(6, 9940) WIN, ALFA, PHN, GF
      WRITE(6, 9945) TMM, TDMN, BTORQ, TFR
 9935 FORMAT(/,2X,'**************************  I N T E R M E D I A T E
     1L O O P - 2:   C O O L A N T   D Y N A M I C S  ******************
```

```
     2*******'/)
 9940 FORMAT(3X,'SODIUM FLOW RATE =',F8.4,3X,'PUMP SPEED =',F8.4,3X,'PUM
     1P HEAD =',F8.4,3X,'MOTOR GEN. SET FREQ. =',F10.3,' CYCLES/SEC')
 9945 FORMAT(3X,'MAIN MOTOR TORQUE =',F8.4,3X,'DRIVE MOTOR TORQUE =',F8.
     14,3X,'PUMP TORQUE =',F8.4,3X,'FRICTION TORQUE =',F8.4)
 9950 FORMAT(/20X,'**** INTERMEDIATE PUMP #2 TRIP AT',F8.4,' SEC ****'/)
 9955 FORMAT(3X,'TAU:',5(I3, F12.6))
      RETURN
      END
      SUBROUTINE DELAY1(W1, MODE)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C  INTERMEDIATE LOOP-1: SODIUM TRANSPORT DELAY SIMULATION  C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION TCS1(10),TCS2(10),TCS3(10),TCS4(10)
      DIMENSION TWS1(10),TWS2(10),TWS3(10),TWS4(10)
      DIMENSION FCS1(10),FCS2(10),FCS3(10),FCS4(10)
      DIMENSION FWS1(10),FWS2(10),FWS3(10),FWS4(10)
      DIMENSION VCTOT(4),VCSEC(4),VWTOT(4),ATOT(4),ROVCW(4)
      DIMENSION TAUC1(10),TAUC2(10),TAUC3(10),TAUC4(10)
      DIMENSION TAUW1(10),TAUW2(10),TAUW3(10),TAUW4(10)
      DIMENSION U1(10),U2(10),U3(10),U4(10),USC1(10),USC2(10),USC3(10),
     1 USC4(10)
      DIMENSION XN(4),DI(4),STOT(4)
      EQUIVALENCE (Y(1),TCS1(1)),(Y(11),TCS2(1)),(Y(21),TCS3(1)),(Y(31),
     1TCS4(1)),(Y(41),TWS1(1)),(Y(51),TWS2(1)),(Y(61),TWS3(1)),(Y(71),
     2TWS4(1))
      EQUIVALENCE (F(1),FCS1(1)),(F(11),FCS2(1)),(F(21),FCS3(1)),(F(31),
     1FCS4(1)),(F(41),FWS1(1)),(F(51),FWS2(1)),(F(61),FWS3(1)),(F(71),
     2FWS4(1))
      COMMON/RUNGNO/KR,KCALC
      COMMON/ALLR/DUR711(239),Y(80),DUR712(170)
      COMMON/ALLF/DUF711(239),F(80),DUF712(170)
      COMMON/ALLNUL/DUN711(239),NULL(80),DUN712(170)
      COMMON/FBR6/TCI1,TCI2,TCI3,TCI4,TSI1,TSO1,TEI1
      COMMON/FBR7/TM1(10),TM2(10),TM3(10),TM4(10)
      COMMON/FBR11/N(4),L(4)
      COMMON/FBR14/D1(21),XL(4),D2(8),ODI(4),DELI(4)
      COMMON/FBR15/DSS,CSS,XKSS
      COMMON/PHY4/DE1(130),DC1(10),DE2(3),DC2(10),DE3,DC3(10),DE4,
     1 DC4(10),DE5(57)
      COMMON/PHY5/VE1(130),VS1(10),VE2(3),VS2(10),VE3,VS3(10),VE4,
     1 VS4(10),VE5(57)
      COMMON/PHY6/CE1(130),CC1(10),CE2(3),CC2(10),CE3,CC3(10),CE4,
     1 CC4(10),CE5(57)
      COMMON/PHY7/XKE1(130),XK1(10),XKE2(3),XK2(10),XKE3,XK3(10),XKE4,
     1 XK4(10),XKE5(57)
      COMMON/PHY8/RN1(130),RE1(10),RN2(3),RE2(10),RN3,RE3(10),RN4,
     1 RE4(10),RN5(57)
      DATA PI/3.141593/
      MGO=KR+2
      GO TO (1000,2100,2000,2000,2000,1000),MGO
C
C          FIX UP THE COMPONENTS OF THE NULL VECTOR AS FUNCTION OF "N", & "L"
C                        FIRST FOR THE COOLANT TEMPERATURE NODES
 1000 DO 1020 I=1, 4
      J2=10*I
      J1=J2-9
      DO 1020 J=J1, J2
      IF((J+10-J2).LE.N(I)) GO TO 1010
      NULL(J)=J
      GO TO 1020
```

```
 1010 NULL(J)=0
 1020 CONTINUE
C          AND NOW, FOR THE PIPE WALL TEMPERATURES
      DO 1050 I=1, 4
      J2=40+10*I
      J1=J2-9
      DO 1050 J=J1, J2
      IF(L(I).NE.1) GO TO 1030
      NULL(J)=J
      GO TO 1050
 1030 IF((J+10-J2).LE.N(I)) GO TO 1040
      NULL(J)=J
      GO TO 1050
 1040 NULL(J)=0
 1050 CONTINUE
      I=1
      DO 1055 J=1, 80
      IF(NULL(J).EQ.0) GO TO 1055
      NULL(I)=NULL(J)
      I=I+1
 1055 CONTINUE
      DO 1056 J=I, 80
      NULL(J)=0
 1056 CONTINUE
      N1=N(1)
      N2=N(2)
      N3=N(3)
      N4=N(4)
      DO 1057 I=1, 10
      TWS1(I)=TCI1
      TWS2(I)=TCI2
      TWS3(I)=TCI3
 1057 TWS4(I)=TCI4
C              COMPUTE QUANTITIES RELATED TO THE PIPE RUNS
      DO 57 I=1,4
      DI(I)=ODI(I)-2.*DELI(I)
      STOT(I)=PI/4.*DI(I)**2/144.
      XCIR=PI*DI(I)/12.
      XSEC=PI*(DI(I)+DELI(I))*DELI(I)/144.
      VCTOT(I)=STOT(I)*XL(I)
      VWTOT(I)=XSEC*XL(I)
      ATOT(I)=XCIR*XL(I)
   57 CONTINUE
      DO 1058 I=1, 10
      TCS1(I)=TM1(I)
      TCS2(I)=TM2(I)
      TCS3(I)=TM3(I)
      TCS3(I)=TM4(I)
 1058 TCS4(I)=TM4(I)
      DO 1059 I=1, 4
      XN(I)=N(I)
      VCSEC(I)=VCTOT(I)/XN(I)
      ROVCW(I)=DSS*VWTOT(I)*CSS/XN(I)
 1059 CONTINUE
      RETURN
 2000 IF(MODE.EQ.0) RETURN
      W2=W1/2.0
      TCI3=TCS2(N(2))
      TCI4=TCS3(N(3))
C        START CALLING ON THE SUBROUTINE PIPE TO GET THE TEMP. DERIVATIVES
C
```

```
C      PIPE RUN # 1
       CALL PIPE(N(1),L(1),KR,W1,TCI1,TCS1,TWS1,FCS1,FWS1,DI(1),DELI(1),
     1 STOT(1),ATOT(1),VCTOT(1),XKSS,ROVCW(1),VCSEC(1),CC1,DC1,VS1,XK1,
     2 RE1,U1,USC1,TAUC1,TAUW1)
C
C      PIPE RUN # 2
       CALL PIPE(N(2),L(2),KR,W2,TCI2,TCS2,TWS2,FCS2,FWS2,DI(2),DELI(2),
     1 STOT(2),ATOT(2),VCTOT(2),XKSS,ROVCW(2),VCSEC(2),CC2,DC2,VS2,XK2,
     2 RE2,U2,USC2,TAUC2,TAUW2)
C
C      PIPE RUN # 3
       CALL PIPE(N(3),L(3),KR,W1,TCI3,TCS3,TWS3,FCS3,FWS3,DI(3),DELI(3),
     1 STOT(3),ATOT(3),VCTOT(3),XKSS,ROVCW(3),VCSEC(3),CC3,DC3,VS3,XK3,
     2 RE3,U3,USC3,TAUC3,TAUW3)
C
C      PIPE RUN # 4
       CALL PIPE(N(4),L(4),KR,W1,TCI4,TCS4,TWS4,FCS4,FWS4,DI(4),DELI(4),
     1 STOT(4),ATOT(4),VCTOT(4),XKSS,ROVCW(4),VCSEC(4),CC4,DC4,VS4,XK4,
     2 RE4,U4,USC4,TAUC4,TAUW4)
       RETURN
  2100 IF(MODE.NE.0) GO TO 2200
       DO 2150 J=1, 10
       TCS1(J)=TCI1
       TCS2(J)=TCI2
       TCS3(J)=TCI3
  2150 TCS4(J)=TCI4
  2200 DO 2201 I=1, 10
       TM1(I)=TCS1(I)
       TM2(I)=TCS2(I)
       TM3(I)=TCS3(I)
  2201 TM4(I)=TCS4(I)
       RETURN
       ENTRY PUTID1
       WRITE(6, 300)
       CALL TMPCON(1,80,Y)
       IF(KCALC.NE.1) GO TO 2205
       J=1
       WRITE(6, 310) J,(I, TAUC1(I), I=1, N1)
       IF(L(1).EQ.0) WRITE(6, 320) J,(I, TAUW1(I), I=1, N1)
       J=2
       WRITE(6, 310) J,(I, TAUC2(I), I=1, N2)
       IF(L(2).EQ.0) WRITE(6, 320) J,(I, TAUW2(I), I=1, N2)
       J=3
       WRITE(6, 310) J,(I, TAUC3(I), I=1, N3)
       IF(L(3).EQ.0) WRITE(6, 320) J,(I, TAUW3(I), I=1, N3)
       J=4
       WRITE(6, 310) J,(I, TAUC4(I), I=1, N4)
       IF(L(4).EQ.0) WRITE(6, 320) J,(I, TAUW4(I), I=1, N4)
  2205 J=1
       WRITE(6, 330) J,(I,TCS1(I), I=1,N1)
       IF(L(1).EQ.0) WRITE(6, 340) J,(I,TWS1(I), I=1,N1)
       J=2
       WRITE(6, 330) J,(I,TCS2(I), I=1,N2)
       IF(L(2).EQ.0) WRITE(6, 340) J,(I,TWS2(I), I=1,N2)
       J=3
       WRITE(6, 330) J,(I,TCS3(I), I=1,N3)
       IF(L(3).EQ.0) WRITE(6, 340) J,(I,TWS3(I), I=1,N3)
       J=4
       WRITE(6, 330) J,(I,TCS4(I), I=1,N4)
       IF(L(4).EQ.0) WRITE(6, 340) J,(I,TWS4(I), I=1,N4)
       CALL TMPCON(0,80,Y)
```

```
  300 FORMAT(/,2X,20('*'),5X,'I N T E R M E D I A T E',5X,
     1 'L O O P - 1:    S O D I U M    T R A N S P O R T',5X,20('*')/)
  310 FORMAT(2X,'TAUC',I1,':',10(I3,F9.5))
  320 FORMAT(2X,'TAUW',I1,':',10(I3,F9.5))
  330 FORMAT(2X,'TCS',I1,':',10(I3,F9.3))
  340 FORMAT(2X,'TWS',I1,':',10(I3,F9.3))
      RETURN
      END
      SUBROUTINE DELAY2(W1, MODE)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C  INTERMEDIATE LOOP-2: SODIUM TRANSPORT DELAY SIMULATION  C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION TCS1(10),TCS2(10),TCS3(10),TCS4(10)
      DIMENSION TWS1(10),TWS2(10),TWS3(10),TWS4(10)
      DIMENSION FCS1(10),FCS2(10),FCS3(10),FCS4(10)
      DIMENSION FWS1(10),FWS2(10),FWS3(10),FWS4(10)
      DIMENSION VCTOT(4),VCSEC(4),VWTOT(4),ATOT(4),ROVCW(4)
      DIMENSION TAUC1(10),TAUC2(10),TAUC3(10),TAUC4(10)
      DIMENSION TAUW1(10),TAUW2(10),TAUW3(10),TAUW4(10)
      DIMENSION U1(10),U2(10),U3(10),U4(10),USC1(10),USC2(10),USC3(10),
     1 USC4(10)
      DIMENSION XN(4),DI(4),STOT(4)
      EQUIVALENCE (Y(1),TCS1(1)),(Y(11),TCS2(1)),(Y(21),TCS3(1)),(Y(31),
     1TCS4(1)),(Y(41),TWS1(1)),(Y(51),TWS2(1)),(Y(61),TWS3(1)),(Y(71),
     2TWS4(1))
      EQUIVALENCE (F(1),FCS1(1)),(F(11),FCS2(1)),(F(21),FCS3(1)),(F(31),
     1FCS4(1)),(F(41),FWS1(1)),(F(51),FWS2(1)),(F(61),FWS3(1)),(F(71),
     2FWS4(1))
      COMMON/RUNGNO/KR,KCALC
      COMMON/ALLR/DUR721(319),Y(80),DUR722(90)
      COMMON/ALLF/DUF721(319),F(80),DUF722(90)
      COMMON/ALLNUL/NUN721(319),NULL(80),DUN722(90)
      COMMON/FBR8/TCI1,TCI2,TCI3,TCI4,TSI1,TSO1,TEI1
      COMMON/FBR9/TM1(10),TM2(10),TM3(10),TM4(10)
      COMMON/FBR12/N(4),L(4)
      COMMON/FBR14/D1(25),XL(4),D2(4),ODI(4),DELI(4)
      COMMON/FBR15/DSS,CSS,XKSS
      COMMON/PHY4/DE1(187),DC1(10),DE2(3),DC2(10),DE3,DC3(10),DE4,DC4(10
     1)
      COMMON/PHY5/VE1(187),VS1(10),VE2(3),VS2(10),VE3,VS3(10),VE4,VS4(10
     1)
      COMMON/PHY6/CE1(187),CC1(10),CE2(3),CC2(10),CE3,CC3(10),CE4,CC4(10
     1)
      COMMON/PHY7/XKE1(187),XK1(10),XKE2(3),XK2(10),XKE3,XK3(10),XKE4,
     1 XK4(10)
      COMMON/PHY8/RN1(187),RE1(10),RN2(3),RE2(10),RN3,RE3(10),RN4,RE4(10
     1)
      DATA PI/3.141593/
      MGO=KR+2
      GO TO (1000,2100,2000,2000,2000,1000),MGO
C
C          FIX UP THE COMPONENTS OF THE NULL VECTOR AS FUNCTION OF "N", & "L"
C                        FIRST FOR THE COOLANT TEMPERATURE NODES
 1000 DO 1020 I=1, 4
      J2=10*I
      J1=J2-9
      DO 1020 J=J1, J2
      IF((J+10-J2).LE.N(I)) GO TO 1010
      NULL(J)=J
      GO TO 1020
 1010 NULL(J)=0
```

```
 1020 CONTINUE
C          AND NOW, FOR THE PIPE WALL TEMPERATURES
      DO 1050 I=1, 4
      J2=40+10*I
      J1=J2-9
      DO 1050 J=J1, J2
      IF(L(I).NE.1) GO TO 1030
      NULL(J)=J
      GO TO 1050
 1030 IF((J+10-J2).LE.N(I)) GO TO 1040
      NULL(J)=J
      GO TO 1050
 1040 NULL(J)=0
 1050 CONTINUE
      I=1
      DO 1055 J=1, 80
      IF(NULL(J).EQ.0) GO TO 1055
      NULL(I)=NULL(J)
      I=I+1
 1055 CONTINUE
      DO 1056 J=I, 80
      NULL(J)=0
 1056 CONTINUE
      N1=N(1)
      N2=N(2)
      N3=N(3)
      N4=N(4)
      DO 1057 I=1, 10
      TWS1(I)=TCI1
      TWS2(I)=TCI2
      TWS3(I)=TCI3
 1057 TWS4(I)=TCI4
C             COMPUTE QUANTITIES RELATED TO THE PIPE RUNS
      DO 57 I=1,4
      DI(I)=ODI(I)-2.*DELI(I)
      STOT(I)=PI/4.*DI(I)**2/144.
      XCIR=PI*DI(I)/12.
      XSEC=PI*(DI(I)+DELI(I))*DELI(I)/144.
      VCTOT(I)=STOT(I)*XL(I)
      VWTOT(I)=XSEC*XL(I)
      ATOT(I)=XCIR*XL(I)
   57 CONTINUE
      DO 1058 I=1, 10
      TCS1(I)=TM1(I)
      TCS2(I)=TM2(I)
      TCS3(I)=TM3(I)
      TCS3(I)=TM4(I)
 1058 TCS4(I)=TM4(I)
      DO 1059 I=1, 4
      XN(I)=N(I)
      VCSEC(I)=VCTOT(I)/XN(I)
      ROVCW(I)=DSS*VWTOT(I)*CSS/XN(I)
 1059 CONTINUE
      RETURN
 2000 IF(MODE.EQ.0) RETURN
      W2=W1/2.0
      TCI3=TCS2(N(2))
      TCI4=TCS3(N(3))
C        START CALLING ON THE SUBROUTINE PIPE TO GET THE TEMP. DERIVATIVES
C
C     PIPE RUN # 1
```

```
      CALL PIPE(N(1),L(1),KR,W1,TCI1,TCS1,TWS1,FCS1,FWS1,DI(1),DELI(1),
     1 STOT(1),ATOT(1),VCTOT(1),XKSS,ROVCW(1),VCSEC(1),CC1,DC1,VS1,XK1,
     2 RE1,U1,USC1,TAUC1,TAUW1)
C
C     PIPE RUN # 2
      CALL PIPE(N(2),L(2),KR,W2,TCI2,TCS2,TWS2,FCS2,FWS2,DI(2),DELI(2),
     1 STOT(2),ATOT(2),VCTOT(2),XKSS,ROVCW(2),VCSEC(2),CC2,DC2,VS2,XK2,
     2 RE2,U2,USC2,TAUC2,TAUW2)
C
C     PIPE RUN # 3
      CALL PIPE(N(3),L(3),KR,W1,TCI3,TCS3,TWS3,FCS3,FWS3,DI(3),DELI(3),
     1 STOT(3),ATOT(3),VCTOT(3),XKSS,ROVCW(3),VCSEC(3),CC3,DC3,VS3,XK3,
     2 RE3,U3,USC3,TAUC3,TAUW3)
C
C     PIPE RUN # 4
      CALL PIPE(N(4),L(4),KR,W1,TCI4,TCS4,TWS4,FCS4,FWS4,DI(4),DELI(4),
     1 STOT(4),ATOT(4),VCTOT(4),XKSS,ROVCW(4),VCSEC(4),CC4,DC4,VS4,XK4,
     2 RE4,U4,USC4,TAUC4,TAUW4)
      RETURN
 2100 IF(MODE.NE.0) GO TO 2200
      DO 2150 J=1, 10
      TCS1(J)=TCI1
      TCS2(J)=TCI2
      TCS3(J)=TCI3
 2150 TCS4(J)=TCI4
 2200 DO 2201 I=1, 10
      TM1(I)=TCS1(I)
      TM2(I)=TCS2(I)
      TM3(I)=TCS3(I)
 2201 TM4(I)=TCS4(I)
      RETURN
      ENTRY PUTID2
      WRITE(6, 300)
      CALL TMPCON(1,80,Y)
      IF(KCALC.NE.1) GO TO 2205
      J=1
      WRITE(6, 310) J,(I, TAUC1(I), I=1, N1)
      IF(L(1).EQ.0) WRITE(6, 320) J,(I, TAUW1(I), I=1, N1)
      J=2
      WRITE(6, 310) J,(I, TAUC2(I), I=1, N2)
      IF(L(2).EQ.0) WRITE(6, 320) J,(I, TAUW2(I), I=1, N2)
      J=3
      WRITE(6, 310) J,(I, TAUC3(I), I=1, N3)
      IF(L(3).EQ.0) WRITE(6, 320) J,(I, TAUW3(I), I=1, N3)
      J=4
      WRITE(6, 310) J,(I, TAUC4(I), I=1, N4)
      IF(L(4).EQ.0) WRITE(6, 320) J,(I, TAUW4(I), I=1, N4)
 2205 J=1
      WRITE(6, 330) J,(I,TCS1(I), I=1,N1)
      IF(L(1).EQ.0) WRITE(6, 340) J,(I,TWS1(I), I=1,N1)
      J=2
      WRITE(6, 330) J,(I,TCS2(I), I=1,N2)
      IF(L(2).EQ.0) WRITE(6, 340) J,(I,TWS2(I), I=1,N2)
      J=3
      WRITE(6, 330) J,(I,TCS3(I), I=1,N3)
      IF(L(3).EQ.0) WRITE(6, 340) J,(I,TWS3(I), I=1,N3)
      J=4
      WRITE(6, 330) J,(I,TCS4(I), I=1,N4)
      IF(L(4).EQ.0) WRITE(6, 340) J,(I,TWS4(I), I=1,N4)
      CALL TMPCON(0,80,Y)
  300 FORMAT(/,2X,20('*'),5X,'I N T E R M E D I A T E',5X,
```

```
     1  'L O O P - 2:   S O D I U M   T R A N S P O R T',5X,20('*')/)
 310 FORMAT(2X,'TAUC',I1,':',10(I3,F9.5))
 320 FORMAT(2X,'TAUW',I1,':',10(I3,F9.5))
 330 FORMAT(2X,'TCS',I1,':',10(I3,F9.3))
 340 FORMAT(2X,'TWS',I1,':',10(I3,F9.3))
     RETURN
     END
```

DATA SET UTILITY - GENERATE

IEB352I WARNING : OUTPUT RECFM/LRECL/BLKSIZE COPIED FROM INPUT

PROCESSING ENDED AT EOD

```
      SUBROUTINE SGTHD1(TISH,KMM,MODE,PD)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                    STEAM GENERATION LOOP-1:                C
C            WATER/STEAM THERMODYNAMICS SIMULATION           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL KMM,KFW,KCV,MINERT
      REAL NU, NUS, MF, MG, MT, MFI
      DIMENSION H(21),TM(21),P(21),TCS(19),G(21)
      DIMENSION GS(19),AT(21),A(21),AS(19),D(21),DEL(21),DS(19),DT(21)
      DIMENSION DTS(19),DH(21),DHS(19),PER(21),V(21),VS(19),XL(21)
      DIMENSION XLS(19),Z(21),CC(21),E(21),DPB(21),TAU(39),AL(21),XY(28)
      DIMENSION XR(28),TMC(21),TMH(21),TCM(39),MG(2),MF(2),MT(2),UI(2)
      DIMENSION X(15),VOID(15),PHI(15),HF(15),HG(15),HFG(15),DF(15)
      DIMENSION DG(15),SVF(15),SVG(21),XKF(15),XKG(21),XK(21),AXK(21)
      DIMENSION XKS(19),AXKS(19),VISF(15),VISG(15),VIS(21),AVIS(21)
      DIMENSION VISS(19),AVISS(19),CF(15),CG(15),CP(21),ACP(21),CS(19)
      DIMENSION DEN(21),ADEN(21),ST(15),DES(19),ADS(19),RE(21),RES(19)
      DIMENSION PR(21),PRS(19),NU(21),NUS(19),HCN(21),HC(21),HPB(21)
      DIMENSION HS(19),TDLOG(19),U(19),UG(2),UF(2),Q(19),HFLUX(10),
     1 CHF(10),OD(21),ACS(19),XN(21)
      DIMENSION TAUS(4)
      COMMON/PHDR/PH,TMSHD
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/ARPP/DSPEED,SSPEED,A1,A2,AZ,TS,TR,TMIN
      COMMON/RUNGNO/KRUNG,KCALC .
      COMMON/ALLR/DUR811(399),Y(39),DUR812(51)
      COMMON/ALLF/DUF811(399),F(39),DUF812(51)
      COMMON/ALLNUL/DUN811(399),NULL(39),DUN812(51)
      COMMON/GET1/WDUM(9),WI100,WI,WSC2,WBRK
      COMMON/NORMS/ADUM(10),W2100,BDUM(2)
      COMMON/SGEN1/TNOFW,TAUX
      COMMON/FACT/XFAC,AFAC,VFAC,WFAC,PFAC,DFAC,CFAC,XKFAC,TFAC,XMFAC,
     1  TQFAC,SPFAC,XILFAC,XHFAC,ENTFAC,GCP
      NAMELIST/SGA01/EPSI,P
      NAMELIST/SGA02/H
      NAMELIST/SGA03/TCS
      NAMELIST/SGA04/XLT,XL,ACF,TKON
      NAMELIST/SGA05/Z
      NAMELIST/SGA06/XLS
      NAMELIST/SGA07/PITCH,D
      NAMELIST/SGA08/DS,DEL,XN
      NAMELIST/SGA09/A1,A2,AZ,TS,TR,TMIN,DSPEED,SSPEED,TMD,MINERT
      NAMELIST/SGA10/KFW,KCV,HDSP
      NAMELIST/SGA11/W1100,W2100,W1,W2,W3,CVP,ALFA
      NAMELIST/SGA12/TAUS
      NAMELIST/SGA13/WFMIN,WFMAX,CVMAX,WAUXM,HAUW,HDAUX,HDMAX
      DATA PI/3.141593/,EPS1/1.E-5/,EPS2/1.E-10/
      M=KRUNG+2
      IF(M.NE.1.AND.M.NE.6) QKMM=KMM+FRICK*KMM
      GO TO (4000,4300,4100,4200,4100,997), M
C
C        RESTART OPTION
  997 DO 998 I=1,21
      P(I)=P(I)*PFAC
      H(I)=H(I)*ENTFAC
      XL(I)=XL(I)*XFAC
      Z(I)=Z(I)*XFAC
      D(I)=D(I)*XFAC/12.
      DEL(I)=DEL(I)*XFAC/12.
      IF(I.GT.19) GO TO 998
      XLS(I)=XLS(I)*XFAC
```

```
      DS(I)=DS(I)*XFAC
  998 CONTINUE
      EPSI=EPSI*PFAC
      CALL TMPCON(1,19,TCS)
      XLT=XLT*XFAC
      PITCH=PITCH*XFAC
      DSPEED=DSPEED*SPFAC
      SSPEED=SSPEED*SPFAC
      TMD=TMD*TQFAC
      MINERT=MINERT*XMFAC
      TKON=TKON*XKFAC
      W1100=W1100*WFAC
      W2100=W2100*WFAC
      ALFA=Y(31)
      W1=W1*WFAC
      W2=W2*WFAC
      W3=W3*WFAC
      WAUXM=WAUXM*WFAC
      HAUW=HAUW*ENTFAC
      IF(PD.NE.1.) GO TO 996
      W2100=W2
      ALFA=1.
      W1100=W3
  996 W1=W3
      WF=W1/W1100
      CVP=CVMAX*(1.+ALOG(WF/WFMAX)/ALOG(WFMAX/WFMIN))
      GO TO 999
C
C       READ INPUT DATA
 4000 READ(5, SGA01)
      READ(5, SGA02)
      READ(5, SGA03)
      READ(5, SGA04)
      READ(5, SGA05)
      READ(5, SGA06)
      READ(5, SGA07)
      READ(5, SGA08)
      READ(5, SGA09)
      READ(5, SGA10)
      READ(5, SGA11)
      READ(5, SGA12)
      READ(5, SGA13)
C
C       PRINT INPUT DATA
  999 WRITE(6, SGA01)
      WRITE(6, SGA02)
      WRITE(6, SGA03)
      WRITE(6, SGA04)
      WRITE(6, SGA05)
      WRITE(6, SGA06)
      WRITE(6, SGA07)
      WRITE(6, SGA08)
      WRITE(6, SGA09)
      WRITE(6, SGA10)
      WRITE(6, SGA11)
      WRITE(6, SGA12)
      WRITE(6, SGA13)
C
C           CONVERT INTO THE PROPER UNITS
      FLXFAC=XHFAC*TFAC
      EFAC=ENTFAC*WFAC*3600.
```

```
      DO 4001 I=1,21
      P(I)=P(I)/PFAC
      H(I)=H(I)/ENTFAC
      XL(I)=XL(I)/XFAC
      Z(I)=Z(I)/XFAC
      D(I)=D(I)/XFAC*12.
      DEL(I)=DEL(I)/XFAC*12.
      IF(I.GT.19) GO TO 4001
      XLS(I)=XLS(I)/XFAC
      DS(I)=DS(I)/XFAC
 4001 CONTINUE
      EPSI=EPSI/PFAC
      CALL TMPCON(0,19,TCS)
      XLT=XLT/XFAC
      PITCH=PITCH/XFAC
      DSPEED=DSPEED/SPFAC
      SSPEED=SSPEED/SPFAC
      TMD=TMD/TQFAC
      MINERT=MINERT/XMFAC
      TKON=TKON/XKFAC
      W1100=W1100/WFAC
      W2100=W2100/WFAC
      W1=W1/WFAC
      W2=W2/WFAC
      W3=W3/WFAC
      WAUXM=WAUXM/WFAC
      HAUW=HAUW/ENTFAC
      GC=GCP*3600.*3600.
      IF(MODE.EQ.0.AND.PD.NE.1.) W3=PD*W1100
      WM1=W1/W1100
      WM3=W3/W1100
      L=0
      N=0
      NCAVO=0
      CALL TFRIC(1.,AZ,TS,TR,TMIN,FRICK)
      QKMM=KMM+FRICK*KMM
C
C       CALCULATE SYSTEM CHARACTERISTICS
      DO 1 I=1, 21
      DH(I)=D(I)/12.
      OD(I)=(D(I)+2.*DEL(I))/12.
      DT(I)=D(I)/12.
      A(I)=PI*((DH(I)/2.)**2)*XN(I)
      IF(I.EQ.9.OR.I.EQ.10) GO TO 1
      AT(I)=PI*OD(I)*XL(I)*XN(I)
      V(I)=XL(I)*A(I)
      AL(I)=(XL(I)/A(I))/GC
    1 CONTINUE
      ALTDD=AL(4)+AL(6)+((AL(7)+AL(8)+((XLT/A(9))/GC)+AL(11)+AL(12))/2.)
     1+AL(13)
      ALTDH=AL(14)+AL(15)+AL(16)+AL(17)+AL(18)+AL(19)+AL(20)+AL(21)
      DO 2 I=8, 19
      XSAV=XN(I)
      IF(I.GE.11.AND.I.LE.15) XSAV=0.
      AS(I)=PI*(((DS(I)/2.)**2)-XSAV*((OD(I)/2.)**2))
      PER(I)=PI*(DS(I)+XSAV*OD(I))
      DHS(I)=4.*AS(I)/PER(I)
      DTS(I)=OD(I)
      VS(I)=AS(I)*XLS(I)
    2 CONTINUE
      PCON1=120.*PI*MINERT/GC
```

```
      PCON2=PCON1*DSPEED/TMD
      CALL SWATER(P(2),TM(2),HF(2),HG(2),HFG(2),DF(2),DG(2),SVF(2),
     1 SVG(2))
      UG(2)=HG(2)-(144./778.)*P(2)*SVG(2)
      UF(2)=HF(2)-(144./778.)*P(2)*SVF(2)
      MG(2)=V(2)/(2.*SVG(2))
      MF(2)=V(2)/(2.*SVF(2))
      MFI=MF(2)
      MT(2)=MG(2)+MF(2)
      UI(2)=MG(2)*UG(2)+MF(2)*UF(2)
      HDA=1.0+SIN((PI/2.)*((MF(2)/MFI)-1.))
      HDM=HDA
      DO 9300 I=1, 11
 9300 Y(I)=TCS(19-I)
      DO 9350 I=12, 30
 9350 Y(I)=H(I-9)
      Y(31)=ALFA
      Y(32)=W2
      Y(33)=W3
      Y(34)=MT(2)
      Y(35)=UI(2)
      Y(36)=HDM
      Y(37)=WM3
      Y(38)=WM1
      Y(39)=CVP
      RETURN
C
C          COMPUTE MASS VELOCITY "G"
 4100 DO 4 J=3, 6
    4 G(J)=W2/A(J)
      DO 5 J=7, 12
    5 G(J)=W2/(2.*A(J))
      G(13)=W2/A(13)
      DO 6 J=14, 21
    6 G(J)=W3/A(J)
      DO 7 J=8, 15
    7 GS(J)=WI/(2.*AS(J))
      DO 8 J=16, 19
    8 GS(J)=WI/AS(J)
      IF(ICOUNT.GT.0) P(21)=PH
      TCS(19)=TISH
 4150 CONTINUE
C
C          COMPUTE THERMODYNAMIC PROPERTIES OF SUBCOOLED & SATURATED
C          WATER, SATURATED & SUPERHEATED STEAM AND INTERMEDIATE NA
      CALL WATER(P(1), H(1), TM(1), DEN(1))
      DO 9 I=3, 8
      CALL WATER(P(I), H(I), TM(I), DEN(I))
      XK(I)=TCOND1(P(I), TM(I))
      VIS(I)=DVISC1(P(I), TM(I))
      CP(I)=SHEAT1(P(I), TM(I))
    9 CONTINUE
      DO 10 I=9, 15
      CALL SWATER(P(I),TM(I),HF(I),HG(I),HFG(I),DF(I),DG(I),SVF(I),
     1 SVG(I))
      IF(ICOUNT.EQ.0) H(9)=HF(9)
      X(I)=(H(I)-HF(I))/HFG(I)
      IF(X(I).GT.1.0) X(I)=1.0
      IF(X(I).LT.0.) CALL WATER(P(I),H(I),TM(I),DEN(I))
      XKF(I)=TCOND1(P(I), TM(I))
      VISF(I)=DVISC1(P(I), TM(I))
```

```
      CF(I)=SHEAT1(P(I), TM(I))
      IF(X(I).LT.0.) GO TO 99
      XKG(I)=TCOND2(TM(I), SVG(I))
      VISG(I)=DVISC2(TM(I), SVG(I))
      CG(I)=SHEAT2(P(I), TM(I))
      XK(I)=(1.-X(I))*XKF(I)+X(I)*XKG(I)
      VIS(I)=(1.-X(I))*VISF(I)+X(I)*VISG(I)
      CP(I)=(1.-X(I))*CF(I)+X(I)*CG(I)
      DEN(I)=1.0/((1.-X(I))*SVF(I)+X(I)*SVG(I))
      GO TO 990
   99 XK(I)=XKF(I)
      VIS(I)=VISF(I)
      CP(I)=CF(I)
      SVF(I)=1.0/DEN(I)
  990 ST(I)=SURFTN(TM(I), SVF(I))
      XKS(I)=THCSOD(TCS(I))
      VISS(I)=VISSOD(TCS(I))
      CS(I)=SPHSOD(TCS(I))
      DES(I)=DENSOD(TCS(I))
      CALL ARMAND(X(I), SVF(I), SVG(I), VOID(I), PHI(I))
   10 CONTINUE
      XKS(8)=THCSOD(TCS(8))
      VISS(8)=VISSOD(TCS(8))
      CS(8)=SPHSOD(TCS(8))
      DES(8)=DENSOD(TCS(8))
      DO 11 I=16, 19
      TM(I)=TSTEAM(H(I), P(I))
      SVG(I)=SPVOL2(TM(I), P(I))
      DEN(I)=1./SVG(I)
      XK(I)=TCOND2(TM(I), SVG(I))
      VIS(I)=DVISC2(TM(I), SVG(I))
      CP(I)=SHEAT2(P(I), TM(I))
      XKS(I)=THCSOD(TCS(I))
      VISS(I)=VISSOD(TCS(I))
      CS(I)=SPHSOD(TCS(I))
      DES(I)=DENSOD(TCS(I))
   11 CONTINUE
      DO 12 I=20, 21
      TM(I)=TSTEAM(H(I), P(I))
      SVG(I)=SPVOL2(TM(I), P(I))
      DEN(I)=1./SVG(I)
      XK(I)=TCOND2(TM(I), SVG(I))
      VIS(I)=DVISC2(TM(I), SVG(I))
      CP(I)=SHEAT2(P(I), TM(I))
   12 CONTINUE
      H(2)=(UI(2)+(144./778.)*P(2)*V(2))/MT(2)
C
C         CALCULATE LOGARITHMIC MEAN TEMPERATURE DIFFERENCES
      DO 13 I=16, 19
   13 CALL LMTDIF(TCS(35-I),TCS(34-I),TM(34-I),TM(35-I),TDLOG(35-I))
      DO 14 I=9, 10
      IF(X(10).LE.0.0.AND.I.EQ.9) GO TO 14
      CALL LMTDIF(TCS(19-I),TCS(18-I),TM(18-I),TM(19-I),TDLOG(19-I))
   14 CONTINUE
      IF(X(10).LE.0.) TDLOG(10)=TDLOG(9)
C
C         INTERMEDIATE SODIUM SIDE REYNOLD,PRANDTL & NUSSELT NUMBERS
C                             AND HEAT TRANSFER COEFFICIENTS
      DO 17 I=9, 19
      ADS(I)=(DES(I-1)+DES(I))/2.0
      AXKS(I)=(XKS(I-1)+XKS(I))/2.0
```

```
      AVISS(I)=(VISS(I-1)+VISS(I))/2.0
      ACS(I)=(CS(I-1)+CS(I))/2.0
      RES(I)=GS(I)*DHS(I)/AVISS(I)
      PRS(I)=AVISS(I)*ACS(I)/AXKS(I)
      IF(RES(I).GT.3000.0) GO TO 15
      NUS(I)=48./11.0
      GO TO 16
   15 NUS(I)=7.0+0.025*((RES(I)*PRS(I))**0.8)
   16 HS(I)=NUS(I)*AXKS(I)/DTS(I)
   17 CONTINUE
C
C        WATER/STEAM SIDE REYNOLDS,PRANDTL & NUSSELT NUMBERS
C        BOILING, CONVECTION & HEAT TRANSFER COEFFICIENTS
      DO 19 I=4, 21
      ADEN(I)=(DEN(I-1)+DEN(I))/2.
      AXK(I)=(XK(I-1)+XK(I))/2.0
      AVIS(I)=(VIS(I-1)+VIS(I))/2.0
      ACP(I)=(CP(I-1)+CP(I))/2.0
      IF(I.EQ.10) GO TO 18
      PR(I)=AVIS(I)*ACP(I)/AXK(I)
      RE(I)=G(I)*DH(I)/AVIS(I)
      IF(RE(I).LT.3000) GO TO 171
      NU(I)=0.023*(RE(I)**0.8)*(PR(I)**0.4)
      GO TO 172
  171 NU(I)=7.15
  172 HC(I)=NU(I)*AXK(I)/DT(I)
      GO TO 19
   18 IF(X(10).LE.0.) GO TO 180
      CALL BRHTC(G(I),DH(I),DT(I),ST(I),VISF(I),VISG(I),DF(I),DG(I),
     1CF(I),CG(I),XKF(I),XKG(I),HFG(I),TDLOG(I),HS(I),X(I),RE(I),PR(I),
     2HC(I),HFB(I))
  180 IF(X(10).LE.0.) HC(10)=HC(9)
   19 CONTINUE
C
C        OVER-ALL HEAT-TRANSFER COEFFICIENT
      DO 20 I=9, 10
      U(I)=USTG(HS(I), HC(I), DT(I), OD(I), TKON)
   20 CONTINUE
      DO 21 I=16, 19
      U(I)=USTC(HS(I), HC(I), DT(I), OD(I), TKON)
   21 CONTINUE
C
C        DETERMINE BOILING, AND NON-BOILING LENGTHS IN THE EVAPORATORS
      IF(TDLOG(9).EQ.0.) GO TO 72
      IF(X(10).LE.0.) GO TO 690
      QNB=W2*(HF(9)-H(8))/2.0
      IF(T.GT.0.0) GO TO 69
      XL(9)=QNB/(U(9)*TDLOG(9)*PI*OD(9)*XN(9))
      QBL=W2*(H(10)-HF(9))/2.0
      XL(10)=QBL/(U(10)*TDLOG(10)*PI*OD(9)*XN(9))
      XLF=XL(9)+XL(10)
      FFC=XLF/XLT
      FFCI=1.0/(2.0*FFC)
      ACFI=1.0/ACF
   69 CONTINUE
      XL(9)=QNB/(FFC*U(9)*TDLOG(9)*PI*OD(9)*XN(9))
      IF(XL(9).LT.0.0) XL(9)=0.0
      IF(XL(9).GE.XLT)XL(9)=XLT
      GO TO 691
  690 XL(9)=XLT
  691 XLB=XLT-XL(9)
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      IF(XL(9).EQ.XLT) U(10)=U(9)
      IF(XL(9).EQ.XLT) TDLOG(10)=TDLOG(9)
      HFLUX(10)=FFC*U(10)*TDLOG(10)
      IF(X(10).LE.0.) GO TO 71
      IF(HFLUX(10).LE.0.0) GO TO 72
      CALL CHFLX(HFLUX(10),P(10),G(10),DH(10),HFG(10),XLC)
      IF(XLC.LE.XLB) GO TO 70
      GO TO 71
   70 XL(10)=XLC
      IF(L.EQ.0) WRITE(6, 800) TSEC
      L=1
      GO TO 72
   71 XL(10)=XLB
   72 CONTINUE
      XLS(9)=XL(9)
      XLS(10)=XL(10)
      V(9)=A(9)*XL(9)
      V(10)=A(10)*XL(10)
      VS(9)=AS(9)*XLS(9)
      VS(10)=AS(10)*XLS(10)
      Z(9)=Z(8)+XL(9)
      AT(9)=PI*OD(9)*XL(9)*XN(9)
      AT(10)=PI*OD(10)*XL(10)*XN(10)
      AL(9)=XL(9)/(A(9)*GC)
      AL(10)=(XLT/(A(9)*GC))-AL(9)
C
C     CALCULATE TOTAL AMOUNT OF HEAT TRANSFERED
      DO 73 I=9, 10
      Q(I)=FFC*U(I)*AT(I)*TDLOG(I)
   73 CONTINUE
      DO 74 I=16, 19
      Q(I)=ACF*U(I)*AT(I)*TDLOG(I)
   74 CONTINUE
C
C          CALCULATE MOMENTUM TERM COEFFICIENT
      DO 22 I=4, 13
      E(I)=DPMOM(A(I-1), A(I), DEN(I-1), DEN(I), GC)
   22 CONTINUE
      ETDD=E(4)+E(5)+E(6)+((E(7)+E(8)+E(9)+E(10)+E(11)+E(12))/4.)+E(13)
      E(14)=DPMOM(A(14),A(14),DG(13),DEN(14),GC)
      DO 23 I=15, 21
      E(I)=DPMOM(A(I-1), A(I), DEN(I-1), DEN(I), GC)
   23 CONTINUE
      ETDH=E(14)+E(15)+E(16)+E(17)+E(18)+E(19)+E(20)+E(21)
C
C          BUOYANCY EFFECT (GRAVITATIONAL CONTRIBUTIONS)
      DO 24 I=4, 13
      DPB(I)=ADEN(I)*(Z(I-1)-Z(I))
   24 CONTINUE
      DPBDD=DPB(4)+DPB(5)+DPB(6)+DPB(7)+DPB(8)+DPB(9)+DPB(10)+DPB(11)+
     1 DPB(12)+DPB(13)
      DO 25 I=14, 21
      DPB(I)=ADEN(I)*(Z(I-1)-Z(I))
   25 CONTINUE
      DPBDH=DPB(14)+DPB(15)+DPB(16)+DPB(17)+DPB(18)+DPB(19)+DPB(20)+
     1 DPB(21)
C
C          COMPUTE FRICTIONAL LOSS COEFFICIENTS
      IF(T.GT.0.0) GO TO 280
      CC(4)=ADEN(4)*(144.*(P(3)-P(4))+DPB(4)+E(4)*(W2**2))/(W2**2)
      CC(6)=ADEN(6)*(144.*(P(5)-P(6))+DPB(6)+E(6)*(W2**2))/(W2**2)
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      DO 26 I=7, 9
      CC(I)=4.*ADEN(I)*(144.*(P(I-1)-P(I))+DPB(I)+E(I)*(W2**2/4.))/
     1 (W2**2)
   26 CONTINUE
      DO 27 I=10, 12
      CC(I)=4.*DF(I)*(144.*(P(I-1)-P(I))+DPB(I)+E(I)*(W2**2/4.))/
     1 ((W2**2)*PHI(I))
   27 CONTINUE
      CC(13)=DF(13)*(144.*(P(12)-P(13))+DPB(13)+E(13)*(W2**2))/((W2**2)*
     1 PHI(13))
      DO 28 I=14, 21
      CC(I)=ADEN(I)*(144.*(P(I-1)-P(I))+DPB(I)+E(I)*(W3**2))/(W3**2)
   28 CONTINUE
      CC(5)=0.0
      IF(MODE.NE.0.OR.PD.EQ.1.) DHEAD=(144.*(P(5)-P(4))-DPB(5)-
     1  E(5)*(W2**2))/144.
      DPRP=DHEAD*144.0
  280 CONTINUE
      FLCDD=(CC(4)/ADEN(4))+(CC(6)/ADEN(6))+(((CC(7)/ADEN(7))+(CC(8)/
     1 ADEN(8))+(CC(9)/ADEN(9))+PHI(10)*(CC(10)/DF(10))+PHI(11)*(CC(11)/
     2 DF(11))+PHI(12)*(CC(12)/DF(12)))/4.)+PHI(13)*(CC(13)/DF(13))
      FLCDH=(CC(14)/ADEN(14))+(CC(15)/ADEN(15))+(CC(16)/ADEN(16))+
     1 (CC(17)/ADEN(17))+(CC(18)/ADEN(18))+(CC(19)/ADEN(19))+(CC(20)/
     2 ADEN(20))+(CC(21)/ADEN(21))
      HDA=1.0+SIN((PI/2.)*((MF(2)/MFI)-1.))
      WN1=WFMAX*EXP((ALOG(WFMAX/WFMIN))*((CVP/CVMAX)-1.))
      WAUXN=0.0
      IF(TSEC.GE.TNOFW) GO TO 9101
      W1=WN1*W1100
      GO TO 9103
 9101 WN1=0.0
      W1=0.0
      IF(TSEC.GE.TAUX) GO TO 9102
      GO TO 9103
 9102 IF(HDM.GT.HDMAX) CVP=0.0
      IF(HDM.LT.HDAUX) CVP=1.0
      WAUX=WAUXM*CVP
      W1=WAUX
      H(1)=HAUW
      WAUXN=WAUX/WAUXM
 9103 CONTINUE
      IF(W2.LT.EPS1) W2=EPS1
      IF(W3.LT.EPS1) W3=EPS1
      WN2=W2/W2100
      WN3=W3/W1100
      WNI=WI/WI100
C         INTRODUCE THE DUMMY VECTOR "Y"
      DO 29 I=1, 11
      Y(I)=TCS(19-I)
   29 CONTINUE
      DO 30 I=12, 30
      Y(I)=H(I-9)
   30 CONTINUE
      Y(31)=ALFA
      Y(32)=W2
      Y(33)=W3
      Y(34)=MT(2)
      Y(35)=UI(2)
      Y(36)=HDM
      Y(37)=WM3
      Y(38)=WM1
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      Y(39)=CVP
C
C        CALCULATE PROCESS VARIABLE TIME CONSTANTS
      IF(KRUNG.NE.3) GO TO 440
      DO 31 J=1, 4
      IF(TCS(20-J).EQ.TM(20-J)) GO TO 9201
      XR(J)=(TCS(19-J)-TM(19-J))/(TCS(20-J)-TM(20-J))
      IF(XR(J).LE.0.0) GO TO 9201
      IF(XR(J).EQ.1.0) GO TO 9201
      XY(J)=(1.0-((XR(J)-1.0)/(XR(J)*ALOG(XR(J)))))/ALOG(XR(J))
      GO TO 9202
 9201 XY(J)=0.0
 9202 TAU(J)=DES(19-J)*CS(19-J)*VS(20-J)/(WI*CS(19-J)+U(20-J)*AT(20-J)*
     1ACF*XY(J))
   31 CONTINUE
      DO 32 J=5, 9
      TAU(J)=2.*DES(19-J)*VS(20-J)/WI
   32 CONTINUE
      DO 33 J=10, 11
      IF(TCS(20-J).EQ.TM(20-J)) GO TO 9203
      XR(J)=(TCS(19-J)-TM(19-J))/(TCS(20-J)-TM(20-J))
      IF(XR(J).LE.0.0) GO TO 9203
      IF(XR(J).EQ.1.0) GO TO 9203
      XY(J)=(1.0-((XR(J)-1.0)/(XR(J)*ALOG(XR(J)))))/ALOG(XR(J))
      GO TO 9204
 9203 XY(J)=0.0
 9204 TAU(J)=DES(19-J)*CS(19-J)*VS(20-J)/((WI/2.0)*CS(19-J)+U(20-J)*
     1FFC*AT(20-J)*XY(J))
   33 CONTINUE
      TAU(12)=0.0
      DO 34 J=13, 15
      TAU(J)=DEN(J-9)*V(J-9)/W2
   34 CONTINUE
      DO 35 J=16, 17
      TAU(J)=2.*DEN(J-9)*V(J-9)/W2
   35 CONTINUE
      XR(18)=XR(11)
      XR(19)=XR(10)
      DO 36 J=18, 19
      IF(XR(J).LE.0.0) GO TO 9205
      IF(XR(J).EQ.1.0) GO TO 9205
      XY(J)=(1.-((XR(J)-1.)/ALOG(XR(J))))/ALOG(XR(J))
      GO TO 9206
 9205 XY(J)=0.0
 9206 TAU(J)=DEN(J-9)*V(J-9)*CP(J-9)/((W2/2.)*CP(J-9)-U(J-9)*AT(J-9)*
     1FFC*XY(J))
   36 CONTINUE
      TAU(20)=2.*DEN(11)*V(11)/W2
      DO 37 J=21, 22
      TAU(J)=DEN(J-9)*V(J-9)/W2
   37 CONTINUE
      DO 38 J=23, 24
      TAU(J)=DEN(J-9)*V(J-9)/W3
   38 CONTINUE
      DO 39 J=25, 28
      XR(J)=XR(29-J)
      IF(XR(J).LE.0.0) GO TO 9207
      IF(XR(J).EQ.1.0) GO TO 9207
      XY(J)=(1.-((XR(J)-1.)/ALOG(XR(J))))/ALOG(XR(J))
      GO TO 9208
 9207 XY(J)=0.0
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9208 TAU(J)=DEN(J-9)*V(J-9)*CP(J-9)/(W3*CP(J-9)-U(J-9)*AT(J-9)*ACF*
    1XY(J))
  39 CONTINUE
     DO 40 J=29, 30
     TAU(J)=DEN(J-9)*V(J-9)/W3
  40 CONTINUE
     SLIP=1.-(DSPEED/SSPEED)*ALFA
     DTDMS=-QKMM*DSPEED/SSPEED*((A2-A1*(SLIP**2))/((A1*(SLIP**2)+A2)**
    12))
     CALL PTIME(ALFA,WN2,AZ,TS,TR,DTRPS,DTRPF)
     TAU(31)=PCON2/(DTRPF+DTRPS-DTDMS)
     TAU(32)=ALTDD/(2.*(FLCDD-ETDD)*W2)
     TAU(33)=ALTDH/(2.*(FLCDH-ETDH)*W3)
     TAU(34)=9999.999/3600.0
     TAU(35)=9999.999/3600.0
     TAU(36)=TAUS(1)/3600.0
     TAU(37)=TAUS(2)/3600.0
     TAU(38)=TAUS(3)/3600.0
     TAU(39)=TAUS(4)/3600.0
     DO 41 I=1, 39
     NULL(I)=0
  41 CONTINUE
     J=1
     DO 42 I=1, 39
     IF(0.7*ABS(TAU(I)).GE.S) GO TO 42
     NULL(J)=I
     J=J+1
  42 CONTINUE
     DO 43 I=1, 39
     TCM(I)=TAU(I)*3600.0
  43 CONTINUE
  44 CONTINUE
     IF(MODE.NE.0) GO TO 440
     DO 143 I=1, 33
     NULL(I)=I
 143 CONTINUE
     NULL(34)=36
     NULL(35)=37
     NULL(36)=38
     NULL(37)=39
     NULL(38)=0
     NULL(39)=0
 440 CONTINUE
C        DETERMINE THE RECIRCULATION PUMP CAVITATION CONDITION
     CALL SWATER(P(4),TSW,HSW,HSS,HWS,DSW,DSS,SSW,SSS)
     IF(H(4).GE.HSW) DPRP=0.0
     IF(XL(9).EQ.XLT) X(10)=0.0
     IF(XL(10).LE.0.0) Y(10)=Y(9)
     IF(XL(10).LE.0.) Y(19)=Y(18)
     NCAV=0
     IF(DPRP.EQ.0.0) NCAV=1
     IF(KMM.NE.0.) GO TO 441
     IF(N.NE.0) GO TO 441
     N=1
     TTRIP=T
     WRITE(6, 9100) TSEC
 441 IF(NCAV.EQ.NCAVO) GO TO 4200
     IF(NCAVO.EQ.0) WRITE(6,9200) TSEC
     IF(NCAVO.EQ.1) WRITE(6,9199) TSEC
     NCAVO=NCAV
4200 IF(Y(31).GT.1.0) Y(31)=1.0
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      IF(Y(32).LT.EPS1) Y(32)=EPS1
      IF(Y(33).LT.EPS1) Y(33)=EPS1
      J=1
      IF(NULL(J).NE.1) GO TO 101
      J=J+1
      GO TO 201
  101 F(1)=(WI*ACS(19)*(TCS(19)-Y(1))-Q(19))/(ACS(19)*ADS(19)*VS(18))
  201 IF(NULL(J).NE.2) GO TO 102
      J=J+1
      GO TO 202
  102 F(2)=(WI*ACS(18)*(Y(1)-Y(2))-Q(18))/(ACS(18)*ADS(18)*VS(17))
  202 IF(NULL(J).NE.3) GO TO 103
      J=J+1
      GO TO 203
  103 F(3)=(WI*ACS(17)*(Y(2)-Y(3))-Q(17))/(ACS(17)*ADS(17)*VS(16))
  203 IF(NULL(J).NE.4) GO TO 104
      J=J+1
      GO TO 204
  104 F(4)=(WI*ACS(16)*(Y(3)-Y(4))-Q(16))/(ACS(16)*ADS(16)*VS(16))
  204 IF(NULL(J).NE.5) GO TO 105
      J=J+1
      GO TO 205
  105 F(5)=(WI/2.0)*(Y(4)-Y(5))/(ADS(15)*VS(14))
  205 IF(NULL(J).NE.6) GO TO 106
      J=J+1
      GO TO 206
  106 F(6)=(WI/2.0)*(Y(5)-Y(6))/(ADS(14)*VS(13))
  206 IF(NULL(J).NE.7) GO TO 107
      J=J+1
      GO TO 207
  107 F(7)=(WI/2.0)*(Y(6)-Y(7))/(ADS(13)*VS(12))
  207 IF(NULL(J).NE.8) GO TO 108
      J=J+1
      GO TO 208
  108 F(8)=(WI/2.0)*(Y(7)-Y(8))/(ADS(12)*VS(11))
  208 IF(NULL(J).NE.9) GO TO 109
      J=J+1
      GO TO 209
  109 F(9)=(WI/2.0)*(Y(8)-Y(9))/(ADS(11)*VS(11))
  209 IF(NULL(J).NE.10) GO TO 110
      J=J+1
      GO TO 210
  110 IF(VS(10).LE.0.0) GO TO 1100
      F(10)=((WI/2.)*ACS(10)*(Y(9)-Y(10))-Q(10))/(ACS(10)*ADS(10)*VS(10)
     1)
      GO TO 210
 1100 F(10)=F(9)
  210 IF(NULL(J).NE.11) GO TO 111
      J=J+1
      GO TO 211
  111 F(11)=((WI/2.0)*ACS(9)*(Y(10)-Y(11))-Q(9))/(ACS(9)*ADS(9)*VS(9))
  211 IF(NULL(J).NE.12) GO TO 112
      J=J+1
      GO TO 212
  112 F(12)=(Y(32)*Y(12)-(Y(32)-W1)*HF(2)-W1*H(1))/(DEN(3)*V(2))
  212 IF(NULL(J).NE.13) GO TO 113
      J=J+1
      GO TO 213
  113 F(13)=Y(32)*(Y(12)-Y(13))/(DEN(4)*V(4))
  213 IF(NULL(J).NE.14) GO TO 114
      J=J+1
```

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      GO TO 214
 114  F(14)=Y(32)*(Y(13)-Y(14))/(DEN(5)*V(5))
 214  IF(NULL(J).NE.15) GO TO 115
      J=J+1
      GO TO 215
 115  F(15)=Y(32)*(Y(14)-Y(15))/(DEN(6)*V(6))
 215  IF(NULL(J).NE.16) GO TO 116
      J=J+1
      GO TO 216
 116  F(16)=Y(32)*(Y(15)-Y(16))/(2.*DEN(7)*V(7))
 216  IF(NULL(J).NE.17) GO TO 117
      J=J+1
      GO TO 217
 117  F(17)=Y(32)*(Y(16)-Y(17))/(2.*DEN(8)*V(8))
 217  IF(NULL(J).NE.18) GO TO 118
      J=J+1
      GO TO 218
 118  IF(V(9).LE.0.) GO TO 1180
      F(18)=0.0
      GO TO 218
1180  F(18)=(Q(9)+(Y(32)*(Y(17)-Y(18))/2.0))/(DEN(9)*V(9))
 218  IF(NULL(J).NE.19) GO TO 119
      J=J+1
      GO TO 219
 119  IF(V(10).LE.0.) GO TO 1190
      F(19)=(Q(10)+(Y(32)*(Y(18)-Y(19))/2.))/(DEN(10)*V(10))
      GO TO 219
1190  Y(19)=Y(18)
      F(19)=F(18)
 219  IF(NULL(J).NE.20) GO TO 120
      J=J+1
      GO TO 220
 120  F(20)=Y(32)*(Y(19)-Y(20))/(2.*DEN(11)*V(11))
 220  IF(NULL(J).NE.21) GO TO 121
      J=J+1
      GO TO 221
 121  F(21)=Y(32)*(Y(20)-Y(21))/(DEN(12)*V(12))
 221  IF(NULL(J).NE.22) GO TO 122
      J=J+1
      GO TO 222
 122  F(22)=Y(32)*(Y(21)-Y(22))/(DEN(13)*V(13))
 222  IF(NULL(J).NE.23) GO TO 123
      J=J+1
      GO TO 223
 123  F(23)=Y(33)*(HG(13)-Y(23))/(DEN(14)*V(14))
 223  IF(NULL(J).NE.24) GO TO 124
      J=J+1
      GO TO 224
 124  F(24)=Y(33)*(Y(23)-Y(24))/(DEN(15)*V(15))
 224  IF(NULL(J).NE.25) GO TO 125
      J=J+1
      GO TO 225
 125  F(25)=(Q(16)+Y(33)*(Y(24)-Y(25)))/(DEN(16)*V(16))
 225  IF(NULL(J).NE.26) GO TO 126
      J=J+1
      GO TO 226
 126  F(26)=(Q(17)+Y(33)*(Y(25)-Y(26)))/(DEN(17)*V(17))
 226  IF(NULL(J).NE.27) GO TO 127
      J=J+1
      GO TO 227
 127  F(27)=(Q(18)+Y(33)*(Y(26)-Y(27)))/(DEN(18)*V(18))
```

```
227 IF(NULL(J).NE.28) GO TO 128
    J=J+1
    GO TO 228
128 F(28)=(Q(19)+Y(33)*(Y(27)-Y(28)))/(DEN(19)*V(19))
228 IF(NULL(J).NE.29) GO TO 129
    J=J+1
    GO TO 229
129 F(29)=Y(33)*(Y(28)-Y(29))/(DEN(20)*V(20))
229 IF(NULL(J).NE.30) GO TO 130
    J=J+1
    GO TO 230
130 F(30)=Y(33)*(Y(29)-Y(30))/(DEN(21)*V(21))
230 IF(NULL(J).NE.31) GO TO 131
    J=J+1
    GO TO 231
131 SLIP=1.-(DSPEED/SSPEED)*Y(31)
    TDM=QKMM*SLIP/(A1*SLIP*SLIP+A2)
    WN2=Y(32)/W2100
    CALL PTORQ(Y(31),WN2,RPT)
    CALL TFRIC(Y(31),AZ,TS,TR,TMIN,TFR)
    F(31)=(TDM-RPT-TFR)/PCON2
231 IF(NULL(J).NE.32) GO TO 132
    J=J+1
    GO TO 232
132 WN2=Y(32)/W2100
    CALL PHEAD(Y(31),WN2,HRP)
    DPRP=144.*HRP*DHEAD
    IF(H(4).GE.HSW) DPRP=0.0
    F(32)=(DPRP+DPBDD+ETDD*(Y(32)**2)-FLCDD*Y(32)*ABS(Y(32)))/ALTDD
232 IF(NULL(J).NE.33) GO TO 133
    J=J+1
    GO TO 233
133 F(33)=(144.*(P(2)-P(21))+DPBDH+ETDH*Y(33)*Y(33)-FLCDH*Y(33)*
   1 ABS(Y(33)))/ALTDH
233 IF(NULL(J).NE.34) GO TO 134
    J=J+1
    GO TO 234
134 F(34)=W1-Y(33)
234 IF(NULL(J).NE.35) GO TO 135
    J=J+1
    GO TO 235
135 F(35)=Y(32)*(Y(22)-Y(12))+W1*H(1)-Y(33)*HG(2)
235 IF(NULL(J).NE.36) GO TO 136
    J=J+1
    GO TO 236
136 F(36)=(HDA-Y(36))/TAU(36)
236 IF(NULL(J).NE.37) GO TO 137
    J=J+1
    GO TO 237
137 F(37)=((Y(33)/W1100)-Y(37))/TAU(37)
237 IF(NULL(J).NE.38) GO TO 138
    J=J+1
    GO TO 238
138 F(38)=((W1/W1100)-Y(38))/TAU(38)
238 IF(NULL(J).NE.39) GO TO 139
    RETURN
139 EHD=HDSP-Y(36)
    TFW=KFW*EHD
    EFWV=TFW+Y(37)-Y(38)
    IF(ABS(EFWV).LE.0.01) EFWV=0.0
    F(39)=(KCV*EFWV)/TAU(39)
```

```
      RETURN
C
C          PROMPT JUMP APPROXIMATION
C
 4300 DO 4301 I=1, 11
 4301 TCS(19-I)=Y(I)
      DO 4302 I=12, 30
 4302 H(I-9)=Y(I)
      ALFA=Y(31)
      W2=Y(32)
      W3=Y(33)
      IF(W2.LT.EPS1) W2=EPS1
      IF(W3.LT.EPS1) W3=EPS1
      MT(2)=Y(34)
      UI(2)=Y(35)
      HDM=Y(36)
      WM3=Y(37)
      WM1=Y(38)
      CVP=Y(39)
      J=1
      IF(NULL(J).EQ.1) GO TO 301
      GO TO 401
  301 CALL PROMTT(WI,ACS(19),TCS(19),Y(1),TM(18),TM(19),U(19),AT(19),
     1ACFI)
      J=J+1
  401 IF(NULL(J).EQ.2) GO TO 302
      GO TO 402
  302 CALL PROMTT(WI,ACS(18),TCS(18),Y(2),TM(17),TM(18),U(18),AT(18),
     1 ACFI)
      J=J+1
  402 IF(NULL(J).EQ.3) GO TO 303
      GO TO 403
  303 CALL PROMTT(WI,ACS(17),TCS(17),Y(3),TM(16),TM(17),U(17),AT(17),
     1 ACFI)
      J=J+1
  403 IF(NULL(J).EQ.4) GO TO 304
      GO TO 404
  304 CALL PROMTT(WI,ACS(16),TCS(16),Y(4),TM(15),TM(16),U(16),AT(16),
     1 ACFI)
      J=J+1
      IF(MODE.EQ.0) TCS(15)=Y(4)
  404 IF(NULL(J).EQ.5) GO TO 305
      GO TO 405
  305 Y(5)=TCS(15)
      J=J+1
      IF(MODE.EQ.0) TCS(14)=Y(5)
  405 IF(NULL(J).EQ.6) GO TO 306
      GO TO 406
  306 Y(6)=TCS(14)
      J=J+1
      IF(MODE.EQ.0) TCS(13)=Y(6)
  406 IF(NULL(J).EQ.7) GO TO 307
      GO TO 407
  307 Y(7)=TCS(13)
      J=J+1
      IF(MODE.EQ.0) TCS(12)=Y(7)
  407 IF(NULL(J).EQ.8) GO TO 308
      GO TO 408
  308 Y(8)=TCS(12)
      J=J+1
      IF(MODE.EQ.0) TCS(11)=Y(8)
```

```
 408 IF(NULL(J).EQ.9) GO TO 309
     GO TO 409
 309 Y(9)=TCS(11)
     J=J+1
     IF(MODE.EQ.0) TCS(10)=Y(9)
 409 IF(NULL(J).EQ.10) GO TO 310
     GO TO 410
 310 CALL PROMTT(WI,ACS(10),TCS(10),Y(10),TM(9),TM(10),U(10),AT(10),
    1 FFCI)
     IF(XL(10).LE.0.0) Y(10)=TCS(10)
     J=J+1
 410 IF(NULL(J).EQ.11) GO TO 311
     GO TO 411
 311 CALL PROMTT(WI,ACS(9),TCS(9),Y(11),TM(8),TM(9),U(9),AT(9),FFCI)
     J=J+1
 411 IF(NULL(J).EQ.12) GO TO 312
     GO TO 412
 312 Y(12)=((W2-W1)*HF(2)+W1*H(1))/W2
     J=J+1
     IF(MODE.EQ.0) H(3)=Y(12)
 412 IF(NULL(J).EQ.13) GO TO 313
     GO TO 413
 313 Y(13)=H(3)
     J=J+1
     IF(MODE.EQ.0) H(4)=Y(13)
 413 IF(NULL(J).EQ.14) GO TO 314
     GO TO 414
 314 Y(14)=H(4)
     J=J+1
     IF(MODE.EQ.0) H(5)=Y(14)
 414 IF(NULL(J).EQ.15) GO TO 315
     GO TO 415
 315 Y(15)=H(5)
     J=J+1
     IF(MODE.EQ.0) H(6)=Y(15)
 415 IF(NULL(J).EQ.16) GO TO 316
     GO TO 416
 316 Y(16)=H(6)
     J=J+1
     IF(MODE.EQ.0) H(7)=Y(16)
 416 IF(NULL(J).EQ.17) GO TO 317
     GO TO 417
 317 Y(17)=H(7)
     J=J+1
 417 IF(NULL(J).EQ.18) GO TO 318
     GO TO 418
 318 IF(XL(10).LE.0.0) GO TO 3180
     Y(18)=HF(9)
     GO TO 3181
3180 Y(18)=H(8)+(2.*Q(9)/W2)
3181 J=J+1
 418 IF(NULL(J).EQ.19) GO TO 319
     GO TO 419
 319 Y(19)=H(9)+(2.*Q(10)/W2)
     IF(XL(10).LE.0.) Y(19)=H(9)
     J=J+1
     IF(MODE.EQ.0) H(10)=Y(19)
 419 IF(NULL(J).EQ.20) GO TO 320
     GO TO 420
 320 Y(20)=H(10)
     J=J+1
```

```
      IF(MODE.EQ.0) H(11)=Y(20)
  420 IF(NULL(J).EQ.21) GO TO 321
      GO TO 421
  321 Y(21)=H(11)
      J=J+1
      IF(MODE.EQ.0) H(12)=Y(21)
  421 IF(NULL(J).EQ.22) GO TO 322
      GO TO 422
  322 Y(22)=H(12)
      J=J+1
  422 IF(NULL(J).EQ.23) GO TO 323
      GO TO 423
  323 Y(23)=HG(13)
      J=J+1
      IF(MODE.EQ.0) H(14)=Y(23)
  423 IF(NULL(J).EQ.24) GO TO 324
      GO TO 424
  324 Y(24)=H(14)
      J=J+1
      IF(MODE.EQ.0) H(15)=Y(24)
  424 IF(NULL(J).EQ.25) GO TO 325
      GO TO 425
  325 CALL ENTH(H(15),W3,TCS(16),TCS(15),TM(15),TM(16),TDLOG(16),U(16),
     1 AT(16),ACF,P(16),Y(25))
      J=J+1
  425 IF(NULL(J).EQ.26) GO TO 326
      GO TO 426
  326 CALL ENTH(H(16),W3,TCS(17),TCS(16),TM(16),TM(17),TDLOG(17),U(17),
     1 AT(17),ACF,P(17),Y(26))
      J=J+1
  426 IF(NULL(J).EQ.27) GO TO 327
      GO TO 427
  327 CALL ENTH(H(17),W3,TCS(18),TCS(17),TM(17),TM(18),TDLOG(18),U(18),
     1 AT(18),ACF,P(18),Y(27))
      J=J+1
  427 IF(NULL(J).EQ.28) GO TO 328
      GO TO 428
  328 CALL ENTH(H(18),W3,TCS(19),TCS(18),TM(18),TM(19),TDLOG(19),U(19),
     1 AT(19),ACF,P(19),Y(28))
      J=J+1
      IF(MODE.EQ.0) H(19)=Y(28)
  428 IF(NULL(J).EQ.29) GO TO 329
      GO TO 429
  329 Y(29)=H(19)
      J=J+1
      IF(MODE.EQ.0) H(20)=Y(29)
  429 IF(NULL(J).EQ.30) GO TO 330
      GO TO 430
  330 Y(30)=H(20)
      J=J+1
  430 IF(NULL(J).EQ.31) GO TO 331
      GO TO 431
  331 WN2=W2/W2100
      CALL RPSPD(Y(31),WN2,QKMM,TDM,RPT,TFR,SLIP)
      J=J+1
  431 IF(NULL(J).EQ.32) GO TO 332
      GO TO 432
  332 ASAV=FLCDD-ETDD
      HSAV=H(4)
      DO 3325 I=1,15
      WN2=Y(32)/W2100
```

```
      CALL PHEAD(ALFA,WN2,HRP)
      DPRP=144.*HRP*DHEAD
      IF(HSAV.GE.HSW) DPRP=0.
      ARG=(DPRP+DPBDD)/ASAV
      IF(ARG.LT.EPS2) ARG=EPS2
      YNEW=SQRT(ARG)
      Y(32)=(Y(32)+YNEW)/2.
      DIV=1.-YNEW/Y(32)
      IF(DIV.LE.EPS1) GO TO 3329
 3325 CONTINUE
 3329 J=J+1
  432 IF(NULL(J).EQ.33) GO TO 333
      GO TO 433
  333 ARG=(144.*(P(2)-P(21))+DPBDH)/(FLCDH-ETDH)
      IF(ARG.LT.EPS2) ARG=EPS2
      Y(33)=SQRT(ARG)
      J=J+1
  433 IF(NULL(J).EQ.34) GO TO 334
      GO TO 434
  334 Y(34)=MT(2)
      J=J+1
  434 IF(NULL(J).EQ.35) GO TO 335
      GO TO 435
  335 Y(35)=UI(2)
      J=J+1
  435 IF(NULL(J).EQ.36) GO TO 336
      GO TO 436
  336 Y(36)=HDA
      J=J+1
  436 IF(NULL(J).EQ.37) GO TO 337
      GO TO 437
  337 Y(37)=W3/W1100
      J=J+1
  437 IF(NULL(J).EQ.38) GO TO 338
      GO TO 438
  338 Y(38)=(W1/W1100)
      J=J+1
  438 IF(NULL(J).EQ.39) GO TO 339
      GO TO 55
  339 ALSAV=(KFW*(HDSP-HDM)+WM3)/WFMAX
      Y(39)=CVMAX+ALOG(ALSAV)/ALOG(WFMAX/WFMIN)
   55 CONTINUE
      DO 56 I=1, 11
      TCS(19-I)=Y(I)
   56 CONTINUE
      DO 57 I=12, 30
      H(I-9)=Y(I)
   57 CONTINUE
      ALFA=Y(31)
      W2=Y(32)
      W3=Y(33)
      MT(2)=Y(34)
      UI(2)=Y(35)
      HDM=Y(36)
      WM3=Y(37)
      WM1=Y(38)
      CVP=Y(39)
      IF(W2.LE.EPS1) W2=EPS1
      IF(W3.LE.EPS1) W3=EPS1
      IF((TAU(32)*0.7).LT.S) F(32)=0.0
      IF((TAU(33)*0.7).LT.S) F(33)=0.0
```

```
      IF(MODE.EQ.0.) F(32)=0.0
      IF(MODE.EQ.0) F(33)=0.0
C
C        CALCULATE LOCAL PRESSURES
      CALL DRUM(P(2),UI(2),V(2),EPSI,MT(2),MG(2),MF(2),PNEW)
      P(2)=PNEW
      P(3)=P(2)
      P(4)=((DPB(4)+E(4)*W2*W2-(CC(4)/ADEN(4))*W2*W2-AL(4)*F(32))/144.)+
     1 P(3)
      CALL PHEAD(ALFA, WN2, HRP)
      DPRP=144.0*HRP*DHEAD
      CALL SWATER(P(4),TSW,HSW,HSS,HWS,DSW,DSS,SSW,SSS)
      IF(H(4).GE.HSW) DPRP=0.0
      P(5)=((DPB(5)+E(5)*W2*W2+DPRP)/144.)+P(4)
      P(6)=((DPB(6)+E(6)*W2*W2-(CC(6)/ADEN(6))*W2*W2-AL(6)*F(32))/144.)+
     1 P(5)
      P(7)=((DPB(7)+(E(7)/4.)*W2*W2-(CC(7)/(4.*ADEN(7)))*W2*W2-(AL(7)/2.
     1 )*F(32))/144.)+P(6)
      P(8)=((DPB(8)+(E(8)/4.)*W2*W2-(CC(8)/(4.*ADEN(8)))*W2*W2-(AL(8)/2.
     1 )*F(32))/144.)+P(7)
      P(9)=((DPB(9)+(E(9)/4.)*W2*W2-(CC(9)/(4.*ADEN(9)))*W2*W2-(AL(9)/2.
     1 )*F(32))/144.)+P(8)
      P(10)=((DPB(10)+(E(10)/4.)*W2*W2-(CC(10)/(4.*DF(10)))*PHI(10)*W2*
     1 W2-(AL(10)/2.)*F(32))/144.)+P(9)
      IF(XL(10).LE.0.) P(10)=P(9)
      P(11)=((DPB(11)+(E(11)/4.)*W2*W2-(CC(11)/(4.*DF(11)))*PHI(11)*W2*
     1 W2-(AL(11)/2.)*F(32))/144.)+P(10)
      P(12)=((DPB(12)+(E(12)/4.)*W2*W2-(CC(12)/(4.*DF(12)))*PHI(12)*W2*
     1 W2-(AL(12)/2.)*F(32))/144.)+P(11)
      P(13)=P(2)
      P(14)=((DPB(14)+E(14)*W3*W3-(CC(14)/ADEN(14))*W3*W3-AL(14)*F(33))/
     1 144.)+P(13)
      P(15)=((DPB(15)+E(15)*W3*W3-(CC(15)/ADEN(15))*W3*W3-AL(15)*F(33))/
     1 144.)+P(14)
      P(16)=((DPB(16)+E(16)*W3*W3-(CC(16)/ADEN(16))*W3*W3-AL(16)*F(33))/
     1 144.)+P(15)
      P(17)=((DPB(17)+E(17)*W3*W3-(CC(17)/ADEN(17))*W3*W3-AL(17)*F(33))/
     1 144.)+P(16)
      P(18)=((DPB(18)+E(18)*W3*W3-(CC(18)/ADEN(18))*W3*W3-AL(18)*F(33))/
     1 144.)+P(17)
      P(19)=((DPB(19)+E(19)*W3*W3-(CC(19)/ADEN(19))*W3*W3-AL(19)*F(33))/
     1 144.)+P(18)
      P(20)=((DPB(20)+E(20)*W3*W3-(CC(20)/ADEN(20))*W3*W3-AL(20)*F(33))/
     1 144.)+P(19)
      IF(X(9).EQ.0.) CALL SWATER(P(9),TM(9),HF(9),HG(9),HFG(9),DF(9),DG(
     19),SVF(9),SVG(9))
      IF(XL(10).GT.0.0) H(9)=HF(9)
      RETURN
      ENTRY PUTSG1
      WRITE(6, 460)
      IF(KCALC.EQ.1) WRITE(6, 7200) (I, TCM(I), I=1, 39)
      WRITE(6, 550) WN1, WN2, WN3, WNI
      IF(TSEC.GE.TAUX) HAUWP=HAUW*ENTFAC
      IF(TSEC.GE.TAUX) WRITE(6, 9104) TAUX,HAUWP,WAUXN
      DO 9991 I=1,21
      P(I)=P(I)*PFAC
 9991 H(I)=H(I)*ENTFAC
      CALL TMPCON(1,21,TM)
      CALL TMPCON(1,19,TCS)
      DO 9992 I=9,10
      TDLOG(I)=TDLOG(I)*TFAC
```

```
      U(I)=U(I)*XHFAC
 9992 XL(I)=XL(I)*XFAC
      DO 9993 I=16,19
      TDLOG(I)=TDLOG(I)*TFAC
 9993 U(I)=U(I)*XHFAC
      HFLUX(10)=HFLUX(10)*FLXFAC
      UI(2)=UI(2)*EFAC
      DPRP=DPRP*PFAC
      WRITE(6, 600) (I, P(I), I=1, 21)
      WRITE(6, 650) (I, H(I), I=1, 21)
      WRITE(6, 700) (I,TM(I), I=1, 21)
      WRITE(6, 750) (I, TCS(I), I=8, 19)
      WRITE(6, 7300)(I, TDLOG(I), I=9, 10)
      WRITE(6, 8000)(I, U(I), I=9, 10)
      WRITE(6, 8300)(I, TDLOG(I),I=16, 19)
      WRITE(6, 9000)(I, U(I), I=16, 19)
      WRITE(6, 950)HFLUX(10),X(10),XL(9),XL(10)
      WRITE(6, 960) UI(2),HDA,CVP,ALFA,DPRP
      DO 9994 I=1,21
      P(I)=P(I)/PFAC
 9994 H(I)=H(I)/ENTFAC
      CALL TMPCON(0,21,TM)
      CALL TMPCON(0,19,TCS)
      DO 9995 I=9,10
      TDLOG(I)=TDLOG(I)/TFAC
      U(I)=U(I)/XHFAC
 9995 XL(I)=XL(I)/XFAC
      DO 9996 I=16,19
      TDLOG(I)=TDLOG(I)/TFAC
 9996 U(I)=U(I)/XHFAC
      HFLUX(10)=HFLUX(10)/FLXFAC
      UI(2)=UI(2)/EFAC
      DPRP=DPRP/PFAC
  460 FORMAT(/,2X,36('*'),3X,'S T E A M',3X,'G E N E R A T I O N',3X,
     1  'L O O P - 1',3X,36('*')/)
  550 FORMAT(2X,'FEED WATER FLOW =',F6.4,2X,'WATER/STEAM FLOW =',F6.4,
     1 2X,'STEAM FLOW =',F6.4,2X,'INT. SODIUM FLOW =',F6.4/)
  600 FORMAT(7(2X,'P',I2,' =',1PE11.4))
  650 FORMAT(7(2X,'H',I2,' =',1PE11.4))
  700 FORMAT(7(2X,'TM',I2,' =',F10.4))
  750 FORMAT(7(2X,'TCS',I2,' =',F10.4))
  600 FORMAT(/,3X,'<<<<<<<<<< W A R N I N G      DRYOUT OCCURED IN THE E
     1VAPORATORS OF LOOP-1 AT TIME =',F12.4,' SECONDS >>>>>>>>>>'/)
  950 FORMAT(/,2X,'HEAT FLUX =',1PE13.6,24X,
     1'OUTLET STEAM QUALITY =',1PE13.6/,2X,'NON-BOILING LENGTH =',
     2  1PE13.6,13X,'BOILING LENGTH =',1PE13.6)
  960 FORMAT(/,2X,'DRUM INT. ENERGY =',1PE11.4,3X,'DRUM LEVEL =',
     10PF7.4,3X,'CVP =',F7.4,3X,'ALFA =',F7.4,3X,'DPRP =',1PE11.4)
 7200 FORMAT(3X,'TAU:',8(I3,F10.6))
 7300 FORMAT(31X,'TDLOG:', 2(I3,F14.4))
 8000 FORMAT(31X,'U    :', 2(I3,F14.4))
 8300 FORMAT(15X,'TDLOG:',4(I3,F14.4))
 9000 FORMAT(15X,'U    :',4(I3,F14.4))
 9100 FORMAT(/20X,'**** RECIRCULATION PUMP #1 TRIP AT',F8.4,
     1  ' SEC ****'/)
 9104 FORMAT(2X,'AUXILIARY FEED WATER AVAILABLE AT',F8.3,' SECONDS',2X,
     1'ENTHALPY =',1PE11.4,2X,'AUX. WATER FLOW  =',0PF6.4)
 9200 FORMAT(/,3X,'<<<<<<<<<< W A R N I N G      RECIRCULATION PUMP IN L
     1OOP-1 ENTERS CAVITATION AT TIME =',F12.4,' SECONDS >>>>>>>>>>'/)
 9199 FORMAT(/,3X,'<<<<<<<<<< W A R N I N G      RECIRCULATION PUMP IN L
     1OOP-1 OUT OF CAVITATION AT TIME =',F12.4,' SECONDS >>>>>>>>>>'/)
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```
      RETURN
      END
      SUBROUTINE SGTHD2(TISH,KMM.MODE,PD)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                     STEAM GENERATION LOOP-2:                       C
C             WATER/STEAM THERMODYNAMICS SIMULATION                  C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL KMM,KFW,KCV,MINERT
      REAL NU, NUS, MF, MG, MT, MFI
      DIMENSION H(21),TM(21),P(21),TCS(19),G(21)
      DIMENSION GS(19),AT(21),A(21),AS(19),D(21),DEL(21),DS(19),DT(21)
      DIMENSION DTS(19),DH(21),DHS(19),PER(21),V(21),VS(19),XL(21)
      DIMENSION XLS(19),Z(21),CC(21),E(21),DPB(21),TAU(39),AL(21),XY(28)
      DIMENSION XR(28),TMC(21),TMH(21),TCM(39),MG(2),MF(2),MT(2),UI(2)
      DIMENSION X(15),VOID(15),PHI(15),HF(15),HG(15),HFG(15),DF(15)
      DIMENSION DG(15),SVF(15),SVG(21),XKF(15),XKG(21),XK(21),AXK(21)
      DIMENSION XKS(19),AXKS(19),VISF(15),VISG(15),VIS(21),AVIS(21)
      DIMENSION VISS(19),AVISS(19),CF(15),CG(15),CP(21),ACP(21),CS(19)
      DIMENSION DEN(21),ADEN(21),ST(15),DES(19),ADS(19),RE(21),RES(19)
      DIMENSION PR(21),PRS(19),NU(21),NUS(19),HCN(21),HC(21),HPB(21)
      DIMENSION HS(19),TDLOG(19),U(19),UG(2),UF(2),Q(19),HFLUX(10),
     1 CHF(10),OD(21),ACS(19),XN(21)
      DIMENSION TAUS(4)
      COMMON/PHDR/PH,TMSHD
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/ARPP/DSPEED,SSPEED,A1,A2,AZ,TS,TR,TMIN
      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/ALLR/DUR821(438),Y(39),DUR822(12)
      COMMON/ALLF/DUF821(438),F(39),DUF822(12)
      COMMON/ALLNUL/DUN821(438),NULL(39),DUN822(12)
      COMMON/GET1/WDUM(9),WI100,WSC1,WI,WBRK
      COMMON/NORMS/ADUM(11),W2100,BDUM
      COMMON/SGEN2/TNOFW,TAUX
      COMMON/FACT/XFAC,AFAC,VFAC,WFAC,PFAC,DFAC,CFAC,XKFAC,TFAC,XMFAC,
     1  TQFAC,SPFAC,XILFAC,XHFAC,ENTFAC,GCP
      NAMELIST/SGB01/EPSI,P
      NAMELIST/SGB02/H
      NAMELIST/SGB03/TCS
      NAMELIST/SCB04/XLT,XL,ACF,TKON
      NAMELIST/SGB05/Z
      NAMELIST/SGB06/XLS
      NAMELIST/SGB07/PITCH,D
      NAMELIST/SGB08/DS,DEL,XN
      NAMELIST/SGB09/TMD,MINERT
      NAMELIST/SGB10/KFW,KCV,HDSP
      NAMELIST/SGB11/W1100,W2100,W1,W2,W3,CVP,ALFA
      NAMELIST/SGB12/TAUS
      NAMELIST/SGB13/WFMIN,WFMAX,CVMAX,WAUXM,HAUW,HDAUX,HDMAX
      DATA PI/3.141593/,EPS1/1.E-5/,EPS2/1.E-10/
      M=KRUNG+2
      IF(M.NE.1.AND.M.NE.6) QKMM=KMM+FRICK*KMM
      GO TO (4000,4300,4100,4200,4100,997), M
C
C          RESTART OPTION
  997 DO 998 I=1,21
      P(I)=P(I)*PFAC
      H(I)=H(I)*ENTFAC
      XL(I)=XL(I)*XFAC
      Z(I)=Z(I)*XFAC
      D(I)=D(I)*XFAC/12.
      DEL(I)=DEL(I)*XFAC/12.
```

```
      IF(I.GT.19) GO TO 998
      XLS(I)=XLS(I)*XFAC
      DS(I)=DS(I)*XFAC
  998 CONTINUE
      EPSI=EPSI*PFAC
      CALL TMPCON(1,19,TCS)
      XLT=XLT*XFAC
      PITCH=PITCH*XFAC
      TMD=TMD*TQFAC
      MINERT=MINERT*XMFAC
      TKON=TKON*XKFAC
      W1100=W1100*WFAC
      W2100=W2100*WFAC
      ALFA=Y(31)
      W1=W1*WFAC
      W2=W2*WFAC
      W3=W3*WFAC
      WAUXM=WAUXM*WFAC
      HAUW=HAUW*ENTFAC
      IF(PD.NE.1.) GO TO 996
      W2100=W2
      ALFA=1.
      W1100=W3
  996 W1=W3
      WF=W1/W1100
      CVP=CVMAX*(1.+ALOG(WF/WFMAX)/ALOG(WFMAX/WFMIN))
      GO TO 999
C
C      READ INPUT DATA
 4000 READ(5, SGB01)
      READ(5, SGB02)
      READ(5, SGB03)
      READ(5, SGB04)
      READ(5, SGB05)
      READ(5, SGB06)
      READ(5, SGB07)
      READ(5, SGB08)
      READ(5, SGB09)
      READ(5, SGB10)
      READ(5, SGB11)
      READ(5, SGB12)
      READ(5, SGB13)
C
C      PRINT INPUT DATA
  999 WRITE(6, SGB01)
      WRITE(6, SGB02)
      WRITE(6, SGB03)
      WRITE(6, SGB04)
      WRITE(6, SGB05)
      WRITE(6, SGB06)
      WRITE(6, SGB07)
      WRITE(6, SGB08)
      WRITE(6, SGB09)
      WRITE(6, SGB10)
      WRITE(6, SGB11)
      WRITE(6, SGB12)
      WRITE(6, SGB13)
C
C         CONVERT INTO THE PROPER UNITS
      FLXFAC=XHFAC*TFAC
      EFAC=ENTFAC*WFAC*3600.
```

```
      DO 4001 I=1,21
      P(I)=P(I)/PFAC
      H(I)=H(I)/ENTFAC
      XL(I)=XL(I)/XFAC
      Z(I)=Z(I)/XFAC
      D(I)=D(I)/XFAC*12.
      DEL(I)=DEL(I)/XFAC*12.
      IF(I.GT.19) GO TO 4001
      XLS(I)=XLS(I)/XFAC
      DS(I)=DS(I)/XFAC
 4001 CONTINUE
      EPSI=EPSI/PFAC
      CALL TMPCON(0,19,TCS)
      XLT=XLT/XFAC
      PITCH=PITCH/XFAC
      TMD=TMD/TQFAC
      TKON=TKON/XKFAC
      MINERT=MINERT/XMFAC
      W1100=W1100/WFAC
      W2100=W2100/WFAC
      W1=W1/WFAC
      W2=W2/WFAC
      W3=W3/WFAC
      WAUXM=WAUXM/WFAC
      HAUW=HAUW/ENTFAC
      GC=CCP*3600.*3600.
      IF(MODE.EQ.0.AND.PD.NE.1.) W3=PD*W1100
      WM1=W1/W1100
      WM3=W3/W1100
      L=0
      N=0
      NCAVO=0
      CALL TFRIC(1.,AZ,TS,TR,TMIN,FRICK)
      QKMM=KMM+FRICK*KMM
C
C       CALCULATE SYSTEM CHARACTERISTICS
      DO 1 I=1, 21
      DH(I)=D(I)/12.
      OD(I)=(D(I)+2.*DEL(I))/12.
      DT(I)=D(I)/12.
      A(I)=PI*((DH(I)/2.)**2)*XN(I)
      IF(I.EQ.9.OR.I.EQ.10) GO TO 1
      AT(I)=PI*OD(I)*XL(I)*XN(I)
      V(I)=XL(I)*A(I)
      AL(I)=(XL(I)/A(I))/GC
    1 CONTINUE
      ALTDD=AL(4)+AL(6)+((AL(7)+AL(8)+((XLT/A(9))/GC)+AL(11)+AL(12))/2.)
     1+AL(13)
      ALTDH=AL(14)+AL(15)+AL(16)+AL(17)+AL(18)+AL(19)+AL(20)+AL(21)
      DO 2 I=8, 19
      XSAV=XN(I)
      IF(I.GE.11.AND.I.LE.15) XSAV=0.
      AS(I)=PI*(((DS(I)/2.)**2)-XSAV*((OD(I)/2.)**2))
      PER(I)=PI*(DS(I)+XSAV*OD(I))
      DHS(I)=4.*AS(I)/PER(I)
      DTS(I)=OD(I)
      VS(I)=AS(I)*XLS(I)
    2 CONTINUE
      PCON1=120.*PI*MINERT/GC
      PCON2=PCON1*DSPEED/TMD
      CALL SWATER(P(2),TM(2),HF(2),HG(2),HFG(2),DF(2),DG(2),SVF(2),
```

```
     1 SVG(2))
      UG(2)=HG(2)-(144./778.)*P(2)*SVG(2)
      UF(2)=HF(2)-(144./778.)*P(2)*SVF(2)
      MG(2)=V(2)/(2.*SVG(2))
      MF(2)=V(2)/(2.*SVF(2))
      MFI=MF(2)
      MT(2)=MG(2)+MF(2)
      UI(2)=MG(2)*UG(2)+MF(2)*UF(2)
      HDA=1.0+SIN((PI/2.)*((MF(2)/MFI)-1.))
      HDM=HDA
      DO 9300 I=1, 11
 9300 Y(I)=TCS(19-I)
      DO 9350 I=12, 30
 9350 Y(I)=H(I-9)
      Y(31)=ALFA
      Y(32)=W2
      Y(33)=W3
      Y(34)=MT(2)
      Y(35)=UI(2)
      Y(36)=HDM
      Y(37)=WM3
      Y(38)=WM1
      Y(39)=CVP
      RETURN
C
C         COMPUTE MASS VELOCITY "G"
 4100 DO 4 J=3, 6
    4 G(J)=W2/A(J)
      DO 5 J=7, 12
    5 G(J)=W2/(2.*A(J))
      G(13)=W2/A(13)
      DO 6 J=14, 21
    6 G(J)=W3/A(J)
      DO 7 J=8, 15
    7 GS(J)=WI/(2.*AS(J))
      DO 8 J=16, 19
    8 GS(J)=WI/AS(J)
      IF(ICOUNT.GT.0) P(21)=PH
      TCS(19)=TISH
 4150 CONTINUE
C
C         COMPUTE THERMODYNAMIC PROPERTIES OF SUBCOOLED & SATURATED
C         WATER, SATURATED & SUPERHEATED STEAM AND INTERMEDIATE NA
      CALL WATER(P(1), H(1), TM(1), DEN(1))
      DO 9 I=3, 8
      CALL WATER(P(I), H(I), TM(I), DEN(I))
      XK(I)=TCOND1(P(I), TM(I))
      VIS(I)=DVISC1(P(I), TM(I))
      CP(I)=SHEAT1(P(I), TM(I))
    9 CONTINUE
      DO 10 I=9, 15
      CALL SWATER(P(I),TM(I),HF(I),HG(I),HFG(I),DF(I),DG(I),SVF(I),
     1 SVG(I))
      IF(ICOUNT.EQ.0) H(9)=HF(9)
      X(I)=(H(I)-HF(I))/HFG(I)
      IF(X(I).GT.1.0) X(I)=1.0
      IF(X(I).LT.0.) CALL WATER(P(I),H(I),TM(I),DEN(I))
      XKF(I)=TCOND1(P(I), TM(I))
      VISF(I)=DVISC1(P(I), TM(I))
      CF(I)=SHEAT1(P(I), TM(I))
      IF(X(I).LT.0.) GO TO 99
```

```
      XKG(I)=TCOND2(TM(I), SVG(I))
      VISG(I)=DVISC2(TM(I), SVG(I))
      CG(I)=SHEAT2(P(I), TM(I))
      XK(I)=(1.-X(I))*XKF(I)+X(I)*XKG(I)
      VIS(I)=(1.-X(I))*VISF(I)+X(I)*VISG(I)
      CP(I)=(1.-X(I))*CF(I)+X(I)*CG(I)
      DEN(I)=1.0/((1.-X(I))*SVF(I)+X(I)*SVG(I))
      GO TO 990
   99 XK(I)=XKF(I)
      VIS(I)=VISF(I)
      CP(I)=CF(I)
      SVF(I)=1.0/DEN(I)
  990 ST(I)=SURFTN(TM(I), SVF(I))
      XKS(I)=THCSOD(TCS(I))
      VISS(I)=VISSOD(TCS(I))
      CS(I)=SPHSOD(TCS(I))
      DES(I)=DENSOD(TCS(I))
      CALL ARMAND(X(I), SVF(I), SVG(I), VOID(I), PHI(I))
   10 CONTINUE
      XKS(8)=THCSOD(TCS(8))
      VISS(8)=VISSOD(TCS(8))
      CS(8)=SPHSOD(TCS(8))
      DES(8)=DENSOD(TCS(8))
      DO 11 I=16, 19
      TM(I)=TSTEAM(H(I), P(I))
      SVG(I)=SPVOL2(TM(I), P(I))
      DEN(I)=1./SVG(I)
      XK(I)=TCOND2(TM(I), SVG(I))
      VIS(I)=DVISC2(TM(I), SVG(I))
      CP(I)=SHEAT2(P(I), TM(I))
      XKS(I)=THCSOD(TCS(I))
      VISS(I)=VISSOD(TCS(I))
      CS(I)=SPHSOD(TCS(I))
      DES(I)=DENSOD(TCS(I))
   11 CONTINUE
      DO 12 I=20, 21
      TM(I)=TSTEAM(H(I), P(I))
      SVG(I)=SPVOL2(TM(I), P(I))
      DEN(I)=1./SVG(I)
      XK(I)=TCOND2(TM(I), SVG(I))
      VIS(I)=DVISC2(TM(I), SVG(I))
      CP(I)=SHEAT2(P(I), TM(I))
   12 CONTINUE
      H(2)=(UI(2)+(144./778.)*P(2)*V(2))/MT(2)
C
C         CALCULATE LOGARITHMIC MEAN TEMPERATURE DIFFERENCES
      DO 13 I=16, 19
   13 CALL LMTDIF(TCS(35-I),TCS(34-I),TM(34-I),TM(35-I),TDLOG(35-I))
      DO 14 I=9, 10
      IF(X(10).LE.0.0.AND.I.EQ.9) GO TO 14
      CALL LMTDIF(TCS(19-I),TCS(18-I),TM(18-I),TM(19-I),TDLOG(19-I))
   14 CONTINUE
      IF(X(10).LE.0.) TDLOG(10)=TDLOG(9)
C
C         INTERMEDIATE SODIUM SIDE REYNOLD,PRANDTL & NUSSELT NUMBERS
C                             AND HEAT TRANSFER COEFFICIENTS
      DO 17 I=9, 19
      ADS(I)=(DES(I-1)+DES(I))/2.0
      AXKS(I)=(XKS(I-1)+XKS(I))/2.0
      AVISS(I)=(VISS(I-1)+VISS(I))/2.0
      ACS(I)=(CS(I-1)+CS(I))/2.0
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```
      RES(I)=GS(I)*DHS(I)/AVISS(I)
      PRS(I)=AVISS(I)*ACS(I)/AXKS(I)
      IF(RES(I).GT.3000.0) GO TO 15
      NUS(I)=48./11.0
      GO TO 16
   15 NUS(I)=7.0+0.025*((RES(I)*PRS(I))**0.8)
   16 HS(I)=NUS(I)*AXKS(I)/DTS(I)
   17 CONTINUE
C
C          WATER/STEAM SIDE REYNOLDS,PRANDTL & NUSSELT NUMBERS
C          BOILING, CONVECTION & HEAT TRANSFER COEFFICIENTS
      DO 19 I=4, 21
      ADEN(I)=(DEN(I-1)+DEN(I))/2.
      AXK(I)=(XK(I-1)+XK(I))/2.0
      AVIS(I)=(VIS(I-1)+VIS(I))/2.0
      ACP(I)=(CP(I-1)+CP(I))/2.0
      IF(I.EQ.10) GO TO 18
      PR(I)=AVIS(I)*ACP(I)/AXK(I)
      RE(I)=G(I)*DH(I)/AVIS(I)
      IF(RE(I).LT.3000.) GO TO 171
      NU(I)=0.023*(RE(I)**0.8)*(PR(I)**0.4)
      GO TO 172
  171 NU(I)=7.15
  172 HC(I)=NU(I)*AXK(I)/DT(I)
      GO TO 19
   18 IF(X(10).LE.0.) GO TO 180
      CALL BRHTC(G(I),DH(I),DT(I),ST(I),VISF(I),VISG(I),DF(I),DG(I),
     1CF(I),CG(I),XKF(I),XKG(I),HFG(I),TDLOG(I),HS(I),X(I),RE(I),PR(I),
     2HC(I),HPB(I))
  180 IF(X(10).LE.0.) HC(10)=HC(9)
   19 CONTINUE
C
C          OVER-ALL HEAT-TRANSFER COEFFICIENT
      DO 20 I=9, 10
      U(I)=USTG(HS(I), HC(I), DT(I), OD(I), TKON)
   20 CONTINUE
      DO 21 I=16, 19
      U(I)=USTG(HS(I), HC(I), DT(I), OD(I), TKON)
   21 CONTINUE
C
C          DETERMINE BOILING, AND NON-BOILING LENGTHS IN THE EVAPORATORS
      IF(TDLOG(9).EQ.0.) GO TO 72
      IF(X(10).LE.0.) GO TO 690
      QNB=W2*(HF(9)-H(8))/2.0
      IF(T.GT.0.0) GO TO 69
      XL(9)=QNB/(U(9)*TDLOG(9)*PI*OD(9)*XN(9))
      QBL=W2*(H(10)-HF(9))/2.0
      XL(10)=QBL/(U(10)*TDLOG(10)*PI*OD(9)*XN(9))
      XLF=XL(9)+XL(10)
      FFC=XLF/XLT
      FFCI=1.0/(2.0*FFC)
      ACFI=1.0/ACF
   69 CONTINUE
      XL(9)=QNB/(FFC*U(9)*TDLOG(9)*PI*OD(9)*XN(9))
      IF(XL(9).LT.0.0) XL(9)=0.0
      IF(XL(9).GE.XLT)XL(9)=XLT
      GO TO 691
  690 XL(9)=XLT
  691 XLB=XLT-XL(9)
      IF(XL(9).EQ.XLT) U(10)=U(9)
      IF(XL(9).EQ.XLT) TDLOG(10)=TDLOG(9)
```

```
      HFLUX(10)=FFC*U(10)*TDLOG(10)
      IF(X(10).LE.0.) GO TO 71
      IF(HFLUX(10).LE.0.0) GO TO 72
      CALL CHFLX(HFLUX(10),P(10),G(10),DH(10),HFG(10),XLC)
      IF(XLC.LE.XLB) GO TO 70
      GO TO 71
   70 XL(10)=XLC
      IF(L.EQ.0) WRITE(6, 800) TSEC
      L=1
      GO TO 72
   71 XL(10)=XLB
   72 CONTINUE
      XLS(9)=XL(9)
      XLS(10)=XL(10)
      V(9)=A(9)*XL(9)
      V(10)=A(10)*XL(10)
      VS(9)=AS(9)*XLS(9)
      VS(10)=AS(10)*XLS(10)
      Z(9)=Z(8)+XL(9)
      AT(9)=PI*OD(9)*XL(9)*XN(9)
      AT(10)=PI*OD(10)*XL(10)*XN(10)
      AL(9)=XL(9)/(A(9)*GC)
      AL(10)=(XLT/(A(9)*GC))-AL(9)
C
C     CALCULATE TOTAL AMOUNT OF HEAT TRANSFERED
      DO 73 I=9, 10
      Q(I)=FFC*U(I)*AT(I)*TDLOG(I)
   73 CONTINUE
      DO 74 I=16, 19
      Q(I)=ACF*U(I)*AT(I)*TDLOG(I)
   74 CONTINUE
C
C          CALCULATE MOMENTUM TERM COEFFICIENT
      DO 22 I=4, 13
      E(I)=DPMOM(A(I-1), A(I), DEN(I-1), DEN(I), GC)
   22 CONTINUE
      ETDD=E(4)+E(5)+E(6)+((E(7)+E(8)+E(9)+E(10)+E(11)+E(12))/4.)+E(13)
      E(14)=DPMOM(A(14),A(14),DG(13),DEN(14),GC)
      DO 23 I=15, 21
      E(I)=DPMOM(A(I-1), A(I), DEN(I-1), DEN(I), GC)
   23 CONTINUE
      ETDH=E(14)+E(15)+E(16)+E(17)+E(18)+E(19)+E(20)+E(21)
C
C          BUOYANCY EFFECT (GRAVITATIONAL CONTRIBUTIONS)
      DO 24 I=4, 13
      DPB(I)=ADEN(I)*(Z(I-1)-Z(I))
   24 CONTINUE
      DPBDD=DPB(4)+DPB(5)+DPB(6)+DPB(7)+DPB(8)+DPB(9)+DPB(10)+DPB(11)+
     1 DPB(12)+DPB(13)
      DO 25 I=14, 21
      DPB(I)=ADEN(I)*(Z(I-1)-Z(I))
   25 CONTINUE
      DPBDH=DPB(14)+DPB(15)+DPB(16)+DPB(17)+DPB(18)+DPB(19)+DPB(20)+
     1 DPB(21)
C
C          COMPUTE FRICTIONAL LOSS COEFFICIENTS
      IF(T.GT.0.0) GO TO 280
      CC(4)=ADEN(4)*(144.*(P(3)-P(4))+DPB(4)+E(4)*(W2**2))/(W2**2)
      CC(6)=ADEN(6)*(144.*(P(5)-P(6))+DPB(6)+E(6)*(W2**2))/(W2**2)
      DO 26 I=7, 9
      CC(I)=4.*ADEN(I)*(144.*(P(I-1)-P(I))+DPB(I)+E(I)*(W2**2/4.))/
```

```
     1 (W2**2)
   26 CONTINUE
      DO 27 I=10, 12
      CC(I)=4.*DF(I)*(144.*(P(I-1)-P(I))+DPB(I)+E(I)*(W2**2/4.))/
     1 ((W2**2)*PHI(I))
   27 CONTINUE
      CC(13)=DF(13)*(144.*(P(12)-P(13))+DPB(13)+E(13)*(W2**2))/((W2**2)*
     1 PHI(13))
      DO 28 I=14, 21
      CC(I)=ADEN(I)*(144.*(P(I-1)-P(I))+DPB(I)+E(I)*(W3**2))/(W3**2)
   28 CONTINUE
      CC(5)=0.0
      IF(MODE.NE.0.OR.PD.EQ.1.) DHEAD=(144.*(P(5)-P(4))-DPB(5)-
     1  E(5)*(W2**2))/144.
      DPRP=DHEAD*144.0
  280 CONTINUE
      FLCDD=(CC(4)/ADEN(4))+(CC(6)/ADEN(6))+(((CC(7)/ADEN(7))+(CC(8)/
     1 ADEN(8))+(CC(9)/ADEN(9))+PHI(10)*(CC(10)/DF(10))+PHI(11)*(CC(11)/
     2 DF(11))+PHI(12)*(CC(12)/DF(12)))/4.)+PHI(13)*(CC(13)/DF(13))
      FLCDH=(CC(14)/ADEN(14))+(CC(15)/ADEN(15))+(CC(16)/ADEN(16))+
     1 (CC(17)/ADEN(17))+(CC(18)/ADEN(18))+(CC(19)/ADEN(19))+(CC(20)/
     2 ADEN(20))+(CC(21)/ADEN(21))
      HDA=1.0+SIN((PI/2.)*((MF(2)/MFI)-1.))
      WN1=WFMAX*EXP((ALOG(WFMAX/WFMIN))*((CVP/CVMAX)-1.))
      WAUXN=0.0
      IF(TSEC.GE.TNOFW) GO TO 9101
      W1=WN1*W1100
      GO TO 9103
 9101 WN1=0.0
      W1=0.0
      IF(TSEC.GE.TAUX) GO TO 9102
      GO TO 9103
 9102 IF(HDM.GT.HDMAX) CVP=0.0
      IF(HDM.LT.HDAUX) CVP=1.0
      WAUX=WAUXM*CVP
      W1=WAUX
      H(1)=HAUW
      WAUXN=WAUX/WAUXM
 9103 CONTINUE
      IF(W2.LE.EPS1) W2=EPS1
      IF(W3.LE.EPS1) W3=EPS1
      WN2=W2/W2100
      WN3=W3/W1100
      WNI=WI/WI100
C        INTRODUCE THE DUMMY VECTOR "Y"
      DO 29 I=1, 11
      Y(I)=TCS(19-I)
   29 CONTINUE
      DO 30 I=12, 30
      Y(I)=H(I-9)
   30 CONTINUE
      Y(31)=ALFA
      Y(32)=W2
      Y(33)=W3
      Y(34)=MT(2)
      Y(35)=UI(2)
      Y(36)=HDM
      Y(37)=WM3
      Y(38)=WM1
      Y(39)=CVP
C
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```
C        CALCULATE PROCESS VARIABLE TIME CONSTANTS
      IF(KRUNG.NE.3) GO TO 440
      DO 31 J=1, 4
      IF(TCS(20-J).EQ.TM(20-J)) GO TO 9201
      XR(J)=(TCS(19-J)-TM(19-J))/(TCS(20-J)-TM(20-J))
      IF(XR(J).LE.0.0) GO TO 9201
      IF(XR(J).EQ.1.0) GO TO 9201
      XY(J)=(1.0-((XR(J)-1.0)/(XR(J)*ALOG(XR(J)))))/ALOG(XR(J))
      GO TO 9202
 9201 XY(J)=0.0
 9202 TAU(J)=DES(19-J)*CS(19-J)*VS(20-J)/(WI*CS(19-J)+U(20-J)*AT(20-J)*
     1ACF*XY(J))
   31 CONTINUE
      DO 32 J=5, 9
      TAU(J)=2.*DES(19-J)*VS(20-J)/WI
   32 CONTINUE
      DO 33 J=10, 11
      IF(TCS(20-J).EQ.TM(20-J)) GO TO 9203
      XR(J)=(TCS(19-J)-TM(19-J))/(TCS(20-J)-TM(20-J))
      IF(XR(J).LE.0.0) GO TO 9203
      IF(XR(J).EQ.1.0) GO TO 9203
      XY(J)=(1.0-((XR(J)-1.0)/(XR(J)*ALOG(XR(J)))))/ALOG(XR(J))
      GO TO 9204
 9203 XY(J)=0.0
 9204 TAU(J)=DES(19-J)*CS(19-J)*VS(20-J)/((WI/2.0)*CS(19-J)+U(20-J)*
     1FFC*AT(20-J)*XY(J))
   33 CONTINUE
      TAU(12)=0.0
      DO 34 J=13, 15
      TAU(J)=DEN(J-9)*V(J-9)/W2
   34 CONTINUE
      DO 35 J=16, 17
      TAU(J)=2.*DEN(J-9)*V(J-9)/W2
   35 CONTINUE
      XR(18)=XR(11)
      XR(19)=XR(10)
      DO 36 J=18, 19
      IF(XR(J).LE.0.0) GO TO 9205
      IF(XR(J).EQ.1.0) GO TO 9205
      XY(J)=(1.-((XR(J)-1.)/ALOG(XR(J))))/ALOG(XR(J))
      GO TO 9206
 9205 XY(J)=0.0
 9206 TAU(J)=DEN(J-9)*V(J-9)*CP(J-9)/((W2/2.)*CP(J-9)-U(J-9)*AT(J-9)*
     1FFC*XY(J))
   36 CONTINUE
      TAU(20)=2.*DEN(11)*V(11)/W2
      DO 37 J=21, 22
      TAU(J)=DEN(J-9)*V(J-9)/W2
   37 CONTINUE
      DO 38 J=23, 24
      TAU(J)=DEN(J-9)*V(J-9)/W3
   38 CONTINUE
      DO 39 J=25, 28
      XR(J)=XR(29-J)
      IF(XR(J).LE.0.0) GO TO 9207
      IF(XR(J).EQ.1.0) GO TO 9207
      XY(J)=(1.-((XR(J)-1.)/ALOG(XR(J))))/ALOG(XR(J))
      GO TO 9208
 9207 XY(J)=0.0
 9208 TAU(J)=DEN(J-9)*V(J-9)*CP(J-9)/(W3*CP(J-9)-U(J-9)*AT(J-9)*ACF*
     1XY(J))
```

```
   39 CONTINUE
      DO 40 J=29, 30
      TAU(J)=DEN(J-9)*V(J-9)/W3
   40 CONTINUE
      SLIP=1.-(DSPEED/SSPEED)*ALFA
      DTDMS=-QKMM*DSPEED/SSPEED*((A2-A1*(SLIP**2))/((A1*(SLIP**2)+A2)**
     12))
      CALL PTIME(ALFA,WN2,AZ,TS,TR,DTRPS,DTRPF)
      TAU(31)=PCON2/(DTRPF+DTRPS-DTDMS)
      TAU(32)=ALTDD/(2.*(FLCDD-ETDD)*W2)
      TAU(33)=ALTDH/(2.*(FLCDH-ETDH)*W3)
      TAU(34)=9999.999/3600.0
      TAU(35)=9999.999/3600.0
      TAU(36)=TAUS(1)/3600.0
      TAU(37)=TAUS(2)/3600.0
      TAU(38)=TAUS(3)/3600.0
      TAU(39)=TAUS(4)/3600.0
      DO 41 I=1, 39
      NULL(I)=0
   41 CONTINUE
      J=1
      DO 42 I=1, 39
      IF(0.7*ABS(TAU(I)).GE.S) GO TO 42
      NULL(J)=I
      J=J+1
   42 CONTINUE
      DO 43 I=1, 39
      TCM(I)=TAU(I)*3600.0
   43 CONTINUE
   44 CONTINUE
      IF(MODE.NE.0) GO TO 440
      DO 143 I=1, 33
      NULL(I)=I
  143 CONTINUE
      NULL(34)=36
      NULL(35)=37
      NULL(36)=38
      NULL(37)=39
      NULL(38)=0
      NULL(39)=0
  440 CONTINUE
C          DETERMINE THE RECIRCULATION PUMP CAVITATION CONDITION
      CALL SWATER(P(4),TSW,HSW,HSS,HWS,DSW,DSS,SSW,SSS)
      IF(H(4).GE.HSW) DPRP=0.0
      IF(XL(9).EQ.XLT) X(10)=0.0
      IF(XL(10).LE.0.0) Y(10)=Y(9)
      IF(XL(10).LE.0.) Y(19)=Y(18)
      NCAV=0
      IF(DPRP.EQ.0.0) NCAV=1
      IF(KMM.NE.0.) GO TO 441
      IF(N.NE.0) GO TO 441
      N=1
      TTRIP=T
      WRITE(6, 9100) TSEC
  441 IF(NCAV.EQ.NCAVO) GO TO 4200
      IF(NCAVO.EQ.0) WRITE(6,9200) TSEC
      IF(NCAVO.EQ.1) WRITE(6,9199) TSEC
      NCAVO=NCAV
 4200 IF(Y(31).GT.1.0) Y(31)=1.0
      IF(Y(32).LT.EPS1) Y(32)=EPS1
      IF(Y(33).LT.EPS1) Y(33)=EPS1
```

```
      J=1
      IF(NULL(J).NE.1) GO TO 101
      J=J+1
      GO TO 201
 101  F(1)=(WI*ACS(19)*(TCS(19)-Y(1))-Q(19))/(ACS(19)*ADS(19)*VS(18))
 201  IF(NULL(J).NE.2) GO TO 102
      J=J+1
      GO TO 202
 102  F(2)=(WI*ACS(18)*(Y(1)-Y(2))-Q(18))/(ACS(18)*ADS(18)*VS(17))
 202  IF(NULL(J).NE.3) GO TO 103
      J=J+1
      GO TO 203
 103  F(3)=(WI*ACS(17)*(Y(2)-Y(3))-Q(17))/(ACS(17)*ADS(17)*VS(16))
 203  IF(NULL(J).NE.4) GO TO 104
      J=J+1
      GO TO 204
 104  F(4)=(WI*ACS(16)*(Y(3)-Y(4))-Q(16))/(ACS(16)*ADS(16)*VS(16))
 204  IF(NULL(J).NE.5) GO TO 105
      J=J+1
      GO TO 205
 105  F(5)=(WI/2.0)*(Y(4)-Y(5))/(ADS(15)*VS(14))
 205  IF(NULL(J).NE.6) GO TO 106
      J=J+1
      GO TO 206
 106  F(6)=(WI/2.0)*(Y(5)-Y(6))/(ADS(14)*VS(13))
 206  IF(NULL(J).NE.7) GO TO 107
      J=J+1
      GO TO 207
 107  F(7)=(WI/2.0)*(Y(6)-Y(7))/(ADS(13)*VS(12))
 207  IF(NULL(J).NE.8) GO TO 108
      J=J+1
      GO TO 208
 108  F(8)=(WI/2.0)*(Y(7)-Y(8))/(ADS(12)*VS(11))
 208  IF(NULL(J).NE.9) GO TO 109
      J=J+1
      GO TO 209
 109  F(9)=(WI/2.0)*(Y(8)-Y(9))/(ADS(11)*VS(11))
 209  IF(NULL(J).NE.10) GO TO 110
      J=J+1
      GO TO 210
 110  IF(VS(10).LE.0.0) GO TO 1100
      F(10)=((WI/2.)*ACS(10)*(Y(9)-Y(10))-Q(10))/(ACS(10)*ADS(10)*VS(10
     1)
      GO TO 210
1100  F(10)=F(9)
 210  IF(NULL(J).NE.11) GO TO 111
      J=J+1
      GO TO 211
 111  F(11)=((WI/2.0)*ACS(9)*(Y(10)-Y(11))-Q(9))/(ACS(9)*ADS(9)*VS(9))
 211  IF(NULL(J).NE.12) GO TO 112
      J=J+1
      GO TO 212
 112  F(12)=(Y(32)*Y(12)-(Y(32)-W1)+HF(2)-W1*H(1))/(DEN(3)*V(2))
 212  IF(NULL(J).NE.13) GO TO 113
      J=J+1
      GO TO 213
 113  F(13)=Y(32)*(Y(12)-Y(13))/(DEN(4)*V(4))
 213  IF(NULL(J).NE.14) GO TO 114
      J=J+1
      GO TO 214
 114  F(14)=Y(32)*(Y(13)-Y(14))/(DEN(5)*V(5))
```

```
 214 IF(NULL(J).NE.15) GO TO 115
     J=J+1
     GO TO 215
 115 F(15)=Y(32)*(Y(14)-Y(15))/(DEN(6)*V(6))
 215 IF(NULL(J).NE.16) GO TO 116
     J=J+1
     GO TO 216
 116 F(16)=Y(32)*(Y(15)-Y(16))/(2.*DEN(7)*V(7))
 216 IF(NULL(J).NE.17) GO TO 117
     J=J+1
     GO TO 217
 117 F(17)=Y(32)*(Y(16)-Y(17))/(2.*DEN(8)*V(8))
 217 IF(NULL(J).NE.18) GO TO 118
     J=J+1
     GO TO 218
 118 IF(V(9).LE.0.) GO TO 1180
     F(18)=0.0
     GO TO 218
1180 F(18)=(Q(9)+(Y(32)*(Y(17)-Y(18))/2.0))/(DEN(9)*V(9))
 218 IF(NULL(J).NE.19) GO TO 119
     J=J+1
     GO TO 219
 119 IF(V(10).LE.0.) GO TO 1190
     F(19)=(Q(10)+(Y(32)*(Y(18)-Y(19))/2.))/(DEN(10)*V(10))
     GO TO 219
1190 Y(19)=Y(18)
     F(19)=F(18)
 219 IF(NULL(J).NE.20) GO TO 120
     J=J+1
     GO TO 220
 120 F(20)=Y(32)*(Y(19)-Y(20))/(2.*DEN(11)*V(11))
 220 IF(NULL(J).NE.21) GO TO 121
     J=J+1
     GO TO 221
 121 F(21)=Y(32)*(Y(20)-Y(21))/(DEN(12)*V(12))
 221 IF(NULL(J).NE.22) GO TO 122
     J=J+1
     GO TO 222
 122 F(22)=Y(32)*(Y(21)-Y(22))/(DEN(13)*V(13))
 222 IF(NULL(J).NE.23) GO TO 123
     J=J+1
     GO TO 223
 123 F(23)=Y(33)*(HG(13)-Y(23))/(DEN(14)*V(14))
 223 IF(NULL(J).NE.24) GO TO 124
     J=J+1
     GO TO 224
 124 F(24)=Y(33)*(Y(23)-Y(24))/(DEN(15)*V(15))
 224 IF(NULL(J).NE.25) GO TO 125
     J=J+1
     GO TO 225
 125 F(25)=(Q(16)+Y(33)*(Y(24)-Y(25)))/(DEN(16)*V(16))
 225 IF(NULL(J).NE.26) GO TO 126
     J=J+1
     GO TO 226
 126 F(26)=(Q(17)+Y(33)*(Y(25)-Y(26)))/(DEN(17)*V(17))
 226 IF(NULL(J).NE.27) GO TO 127
     J=J+1
     GO TO 227
 127 F(27)=(Q(18)+Y(33)*(Y(26)-Y(27)))/(DEN(18)*V(18))
 227 IF(NULL(J).NE.28) GO TO 128
     J=J+1
```

```
      GO TO 228
  128 F(28)=(Q(19)+Y(33)*(Y(27)-Y(28)))/(DEN(19)*V(19))
  228 IF(NULL(J).NE.29) GO TO 129
      J=J+1
      GO TO 229
  129 F(29)=Y(33)*(Y(28)-Y(29))/(DEN(20)*V(20))
  229 IF(NULL(J).NE.30) GO TO 130
      J=J+1
      GO TO 230
  130 F(30)=Y(33)*(Y(29)-Y(30))/(DEN(21)*V(21))
  230 IF(NULL(J).NE.31) GO TO 131
      J=J+1
      GO TO 231
  131 SLIP=1.-(DSPEED/SSPEED)*Y(31)
      TDM=QKMM*SLIP/(A1*SLIP*SLIP+A2)
      WN2=Y(32)/W2100
      CALL PTORQ(Y(31),WN2,RPT)
      CALL TFRIC(Y(31),AZ,TS,TR,TMIN,TFR)
      F(31)=(TDM-RPT-TFR)/PCON2
  231 IF(NULL(J).NE.32) GO TO 132
      J=J+1
      GO TO 232
  132 WN2=Y(32)/W2100
      CALL PHEAD(Y(31),WN2,HRP)
      DPRP=144.*HRP*DHEAD
      IF(H(4).GE.HSW) DPRP=0.0
      F(32)=(DPRP+DPBDD+ETDD*(Y(32)**2)-FLCDD*Y(32)*ABS(Y(32)))/ALTDD
  232 IF(NULL(J).NE.33) GO TO 133
      J=J+1
      GO TO 233
  133 F(33)=(144.*(P(2)-P(21))+DPBDH+ETDH*Y(33)*Y(33)-FLCDH*Y(33)*
     1 ABS(Y(33)))/ALTDH
  233 IF(NULL(J).NE.34) GO TO 134
      J=J+1
      GO TO 234
  134 F(34)=W1-Y(33)
  234 IF(NULL(J).NE.35) GO TO 135
      J=J+1
      GO TO 235
  135 F(35)=Y(32)*(Y(22)-Y(12))+W1*H(1)-Y(33)*HG(2)
  235 IF(NULL(J).NE.36) GO TO 136
      J=J+1
      GO TO 236
  136 F(36)=(HDA-Y(36))/TAU(36)
  236 IF(NULL(J).NE.37) GO TO 137
      J=J+1
      GO TO 237
  137 F(37)=((Y(33)/W1100)-Y(37))/TAU(37)
  237 IF(NULL(J).NE.38) GO TO 138
      J=J+1
      GO TO 238
  138 F(38)=((W1/W1100)-Y(38))/TAU(38)
  238 IF(NULL(J).NE.39) GO TO 139
      RETURN
  139 EHD=HDSP-Y(36)
      TFW=KFW*EHD
      EFWV=TFW+Y(37)-Y(38)
      IF(ABS(EFWV).LE.0.01) EFWV=0.0
      F(39)=(KCV*EFWV)/TAU(39)
      RETURN
C
```

```
C        PROMPT JUMP APPROXIMATION
C
 4300 DO 4301 I=1, 11
 4301 TCS(19-I)=Y(I)
      DO 4302 I=12, 30
 4302 H(I-9)=Y(I)
      ALFA=Y(31)
      W2=Y(32)
      W3=Y(33)
      IF(W2.LT.EPS1) W2=EPS1
      IF(W3.LT.EPS1) W3=EPS1
      MT(2)=Y(34)
      UI(2)=Y(35)
      HDM=Y(36)
      WM3=Y(37)
      WM1=Y(38)
      CVP=Y(39)
      J=1
      IF(NULL(J).EQ.1) GO TO 301
      GO TO 401
  301 CALL PROMTT(WI,ACS(19),TCS(19),Y(1),TM(18),TM(19),U(19),AT(19),
     1ACFI)
      J=J+1
  401 IF(NULL(J).EQ.2) GO TO 302
      GO TO 402
  302 CALL PROMTT(WI,ACS(18),TCS(18),Y(2),TM(17),TM(18),U(18),AT(18),
     1 ACFI)
      J=J+1
  402 IF(NULL(J).EQ.3) GO TO 303
      GO TO 403
  303 CALL PROMTT(WI,ACS(17),TCS(17),Y(3),TM(16),TM(17),U(17),AT(17),
     1 ACFI)
      J=J+1
  403 IF(NULL(J).EQ.4) GO TO 304
      GO TO 404
  304 CALL PROMTT(WI,ACS(16),TCS(16),Y(4),TM(15),TM(16),U(16),AT(16),
     1 ACFI)
      J=J+1
      IF(MODE.EQ.0) TCS(15)=Y(4)
  404 IF(NULL(J).EQ.5) GO TO 305
      GO TO 405
  305 Y(5)=TCS(15)
      J=J+1
      IF(MODE.EQ.0) TCS(14)=Y(5)
  405 IF(NULL(J).EQ.6) GO TO 306
      GO TO 406
  306 Y(6)=TCS(14)
      J=J+1
      IF(MODE.EQ.0) TCS(13)=Y(6)
  406 IF(NULL(J).EQ.7) GO TO 307
      GO TO 407
  307 Y(7)=TCS(13)
      J=J+1
      IF(MODE.EQ.0) TCS(12)=Y(7)
  407 IF(NULL(J).EQ.8) GO TO 308
      GO TO 408
  308 Y(8)=TCS(12)
      J=J+1
      IF(MODE.EQ.0) TCS(11)=Y(8)
  408 IF(NULL(J).EQ.9) GO TO 309
      GO TO 409
```

```
 309 Y(9)=TCS(11)
     J=J+1
     IF(MODE.EQ.0) TCS(10)=Y(9)
 409 IF(NULL(J).EQ.10) GO TO 310
     GO TO 410
 310 CALL PROMTT(WI,ACS(10),TCS(10),Y(10),TM(9),TM(10),U(10),AT(10),
    1 FFCI)
     IF(XL(10).LE.0.0) Y(10)=TCS(10)
     J=J+1
 410 IF(NULL(J).EQ.11) GO TO 311
     GO TO 411
 311 CALL PROMTT(WI,ACS(9),TCS(9),Y(11),TM(8),TM(9),U(9),AT(9),FFCI)
     J=J+1
 411 IF(NULL(J).EQ.12) GO TO 312
     GO TO 412
 312 Y(12)=((W2-W1)*HF(2)+W1*H(1))/W2
     J=J+1
     IF(MODE.EQ.0) H(3)=Y(12)
 412 IF(NULL(J).EQ.13) GO TO 313
     GO TO 413
 313 Y(13)=H(3)
     J=J+1
     IF(MODE.EQ.0) H(4)=Y(13)
 413 IF(NULL(J).EQ.14) GO TO 314
     GO TO 414
 314 Y(14)=H(4)
     J=J+1
     IF(MODE.EQ.0) H(5)=Y(14)
 414 IF(NULL(J).EQ.15) GO TO 315
     GO TO 415
 315 Y(15)=H(5)
     J=J+1
     IF(MODE.EQ.0) H(6)=Y(15)
 415 IF(NULL(J).EQ.16) GO TO 316
     GO TO 416
 316 Y(16)=H(6)
     J=J+1
     IF(MODE.EQ.0) H(7)=Y(16)
 416 IF(NULL(J).EQ.17) GO TO 317
     GO TO 417
 317 Y(17)=H(7)
     J=J+1
 417 IF(NULL(J).EQ.18) GO TO 318
     GO TO 418
 318 IF(XL(10).LE.0.0) GO TO 3180
     Y(18)=HF(9)
     GO TO 3181
3180 Y(18)=H(8)+(2.*Q(9)/W2)
3181 J=J+1
 418 IF(NULL(J).EQ.19) GO TO 319
     GO TO 419
 319 Y(19)=H(9)+(2.*Q(10)/W2)
     IF(XL(10).LE.0.) Y(19)=H(9)
     J=J+1
     IF(MODE.EQ.0) H(10)=Y(19)
 419 IF(NULL(J).EQ.20) GO TO 320
     GO TO 420
 320 Y(20)=H(10)
     J=J+1
     IF(MODE.EQ.0) H(11)=Y(20)
 420 IF(NULL(J).EQ.21) GO TO 321
```

```
      GO TO 421
  321 Y(21)=H(11)
      J=J+1
      IF(MODE.EQ.0) H(12)=Y(21)
  421 IF(NULL(J).EQ.22) GO TO 322
      GO TO 422
  322 Y(22)=H(12)
      J=J+1
  422 IF(NULL(J).EQ.23) GO TO 323
      GO TO 423
  323 Y(23)=HG(13)
      J=J+1
      IF(MODE.EQ.0) H(14)=Y(23)
  423 IF(NULL(J).EQ.24) GO TO 324
      GO TO 424
  324 Y(24)=H(14)
      J=J+1
      IF(MODE.EQ.0) H(15)=Y(24)
  424 IF(NULL(J).EQ.25) GO TO 325
      GO TO 425
  325 CALL ENTH(H(15),W3,TCS(16),TCS(15),TM(15),TM(16),TDLOG(16),U(16),
     1 AT(16),ACF,P(16),Y(25))
      J=J+1
  425 IF(NULL(J).EQ.26) GO TO 326
      GO TO 426
  326 CALL ENTH(H(16),W3,TCS(17),TCS(16),TM(16),TM(17),TDLOG(17),U(17),
     1 AT(17),ACF,P(17),Y(26))
      J=J+1
  426 IF(NULL(J).EQ.27) GO TO 327
      GO TO 427
  327 CALL ENTH(H(17),W3,TCS(18),TCS(17),TM(17),TM(18),TDLOG(18),U(18),
     1 AT(18),ACF,P(18),Y(27))
      J=J+1
  427 IF(NULL(J).EQ.28) GO TO 328
      GO TO 428
  328 CALL ENTH(H(18),W3,TCS(19),TCS(18),TM(18),TM(19),TDLOG(19),U(19),
     1 AT(19),ACF,P(19),Y(28))
      J=J+1
      IF(MODE.EQ.0) H(19)=Y(28)
  428 IF(NULL(J).EQ.29) GO TO 329
      GO TO 429
  329 Y(29)=H(19)
      J=J+1
      IF(MODE.EQ.0) H(20)=Y(29)
  429 IF(NULL(J).EQ.30) GO TO 330
      GO TO 430
  330 Y(30)=H(20)
      J=J+1
  430 IF(NULL(J).EQ.31) GO TO 331
      GO TO 431
  331 WN2=W2/W2100
      CALL RPSPD(Y(31),WN2,QKMM,TDM,RPT,TFR,SLIP)
      J=J+1
  431 IF(NULL(J).EQ.32) GO TO 332
      GO TO 432
  332 ASAV=FLCDD-ETDD
      HSAV=H(4)
      DO 3325 I=1,15
      WN2=Y(32)/W2100
      CALL PHEAD(ALFA,WN2,HRP)
      DPRP=144.*HRP*DHEAD
```

```
      IF(HSAV.GE.HSW) DPRP=0.
      ARG=(DPRP+DPBDD)/ASAV
      IF(ARG.LT.EPS2) ARG=EPS2
      YNEW=SQRT(ARG)
      Y(32)=(Y(32)+YNEW)/2.
      DIV=1.-YNEW/Y(32)
      IF(DIV.LE.EPS1) GO TO 3329
 3325 CONTINUE
 3329 J=J+1
  432 IF(NULL(J).EQ.33) GO TO 333
      GO TO 433
  333 ARG=(144.*(P(2)-P(21))+DPBDH)/(FLCDH-ETDH)
      IF(ARG.LT.EPS2) ARG=EPS2
      Y(33)=SQRT(ARG)
      J=J+1
  433 IF(NULL(J).EQ.34) GO TO 334
      GO TO 434
  334 Y(34)=MT(2)
      J=J+1
  434 IF(NULL(J).EQ.35) GO TO 335
      GO TO 435
  335 Y(35)=UI(2)
      J=J+1
  435 IF(NULL(J).EQ.36) GO TO 336
      GO TO 436
  336 Y(36)=HDA
      J=J+1
  436 IF(NULL(J).EQ.37) GO TO 337
      GO TO 437
  337 Y(37)=W3/W1100
      J=J+1
  437 IF(NULL(J).EQ.38) GO TO 338
      GO TO 438
  338 Y(38)=(W1/W1100)
      J=J+1
  438 IF(NULL(J).EQ.39) GO TO 339
      GO TO 55
  339 ALSAV=(KFW*(HDSP-HDM)+WM3)/WFMAX
      Y(39)=CVMAX+ALOG(ALSAV)/ALOG(WFMAX/WFMIN)
   55 CONTINUE
      DO 56 I=1, 11
      TCS(19-I)=Y(I)
   56 CONTINUE
      DO 57 I=12, 30
      H(I-9)=Y(I)
   57 CONTINUE
      ALFA=Y(31)
      W2=Y(32)
      W3=Y(33)
      MT(2)=Y(34)
      UI(2)=Y(35)
      HDM=Y(36)
      WM3=Y(37)
      WM1=Y(38)
      CVP=Y(39)
      IF(W3.LE.EPS1) W3=EPS1
      IF(W2.LE.EPS1) W2=EPS1
      IF((TAU(32)*0.7).LT.S) F(32)=0.0
      IF((TAU(33)*0.7).LT.S) F(33)=0.0
      IF(MODE.EQ.0) F(32)=0.0
      IF(MODE.EQ.0) F(33)=0.0
```

```
C
C        CALCULATE LOCAL PRESSURES
      CALL DRUM(P(2),UI(2),V(2),EPSI,MT(2),MG(2),MF(2),PNEW)
      P(2)=PNEW
      P(3)=P(2)
      P(4)=((DPB(4)+E(4)*W2*W2-(CC(4)/ADEN(4))*W2*W2-AL(4)*F(32))/144.)+
     1 P(3)
      CALL PHEAD(ALFA, WN2, HRP)
      DPRP=144.0*HRP*DHEAD
      CALL SWATER(P(4),TSW,HSW,HSS,HWS,DSW,DSS,SSW,SSS)
      IF(H(4).GE.HSW) DPRP=0.0
      P(5)=((DPB(5)+E(5)*W2*W2+DPRP)/144.)+P(4)
      P(6)=((DPB(6)+E(6)*W2*W2-(CC(6)/ADEN(6))*W2*W2-AL(6)*F(32))/144.)+
     1 P(5)
      P(7)=((DPB(7)+(E(7)/4.)*W2*W2-(CC(7)/(4.*ADEN(7)))*W2*W2-(AL(7)/2.
     1 )*F(32))/144.)+P(6)
      P(8)=((DPB(8)+(E(8)/4.)*W2*W2-(CC(8)/(4.*ADEN(8)))*W2*W2-(AL(8)/2.
     1 )*F(32))/144.)+P(7)
      P(9)=((DPB(9)+(E(9)/4.)*W2*W2-(CC(9)/(4.*ADEN(9)))*W2*W2-(AL(9)/2.
     1 )*F(32))/144.)+P(8)
      P(10)=((DPB(10)+(E(10)/4.)*W2*W2-(CC(10)/(4.*DF(10)))*PHI(10)*W2*
     1 W2-(AL(10)/2.)*F(32))/144.)+P(9)
      IF(XL(10).LE.0.) P(10)=P(9)
      P(11)=((DPB(11)+(E(11)/4.)*W2*W2-(CC(11)/(4.*DF(11)))*PHI(11)*W2*
     1 W2-(AL(11)/2.)*F(32))/144.)+P(10)
      P(12)=((DPB(12)+(E(12)/4.)*W2*W2-(CC(12)/(4.*DF(12)))*PHI(12)*W2*
     1 W2-(AL(12)/2.)*F(32))/144.)+P(11)
      P(13)=P(2)
      P(14)=((DPB(14)+E(14)*W3*W3-(CC(14)/ADEN(14))*W3*W3-AL(14)*F(33))/
     1 144.)+P(13)
      P(15)=((DPB(15)+E(15)*W3*W3-(CC(15)/ADEN(15))*W3*W3-AL(15)*F(33))/
     1 144.)+P(14)
      P(16)=((DPB(16)+E(16)*W3*W3-(CC(16)/ADEN(16))*W3*W3-AL(16)*F(33))/
     1 144.)+P(15)
      P(17)=((DPB(17)+E(17)*W3*W3-(CC(17)/ADEN(17))*W3*W3-AL(17)*F(33))/
     1 144.)+P(16)
      P(18)=((DPB(18)+E(18)*W3*W3-(CC(18)/ADEN(18))*W3*W3-AL(18)*F(33))/
     1 144.)+P(17)
      P(19)=((DPB(19)+E(19)*W3*W3-(CC(19)/ADEN(19))*W3*W3-AL(19)*F(33))/
     1 144.)+P(18)
      P(20)=((DPB(20)+E(20)*W3*W3-(CC(20)/ADEN(20))*W3*W3-AL(20)*F(33))/
     1 144.)+P(19)
      IF(X(9).EQ.0.) CALL SWATER(P(9),TM(9),HF(9),HG(9),HFG(9),DF(9),DG(
     19),SVF(9),SVG(9))
      IF(XL(10).GT.0.0) H(9)=HF(9)
      RETURN
      ENTRY PUTSG2
      WRITE(6, 460)
      IF(KCALC.EQ.1) WRITE(6, 7200) (I, TCM(I), I=1, 39)
      WRITE(6, 550) WN1, WN2, WN3, WNI
      IF(TSEC.GE.TAUX) HAUWP=HAUW*ENTFAC
      IF(TSEC.GE.TAUX) WRITE(6, 9104) TAUX,HAUWP,WAUXN
      DO 9991 I=1,21
      P(I)=P(I)*PFAC
 9991 H(I)=H(I)*ENTFAC
      CALL TMPCON(1,21,TM)
      CALL TMPCON(1,19,TCS)
      DO 9992 I=9,10
      TDLOG(I)=TDLOG(I)*TFAC
      U(I)=U(I)*XHFAC
 9992 XL(I)=XL(I)*XFAC
```

```
      DO 9993 I=16,19
      TDLOG(I)=TDLOG(I)*TFAC
 9993 U(I)=U(I)*XHFAC
      HFLUX(10)=HFLUX(10)*FLXFAC
      UI(2)=UI(2)*EFAC
      DPRP=DPRP*PFAC
      WRITE(6, 600) (I, P(I), I=1, 21)
      WRITE(6, 650) (I, H(I), I=1, 21)
      WRITE(6, 700) (I,TM(I), I=1, 21)
      WRITE(6, 750) (I, TCS(I), I=8, 19)
      WRITE(6, 7300)(I, TDLOG(I), I=9, 10)
      WRITE(6, 8000)(I, U(I), I=9, 10)
      WRITE(6, 8300)(I, TDLOG(I),I=16, 19)
      WRITE(6, 9000)(I, U(I), I=16, 19)
      WRITE(6, 950)HFLUX(10),X(10),XL(9),XL(10)
      WRITE(6, 960) UI(2),HDA,CVP,ALFA,DPRP
      DO 9994 I=1,21
      P(I)=P(I)/PFAC
 9994 H(I)=H(I)/ENTFAC
      CALL TMPCON(0,21,TM)
      CALL TMPCON(0,19,TCS)
      DO 9995 I=9,10
      TDLOG(I)=TDLOG(I)/TFAC
      U(I)=U(I)/XHFAC
 9995 XL(I)=XL(I)/XFAC
      DO 9996 I=16,19
      TDLOG(I)=TDLOG(I)/TFAC
 9996 U(I)=U(I)/XHFAC
      HFLUX(10)=HFLUX(10)/FLXFAC
      UI(2)=UI(2)/EFAC
      DPRP=DPRP/PFAC
  460 FORMAT(/,2X,36('*'),3X,'S T E A M',3X,'G E N E R A T I O N',3X,
     1  'L O O P - 2',3X,36('*')/)
  550 FORMAT(2X,'FEED WATER FLOW =',F6.4,2X,'WATER/STEAM FLOW =',F6.4,
     1 2X,'STEAM FLOW =',F6.4,2X,'INT. SODIUM FLOW =',F6.4/)
  600 FORMAT(7(2X,'P',I2,' =',1PE11.4))
  650 FORMAT(7(2X,'H',I2,' =',1PE11.4))
  700 FORMAT(7(2X,'TM',I2,' =',F10.4))
  750 FORMAT(7(2X,'TCS',I2,' =',F10.4))
  800 FORMAT(/,3X,'<<<<<<<<<< W A R N I N G      DRYOUT OCCURED IN THE E
     1VAPORATORS OF LOOP-2 AT TIME =',F12.4,' SECONDS >>>>>>>>>>'/)
  950 FORMAT(/,2X,'HEAT FLUX =',1PE13.6,24X,
     1'OUTLET STEAM QUALITY =',1PE13.6/,2X,'NON-BOILING LENGTH =',
     2  1PE13.6,13X,'BOILING LENGTH =',1PE13.6)
  960 FORMAT(/,2X,'DRUM INT. ENERGY =',1PE11.4,3X,'DRUM LEVEL =',
     10PF7.4,3X,'CVP =',F7.4,3X,'ALFA =',F7.4,3X,'DPRP =',1PE11.4)
 7200 FORMAT(3X,'TAU:',8(I3,F10.6))
 7300 FORMAT(31X,'TDLOG:', 2(I3,F14.4))
 8000 FORMAT(31X,'U    :', 2(I3,F14.4))
 8300 FORMAT(15X,'TDLOG:',4(I3,F14.4))
 9000 FORMAT(15X,'U    :',4(I3,F14.4))
 9100 FORMAT(/20X,'**** RECIRCULATION PUMP #2 TRIP AT',F8.4,
     1  ' SEC ****'/)
 9104 FORMAT(2X,'AUXILIARY FEED WATER AVAILABLE AT',F8.3,' SECONDS',2X,
     1'ENTHALPY =',1PE11.4,2X,'AUX. WATER FLOW  =',0PF6.4)
 9200 FORMAT(/,3X,'<<<<<<<<<< W A R N I N G      RECIRCULATION PUMP IN L
     1OOP-2 ENTERS CAVITATION AT TIME =',F12.4,' SECONDS >>>>>>>>>>'/)
 9199 FORMAT(/,3X,'<<<<<<<<<< W A R N I N G      RECIRCULATION PUMP IN L
     1OOP-2 OUT OF CAVITATION AT TIME =',F12.4,' SECONDS >>>>>>>>>>'/)
      RETURN
      END
```

```
      SUBROUTINE TURBO(MODE, W31, W32, H211, H212, PD)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                              C
C     STEAM HEADER THERMODYNAMICS AND CONTROL SIMULATION      C
C                                                              C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL MH, KTV, KDV, IE
      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/ALLR/DUR91(477),Y(5),DUR92(7)
      COMMON/ALLF/DUF91(477),F(5),DUF92(7)
      COMMON/ALLNUL/DUN91(477),NULL(5),DUN92(7)
      COMMON/PHDR/PH,TMH
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/LOOP/XLOOP
      COMMON/FACT/FDUM1(2),VFAC,WFAC,PFAC,FDUM2(9),ENTFAC,GC
      NAMELIST/SHD1/VH,KTV,KDV,TVP,DVP,TAU,PSPTV,PSPDV,PSPRV
      NAMELIST/SHD2/WT100,WNMAX,WNMIN,PH,PC,CT,CTV,CDV,CRV
      M=KRUNG+2
      GO TO (4000,4300,4100,4200,4150,998),M
C
C        RESTART OPTION
  998 VH=VH*VFAC
      PSPTV=PSPTV*PFAC
      PSPDV=PSPDV*PFAC
      PSPRV=PSPRV*PFAC
      WT100=WT100*WFAC
      PH=PH*PFAC
      PC=PC*PFAC
      CT=CT*PFAC
      CTV=CTV*PFAC
      CDV=CDV*PFAC
      CRV=CRV/PFAC
      KTV=KTV/3600.
      KDV=KDV/3600.
      TAU=TAU*3600.
      IF(PD.EQ.1.) WT100=WT100*WNTV
      GO TO 999
C       READ INPUT DATA
 4000 READ(5, SHD1)
      READ(5, SHD2)
C
C       PRINT INPUT DATA
  999 WRITE(6, SHD1)
      WRITE(6, SHD2)
C          CONVERT INTO PROPER UNITS
      VH=VH/VFAC
      PSPTV=PSPTV/PFAC
      PSPDV=PSPDV/PFAC
      PSPRV=PSPRV/PFAC
      WT100=WT100/WFAC
      PH=PH/PFAC
      PC=PC/PFAC
      CT=CT/PFAC
      CTV=CTV/PFAC
      CDV=CDV/PFAC
      CRV=CRV*PFAC
      L=0
      KTV=KTV*3600.0
      KDV=KDV*3600.0
      TAU=TAU/3600.0
C
```

```
C      CALL STEAM TABLES & DETERMINE INITIAL CONDITIONS
       H=H211
       TMH=TSTEAM(H, PH)
       SVG=SPVOL2(TMH, PH)
       MH=VH/SVG
       SIE=H-(144./778.)*PH*SVG
       IE=SIE*MH
       PM=PH
       WTV=W31+XLOOP*W32
       WDV=0.0
       WRV=0.0
       XR=WNMAX/WNMIN
       A=ALOG(XR)
       Y(1)=MH
       Y(2)=IE
       Y(3)=PM
       Y(4)=TVP
       Y(5)=DVP
       RETURN
C
C       SET-UP THE COMPONENTS OF NULL VECTOR
 4150  DO 1 J=1, 5
    1  NULL(J)=0
       IF(TAU.LE.S) NULL(1)=3
       IF(MODE.EQ.0) NULL(1)=3
       TAUSC=TAU*3600.0
C
C       DEFINE THE FUNCTION OF VARIABLES "Y"
 4100  Y(1)=MH
       Y(2)=IE
       Y(3)=PM
       Y(4)=TVP
       Y(5)=DVP
       IF(MODE.EQ.4) GO TO 10
       IF(MODE.EQ.5) GO TO 11
       GO TO 12
   10  IF(L.EQ.0) WRITE(6, 500) TSEC
       L=1
       GO TO 12
   11  IF(L.EQ.0) WRITE(6, 600) TSEC
       L=1
   12  CONTINUE
 4200  IF(Y(4).LT.0.) Y(4)=0.0
       IF(Y(4).GT.1.) Y(4)=1.0
       IF(Y(5).LT.0.) Y(5)=0.0
       IF(Y(5).GT.1.) Y(5)=1.0
       ALFA=(EXP(-2.0*Y(4)*A))/(WNMIN**2)
       WNTV=((PH-PC)/((CT+CTV)*ALFA))**0.5
       IF(MODE.EQ.4) WNTV=0.0
       WTV=WNTV*WT100
       IF(MODE.EQ.5) Y(5)=1.0
       WNDV=Y(5)*(((PH-PC)/CDV)**0.5)
       WDV=WNDV*WT100
       WNRV=CRV*(PH-PSPRV)
       IF(WNRV.LT.0.0) WNRV=0.0
       IF(WNRV.GT.1.0) WNRV=1.0
       WRV=WNRV*WT100
       ETV=(Y(3)-PSPTV)/PSPTV
       EDV=(Y(3)-PSPDV)/PSPDV
C
C       THROTTLE VALVE DEADBAND
```

```
      IF(ABS(ETV).LE.0.001) ETV=0.0
      IF(ETV.LT.0.0) GO TO 4
      IF(ABS(ETV).GE.0.1) ETV=0.1
      GO TO 5
    4 IF(ABS(ETV).GE.0.10) ETV=-0.1
    5 CONTINUE
C
C       DUMP VALVE DEADBAND
      IF(ABS(EDV).LE.0.001) EDV=0.0
      IF(EDV.LT.0.) GO TO 6
      IF(ABS(EDV).GE.0.03) EDV=0.03
      GO TO 7
    6 IF(ABS(EDV).GE.0.03) EDV=-0.03
    7 CONTINUE
      F(1)=(W31+XLOOP*W32)-(WTV+WDV+WRV)
      F(2)=W31*H211+XLOOP*W32*H212-(WTV+WDV+WRV)*H
      IF(NULL(1).EQ.3) GO TO 8
      F(3)=(PH-Y(3))/TAU
    8 F(4)=KTV*ETV
      F(5)=KDV*EDV
      RETURN
 4300 IF(NULL(1).NE.3) GO TO 9
      Y(3)=PH
    9 MH=Y(1)
      IE=Y(2)
      PM=Y(3)
      TVP=Y(4)
      DVP=Y(5)
      IF(TVP.LT.0.0) TVP=0.0
      IF(TVP.GT.1.0) TVP=1.0
      IF(DVP.LT.0.0) DVP=0.0
      IF(DVP.GT.1.0) DVP=1.0
      SIE=IE/MH
      SVH=VH/MH
      CALL HEADER(PH,SIE,SVH,H,TMH,PNEW)
      PH=PNEW
      ALFA=(EXP(-2.0*TVP*A))/(WNMIN**2)
      WNTV=((PH-PC)/((CT+CTV)*ALFA))**0.5
      IF(MODE.EQ.1) WNTV=0.0
      WNDV=DVP*(((PH-PC)/CDV)**0.5)
      WNRV=CRV*(PH-PSPRV)
      IF(WNRV.LT.0.0) WNRV=0.0
      IF(WNRV.GT.1.0) WNRV=1.0
      RETURN
      ENTRY PUTTUR
      WRITE(6, 100)
      IF(KCALC.EQ.1) WRITE(6, 700) TAUSC
      WRITE(6, 200) TVP, DVP
      WRITE(6, 300) WNTV, WNRV, WNDV
      PH=PH*PFAC
      CALL TMPCON(1,1,TMH)
      H=H*ENTFAC
      WRITE(6, 400) PH, TMH, H
      PH=PH/PFAC
      CALL TMPCON(0,1,TMH)
      H=H/ENTFAC
  100 FORMAT(/,2X,30('*'),3X,'S T E A M   H E A D E R',3X,
     1  'T H E R M O D Y N A M I C S',3X,30('*')/)
  200 FORMAT(8X,'THROTTLE VALVE POSITION =',F6.4,31X,'DUMP(BYPASS) VALVE
     1 POSITION =',F6.4)
  300 FORMAT(8X,'THROTTLE VALVE FLOW     =',F6.4,3X,'RELIEF VALVE FLOW =
```

```
     1',F6.4,3X,'DUMP(BYPASS) VALVE FLOW      =',F6.4)
  400 FORMAT(8X,'HEADER PRESSURE =',1PE11.4,7X,'TEMPERATURE =',0PF10.4,
     1  6X,'SPECIFIC ENTHALPY=',1PE11.4)
  500 FORMAT(/10X,15('<'),' W A R N I N G     TURBINE TRIPPED AT TIME =',
     1    F12.4,' SECONDS',15('>')/)
  600 FORMAT(/10X,15('<'),' W A R N I N G    BYPASS(DUMP) VALVE',
     1    ' ACCIDENTALLY OPENED AT TIME =',F12.4,' SECONDS ',15('>')/)
  700 FORMAT(25X,'TIME CONSTANT OF THE HEADER PRESSURE GAUGE =',F10.6,
     1 ' SECONDS')
      RETURN
      END
      SUBROUTINE SCRAM(MSCRAM,KMM1,KMM2,KMS1,KMS2,KMG1,KMG2)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C             PLANT PROTECTION SYSTEM SIMULATION                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      REAL KMM1,KMM2,KMS1,KMS2,KMG1,KMG2
      DIMENSION NOSCRM(15),PMPDEL(6),TAU(7)
      DIMENSION IPRT(4)
      COMMON/FACT/XFAC,FDUM1(15)
      COMMON/MISC/THOUR,T,ICOUNT,SHOUR,DT,IPRINT,TMAXSC
      COMMON/RUNGNO/KRUNG,KCALC
      COMMON/ALLR/DUM10(482),R(7)
      COMMON/ALLF/DUF10(482),F(7)
      COMMON/ALLNUL/DUN10(482),NULL(7)
      COMMON/TRIPS/TSCRM(2),TTRIP(6)
      COMMON/SCRH/ALM1,ALM2,PRES,WM1,WM2,ZRVOP
      COMMON/SCRM/ALIM1,ALIM2,WIM1,WIM2,TIHX1,TIHX2
      COMMON/SCRP/PNRM,RO
      COMMON/SCRT/HDM1,HDM2,TEVAP1,TEVAP2,WSTM1,WSTM2,WFWM1,WFWM2
      NAMELIST/SCR1/NOSCRM,DELAY,PMPDEL
      NAMELIST/SCR2/PLIM,TCON,A2,B2,C2,D2,A3,B3,C3,D3,A4,B4,C4,A6,B6,C6,
     1     A8,ZLEVEL,THXSCR
      NAMELIST/SCR3/A11,B11,C11,A12,B12,C12,DRUMAX,TVAPSC
      NAMELIST/SCR4/TAU
      DATA L,M/0,0/
      MGO=KRUNG+2
      GO TO (1,4,1001,1002,2,999),MGO
C
C          RESTART OPTION
  999 CALL TMPCON(1,1,THXSCR)
      CALL TMPCON(1,1,TVAPSC)
      ZLEVEL=ZLEVEL*XFAC
      GO TO 1000
C           READ INPUT DATA
    1 READ(5,SCR1)
      READ(5,SCR2)
      READ(5,SCR3)
      READ(5.SCR4)
C          PRINT INPUT DATA
 1000 WRITE(6,SCR1)
      WRITE(6,SCR2)
      WRITE(6,SCR3)
      WRITE(6,SCR4)
      CALL TMPCON(0,1,THXSCR)
      CALL TMPCON(0,1,TVAPSC)
      ZLEVEL=ZLEVEL/XFAC
      R(1)=PRES
      R(2)=ZRVOP
      R(3)=PNRM
      R(4)=TIHX1
      R(5)=TIHX2
```

```
      R(6)=TEVAP1
      R(7)=TEVAP2
      DELINT=1.
      GO TO 2080
    2 J=1
      DO 3 I=1,7
      IF((TAU(I)*0.7).GE.DT) GO TO 3
      NULL(J)=I
      J=J+1
    3 CONTINUE
 1001 CONTINUE
 1002 J=1
      IF(NULL(J).NE.1) GO TO 1015
      J=J+1
      GO TO 1020
 1015 F(1)=(PRES-R(1))/TAU(1)*3600.
 1020 IF(NULL(J).NE.2) GO TO 1025
      J=J+1
      GO TO 1030
 1025 F(2)=(ZRVOP-R(2))/TAU(2)*3600.
 1030 IF(NULL(J).NE.3) GO TO 1035
      J=J+1
      GO TO 1040
 1035 F(3)=(PNRM-R(3))/TAU(3)*3600.
 1040 IF(NULL(J).NE.4) GO TO 1045
      J=J+1
      GO TO 1050
 1045 F(4)=(TIHX1-R(4))/TAU(4)*3600.
 1050 IF(NULL(J).NE.5) GO TO 1055
      J=J+1
      GO TO 1060
 1055 F(5)=(TIHX2-R(5))/TAU(5)*3600.
 1060 IF(NULL(J).NE.6) GO TO 1065
      J=J+1
      GO TO 1070
 1065 F(6)=(TEVAP1-R(6))/TAU(6)*3600.
 1070 IF(NULL(J).NE.7) GO TO 1075
      RETURN
 1075 F(7)=(TEVAP2-R(7))/TAU(7)*3600.
      RETURN
    4 J=1
      IF(NULL(J).NE.1) GO TO 2020
      R(1)=PRES
      J=J+1
 2020 IF(NULL(J).NE.2) GO TO 2030
      R(2)=ZRVOP
      J=J+1
 2030 IF(NULL(J).NE.3) GO TO 2040
      R(3)=PNRM
      J=J+1
 2040 IF(NULL(J).NE.4) GO TO 2050
      R(4)=TIHX1
      J=J+1
 2050 IF(NULL(J).NE.5) GO TO 2060
      R(5)=TIHX2
      J=J+1
 2060 IF(NULL(J).NE.6) GO TO 2070
      R(6)=TEVAP1
      J=J+1
 2070 IF(NULL(J).NE.7) GO TO 2080
      R(7)=TEVAP2
```

```
2080 PRESM=R(1)
     ZRVOPM=R(2)
     PNRMM=R(3)
     TIHX1M=R(4)
     TIHX2M=R(5)
     TVAP1M=R(6)
     TVAP2M=R(7)
   5 IF(TSCRM(1).GT.T) GO TO 6
     IF(M.EQ.0) M=1
     IF(M.EQ.2) M=3
     IF(MSCRAM.EQ.0) MSCRAM=1
     IF(MSCRAM.EQ.2) MSCRAM=3
   6 IF(TSCRM(2).GT.T) GO TO 9
     IF(M.EQ.0) M=2
     IF(M.EQ.1) M=3
     IF(MSCRAM.EQ.0) MSCRAM=2
     IF(MSCRAM.EQ.1) MSCRAM=3
   9 J=1
     IF(M.EQ.1) GO TO 110
     IF(M.EQ.3) GO TO 200
  10 IF(NOSCRM(J).NE.1) GO TO 15
     J=J+1
     GO TO 20
  15 IF(PNRMM.LT.PLIM) GO TO 20
     M=M+1
     T1=T+DELAY
     WRITE(6,901) T
     GO TO 110
  20 DELINT=(1.-DT/TCON)*DELINT+PNRMM*DT/TCON
     ALAVE=(ALM1+2.*ALM2)/3.
     IF(NOSCRM(J).NE.2) GO TO 25
     J=J+1
     GO TO 30
  25 Y=A2*DELINT+B2*PNRMM+C2*ALAVE+D2
     IF(RO.LT.0.) GO TO 30
     IF(Y.GT.0.) GO TO 30
     M=M+1
     T1=T+DELAY
     WRITE(6,902) T
     GO TO 110
  30 IF(NOSCRM(J).NE.3) GO TO 35
     J=J+1
     GO TO 40
  35 Y=A3*DELINT+B3*PNRMM+C3*ALAVE+D3
     IF(RO.GT.0.) GO TO 40
     IF(Y.GT.0.) GO TO 40
     M=M+1
     T1=T+DELAY
     WRITE(6,903) T
     GO TO 110
  40 IF(NOSCRM(J).NE.4) GO TO 45
     J=J+1
     GO TO 50
  45 Y=A4*PRESM**0.5+B4*PNRMM+C4
     IF(Y.GT.0.) GO TO 50
     M=M+1
     T1=T+DELAY
     WRITE(6,904) T
     GO TO 110
  50 IF(NOSCRM(J).NE.5) GO TO 55
     J=J+1
```

```
      GO TO 60
   55 IF((KMM1*KMM2).NE.0) GO TO 60
      M=M+1
      T1=T+DELAY
      WRITE(6,905) T
      GO TO 110
   60 IF(NOSCRM(J).NE.6) GO TO 65
      J=J+1
      GO TO 70
   65 XY=ABS(1.-ALIM1/ALM1+C6/ALM1)-A6/ALM1-B6
      IF(XY.GE.0.) GO TO 67
      XY=ABS(1.-ALIM2/ALM2+C6/ALM1)-A6/ALM2-B6
      IF(XY.LT.0.) GO TO 70
   67 M=M+1
      T1=T+DELAY
      WRITE(6,906) T
      GO TO 110
   70 IF(NOSCRM(J).NE.7) GO TO 75
      J=J+1
      GO TO 80
   75 IF(ZRVOPM.GT.ZLEVEL) GO TO 80
      M=M+1
      T1=T+DELAY
      WRITE(6,907) T
      GO TO 110
   80 IF(NOSCRM(J).NE.8) GO TO 85
      J=J+1
      GO TO 90
   85 XY=ABS(1.-WSTM1/WFWM1)-A8
      IF(XY.GE.0.) GO TO 87
      XY=ABS(1.-WSTM2/WFWM2)-A8
      IF(XY.LT.0.) GO TO 90
   87 M=M+1
      T1=T+DELAY
      WRITE(6,908) T
      GO TO 110
   90 IF(NOSCRM(J).NE.9) GO TO 95
      J=J+1
      GO TO 100
   95 IF(TIHX1M.GE.THXSCR) GO TO 97
      IF(TIHX2M.LT.THXSCR) GO TO 100
   97 M=M+1
      T1=T+DELAY
      WRITE(6,909) T
      GO TO 110
  100 IF(NOSCRM(J).NE.10) GO TO 105
      J=J+1
      GO TO 110
  105 CONTINUE
  110 IF(M.GE.2) GO TO 200
      DO 111 I=1,11
      K=I+J-1
      IF(NOSCRM(K).EQ.0) GO TO 113
      IF(NOSCRM(K).GE.11) GO TO 113
  111 CONTINUE
  113 J=K
      IF(NOSCRM(J).NE.11) GO TO 115
      J=J+1
      GO TO 120
  115 Y=A11*(WM1+2.*WM2)/3.+B11*PNRMM+C11
      IF(Y.GT.0.) GO TO 120
```

```
      M=M+2
      T2=T+DELAY
      WRITE(6,911) T
      GO TO 200
  120 IF(NOSCRM(J).NE.12) GO TO 125
      J=J+1
      GO TO 130
  125 XY=ABS(1.-WIM1/WM1+C12/WM1)-A12/WM1-B12
      IF(XY.GE.0.) GO TO 127
      XY=ABS(1.-WIM2/WM2+C12/WM1)-A12/WM2-B12
      IF(XY.LT.0.) GO TO 130
  127 M=M+2
      T2=T+DELAY
      WRITE(6,912) T
      GO TO 200
  130 IF(NOSCRM(J).NE.13) GO TO 135
      J=J+1
      GO TO 140
  135 XY=ABS(1.-HDM1)-DRUMAX
      IF(XY.GE.0.) GO TO 137
      XY=ABS(1.-HDM2)-DRUMAX
      IF(XY.LT.0.) GO TO 140
  137 M=M+2
      T2=T+DELAY
      WRITE(6,913) T
      GO TO 200
  140 IF(NOSCRM(J).NE.14) GO TO 145
      J=J+1
      GO TO 200
  145 IF(TVAP1M.LT.TVAPSC.AND.TVAP2M.LT.TVAPSC) GO TO 150
      M=M+2
      T2=T+DELAY
      WRITE(6,914) T
      GO TO 200
  150 IF(NOSCRM(J).NE.15) GO TO 155
      GO TO 200
  155 CONTINUE
  200 J=M+1
      GO TO (250,210,220,230),J
  210 IF(MSCRAM.EQ.1) GO TO 240
      IF(T1.LE.T) MSCRAM=1
      GO TO 240
  220 IF(MSCRAM.EQ.2) GO TO 240
      IF(T2.LE.T) MSCRAM=2
      GO TO 240
  230 IF(MSCRAM.EQ.3) GO TO 240
      MSCRAM=0
      IF(T1.LE.T) MSCRAM=1
      IF(T2.LE.T) MSCRAM=MSCRAM+2
  240 IF(L.NE.0) GO TO 250
      L=1
      DO 245 I=1,6
  245 TTRIP(I)=T+PMPDEL(I)
  250 IF(TTRIP(1).LE.T) KMM1=0.
      IF(TTRIP(2).LE.T) KMM2=0.
      IF(TTRIP(3).LE.T) KMS1=0.
      IF(TTRIP(4).LE.T) KMS2=0.
      IF(TTRIP(5).LE.T) KMG1=0.
      IF(TTRIP(6).LE.T) KMG2=0.
      RETURN
      ENTRY PUTSCR
```

```
      WRITE(6,990)
      DO 3001 I=1,4
 3001 TPRT(I)=R(I+3)
      CALL TMPCON(1,4,TPRT)
      IF(KCALC.EQ.1) WRITE(6,991) TAU
      R(2)=R(2)*XFAC
      WRITE(6,992) (R(I),I=1,3)
      R(2)=R(2)/XFAC
      WRITE(6,993) TPRT
      RETURN
  901 FORMAT(/10X,'**** HIGH FLUX TRIP OCCURS AT',F8.4,' SEC ****'/)
  902 FORMAT(/10X,'**** FLUX - DELAYED FLUX TRIP ( RO > 0 ) AT',F8.4,
     1  ' SEC ****'/)
  903 FORMAT(/10X,'**** FLUX - DELAYED FLUX TRIP ( RO < 0 ) AT',F8.4,
     1  ' SEC ****'/)
  904 FORMAT(/10X,'**** FLUX - SQUARE ROOT OF PRESSURE TRIP AT',F8.4,
     1  ' SEC ****'/)
  905 FORMAT(/10X,'**** PRIMARY PUMP ELECTRICS TRIP AT',F8.4,
     1  ' SEC ****'/)
  906 FORMAT(/10X,'**** PRIMARY - INTERMEDIATE SPEED RATIO TRIP AT',
     1  F8.4,' SEC ****'/)
  907 FORMAT(/10X,'**** REACTOR VESSEL LEVEL TRIP AT',F8.4,' SEC ****'/)
  908 FORMAT(/10X,'**** STEAM - FEEDWATER FLOW MISMATCH TRIP AT',F8.4,
     1  ' SEC ****'/)
  909 FORMAT(/10X,'**** IHX PRIMARY OUTLET TEMPERATURE TRIP AT',F8.4,
     1  ' SEC ****'/)
  911 FORMAT(/10X,'**** FLUX - TOTAL FLOW TRIP AT',F8.4,' SEC ****'/)
  912 FORMAT(/10X,'**** PRIMARY - INTERMEDIATE FLOW RATIO TRIP AT',
     1  F8.4,' SEC ****'/)
  913 FORMAT(/10X,'**** STEAM DRUM LEVEL TRIP AT',F8.4,' SEC ****'/)
  914 FORMAT(/10X,'**** EVAPORATOR OUTLET TEMPERATURE TRIP AT',F8.4,
     1  ' SEC ****'/)
  990 FORMAT(/2X,31('*'),5X,'M E A S U R E D',5X,'V A L U E S',5X,
     1    'F O R',5X,'P P S',5X,31('*')/)
  991 FORMAT(3X,'TAU :',7(F9.4,6X))
  992 FORMAT(3X,'PRESNORM =',F9.5,10X,'VESSEL LEVEL =',F9.4,
     1    10X,'PTOTNORM =',F9.5)
  993 FORMAT (3X,'TIHX1 =',F9.3,5X,'TIHX2 =',F9.3,5X,'TEVAP1 =',
     1    F9.3,5X,'TEVAP2 =',F9.3)
      END
```

DATA SET UTILITY - GENERATE

IEB352I WARNING : OUTPUT RECFM/LRECL/BLKSIZE COPIED FROM INPUT

PROCESSING ENDED AT EOD

```
C **** THERMODYNAMIC PROPRETIES OF LIQUID SODIUM
C
      FUNCTION VISSOD(X)
      REAL LOGETA
      XKEL=273.15+(X-32.)*5./9.
      LOGETA=234.65/XKEL-.4296*ALOG10(XKEL)-1.6814
      EPOISE=10.**LOGETA
C     COMPUTE ABSOLUTE VISCOSITY IN LB/FT-HR
      VISSOD=241.91*EPOISE
      RETURN
      END
C ****
      FUNCTION SPHSOD(X)
      XC=(X-32.0)*5.0/9.0
      SPHSOD=0.34324-(1.3868E-4)*XC+(1.1044E-7)*XC**2
      RETURN
      END
C ****
      FUNCTION THCSOD(X)
      XC=(X-32.0)*5.0/9.0
      THCSOD=57.818*(0.918-(4.9E-4)*XC)
      RETURN
      END
C ****
      FUNCTION DENSOD(X)
      DENSOD=59.566-(7.9504E-3)*X-(0.2872E-6)*X**2+(0.0603E-9)*X**3
      RETURN
      END
C
C **** THIS PROGRAM CALCULATES THERMODYNAMIC PROPERTIES OF LIQUID SODIUM
C
      SUBROUTINE PHYPRS(N)
      COMMON/PHY1/TCAV(232)
      COMMON/PHY2/G(232)
      COMMON/PHY3/DH(232)
      COMMON/PHY4/DEN(232)
      COMMON/PHY5/VIS(232)
      COMMON/PHY6/CPS(232)
      COMMON/PHY7/XKS(232)
      COMMON/PHY8/RES(232)
      DO 1 J=1, N
      DEN(J)=DENSOD(TCAV(J))
      VIS(J)=VISSOD(TCAV(J))
      CPS(J)=SPHSOD(TCAV(J))
      XKS(J)=THCSOD(TCAV(J))
      RES(J)=ABS(G(J)*DH(J)/VIS(J))
    1 CONTINUE
      RETURN
      END
C
C **** MOODY FRICTION FACTOR FOR THE WIRE-RAPPED FUEL BUNDLE AND PIPES
C
      FUNCTION FRFAC(RED,P,D,WL,M)
      RE=RED
C
C     WHERE: RE=REYNOLDS NUMBER, P=PITCH, D=EQUIVALENT DIAMETER, WL=WIRE LEAD
C            M=CONTROL INTEGER (0 : PIPE, 1: FUEL BUNDLE)
      IF(M.EQ.0) GO TO 1
      IF(RED.LE.2000.0) GO TO 3
      IF(RED.LT.3000.) RE=3000.0
      POD=P/D
```

```
      WLD=WL/D
      CF1=1.034/(POD**0.124)
      CF2=29.70*(POD**6.94)*(RE**0.086)/(WLD**2.239)
      CFT=(CF1+CF2)**0.885
      FRFAC=CFT*0.316/(RE**0.25)
      IF(RED.GE.3000.) RETURN
      FRFAC=0.032+(FRFAC-0.032)*(RED-2000.)*1.E-3
      RETURN
    1 IF(RE.LT.3000.) GO TO 2
      FRFAC=0.00550+0.55*(RE**(-1./3.))
      RETURN
    2 IF(RE.LE.2000.) GO TO 3
      FRFAC=0.032+1.1635E-5*(RE-2000.)
      RETURN
    3 FRFAC=64.0/RE
      RETURN
      END
C
C **** THIS SUBPROGRAM CALCULATES THE GRAVITATIONAL HEAD AND THE VELOCITY
C      HEAD FACTORS (INITIALLY), AND THE 4F L/2GC ROW D A2 TERM
C
      SUBROUTINE GHEAD(N,GC,ZO,Z,DO,DC,W,P1,P2,F,A,DE,XL,DPG,FT,XKT)
      DIMENSION Z(N),DC(N),F(N),XL(N),ADC(13),DUM(13),FROW(13)
      COMMON/MISC/T,TSEC,ICOUNT,S,SSEC,IPRINT,TMAXSC
      COMMON/HYD2/NODB,PBRK,ZBRK,XLBRK,CROBB,CROAB,HEADBB,HEADAB,DENAB
      ADC(1)=(DO+DC(1))/2.0
      DPG=ADC(1)*(ZO-Z(1))
      FROW(1)=F(1)*XL(1)/ADC(1)
      IF(N.GT.1) GO TO 1
      FT=FROW(1)/(2.*GC*DE*A*A)
      IF(ICOUNT.EQ.0) GO TO 3
      RETURN
    1 DUF=FROW(1)
      DO 2 I=2, N
      ADC(I)=(DC(I-1)+DC(I))/2.0
      DUM(I)=ADC(I)*(Z(I-1)-Z(I))
      DPG=DPG+DUM(I)
      FROW(I)=F(I)*XL(I)/ADC(I)
      DUF=DUF+FROW(I)
    2 CONTINUE
      FT=DUF/(2.*GC*DE*A*A)
      IF(NODB.EQ.0) GO TO 29
      DUF2=F(NODB)*XLBRK/ADC(NODB)
      HEADAB=(ZBRK-Z(NODB))*ADC(NODB)
      NPP=NODB+1
      IF(NODB.EQ.N) GO TO 26
      DO 25 I=NPP,N
      HEADAB=HEADAB+DUM(I)
      DUF2=DUF2+FROW(I)
   25 CONTINUE
   26 CONTINUE
      HEADBB=DPG-HEADAB
      FT2=DUF2/(2.*GC*DE*A*A)
      FT1=FT-FT2
   29 IF(ICOUNT.EQ.0) GO TO 3
      IF(NODB.NE.0) GO TO 31
      RETURN
    3 DPF=144.*(P1-P2)
      CROW=(DPF+DPG)/(W*W)
      XKT=CROW-FT
      IF(NODB.EQ.0) RETURN
```

```
      DP2=144.*(PBRK-P2)
      DP1=DPF-DP2
      CROW1=(DP1+HEADBB)/(W*W)
      CROW2=(DP2+HEADAB)/(W*W)
      XKT1=CROW1-FT1
      XKT2=CROW2-FT2
   31 CROBB=FT1+XKT1
      CROAB=FT2+XKT2
      RETURN
      END
C
C **** OVERALL HEAT TRANSFER COEFFICIENT IN THE REACTOR CORE
C
      SUBROUTINE UATOT(L,N,KM,KG,KC,DG,DC,H,D,R,Q,UA,TM,TSOD,TMAX,TCLAD,
     1 TFILM)
      REAL L,N,KM,KG,KC
      PINL=3.141592*N*L
      RTM=1./(8.*KM)
      QR2=Q*R**2
      RTG=DG/(2.*KG*R)
      RTC=ALOG(D/(D-2.*DC))/(2.*KC)
      RTFILM=1./(H*D)
      TMAX=TM+QR2*RTM
      UO=1.0/(RTM+RTG+RTC+RTFILM)
C     CALCULATE THE HEAT TRANSFER RATE PER UNIT LENGTH OF A FUEL PIN
      QLNP=UO*(TM-TSOD)
      TFILM=TSOD+QLNP*RTFILM
      TCLAD=TFILM+QLNP*RTC
      UA=PINL*UO
      RETURN
      END
C
C **** JET PENETRATION DISTANCE IN THE UPPER PLENUM SODIUM POOL
C
      SUBROUTINE JET(ZCH,RO,WC,DB,DC,ZJET)
      G=32.0
      WCP=WC/3600.0
      A1=(WCP/(3.1415*RO*RO*DC))**2
      A2=DB/(G*RO*(DC-DB))
      FRO=ABS(A1*A2)
      ZJET=(1.0383*FRO**0.785)*RO+ZCH
      RETURN
      END
C
C **** FUEL REGION ENERGY EQUATION
C
      SUBROUTINE DFUEL(DF,VF,CF,QFV,UA,TF,TCIN,TCOUT,DTF)
      XMF=DF*VF
      QF=QFV*VF
      TCAV=(TCIN+TCOUT)/2.0
      QT=UA*(TF-TCAV)
      DTF=(QF-QT)/(XMF*CF)
      RETURN
      END
C
C **** COOLANT REGION ENERGY EQUATION
C
      SUBROUTINE DCOOL(DC,VC,CC,UA,TF,TCIN,TCOUT,W,DTC)
      XMC=DC*VC
      TCAV=(TCIN+TCOUT)/2.0
      QT=UA*(TF-TCAV)
```

```
      QC=W*CC*(TCOUT-TCIN)
      DTC=(QT-QC)/(XMC*CC)
      RETURN
      END
C
C **** FUEL REGION TIME CONSTANT
      SUBROUTINE TIMECF(D,V,C,UA,TAU)
      TAU=D*V*C/UA
      RETURN
      END
C
C **** COOLANT REGION TIME CONSTANT
C
      SUBROUTINE TIMECC(D,V,C,UA,W,TAU)
      A1=D*V*C
      A2=(UA/2.0)+W*C
      TAU=A1/A2
      RETURN
      END
C
C **** FUEL TEMPERATURE IN THE PROMPT APPROXIMATION MODE
C
      SUBROUTINE TFUEL(QFV,VF,UA,TCAV,TF)
      QF=QFV*VF
      TF=(QF/UA)+TCAV
      RETURN
      END
C
C **** COOLANT TEMPERATURE IN THE PROMPT APPROXIMATION MODE
      SUBROUTINE TCOOL(CC,UA,W,TF,TCIN,TCOUT)
      A1=(ABS(W))*CC/UA
      A2=A1+0.5
      A3=TF-0.5*TCIN
      A4=A1*TCIN
      TCOUT=(A3+A4)/A2
      RETURN
      END
C
C **** INNER PLENUM LOWER REGION TEMPERATURE IN THE PROMPT APPROXIMATION MODE
C
      SUBROUTINE PLENI1(WI1,WI2,TI1,TI2,TIP2,TIP1,CPI1,CPI2)
      COMMON/LOOP/XN
      IF(WI1.GE.0..AND.WI2.GE.0.) GO TO 1
      IF(WI1.GE.0..AND.WI2.LT.0.) GO TO 2
      IF(WI1.LT.0..AND.WI2.GT.0.) GO TO 3
      IF(WI1.LT.0..AND.WI2.LT.0.) GO TO 4
    1 TIP1=(WI1*CPI1*TI1+XN*WI2*CPI2*TI2)/(WI1*CPI1+XN*WI2*CPI2)
      RETURN
    2 TIP1=WI1*CPI1*TI1/(WI1*CPI1+XN*WI2*CPI2)
      RETURN
    3 TIP1=WI2*CPI2*TI2/(WI1*CPI1+XN*WI2*CPI2)
      RETURN
    4 TIP1=TIP2
      RETURN
      END
C
C **** INNER PLENUM UPPER REGION TEMPERATURE IN THE PROMPT APPROXIMATION MODE
C
      SUBROUTINE PLENI2(MODE,CPIA,TPI1,TPI2)
      COMMON/GET1/WI100,WLP1,WI2,WIC,WOC,WHC,WCA,WRB,WBP,WS100,WS1,WS2,
     1WBRK
```

```
      COMMON/FBR1/TDUM1(14),TC1,TC2,TC3,TC4,TC5,TC6,TDUM2(14)
      COMMON/PHY6/CDUM1(17),CP1,CP2,CP3,CP4,CP5,CP6,CDUM2(209)
      WI1=WLP1
      IF(MODE.EQ.2) WI1=WBRK
      IF(WHC.GE.0..AND.WIC.GE.0..AND.WOC.GE.0..AND.WCA.GE.0..AND.WRB.GE.
     10..AND.WBP.GE.0.)GO TO 2
      A1=1.
      A2=1.
      A3=1.
      A4=1.
      A5=1.
      A6=1.
      IF(WHC.LT.0.) A1=0.0
      IF(WIC.LT.0.) A2=0.0
      IF(WOC.LT.0.) A3=0.0
      IF(WCA.LT.0.) A4=0.0
      IF(WRB.LT.0.) A5=0.0
      IF(WBP.LT.0.) A6=0.0
      REV1=(1.-A1)*WHC*CP1*TC1+(1.-A2)*WIC*CP2*TC2+(1.-A3)*WOC*CP3*TC3+
     1(1.-A4)*WCA*CP4*TC4+(1.-A5)*WRB*CP5*TC5+(1.-A6)*WBP*CP6*TC6
      REV2=A1*CP1*WHC+A2*CP2*WIC+A3*CP3*WOC+A4*CP4*WCA+A5*CP5*WRB+A6*CP6
     1WBP
      TPI2=((WI1+2.*WI2)*CPIA*TPI1-REV1)/REV2
      RETURN
    2 TPI2=TPI1
      RETURN
      END
C
C **** OUTLET PLENUM LOWER REGION TEMPERATURE IN THE PROMPT APPROXIMATION MODE
C
      SUBROUTINE PLENO1(BETA2,HOP,ZJET,AOPT,HIF,TA,TB)
      COMMON/FBR1/TD1(2),THC,TD2(2),TIC,TD3(2),TOC,TCA,TRB,TBP,TD4(22)
      COMMON/GET1/WI100,WLP1,WI2,WIC,WOC,WHC,WCA,WRB,WBP,WS100,WS1,WS2,
     1WBRK
      COMMON/PLNO/CHC,CIC,COC,CCA,CRB,CBP
      A1=1.
      A2=1.
      A3=1.
      A4=1.
      A5=1.
      A6=1.
      TP=TA
      IF(ZJET.GE.HOP) TP=TBP
      IF(WHC.GE.0..AND.WIC.GE.0..AND.WOC.GE.0..AND.WCA.GE.0..AND.WRB.GE.
     10..AND.WBP.GE.0.) GO TO 1
      IF(WHC.LT.0.) A1=0.0
      IF(WIC.LT.0.) A2=0.0
      IF(WOC.LT.0.) A3=0.0
      IF(WCA.LT.0.) A4=0.0
      IF(WRB.LT.0.) A5=0.0
      IF(WBP.LT.0.) A6=0.0
    1 TB=(WHC*CHC*THC*A1+WIC*CIC*TIC*A2+WOC*COC*TOC*A3+WCA*CCA*TCA*A4+
     1WRB*CRB*TRB*A5+WBP*CBP*TP*A6*BETA2+HIF*AOPT*TP)/(ABS(WHC)*CHC+
     2ABS(WIC)*CIC+ABS(WOC)*COC+ABS(WCA)*CCA+ABS(WRB)*CRB+ABS(WBP)*CBP*
     3BETA2+HIF*AOPT)
      RETURN
      END
C
C **** RUNGE-KUTTA ALGORITHM
C
      FUNCTION RUNGE(N,Y,F,X,H,NO)
```

```
      INTEGER RUNGE
      DIMENSION Y(N),F(N),NO(N)
      DIMENSION PHI(489),SAVEY(489)
      DATA M/0/
      M=M+1
      L=1
      GO TO (1,2,3),M
C         PASS 1
    1 RUNGE=1
      RETURN
C         PASS 2
    2 DO 22 J=1,N
      IF(J.NE.NO(L)) GO TO 21
      L=L+1
      GO TO 22
   21 SAVEY(J)=Y(J)
      PHI(J)=F(J)
      Y(J)=SAVEY(J)+H*PHI(J)
   22 CONTINUE
      X=X+H
      RUNGE=2
      RETURN
C         PASS 3
    3 DO 33 J=1,N
      IF(J.NE.NO(L)) GO TO 32
      L=L+1
      GO TO 33
   32 Y(J)=SAVEY(J)+(PHI(J)+F(J))*H/2.
   33 CONTINUE
      RUNGE=0
      M=0
      RETURN
      END
C
C **** PUMP TORQUE
C
      SUBROUTINE PTORQ(A,V,BP)
      COMMON/PTRQ/BB(8),DD(8)
      IF(A.EQ.0.) GO TO 10
      RVA=V/A
      IF(ABS(RVA).LE.1..AND.A.GT.0.) GO TO 100
      IF(ABS(RVA).LE.1..AND.A.LT.0.) GO TO 200
   10 IF(V.EQ.0.) GO TO 500
      RAV=A/V
      IF(ABS(RAV).LT.1..AND.V.GT.0.) GO TO 300
      IF(ABS(RAV).LT.1..AND.V.LT.0.) GO TO 400
  100 BP=A*A*(BB(1)+BB(2)*RVA+BB(3)*RVA*RVA+BB(4)*RVA*RVA*RVA)
      RETURN
  200 BP=A*A*(BB(5)+BB(6)*RVA+BB(7)*RVA*RVA+BB(8)*RVA*RVA*RVA)
      RETURN
  300 BP=V*V*(DD(1)+DD(2)*RAV+DD(3)*RAV*RAV+DD(4)*RAV*RAV*RAV)
      RETURN
  400 BP=V*V*(DD(5)+DD(6)*RAV+DD(7)*RAV*RAV+DD(8)*RAV*RAV*RAV)
      RETURN
  500 BP=0.0
      RETURN
      END
C
C **** PUMP FRICTION TORQUE
C
      SUBROUTINE TFRIC(A,AZ,TS,TR,TMIN,TFR)
```

```
      TFR=TS*EXP(-A/AZ)+TR*A+TMIN
      RETURN
      END
C
C **** PUMP HEAD
C
      SUBROUTINE PHEAD(A,V,HEAD)
      COMMON/PHED/AA(8),CC(8)
      IF(A.EQ.0.) GO TO 10
      RVA=V/A
      IF(ABS(RVA).LE.1..AND.A.GT.0.) GO TO 100
      IF(ABS(RVA).LE.1..AND.A.LT.0.) GO TO 200
   10 IF(V.EQ.0.) GO TO 500
      RAV=A/V
      IF(ABS(RAV).LT.1..AND.V.GT.0.) GO TO 300
      IF(ABS(RAV).LT.1..AND.V.LT.0.) GO TO 400
  100 HEAD=A*A*(AA(1)+AA(2)*RVA+AA(3)*RVA*RVA+AA(4)*RVA*RVA*RVA)
      RETURN
  200 HEAD=A*A*(AA(5)+AA(6)*RVA+AA(7)*RVA*RVA+AA(8)*RVA*RVA*RVA)
      RETURN
  300 HEAD=V*V*(CC(1)+CC(2)*RAV+CC(3)*RAV*RAV+CC(4)*RAV*RAV*RAV)
      RETURN
  400 HEAD=V*V*(CC(5)+CC(6)*RAV+CC(7)*RAV*RAV+CC(8)*RAV*RAV*RAV)
      RETURN
  500 HEAD=0.0
      RETURN
      END
C
C **** PRIMARY PUMP SPEED (SHORT TIME CONSTANT CASE)
C
      SUBROUTINE ALPHP(A,V,GF,KMM,KPM,TMM,TDM,BP,TFR,SLIP)
      REAL KMM, KPM
      COMMON/ALPA/PMSSP,DSPEED,XNP,A1,A2,A3,AZ,TS,TR,TM
      SSPEED=60.*GF/XNP
      DO 100 I=1, 4
      SLIP=1.0-(DSPEED/SSPEED)*A
      SLPM=1.0-(DSPEED/PMSSP)*A
      TMM=SLIP/(A1*SLIP*SLIP+A2)
      TPM=A3*SLPM/(A1*SLPM*SLPM+A2)
      TDM=KMM*TMM+KPM*TPM
      DTMM=-(DSPEED/SSPEED)*(A2-A1*SLIP*SLIP)/((A1*SLIP*SLIP+A2)**2)
      DTPM=-(DSPEED/PMSSP)*A3*(A2-A1*SLPM*SLPM)/((A1*SLPM*SLPM+A2)**2)
      DTDM=KMM*DTMM+KPM*DTPM
      CALL PTORQ(A,V,BP)
      CALL TFRIC(A,AZ,TS,TR,TM,TFR)
      CALL PTIME(A,V,AZ,TS,TR,DTPD,DTFD)
      F=TDM-BP-TFR
      DF=DTDM-DTPD-DTFD
      A=A-(F/DF)
      IF(A.LE.0.0) GO TO 200
  100 CONTINUE
      RETURN
  200 A=0.0
      RETURN
      END
C
C **** SECONDARY PUMP SPEED (SHORT TIME CONSTANT CASE)
C
      SUBROUTINE ALPHA(A,V,GF,KMM,KPM,TMM,TDM,BP,TFR,SLIP)
      REAL KMM,KPM
      COMMON/ALPB/PMSSP,DSPEED,XNP,A1,A2,A3,AZ,TS,TR,TM
```

```
      SSPEED=60.*GF/XNP
      DO 100 I=1, 4
      SLIP=1.0-(DSPEED/SSPEED)*A
      SLPM=1.0-(DSPEED/PMSSP)*A
      TMM=SLIP/(A1*SLIP*SLIP+A2)
      TPM=A3*SLPM/(A1*SLPM*SLPM+A2)
      TDM=KMM*TMM+KPM*TPM
      DTMM=-(DSPEED/SSPEED)*(A2-A1*SLIP*SLIP)/((A1*SLIP*SLIP+A2)**2)
      DTPM=-(DSPEED/PMSSP)*A3*(A2-A1*SLPM*SLPM)/((A1*SLPM*SLPM+A2)**2)
      DTDM=KMM*DTMM+KPM*DTPM
      CALL PTORQ(A,V,BP)
      CALL TFRIC(A,AZ,TS,TR,TM,TFR)
      CALL PTIME(A,V,AZ,TS,TR,DTPD,DTFD)
      F=TDM-BP-TFR
      DF=DTDM-DTPD-DTFD
      A=A-(F/DF)
      IF(A.LE.0.0) GO TO 200
  100 CONTINUE
      RETURN
  200 A=0.0
      RETURN
      END
C
C **** RECIRCULATION PUMP SPEED FOR THE CASE OF SHORT TIME CONSTANT
C
      SUBROUTINE RPSPD(A,V,KMM,TDM,TRP,TFR,SLIP)
      REAL KMM
      COMMON/ARPP/DSPEED,SSPEED,A1,A2,AZ,TS,TR,TM
      DO 100 I=1, 4
      SLIP=1.0-(DSPEED/SSPEED)*A
      TMM=SLIP/(A1*SLIP*SLIP+A2)
      TDM=KMM*TMM
      DTMM=-(DSPEED/SSPEED)*(A2-A1*SLIP*SLIP)/((A1*SLIP*SLIP+A2)**2)
      DTDM=KMM*DTMM
      CALL PTORQ(A,V,TRP)
      CALL TFRIC(A,AZ,TS,TR,TM,TFR)
      CALL PTIME(A,V,AZ,TS,TR,DTPD,DTFD)
      F=TDM-TRP-TFR
      DF=DTDM-DTPD-DTFD
      A=A-(F/DF)
      IF(A.LE.0.0) GO TO 200
  100 CONTINUE
      RETURN
  200 A=0.0
      RETURN
      END
C
C **** PARTIAL DERIVATIVE VALUES OF THE HYDRAULIC AND FRICTION TORQUES
C                              W. R. T. PUMP SPEED
C
      SUBROUTINE PTIME(A,V,AZ,TS,TR,DTP,DTF)
      COMMON/PTRQ/BB(8),DD(8)
      IF(A.EQ.0.) GO TO 10
      RVA=V/A
      IF(ABS(RVA).LE.1..AND.A.GT.0.) GO TO 100
      IF(ABS(RVA).LE.1..AND.A.LT.0.) GO TO 200
   10 IF(V.EQ.0.) GO TO 500
      RAV=A/V
      IF(ABS(RAV).LT.1..AND.V.GT.0.) GO TO 300
      IF(ABS(RAV).LT.1..AND.V.LT.0.) GO TO 400
  100 DTP=A*(2.*BB(1)+BB(2)*RVA-BB(4)*RVA*RVA)
```

```
      GO TO 600
  200 DTP=A*(2.*BB(5)+BB(6)*RVA-BB(8)*RVA*RVA*RVA)
      GO TO 600
  300 DTP=V*(DD(2)+2.*DD(3)*RAV+3.*DD(4)*RAV*RAV)
      GO TO 600
  400 DTP=V*(DD(6)+2.*DD(7)*RAV+3.*DD(8)*RAV*RAV)
      GO TO 600
  500 DTP=0.0
  600 DTF=-(TS/AZ)*EXP(-A/AZ)+TR
      RETURN
      END
C
C **** PIPE SEGMENT HEAT-TRANSFER MODEL
C
      SUBROUTINE PIPE(N,L,K,W,TCI,TC,TW,FC,FW,DI,DEL,STOT,ATOT,VCTOT,
     1XKSS,ROVCW,VCPRIM,CC,DC,VIS,XK,REC,U,UAPR,TAUC,TAUW)
      DIMENSION TC(10),TW(10),FC(10),FW(10),CC(10),DC(10),VIS(10),
     1 XK(10),REC(10),PRC(10),PEC(10),U(10),UAPR(10),HEAT(10),XNU(10),
     2 HC(10),TAUC(10),TAUW(10)
      XN=N
      IF(K.EQ.2) GO TO 8
      IF(L.EQ.1) GO TO 4
      DO 3 I=1, N
      IF(REC(I).GT.3000.) GO TO 1
      XNU(I)=4.363636
      GO TO 2
    1 PRC(I)=CC(I)*VIS(I)/XK(I)
      PEC(I)=REC(I)*PRC(I)
      XNU(I)=7.0+0.025*PEC(I)**0.8
    2 HC(I)=XK(I)*XNU(I)/(DI/12.)
    3 U(I)=1.0/(1./HC(I)+DI/(24.*XKSS)*ALOG((DI+2.*DEL)/DI))
    4 DO 5 I=1, N
      IF(L.EQ.1) U(I)=0.0
    5 UAPR(I)=U(I)*ATOT/XN
      IF(K.NE.3) GO TO 8
      DO 7 I=1, N
      TAUC(I)=3600.*DC(I)*VCTOT*CC(I)/(XN*W*CC(I)+0.5*U(I)*ATOT)
      IF(L.EQ.1) GO TO 6
      TAUW(I)=3600.*ROVCW/UAPR(I)
      GO TO 7
    6 TAUW(I)=1000.0
    7 CONTINUE
    8 HEAT(1)=UAPR(1)*(0.5*(TCI+TC(1))-TW(1))
      FW(1)=HEAT(1)/ROVCW
      FC(1)=(W*CC(1)*(TCI-TC(1))-HEAT(1))/(DC(1)*VCPRIM*CC(1))
      IF(N.EQ.1) GO TO 10
      DO 9 I=2, N
      HEAT(I)=UAPR(I)*(0.5*(TC(I-1)+TC(I))-TW(I))
      FW(I)=HEAT(I)/ROVCW
      FC(I)=(W*CC(I)*(TC(I-1)-TC(I))-HEAT(I))/(DC(I)*VCPRIM*CC(I))
    9 CONTINUE
   10 CONTINUE
      RETURN
      END
C
C **** MOMENTUM TERM COEFFICIENT
C
      FUNCTION DPMOM(A1, A2, D1, D2, GC)
      B1=1./(A1*D1)
      B2=1./(A2*D2)
      B3=1./A1
```

```
      B4=1./A2
      DPMOM=(B3+B4)*(B1-B2)/(2.*GC)
      RETURN
      END
C
C **** TUBE WALL TO BULK WATER TEMPERATURE DROP
C
      FUNCTION TMETAL(C, HS, HW, DTTOT)
      REAL NUM
      TX=DTTOT
      DO 1 I=1, 6
      NUM=(C/HS)*TX**3+(1.+HW/HS)*TX-DTTOT
      DENOM=3.0*(C/HS)*TX**2+HW/HS+1.0
      TX=TX-NUM/DENOM
    1 CONTINUE
      TMETAL=TX
      RETURN
      END
C
C **** STEAM GENERATOR UNITS OVER-ALL HEAT-TRANSFER COEFFICIENT BASED ON THE
C                  TUBE OUTSIDE DIAMETER
      FUNCTION USTG(HO, HI, XID, OD, TK)
      DENOM=(OD/XID)*(1./HI)+(OD/(2.*TK))*ALOG(OD/XID)+(1./HO)
      USTG=1.0/DENOM
      RETURN
      END
C
C **** ARMAND'S TWO-PHASE FLOW MULTIPLIER
C
      SUBROUTINE ARMAND(XX,VF,VG,VOID,PHI)
      IF(XX.LE.0.0) X=0.0
      IF(XX.LE.0.0) XX=0.0
      IF(XX.GE.0.95) X=0.95
      IF(XX.GE.1.0) XX=0.99
      VOID=(0.833+0.167*X)*X*VG/(X*VG+(1.-X)*VF)
      IF(VOID.GE.0.978) VOID=0.978
      Y=1.0-VOID
      IF(Y.LT.1.0) GO TO 50
      PHI=1.0
      RETURN
   50 IF(Y.LE.0.39) GO TO 100
      PHI=(1.-X)**2/(Y**1.42)
      RETURN
  100 PHI=0.478*(1.-X)**2/(Y**2.2)
      RETURN
      END
C
C **** CRITICAL HEAT FLUX CORRILATION
C
      SUBROUTINE CHFLX(HFLUX,P,G,D,HFG,XLC)
      PR=P/3208.5
      A=(1.-PR)/((1.356*G*1.E-6)**(1./3.))
      IF(P.GT.700.) GO TO 1
      B=168.*(((1./PR)-1.)**0.4)*(D**1.4)*G*1.E-6
      GO TO 2
    1 B=0.
    2 XLC=(D*A*G*HFG/(4.*HFLUX))-B
      RETURN
      END
C
C **** NUCLEATE BOILING HEAT-TRANSFER COEFFICIENT
```

```
C
      SUBROUTINE BRHTC(G,D,DT,ST,VISF,VISG,DF,DG,CF,CG,XKF,XKG,HFG,TDLOG
     1,HS,X,RE,PR,HC,HPB)
      REF=G*D/VISF
      PRF=VISF*CF/XKF
      PR=PRF
      CONST1=VISF*HFG/((ST/(DF-DG))**0.5)
      CONST2=0.013*HFG*(PRF**1.7)
      CONST3=CONST1*((CF/CONST2)**3)
      HCN=0.023*(REF**0.8)*(PRF**0.4)*XKF/DT
      TX=TMETAL(CONST3,HS,HCN,TDLOG)
      HPB=CONST3*(TX**2)
      XML=((X/(1.-X))**0.9)*((DF/DG)**0.5)*((VISG/VISF)**0.1)
      IF(XML.GE.2.) GO TO 1
      F=2.84*(XML**0.45)
      GO TO 2
    1 F=2.57+0.7643*XML
    2 RE=REF*(F**1.25)
      IF(RE.GT.2.5E4) GO TO 3
      S=1.05-1.3E-5*RE
      GO TO 7
    3 IF(RE.GT.1.E5) GO TO 4
      S=0.833325-4.333E-6*RE
      GO TO 7
    4 IF(RE.GT.6.E5) GO TO 5
      S=0.32*EXP(-1.91582E-6*RE)
      GO TO 7
    5 S=0.09
    7 HC=S*HPB+F*HCN
      RETURN
      END
C
C **** LOGARITHMIC MEAN TEMPERATURE DIFFERENCE
C
      SUBROUTINE LMTDIF(TA,TB,TC,TD,TDLOG)
      DATA EPS/1.E-7/
      DIFMAX=TB-TC
      DIFMIN=TA-TD
      IF(DIFMAX.EQ.0.0.OR.DIFMIN.EQ.0.0) GO TO 1
      DIFFER=DIFMAX-DIFMIN
      IF(ABS(DIFFER).LE.EPS) GO TO 2
      RATIO=DIFMAX/DIFMIN
      IF(RATIO.LE.EPS) GO TO 1
      TDLOG=DIFFER/ALOG(RATIO)
      RETURN
    1 TDLOG=0.
      RETURN
    2 TDLOG=DIFMAX
      RETURN
      END
C
C **** REACTOR OUTLET TEMPERATURE SET POINT
C
      FUNCTION RVOTSP(PD)
      COMMON/RTSETP/AT1,AT2,AT3
      RVOTSP=PD*(AT1*PD+AT2)+AT3
      RETURN
      END
C
C **** GAUSSIAN ELIMINATION METHOD
C
```

```
      SUBROUTINE SYSTEM(A,X,M,N)
      DIMENSION A(8,9), X(8)
      IF(M.NE.1) GO TO 10
      X(1)=A(1,2)/A(1,1)
      GO TO 700
   10 LAST=M-1
C         START OVEROL LOOP FO (M-1) PIVOTS
      DO 200 I=1,LAST
C         FIND THE LARGEST REMAINING TERM IN I-TH COLUMN FOR PIVOT
      BIG=0.
      DO 50 K=I,M
      TERM=ABS(A(K,I))
      IF(TERM-BIG)50,50,30
   30 BIG=TERM
      L=K
   50 CONTINUE
C         CHECK WHETHER A NON ZERO TERM HAS BEEN FOUND
      IF(BIG)80,60,80
   60 RETURN
C         L-TH ROW HAS THE BIGEEST TERM... IS I=L
   80 IF(I-L)90,120,90
C         I IS NOT EQUAL TO L, SWITCH ROWS I AND L
   90 DO 100 J=1,N
      TEMP=A(I,J)
      A(I,J)=A(L,J)
  100 A(L,J)=TEMP
C         NOW START PIVOTAL REDUCTION
  120 PIVOT=A(I,I)
      NEXTR=I+1
C         FOR EACH OF THE ROWS AFTER THE I-TH
      DO 200 J=NEXTR,M
C         MULTIPLAING CONSTANT FOR THE J-TH ROWS IS
      CONST=A(J,I)/PIVOT
C         NOW REDUCE EACH TERM OF THE J-TH ROW
      DO 200 K=I,N
  200 A(J,K)=A(J,K)-CONST*A(I,K)
C         PIVOTAL REDUCTION ENDS HERE
C         PERFORM BACK SUBSTITUTION
  350 DO 500 I=1,M
C         IREV IS THE BACKWARD INDEX, GOING FROM M BACK TO 1
      IREV=M+1-I
C         GET Y(IREV) IN PREPARATION
      Y=A(IREV,N)
      IF(IREV-M)400,500,400
C         NOT WORKING ON LAST ROW, I IS 2 OR GREATER
  400 DO 450 J=2,I
C         WORK BACKWARD FOR X(N), X(N-1),...,SUBSTITUTING PREVIOUSLY FOUND VALUES
      K=N+1-J
  450 Y=Y-A(IREV,K)*X(K)
C         FINALLY, COMPUTE X(IREV)
  500 X(IREV)=Y/A(IREV,IREV)
  700 RETURN
      END
C
C ****
C
      FUNCTION SOLVE(A,X,INDEX,EPS)
C
C    WHEN INDEX IS ZERO, SOLVE COMPUTES THE SOLUTIONS: X(1) THROUGH X(7)
C    OF THE SET OF SEVEN LINEAR EQUATIONS WITH THE AUGMENTED MATRIX OF
C    COEFFICIENTS IN A 7 BY 8 ARRAY AND IN ADDITION COMPUTES THE INVERSE
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C   OF THE COEFFICIENT MATRIX (THE FIRST 7 COLUMNS OF MATRIX A) IN PLACE.
C   WHEN INDEX IS POSITIVE, THE SEVEN SOLUTIONS: X(1) THROUGH X(7) ARE COMPUTEI
C   BY MULTIPLYING THE INVERSE MATRIX OBTAINED ABOVE BY THE LAST
C   COLUMN OF A, WHICH ALWAYS HOLDS THE COEFFICIENTS OF THE SYSTEM OF EQN'S.
C   THE VALUE OF THE DETERMINANT IS RETURNED AS THE VALUE OF THE FUNCTION
C   WHEN INDEX IS ZERO AND AS 1 WHEN INDEX IS POSITIVE. SHOULD THE POTENTIAL
C   PIVOT OF LARGEST MAGNITUDE BE SMALLER IN MAGNITUDE THAN EPS, THE MATRIX
C   IS CONSIDERED TO BE SINGULAR AND A TRUE ZERO IS RETURNED AS THE VALUE OF
C   THE FUNCTION.
C
      DIMENSION IROW(7),JCOL(7),JORD(7),Y(7),A(7,8),X(7)
      N=7
      N1=N+1
      IF(INDEX.GT.0) GO TO 31
C        BEGIN ELIMINATION PROCEDURE
      DETER=1.
      DO 18 K=1,N
      KM1=K-1
C        SEARCH FOR THE PIVOT ELEMENT
      PIVOT=0.
      DO 11 I=1,N
      DO 11 J=1,N
C        SCAN IROW AND JCOL ARRAYS FOR THE INVALID PIVOT SUBSCRIPTS
      IF(K.EQ.1) GO TO 9
      DO 8 ISCAN=1,KM1
      DO 8 JSCAN=1,KM1
      IF(I.EQ.IROW(ISCAN)) GO TO 11
      IF(J.EQ.JCOL(JSCAN)) GO TO 11
    8 CONTINUE
    9 IF(ABS(A(I,J)).LE.ABS(PIVOT)) GO TO 11
      PIVOT=A(I,J)
      IROW(K)=I
      JCOL(K)=J
   11 CONTINUE
C        INSURE THAT SELECTED PIVOT IS LARGER THAN EPS
      IF(ABS(PIVOT).GT.EPS) GO TO 13
      SOLVE=0.
      RETURN
C        UPDATE THE DETERMINANT VALUE
   13 IROWK=IROW(K)
      JCOLK=JCOL(K)
      DETER=DETER*PIVOT
C        NORMALIZE PIVOT ROW ELEMENTS
      DO 14 J=1,N1
   14 A(IROWK,J)=A(IROWK,J)/PIVOT
C        CARRY OUT ELIMINATION AND DEVELOP INVERSE MATRIX
      A(IROWK,JCOLK)=1./PIVOT
      DO 18 I=1,N
      AIJCK=A(I,JCOLK)
      IF(I.EQ.IROWK) GO TO 18
      A(I,JCOLK)=-AIJCK/PIVOT
      DO 17 J=1,N1
   17 IF(J.NE.JCOLK) A(I,J)=A(I,J)-AIJCK*A(IROWK,J)
   18 CONTINUE
C        ORDER SOLUTION VALUES (IF ANY) AND CREATE JORD ARRAY
      DO 20 I=1,N
      IROWI=IROW(I)
      JCOLI=JCOL(I)
      JORD(IROWI)=JCOLI
   20 X(JCOLI)=A(IROWI,N1)
C        UNSCRAMBLE THE INVERSE MATRIX
```

```
C         FIRST BY ROWS
      DO 28 J=1,N
      DO 27 I=1,N
      IROWI=IROW(I)
      JCOLI=JCOL(I)
   27 Y(JCOLI)=A(IROWI,J)
      DO 28 I=1,N
   28 A(I,J)=Y(I)
C         THEN BY COLUMNS
      DO 30 I=1,N
      DO 29 J=1,N
      IROWJ=IROW(J)
      JCOLJ=JCOL(J)
   29 Y(IROWJ)=A(I,JCOLJ)
      DO 30 J=1,N
   30 A(I,J)=Y(J)
C         RETURN FOR INDEX ZERO
      SOLVE=DETER
      RETURN
C         COMPUTE SOLUTIONS WHEN INDEX IS POSITIVE
   31 DO 32 I=1,N
      X(I)=0.
      DO 32 J=1,N
   32 X(I)=X(I)+A(I,J)*A(J,N1)
      SOLVE=1.
      RETURN
      END
C
C **** PARTIAL DERIVATIVE OF PUMP HEAD W.R.T. PUMP FLOW
C
      FUNCTION PDERIV(A,V,DESHD,DENS)
      COMMON/PHED/AA(8),CC(8)
      CONST=DESHD*DENS
      IF(A.EQ.0.) GO TO 10
      RVA=V/A
      IF(ABS(RVA).LE.1..AND.A.GT.0.) GO TO 100
      IF(ABS(RVA).LE.1..AND.A.LT.0.) GO TO 200
   10 IF(V.EQ.0.) GO TO 500
      RAV=A/V
      IF(ABS(RAV).LT.1..AND.V.GT.0.) GO TO 300
      IF(ABS(RAV).LT.1..AND.V.LT.0.) GO TO 400
  100 PDERIV=A*(AA(2)+2.*AA(3)*RVA+3.*AA(4)*RVA*RVA)*CONST
      RETURN
  200 PDERIV=A*(AA(6)+2.*AA(7)*RVA+3.*AA(8)*RVA*RVA)*CONST
      RETURN
  300 PDERIV=V*(2.*CC(1)+CC(2)*RAV-CC(4)*RAV*RAV*RAV)*CONST
      RETURN
  400 PDERIV=V*(2.*CC(5)+CC(6)*RAV-CC(8)*RAV*RAV*RAV)*CONST
      RETURN
  500 PDERIV=0.
      RETURN
      END
C
C **** STEAM DRUM COMPRESSIBLE FLOW MODEL
C
      SUBROUTINE DRUM(POLD,UT,VT,EPSI,XMT,XMG,XMF,PNEW)
    1 CALL SWATER(POLD,TM,HF,HG,HFG,DF,DG,SVF,SVG)
      UG=HG-(144./778.)*POLD*SVG
      UF=HF-(144./778.)*POLD*SVF
      VM=VT/XMT
      US=UT/XMT
```

```
      A=(US-UF)*SVG-(US-UG)*SVF
      B=(UG-UF)*VM
      PNEW=POLD*A/B
      EP=PNEW-POLD
      IF(ABS(EP).LE.EPSI) GO TO 2
      POLD=(POLD+PNEW)/2.0
      GO TO 1
    2 CALL SWATER(PNEW,TM,HF,HG,HFG,DF,DG,SVF,SVG)
      UG=HG-(144./778.)*PNEW*SVG
      UF=HF-(144./778.)*PNEW*SVF
      XMG=XMT*(US-UF)/(UG-UF)
      XMF=XMT-XMG
      RETURN
      END
C
C **** STEAM HEADER COMPRESSIBLE FLOW MODEL
C
      SUBROUTINE HEADER(POLD, SU, SV, H, T, PNEW)
      H=SU+(144.0/778.0)*POLD*SV
      T=TSTEAM(H, POLD)
      PNEW=10.731*(T+460.)/(20.*SV)
      RETURN
      END
C
C **** SODIUM TEMPERATURE IN THE HEAT EXCHANGERS (SHORT TIME CONSTANT)
C
      SUBROUTINE PROMTP(W,C,TP1,TP2,TS2,TS1,U,A,XN)
      DO 1 I=1, 6
      CALL LMTDIF(TP1,TP2,TS2,TS1,TDLOG)
      HEAT=U*A*TDLOG/XN
      TDROP=HEAT/(W*C)
      TP2=(TP1-TDROP+TP2)/2.0
    1 CONTINUE
      RETURN
      END
      SUBROUTINE PROMTS(W,C,TP1,TP2,TS2,TS1,U,A,XN)
      DO 1 I=1, 6
      CALL LMTDIF(TP1,TP2,TS2,TS1,TDLOG)
      HEAT=U*A*TDLOG/XN
      TRISE=HEAT/(W*C)
      TS1=(TS2+TRISE+TS1)/2.0
    1 CONTINUE
      RETURN
      END
C
C **** SUPER-HEATED STEAM REGION ENTHALPY (SHORT TIME CONSTANT)
C
      SUBROUTINE ENTH(HIN,WS,TA,TB,TC,TD,TDLOG,U,A,ACF,POUT,HOUT)
      DATA EPSI/1.E-5/
      TO=TD
      TLMD=TDLOG
      IF(TLMD.EQ.0.0) GO TO 3
      UA=ACF*U*A
      DO 1 J=1, 8
      FH=WS*(HIN-HOUT)+UA*TLMD
      R=(TB-TC)/(TA-TO)
      IF(R.LE.0.) GO TO 3
      X=ALOG(R)
      CP=SHEAT2(POUT,TO)
      DFDH=-WS+((UA/CP)*(1.-((R-1.)/X))/X)
      HO=HOUT-(FH/DFDH)
```

```
      TO=TSTEAM(HO,POUT)
      IF(TO.GT.TA) TO=(TO+TC)/2.0
      IF(TO.GT.TA) HO=HSTEAM(TO,POUT)
      DIFF=(HOUT-HO)/HOUT
      IF(ABS(DIFF).LE.EPSI) GO TO 2
      CALL LMTDIF(TA,TB,TC,TO,TLMD)
      IF(TLMD.EQ.0.) GO TO 3
      HOUT=HO
    1 CONTINUE
      RETURN
    2 HOUT=HO
      RETURN
    3 HOUT=HIN
      RETURN
      END
      SUBROUTINE PROMTT(WI,C,TA,TB,TC,TD,U,A,ACFI)
      DATA EPSI/1.E-5/
      UA=U*A/ACFI
      DO 3 J=1, 4
      CALL LMTDIF(TA,TB,TC,TD,TDLOG)
      Q=UA*TDLOG
      FT=WI*C*(TA-TB)-Q
      DIFF=(TB-TC)-(TA-TD)
      DIV=(TB-TC)/(TA-TD)
      IF(DIV.LE.0.) GO TO 1
      R=ALOG(DIV)
      DLGDT=(R-(DIFF/(TB-TC)))/(R*R)
      GO TO 2
    1 DLGDT=0.0
    2 DFDT=-WI*C-UA*DLGDT
      TOUT=TB-(FT/DFDT)
      TDIF=(TOUT-TB)/TOUT
      IF(ABS(TDIF).LE.EPSI) GO TO 4
      TB=TOUT
    3 CONTINUE
      RETURN
    4 TB=TOUT
      RETURN
      END
C
C **** THERMODYNAMIC PROPERTIES OF WATER, SATURATED WATER, SATURATED STEAM,
C                         AND SUPER-HEATED STEAM
      SUBROUTINE WATER(P, H, T, D)
      IF(P.LE.1060) GO TO 50
      CALL SWATER(P,T,HF,HG,HFG,D,DG,SVF,SVG)
      IF(H.GE.HF) RETURN
   50 CONTINUE
      IF(H.GE.350.) GO TO 100
      T1=169.72-0.02935*P
      T2=0.050093+1.81624E-4*P
      T3=0.00223464-4.02203E-7*P
      T4=-1.94529E-6+3.1477E-10*P
      T=T1+T2*H+T3*H**2+T4*H**3
      GO TO 200
  100 T5=51.14-0.0034158*P
      T6=1.03365+3.5916E-6*P
      T7=14541.2-0.30063*P
      T=T5+T6*H+(T7/(H-754.79))
  200 IF(H.GT.280.) GO TO 300
      D1=62.4+2.14E-4*P
      D2=-8.73E-5+1.438E-9*P
```

```
      D3=2.32E-10-6.2E-15*P
      D=D1+D2*H**2+D3*H**4
      GO TO 400
  300 D4=92.924+5.761E-4*P
      D5=39440.2+1.6386*P
      D6=1377.35+0.035704*P
      D=D4+(D5/(H-D6))
  400 RETURN
      END
C ****
      SUBROUTINE SWATER(P, T, HF, HG, HFG, DF, DG, SVF, SVG)
      XL=ALOG10(P)
      Y=(3208.5-P)**0.35
      IF(P.GT.2120.) GO TO 200
      IF(XL.GT.2.7611) GO TO 100
      HF=(1376.8/(5.1085-XL))-199.78+24.262*XL+1.71*XL**2
      HFG=(500./(XL-4.062))+1158.86-13.56*XL
      GO TO 300
  100 HF=(25.847/(3.6635-XL))+426.45-244.*XL+89.91*XL**2
      HFG=(354.4/(XL-3.962))+1193.33-58.3*XL
      GO TO 300
  200 HF=900.67+(0.003908*P-26.833)*Y
      HFG=-22.5+(49.05-0.0042*P)*Y
  300 HG=HFG+HF
      IF(P.GT.2120.) GO TO 500
      IF(P.LE.1060) GO TO 400
      DF=53.526-0.007207*P-3.5E-8*P**2
      GO TO 600
  400 CALL WATER(P, HF, X1, DF)
      GO TO 600
  500 DF=19.17+(1.875-1.14E-4*P)*Y
  600 SVF=1.0/DF
      IF(P.GT.130.) GO TO 700
      DG=((0.0016/(P+10.))+0.0028529)*P**0.948
      GO TO 900
  700 IF(P.GT.2120) GO TO 800
      DG=0.01254+0.0021282*P-6.69E-8*P**2+1.65E-10*P**3
      GO TO 900
  800 DG=20.2-(1.148+4.6E-5*P)*Y
  900 SVG=1./DG
      IF(P.GT.1080) GO TO 1100
      IF(XL.GT.1.653) GO TO 1000
      T=(2634.7/(6.026-XL))-335.486+4.484*XL
      GO TO 1200
 1000 T=105.802+65.14*XL+24.859*XL**2-4.3391*XL**3+1.6889*XL**4
      GO TO 1200
 1100 T=620.994+0.055386*P-3.56E-6*P**2-(226805./(P+768.85))
 1200 RETURN
      END
C ****
      FUNCTION SURFTN(TF, VF)
      TC=(TF-32.)*5./9.
      DX=1.601846E-2/VF
      SIGMA=1.74716E-1*DX**(2./3.)*(368.1-TC)
      SURFTN=6.852177E-5*SIGMA
      RETURN
      END
C ****
C ****
      FUNCTION PSAT(T)
      DIMENSION SK(9)
```

```
      DATA SK/-7.691235,-26.08024,-168.1707,64.23285,-118.9646,4.167117,
     1   20.97507,1.0E9,6.0/
      RT=(T+459.67)/1165.14
      SUM=0
      DO 91 N=1,5
      SUM=SUM+SK(N)*(1.-RT)**N
   91 CONTINUE
      ARG=SUM/RT/(1.+(SK(6)+SK(7)*(1.-RT))*(1.-RT))-
     1 (1.-RT)/(SK(8)*(1.-RT)**2+SK(9))
      RPSAT=EXP(ARG)
      PSAT=3208.2*RPSAT
      RETURN
      END
C
C **** CORE HEAT TRANSFER COEFFICIENT
C
      FUNCTION HCORE(RE,PE,DEQT,XK)
      REAL NUSS
      IF(ABS(RE).GT.3000.) GO TO 100
      NUSS=4.363636
      GO TO 200
  100 NUSS=7.0+0.025*PE**0.8
  200 HCORE=NUSS*XK/DEQT
      RETURN
      END
C ****
      FUNCTION TCOND1(P, TF)
      DATA T0/491.67/,A0/-532.99/,A1/1640.6/,A2/-1040.4/,A3/303.78/,
     1 A4/-42.433/,B0/-3.7738E-2/,B1/0.10033/,B2/-7.9722E-2/,
     2 B3/2.053E-2/,C0/4.5493E-6/,C1/-1.0693E-5/,C2/8.054E-6/,
     3 C3/-1.9692E-6/
      PS=PSAT(TF)
      T=TF+459.67
      X=T/T0
      TCOND1=(1.E-3)*(A0+(A1+(A2+(A3+A4*X)*X)*X)*X+
     1(P-PS)*(B0+(B1+(B2+B3*X)*X)*X)+
     2(P-PS)**2*(C0+(C1+(C2+C3*X)*X)*X))
      RETURN
      END
C ****
      FUNCTION TCOND2(T,V)
      DATA A1/0.8889/,B1/2.1636E-3/,C1/-0.07916E-6/,D1/3.7594E11/,
     1 E1/32./,A2/9.59/,B2/1.767E-2/,C2/0.1898E-4/,D2/-0.4468E-8/
      TCOND2=1.E-3*((A1+(B1+C1*T)*T)/V+D1/(T-E1)**4.2/V**2+A2+
     1 (B2+(C2+D2*T)*T)*T)
      RETURN
      END
C ****
      FUNCTION DVISC1(P, TF)
      DATA T0/559.8/,AS/3.849/,BS/5.5362E-4/,CS/-1.2204E-6/
      DATA A/16.087/,B/447.07/,C/252./,D/1.E8/
      PS=PSAT(TF)
      T=TF+459.67
      F=1.+(P-PS)*(T-T0)*(AS+(BS+CS*(T-T0))*(T-T0))/D
      DVIS=(1.E-6)*A*10.**(B/(T-C))*F
      DVISC1=3600.0*DVIS
      RETURN
      END
C ****
      FUNCTION DVISC2(TF,V)
      DATA A1/0.33/,B1/1.3446E-2/,C1/1.036E-5/
```

```
      DATA A2/-0.44104/,B2/9.9675E-3/,C2/5.2886E-6/,D2/-1.5328E-9/
      DATA E2/-1.4387E-13/,F2/6.5747E-17/
      T=TF+459.67
      DVIS=(1.E-6)*((A1+(B1+C1/V)/V)/V+
     1A2+(B2+(C2+(D2+(E2+F2*T)*T)*T)*T)*T)
      DVISC2=DVIS*3600.0
      RETURN
      END
C ****
      FUNCTION TSTEAM(H, P)
      CALL SWATER(P,TM,HF,HG,HFG,DF,DG,SVF,SVG)
      IF(H.LE.HG) GO TO 1
      PN=6894.7573*P
      HJ=H*2326.0
      D0=656.59+(9.9066E-5-2.1879E-12*PN)*PN
      D1=-5.2569E-4+(-3.4406E-11+7.0081E-19*PN)*PN
      D2=1.6221E-10+(1.8674E-18-1.4567E-26*PN)*PN
      TK=D0+(D1+D2*HJ)*HJ
      TR=1.80*TK
      TSTEAM=TR-459.67
      RETURN
    1 TSTEAM=TM
      RETURN
      END
C ****
      FUNCTION HSTEAM(T, P)
      TK=(T+459.67)/1.8
      PN=P*6894.7573
      D0=656.59+(9.9066E-5-2.1879E-12*PN)*PN
      D1=-5.2569E-4+(-3.4406E-11+7.0081E-19*PN)*PN
      D2=1.6221E-10+(1.8674E-18-1.4567E-26*PN)*PN
      C=D0-TK
      CROOT=(D1*D1-4.*D2*C)**0.5
      HJ=(-D1+CROOT)/(2.*D2)
      HSTEAM=HJ/2326.0
      RETURN
      END
C ****
      FUNCTION SHEAT1(P, T)
      DATA A1/9.6566E-1/,A2/4.9842E-6/,A3/8.8434E+3/,A4/8.2445/
      DATA A5/2.0392E+4/,A6/6.6112/
      H2=A1-A2*P
      H3=A3+A4*P
      H4=-A5+A6*P
      SHEAT1=H2+(H3/((802.-T)**2))-(H4/((T-750.)**2))
      RETURN
      END
C ****
      FUNCTION SHEAT2(P, T)
      PN=P*6894.7573
      TK=(T+459.67)/1.8
      D0=656.59+(9.9066E-5-2.1879E-12*PN)*PN
      D1=-5.2569E-4+(-3.4406E-11+7.0081E-19*PN)*PN
      D2=1.6221E-10+(1.8674E-18-1.4567E-26*PN)*PN
      DENOM=D1*D1-4.*D2*(D0-TK)
      CJ=DENOM**(-0.5)
      SHEAT2=CJ/(2326.*1.80)
      RETURN
      END
C ****
      FUNCTION SPVOL2(T, P)
```

```
      SPVOL2=10.731*(T+460.)/(20.*P)
      RETURN
      END
C ****
      SUBROUTINE CONVRT
      COMMON/FACT/XFAC,AFAC,VFAC,WFAC,PFAC,DFAC,CFAC,XKFAC,TFAC,XMFAC,
     C    TQFAC,SPFAC,XILFAC,XHFAC,ENTFAC,GC
      COMMON/GET1/W(13)
      COMMON/FBR1/TEMP(34)
      COMMON/FBR2/TX1(25)
      COMMON/FBR3/TX2(25)
      COMMON/FBR4/TCI(6)
      COMMON/FBR6/TI1(7)
      COMMON/FBR8/TI2(7)
      COMMON/FBR13/DH(12),AH(14),OD(11)
      COMMON/FBR14/DPX,APX,DIM(18),ASX,DIM2(20)
      COMMON/FBR15/DSS,CSS,XKSS
      COMMON/CNV1/XL(35),ASG,ODSE,DELSE
      COMMON/CNV2/ZC(6)
      COMMON/CNV3/ZP(60)
      COMMON/CNV4/ZX(26)
      COMMON/CNV5/ZS(80)
      COMMON/CNV6/ZIO(10)
      COMMON/CNV7/PP(12)
      COMMON/CNV8/PS1(9)
      COMMON/CNV9/PS2(9)
C
C         THESE ARE THE BASIC CONVERSION FACTORS
C
      GC=32.17
      FACLEN=.3048
      FACMAS=.453592
      FACTEM=5./9.
      FACNRG=1055.06
C
C         THESE ARE THE REQUIRED DERIVED CONVERSION FACTORS
C
      XFAC=FACLEN
      AFAC=XFAC*XFAC
      VFAC=AFAC*XFAC
      WFAC=FACMAS/3600.
      PFAC=FACMAS/FACLEN*144.*GC
      DFAC=FACMAS/VFAC
      CFAC=FACNRG/(FACMAS*FACTEM)
      XKFAC=FACNRG/(3600.*XFAC*FACTEM)
      TFAC=FACTEM
      XMFAC=FACMAS*AFAC
      TQFAC=GC*AFAC*FACMAS
      SPFAC=1./60.
      XILFAC=GC*3600.**2/XFAC
      XHFAC=XKFAC/XFAC
      ENTFAC=FACNRG/FACMAS
C
      DO 1000 I=15,20
 1000 TEMP(I)=TEMP(14)
      TEMP(23)=TEMP(21)
C         CONVERT ALL THE PARAMETERS FROM SUBROUTINE LMFBR
C
      DPX=DPX/XFAC
      APX=APX/AFAC
      ASX=ASX/AFAC
```

```
      ASG=ASG/AFAC
      ODSE=ODSE/XFAC*12.
      DELSE=DELSE/XFAC*12.
      DSS=DSS/DFAC
      CSS=CSS/CFAC
      XKSS=XKSS/XKFAC
      DO 1 I=1,80
      ZS(I)=ZS(I)/XFAC
      IF(I.GT.60) GO TQ 1
      ZP(I)=ZP(I)/XFAC
      IF(I.GT.35) GO TO 1
      XL(I)=XL(I)/XFAC
      IF(I.GT.26) GO TO 1
      ZX(I)=ZX(I)/XFAC
      IF(I.GT.20) GO TO 1
      DIM2(I)=DIM2(I)/XFAC
      IF(I.GT.18) GO TO 1
      DIM(I)=DIM(I)/XFAC
      IF(I.GT.14) GO TO 1
      AH(I)=AH(I)/AFAC
      IF(I.GT.13) GO TO 1
      W(I)=W(I)/WFAC
      IF(I.GT.12) GO TO 1
      DH(I)=DH(I)/XFAC
      PP(I)=PP(I)/PFAC
      IF(I.GT.11) GO TO 1
      OD(I)=OD(I)/XFAC
      IF(I.GT.10) GO TO 1
      ZIO(I)=ZIO(I)/XFAC
      IF(I.GT.9) GO TO 1
      PS1(I)=PS1(I)/PFAC
      PS2(I)=PS2(I)/PFAC
      IF(I.GT.6) GO TO 1
      ZC(I)=ZC(I)/XFAC
    1 CONTINUE
      CALL TMPCON(0,34,TEMP)
      CALL TMPCON(0,25,TX1)
      CALL TMPCON(0,25,TX2)
      CALL TMPCON(0,7,TI1)
      CALL TMPCON(0,7,TI2)
      CALL TMPCON(0,6,TCI)
      DO 2 I=1,6
    2 DIM(I)=DIM(I)*12.
      DO 3 I=13,20
    3 DIM2(I)=DIM2(I)*12.
      RETURN
      ENTRY RSTCON
      DO 101 I=1,80
  101 ZS(I)=ZS(I)*XFAC
      DO 102 I=1,60
  102 ZP(I)=ZP(I)*XFAC
      DO 103 I=1,35
  103 XL(I)=XL(I)*XFAC
      DO 104 I=1,26
  104 ZX(I)=ZX(I)*XFAC
      DO 105 I=1,20
  105 DIM2(I)=DIM2(I)*XFAC
      DO 106 I=1,18
  106 DIM(I)=DIM(I)*XFAC
      DO 107 I=1,14
  107 AH(I)=AH(I)*AFAC
```

```
      DO 108 I=1,13
  108 W(I)=W(I)*WFAC
      DO 109 I=1,12
      DH(I)=DH(I)*XFAC
  109 PP(I)=PP(I)*PFAC
      DO 110 I=1,11
  110 OD(I)=OD(I)*XFAC
      DO 111 I=1,10
  111 ZIO(I)=ZIO(I)*XFAC
      DO 112 I=1,9
      PS1(I)=PS1(I)*PFAC
  112 PS2(I)=PS2(I)*PFAC
      DO 113 I=1,6
  113 ZC(I)=ZC(I)*XFAC
      CALL TMPCON(1,34,TEMP)
      CALL TMPCON(1,25,TX1)
      CALL TMPCON(1,25,TX2)
      CALL TMPCON(1,7,TI1)
      CALL TMPCON(1,7,TI2)
      CALL TMPCON(1,6,TCI)
      DPX=DPX*XFAC
      APX=APX*AFAC
      ASX=ASX*AFAC
      ASG=ASG*AFAC
      ODSE=ODSE*XFAC/12.
      DELSE=DELSE*XFAC/12.
      DSS=DSS*DFAC
      CSS=CSS*CFAC
      XKSS=XKSS*XKFAC
      DO 121 I=1,6
  121 DIM(I)=DIM(I)/12.
      DO 122 I=13,20
  122 DIM2(I)=DIM2(I)/12.
      RETURN
      END
      SUBROUTINE TMPCON(M,N,T)
      DIMENSION T(N)
C         IF M=0, CONVERT FROM CENTIGRADE TO FAHRENHEIT
C         IF M=1, CONVERT FROM FAHRENHEIT TO CENTIGRADE
C
      IF(M.EQ.1) GO TO 100
      DO 50 I=1,N
   50 T(I)=1.8*T(I)+32.
      RETURN
  100 DO 150 I=1,N
  150 T(I)=(T(I)-32.)/1.8
      RETURN
      END
```

APPENDIX B

SAMPLE PROBLEM

A sample problem was chosen to show some of the versatility of the EPRI-CURL code. The reactor design chosen was essentially CRBRP (13). The input is found in Table 11-1.

The critical features of the sample problem are:

- reactor operating initially at 90% full power,
- all primary, secondary, and tertiary pumps trip at time = 0.,
- 50¢ reactivity insertion at time = 0.5 seconds,
- pony motors are available when needed,
- all feedwater is lost at time = 0.,
- the turbine is tripped at time = 0.,
- all primary scrams operate except for the primary pump electrics trip,
- automatic secondary scram systems inoperable, and
- a manual secondary system scram is achieved at time = 10.0 seconds.

A possible scenario for this transient would be a seismic shock causing the turbine and pumps trips, as well as a subsequent reactivity insertion.

In order to find a steady state for a power not equal to 100%, the code presently requires a steady-state initialization at 100% be run first, in order to set up the proper normalization.

Thus, the sample problem consists of a steady-state run at 100% power, a steady-state run at 90% power, and the transient run described above. Note that the input data for the second and third runs consists of only the transient defining input of the main program (MASA → MASG) (see Table 11-1).

The transient calculation was terminated at time = 50. seconds. The total execution time for all three runs on an IBM 370/168 came to only 58.7 seconds.

```
*****************************************************************
*                                                               *
*                  C U R L - LOOP VERSION                       *
*                                                               *
*                                                               *
*     DYNAMIC SIMULATION OF A LIQUID-METAL-COOLED               *
*                                                               *
*                  FAST BREEDER REACTOR                         *
*                                                               *
*                                                               *
*                  CORNELL UNIVERSITY  1978                     *
*                                                               *
*****************************************************************
```

DETERMINATION OF STEADY STATE VALUES

```
******************************     I N P U T   D A T A     ******************************

&MASA
MODE=          0,IPRINT=         50,IPK=         10,SSEC=  .199999988    ,TMAXSC=  19.8999939
&END
&MASB
P100=  975.000000    ,PD0=  1.00000000    ,SLOPEP=  .0            ,PDEND=  1.00000000    ,XLOOP=  2.00000000
&END
&MASC
TNEW=  19.0000000    ,  50.0000000    ,  50.0000000    ,SNEW=  .199999988    ,  .199999988    ,  .199999988    ,IPNEW=          1,
          5,          1
&END
&MASD
TSCRM=  50.0000000    ,  50.0000000    ,TTRIP=  50.0000000    ,  50.0000000    ,  50.0000000    ,  50.0000000    ,  50.0000000    ,
  50.0000000
&END
&MASE
NOPON=          0,          0,          0,          0,MTURB=          0,MDUMP=          0,RSTART=          1,EPSILN=
  .100000005E-03
&END
&MASF
RNSERT=  .100000024    ,TNSERT=  50.0000000
&END
&MASG
TNOFW1=  50.0000000    ,TNOFW2=  50.0000000    ,TAUX1=  50.0000000    ,TAUX2=  50.0000000
&END
&BRO1
WI100=  1740.69995    ,WI1=  1740.69995    ,WI2=  1740.69995    ,WIC=  2153.08008    ,WOC=  1885.17993    ,WHC=  139.431000    ,
WCA=  81.4651947    ,WRB=  745.718018    ,WBP=  217.225006    ,WS100=  1610.25000    ,WS1=  1610.25000    ,WS2=  1610.25000    ,
WBRK=  1740.69995
&END
&BRO2
TC=  393.489990    ,  590.129883    ,  592.389893    ,  392.520020    ,  566.669922    ,  568.530029    ,  392.459961    ,
  542.189941    ,  544.020020    ,  444.560059    ,  460.739990    ,  387.969971    ,TIP1=  387.969971    ,TIP2=  387.969971    ,
TOP1=  535.169922    ,TOP2=  535.169922    ,TM=  460.610107    ,  1876.58008    ,  619.270020    ,  442.620117    ,  1595.15991    ,
```

```
  588.560059    ,  441.419922    ,  1420.46997    ,  563.600098    ,  492.479980    ,  550.189941
&END
&BR03
K1=          8,K2=          8,NP=          10,          10,          10,          10,          10,          10,LP=          0,          0,
          0,          0,          0,          0,N1=          10,          1,          2,          10,L1=          0,          0,
          0,          0,N2=          10,          1,          2,          10,L2=          0,          0,          0,          0
&END
&BR04
TP1=  535.169922    ,  517.840088    ,  500.080078    ,  481.840088    ,  463.129883    ,  443.939941    ,  424.280029    ,
  404.129883    ,  383.489990    ,  535.169922    ,  387.969971    ,  .0            ,  .0            ,TS1=  502.139893    ,
  484.020020    ,  465.459961    ,  446.419922    ,  426.879883    ,  406.870117    ,  386.360107    ,  365.370117    ,
  343.889893    ,  502.139893    ,  .0            ,  .0
&END
&BR05
TP2=  535.169922    ,  517.840088    ,  500.080078    ,  481.840089    ,  463.129883    ,  443.939941    ,  424.280029    ,
  404.129883    ,  383.489990    ,  535.169922    ,  387.969971    ,  .0            ,  .0            ,TS2=  502.139893    ,
  484.020020    ,  465.459961    ,  446.419922    ,  426.879883    ,  406.870117    ,  386.360107    ,  365.370117    ,
  343.889893    ,  502.139893    ,  .0            ,  .0
&END
&BR06
TCI1=  535.169922    ,TCI2=  535.169922    ,TCI3=  387.969971    ,TCI4=  535.169922    ,TCI5=  535.169922    ,TCI6=  387.969971
&END
&BR07
TI11=  502.139893    ,TI12=  343.889893    ,TI13=  343.889893    ,TI14=  343.889893    ,TSI1=  502.139893    ,TSO1=  457.540039    ,
TEI1=  457.540039
&END
&BR08
TI21=  502.139893    ,TI22=  343.889893    ,TI23=  343.889893    ,TI24=  343.889893    ,TSI2=  502.139893    ,TSO2=  457.540039    ,
TEI2=  457.540039
&END
&BR09
DH=  .429769978E-02,  .429769978E-02,  .429769978E-02,  .429769978E-02,  .429769978E-02,  .429769978E-02,  .429769978E-02,
  .429769978E-02,  .429769978E-02,  .359659991E-02,  .371859991E-02,  .323700011    ,AH=  .185800008E-01,  .185800008E-01,
  .185800008E-01,  .320500016    ,  .320500016    ,  .320500016    ,  .282400012    ,  .282400012    ,  .282400012    ,
  .715300068E-02,  .985699892E-01,  .822200179E-01,AIPT=  27.8699951    ,AOPT=  27.8699951
&END
&BR10
XL=  .355700016    ,  .914399981    ,  1.64070034    ,  .355700016    ,  .914399981    ,  1.64070034    ,  .355700016    ,
  .914399981    ,  1.64070034    ,  2.91079998    ,  2.91079998    ,  9.31130028    ,P=  .731519982E-02,  .731519982E-02,
  .731519982E-02,  .731519982E-02,  .731519982E-02,  .731519982E-02,  .731519982E-02,  .731519982E-02,  .731519982E-02,
  .161539987E-01,  .143259987E-01,WL=  .302359998    ,  .302359998    ,  .302359998    ,  .302359998    ,  .302359998    ,
  .302359998    ,  .302359998    ,  .302359998    ,  .302359998    ,  .152400017    ,  .101499975    ,OD=  .585220009E-02,
  .585220009E-02,  .585220009E-02,  .585220009E-02,  .585220009E-02,  .585220009E-02,  .585220009E-02,  .585220009E-02,
  .585220009E-02,  .155449994E-01,  .131059997E-01
&END
&BR11
DPX=  .329179987E-01,APX=  1.93610001    ,ODP=  .914399981    ,  .609600008    ,  .609600008    ,DELP=  .126999989E-01,
  .126999989E-01,  .126999989E-01,XLP=  37.4539948    ,  32.7480011    ,  52.7149963    ,  37.4539948    ,  32.7480011    ,
  52.7149963    ,  7.37919998    ,XL11=  2.31000042    ,XL12=  2.65799999    ,XL21=  2.31000042    ,XL22=  2.65799999
&END
&BR12
DSX=  .199400000E-01,ASX=  .889999986    ,ODI=  .609600008    ,  .457199991    ,  .609600008    ,  .609600008    ,DELI=
  .126999989E-01,  .126999989E-01,  .126999989E-01,  .126999989E-01,DSG=  .516600013E-01,ASG=  .525229990    ,ODSE=  .457199991    ,
DELSE=  .126999989E-01,XLS=  150.000000    ,  9.14400005    ,  25.9080048    ,  60.6369934    ,  248.679993    ,  9.14400005    ,
  25.9080048    ,  110.919998    ,  7.61999989    ,  14.0200005    ,  37.7949982    ,  14.0200005
&END
&BR13
ZIN1= -19.1790009    ,ZIN2= -16.1829987    ,ZON= -11.4340000    ,ZP1= -15.7980003    ,ZP2= -15.7980003    ,ZOPLEV= -6.87170029
&END
&BR14
```

```
Z1= -11.4300003    , -7.49800014    , -7.49800014    , -5.79100037    , -5.79100037    , -5.79100037    , -8.22999954    ,
 -10.6700001    , -13.2600002    , -13.2600002    ,Z2= -17.0700073    , -14.0200005    , -10.6700001    , -7.50000000    ,
 -7.50000000    , -7.50000000    , -7.50000000    , -7.50000000    , -7.50000000    , -9.51000023    ,Z3= -16.4600067    ,
 -11.0600004    , -5.64000034    , -5.64000034    , -5.93999958    , -6.55000019    , -7.18999958    , -10.2100000    ,
 -15.6099997    , -19.1799927
&END
&BR15
Z4= -11.4300003    , -7.49800014    , -7.49800014    , -5.79100037    , -5.79100037    , -5.79100037    , -8.22999954    ,
 -10.6700001    , -13.2600002    , -13.2600002    ,Z5= -17.0700073    , -14.0200005    , -10.6700001    , -7.50000000    ,
 -7.50000000    , -7.50000000    , -7.50000000    , -7.50000000    , -7.50000000    , -9.51000023    ,Z6= -16.4600067    ,
 -11.0600004    , -5.64000034    , -5.64000034    , -5.93999958    , -6.55000019    , -7.18999958    , -10.2100000    ,
 -15.6099997    , -19.1799927
&END
&BR16
ZX1= -7.18999958    , -8.02000046    , -8.84500027    , -9.67000008    , -10.5000000    , -11.3199997    , -12.1499996    ,
 -12.9750004    , -13.8000002    , -16.4649963    , -16.4649963    , .0    , .0    ,ZX2= -7.18999958    ,
 -8.02000046    , -8.84500027    , -9.67000008    , -10.5000000    , -11.3199997    , -12.1499996    , -12.9750004    ,
 -13.8000002    , -16.4649963    , -16.4649963    , .0    , .0
&END
&BR17
P1= 845900.000    ,P2= 253000.000    ,P3= 219900.000    ,P4= 36540.0000    ,P5= 1140000.00    ,P6= 1034000.00    ,P7=
 938900.000    ,P8= 939600.000    ,P9= 36540.0000    ,P10= 1140000.00    ,P11= 1034000.00    ,P12= 938900.000
&END
&BR18
DSS= 8000.00000    ,CSS= 502.399902    ,XKSS= 16.7469940
&END
&BR19
PS1= 1568000.00    ,PS2= 253000.000    ,PS3= 219900.000    ,PS4= 1089000.00    ,PS5= 813500.000    ,PS6= 737600.000    ,PS7=
 751400.000    ,PS8= 754900.000    ,PS9= 682500.000
&END
&BR20
PI1= 1568000.00    ,PI2= 253000.000    ,PI3= 219900.000    ,PI4= 1089000.00    ,PI5= 813500.000    ,PI6= 737600.000    ,PI7=
 751400.000    ,PI8= 754900.000    ,PI9= 682500.000
&END
&BR21
ZS1= -4.75000000    , -4.75000000    , -10.3599997    , -13.5000000    , -14.0200005    , -14.1700001    , -14.3299999    ,
 -14.4799995    , -14.6300001    , .100000024    ,ZS2= -12.4700003    , .0    , .0    , .0    ,
 .0    , .0    , .0    , .0    , .0    , .0    ,ZS3= -6.18999958    ,
 .100000024    , .0    , .0    , .0    , .0    , .0    , .0    ,
 .0    , .0    ,ZS4= -7.52999973    , -10.9700003    , -10.6099997    , -3.40999985    , -3.26000023    ,
 -3.26000023    , -3.05000019    , -2.93000031    , -2.80000019    , -2.68000031
&END
&BR22
ZS5= -4.75000000    , -12.6800003    , -13.0100002    , -13.1999998    , -13.4899998    , -13.7799997    , -14.0600004    ,
 -14.3599997    , -14.6300001    , .100000024    ,ZS6= -12.4700003    , .0    , .0    , .0    ,
 .0    , .0    , .0    , .0    , .0    , .0    ,ZS7= -6.18999958    ,
 .100000024    , .0    , .0    , .0    , .0    , .0    , .0    ,
 .0    , .0    ,ZS8= -10.9700003    , -10.5500002    , -10.1300001    , -10.1300001    , -10.1199999    ,
 -10.1199999    , -3.40999985    , -3.17000008    , -2.93000031    , -2.68000031
&END
&BR23
ZHX1= -5.88000011    ,ZHX2= -5.88000011    ,ZSH1= -12.0100002    ,ZSH2= -12.0100002    ,ZEVI1= .100000024    ,ZEVI2=
 .100000024    ,ZEVO1= -12.0100002    ,ZEVO2= -12.0100002    ,ZSP1= -3.10000038    ,ZSP2= -3.10000038
&END
&BR24
PBRK= 951900.000    ,ZBRK= -19.0500031    ,XBRK= 1.00000000    ,PGV= 102000.000
&END
&BR25
AA= 2.64999962    , -2.10000038    , .850000024    , -.399999976    , -2.60000038    , 3.94999981    , -.300000012    ,
 -.850000024    ,BB= 2.25000000    , -1.75000000    , .750000000    , -.250000000    , -2.60000038    , 2.60000038    ,
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  .0              , -.199999988   ,CC= -.899999976    ,  1.85000038     , -1.60000038     ,  1.64999962     ,  1.44999981     ,
 -2.50000000      ,  1.64999962   , -.399999976   ,DD= -.750000000     ,  1.75000000     , -1.25000000     ,  1.25000000     ,
  1.30000019      , -2.00000000   ,  1.10000038   , -.600000024
&END
&KINA
LAM= .199299991    ,  .207500011E-01, .832999945E-01, .750000030E-02, .136999995E-03,B= .299250009E-02, .507500023E-03,
  .284000002E-01, .210000016E-01, .329999998E-01
&END
&KINB
X0= .939999998    ,  .939999998   ,ROMAX= 31.0000000    ,  8.39999962   ,ROSTUK= 2.75000000    ,  2.10000038    ,RINMAX=
  .240000002E-01,ROSUBC= -18.0000000    ,TRESET= 60.0000000    ,XKT= 1.00000000
&END
&KINC
TROM= 558.300049    ,TSTM= 482.199951    ,TSTSP= 482.199951    ,TAURO= 2.00000000    ,TAUST= 2.00000000
&END
&KIND
TFREF= 176.699997   ,TCREF= 176.699997   ,ASOD= -.829999976E-06, .863999958E-05, -.829999976E-06, -.143999996E-04,
  .146899998E-03, -.143999996E-04, -.124999997E-04, -.940000027E-04, -.124999997E-04, .0              , -.389000052E-04,ADOP=
 -.357199996E-02, -.436999984E-01, -.754999928E-03, -.619099997E-01, -.743799984    , -.130899996E-01, -.535800010E-01,
 -.245000005      , -.113300011E-01, .0              , -.251800001     ,ACAE= .0              , .0              , .0              ,
  .0              , -.128000000E-03, .0              , .0              , .0              , .0              , .0              ,
  .0              ,ACRE= -.166999991E-02
&END
&KINE
PRIMA= 11.6800003    ,PRIMB= 10.3299999    ,SECA= 8.96199989    ,SECB= 7.16670036
&END
&KINF
AT= 27.8000031    ,  2.80000019    ,  527.699951
&END
&HYDA
AX= 57.9400024    ,  21.2599945    ,  131.229996    ,  32.8000031    ,  131.229996    ,  8.19999981    ,  57.9400024    ,
  21.2599945      ,  131.229996    ,  32.8000031    ,  131.229996    ,  8.19999981    ,  4.59000015    ,  12.1499996    ,
  655.699951      ,  78.3899994    ,  7.13000011    ,  67.2299957
&END
&HYDB
CA= 1.03999996    ,CB= .649039745E-01,CE= .135000013E-01,MINERT= 1071.19995    ,TMMD= 25496.0000    ,DSPEED= 18.6000061    ,
POLES= 3.00000000    ,PMSSP= 2.00000000
&END
&HYDC
CDBRK= .809999928E-02,AX5BB= 129.919998    ,AXAB= 1.31000042    ,VOLGV= 81.3000031    ,SGVMID= 4.10000038    ,SGVTOP=
  4.60000038    ,ZGVMID= -11.3999996    ,ZGVTOP= -7.60000038
&END
&HYDD
CONVG= .500000000    ,FREQ0= 60.0000000    ,XKA= .500000000    ,TK= .399999976    ,TS= .105000019    ,TR= .229999982E-01,
TMIN= .119999982E-01,AL0= .100000016E-01
&END
&HYDE
FREQ1= 60.0000000    ,FREQ2= 60.0000000    ,AL1= 1.00000000    ,AL2= 1.00000000
&END
&HYDF
TAUWM= .500000000    ,TAUAM= .199999996E-01,TAUTM= 5.00000000    ,TRISPN= 387.780029
&END
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MATRIX OF INERTIAL LOSS COEFFICIENTS

A11 = 3.954E+02	A12 = 4.198E+01	A13 =-4.590E+00	A14 =-4.590E+00	A15 =-4.590E+00	A16 =-4.590E+00	A17 =-4.590E+00
A21 = 3.909E+02	A22 = 3.280E+01	A23 = 1.215E+01	A24 = 0.0	A25 = 0.0	A26 = 0.0	A27 = 0.0
A31 = 3.909E+02	A32 = 3.280E+01	A33 = 0.0	A34 = 6.557E+02	A35 = 0.0	A36 = 0.0	A37 = 0.0
A41 = 3.909E+02	A42 = 3.280E+01	A43 = 0.0	A44 = 0.0	A45 = 7.839E+01	A46 = 0.0	A47 = 0.0
A51 = 3.909E+02	A52 = 3.280E+01	A53 = 0.0	A54 = 0.0	A55 = 0.0	A56 = 7.130E+00	A57 = 0.0
A61 = 3.909E+02	A62 = 3.280E+01	A63 = 0.0	A64 = 0.0	A65 = 0.0	A66 = 0.0	A67 = 6.723E+01

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A71 = 2.099E+01   A72 = 4.164E+02   A73 =-4.590E+00   A74 =-4.590E+00   A75 =-4.590E+00   A76 =-4.590E+00   A77 =-4.590E+00

               VALUE OF DETERMINANT IS  1.039E+14


               INVERSE MATRIX OF INERTIAL LOSS COEFFICIENTS

A11 = 1.309E-03   A12 = 4.076E-04   A13 = 7.552E-06   A14 = 6.317E-05   A15 = 6.945E-04   A16 = 7.366E-05   A17 =-2.301E-04
A21 =-1.362E-03   A22 = 4.076E-04   A23 = 7.552E-06   A24 = 6.317E-05   A25 = 6.945E-04   A26 = 7.366E-05   A27 = 2.440E-03
A31 =-3.843E-02   A32 = 6.809E-02   A33 =-2.633E-04   A34 =-2.203E-03   A35 =-2.422E-02   A36 =-2.568E-03   A37 = 8.151E-04
A41 =-7.122E-04   A42 =-2.633E-04   A43 = 1.520E-03   A44 =-4.082E-05   A45 =-4.487E-04   A46 =-4.759E-05   A47 = 1.510E-05
A51 =-5.957E-03   A52 =-2.203E-03   A53 =-4.082E-05   A54 = 1.242E-02   A55 =-3.754E-03   A56 =-3.981E-04   A57 = 1.263E-04
A61 =-6.549E-02   A62 =-2.422E-02   A63 =-4.487E-04   A64 =-3.754E-03   A65 = 9.898E-02   A66 =-4.377E-03   A67 = 1.389E-03
A71 =-6.946E-03   A72 =-2.568E-03   A73 =-4.759E-05   A74 =-3.981E-04   A75 =-4.377E-03   A76 = 1.441E-02   A77 = 1.473E-04


       DESIGN PUMP HEAD IS    134.04768
       COVER GAS PRESSURE IS 1.8305E+05
&RTH1
PF= .101100001E-02, .355210006E-01, .405000057E-03, .128789991E-01, .486384988    , .515199825E-02, .111100003E-01,
 .366693974    , .444300100E-02, .549999997E-02, .705999732E-01
&END
&RTH2
VX= .651000068E-02, .170000009E-01, .306000002E-01, .114000022    , .292999983    , .526000023    , .101000011    ,
 .258000016    , .463000000    , .208999999E-01, .277000010    , .797999978    ,DT= .411000103E-02, .411000103E-02,
 .411000103E-02, .411000103E-02, .411000103E-02, .411000103E-02, .411000103E-02, .411000103E-02, .411000103E-02,
 .337999989E-02, .465999916E-02,VIP1= 81.1670074    ,VIP2= 9.01799965
&END
&RTH3
DF= 11000.0000    , 11000.0000    , 11000.0000    , 11000.0000    , 11000.0000    , 11000.0000    , 11000.0000    ,
 11000.0000    , 11000.0000    , 2450.80005    , 11000.0000    ,CF= 326.570068    , 326.570068    , 326.570068    ,
 326.570068    , 326.570068    , 326.570068    , 326.570068    , 326.570068    , 326.570068    , 1297.89990    ,
 326.570068    ,XKF= 3.76799965    , 3.53400040    , 3.76799965    , 3.76799965    , 3.33399963    , 3.76799965    ,
 3.76799965    , 3.53400040    , 3.76799965    , 10.3850002    , 3.76799965    ,DG= .165200006E-03, .165200006E-03,
 .165200006E-03, .165200006E-03, .165200006E-03, .165200006E-03, .165200006E-03, .165200006E-03, .165200006E-03,
 .165200006E-03, .190499995E-03,XKG= .308099985    ,DC= .380999991E-04, .380999991E-04, .380999991E-04, .380999991E-04,
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 16.7469940
&END
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VF= .821200013E-02, .210999995E-01, .821200013E-02, .139500022    , .358600020    , .139500022    , .123099983    ,
 .316399992    , .123099983    , .155900002    , 1.70100021    ,XL= .507799983    , .914399981    , .507799983    ,
 .507799983    , .914399981    , .507799983    , .507799983    , .914399981    , .507799983    , 1.98099995    ,
 1.62500000    ,R= .237499992E-02, .237499992E-02, .237499992E-02, .237499992E-02, .237499992E-02, .237499992E-02,
 .237499992E-02, .237499992E-02, .237499992E-02, .596699864E-02, .603500009E-02,XN= 1302.00000    , 1302.00000    ,
 1302.00000    , 22134.0000    , 22134.0000    , 22134.0000    , 19530.0000    , 19530.0000    , 19530.0000    ,
 703.000000    , 9150.00000
&END
&RTH5
RO= .643100023    ,ZCH= 3.40999985    ,DON= .914399981    ,HIF= 559.879883
&END
&RTH6
HCFAC= 1.53999996    ,FLFAC= 3.48999977    ,CLFAC= 1.19200039
&END
&HX1A
DEXT= .222200006E-01,PITCH= .254000016E-01,XKSS= 16.7469940    ,NT= 2850.00000    ,BP= .300000012E-01,ACF= .800000012
&END
&HX1B
VIP= 8.36200047    ,VOP= 1.99600029    ,VRP= 5.69200039    ,VIS= 7.12199974    ,VOS= 9.49199963
&END
```

```
&HX2A
DEXT=  .222200006E-01,PITCH=  .254000016E-01,XKSS=  16.7469940    ,NT=  2850.00000    ,BP=  .300000012E-01,ACF=  .800000012
&END
&HX2B
VIP=  8.36200047    ,VOP=  1.99600029    ,VBP=  5.69200039    ,VIS=  7.12199974    ,VOS=  9.49199963
&END
&IHA1
DSPEED=  18.6000061    ,TMMD=  25496.0000    ,MINERT=  1071.19995    ,PMSSP=  2.00000000
&END
&IHA2
PTSP=  9996000.00    ,KFT=  .500000000    ,KST=  .500000000    ,KSF=  .500000000    ,TAUS=  .500000000    ,  .199999996E-01,
  4.00000000
&END
&THA3
A1=  1.03999996    ,A2=  .649039745E-01,A3=  .135000013E-01,AZ=  .100000016E-01,TS=  .105000019    ,TR=  .229999982E-01,TMIN=
  .119999982E-01,GFI=  60.0000000    ,XNP=  3.00000000    ,ALFA=  1.00000000    ,GF=  60.0000000
&END
&IHB1
TMMD=  25496.0000    ,MINERT=  1071.19995    ,GFI=  60.0000000    ,ALFA=  1.00000000    ,GF=  60.0000000
&END
&IHB2
PTSP=  9996000.00    ,KFT=  .500000000    ,KST=  .500000000    ,KSF=  .500000000    ,TAUS=  .500000000    ,  .199999996E-01,
  4.00000000
&END
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  13170000.0    ,  13130000.0    ,  12890000.0    ,  12430000.0    ,  12330000.0    ,  12200000.0    ,  12150000.0    ,
  12080000.0    ,  11970000.0    ,  11610000.0    ,  11240000.0    ,  10880000.0    ,  10510000.0    ,  10410000.0    ,
  9996000.00
&END
&SGA02
H=  1003000.00    ,  1614000.00    ,  1250000.00    ,  1250000.00    ,  1250000.00    ,  1250000.00    ,  1250000.00    ,
  1250000.00    ,  1527000.00    ,  2087500.00    ,  2087500.00    ,  2087500.00    ,  2087500.00    ,  2681000.00    ,
  2681000.00    ,  3000000.00    ,  3178000.00    ,  3277500.00    ,  3331000.00    ,  3331000.00    ,  3331000.00
&END
&SGA03
TCS=  .0    ,  .0    ,  .0    ,  .0    ,  .0    ,  .0    ,  .0    ,
  343.889893    ,  381.239990    ,  457.540039    ,  457.540039    ,  457.540039    ,  457.540039    ,  457.540039    ,
  457.540039    ,  479.389893    ,  491.649902    ,  498.469971    ,  502.139893
&END
&SGA04
XLT=  14.0200005    ,XL=  .0    ,  9.14400005    ,  .0    ,  36.5760040    ,  1.52400017    ,  10.2399998    ,
  72.1459961    ,  2.62300014    ,  .0    ,  .0    ,  7.05500031    ,  35.3569946    ,  6.09599972    ,
  45.7200012    ,  2.62300014    ,  3.50500011    ,  3.50500011    ,  3.50500011    ,  3.50500011    ,  7.05500031    ,
  106.679993    ,ACF=  .649999976    ,TKON=  37.7299957
&END
&SGA05
Z=  3.81000042    ,  4.26700020    ,  4.26700020    ,  -15.0629997    ,  -13.4110003    ,  -14.9350004    ,  -17.9830017    ,
  -15.3599997    ,  .0    ,  -1.34000015    ,  2.70499992    ,  9.75399971    ,  4.26700020    ,  -17.9830017    ,
  -15.3599997    ,  -11.8549995    ,  -8.35000038    ,  -4.84500027    ,  -1.34000015    ,  2.70499992    ,  2.70499992
&END
&SGA06
XLS=  .0    ,  .0    ,  .0    ,  .0    ,  .0    ,  .0    ,  .0    ,
  .0    ,  .0    ,  .0    ,  7.43700027    ,  7.43700027    ,  7.43700027    ,  7.43700027    ,
  7.43700027    ,  3.50500011    ,  3.50500011    ,  3.50500011    ,  3.50500011
&END
&SGA07
PITCH=  .309999995E-01,D=  .228600025    ,  1.82900047    ,  .431999981    ,  .431999981    ,  .380999982    ,  .380999982    ,
  .228600025    ,  .102999993E-01,  .102999993E-01,  .102999993E-01,  .102999993E-01,  .380999982    ,  .329999983    ,
  .278999984    ,  .102999993E-01,  .102999993E-01,  .102999993E-01,  .102999993E-01,  .102999993E-01,  .102999993E-01,
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 .431999981
&END
&SGA08
DS=  .0              ,  .0              ,  .0              ,  .0              ,  .0              ,  .0              ,  .0              ,
 .926999986      ,  .926999986      , .926999986      , .431999981      , .431999981      , .431999981      , .431999981      ,
 .431999981      ,  .926999986      , .926999986      , .926999986      , .926999986      ,DEL=  .254000016E-01,  .254000016E-01,
 .254000016E-01,  .254000016E-01,  .254000016E-01,  .254000016E-01,  .254000016E-01,  .276899990E-02,  .276899990E-02,
 .276899990E-02,  .276899990E-02,  .254000016E-01,  .254000016E-01,  .254000016E-01,  .276899990E-02,  .276899990E-02,
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&SGA11
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ALFA=  1.00000000
&END
&SGA12
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&END
&SGA13
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&END
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&END
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&END
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&END
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&END
&SGB10
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&END
&SGB11
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ALFA=  1.00000000
&END
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&END
&SGB13
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  1.00000000    ,HDMAX=  1.50000000
&END
&SHD1
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  9996000.00    ,PSPDV=  10100000.0    ,PSPRV=  11030000.0
&END
&SHD2
WT100=  419.550049    ,WNMAX=  1.00000000    ,WNMIN=  .199999996E-01,PH=  9996000.00    ,PC=  .0             ,CT=  9307000.00    ,
CTV=  689400.000    ,COV=  15780000.0    ,CRV=  .145099966E-05
&END
&SCR1
NOSCRM=           5,          11,          12,          13,          14,          15,           0,           0,           0,           0,
           0,           0,           0,           0,           0,DELAY=  .689999998    ,PMPDEL=  .689999998    ,  .689999998    ,
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&END
&SCR2
PLIM=  1.14999962    ,TCON=  28.0000000    ,A2=  1.01000023    ,B2= -.990000010    ,C2=  .170599997    ,D2=  .364000015E-01,A3=
 -1.01000023    ,B3=  1.01000023    ,C3=  .196900010    ,D3=  .416000001E-01,A4=  1.31799984    ,R4= -1.00000000    ,C4=
  .425000004E-01,A6=  .588000007E-01,B6=  .144999981    ,C6= -.249999994E-02,A8=  .300000012    ,ZLEVEL=  4.19999981    ,THXSCR=
  443.000000
&END
&SCR3
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DRUMAX=  .220000029    ,TVAPSC=  400.000000
&END
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&SCR4
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&END
```

```
STEP #      0                           S T E A D Y   S T A T E   C A L C U L A T I O N
                                           POWER HELD CONSTANT AT  975.00 MWT


                                                    TOTAL VECTOR OF CONTROL INTEGERS
  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   18   19   20   21   23   24   25   26   27
 28   29   30   31   32   33   34   35   36   37   38   39   40   41   42   43   44   45   46   47   48   49   50   51   52
 53   54   55   56   57   58   59   60   61   62   63   64   65   66   67   68   69   70   71   72   73   74   75   76   77
 78   79   80   81   82   83   84   85   86   87   88   89   90   91   92   93   94   95   96   97   98   99  100  101  102
103  104  105  106  107  108  109  110  111  112  113  114  115  116  117  118  119  120  121  122  123  124  125  126  127
128  129  130  131  132  133  134  135  136  137  138  139  140  141  142  143  144  145  146  147  148  149  150  151  152
153  154  155  156  157  158  159  160  161  162  163  164  165  166  167  168  169  170  171  172  173  174  175  176  177
178  179  180  181  182  183  184  185  186  187  188  189  190  191  192  193  194  195  196  197  198  199  200  201  202
203  204  205  206  207  208  209  210  211  212  213  214  215  216  217  218  219  220  221  222  223  224  225  226  227
228  229  230  231  232  233  235  236  237  238  240  241  242  243  244  245  246  247  248  249  250  251  252  253  254
255  256  257  258  259  260  261  262  263  264  265  266  267  268  269  270  271  272  273  274  275  276  277  278  279
280  281  282  283  284  285  286  287  288  289  290  291  292  293  294  295  296  297  298  299  300  301  302  303  304
305  306  307  308  309  310  311  312  313  314  315  316  317  318  319  320  321  322  323  324  325  326  327  328  329
330  331  332  333  334  335  336  337  338  339  340  341  342  343  344  345  346  347  348  349  350  351  352  353  354
355  356  357  358  359  360  361  362  363  364  365  366  367  368  369  370  371  372  373  374  375  376  377  378  379
380  381  382  383  384  385  386  387  388  389  390  391  392  393  394  395  396  397  398  399  400  401  402  403  404
405  406  407  408  409  410  411  412  413  414  415  416  417  418  419  420  421  422  423  424  425  426  427  428  429
430  431  432  435  436  437  438  439  440  441  442  443  444  445  446  447  448  449  450  451  452  453  454  455  456
457  458  459  460  461  462  463  464  465  466  467  468  469  470  471  474  475  476  477  480  483  484  485  486  487
488  489    0    0    0    0    0    0    0    0    0    0    0    0

********************************     P R I M A R Y     C O O L A N T     D Y N A M I C S     ********************************

 FZ1NRM = 1.0000                               FZ2NRM = 1.0000  FZ3NRM = 1.0000  CANRM = 1.0000   RBNRM = 1.0000   BPNRM = 1.0000
 FLOWS: 1   1.7407E+03   2   1.7407F+03   3   1.8852E+03   4   1.3943E+02   5   8.1465E+01   6   7.4572F+02   7   2.1723E+02
 AL1=   1.0000   NEW1=    1.0000   BP1=    1.0000   TMOTN1=    1.0350   HP1=   1.0000   FREQ1=   60.000
 AL2=   1.0000   NEW2=    1.0000   BP2=    1.0000   TMOTN2=    1.0350   HP2=   1.0000   FREQ2=   60.000
 PD =   1.0000   TRISP =  387.780   NEWSP =   1.0000   ASP =    1.0000   XKW = 1.190E-03   EPS = 1.000E-05   N =  0
 TRIM:     387.970    387.970       NEWM:       1.0000      1.0000       ALM:       1.0000      1.0000       INLET PRSNRM = 0.9998
 ET:       0.0             0.0              EW:       0.0             0.0              EA:      0.0            0.0
 TAU 1 =    0.22482   TAU 2 =    0.20307   TAU 3 =    0.01640   TAU 4 =    0.07826   TAU 5 =    0.00567   TAU 6 =    0.00541
 TAU 7 =    0.01268   TAU 8 =    0.33240   TAU 9 =**********   TAU10 =    5.00000   TAU11 =    0.50000   TAU12 =    0.02000
 TAU13 =    0.33240   TAU14 =**********   TAU15 =    5.00000   TAU16 =    0.50000   TAU17 =    0.02000   TAU18 =    0.0

******************************     R E A C T O R     H E A T     T R A N S F E R     ******************************

 TAU 1 =     2.0924 SEC   TAU 2 =     3.0311 SEC   TAU 3 =     2.0938 SEC   TAU 4 =     2.0912 SEC   TAU 5 =     3.0737 SEC
 TAU 6 =     2.0925 SEC   TAU 7 =     2.0915 SEC   TAU 8 =     3.0305 SEC   TAU 9 =     2.0926 SEC   TAU10 =     7.2802 SEC
 TAU11 =    11.1250 SEC   TAU12 =    13.3524 SEC   TAU13 =     1.4835 SEC   TAU14 =     0.0386 SEC   TAU15 =     0.0950 SEC
 TAU16 =     0.1709 SEC   TAU17 =     0.0436 SEC   TAU18 =     0.1058 SEC   TAU19 =     0.1909 SEC   TAU20 =     0.0441 SEC
 TAU21 =     0.1066 SEC   TAU22 =     0.1932 SEC   TAU23 =     0.1647 SEC   TAU24 =     0.2450 SEC   TAU25 =     3.1559 SEC
 TAU26 =    28.0756 SEC   TAU27 =     0.0    SEC   TAU28 =     0.0386 SEC   TAU29 =     0.0436 SEC   TAU30 =     0.0441 SEC
 TAU31 =     0.1647 SEC   TAU32 =     0.2450 SEC   TAU33 =     3.1559 SEC   TAU
   CORE HOT SPOT:          MAX. COOLANT TEMP. =   699.296         MAX. CLAD TEMP. =    733.572
 PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =  2204.110   CLAD INNER =   504.016   CLAD OUTER =   500.394
 TM 1 =    460.610   TM 2 =  1876.580   TM 3 =    619.270   TM 4 =    442.620   TM 5 =  1595.160   TM 6 =   588.560
 TM 7 =    441.420   TM 8 =  1420.470   TM 9 =    563.600   TM10 =    492.480   TM11 =    550.190   TM
 TC 1 =    393.490   TC 2 =    590.130   TC 3 =    592.390   TC 4 =    392.520   TC 5 =    566.670   TC 6 =   568.530
 TC 7 =    392.460   TC 8 =    542.190   TC 9 =    544.020   TC10 =    444.560   TC11 =    460.740   TC12 =   387.970
 TCI1 =    387.970   TCI2 =    387.970   TCI3 =    387.970   TCI4 =    387.970   TCI5 =    387.970   TCI6 =   387.970
 LOWER PLENUM:                          TOP ZONE TEMP. =    387.970   BOTTOM ZONE TEMP. =    387.970
 UPPER PLENUM:  ZJET =      6.400   TOP ZONE TEMP. =    535.170   BOTTOM ZONE TEMP. =    535.170   NOZZLE TEMP. =    535.170

*************************     I H X - 1     T H E R M A L     C A L C U L A T I O N S     *************************
```

```
   PRI. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
     1    3.0707E+04  2    3.0875E+04  3    3.1206E+04  4    3.1548E+04  5    3.1900E+04  6    3.2263E+04  7    3.2636E+04
 8   3.3021E+04

   SEC. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
     1    3.9118E+04  2    3.9319E+04  3    3.9703E+04  4    4.0101E+04  5    4.0512E+04  6    4.0936E+04  7    4.1375E+04
 8   4.1828E+04

     8 OVERALL HEAT-TRANSF. COEF. VALUES
     1    7.5259E+03  2    7.5441E+03  3    7.5795E+03  4    7.6156E+03  5    7.6524E+03  6    7.6899E+03  7    7.7282E+03
 8   7.7671E+03

     8 LOG-MEAN-TEMP-DIF. VALUES
     1    3.2628E+69  2    6.1595E+01  3    6.3035E+01  4    6.4502E+01  5    6.5987E+01  6    6.7490E+01  7    6.9011E+01
 8   7.0522E+01
 TAUP: 1   4.0797  2   0.6947  3   0.6984  4   0.7014  5   0.7047  6   0.7083  7   0.7119  8   0.7155  9   0.7190 10  89.7922
11   0.9856
 TAUS: 12   0.3338 13   0.3355 14   0.3371 15   0.3388 16   0.3406 17   0.3424 18   0.3443 19   0.3463 20   3.8347 21   5.1258
 TP: 1  535.170  2  517.840  3  500.080  4  481.840  5  463.130  6  443.940  7  424.280  8  404.130  9  383.490 10  535.170
11  387.970
 TS: 1  502.140  2  484.020  3  465.460  4  446.420  5  426.880  6  406.870  7  386.360  8  365.370  9  343.890 10  502.140

 ************************    I H X - 2    T H E R M A L    C A L C U L A T I O N S    ************************

   PRI. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
     1    3.0707E+04  2    3.0875E+04  3    3.1206E+04  4    3.1548E+04  5    3.1900E+04  6    3.2263E+04  7    3.2636E+04
 8   3.3021E+04

   SEC. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
     1    3.9118E+04  2    3.9319E+04  3    3.9703E+04  4    4.0101E+04  5    4.0512E+04  6    4.0936E+04  7    4.1375E+04
 8   4.1828E+04

     8 OVERALL HEAT-TRANSF. COEF. VALUES
     1    7.5259E+03  2    7.5441E+03  3    7.5795E+03  4    7.6156E+03  5    7.6524E+03  6    7.6899E+03  7    7.7282E+03
 8   7.7671E+03

     8 LOG-MEAN-TEMP-DIF. VALUES
     1    3.3424E+01  2    3.4220E+01  3    3.5019E+01  4    3.5834E+01  5    3.6660E+01  6    3.7495E+01  7    3.8339E+01
 8   3.9179E+01
 TAUP: 1   4.0797  2   0.6947  3   0.6984  4   0.7014  5   0.7047  6   0.7083  7   0.7119  8   0.7155  9   0.7190 10  89.7922
11   0.9856
 TAUS: 12   0.3338 13   0.3355 14   0.3371 15   0.3388 16   0.3406 17   0.3424 18   0.3443 19   0.3463 20   3.8347 21   5.1258
 TP: 1  535.170  2  517.840  3  500.080  4  481.840  5  463.130  6  443.940  7  424.280  8  404.130  9  383.490 10  535.170
11  387.970
 TS: 1  502.140  2  484.020  3  465.460  4  446.420  5  426.880  6  406.870  7  386.360  8  365.370  9  343.890 10  502.140

 ************************  I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S  ************************

  TAU: 1   1.024112  2   0.332401  3   0.500000  4   0.020000  5   3.999999
  SODIUM FLOW RATE =  1.0000   PUMP SPEED =  1.0000   PUMP HEAD =  1.0000   MOTOR GEN. SET FREQ. =   60.000 CYCLES/SEC
  MAIN MOTOR TORQUE =  1.0000   DRIVE MOTOR TORQUE =  1.0350   PUMP TORQUE =  1.0000   FRICTION TORQUE =  0.0350

 ************************  I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S  ************************

  TAU: 1   1.545609  2   0.332401  3   0.500000  4   0.020000  5   3.999999
  SODIUM FLOW RATE =  1.0000   PUMP SPEED =  1.0000   PUMP HEAD =  1.0000   MOTOR GEN. SET FREQ. =   60.000 CYCLES/SEC
  MAIN MOTOR TORQUE =  1.0000   DRIVE MOTOR TORQUE =  1.0350   PUMP TORQUE =  1.0000   FRICTION TORQUE =  0.0350
```

```
************************************   S T E A M   G E N E R A T I O N   L O O P - 1   ************************************

 TAU:  1  0.896206  2  0.896492  3  0.895702  4  0.887388  5  1.140580  6  1.140580  7  1.140580  8  1.140580
 9  1.140580 10  2.378362 11  3.090784 12  0.0        13 14.449261 14  0.469181 15  3.152439 16 15.991289
17  0.893417 18  1.611632 19  0.318090 20  0.418916 21  1.870427 22  0.481188 23  1.418368 24  0.083072
25  0.047594 26  0.041209 27  0.036878 28  0.034161 29  0.105165 30  3.557830 31  0.332401 32  0.207408
33  0.059743 34********** 35********** 36  1.000000 37  1.999999 38  1.999999 39  1.999999
 FEED WATER FLOW =1.0000  WATER/STEAM FLOW =1.0000  STEAM FLOW =1.0000  INT. SODIUM FLOW =1.0000

 P 1 = 1.2150E+07  P 2 = 1.2150E+07  P 3 = 1.2150E+07  P 4 = 1.2190E+07  P 5 = 1.3190E+07  P 6 = 1.3180E+07  P 7 = 1.3170E+07
 P 8 = 1.3130E+07  P 9 = 1.2890E+07  P10 = 1.2430E+07  P11 = 1.2330E+07  P12 = 1.2200E+07  P13 = 1.2150E+07  P14 = 1.2080E+07
 P15 = 1.1970E+07  P16 = 1.1610E+07  P17 = 1.1240E+07  P18 = 1.0880E+07  P19 = 1.0510E+07  P20 = 1.0410E+07  P21 = 9.9960E+06
 H 1 = 1.0030E+06  H 2 = 1.6142E+06  H 3 = 1.2500E+06  H 4 = 1.2500E+06  H 5 = 1.2500E+06  H 6 = 1.2500E+06  H 7 = 1.2500E+06
 H 8 = 1.2500E+06  H 9 = 1.5272E+06  H10 = 2.0875E+06  H11 = 2.0875E+06  H12 = 2.0875E+06  H13 = 2.0875E+06  H14 = 2.6810E+06
 H15 = 2.6810E+06  H16 = 3.0000E+06  H17 = 3.1780E+06  H18 = 3.2775E+06  H19 = 3.3310E+06  H20 = 3.3310E+06  H21 = 3.3310E+06
 TM 1 =  232.3714  TM 2 =  325.5271  TM 3 =  281.9736  TM 4 =  281.9731  TM 5 =  281.9648  TM 6 =  281.9651  TM 7 =  281.9648
 TM 8 =  281.9653  TM 9 =  330.0837  TM10 =  327.2764  TM11 =  326.6553  TM12 =  325.8418  TM13 =  325.5271  TM14 =  325.0847
 TM15 =  324.3855  TM16 =  383.9946  TM17 =  433.9280  TM18 =  466.5303  TM19 =  484.9429  TM20 =  484.4565  TM21 =  482.4404
 TCS 8 =  343.8896  TCS 9 =  381.2397  TCS10 =  457.5398  TCS11 =  457.5398  TCS12 =  457.5398  TCS13 =  457.5398  TCS14 =  457.5398
 TCS15 =  457.5398  TCS16 =  479.3896  TCS17 =  491.6497  TCS18 =  498.4697  TCS19 =  502.1396  TCS
                             TDLOG:  9        56.3690 10        84.6359
                             U    :  9      6288.9023 10      8768.2266
            TDLOG: 16       113.2274 17        74.9877 18        43.5664 19        23.8123
            U    : 16      4585.5977 17      3885.2039 18      3718.3333 19      3645.6289

 HEAT FLUX = 3.020586E+05                          OUTLET STEAM QUALITY = 4.962092E-01
 NON-BOILING LENGTH = 7.132591E+00               BOILING LENGTH = 6.887406E+00

 DRUM INT. ENERGY = 1.3739E+10   DRUM LEVEL = 1.0000   CVP = 0.9201   ALFA = 1.0000   DPRP = 1.4599E+08

************************************   S T E A M   G E N E R A T I O N   L O O P - 2   ************************************

 TAU:  1  0.896206  2  0.896492  3  0.895702  4  0.887388  5  1.140580  6  1.140580  7  1.140580  8  1.140580
 9  1.140580 10  2.378362 11  3.090784 12  0.0        13 14.449261 14  0.469181 15  3.152439 16 15.991289
17  0.893417 18  1.611632 19  0.318090 20  0.418916 21  1.870427 22  0.481188 23  1.418368 24  0.083072
25  0.047594 26  0.041209 27  0.036878 28  0.034161 29  0.105165 30  3.557830 31  0.332401 32  0.207408
33  0.059743 34********** 35********** 36  1.000000 37  1.999999 38  1.999999 39  1.999999
 FEED WATER FLOW =1.0000  WATER/STEAM FLOW =1.0000  STEAM FLOW =1.0000  INT. SODIUM FLOW =1.0000

 P 1 = 1.2150E+07  P 2 = 1.2150E+07  P 3 = 1.2150E+07  P 4 = 1.2190E+07  P 5 = 1.3190E+07  P 6 = 1.3180E+07  P 7 = 1.3170E+07
 P 8 = 1.3130E+07  P 9 = 1.2890E+07  P10 = 1.2430E+07  P11 = 1.2330E+07  P12 = 1.2200E+07  P13 = 1.2150E+07  P14 = 1.2080E+07
 P15 = 1.1970E+07  P16 = 1.1610E+07  P17 = 1.1240E+07  P18 = 1.0880E+07  P19 = 1.0510E+07  P20 = 1.0410E+07  P21 = 9.9960E+06
 H 1 = 1.0030E+06  H 2 = 1.6142E+06  H 3 = 1.2500E+06  H 4 = 1.2500E+06  H 5 = 1.2500E+06  H 6 = 1.2500E+06  H 7 = 1.2500E+06
 H 8 = 1.2500E+06  H 9 = 1.5272E+06  H10 = 2.0875E+06  H11 = 2.0875E+06  H12 = 2.0875E+06  H13 = 2.0875E+06  H14 = 2.6810E+06
 H15 = 2.6810E+06  H16 = 3.0000E+06  H17 = 3.1780E+06  H18 = 3.2775E+06  H19 = 3.3310E+06  H20 = 3.3310E+06  H21 = 3.3310E+06
 TM 1 =  232.3714  TM 2 =  325.5271  TM 3 =  281.9736  TM 4 =  281.9731  TM 5 =  281.9648  TM 6 =  281.9651  TM 7 =  281.9648
 TM 8 =  281.9653  TM 9 =  330.0837  TM10 =  327.2764  TM11 =  326.6553  TM12 =  325.8418  TM13 =  325.5271  TM14 =  325.0847
 TM15 =  324.3855  TM16 =  383.9946  TM17 =  433.9280  TM18 =  466.5303  TM19 =  484.9429  TM20 =  484.4565  TM21 =  482.4404
 TCS 8 =  343.8896  TCS 9 =  381.2397  TCS10 =  457.5398  TCS11 =  457.5398  TCS12 =  457.5398  TCS13 =  457.5398  TCS14 =  457.5398
 TCS15 =  457.5398  TCS16 =  479.3896  TCS17 =  491.6497  TCS18 =  498.4697  TCS19 =  502.1396  TCS
                             TDLOG:  9        56.3690 10        84.6359
                             U    :  9      6288.9023 10      8768.2266
            TDLOG: 16       113.2274 17        74.9877 18        43.5664 19        23.8123
            U    : 16      4585.5977 17      3885.2039 18      3718.3333 19      3645.6289

 HEAT FLUX = 3.020586E+05                          OUTLET STEAM QUALITY = 4.962092E-01
 NON-BOILING LENGTH = 7.132591E+00               BOILING LENGTH = 6.887406E+00

 DRUM INT. ENERGY = 1.3739E+10   DRUM LEVEL = 1.0000   CVP = 0.9201   ALFA = 1.0000   DPRP = 1.4599E+08
```

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****************************** S T E A M   H E A D E R   T H E R M O D Y N A M I C S ******************************

                  TIME CONSTANT OF THE HEADER PRESSURE GAUGE =  0.150000 SECONDS
      THROTTLE VALVE POSITION =1.0000                          DUMP(BYPASS) VALVE POSITION =0.0
      THROTTLE VALVE FLOW     =1.0000   RELIEF VALVE FLOW =0.0     DUMP(BYPASS) VALVE FLOW     =0.0
      HEADER PRESSURE = 9.9960E+06       TEMPERATURE =  482.4404     SPECIFIC ENTHALPY= 3.3310E+06

         *****     NO CONVERGENCE IN    1 STEPS.   VARIABLE #  49 CHANGED BY  1.09154 %     *****

         *****     NO CONVERGENCE IN    2 STEPS.   VARIABLE #  36 CHANGED BY  0.48926 %     *****

         *****     NO CONVERGENCE IN    3 STEPS.   VARIABLE #  45 CHANGED BY  0.34203 %     *****

         *****     NO CONVERGENCE IN    4 STEPS.   VARIABLE # 110 CHANGED BY  0.16218 %     *****

         *****     NO CONVERGENCE IN    5 STEPS.   VARIABLE # 120 CHANGED BY  0.16218 %     *****

         *****     NO CONVERGENCE IN    6 STEPS.   VARIABLE # 120 CHANGED BY  0.14741 %     *****

         *****     NO CONVERGENCE IN    7 STEPS.   VARIABLE # 402 CHANGED BY  0.02795 %     *****

         *****     NO CONVERGENCE IN    8 STEPS.   VARIABLE # 403 CHANGED BY  0.02435 %     *****

         *****     NO CONVERGENCE IN    9 STEPS.   VARIABLE # 418 CHANGED BY  0.03508 %     *****
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               ***************     CONVERGENCE IN   10 ITERATIONS     ***************


         ******************************     I N P U T   D A T A     ******************************

 DETERMINATION OF STEADY STATE VALUES


         ******************************     I N P U T   D A T A     ******************************

&MASA
MODE=          0,IPRINT=        50,IPK=         10,SSEC= .199999988    ,TMAXSC= 19.8999939
&END
&MASB
P100=  975.000000    ,PD0= .899999976    ,SLOPEP= .0            ,PDEND= .899999976    ,XLOOP= 2.00000000
&END
&MASC
TNEW= 19.0000000    ,  50.0000000    ,  50.0000000    ,SNEW= .199999988    , .199999988    , .199999988    ,IPNEW=          1,
          5,          5
&END
&MASD
TSCRM= 50.0000000    ,  50.0000000    ,TTRIP= 50.0000000    ,  50.0000000    ,  50.0000000    ,  50.0000000    ,  50.0000000    ,
  50.0000000
&END
&MASE
NOPON=          0,          0,          0,          0,MTURB=          0,MDUMP=          0,RSTART=          1,EPSILN=
 .100000005E-03
&END
&MASF
RNSERT= .100000024    ,TNSERT= 50.0000000
&END
&MASG
TNOFW1= 50.0000000    ,TNOFW2= 50.0000000    ,TAUX1= 50.0000000    ,TAUX2= 50.0000000
&END
&BRO1
WI100= 1740.69971    ,WI1= 1740.67310    ,WI2= 1740.67407    ,WIC= 2153.09619    ,WOC= 1885.19702    ,WHC= 139.432144    ,
WCA= 81.3656311    ,WRB= 745.695801    ,WBP= 217.227707    ,WS100= 1610.24976    ,WS1= 1610.24512    ,WS2= 1610.24512    ,
WBRK= 1740.69971
&END
&BRO2
TC= 393.400879    , 590.043701    , 592.302002    , 392.434082    , 566.583496    , 568.442627    , 392.366943    ,
 542.112061    , 543.941162    , 439.545166    , 460.352783    , 387.880127    ,TIP1= 387.880127    ,TIP2= 387.880127    ,
TOP1= 534.703125    ,TOP2= 534.703125    ,TM= 460.573730    , 1876.92920    , 619.207764    , 442.572510    , 1611.25049    ,
 588.495117    , 441.368652    , 1420.69067    , 563.532471    , 492.454346    , 549.467041
&END
```

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&BR03
K1=         8,K2=         8,NP=        10,        10,        10,        10,        10,        10,LP=         0,         0,
         0,         0,         0,         0,N1=        10,         1,         2,        10,L1=         0,         0,
         0,         0,N2=        10,         1,         2,        10,L2=         0,         0,         0,         0
&END
&BR04
TP1=  534.702881    ,  517.447754    ,  499.767578    ,  481.599121    ,  462.952637    ,  443.803223    ,  424.175049    ,
  404.029297    ,  383.415771    ,  534.702881    ,  387.876709    ,  .0            ,  .0            ,TS1=  501.885498    ,
  483.836670    ,  465.335693    ,  446.342041    ,  426.845215    ,  406.848877    ,  386.347412    ,  365.354492    ,
  343.858643    ,  501.885498    ,  .0            ,  .0
&END
&BR05
TP2=  534.702881    ,  517.447998    ,  499.767334    ,  481.599121    ,  462.952637    ,  443.803467    ,  424.175049    ,
  404.029297    ,  383.415771    ,  534.702881    ,  387.876709    ,  .0            ,  .0            ,TS2=  501.885742    ,
  483.836914    ,  465.335693    ,  446.342041    ,  426.844971    ,  406.848877    ,  386.347168    ,  365.354492    ,
  343.858643    ,  501.885742    ,  .0            ,  .0
&END
&BR06
TCI1=  534.702881    ,TCI2=  534.699463    ,TCI3=  387.876709    ,TCI4=  534.702881    ,TCI5=  534.699463    ,TCI6=  387.876709
&END
&BR07
TI11=  501.885498    ,TI12=  343.827637    ,TI13=  343.819580    ,TI14=  343.852295    ,TSI1=  501.885498    ,TSO1=  457.380127    ,
TEI1=  457.380127
&END
&BR08
TI21=  501.885742    ,TI22=  343.827637    ,TI23=  343.819580    ,TI24=  343.852295    ,TSI2=  501.885742    ,TSO2=  457.380127    ,
TEI2=  457.380127
&END
&BR09
DH=  .429769605E-02,  .429769605E-02,  .429769605E-02,  .429769605E-02,  .429769605E-02,  .429769605E-02,  .429769605E-02,
  .429769605E-02,  .429769605E-02,  .359659945E-02,  .371859875E-02,  .323699951    ,AH=  .185799971E-01,  .185799971E-01,
  .185799971E-01,  .320499957    ,  .320499957    ,  .320499957    ,  .282399952    ,  .282399952    ,  .282399952    ,
  .715299696E-02,  .985698700E-01,  .822199583E-01,AIPT=  27.8699646    ,AOPT=  27.8699646
&END
&BR10
XL=  .355699718    ,  .914399922    ,  1.64069939    ,  .355699718    ,  .914399922    ,  1.64069939    ,  .355699718    ,
  .914399922    ,  1.64069939    ,  2.91079903    ,  2.91079903    ,  9.31129551    ,P=  .731519610E-02,  .731519610E-02,
  .731519610E-02,  .731519610E-02,  .731519610E-02,  .731519610E-02,  .731519610E-02,  .731519610E-02,  .731519610E-02,
  .161539949E-01,  .143259950E-01,WL=  .302359939    ,  .302359939    ,  .302359939    ,  .302359939    ,  .302359939    ,
  .302359939    ,  .302359939    ,  .302359939    ,  .302359939    ,  .152399957    ,  .101499915    ,OD=  .585219637E-02,
  .585219637E-02,  .585219637E-02,  .585219637E-02,  .585219637E-02,  .585219637E-02,  .585219637E-02,  .585219637E-02,
  .585219637E-02,  .155449957E-01,  .131059960E-01
&END
&BR11
DPX=  .329179913E-01,APX=  1.93609905    ,ODP=  .914399862    ,  .609599888    ,  .609599888    ,DELP=  .126999952E-01,
  .126999952E-01,  .126999952E-01,XLP=  37.4539795    ,  32.7479858    ,  52.7149811    ,  37.4539795    ,  32.7479858    ,
  52.7149811    ,  7.37919521    ,XL11=  2.30999947    ,XL12=  2.65799904    ,XL21=  2.30999947    ,XL22=  2.65799904
&END
&BR12
DSX=  .199399851E-01,ASX=  .889999866    ,ODI=  .609599888    ,  .457199872    ,  .609599888    ,  .609599888    ,DELI=
  .126999952E-01,  .126999952E-01,  .126999952E-01,  .126999952E-01,DSG=  .516599938E-01,ASG=  .525229871    ,ODSE=  .457199872    ,
DELSE=  .126999952E-01,XLS=  149.999985    ,  9.14399910    ,  25.9079895    ,  60.6369781    ,  248.679932    ,  9.14399910    ,
  25.9079895    ,  110.919952    ,  7.61999893    ,  14.0199986    ,  37.7949829    ,  14.0199986
&END
&BR13
ZIN1= -19.1789856    ,ZIN2= -16.1829834    ,ZON= -11.4339981    ,ZP1= -15.7979965    ,ZP2= -15.7979965    ,ZOPLEV= -6.87169552
&END
&BR14
Z1= -11.4299984    , -7.49799728    , -7.49799728    , -5.79099941    , -5.79099941    , -5.79099941    , -8.22999859    ,
 -10.6699982    , -13.2599983    , -13.2599983    ,Z2= -17.0699921    , -14.0199986    , -10.6699982    , -7.49999714    ,
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 -7.49999714    , -7.49999714    , -7.49999714    , -7.49999714    , -7.49999714    , -9.50999928    ,Z3= -16.4599915    ,
 -11.0599976    , -5.63999939    , -5.63999939    , -5.93999481    , -6.54999924    , -7.18999767    , -10.2099991    ,
 -15.6099987    , -19.1799774
&END
&BR15
Z4= -11.4299984    , -7.49799728    , -7.49799728    , -5.79099941    , -5.79099941    , -5.79099941    , -8.22999859    ,
 -10.6699982    , -13.2599983    , -13.2599983    ,Z5= -17.0699921    , -14.0199986    , -10.6699982    , -7.49999714    ,
 -7.49999714    , -7.49999714    , -7.49999714    , -7.49999714    , -7.49999714    , -9.50999928    ,Z6= -16.4599915    ,
 -11.0599976    , -5.63999939    , -5.63999939    , -5.93999481    , -6.54999924    , -7.18999767    , -10.2099991    ,
 -15.6099987    , -19.1799774
&END
&BR16
ZX1= -7.18999767    , -8.01999760    , -8.84499836    , -9.66999912    , -10.4999952    , -11.3199959    , -12.1499968    ,
 -12.9749975    , -13.7999983    , -16.4649811    , -16.4649811    ,  .0           ,  .0           ,ZX2= -7.18999767    ,
 -8.01999760    , -8.84499836    , -9.66999912    , -10.4999952    , -11.3199959    , -12.1499968    , -12.9749975    ,
 -13.7999983    , -16.4649811    , -16.4649811    ,  .0           ,  .0
&END
&BR17
P1=  845918.750    ,P2=  253006.375    ,P3=  219905.000    ,P4=  36553.7773    ,P5=  1140012.00    ,P6=  1034007.94    ,P7=
  938915.750    ,P8=  939617.187    ,P9=  36554.3047    ,P10=  1140012.00    ,P11=  1034008.19    ,P12=  938915.750
&END
&BR18
DSS=  7999.99609    ,CSS=  502.399658    ,XKSS=  16.7469788
&END
&BR19
PS1=  1567991.00    ,PS2=  252999.812    ,PS3=  219900.375    ,PS4=  1088992.00    ,PS5=  813501.562    ,PS6=  737597.687    ,PS7=
  751401.312    ,PS8=  754901.375    ,PS9=  682499.875
&END
&BR20
PI1=  1567990.00    ,PI2=  252999.125    ,PI3=  219899.625    ,PI4=  1088993.00    ,PI5=  813501.562    ,PI6=  737597.687    ,PI7=
  751401.312    ,PI8=  754901.375    ,PI9=  682499.875
&END
&BR21
ZS1= -4.74999905    , -4.74999905    , -10.3599987    , -13.4999971    , -14.0199986    , -14.1699982    , -14.3299980    ,
 -14.4799986    , -14.6299982    ,  .999999642E-01,ZS2= -12.4699955    ,  .0           ,  .0           ,  .0           ,
  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,ZS3= -6.18999767    ,
  .999999642E-01,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,
  .0           ,  .0           ,ZS4= -7.52999496    , -10.9699984    , -10.6099977    , -3.40999889    , -3.25999928    ,
 -3.25999928    , -3.04999924    , -2.92999935    , -2.79999924    , -2.67999935
&END
&BR22
ZS5= -4.74999905    , -12.6799965    , -13.0099993    , -13.1999969    , -13.4899979    , -13.7799988    , -14.0599957    ,
 -14.3599958    , -14.6299982    ,  .999999642E-01,ZS6= -12.4699955    ,  .0           ,  .0           ,  .0           ,
  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,ZS7= -6.18999767    ,
  .999999642E-01,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,
  .0           ,  .0           ,ZS8= -10.9699984    , -10.5499964    , -10.1299992    , -10.1299992    , -10.1199951    ,
 -10.1199951    , -3.40999889    , -3.16999912    , -2.92999935    , -2.67999935
&END
&BR23
ZHX1= -5.87999821    ,ZHX2= -5.87999821    ,ZSH1= -12.0099955    ,ZSH2= -12.0099955    ,ZEVI1=  .999999642E-01,ZEVI2=
  .999999642E-01,ZEVO1= -12.0099955    ,ZEVO2= -12.0099955    ,ZSP1= -3.09999943    ,ZSP2= -3.09999943
&END
&BR24
PBRK=  951899.937    ,ZBRK= -19.0499878    ,XBRK=  .999999881    ,PGV=  101999.937
&END
&BR25
AA=  2.64999962    , -2.10000038    ,  .850000024    , -.399999976    , -2.60000038    ,  3.94999981    , -.300000012    ,
 -.850000024    ,BB=  2.25000000    , -1.75000000    ,  .750000000    , -.250000000    , -2.60000038    ,  2.60000038    ,
  .0           , -.199999988    ,CC= -.899999976    ,  1.85000038    , -1.60000038    ,  1.64999962    ,  1.44999981    ,
 -2.50000000    ,  1.64999962    , -.399999976    ,DD= -.750000000    ,  1.75000000    , -1.25000000    ,  1.25000000    ,
```

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  1.30000019    , -2.00000000    , 1.10000038    , -.600000024
&END
&KINA
LAM= .199299991    , .207500011E-01, .832999945E-01, .750000030E-02, .136999995E-03,B= .299250009E-02, .507500023E-03,
  .284000002E-01, .210000016E-01, .329999998E-01
&END
&KINB
X0= .939999998    , .939999998    ,ROMAX= 31.0000000    , 8.39999962    ,ROSTUK= 2.75000000    , 2.10000038    ,RINMAX=
  .240000002E-01,ROSUBC= -18.0000000    ,TRESET= 60.0000000    ,XKT= 1.00000000
&END
&KINC
TROM= 558.299805    ,TSTM= 482.199707    ,TSTSP= 482.199707    ,TAURO= 2.00000000    ,TAUST= 2.00000000
&END
&KIND
TFREF= 176.699875    ,TCREF= 176.699875    ,ASOD= -.829999749E-06, .863999685E-05, -.829999749E-06, -.143999923E-04,
  .146899954E-03, -.143999923E-04, -.124999970E-04, -.939999882E-04, -.124999970E-04, .0            , -.388999906E-04,ADOP=
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  .0            ,ACRE= -.166999968E-02
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MATRIX OF INERTIAL LOSS COEFFICIENTS

A11 = 3.954E+02	A12 = 4.198E+01	A13 =-4.590E+00	A14 =-4.590E+00	A15 =-4.590E+00	A16 =-4.590E+00	A17 =-4.590E+00
A21 = 3.909E+02	A22 = 3.280E+01	A23 = 1.215E+01	A24 = 0.0	A25 = 0.0	A26 = 0.0	A27 = 0.0
A31 = 3.909E+02	A32 = 3.280E+01	A33 = 0.0	A34 = 6.557E+02	A35 = 0.0	A36 = 0.0	A37 = 0.0
A41 = 3.909E+02	A42 = 3.280E+01	A43 = 0.0	A44 = 0.0	A45 = 7.839E+01	A46 = 0.0	A47 = 0.0
A51 = 3.909E+02	A52 = 3.280E+01	A53 = 0.0	A54 = 0.0	A55 = 0.0	A56 = 7.130E+00	A57 = 0.0
A61 = 3.909E+02	A62 = 3.280E+01	A63 = 0.0	A64 = 0.0	A65 = 0.0	A66 = 0.0	A67 = 6.723E+01
A71 = 2.099E+01	A72 = 4.164E+02	A73 =-4.590E+00	A74 =-4.590E+00	A75 =-4.590E+00	A76 =-4.590E+00	A77 =-4.590E+00

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                    VALUE OF DETERMINANT IS  1.039E+14

                    INVERSE MATRIX OF INERTIAL LOSS COEFFICIENTS

   A11 = 1.309E-03   A12 = 4.076E-04   A13 = 7.552E-06   A14 = 6.317E-05   A15 = 6.945E-04   A16 = 7.366E-05   A17 =-2.301E-04
   A21 =-1.362E-03   A22 = 4.076E-04   A23 = 7.552E-06   A24 = 6.317E-05   A25 = 6.945E-04   A26 = 7.366E-05   A27 = 2.440E-03
   A31 =-3.843E-02   A32 = 6.809E-02   A33 =-2.633E-04   A34 =-2.203E-03   A35 =-2.422E-02   A36 =-2.568E-03   A37 = 8.151E-04
   A41 =-7.122E-04   A42 =-2.633E-04   A43 = 1.520E-03   A44 =-4.082E-05   A45 =-4.487E-04   A46 =-4.759E-05   A47 = 1.510E-05
   A51 =-5.957E-03   A52 =-2.203E-03   A53 =-4.082E-05   A54 = 1.242E-02   A55 =-3.754E-03   A56 =-3.981E-04   A57 = 1.263E-04
   A61 =-6.549E-02   A62 =-2.422E-02   A63 =-4.487E-04   A64 =-3.754E-03   A65 = 9.898E-02   A66 =-4.377E-03   A67 = 1.389E-03
   A71 =-6.946E-03   A72 =-2.568E-03   A73 =-4.759E-05   A74 =-3.981E-04   A75 =-4.377E-03   A76 = 1.441E-02   A77 = 1.473E-04


         DESIGN PUMP HEAD IS    134.04768
         COVER GAS PRESSURE IS 1.8305E+05
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  .366693974    ,  .444300100E-02,  .549999997E-02,  .705999732E-01
&END
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VX=  .650999695E-02,  .169999972E-01,  .305999778E-01,  .113999963    ,  .292999923    ,  .525999844    ,  .100999951    ,
  .257999957    ,  .462999880    ,  .208999962E-01,  .276999950    ,  .797999740    ,DT=  .410999730E-02,  .410999730E-02,
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&END
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&END
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&END
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&END
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ALFA= 1.00000000
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&SGB13
WFMIN= .199999988    ,WFMAX= 1.14999962    ,CVMAX= 1.00000000    ,WAUXM= 34.9269867    ,HAUW= 155799.937    ,HDAUX=
  1.00000000    ,HDMAX= 1.50000000
&END
&SHD1
VH= 38.5109863    ,KTV= .299999952    ,KDV= 5.00000000    ,TVP= 1.00000000    ,DVP= .0            ,TAU= .149999917    ,PSPTV=
  9995999.00    ,PSPDV= 10099998.0    ,PSPRV= 11029999.0
&END
&SHD2
WT100= 419.549805    ,WNMAX= 1.00000000    ,WNMIN= .199999996E-01,PH= 9994064.00    ,PC= .0            ,CT= 9306999.00    ,
CTV= 689399.937    ,CDV= 15779999.0    ,CRV= .145099875E-05
&END
&SCR1
NOSCRM=          5,         11,         12,         13,         14,         15,          0,          0,          0,          0,
          0,          0,          0,          0,          0,DELAY= .689999998    ,PMPDEL= .689999998    , .689999998    ,
  .689999998    , .689999998    , .689999998    , .689999998
&END
&SCR2
PLIM= 1.14999962    ,TCON= 28.0000000    ,A2= 1.01000023    ,B2= -.990000010    ,C2= .170599997    ,D2= .364000015E-01,A3=
 -1.01000023    ,B3= 1.01000023    ,C3= .196900010    ,D3= .416000001E-01,A4= 1.31799984    ,B4= -1.00000000    ,C4=
  .425000004E-01,A6= .588000007E-01,B6= .144999981    ,C6= -.249999994E-02,A8= .300000012    ,ZLEVEL= 4.19999886    ,THXSCR=
  442.999756
&END
&SCR3
A11= 1.199999981    ,B11= -.990000010    ,C11= .870000124E-01,A12= .493000001E-01,B12= .144999981    ,C12= -.249999994E-02,
DRUMAX= .220000029    ,TVAPSC= 399.999756
&END
&SCR4
TAU= .149999976    , .500000000    , .100000024    , 5.00000000    , 5.00000000    , 5.00000000    , 5.00000000
```

```
STEP #    0                              S T E A D Y   S T A T E   C A L C U L A T I O N
                                            POWER HELD CONSTANT AT  877.50 MWT


                                                 TOTAL VECTOR OF CONTROL INTEGERS
  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   18   19   20   21   23   24   25   26   27
 28   29   30   31   32   33   34   35   36   37   38   39   40   41   42   43   44   45   46   47   48   49   50   51   52
 53   54   55   56   57   58   59   60   61   62   63   64   65   66   67   68   69   70   71   72   73   74   75   76   77
 78   79   80   81   82   83   84   85   86   87   88   89   90   91   92   93   94   95   96   97   98   99  100  101  102
103  104  105  106  107  108  109  110  111  112  113  114  115  116  117  118  119  120  121  122  123  124  125  126  127
128  129  130  131  132  133  134  135  136  137  138  139  140  141  142  143  144  145  146  147  148  149  150  151  152
153  154  155  156  157  158  159  160  161  162  163  164  165  166  167  168  169  170  171  172  173  174  175  176  177
178  179  180  181  182  183  184  185  186  187  188  189  190  191  192  193  194  195  196  197  198  199  200  201  202
203  204  205  206  207  208  209  210  211  212  213  214  215  216  217  218  219  220  221  222  223  224  225  226  227
228  229  230  231  232  233  235  236  237  238  240  241  242  243  244  245  246  247  248  249  250  251  252  253  254
255  256  257  258  259  260  261  262  263  264  265  266  267  268  269  270  271  272  273  274  275  276  277  278  279
280  281  282  283  284  285  286  287  288  289  290  291  292  293  294  295  296  297  298  299  300  301  302  303  304
305  306  307  308  309  310  311  312  313  314  315  316  317  318  319  320  321  322  323  324  325  326  327  328  329
330  331  332  333  334  335  336  337  338  339  340  341  342  343  344  345  346  347  348  349  350  351  352  353  354
355  356  357  358  359  360  361  362  363  364  365  366  367  368  369  370  371  372  373  374  375  376  377  378  379
380  381  382  383  384  385  386  387  388  389  390  391  392  393  394  395  396  397  398  399  400  401  402  403  404
405  406  407  408  409  410  411  412  413  414  415  416  417  418  419  420  421  422  423  424  425  426  427  428  429
430  431  432  435  436  437  438  439  440  441  442  443  444  445  446  447  448  449  450  451  452  453  454  455  456
457  458  459  460  461  462  463  464  465  466  467  468  469  470  471  474  475  476  477  480  483  484  485  486  487
488  489    0    0    0    0    0    0    0    0    0    0    0    0

********************************     P R I M A R Y     C O O L A N T     D Y N A M I C S     **********************************

 FZ1NRM = 0.9000                              FZ2NRM = 0.9000  FZ3NRM = 0.9000  CANRM = 0.9000    RBNRM = 0.9000    BPNRM = 0.9000
 FLOWS: 1    1.5666E+03    2   1.5666E+03    3   1.6967E+03    4   1.2549E+02    5   7.3229E+01    6   6.7113E+02    7   1.9550E+02
 AL1=   0.9000   NEW1=    0.9000   BP1=    0.8100   TMOTN1=    1.0350   HP1=    0.8100   FREQ1=   54.000
 AL2=   0.9000   NEW2=    0.9000   BP2=    0.8100   TMOTN2=    1.0350   HP2=    0.8100   FREQ2=   54.000
 PD =   0.9000   TRISP =  387.780   NEWSP =     0.9000    ASP =    0.9000   XKW = 1.316E-03   EPS = 1.000E-05   N =  0
 TRIM:     387.876     387.876      NEWM:       0.9000       0.9000        ALM:       0.9000       0.9000       INLET PRSNRM = 0.8676
 ET:       0.0              0.0              EW:       -1.3590E-05     -1.3173E-05        EA:        0.0              0.0
 TAU 1 =    0.24978   TAU 2 =    0.22562   TAU 3 =    0.01822   TAU 4 =    0.08695   TAU 5 =    0.00629   TAU 6 =    0.00601
 TAU 7 =    0.01409   TAU 8 =    0.31122   TAU 9 =**********   TAU10 =    5.00000   TAU11 =    0.50000   TAU12 =    0.02000
 TAU13 =    0.31122   TAU14 =**********   TAU15 =    5.00000   TAU16 =    0.50000   TAU17 =    0.02000   TAU18 =    0.0

******************************     R E A C T O R     H E A T     T R A N S F E R     ******************************

 TAU 1 =     2.0924 SEC    TAU 2 =     3.0311 SEC    TAU 3 =     2.0938 SEC    TAU 4 =     2.0912 SEC    TAU 5 =     3.0737 SEC
 TAU 6 =     2.0925 SEC    TAU 7 =     2.0915 SEC    TAU 8 =     3.0305 SEC    TAU 9 =     2.0926 SEC    TAU10 =     7.2801 SEC
 TAU11 =    11.1250 SEC    TAU12 =    14.8366 SEC    TAU13 =     1.6484 SEC    TAU14 =     0.0427 SEC    TAU15 =     0.1048 SEC
 TAU16 =     0.1891 SEC    TAU17 =     0.0482 SEC    TAU18 =     0.1166 SEC    TAU19 =     0.2111 SEC    TAU20 =     0.0487 SEC
 TAU21 =     0.1175 SEC    TAU22 =     0.2137 SEC    TAU23 =     0.1784 SEC    TAU24 =     0.2657 SEC    TAU25 =     3.5066 SEC
 TAU26 =    31.1919 SEC    TAU27 =     0.0    SEC    TAU28 =     0.0427 SEC    TAU29 =     0.0482 SEC    TAU30 =     0.0487 SEC
 TAU31 =     0.1784 SEC    TAU32 =     0.2657 SEC    TAU33 =     3.5066 SEC    TAU
   CORE HOT SPOT:          MAX. COOLANT TEMP. =     699.212          MAX. CLAD TEMP. =     733.496
 PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =  2171.705   CLAD INNER =    503.932   CLAD OUTER =    500.308
 TM 1 =    460.573    TM 2 =  1876.929    TM 3 =    619.208    TM 4 =    442.572    TM 5 =  1611.250    TM 6 =    588.495
 TM 7 =    441.368    TM 8 =  1420.690    TM 9 =    563.532    TM10 =    492.454    TM11 =    549.467    TM
 TC 1 =    393.401    TC 2 =    590.043    TC 3 =    592.302    TC 4 =    392.434    TC 5 =    566.583    TC 6 =    568.442
 TC 7 =    392.367    TC 8 =    542.112    TC 9 =    543.941    TC10 =    439.545    TC11 =    460.353    TC12 =    387.880
 TCI1 =    387.880    TCI2 =    387.880    TCI3 =    387.880    TCI4 =    387.880    TCI5 =    387.880    TCI6 =    387.880
 LOWER PLENUM:                          TOP ZONE TEMP. =    387.880   BOTTOM ZONE TEMP. =    387.880
 UPPER PLENUM:  ZJET =      6.400    TOP ZONE TEMP. =    534.703   BOTTOM ZONE TEMP. =    534.703   NOZZLE TEMP. =    534.703

*************************     I H X - 1     T H E R M A L     C A L C U L A T I O N S     *************************
```

```
   PRI. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
    1    3.0716E+04  2    3.0883E+04  3    3.1213E+04  4    3.1553E+04  5    3.1904E+04  6    3.2266E+04  7    3.2638E+04
 8    3.3023E+04

   SEC. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
    1    3.9124E+04  2    3.9323E+04  3    3.9707E+04  4    4.0103E+04  5    4.0513E+04  6    4.0937E+04  7    4.1376E+04
 8    4.1829E+04

    8 OVERALL HEAT-TRANSF. COEF. VALUES
    1    7.5266E+03  2    7.5448E+03  3    7.5800E+03  4    7.6160E+03  5    7.6527E+03  6    7.6901E+03  7    7.7283E+03
 8    7.7672E+03

    8 LOG-MEAN-TEMP-DIF. VALUES
    1    3.2628E+69  2    6.1236E+01  3    6.2718E+01  4    6.4226E+01  5    6.5753E+01  6    6.7301E+01  7    6.8850E+01
 8    7.0407E+01
 TAUP: 1   4.5337  2   0.7547  3   0.7584  4   0.7619  5   0.7654  6   0.7691  7   0.7728  8   0.7769  9   0.7811 10  99.7843
11  1.0951
 TAUS: 12   0.3622 13   0.3641 14   0.3658 15   0.3676 16   0.3695 17   0.3715 18   0.3736 19   0.3757 20   4.2608 21   5.6955
 TP: 1  534.703  2  517.448  3  499.767  4  481.599  5  462.952  6  443.803  7  424.175  8  404.029  9  383.416 10  534.703
11  387.876
 TS: 1  501.885  2  483.836  3  465.335  4  446.342  5  426.845  6  406.849  7  386.347  8  365.354  9  343.858 10  501.885

 *************************     I H X - 2     T H E R M A L     C A L C U L A T I O N S     *************************


   PRI. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
    1    3.0716E+04  2    3.0883E+04  3    3.1213E+04  4    3.1553E+04  5    3.1904E+04  6    3.2266E+04  7    3.2638E+04
 8    3.3023E+04

   SEC. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
    1    3.9124E+04  2    3.9323E+04  3    3.9707E+04  4    4.0103E+04  5    4.0513E+04  6    4.0937E+04  7    4.1376E+04
 8    4.1829E+04

    8 OVERALL HEAT-TRANSF. COEF. VALUES
    1    7.5266E+03  2    7.5448E+03  3    7.5800E+03  4    7.6160E+03  5    7.6527E+03  6    7.6901E+03  7    7.7283E+03
 8    7.7672E+03

    8 LOG-MEAN-TEMP-DIF. VALUES
    1    3.3214E+01  2    3.4021E+01  3    3.4844E+01  4    3.5681E+01  5    3.6530E+01  6    3.7391E+01  7    3.8251E+01
 8    3.9115E+01
 TAUP: 1   4.5337  2   0.7552  3   0.7587  4   0.7622  5   0.7654  6   0.7690  7   0.7733  8   0.7771  9   0.7811 10  99.7842
11  1.0951
 TAUS: 12   0.3622 13   0.3641 14   0.3658 15   0.3676 16   0.3695 17   0.3715 18   0.3736 19   0.3757 20   4.2608 21   5.6955
 TP: 1  534.703  2  517.448  3  499.767  4  481.599  5  462.952  6  443.803  7  424.175  8  404.029  9  383.416 10  534.703
11  387.876
 TS: 1  501.885  2  483.837  3  465.335  4  446.342  5  426.845  6  406.849  7  386.347  8  365.354  9  343.858 10  501.885

 ************************* I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S *************************

  TAU: 1    1.137913  2    0.311219  3    0.500000  4    0.020000  5    3.999999
  SODIUM FLOW RATE =  0.9000   PUMP SPEED =  0.9000   PUMP HEAD =  0.8100   MOTOR GEN. SET FREQ. =    54.000 CYCLES/SEC
  MAIN MOTOR TORQUE =  1.0000   DRIVE MOTOR TORQUE =  1.0350   PUMP TORQUE =  0.8100   FRICTION TORQUE =  0.0327

 ************************* I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S *************************

  TAU: 1    1.717360  2    0.311219  3    0.500000  4    0.020000  5    3.999999
  SODIUM FLOW RATE =  0.9000   PUMP SPEED =  0.9000   PUMP HEAD =  0.8100   MOTOR GEN. SET FREQ. =    54.000 CYCLES/SEC
  MAIN MOTOR TORQUE =  1.0000   DRIVE MOTOR TORQUE =  1.0350   PUMP TORQUE =  0.8100   FRICTION TORQUE =  0.0327
```

```
************************************   S T E A M   G E N E R A T I O N   L O O P - 1   ************************************

 TAU:  1  0.992828  2  0.993061  3  0.991960  4  0.981507  5  1.267370  6  1.267370  7  1.267370  8  1.267370
 9  1.267370 10  2.536993 11  3.342580 12  0.0        13 14.447732 14  0.469131 15  3.152107 16 15.989627
17  0.893324 18  1.610137 19  0.318660 20  0.419236 21  1.871841 22  0.481551 23  1.575138 24  0.092253
25  0.052009 26  0.045010 27  0.040285 28  0.037319 29  0.116863 30  3.953700 31  0.332400 32  0.207408
33  0.053783 34********** 35********** 36  1.000000 37  1.999999 38  1.999999 39  1.999999
 FEED WATER FLOW =0.9999  WATER/STEAM FLOW =1.0000  STEAM FLOW =0.9000  INT. SODIUM FLOW =0.9000

 P 1 = 1.2150E+07  P 2 = 1.2147E+07  P 3 = 1.2147E+07  P 4 = 1.2187E+07  P 5 = 1.3187E+07  P 6 = 1.3177E+07  P 7 = 1.3167E+07
 P 8 = 1.3127E+07  P 9 = 1.2887E+07  P10 = 1.2427E+07  P11 = 1.2327E+07  P12 = 1.2197E+07  P13 = 1.2147E+07  P14 = 1.2077E+07
 P15 = 1.1967E+07  P16 = 1.1607E+07  P17 = 1.1238E+07  P18 = 1.0878E+07  P19 = 1.0508E+07  P20 = 1.0408E+07  P21 = 9.9941E+06
 H 1 = 1.0030E+06  H 2 = 1.6141E+06  H 3 = 1.2502E+06  H 4 = 1.2502E+06  H 5 = 1.2502E+06  H 6 = 1.2502E+06  H 7 = 1.2502E+06
 H 8 = 1.2502E+06  H 9 = 1.5271E+06  H10 = 2.0867E+06  H11 = 2.0867E+06  H12 = 2.0867E+06  H13 = 2.0867E+06  H14 = 2.6814E+06
 H15 = 2.6814E+06  H16 = 2.9996E+06  H17 = 3.1781E+06  H18 = 3.2771E+06  H19 = 3.3304E+06  H20 = 3.3304E+06  H21 = 3.3304E+06
 TM 1 =  232.3711  TM 2 =  325.5110  TM 3 =  282.0112  TM 4 =  282.0107  TM 5 =  282.0027  TM 6 =  282.0027  TM 7 =  282.0029
 TM 8 =  282.0032  TM 9 =  330.0681  TM10 =  327.2607  TM11 =  326.6392  TM12 =  325.8257  TM13 =  325.5110  TM14 =  325.0688
 TM15 =  324.3694  TM16 =  383.8831  TM17 =  433.9324  TM18 =  466.3872  TM19 =  484.6914  TM20 =  484.2046  TM21 =  482.1868
 TCS 8 =  343.8274  TCS 9 =  381.1807  TCS10 =  457.3799  TCS11 =  457.3799  TCS12 =  457.3799  TCS13 =  457.3799  TCS14 =  457.3799
 TCS15 =  457.3799  TCS16 =  479.1909  TCS17 =  491.4326  TCS18 =  498.2358  TCS19 =  501.8853  TCS
                         TDLOG:  9       56.2987 10        84.5514
                         U    :  9     6263.6211 10      8712.9180
            TDLOG: 16      113.1140 17      74.8187 18       43.4189 19       23.7732
            U    : 16     4366.0352 17    3679.7844 18     3517.0022 19     3446.4854

 HEAT FLUX = 3.013942E+05                       OUTLET STEAM QUALITY = 4.955758E-01
 NON-BOILING LENGTH = 7.125531E+00             BOILING LENGTH = 6.894462E+00

 DRUM INT. ENERGY = 1.3738E+10   DRUM LEVEL = 1.0000   CVP = 0.9200   ALFA = 1.0000   DPRP = 1.4599E+08

************************************   S T E A M   G E N E R A T I O N   L O O P - 2   ************************************

 TAU:  1  0.992829  2  0.993061  3  0.991960  4  0.981507  5  1.267370  6  1.267370  7  1.267370  8  1.267370
 9  1.267370 10  2.536993 11  3.342580 12  0.0        13 14.447732 14  0.469131 15  3.152107 16 15.989627
17  0.893324 18  1.610137 19  0.318660 20  0.419236 21  1.871841 22  0.481551 23  1.575138 24  0.092253
25  0.052009 26  0.045010 27  0.040285 28  0.037319 29  0.116863 30  3.953697 31  0.332400 32  0.207408
33  0.053783 34********** 35********** 36  1.000000 37  1.999999 38  1.999999 39  1.999999
 FEED WATER FLOW =0.9999  WATER/STEAM FLOW =1.0000  STEAM FLOW =0.9000  INT. SODIUM FLOW =0.9000

 P 1 = 1.2150E+07  P 2 = 1.2147E+07  P 3 = 1.2147E+07  P 4 = 1.2187E+07  P 5 = 1.3187E+07  P 6 = 1.3177E+07  P 7 = 1.3167E+07
 P 8 = 1.3127E+07  P 9 = 1.2887E+07  P10 = 1.2427E+07  P11 = 1.2327E+07  P12 = 1.2197E+07  P13 = 1.2147E+07  P14 = 1.2077E+07
 P15 = 1.1967E+07  P16 = 1.1607E+07  P17 = 1.1238E+07  P18 = 1.0878E+07  P19 = 1.0508E+07  P20 = 1.0408E+07  P21 = 9.9941E+06
 H 1 = 1.0030E+06  H 2 = 1.6141E+06  H 3 = 1.2502E+06  H 4 = 1.2502E+06  H 5 = 1.2502E+06  H 6 = 1.2502E+06  H 7 = 1.2502E+06
 H 8 = 1.2502E+06  H 9 = 1.5271E+06  H10 = 2.0867E+06  H11 = 2.0867E+06  H12 = 2.0867E+06  H13 = 2.0867E+06  H14 = 2.6814E+06
 H15 = 2.6814E+06  H16 = 2.9996E+06  H17 = 3.1781E+06  H18 = 3.2771E+06  H19 = 3.3304E+06  H20 = 3.3304E+06  H21 = 3.3304E+06
 TM 1 =  232.3711  TM 2 =  325.5110  TM 3 =  282.0112  TM 4 =  282.0107  TM 5 =  282.0027  TM 6 =  282.0027  TM 7 =  282.0029
 TM 8 =  282.0032  TM 9 =  330.0681  TM10 =  327.2607  TM11 =  326.6392  TM12 =  325.8257  TM13 =  325.5110  TM14 =  325.0688
 TM15 =  324.3694  TM16 =  383.8831  TM17 =  433.9324  TM18 =  466.3872  TM19 =  484.6921  TM20 =  484.2051  TM21 =  482.1875
 TCS 8 =  343.8274  TCS 9 =  381.1807  TCS10 =  457.3799  TCS11 =  457.3799  TCS12 =  457.3799  TCS13 =  457.3799  TCS14 =  457.3799
 TCS15 =  457.3799  TCS16 =  479.1912  TCS17 =  491.4326  TCS18 =  498.2363  TCS19 =  501.8855  TCS
                         TDLOG:  9       56.2987 10        84.5514
                         U    :  9     6263.6211 10      8712.9180
            TDLOG: 16      113.1142 17      74.8188 18       43.4191 19       23.7730
            U    : 16     4366.0352 17    3679.7844 18     3517.0022 19     3446.4866

 HEAT FLUX = 3.013942E+05                       OUTLET STEAM QUALITY = 4.955758E-01
 NON-BOILING LENGTH = 7.125531E+00             BOILING LENGTH = 6.894462E+00

 DRUM INT. ENERGY = 1.3738E+10   DRUM LEVEL = 1.0000   CVP = 0.9200   ALFA = 1.0000   DPRP = 1.4599E+08
```

****************************** S T E A M   H E A D E R   T H E R M O D Y N A M I C S ******************************

TIME CONSTANT OF THE HEADER PRESSURE GAUGE = 0.150000 SECONDS

THROTTLE VALVE POSITION =1.0000 DUMP(BYPASS) VALVE POSITION =0.0

THROTTLE VALVE FLOW =0.9999 RELIEF VALVE FLOW =0.0 DUMP(BYPASS) VALVE FLOW =0.0

HEADER PRESSURE = 9.9941E+06 TEMPERATURE = 482.1868 SPECIFIC ENTHALPY= 3.3304E+06

***** NO CONVERGENCE IN 5 STEPS. VARIABLE # 110 CHANGED BY 1.97781 % *****

***** NO CONVERGENCE IN 10 STEPS. VARIABLE # 232 CHANGED BY 0.70130 % *****

***** NO CONVERGENCE IN 15 STEPS. VARIABLE # 436 CHANGED BY 0.41212 % *****

***** NO CONVERGENCE IN 20 STEPS. VARIABLE # 476 CHANGED BY 0.36457 % *****

***** NO CONVERGENCE IN 25 STEPS. VARIABLE # 476 CHANGED BY 0.26449 % *****

***** NO CONVERGENCE IN 30 STEPS. VARIABLE # 237 CHANGED BY 0.15881 % *****

***** NO CONVERGENCE IN 35 STEPS. VARIABLE # 235 CHANGED BY 0.17716 % *****

***** NO CONVERGENCE IN 40 STEPS. VARIABLE # 237 CHANGED BY 0.13743 % *****

***** NO CONVERGENCE IN 45 STEPS. VARIABLE # 237 CHANGED BY 0.07627 % *****

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STEP #    50                         S T E A D Y   S T A T E   C A L C U L A T I O N
                                          POWER HELD CONSTANT AT  877.50 MWT
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TOTAL VECTOR OF CONTROL INTEGERS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	23	24	25	26	27
28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77
78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102
103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152
153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177
178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202
203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227
228	229	230	231	232	233	235	236	237	238	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254
255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279
280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304
305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329
330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354
355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379
380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404
405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429
430	431	432	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456
457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	474	475	476	477	480	483	484	485	486	487
488	489	0	0	0	0	0	0	0	0	0	0	0	0											

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********************************    P R I M A R Y    C O O L A N T    D Y N A M I C S    ********************************

FZ1NRM = 0.9035                         FZ2NRM = 0.9036  FZ3NRM = 0.9021  CANRM = 0.8738   RBNRM = 0.8900   BPNRM = 0.9099
FLOWS: 1   1.5690E+03   2  1.5690E+03   3  1.7034E+03   4   1.2578E+02   5  7.1095E+01   6  6.6366E+02   7   1.9766E+02
AL1=  0.9034   NEW1=   0.9014   BP1=   0.8178   TMOTN1=    0.8506   HP1=   0.8189   FREQ1=   53.399
AL2=  0.9034   NEW2=   0.9014   BP2=   0.8179   TMOTN2=    0.8507   HP2=   0.8190   FREQ2=   53.401
PD =  0.9000   TRISP =  387.780   NEWSP =   0.9000   ASP =   0.9000   XKW = 1.316E-03   EPS = 1.000E-05   N =  1
TRIM:     379.973     379.972      NEWM:       0.9014      0.9014        ALM:       0.9034       0.9034      INLET PRSNRM = 0.8791
ET:      1.4053E+01     1.4054E+01      EW:        1.7098E-02     1.7133E-02       EA:      0.0              0.0
TAU 1 =   0.24830   TAU 2 =    0.22393   TAU 3 =    0.01788   TAU 4 =    0.08521   TAU 5 =    0.00598   TAU 6 =    0.00583
TAU 7 =   0.01393   TAU 8 =    0.28745   TAU 9 =**********   TAU10 =    5.00000   TAU11 =    0.50000   TAU12 =    0.02000
TAU13 =   0.28746   TAU14 =**********   TAU15 =    5.00000   TAU16 =    0.50000   TAU17 =    0.02000   TAU18 =    0.0

******************************    R E A C T O R    H E A T    T R A N S F E R    ******************************

TAU 1 =    2.0927 SEC   TAU 2 =    3.0316 SEC   TAU 3 =    2.0942 SEC   TAU 4 =    2.0915 SEC   TAU 5 =    3.0742 SEC
TAU 6 =    2.0929 SEC   TAU 7 =    2.0917 SEC   TAU 8 =    3.0310 SEC   TAU 9 =    2.0929 SEC   TAU10 =    7.2813 SEC
TAU11 =   11.1267 SEC   TAU12 =   14.8466 SEC   TAU13 =    1.6495 SEC   TAU14 =    0.0427 SEC   TAU15 =    0.1048 SEC
TAU16 =    0.1892 SEC   TAU17 =    0.0481 SEC   TAU18 =    0.1165 SEC   TAU19 =    0.2109 SEC   TAU20 =    0.0487 SEC
TAU21 =    0.1174 SEC   TAU22 =    0.2135 SEC   TAU23 =    0.1827 SEC   TAU24 =    0.2686 SEC   TAU25 =    3.4760 SEC
TAU26 =   31.2203 SEC   TAU27 =    0.0    SEC   TAU28 =    0.0427 SEC   TAU29 =    0.0481 SEC   TAU30 =    0.0487 SEC
TAU31 =    0.1827 SEC   TAU32 =    0.2686 SEC   TAU33 =    3.4760 SEC   TAU
  CORE HOT SPOT:         MAX. COOLANT TEMP. =   690.375          MAX. CLAD TEMP. =   721.930
PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =  2025.194   CLAD INNER =   494.694   CLAD OUTER =   491.432
TM 1 =   445.696   TM 2 =  1730.418   TM 3 =   607.942   TM 4 =   429.442   TM 5 =  1489.920   TM 6 =   577.704
TM 7 =   428.355   TM 8 =  1317.219   TM 9 =   552.893   TM10 =   477.472   TM11 =   529.447   TM
TC 1 =   385.477   TC 2 =   581.532   TC 3 =   583.821   TC 4 =   384.507   TC 5 =   557.844   TC 6 =   559.732
TC 7 =   384.440   TC 8 =   533.478   TC 9 =   535.335   TC10 =   433.167   TC11 =   453.212   TC12 =   379.972
TCI1 =   379.972   TCI2 =   379.972   TCI3 =   379.972   TCI4 =   379.972   TCI5 =   379.972   TCI6 =   379.972
LOWER PLENUM:                      TOP ZONE TEMP. =   379.972   BOTTOM ZONE TEMP. =   379.972
UPPER PLENUM:  ZJET =     6.400   TOP ZONE TEMP. =   526.469   BOTTOM ZONE TEMP. =   526.469   NOZZLE TEMP. =   526.469

*************************    I H X - 1    T H E R M A L    C A L C U L A T I O N S    *************************
```

```
 TAUP: 1   4.5376  2   0.7577  3   0.7615  4   0.7649  5   0.7681  6   0.7720  7   0.7758  8   0.7799  9   0.7836 10  99.8685
11   1.0959
 TAUS: 12   0.3617 13   0.3635 14   0.3653 15   0.3671 16   0.3690 17   0.3709 18   0.3730 19   0.3751 20   4.2383 21   5.6654
 TP: 1 526.469  2  509.418  3  491.890  4  473.838  5  455.249  6  436.118  7  416.442  8  396.231  9  375.493 10  526.469
11  379.941
 TS: 1 496.887  2  479.031  3  460.679  4  441.782  5  422.339  6  402.348  7  381.824  8  360.767  9  339.226 10  496.887

 ************************    I H X - 2    T H E R M A L    C A L C U L A T I O N S    ************************

 TAUP: 1   4.5377  2   0.7575  3   0.7614  4   0.7648  5   0.7684  6   0.7720  7   0.7755  8   0.7796  9   0.7839 10  99.8722
11   1.0959
 TAUS: 12   0.3617 13   0.3636 14   0.3653 15   0.3671 16   0.3690 17   0.3710 18   0.3730 19   0.3752 20   4.2389 21   5.6662
 TP: 1 526.469  2  509.422  3  491.897  4  473.847  5  455.258  6  436.126  7  416.449  8  396.235  9  375.492 10  526.469
11  379.941
 TS: 1 496.896  2  479.043  3  460.692  4  441.794  5  422.350  6  402.356  7  381.829  8  360.765  9  339.218 10  496.896

 ************************ I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S ************************

  TAU: 1    1.128484  2    0.288562  3    0.500000  4    0.020000  5    3.999999
  SODIUM FLOW RATE =  0.9059   PUMP SPEED =  0.9062   PUMP HEAD =  0.8222   MOTOR GEN. SET FREQ. =    53.586 CYCLES/SEC
  MAIN MOTOR TORQUE =  0.8258   DRIVE MOTOR TORQUE =  0.8547   PUMP TORQUE =  0.8218   FRICTION TORQUE =  0.0328

 ************************ I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S ************************

  TAU: 1    1.702390  2    0.288571  3    0.500000  4    0.020000  5    3.999999
  SODIUM FLOW RATE =  0.9058   PUMP SPEED =  0.9062   PUMP HEAD =  0.8225   MOTOR GEN. SET FREQ. =    53.586 CYCLES/SEC
  MAIN MOTOR TORQUE =  0.8259   DRIVE MOTOR TORQUE =  0.8548   PUMP TORQUE =  0.8220   FRICTION TORQUE =  0.0328

 ***********************************    S T E A M   G E N E R A T I O N   L O O P - 1    ***********************************

  TAU: 1  0.988237  2  0.988510  3  0.987433  4  0.977060  5  1.260592  6  1.260592  7  1.260592  8  1.260592
 9  1.260592 10  2.458376 11  3.400341 12  0.0        13 14.311958 14  0.464765 15  3.122768 16 15.840751
17  0.885004 18  1.664355 19  0.336943 20  0.453204 21  2.022572 22  0.520252 23  1.572708 24  0.092106
25  0.051660 26  0.044781 27  0.040190 28  0.037351 29  0.116929 30  3.955304 31  0.332548 32  0.207196
33  0.053813 34*********** 35********** 36  1.000000 37  1.999999 38  1.999999 39  1.999999
 FEED WATER FLOW =0.9046  WATER/STEAM FLOW =0.9983  STEAM FLOW =0.9052  INT. SODIUM FLOW =0.9059

 P 1 = 1.2150E+07  P 2 = 1.2181E+07  P 3 = 1.2181E+07  P 4 = 1.2218E+07  P 5 = 1.3221E+07  P 6 = 1.3211E+07  P 7 = 1.3200E+07
 P 8 = 1.3160E+07  P 9 = 1.2918E+07  P10 = 1.2463E+07  P11 = 1.2362E+07  P12 = 1.2231E+07  P13 = 1.2181E+07  P14 = 1.2116E+07
 P15 = 1.2005E+07  P16 = 1.1641E+07  P17 = 1.1268E+07  P18 = 1.0905E+07  P19 = 1.0534E+07  P20 = 1.0433E+07  P21 = 1.0016E+07
 H 1 = 1.0030E+06  H 2 = 1.6155E+06  H 3 = 1.2734E+06  H 4 = 1.2734E+06  H 5 = 1.2734E+06  H 6 = 1.2734E+06  H 7 = 1.2734E+06
 H 8 = 1.2734E+06  H 9 = 1.5283E+06  H10 = 2.0358E+06  H11 = 2.0358E+06  H12 = 2.0358E+06  H13 = 2.0358E+06  H14 = 2.6807E+06
 H15 = 2.6807E+06  H16 = 3.0025E+06  H17 = 3.1779E+06  H18 = 3.2728E+06  H19 = 3.3226E+06  H20 = 3.3226E+06  H21 = 3.3226E+06
 TM 1 =  232.3710  TM 2 =  325.5107  TM 3 =  286.0425  TM 4 =  286.0425  TM 5 =  286.0425  TM 6 =  286.0425  TM 7 =  286.0430
 TM 8 =  286.0425  TM 9 =  330.2527  TM10 =  327.4780  TM11 =  326.8572  TM12 =  326.0369  TM13 =  325.7212  TM14 =  325.3093
 TM15 =  324.6064  TM16 =  384.8784  TM17 =  434.0586  TM18 =  464.9470  TM19 =  481.7961  TM20 =  481.2998  TM21 =  479.2344
 TCS 8 =  339.1775  TCS 9 =  377.0586  TCS10 =  453.1650  TCS11 =  453.1650  TCS12 =  453.1650  TCS13 =  453.1650  TCS14 =  453.1650
 TCS15 =  453.1650  TCS16 =  475.1301  TCS17 =  487.0876  TCS18 =  493.5298  TCS19 =  496.8875  TCS
                         TDLOG:  9       49.9035 10       79.8564
                         U    :  9     6270.4102 10     8672.1367
            TDLOG: 16      108.2781 17       69.9985 18       39.5547 19       21.1237
            U    : 16     4382.1641 17     3690.7529 18     3530.8376 19     3462.0576

 HEAT FLUX = 2.833262E+05                        OUTLET STEAM QUALITY = 4.515266E-01
 NON-BOILING LENGTH = 7.382018E+00               BOILING LENGTH = 6.637975E+00

 DRUM INT. ENERGY = 1.3754E+10   DRUM LEVEL = 1.0000   CVP = 0.8628   ALFA = 0.9999   DPRP = 1.4631E+08

 ***********************************    S T E A M   G E N E R A T I O N   L O O P - 2    ***********************************
```

```
 TAU! 1  0.988364  2  0.988638  3  0.987559  4  0.977185  5  1.260765  6  1.260765  7  1.260765  8  1.260765
 9  1.260765 10  2.458522 11  3.400727 12  0.0        13 14.311878 14  0.464762 15  3.122749 16 15.840656
17  0.884998 18  1.664430 19  0.336967 20  0.453250 21  2.022773 22  0.520303 23  1.572760 24  0.092109
25  0.051661 26  0.044782 27  0.040190 28  0.037352 29  0.116933 30  3.955463 31  0.332548 32  0.207197
33  0.053815 34********** 35********** 36  1.000000 37  1.999999 38  1.999999 39  1.999999
 FEED WATER FLOW =0.9046  WATER/STEAM FLOW =0.9983  STEAM FLOW =0.9051  INT. SODIUM FLOW =0.9058

 P 1 = 1.2150E+07  P 2 = 1.2181E+07  P 3 = 1.2181E+07  P 4 = 1.2218E+07  P 5 = 1.3221E+07  P 6 = 1.3210E+07  P 7 = 1.3200E+07
 P 8 = 1.3160E+07  P 9 = 1.2918E+07  P10 = 1.2462E+07  P11 = 1.2362E+07  P12 = 1.2231E+07  P13 = 1.2181E+07  P14 = 1.2115E+07
 P15 = 1.2005E+07  P16 = 1.1641E+07  P17 = 1.1268E+07  P18 = 1.0905E+07  P19 = 1.0534E+07  P20 = 1.0433E+07  P21 = 1.0016E+07
 H 1 = 1.0030E+06  H 2 = 1.6155E+06  H 3 = 1.2734E+06  H 4 = 1.2734E+06  H 5 = 1.2734E+06  H 6 = 1.2734E+06  H 7 = 1.2734E+06
 H 8 = 1.2734E+06  H 9 = 1.5283E+06  H10 = 2.0357E+06  H11 = 2.0357E+06  H12 = 2.0357E+06  H13 = 2.0357E+06  H14 = 2.6807E+06
 H15 = 2.6807E+06  H16 = 3.0025E+06  H17 = 3.1779E+06  H18 = 3.2728E+06  H19 = 3.3226E+06  H20 = 3.3226E+06  H21 = 3.3226E+06
 TM 1 =  232.3710  TM 2 =  325.5107  TM 3 =  286.0444  TM 4 =  286.0444  TM 5 =  286.0447  TM 6 =  286.0444  TM 7 =  286.0444
 TM 8 =  286.0444  TM 9 =  330.2520  TM10 =  327.4768  TM11 =  326.8560  TM12 =  326.0356  TM13 =  325.7200  TM14 =  325.3081
 TM15 =  324.6052  TM16 =  384.8816  TM17 =  434.0637  TM18 =  464.9548  TM19 =  481.8044  TM20 =  481.3081  TM21 =  479.2432
 TCS 8 =  339.1687  TCS 9 =  377.0569  TCS10 =  453.1670  TCS11 =  453.1670  TCS12 =  453.1670  TCS13 =  453.1670  TCS14 =  453.1670
 TCS15 =  453.1670  TCS16 =  475.1348  TCS17 =  487.0950  TCS18 =  493.5376  TCS19 =  496.8965  TCS
                         TDLOG:  9        49.8983 10        79.8570
                         U    :  9      6270.3828 10      8672.0117
             TDLOG: 16      108.2804 17        70.0006 18        39.5557 19        21.1242
             U    : 16     4382.0156 17      3690.6169 18      3530.7141 19      3461.9370

 HEAT FLUX = 2.833240E+05                       OUTLET STEAM QUALITY = 4.514589E-01
 NON-BOILING LENGTH = 7.382274E+00             BOILING LENGTH = 6.637719E+00

 DRUM INT. ENERGY = 1.3754E+10   DRUM LEVEL = 1.0000   CVP = 0.8628   ALFA = 0.9999   DPRP = 1.4631E+08

 ******************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   ******************************

                     TIME CONSTANT OF THE HEADER PRESSURE GAUGE =  0.150000 SECONDS
    THROTTLE VALVE POSITION =0.9738                              DUMP(BYPASS) VALVE POSITION =0.0
    THROTTLE VALVE FLOW     =0.9035   RELIEF VALVE FLOW =0.0     DUMP(BYPASS) VALVE FLOW     =0.0
    HEADER PRESSURE = 1.0016E+07      TEMPERATURE =  481.1809      SPECIFIC ENTHALPY= 3.3276E+06

           *****     NO CONVERGENCE IN    50 STEPS.   VARIABLE # 237 CHANGED BY  0.04426 %     *****

           *****     NO CONVERGENCE IN    55 STEPS.   VARIABLE # 475 CHANGED BY  0.02827 %     *****

           *****     NO CONVERGENCE IN    60 STEPS.   VARIABLE # 436 CHANGED BY  0.02092 %     *****

           *****     NO CONVERGENCE IN    65 STEPS.   VARIABLE # 437 CHANGED BY  0.01269 %     *****
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```
             *************** CONVERGENCE IN  69 ITERATIONS    ***************

         ******************************    I N P U T   D A T A    ******************************

       ******************************    TRANSIENT CALCULATION BEGINS    ******************************
REACTOR INITIALLY AT STEADY - STATE, OPERATING AT  90.0 % OF FULL POWER

PIPING INTEGRITY MAINTAINED

         ******************************    I N P U T   D A T A    ******************************

&MASA
MODE=         1,IPRINT=         20,IPK=        100,SSEC=  .100000024    ,TMAXSC=  49.8999939
&END
&MASB
P100=  975.000000    ,PD0=  .899999976    ,SLOPEP=  .0             ,PDEND=  .899999976    ,XLOOP=  2.00000000
&END
&MASC
TNEW=  1.98999977    ,  9.98999977    ,  39.9900055    ,SNEW=  .199999988    ,  .199999988    ,  .399999976    ,IPNEW=         10,
       50,        10
&END
&MASD
TSCRM=  200.000000    ,  9.98999977    ,TTRIP=  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0
&END
&MASE
NOPON=         0,         0,         0,         0,MTURB=         1,MDUMP=         0,RSTART=         0,EPSILN=
  .100000005E-03
&END
&MASF
RNSERT=  .500000000    ,TNSERT=  .490000010
&END
&MASG
TNOFW1=  .0             ,TNOFW2=  .0             ,TAUX1=  29.9996033    ,TAUX2=  29.9996033
&END
&BRO1
WI100=  1740.69946    ,WI1=  1569.09644    ,WI2=  1569.03882    ,WTC=  1945.48975    ,WOC=  1703.45581    ,WHC=  125.784042    ,
WCA=  71.0930023    ,WRB=  663.677979    ,WBP=  197.667816    ,WS100=  1610.24951    ,WS1=  1458.46899    ,WS2=  1458.26880    ,
WBRK=  1740.69946
```

```
&END
&BR02
TC= 385.027832    , 581.052979    , 583.325684    , 384.058105    , 557.365967    , 559.237549    , 383.991211    ,
  533.001953    , 534.842773    , 432.701172    , 452.744141    , 379.525635    ,TIP1= 379.525635    ,TIP2= 379.525635    ,
TOP1= 525.973145    ,TOP2= 525.973145    ,TM= 445.240479    , 1729.94043    , 607.442627    , 428.986572    , 1489.44409    ,
  577.206055    , 427.899658    , 1316.74365    , 552.397705    , 477.007812    , 528.981689
&END
&BR03
K1=          8,K2=          8,NP=         10,         10,         10,         10,         10,         10,LP=          0,          0,
          0,          0,          0,          0,N1=         10,          1,          2,         10,L1=          0,          0,
          0,          0,N2=         10,          1,          2,         10,L2=          0,          0,          0,          0
&END
&BR04
TP1= 525.972900    , 508.828613    , 491.233398    , 473.139160    , 454.540527    , 435.432373    , 415.814209    ,
  395.687988    , 375.061523    , 525.972900    , 379.507568    , .0            , .0            ,TS1= 496.245361    ,
  478.341064    , 459.969971    , 441.087646    , 421.690430    , 401.778320    , 381.354736    , 360.427490    ,
  339.009277    , 496.245361    , .0            , .0
&END
&BR05
TP2= 525.972900    , 508.833496    , 491.241943    , 473.150391    , 454.552734    , 435.444092    , 415.823975    ,
  395.694580    , 375.062988    , 525.972900    , 379.508789    , .0            , .0            ,TS2= 496.256104    ,
  478.354980    , 459.985107    , 441.103027    , 421.704346    , 401.790039    , 381.362061    , 360.428467    ,
  339.002197    , 496.256104    , .0            , .0
&END
&BR06
TCI1= 525.972900    ,TCI2= 525.992676    ,TCI3= 379.507568    ,TCI4= 525.972900    ,TCI5= 525.992676    ,TCI6= 379.508789
&END
&BR07
TI11= 496.245361    ,TI12= 338.990967    ,TI13= 338.993652    ,TI14= 339.004395    ,TSI1= 496.245361    ,TS01= 452.382568    ,
TEI1= 452.382568
&END
&BR08
TI21= 496.256104    ,TI22= 338.981934    ,TI23= 338.987549    ,TI24= 338.995361    ,TSI2= 496.256104    ,TS02= 452.386719    ,
TEI2= 452.386719
&END
&BR09
DH= .429769233E-02, .429769233E-02, .429769233E-02, .429769233E-02, .429769233E-02, .429769233E-02, .429769233E-02,
  .429769233E-02, .429769233E-02, .359659828E-02, .371859758E-02, .323699653    ,AH= .185799897E-01, .185799897E-01,
  .185799897E-01, .320499837    , .320499837    , .320499837    , .282399893    , .282399893    , .282399893    ,
  .715298951E-02, .985698104E-01, .822198987E-01,AIPT= 27.8699493    ,AOPT= 27.8699493
&END
&BR10
XL= .355699420    , .914399922    , 1.64069843    , .355699420    , .914399922    , 1.64069843    , .355699420    ,
  .914399922    , 1.64069843    , 2.91079807    , 2.91079807    , 9.31129074    ,P= .731519237E-02, .731519237E-02,
  .731519237E-02, .731519237E-02, .731519237E-02, .731519237E-02, .731519237E-02, .731519237E-02, .731519237E-02,
  .161539912E-01, .143259913E-01,WL= .302359879    , .302359879    , .302359879    , .302359879    , .302359879    ,
  .302359879    , .302359879    , .302359879    , .302359879    , .152399898    , .101499856    ,OD= .585219264E-02,
  .585219264E-02, .585219264E-02, .585219264E-02, .585219264E-02, .585219264E-02, .585219264E-02, .585219264E-02,
  .585219264E-02, .155449919E-01, .131059922E-01
&END
&BR11
DPX= .329179727E-01,APX= 1.93609810    ,ODP= .914399445    , .609599471    , .609599471    ,DELP= .126999915E-01,
  .126999915E-01, .126999915E-01,XLP= 37.4539642    , 32.7479706    , 52.7149658    , 37.4539642    , 32.7479706    ,
  52.7149658    , 7.37919044    ,XL11= 2.30999851    ,XL12= 2.65799809    ,XL21= 2.30999851    ,XL22= 2.65799809
&END
&BR12
DSX= .199399665E-01,ASX= .889999807    ,ODI= .609599471    , .457199454    , .609599471    , .609599471    ,DELI=
  .126999915E-01, .126999915E-01, .126999915E-01, .126999915E-01,DSG= .516599752E-01,ASG= .525229812    ,ODSE= .457199454    ,
DELSE= .126999915E-01,XLS= 149.999908    , 9.14399433    , 25.9079742    , 60.6369629    , 248.679855    , 9.14399433    ,
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&END
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ZIN1= -19.1789703    ,ZIN2= -16.1829681    ,ZON= -11.4339933    ,ZP1= -15.7979918    ,ZP2= -15.7979918    ,ZOPLEV= -6.87169075
&END
&BR14
Z1= -11.4299936    , -7.49799252    , -7.49799252    , -5.79099464    , -5.79099464    , -5.79099464    , -8.22999382    ,
 -10.6699934    , -13.2599936    , -13.2599936    ,Z2= -17.0699768    , -14.0199938    , -10.6699934    , -7.49999237    ,
 -7.49999237    , -7.49999237    , -7.49999237    , -7.49999237    , -7.49999237    , -9.50999451    ,Z3= -16.4599762    ,
 -11.0599928    , -5.63999462    , -5.63999462    , -5.93999004    , -6.54999447    , -7.18999290    , -10.2099943    ,
 -15.6099939    , -19.1799622
&END
&BR15
Z4= -11.4299936    , -7.49799252    , -7.49799252    , -5.79099464    , -5.79099464    , -5.79099464    , -8.22999382    ,
 -10.6699934    , -13.2599936    , -13.2599936    ,Z5= -17.0699768    , -14.0199938    , -10.6699934    , -7.49999237    ,
 -7.49999237    , -7.49999237    , -7.49999237    , -7.49999237    , -7.49999237    , -9.50999451    ,Z6= -16.4599762    ,
 -11.0599928    , -5.63999462    , -5.63999462    , -5.93999004    , -6.54999447    , -7.18999290    , -10.2099943    ,
 -15.6099939    , -19.1799622
&END
&BR16
ZX1= -7.18999290    , -8.01999283    , -8.84499359    , -9.66999435    , -10.4999905    , -11.3199911    , -12.1499920    ,
 -12.9749928    , -13.7999935    , -16.4649658    , -16.4649658    , .0    , .0    ,ZX2= -7.18999290    ,
 -8.01999283    , -8.84499359    , -9.66999435    , -10.4999905    , -11.3199911    , -12.1499920    , -12.9749928    ,
 -13.7999935    , -16.4649658    , -16.4649658    , .0    , .0
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&BR17
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  821193.312    ,P8=  826056.062    ,P9=  73723.6250    ,P10=  983433.437    ,P11=  887574.750    ,P12=  821192.062
&END
&BR18
DSS=  7999.99219    ,CSS=  502.399414    ,XKSS=  16.7469635
&END
&BR19
PS1=  1415159.00    ,PS2=  335587.812    ,PS3=  313135.375    ,PS4=  1016924.44    ,PS5=  808656.750    ,PS6=  728168.687    ,PS7=
  757797.625    ,PS8=  761350.625    ,PS9=  682499.750
&END
&BR20
PI1=  1415368.00    ,PI2=  335973.187    ,PI3=  313534.062    ,PI4=  1016907.94    ,PI5=  808650.312    ,PI6=  728156.875    ,PI7=
  757805.625    ,PI8=  761358.687    ,PI9=  682499.750
&END
&BR21
ZS1= -4.74999809    , -4.74999809    , -10.3599939    , -13.4999933    , -14.0199938    , -14.1699934    , -14.3299932    ,
 -14.4799938    , -14.6299934    , .999999046E-01,ZS2= -12.4699907    , .0    , .0    , .0    ,
 .0    , .0    , .0    , .0    , .0    , .0    ,ZS3= -6.18999290    ,
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 -3.25999832    , -3.04999828    , -2.92999840    , -2.79999828    , -2.67999840
&END
&BR22
ZS5= -4.74999809    , -12.6799917    , -13.0099955    , -13.1999931    , -13.4899931    , -13.7799940    , -14.0599909    ,
 -14.3599911    , -14.6299934    , .999999046E-01,ZS6= -12.4699907    , .0    , .0    , .0    ,
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 -10.1199903    , -3.40999794    , -3.16999817    , -2.92999840    , -2.67999840
&END
&BR23
ZHX1= -5.87999344    ,ZHX2= -5.87999344    ,ZSH1= -12.0099907    ,ZSH2= -12.0099907    ,ZEVI1=  .999999046E-01,ZEVI2=
 .999999046E-01,ZEVO1= -12.0099907    ,ZEVO2= -12.0099907    ,ZSP1= -3.09999847    ,ZSP2= -3.09999847
&END
&BR24
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PBRK=  951899.812     ,ZBRK= -19.0499725     ,XBRK=  .999999583     ,pGV=  101999.875
&END
&BR25
AA=  2.64999962     , -2.10000038     ,  .850000024     , -.399999976     , -2.60000038     ,  3.94999981     , -.300000012     ,
 -.850000024     ,BB=  2.25000000     , -1.75000000     ,  .750000000     , -.250000000     , -2.60000038     ,  2.60000038     ,
  .0             , -.199999988     ,CC= -.899999976     ,  1.85000038     , -1.60000038     ,  1.64999962     ,  1.44999981     ,
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  1.30000019     , -2.00000000     ,  1.10000038     , -.600000024
&END
&KINA
LAM=  .199299991     ,  .207500011E-01,  .832999945E-01,  .750000030E-02,  .136999995E-03,B=  .299250009E-02,  .507500023E-03,
  .284000002E-01,  .210000016E-01,  .329999998E-01
&END
&KINB
X0=  .939999998     ,  .939999998     ,ROMAX=  31.0000000     ,  8.39999962     ,ROSTUK=  2.75000000     ,  2.10000038     ,RINMAX=
  .240000002E-01,ROSUBC= -18.0000000     ,TRESET=  60.0000000     ,XKT=  1.00000000
&END
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TROM=  558.299561     ,TSTM=  482.199463     ,TSTSP=  482.199463     ,TAURO=  2.00000000     ,TAUST=  2.00000000
&END
&KIND
TFREF=  176.699738     ,TCREF=  176.699738     ,ASOD= -.829999237E-06,  .863998866E-05, -.829999237E-06, -.143999841E-04,
  .146899823E-03, -.143999841E-04, -.124999888E-04, -.939999736E-04, -.124999888E-04,  .0             , -.388999761E-04,ADOP=
 -.357199996E-02, -.436999984E-01, -.754999928E-03, -.619099997E-01, -.743799984     , -.130899996E-01, -.535800010E-01,
 -.245000005     , -.113300011E-01,  .0             , -.251800001     ,ACAE=  .0             ,  .0             ,  .0             ,
  .0             , -.127999971E-03,  .0             ,  .0             ,  .0             ,  .0             ,  .0             ,
  .0             ,ACRE= -.166999944E-02
&END
&KINE
PRIMA=  11.6800003     ,PRIMB=  10.3299999     ,SECA=  8.96199989     ,SECB=  7.16670036
&END
&KINF
AT=  27.7999725     ,  2.79998684     ,  527.699463
&END
&HYDA
AX=  57.9399719     ,  21.2599640     ,  131.229843     ,  32.7999725     ,  131.229843     ,  8.19999409     ,  57.9399719     ,
  21.2599640     ,  131.229843     ,  32.7999725     ,  131.229843     ,  8.19999409     ,  4.58999825     ,  12.1499901     ,
  655.699463     ,  78.3899689     ,  7.12999153     ,  67.2299652
&END
&HYDB
CA=  1.03999996     ,CB=  .649039745E-01,CE=  .135000013E-01,MINFRT=  1071.19946     ,TMMD=  25495.9883     ,DSPEED=  18.5999756     ,
POLES=  3.00000000     ,PMSSP=  1.99999809
&END
&HYDC
CDBRK=  .809999183E-02,AX5BB=  129.919998     ,AXAB=  1.30999851     ,VOLGV=  81.2999725     ,SGVMID=  4.09999752     ,SGVTOP=
  4.59999752     ,ZGVMID= -11.3999910     ,ZGVTOP= -7.59999084
&END
&HYDD
CONVG=  .500000000     ,FREQ0=  60.0000000     ,XKA=  .500000000     ,TK=  .399999976     ,TS=  .105000019     ,TR=  .229999982E-01,
TMIN=  .119999982E-01,AL0=  .100000016E-01
&END
&HYDE
FREQ1=  53.3993225     ,FREQ2=  53.4010468     ,AL1=  .903365552     ,AL2=  .903388023
&END
&HYDF
TAUWM=  .500000000     ,TAUAM=  .199999996E-01,TAUTM=  5.00000000     ,TRISPN=  387.779541
&END
                    MATRIX OF INERTIAL LOSS COEFFICIENTS

  A11 = 3.954E+02   A12 = 4.198E+01   A13 =-4.590E+00   A14 =-4.590E+00   A15 =-4.590E+00   A16 =-4.590E+00   A17 =-4.590E+00
```

```
A21 = 3.909E+02   A22 = 3.280E+01   A23 = 1.215E+01   A24 = 0.0         A25 = 0.0         A26 = 0.0         A27 = 0.0
A31 = 3.909E+02   A32 = 3.280E+01   A33 = 0.0         A34 = 6.557E+02   A35 = 0.0         A36 = 0.0         A37 = 0.0
A41 = 3.909E+02   A42 = 3.280E+01   A43 = 0.0         A44 = 0.0         A45 = 7.839E+01   A46 = 0.0         A47 = 0.0
A51 = 3.909E+02   A52 = 3.280E+01   A53 = 0.0         A54 = 0.0         A55 = 0.0         A56 = 7.130E+00   A57 = 0.0
A61 = 3.909E+02   A62 = 3.280E+01   A63 = 0.0         A64 = 0.0         A65 = 0.0         A66 = 0.0         A67 = 6.723E+01
A71 = 2.099E+01   A72 = 4.164E+02   A73 =-4.590E+00   A74 =-4.590E+00   A75 =-4.590E+00   A76 =-4.590E+00   A77 =-4.590E+00

                    VALUE OF DETERMINANT IS  1.039E+14


                    INVERSE MATRIX OF INERTIAL LOSS COEFFICIENTS

A11 = 1.309E-03   A12 = 4.076E-04   A13 = 7.552E-06   A14 = 6.317E-05   A15 = 6.945E-04   A16 = 7.366E-05   A17 =-2.301E-04
A21 =-1.362E-03   A22 = 4.076E-04   A23 = 7.552E-06   A24 = 6.317E-05   A25 = 6.945E-04   A26 = 7.366E-05   A27 = 2.440E-03
A31 =-3.843E-02   A32 = 6.809E-02   A33 =-2.633E-04   A34 =-2.203E-03   A35 =-2.422E-02   A36 =-2.568E-03   A37 = 8.151E-04
A41 =-7.122E-04   A42 =-2.633E-04   A43 = 1.520E-03   A44 =-4.082E-05   A45 =-4.487E-04   A46 =-4.759E-05   A47 = 1.510E-05
A51 =-5.957E-03   A52 =-2.203E-03   A53 =-4.082E-05   A54 = 1.242E-02   A55 =-3.754E-03   A56 =-3.981E-04   A57 = 1.263E-04
A61 =-6.549E-02   A62 =-2.422E-02   A63 =-4.487E-04   A64 =-3.754E-03   A65 = 9.898E-02   A66 =-4.377E-03   A67 = 1.389E-03
A71 =-6.946E-03   A72 =-2.568E-03   A73 =-4.759E-05   A74 =-3.981E-04   A75 =-4.377E-03   A76 = 1.441E-02   A77 = 1.473E-04


     DESIGN PUMP HEAD IS    134.04768
     COVER GAS PRESSURE IS 1.8305E+05
&RTH1
PF= .101100001E-02, .355210006E-01, .405000057E-03, .128789991E-01, .486384988    , .515199825E-02, .111100003E-01,
 .366693974    , .444300100E-02, .549999997E-02, .705999732E-01
&END
&RTH2
VX= .6509993?3E-02, .169999935E-01, .305999480E-01, .113999903    , .292999864    , .525999367    , .100999892    ,
 .257999897    , .462999463    , .208999924E-01, .276999891    , .797999322    ,DT= .410999358E-02, .410999358E-02,
 .410999358E-02, .410999358E-02, .410999358E-02, .410999358E-02, .410999358E-02, .410999358E-02, .410999358E-02,
 .337999850E-02, .465999171E-02,VIP1= 81.1669769    ,VIP2= 9.01798534
&END
&RTH3
DF= 10999.9922    , 10999.9922    , 10999.9922    , 10999.9922    , 10999.9922    , 10999.9922    , 10999.9922    ,
 10999.9922    , 10999.9922    , 2450.79956    , 10999.9922    ,CF= 326.569580    , 326.569580    , 326.569580    ,
 326.569580    , 326.569580    , 326.569580    , 326.569580    , 326.569580    , 326.569580    , 1297.89941    ,
 326.569580    ,XKF= 3.76799583    , 3.53399658    , 3.76799583    , 3.76799583    , 3.33399677    , 3.76799583    ,
 3.76799583    , 3.53399658    , 3.76799583    , 10.3849974    , 3.76799583    ,DG= .165199934E-03, .165199934E-03,
 .165199934E-03, .165199934E-03, .165199934E-03, .165199934E-03, .165199934E-03, .165199934E-03, .165199934E-03,
 .165199934E-03, .190499864E-03,XKG= .308099806    ,DC= .380999700E-04, .380999700E-04, .380999700E-04, .380999700E-04,
 .380999700E-04, .380999700E-04, .380999700E-04, .380999700E-04, .380999700E-04, .162599864E-02, .380999700E-04,XKCL=
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&END
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VF= .821199268E-02, .210999921E-01, .821199268E-02, .139499903    , .358599901    , .139499903    , .123099864    ,
 .316399872    , .123099864    , .155899882    , 1.70099831    ,XL= .507799447    , .914399922    , .507799447    ,
 .507799447    , .914399922    , .507799447    , .507799447    , .914399922    , .507799447    , 1.98099804    ,
 1.62499809    ,R= .237499783E-02, .237499783E-02, .237499783E-02, .237499783E-02, .237499783E-02, .237499783E-02,
 .237499783E-02, .237499783E-02, .237499783E-02, .596699119E-02, .603499264E-02,XN= 1302.00000    , 1302.00000    ,
 1302.00000    , 22134.0000    , 22134.0000    , 22134.0000    , 19530.0000    , 19530.0000    , 19530.0000    ,
 703.000000    , 9150.00000
&END
&RTH5
RO= .643099606    ,ZCH= 3.40999794    ,DON= .914399922    ,HIF= 559.879639
&END
&RTH6
HCFAC= 1.53999996    ,FLFAC= 3.48999977    ,CLFAC= 1.19200039
&END
&HX1A
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DEXT= .222199708E-01,PITCH= .253999718E-01,XKSS= 16.7469635    ,NT= 2850.00000    ,BP= .300000012E-01,ACF= .800000012
&END
&HX1B
VIP= 8.36199093    ,VOP= 1.99599838    ,VBP= 5.69199848    ,VIS= 7.12199783    ,VOS= 9.49198818
&END
&HX2A
DEXT= .222199708E-01,PITCH= .253999718E-01,XKSS= 16.7469635    ,NT= 2850.00000    ,BP= .300000012E-01,ACF= .800000012
&END
&HX2B
VIP= 8.36199093    ,VOP= 1.99599838    ,VBP= 5.69199848    ,VIS= 7.12199783    ,VOS= 9.49198818
&END
&IHA1
DSPEED= 18.5999756    ,TMMD= 25495.9883    ,MINERT= 1071.19946    ,PMSSP= 1.99999809
&END
&IHA2
PTSP= 9995998.00    ,KFT= .500000000    ,KST= .500000000    ,KSF= .500000000    ,TAUS= .500000000    , .199999996E-01,
  4.00000000
&END
&IHA3
A1= 1.03999996    ,A2= .649039745E-01,A3= .135000013E-01,AZ= .100000016E-01,TS= .105000019    ,TR= .229999982E-01,TMIN=
  .119999982E-01,GFI= 60.0000000    ,XNP= 3.00000000    ,ALFA= .906249166    ,GF= 53.5860138
&END
&IHB1
TMMD= 25495.9883    ,MINERT= 1071.19946    ,GFI= 60.0000000    ,ALFA= .906235397    ,GF= 53.5857697
&END
&IHB2
PTSP= 9995998.00    ,KFT= .500000000    ,KST= .500000000    ,KSF= .500000000    ,TAUS= .500000000    , .199999996E-01,
  4.00000000
&END
&SGA01
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  13195170.0    , 13155222.0    , 12913103.0    , 12457882.0    , 12357681.0    , 12226174.0    , 12175901.0    ,
  12110594.0    , 11999104.0    , 11633878.0    , 11258571.0    , 10894070.0    , 10520077.0    , 10419020.0    ,
  10001032.0
&END
&SGA02
H= 1002997.37    , 1615281.00    , 1272522.00    , 1272522.00    , 1272522.00    , 1272522.00    , 1272522.00    ,
  1272522.00    , 1528115.00    , 2031189.00    , 2031189.00    , 2031189.00    , 2031189.00    , 2680753.00    ,
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&END
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TCS= .0         , .0          , .0          , .0          , .0          , .0          , .0          ,
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&END
&SGA04
XLT= 14.0199938    ,XL= .0    , 9.14399433    , .0    , 36.5759735    , 1.52399826    , 10.2399921    ,
  72.1459656    , 2.62299824    , 7.41022110    , 6.60977268    , 7.05499172    , 35.3569641    , 6.09599400    ,
  45.7199707    , 2.62299824    , 3.50499821    , 3.50499821    , 3.50499821    , 3.50499821    , 7.05499172    ,
  106.679916    ,ACF= .649999976    ,TKON= 37.7299500
&END
&SGA05
Z= 3.80999851    , 4.26699829    , 4.26699829    , -15.0629902    , -13.4109936    , -14.9349937    , -17.9829712    ,
 -15.3599911    , -7.94976902    , -1.33999825    , 2.70499802    , 9.75399399    , 4.26699829    , -17.9829712    ,
 -15.3599911    , -11.8549910    , -8.34999180    , -4.84499836    , -1.33999825    , 2.70499802    , 2.70499802
&END
&SGA06
XLS= .0         , .0          , .0          , .0          , .0          , .0          , .0          ,
  .0            , 7.41022110    , 6.60977268    , 7.43699169    , 7.43699169    , 7.43699169    , 7.43699169    ,
  7.43699169    , 3.50499821    , 3.50499821    , 3.50499821    , 3.50499821
```

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&END
&SGA07
PITCH= .309999734E-01,D= .228599846    , 1.82899857    , .431999087    , .431999087    , .380999625    , .380999625    ,
  .228599846    , .102999881E-01, .102999881E-01, .102999881E-01, .102999881E-01, .380999625    , .329999506    ,
  .278999805    , .102999881E-01, .102999881E-01, .102999881E-01, .102999881E-01, .102999881E-01, .102999881E-01,
  .431999087
&END
&SGA08
DS= .0           , .0            , .0            , .0            , .0            , .0            , .0            ,
  .926999390    , .926999390    , .926999390    , .431999445    , .431999445    , .431999445    , .431999445    ,
  .431999445    , .926999390    , .926999390    , .926999390    , .926999390    ,DEL= .253999718E-01, .253999718E-01,
  .253999718E-01, .253999718E-01, .253999718E-01, .253999718E-01, .253999718E-01, .276899710E-02, .276899710E-02,
  .276899710E-02, .276899710E-02, .253999718E-01, .253999718E-01, .253999718E-01, .276899710E-02, .276899710E-02,
  .276899710E-02, .276899710E-02, .276899710E-02, .276899710E-02, .253999718E-01,XN= 1.00000000    , 1.00000000    ,
  1.00000000    , 1.00000000    , 1.00000000    , 1.00000000    , 1.00000000    , 757.000000    , 757.000000    ,
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  757.000000    , 757.000000    , 757.000000    , 757.000000    , 1.00000000
&END
&SGA09
A1= 1.03999996    ,A2= .649039745E-01,AZ= .100000016E-01,TS= .105000019    ,TR= .229999982E-01,TMIN= .119999982E-01,DSPEED=
  18.5999756    ,SSPEED= 19.9999695    ,TMD= 25495.9883    ,MINERT= 1071.19946
&END
&SGA10
KFW= .499999896E-02,KCV= .500000000    ,HDSP= 1.00000000
&END
&SGA11
W1100= 139.849838    ,W2100= 279.699219    ,W1= 126.936295    ,W2= 279.245117    ,W3= 126.936295    ,CVP= .864712059    ,
ALFA= .999889493
&END
&SGA12
TAUS= 1.00000000    , 2.00000000    , 2.00000000    , 2.00000000
&END
&SGA13
WFMIN= .199999988    ,WFMAX= 1.14999962    ,CVMAX= 1.00000000    ,WAUXM= 34.9269714    ,HAUW= 155799.875    ,HDAUX=
  1.00000000    ,HDMAX= 1.50000000
&END
&SGB01
EPSI= 344.999512    ,P= 12149991.0    , 12175599.0    , 12175599.0    , 12213279.0    , 13215631.0    , 13205349.0    ,
  13194864.0    , 13154916.0    , 12912793.0    , 12457577.0    , 12357378.0    , 12225871.0    , 12175599.0    ,
  12110305.0    , 11998829.0    , 11633652.0    , 11258394.0    , 10893942.0    , 10520000.0    , 10418956.0    ,
  10001032.0
&END
&SGB02
H= 1002997.37    , 1615268.00    , 1272538.00    , 1272538.00    , 1272538.00    , 1272538.00    , 1272538.00    ,
  1272538.00    , 1528102.00    , 2031115.00    , 2031115.00    , 2031115.00    , 2031115.00    , 2680760.00    ,
  2680760.00    , 3000597.00    , 3175492.00    , 3270554.00    , 3320652.00    , 3320652.00    , 3320652.00
&END
&SGB03
TCS= .0          , .0            , .0            , .0            , .0            , .0            , .0            ,
  338.981934    , 376.948242    , 452.386719    , 452.386719    , 452.386719    , 452.386719    , 452.386719    ,
  452.386719    , 474.323242    , 486.326172    , 492.838135    , 496.256104
&END
&SGB04
XLT= 14.0199938    ,XL= .0            , 9.14399433    , .0            , 36.5759735    , 1.52399826    , 10.2399921    ,
  72.1459656    , 2.62299824    , 7.41031361    , 6.60967922    , 7.05499172    , 35.3569641    , 6.09599400    ,
  45.7199707    , 2.62299824    , 3.50499821    , 3.50499821    , 3.50499821    , 3.50499821    , 7.05499172    ,
  106.679916    ,ACF= .649999976    ,TKON= 37.7299500
&END
&SGB05
Z= 3.80999851    , 4.26699829    , 4.26699829    , -15.0629902    , -13.4109936    , -14.9349937    , -17.9829712    ,
```

```
 -15.3599911    , -7.94967651   , -1.33999825   ,  2.70499802   ,  9.75399399   ,  4.26699829   , -17.9829712   ,
 -15.3599911    , -11.8549910   , -8.34999180   , -4.84499836   , -1.33999825   ,  2.70499802   ,  2.70499802
&END
&SGB06
XLS=  .0        ,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,
  .0            ,  7.41031361   ,  6.60967922   ,  7.43699169   ,  7.43699169   ,  7.43699169   ,  7.43699169   ,
  7.43699169    ,  3.50499821   ,  3.50499821   ,  3.50499821   ,  3.50499821
&END
&SGB07
PITCH=  .309999734E-01,D=  .228599846    ,  1.82899857   ,  .431999087   ,  .431999087   ,  .380999625   ,  .380999625   ,
  .228599846    , .102999881E-01, .102999881E-01, .102999881E-01, .102999881E-01, .380999625   , .329999506    ,
  .278999805    , .102999881E-01, .102999881E-01, .102999881E-01, .102999881E-01, .102999881E-01, .102999881E-01,
  .431999087
&END
&SGB08
DS=  .0         ,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,  .0           ,
  .926999390    , .926999390    , .926999390    , .431999445    , .431999445    , .431999445    , .431999445    ,
  .431999445    , .926999390    , .926999390    , .926999390    , .926999390    ,DEL=  .253999718E-01,  .253999718E-01,
  .253999718E-01, .253999718E-01, .253999718E-01, .253999718E-01, .253999718E-01, .276899710E-02, .276899710E-02,
  .276899710E-02, .276899710E-02, .253999718E-01, .253999718E-01, .253999718E-01, .276899710E-02, .276899710E-02,
  .276899710E-02, .276899710E-02, .276899710E-02, .276899710E-02, .253999718E-01,XN=  1.00000000   ,  1.00000000   ,
  1.00000000    , 1.00000000    , 1.00000000    , 1.00000000    , 1.00000000    , 757.000000    , 757.000000    ,
  757.000000    , 757.000000    , 1.00000000    , 2.00000000    , 1.00000000    , 757.000000    , 757.000000    ,
  757.000000    , 757.000000    , 757.000000    , 757.000000    , 1.00000000
&END
&SGB09
TMD=  25495.9883    ,MINERT=  1071.19946
&END
&SGB10
KFW=  .499999896E-02,KCV=  .500000000    ,HDSP=  1.00000000
&END
&SGB11
W1100=  139.849838    ,W2100=  279.699219    ,W1=  126.926254    ,W2=  279.245361    ,W3=  126.926254    ,CVP=  .864666820    ,
ALFA=  .999889553
&END
&SGB12
TAUS=  1.00000000    ,  2.00000000    ,  2.00000000    ,  2.00000000
&END
&SGB13
WFMIN=  .199999988    ,WFMAX=  1.14999962    ,CVMAX=  1.00000000    ,WAUXM=  34.9269714    ,HAUW=  155799.875    ,HDAUX=
  1.00000000    ,HDMAX=  1.50000000
&END
&SHD1
VH=  38.5109711    ,KTV=  .299999893    ,KDV=  5.00000000    ,TVP=  .974957764    ,DVP=  .0           ,TAU=  .149999857    ,PSPTV=
  9995998.00    ,PSPDV=  10099997.0    ,PSPRV=  11029997.0
&END
&SHD2
WT100=  419.549561    ,WNMAX=  1.00000000    ,WNMIN=  .199999996E-01,PH=  10001032.0    ,PC=  .0           ,CT=  9306997.00    ,
CTV=  689399.875    ,CDV=  15779997.0    ,CRV=  .145099784E-05
&END
&SCR1
NOSCRM=          5,          11,          12,          13,          14,          15,           0,           0,           0,           0,
           0,           0,           0,           0,           0,DELAY=  .689999998    ,PMPDEL=  .689999998    ,  .689999998    ,
  .689999998    ,  .689999998    ,  .689999998    ,  .689999998
&END
&SCR2
PLIM=  1.14999962    ,TCON=  28.0000000    ,A2=  1.01000023    ,B2= -.990000010    ,C2=  .170599997    ,D2=  .364000015E-01,A3=
 -1.01000023    ,B3=  1.01000023    ,C3=  .196900010    ,D3=  .416000001E-01,A4=  1.31799984    ,B4= -1.00000000    ,C4=
  .425000004E-01,A6=  .588000007E-01,B6=  .144999981    ,C6= -.249999994E-02,A8=  .300000012    ,ZLEVEL=  4.19999790    ,THXSCR=
  442.999512
```

```
&END
&SCR3
A11=  1.19999981     ,B11= -.990000010     ,C11=  .870000124E-01,A12=  .493000001E-01,B12=  .144999981     ,C12= -.249999994E-02,
DRUMAX=  .220000029     ,TVAPSC=  399.999512
&END
&SCR4
TAU=  .149999976     ,  .500000000     ,  .100000024     ,  5.00000000     ,  5.00000000     ,  5.00000000     ,  5.00000000
&END
                    **** PRIMARY PUMP #1 TRIP AT  0.0    SEC ****

                    **** PRIMARY PUMP #2 TRIP AT  0.0    SEC ****

                    **** INTERMEDIATE PUMP #1 TRIP AT  0.0    SEC ****

                    **** INTERMEDIATE PUMP #2 TRIP AT  0.0    SEC ****

                    **** RECIRCULATION PUMP #1 TRIP AT  0.0    SEC ****

                    **** RECIRCULATION PUMP #2 TRIP AT  0.0    SEC ****

          <<<<<<<<<<<<<<<< W A R N I N G    TURBINE TRIPPED AT TIME =      0.0    SECONDS>>>>>>>>>>>>>>>>
```

```
   STEP #      0   TIME =     0.0       SEC    S =  0.10000 SEC

                                                       TOTAL VECTOR OF CONTROL INTEGERS
  11   12   13   14   15   20   25   26   40   41   43   44   46   47   53   54   55   56   81   82   83   84  106  107  108
 109  233  238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292  293  294  295
 296  297  298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342  343  344  345
 346  347  348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411  423  424  425
 426  427  428  432  450  462  463  464  465  466  467  471  485    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0

*************************    N E U T R O N    K I N E T I C S    C A L C U L A T I O N S    *************************

 PTOT =       877.499 MWT       PN =        805.193 MWT      PFP =          72.306 MWT
 PDN :     1     2.410 MWT     2    0.409 MWT     PFP :     3   24.921 MWT     4    18.427 MWT     5    28.957 MWT
 ROTOT =        0.0      $      ROCR1 =       21.265839 $      ROCR2 =        0.0       $      ROFDBK =      -3.265839 $
 RODOP =       -1.604691 $      ROSOD =       -0.019278 $      ROCRE =       -1.097449 $      ROCAE  =      -0.544421 $
 TRO    =     549.025            TROM   =     558.299             TSTM   =     482.199
 PD =           0.9000          ETST   =       0.0              ETRO   =       44.708008    EF =      0.050000    DELRO =      0.0
 PTOTNORM =     0.9000          PNNORM =       0.8258           PFPNORM =       0.0742      SCRAM RODS!    PRIM =    0.0    %    SEC =     0.0    %
 TAU 1 =      5.0176            TAU 2 =     48.1928             TAU 3 =     12.0048               TAU 4 =    133.3333
 TAU 5 = 7299.2695              TAU 6 =      2.0000             TAU 7 =       2.0000              TAU 8 =     60.0000

*******************************    P R I M A R Y    C O O L A N T    D Y N A M I C S    *******************************

 FZ1NRM = 0.9036                                  FZ2NRM = 0.9036  FZ3NRM = 0.9021  CANRM = 0.8737   RBNRM = 0.8900   BPNRM = 0.9100
 FLOWS: 1    1.5691E+03    2    1.5690E+03    3    1.7035E+03    4    1.2578E+02    5    7.1093E+01    6    6.6368E+02    7    1.9767E+02
 AL1=   0.9034   NEW1=    0.9014   BP1=    0.8178   TMOTN1=    0.0         HP1=    0.8189   FREQ1=    53.399
 AL2=   0.9034   NEW2=    0.9014   BP2=    0.8179   TMOTN2=    0.0         HP2=    0.8190   FREQ2=    53.401
 PD =   0.9000   TRISP =  387.779   NEWSP =    0.9000   ASP =    0.9000   XKW = 1.316E-03   EPS = 1.000E-05   N =  0
 TRIM:       379.507     379.509     NEWM:        0.9014      0.9014      ALM:        0.9034       0.9034       INLET PRSNRM = 0.8792
 ET:       1.4890E+01    1.4887E+01       EW:       1.8161E-02      1.8192E-02       EA:       0.0             0.0
 TAU 1 =    0.24827    TAU 2 =    0.22391    TAU 3 =    0.01788    TAU 4 =    0.08521    TAU 5 =    0.00598    TAU 6 =    0.00583
 TAU 7 =    0.01393    TAU 8 =    1.79495    TAU 9 =***********    TAU10 =    5.00000    TAU11 =    0.50000    TAU12 =    0.02000
 TAU13 =    1.79486    TAU14 =**********    TAU15 =    5.00000    TAU16 =    0.50000    TAU17 =    0.02000    TAU18 =    0.0

******************************    R E A C T O R    H E A T    T R A N S F E R    ******************************

 TAU 1 =      2.0927 SEC    TAU 2 =      3.0316 SEC    TAU 3 =      2.0942 SEC    TAU 4 =      2.0915 SEC    TAU 5 =      3.0742 SEC
 TAU 6 =      2.0929 SEC    TAU 7 =      2.0917 SEC    TAU 8 =      3.0310 SEC    TAU 9 =      2.0929 SEC    TAU10 =      7.2813 SEC
 TAU11 =     11.1266 SEC    TAU12 =     14.8478 SEC    TAU13 =      1.6497 SEC    TAU14 =      0.0427 SEC    TAU15 =      0.1048 SEC
 TAU16 =      0.1892 SEC    TAU17 =      0.0481 SEC    TAU18 =      0.1165 SEC    TAU19 =      0.2109 SEC    TAU20 =      0.0487 SEC
 TAU21 =      0.1174 SEC    TAU22 =      0.2135 SEC    TAU23 =      0.1828 SEC    TAU24 =      0.2686 SEC    TAU25 =      3.4762 SEC
 TAU26 =     31.2235 SEC    TAU27 =      0.0    SEC    TAU28 =      0.0427 SEC    TAU29 =      0.0481 SEC    TAU30 =      0.0487 SEC
 TAU31 =      0.1828 SEC    TAU32 =      0.2686 SEC    TAU33 =      3.4762 SEC    TAU
   CORE HOT SPOT:          MAX. COOLANT TEMP. =     689.877          MAX. CLAD TEMP. =     721.425
 PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =  2024.717   CLAD INNER =   494.227   CLAD OUTER =   490.966
```

```
TM 1 =    445.240   TM 2 =  1729.940   TM 3 =    607.442   TM 4 =    428.986   TM 5 =  1489.444   TM 6 =    577.206
TM 7 =    427.899   TM 8 =  1316.743   TM 9 =    552.397   TM10 =    477.008   TM11 =    528.981   TM
TC 1 =    385.028   TC 2 =    581.053   TC 3 =    583.325   TC 4 =    384.058   TC 5 =    557.366   TC 6 =    559.237
TC 7 =    383.991   TC 8 =    533.002   TC 9 =    534.843   TC10 =    432.701   TC11 =    452.744   TC12 =    379.525
TCI1 =    379.525   TCI2 =    379.525   TCI3 =    379.525   TCI4 =    379.525   TCI5 =    379.525   TCI6 =    379.525
LOWER PLENUM:                         TOP ZONE TEMP. =   379.525   BOTTOM ZONE TEMP. =   379.525
UPPER PLENUM:  ZJET =     6.400   TOP ZONE TEMP. =    525.973   BOTTOM ZONE TEMP. =    525.973   NOZZLE TEMP. =   525.973

************************     I H X - 1     T H E R M A L     C A L C U L A T I O N S     ************************


   PRI. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
     1    3.0262E+04  2    3.0427E+04  3    3.0754E+04  4    3.1091E+04  5    3.1439E+04  6    3.1798E+04  7    3.2168E+04
 8    3.2550E+04

   SEC. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
     1    3.8058E+04  2    3.8253E+04  3    3.8629E+04  4    3.9018E+04  5    3.9421E+04  6    3.9837E+04  7    4.0268E+04
 8    4.0713E+04

     8 OVERALL HEAT-TRANSF. COEF. VALUES
     1    7.4544E+03  2    7.4728E+03  3    7.5083E+03  4    7.5445E+03  5    7.5816E+03  6    7.6194E+03  7    7.6580E+03
 8    7.6973E+03

     8 LOG-MEAN-TEMP-DIF. VALUES
     1    3.2628E+69  2    5.5573E+01  3    5.6982E+01  4    5.8410E+01  5    5.9853E+01  6    6.1302E+01  7    6.2746E+01
 8    6.4180E+01
TAUP: 1   4.5381  2   0.7578  3   0.7611  4   0.7648  5   0.7685  6   0.7721  7   0.7760  8   0.7796  9   0.7838 10  99.8794
11   1.0960
TAUS: 12   0.3619 13   0.3637 14   0.3654 15   0.3672 16   0.3691 17   0.3711 18   0.3731 19   0.3752 20   4.2395 21   5.6668
TP: 1  525.973  2  508.828  3  491.233  4  473.139  5  454.540  6  435.432  7  415.814  8  395.688  9  375.061 10  525.973
11  379.507
TS: 1  496.245  2  478.341  3  459.970  4  441.087  5  421.690  6  401.778  7  381.354  8  360.427  9  339.009 10  496.245

************************     I H X - 2     T H E R M A L     C A L C U L A T I O N S     ************************


   PRI. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
     1    3.0262E+04  2    3.0427E+04  3    3.0754E+04  4    3.1091E+04  5    3.1439E+04  6    3.1798E+04  7    3.2168E+04
 8    3.2550E+04

   SEC. SOD.  8 CONVECTION HEAT-TRANS. COEF. VALUES
     1    3.8056E+04  2    3.8251E+04  3    3.8627E+04  4    3.9016E+04  5    3.9419E+04  6    3.9836E+04  7    4.0266E+04
 8    4.0712E+04

     8 OVERALL HEAT-TRANSF. COEF. VALUES
     1    7.4544E+03  2    7.4727E+03  3    7.5082E+03  4    7.5444E+03  5    7.5815E+03  6    7.6193E+03  7    7.6579E+03
 8    7.6972E+03

     8 LOG-MEAN-TEMP-DIF. VALUES
     1    3.0097E+01  2    3.0866E+01  3    3.1651E+01  4    3.2447E+01  5    3.3250E+01  6    3.4056E+01  7    3.4863E+01
 8    3.5662E+01
TAUP: 1   4.5382  2   0.7578  3   0.7612  4   0.7648  5   0.7683  6   0.7720  7   0.7755  8   0.7798  9   0.7838 10  99.8831
11   1.0960
TAUS: 12   0.3619 13   0.3637 14   0.3655 15   0.3673 16   0.3692 17   0.3711 18   0.3731 19   0.3752 20   4.2401 21   5.6676
TP: 1  525.973  2  508.833  3  491.242  4  473.150  5  454.552  6  435.444  7  415.824  8  395.694  9  375.063 10  525.973
11  379.509
TS: 1  496.256  2  478.355  3  459.985  4  441.103  5  421.704  6  401.790  7  381.362  8  360.428  9  339.002 10  496.256

***************     P R I M A R Y     S O D I U M     T R A N S P O R T     C A L C U L A T I O N S     ***************
```

```
TAUC1:  1  1.22003  2  1.22003  3  1.22003  4  1.22003  5  1.22003  6  1.22003  7  1.22003  8  1.22003  9  1.22003 10  1.22003
TAUW1:  1 43.91223  2 43.91223  3 43.91223  4 43.91223  5 43.91223  6 43.91223  7 43.91223  8 43.91223  9 43.91223 10 43.91223
TAUC2:  1  0.46120  2  0.46120  3  0.46120  4  0.46120  5  0.46120  6  0.46120  7  0.46120  8  0.46120  9  0.46120 10  0.46120
TAUW2:  1 41.21223  2 41.21223  3 41.21223  4 41.21223  5 41.21223  6 41.21223  7 41.21223  8 41.21223  9 41.21223 10 41.21223
TAUC3:  1  0.77307  2  0.77307  3  0.77307  4  0.77307  5  0.77307  6  0.77307  7  0.77307  8  0.77307  9  0.77307 10  0.77307
TAUW3:  1 41.11850  2 41.11850  3 41.11850  4 41.11850  5 41.11850  6 41.11850  7 41.11850  8 41.11850  9 41.11850 10 41.11850
TAUC4:  1  1.22003  2  1.22003  3  1.22003  4  1.22003  5  1.22003  6  1.22003  7  1.22003  8  1.22003  9  1.22003 10  1.22003
TAUW4:  1 43.91237  2 43.91237  3 43.91237  4 43.91237  5 43.91237  6 43.91237  7 43.91237  8 43.91237  9 43.91237 10 43.91237
TAUC5:  1  0.46120  2  0.46120  3  0.46120  4  0.46120  5  0.46120  6  0.46120  7  0.46120  8  0.46120  9  0.46120 10  0.46120
TAUW5:  1 41.21230  2 41.21230  3 41.21230  4 41.21230  5 41.21230  6 41.21230  7 41.21230  8 41.21230  9 41.21230 10 41.21230
TAUC6:  1  0.77307  2  0.77307  3  0.77307  4  0.77307  5  0.77307  6  0.77307  7  0.77307  8  0.77307  9  0.77307 10  0.77307
TAUW6:  1 41.11858  2 41.11858  3 41.11858  4 41.11858  5 41.11858  6 41.11858  7 41.11858  8 41.11858  9 41.11858 10 41.11858
TC1:  1  525.973  2  525.973  3  525.973  4  525.973  5  525.973  6  525.973  7  525.973  8  525.973  9  525.973 10  525.973
TW1:  1  525.973  2  525.973  3  525.973  4  525.973  5  525.973  6  525.973  7  525.973  8  525.973  9  525.973 10  525.973
TC2:  1  525.992  2  525.992  3  525.992  4  525.992  5  525.992  6  525.992  7  525.992  8  525.992  9  525.992 10  525.992
TW2:  1  525.992  2  525.992  3  525.992  4  525.992  5  525.992  6  525.992  7  525.992  8  525.992  9  525.992 10  525.992
TC3:  1  379.507  2  379.507  3  379.507  4  379.507  5  379.507  6  379.507  7  379.507  8  379.507  9  379.507 10  379.507
TW3:  1  379.507  2  379.507  3  379.507  4  379.507  5  379.507  6  379.507  7  379.507  8  379.507  9  379.507 10  379.507
TC4:  1  525.973  2  525.973  3  525.973  4  525.973  5  525.973  6  525.973  7  525.973  8  525.973  9  525.973 10  525.973
TW4:  1  525.973  2  525.973  3  525.973  4  525.973  5  525.973  6  525.973  7  525.973  8  525.973  9  525.973 10  525.973
TC5:  1  525.992  2  525.992  3  525.992  4  525.992  5  525.992  6  525.992  7  525.992  8  525.992  9  525.992 10  525.992
TW5:  1  525.992  2  525.992  3  525.992  4  525.992  5  525.992  6  525.992  7  525.992  8  525.992  9  525.992 10  525.992
TC6:  1  379.509  2  379.509  3  379.509  4  379.509  5  379.509  6  379.509  7  379.509  8  379.509  9  379.509 10  379.509
TW6:  1  379.509  2  379.509  3  379.509  4  379.509  5  379.509  6  379.509  7  379.509  8  379.509  9  379.509 10  379.509

************************* I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S *************************

 TAU:  1    1.128694  2    1.790452  3    0.500000  4    0.020000  5    3.999999
 SODIUM FLOW RATE =  0.9057   PUMP SPEED =  0.9062   PUMP HEAD =  0.8220   MOTOR GEN. SET FREQ. =    53.586 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.8256   DRIVE MOTOR TORQUE =  0.0       PUMP TORQUE =  0.8217   FRICTION TORQUE =  0.0328

************************* I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S *************************

 TAU:  1    1.702707  2    1.790388  3    0.500000  4    0.020000  5    3.999999
 SODIUM FLOW RATE =  0.9056   PUMP SPEED =  0.9062   PUMP HEAD =  0.8222   MOTOR GEN. SET FREQ. =    53.586 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.8258   DRIVE MOTOR TORQUE =  0.0       PUMP TORQUE =  0.8218   FRICTION TORQUE =  0.0328

********************    I N T E R M E D I A T E   L O O P - 1:   S O D I U M   T R A N S P O R T    ********************

TAUC1:  1  2.27537  2  2.27537  3  2.27537  4  2.27537  5  2.27537  6  2.27537  7  2.27537  8  2.27537  9  2.27537 10  2.27537
TAUW1:  1 41.33817  2 41.33817  3 41.33817  4 41.33817  5 41.33817  6 41.33817  7 41.33817  8 41.33817  9 41.33817 10 41.33817
TAUC2:  1  1.58555
TAUW2:  1 41.23648
TAUC3:  1  2.05661  2  2.05661
TAUW3:  1 41.22624  2 41.22624
TAUC4:  1  0.96675  2  0.96675  3  0.96675  4  0.96675  5  0.96675  6  0.96675  7  0.96675  8  0.96675  9  0.96675 10  0.96675
TAUW4:  1 41.22624  2 41.22624  3 41.22624  4 41.22624  5 41.22624  6 41.22624  7 41.22624  8 41.22624  9 41.22624 10 41.22624
TCS1:  1   496.245  2   496.245  3   496.245  4   496.245  5   496.245  6   496.245  7   496.245  8   496.245  9   496.245 10   496.245
TWS1:  1   496.245  2   496.245  3   496.245  4   496.245  5   496.245  6   496.245  7   496.245  8   496.245  9   496.245 10   496.245
TCS2:  1   338.991
TWS2:  1   338.991
TCS3:  1   339.004  2   339.004
TWS3:  1   338.993  2   338.993
TCS4:  1   339.004  2   339.004  3   339.004  4   339.004  5   339.004  6   339.004  7   339.004  8   339.004  9   339.004 10   339.004
TWS4:  1   339.004  2   339.004  3   339.004  4   339.004  5   339.004  6   339.004  7   339.004  8   339.004  9   339.004 10   339.004

********************    I N T E R M E D I A T E   L O O P - 2:   S O D I U M   T R A N S P O R T    ********************

TAUC1:  1  3.74972  2  3.74972  3  3.74972  4  3.74972  5  3.74972  6  3.74972  7  3.74972  8  3.74972  9  3.74972 10  3.74972
TAUW1:  1 41.33850  2 41.33850  3 41.33850  4 41.33850  5 41.33850  6 41.33850  7 41.33850  8 41.33850  9 41.33850 10 41.33850
```

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TAUC2:  1  1.58577
TAUW2:  1 41.23676
TAUC3:  1   2.05690   2   2.05690
TAUW3:  1 41.22649   2 41.22649
TAUC4:  1   1.76324   2   1.76324   3   1.76324   4   1.76324   5   1.76324   6   1.76324   7   1.76324   8   1.76324   9   1.76324 10   1.76324
TAUW4:  1 41.22646   2 41.22646   3 41.22646   4 41.22646   5 41.22646   6 41.22646   7 41.22646   8 41.22646   9 41.22646 10 41.22646
TCS1:  1   496.256   2   496.256   3   496.256   4   496.256   5   496.256   6   496.256   7   496.256   8   496.256   9   496.256 10   496.256
TWS1:  1   496.256   2   496.256   3   496.256   4   496.256   5   496.256   6   496.256   7   496.256   8   496.256   9   496.256 10   496.256
TCS2:  1   338.982
TWS2:  1   338.982
TCS3:  1   338.995   2   338.995
TWS3:  1   338.987   2   338.987
TCS4:  1   338.995   2   338.995   3   338.995   4   338.995   5   338.995   6   338.995   7   338.995   8   338.995   9   338.995 10   338.995
TWS4:  1   338.995   2   338.995   3   338.995   4   338.995   5   338.995   6   338.995   7   338.995   8   338.995   9   338.995 10   338.995

***********************************   S T E A M   G E N E R A T I O N   L O O P - 1   ***********************************

 TAU:  1   0.988413   2   0.988702   3   0.987633   4   0.977283   5   1.261121   6   1.261121   7   1.261121   8   1.261121
 9   1.261121 10   2.454725 11   3.410241 12   0.0         13 14.317135 14   0.464932 15   3.123891 16 15.846477
17   0.885323 18   1.668951 19   0.337935 20   0.456025 21   2.035048 22   0.523451 23   1.567528 24   0.091797
25   0.051604 26   0.044744 27   0.040156 28   0.037308 29   0.116579 30   3.942929 31   1.623410 32   0.207237
33   0.053679 34*********** 35********** 36   1.000000 37   1.999999 38   1.999999 39   1.999999
FEED WATER FLOW =0.0      WATER/STEAM FLUW =0.9984   STEAM FLOW =0.9077   INT. SODIUM FLOW =0.9057

P 1 = 1.2150E+07   P 2 = 1.2176E+07   P 3 = 1.2176E+07   P 4 = 1.2214E+07   P 5 = 1.3216E+07   P 6 = 1.3206E+07   P 7 = 1.3195E+07
P 8 = 1.3155E+07   P 9 = 1.2913E+07   P10 = 1.2458E+07   P11 = 1.2358E+07   P12 = 1.2226E+07   P13 = 1.2176E+07   P14 = 1.2111E+07
P15 = 1.1999E+07   P16 = 1.1634E+07   P17 = 1.1259E+07   P18 = 1.0894E+07   P19 = 1.0520E+07   P20 = 1.0419E+07   P21 = 1.0001E+07
H 1 = 1.0030E+06   H 2 = 1.6154E+06   H 3 = 1.2725E+06   H 4 = 1.2725E+06   H 5 = 1.2725E+06   H 6 = 1.2725E+06   H 7 = 1.2725E+06
H 8 = 1.2725E+06   H 9 = 1.5281E+06   H10 = 2.0312E+06   H11 = 2.0312E+06   H12 = 2.0312E+06   H13 = 2.0312E+06   H14 = 2.6808E+06
H15 = 2.6808E+06   H16 = 3.0006E+06   H17 = 3.1755E+06   H18 = 3.2705E+06   H19 = 3.3206E+06   H20 = 3.3206E+06   H21 = 3.3206E+06
TM 1 =  232.3707   TM 2 =  325.6902   TM 3 =  285.8984   TM 4 =  285.8984   TM 5 =  285.8982   TM 6 =  285.8984   TM 7 =  285.8982
TM 8 =  285.8982   TM 9 =  330.2227   TM10 =  327.4492   TM11 =  326.8276   TM12 =  326.0061   TM13 =  325.6902   TM14 =  325.2781
TM15 =  324.5708   TM16 =  384.3271   TM17 =  433.2097   TM18 =  464.0471   TM19 =  480.9570   TM20 =  480.4551   TM21 =  478.3772
TCS 8 =  338.9907   TCS 9 =  376.9502   TCS10 =  452.3823   TCS11 =  452.3823   TCS12 =  452.3823   TCS13 =  452.3823   TCS14 =  452.3823
TCS15 =  452.3823   TCS16 =  474.3157   TCS17 =  486.3164   TCS18 =  492.8281   TCS19 =  496.2451   TCS
                         TDLOG:  9        49.8424 10        79.5221
                         U    :  9      6270.1172 10      8668.4687
              TDLOG: 16        107.7964 17        69.9342 18        39.7098 19        21.3280
              U    : 16       4387.8633 17      3697.8660 18      3537.2048 19      3467.7969

HEAT FLUX = 2.820754E+05                        OUTLET STEAM QUALITY = 4.476406E-01
NON-BOILING LENGTH = 7.408863E+00             BOILING LENGTH = 6.611126E+00

DRUM INT. ENERGY = 1.3745E+10   DRUM LEVEL = 1.0000   CVP = 0.8647   ALFA = 0.9999   DPRP = 1.4663E+08

***********************************   S T E A M   G E N E R A T I O N   L O O P - 2   ***********************************

 TAU:  1   0.988541   2   0.988830   3   0.987762   4   0.977409   5   1.261292   6   1.261292   7   1.261292   8   1.261292
 9   1.261292 10   2.454868 11   3.410754 12   0.0         13 14.317001 14   0.464928 15   3.123863 16 15.846330
17   0.885315 18   1.669097 19   0.337946 20   0.456059 21   2.035196 22   0.523489 23   1.567602 24   0.091801
25   0.051605 26   0.044745 27   0.040157 28   0.037309 29   0.116586 30   3.943178 31   1.623410 32   0.207238
33   0.053682 34*********** 35********** 36   1.000000 37   1.999999 38   1.999999 39   1.999999
FEED WATER FLOW =0.0      WATER/STEAM FLOW =0.9984   STEAM FLOW =0.9076   INT. SODIUM FLOW =0.9056

P 1 = 1.2150E+07   P 2 = 1.2176E+07   P 3 = 1.2176E+07   P 4 = 1.2213E+07   P 5 = 1.3216E+07   P 6 = 1.3205E+07   P 7 = 1.3195E+07
P 8 = 1.3155E+07   P 9 = 1.2913E+07   P10 = 1.2458E+07   P11 = 1.2357E+07   P12 = 1.2226E+07   P13 = 1.2176E+07   P14 = 1.2110E+07
P15 = 1.1999E+07   P16 = 1.1634E+07   P17 = 1.1258E+07   P18 = 1.0894E+07   P19 = 1.0520E+07   P20 = 1.0419E+07   P21 = 1.0001E+07
H 1 = 1.0030E+06   H 2 = 1.6154E+06   H 3 = 1.2725E+06   H 4 = 1.2725E+06   H 5 = 1.2725E+06   H 6 = 1.2725E+06   H 7 = 1.2725E+06
H 8 = 1.2725E+06   H 9 = 1.5281E+06   H10 = 2.0311E+06   H11 = 2.0311E+06   H12 = 2.0311E+06   H13 = 2.0311E+06   H14 = 2.6808E+06
H15 = 2.6808E+06   H16 = 3.0006E+06   H17 = 3.1755E+06   H18 = 3.2706E+06   H19 = 3.3207E+06   H20 = 3.3207E+06   H21 = 3.3207E+06
```

```
TM 1 =  232.3707  TM 2 =  325.6882  TM 3 =  285.9014  TM 4 =  285.9014  TM 5 =  285.9009  TM 6 =  285.9009  TM 7 =  285.9011
TM 8 =  285.9009  TM 9 =  330.2207  TM10 =  327.4470  TM11 =  326.8257  TM12 =  326.0042  TM13 =  325.6882  TM14 =  325.2766
TM15 =  324.5691  TM16 =  384.3313  TM17 =  433.2185  TM18 =  464.0574  TM19 =  480.9675  TM20 =  480.4666  TM21 =  478.3892
TCS 8 =  338.9817  TCS 9 =  376.9480  TCS10 =  452.3865  TCS11 =  452.3865  TCS12 =  452.3865  TCS13 =  452.3865  TCS14 =  452.3865
TCS15 =  452.3865  TCS16 =  474.3230  TCS17 =  486.3259  TCS18 =  492.8379  TCS19 =  496.2559  TCS
                          TDLOG:  9        49.8367 10        79.5242
                          U    :  9      6270.0859 10      8668.3555
             TDLOG: 16       107.800A 17        69.9360 18        39.7097 19        21.3279
             U    : 16      4387.6367 17      3697.6650 18      3537.0205 19      3467.6235

HEAT FLUX = 2.820624E+05                          OUTLET STEAM QUALITY = 4.475A06E-01
NON-BOILING LENGTH = 7.409361E+00                BOILING LENGTH = 6.610628E+00

DRUM INT. ENERGY = 1.3745E+10   DRUM LEVEL = 1.0000   CVP = 0.8647   ALFA = 0.9999   DPRP = 1.4663E+08

*****************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   *****************************

                  TIME CONSTANT OF THE HEADER PRESSURE GAUGE =  0.150000 SECONDS
     THROTTLE VALVE POSITION =0.9750                                   DUMP(BYPASS) VALVE POSITION =0.0
     THROTTLE VALVE FLOW     =0.0       RELIEF VALVE FLOW =0.0         DUMP(BYPASS) VALVE FLOW     =0.0
     HEADER PRESSURE = 1.0001E+07       TEMPERATURE =  478.3772          SPECIFIC ENTHALPY= 3.3206E+06

******************************   M E A S U R E D   V A L U E S   F O R   P P S   ******************************

TAU :  0.1500        0.5000        0.1000        5.0000        5.0000        5.0000        5.0000
PRESNORM =  0.87915          VESSEL LEVEL =   4.5623          PTOTNORM =  0.90000
TIHX1 =  379.507     TIHX2 =  379.509     TEVAP1 =  338.991     TEVAP2 =  338.982

      **** REACTIVITY INSERTION OF $ 0.500 AT 0.5000 SEC ****

      **** STEAM - FEEDWATER FLOW MISMATCH TRIP AT  0.7000 SEC ****

<<<<<<<<<< W A R N I N G      DRYOUT OCCURED IN THE EVAPORATORS OF LOOP-1 AT TIME =      0.8000 SECONDS >>>>>>>>>>

<<<<<<<<<< W A R N I N G      DRYOUT OCCURED IN THE EVAPORATORS OF LOOP-2 AT TIME =      0.8000 SECONDS >>>>>>>>>>

      **** PRIMARY SCRAM INITIATED AT TIME =   1.400 SEC ****
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```
STEP #    20   TIME =    1.99999 SEC   S =  0.20000 SEC

                                          TOTAL VECTOR OF CONTROL INTEGERS
 11   12   13   14   15   20   25   26   40   41   42   43   44   46   47   49   53   54   55   56   57   81   82   83   84
106  107  108  109  233  238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292
293  294  295  296  297  298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342
343  344  345  346  347  348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411
423  424  425  426  427  428  431  432  450  462  463  464  465  466  467  470  471  480  483  485    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0

*************************    N E U T R O N    K I N E T I C S    C A L C U L A T I O N S    *************************

PTOT =        132.381 MWT     PN =          59.121 MWT      PFP =          73.260 MWT
PDN :    1     2.595 MWT     2    0.413 MWT     PFP :     3   25.807 MWT     4    18.494 MWT     5    28.959 MWT
ROTOT =     -13.534317 $      ROCR1 =        7.854942 $      ROCR2 =        0.0        $      ROFDBK =       -3.389259 $
RODOP =      -1.678378 $      ROSOD =       -0.017169 $      ROCRE =       -1.097438 $      ROCAE  =       -0.596275 $
TRO    =    614.969            TROM   =     571.702              TSTM  =     490.680
PD =           0.9000          ETST   =    -11.749756          ETRO   =     29.025635   EF =    -0.050000   DELRO =      -0.000333
PTOTNORM =    0.1358           PNNORM =        0.0606           PFPNORM =      0.0751    SCRAM RODS:   PRIM =  62.145 %   SEC =    0.0    %

*******************************    P R I M A R Y    C O O L A N T    D Y N A M I C S    *******************************

FZ1NRM = 0.6843                              FZ2NRM = 0.6832  FZ3NRM = 0.6797  CANRM = 0.6177   RBNRM = 0.6504   BPNRM = 0.6981
FLOWS: 1    1.1813E+03    2    1.1809E+03    3    1.2880E+03    4    9.4771E+01    5    5.0258E+01    6    4.8501E+02    7    1.5165E+02
AL1=    0.6569   NEW1=    0.6786   BP1=    0.4174   TMOTN1=    0.0        HP1=    0.4090   FREQ1=    78.784
AL2=    0.6569   NEW2=    0.6784   BP2=    0.4175   TMOTN2=    0.0        HP2=    0.4091   FREQ2=    78.791
PD =    0.9000   TRISP =  387.779   NEWSP =     0.9000   ASP =    0.9000   XKW = 1.316E-03   EPS = 1.000E-05    N =  3
TRIM:        379.506      379.507        NEWM:          0.7311      0.7309        ALM:        0.6569        0.6569       INLET PRSNRM = 0.6330
ET:       1.4892E+01       1.4890E+01       EW:       1.8849E-01       1.8864E-01       EA:        3.3737E-01       3.3746E-01

******************************    R E A C T O R    H E A T    T R A N S F E R    ******************************

  CORE HOT SPOT:          MAX. COOLANT TEMP. =    823.231          MAX. CLAD TEMP. =    860.560
PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =  1928.051   CLAD INNER =    540.638   CLAD OUTER =    537.094
TM 1 =    453.964    TM 2 =   1883.580    TM 3 =     640.516    TM 4 =     435.557    TM 5 =   1614.478    TM 6 =    604.632
TM 7 =    434.327    TM 8 =   1423.168    TM 9 =     576.417    TM10 =     482.266    TM11 =    534.508    TM
TC 1 =    387.572    TC 2 =    667.645    TC 3 =     665.797    TC 4 =     386.114    TC 5 =    634.956    TC 6 =    628.957
TC 7 =    386.027    TC 8 =    600.398    TC 9 =     595.244    TC10 =     449.018    TC11 =    471.395    TC12 =    379.524
TCI1 =    379.523    TCI2 =    379.523    TCI3 =     379.523    TCI4 =     379.523    TCI5 =    379.523    TCI6 =    379.523
LOWER PLENUM:                           TOP ZONE TEMP. =    379.523   BOTTOM ZONE TEMP. =    379.523
UPPER PLENUM:  ZJET =     6.400   TOP ZONE TEMP. =    527.115   BOTTOM ZONE TEMP. =    527.115   NOZZLE TEMP. =    527.115

************************    I H X - 1    T H E R M A L    C A L C U L A T I O N S    ************************

TP:  1  525.978  2  507.514  3  489.494  4  471.259  5  452.592  6  433.422  7  413.713  8  393.392  9  372.285 10  525.973
11  378.498
```

```
TS:  1  499.460  2  481.283  3  462.900  4  444.069  5  424.718  6  404.784  7  384.129  8  362.434  9  339.006 10  496.588

************************     I H X - 2     T H E R M A L     C A L C U L A T I O N S     ************************

TP:  1  525.978  2  507.226  3  489.133  4  470.879  5  452.203  6  433.028  7  413.324  8  393.042  9  372.073 10  525.973
11  378.429
TS:  1  498.560  2  480.306  3  461.890  4  443.036  5  423.668  6  403.737  7  383.151  8  361.707  9  338.999 10  496.504

**************     P R I M A R Y     S O D I U M     T R A N S P O R T     C A L C U L A T I O N S     **************

TC1:  1  526.250  2  526.031  3  525.982  4  525.973  5  525.972  6  525.972  7  525.972  8  525.972  9  525.972 10  525.972
TW1:  1  525.979  2  525.973  3  525.972  4  525.972  5  525.972  6  525.972  7  525.972  8  525.972  9  525.972 10  525.972
TC2:  1  525.973  2  525.974  3  525.977  4  525.981  5  525.985  6  525.987  7  525.989  8  525.990  9  525.990 10  525.990
TW2:  1  525.990  2  525.990  3  525.990  4  525.991  5  525.991  6  525.991  7  525.992  8  525.992  9  525.992 10  525.992
TC3:  1  379.110  2  379.371  3  379.465  4  379.495  5  379.503  6  379.505  7  379.505  8  379.505  9  379.506 10  379.506
TW3:  1  379.497  2  379.503  3  379.505  4  379.506  5  379.507  6  379.507  7  379.507  8  379.507  9  379.507 10  379.507
TC4:  1  526.250  2  526.031  3  525.982  4  525.973  5  525.972  6  525.972  7  525.972  8  525.972  9  525.972 10  525.972
TW4:  1  525.979  2  525.973  3  525.972  4  525.972  5  525.972  6  525.972  7  525.972  8  525.972  9  525.972 10  525.972
TC5:  1  525.973  2  525.974  3  525.977  4  525.981  5  525.985  6  525.987  7  525.989  8  525.990  9  525.990 10  525.990
TW5:  1  525.990  2  525.990  3  525.990  4  525.991  5  525.991  6  525.991  7  525.992  8  525.992  9  525.992 10  525.992
TC6:  1  379.085  2  379.364  3  379.464  4  379.496  5  379.504  6  379.506  7  379.507  8  379.507  9  379.507 10  379.507
TW6:  1  379.498  2  379.504  3  379.507  4  379.507  5  379.508  6  379.508  7  379.508  8  379.508  9  379.508 10  379.508

************************  I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S  ************************

 SODIUM FLOW RATE =  0.7082    PUMP SPEED =  0.6616    PUMP HEAD =  0.3898    MOTOR GEN. SET FREQ. =     55.441 CYCLES/SEC
 MAIN MOTOR TORQUE =  1.8459    DRIVE MOTOR TORQUE =  0.0        PUMP TORQUE =  0.4078    FRICTION TORQUE =  0.0272

************************  I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S  ************************

 SODIUM FLOW RATE =  0.7429    PUMP SPEED =  0.6660    PUMP HEAD =  0.3650    MOTOR GEN. SET FREQ. =     55.313 CYCLES/SEC
 MAIN MOTOR TORQUE =  1.8550    DRIVE MOTOR TORQUE =  0.0        PUMP TORQUE =  0.3945    FRICTION TORQUE =  0.0273

*******************     I N T E R M E D I A T E     L O O P - 1:   S O D I U M   T R A N S P O R T     *******************

TCS1:  1  496.304  2  496.252  3  496.245  4  496.245  5  496.245  6  496.245  7  496.245  8  496.245  9  496.245 10  496.245
TWS1:  1  496.247  2  496.245  3  496.245  4  496.245  5  496.245  6  496.245  7  496.245  8  496.245  9  496.245 10  496.245
TCS2:  1  339.031
TWS2:  1  338.991
TCS3:  1  339.007  2  339.002
TWS3:  1  338.993  2  338.993
TCS4:  1  339.002  2  339.002  3  339.002  4  339.002  5  339.002  6  339.002  7  339.002  8  339.002  9  339.002 10  339.003
TWS4:  1  339.004  2  339.004  3  339.004  4  339.004  5  339.004  6  339.004  7  339.004  8  339.004  9  339.004 10  339.004

*******************     I N T E R M E D I A T E     L O O P - 2:   S O D I U M   T R A N S P O R T     *******************

TCS1:  1  496.282  2  496.257  3  496.256  4  496.256  5  496.256  6  496.256  7  496.256  8  496.256  9  496.256 10  496.256
TWS1:  1  496.257  2  496.256  3  496.256  4  496.256  5  496.256  6  496.256  7  496.256  8  496.256  9  496.256 10  496.256
TCS2:  1  339.154
TWS2:  1  338.987
TCS3:  1  339.023  2  338.997
TWS3:  1  338.988  2  338.987
TCS4:  1  338.994  2  338.994  3  338.994  4  338.994  5  338.994  6  338.994  7  338.994  8  338.995  9  338.995 10  338.995
TWS4:  1  338.995  2  338.995  3  338.995  4  338.995  5  338.995  6  338.995  7  338.995  8  338.995  9  338.995 10  338.995

***********************************     S T E A M   G E N E R A T I O N   L O O P - 1     ***********************************

FEED WATER FLOW =0.0      WATER/STEAM FLOW =0.7313   STEAM FLOW =0.6130   INT. SODIUM FLOW =0.7082

P 1 = 1.2150E+07  P 2 = 1.2242E+07  P 3 = 1.2242E+07  P 4 = 1.2321E+07  P 5 = 1.2788E+07  P 6 = 1.2790E+07  P 7 = 1.2819E+07
```

```
P 8 = 1.2789E+07  P 9 = 1.2647E+07  P10 = 1.2385E+07  P11 = 1.2332E+07  P12 = 1.2264E+07  P13 = 1.2242E+07  P14 = 1.2225E+07
P15 = 1.2174E+07  P16 = 1.2008E+07  P17 = 1.1839E+07  P18 = 1.1680E+07  P19 = 1.1521E+07  P20 = 1.1478E+07  P21 = 1.1300E+07
H 1 = 1.0030E+06  H 2 = 1.6240E+06  H 3 = 1.4984E+06  H 4 = 1.2968E+06  H 5 = 1.2902E+06  H 6 = 1.2758E+06  H 7 = 1.2726E+06
H 8 = 1.2725E+06  H 9 = 1.5174E+06  H10 = 2.1744E+06  H11 = 2.1438E+06  H12 = 2.0601E+06  H13 = 2.0454E+06  H14 = 2.6802E+06
H15 = 2.6802E+06  H16 = 3.0497E+06  H17 = 3.2161E+06  H18 = 3.2927E+06  H19 = 3.3270E+06  H20 = 3.3269E+06  H21 = 3.3215E+06
TM 1 =  232.3706  TM 2 =  325.6899  TM 3 =  309.1121  TM 4 =  289.9421  TM 5 =  288.8733  TM 6 =  286.4548  TM 7 =  285.9138
TM 8 =  285.9023  TM 9 =  328.6133  TM10 =  326.9978  TM11 =  326.6685  TM12 =  326.2444  TM13 =  326.1042  TM14 =  325.9956
TM15 =  325.6750  TM16 =  400.2351  TM17 =  450.1682  TM18 =  476.3013  TM19 =  488.3032  TM20 =  488.0789  TM21 =  485.1472
TCS 8 =  339.0183  TCS 9 =  372.3481  TCS10 =  452.3872  TCS11 =  452.4150  TCS12 =  452.5430  TCS13 =  453.0010  TCS14 =  454.1841
TCS15 =  455.9775  TCS16 =  477.9290  TCS17 =  488.7278  TCS18 =  493.9797  TCS19 =  496.2449  TCS
                           TDLOG:  9      48.2737 10      77.5241
                           U    :  9    5662.0117 10    8515.1445
           TDLOG: 16      101.7411 17      55.8603 18      26.7755 19      12.1677
           U    : 16     3620.7017 17    2966.9624 18    2853.4548 19    2812.2305

HEAT FLUX = 2.701242E+05                     OUTLET STEAM QUALITY = 5.708956E-01
NON-BOILING LENGTH = 5.944664E+00           BOILING LENGTH = 6.770483E+00

DRUM INT. ENERGY = 1.3526E+10   DRUM LEVEL = 0.9583   CVP = 0.9885   ALFA = 0.7064   DPRP = 6.8986E+07

***********************************   S T E A M   G E N E R A T I O N   L O O P - 2   ***********************************

FEED WATER FLOW =0.0      WATER/STEAM FLOW =0.7313  STEAM FLOW =0.6129  INT. SODIUM FLOW =0.7429

P 1 = 1.2150E+07  P 2 = 1.2242E+07  P 3 = 1.2242E+07  P 4 = 1.2321E+07  P 5 = 1.2787E+07  P 6 = 1.2789E+07  P 7 = 1.2819E+07
P 8 = 1.2789E+07  P 9 = 1.2648E+07  P10 = 1.2385E+07  P11 = 1.2332E+07  P12 = 1.2264E+07  P13 = 1.2242E+07  P14 = 1.2224E+07
P15 = 1.2173E+07  P16 = 1.2008E+07  P17 = 1.1839E+07  P18 = 1.1680E+07  P19 = 1.1521E+07  P20 = 1.1478E+07  P21 = 1.1300E+07
H 1 = 1.0030E+06  H 2 = 1.6240E+06  H 3 = 1.4984E+06  H 4 = 1.2968E+06  H 5 = 1.2902E+06  H 6 = 1.2758E+06  H 7 = 1.2726E+06
H 8 = 1.2726E+06  H 9 = 1.5174E+06  H10 = 2.1747E+06  H11 = 2.1443E+06  H12 = 2.0603E+06  H13 = 2.0455E+06  H14 = 2.6802E+06
H15 = 2.6802E+06  H16 = 3.0511E+06  H17 = 3.2172E+06  H18 = 3.2934E+06  H19 = 3.3272E+06  H20 = 3.3272E+06  H21 = 3.3216E+06
TM 1 =  232.3706  TM 2 =  325.6880  TM 3 =  309.1123  TM 4 =  289.9438  TM 5 =  288.8757  TM 6 =  286.4575  TM 7 =  285.9165
TM 8 =  285.9050  TM 9 =  328.6143  TM10 =  326.9966  TM11 =  326.6672  TM12 =  326.2432  TM13 =  326.1030  TM14 =  325.9946
TM15 =  325.6741  TM16 =  400.6309  TM17 =  450.5471  TM18 =  476.5366  TM19 =  488.4131  TM20 =  488.1724  TM21 =  485.1675
TCS 8 =  339.4619  TCS 9 =  373.0388  TCS10 =  452.3933  TCS11 =  452.4280  TCS12 =  452.5825  TCS13 =  453.1216  TCS14 =  454.5002
TCS15 =  456.6853  TCS16 =  478.3179  TCS17 =  488.9277  TCS18 =  494.0630  TCS19 =  496.2556  TCS
                           TDLOG:  9      48.8487 10      78.0311
                           U    :  9    5671.4062 10    8539.7500
           TDLOG: 16      102.0375 17      55.7431 18      26.6049 19      12.0424
           U    : 16     3623.4604 17    2967.9551 18    2854.9492 19    2814.0132

HEAT FLUX = 2.726601E+05                     OUTLET STEAM QUALITY = 5.711323E-01
NON-BOILING LENGTH = 5.865711E+00           BOILING LENGTH = 6.708176E+00

DRUM INT. ENERGY = 1.3526E+10   DRUM LEVEL = 0.9583   CVP = 0.9884   ALFA = 0.7064   DPRP = 6.8975E+07

******************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   ******************************

     THROTTLE VALVE POSITION =1.0000                                  DUMP(BYPASS) VALVE POSITION =0.2632
     THROTTLE VALVE FLOW     =0.0        RELIEF VALVE FLOW =0.3914   DUMP(BYPASS) VALVE FLOW     =0.2227
     HEADER PRESSURE = 1.1300E+07        TEMPERATURE =  495.2581        SPECIFIC ENTHALPY= 3.3477E+06

******************************   M E A S U R E D   V A L U E S   F O R   P P S   ******************************

 PRESNORM =  0.65389       VESSEL LEVEL =    4.5623        PTOTNORM =  0.90000
 TIHX1 =  379.401     TIHX2 =  379.396     TEVAP1 =  339.010     TEVAP2 =  339.058
```

```
   STEP #    30   TIME =    3.99999 SEC    S =  0.20000 SEC

                                                   TOTAL VECTOR OF CONTROL INTEGERS
  11   12   13   14   15   20   25   26   40   41   43   44   46   47   53   54   55   56   81   82   83   84   84  106  107
 108  109  233  238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292  293  294
 295  296  297  298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342  343  344
 345  346  347  348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411  423  424
 425  426  427  428  432  450  462  463  464  465  466  467  471  480  483  485    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0

**************************    N E U T R O N    K I N E T I C S    C A L C U L A T I O N S    **************************

 PTOT =       102.016 MWT     PN =         32.486 MWT     PFP =         69.530 MWT
 PDN :    1    1.779 MWT    2    0.397 MWT     PFP :    3   22.325 MWT    4   18.253 MWT    5   28.952 MWT
 ROTOT =     -18.139771 $     ROCR1 =       2.749999 $     ROCR2 =        0.0        $     ROFDBK =     -2.889784 $
 RODOP =      -1.372159 $     ROSOD =      -0.020969 $     ROCRE =       -1.097430 $     ROCAE  =     -0.399226 $
 TRO   =    574.549            TROM  =     586.883           TSTM  =      491.730
 PD =          0.9000         ETST  =     -11.749756        ETRO  =       29.025635   EF =    -0.050000   DELRO =     -0.000333
 PTOTNORM =   0.1046          PNNORM =       0.0333         PFPNORM =      0.0713    SCRAM RODS!   PRIM = 100.000 %   SEC =    0.0   %

********************************    P R I M A R Y    C O O L A N T    D Y N A M I C S    ********************************

 FZ1NRM = 0.5329                             FZ2NRM = 0.5331  FZ3NRM = 0.5283  CANRM = 0.4576   RBNRM = 0.4945   BPNRM = 0.5537
 FLOWS: 1   9.1783E+02   2   9.1723E+02   3   1.0050E+03   4   7.3665E+01   5   3.7234E+01   6   3.6871E+02   7   1.2028E+02
 AL1=   0.5132   NEW1=   0.5273   BP1=   0.2563   TMOTN1=   0.0      HP1=   0.2520   FREQ1=  146.777
 AL2=   0.5132   NEW2=   0.5269   BP2=   0.2563   TMOTN2=   0.0      HP2=   0.2522   FREQ2=  146.807
 PD =   0.9000   TRISP =  387.779   NEWSP =    0.9000   ASP =   0.9000   XKW = 1.316E-03   EPS = 1.000E-05   N =  3
 TRIM:      379.505     379.506      NEWM:       0.5608     0.5605       ALM:       0.5132      0.5132       INLET PRSNRM = 0.5102
 ET:      1.4894E+01      1.4892E+01      EW:       3.5879E-01      3.5910E-01       EA:       5.6618F-01      5.6639E-01

******************************    R E A C T O R    H E A T    T R A N S F E R    ******************************

   CORE HOT SPOT:        MAX. COOLANT TEMP. =   712.473        MAX. CLAD TEMP. =   735.315
 PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =  1329.390   CLAD INNER =   497.957   CLAD OUTER =   495.853
 TM 1 =    414.939   TM 2 =  1295.120   TM 3 =    636.776   TM 4 =    406.284   TM 5 =  1139.340   TM 6 =    604.256
 TM 7 =    405.706   TM 8 =  1018.375   TM 9 =    574.473   TM10 =    468.333   TM11 =    519.361   TM
 TC 1 =    384.330   TC 2 =    595.724   TC 3 =    613.618   TC 4 =    383.463   TC 5 =    570.413   TC 6 =    586.686
 TC 7 =    383.405   TC 8 =    543.240   TC 9 =    557.844   TC10 =    452.398   TC11 =    480.193   TC12 =    379.522
 TCI1 =    379.522   TCI2 =    379.522   TCI3 =    379.522   TCI4 =    379.522   TCI5 =    379.522   TCI6 =    379.522
 LOWER PLENUM:                            TOP ZONE TEMP. =   379.522   BOTTOM ZONE TEMP. =   379.521
 UPPER PLENUM:  ZJET =     6.400   TOP ZONE TEMP. =    528.840   BOTTOM ZONE TEMP. =    528.840   NOZZLE TEMP. =    528.839

************************    I H X - 1    T H E R M A L    C A L C U L A T I O N S    ************************

TP:  1  525.980  2  506.288  3  486.881  4  468.885  5  450.105  6  430.760  7  410.765  8  389.905  9  367.772 10  525.973
11  375.529
```

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TS:  1  503.460  2  484.525  3  465.901  4  447.115  5  427.705  6  407.589  7  386.500  8  363.937  9  339.005 10  497.667

************************     I H X - 2     T H E R M A L     C A L C U L A T I O N S     ************************

TP:  1  525.980  2  505.368  3  486.314  4  467.608  5  448.700  6  429.340  7  409.392  8  388.713  9  367.075 10  525.973
11  375.179
TS:  1  501.685  2  482.534  3  463.771  4  444.796  5  425.353  6  405.281  7  384.404  8  362.449  9  338.997 10  497.346

***************     P R I M A R Y     S O D I U M     T R A N S P O R T     C A L C U L A T I O N S     ***************

TC1:  1  527.511  2  526.637  3  526.209  4  526.043  5  525.990  6  525.976  7  525.972  8  525.972  9  525.972 10  525.972
TW1:  1  526.041  2  525.999  3  525.980  4  525.974  5  525.972  6  525.972  7  525.972  8  525.972  9  525.972 10  525.972
TC2:  1  525.972  2  525.972  3  525.973  4  525.974  5  525.975  6  525.978  7  525.981  8  525.984  9  525.986 10  525.987
TW2:  1  525.988  2  525.988  3  525.989  4  525.989  5  525.990  6  525.990  7  525.991  8  525.991  9  525.991 10  525.991
TC3:  1  377.189  2  378.281  3  378.918  4  379.249  5  379.403  6  379.468  7  379.493  8  379.501  9  379.504 10  379.504
TW3:  1  379.411  2  379.460  3  379.485  4  379.497  5  379.503  6  379.505  7  379.506  8  379.506  9  379.506 10  379.506
TC4:  1  527.511  2  526.637  3  526.209  4  526.043  5  525.990  6  525.976  7  525.972  8  525.972  9  525.972 10  525.972
TW4:  1  526.041  2  525.999  3  525.980  4  525.974  5  525.972  6  525.972  7  525.972  8  525.972  9  525.972 10  525.972
TC5:  1  525.972  2  525.972  3  525.973  4  525.974  5  525.975  6  525.978  7  525.981  8  525.984  9  525.986 10  525.987
TW5:  1  525.988  2  525.988  3  525.989  4  525.989  5  525.990  6  525.990  7  525.991  8  525.991  9  525.991 10  525.991
TC6:  1  376.998  2  378.186  3  378.876  4  379.232  5  379.398  6  379.467  7  379.493  8  379.502  9  379.505 10  379.505
TW6:  1  379.405  2  379.458  3  379.485  4  379.498  5  379.504  6  379.506  7  379.507  8  379.507  9  379.507 10  379.507

************************* I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S *************************

 SODIUM FLOW RATE =  0.5609   PUMP SPEED =  0.5209   PUMP HEAD =  0.2390   MOTOR GEN. SET FREQ. =    61.246 CYCLES/SEC
 MAIN MOTOR TORQUE =  1.4926   DRIVE MOTOR TORQUE =  0.0     PUMP TORQUE =  0.2511   FRICTION TORQUE =  0.0240

************************* I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S *************************

 SODIUM FLOW RATE =  0.6012   PUMP SPEED =  0.5294   PUMP HEAD =  0.2222   MOTOR GEN. SET FREQ. =    60.807 CYCLES/SEC
 MAIN MOTOR TORQUE =  1.5128   DRIVE MOTOR TORQUE =  0.0     PUMP TORQUE =  0.2440   FRICTION TORQUE =  0.0242

********************     I N T E R M E D I A T E     L O O P - 1:   S O D I U M     T R A N S P O R T     ********************

TCS1:  1  496.668  2  496.348  3  496.265  4  496.248  5  496.245  6  496.245  7  496.245  8  496.245  9  496.245 10  496.245
TWS1:  1  496.270  2  496.250  3  496.245  4  496.245  5  496.245  6  496.245  7  496.245  8  496.245  9  496.245 10  496.245
TCS2:  1  338.758
TWS2:  1  338.980
TCS3:  1  338.972  2  339.000
TWS3:  1  338.991  2  338.993
TCS4:  1  339.002  2  339.002  3  339.002  4  339.002  5  339.002  6  339.002  7  339.002  8  339.002  9  339.002 10  339.002
TWS4:  1  339.003  2  339.003  3  339.003  4  339.003  5  339.003  6  339.003  7  339.004  8  339.004  9  339.004 10  339.004

********************     I N T E R M E D I A T E     L O O P - 2:   S O D I U M     T R A N S P O R T     ********************

TCS1:  1  496.476  2  496.290  3  496.260  4  496.255  5  496.255  6  496.255  7  496.255  8  496.255  9  496.255 10  496.255
TWS1:  1  496.273  2  496.258  3  496.255  4  496.255  5  496.255  6  496.255  7  496.255  8  496.255  9  496.255 10  496.255
TCS2:  1  339.353
TWS2:  1  339.005
TCS3:  1  339.157  2  339.045
TWS3:  1  338.996  2  338.989
TCS4:  1  339.007  2  338.996  3  338.994  4  338.994  5  338.994  6  338.994  7  338.994  8  338.994  9  338.994 10  338.994
TWS4:  1  338.995  2  338.995  3  338.995  4  338.995  5  338.995  6  338.995  7  338.995  8  338.995  9  338.995 10  338.995

************************************   S T E A M   G E N E R A T I O N   L O O P - 1   ************************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.5766  STEAM FLOW =0.6372  INT. SODIUM FLOW =0.5609

P 1 = 1.2150E+07  P 2 = 1.2171E+07  P 3 = 1.2171E+07  P 4 = 1.2270E+07  P 5 = 1.2533E+07  P 6 = 1.2538E+07  P 7 = 1.2564E+07
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P 8 = 1.2538E+07  P 9 = 1.2439E+07  P10 = 1.2261E+07  P11 = 1.2227E+07  P12 = 1.2183E+07  P13 = 1.2171E+07  P14 = 1.2147E+07
P15 = 1.2092E+07  P16 = 1.1912E+07  P17 = 1.1730E+07  P18 = 1.1557E+07  P19 = 1.1383E+07  P20 = 1.1337E+07  P21 = 1.1144E+07
H 1 = 1.0030E+06  H 2 = 1.6264E+06  H 3 = 1.4984E+06  H 4 = 1.3145E+06  H 5 = 1.3083E+06  H 6 = 1.2840E+06  H 7 = 1.2732E+06
H 8 = 1.2728E+06  H 9 = 1.5090E+06  H10 = 2.2420E+06  H11 = 2.2212E+06  H12 = 2.1244E+06  H13 = 2.0998E+06  H14 = 2.6801E+06
H15 = 2.6801E+06  H16 = 3.0411E+06  H17 = 3.2109E+06  H18 = 3.2907E+06  H19 = 3.3268E+06  H20 = 3.3269E+06  H21 = 3.3230E+06
TM 1 =  232.3704  TM 2 =  325.6897  TM 3 =  325.6616  TM 4 =  292.7563  TM 5 =  291.7932  TM 6 =  287.8433  TM 7 =  286.0071
TM 8 =  285.9485  TM 9 =  327.3325  TM10 =  326.2268  TM11 =  326.0112  TM12 =  325.7334  TM13 =  325.6616  TM14 =  325.5100
TM15 =  325.1606  TM16 =  397.1941  TM17 =  447.7944  TM18 =  474.9141  TM19 =  487.5779  TM20 =  487.3752  TM21 =  484.9414
TCS 8 =  337.9612  TCS 9 =  366.6172  TCS10 =  452.5291  TCS11 =  452.7981  TCS12 =  453.3530  TCS13 =  454.1558  TCS14 =  454.6035
TCS15 =  453.2322  TCS16 =  477.2371  TCS17 =  488.5334  TCS18 =  493.8264  TCS19 =  496.2446  TCS
                             TDLOG:  9        45.3515 10        74.5114
                             U    :  9      5184.4297 10      8356.7187
           TDLOG: 16       102.1829 17       58.1955 18        28.4435 19        13.1300
           U    : 16      3666.9460 17      3019.9648 18      2901.4612 19      2857.8882

HEAT FLUX = 2.547964E+05                           OUTLET STEAM QUALITY = 6.287921E-01
NON-BOILING LENGTH = 5.256315E+00                BOILING LENGTH = 6.245241E+00

DRUM INT. ENERGY = 1.3263E+10   DRUM LEVEL = 0.9201   CVP = 1.2282   ALFA = 0.5456   DPRP = 3.9670E+07

***********************************   S T E A M   G E N E R A T I O N   L O O P - 2   ***********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.5769  STEAM FLOW =0.6370  INT. SODIUM FLOW =0.6012

P 1 = 1.2150E+07  P 2 = 1.2171E+07  P 3 = 1.2171E+07  P 4 = 1.2270E+07  P 5 = 1.2533E+07  P 6 = 1.2538E+07  P 7 = 1.2564E+07
P 8 = 1.2538E+07  P 9 = 1.2440E+07  P10 = 1.2262E+07  P11 = 1.2227E+07  P12 = 1.2183E+07  P13 = 1.2171E+07  P14 = 1.2147E+07
P15 = 1.2092E+07  P16 = 1.1912E+07  P17 = 1.1730E+07  P18 = 1.1556E+07  P19 = 1.1383E+07  P20 = 1.1336E+07  P21 = 1.1144E+07
H 1 = 1.0030E+06  H 2 = 1.6265E+06  H 3 = 1.4984E+06  H 4 = 1.3145E+06  H 5 = 1.3083E+06  H 6 = 1.2840E+06  H 7 = 1.2732E+06
H 8 = 1.2728E+06  H 9 = 1.5091E+06  H10 = 2.2422E+06  H11 = 2.2214E+06  H12 = 2.1247E+06  H13 = 2.1001E+06  H14 = 2.6801E+06
H15 = 2.6801E+06  H16 = 3.0441E+06  H17 = 3.2132E+06  H18 = 3.2920E+06  H19 = 3.3274E+06  H20 = 3.3274E+06  H21 = 3.3231E+06
TM 1 =  232.3704  TM 2 =  325.6877  TM 3 =  325.6624  TM 4 =  292.7588  TM 5 =  291.7959  TM 6 =  287.8459  TM 7 =  286.0100
TM 8 =  285.9514  TM 9 =  327.3386  TM10 =  326.2280  TM11 =  326.0122  TM12 =  325.7341  TM13 =  325.6624  TM14 =  325.5107
TM15 =  325.1614  TM16 =  398.0161  TM17 =  448.5857  TM18 =  475.4028  TM19 =  487.8108  TM20 =  487.5847  TM21 =  484.9976
TCS 8 =  339.3235  TCS 9 =  368.5400  TCS10 =  452.5867  TCS11 =  452.9360  TCS12 =  453.6467  TCS13 =  454.7092  TCS14 =  455.5613
TCS15 =  454.8467  TCS16 =  478.1023  TCS17 =  488.9504  TCS18 =  493.9861  TCS19 =  496.2554  TCS
                             TDLOG:  9        47.0245 10        75.9889
                             U    :  9      5196.0742 10      8391.6445
           TDLOG: 16       102.9012 17       57.9751 18        28.0800 19        12.8543
           U    : 16      3671.0356 17      3021.0103 18      2903.6682 19      2860.7288

HEAT FLUX = 2.609192E+05                           OUTLET STEAM QUALITY = 6.290042E-01
NON-BOILING LENGTH = 5.061234E+00                BOILING LENGTH = 6.100469E+00

DRUM INT. ENERGY = 1.3263E+10   DRUM LEVEL = 0.9201   CVP = 1.2281   ALFA = 0.5456   DPRP = 3.9645E+07

******************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   ******************************

     THROTTLE VALVE POSITION =1.0000                               DUMP(BYPASS) VALVE POSITION =0.5632
     THROTTLE VALVE FLOW     =0.0      RELIEF VALVE FLOW =0.1652   DUMP(BYPASS) VALVE FLOW     =0.4733
     HEADER PRESSURE = 1.1144E+07       TEMPERATURE =  489.9846     SPECIFIC ENTHALPY= 3.3359E+06

*******************************   M E A S U R E D   V A L U E S   F O R   P P S   *******************************

 PRESNORM =  0.51018          VESSEL LEVEL =   4.5623         PTOTNORM =  0.13578
 TIHX1 =  378.607     TIHX2 =  378.535     TEVAP1 =  338.866     TEVAP2 =  339.202
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```
    STEP #    40   TIME =    5.99999 SEC   S =  0.20000 SEC

                                              TOTAL VECTOR OF CONTROL INTEGERS
 11  12  13  14  15  20  25  26  40  41  43  44  46  47  53  54  55  56  81  82  83  84  84 106 107
108 109 233 238 251 252 253 254 255 256 257 258 259 262 263 264 265 266 267 268 269 291 292 293 294
295 296 297 298 299 302 303 304 305 306 307 308 309 331 332 333 334 335 336 337 338 339 342 343 344
345 346 347 348 349 371 372 373 374 375 376 377 378 379 382 383 384 385 386 387 388 389 411 423 424
425 426 427 428 432 450 462 463 464 465 466 467 471 480 483 485   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0   0   0   0   0   0   0   0   0   0   0   0   0   0

*************************    N E U T R O N    K I N E T I C S    C A L C U L A T I O N S    *************************

 PTOT =        90.628 MWT     PN =        24.355 MWT     PFP =          66.273 MWT
 PDN :    1     1.222 MWT     2    0.381 MWT      PFP :    3   19.317 MWT    4    18.011 MWT    5    28.945 MWT
 ROTOT =     -17.808548 $     ROCR1 =       2.749999 $    ROCR2 =        0.0        $     ROFDBK =      -2.558554 $
 RODOP =      -1.150315 $     ROSOD =      -0.023098 $    ROCRE =       -1.097424 $       ROCAE  =      -0.287718 $
 TRO    =    534.842           TROM  =     565.122           TSTM  =      489.251
 PD =          0.9000         ETST  =    -11.749756        ETRO  =       29.025635    EF =     -0.050000    DELRO =     -0.000333
 PTOTNORM =    0.0930         PNNORM =       0.0250        PFPNORM =      0.0680     SCRAM RODS:   PRIM = 100.000 %   SEC =    0.0    %

********************************    P R I M A R Y    C O O L A N T    D Y N A M I C S    ********************************

 FZ1NRM = 0.4337                          FZ2NRM = 0.4336  FZ3NRM = 0.4281  CANRM = 0.3563   RBNRM = 0.3932   BPNRM = 0.4574
 FLOWS: 1    7.4467E+02    2   7.4393E+02    3   8.1742E+02    4   5.9694E+01    5   2.8992E+01    6   2.9322E+02    7   9.9361E+01
 AL1=   0.4185   NEW1=    0.4278   BP1=   0.1713   TMOTN1=    0.0         HP1=   0.1690   FREQ1=  241.120
 AL2=   0.4185   NEW2=    0.4274   BP2=   0.1714   TMOTN2=    0.0         HP2=   0.1692   FREQ2=  241.168
 PD =   0.9000   TRISP =  387.779   NEWSP =     0.9000   ASP =    0.9000   XKW = 1.316E-03   EPS = 1.000E-05   N =  3
 TRIM:      379.503     379.504      NEWM:        0.4503      0.4499        ALM:        0.4185       0.4185       INLET PRSNRM = 0.4441
 ET:      1.4897E+01      1.4895E+01       EW:         4.6928E-01      4.6969E-01        EA:        6.8146E-01      6.8155E-01

******************************    R E A C T O R    H E A T    T R A N S F E R    ******************************

   CORE HOT SPOT:          MAX. COOLANT TEMP. =    634.857          MAX. CLAD TEMP. =    649.446
 PEAK CORE AVERAGE TEMPERATURE OF:    FUEL CENTERLINE =    996.351    CLAD INNER =    469.042    CLAD OUTER =    467.730
 TM 1 =    398.578    TM 2 =    965.907    TM 3 =    600.902    TM 4 =    393.966    TM 5 =    870.464    TM 6 =    574.282
 TM 7 =    393.659    TM 8 =    790.816    TM 9 =    547.535    TM10 =    457.771    TM11 =    506.960    TM
 TC 1 =    382.672    TC 2 =    545.324    TC 3 =    565.116    TC 4 =    382.099    TC 5 =    526.467    TC 6 =    544.803
 TC 7 =    382.062    TC 8 =    505.052    TC 9 =    521.266    TC10 =    453.765    TC11 =    485.700    TC12 =    379.521
 TCI1 =    379.521    TCI2 =    379.521    TCI3 =    379.521    TCI4 =    379.521    TCI5 =    379.521    TCI6 =    379.521
 LOWER PLENUM:                          TOP ZONE TEMP. =    379.521   BOTTOM ZONE TEMP. =    379.520
 UPPER PLENUM:  ZJET =      6.400    TOP ZONE TEMP. =    529.044   BOTTOM ZONE TEMP. =    529.044   NOZZLE TEMP. =    529.043

************************    I H X - 1    T H E R M A L    C A L C U L A T I O N S    ************************

 TP:  1  525.980  2  505.385  3  485.938  4  467.087  5  448.108  6  428.580  7  408.272  8  386.868  9  363.812 10  525.973
11  372.251
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TS: 1 506.429 2 486.891 3 467.945 4 448.979 5 429.500 6 409.228 7 387.831 8 364.739 9 339.004 10 498.984

************************ I H X - 2   T H E R M A L   C A L C U L A T I O N S   ************************

TP: 1 525.980 2 503.869 3 483.990 4 464.822 5 445.637 6 426.053 7 405.841 8 384.794 9 362.650 10 525.973
11 371.541
TS: 1 504.146 2 484.024 3 464.797 4 445.598 5 426.024 6 405.819 7 384.759 8 362.583 9 338.996 10 498.427

**************   P R I M A R Y   S O D I U M   T R A N S P O R T   C A L C U L A T I O N S   **************

TC1: 1 528.372 2 527.440 3 526.713 4 526.290 5 526.090 6 526.010 7 525.982 8 525.974 9 525.972 10 525.972
TW1: 1 526.143 2 526.061 3 526.011 4 525.987 5 525.976 6 525.973 7 525.972 8 525.972 9 525.972 10 525.972
TC2: 1 525.972 2 525.972 3 525.972 4 525.972 5 525.973 6 525.974 7 525.975 8 525.977 9 525.980 10 525.982
TW2: 1 525.986 2 525.987 3 525.987 4 525.988 5 525.988 6 525.989 7 525.989 8 525.989 9 525.989 10 525.989
TC3: 1 374.545 2 376.346 3 377.639 4 378.485 5 378.988 6 379.262 7 379.399 8 379.461 9 379.488 10 379.498
TW3: 1 379.202 2 379.328 3 379.409 4 379.456 5 379.482 6 379.495 7 379.501 8 379.503 9 379.504 10 379.504
TC4: 1 528.372 2 527.440 3 526.713 4 526.290 5 526.090 6 526.010 7 525.982 8 525.974 9 525.972 10 525.972
TW4: 1 526.143 2 526.061 3 526.011 4 525.987 5 525.976 6 525.973 7 525.972 8 525.972 9 525.972 10 525.972
TC5: 1 525.972 2 525.972 3 525.972 4 525.972 5 525.973 6 525.974 7 525.975 8 525.977 9 525.980 10 525.982
TW5: 1 525.986 2 525.987 3 525.987 4 525.988 5 525.988 6 525.989 7 525.989 8 525.989 9 525.989 10 525.989
TC6: 1 374.083 2 376.067 3 377.483 4 378.403 5 378.949 6 379.245 7 379.393 8 379.460 9 379.488 10 379.499
TW6: 1 379.177 2 379.315 3 379.403 4 379.454 5 379.481 6 379.496 7 379.502 8 379.504 9 379.505 10 379.506

************************ I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S ************************

SODIUM FLOW RATE = 0.4616   PUMP SPEED = 0.4276   PUMP HEAD = 0.1604   MOTOR GEN. SET FREQ. =   69.104 CYCLES/SEC
MAIN MOTOR TORQUE = 1.2820   DRIVE MOTOR TORQUE = 0.0     PUMP TORQUE = 0.1688   FRICTION TORQUE = 0.0218

************************ I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S ************************

SODIUM FLOW RATE = 0.5004   PUMP SPEED = 0.4380   PUMP HEAD = 0.1502   MOTOR GEN. SET FREQ. =   68.524 CYCLES/SEC
MAIN MOTOR TORQUE = 1.2988   DRIVE MOTOR TORQUE = 0.0     PUMP TORQUE = 0.1658   FRICTION TORQUE = 0.0221

*******************   I N T E R M E D I A T E   L O O P - 1:   S O D I U M   T R A N S P O R T   *******************

TCS1: 1 497.301 2 496.587 3 496.339 4 496.267 5 496.248 6 496.245 7 496.244 8 496.244 9 496.244 10 496.244
TWS1: 1 496.332 2 496.271 3 496.250 4 496.245 5 496.244 6 496.244 7 496.244 8 496.244 9 496.244 10 496.244
TCS2: 1 337.839
TWS2: 1 338.919
TCS3: 1 338.705 2 338.940
TWS3: 1 338.973 2 338.989
TCS4: 1 338.982 2 338.996 3 339.000 4 339.001 5 339.001 6 339.001 7 339.001 8 339.001 9 339.001 10 339.001
TWS4: 1 339.002 2 339.002 3 339.002 4 339.002 5 339.002 6 339.002 7 339.003 8 339.003 9 339.003 10 339.003

*******************   I N T E R M E D I A T E   L O O P - 2:   S O D I U M   T R A N S P O R T   *******************

TCS1: 1 496.846 2 496.385 3 496.278 4 496.258 5 496.255 6 496.255 7 496.255 8 496.255 9 496.255 10 496.255
TWS1: 1 496.318 2 496.268 3 496.257 4 496.255 5 496.255 6 496.255 7 496.255 8 496.255 9 496.255 10 496.255
TCS2: 1 339.037
TWS2: 1 339.005
TCS3: 1 339.188 2 339.107
TWS3: 1 339.006 2 338.995
TCS4: 1 339.043 2 339.010 3 338.997 4 338.994 5 338.993 6 338.993 7 338.994 8 338.994 9 338.994 10 338.994
TWS4: 1 338.997 2 338.995 3 338.994 4 338.994 5 338.994 6 338.994 7 338.994 8 338.994 9 338.994 10 338.994

**********************************  S T E A M   G E N E R A T I O N   L O O P - 1   **********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.4817   STEAM FLOW =0.6454   INT. SODIUM FLOW =0.4616

P 1 = 1.2150E+07  P 2 = 1.2026E+07  P 3 = 1.2026E+07  P 4 = 1.2133E+07  P 5 = 1.2295E+07  P 6 = 1.2302E+07  P 7 = 1.2326E+07
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P 8 = 1.2302E+07  P 9 = 1.2224E+07  P10 = 1.2089E+07  P11 = 1.2064E+07  P12 = 1.2032E+07  P13 = 1.2026E+07  P14 = 1.1996E+07
P15 = 1.1938E+07  P16 = 1.1752E+07  P17 = 1.1563E+07  P18 = 1.1384E+07  P19 = 1.1204E+07  P20 = 1.1155E+07  P21 = 1.0921E+07
H 1 = 1.0030E+06  H 2 = 1.6256E+06  H 3 = 1.4984E+06  H 4 = 1.3278E+06  H 5 = 1.3221E+06  H 6 = 1.2931E+06  H 7 = 1.2741E+06
H 8 = 1.2734E+06  H 9 = 1.5003E+06  H10 = 2.2994E+06  H11 = 2.2798E+06  H12 = 2.1839E+06  H13 = 2.1583E+06  H14 = 2.6815E+06
H15 = 2.6815E+06  H16 = 3.0321E+06  H17 = 3.2044E+06  H18 = 3.2877E+06  H19 = 3.3266E+06  H20 = 3.3266E+06  H21 = 3.3240E+06
TM 1 =  232.3703  TM 2 =  325.6895  TM 3 =  324.7397  TM 4 =  294.7893  TM 5 =  293.9280  TM 6 =  289.3516  TM 7 =  286.1753
TM 8 =  286.0540  TM 9 =  325.9941  TM10 =  325.1414  TM11 =  324.9834  TM12 =  324.7781  TM13 =  324.7397  TM14 =  324.5508
TM15 =  324.1841  TM16 =  393.5879  TM17 =  444.6536  TM18 =  472.9465  TM19 =  486.6299  TM20 =  486.3948  TM21 =  484.2476
TCS 8 =  335.8564  TCS 9 =  360.4839  TCS10 =  452.8616  TCS11 =  453.3008  TCS12 =  453.7563  TCS13 =  453.6714  TCS14 =  451.9902
TCS15 =  447.5061  TCS16 =  474.2988  TCS17 =  487.0967  TCS18 =  493.2419  TCS19 =  496.2444  TCS
                        TDLOG:  9       41.6784 10        71.2129
                        U    :  9     4821.4844 10      8248.6562
          TDLOG: 16      100.5157 17      59.5413 18       30.0198 19        14.2961
          U    : 16     3659.3503 17    3030.1140 18     2908.1416 19      2862.4575

HEAT FLUX = 2.403677E+05                         OUTLET STEAM QUALITY = 6.773223E-01
NON-BOILING LENGTH = 4.934828E+00               BOILING LENGTH = 6.029021E+00

DRUM INT. ENERGY = 1.2969E+10   DRUM LEVEL = 0.8827   CVP = 1.5175   ALFA = 0.4440   DPRP = 2.5067E+07

**********************************   S T E A M   G E N E R A T I O N   L O O P - 2   **********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.4822  STEAM FLOW =0.6455  INT. SODIUM FLOW =0.5004

P 1 = 1.2150E+07  P 2 = 1.2027E+07  P 3 = 1.2027E+07  P 4 = 1.2134E+07  P 5 = 1.2296E+07  P 6 = 1.2303E+07  P 7 = 1.2326E+07
P 8 = 1.2303E+07  P 9 = 1.2227E+07  P10 = 1.2090E+07  P11 = 1.2065E+07  P12 = 1.2033E+07  P13 = 1.2027E+07  P14 = 1.1997E+07
P15 = 1.1939E+07  P16 = 1.1753E+07  P17 = 1.1564E+07  P18 = 1.1384E+07  P19 = 1.1204E+07  P20 = 1.1155E+07  P21 = 1.0921E+07
H 1 = 1.0030E+06  H 2 = 1.6257E+06  H 3 = 1.4984E+06  H 4 = 1.3278E+06  H 5 = 1.3221E+06  H 6 = 1.2932E+06  H 7 = 1.2742E+06
H 8 = 1.2734E+06  H 9 = 1.5004E+06  H10 = 2.2996E+06  H11 = 2.2800E+06  H12 = 2.1842E+06  H13 = 2.1586E+06  H14 = 2.6815E+06
H15 = 2.6815E+06  H16 = 3.0363E+06  H17 = 3.2079E+06  H18 = 3.2897E+06  H19 = 3.3275E+06  H20 = 3.3274E+06  H21 = 3.3243E+06
TM 1 =  232.3703  TM 2 =  325.6875  TM 3 =  324.7461  TM 4 =  294.7927  TM 5 =  293.9321  TM 6 =  289.3552  TM 7 =  286.1780
TM 8 =  286.0566  TM 9 =  326.0098  TM10 =  325.1489  TM11 =  324.9905  TM12 =  324.7849  TM13 =  324.7461  TM14 =  324.5574
TM15 =  324.1902  TM16 =  394.7532  TM17 =  445.8064  TM18 =  473.6755  TM19 =  486.9509  TM20 =  486.7053  TM21 =  484.3647
TCS 8 =  338.1323  TCS 9 =  363.5491  TCS10 =  453.0667  TCS11 =  453.6750  TCS12 =  454.3738  TCS13 =  454.6287  TCS14 =  453.4673
TCS15 =  449.8508  TCS16 =  475.5874  TCS17 =  487.7268  TCS18 =  493.4878  TCS19 =  496.2551  TCS
                        TDLOG:  9       44.4117 10        73.7181
                        U    :  9     4834.0156 10      8288.6328
          TDLOG: 16      101.6046 17      59.2631 18       29.4983 19        13.9026
          U    : 16     3664.5227 17    3031.3284 18     2911.0530 19      2866.3225

HEAT FLUX = 2.500151E+05                         OUTLET STEAM QUALITY = 6.775277E-01
NON-BOILING LENGTH = 4.626612E+00               BOILING LENGTH = 5.799929E+00

DRUM INT. ENERGY = 1.2969E+10   DRUM LEVEL = 0.8827   CVP = 1.5173   ALFA = 0.4441   DPRP = 2.5028E+07

******************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   ******************************

     THROTTLE VALVE POSITION =1.0000                              DUMP(BYPASS) VALVE POSITION =0.8632
     THROTTLE VALVE FLOW     =0.0       RELIEF VALVE FLOW =0.0    DUMP(BYPASS) VALVE FLOW     =0.7181
     HEADER PRESSURE = 1.0921E+07        TEMPERATURE =  485.7788     SPECIFIC ENTHALPY= 3.3273E+06

*******************************   M E A S U R E D   V A L U E S   F O R   P P S   *******************************

 PRESNORM =  0.44410         VESSEL LEVEL =   4.5623         PTOTNORM =  0.10463
 TIHX1 =  377.010      TIHX2 =  376.784      TEVAP1 =  338.222      TEVAP2 =  339.061
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```
STEP #    50   TIME =     7.99999 SEC    S =  0.20000 SEC

                                                 TOTAL VECTOR OF CONTROL INTEGERS
 11   12   13   14   15   20   25   26   40   41   43   44   46   47   53   54   55   56   63   81   82   83   84  106  107
108  109  109  233  238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292  293
294  295  296  297  298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342  343
344  345  346  347  348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411  423
424  425  426  427  428  432  450  462  463  464  465  466  467  471  480  483  485    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0

**************************    N E U T R O N    K I N E T I C S    C A L C U L A T I O N S    **************************

PTOT =         81.988 MWT     PN =         18.553 MWT     PFP =          63.435 MWT
PDN :    1     0.841 MWT     2    0.366 MWT    PFP :     3   16.727 MWT    4    17.770 MWT    5   28.938 MWT
ROTOT =     -17.592834 $     ROCR1 =        2.749999 $     ROCR2 =        0.0       $     ROFDBK =      -2.342841 $
RODOP =      -0.997528 $     ROSOD =       -0.024454 $     ROCRE =       -1.097416 $     ROCAE  =      -0.223444 $
TRO    =    505.151           TROM   =     535.473           TSTM   =     483.007
PD =           0.9000         ETST   =    -11.749756         FTRO   =     29.025635   EF =      -0.050000   DELRO =      -0.000333
PTOTNORM =   0.0841           PNNORM =       0.0190          PFPNORM =     0.0651     SCRAM RODS:   PRIM = 100.000 %   SEC =    0.0    %

*********************************    P R I M A R Y    C O O L A N T    D Y N A M I C S    *********************************

FZ1NRM = 0.3634                             FZ2NRM = 0.3631  FZ3NRM = 0.3574  CANRM = 0.2887   RBNRM = 0.3235   BPNRM = 0.3881
FLOWS: 1    6.2248E+02    2    6.2166E+02    3    6.8458E+02    4    4.9832E+01    5    2.3487E+01    6    2.4123E+02    7    8.4301E+01
AL1=    0.3513   NEW1=    0.3576   BP1=    0.1212   TMOTN1=    0.0          HP1=     0.1199   FREQ1=  348.136
AL2=    0.3512   NEW2=    0.3571   BP2=    0.1213   TMOTN2=    0.0          HP2=     0.1200   FREQ2=  348.199
PD =    0.9000   TRISP =  387.779   NEWSP =    0.9000   ASP =    0.9000   XKW = 1.316E-03   EPS = 1.000E-05    N =  3
TRIM:      379.497     379.498        NEWM:        0.3738      0.3733          ALM:         0.3513       0.3512        INLET PRSNRM = 0.4045
ET:      1.4908E+01     1.4906E+01      EW:         5.4586E-01      5.4632E-01        EA:         7.4871E-01      7.4881E-01

******************************    R E A C T O R    H E A T    T R A N S F E R    ******************************

  CORE HOT SPOT:          MAX. COOLANT TEMP. =    581.553          MAX. CLAD TEMP. =    591.388
PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =    805.816    CLAD INNER =    449.672    CLAD OUTER =    448.804
TM 1 =    391.478    TM 2 =    778.274    TM 3 =    561.562    TM 4 =    388.598    TM 5 =    715.482    TM 6 =    540.476
TM 7 =    388.406    TM 8 =    660.450    TM 9 =    517.841    TM10 =    449.603    TM11 =    496.730    TM
TC 1 =    381.855    TC 2 =    510.710    TC 3 =    529.167    TC 4 =    381.424    TC 5 =    496.014    TC 6 =    513.362
TC 7 =    381.398    TC 8 =    478.819    TC 9 =    494.029    TC10 =    453.662    TC11 =    488.883    TC12 =    379.520
TCI1 =    379.519    TCI2 =    379.519    TCI3 =    379.519    TCI4 =    379.519    TCI5 =    379.519    TCI6 =    379.519
LOWER PLENUM:                             TOP ZONE TEMP. =    379.519    BOTTOM ZONE TEMP. =    379.517
UPPER PLENUM:  ZJET =      6.400    TOP ZONE TEMP. =    528.463    BOTTOM ZONE TEMP. =    528.463    NOZZLE TEMP. =    528.463

************************    I H X - 1    T H E R M A L    C A L C U L A T I O N S    ************************

TP:  1  525.979  2  504.691  3  484.926  4  465.737  5  446.509  6  426.773  7  406.182  8  384.322  9  360.546 10  525.973
11  369.269
```

```
TS:  1  508.725  2  488.663  3  469.404  4  450.212  5  430.609  6  410.206  7  388.595  8  365.169  9  339.002 10  500.300

************************    I H X - 2    T H E R M A L    C A L C U L A T I O N S    ************************

TP:  1  525.979  2  502.516  3  481.861  4  461.681  5  442.733  6  423.154  7  402.751  8  381.437  9  359.015 10  525.973
11  368.221
TS:  1  506.009  2  484.833  3  464.838  4  445.442  5  426.041  6  405.793  7  384.635  8  362.403  9  338.995 10  499.530

**************    P R I M A R Y    S O D I U M    T R A N S P O R T    C A L C U L A T I O N S    **************

TC1:  1  528.573  2  527.978  3  527.236  4  526.648  5  526.285  6  526.100  7  526.018  8  525.986  9  525.975 10  525.972
TW1:  1  526.245  2  526.144  3  526.065  4  526.016  5  525.990  6  525.978  7  525.973  8  525.972  9  525.972 10  525.972
TC2:  1  525.972  2  525.972  3  525.972  4  525.972  5  525.972  6  525.972  7  525.973  8  525.974  9  525.975 10  525.977
TW2:  1  525.985  2  525.985  3  525.985  4  525.986  5  525.986  6  525.987  7  525.988  8  525.988  9  525.988 10  525.988
TC3:  1  371.892  2  374.144  3  375.949  4  377.292  5  378.215  6  378.801  7  379.145  8  379.332  9  379.426 10  379.471
TW3:  1  378.874  2  379.096  3  379.255  4  379.360  5  379.426  6  379.465  7  379.485  8  379.495  9  379.500 10  379.502
TC4:  1  528.573  2  527.978  3  527.236  4  526.648  5  526.285  6  526.100  7  526.018  8  525.986  9  525.975 10  525.972
TW4:  1  526.245  2  526.144  3  526.065  4  526.016  5  525.990  6  525.978  7  525.973  8  525.972  9  525.972 10  525.972
TC5:  1  525.972  2  525.972  3  525.972  4  525.972  5  525.972  6  525.972  7  525.973  8  525.974  9  525.975 10  525.977
TW5:  1  525.985  2  525.985  3  525.985  4  525.986  5  525.986  6  525.987  7  525.988  8  525.988  9  525.988 10  525.988
TC6:  1  371.136  2  373.632  3  375.624  4  377.099  5  378.108  6  378.745  7  379.118  8  379.320  9  379.422 10  379.470
TW6:  1  378.816  2  379.061  3  379.235  4  379.349  5  379.421  6  379.463  7  379.485  8  379.496  9  379.501 10  379.504

************************ I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S ************************

 SODIUM FLOW RATE =  0.3906    PUMP SPEED =  0.3610    PUMP HEAD =  0.1138    MOTOR GEN. SET FREQ. =    78.165 CYCLES/SEC
 MAIN MOTOR TORQUE =  1.1636    DRIVE MOTOR TORQUE =  0.0      PUMP TORQUE =  0.1200    FRICTION TORQUE =  0.0203

************************ I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S ************************

 SODIUM FLOW RATE =  0.4268    PUMP SPEED =  0.3720    PUMP HEAD =  0.1075    MOTOR GEN. SET FREQ. =    77.423 CYCLES/SEC
 MAIN MOTOR TORQUE =  1.1767    DRIVE MOTOR TORQUE =  0.0      PUMP TORQUE =  0.1191    FRICTION TORQUE =  0.0206

*******************    I N T E R M E D I A T E    L O O P - 1:   S O D I U M    T R A N S P O R T    *******************

TCS1:  1  498.065  2  496.944  3  496.477  4  496.311  5  496.260  6  496.247  7  496.244  8  496.244  9  496.244 10  496.244
TWS1:  1  496.437  2  496.312  3  496.264  4  496.249  5  496.245  6  496.244  7  496.244  8  496.244  9  496.244 10  496.244
TCS2:  1  336.375
TWS2:  1  338.778
TCS3:  1  338.139  2  338.760
TWS3:  1  338.919  2  338.973
TCS4:  1  338.901  2  338.963  3  338.988  4  338.996  5  338.999  6  339.000  7  339.000  8  339.000  9  339.000 10  339.000
TWS4:  1  338.997  2  339.000  3  339.001  4  339.001  5  339.001  6  339.001  7  339.001  8  339.001  9  339.001 10  339.002

*******************    I N T E R M E D I A T E    L O O P - 2:   S O D I U M    T R A N S P O R T    *******************

TCS1:  1  497.326  2  496.542  3  496.318  4  496.266  5  496.256  6  496.255  7  496.255  8  496.255  9  496.255 10  496.255
TWS1:  1  496.395  2  496.290  3  496.261  4  496.255  5  496.255  6  496.255  7  496.255  8  496.255  9  496.255 10  496.255
TCS2:  1  338.144
TWS2:  1  338.954
TCS3:  1  338.965  2  339.101
TWS3:  1  338.998  2  339.000
TCS4:  1  339.072  2  339.031  3  339.007  4  338.997  5  338.994  6  338.993  7  338.993  8  338.993  9  338.993 10  338.993
TWS4:  1  339.000  2  338.996  3  338.994  4  338.994  5  338.994  6  338.994  7  338.994  8  338.994  9  338.994 10  338.994

***********************************    S T E A M    G E N E R A T I O N    L O O P - 1    ***********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.4186  STEAM FLOW =0.7625  INT. SODIUM FLOW =0.3906

P 1 = 1.2150E+07  P 2 = 1.1768E+07  P 3 = 1.1768E+07  P 4 = 1.1880E+07  P 5 = 1.1985E+07  P 6 = 1.1993E+07  P 7 = 1.2015E+07
```

```
P 8 = 1.1993E+07  P 9 = 1.1927E+07  P10 = 1.1816E+07  P11 = 1.1796E+07  P12 = 1.1771E+07  P13 = 1.1768E+07  P14 = 1.1712E+07
P15 = 1.1630E+07  P16 = 1.1365E+07  P17 = 1.1096E+07  P18 = 1.0837E+07  P19 = 1.0573E+07  P20 = 1.0502E+07  P21 = 1.0209E+07
H 1 = 1.0030E+06  H 2 = 1.6202E+06  H 3 = 1.4984E+06  H 4 = 1.3385E+06  H 5 = 1.3331E+06  H 6 = 1.3019E+06  H 7 = 1.2754E+06
H 8 = 1.2743E+06  H 9 = 1.4882E+06  H10 = 2.3571E+06  H11 = 2.3357E+06  H12 = 2.2390E+06  H13 = 2.2134E+06  H14 = 2.6848E+06
H15 = 2.6848E+06  H16 = 3.0021E+06  H17 = 3.1805E+06  H18 = 3.2756E+06  H19 = 3.3242E+06  H20 = 3.3245E+06  H21 = 3.3247E+06
TM 1 =  232.3703  TM 2 =  325.6892  TM 3 =  323.0854  TM 4 =  296.3521  TM 5 =  295.5725  TM 6 =  290.7742  TM 7 =  286.3943
TM 8 =  286.2090  TM 9 =  324.1101  TM10 =  323.3958  TM11 =  323.2703  TM12 =  323.1067  TM13 =  323.0854  TM14 =  322.7241
TM15 =  322.1909  TM16 =  382.6736  TM17 =  433.8542  TM18 =  465.6130  TM19 =  482.5979  TM20 =  482.3879  TM21 =  480.9944
TCS 8 =  333.1003  TCS 9 =  353.9302  TCS10 =  453.1487  TCS11 =  453.4167  TCS12 =  453.1714  TCS13 =  451.5608  TCS14 =  447.3638
TCS15 =  438.9026  TCS16 =  468.9556  TCS17 =  484.2253  TCS18 =  491.9912  TCS19 =  496.2441  TCS
                          TDLOG:  9       37.7140 10       67.9607
                          U    :  9     4537.6875 10     8191.1797
          TDLOG: 16      100.7321 17      66.7236 18       37.0902 19       19.3179
          U    : 16     3922.6077 17    3307.2439 18     3163.9294 19     3105.5122

HEAT FLUX = 2.277921E+05                         OUTLET STEAM QUALITY = 7.248732E-01
NON-BOILING LENGTH = 4.747912E+00              BOILING LENGTH = 6.037077E+00

DRUM INT. ENERGY = 1.2609E+10   DRUM LEVEL = 0.8434   CVP = 1.8357   ALFA = 0.3742   DPRP = 1.6759E+07

************************************   S T E A M   G E N E R A T I O N   L O O P - 2   ************************************

FEED WATER FLOW =0.0      WATER/STEAM FLOW =0.4196  STEAM FLOW =0.7625  INT. SODIUM FLOW =0.4268

P 1 = 1.2150E+07  P 2 = 1.1770E+07  P 3 = 1.1770E+07  P 4 = 1.1882E+07  P 5 = 1.1986E+07  P 6 = 1.1994E+07  P 7 = 1.2017E+07
P 8 = 1.1994E+07  P 9 = 1.1931E+07  P10 = 1.1818E+07  P11 = 1.1798E+07  P12 = 1.1773E+07  P13 = 1.1770E+07  P14 = 1.1714E+07
P15 = 1.1632E+07  P16 = 1.1367E+07  P17 = 1.1097E+07  P18 = 1.0837E+07  P19 = 1.0574E+07  P20 = 1.0503E+07  P21 = 1.0209E+07
H 1 = 1.0030E+06  H 2 = 1.6203E+06  H 3 = 1.4984E+06  H 4 = 1.3385E+06  H 5 = 1.3332E+06  H 6 = 1.3020E+06  H 7 = 1.2755E+06
H 8 = 1.2744E+06  H 9 = 1.4884E+06  H10 = 2.3573E+06  H11 = 2.3359E+06  H12 = 2.2393E+06  H13 = 2.2138E+06  H14 = 2.6848E+06
H15 = 2.6848E+06  H16 = 3.0091E+06  H17 = 3.1850E+06  H18 = 3.2785E+06  H19 = 3.3255E+06  H20 = 3.3258E+06  H21 = 3.3252E+06
TM 1 =  232.3703  TM 2 =  325.6873  TM 3 =  323.0989  TM 4 =  296.3579  TM 5 =  295.5786  TM 6 =  290.7805  TM 7 =  286.3979
TM 8 =  286.2122  TM 9 =  324.1362  TM10 =  323.4102  TM11 =  323.2847  TM12 =  323.1204  TM13 =  323.0989  TM14 =  322.7373
TM15 =  322.2041  TM16 =  384.5244  TM17 =  435.3733  TM18 =  466.6599  TM19 =  483.1208  TM20 =  482.8931  TM21 =  481.2053
TCS 8 =  336.1169  TCS 9 =  357.9482  TCS10 =  453.5344  TCS11 =  454.0090  TCS12 =  454.0266  TCS13 =  452.7913  TCS14 =  449.2146
TCS15 =  441.8599  TCS16 =  470.6782  TCS17 =  485.1111  TCS18 =  492.3582  TCS19 =  496.2549  TCS
                          TDLOG:  9       41.3376 10       71.4655
                          U    :  9     4551.3711 10     8234.0039
          TDLOG: 16      101.9894 17      66.2870 18       36.4046 19       18.7186
          U    : 16     3927.8672 17    3307.2466 18     3167.3315 19     3110.2422

HEAT FLUX = 2.407779E+05                         OUTLET STEAM QUALITY = 7.250452E-01
NON-BOILING LENGTH = 4.331699E+00              BOILING LENGTH = 5.718166E+00

DRUM INT. ENERGY = 1.2610E+10   DRUM LEVEL = 0.8434   CVP = 1.8355   ALFA = 0.3743   DPRP = 1.6708E+07

******************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   ******************************

   THROTTLE VALVE POSITION =1.0000                               DUMP(BYPASS) VALVE POSITION =1.0000
   THROTTLE VALVE FLOW     =0.0       RELIEF VALVE FLOW =0.0     DUMP(BYPASS) VALVE FLOW     =0.8044
   HEADER PRESSURE = 1.0209E+07      TEMPERATURE =  475.0684     SPECIFIC ENTHALPY= 3.3089E+06

*******************************   M E A S U R E D   V A L U E S   F O R   P P S   *******************************

 PRESNORM =  0.40450          VESSEL LEVEL =   4.5623          PTOTNORM =  0.09295
 TIHX1 =  374.906     TIHX2 =  374.459     TEVAP1 =  336.971     TEVAP2 =  338.420

      **** SECONDARY SCRAM INITIATED AT TIME =  10.000 SEC ****
```

```
STEP #    60   TIME =    9.99998 SEC   S =  0.20000 SEC

                                                    TOTAL VECTOR OF CONTROL INTEGERS
 11   12   13   14   15   20   25   26   40   43   46   53   54   55   56   81   82   83   84   84  106  107  108  109  109
233  238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292  293  294  295  296
297  298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342  343  344  345  346
347  348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411  423  424  425  426
427  428  432  450  462  463  464  465  466  467  471  480  483  485    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0

**************************   N E U T R O N   K I N E T I C S   C A L C U L A T I O N S   **************************

PTOT =       75.397 MWT    PN =        14.435 MWT    PFP =          60.962 MWT
PDN :    1    0.581 MWT   2    0.352 MWT    PFP :    3  14.502 MWT    4   17.529 MWT    5   28.931 MWT
ROTOT =    -17.454514 $    ROCR1 =       2.749999 $    ROCR2 =       0.0      $    ROFDBK =     -2.204514 $
RODOP =     -0.896204 $    ROSOD =      -0.025126 $    ROCRE =      -1.097405 $    ROCAE  =     -0.185779 $
TRO   =    485.464          TROM  =    509.278           TSTM  =     477.277
PD =          0.9000       ETST  =    -11.749756        ETRO  =      29.025635   EF =    -0.050000   DELRO =    -0.000333
PTOTNORM =   0.0773        PNNORM =      0.0148         PFPNORM =     0.0625    SCRAM RODS:  PRIM = 100.000 %   SEC =   0.0   %

*******************************   P R I M A R Y   C O O L A N T   D Y N A M I C S   *******************************

FZ1NRM = 0.3109                           FZ2NRM = 0.3106  FZ3NRM = 0.3048  CANRM = 0.2403   RBNRM = 0.2726   BPNRM = 0.3355
FLOWS: 1   5.3156E+02   2   5.3072E+02   3   5.8550E+02   4   4.2497E+01   5   1.9551E+01   6   2.0325E+02   7   7.2878E+01
AL1=   0.3010   NEW1=   0.3054   BP1=   0.0892   TMOTN1=   0.0       HP1=   0.0885   FREQ1=  464.005
AL2=   0.3008   NEW2=   0.3049   BP2=   0.0893   TMOTN2=   0.0       HP2=   0.0886   FREQ2=  464.086
PD =   0.9000   TRISP =  387.779   NEWSP =   0.9000   ASP =   0.9000   XKW = 1.316E-03   EPS = 1.000E-05   N =  3
TRIM:      379.477      379.476     NEWM:        0.3175      0.3170       ALM:        0.3010       0.3008      INLET PRSNRM = 0.3789
ET:       1.4944E+01       1.4945E+01      EW:       6.0213E-01      6.0262E-01       EA:       7.9905E-01      7.9917E-01

******************************   R E A C T O R   H E A T   T R A N S F E R   ******************************

  CORE HOT SPOT:        MAX. COOLANT TEMP. =    549.721        MAX. CLAD TEMP. =    556.749
PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =    694.417   CLAD INNER =    438.177   CLAD OUTER =    437.567
TM 1 =    388.238    TM 2 =    669.088    TM 3 =    528.732    TM 4 =    386.139    TM 5 =    624.663    TM 6 =    512.604
TM 7 =    386.000    TM 8 =    584.539    TM 9 =    493.726    TM10 =    443.176    TM11 =    488.211    TM
TC 1 =    381.484    TC 2 =    490.039    TC 3 =    504.208    TC 4 =    381.115    TC 5 =    478.708    TC 6 =    492.446
TC 7 =    381.094    TC 8 =    464.072    TC 9 =    476.130    TC10 =    452.805    TC11 =    490.554    TC12 =    379.518
TCI1 =    379.517    TCI2 =    379.517    TCI3 =    379.517    TCI4 =    379.517    TCI5 =    379.517    TCI6 =    379.517
LOWER PLENUM:                          TOP ZONE TEMP. =    379.517   BOTTOM ZONE TEMP. =    379.513
UPPER PLENUM:  ZJET =     6.400   TOP ZONE TEMP. =    527.530   BOTTOM ZONE TEMP. =    527.530   NOZZLE TEMP. =    527.530

************************   I H X - 1   T H E R M A L   C A L C U L A T I O N S   ************************

TP:  1  525.978  2  504.068  3  483.936  4  464.176  5  445.037  6  425.217  7  404.393  8  382.165  9  357.854 10  525.973
11  366.683
```

```
TS:  1  510.498  2  489.886  3  470.157  4  450.800  5  431.267  6  410.785  7  389.020  8  365.376  9  339.001 10  501.532

************************     I H X - 2     T H E R M A L     C A L C U L A T I O N S     ************************

TP:  1  525.978  2  501.224  3  479.956  4  459.834  5  440.358  6  420.581  7  400.033  8  378.553  9  356.045 10  525.973
11  365.351
TS:  1  507.454  2  485.336  3  465.027  4  445.385  5  425.737  6  405.434  7  384.235  8  362.043  9  338.994 10  500.567

**************     P R I M A R Y     S O D I U M     T R A N S P O R T     C A L C U L A T I O N S     **************

TC1:  1  528.312  2  528.181  3  527.619  4  527.003  5  526.531  6  526.239  7  526.085  8  526.014  9  525.985 10  525.975
TW1:  1  526.324  2  526.228  3  526.132  4  526.059  5  526.013  6  525.989  7  525.978  8  525.973  9  525.971 10  525.971
TC2:  1  525.973  2  525.972  3  525.972  4  525.972  5  525.972  6  525.972  7  525.972  8  525.972  9  525.973 10  525.974
TW2:  1  525.983  2  525.984  3  525.984  4  525.985  5  525.985  6  525.985  7  525.986  8  525.986  9  525.986 10  525.986
TC3:  1  369.472  2  371.990  3  374.147  4  375.885  5  377.193  6  378.113  7  378.714  8  379.081  9  379.290 10  379.402
TW3:  1  378.445  2  378.772  3  379.022  4  379.202  5  379.324  6  379.403  7  379.450  8  379.476  9  379.490 10  379.497
TC4:  1  528.312  2  528.181  3  527.619  4  527.003  5  526.531  6  526.239  7  526.085  8  526.014  9  525.985 10  525.975
TW4:  1  526.324  2  526.228  3  526.132  4  526.059  5  526.013  6  525.989  7  525.978  8  525.973  9  525.971 10  525.971
TC5:  1  525.973  2  525.972  3  525.972  4  525.972  5  525.972  6  525.972  7  525.972  8  525.972  9  525.973 10  525.974
TW5:  1  525.983  2  525.984  3  525.984  4  525.985  5  525.985  6  525.985  7  525.986  8  525.986  9  525.986 10  525.986
TC6:  1  368.448  2  371.242  3  373.631  4  375.549  5  376.987  6  377.994  7  378.650  8  379.048  9  379.275 10  379.395
TW6:  1  378.344  2  378.704  3  378.979  4  379.176  5  379.310  6  379.395  7  379.447  8  379.476  9  379.490 10  379.498

************************  I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S  ************************

 SODIUM FLOW RATE =  0.3374   PUMP SPEED =  0.3109   PUMP HEAD =  0.0840   MOTOR GEN. SET FREQ. =    88.103 CYCLES/SEC
 MAIN MOTOR TORQUE =  1.0917   DRIVE MOTOR TORQUE =  0.0      PUMP TORQUE =  0.0887   FRICTION TORQUE =  0.0192

************************  I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S  ************************

 SODIUM FLOW RATE =  0.3708   PUMP SPEED =  0.3220   PUMP HEAD =  0.0798   MOTOR GEN. SET FREQ. =    87.196 CYCLES/SEC
 MAIN MOTOR TORQUE =  1.1020   DRIVE MOTOR TORQUE =  0.0      PUMP TORQUE =  0.0888   FRICTION TORQUE =  0.0194

*******************     I N T E R M E D I A T E     L O O P - 1:   S O D I U M     T R A N S P O R T     *******************

TCS1:  1  498.871  2  497.377  3  496.670  4  496.385  5  496.284  6  496.253  7  496.245  8  496.244  9  496.244 10  496.244
TWS1:  1  496.581  2  496.378  3  496.290  4  496.257  5  496.247  6  496.244  7  496.244  8  496.244  9  496.244 10  496.244
TCS2:  1  334.522
TWS2:  1  338.541
TCS3:  1  337.301  2  338.437
TWS3:  1  338.814  2  338.936
TCS4:  1  338.730  2  338.880  3  338.951  4  338.981  5  338.993  6  338.997  7  338.998  8  338.998  9  338.999 10  338.999
TWS4:  1  338.983  2  338.993  3  338.998  4  338.999  5  339.000  6  339.000  7  339.000  8  339.000  9  339.000 10  339.000

*******************     I N T E R M E D I A T E     L O O P - 2:   S O D I U M     T R A N S P O R T     *******************

TCS1:  1  497.856  2  496.746  3  496.381  4  496.281  5  496.258  6  496.255  7  496.255  8  496.255  9  496.255 10  496.255
TWS1:  1  496.503  2  496.326  3  496.271  4  496.257  5  496.255  6  496.255  7  496.255  8  496.255  9  496.255 10  496.255
TCS2:  1  336.759
TWS2:  1  338.828
TCS3:  1  338.455  2  338.971
TWS3:  1  338.958  2  338.994
TCS4:  1  339.059  2  339.044  3  339.018  4  339.002  5  338.995  6  338.993  7  338.993  8  338.993  9  338.993 10  338.993
TWS4:  1  339.002  2  338.997  3  338.995  4  338.994  5  338.994  6  338.994  7  338.994  8  338.994  9  338.994 10  338.994

***********************************     S T E A M     G E N E R A T I O N     L O O P - 1     ***********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.3747   STEAM FLOW =0.7428   INT. SODIUM FLOW =0.3374

P 1 = 1.2150E+07   P 2 = 1.1433E+07   P 3 = 1.1433E+07   P 4 = 1.1549E+07   P 5 = 1.1618E+07   P 6 = 1.1626E+07   P 7 = 1.1648E+07
```

```
P 8 = 1.1626E+07  P 9 = 1.1567E+07  P10 = 1.1471E+07  P11 = 1.1455E+07  P12 = 1.1434E+07  P13 = 1.1433E+07  P14 = 1.1374E+07
P15 = 1.1293E+07  P16 = 1.1035E+07  P17 = 1.0774E+07  P18 = 1.0521E+07  P19 = 1.0264E+07  P20 = 1.0195E+07  P21 = 9.9309E+06
H 1 = 1.0030E+06  H 2 = 1.6114E+06  H 3 = 1.4964E+06  H 4 = 1.3474E+06  H 5 = 1.3423E+06  H 6 = 1.3101E+06  H 7 = 1.2769E+06
H 8 = 1.2755E+06  H 9 = 1.4735E+06  H10 = 2.4210E+06  H11 = 2.3976E+06  H12 = 2.2946E+06  H13 = 2.2679E+06  H14 = 2.6906E+06
H15 = 2.6906E+06  H16 = 2.9931E+06  H17 = 3.1714E+06  H18 = 3.2706E+06  H19 = 3.3237E+06  H20 = 3.3236E+06  H21 = 3.3244E+06
TM 1 =  232.3702  TM 2 =  325.6890  TM 3 =  320.8948  TM 4 =  297.6079  TM 5 =  296.8955  TM 6 =  292.0720  TM 7 =  286.6477
TM 8 =  286.4019  TM 9 =  321.7817  TM10 =  321.1475  TM11 =  321.0430  TM12 =  320.9062  TM13 =  320.8948  TM14 =  320.5059
TM15 =  319.9683  TM16 =  377.7112  TM17 =  428.8491  TM18 =  462.0442  TM19 =  480.9065  TM20 =  480.4912  TM21 =  479.5002
TCS 8 =  329.9434  TCS 9 =  346.6646  TCS10 =  453.1763  TCS11 =  452.9309  TCS12 =  451.5588  TCS13 =  447.9915  TCS14 =  440.9084
TCS15 =  429.2488  TCS16 =  462.2927  TCS17 =  480.4048  TCS18 =  490.3333  TCS19 =  496.2439  TCS
                            TDLOG:  9        33.3467 10       64.2037
                            U    :  9      4313.0234 10     8186.9531
             TDLOG: 16      96.4044 17       66.7116 18       38.7655 19       21.1566
             U    : 16    3822.5444 17     3245.2927 18     3102.1267 19     3042.2080

HEAT FLUX = 2.150886E+05                        OUTLET STEAM QUALITY = 7.758678E-01
NON-BOILING LENGTH = 4.682474E+00              BOILING LENGTH = 6.246250E+00

DRUM INT. ENERGY = 1.2206E+10   DRUM LEVEL = 0.8032   CVP = 2.1897   ALFA = 0.3232   DPRP = 1.1593E+07

***********************************   S T E A M   G E N E R A T I O N   L O O P - 2   ***********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.3761  STEAM FLOW =0.7431  INT. SODIUM FLOW =0.3708

P 1 = 1.2150E+07  P 2 = 1.1436E+07  P 3 = 1.1436E+07  P 4 = 1.1552E+07  P 5 = 1.1621E+07  P 6 = 1.1629E+07  P 7 = 1.1651E+07
P 8 = 1.1629E+07  P 9 = 1.1573E+07  P10 = 1.1475E+07  P11 = 1.1459E+07  P12 = 1.1438E+07  P13 = 1.1436E+07  P14 = 1.1377E+07
P15 = 1.1296E+07  P16 = 1.1037E+07  P17 = 1.0775E+07  P18 = 1.0522E+07  P19 = 1.0265E+07  P20 = 1.0196E+07  P21 = 9.9309E+06
H 1 = 1.0030E+06  H 2 = 1.6115E+06  H 3 = 1.4984E+06  H 4 = 1.3475E+06  H 5 = 1.3424E+06  H 6 = 1.3102E+06  H 7 = 1.2770E+06
H 8 = 1.2755E+06  H 9 = 1.4738E+06  H10 = 2.4210E+06  H11 = 2.3978E+06  H12 = 2.2950E+06  H13 = 2.2684E+06  H14 = 2.6906E+06
H15 = 2.6906E+06  H16 = 2.9995E+06  H17 = 3.1772E+06  H18 = 3.2743E+06  H19 = 3.3254E+06  H20 = 3.3253E+06  H21 = 3.3252E+06
TM 1 =  232.3702  TM 2 =  325.6870  TM 3 =  320.9175  TM 4 =  297.6169  TM 5 =  296.9050  TM 6 =  292.0820  TM 7 =  286.6521
TM 8 =  286.4060  TM 9 =  321.8213  TM10 =  321.1719  TM11 =  321.0667  TM12 =  320.9294  TM13 =  320.9175  TM14 =  320.5281
TM15 =  319.9902  TM16 =  379.4131  TM17 =  430.7644  TM18 =  463.4150  TM19 =  481.5442  TM20 =  481.1731  TM21 =  479.8433
TCS 8 =  333.4758  TCS 9 =  351.4087  TCS10 =  453.7063  TCS11 =  453.6541  TCS12 =  452.5242  TCS13 =  449.3477  TCS14 =  443.0149
TCS15 =  432.7937  TCS16 =  464.5237  TCS17 =  481.6284  TCS18 =  490.8760  TCS19 =  496.2546  TCS
                            TDLOG:  9        37.6546 10       68.6546
                            U    :  9      4328.5312 10     8230.8906
             TDLOG: 16      98.3080 17       66.5246 18       37.9679 19       20.4268
             U    : 16    3828.8672 17     3246.1218 18     3105.6050 19     3047.3914

HEAT FLUX = 2.312200E+05                        OUTLET STEAM QUALITY = 7.758825E-01
NON-BOILING LENGTH = 4.152223E+00              BOILING LENGTH = 5.821755E+00

DRUM INT. ENERGY = 1.2208E+10   DRUM LEVEL = 0.8032   CVP = 2.1896   ALFA = 0.3235   DPRP = 1.1530E+07

******************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   ******************************

     THROTTLE VALVE POSITION =0.9998                                    DUMP(BYPASS) VALVE POSITION =0.9608
     THROTTLE VALVE FLOW     =0.0        RELIEF VALVE FLOW =0.0         DUMP(BYPASS) VALVE FLOW     =0.7622
     HEADER PRESSURE = 9.9309E+06        TEMPERATURE =  473.2505         SPECIFIC ENTHALPY= 3.3082E+06

********************************   M E A S U R E D   V A L U E S   F O R   P P S   ********************************

 PRESNORM =  0.37890          VESSEL LEVEL =   4.5623          PTOTNORM =  0.08409
 TIHX1 =  372.581     TIHX2 =  371.885     TEVAP1 =  335.150     TEVAP2 =  337.214
```

```
STEP #   110   TIME =   19.99994 SEC    S =  0.20000 SEC

                                              TOTAL VECTOR OF CONTROL INTEGERS
  11   13   14   15   20   25   26   40   43   46   53   54   55   56   81   82   83   84   84  106  107  108  109  109  233
 238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292  293  294  295  296  297
 298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342  343  344  345  346  347
 348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411  423  424  425  426  427
 428  432  450  462  463  464  465  466  467  471  480  483  485    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0

*************************     N E U T R O N    K I N E T I C S    C A L C U L A T I O N S    *************************

 PTOT =        56.993 MWT     PN =          4.438 MWT     PFP =          52.555 MWT
 PDN :    1     0.094 MWT     2    0.287 MWT      PFP :    3     7.303 MWT    4   16.358 MWT     5    28.893 MWT
 ROTOT =     -23.527359 $     ROCR1 =        2.749999 $     ROCR2 =        -6.299999 $    ROFDBK =      -1.977362 $
 RODOP =      -0.723748 $     ROSOD =       -0.025864 $     ROCRE =        -1.097217 $    ROCAE  =      -0.130534 $
 TRO    =    447.667           TROM   =    451.037            TSTM   =     480.172
 PD =          0.9000         ETST   =    -11.749756        ETRO   =      29.025635   EF =     -0.050000    DELRO =     -0.000333
 PTOTNORM =   0.0585          PNNORM =       0.0046         PFPNORM =      0.0539     SCRAM RODS!   PRIM = 100.000 %    SEC = 100.000 %
 TAU 1 =     5.0176           TAU 2 =     48.1928           TAU 3 =     12.0048            TAU 4 =   133.3333
 TAU 5 = 7299.2695            TAU 6 =      2.0000           TAU 7 =      2.0000            TAU 8 =    60.0000

********************************     P R I M A R Y     C O O L A N T     D Y N A M I C S     ********************************

 FZ1NRM = 0.1694                             FZ2NRM = 0.1691  FZ3NRM = 0.1675  CANRM = 0.1196   RBNRM = 0.1408   BPNRM = 0.1884
 FLOWS: 1   2.8796E+02    2   2.8729E+02    3   3.1872E+02    4   2.3354E+01    5   9.7278E+00    6   1.0498E+02    7   4.0928E+01
 AL1=   0.1640   NEW1=    0.1654   BP1=    0.0266   TMOTN1=    0.0        HP1=    0.0265   FREQ1= 1121.600
 AL2=   0.1638   NEW2=    0.1650   BP2=    0.0266   TMOTN2=    0.0        HP2=    0.0265   FREQ2= 1121.785
 PD =   0.9000   TRISP =  387.779   NEWSP =     0.9000   ASP =    0.9000   XKW = 1.316E-03   EPS = 1.000E-05   N =  3
 TRIM:      378.848      378.792      NEWM:        0.1699      0.1695        ALM:        0.1640       0.1638       INLET PRSNRM = 0.3275
 ET:       1.6077E+01       1.6177E+01        EW:        7.5123E-01      7.5175E-01        EA:        9.3605E-01       9.3619E-01
 TAU 1 =   1.30600    TAU 2 =    1.13528    TAU 3 =    0.07325    TAU 4 =    0.33449    TAU 5 =    0.01805    TAU 6 =    0.02077
 TAU 7 =   0.06668    TAU 8 =    9.59087    TAU 9 =**********    TAU10 =    5.00000    TAU11 =    0.50000    TAU12 =    0.02000
 TAU13 =   9.58971    TAU14 =**********    TAU15 =    5.00000    TAU16 =    0.50000    TAU17 =    0.02000    TAU18 =    0.0

*****************************     R E A C T O R     H E A T     T R A N S F E R     *****************************

 TAU 1 =     2.0970 SEC    TAU 2 =     3.0374 SEC    TAU 3 =     2.0979 SEC    TAU 4 =     2.0957 SEC    TAU 5 =     3.0797 SEC
 TAU 6 =     2.0965 SEC    TAU 7 =     2.0958 SEC    TAU 8 =     3.0365 SEC    TAU 9 =     2.0965 SEC    TAU10 =     7.2947 SEC
 TAU11 =    11.1483 SEC    TAU12 =    81.0239 SEC    TAU13 =     9.0029 SEC    TAU14 =     0.1944 SEC    TAU15 =     0.4368 SEC
 TAU16 =     0.8915 SEC    TAU17 =     0.2143 SEC    TAU18 =     0.4724 SEC    TAU19 =     0.9674 SEC    TAU20 =     0.2169 SEC
 TAU21 =     0.4734 SEC    TAU22 =     0.9757 SEC    TAU23 =     0.4903 SEC    TAU24 =     0.7330 SEC    TAU25 =    16.7892 SEC
 TAU26 =   168.0855 SEC    TAU27 =     0.0    SEC    TAU28 =     0.1944 SEC    TAU29 =     0.2143 SEC    TAU30 =     0.2169 SEC
 TAU31 =     0.4903 SEC    TAU32 =     0.7330 SEC    TAU33 =    16.7892 SEC    TAU
   CORE HOT SPOT:        MAX. COOLANT TEMP. =   500.892          MAX. CLAD TEMP. =    503.850
 PEAK CORE AVERAGE TEMPERATURE OF:    FUEL CENTERLINE =    531.733    CLAD INNER =    420.895    CLAD OUTER =    420.653
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```
TM 1 =    384.717    TM 2 =    512.588    TM 3 =    464.452    TM 4 =    383.468    TM 5 =    491.453    TM 6 =    454.568
TM 7 =    383.386    TM 8 =    474.116    TM 9 =    444.035    TM10 =    425.317    TM11 =    461.524    TM
TC 1 =    381.456    TC 2 =    458.320    TC 3 =    461.216    TC 4 =    381.091    TC 5 =    449.065    TC 6 =    451.967
TC 7 =    381.070    TC 8 =    439.279    TC 9 =    441.755    TC10 =    446.724    TC11 =    489.791    TC12 =    379.508
TCI1 =    379.482    TCI2 =    379.482    TCI3 =    379.482    TCI4 =    379.482    TCI5 =    379.482    TCI6 =    379.482
LOWER PLENUM:                          TOP ZONE TEMP. =    379.482   BOTTOM ZONE TEMP. =    379.423
UPPER PLENUM:  ZJET =      6.400   TOP ZONE TEMP. =    522.443   BOTTOM ZONE TEMP. =    522.443   NOZZLE TEMP. =    522.443

*************************     I H X - 1    T H E R M A L     C A L C U L A T I O N S     *************************

TAUP:  1  24.7281  2    2.1515  3    2.2166  4    2.2494  5    2.2703  6    2.2881  7    2.3064  8    2.3230  9    2.3244 10 544.2476
11   6.0079
TAUS: 12    1.0178 13    1.0021 14    0.9955 15    0.9922 16    0.9904 17    0.9902 18    0.9920 19    1.0019 20   19.8873 21   26.5991
TP:  1  525.973  2  501.172  3  479.980  4  459.886  5  439.939  6  419.469  7  397.893  8  374.661  9  349.410 10  525.973
11  358.178
TS:  1  515.438  2  492.461  3  471.868  4  451.931  5  431.856  6  411.020  7  388.855  8  364.843  9  338.994 10  506.128

*************************     I H X - 2    T H E R M A L     C A L C U L A T I O N S     *************************

TAUP:  1  24.7860  2    2.0842  3    2.1922  4    2.2362  5    2.2787  6    2.2831  7    2.2910  8    2.3027  9    2.2272 10 545.5227
11   6.0261
TAUS: 12    0.9851 13    0.9575 14    0.9461 15    0.9421 16    0.9418 17    0.9448 18    0.9553 19    0.9838 20   17.6957 21   23.6485
TP:  1  525.973  2  495.224  3  472.193  4  451.419  5  431.216  6  410.802  7  389.756  8  368.070  9  346.889 10  525.973
11  355.724
TS:  1  511.482  2  484.898  3  463.101  4  442.691  5  422.467  6  401.826  7  380.498  8  358.874  9  338.993 10  504.469

***************     P R I M A R Y     S O D I U M     T R A N S P O R T     C A L C U L A T I O N S     ***************

 TAUC1:  1  6.58571  2  6.58185  3  6.57948  4  6.57851  5  6.57853  6  6.57909  7  6.57979  8  6.58041  9  6.58085 10  6.58113
 TAUW1:  1 56.24971  2 56.26044  3 56.26701  4 56.26971  5 56.26959  6 56.26805  7 56.26611  8 56.26442  9 56.26318 10 56.26242
 TAUC2:  1  2.49519  2  2.49520  3  2.49522  4  2.49523  5  2.49523  6  2.49524  7  2.49524  8  2.49524  9  2.49524 10  2.49524
 TAUW2:  1 47.45781  2 47.45779  3 47.45773  4 47.45769  5 47.45766  6 47.45766  7 47.45766  8 47.45766  9 47.45766 10 47.45766
 TAUC3:  1  4.18795  2  4.18456  3  4.18131  4  4.17825  5  4.17543  6  4.17294  7  4.17082  8  4.16909  9  4.16775 10  4.16676
 TAUW3:  1 47.01898  2 47.02719  3 47.03505  4 47.04245  5 47.04926  6 47.05524  7 47.06035  8 47.06451  9 47.06773 10 47.07008
 TAUC4:  1  6.58575  2  6.58189  3  6.57952  4  6.57855  5  6.57857  6  6.57913  7  6.57984  8  6.58045  9  6.58089 10  6.58117
 TAUW4:  1 56.27673  2 56.28752  3 56.29410  4 56.29678  5 56.29672  6 56.29515  7 56.29323  8 56.29149  9 56.29025 10 56.28951
 TAUC5:  1  2.49519  2  2.49521  3  2.49522  4  2.49524  5  2.49524  6  2.49524  7  2.49525  8  2.49525  9  2.49525 10  2.49525
 TAUW5:  1 47.47202  2 47.47198  3 47.47192  4 47.47188  5 47.47188  6 47.47186  7 47.47186  8 47.47186  9 47.47186 10 47.47186
 TAUC6:  1  4.19065  2  4.18689  3  4.18319  4  4.17971  5  4.17655  6  4.17377  7  4.17141  8  4.16950  9  4.16803 10  4.16695
 TAUW6:  1 47.02574  2 47.03493  3 47.04391  4 47.05238  5 47.06000  6 47.06670  7 47.07239  8 47.07701  9 47.08054 10 47.08315
TC1:  1   524.921  2   526.563  3   527.397  4   527.581  5   527.367  6   526.997  7   526.633  8   526.355  9   526.172 10   526.066
TW1:  1   526.233  2   526.381  3   526.389  4   526.321  5   526.224  6   526.133  7   526.064  8   526.020  9   525.993 10   525.979
TC2:  1   526.036  2   526.014  3   525.998  4   525.987  5   525.980  6   525.976  7   525.973  8   525.972  9   525.972 10   525.973
TW2:  1   525.984  2   525.982  3   525.980  4   525.980  5   525.979  6   525.979  7   525.979  8   525.979  9   525.979 10   525.979
TC3:  1   361.146  2   364.015  3   366.750  4   369.299  5   371.601  6   373.600  7   375.262  8   376.579  9   377.570 10   378.280
TW3:  1   375.452  2   376.275  3   377.000  4   377.620  5   378.132  6   378.539  7   378.850  8   379.077  9   379.235 10   379.341
TC4:  1   524.921  2   526.563  3   527.397  4   527.581  5   527.367  6   526.997  7   526.634  8   526.355  9   526.172 10   526.066
TW4:  1   526.233  2   526.380  3   526.389  4   526.321  5   526.224  6   526.133  7   526.064  8   526.020  9   525.993 10   525.979
TC5:  1   526.036  2   526.014  3   525.998  4   525.987  5   525.980  6   525.976  7   525.973  8   525.972  9   525.972 10   525.973
TW5:  1   525.984  2   525.982  3   525.980  4   525.980  5   525.979  6   525.979  7   525.979  8   525.979  9   525.979 10   525.979
TC6:  1   358.955  2   362.213  3   365.337  4   368.218  5   370.793  6   373.013  7   374.852  8   376.303  9   377.394 10   378.171
TW6:  1   375.002  2   375.929  3   376.742  4   377.431  5   377.998  6   378.448  7   378.790  8   379.040  9   379.213 10   379.329

************************* I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S *************************

 TAU:  1     5.103650  2     9.595160  3     0.500000  4     0.020000  5     3.999999
 SODIUM FLOW RATE =  0.1930   PUMP SPEED =  0.1735   PUMP HEAD =  0.0249   MOTOR GEN. SET FREQ. =   145.624 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.9612   DRIVE MOTOR TORQUE =  0.0      PUMP TORQUE =  0.0268   FRICTION TORQUE =  0.0160

************************* I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S *************************
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 TAU: 1    6.794784  2    9.383678  3    0.500000  4    0.020000  5    3.999999
 SODIUM FLOW RATE =  0.2170   PUMP SPEED =  0.1828   PUMP HEAD =  0.0240   MOTOR GEN. SET FREQ. =   143.943 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.9651   DRIVE MOTOR TORQUE =  0.0      PUMP TORQUE =  0.0275   FRICTION TORQUE =  0.0162

********************     I N T E R M E D I A T E    L O O P - 1:   S O D I U M   T R A N S P O R T    ********************

TAUC1:  1 10.35221  2 10.36182  3 10.36845  4 10.37248  5 10.37465  6 10.37569  7 10.37614  8 10.37630  9 10.37637 10 10.37638
TAUW1:  1 46.95613  2 46.94862  3 46.94347  4 46.94032  5 46.93860  6 46.93779  7 46.93747  8 46.93730  9 46.93727 10 46.93727
TAUC2:  1  7.29022
TAUW2:  1 46.25505
TAUC3:  1  9.44886  2  9.43366
TAUW3:  1 46.50749  2 46.52324
TAUC4:  1  4.48893  2  4.48748  3  4.48651  4  4.48589  5  4.48553  6  4.48532  7  4.48520  8  4.48515  9  4.48512 10  4.48511
TAUW4:  1 46.53088  2 46.53409  3 46.53619  4 46.53754  5 46.53833  6 46.53876  7 46.53903  8 46.53914  9 46.53922 10 46.53925
TCS1:  1   502.431  2   499.740  3   498.022  4   497.059  5   496.580  6   496.368  7   496.283  8   496.253  9   496.245 10   496.244
TWS1:  1   497.733  2   497.029  3   496.618  4   496.404  5   496.305  6   496.263  7   496.248  8   496.244  9   496.244 10   496.244
TCS2:  1   323.555
TWS2:  1   335.889
TCS3:  1   330.906  2   335.186
TWS3:  1   337.361  2   338.264
TCS4:  1   336.592  2   337.545  3   338.160  4   338.537  5   338.756  6   338.877  7   338.940  8   338.971  9   338.985 10   338.990
TWS4:  1   338.659  2   338.803  3   338.890  4   338.941  5   338.969  6   338.983  7   338.990  8   338.993  9   338.993 10   338.994

********************     I N T E R M E D I A T E    L O O P - 2:   S O D I U M   T R A N S P O R T    ********************

TAUC1:  1 14.98871  2 15.00276  3 15.01035  4 15.01377  5 15.01508  6 15.01551  7 15.01563  8 15.01566  9 15.01566 10 15.01566
TAUW1:  1 46.29887  2 46.29208  3 46.28838  4 46.28671  5 46.28606  6 46.28584  7 46.28577  8 46.28577  9 46.28577 10 46.28577
TAUC2:  1  6.49930
TAUW2:  1 45.69514
TAUC3:  1  8.42284  2  8.41060
TAUW3:  1 45.90024  2 45.91319
TAUC4:  1  7.22649  2  7.22418  3  7.22318  4  7.22282  5  7.22272  6  7.22271  7  7.22272  8  7.22273  9  7.22273 10  7.22273
TAUW4:  1 45.91965  2 45.92249  3 45.92369  4 45.92413  5 45.92427  6 45.92427  7 45.92427  8 45.92427  9 45.92427 10 45.92427
TCS1:  1   500.384  2   498.029  3   496.912  4   496.465  5   496.312  6   496.266  7   496.254  8   496.254  9   496.254 10   496.254
TWS1:  1   497.390  2   496.715  3   496.415  4   496.302  5   496.265  6   496.255  7   496.254  8   496.254  9   496.254 10   496.254
TCS2:  1   325.802
TWS2:  1   336.680
TCS3:  1   332.621  2   336.305
TWS3:  1   337.878  2   338.557
TCS4:  1   337.908  2   338.627  3   338.903  4   338.987  5   339.002  6   338.999  7   338.994  8   338.993  9   338.993 10   338.993
TWS4:  1   338.846  2   338.949  3   338.984  4   338.991  5   338.994  6   338.994  7   338.994  8   338.994  9   338.994 10   338.994

***********************************   S T E A M   G E N E R A T I O N   L O O P - 1   ***********************************

 TAU:  1  4.148453  2  4.148062  3  4.148745  4  3.989085  5  5.980364  6  5.963360  7  5.947426  8  5.934986
9   5.926722 10  2.158783 11 13.990131 12  0.0       13 52.178253 14  1.695069 15 11.591403 16 60.600037
17  3.390615 18  3.737224 19  0.613876 20  1.072028 21  4.249234 22  1.072855 23  2.768442 24  0.163329
25  0.087560 26  0.076395 27  0.069742 28  0.066306 29  0.237930 30  8.324181 31  9.358294 32  0.814383
33  0.103421 34********** 35********** 36  1.000000 37  1.999999 38  1.999999 39  1.999999
 FEED WATER FLOW =0.0      WATER/STEAM FLOW =0.2581  STEAM FLOW =0.4305  INT. SODIUM FLOW =0.1930

 P 1 = 1.2150E+07  P 2 = 1.0590E+07  P 3 = 1.0590E+07  P 4 = 1.0714E+07  P 5 = 1.0719E+07  P 6 = 1.0729E+07  P 7 = 1.0750E+07
 P 8 = 1.0730E+07  P 9 = 1.0664E+07  P10 = 1.0611E+07  P11 = 1.0602E+07  P12 = 1.0589E+07  P13 = 1.0590E+07  P14 = 1.0573E+07
 P15 = 1.0542E+07  P16 = 1.0448E+07  P17 = 1.0355E+07  P18 = 1.0266E+07  P19 = 1.0177E+07  P20 = 1.0153E+07  P21 = 1.0067E+07
 H 1 = 1.0030E+06  H 2 = 1.5984E+06  H 3 = 1.4984E+06  H 4 = 1.3780E+06  H 5 = 1.3740E+06  H 6 = 1.3429E+06  H 7 = 1.2859E+06
 H 8 = 1.2830E+06  H 9 = 1.4360E+06  H10 = 2.2318E+06  H11 = 2.2736E+06  H12 = 2.4095E+06  H13 = 2.4367E+06  H14 = 2.7108E+06
 H15 = 2.7108E+06  H16 = 3.0232E+06  H17 = 3.1974E+06  H18 = 3.2899E+06  H19 = 3.3369E+06  H20 = 3.3367E+06  H21 = 3.3298E+06
 TM 1 =  232.3700  TM 2 =  325.6887  TM 3 =  315.1523  TM 4 =  301.5674  TM 5 =  301.0742  TM 6 =  296.9487  TM 7 =  288.1418
 TM 8 =  287.6707  TM 9 =  315.6699  TM10 =  315.3020  TM11 =  315.2346  TM12 =  315.1450  TM13 =  315.1523  TM14 =  315.0352
```

```
TM15 =  314.8188  TM16 =  381.2471  TM17 =  434.9990  TM18 =  467.8972  TM19 =  485.6501  TM20 =  485.4465  TM21 =  482.3091
TCS 8 =  315.2180  TCS 9 =  320.3560  TCS10 =  448.0515  TCS11 =  443.1326  TCS12 =  435.7246  TCS13 =  426.2317  TCS14 =  416.0908
TCS15 =  407.2554  TCS16 =  449.7612  TCS17 =  474.7136  TCS18 =  488.7559  TCS19 =  496.2437  TCS
                        TDLOG:  9        12.9062 10        38.2975
                        U    :  9      3597.5076 10      7403.7773
           TDLOG: 16         79.8794 17       52.8120 18       29.2817 19       15.1509
           U    : 16       2756.9060 17     2327.6504 18     2231.2263 19     2194.4602

HEAT FLUX = 1.160271E+05                              OUTLET STEAM QUALITY = 6.237263E-01
NON-BOILING LENGTH = 7.714686E+00                   BOILING LENGTH = 6.305303E+00

DRUM INT. ENERGY = 1.0874E+10   DRUM LEVEL = 0.6529   CVP = 3.7186   ALFA = 0.1902   DPRP = 2.4806E+06

***********************************   S T E A M   G E N E R A T I O N   L O O P - 2   ***********************************

 TAU:  1  3.749331  2  3.749028  3  3.734439  4  3.621024  5  5.310940  6  5.298656  7  5.286373  8  5.276160
 9  5.268980 10  2.122417 11 12.575969 12  0.0       13 51.445328 14  1.671246 15 11.428211 16 59.755737
17  3.343400 18  3.582349 19  0.548836 20  0.919251 21  3.850746 22  0.992176 23  2.694365 24  0.158930
25  0.084314 26  0.073652 27  0.067370 28  0.064168 29  0.230565 30  8.060205 31  9.318667 32  0.801297
33  0.099994 34********** 35********** 36  1.000000 37  1.999999 38  1.999999 39  1.999999
 FEED WATER FLOW =0.0      WATER/STEAM FLOW =0.2617  STEAM FLOW =0.4441  INT. SODIUM FLOW =0.2170

P 1 = 1.2150E+07  P 2 = 1.0629E+07  P 3 = 1.0629E+07  P 4 = 1.0753E+07  P 5 = 1.0758E+07  P 6 = 1.0767E+07  P 7 = 1.0788E+07
P 8 = 1.0768E+07  P 9 = 1.0704E+07  P10 = 1.0649E+07  P11 = 1.0640E+07  P12 = 1.0628E+07  P13 = 1.0629E+07  P14 = 1.0609E+07
P15 = 1.0576E+07  P16 = 1.0476E+07  P17 = 1.0376E+07  P18 = 1.0282E+07  P19 = 1.0187E+07  P20 = 1.0161E+07  P21 = 1.0067E+07
H 1 = 1.0030E+06  H 2 = 1.6007E+06  H 3 = 1.4984E+06  H 4 = 1.3784E+06  H 5 = 1.3744E+06  H 6 = 1.3433E+06  H 7 = 1.2860E+06
H 8 = 1.2832E+06  H 9 = 1.4377E+06  H10 = 2.3455E+06  H11 = 2.4229E+06  H12 = 2.5116E+06  H13 = 2.5165E+06  H14 = 2.7105E+06
H15 = 2.7105E+06  H16 = 3.0329E+06  H17 = 3.2061E+06  H18 = 3.2951E+06  H19 = 3.3389E+06  H20 = 3.3387E+06  H21 = 3.3318E+06
TM 1 =  232.3700  TM 2 =  325.6868  TM 3 =  315.4260  TM 4 =  301.6143  TM 5 =  301.1238  TM 6 =  297.0115  TM 7 =  288.1697
TM 8 =  287.6960  TM 9 =  315.9541  TM10 =  315.5701  TM11 =  315.5039  TM12 =  315.4197  TM13 =  315.4260  TM14 =  315.2842
TM15 =  315.0562  TM16 =  384.1936  TM17 =  438.1411  TM18 =  469.9697  TM19 =  486.4937  TM20 =  486.3076  TM21 =  483.1128
TCS 8 =  317.5830  TCS 9 =  320.8281  TCS10 =  448.2507  TCS11 =  443.4448  TCS12 =  436.6052  TCS13 =  428.3738  TCS14 =  420.1377
TCS15 =  413.3320  TCS16 =  454.2502  TCS17 =  477.3564  TCS18 =  489.8735  TCS19 =  496.2544  TCS
                        TDLOG:  9        13.7928 10        38.6824
                        U    :  9      3628.9988 10      7650.5039
           TDLOG: 16         83.3720 17       53.1530 18       28.4764 19       14.2350
           U    : 16       2808.8630 17     2368.5295 18     2273.9202 19     2238.5916

HEAT FLUX = 1.210910E+05                              OUTLET STEAM QUALITY = 7.126595E-01
NON-BOILING LENGTH = 7.331756E+00                   BOILING LENGTH = 6.688232E+00

DRUM INT. ENERGY = 1.0881E+10   DRUM LEVEL = 0.6512   CVP = 3.7235   ALFA = 0.1912   DPRP = 2.4170E+06

*****************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   *****************************

                    TIME CONSTANT OF THE HEADER PRESSURE GAUGE =  0.150000 SECONDS
     THROTTLE VALVE POSITION =1.0000                                   DUMP(BYPASS) VALVE POSITION =0.5530
     THROTTLE VALVE FLOW      =0.0       RELIEF VALVE FLOW =0.0       DUMP(BYPASS) VALVE FLOW      =0.4417
     HEADER PRESSURE = 1.0067E+07       TEMPERATURE =  481.0422       SPECIFIC ENTHALPY= 3.3266E+06

******************************    M E A S U R E D    V A L U E S    F O R    P P S    ******************************

 TAU :   0.1500          0.5000          0.1000          5.0000          5.0000          5.0000          5.0000
 PRESNORM =  0.32749           VESSEL LEVEL =    4.5623           PTOTNORM =  0.07733
 TIHX1 =  362.264     TIHX2 =  360.223     TEVAP1 =  321.662     TEVAP2 =  324.583
```

STEP # 160 TIME = 29.99988 SEC S = 0.20000 SEC

TOTAL VECTOR OF CONTROL INTEGERS

11	13	14	15	20	25	26	53	81	82	83	84	84	106	107	108	109	109	233	238	251	252	253	254	255
256	257	258	259	262	263	264	265	266	267	268	269	291	292	293	294	295	296	297	298	299	302	303	304	305
306	307	308	309	331	332	333	334	335	336	337	338	339	342	343	344	345	346	347	348	349	371	372	373	374
375	376	377	378	379	382	383	384	385	386	387	388	389	411	423	424	425	426	427	432	450	462	463	464	465
466	471	480	483	485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0											

```
**************************    N E U T R O N    K I N E T I C S    C A L C U L A T I O N S    **************************

PTOT =        51.114 MWT       PN =          2.970 MWT      PFP =         48.145 MWT
PDN :    1     0.022 MWT    2     0.233 MWT       PFP :     3     4.031 MWT    4    15.258 MWT    5    28.856 MWT
ROTOT =     -23.504547 $       ROCR1 =       2.749999 $      ROCR2 =       -6.299999 $     ROFDBK =      -1.954556 $
RODOP =      -0.706582 $       ROSOD =      -0.024863 $      ROCRE =       -1.096736 $     ROCAE  =      -0.126375 $
TRO    =    454.381             TROM   =    451.799             TSTM  =      482.964
PD =          0.9000           ETST   =    -11.749756         ETRO   =      29.025635    EF =     -0.050000    DELRO =      -0.000333
PTOTNORM =    0.0524           PNNORM =      0.0030           PFPNORM =      0.0494     SCRAM RODS!   PRIM = 100.000 %    SEC = 100.000 %

********************************    P R I M A R Y    C O O L A N T    D Y N A M I C S    ********************************

FZ1NRM = 0.1052                                    FZ2NRM = 0.1047  FZ3NRM = 0.1040  CANRM = 0.0695   RBNRM = 0.0838   BPNRM = 0.1158
FLOWS: 1    1.7734E+02    2    1.7722E+02    3    1.9742E+02    4    1.4497E+01    5    5.6534E+00    6    6.2474E+01    7    2.5150E+01
AL1=   0.0998   NEW1=    0.1019    BP1=    0.0098    TMOTN1=    0.0138    HP1=    0.0096    FREQ1= 1849.606
AL2=   0.0997   NEW2=    0.1018    BP2=    0.0097    TMOTN2=    0.0139    HP2=    0.0096    FREQ2= 1849.884
PD =   0.9000    TRISP =  387.779    NEWSP =    0.9000    ASP =    0.9000    XKW = 1.316E-03    EPS = 1.000E-03    N =  2
TRIM:      377.417      377.222       NEWM:       0.1043      0.1042        ALM:        0.0998       0.0997       INLET PRSNRM = 0.3131
ET:      1.8653E+01     1.9003E+01     EW:       8.2025E-01     8.2080E-01     EA:       1.0002E+00      1.0003E+00

******************************    R E A C T O R    H E A T    T R A N S F E R    ******************************

  CORE HOT SPOT:          MAX. COOLANT TEMP. =    528.458          MAX. CLAD TEMP. =    530.848
PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =    518.291   CLAD INNER =    429.967   CLAD OUTER =    429.779
TM 1 =     384.445    TM 2 =    501.120    TM 3 =    470.898    TM 4 =     383.265    TM 5 =    481.424    TM 6 =    459.050
TM 7 =     383.191    TM 8 =    466.307    TM 9 =    448.314    TM10 =     418.692    TM11 =    449.234    TM
TC 1 =     382.128    TC 2 =    476.188    TC 3 =    470.812    TC 4 =     381.618    TC 5 =    463.723    TC 6 =    458.848
TC 7 =     381.595    TC 8 =    452.315    TC 9 =    448.051    TC10 =     444.181    TC11 =    487.601    TC12 =    379.480
TCI1 =     379.393    TCI2 =    379.393    TCI3 =    379.393    TCI4 =     379.393    TCI5 =    379.393    TCI6 =    379.393
LOWER PLENUM:                             TOP ZONE TEMP. =    379.393    BOTTOM ZONE TEMP. =    379.231
UPPER PLENUM:  ZJET =     6.400    TOP ZONE TEMP. =    519.177    BOTTOM ZONE TEMP. =    519.177    NOZZLE TEMP. =    519.177

************************    I H X - 1    T H E R M A L    C A L C U L A T I O N S    ************************

TP:  1  525.973  2  498.073  3  476.465  4  456.163  5  435.968  6  415.167  7  393.173  8  369.524  9  344.905 10  525.973
11  353.610
```

TS: 1 517.636 2 492.205 3 471.105 4 450.919 5 430.634 6 409.584 7 387.204 8 363.104 9 338.985 10 508.888

************************ I H X - 2 T H E R M A L C A L C U L A T I O N S ************************

TP: 1 525.973 2 488.838 3 465.399 4 444.469 5 424.054 6 403.388 7 382.246 8 361.185 9 342.771 10 525.973
11 351.313
TS: 1 512.927 2 481.729 3 459.283 4 438.606 5 418.171 6 397.379 7 376.181 8 355.500 9 338.993 10 506.771

*************** P R I M A R Y S O D I U M T R A N S P O R T C A L C U L A T I O N S ***************

TC1:	1	521.947	2	524.254	3	525.911	4	526.877	5	527.251	6	527.219	7	526.978	8	526.683	9	526.423	10	526.231
TW1:	1	525.570	2	526.060	3	526.327	4	526.417	5	526.390	6	526.305	7	526.205	8	526.119	9	526.056	10	526.015
TC2:	1	526.168	2	526.117	3	526.076	4	526.044	5	526.021	6	526.003	7	525.991	8	525.982	9	525.976	10	525.973
TW2:	1	526.007	2	525.997	3	525.990	4	525.985	5	525.981	6	525.979	7	525.978	8	525.977	9	525.976	10	525.975
TC3:	1	356.666	2	359.597	3	362.417	4	365.113	5	367.655	6	369.998	7	372.097	8	373.914	9	375.426	10	376.633
TW3:	1	372.038	2	373.259	3	374.379	4	375.389	5	376.280	6	377.045	7	377.683	8	378.196	9	378.594	10	378.892
TC4:	1	521.947	2	524.254	3	525.911	4	526.877	5	527.251	6	527.219	7	526.978	8	526.683	9	526.423	10	526.231
TW4:	1	525.570	2	526.061	3	526.327	4	526.417	5	526.390	6	526.304	7	526.205	8	526.119	9	526.056	10	526.015
TC5:	1	526.168	2	526.117	3	526.076	4	526.044	5	526.021	6	526.003	7	525.991	8	525.982	9	525.976	10	525.973
TW5:	1	526.007	2	525.997	3	525.990	4	525.985	5	525.981	6	525.979	7	525.978	8	525.977	9	525.976	10	525.975
TC6:	1	354.375	2	357.434	3	360.492	4	363.490	5	366.346	6	368.979	7	371.327	8	373.349	9	375.025	10	376.359
TW6:	1	371.236	2	372.573	3	373.818	4	374.946	5	375.941	6	376.795	7	377.503	8	378.071	9	378.509	10	378.837

************************ I N T E R M E D I A T E L O O P - 1: C O O L A N T D Y N A M I C S ************************

SODIUM FLOW RATE = 0.1267 PUMP SPEED = 0.1082 PUMP HEAD = 0.0087 MOTOR GEN. SET FREQ. = 210.243 CYCLES/SEC
MAIN MOTOR TORQUE = 0.9285 DRIVE MOTOR TORQUE = 0.0 PUMP TORQUE = 0.0098 FRICTION TORQUE = 0.0145

************************ I N T E R M E D I A T E L O O P - 2: C O O L A N T D Y N A M I C S ************************

SODIUM FLOW RATE = 0.1461 PUMP SPEED = 0.1161 PUMP HEAD = 0.0083 MOTOR GEN. SET FREQ. = 207.918 CYCLES/SEC
MAIN MOTOR TORQUE = 0.9306 DRIVE MOTOR TORQUE = 0.0 PUMP TORQUE = 0.0102 FRICTION TORQUE = 0.0147

******************** I N T E R M E D I A T E L O O P - 1: S O D I U M T R A N S P O R T ********************

TCS1:	1	504.848	2	501.638	3	499.339	4	497.865	5	497.018	6	496.580	7	496.375	8	496.288	9	496.255	10	496.243
TWS1:	1	499.221	2	498.005	3	497.199	4	496.718	5	496.458	6	496.330	7	496.273	8	496.251	9	496.243	10	496.243
TCS2:	1	316.316																		
TWS2:	1	331.977																		
TCS3:	1	324.969	2	331.222																
TWS3:	1	334.756	2	336.776																
TCS4:	1	333.538	2	335.312	3	336.606	4	337.506	5	338.103	6	338.482	7	338.712	8	338.844	9	338.918	10	338.956
TWS4:	1	337.790	2	338.219	3	338.514	4	338.707	5	338.829	6	338.903	7	338.945	8	338.968	9	338.980	10	338.985

******************** I N T E R M E D I A T E L O O P - 2: S O D I U M T R A N S P O R T ********************

TCS1:	1	502.226	2	499.207	3	497.531	4	496.739	5	496.414	6	496.298	7	496.261	8	496.254	9	496.254	10	496.254
TWS1:	1	498.560	2	497.340	3	496.703	4	496.416	5	496.303	6	496.264	7	496.254	8	496.254	9	496.254	10	496.254
TCS2:	1	317.501																		
TWS2:	1	332.900																		
TCS3:	1	325.979	2	332.042																
TWS3:	1	335.426	2	337.220																
TCS4:	1	335.391	2	337.308	3	338.289	4	338.736	5	338.914	6	338.974	7	338.989	8	338.991	9	338.991	10	338.992
TWS4:	1	338.183	2	338.638	3	338.893	4	338.943	5	338.978	6	338.988	7	338.991	8	338.992	9	338.993	10	338.993

*********************************** S T E A M G E N E R A T I O N L O O P - 1 ***********************************

FEED WATER FLOW =0.0 WATER/STEAM FLOW =0.2098 STEAM FLOW =0.2458 INT. SODIUM FLOW =0.1267

AUXILIARY FEED WATER AVAILABLE AT 30.000 SECONDS ENTHALPY = 1.5580E+05 AUX. WATER FLOW =1.0000

```
P 1 = 1.2150E+07  P 2 = 1.0228E+07  P 3 = 1.0228E+07  P 4 = 1.0354E+07  P 5 = 1.0344E+07  P 6 = 1.0353E+07  P 7 = 1.0374E+07
P 8 = 1.0354E+07  P 9 = 1.0283E+07  P10 = 1.0245E+07  P11 = 1.0237E+07  P12 = 1.0225E+07  P13 = 1.0228E+07  P14 = 1.0235E+07
P15 = 1.0223E+07  P16 = 1.0190E+07  P17 = 1.0158E+07  P18 = 1.0127E+07  P19 = 1.0097E+07  P20 = 1.0088E+07  P21 = 1.0062E+07
H 1 = 1.5580E+05  H 2 = 1.5994E+06  H 3 = 1.4984E+06  H 4 = 1.3971E+06  H 5 = 1.3937E+06  H 6 = 1.3659E+06  H 7 = 1.2954E+06
H 8 = 1.2917E+06  H 9 = 1.4198E+06  H10 = 2.0231E+06  H11 = 2.0545E+06  H12 = 2.1720E+06  H13 = 2.2012E+06  H14 = 2.7183E+06
H15 = 2.7183E+06  H16 = 3.0668E+06  H17 = 3.2343E+06  H18 = 3.3131E+06  H19 = 3.3489E+06  H20 = 3.3483E+06  H21 = 3.3377E+06
TM 1 =  232.3699  TM 2 =  325.6885  TM 3 =  312.5757  TM 4 =  303.7229  TM 5 =  303.3557  TM 6 =  300.0415  TM 7 =  289.6987
TM 8 =  289.0999  TM 9 =  312.9712  TM10 =  312.7007  TM11 =  312.6406  TM12 =  312.5557  TM13 =  312.5757  TM14 =  312.6243
TM15 =  312.5422  TM16 =  391.8882  TM17 =  446.7979  TM18 =  476.0901  TM19 =  490.0461  TM20 =  489.7654  TM21 =  485.4241
TCS 8 =  308.1462  TCS 9 =  315.5852  TCS10 =  439.3267  TCS11 =  431.7590  TCS12 =  422.9417  TCS13 =  414.0818  TCS14 =  406.6677
TCS15 =  402.3430  TCS16 =  450.0356  TCS17 =  476.2749  TCS18 =  489.8916  TCS19 =  496.2434  TCS
                        TDLOG:  9        8.2742 10        31.9591
                        U    :  9     3228.0015 10      7026.1328
          TDLOG: 16       72.8312 17        42.2013 18        20.6573 19         9.4973
          U    : 16     1927.0884 17      1602.6482 18      1543.5420 19      1523.5625

HEAT FLUX = 9.188531E+04                          OUTLET STEAM QUALITY = 4.645455E-01
NON-BOILING LENGTH = 9.135018E+00               BOILING LENGTH = 4.884971E+00

DRUM INT. ENERGY = 1.0132E+10   DRUM LEVEL = 0.5645   CVP = 1.0000   ALFA = 0.1302   DPRP = 1.6645E+05

***********************************   S T E A M   G E N E R A T I O N   L O O P - 2   ***********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.2139  STEAM FLOW =0.2804  INT. SODIUM FLOW =0.1461

AUXILIARY FEED WATER AVAILABLE AT  30.000 SECONDS  ENTHALPY = 1.5580E+05  AUX. WATER FLOW  =1.0000
P 1 = 1.2150E+07  P 2 = 1.0282E+07  P 3 = 1.0282E+07  P 4 = 1.0407E+07  P 5 = 1.0397E+07  P 6 = 1.0406E+07  P 7 = 1.0427E+07
P 8 = 1.0407E+07  P 9 = 1.0339E+07  P10 = 1.0299E+07  P11 = 1.0291E+07  P12 = 1.0279E+07  P13 = 1.0282E+07  P14 = 1.0284E+07
P15 = 1.0270E+07  P16 = 1.0228E+07  P17 = 1.0186E+07  P18 = 1.0147E+07  P19 = 1.0108E+07  P20 = 1.0097E+07  P21 = 1.0062E+07
H 1 = 1.5580E+05  H 2 = 1.6046E+06  H 3 = 1.4984E+06  H 4 = 1.3977E+06  H 5 = 1.3943E+06  H 6 = 1.3666E+06  H 7 = 1.2957E+06
H 8 = 1.2920E+06  H 9 = 1.4222E+06  H10 = 2.1009E+06  H11 = 2.1295E+06  H12 = 2.2435E+06  H13 = 2.2725E+06  H14 = 2.7173E+06
H15 = 2.7173E+06  H16 = 3.0668E+06  H17 = 3.2350E+06  H18 = 3.3134E+06  H19 = 3.3485E+06  H20 = 3.3480E+06  H21 = 3.3393E+06
TM 1 =  232.3699  TM 2 =  325.6865  TM 3 =  312.9626  TM 4 =  303.7869  TM 5 =  303.4231  TM 6 =  300.1348  TM 7 =  289.7563
TM 8 =  289.1545  TM 9 =  313.3748  TM10 =  313.0852  TM11 =  313.0271  TM12 =  312.9453  TM13 =  312.9626  TM14 =  312.9829
TM15 =  312.8801  TM16 =  392.1814  TM17 =  447.2185  TM18 =  476.2993  TM19 =  489.9407  TM20 =  489.6748  TM21 =  486.0410
TCS 8 =  309.6357  TCS 9 =  316.2944  TCS10 =  438.8733  TCS11 =  431.9829  TCS12 =  424.4753  TCS13 =  417.2803  TCS14 =  411.2185
TCS15 =  407.1428  TCS16 =  453.3604  TCS17 =  478.0623  TCS18 =  490.5195  TCS19 =  496.2542  TCS
                        TDLOG:  9        9.0151 10        32.6509
                        U    :  9     3266.3203 10      7118.9453
          TDLOG: 16       76.5328 17        44.2934 18        21.4699 19         9.7376
          U    : 16     2098.1108 17      1748.8782 18      1685.0640 19      1663.5762

HEAT FLUX = 9.510869E+04                          OUTLET STEAM QUALITY = 5.238823E-01
NON-BOILING LENGTH = 8.585405E+00               BOILING LENGTH = 5.434584E+00

DRUM INT. ENERGY = 1.0088E+10   DRUM LEVEL = 0.5541   CVP = 1.0000   ALFA = 0.1314   DPRP = 9.8852E+04

******************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   ******************************

     THROTTLE VALVE POSITION =1.0000                             DUMP(BYPASS) VALVE POSITION =0.3389
     THROTTLE VALVE FLOW     =0.0       RELIEF VALVE FLOW =0.0     DUMP(BYPASS) VALVE FLOW     =0.2706
     HEADER PRESSURE = 1.0062E+07        TEMPERATURE =  483.5171      SPECIFIC ENTHALPY= 3.3329E+06

*******************************   M E A S U R E D   V A L U E S   F O R   P P S   *******************************

 PRESNORM =  0.31306         VESSEL LEVEL =   4.5623          PTOTNORM =  0.05845
 TIHX1 =  355.974    TIHX2 =  353.654    TEVAP1 =  311.774     TEVAP2 =  313.661
```

```
STEP #  210   TIME =   39.99983 SEC   S =  0.40000 SEC

                                                 TOTAL VECTOR OF CONTROL INTEGERS
 11   12   13   14   15   19   20   24   25   26   40   43   46   53   54   55   56   81   82   83   84   84  106  107  108
109  109  232  233  237  238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292
293  294  295  296  297  298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342
343  344  345  346  347  348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411
423  424  425  426  427  428  432  450  462  463  464  465  466  467  471  480  483  484  485    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0

*************************    N E U T R O N    K I N E T I C S    C A L C U L A T I O N S    *************************

PTOT =        47.913 MWT     PN =          2.322 MWT     PFP =         45.590 MWT
PDN :    1    0.009 MWT      2    0.190 MWT     PFP :    3    2.542 MWT    4    14.230 MWT    5    28.819 MWT
ROTOT =    -23.506256 $      ROCR1 =       2.749999 $     ROCR2 =      -6.299999 $     ROFDBK =     -1.956256 $
RODOP =     -0.708551 $      ROSOD =      -0.024144 $     ROCRE =      -1.096045 $     ROCAE  =     -0.127517 $
TRO   =    467.466            TROM  =    465.368            TSTM  =    485.463
PD =         0.9000          ETST  =    -11.749756       ETRO  =      29.025635   EF =    -0.050000   DELRO =    -0.000333
PTOTNORM =   0.0491          PNNORM =      0.0024        PFPNORM =     0.0468     SCRAM RODS:  PRIM = 100.000 %   SEC = 100.000 %
TAU 1 =     5.0176           TAU 2 =    48.1928          TAU 3 =    12.0048           TAU 4 =  133.3333
TAU 5 = 7299.2695            TAU 6 =     2.0000          TAU 7 =     2.0000           TAU 8 =   60.0000

********************************    P R I M A R Y    C O O L A N T    D Y N A M I C S    ********************************

FZ1NRM = 0.0909                              FZ2NRM = 0.0907  FZ3NRM = 0.0882  CANRM = 0.0587   RBNRM = 0.0713   BPNRM = 0.0988
FLOWS: 1   1.5237E+02   2   1.5305E+02   3   1.7101E+02   4   1.2300E+01   5   4.7786E+00   6   5.3185E+01   7   2.1458E+01
AL1=   0.0925   NEW1=   0.0875   BP1=   0.0090   TMOTN1=   0.0221   HP1=   0.0093   FREQ1= 2603.426
AL2=   0.0925   NEW2=   0.0879   BP2=   0.0090   TMOTN2=   0.0221   HP2=   0.0092   FREQ2= 2603.722
PD =   0.9000   TRISP =  387.779   NEWSP =   0.9000   ASP =   0.9000   XKW = 1.316E-03   EPS = 1.000E-03   N =  1
TRIM:      375.847     375.488      NEWM:        0.0877      0.0881      ALM:        0.0925      0.0925      INLET PRSNRM = 0.3109
ET:       2.1478E+01      2.2124E+01      EW:       8.4054E-01      8.4102E-01      EA:       1.0075E+00      1.0075E+00
TAU 1 =   2.35044   TAU 2 =   2.01674   TAU 3 =   0.12302   TAU 4 =   0.56213   TAU 5 =   0.02844   TAU 6 =   0.03369
TAU 7 =   0.12623   TAU 8 =  16.06007   TAU 9 =**********   TAU10 =   5.00000   TAU11 =   0.50000   TAU12 =   0.02000
TAU13 =  16.08324   TAU14 =**********   TAU15 =   5.00000   TAU16 =   0.50000   TAU17 =   0.02000   TAU18 =   0.0

*****************************    R E A C T O R    H E A T    T R A N S F E R    *****************************

TAU 1 =     2.0979 SEC   TAU 2 =     3.0390 SEC   TAU 3 =     2.0993 SEC   TAU 4 =     2.0964 SEC   TAU 5 =     3.0811 SEC
TAU 6 =     2.0976 SEC   TAU 7 =     2.0966 SEC   TAU 8 =     3.0379 SEC   TAU 9 =     2.0976 SEC   TAU10 =     7.2969 SEC
TAU11 =    11.1518 SEC   TAU12 =   152.4114 SEC   TAU13 =    16.9387 SEC   TAU14 =     0.3152 SEC   TAU15 =     0.6517 SEC
TAU16 =     1.4303 SEC   TAU17 =     0.3397 SEC   TAU18 =     0.6915 SEC   TAU19 =     1.5204 SEC   TAU20 =     0.3434 SEC
TAU21 =     0.6908 SEC   TAU22 =     1.5331 SEC   TAU23 =     0.5683 SEC   TAU24 =     0.8760 SEC   TAU25 =    32.0244 SEC
TAU26 =   313.0940 SEC   TAU27 =     0.0    SEC   TAU28 =     0.3152 SEC   TAU29 =     0.3397 SEC   TAU30 =     0.3434 SEC
TAU31 =     0.5683 SEC   TAU32 =     0.8760 SEC   TAU33 =    32.0244 SEC   TAU
  CORE HOT SPOT:         MAX. COOLANT TEMP. =   550.847          MAX. CLAD TEMP. =   553.145
PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =   520.831   CLAD INNER =   437.313   CLAD OUTER =   437.135
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```
TM 1 =   384.335   TM 2 =   504.736   TM 3 =   488.599   TM 4 =   383.157   TM 5 =   484.178   TM 6 =   473.200
TM 7 =   383.084   TM 8 =   468.885   TM 9 =   460.646   TM10 =   415.990   TM11 =   442.844   TM
TC 1 =   382.393   TC 2 =   490.682   TC 3 =   487.983   TC 4 =   381.779   TC 5 =   475.012   TC 6 =   472.633
TC 7 =   381.749   TC 8 =   462.075   TC 9 =   460.081   TC10 =   441.715   TC11 =   481.901   TC12 =   379.436
TCI1 =   379.266   TCI2 =   379.266   TCI3 =   379.266   TCI4 =   379.266   TCI5 =   379.266   TCI6 =   379.266
LOWER PLENUM:                        TOP ZONE TEMP. =   379.266   BOTTOM ZONE TEMP. =   378.988
UPPER PLENUM:  ZJET =     6.400   TOP ZONE TEMP. =   517.282   BOTTOM ZONE TEMP. =   517.282   NOZZLE TEMP. =   517.281

************************    I H X - 1    T H E R M A L    C A L C U L A T I O N S    ************************

TAUP: 1  46.7323  2   2.5938  3   2.7693  4   2.8489  5   2.8892  6   2.9077  7   2.9337  8   2.9306  9   2.8129 101028.5457
11  11.3774
TAUS: 12   1.4034 13   1.3401 14   1.3086 15   1.2992 16   1.2941 17   1.2908 18   1.3033 19   1.3661 20  40.0645 21  53.5647
TP: 1  525.973  2  496.535  3  474.450  4  454.051  5  433.724  6  412.748  7  390.532  8  366.743  9  343.243 10  525.973
11  350.854
TS: 1  519.086  2  491.752  3  470.255  4  449.951  5  429.555  6  408.386  7  385.855  8  361.843  9  338.967 10  510.686

************************    I H X - 2    T H E R M A L    C A L C U L A T I O N S    ************************

TAUP: 1  46.5263  2   2.3508  3   2.7403  4   2.8076  5   2.8688  6   2.9211  7   2.8438  8   2.8181  9   2.5154 101024.0103
11  11.3338
TAUS: 12   1.4456 13   1.3027 14   1.2760 15   1.2614 16   1.2412 17   1.2817 18   1.3007 19   1.4309 20  35.4947 21  47.3978
TP: 1  525.973  2  484.689  3  460.783  4  439.406  5  419.068  6  398.515  7  377.156  8  357.168  9  341.319 10  525.973
11  348.784
TS: 1  514.213  2  478.951  3  455.948  4  434.920  5  414.642  6  393.770  7  372.667  8  353.130  9  338.987 10  508.203

***************    P R I M A R Y    S O D I U M    T R A N S P O R T    C A L C U L A T I O N S    ***************

 TAUC1:  1 12.36089  2 12.35185  3 12.34377  4 12.33752  5 12.33340  6 12.33127  7 12.33068  8 12.33105  9 12.33184 10 12.33269
 TAUW1:  1 64.78662  2 64.80974  3 64.83034  4 64.84634  5 64.85684  6 64.86226  7 64.86375  8 64.86281  9 64.86079 10 64.85866
 TAUC2:  1  4.68460  2  4.68471  3  4.68480  4  4.68487  5  4.68493  6  4.68499  7  4.68503  8  4.68506  9  4.68508 10  4.68510
 TAUW2:  1 52.08653  2 52.08620  3 52.08594  4 52.08568  5 52.08548  6 52.08537  7 52.08522  8 52.08514  9 52.08505 10 52.08501
 TAUC3:  1  7.84898  2  7.84264  3  7.83634  4  7.83024  5  7.82440  6  7.81886  7  7.81370  8  7.80899  9  7.80480 10  7.80118
 TAUW3:  1 51.31136  2 51.32491  3 51.33839  4 51.35139  5 51.36382  6 51.37560  7 51.38652  8 51.39655  9 51.40547 10 51.41307
 TAUC4:  1 12.36062  2 12.35158  3 12.34350  4 12.33724  5 12.33312  6 12.33100  7 12.33041  8 12.33077  9 12.33156 10 12.33241
 TAUW4:  1 64.71877  2 64.74184  3 64.76234  4 64.77823  5 64.78874  6 64.79414  7 64.79567  8 64.79471  9 64.79271 10 64.79057
 TAUC5:  1  4.68455  2  4.68465  3  4.68474  4  4.68482  5  4.68488  6  4.68494  7  4.68498  8  4.68500  9  4.68503 10  4.68504
 TAUW5:  1 52.04892  2 52.04858  3 52.04829  4 52.04807  5 52.04784  6 52.04773  7 52.04759  8 52.04747  9 52.04741 10 52.04738
 TAUC6:  1  7.85344  2  7.84718  3  7.84077  4  7.83436  5  7.82805  6  7.82193  7  7.81618  8  7.81090  9  7.80622 10  7.80221
 TAUW6:  1 51.26669  2 51.28001  3 51.29372  4 51.30733  5 51.32074  6 51.33366  7 51.34589  8 51.35704  9 51.36691 10 51.37541
TC1:  1   519.902  2   522.375  3   524.423  4   525.880  5   526.729  6   527.068  7   527.058  8   526.864  9   526.616 10   526.392
TW1:  1   524.693  2   525.481  3   526.020  4   526.321  5   526.431  6   526.415  7   526.331  8   526.228  9   526.139 10   526.070
TC2:  1   526.310  2   526.237  3   526.176  4   526.125  5   526.083  6   526.051  7   526.026  8   526.007  9   525.993 10   525.983
TW2:  1   526.051  2   526.031  3   526.015  4   526.003  5   525.993  6   525.986  7   525.981  8   525.977  9   525.975 10   525.975
TC3:  1   353.746  2   356.689  3   359.551  4   362.301  5   364.922  6   367.390  7   369.673  8   371.730  9   373.530 10   375.051
TW3:  1   368.746  2   370.284  3   371.723  4   373.049  5   374.255  6   375.329  7   376.265  8   377.056  9   377.706 10   378.221
TC4:  1   519.902  2   522.375  3   524.423  4   525.880  5   526.729  6   527.068  7   527.058  8   526.864  9   526.616 10   526.392
TW4:  1   524.692  2   525.481  3   526.020  4   526.321  5   526.431  6   526.414  7   526.331  8   526.228  9   526.139 10   526.070
TC5:  1   526.310  2   526.237  3   526.176  4   526.125  5   526.083  6   526.051  7   526.026  8   526.007  9   525.993 10   525.983
TW5:  1   526.051  2   526.031  3   526.015  4   526.003  5   525.993  6   525.986  7   525.981  8   525.977  9   525.975 10   525.975
TC6:  1   351.598  2   354.539  3   357.498  4   360.437  5   363.310  6   366.056  7   368.608  8   370.909  9   372.915 10   374.605
TW6:  1   367.694  2   369.328  3   370.888  4   372.348  5   373.687  6   374.886  7   375.928  8   376.809  9   377.528 10   378.098

************************ I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S ************************

 TAU: 1   10.036556  2   16.428894  3    0.500000  4    0.020000  5    3.999999
 SODIUM FLOW RATE =  0.0958   PUMP SPEED =  0.0936   PUMP HEAD =  0.0084   MOTOR GEN. SET FREQ. =   277.931 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.9203   DRIVE MOTOR TORQUE =  0.0212   PUMP TORQUE =  0.0086   FRICTION TORQUE =  0.0142

************************ I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S ************************
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```
TAU: 1   13.220416  2   17.178558  3    0.500000  4    0.020000  5    3.999999
SODIUM FLOW RATE =  0.1083   PUMP SPEED =  0.0948   PUMP HEAD =  0.0070   MOTOR GEN. SET FREQ. =   275.363 CYCLES/SEC
MAIN MOTOR TORQUE =  0.9206   DRIVE MOTOR TORQUE =  0.0201   PUMP TORQUE =  0.0078   FRICTION TORQUE =  0.0142

********************     I N T E R M E D I A T E     L O O P - 1:    S O D I U M    T R A N S P O R T     ********************

TAUC1:  1 20.19737  2 20.21983  3 20.23769  4 20.25067  5 20.25926  6 20.26442  7 20.26723  8 20.26863  9 20.26926 10 20.26952
TAUW1:  1 51.90466  2 51.88837  3 51.87544  4 51.86600  5 51.85974  6 51.85597  7 51.85393  8 51.85292  9 51.85245 10 51.85225
TAUC2:  1 14.31790
TAUW2:  1 50.30977
TAUC3:  1 18.58925  2 18.54776
TAUW3:  1 51.04572  2 51.08313
TAUC4:  1  8.94214  2  8.93585  3  8.93077  4  8.92686  5  8.92399  6  8.92196  7  8.92060  8  8.91971  9  8.91917 10  8.91884
TAUW4:  1 51.10619  2 51.11806  3 51.12759  4 51.13495  5 51.14035  6 51.14420  7 51.14676  8 51.14839  9 51.14941 10 51.15004
TCS1:  1   506.476  2   503.010  3   500.383  4   498.574  5   497.449  6   496.815  7   496.490  8   496.338  9   496.273 10   496.250
TWS1:  1   500.746  2   499.079  3   497.898  4   497.133  5   496.683  6   496.441  7   496.322  8   496.269  9   496.249 10   496.243
TCS2:  1   311.928
TWS2:  1   327.921
TCS3:  1   320.854  2   327.969
TWS3:  1   331.786  2   334.848
TCS4:  1   330.773  2   333.082  3   334.896  4   336.255  5   337.230  6   337.898  7   338.338  8   338.615  9   338.782 10   338.879
TWS4:  1   336.523  2   337.296  3   337.866  4   338.270  5   338.545  6   338.725  7   338.836  8   338.905  9   338.944 10   338.965

********************     I N T E R M E D I A T E     L O O P - 2:    S O D I U M    T R A N S P O R T     ********************

TAUC1:  1 28.70914  2 28.74286  3 28.76544  4 28.77843  5 28.78487  6 28.78767  7 28.78874  8 28.78911  9 28.78920 10 28.78920
TAUW1:  1 50.89523  2 50.87973  3 50.86934  4 50.86339  5 50.86041  6 50.85916  7 50.85861  8 50.85844  9 50.85840 10 50.85840
TAUC2:  1 12.74428
TAUW2:  1 49.50925
TAUC3:  1 16.54039  2 16.50426
TAUW3:  1 50.12859  2 50.16202
TAUC4:  1 14.21530  2 14.20078  3 14.19163  4 14.18644  5 14.18377  6 14.18254  7 14.18202  8 14.18184  9 14.18179 10 14.18178
TAUW4:  1 50.18631  2 50.20184  3 50.21162  4 50.21716  5 50.22000  6 50.22134  7 50.22189  8 50.22206  9 50.22212 10 50.22212
TCS1:  1   503.486  2   500.117  3   498.074  4   497.012  5   496.532  6   496.341  7   496.275  8   496.254  9   496.254 10   496.254
TWS1:  1   499.769  2   498.057  3   497.073  4   496.583  5   496.368  6   496.285  7   496.259  8   496.254  9   496.254 10   496.254
TCS2:  1   312.564
TWS2:  1   328.806
TCS3:  1   321.240  2   328.282
TWS3:  1   332.418  2   335.286
TCS4:  1   332.717  2   335.632  3   337.350  4   338.263  5   338.700  6   338.887  7   338.958  8   338.980  9   338.985 10   338.985
TWS4:  1   337.047  2   338.009  3   338.535  4   338.798  5   338.917  6   338.964  7   338.981  8   338.985  9   338.986 10   338.987

***********************************    S T E A M    G E N E R A T I O N    L O O P - 1    ***********************************

 TAU: 1   8.060769  2   8.050859  3   8.007442  4   7.639487  5 12.084133  6 12.068241  7 12.044953  8 12.017323
 9 11.989758 10   1.968162 11 23.202072 12   0.0        13 64.187469 14   2.060058 15 13.524072 16 70.761871
17   3.961038 18   5.079752 19   0.860580 20   2.219094 21   8.095321 22   1.990541 23   5.189256 24   0.306850
25   0.141049 26   0.123444 27   0.114107 28   0.109893 29   0.460677 30 16.218338 31 14.955339 32   0.988346
33   0.199982 34*********** 35*********** 36   1.000000 37   1.999999 38   1.999999 39   1.999999
 FEED WATER FLOW =0.0      WATER/STEAM FLOW =0.2187   STEAM FLOW =0.2195   INT. SODIUM FLOW =0.0958

 AUXILIARY FEED WATER AVAILABLE AT   30.000 SECONDS  ENTHALPY = 1.5580E+05  AUX. WATER FLOW  =1.0000
 P 1 = 1.2150E+07   P 2 = 1.0203E+07   P 3 = 1.0203E+07   P 4 = 1.0354E+07   P 5 = 1.0331E+07   P 6 = 1.0341E+07   P 7 = 1.0361E+07
 P 8 = 1.0341E+07   P 9 = 1.0259E+07   P10 = 1.0225E+07   P11 = 1.0215E+07   P12 = 1.0199E+07   P13 = 1.0203E+07   P14 = 1.0216E+07
 P15 = 1.0207E+07   P16 = 1.0180E+07   P17 = 1.0153E+07   P18 = 1.0129E+07   P19 = 1.0105E+07   P20 = 1.0097E+07   P21 = 1.0075E+07
 H 1 = 1.5580E+05   H 2 = 1.5966E+06   H 3 = 7.3163E+05   H 4 = 1.3012E+06   H 5 = 1.3197E+06   H 6 = 1.3619E+06   H 7 = 1.3052E+06
 H 8 = 1.3015E+06   H 9 = 1.4188E+06   H10 = 1.8116E+06   H11 = 1.8299E+06   H12 = 1.9569E+06   H13 = 1.9915E+06   H14 = 2.7201E+06
 H15 = 2.7200E+06   H16 = 3.0758E+06   H17 = 3.2443E+06   H18 = 3.3197E+06   H19 = 3.3516E+06   H20 = 3.3513E+06   H21 = 3.3438E+06
 TM 1 =    65.1202   TM 2 =   325.6882   TM 3 =   172.6357   TM 4 =   290.6458   TM 5 =   293.5320   TM 6 =   299.5227   TM 7 =   291.2732
```

```
TM 8 =  290.6926  TM 9 =  312.8013  TM10 =  312.5562  TM11 =  312.4805  TM12 =  312.3711  TM13 =  312.3987  TM14 =  312.4900
TM15 =  312.4224  TM16 =  394.5120  TM17 =  450.4014  TM18 =  478.6570  TM19 =  491.1609  TM20 =  491.0205  TM21 =  487.8945
TCS 8 =  303.5991  TCS 9 =  315.7480  TCS10 =  431.8298  TCS11 =  423.6724  TCS12 =  415.4907  TCS13 =  408.5920  TCS14 =  403.8831
TCS15 =  400.2437  TCS16 =  451.9731  TCS17 =  478.3350  TCS18 =  490.8777  TCS19 =  496.2495  TCS
                        TDLOG:  9        6.7431 10       31.4337
                        U    :  9     3288.1504 10     6850.6094
           TDLOG: 16       71.5713 17      40.9377 18      19.0067 19       8.1405
           U    : 16     1784.0374 17    1479.5876 18    1426.0757 19    1408.9807

HEAT FLUX = 8.811694E+04                     OUTLET STEAM QUALITY = 3.024936E-01
NON-BOILING LENGTH = 1.049555E+01           BOILING LENGTH = 3.524435E+00

DRUM INT. ENERGY = 1.0161E+10   DRUM LEVEL = 0.5707   CVP = 1.0000   ALFA = 0.1016   DPRP =-1.5391E+06

***********************************   S T E A M   G E N E R A T I O N   L O O P - 2   ***********************************

 TAU:  1  7.211903  2  7.205088  3  7.166917  4  6.856581  5 10.680674  6 10.668674  7 10.652209  8 10.632288
 9 10.611320 10  1.975670 11 21.854080 12  0.0        13 63.150223 14  2.027132 15 13.307721 16 69.628738
17  3.897620 18  4.863976 19  0.846487 20  2.004570 21  7.419954 22  1.830501 23  4.733278 24  0.279828
25  0.130097 26  0.113827 27  0.105185 28  0.101426 29  0.418930 30 14.732140 31 14.736311 32  0.971152
33  0.181573 34********** 35********** 36  1.000000 37  1.999999 38  1.999999 39  1.999999
 FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.2222  STEAM FLOW =0.2415  INT. SODIUM FLOW =0.1083

AUXILIARY FEED WATER AVAILABLE AT  30.000 SECONDS  ENTHALPY = 1.5580E+05  AUX. WATER FLOW  =1.0000
P 1 = 1.2150E+07  P 2 = 1.0234E+07  P 3 = 1.0234E+07  P 4 = 1.0384E+07  P 5 = 1.0361E+07  P 6 = 1.0370E+07  P 7 = 1.0390E+07
P 8 = 1.0370E+07  P 9 = 1.0292E+07  P10 = 1.0255E+07  P11 = 1.0245E+07  P12 = 1.0231E+07  P13 = 1.0234E+07  P14 = 1.0244E+07
P15 = 1.0233E+07  P16 = 1.0201E+07  P17 = 1.0169E+07  P18 = 1.0140E+07  P19 = 1.0111E+07  P20 = 1.0102E+07  P21 = 1.0075E+07
H 1 = 1.5580E+05  H 2 = 1.6024E+06  H 3 = 7.4373E+05  H 4 = 1.3021E+06  H 5 = 1.3202E+06  H 6 = 1.3624E+06  H 7 = 1.3057E+06
H 8 = 1.3021E+06  H 9 = 1.4202E+06  H10 = 1.8590E+06  H11 = 1.8799E+06  H12 = 2.0083E+06  H13 = 2.0431E+06  H14 = 2.7194E+06
H15 = 2.7194E+06  H16 = 3.0772E+06  H17 = 3.2456E+06  H18 = 3.3202E+06  H19 = 3.3514E+06  H20 = 3.3512E+06  H21 = 3.3449E+06
TM 1 =   65.1202  TM 2 =  325.6863  TM 3 =  175.2680  TM 4 =  290.7803  TM 5 =  293.6064  TM 6 =  299.5881  TM 7 =  291.3613
TM 8 =  290.7805  TM 9 =  313.0342  TM10 =  312.7727  TM11 =  312.7000  TM12 =  312.5952  TM13 =  312.6194  TM14 =  312.6926
TM15 =  312.6130  TM16 =  395.0869  TM17 =  450.9463  TM18 =  478.9009  TM19 =  491.1309  TM20 =  490.9934  TM21 =  488.3503
TCS 8 =  304.7625  TCS 9 =  316.0269  TCS10 =  431.2375  TCS11 =  424.2253  TCS12 =  417.5605  TCS13 =  412.0479  TCS14 =  408.0308
TCS15 =  404.2925  TCS16 =  454.5562  TCS17 =  479.6213  TCS18 =  491.2922  TCS19 =  496.2539  TCS
                        TDLOG:  9        7.1286 10       31.3918
                        U    :  9     3319.0635 10     6902.2461
           TDLOG: 16       74.4160 17      42.2166 18      19.4077 19       8.2290
           U    : 16     1898.8452 17    1577.1348 18    1520.9065 19    1503.0120

HEAT FLUX = 8.865737E+04                     OUTLET STEAM QUALITY = 3.383766E-01
NON-BOILING LENGTH = 1.006517E+01           BOILING LENGTH = 3.954823E+00

DRUM INT. ENERGY = 1.0060E+10   DRUM LEVEL = 0.5531   CVP = 1.0000   ALFA = 0.1032   DPRP =-1.5928E+06

*******************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   *****************************

                    TIME CONSTANT OF THE HEADER PRESSURE GAUGE =  0.150000 SECONDS
   THROTTLE VALVE POSITION =1.0000                                DUMP(BYPASS) VALVE POSITION =0.2956
   THROTTLE VALVE FLOW     =0.0       RELIEF VALVE FLOW =0.0      DUMP(BYPASS) VALVE FLOW     =0.2362
   HEADER PRESSURE = 1.0075E+07       TEMPERATURE =  485.6484       SPECIFIC ENTHALPY= 3.3381E+06

*******************************   M E A S U R E D   V A L U E S   F O R   P P S   *******************************

 TAU :   0.1500        0.5000        0.1000        5.0000        5.0000        5.0000        5.0000
 PRESNORM =  0.31089          VESSEL LEVEL =   4.5623          PTOTNORM =  0.05243
 TIHX1 =  352.262     TIHX2 =  350.097     TEVAP1 =  305.947     TEVAP2 =  307.285
```

```
    STEP #   220    TIME =   43.99980 SEC    S =  0.40000 SEC

                                                   TOTAL VECTOR OF CONTROL INTEGERS
 11   12   13   14   15   19   20   24   25   26   40   43   46   53   54   55   56   81   82   83   84   84  106  107  108
109  109  232  233  237  238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292
293  294  295  296  297  298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342
343  344  345  346  347  348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411
423  424  425  426  427  432  450  462  463  464  465  466  471  480  483  484  485    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0

*************************   N E U T R O N    K I N E T I C S    C A L C U L A T I O N S    **************************

 PTOT =        46.975 MWT     PN =          2.129 MWT      PFP =          44.846 MWT
 PDN :    1    0.008 MWT    2    0.175 MWT     PFP :     3     2.203 MWT    4   13.839 MWT    5   28.804 MWT
 ROTOT =     -23.504410 $      ROCR1 =        2.749999 $       ROCR2 =        -6.299999 $      ROFDBK =      -1.954412 $
 RODOP =      -0.707361 $      ROSOD =       -0.024010 $       ROCRE =        -1.095684 $      ROCAE  =      -0.127358 $
 TRO   =     469.577            TROM   =     468.396              TSTM  =      486.037
 PD =          0.9000          ETST   =    -11.749756          ETRO   =       29.025635    EF =     -0.050000    DELRO =     -0.000333
 PTOTNORM =    0.0482          PNNORM =       0.0022           PFPNORM =        0.0460      SCRAM RODS:   PRIM = 100.000 %    SEC = 100.000 %

********************************    P R I M A R Y    C O O L A N T    D Y N A M I C S    **********************************

 FZ1NRM = 0.0900                              FZ2NRM = 0.0899  FZ3NRM = 0.0872  CANRM = 0.0581   RBNRM = 0.0705   BPNRM = 0.0977
 FLOWS: 1    1.5077E+02    2   1.5163E+02    3   1.6943E+02    4   1.2159E+01    5   4.7255E+00    6   5.2600E+01    7   2.1233E+01
 AL1=   0.0919   NEW1=    0.0866   BP1=    0.0089   TMOTN1=    0.0226   HP1=    0.0092   FREQ1= 2905.766
 AL2=   0.0919   NEW2=    0.0871   BP2=    0.0089   TMOTN2=    0.0226   HP2=    0.0092   FREQ2= 2906.056
 PD =   0.9000   TRISP =  387.779   NEWSP =    0.9000   ASP =    0.9000   XKW = 1.316E-03   EPS = 1.000E-03   N =  1
 TRIM:      375.198     374.768       NEWM:        0.0866      0.0871        ALM:        0.0919        0.0919      INLET PRSNRM = 0.3108
 ET:        2.2647E+01      2.3421E+01        EW:         8.4318E-01       8.4371E-01       EA:        1.0081E+00       1.0081E+00

*****************************    R E A C T O R    H E A T    T R A N S F E R    ******************************

   CORE HOT SPOT:          MAX. COOLANT TEMP. =   551.847          MAX. CLAD TEMP. =    554.126
 PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =    520.177   CLAD INNER =   437.580   CLAD OUTER =    437.403
 TM 1 =    384.213    TM 2 =    504.397    TM 3 =    491.468    TM 4 =    383.049    TM 5 =    483.794    TM 6 =    475.401
 TM 7 =    382.976    TM 8 =    468.575    TM 9 =    462.565    TM10 =    415.131    TM11 =    440.735    TM
 TC 1 =    382.313    TC 2 =    491.308    TC 3 =    490.783    TC 4 =    381.697    TC 5 =    475.333    TC 6 =    474.852
 TC 7 =    381.665    TC 8 =    462.355    TC 9 =    462.026    TC10 =    440.405    TC11 =    478.768    TC12 =    379.412
 TCI1 =    379.199    TCI2 =    379.199    TCI3 =    379.199    TCI4 =    379.199    TCI5 =    379.199    TCI6 =    379.199
 LOWER PLENUM:                          TOP ZONE TEMP. =    379.199    BOTTOM ZONE TEMP. =    378.869
 UPPER PLENUM:  ZJET =      6.400    TOP ZONE TEMP. =    516.644    BOTTOM ZONE TEMP. =    516.644    NOZZLE TEMP. =    516.644

************************    I H X - 1    T H E R M A L    C A L C U L A T I O N S    ************************

 TP:  1  525.974   2  496.810   3  474.353   4  453.890   5  433.523   6  412.511   7  390.245   8  366.527   9  343.202  10  525.973
11  350.178
```

```
TS:  1  519.587  2  492.092  3  470.303  4  449.946  5  429.514  6  408.322  7  385.740  8  361.915  9  338.956 10  511.292

************************     I H X - 2     T H E R M A L     C A L C U L A T I O N S     ************************

TP:  1  525.974  2  484.598  3  459.958  4  438.650  5  418.259  6  397.588  7  376.397  8  356.599  9  341.266 10  525.973
11  348.164
TS:  1  515.045  2  478.888  3  455.393  4  434.373  5  414.031  6  393.161  7  372.128  8  352.931  9  338.986 10  508.703

**************     P R I M A R Y     S O D I U M     T R A N S P O R T     C A L C U L A T I O N S     **************

TC1:  1  519.185  2  521.658  3  523.800  4  525.414  5  526.437  6  526.931  7  527.033  8  526.905  9  526.682 10  526.456
TW1:  1  524.308  2  525.199  3  525.842  4  526.234  5  526.411  6  526.437  7  526.372  8  526.271  9  526.176 10  526.097
TC2:  1  526.371  2  526.293  3  526.224  4  526.166  5  526.117  6  526.078  7  526.046  8  526.023  9  526.005 10  525.992
TW2:  1  526.075  2  526.051  3  526.031  4  526.014  5  526.002  6  525.992  7  525.986  8  525.980  9  525.977 10  525.975
TC3:  1  352.786  2  355.627  3  358.475  4  361.238  5  363.884  6  366.389  7  368.724  8  370.853  9  372.744 10  374.371
TW3:  1  367.481  2  369.116  3  370.663  4  372.100  5  373.417  6  374.603  7  375.649  8  376.546  9  377.294 10  377.899
TC4:  1  519.185  2  521.658  3  523.800  4  525.414  5  526.437  6  526.931  7  527.033  8  526.905  9  526.682 10  526.456
TW4:  1  524.307  2  525.199  3  525.842  4  526.234  5  526.411  6  526.436  7  526.371  8  526.272  9  526.176 10  526.097
TC5:  1  526.370  2  526.292  3  526.224  4  526.166  5  526.117  6  526.077  7  526.046  8  526.023  9  526.005 10  525.992
TW5:  1  526.075  2  526.051  3  526.031  4  526.014  5  526.002  6  525.992  7  525.986  8  525.980  9  525.977 10  525.975
TC6:  1  350.701  2  353.514  3  356.416  4  359.323  5  362.186  6  364.948  7  367.549  8  369.928  9  372.038 10  373.848
TW6:  1  366.351  2  368.071  3  369.732  4  371.302  5  372.758  6  374.078  7  375.242  8  376.241  9  377.072 10  377.742

************************ I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S ************************

 SODIUM FLOW RATE =  0.0910   PUMP SPEED =  0.0927   PUMP HEAD =  0.0088   MOTOR GEN. SET FREQ. =   305.135 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.9188   DRIVE MOTOR TORQUE =  0.0220   PUMP TORQUE =  0.0087   FRICTION TORQUE =  0.0141

************************ I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S ************************

 SODIUM FLOW RATE =  0.1007   PUMP SPEED =  0.0936   PUMP HEAD =  0.0077   MOTOR GEN. SET FREQ. =   302.535 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.9190   DRIVE MOTOR TORQUE =  0.0212   PUMP TORQUE =  0.0081   FRICTION TORQUE =  0.0142

*******************     I N T E R M E D I A T E     L O O P - 1:   S O D I U M     T R A N S P O R T     *******************

TCS1:  1  507.032  2  503.490  3  500.761  4  498.844  5  497.623  6  496.915  7  496.542  8  496.363  9  496.283 10  496.253
TWS1:  1  501.346  2  499.516  3  498.194  4  497.318  5  496.789  6  496.496  7  496.348  8  496.280  9  496.252 10  496.244
TCS2:  1  310.482
TWS2:  1  326.328
TCS3:  1  319.465  2  326.800
TWS3:  1  330.574  2  334.015
TCS4:  1  329.740  2  332.208  3  334.191  4  335.715  5  336.833  6  337.621  7  338.152  8  338.495  9  338.708 10  338.835
TWS4:  1  335.944  2  336.856  3  337.545  4  338.044  5  338.392  6  338.625  7  338.773  8  338.866  9  338.921 10  338.951

*******************     I N T E R M E D I A T E     L O O P - 2:   S O D I U M     T R A N S P O R T     *******************

TCS1:  1  503.900  2  500.429  3  498.272  4  497.119  5  496.582  6  496.361  7  496.281  8  496.255  9  496.254 10  496.254
TWS1:  1  500.243  2  498.352  3  497.234  4  496.660  5  496.400  6  496.297  7  496.262  8  496.254  9  496.254 10  496.254
TCS2:  1  311.031
TWS2:  1  327.188
TCS3:  1  319.714  2  326.970
TWS3:  1  331.173  2  334.427
TCS4:  1  331.702  2  334.938  3  336.925  4  338.029  5  338.583  6  338.835  7  338.937  8  338.973  9  338.982 10  338.984
TWS4:  1  336.502  2  337.683  3  338.357  4  338.709  5  338.876  6  338.948  7  338.975  8  338.983  9  338.985 10  338.986

***********************************   S T E A M   G E N E R A T I O N   L O O P - 1   *********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.2155  STEAM FLOW =0.1346  INT. SODIUM FLOW =0.0910

AUXILIARY FEED WATER AVAILABLE AT  30.000 SECONDS  ENTHALPY = 1.5580E+05  AUX. WATER FLOW  =1.0000
```

```
P 1 = 1.2150E+07  P 2 = 1.0158E+07  P 3 = 1.0158E+07  P 4 = 1.0310E+07  P 5 = 1.0286E+07  P 6 = 1.0295E+07  P 7 = 1.0316E+07
P 8 = 1.0296E+07  P 9 = 1.0213E+07  P10 = 1.0180E+07  P11 = 1.0169E+07  P12 = 1.0154E+07  P13 = 1.0158E+07  P14 = 1.0176E+07
P15 = 1.0172E+07  P16 = 1.0160E+07  P17 = 1.0150E+07  P18 = 1.0140E+07  P19 = 1.0130E+07  P20 = 1.0126E+07  P21 = 1.0113E+07
H 1 = 1.5580E+05  H 2 = 1.5929E+06  H 3 = 7.2036E+05  H 4 = 1.2670E+06  H 5 = 1.2849E+06  H 6 = 1.3465E+06  H 7 = 1.3079E+06
H 8 = 1.3049E+06  H 9 = 1.4168E+06  H10 = 1.7820E+06  H11 = 1.7981E+06  H12 = 1.9026E+06  H13 = 1.9311E+06  H14 = 2.7208E+06
H15 = 2.7208E+06  H16 = 3.0942E+06  H17 = 3.2549E+06  H18 = 3.3248E+06  H19 = 3.3537E+06  H20 = 3.3530E+06  H21 = 3.3455E+06
TM 1 =   65.1202  TM 2 =  325.6880  TM 3 =  170.1942  TM 4 =  284.9592  TM 5 =  287.9834  TM 6 =  297.4468  TM 7 =  291.6985
TM 8 =  291.2261  TM 9 =  312.4658  TM10 =  312.2312  TM11 =  312.1541  TM12 =  312.0410  TM13 =  312.0730  TM14 =  312.2009
TM15 =  312.1689  TM16 =  399.9868  TM17 =  454.2429  TM18 =  480.7151  TM19 =  492.1265  TM20 =  491.8396  TM21 =  488.7600
TCS 8 =  302.1956  TCS 9 =  315.5249  TCS10 =  429.1924  TCS11 =  421.0981  TCS12 =  413.3723  TCS13 =  407.1274  TCS14 =  402.7705
TCS15 =  399.8425  TCS16 =  452.5415  TCS17 =  478.8799  TCS18 =  491.1313  TCS19 =  496.2532  TCS
                              TDLOG:  9        6.1944 10        31.2594
                              U    :  9     3262.8337 10      6821.9648
          TDLOG: 16        68.6230 17        36.8498 18        16.5186 19         6.7929
          U    : 16      1285.4038 17      1052.6687 18      1016.3093 19      1004.9570

HEAT FLUX = 8.726206E+04                          OUTLET STEAM QUALITY = 2.806481E-01
NON-BOILING LENGTH = 1.083017E+01               BOILING LENGTH = 3.189814E+00

DRUM INT. ENERGY = 1.0181E+10   DRUM LEVEL = 0.5770   CVP = 1.0000   ALFA = 0.0939   DPRP =-1.7729E+06

************************************   S T E A M   G E N E R A T I O N   L O O P - 2   ************************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.2186  STEAM FLOW =0.1601  INT. SODIUM FLOW =0.1007

AUXILIARY FEED WATER AVAILABLE AT  30.000 SECONDS  ENTHALPY = 1.5580E+05  AUX. WATER FLOW  =1.0000
P 1 = 1.2150E+07  P 2 = 1.0180E+07  P 3 = 1.0180E+07  P 4 = 1.0332E+07  P 5 = 1.0307E+07  P 6 = 1.0317E+07  P 7 = 1.0337E+07
P 8 = 1.0317E+07  P 9 = 1.0236E+07  P10 = 1.0202E+07  P11 = 1.0192E+07  P12 = 1.0176E+07  P13 = 1.0180E+07  P14 = 1.0196E+07
P15 = 1.0190E+07  P16 = 1.0175E+07  P17 = 1.0161E+07  P18 = 1.0147E+07  P19 = 1.0134E+07  P20 = 1.0129E+07  P21 = 1.0113E+07
H 1 = 1.5580E+05  H 2 = 1.5986E+06  H 3 = 7.3149E+05  H 4 = 1.2680E+06  H 5 = 1.2856E+06  H 6 = 1.3468E+06  H 7 = 1.3085E+06
H 8 = 1.3055E+06  H 9 = 1.4179E+06  H10 = 1.8191E+06  H11 = 1.8387E+06  H12 = 1.9477E+06  H13 = 1.9769E+06  H14 = 2.7203E+06
H15 = 2.7203E+06  H16 = 3.0937E+06  H17 = 3.2553E+06  H18 = 3.3249E+06  H19 = 3.3534E+06  H20 = 3.3529E+06  H21 = 3.3465E+06
TM 1 =   65.1202  TM 2 =  325.6860  TM 3 =  172.6089  TM 4 =  285.1267  TM 5 =  288.0884  TM 6 =  297.4895  TM 7 =  291.7905
TM 8 =  291.3208  TM 9 =  312.6370  TM10 =  312.3882  TM11 =  312.3135  TM12 =  312.2046  TM13 =  312.2332  TM14 =  312.3472
TM15 =  312.3059  TM16 =  399.9451  TM17 =  454.4363  TM18 =  480.7891  TM19 =  492.0420  TM20 =  491.8276  TM21 =  489.1646
TCS 8 =  303.2847  TCS 9 =  315.6331  TCS10 =  428.7258  TCS11 =  421.8918  TCS12 =  415.6582  TCS13 =  410.6138  TCS14 =  406.7021
TCS15 =  403.3872  TCS16 =  454.7776  TCS17 =  479.9685  TCS18 =  491.4690  TCS19 =  496.2537  TCS
                              TDLOG:  9        6.4769 10        30.9747
                              U    :  9     3290.1216 10      6858.6797
          TDLOG: 16        71.4306 17        38.3340 18        17.0407 19         6.9513
          U    : 16      1447.7463 17      1189.1826 18      1148.5095 19      1135.8804

HEAT FLUX = 8.692731E+04                          OUTLET STEAM QUALITY = 3.086474E-01
NON-BOILING LENGTH = 1.046056E+01               BOILING LENGTH = 3.559428E+00

DRUM INT. ENERGY = 1.0062E+10   DRUM LEVEL = 0.5572   CVP = 1.0000   ALFA = 0.0955   DPRP =-1.8136E+06

******************************   S T E A M   H E A D E R   T H E R M O D Y N A M I C S   ******************************

     THROTTLE VALVE POSITION =1.0000                              DUMP(BYPASS) VALVE POSITION =0.2377
     THROTTLE VALVE FLOW     =0.0       RELIEF VALVE FLOW =0.0     DUMP(BYPASS) VALVE FLOW     =0.1903
     HEADER PRESSURE = 1.0113E+07       TEMPERATURE =  487.0974      SPECIFIC ENTHALPY= 3.3413E+06

********************************   M E A S U R E D   V A L U E S   F O R   P P S   ********************************

 PRESNORM =  0.31078          VESSEL LEVEL =   4.5623         PTOTNORM =  0.04914
 TIHX1 =  351.265     TIHX2 =  349.171     TEVAP1 =  304.207     TEVAP2 =  305.425
```

```
STEP #  230   TIME =   47.99979 SEC   S =  0.40000 SEC

                                   TOTAL VECTOR OF CONTROL INTEGERS
  11   12   13   14   15   19   20   24   25   26   40   43   46   53   54   55   56   81   82   83   84   84  106  107  108
 109  109  232  233  237  238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292
 293  294  295  296  297  298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342
 343  344  345  346  347  348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411
 423  424  425  426  427  428  432  450  480  483  484  485    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0    0    0    0    0

**************************   N E U T R O N   K I N E T I C S   C A L C U L A T I O N S   **************************

PTOT =       46.157 MWT    PN =        1.956 MWT    PFP =         44.201 MWT
PDN :   1     0.007 MWT   2   0.161 MWT    PFP :   3    1.953 MWT    4   13.459 MWT    5   28.789 MWT
ROTOT =   -23.501480 $    ROCR1 =      2.749999 $    ROCR2 =      -6.299999 $    ROFDBK =    -1.951494 $
RODOP =    -0.705384 $    ROSOD =     -0.023890 $    ROCRE =      -1.095261 $    ROCAE  =    -0.126960 $
TRO    =   470.282         TROM  =    469.863          TSTM  =     486.464
PD =         0.9000        ETST  =    -11.749756       ETRO  =     29.025635   EF =    -0.050000   DELRO =    -0.000333
PTOTNORM =   0.0473        PNNORM =     0.0020         PFPNORM =    0.0453     SCRAM RODS:  PRIM = 100.000 %   SEC = 100.000 %

*********************************   P R I M A R Y   C O O L A N T   D Y N A M I C S   *********************************

FZ1NRM = 0.0896                          FZ2NRM = 0.0895  FZ3NRM = 0.0868  CANRM = 0.0578   RBNRM = 0.0701   BPNRM = 0.0973
FLOWS: 1   1.4998E+02   2   1.5098E+02   3   1.6868E+02   4   1.2105E+01   5   4.6996E+00   6   5.2305E+01   7   2.1134E+01
AL1=   0.0916   NEW1=    0.0862   BP1=    0.0089   TMOTN1=    0.0228   HP1=    0.0092   FREQ1= 3208.233
AL2=   0.0917   NEW2=    0.0867   BP2=    0.0089   TMOTN2=    0.0227   HP2=    0.0091   FREQ2= 3208.513
PD =   0.9000   TRISP =  387.779   NEWSP =    0.9000   ASP =    0.9000   XKW = 1.316E-03   EPS = 1.000E-03    N =  1
TRIM:      374.521     374.015      NEWM:       0.0862      0.0867       ALM:       0.0916      0.0917      INLET PRSNRM = 0.3107
ET:      2.3866E+01     2.4776E+01      EW:        8.4524E-01      8.4586E-01       EA:      1.0084E+00      1.0083E+00

******************************   R E A C T O R   H E A T   T R A N S F E R   ******************************

  CORE HOT SPOT:          MAX. COOLANT TEMP. =   550.989          MAX. CLAD TEMP. =    553.243
PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =    518.802   CLAD INNER =    437.224   CLAD OUTER =    437.050
TM 1 =    384.069   TM 2 =    503.297   TM 3 =    492.422   TM 4 =    382.922   TM 5 =    482.833   TM 6 =    476.107
TM 7 =    382.850   TM 8 =    467.760   TM 9 =    463.187   TM10 =    414.316   TM11 =    438.751   TM
TC 1 =    382.204   TC 2 =    490.724   TC 3 =    491.711   TC 4 =    381.595   TC 5 =    474.791   TC 6 =    475.588
TC 7 =    381.564   TC 8 =    461.888   TC 9 =    462.681   TC10 =    439.122   TC11 =    475.713   TC12 =    379.382
TCI1 =    379.121   TCI2 =    379.121   TCI3 =    379.121   TCI4 =    379.121   TCI5 =    379.121   TCI6 =    379.121
LOWER PLENUM:                         TOP ZONE TEMP. =    379.121   BOTTOM ZONE TEMP. =    378.735
UPPER PLENUM:  ZJET =     6.400   TOP ZONE TEMP. =    516.027   BOTTOM ZONE TEMP. =    516.027   NOZZLE TEMP. =    516.027

************************   I H X - 1   T H E R M A L   C A L C U L A T I O N S   ************************

TP:  1  525.975  2  497.313  3  474.488  4  453.932  5  433.528  6  412.490  7  390.186  8  366.584  9  343.268 10  525.973
11  349.711
```

```
TS:  1  520.014  2  492.608  3  470.508  4  450.078  5  429.614  6  408.402  7  385.785  8  362.170  9  338.943 10  511.865

************************     I H X - 2     T H E R M A L     C A L C U L A T I O N S     ************************

TP:  1  525.975  2  485.015  3  459.588  4  438.249  5  417.793  6  397.071  7  375.989  8  356.414  9  341.307 10  525.973
11  347.730
TS:  1  515.884  2  479.244  3  455.176  4  434.131  5  413.705  6  392.847  7  371.883  8  352.999  9  338.984 10  509.199

**************     P R I M A R Y     S O D I U M     T R A N S P O R T     C A L C U L A T I O N S     **************

TC1:  1  518.501  2  520.955  3  523.164  4  524.912  5  526.099  6  526.749  7  526.974  8  526.923  9  526.737 10  526.518
TW1:  1  523.906  2  524.892  3  525.636  4  526.119  5  526.369  6  526.443  7  526.404  8  526.312  9  526.213 10  526.126
TC2:  1  526.431  2  526.350  3  526.276  4  526.211  5  526.155  6  526.109  7  526.072  8  526.042  9  526.019 10  526.002
TW2:  1  526.101  2  526.073  3  526.049  4  526.029  5  526.013  6  526.001  7  525.991  8  525.984  9  525.979 10  525.977
TC3:  1  351.979  2  354.641  3  357.427  4  360.185  5  362.850  6  365.386  7  367.767  8  369.960  9  371.933 10  373.657
TW3:  1  366.257  2  367.964  3  369.604  4  371.144  5  372.565  6  373.856  7  375.006  8  376.005  9  376.850 10  377.545
TC4:  1  518.501  2  520.955  3  523.164  4  524.912  5  526.099  6  526.749  7  526.974  8  526.923  9  526.737 10  526.518
TW4:  1  523.905  2  524.892  3  525.635  4  526.119  5  526.369  6  526.443  7  526.404  8  526.312  9  526.213 10  526.126
TC5:  1  526.431  2  526.350  3  526.276  4  526.211  5  526.155  6  526.109  7  526.072  8  526.042  9  526.019 10  526.002
TW5:  1  526.101  2  526.073  3  526.049  4  526.029  5  526.013  6  526.001  7  525.991  8  525.984  9  525.979 10  525.977
TC6:  1  349.946  2  352.570  3  355.378  4  358.239  5  361.083  6  363.852  7  366.488  8  368.931  9  371.132 10  373.053
TW6:  1  365.058  2  366.842  3  368.587  4  370.255  5  371.817  6  373.249  7  374.528  8  375.641  9  376.580 10  377.350

************************  I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S  ************************

 SODIUM FLOW RATE =  0.0881   PUMP SPEED =  0.0921   PUMP HEAD =  0.0091   MOTOR GEN. SET FREQ. =   332.361 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.9176   DRIVE MOTOR TORQUE =  0.0224   PUMP TORQUE =  0.0089   FRICTION TORQUE =  0.0141

************************  I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S  ************************

 SODIUM FLOW RATE =  0.0954   PUMP SPEED =  0.0929   PUMP HEAD =  0.0083   MOTOR GEN. SET FREQ. =   329.735 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.9178   DRIVE MOTOR TORQUE =  0.0218   PUMP TORQUE =  0.0084   FRICTION TORQUE =  0.0141

*******************     I N T E R M E D I A T E     L O O P - 1:   S O D I U M   T R A N S P O R T     *******************

TCS1:  1  507.568  2  503.956  3  501.135  4  499.116  5  497.801  6  497.021  7  496.599  8  496.390  9  496.296 10  496.257
TWS1:  1  501.939  2  499.956  3  498.497  4  497.511  5  496.902  6  496.557  7  496.378  8  496.294  9  496.258 10  496.246
TCS2:  1  309.132
TWS2:  1  324.763
TCS3:  1  318.141  2  325.660
TWS3:  1  329.358  2  333.156
TCS4:  1  328.715  2  331.325  3  333.464  4  335.143  5  336.405  6  337.312  7  337.940  8  338.355  9  338.619 10  338.781
TWS4:  1  335.330  2  336.381  3  337.190  4  337.789  5  338.215  6  338.506  7  338.696  8  338.818  9  338.892 10  338.935

*******************     I N T E R M E D I A T E     L O O P - 2:   S O D I U M   T R A N S P O R T     *******************

TCS1:  1  504.292  2  500.728  3  498.465  4  497.226  5  496.632  6  496.382  7  496.289  8  496.257  9  496.253 10  496.253
TWS1:  1  500.710  2  498.648  3  497.400  4  496.741  5  496.436  6  496.311  7  496.266  8  496.254  9  496.253 10  496.253
TCS2:  1  309.644
TWS2:  1  325.599
TCS3:  1  318.307  2  325.725
TWS3:  1  329.923  2  333.537
TCS4:  1  330.705  2  334.229  3  336.475  4  337.770  5  338.449  6  338.771  7  338.909  8  338.962  9  338.979 10  338.982
TWS4:  1  335.917  2  337.320  3  338.151  4  338.602  5  338.825  6  338.925  7  338.966  8  338.979  9  338.983 10  338.984

***********************************   S T E A M   G E N E R A T I O N   L O O P - 1   ***********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.2118   STEAM FLOW =0.3427   INT. SODIUM FLOW =0.0881

AUXILIARY FEED WATER AVAILABLE AT  30.000 SECONDS  ENTHALPY = 1.5580E+05  AUX. WATER FLOW  =1.0000
```

```
P 1 = 1.2150E+07  P 2 = 1.0170E+07  P 3 = 1.0170E+07  P 4 = 1.0324E+07  P 5 = 1.0298E+07  P 6 = 1.0308E+07  P 7 = 1.0329E+07
P 8 = 1.0309E+07  P 9 = 1.0221E+07  P10 = 1.0192E+07  P11 = 1.0181E+07  P12 = 1.0165E+07  P13 = 1.0170E+07  P14 = 1.0178E+07
P15 = 1.0157E+07  P16 = 1.0098E+07  P17 = 1.0046E+07  P18 = 9.9988E+06  P19 = 9.9477E+06  P20 = 9.9303E+06  P21 = 1.0024E+07
H 1 = 1.5580E+05  H 2 = 1.5912E+06  H 3 = 7.0669E+05  H 4 = 1.2352E+06  H 5 = 1.2524E+06  H 6 = 1.3270E+06  H 7 = 1.3094E+06
H 8 = 1.3074E+06  H 9 = 1.4172E+06  H10 = 1.7343E+06  H11 = 1.7663E+06  H12 = 1.8605E+06  H13 = 1.8850E+06  H14 = 2.7211E+06
H15 = 2.7211E+06  H16 = 3.0616E+06  H17 = 2.3675E+06  H18 = 2.0482E+06  H19 = 3.1393E+06  H20 = 3.0682E+06  H21 = 3.3468E+06
TM 1 =   65.1202  TM 2 =  325.6877  TM 3 =  167.2324  TM 4 =  279.3311  TM 5 =  282.4104  TM 6 =  294.6228  TM 7 =  291.9441
TM 8 =  291.6228  TM 9 =  312.5264  TM10 =  312.3181  TM11 =  312.2385  TM12 =  312.1213  TM13 =  312.1589  TM14 =  312.2134
TM15 =  312.0625  TM16 =  389.6421  TM17 =  311.2578  TM18 =  310.9089  TM19 =  412.8604  TM20 =  390.3533  TM21 =  488.8730
TCS 8 =  300.9851  TCS 9 =  316.5251  TCS10 =  426.7002  TCS11 =  418.7754  TCS12 =  411.5305  TCS13 =  405.8931  TCS14 =  402.4536
TCS15 =  401.2153  TCS16 =  449.2756  TCS17 =  473.9255  TCS18 =  487.4421  TCS19 =  496.2573  TCS
                        TDLOG:  9        6.3050 10        32.9155
                        U    :  9     3234.4824 10      6819.5859
           TDLOG: 16        73.4067 17      102.6756 18       169.5059 19       124.1988
           U    : 16      2339.8416 17     2237.3550 18      2423.5547 19      2208.2192

HEAT FLUX = 9.185300E+04                        OUTLET STEAM QUALITY = 2.439135E-01
NON-BOILING LENGTH = 1.034564E+01              BOILING LENGTH = 3.674352E+00

DRUM INT. ENERGY = 1.0252E+10   DRUM LEVEL = 0.5870   CVP = 1.0000   ALFA = 0.0876   DPRP =-1.9152E+06

************************************  S T E A M   G E N E R A T I O N   L O O P - 2  ************************************

FEED WATER FLOW =0.0      WATER/STEAM FLOW =0.2157  STEAM FLOW =0.0630  INT. SODIUM FLOW =0.0954

AUXILIARY FEED WATER AVAILABLE AT  30.000 SECONDS  ENTHALPY = 1.5580E+05  AUX. WATER FLOW  =1.0000
P 1 = 1.2150E+07  P 2 = 1.0163E+07  P 3 = 1.0163E+07  P 4 = 1.0316E+07  P 5 = 1.0289E+07  P 6 = 1.0299E+07  P 7 = 1.0319E+07
P 8 = 1.0300E+07  P 9 = 1.0219E+07  P10 = 1.0185E+07  P11 = 1.0174E+07  P12 = 1.0158E+07  P13 = 1.0163E+07  P14 = 1.0262E+07
P15 = 1.0264E+07  P16 = 1.0266E+07  P17 = 1.0269E+07  P18 = 1.0272E+07  P19 = 1.0275E+07  P20 = 1.0285E+07  P21 = 1.0024E+07
H 1 = 1.5580E+05  H 2 = 1.5960E+06  H 3 = 7.2127E+05  H 4 = 1.2362E+06  H 5 = 1.2532E+06  H 6 = 1.3271E+06  H 7 = 1.3100E+06
H 8 = 1.3080E+06  H 9 = 1.4171E+06  H10 = 1.7888E+06  H11 = 1.7999E+06  H12 = 1.8992E+06  H13 = 1.9252E+06  H14 = 2.7208E+06
H15 = 2.7208E+06  H16 = 2.7716E+06  H17 = 2.5317E+06  H18 = 2.4699E+06  H19 = 2.6142E+06  H20 = 3.1468E+06  H21 = 3.3455E+06
TM 1 =   65.1202  TM 2 =  325.6858  TM 3 =  170.3913  TM 4 =  279.5286  TM 5 =  282.5486  TM 6 =  294.6472  TM 7 =  292.0359
TM 8 =  291.7190  TM 9 =  312.5103  TM10 =  312.2651  TM11 =  312.1875  TM12 =  312.0737  TM13 =  312.1052  TM14 =  312.8191
TM15 =  312.8352  TM16 =  320.1602  TM17 =  312.8716  TM18 =  312.8923  TM19 =  312.9133  TM20 =  417.5703  TM21 =  488.3433
TCS 8 =  302.0085  TCS 9 =  315.8171  TCS10 =  426.4399  TCS11 =  419.8437  TCS12 =  414.0134  TCS13 =  409.3730  TCS14 =  406.2739
TCS15 =  409.8281  TCS16 =  457.8403  TCS17 =  481.4836  TCS18 =  492.0493  TCS19 =  496.2534  TCS
                        TDLOG:  9        6.1514 10        31.3033
                        U    :  9     3267.2185 10      6836.7539
           TDLOG: 16       116.1512 17      152.6239 18       173.8311 19       181.2399
           U    : 16       826.0146 17      785.1709 18       799.9067 19       799.9626

HEAT FLUX = 8.756887E+04                        OUTLET STEAM QUALITY = 2.858016E-01
NON-BOILING LENGTH = 1.062642E+01              BOILING LENGTH = 3.393564E+00

DRUM INT. ENERGY = 1.0102E+10   DRUM LEVEL = 0.5647   CVP = 1.0000   ALFA = 0.0892   DPRP =-1.9878E+06

*****************************  S T E A M   H E A D E R   T H E R M O D Y N A M I C S  *****************************

     THROTTLE VALVE POSITION =0.9985                               DUMP(BYPASS) VALVE POSITION =0.1909
     THROTTLE VALVE FLOW     =0.0      RELIEF VALVE FLOW =0.0      DUMP(BYPASS) VALVE FLOW     =0.1522
     HEADER PRESSURE = 1.0024E+07      TEMPERATURE =  484.0427      SPECIFIC ENTHALPY= 3.3361E+06

*******************************  M E A S U R E D   V A L U E S   F O R   P P S   *******************************

 PRESNORM =  0.31073         VESSEL LEVEL =   4.5623        PTOTNORM =  0.04818
 TIHX1 =  350.512    TIHX2 =  348.473    TEVAP1 =  302.714    TEVAP2 =  303.841
```

```
STEP #   235   TIME =   49.99977 SEC    S =  0.40000 SEC

                                         TOTAL VECTOR OF CONTROL INTEGERS
 11   12   13   14   15   19   20   24   25   26   40   43   46   53   54   55   56   81   82   83   84   84  106  107  108
109  109  232  233  237  238  251  252  253  254  255  256  257  258  259  262  263  264  265  266  267  268  269  291  292
293  294  295  296  297  298  299  302  303  304  305  306  307  308  309  331  332  333  334  335  336  337  338  339  342
343  344  345  346  347  348  349  371  372  373  374  375  376  377  378  379  382  383  384  385  386  387  388  389  411
423  424  425  426  427  432  450  462  463  464  465  466  467  471  480  483  484  485    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  0    0    0    0    0    0    0    0    0    0    0    0    0    0

*************************     N E U T R O N    K I N E T I C S     C A L C U L A T I O N S     *************************

 PTOT =        45.784 MWT     PN =          1.876 MWT      PFP =         43.908 MWT
 PDN :    1     0.007 MWT    2    0.154 MWT     PFP :     3    1.854 MWT    4   13.273 MWT    5   28.781 MWT
 ROTOT =     -23.499786 $     ROCR1 =        2.749999 $      ROCR2 =       -6.299999 $     ROFDBK =      -1.949793 $
 RODOP =      -0.704228 $     ROSOD =       -0.023830 $      ROCRE =       -1.095026 $     ROCAE  =      -0.126709 $
 TRO    =    470.267            TROM  =     470.132             TSTM  =     487.224
 PD =           0.9000        ETST  =     -11.749756          ETRO  =       29.025635    EF =     -0.050000    DELRO =      -0.000333
 PTOTNORM =     0.0470        PNNORM =       0.0019          PFPNORM =      0.0450      SCRAM RODS:   PRIM = 100.000 %    SEC = 100.000 %

********************************     P R I M A R Y     C O O L A N T     D Y N A M I C S     ********************************

 FZ1NRM = 0.0895                               FZ2NRM = 0.0894  FZ3NRM = 0.0867  CANRM = 0.0577   RBNRM = 0.0700   BPNRM = 0.0972
 FLOWS: 1    1.4974E+02    2   1.5079E+02    3    1.6846E+02    4   1.2089E+01    5   4.6922E+00    6   5.2217E+01    7   2.1108E+01
 AL1=    0.0915   NEW1=    0.0860   BP1=   0.0089   TMOTN1=    0.0228   HP1=    0.0092   FREQ1= 3359.493
 AL2=    0.0916   NEW2=    0.0866   BP2=   0.0088   TMOTN2=    0.0228   HP2=    0.0091   FREQ2= 3359.767
 PD =    0.9000   TRISP =  387.779   NEWSP =   0.9000   ASP =    0.9000   XKW = 1.316E-03   EPS = 1.000E-03   N =  1
 TRIM:     374.171     373.625       NEWM:       0.0860       0.0866      ALM:         0.0915        0.0916       INLET PRSNRM = 0.3107
 ET:      2.4495E+01      2.5477E+01       EW:        8.4621E-01       8.4689E-01       EA:         1.0085E+00      1.0084E+00

********************************     R E A C T O R     H E A T     T R A N S F E R     ********************************

   CORE HOT SPOT:         MAX. COOLANT TEMP. =    550.201         MAX. CLAD TEMP. =    552.440
 PEAK CORE AVERAGE TEMPERATURE OF:   FUEL CENTERLINE =     517.963    CLAD INNER =     436.925    CLAD OUTER =     436.752
 TM 1 =     383.992    TM 2 =     502.583    TM 3 =     492.410    TM 4 =     382.854    TM 5 =     482.229    TM 6 =     476.076
 TM 7 =     382.783    TM 8 =     467.243    TM 9 =     463.162    TM10 =     413.921    TM11 =     437.798    TM
 TC 1 =     382.143    TC 2 =     490.197    TC 3 =     491.693    TC 4 =     381.538    TC 5 =     474.330    TC 6 =     475.569
 TC 7 =     381.507    TC 8 =     461.489    TC 9 =     462.670    TC10 =     438.493    TC11 =     474.226    TC12 =     379.365
 TCI1 =     379.077    TCI2 =     379.077    TCI3 =     379.077    TCI4 =     379.077    TCI5 =     379.077    TCI6 =     379.077
 LOWER PLENUM:                          TOP ZONE TEMP. =    379.077    BOTTOM ZONE TEMP. =    378.662
 UPPER PLENUM:  ZJET =      6.400    TOP ZONE TEMP. =     515.722    BOTTOM ZONE TEMP. =     515.722    NOZZLE TEMP. =     515.722

************************     I H X - 1     T H E R M A L     C A L C U L A T I O N S     ************************

 TP:  1  525.976   2  497.611   3  474.618   4  454.005   5  433.584   6  412.534   7  390.218   8  366.781   9  343.315  10  525.973
11  349.542
```

```
TS:  1  520.201  2  492.907  3  470.654  4  450.180  5  429.703  6  408.477  7  385.875  8  362.354  9  338.934 10  512.141

************************     I H X - 2     T H E R M A L     C A L C U L A T I O N S     ************************

TP:  1  525.976  2  485.354  3  459.536  4  438.148  5  417.662  6  396.924  7  375.885  8  356.423  9  341.347 10  525.973
11  347.571
TS:  1  516.278  2  479.544  3  455.168  4  434.088  5  413.627  6  392.774  7  371.845  8  353.102  9  338.984 10  509.448

**************     P R I M A R Y     S O D I U M     T R A N S P O R T     C A L C U L A T I O N S     **************

TC1:  1  518.168  2  520.609  3  522.843  4  524.649  5  525.914  6  526.642  7  526.931  8  526.923  9  526.760 10  526.548
TW1:  1  523.700  2  524.730  3  525.522  4  526.051  5  526.339  6  526.439  7  526.416  8  526.330  9  526.231 10  526.141
TC2:  1  526.462  2  526.379  3  526.303  4  526.235  5  526.176  6  526.126  7  526.086  8  526.053  9  526.028 10  526.009
TW2:  1  526.115  2  526.084  3  526.059  4  526.037  5  526.019  6  526.005  7  525.995  8  525.986  9  525.981 10  525.978
TC3:  1  351.635  2  354.183  3  356.918  4  359.664  5  362.333  6  364.884  7  367.286  8  369.508  9  371.518 10  373.287
TW3:  1  365.664  2  367.397  3  369.077  4  370.663  5  372.133  6  373.475  7  374.675  8  375.724  9  376.617 10  377.356
TC4:  1  518.168  2  520.609  3  522.843  4  524.649  5  525.914  6  526.642  7  526.931  8  526.923  9  526.760 10  526.548
TW4:  1  523.698  2  524.729  3  525.521  4  526.051  5  526.339  6  526.439  7  526.416  8  526.331  9  526.231 10  526.141
TC5:  1  526.461  2  526.379  3  526.303  4  526.235  5  526.176  6  526.126  7  526.086  8  526.053  9  526.028 10  526.009
TW5:  1  526.115  2  526.085  3  526.059  4  526.037  5  526.019  6  526.005  7  525.995  8  525.986  9  525.981 10  525.978
TC6:  1  349.623  2  352.134  3  354.879  4  357.709  5  360.539  6  363.308  7  365.957  8  368.428  9  370.669 10  372.641
TW6:  1  364.434  2  366.239  3  368.020  4  369.732  5  371.343  6  372.827  7  374.160  8  375.328  9  376.320 10  377.141

************************ I N T E R M E D I A T E   L O O P - 1:   C O O L A N T   D Y N A M I C S ************************

 SODIUM FLOW RATE =  0.0871   PUMP SPEED =  0.0919   PUMP HEAD =  0.0091   MOTOR GEN. SET FREQ. =   345.980 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.9170   DRIVE MOTOR TORQUE =  0.0226   PUMP TORQUE =  0.0089   FRICTION TORQUE =  0.0141

************************ I N T E R M E D I A T E   L O O P - 2:   C O O L A N T   D Y N A M I C S ************************

 SODIUM FLOW RATE =  0.0935   PUMP SPEED =  0.0926   PUMP HEAD =  0.0085   MOTOR GEN. SET FREQ. =   343.343 CYCLES/SEC
 MAIN MOTOR TORQUE =  0.9172   DRIVE MOTOR TORQUE =  0.0220   PUMP TORQUE =  0.0085   FRICTION TORQUE =  0.0141

*******************     I N T E R M E D I A T E     L O O P - 1:   S O D I U M   T R A N S P O R T     *******************

TCS1:  1  507.831  2  504.187  3  501.322  4  499.254  5  497.893  6  497.076  7  496.630  8  496.406  9  496.302 10  496.260
TWS1:  1  502.234  2  500.176  3  498.652  4  497.611  5  496.962  6  496.590  7  496.395  8  496.301  9  496.261 10  496.246
TCS2:  1  308.487
TWS2:  1  323.991
TCS3:  1  317.497  2  325.095
TWS3:  1  328.749  2  332.717
TCS4:  1  328.203  2  330.878  3  333.091  4  334.845  5  336.177  6  337.146  7  337.823  8  338.277  9  338.569 10  338.750
TWS4:  1  335.011  2  336.130  3  337.000  4  337.650  5  338.117  6  338.439  7  338.653  8  338.790  9  338.875 10  338.925

*******************     I N T E R M E D I A T E     L O O P - 2:   S O D I U M   T R A N S P O R T     *******************

TCS1:  1  504.484  2  500.873  3  498.561  4  497.280  5  496.659  6  496.393  7  496.292  8  496.259  9  496.253 10  496.253
TWS1:  1  500.941  2  498.797  3  497.485  4  496.784  5  496.455  6  496.318  7  496.268  8  496.254  9  496.253 10  496.253
TCS2:  1  308.994
TWS2:  1  324.817
TCS3:  1  317.638  2  325.121
TWS3:  1  329.298  2  333.083
TCS4:  1  330.211  2  333.869  3  336.239  4  337.631  5  338.374  6  338.735  7  338.893  8  338.955  9  338.976 10  338.981
TWS4:  1  335.611  2  337.125  3  338.038  4  338.541  5  338.795  6  338.912  7  338.960  8  338.977  9  338.982 10  338.983

***********************************   S T E A M   G E N E R A T I O N   L O O P - 1   ***********************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.2118  STEAM FLOW =0.1193  INT. SODIUM FLOW =0.0871

AUXILIARY FEED WATER AVAILABLE AT  30.000 SECONDS  ENTHALPY = 1.5580E+05  AUX. WATER FLOW  =1.0000
```

```
P 1 = 1.2150E+07  P 2 = 1.0158E+07  P 3 = 1.0158E+07  P 4 = 1.0312E+07  P 5 = 1.0285E+07  P 6 = 1.0296E+07  P 7 = 1.0316E+07
P 8 = 1.0296E+07  P 9 = 1.0211E+07  P10 = 1.0180E+07  P11 = 1.0169E+07  P12 = 1.0153E+07  P13 = 1.0158E+07  P14 = 1.0217E+07
P15 = 1.0216E+07  P16 = 1.0210E+07  P17 = 1.0205E+07  P18 = 1.0201E+07  P19 = 1.0197E+07  P20 = 1.0200E+07  P21 = 9.9733E+06
H 1 = 1.5580E+05  H 2 = 1.5895E+06  H 3 = 7.0681E+05  H 4 = 1.2200E+06  H 5 = 1.2369E+06  H 6 = 1.3161E+06  H 7 = 1.3098E+06
H 8 = 1.3083E+06  H 9 = 1.4168E+06  H10 = 1.7422E+06  H11 = 1.7608E+06  H12 = 1.8427E+06  H13 = 1.8654E+06  H14 = 2.7213E+06
H15 = 2.7213E+06  H16 = 3.0142E+06  H17 = 2.7709E+06  H18 = 3.0550E+06  H19 = 3.2960E+06  H20 = 2.8021E+06  H21 = 3.3129E+06
TM 1 =   65.1202  TM 2 =  325.6875  TM 3 =  167.2605  TM 4 =  276.5630  TM 5 =  279.6406  TM 6 =  292.9790  TM 7 =  291.9954
TM 8 =  291.7598  TM 9 =  312.4521  TM10 =  312.2324  TM11 =  312.1519  TM12 =  312.0332  TM13 =  312.0713  TM14 =  312.5012
TM15 =  312.4895  TM16 =  376.8252  TM17 =  319.3660  TM18 =  388.4749  TM19 =  469.8481  TM20 =  325.4795  TM21 =  475.2266
TCS 8 =  300.4263  TCS 9 =  316.1646  TCS10 =  425.5032  TCS11 =  417.6943  TCS12 =  410.7012  TCS13 =  405.3877  TCS14 =  402.2244
TCS15 =  402.6633  TCS16 =  444.1516  TCS17 =  461.8416  TCS18 =  478.0393  TCS19 =  496.2598  TCS
                         TDLOG:  9        5.8436 10        32.0524
                         U    :  9     3234.4768 10      6806.2969
          TDLOG: 16       78.1948 17       100.2499 18       113.9805 19        51.7157
          U    : 16     1201.5811 17      1122.3337 18      1113.1074 19       971.8298

HEAT FLUX = 8.927019E+04                        OUTLET STEAM QUALITY = 2.501656E-01
NON-BOILING LENGTH = 1.103090E+01              BOILING LENGTH = 2.989091E+00

DRUM INT. ENERGY = 1.0280E+10   DRUM LEVEL = 0.5921   CVP = 1.0000   ALFA = 0.0849   DPRP =-2.0306E+06

************************************  S T E A M   G E N E R A T I O N   L O O P - 2  ************************************

FEED WATER FLOW =0.0     WATER/STEAM FLOW =0.2134  STEAM FLOW =0.3010  INT. SODIUM FLOW =0.0935

AUXILIARY FEED WATER AVAILABLE AT  30.000 SECONDS  ENTHALPY = 1.5580E+05  AUX. WATER FLOW  =1.0000
P 1 = 1.2150E+07  P 2 = 1.0241E+07  P 3 = 1.0241E+07  P 4 = 1.0395E+07  P 5 = 1.0368E+07  P 6 = 1.0378E+07  P 7 = 1.0399E+07
P 8 = 1.0379E+07  P 9 = 1.0295E+07  P10 = 1.0263E+07  P11 = 1.0252E+07  P12 = 1.0236E+07  P13 = 1.0241E+07  P14 = 1.0251E+07
P15 = 1.0235E+07  P16 = 1.0188E+07  P17 = 1.0144E+07  P18 = 1.0108E+07  P19 = 1.0062E+07  P20 = 1.0051E+07  P21 = 9.9733E+06
H 1 = 1.5580E+05  H 2 = 1.5984E+06  H 3 = 7.1290E+05  H 4 = 1.2212E+06  H 5 = 1.2378E+06  H 6 = 1.3163E+06  H 7 = 1.3104E+06
H 8 = 1.3089E+06  H 9 = 1.4204E+06  H10 = 1.7564E+06  H11 = 1.7831E+06  H12 = 1.8784E+06  H13 = 1.9030E+06  H14 = 2.7209E+06
H15 = 2.7209E+06  H16 = 3.1002E+06  H17 = 2.3120E+06  H18 = 4.1245E+06  H19 = 9.4915E+05  H20 = 3.3734E+06  H21 = 3.3356E+06
TM 1 =   65.1202  TM 2 =  325.6855  TM 3 =  168.5625  TM 4 =  276.7749  TM 5 =  279.8042  TM 6 =  293.0061  TM 7 =  292.0867
TM 8 =  291.8562  TM 9 =  313.0583  TM10 =  312.8318  TM11 =  312.7527  TM12 =  312.6375  TM13 =  312.6721  TM14 =  312.7446
TM15 =  312.6270  TM16 =  402.0422  TM17 =  311.9702  TM18 =  909.2000  TM19 =  311.3713  TM20 =  499.8030  TM21 =  484.1477
TCS 8 =  301.4336  TCS 9 =  316.5256  TCS10 =  425.3689  TCS11 =  418.9058  TCS12 =  413.2786  TCS13 =  408.9524  TCS14 =  406.9539
TCS15 =  412.2534  TCS16 =  456.0601  TCS17 =  476.7327  TCS18 =  488.9958  TCS19 =  496.2532  TCS
                         TDLOG:  9        6.0138 10        31.3431
                         U    :  9     3250.9961 10      6812.8906
          TDLOG: 16       74.5101 17        99.3055 18         0.0    19         0.0
          U    : 16     2161.4758 17      2066.2688 18      2083.7502 19      2077.9666

HEAT FLUX = 8.737419E+04                        OUTLET STEAM QUALITY = 2.593098E-01
NON-BOILING LENGTH = 1.104369E+01              BOILING LENGTH = 2.976296E+00

DRUM INT. ENERGY = 1.0185E+10   DRUM LEVEL = 0.5716   CVP = 1.0000   ALFA = 0.0865   DPRP =-2.0230E+06

******************************  S T E A M   H E A D E R   T H E R M O D Y N A M I C S  ******************************

     THROTTLE VALVE POSITION =1.0000                              DUMP(BYPASS) VALVE POSITION =0.1791
     THROTTLE VALVE FLOW     =0.0      RELIEF VALVE FLOW =0.0     DUMP(BYPASS) VALVE FLOW     =0.1424
     HEADER PRESSURE = 9.9733E+06       TEMPERATURE =  485.4158     SPECIFIC ENTHALPY= 3.3385E+06

*******************************  M E A S U R E D   V A L U E S   F O R   P P S  *******************************

 PRESNORM =  0.31072         VESSEL LEVEL =   4.5623         PTOTNORM =  0.04734
 TIHX1 =  350.217    TIHX2 =  348.199    TEVAP1 =  302.043    TEVAP2 =  303.134
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