MASTER

**ORTAP: A Nuclear Steam Supply
System Simulation for the Dynamic
Analysis of High Temperature Gas
Cooled Reactor Transients**

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FOR THE DYNAMIC ANALYSIS OF HIGH TEMPERATURE
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ABSTRACT

ORTAP was developed to predict the dynamic behavior of the high temperature gas cooled reactor (HTGR) Nuclear Steam Supply System for normal operational transients and postulated accident conditions. It was developed for the Nuclear Regulatory Commission (NRC) as an independent means of obtaining conservative predictions of the transient response of HTGRs over a wide range of conditions. The approach has been to build sufficient detail into the component models so that the coupling between the primary and secondary systems can be accurately represented and so that transients which cover a wide range of conditions can be simulated.

System components which are modeled in ORTAP include the reactor core, a typical reheater and steam generator module, a typical helium circulator and circulator turbine and the turbine generator plant. The major plant control systems are also modeled.

Normal operational transients which can be analyzed with ORTAP include reactor start-up and shutdown, normal and rapid load changes. Upset transients which can be analyzed with ORTAP include reactor trip, turbine trip and sudden reduction in feedwater flow. ORTAP has also been used to predict plant response to emergency or faulted conditions such as primary system depressurization, loss of primary coolant flow and uncontrolled removal of control poison from the reactor core.

ORTAP predictions will be compared with dynamic test results obtained from the Fort St. Vrain reactor owned by Public Service of Colorado, and based on these comparisons, appropriate improvements will be made in the code.

NOMENCLATURE

A	- area; or flow constant in ideal gas flow equation
β_i	- delayed neutron fraction for group i
β_T	- total delayed neutron fraction
c_p	- specific heat of solid
$c_{p,He}$	- specific heat of helium
C	- heat conductance
C_i	- delayed neutron precursor concentration for group i
D_H	- hydraulic diameter
f_{Re}	- friction factor
g	- acceleration of gravity
g_c	- gravitational conversion constant
γ	- ratio of specific heat at constant pressure to specific heat at constant volume
h	- specific enthalpy
H	- enthalpy
k	- neutron multiplication factor in neutron kinetics equations; conductivity in heat transfer equation
ℓ	- average neutron lifetime from release to loss
λ_i	- delayed neutron decay constant for group i
L	- nodal flow length
M	- mass
n	- neutron density
η	- efficiency
P	- pressure
ΔP	- pressure difference
Q	- heat generation rate density

x

ρ - density

s - entropy

t - time

Δt - time increment

T - temperature

τ - hold up time

τ_c - time constant

U - internal energy; or overall heat transfer coefficient

v - specific volume

V - volume

W - mass flow

ΔZ - segment length

1. INTRODUCTION

ORTAP was developed as an independent method of predicting the dynamic response of the HTGR nuclear steam supply system to a wide range of conditions. The General Atomic Company uses the proprietary TAP¹ code to predict HTGR transient response. ORTAP contains coupled component simulations of the core (CORTAP,² ORECA³); the reheater and steam generator (BLAST⁴); the helium circulator and circulator turbine; the high, intermediate, and low pressure turbines; the feedwater heaters; the turbine bypass system; desuperheater and flash tank.⁵ The major plant control systems are also modeled.⁶

The core is normally simulated by a single-channel model (CORTAP) which couples the heat transfer equations for the fuel, the graphite moderator and the helium coolant with the neutron kinetics equations. The core model includes nonlinear effects introduced by temperature dependent fuel, moderator and coolant properties. An alternate core model (ORECA) is used for transients involving low-power and flow cases for which a single-channel model is inadequate. This model includes three-dimensional temperature distribution calculations, accounts for the varying flow distribution among the individual refueling regions and accommodates flow reversals.

The reheater and steam generator are simulated with the multi-node, fixed boundary homogeneous flow model (BLAST). The time dependent conservation of energy, mass and momentum equations for both the helium side and the water/steam side are solved by an implicit integration technique. Transients involving both start-up and flood-out of the steam generator can be simulated.

A detailed model of the turbine generator plant is necessary in order to accurately predict primary system component response because of the close coupling between the primary system and the secondary system. These systems are coupled by heat-transfer in the reheater and steam generator. Also, the exhaust steam from the high pressure turbine drives the helium circulator turbine before entering the reheater. Additional coupling is introduced by the plant control loops. The turbine generator model determines pressures, enthalpies and flows at several points, including extraction and exhaust lines in the high, intermediate, and low pressure turbines. The dynamic response of each feedwater heater and the deaerator is explicitly treated in the model.

As has been indicated above, the circulator turbine is a critical link between the steam and helium systems in an HTGR. This is especially true during emergency shutdown and accident transients in which the ever-dwindling nuclear steam production provides the power to circulate the primary coolant for afterheat removal. The circulator-turbine model includes calculations of the steam side turbine pressures, flows and enthalpies and the helium circulator side pressure rise, flow and temperature rise. The turbine speed and pressure ratio controls are included.

Following turbine trip, steam to drive the circulator-turbine is provided by the main steam bypass system which includes a desuperheater and a flash tank. The dynamic response of these components is included in ORTAP.

This report contains a description of the HTGR nuclear steam supply (NSS) system and the modeling techniques used in the system simulation. The version of ORTAP described here is for the Fort St. Vrain plant. ORTAP can be used to simulate other HTGRs with changes in input and minor programming modifications. A sample transient, input instructions and a sample input listing are included. A deck and listing of the code are available upon request.

2. DESCRIPTION OF THE HTGR NUCLEAR STEAM SUPPLY SYSTEM

The Fort St. Vrain (FSV) nuclear steam supply system flow diagram is shown in Fig. 2.1. More detailed diagrams of the core, the reheater-steam generator module and the helium circulator are given in Figs. 2.2 through 2.6. There are two primary coolant loops in the FSV plant. Each primary coolant loop contains six identical reheater-steam generator modules acting in parallel and two helium circulators, also acting in parallel. The core, reheater-steam generator modules, and the helium circulators are contained in the prestressed concrete reactor vessel (PCRV). Helium coolant at ~ 4.83 MPa (700 psi) flows downward in the core through coolant channels in the graphite moderator exiting the core at $\sim 777^{\circ}\text{C}$ (1430°F). The hot helium then flows downward through ducts and across helically coiled tubes in the reheater-steam generator modules decreasing the helium temperature to $\sim 404^{\circ}\text{C}$ (760°F). Except for the superheater II section of the main steam generator (Fig. 2.5), the reheater and steam generators are counterflow heat exchangers with the water/steam flowing in the upward direction. After exiting from the economizer end of the steam generator, the helium passes

Fig. 2.1. Flow diagram of the Fort St. Vrain Reactor.

ORNL-DWG 71-10131R

Fig. 2.2. Core element arrangement for the Fort St. Vrain Reactor.

Fig. 2.3. Nuclear steam supply system component arrangement.

Fig. 2.5. Steam generator schematic.

ORNL-DWG 76-19519

Fig. 2.6. Fort St. Vrain helium circulator.

through a plenum to the helium circulator (Fig. 2.6) and then returns to the upper core plenum.

The feedwater flows upward through the helically coiled tubes in the economizer-evaporator-superheater I sections of the steam generator and then flows downward through the superheater II section. The main steam condition at the stop valves of the turbine generator unit is $\sim 538^{\circ}\text{C}$ (1000°F) and 16.55 MPa (2400 psi). As can be seen in Fig. 2.1, the main steam first drives the high pressure turbine and then the helium circulator turbine. After passing through the circulator turbine, the steam is reheated to $\sim 538^{\circ}\text{C}$ (1000°F) at 6.14 MPa (890 psi). It then drives the intermediate and low pressure turbines (Fig. 2.1) before passing to the condenser. There are various extraction points (not shown in Fig. 2.1) from the intermediate and low pressure turbines which supply steam to the shell sides of the feedwater heaters, two turbine driven boiler feedpumps and the deaerator.

The steam generators are also used for decay heat removal following reactor shutdown. At these conditions the evaporator and superheater flood, and the superheater discharges heated water to a flash tank.

The main steam bypass system operates whenever the pressure in the steam line to the high pressure turbine exceeds preset limits, (e.g., after a turbine trip). For pressures above 17.68 MPa (2564 psia), the main steam is diverted through a desuperheater to a flash tank, and the steam from the flash tank is then used to drive the circulator turbines. Flow through the desuperheater is limited (due to a limited supply of desuperheating water), so any excess steam is discharged to the atmosphere whenever the line pressure exceeds 19.06 MPa (2764 psia). After

a turbine trip, the reheat steam is also bypassed, via a desuperheater, to the main condenser.

3. COMPONENT SIMULATION

3.1 Core Models

The Fort St. Vrain reactor core is shown in Figs. 2.2 and 2.3. A detailed description of the HTGR fuel element is given in Figs. 3.1.1 and 3.1.2. The FSV core design is quite similar to the large HTGR core design. Each hexagonal element (Fig. 3.1.1) is ~35.6 cm (14 in.) across the flats and ~78.7 cm (31 in.) high. These blocks consist of fuel sticks which contain bonded coated fuel particles, graphite moderator, and coolant channels. During reactor operation helium flows downward through the channels. A stack of six layers of fuel elements with seven hexagonal fuel elements in each layer is referred to as a refueling region. The central hexagonal element in each layer is a control rod element (Fig. 3.1.2) which contains two control rod channels and a channel for the reserve shutdown spheres. Reflector elements are located both above and below each active fuel column as well as around the circumference of the active core. The core is supported on support blocks (Fig. 3.1.3) which rest on core support posts located in the lower core plenum.

The reference core model which is used in ORTAP is CORTAP,² a coupled neutron kinetics-heat transfer core simulation. The reader is referred to Ref. 2 for the details of the modeling techniques used in CORTAP. The core inlet flow rate and temperature are required as inputs. CORTAP determines the dynamic response of the core by coupling

Fig. 3.1.1. Typical HTGR fuel element.

ORNL-DWG 74-10133R

Fig. 3.1.2. HTGR fuel element, showing holes for control rods.

Fig. 3.1.3. Lower plenum arrangement.

the space independent neutron kinetics equations,

$$\frac{dC_i}{dt} = -\lambda_i C_i + \frac{\beta_i}{\ell} \beta_i, \quad i = 1, \dots, 6, \quad (3.1)$$

and

$$\frac{dn}{dt} = \frac{n}{\ell} [k(1 - \beta_T) - 1] + \sum_{i=1}^6 \lambda_i C_i, \quad (3.2)$$

with the equation for heat transfer in the fuel and graphite,

$$\nabla \cdot (k \nabla T) + Q = \frac{\partial}{\partial t} (\rho c_p T), \quad (3.3)$$

and the equation for heat transfer to the coolant,

$$W_{c,p,He} \frac{dT_{gas}}{dz} = \frac{C}{\Delta Z} (T_{wall} - T_{gas}), \quad (3.4)$$

for an average power region of the reactor core. These equations are solved by the matrix exponential technique as described in Ref. 7. CORTAP also has the capability to determine conservative values of fuel, moderator and coolant temperatures in the highest power fuel region by using time-dependent core power, flow, and inlet temperature calculated by ORTAP as forcing functions.

For transients involving a reactor trip, the core heat generation rate is determined from an expression for decay heat following a scram. Nonlinear effects introduced by temperature dependent fuel, moderator and coolant properties are included in the model. CORTAP also models the heat transfer in the side reflector and in the core support blocks

and combines outlet gas temperatures from the reflector and the support blocks to obtain a mixed mean core outlet gas temperature.

For transients involving low core coolant flow rates, the single-channel model used in CORTAP may no longer be adequate, since the distribution of flow between regions can change markedly. There are even instances in which the buoyancy forces cause reverse (upward) flow in some channels. For low-flow regimes, then, the ORECA³ core model is substituted for the CORTAP model. For details of the ORECA code, the reader is referred to ref. 3. Like CORTAP, ORECA also requires total flow and upper plenum coolant inlet temperature vs time as inputs. In addition, core power is an input function since reactivity feedback effects are not considered in ORECA.

The major features of the ORECA core model for FSV are as follows:

1. Each of the 37 refueling regions and 18 side reflector blocks is represented by eight axial nodes (a total of 440 nodes for the core simulation). Of each group of eight axial nodes, six represent the active core, one the top reflector, and one the bottom reflector and core support blocks.
2. Coolant heat transfer coefficients include the effects of changing flow regimes (turbulent-transition-laminar) and of helium conductivity and viscosity variations with temperature.
3. Input values of axial and radial power peaking factors are assumed constant throughout the run.
4. The flow calculated for each channel is dependent on friction losses, acceleration losses, buoyancy effects, entrance/exit losses, and orifice pressure drops. Friction losses are dependent on the flow regime.

5. Channel flows are calculated at each time step by an iterative scheme that determines the overall core pressure drop which will produce the input total flow rate. Reverse channel flows are also accommodated.
6. Composite core and graphite reflector conductivities and specific heats are calculated as functions of temperature.

3.2 Reheater-Steam Generator Model

Each of the 12 identical steam generator modules in the Fort St. Vrain plant is composed of a reheater and a main steam bundle as shown schematically in Fig. 2.5. The once through heat exchanger bundles consist of multistart coils wound in a helical arrangement. The water/steam flow is through the helically coiled tubes over which the helium gas flows.

The reheater-steam generator model which is used in ORTAP is BLAST,⁴ a multi-node, fixed boundary, homogeneous flow, single average tube model. The reader is referred to ref. 4 for details of the modeling techniques used in BLAST. On the helium side, BLAST requires as input the inlet helium flow and enthalpy to the reheater section and the helium pressure at the outlet of the steam generator module. On the water/steam side the code requires as input the inlet flow and enthalpy and outlet pressure for both the reheater and the main steam bundle.

BLAST solves the nodal form of the time dependent conservation of energy, mass and momentum equations on both the helium and the water/steam sides:

Conservation of energy:

$$\frac{dU}{dt} = h_{in} W_{in} - h_{out} W_{out} + C(T_{tube} - T_{fluid}) , \quad (3.5)$$

Conservation of mass:

$$\frac{dM}{dt} = W_{in} - W_{out} , \quad (3.6)$$

Conservation of momentum:

$$L \frac{dW}{dt} = 144 g_c A(\Delta P) - \rho g A(\Delta Z) + \left(\frac{W_{in}^2}{\rho_{in} A_{in}} - \frac{W_{out}^2}{\rho_{out} A_{out}} \right) - f_{Re} \left(\frac{12 L |W| W}{D_H 2 \rho A} \right) . \quad (3.7)$$

BLAST contains friction factor correlations for both helium and water and correlations for heat transfer on the helium side and for the various two phase flow regimes on the water/steam side. The solution of Eqs. (3.5), (3.6), and (3.7) is obtained by an implicit integration technique and yields helium and water temperature, pressure, flow rate and tube wall and bulk temperatures at various points in a reheater-steam generator module during steady-state or transient conditions.

BLAST is not limited to a specific HTGR steam generator design and can be used to simulate different designs with appropriate input description. The number of nodes used to simulate a specific steam generator can be varied depending on the detail desired. Since a more detailed nodal structure is often desirable on the water side than on the helium side, the code allows for more than one tube metal node to receive heat from a given helium node. BLAST has been used in

an ERDA program to calculate pressures and tube temperature gradients in sufficient detail for input to stress analyses for transients resulting from a reactor start-up from refueling status and a postulated rapid depressurization accident.

Figure 3.2.1 shows the BLAST nodal description used in ORTAP to simulate a PSV reheater-steam generator module. As can be seen, the water/steam side of the evaporator is represented in more detail than other portions of the module. This is done because of the large variation in the heat transfer coefficient, which occurs as the flow regime of the two phase water/steam flow changes from nucleate boiling to film boiling.

3.3 Turbine Generator Plant Model

A diagram of the Fort St. Vrain turbine generator plant is shown in Fig. 3.3.1. The components which are simulated by the turbine generator plant model are the high, intermediate, and low pressure turbines, the feedwater pump turbine, the high and low pressure feedwater heaters, the deaerator and several steam lines. The helium circulator, circulator turbine and the circulator turbine bypass are simulated in a separate model. There is also a model of the high pressure turbine bypass system, the desuperheater and the flash tank which is used in ORTAP following a turbine trip. It is assumed that the feedwater pump provides the feedwater flow requested by the feedwater flow control system with a specified lag so the feed pump itself is not modeled. The condensate flow in the low pressure feedwater heaters is controlled to maintain a constant deaerator level.

Fig. 3.2.1. Nodal arrangement for BLAST simulation of FSV steam generator.

Fig. 3.3.1. Fort St. Vrain Reactor turbine-generator plant flow diagram.

The turbine generator plant simulation is a modification of that presented in Ref. 8. The technique used is to isolate each component from the others during a calculational time step. The mass and heat flow rates between components remain constant during a time step and are updated after each time step.

In order to establish initial conditions, the simulation requires the following steady-state information as input:

1. mass flow rate in each turbine inlet, extraction and exhaust line;
2. pressure and enthalpy at each number turbine location in Fig. 3.3.1;
3. pressure and enthalpy in each steam holdup line;
4. pressure at the end of each extraction and exhaust line;
5. drain coolant flow from each feedwater heater and feedwater flow through each feedwater heater;
6. temperature of feedwater entering and leaving each feedwater heater; temperature of liquid leaving drain cooler and vapor pressure in each feedwater heater shell;
7. one set for each feedwater heater:
 - a. holdup time of feedwater in drain cooler section,
 - b. drain cooler holdup time,
 - c. holdup time of feedwater in evaporator section, and
 - d. steam holdup time;
8. holdup time of each steam line; and
9. time dependent electrical demand.

The procedures used in simulating the high, intermediate, and low pressure turbines (and feedpump turbine) are essentially the same. It is assumed that the rotor speed remains unchanged, in which case the

turbine steam conditions respond very swiftly to perturbations in inlet variables. It is assumed that this reaction time is short compared with the computational time step (usually from 0.1 to 0.5 sec) so that the turbine is always essentially in steady-state.

At $t = 0$, the following calculations are performed based on the initial steady-state input information:

1. Calculate flow constants (A's) for each turbine stage, each inlet line, extraction line, and exhaust line from the ideal gas flow equation:

$$W = A \left\{ \frac{\gamma}{\gamma - 1} \left(\frac{P_1}{v_1} \right) \left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{\gamma}} - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma+1}{\gamma}} \right] \right\}^{\frac{1}{2}}, \quad (3.8)$$

where the subscript 1 refers to upstream values, and 2 refers to downstream values.

2. Calculate efficiency η of each turbine stage from input information by the following technique:

$$s = s(P_{in}, h_{in}), \quad (3.9)$$

$$h_{s,out} = h(s, P_{out}), \quad (3.10)$$

then

$$\eta = \frac{h_{in} - h_{out}}{h_{in} - h_{s,out}}, \quad (3.11)$$

where

$h \equiv$ enthalpy, (Btu/lbm),

$h_{s,out} \equiv$ enthalpy for isentropic expansion to P_{out} , (Btu/lbm),

$s \equiv$ entropy, (Btu/lbm-°F),

$P \equiv$ pressure, (psia).

ORTAP assumes that the efficiency of each turbine stage is constant during transients.

For $t > 0$, the flow through the high pressure turbine throttle valve is controlled to produce the required electrical power, which may vary with time according to input information. The following calculations are performed for the intermediate and low pressure turbines at each time step.

1. From values of P (steam line 3) and pressures at end of extraction and exhaust lines, the simulator iterates to solve a pressure-flow balance over each section of the turbine using the ideal gas flow equation (3.8). P (steam line 3) and the pressures at the end of extraction and exhaust lines are assumed constant during the time step and updated at the end of the time step.
2. Following calculation of the pressure at the end of each section in the intermediate and low pressure turbines (Fig. 3.3.1), the steam expansion calculation provides the enthalpy at the end of each section using the following technique:

$$h_1 = h(\text{steam line 3}) ,$$

$$h_{i+1} = h_1 - \eta_{i,i+1}(h_1 - h_{s,i+1}) , \quad (3.12)$$

where

$\eta_{i,i+1} \equiv$ the efficiency of the section between points i and $i+1$,

$h_{s,i+1} \equiv$ the enthalpy for an isentropic expansion to P_{i+1} and is obtained from

$$s = s(P_i, h_i) , \quad (3.13)$$

$$h_{s,i+1} = h(P_{i+1}, s) . \quad (3.14)$$

This calculated enthalpy is then used to determine the specific volume. Following convergence of the flow-pressure balance calculations, the power generated by the intermediate and low pressure turbine is then calculated from $P = \Sigma W \Delta h$ over each section. The electrical output, P_e , is determined by $P_e = P \eta_s$, where η_s is the assumed value of the generator shaft efficiency.

3. Next, a pressure-flow iteration is performed for the high pressure turbine, given the pressures in steam lines 1 and 2, and the electrical output from the high pressure turbine is determined. If the total electrical output from the high, intermediate, and low pressure turbines differs from the required electrical demand at time t the flow constant of the valve upstream of the high pressure turbine is changed. The high pressure turbine calculations are repeated until the power production and the electrical demand converge.

Steps 1, 2, and 3 above are repeated for each time step.

Steam lines 1, 2, 3, and 4 (Fig. 3.3.1) are modeled as "mixing tanks." From input values of steam line flow rate, enthalpy, pressure and holdup time, the following quantities are calculated at $t = 0$:

$$M = W \cdot \tau$$

$$H = M \cdot h$$

$$T = T(P, h)$$

$$v = v(T, P)$$

$$V = Mv, \quad (3.16)$$

where

$M \equiv$ mass of steam in line (lbm),

$H \equiv$ enthalpy (Btu),

$h \equiv$ specific enthalpy (Btu/lbm),

$v \equiv$ specific volume (ft^3/lbm),

$V \equiv$ steam line volume (ft^3).

For $t > 0$, the mass and enthalpy in each steam line is determined from

$$M(t + \Delta t) = M(t) + (\Sigma W_{in} - \Sigma W_{out}) \Delta t, \quad (3.17)$$

$$H(t + \Delta t) = H(t) + (\Sigma W_{in} h_{in} - \Sigma W_{out} h_{out}) \Delta t, \quad (3.18)$$

where inlet and outlet flow rates and enthalpies are assumed constant during the time step and are updated at the end of each time step.

The pressure in each steam line is then determined from

$$v(t + \Delta t) = V/M(t + \Delta t), \quad (3.19)$$

and

$$P = P(v,h) .$$

These pressures are used to compute flows in and out of the steam lines for the next time step using the ideal flow equation.

A diagram of the feedwater heater model used in the turbine generator plant simulation is shown in Fig. 3.3.2. A lumped parameter model using nine differential equations is used to describe each feedwater heater. The model determines the time dependent feedwater exit temperature from each feedwater heater. The simulation used in ORTAP is the same as is used for the feedwater heater simulation in Ref. 8, and the reader is referred to that report for a more detailed description of the modeling technique.

As shown in Fig. 3.3.2, steam from the turbine extraction enters the shell side vapor section of the feedwater heater. If this steam is superheated, it is assumed first to give up this superheat to the exiting feedwater. If the steam is wet, it is divided into a saturated steam part and a saturated liquid part.

Liquid from a previous feedwater heater may also enter the shell side drain cooler section of the heater. Since its temperature is usually hotter than the saturated vapor temperature, some of it flashes. The vapor goes into the vapor space and combines with the steam from the extraction line. Steam in the vapor space condenses on the tubes containing the feedwater. This liquid eventually flows into the drain cooler section of the feedwater heater. As it flows through the drain cooler, it loses some of its heat to the feedwater.

The feedwater enters the feedwater heater in the tube bundles and flows counter to the direction of the drain coolant flow. After

Fig. 3.3.2. Feedwater heater model.

leaving the drain cooler section, the feedwater heater enters tube bundles in the vapor space where it heats up some more as shell side steam is condensed. Before leaving the heater, the feedwater in the tube bundle passes through a superheat section where the superheat in the extraction steam (if any) is removed.

In the simulation, the drain cooler section of the feedwater heater is treated as a tube-in-shell counterflow heat exchanger where the shell side has a uniform (saturated) temperature. The superheated extraction steam section is handled by a simple heat balance.

3. Helium Circulator and Circulator-Turbine Model

The circulator-turbine model subroutine (ORCIRT) calculates the steam-turbine side pressures, flows, and enthalpies, as well as the helium-circulator side pressure drop, flow, and temperature rise (Fig. 3.4.1). It also incorporates the turbine speed and pressure ratio control systems.

ORCIRT is integrated into the turbine-generator plant routines, using the pressure and enthalpy of the high-pressure turbine exhaust steam and the reheater steam inlet pressure as boundary conditions; each of these is assumed to be constant over the computation time interval. The desired circulator speed is "requested" by the overall plant average main steam temperature control system. This input request is normally satisfied as long as adequate steam is available. However, with the speed control valve wide open and the bypass valve closed, if the turbine power output is insufficient to maintain the requested speed, the speed will droop accordingly. This is known as the pressure-limited mode. Occasionally, for rapid decreases in

ORNL-DWG 76-13359

Fig. 3.4.1. Circulator turbine model.

requested speed, the rotor inertia will make the actual speed exceed the requested speed even with no turbine steam flow. This is the coastdown mode.

The circulator and turbine characteristics modeled in ORCIRT are derived from empirical data supplied by GAC in the FSV-FSAR⁹ and the TAP code report,¹ and from personal communication with GAC.

The circulator performance map for the FSV units was recast in terms of a normalized pressure rise as a function of normalized flow and then was represented by a quadratic equation, as suggested by LASL.¹⁰ Primary loop flow is calculated explicitly by using a quadratic formulation for the circulator map and assuming that ΔP is proportional to flow squared in the primary loop components. The circulator power required for given speed and helium-side conditions is calculated from a quadratic fit to a GAC-supplied normalized power curve. Other power losses included are due to bearing friction and rotor acceleration.

Once the power requirements have been established for a given rotor speed, the required turbine inlet pressure is determined for an assumed value of turbine steam flow. If this pressure is available, a comparison is made between the average specific volume based on inlet/outlet conditions and that required to satisfy the turbine torque map. The assumed value of steam flow is adjusted until the difference in specific volume calculations is sufficiently small.

If the available pressure is not sufficient to maintain the requested speed, another iterative loop is used to determine the maximum speed obtainable with the speed control valve wide open and the bypass valve closed. Provisions are made for entering and exiting the pressure-limited mode.

The turbine efficiency, with an imposed lower limit, is updated for each iteration. Messages are printed out if the turbine is supersonic or has wet exhaust steam, or if the circulator is in the stall region.

A calculation is then made of the approximate bypass flow required to maintain a constant pressure ratio between the high-pressure turbine exhaust and the circulator-turbine exhaust. Because of the holdup volumes at these two points, the calculation cannot be made explicitly; instead, the bypass flow is adjusted at each time step to correct the pressure ratio to the desired value on a 2-sec time constant.

3.5 Turbine Bypass, Desuperheater, and Flash Tank Models

The main steam turbine bypass system, including the desuperheater and flash tank, is shown in Fig. 3.5.1. In the main steam bypass (MSBP) model it is assumed that the pressure control systems respond instantaneously compared to other system dynamic responses. Hence the MSBP valve opens whenever the main steam pressure exceeds 17.68 MPa (2564 psia) and attempts to maintain that pressure. The flow through the MSBP valve is assumed to have a specified upper limit. Any flow in excess of this limit causes the pressure to build up until it reaches a second upper limit of 19.06 MPa (2764 psia). At that point, the vent valve opens and allows enough steam to escape to the atmosphere to maintain that pressure.

In the model for steam temperature control at the desuperheater outlet, it is assumed that there are no pressure drops in the lines between the desuperheater outlet, the flash tank, and the high-pressure turbine outlet; i.e., it is all at the pressure of the node designated

NORMAL OPERATION OF SECONDARY COOLANT SYSTEM

Fig. 3.5.1. Turbine bypass systems.

as "steam line 2" in Fig. 3.3.1. Given this pressure and the set point temperature, the corresponding enthalpy "set point" for the desuperheater exit steam can be found. From this it can be determined how much desuperheating water must be added to the bypass steam to reduce it to the set point temperature. The phase of the fluid to the flash tank is also calculated, and only superheated or dry steam is assumed to flow to the circulator turbine. Any liquid is returned to the condenser hot well.

4. CONTROL SYSTEM SIMULATION

Three overall plant control loops are simulated in ORTAP. The controlled variable, dependent variable and feed-forward variable for each loop are given below.

<u>Controlled Variable</u>	<u>Dependent Variable</u>	<u>Feed-Forward Variable</u>
Main steam temperature	Helium circulator speed	Feedwater flow
High pressure turbine throttle pressure	Feedwater flow	High pressure turbine first stage pressure
Reheat steam temperature	Reactor power	High pressure turbine first stage pressure

Figure 4.1 is a block diagram showing the typical relationship between the controlled, dependent, and feed-forward variables, using the main steam temperature controller as an example. The feed-forward variable is used to enhance the response to load changes and is added directly to the controller output signal as shown in Fig. 4.1. The model for the controller shows the set point signal entering downstream

Fig. 4.1. Typical control system model.

of the signal to the derivative stage, as in the Foxboro Spec. 200 electronic controllers used at FSV. This eliminates spurious system responses to rapid set point changes. The model also includes both integral (or reset) gain and derivative gain limits of 100 and 10, respectively.

5. COUPLING OF COMPONENT MODELS IN THE SYSTEM SIMULATION

ORTAP was developed by coupling the individual component simulations with the plant control systems. It is assumed that the helium flow, as calculated by the helium circulator model, is the same at all points in the primary system. The system pressure is computed for each time step as an instantaneous function of the total helium mass in the primary system and the volume average temperature of helium in the primary system components. The helium pressure drops across the core and across the reheater steam generator module are determined at each calculational time step from $\Delta P = k W^2 / \rho$ where the value of k is determined from initial steady-state values of pressure drop, flow, and density in each component. The helium circulator model computes the outlet pressure from the inlet pressure and the compressor map. The circulator helium inlet pressure required by the circulator model is set equal to the total system pressure.

Heat transfer to the PCRV liner cooling system is taken into account in the following manner: the reheater helium inlet temperature required by BLAST is calculated from the mixed mean core outlet temperature, an overall heat conductance from helium through the PCRV liner insulation to the cooling water, and a cooling system "sink"

temperature of 54°C (130°F). At the initial steady-state operating conditions, the gas temperature through the duct from the core outlet to the reheater inlet is assumed to vary with position according to

$$\frac{dT_{\text{gas}}}{dz} = \frac{-UA/\Delta Z}{Wc_{p,\text{He}}} (T_{\text{gas}} - T_{\text{sink}}) , \quad (5.1)$$

where U is the overall heat transfer coefficient from the helium to the liner cooling system. Therefore

$$T_{\text{in, reheater}} = e^{-UA/Wc_{p,\text{He}}} T_{\text{out, core}} + [1.0 - e^{-UA/Wc_{p,\text{He}}}] T_{\text{sink}} . \quad (5.2)$$

The value of UA for initial steady-state conditions can be determined by Eq. (5.2) from initial steady-state values of $T_{\text{in, reheater}}$ and $T_{\text{out, core}}$. Equation (5.2) is then used at each time step to determine $T_{\text{in, reheater}}$ from the primary system flow rate as determined by the helium circulator turbine model and from the mixed mean core outlet helium temperature as determined by the core model. This approach implicitly assumes that the value of UA , the overall conductance, is independent of flow. This is a reasonable assumption since the resistance to heat flow through the PCRV thermal insulation is significantly larger than the flow dependent helium film resistance at the duct wall. The above approach is also used to determine the helium circulator inlet helium temperature from the calculated steam generator helium outlet temperature.

As has been mentioned, the feedwater flow rate is specified by the plant control system and is varied to maintain the pressure at the high pressure turbine throttle valve at its set point. Since there is presently no feedwater pump model in ORTAP, it is assumed that the actual feedwater flow to the economizer section of the steam generator lags the flow requested by the control system by 2.0 sec, i.e.,

$$\frac{dW_{FW}}{dt} = \frac{1}{2}(W_{FW,Request} - W_{FW}) ,$$

so

$$W_{FW}(t) = W_{FW,Request}(t) + [W_{FW}(t - \Delta t) - W_{FW,Request}] e^{-\Delta t/2.0} .$$

This feedwater flow is provided at each time step to the BLAST steam generator model. The feedwater enthalpy at the economizer inlet, also required by the BLAST steam generator model, is determined in ORTAP by the simulation of the feedwater heaters in the turbine generator plant model. The pressure at the economizer inlet as a function of time is specified in the input to ORTAP. The main steam outlet pressure required by the BLAST simulation is provided by the calculation of steam pressure in steam line 1 (Fig. 3.3.1) by the turbine generator model.

The inlet steam-side pressure and enthalpy to the reheater, also required by BLAST is determined in the turbine generator model for steam line 4 (Fig. 3.3.1). The reheater outlet pressure is set equal to the pressure of steam line 3. Reheater inlet flow is determined from the

ideal gas flow equation [Eq. (3.8)] using the pressures in steam lines 3 and 4.

The plant control system determines the helium circulator speed command based on the difference between the measured main steam temperature and its set point, plus the feedwater flow feed-forward signal. Following a turbine trip, this command may be overridden if the circulator inlet pressure is less than a low pressure set point. ORTAP applies a flow rate dependent measurement time constant to the value of main steam outlet temperature as calculated by BLAST to account for sensor response. That is,

$$T_{\text{measured}}(t + \Delta t) = T_{\text{calculated}} + [T_{\text{measured}}(t) - T_{\text{calculated}}] e^{-\Delta t / \tau_c},$$

where

$$\tau_c = 17.5 \text{ sec} + 2.19 \times 10^{-6} \left(125 - 100 \frac{W_{\text{ms}}}{W_{\text{ms},0}} \right)^{3.5},$$

where W_{ms} is the main steam flow and $W_{\text{ms},0}$ is the main steam flow at 100% conditions. This flow dependent measurement time constant is also used for determining the measured reheat steam temperature from the reheat steam temperature calculated by BLAST.

Currently the proportional, integral, and derivative gains for the controllers are those given in Ref. 6 for 100% power operation. When actual gain settings for the FSV reactor become available, they will be used in the FSV version of ORTAP.

6. SAMPLE TRANSIENT

The sample transient described here is presented mainly to illustrate the more important features of the code, show a complete sample input data set, and demonstrate a few of the characteristics of HTGR transients. The example chosen is a rod pair withdrawal accident with a subsequent reactor scram when the core power reaches 140%. It is assumed that the reactor is initially at 100% power, with nuclear characteristics corresponding to an end-of-equilibrium cycle core, a rod pair worth of $0.012 \Delta k$ (for the pair being withdrawn) and a total scram reactivity worth of $0.064 \Delta k$. These conditions represent the most conservative case from the standpoint of maximum fuel temperatures attained. It is also assumed that the normal flux control system, which varies reactor power to maintain the reheat steam temperature constant, and the rod withdraw inhibit at 120% power are inoperative.

Figures 6.1 through 6.5 show some of the results of the simulation. The runaway rod pair begins withdrawing at time $t = 0$ from the fully inserted position at the normal withdrawal speed of 180 sec for full travel. The core power reaches the trip level of 140% in 39 sec, after which the remaining rods driven in (requiring 152 sec for full travel), the feedwater flow is ramped down to 25% of full-flow at 0.5%/sec, and the turbine throttle valve is ramped to 10% of its nominal full-power position at a rate of 0.5%/sec. Two minutes after the reactor is tripped, the turbine is tripped also. As the high-pressure turbine flow is reduced, the main steam pressure increases and the main steam bypass (MSBP) system begins diverting steam to the flash tank in order to limit the pressure to 17.68 MPa (2564 psia). In this example,

Fig. 6.1. Response of system parameters to a FSV rod-pair-withdrawal transient from an initially fully inserted position. Trip signal 140% rated core power.

Fig. 6.2. Response of system parameters to a FSV rod-pair-withdrawal transient from an initially fully inserted position. Trip signal 140% rated core power.

Fig. 6.3. Response of system parameters to a FSV rod-pair-with-drawal transient from an initially fully inserted position. Trip signal 140% rated core power.

Fig. 6.4. Response of system parameters to a FSV rod-pair-withdrawal transient from an initially fully inserted position. Trip signal 140% rated core power.

Fig. 6.5. Response of system parameters to a FSV rod-pair-withdrawal transient from an initially fully inserted position. Trip signal 140% rated core power.

the maximum MSBP flow limit is not reached, so the vent valve is not opened.

The plot of normalized power (Fig. 6.1) peaks at 1.4, where the trip occurs, and decreases eventually to the afterheat level. The relatively slow reduction in power is due to the slow-moving rods and the conservatively low value of total scram reactivity assumed. The ramp down of feedwater flow following the reactor trip causes a similar ramp down of the helium flow (Fig. 6.1) since feedwater flow is the feed-forward variable in the main steam temperature control system in which circulator speed (helium flow) is the dependent variable (see Sect. 4). The helium flow continues to decrease until $t \approx 6.7$ min, when it increases sharply after the main steam temperature has fallen below its setpoint. The sharpness of the increase is due to the fact that the controller output was saturated at its lower limit for several minutes. The helium flow peaks at $t \approx 11.2$ min in a final attempt to maintain the main steam temperature; after that, the circulator speed is limited by the steam pressure available to the turbine drive. Figure 6.1 also shows the primary system (helium) pressure, which follows the trends of the average system temperature.

The reheater and steam generator outlet steam temperatures (Fig. 6.2) increase somewhat initially due to the increase in core helium outlet temperature, but the primary cause of the sharp increases is the forced reduction of feedwater flow that occurs when the reactor is tripped. Other cases were run which showed the high sensitivity of the peak temperatures to the rate of power reduction after the trip. It would appear that a delay in the feedwater ramp down would be desirable

in order to minimize the peak steam temperatures. Note that the leveling off of the main steam temperature after ~12.5 minutes indicates that wet steam is exiting the steam generator.

Secondary coolant steam flows normalized to the initial steam generator outlet steam flow are shown in Fig. 6.3. The steam generator and high pressure turbine (HPT) flows decline slightly at the start in response to the increasing helium temperature. After the reactor trip, they are both ramped down quickly to about 25%. The HPT flow goes to zero at $t \approx 2.7$ min when the turbine is tripped. Since the feedwater flow is held constant at 25% after $t \approx 3$ min, any variations of steam generator outlet flow after that time are due to changes in the water and steam inventories.

The primary loop helium temperatures at the core inlet and outlet and the reheater outlet are shown in Fig. 6.4. As seen, little or no overshoot for any of these temperatures is predicted. The initial decrease in core inlet temperature is due to the reduction in helium flow, which causes a closer approach of the steam generator helium outlet temperature to the nearly-constant feedwater inlet temperature. The rapid increase in core inlet temperature at $t \approx 6.7$ min is due to the increase in helium flow mentioned earlier. The core outlet temperature T_{CO} , as plotted, is derived from both the CORTAP (single channel) and ORECA (multi-channel) core models. Above 40% helium flow, T_{CO} is the CORTAP output, and below 20% it is the ORECA output; in between, T_{CO} is a flow-weighted average of the two. In this transient, the difference between the two model outputs was typically small, with a maximum difference of $\sim 30^\circ\text{C}$ (54°F).

The ORECA model determines the average core temperature while CORTAP calculates separately the average fuel and the average graphite temperatures. ORECA also flags the peak temperature of the ORECA nodal masses. As discussed in Sect. 3.1 each of these nodal masses represents one of the six axial segments in each of the 37 refueling regions. The maximum core temperatures (ORECA) late in the transient typically occur in low-flow channels and thus take longer to cool down. The behavior of the average core temperatures in the two models is very similar.

Many other variations of the rod-withdrawal accident have been run and are reported in Refs. 11 and 12.

The sample transient was run with 0.1 sec computation time steps and required 29 minutes of CPU time on the IBM 360/91. Including a one minute preaccident settling time, this corresponds to 1.8 minutes of CPU time per minute of simulated reactor time. Input instructions and the input data set corresponding to this transient are shown in the Appendix.

7. FUTURE APPLICATIONS OF ORTAP

ORTAP has been used to analyze system transients in the FSV plant resulting from uncontrolled removal of poison from the reactor core and from a postulated depressurization accident.¹³ In addition to these, ORTAP will be used to analyze transients resulting from a turbine trip, sudden reduction in feedwater flow and loss of primary coolant flow. When results of dynamics tests on the Fort St. Vrain reactor become available, comparisons will be made with ORTAP predictions, and, based on these comparisons, appropriate improvements in ORTAP will be made.

With only very minor modifications, ORTAP could be used to simulate large HTGRs. Also, with only slight modifications, ORTAP could be used to simulate a Gas Cooled Fast Breeder Reactor nuclear steam supply system.

8. REFERENCES

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APPENDIX

ORTAP INPUT INSTRUCTIONS AND SAMPLE INPUT LISTING

The input instructions and a sample input listing for a Fort St. Vrain simulation with ORTAP follow. The instructions can be more easily understood by referring to the sample input listing. It is important to note that once the input is generated for a given plant—as it has been for FSV—there are very few changes necessary to run different transients. The bulk of the input describes initial steady-state conditions and plant design.

The initial portion of the input is that required for the CORTAP core simulation.

Card No. 1 (FORMA 20A4)

Title card.

Card No. 2 (FORMAT 10X, 315)

IPOWER - Flag indicating how core power prior to reactor trip will be determined.

1 = core power is determined by neutron flux controller.

0 = core power is calculated from neutron kinetics equations.

IROD - This parameter is ignored if IPOWER = 1. If IPOWER = 0, this parameter specifies whether control rod motion will introduce reactivity during the transient or not.

0 = no control rod motion.

1 = control rod motion.

If IROD = 1, the user must supply a subroutine to be called from the main program specifying the reactivity

change due to rod motion as a function of time.

IPPNCH - Flag indicating whether core normalized power, inlet temperature, and helium flow vs time is to be punched on cards for a subsequent CORTAP highest-power fuel region calculation.

1 = punch.

0 = do not punch.

Card No. 3 (FORMAT 10X, 5D10.4)

CORPWR - Initial thermal power level in MW.

FPC - Fraction of total thermal power deposited to coolant flowing through coolant channels in active core.

FPSR - Fraction of total thermal power deposited to coolant flowing through side reflector elements.

FPGT - Fraction of total thermal power deposited to coolant flowing through control rod channels.

FPAFS - Fraction of $FPC \times CORPWR$ that is generated in the entire axial length of an average fuel stick column.

Card No. 4 (FORMAT 10X, 5D10.4)

FLOW - Initial total core flow (lbm/hr).

FFC - The fraction of the total core flow which flows through coolant channels.

FFSR - The fraction of the total core flow which flows through side reflector.

FFCT - The fraction of the total core flow which flows through control rod channels.

FFACC - The fraction of $FFC \cdot FLOW$ which flows through the average coolant channel.

Card No. 5 (FORMAT 10X, 7I5)

JMAX - Number of axial nodes in the active fuel portion of the unit cell.

NF - Number of radial nodes in the fuel stick.

NM - Number of radial nodes in the moderator.

NATR - Number of axial nodes in top reflector.

NABR - Number of axial nodes in bottom reflector.

NGTN - Number of axial nodes representing mass of graphite transferring heat with coolant flowing through a control rod channel.

NSRN - Number of axial nodes in side reflector.

The restrictions are

$$JMAX \cdot (NF + NM) + NATR + NABR \leq 60$$

$$NGTN \leq 8$$

$$NSRN \leq 8$$

Card No. 6 (FORMAT 10X, 2D10.4)

RPF - Radial power peaking factor. This should be set equal to 1.0 since ORTAP uses the CORTAP core simulation for an average channel.

RFF - Radial flow factor for coolant in cell being simulated. This should also be set equal to 1.0.

Card No. 7 (FORMAT 10X, 4D10.4)

RF - Radius of the fuel stick (in.).

GAP - Width of gap between fuel stick and moderator (in.).

NOTE: This is used to determine gap conductance,

$$c_{\text{gap}} = (h_{\text{gap}} * A) / \text{GAP}.$$

RM - Outer radius of graphite annulus in cylindrical cell simulation (in.). This should be calculated to conserve the graphite volume in the triangular cell.

HEIGHT - Active core height (in.).

Card(s) No. 8 (FORMAT 10X, 7D10.4)

AXZ(J), J=1, JMAX - The axial location of the centers of the nodal volumes in the active fuel (in.). By definition $z = 0$ at the top of the active fuel column increasing in the downward direction.

Card(s) No. 9 (FORMAT 10X, 7D10.4)

R(I), I=1, IMAX, where IMAX = NF + NM.

Distances from the fuel stick centerline to the radial surfaces of the nodes in the cylindrical representation of the unit triangular cell (in.).

Card No. 10 (FORMAT 10X, 2D10.4 2I5)

SRH - The height of the side reflector (in.).

SRAREA - The cross-sectional area of a side reflector symmetry element (in.²).

NCCSRE - The number of coolant channels in a side reflector element.

NSRC - The number of side reflector columns.

Card No. 11 (FORMAT 10X, D10.4)

TRT - The thickness of the top reflector (in.).

Card No. 12 (FORMAT 10X, D10.4, I5)

HDGT - The hydraulic diameter of the control rod channels (ft).

NGT - The number of control rod channels.

Card No. 13 (FORMAT 10X, D10.4)

VOLGTT - The total volume of graphite which the user allows to transfer heat with the average control rod channel (in.³).

This is used for heat capacity effects.

Card No. 14 (FORMAT 10X, 6D10.4)

RHOFUL - The density of the fuel stick (lbm/ft³). See note.

RHOMOD - The density of the bulk moderator (lbm/ft³). See note.

DENRAT - The ratio of the density of the graphite in the fuel stick to the density of the graphite in the bulk moderator.

F - The volume fraction of the graphite in the fuel stick.

RHOGT - The density of the graphite in the mass transferring heat with coolant flowing through the average control rod channel (lbm/ft³). See note.

RHOSR - The density of the side reflector (lbm/ft³). See note.

NOTE: If the temperature dependent heat capacities in subroutines CPFUEL AND CPMOD have units of Btu/ft³-°F, the corresponding "densities" (RHOFUL and RHOMOD) should be input as 1.0. If it is desired to account for the larger graphite to fuel stick mass ratio in the refueling region than in the unit cell, the value input for RHOMOD can be used to account for this.

Card No. 15 (FORMAT 10X, 3D10.4, I5)

BRT - The thickness of the bottom reflector (in.).

BRCHAN - The radius of the coolant channel through the bottom reflector (in.).

ABR - The cross-sectional area of the triangular graphite symmetry element in the bottom reflector (in.²).

NCCELM - The number of coolant channels in the active fuel feeding the bottom reflector channel.

Card(s) No. 16 (FORMAT 10X, 7D10.4)

AXPF(J), J=1, JMAX - The axial power peaking factors for the fuel stick.

Card No. 17 (FORMAT 10X, I5)

NINC - The number of neutron kinetics time steps per heat transfer time step.

Card No. 18 (FORMAT 10X, 2D10.4, 2I5)

DELTMP - The maximum amount that any nodal temperature can change without recalculating the components of the A matrix [Eq. (3.18)] (°F). Some experimentation on this parameter by the user is advisable to minimize computer time while maintaining sufficient accuracy. In general, the "weaker" the temperature dependence of fuel and moderator conductivities and specific heats, the larger this value can be.

DLMDOT - The maximum amount that the total core flow rate can change without recalculating the components of the A matrix [Eq. (3.17)] (lbm/hr). No single value for this parameter can be recommended since the value which would maintain sufficient accuracy while keeping computer time as low as possible depends on how low the core flow becomes in any given transient. Some experimentation on this parameter with CORTAP by the user is advisable to minimize computer time while maintaining sufficient accuracy.

NOUPDT - Flag for updating the A matrix [Eq. (3.17)] due to temperature dependence of its elements after each iteration on feedback reactivity.

= 0 update A .

= 1 do not update A .

This option is somewhat obsolete and NOUPDT = 1 is recommended. If NOUPDT = 0 is used, problem execution time is greatly increased with essentially no improvement in accuracy.

NPT - Number of heat transfer time steps between printouts.

Card No. 19 (FORMAT 10X, 3D10.4)

HGAP - The heat transfer coefficient of the gap between the fuel and moderator (Btu/hr-ft²-°F).

D - The hydraulic diameter of a coolant channel (ft).

TINLET - The initial inlet temperature (°F).

Card No. 20 (FORMAT 10X, 15, 2D10.4)

NG - Number of groups of delayed neutron precursors.

EPSLON - The convergence criteria for reactivity feedback.

Recommend 1.0D-10.

RLSTAR - The average neutron lifetime from release to loss (sec).

Card No. 21 (FORMAT 10X, 7D10.4)

BETA(I), I=1,...,NG - The delayed neutron fraction for precursor group I.

Card No. 22 (FORMAT 10X, 7D10.4)

RLMBDA(I), I=1,...,NG - The decay constant for precursor group I (sec⁻¹).

Card No. 23 (FORMAT 10X, 2D10.4)

TMREF - The reference graphite temperature for reactivity feedback ($^{\circ}\text{F}$).

TFREF - The reference fuel stick temperature for reactivity feedback ($^{\circ}\text{F}$).

Card No. 24 (FORMAT 10X, D10.4, 5X, I5, D10.4)

This card contains information pertaining to the MATEXP integration technique. For further details see ref. 9.

P - Precision of $e^{\tilde{A}\Delta t}$ and $[e^{\tilde{A}\Delta t} - \tilde{I}]\tilde{A}^{-1}$. Recommend 10^{-6} or less.

ITMAX - Maximum number of terms in series approximation of $e^{\tilde{A}\Delta t}$.
The value of 64 for this parameter is sufficient.

VAR - Maximum allowable value of largest coefficient matrix element Δt (Recommend VAR=1.0).

Cards No. 25 (FORMAT 10X, 7D10.4)

XICT(I), I=1,..., NET, where NET = IMAX*JMAX + NABR + NATR.

Initial nodal temperatures in upper reflector, active fuel cell and lower reflector ($^{\circ}\text{F}$). These are determined by a CORTAP calculation.

Cards No. 26 (FORMAT 10X, 7D10.4)

TBULK(J), J=1, JEND, where JEND = NATR + JMAX + NABR.

Gas temperatures corresponding to each solid nodal increment in the upper reflector, the active fuel cell and the lower reflector. These are the temperatures from which the temperature dependent helium transport properties are obtained ($^{\circ}\text{F}$).

The input data required by the ORECA subroutine portion of ORTAP follows. This consists of one control card plus 55 cards containing the core initial nodal temperatures, which are normally provided by a special run of the ORECA code.

Card No. 1 (FORMAT 7F10.0, 2I2)

- AL - Reference value of composite core heat diffusivity divided by the square of the characteristic length between nodes, $D_H/(\Delta x)^2$, min^{-1} . This assumes reference values of specific heat $C_p = 0.33 \text{ Btu-lb}^{-1}\text{-}^\circ\text{F}^{-1}$, conductivity $k = 10 \text{ Btu-hr}^{-1}\text{-ft}^{-1}\text{-}^\circ\text{F}^{-1}$, and normally incorporates the enhanced effective conductance and hexagonal geometry correction factor noted in ref. 3.
- QZ - Initial value of $[Q/MC_p]$ for an average refueling region, $^\circ\text{F/min}$, using reference values of C_p and k noted above.
- DP - Initial pressure drop across the core, psi.
- FSQ - Channel flow "skew factor" (0.0 to 1.0): set = 0.0 to make all initial refueling region flows equal; or = 1.0 to make them proportional to the radial power factor QR_{ij} ; or in between as desired.
- FFPRNT - Fraction of initial core flow below which core temperature maps are to be printed.
- FFBEGC - Fraction of initial core flow below which ORECA-derived core outlet temperatures begin to merge with ORTAP-derived core outlet temperatures in determining the best estimate value.

FFENDC - Fraction of initial core flow below which only ORECA-derived core outlet temperatures are used as the best estimate. At flow fraction values between FFBEGC and FFENDC, the CORTAP- and ORECA-derived temperatures are weighted linearly with flow.

NTP - Number of ORTAP Δt intervals between each ORECA computation.

JPF - Flag for channel flow and ΔP print-out at each time step.
 1 = print.
 0 = do not print.

Cards Nos. 2-56 (FORMAT 8F10.8)

Initial core temperature distributions. These 55 cards are normally punched by a previous run of ORECA:

([XP (I,J), J = 1,8], I = 1,55), where J is the axial region index, and I is the radial index (37 refueling regions plus 18 side reflector regions).

[Repeat sequence if desired.]

Other data which are incorporated in the ORECA program as DATA statements are the axial and radial power factors for each refueling region, flow iteration error limits, plus a variety of other data peculiar to the FSV design and construction which would not normally need to be altered.

The following describes the input required for the FSV turbine generator plant simulation in ORTAP.

Cards No. 1 (FORMAT 20A4)

Two title cards.

Card No. 2 (FORMAT I5)

Number of steam generator modules feeding the high pressure turbine. For FSV set equal to 12.

Card No. 3 (FORMAT 16I5)

IND(I), I=1, 16 - Set all = 0 except:

IND(3) = Number of time steps between T-G plant printouts.

IND(9) = 0 for fixed throttle valve; = 1 for controlled electrical output.

IND(11) = 1 to disable reactor trip on He pressure >753 psia.

IND(13) = Number of time steps between summary print/punch.

IND(15) = 1 to disable reactor trip on 140% power.

IND(16) = 1 to disable reactor trip on high reheat steam temperature.

Card No. 4 (FORMAT E10.3)

VLVH - Initial high pressure turbine throttle valve setting.

0.0 = full closed; 1.05 = valve wide open.

Card No. 5 (FORMAT E10.3)

WHP - Flow rate into high pressure turbine (lbm/sec) at $t = 0.0$.

Card No. 6 (FORMAT 4E10.5)

HH(I), I=1,..., 4 - Enthalpies (Btu/lbm) at each numbered section (see Fig. 3.3.1) in the high pressure turbine at $t = 0.0$.

NOTE: Four values are necessary for the FSV simulation.

Card No. 7 (FORMAT 4E10.3)

PH(I), I=1,..., 4 - Pressures (psia) at each numbered section in the high pressure turbine at $t = 0.0$. NOTE: Four values are necessary for the FSV simulation.

Cards No. 8 (FORMAT 6E10.3)

WLP(I), I=1,..., 14 - Flow rate (lbm/sec) at various points in the

turbine generator plant downstream of the reheater at $t = 0.0$. The numbering scheme used for the FSV simulation is described below and should be read in conjunction with Fig. 3.3.1:

- WLP(1) - flow from point 3 to point 4 in intermediate pressure turbine.
- WLP(2) - flow from point 4 of intermediate pressure turbine to point 5 of low pressure turbine.
- WLP(3) - flow from point 6 to point 8 of low pressure turbine.
- WLP(4) - flow from point 8 to point 10 of low pressure turbine.
- WLP(5) - flow from point 10 to point 12 of low pressure turbine.
- WLP(6) - flow from point 12 to point 14 of low pressure turbine.
- WLP(7) - flow from point 4 of intermediate pressure turbine to boiler feedpump (BFP) turbines.
- WLP(8) - flow from point 4 of intermediate pressure turbine to feedwater heater 5.
- WLP(9) - extraction flow from point 6 of low pressure turbine.
- WLP(10) - extraction flow from point 8 of low pressure turbine.
- WLP(11) - extraction flow from point 10 of low pressure turbine.

WLP(12) - extraction flow from point 12 of low pressure turbine.

WLP(13) - extraction flow from point 3 of intermediate pressure turbine.

WLP(14) - flow from point 1 to point 3 of intermediate pressure turbine.

Cards No. 9 (FORMAT 6E10.3)

HL(I), I=1,..., 18 - Enthalpy array (Btu/lbm) for intermediate and low pressure turbines at numbered locations (see Fig. 3.3.1). To satisfy the turbine model set $HL(15) = HL(10)$, $HL(16) = HL(12)$, $HL(17) = HL(14)$, and $HL(18) =$ condenser outlet enthalpy (Btu/lbm).

Cards No. 10 (FORMAT 6E10.3)

PL(I), I=1,..., 18 - Pressure (psia) array in intermediate and low pressure turbines at numbered locations at $t = 0.0$ (see Fig. 3.3.1). Set $PL(15) = PL(10)$, $PL(16) = PL(12)$, $PL(17) = PL(14)$ and $PL(18) =$ condenser pressure.

Cards No. 11 (FORMAT 4E10.3)

PFPI - Pressure (psia) at feedpump turbine inlet at $t = 0.0$.
 HFPI - Enthalpy (Btu/lbm) at feedpump turbine inlet at $t = 0.0$.
 HFP - Enthalpy (Btu/lbm) at feedpump turbine outlet at $t = 0.0$.
 PFP - Pressure (psia) at feedpump turbine outlet at $t = 0.0$.

Cards No. 12 (FORMAT 6E10.3)

One card is required for each feedwater heater (numbered as in Fig. 3.3.1) at $t = 0.0$. The deaerator is considered feedwater heater

- WDC - Drain coolant flow (lbm/sec).
- WFW - Feedwater flow (lbm/sec).
- TFWI - Temperature of feedwater entering heater ($^{\circ}$ F).
- TFWO - Temperature of feedwater leaving heater ($^{\circ}$ F).
- TDCO - Temperature of liquid leaving drain cooler ($^{\circ}$ F).
- PFHV - Vapor pressure in feedheater shell (psia).

Cards No. 13 (FORMAT 4E10.3)

One card is required for each feedwater heater at $t = 0.0$.

- HFWC - Holdup time of feedwater in draincooler portion (sec).
- HDC - Drain coolant holdup time (sec).
- HFWE - Holdup time of feedwater in evaporator portion (sec).
- HVFH - Steam holdup time on shell side of feedwater heater (sec).

Card No. 14 (FORMAT 3E10.3)

- HSG - Enthalpy (Btu/lbm) of steam exiting steam generator at
 $t = 0.0$.
- HSGI - Enthalpy (Btu/lbm) of feedwater entering steam generator
at $t = 0.0$.
- PSG - Pressure upstream of high pressure turbine throttle valve
at $t = 0.0$. Set equal to pressure of steam line 1 (psia).

Card No. 15 (FORMAT 4E10.3)

- HTV(I), $I=1, \dots, 4$ - Holdup time (sec) of steam lines 1 through 4
at $t = 0.0$.

Card No. 16 (FORMAT 4E10.3)

- PSL(I), $I=1, \dots, 4$ - Pressure in the four steam lines at $t = 0.0$
(psia).

Card No. 17 (FORMAT 4E10.3)

HSL(I), I=1,..., 4 - Enthalpy in the four steam lines at $t = 0.0$
(Btu/lbm).

Card No. 18 (FORMAT I10, 3E10.3, I5)

These cards are optional. They may be used to cause perturbations in the turbine generator plant.

I - Perturbation type.

I = 1 - electrical demand change.

I = 3 - change in the turbine generator plant printout frequency.

TM - Time at which perturbation occurs (sec).

AMT - Fractional step electrical demand change for I = 1.

BMT - Ramp electrical demand change (in fractional change/sec)
for I = 1.

IC - New value of IND(3) - see card No. 3 for I = 3.

End turbine generator plant data with a 0 in column 10.

The input data required by the BLAST portion of the ORTAP code is described below. In determining a nodal arrangement such as in Fig. 3.2.1, the user should place nodal boundaries where the tube material or diameter changes. Also, dividing a length of tube of a given material and diameter into more than one node provides finer calculational detail and therefore more accurate results.

The first entry on each data card required by BLAST is a card series number. The data cards must be ordered numerically according to this series number. The series number is in format I10, and the remaining entries are in 10 column fields.

<u>CARD SERIES</u>	<u>CARD FORMAT</u>
------------------------	------------------------

10NN	I10, 7D10.2
------	-------------

NN = 01, ..., k, where $k \leq 9$

This card series provides the time step information for each component model in ORTAP. Time interval and associated time step information is given in ordered triplets: $\Delta t(\text{sec})$, end of interval (sec), number of output edits during interval. Up to 20 ordered triplets are allowed.

The time step Δt should be chosen less than nodal mass transport times, M_1/W_1 and at least factor of three less than the holdup times in the feedwater heaters and steam lines in the turbine generator plant simulation. The last card in series 10NN should be blank in columns 71-80.

25NN	
------	--

Optional steam generator conditions plot request series. See p. 70.

70NN	I10, 4D10.2, 3I10
------	-------------------

NN = $2*N_w - 1$, where $N_w \equiv$ water node number and $(1 \leq N_w \leq 20)$.

Columns 11-20: Water node N_w pressure guess (psia) for steady state search.

Columns 21-30: Water node N_w enthalpy guess (Btu/lbm) for steady state search.

<u>CARD</u>	<u>CARD</u>
<u>SERIES</u>	<u>FORMAT</u>

Columns 31-40: Water node N_w flow area (ft^2).

Columns 41-50: Tube length (ft) associated with water node N_w .

Columns 51-60: Outlet position (1 = top, 0 = bottom). NOTE: If node is horizontal, input 0 in column 60 and column 70.

Normally the code uses the height (ft) of the associated helium node for the Δz factor in the static head term in the water side momentum equation. However, the user can specify the value of Δz by inputting, in integer form, $1000 \cdot \Delta z$ in columns 61-70.

Columns 71-80: Number of helium node (N_h) which can transfer heat to this water node.

70KK 2I10, D10.2, 2I10 KK = $2 \cdot N_w$. Continuation of information on card 70NN for water node N_w .

Columns 11-20: Tube type (specify 1, 2, or 3)

= 1 for carbon steel (SA-210-A1)

= 2 for Incoloy 800

= 3 for Croloy (SA-213-T22)

Columns 21-30: Number of tubes which transfer heat with the helium node referred

<u>CARD</u> <u>SERIES</u>	<u>CARD</u> <u>FORMAT</u>
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to in columns 71-80 of previous card.

Columns 31-40: Upstream node number

(= 201 for first reheater node)

(= 230 for first economizer node).

Columns 41-50: Downstream node number.

(= 215 for last reheater node).

Use 216, 217, ..., for multiple reheater exits.

(= 251 for last superheater node).

Use 252, 253, ..., for multiple superheater exits.

75LL I10, 4D10.2, I10,
 D10.2, I10

LL = $2 * N_w - 1$.

Columns 11-20: Mass flow rate (lbm/sec)

in one tube coil in water node N_w at initial steady state conditions.

Columns 21-30: Tube inner radius (in.).

Columns 31-40: Tube outer radius (in.).

Columns 41-50: Tube hydraulic diameter (in.).

Columns 51-60: DNB correlation number

= 1 for user supplied correlation.

See card series 9101.

= 2 for W-3, Jansen, Levy. See card series 9101.

<u>CARD</u>	<u>CARD</u>
<u>SERIES</u>	<u>FORMAT</u>

= 3 for B&W-2, Barnett.

If 1, 2, or 3 is chosen, the code will not return to nucleate boiling once DNB has occurred.

= 4 for user supplied correlation. See card series 9101.

= 5 for W-3, Jansen, Levy. See card series 9101.

= 6 for B&W-2, Barnett.

If 4, 5, or 6 is chosen, the code will return to nucleate boiling once DNB has occurred.

Columns 61-70: Minimum heat transfer coefficient ($\text{Btu/hr-ft}^2\text{-}^\circ\text{F}$).

Columns 71-80: Film boiling correlation key.

(= 0 for Dougall-Rosenhow)

(= 1 for Groeneveld).

75MM I10, 3D10.2

$MM = 2 \cdot N_w$. Continuation of information on card 75LL for node N_w .

Columns 11-20: Constant friction factor for node N_w . This friction factor is added to that calculated from the Fanning friction factor curves to determine the friction losses.

<u>CARD</u>	<u>CARD</u>
<u>SERIES</u>	<u>FORMAT</u>

Columns 21-30: ϵ/D (Roughness to diameter ratio for tube; D = inner diameter.)

Columns 31-40: Relative curvature of tubes associated with water node N_w .

(Input 0.0 for straight tubes.)

80NN I1G, 5D10.2, 2I10 $NN = 2*N_h - 1$, where $N_h \equiv$ helium node number and $(1 \leq N_h \leq 20)$.

Columns 11-20: Helium node N_h pressure guess (psia) for steady state search.

Columns 21-30: Helium node N_h enthalpy guess (Btu/lbm) for steady state search.

Columns 31-40: Helium node N_h flow area (ft^2).

Columns 41-50: Helium node N_h flow length (ft).

Columns 51-60: Height of nodal volume (ft).

Columns 61-70: Inlet position (1 = top, 0 = bottom).

Columns 71-80: Outlet position (1 = top, 0 = bottom).

NOTE: Input 0 in column 70 and column 80 if node is horizontal.

80KK I1G, D10.2, 2I10 $KK = 2*N_h$. Continuation of information on card 80NN for node N_h .

<u>CARD</u>	<u>CARD</u>
<u>SERIES</u>	<u>FORMAT</u>

Columns 11-20: Nodal volume (ft^3).

Columns 21-30: Upstream node number.

(= 201 for first reheater node)

(= 215 for first tunnel node)

(= 230 for first superheater node)

Columns 31-40: Downstream node number.

(= 215 for last reheater node)

Use 216, 217, ..., for multiple reheater exits.

(= 230 for last tunnel node)

(= 251 for last steam generator node)

Use 252, 253, ..., for multiple steam generator exits.

85LL I10, 4D10.2, 2I10, LL = $2*N_h - 1$.
 D10.2

Columns 11-20: Mass flow rate (lbm/sec) in helium node N_h at initial steady-state conditions.

Columns 21-30: Average tube OD (in.) in helium node N_h .

Columns 31-40: Constant friction factor.

Columns 41-50: A key used to determine how the total helium side friction factor is calculated. If ≤ 0.0 , only the constant friction factor will be used to compute friction losses. If > 0.0 , the code

<u>CARD</u> <u>SERIES</u>	<u>CARD</u> <u>FORMAT</u>
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will calculate a friction factor from the input values of the next four input variables based on the correlation described in ref. 4 and add this to the constant friction factor to determine the friction losses.

Columns 51-60: Number of inline rows of tubes in helium node N_h .

Columns 61-70: Number of staggered rows of tubes in helium node N_h .

Columns 71-80: Pitch to diameter ratio-transverse.

85MM I10, D10.2

$MM = 2 * N_h$. Continuation of information on card 85LL for helium node N_h .

Columns 11-20: Pitch to diameter ratio-longitudinal.

9001 3I10

Columns 11-20: Number of first helium node in the tunnel section between the reheater and the steam generator.

Columns 21-30: Number of last helium node in tunnel.

9101

This card series is required if DNB correlation number on card series 75LL is 1, 2, 4, or 5. Otherwise, this series is omitted.

<u>CARD</u> <u>SERIES</u>	<u>CARD</u> <u>FORMAT</u>
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Columns 11-20: DNB flux (Btu/hr-ft^2) for zero quality. Used only for DNB correlation number = 1 or 4.

Columns 21-30: Quality at which DNB occurs. Used only for DNB correlation number = 1 or 4.

Columns 31-40: Quality at which DNB flux becomes zero. Used only for DNB correlation number = 1 or 4.

Columns 41-50: "E factor" in Jansen-Levy correlation. See ref. 13. Used only for DNB correlation number = 2 or 5.

9201 110, 2D10.2

Columns 11-20: Allowable temperature change ($^{\circ}\text{F}$) for water before recomputing thermodynamic transport properties.

Columns 21-30: Allowable temperature change ($^{\circ}\text{F}$) for helium before recomputing thermodynamic transport properties.

It is recommended that both inputs on this card be 1.0 or less.

18001 2110, 2D10.2

Steam generator (water side) inlet flow rate at $t = 0.0$ in one tube.

Columns 11-20: Number of pairs (time, flow rate) describing water side inlet flow rate

CARD
SERIESCARD
FORMAT

vs time. Input 1 since feedwater flow rate is determined by the plant control system after time zero.

Columns 21-30: Time (sec). Input 0.0.

Columns 31-40: Flow rate (lbm/sec) at $t = 0.0$.

18101 2I10, 6D10.2

Steam generator (water side) inlet pressure vs time. Since there is no feedwater pump model, this must be specified for the entire time duration of the transient.

Columns 11-20: Number of pairs, (time, pressure) describing water side inlet pressure vs time.

Columns 21-30: Time (sec).

Columns 31-40: Pressure (psia).

Columns 41-50: Repeat Columns 21-30.

Columns 61-80: Repeat Columns 31-40.

181NN I10, 7D10.2

NN = 2, ..., k, where $k \leq 42$. Continuation of card 18101.

18201 2I10, 2D10.2

Steam generator (water side) inlet enthalpy at $t = 0.0$.

Columns 11-20: Number of pairs (time, enthalpy). Input 1 since feedwater heater

<u>CARD</u>	<u>CARD</u>
<u>SERIES</u>	<u>FORMAT</u>

model determines this after time zero.

Columns 21-30: Time (sec). Input C.O.

Columns 31-40: Inlet enthalpy (Btu/lbm)
at $t = 0.0$.

18501 2I10, 2D10.2

Reheater (helium side) inlet flow rate at
 $t = 0.0$.

Columns 11-20: Number of pairs (time, flow
rate) describing helium inlet flow rate vs
time. Input 1 since core model determines
this after time zero.

Columns 21-30: Time (sec).

Columns 31-40: Flow rate (lbm/sec) at
 $t = 0.0$.

18601 2I10, 2D10.2

Reheater (helium side) inlet pressure vs
time.

Columns 11-20: Number of pairs (time,
pressure) describing helium inlet pressure
vs time. Input 1 since this is determined
by the circulator model after $t = 0.0$.

Columns 21-30: Time (sec). Input 0.0.

Columns 31-40: Pressure (psia).

18701 2I10, 2D10.2

Reheater (helium side) inlet enthalpy at
 $t = 0.0$.

<u>CARD</u>	<u>CARD</u>
<u>SERIES</u>	<u>FORMAT</u>

Columns 11-20: Number of pairs (time, enthalpy) describing helium inlet enthalpy vs time. Input 1 since this is determined by core model after time zero.

Columns 21-30: Time (sec).

Columns 31-40: Inlet enthalpy (Btu/lbm) at $t = 0.0$.

In addition to the above required input, data cards may be supplied which request plots. Two data cards with successive card series numbers are required for each plot. Card series numbers for the plot request cards begin with 2501, cannot exceed 2580 and must be consecutive. They must also be in numerical order with the required input cards, i.e., they must follow the last 10NN card.

The two cards required for each plot are:

First Card - (2I10, 3D10.2, I10, D10.2)

Columns 1-10: Card series number.

Columns 11-20: IDPLT - a number defining variable to be plotted vs time. (See Table A-1)

Columns 21-30: XMINP - minimum value of time (sec) for plot.

Columns 31-40: XMAXP - maximum value of time (sec) for plot.

Columns 41-50: XLENP - length of plot (in.) including vertical axis label. (Choose 8.5 for $(8\frac{1}{2} \times 11 \text{ sheet.})$)

Table A-1. Values of IDPLT for card series 25NN

IDPLT		
1100	Steam generator helium inlet pressure	psia
1200	Steam generator helium outlet pressure	psia
1300	Steam generator helium inlet temperature	°F
1400	Steam generator helium outlet temperature	°F
1500	Steam generator helium inlet flow rate	lbm/sec
1600	Steam generator helium outlet flow rate	lbm/sec
1700	Steam generator helium inlet enthalpy	Btu/lbm
1800	Steam generator helium outlet enthalpy	Btu/lbm
2100	Reheater helium inlet pressure	psia
2200	Reheater helium outlet pressure	psia
2300	Reheater helium inlet temperature	°F
2400	Reheater helium outlet temperature	°F
2500	Reheater helium inlet flow rate	lbm/sec
2600	Reheater helium outlet flow rate	lbm/sec
2700	Reheater helium inlet enthalpy	Btu/lbm
2800	Reheater helium outlet enthalpy	Btu/lbm
3100	Steam generator water inlet pressure	psia
3200	Steam generator water outlet pressure	psia
3300	Steam generator water inlet temperature	°F
3400	Steam generator water outlet temperature	°F
3500	Steam generator water inlet flow rate	lbm/sec
3600	Steam generator water outlet flow rate	lbm/sec
3700	Steam generator water inlet enthalpy	Btu/lbm
3800	Steam generator water outlet enthalpy	Btu/lbm
4100	Reheater water inlet pressure	psia
4200	Reheater water outlet pressure	psia
4300	Reheater water inlet temperature	°F
4400	Reheater water outlet temperature	°F
4500	Reheater water inlet flow rate	lbm/sec
4600	Reheater water outlet flow rate	lbm/sec
4700	Reheater water inlet enthalpy	Btu/lbm
4800	Reheater water outlet enthalpy	Btu/lbm

Table A-1. (Continued)

IDPLT	NNN $\equiv$ NODE NUMBER
11NNN	Helium pressure of node NNN, psia
12NNN	Helium temperature of node NNN, °F
13NNN	Helium flow rate of node NNN, lbm/sec
14NNN	Heat flux from helium node NNN, Btu/hr-ft ²
16NNN	Heat transfer coefficient for helium node NNN, Btu/hr-ft ² -°F
17NNN	Helium density of node NNN, lbm/ft ³
18NNN	Tube wall temperature, helium side, for tube node NNN, °F
22NNN	Tube temperature for tube node NNN, °F
31NNN	Water pressure of node NNN, psia
32NNN	Water temperature of node NNN, °F
33NNN	Water flow rate of node NNN, lbm/sec
34NNN	Heat flux to water for water node NNN, Btu/hr-ft ²
35NNN	Quality in water node NNN
36NNN	Heat transfer coefficient for water node NNN, Btu/hr-ft ² -°F
37NNN	Water density in node NNN, lbm/ft ³
38NNN	Tube wall temperature, water side, for tube node NNN, °F
50000	ΔP Helium node N1PLT to helium node N2PLT, psid
51000	ΔP Helium node N1PLT to water node N2PLT, psid
52000	ΔP Water node N1PLT to water node N2PLT, psid

Columns 51-60: Not used.

Columns 61-70: YMINP - minimum value of dependent variable for plot.

Second Card - (I10, 2D10.2, 2I10)

Columns 1-10: Value of series number on first card (for this plot) plus 1.

Columns 11-20: YMAXP - maximum value of dependent variable for plot.

NOTE: If YMINP and YMAXP are both input as 0.0, the code searches for a maximum and a minimum.

Columns 21-30: YLENP - height of plot (in.) including horizontal axis labels. (Choose 11.0 for 8-1/2 × 11 sheet.)

Columns 31-40: N1PLT - if plotting ΔP , N1PLT is the first node number for the ΔP . Otherwise N1PLT = 0.

Columns 41-50: N2PLT - if plotting ΔP , N2PLT is the second node number for the ΔP . Otherwise N2PLT = 0.

FSV ORTAP MODEL 1/3/77 ROD WITHDRAWAL FROM FULL IN ROOMWORTH = .012

	0	1	1				
	842.0	.9415	0.01090	.047	.20685E-4		
	3.39E+6	.87316	0.0354	.09145	0.4137E-4		
	6	4	2	3	4	8	
	1.00	1.00					
	0.245	0.005	0.42143	177.0			
	14.75	44.25	73.75	103.25	132.75	162.25	
	.06125	.1225	.18375	.245	.33635	.42143	
	270.6	0.56	108	66			
	46.8						
	0.3333	74					
	4820.0						
	1.0	1.0	1.0	0.6	1.0	1.0	
	46.8	0.309	1.1227	1			
FIG 3.5-10	0.74	1.08	1.35	1.15	0.99	0.69	
FSAR	20						
	20.	97500.	1	50			
	400.0	.0515	748.0				
TAB 3.5-10	6	1.00-10	3.410-4				
	0.000222	.001099	.000961	.001619	.00043	.000179	
	0.01251	0.03164	0.1199	0.3068	1.135	2.859	
	1390.1723	1506.7677					
	1.00-6	64	1.0				
	748.0000	748.0000	748.0000	1104.8443	1097.8612	1083.8950	1062.9453
	979.8318	953.7352	1358.9014	1348.7220	1328.3632	1297.8249	1176.6718
	1138.6314	1620.7499	1608.0339	1582.6022	1544.4552	1393.1200	1345.6028
	1688.9788	1678.1465	1656.4821	1623.9861	1495.0702	1454.5923	1751.4288
	1742.1021	1723.4489	1695.4697	1584.4726	1549.6210	1727.7276	1721.2248
	1709.2193	1688.7113	1611.3205	1587.0208	1482.6854	1482.6854	1482.6854
	748.0000	748.0000	748.0000	793.3721	904.8824	1053.6351	1206.6256
	1337.5954	1440.4373	1482.6854	1482.6854	1482.6854		
.0005059	341.67	8.6	1.0	0.4	0.43	0.22	50 0
747.87	930.82	1088.62	1248.66	1345.61	1432.38	1496.45	1438.32
747.80	1004.24	1187.31	1359.38	1435.50	1507.77	1555.44	1437.19
747.80	1007.36	1191.54	1364.18	1439.44	1511.11	1558.09	1437.20
747.80	1000.28	1181.95	1353.33	1430.56	1503.61	1552.18	1437.26
747.82	976.35	1149.61	1316.81	1400.73	1478.44	1532.36	1437.40
747.82	968.87	1139.52	1305.47	1391.49	1470.66	1526.25	1437.47
747.81	994.95	1174.72	1345.13	1423.83	1497.90	1547.65	1437.21
747.81	993.38	1172.60	1342.75	1421.88	1496.26	1546.36	1437.22
747.81	990.16	1168.24	1337.81	1417.85	1492.85	1543.68	1437.24
747.82	974.11	1146.58	1313.39	1397.93	1476.06	1530.47	1437.35
747.80	1032.16	1225.24	1402.44	1470.82	1537.69	1579.09	1437.16
747.81	996.12	1176.34	1347.00	1425.41	1499.29	1548.81	1437.39
747.80	1012.75	1198.86	1372.49	1446.25	1516.87	1562.64	1437.20
747.80	1013.09	1199.32	1373.01	1446.69	1517.24	1562.94	1437.21
747.80	1014.01	1200.59	1374.45	1447.89	1518.28	1563.77	1437.27
747.80	1036.42	1231.03	1409.01	1476.22	1542.25	1582.69	1437.12
747.81	984.54	1160.66	1329.28	1410.92	1487.04	1539.14	1437.40
747.80	1003.98	1186.95	1358.97	1435.16	1507.47	1555.19	1437.15
747.81	981.49	1156.55	1324.65	1407.15	1483.87	1536.65	1437.45
747.90	928.75	1085.81	1245.44	1342.84	1429.83	1494.12	1436.85
747.85	950.43	1114.73	1277.61	1368.76	1451.44	1510.98	1436.69
747.85	952.10	1116.96	1280.10	1370.76	1453.11	1512.28	1436.66
747.89	932.51	1090.79	1250.92	1347.19	1433.39	1496.84	1436.65
747.82	976.84	1150.26	1317.52	1401.26	1478.81	1532.54	1436.82
747.80	1035.42	1229.67	1407.46	1474.92	1541.11	1581.74	1436.79
747.83	976.34	1149.58	1316.77	1400.67	1478.33	1532.18	1436.88
747.81	1013.19	1199.44	1373.12	1446.73	1517.22	1562.83	1436.76
747.85	954.12	1119.71	1283.22	1373.37	1455.37	1514.14	1436.92
747.84	960.06	1127.67	1292.14	1380.60	1461.43	1518.88	1436.87
747.80	1054.71	1255.95	1437.37	1499.50	1561.97	1598.24	1436.79
747.81	1003.14	1185.82	1357.71	1434.13	1506.59	1554.48	1436.87
747.84	959.66	1127.14	1291.55	1380.14	1461.06	1518.61	1436.93
747.81	1022.25	1211.75	1387.09	1458.20	1526.93	1570.52	1436.77

747.83	974.99	1147.75	1314.69	1398.93	1476.84	1530.98	1436.77
747.90	926.82	1083.26	1242.62	1340.59	1427.97	1492.68	1436.88
747.81	999.02	1180.23	1351.36	1428.90	1502.14	1550.92	1436.76
747.80	1026.10	1216.98	1393.02	1463.05	1531.04	1573.75	1436.73
767.86	1088.79	1230.25	1319.45	1279.74	1254.04	1209.52	967.55
767.81	1086.30	1227.00	1315.90	1276.80	1251.55	1207.57	967.52
767.81	1086.79	1227.64	1316.59	1277.36	1252.02	1207.93	967.51
767.81	1086.84	1227.69	1316.65	1277.41	1252.06	1207.96	967.51
767.81	1086.37	1227.08	1315.99	1276.87	1251.60	1207.61	967.51
767.83	1087.53	1228.60	1317.64	1278.23	1252.75	1208.50	967.53
767.87	1089.05	1230.59	1319.83	1280.06	1254.31	1209.73	967.56
767.83	1087.58	1228.65	1317.69	1278.28	1252.80	1208.54	967.54
767.85	1088.46	1229.81	1318.96	1279.34	1253.69	1209.24	967.55
767.82	1086.95	1227.84	1316.81	1277.55	1252.17	1208.05	967.52
767.82	1087.13	1228.07	1317.06	1277.76	1252.35	1208.19	967.53
767.89	1089.56	1231.27	1320.57	1280.68	1254.84	1210.15	967.57
767.85	1088.25	1229.54	1318.66	1279.09	1253.48	1209.08	967.55
767.82	1087.13	1228.07	1317.06	1277.76	1252.35	1208.20	967.53
767.86	1088.70	1230.12	1319.31	1279.63	1253.94	1209.44	967.55
767.83	1087.47	1228.52	1317.55	1278.16	1252.69	1208.46	967.53
767.81	1086.25	1226.94	1315.83	1276.74	1251.50	1207.53	967.52
767.84	1088.10	1229.34	1318.45	1278.91	1253.33	1208.96	967.54

FORT ST VRAIN HEAT CYCLE -- 100 PCT CORE THERMAL POWER
 INFORMATION OBTAINED 5-76 FROM GA

12

0	0	50	0	0	0	0	0	1
1.0								
635.13								
1471.5	1443.0	1408.0	1359.2					
2412.	1907.	1402.	897.					
597.3	557.2	517.73	498.86	479.43	455.61			
19.40	20.70	39.47	18.87	19.43	23.82			
27.55	624.85							
1519.2	1460.	1429.	1365.	1339.	1302.			
1248.	1208.	1187.	1160.	1138.	1109.			
1080.	1070.	1160.	1109.	1070.	105.			
557.	362.	280.5	158.8	120.0	83.9			
47.6	27.5	20.	14.	10.	6.263			
3.	1.23	14.	6.263	1.23	1.23			
150.	1365.	1065.	1.48					
62.12	602.01	124.	170.	138.	5.77			
38.30	602.01	170.	204.	173.	13.0			
18.87	602.01	204.	236.	211.	25.3			
641.48	602.01	236.	303.8	303.90	77.3			
48.25	641.48	323.5	358.9	326.0	150.9			
27.55	641.48	358.9	403.8	269.0	252.0			
10.	30.	10.	1.7					
10.	26.5	10.	2.7					
10.	48.	10.	4.6					
150.0	465.	150.	5.4					
6.7	38.	6.7	4.75					
6.7	58.	6.7	5.5					
1471.5	382.7	2512.						
2.5	3.12	2.5	1.82					
2512.	887.0	591.0	631.5					
1471.5	1359.2	1519.2	1330.0					
0								
1001	00.1	100.	10.	00.1	500.	40.		
7001	621.5	1429.0	.003894	7.85	0	1		2
7002	2	88.	201	2				
7003	611.9	1495.0	.003894	7.85	0	1		1
7004	2	88.	1	215				
7005	2974.0	525.0	.002859	38.4	0	1		7
7006	3	54.0	230	4				
7007	2971.0	660.0	.002859	38.4	0	1		7
7008	3	54.0	3	5				
7009	2956.	840.0	.002859	25.51	0	1		6
7010	3	54.0	4	6				

7011	2951.0	975.0	.002859	11.69	0	1	5
7012	3	54.0	5	7			
7013	2946.0	1030.0	.002859	11.69	0	1	5
7014	3	54.0	6	8			
7015	2936.0	1133.0	.001650	12.15	0	1	4
7016	3	54.0	7	9			
7017	2884.0	1213.0	.001650	12.15	0	1	4
7018	3	54.0	8	10			
7019	2720.0	1420.0	.001899	49.81	1	0	3
7020	2	54.0	9	251			
7501	.59075	.425	.5625	.850	6	30.	0
7502	.0	.001	.019				
7503	.59075	.425	.5625	.850	6	30.	0
7504	.0	.001	.019				
7505	.98822	.362	.5	.724	6	30.	0
7506	.0	.003	.016				
7507	.98822	.362	.5	.724	6	30.	0
7508	.0	.003	.016				
7509	.98822	.362	.5	.724	6	30.	0
7510	.0	.003	.016				
7511	.98822	.362	.5	.724	6	30.	0
7512	.0	.003	.016				
7513	.98822	.362	.5	.724	6	30.	0
7514	.0	.003	.016				
7515	.98822	.275	.5	.55	6	30.	0
7516	.0	.004	.012				
7517	.98822	.275	.5	.55	6	30.	0
7518	.0	.004	.012				
7519	.98822	.295	.5	.59	6	30.	0
7520	.0	.0015	.013				
8001	689.4	2275.0	6.123	1.0	1.0	1	0
8002	180.0	201	2				
8003	689.1	2180.0	6.123	1.0	1.0	1	0
8004	180.0	1	215				
8005	688.6	2090.0	5.782	4.0	4.0	1	0
8006	600.0	230	4				
8007	688.3	2018.0	6.542	1.0	1.0	1	0
8008	180.0	3	5				
8009	688.0	1923.0	6.542	2.0	2.0	1	0
8010	540.0	4	6				
8011	687.3	1730.0	6.542	4.0	4.0	1	0
8012	720.0	5	7				
8013	686.7	1594.0	6.542	3.0	3.0	1	0
8014	540.0	6	251				
8015	688.9	2140.0	6.542	1.0	1.0	1	0
8016	200.0	215	9				
8017	688.85	2140.0	6.542	1.0	1.0	1	0
8018	200.0	8	10				
8019	688.80	2140.0	6.542	1.0	1.0	1	0
8020	200.0	9	230				
8501	78.936	1.125	0.0	1.0	4	2	1.4
8502	1.4						
8503	78.936	1.125	0.0	1.0	4	2	1.4
8504	1.4						
8505	78.936	1.0	0.0	1.0	15	5	1.48
8506	1.44						
8507	78.936	1.0	0.0	1.0	15	5	1.42
8508	1.47						
8509	78.936	1.0	0.0	1.0	15	5	1.42
8510	1.47						
8511	78.936	1.0	0.0	1.0	15	5	1.42
8512	1.47						
8513	78.936	1.0	0.0	1.0	15	5	1.42
8514	1.47						
8515	78.936	1.0	0.0	-1.0	0	0	1.40
8516	1.40						
8517	78.936	1.0	0.0	-1.0	0	0	1.40
8518	1.40						

8519	78.936	1.0	0.0	-1.0	0	0	1.40
8520	1.40						
9001	8	10					
9201	1.0	0.1					
18001	1	0.0	.98822				
18101	2	0.0	2850.	1000.	2850.		
18201	1	0.0	394.35				
18501	1	0.0	78.936				
18601	2	0.0	689.6	1000.	689.6		
18701	1	0.0	2351.6				