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TECHNICAL DATA RECORD

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DEPT. & GROUP NO.

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DATE 3/5/64

GO NO. 7623

TITLE

TRANCORE-10A: A Digital Program
Evaluating Transient Temperatures
Within the SNAP 10A Reactor Core

S/A NO. 1341

TWR

SECURITY CLASSIFICATION

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PROGRAM

SNAP 10A/2

SUBACCOUNT TITLE

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SNAP 10A Thermal and
Hydraulic Analysis

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Thermal Analysis

Unit (6)

STATEMENT OF PROBLEM

Develop a mathematical model of the SNAP 10A reactor for predicting transient temperatures within the reactor core under various operating conditions.

ABSTRACT:

A mathematical model has been developed which describes the reactor kinetics, core heat transfer and thermoelectric pump performance of the SNAP 10A system. From the model, a digital computer code, "TRANCORE-10A", has been prepared which predicts transient temperatures within the reactor core. The code can be used to investigate a wide variety of reactor operational behavior: steady-state, startup, scram, loss of coolant flow, etc. It has been used extensively to predict startup transients. However, the code cannot be used to evaluate the effects of rapid reactivity changes, i.e., operation near prompt critical.

The digital code is divided into three routines: core heat transfer, reactor kinetics and thermoelectric pump. The heat transfer model considers a fuel element with its associated lower and upper end caps, upper grid plate and surrounding coolant. Depending on the radial power factor used, the model is representative of fuel elements at various radial locations within the core. The kinetics routine simulates the nuclear behavior of the reactor and generates reactor power as a function of time. Coolant flow rate is generated by the pump routine. If the variations of power and flow rate are assumed and introduced into the code as inputs, the heat transfer routine can be run independently of the other two.

A known inlet temperature variation can be introduced into the code as an input, or the inlet temperature can be calculated by an option within the pump routine.

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~~CONFIDENTIAL~~Nomenclature and SymbolsHeat Transfer Routine

- A - area for heat transfer, ft^2
- C - specific heat, $\text{Btu/lb-}^\circ\text{F}$
- h - convective heat transfer coefficient, $\text{Btu/hr-ft}^2\text{-}^\circ\text{F}$
- K - thermal conductance between nodes, $\text{Btu/hr-}^\circ\text{F}$
- k - thermal conductivity, $\text{Btu/hr-ft-}^\circ\text{F}$
- M - mass of node, lb
- q''' - internal heat generation per unit volume, Btu/hr-ft^3
- r - radial coordinate, ft
- T - temperature of node, $^\circ\text{F}$
- T' - temperature of node at next time interval, $^\circ\text{F}$
- U - thermal conductance between surface fuel node and adjacent coolant node, $\text{Btu/hr-ft}^3\text{-}^\circ\text{F}$
- V - volume of node, ft^3
- w - coolant flow rate per fuel element, lb/hr
- z - axial coordinate, ft
- $\Delta\tau$ - time increment

Subscripts (refer to):

- b - lower end cap node
- c - coolant node
- f - fuel node
- g - upper grid plate node
- in - core inlet
- out - core outlet
- p - upper plenum
- r - adjacent radial nodes
- t - upper end cap node
- z - adjacent axial nodes

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- c_i - neutron concentration in i^{th} delay group, nt/cm^3
- C_i - c_i/c_{i0} , normalized neutron concentration in i^{th} delay group
- k - effective multiplication factor
- l - total neutron lifetime, hr
- n - neutron concentration, nt/cm^3
- N - n/n_0 , normalized neutron concentration
- S - neutron source, $\text{nt}/\text{cm}^3\text{-hr}$
- T - temperature, $^{\circ}\text{F}$
- α - temperature coefficient of reactivity, $\$/^{\circ}\text{F}$
- β - fraction of neutrons which are delayed
- δk - excess multiplication
- $\rho(\tau)$ - reactivity inserted by fine control drums, $\$$
- ρ_T - total reactivity, $\$$
- ρ_0 - shutdown reactivity, $\$$
- $\Delta\rho_0$ - reactivity step at zero time (coarse drums), $\$$
- λ_i - delay constant for i^{th} precursor, hr^{-1}
- τ - time, hr

Subscripts (refer to):

- f - fuel
- g - grid plates
- i - i^{th} delay group of neutrons
- LG - lower grid plate
- o - initial concentration (at zero time)
- ref - reference temperature, 70°F
- UG - upper grid plate

Thermoelectric Pump Routine

- a_{te} - area of thermoelectric element, in^2
- b - height of pump throat, in
- d - pump wall thickness, in
- e - electrical resistivity of thermoelectric, ohm-in

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- E_{te} - voltage produced by one thermoelectric (plus associated batteries), volts
 E_p - required pump voltage, $E_{te} - I(2R_{cu} + R_{bus})$
 I - total current, amps
 k - a_{te}/ρ_b
 K_I - inertial constant, $\frac{1}{g} \sum \frac{L}{A}$, 0.4625 #sec²/in²lb
 K_1 - constant, 0.12×10^{-6}
 K_2 - constant, 8.84×10^{-8}
 K_3 - $K_1 K_2$, 1.061×10^{-14}
 Q - width of pump, in
 L - length of pump, in
 L/A - length to cross-sectional area ratio of piping, in⁻¹
 r - electrical resistivity, ohm-in
 R - electrical resistance, ohm
 S - Seebeck coefficient, volts/°F
 t - thickness of thermoelectric element, in
 $\bar{T}$ - average temperature, °F
 ΔT - temperature difference, °F
 V - velocity of fluid in pump throat, ft/sec
 w - flow rate, lb/sec
 $\dot{w}$ - flow acceleration, lb/sec²
 X_1 - dr_{wall}/br_{NaK}
 X_2 - de/br_{NaK}
 ΔP_F - frictional pressure drop, psi
 ΔP_I - inertia pressure drop, psi
 ΔP_P - pressure rise across pump, psi
 π - Peltier coefficient, $S\bar{T}_{te}$, volts
 τ - time, sec
 $\Delta\tau$ - time increment, sec

Subscripts (refer to):

- bus - bus between electrodes
 cu - copper conductor
 NaK - NaK in pump throat
 te - thermoelectric element
 wall - pump throat wall

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~~CONFIDENTIAL~~Introduction

To simulate transient behavior of the SNAP 10A reactor, the digital computer code, TRANCORE-10A, was prepared by the Thermal Analysis Unit of the SNAP 10A/2 Reactor Engineering Group. The code is used to determine transient temperatures and, subsequently, thermal stresses within the reactor core. In addition, the code predicts power, flow rate and reactor inlet and outlet temperatures.

The code can be used to investigate many types of reactor operational behavior: steady-state, startup, scram, loss of coolant flow, flow and/or power perturbations from steady-state, etc. The code has been extensively used to predict startup transients. In particular, the effects of variations in source strength, drum stepping rate, fuel temperature coefficient of reactivity and overall thermal conductance (UA) have been investigated (Refs. 1, 2, 3).

The code is specifically written for the SNAP 10A reactor system, but with minor modifications (e.g., dimensions, number of fuel elements, drum worth curves) the heat transfer and kinetics routines are applicable to any SNAP reactor. Extensive rewriting of the thermoelectric pump routine will be required before it adequately simulates other pump systems. While the basic electromagnetic pump equations are generally valid, the forms of the equations in the routine are extremely dependent on the physical configuration of the pump.*

General Description of Code

The digital code is divided into three routines: core thermal response, reactor kinetics and thermoelectric pump. A schematic of the basic code indicating the various inputs and outputs of each of the three routines is shown in Figure 1. As one would anticipate, the three sections are interrelated: core temperatures are dependent on the reactor power, flow rate and inlet temperature; power is dependent on average fuel and grid plate temperatures; and the flow rate is dependent on the reactor outlet temperature.

The heat-transfer routine, using the physical constants associated with the 10A reactor, calculates temperatures for one or two fuel elements within the core. The model consists of a fuel element with its associated lower and upper end caps, upper grid plate and surrounding coolant. Average upper and lower plenum temperatures and the average lower grid plate temperature are also calculated. Required inputs to this routine are reactor power, flow rate and inlet temperature. These are obtained from the kinetics and thermoelectric pump routines or else supplied as input data.

* A SNAP 2A thermoelectric pump simulation is currently being developed and will be incorporated in TRANCORE-2.

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The reactor kinetics routine simulates the nuclear behavior of the reactor and generates reactor power as a function of time. External inputs required are drum worth, drum stepping rate, source strength and shutdown reactivity. In addition, the core average fuel and upper and lower grid plate temperatures, calculated by the heat transfer routine, are used in the determination of reactivity changes.

Coolant flow rate is generated by the thermoelectric pump routine. The mathematical model simulates the thermal, electrical and hydraulic behavior of the LOA pump. The only required inputs are the reactor outlet temperature and the equivalent space temperature. An option within the pump routine permits calculation of the reactor inlet temperature by means of a simplified system heat-transfer equation.

The mathematical models used in the three routines are described in detail in the following sections.

Heat-Transfer Routine

The thermal model of the reactor core considers one fuel element with its associated lower and upper end caps, upper grid plate, surrounding coolant and the upper and lower plenums. As shown in Figure 2, the fuel element is divided into five radial and ten axial sections to give a fifty node representation. Ten coolant nodes are employed, at axial positions identical to those of the fuel nodes. The associated upper end cap and grid plate are each divided into five radial nodes, matching those of the fuel elements.

Energy balances on each node are programmed for digital solution. The general form of the finite difference equation for each specific type of node is given below:

a. Interior fuel node

$$M_f C_f \frac{T_f' - T_f}{\Delta \tau} = q_f'''(z, r) V_f + \sum k_f A_z \frac{\Delta T_f}{\Delta z} + \sum k_f A_r \frac{\Delta T_f}{\Delta r} \quad (1)$$

where $M_f C_f$ = heat capacity of node

$q_f'''(z, r) V_f$ = product of local internal heat generation rate and the node volume. The heat generation rate is a function of axial position along the fuel element and the radial position of the element: e.g., centerline, average, edge of core.

$\sum k_f A_z \frac{\Delta T_f}{\Delta z}$ = rate of heat conducted into the node from axially adjacent fuel nodes.

$\sum k_f A_r \frac{\Delta T_f}{\Delta r}$ = rate of heat conducted into the node from radially adjacent fuel nodes.

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b. Surface fuel node

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$$M_f C_f \frac{T'_f - T_f}{\Delta \tau} = q_f''' V_f + \sum k_f A_z \frac{\Delta T_f}{\Delta z} + \sum k_f A_r \frac{\Delta T_f}{\Delta r} - UA(T_f - T_c) \quad (2)$$

$UA(T_f - T_c)$ = rate of heat flow to adjacent coolant node at temperature T_c .

c. End-of-element fuel node

$$M_f C_f \frac{T'_f - T_f}{\Delta \tau} = q_f''' V_f + \sum k_f A_z \frac{\Delta T_f}{\Delta z} + \sum k_f A_r \frac{\Delta T_f}{\Delta r} + K_b(T_b - T_f) - UA(T_f - T_c) \quad (3)$$

(The latter term is included only for the surface nodes)

d. Lower end cap node

$$M_b C_b \frac{T'_b - T_b}{\Delta \tau} = q_b''' V_b + \sum k_b A_r \frac{\Delta T_b}{\Delta r} + K_b(T_b - T_f) - UA_b(T_b - T_{in}) \quad (4)$$

(The latter term is included only for the surface node)

$q_b''' V_b$ = rate of heat generation within end cap node.

$K_b(T_f - T_b)$ = rate of heat conducted into end cap node from adjacent fuel node at end of element.

e. Upper end cap node

$$M_t C_t \frac{T'_t - T_t}{\Delta \tau} = q_t''' V_t + \sum k_t A_r \frac{\Delta T_t}{\Delta r} + K_t(T_f - T_t) + K_g(T_g - T_t) - UA_t(T_t - T_{out}) \quad (5)$$

(The latter term is included only for the surface node)

$K_t(T_f - T_t)$ = rate of heat conducted into end cap node from adjacent fuel node at end of element.

$K_g(T_g - T_t)$ = rate of heat conducted into end cap node from adjacent grid plate node (includes effect of stagnant NaK layer between end cap and grid plate).

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f. Upper grid plate node

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$$M_g C_g \frac{T'_g - T_g}{\Delta \tau} = q_g''' V_g + \sum k_g A_r \frac{\Delta T_g}{\Delta r} + K_g (T_t - T_g) - A_p h_p (T_g - T_p) \quad (6)$$

$A_{p p} h_p$ = thermal conductance between grid plate and bulk fluid in upper plenum at temperature T_p .

g. Coolant node

$$M_c C_c \frac{T'_c - T_c}{\Delta \tau} = U A (T_f - T_c) + w C_c \Delta T_c \quad (7)$$

$w C_c \Delta T_c$ = rate of heat convection into coolant node.

$\Delta T_c = \frac{1}{2} [T_{c,i-1} - T_{c,i+1}]$ for general coolant node.

$T_m - \frac{1}{2} [T_{c,1} + T_{c,2}]$ for first node.

$T_{c,9} - T_{c,10}$ for last node.

A mixing routine is used to relate the bulk fluid temperature in the upper plenum to that of the coolant leaving the core. The upper plenum temperature is calculated only for the core average element as the coolant streams exiting past other elements are not necessarily at the average exit temperature.

$$M_p C_c \frac{T'_p - T_p}{\Delta \tau} = 37w C_c (T_{out} - T_p) \quad (8)$$

where $37w$ = total flow rate

$T_{out} = 0.5 (3 T_{c10} - T_{c9})$, linear approximation for core exit temperature.

Because of radial power peaking, the power generation rate on the center-line element is 31 per cent greater than the core average and the rate on the edge element is 35 per cent less than the average. Heat generation terms for individual nodes along the axis of the fuel rod are weighted according to the axial power distribution, as shown in the following table:

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<u>Nodes</u>	<u>Axial Power Factor</u>
1-5	0.35
11-15	0.76
21-25	1.09
31-35	1.32
41-45	1.45
51-55	1.45
61-65	1.32
71-75	1.09
81-85	0.76
91-95	0.35

The mean temperature of the fifty fuel nodes is taken as the average fuel temperature. An average coolant temperature is similarly determined from the ten coolant node temperatures. Core average upper and lower grid plate temperatures are calculated for use with the kinetics routine.

Temperatures employed in the reactivity calculations (average fuel, upper and lower grid plate temperatures) must be those associated with the core average fuel element. However, the most severe thermal stresses occur on the centerline element and, consequently, the transient temperatures within this element are of primary importance. Therefore, an option is provided whereby temperatures of any two elements in the core can be calculated simultaneously. (If the kinetics routine is used, the first element must be the core average element.)

Kinetics Routine*

The standard six delay group reactor kinetics equations are

$$\frac{dn}{d\tau} = \frac{\delta k}{\ell} n - \frac{\beta k}{\ell} n + \sum_{i=1}^6 \lambda_i c_i + S \quad (9)$$

and, for $i = 1$ to 6 ,

$$\frac{dc_i}{d\tau} = \frac{\beta_i k}{\ell} n - \lambda_i c_i \quad (10)$$

* Abstracted from Reference 4.

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Implicit in these equations are the following assumptions:

1. The neutrons can be assumed to be in one energy group.
2. The flux is spatially independent.
3. The reactor is near criticality.
4. The reactor is not reflected.

Equation 9 can be rewritten in terms of the total reactivity, ρ_T , as

$$\frac{dn}{d\tau} = \frac{\beta k}{\ell} (\rho_T - 1) n + \sum_{i=1}^6 \lambda_i c_i + S \quad (11)$$

The neutron concentration (or multiplied source) at zero time is

$$n_0 = - \frac{\ell S}{\beta k_0 \rho_0}$$

and the number of neutrons in the i^{th} delay group at zero time is

$$c_{i,0} = \frac{\beta_i k_0 n_0}{\ell \lambda_i}$$

If dimensionless variables,

$$N = \frac{n}{n_0}$$

and

$$C_i = \frac{c_i}{c_{i0}}$$

are introduced, the kinetics equations can be normalized to give

$$\frac{dN}{d\tau} = \frac{\beta}{\ell} \left[k (\rho_T - 1) N + k_0 \sum_{i=1}^6 \frac{\beta_i}{\beta} C_i - \rho_0 k_0 \right] \quad (12)$$

and, for $i = 1$ to 6,

$$\frac{dC_i}{d\tau} = \lambda_i \left[\frac{k}{k_0} N - C_i \right] \quad (13)$$

To reduce the computing time required for solution, these equations are simplified by the use of the following assumptions:

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1. $\lambda/\beta = 0$ For the SNAP 10A/2 system $\beta/\lambda \approx 1600$ or $\lambda/\beta \approx .000625$.
2. $C_6 = N$ The neutrons in the sixth delayed group are considered as prompt. This assumption and the fact that β_6/β is small permit the calculational time step to be expanded by a factor of two or three with little loss in accuracy.
3. $k = k_0$

The reduced equations, suitable for computer solution, are

$$N = (\rho_0 - \sum_{i=1}^6 \frac{\beta_i}{\beta} C_i) / (\rho_T - 1) \quad (14)$$

$$\frac{dC_i}{d\tau} = \lambda_i (N - C_i) \quad \text{for } i = 1 \text{ to } 5 \quad (15)$$

and

$$C_6 = N \quad (16)$$

For the SNAP 10A/2 reactor, the total reactivity equals the shutdown reactivity ρ_0 plus the reactivity added by the coarse drums $\Delta\rho_0$ plus the fine drum reactivity $\rho(\tau)$, added in incremental steps, minus the reactivity losses due to negative fuel and grid plate temperature coefficients:

$$\rho_T = \rho_0 + \Delta\rho_0 + \rho(\tau) + \alpha_f (\bar{T}_f - T_{ref}) + \alpha_g (\bar{T}_{UG} + \bar{T}_{LG} - 2T_{ref}) \quad (17)$$

Because of the assumptions made in the kinetics model (particularly $\lambda/\beta = 0$ which implies $dN/d\tau = 0$), the routine cannot accurately evaluate very rapid reactivity changes. In other words, the model is inadequate when the reactor behavior approaches prompt critical. However, it accurately predicts the slower transients which are encountered during startups and normal operation.

A comparison of results obtained from the simplified equations and from the standard AIREK III kinetics code has been made by J. Gordon and is reported in Reference 4. A hypothetical test case, closely resembling SNAP reactor startup, was run. The maximum difference in neutron flux predicted by the two codes is less than 6.5% and occurs between one and ten per cent of peak power. The two codes predict identical peak powers and total energy releases. The running time for the new code was half that for AIREK III.

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Power and flow perturbations from steady state can be determined by use of an option within the kinetics routine. If a negative source strength is read in as initial data, a specified power will be maintained for a time TAUPI. This time must be sufficient to allow all temperatures to reach their steady-state values. Beyond TAUPI, the kinetics routine will calculate the instantaneous reactivity and power level using the simplified kinetics equations. Thus, after the system has reach steady state, an arbitrary amount of reactivity can be added (or subtracted) at time TAUPI and the perturbations resulting from this reactivity insertion can be determined. Or, a flow perturbation can be inserted at time TCUT and the subsequent response of the system determined.

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Thermoelectric Pump Routine

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This routine simulates the behavior of the thermoelectric liquid-metal pump and generates the instantaneous coolant flow rate. Required inputs are the reactor outlet temperature and the equivalent space temperature.

The pump, located above the reactor on the coolant exit line, consists of three major components: a D.C. electromagnetic liquid-metal pump, two positive and two negative thermoelectric elements, and four heat-radiating fins. Heat flow is from the relatively hot NaK in the throat of the pump out through copper conductors and the thermoelectric elements and along the fins which radiate to space. The imposed temperature differences across the thermoelectric elements generate a D.C. voltage by the Seebeck effect. This voltage sets up a current through the NaK at right angles to the field of the attached permanent magnet. The resulting electromagnetic interaction produces a force within the NaK, driving the coolant through the pump and around the loop.

The computer simulation is accomplished by solving finite-difference approximations to the basic pump equations. These are of three types: nodal thermal equations, electrical circuit equations, and pressure-momentum flow equations.

The thermal model, illustrated in Figure 3, consists of ten nodes of heat capacity connected by thermal resistances. The conductance path is from the NaK in the pump throat through the thermoelectric elements and along the fins. Heat is radiated from each of the fin nodes to the assumed equilibrium space temperature. Nodes 3 and 4 are located on the edges of the model thermoelectric; their temperature difference is that across the thermoelectric.

The thermal model is complicated by two thermoelectric effects not found in normal heat-transfer situations. First, the current flow produces significant resistance (I^2R) heating in the thermoelectrics. In the thermal model, this internal heating is split evenly between nodes 3 and 4. Second, the heat transfer across the thermoelectric is reduced by the Peltier effect. When a current flows through a thermoelectric device, heat is transferred from one side of the thermoelectric to the other in such a direction as to oppose the current flow. This "Peltier heat" is proportional to the current, the coefficient of proportionality being the Peltier coefficient π , which equals the Seebeck coefficient times the average absolute temperature of the thermoelectric ($\pi = S \bar{T}_{te}$). Thus, in the 10A pump model, the heat transfer between nodes 3 and 4 is decreased an amount $S \bar{T}_{te} I/2$, and the temperature difference is correspondingly reduced.

The electrical circuit of the pump and a simplified equivalent circuit are shown in Figure 4. The voltage (E_{te}) generated by each thermoelectric element is equal to its Seebeck coefficient times the temperature difference across the thermoelectric ($S \Delta T_{te}$). The voltage also includes that generated by the batteries installed to insure 6-per-cent flow prior to orbital startup. The basic circuit equation is

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$$2E_{te} = I \left(2R_{te} + 2R_{Cu} + R_{bus} + \frac{R_{NaK} R_{wall}}{R_{NaK} + R_{wall}} \right) + K_1 B \ell V \left(\frac{R_{wall}}{R_{NaK} + R_{wall}} \right) \quad (18)$$

where

 E_{te} = total voltage produced by one thermoelectric element (plus associated batteries). $K_1 B \ell V$ = voltage drop due to NaK flow in pump throat at velocity V .

The pressure-momentum equation expresses the physical fact that the pressure drop around the NaK loop must be exactly matched by the pressure rise across the pump. The pressure losses are of two types: (1) inertia losses due to acceleration of the fluid and (2) hydraulic friction losses.

The inertia losses are given by

$$\Delta P_I = \frac{1}{g_c} \sum \frac{L}{A} \dot{w} = K_I \dot{w} \quad (19)$$

In this equation, $\sum \frac{L}{A}$ is the composite length to cross-sectional area ratio of the total piping in the system: that is, the sum of the length to cross-sectional areas of the individual runs of piping (including the pump and treating the parallel converter tubes as one composite tube). $\dot{w}$ is the rate of change of flow rate (flow acceleration).

Frictional pressure losses have been experimentally determined as a function of flow rate for the FS-1 system by J. V. Addison (Reference 5). These results are applicable to the other flight systems as well. A best fit curve to the experimental data is

$$\Delta P_F = 0.619 w^{1.782} \quad (20)$$

where

 ΔP_F = frictional pressure drop, psi w = NaK flow rate, lb/min

This equation is an excellent representation of the experimental data over the range measured, 12.5 lb/min to 95 lb/min, and should be adequate at lower flow rates, down to and below the 4.92 lb/min minimum flow provided by the batteries.

The pressure developed across the pump can be expressed as (References 6 and 7)

$$\Delta P_P = \left[K_2 E_P B - \frac{K_3 B^2 V}{b \ell} \left(4 \frac{x_2 t}{k} + \ell \right) \right] \frac{L}{r_1 \ell + \frac{2 E t}{k} (1 + 2 x_1)} \quad (21)$$

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The first term in the bracket is the total head generated by the electromagnetic pump; the second term is the magnetohydrodynamic losses within the pump.

Numerical calculations are made by the pump routine, at each increment of time, in the following order:

1. Using the reactor outlet temperature calculated by the heat transfer routine at time $\tau + \Delta\tau$, new temperatures throughout the pump are determined. The current at the previous time increment τ is used to evaluate the Peltier effect and the internal resistance heating.
2. The thermoelectric voltage is calculated as $\bar{S} \Delta T_{te}$ where $\bar{S}$ is the Seebeck coefficient averaged between the "N" and "P" elements.
3. The pressure head developed by the pump ΔP_p is estimated. (Note that the velocity V used is that at the previous time increment.)
4. The flow acceleration is given by

$$\dot{w} = (\Delta P_p - \Delta P_f) / K_I$$

5. The flow rate at the mid-point of the time interval, $\tau + \frac{1}{2}\Delta\tau$, is calculated:

$$w(\tau + \frac{1}{2}\Delta\tau) = w(\tau) + \frac{1}{2} \dot{w} \Delta\tau$$

6. The NaK velocity in the pump throat, corresponding to this flow rate, is found.
7. The total electrical current is calculated.
8. The calculations of pressure head and acceleration are repeated and the flow rate at time $\tau + \Delta\tau$ is determined.

The thermoelectric pump model has been checked in three ways. First, the thermal model, excluding resistance heating and Peltier effect, was compared to a 48-node model solved by the standard Thermal Analyzer (TAP-2) computer program. Agreement within one per cent was found at steady-state and during reactor outlet temperature transients more severe than startup. Second, the reactor outlet temperature determined for the nominal 10A startup by a Space Systems Department analog study (Reference 8) was programmed as input to the pump routine. The flow rate generated by the routine was compared to that predicted by the analog study and the two were found to be in excellent agreement (Reference 3). Finally, the entire digital code was used to simulate 10A startup. The results are in good agreement with those from the Space System Department analog study.

Comparison with SSD Analog Startup Analysis

An analog model of the SNAP 10A flight system has been developed by G. S. Drucker of the Space Systems Department. The model simulates the complete

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APU system behavior during startup and includes reactor kinetics, thermo-electric pump, sensor-actuated controls and system thermal and hydraulic response. Although the analog is not designed to provide detailed information on the reactor (having only three fuel and three coolant nodes in its core thermal model), it does furnish a good comparison for the digital model discussed in this report; certainly the two should be relatively compatible in predicting gross behavior of the 10A reactor.

Results obtained from the two models are compared in Figure 5 for nominal startup conditions (Reference 8). The curves of power, reactor outlet temperature and flow rate are for the first 210 seconds past sensible heat (defined as 100 watts). The excess reactivity inserted at sensible heat is approximately 26.5 cents. The digital analysis assumes a constant reactor inlet temperature of 70 F. The validity of this approximation during the initial startup transient is indicated by the curve of inlet temperature generated by the analog study. Due to the long transport time of the fluid around the system, the increase in reactor outlet temperature is not reflected in the inlet temperature until 170 or 180 seconds past sensible heat. Consequently, the assumption of constant inlet temperature is reasonably valid until approximately the time of maximum outlet temperature and flow rate.

The peak values of power, outlet temperature and flow rate predicted by the two models are almost identical, a maximum difference of 7.5% occurring in peak flow rate. The shapes of the curves are similar but some differences in timing can be seen. In particular, the delay time between peak power and maximum outlet temperature is approximately 20 seconds less for the digital study than for the analog. This timing difference is due to differences within the thermal models of the two studies and is not serious.

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FIGURE 1
BLOCK DIAGRAM OF CODE

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FIGURE 2
CORE THERMAL MODEL

Notes

1. Radial location of fuel nodes.

No	Distance from 4, in
1	0.203
2	0.326
3	0.425
4	0.504
5	0.572

2. Fuel nodes have equal volume.

3. Required inputs for heat transfer routine are coolant inlet temperature, flowrate & reactor power as functions of time.

4. Thermal resistance from coolant nodes to outermost fuel nodes (5, 15, etc.) include effect of film, clad, barrier, gas gap & 0.032 in. of fuel.

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FIGURE 3
PUMP THERMAL MODEL

Heat Capacity

Node	Btu/°F	
2	.01001	Wall + 1/2 Cu
3	.01645	1/2 Cu + 1/2 TE
4	.02275	1/2 TE + Fin
5	.01827	Fin
6	.0692	Fin
7	.0769	Fin
8	.0881	Fin
9	.0786	Fin
10	.0420	Fin

Thermal Resistance

Between Nodes	sec °F/Btu
1-2	493
2-3	123
3-4	2560
4-5	833
5-6	278
6-7	182
7-8	208
8-9	251
9-10	545

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FIGURE 4
T/E PUMP ELECTRICAL CIRCUIT

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FIGURE 3
SNAP 10A INITIAL STARTUP TRANSIENT-
COMPARISON OF ANALOG AND DIGITAL STUDIES

Sensible heat = 100 watts

Nominal startup conditions (Ref. 5)

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APPENDIX A

Program Inputs

The required inputs for the program are listed in the following table. The first 15 cards are required on all runs. Cards 16 and 17 are required only if the kinetics routine is used to generate reactor power; cards 18, 19, and 20 are required if the flow rate is calculated by the thermoelectric pump routine. Units of all quantities are given in the table as well as constants for the SNAP 10A core (i.e., conductances between nodes, axial power factors, etc.)

Main Program

Card 1:	1.	RUN	Run number [integer]
	2.	24 spaces,	alpha-numeric
	3.		Identification of run
			i.e. = NOM RUN, AVG AND CL ELEM STEP = 300 SEC, AVG ELEM CHECK ON KINETICS ROUT.
Card 2:	1.	TØ	Initial temperature of system [°F]
	2.	DELTAU	Time step for computations [hr]
	3.	TAUL	Maximum running time [hr]
	4.	PF	Printing frequency [hr]
	5.	PWR	Nominal power [kw]
	6.	FLØW	Nominal flow per fuel element [lb/hr per element]
Card 3:	1.	FRAD	Radial power factor for first element (1.00 avg. element)
	2.	FRAD2	Radial power factor for second element (1.31 $\frac{1}{2}$ element)
	3.	QE	Heat generated in upper end cap node at nom. power [.11 Btu/hr]
	4.	QG	Heat generated in upper grid plate node at nom. power [.1609 Btu/hr]
	5.	TLIM	Temperature limit; used as check [°F]
	6.	CA	Axial conductance along fuel [.203 Btu/hr °F]
Card 4:	1.	CAE	Axial conductance fuel to end cap [.245 Btu/hr °F]
	2.	CAG	Axial conductance upper end cap to grid plate [2.67 Btu/hr °F]
	3.	CR(1)	Radial conductance fuel nodes 1 to 2 [18.3 Btu/hr °F]
	4.	CR(2)	Radial conductance fuel 2 to 3 [32.2 Btu/hr °F]
	5.	CR(3)	Radial conductance fuel 3 to 4 [49.5 Btu/hr °F]
	6.	CR(4)	Radial conductance fuel 4 to 5 [66.1 Btu/hr °F]

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Card 5:

1. CRS	Radial conductance fuel node 5 to coolant	[16.1 Btu/hr °F]
2. CRE(1)	Radial conductance end cap nodes 1 to 2	[1.29 Btu/hr °F]
3. CRE(2)	Radial conductance end cap nodes 2 to 3	[2.26 Btu/hr °F]
4. CRE(3)	Radial conductance end cap nodes 3 to 4	[3.47 Btu/hr °F]
5. CRE(4)	Radial conductance end cap nodes 4 to 5	[4.65 Btu/hr °F]
6. CRES	Radial conductance end cap node to coolant	[3.05 Btu/hr °F]

Card 6:

1. CRG(1)	Radial conductance grid plate nodes 1 to 2	[2.59 Btu/hr °F]
2. CRG(2)	Radial conductance grid plate nodes 2 to 3	[4.55 Btu/hr °F]
3. CRG(3)	Radial conductance grid plate nodes 3 to 4	[6.98 Btu/hr °F]
4. CRG(4)	Radial conductance grid plate nodes 4 to 5	[9.36 Btu/hr °F]
5. CF	Fuel node heat capacity	[.00916 Btu/°F]
6. CE	End cap node heat capacity	[.000531 Btu/°F]

Card 7:

1. CG	Upper grid plate node heat capacity	[.000911 Btu/°F]
2. CC	Coolant node heat capacity	[.00120 Btu/°F]
3. FA(1)	Axial power factor nodes 1 - 5	[0.35]
4. FA(2)	Axial power factor nodes 11-15	[0.76]
5. FA(3)	Axial power factor nodes 21-25	[1.09]
6. FA(4)	Axial power factor nodes 31-35	[1.32]

Card 8:

1. FA(5)	Axial power factor nodes 41-45	[1.45]
2. FA(6)	Axial power factor nodes 51-55	[1.45]
3. FA(7)	Axial power factor nodes 61-65	[1.32]
4. FA(8)	Axial power factor nodes 71-75	[1.09]
5. FA(9)	Axial power factor nodes 81-85	[0.76]
6. FA(10)	Axial power factor nodes 91-95	[0.35]

Card 9:

1. P(1)	First set of power coefficients
2. P(2)	If $\text{TAU} \leq \text{TAUPI}$, power ratio = $P_1 + P_2\tau + P_3\tau^2$
3. P(3)	(power ratio = act. power/nominal power)
4. P(4)	Second set of power coefficients
	If $\text{TAUPI} < \text{TAU} \leq \text{TAUP}_2$, power ratio =
5. P(5)	$P_4 + P_5\tau + P_6\tau^2$
6. P(6)	

Card 10:

1. P(7)	Third set of power coefficients
2. P(8)	If $\text{TAU} > \text{TAUP}_2$, power ratio = $P_7 + P_8\tau + P_9\tau^2$
3. P(9)	
4. TAUPI	First time division, power [hr]
5. TAUP2	Second time division, power [hr]
6. W(1)	First set of flow coefficients

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- Card 11: 1. W(2) If $\text{TAU} \leq \text{TAUWI}$, $\text{WRATIO} = W_1 + W_2\tau + W_3\tau^2$
 2. W(3) where $\text{WRATIO} = \text{act. flow/nominal flow}$
 3. W(4) Second set of flow coefficients
 4. W(5) If $\text{TAUWI} < \text{TAU} \leq \text{TAUW2}$, $\text{WRATIO} = W_4 + W_5\tau + W_6\tau^2$
 5. W(6)
 6. W(7) Third set of flow coefficients
- Card 12: 1. W(8) If $\text{TAU} > \text{TAUW2}$, $\text{WRATIO} = W_7 + W_8\tau + W_9\tau^2$
 2. W(9)
 3. TAUWI First time division, flow [hr]
 4. TAUW2 Second time division, flow [hr]
 5. TINL(1) First set of inlet temperature coefficients
 6. TINL(2)
- Card 13: 1. TINL(3)
 2. TINL(4) Second set of inlet temperature coefficients
 3. TINL(5)
 4. TINL(6)
 5. TINL(7) Third set of inlet temperature coefficients
 6. TINL(8)
- Card 14: 1. TINL(9)
 2. TAUT1 First time division, inlet temperature [hr]
 3. TAUT2 Second time division, inlet temperature [hr]
 4. ØPTP 1 if kinetics routine used; 0 if power coeffs. used.
 5. ØPTH 1 if CRS computed from UA curve; 0 if value read in.
 6. ØPTW 1 if pump routine used; 0 if flow coeffs. used.
- Card 15: 1. ØPTG 1 if two fuel elements run; 0 if only one element.

If Kinetics Used

- Card 16: 1. SØURCE Source strength [kw] ; negative source indicates
 steady-state solution until time TAUPI
 2. STEP Stepping time increments [hr]
 3. STEPA Stepping angle [0.5°]
 4. FALPHA Fuel temperature coefficient [\$/°F]
 5. GALPHA Grid plate temperature coefficient [\$/°F]
 (each alone)
 6. RHØØ Shut down reactivity [- \$5.60]
- Card 17: 1. DRHØØ Reactivity added by coarse drums [\$4.20]
 2. U Initial drum angle [degrees]
 3. WUZ Initial reactivity inserted by drum [\$]
 4. CEXT Steady-state power ratio; i.e., actual power/
 nominal power (used only with negative source)

If Pump Used

- Card 18: 1. ZFLØW Initial flow rate through pump [lb/sec]
 2. ZCUR Initial current through pump [amp]
 3. TSPACE Equivalent space temperature [°F]

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Card 18 - continued:

4.	EFFP	Pump efficiency [100% = 1.0]
5.	EFFB	Startup battery efficiency [100% = 1.0]
6.	ØLØØP	1 if inlet temperature is calculated; 0 if
inlet temperature coefficients used.

Card 19:	1.	ZT2	Initial pump nodal temperatures [°F]

(Refer to Figure 3.) |
	2.	ZT3	
	3.	ZT4	
	4.	ZT5	
	5.	ZT6	
	6.	ZT7	

Card 20:	1.	ZT8	Time [hr] at which flow rate is first taken from
pump routine calculations; prior to TCUT, flow
coefficients are used.
	2.	ZT9	
	3.	ZT10	
	4.	TCUT	

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APPENDIX B

Program Outputs

A typical output page is reproduced as Figure B.1. It illustrates the three types of output: temperatures, kinetics data, and pump parameters. Explanations of the various output symbols follow:

1. Temperatures

TAU = running time (hr)
PRATIO = ratio of actual power to specified nominal power
WRATIO = ratio of instantaneous flow rate to specified nominal flow rate
TIN = reactor inlet temperature (F)

Fuel, end cap, and upper grid plate temperatures are listed, left to right, from the element centerline to surface. Coolant temperatures are listed consecutively from the bottom (inlet) of the core to the top (exit). Thus, the first coolant node listed is at the same axial position as fuel nodes 1 through 5.

Mean fuel and coolant temperatures are averaged over the corresponding nodes for the fuel element under discussion. The mean fuel temperature is the core average temperature only when an element with a radial power factor of one is considered.

2. Kinetics

TAU = running time (hr)
ENN = neutron concentration
RHOT = total reactivity (dollars)

The remaining 12 outputs are, in order:

RHØ = reactivity inserted by fine drums (dollars)
A = insertion angle of fine drum, measured from full-out position (degrees)
FTBAR = core average fuel temperature (F)
TGUBAR = average upper grid plate temperature (F)
TPU = temperature of upper plenum (F)
SUM = $\sum \beta_i C_i / \beta$

C(1) to C(6) = normalized neutron concentration for i^{th} delay group.

3. Thermoelectric Pump

The ten unlabeled outputs are the temperatures of the ten nodes in the pump thermal model. The first node is the NaK temperature in the pump throat. The third and fourth nodes bracket the thermoelectric element; the temperature potential across the element is given by their difference.

TAU= 0.61832E 01 PRATIO= 0.12953E 01 WRATIO= 0.82485E-01 TIN= 0.70000E 02

FUEL ELEMENT NO 2, RADIAL POWER FACTOR= 1.3100

LOWER END CAP TEMPS 94.14 91.55 88.16 84.31 79.86

FUEL TEMPS	1- 5	102.83	101.70	100.42	99.17	97.92
11-15	149.31	148.00	146.47	144.94	143.37	
21-25	189.50	188.05	186.38	184.70	182.98	
31-35	218.79	217.34	215.66	213.98	212.27	
41-45	236.39	235.04	233.49	231.94	230.36	
51-55	239.80	238.68	237.39	236.11	234.81	
61-65	228.62	227.81	226.88	225.96	225.03	
71-75	205.05	204.61	204.10	203.61	203.12	
81-85	169.48	169.48	169.50	169.53	169.57	
91-95	122.11	122.55	123.06	123.59	124.14	

UPPER END CAP TEMPS 100.68 101.07 101.65 102.47 103.73

UPPER GRID TEMPS 97.07 97.35 97.70 98.04 98.29

COOLANT TEMPERATURES

0.88460378E 02 0.13084865E 03 0.16909713E 03 0.19827960E 03 0.21732665E 03
 0.22391984E 03 0.21709468E 03 0.19867963E 03 0.16943765E 03 0.12812130E 03

AVG FUEL TEMP= 184.3118 AVG NAK TEMP= 174.1265 TOUT= 107.4631 TPU= 92.0952

KINETICS TAU= 0.61841E 01 ENN= 0.47032E 13 RHOT= 0.18612E-00

0.1697E 01 0.7450E 02 0.1807E 03 0.1019E 03 0.9630E 02 0.3828E 13
 0.1339E 13 0.2453E 13 0.3929E 13 0.4444E 13 0.4659E 13 0.4703E 13

THERMOELECTRIC PUMP

TIME = 0.61860E 01 106.842 91.188 88.587 73.104 70.848
 70.308 70.144 70.064 70.031 70.016

TE VOLTAGE = 3.01 MV, CURRENT = 13.36 AMP, FLOW RATE = 8.01 LB/MIN, DEVELOPED PUMP HEAD = 0.0195 PSI

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APPENDIX C

Program Flow Diagrams

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BASIC FLOW DIAGRAM		MODEL NO.

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		MODEL NO.

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APPENDIX D

Program Listing

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C   TRANCORE-10A  TRANSIENT TEMPERATURES WITHIN 10A REACTOR CORE  00000010
C   P.M.MAGEE  727-711  X-1603  00000015
    DIMENSION FA(10),P(12),W(12),TIN L(12),T(100),TC(10),TB(5),TT(5), 00000020
1   DT(100),DTC(10),DTB(5),DTT(5),DTGU(5),TGU(5) 00000030
    DIMENSION CR(4),CRE(4),CRG(4) 00000040
    DIMENSION BETA(6),AMBDA(6),C(6) 00000050
10  READ INPUT TAPE 5, 3,RUN,X1,X2,X3,X4 00000060
    DIMENSION T1(100),T2(100),TC1(10),TC2(10),TB1(5),TB2(5),TT1(5),TT2 00000065
1   (5),TGU1(5),TGU2(5) 00000066
3   FORMAT (I12,4A6) 00000070
    WRITE OUTPUT TAPE 6,5,RUN,X1,X2,X3,X4 00000080
5   FORMAT (17H1 FIRST RUNI4,4X,4A6) 00000090
    READ INPUT TAPE 5,12,T0,DELTAU,TAUL,PF,PWR,FLOW,FRAD,FRAD2,QE,QG, 00000100
1   TLIM,CA,CAE,CAG,(CR(I),I=1,4),CRS,(CRE(I),I=1,4),CRES,(CRG(I), 00000110
2   I=1,4),CF,CE,CG,CC,(FA(I),I=1,10),(P(I),I=1,9),TAUP1,TAUP2,(W(I), 00000120
3   I=1,9),TAUW1,TAUW2,(TINL(I),I=1,9),TAUT1,TAUT2,OPTP,OPTH,OPTW 00000130
4   ,OPTG 00000135
12  FORMAT (6E12.8) 00000140
20  WRITE OUTPUT TAPE 6,22,T0,DELTAU,TAUL,PF,PWR,FLOW,FRAD,QE,QG,TLIM 00000150
1   ,CA,CAE,CAG,(CR(I),I=1,4),CRS,(CRE(I),I=1,4),CRES,(CRG(I), 00000160
2   I=1,4),CF,CE,CG,CC 00000170
22  FORMAT (10X,6F12.6) 00000180
30  WRITE OUTPUT TAPE 6,32,(FA(I),I=1,10),(P(I),I=1,9),TAUP1,TAUP2,( 00000190
1   W(I),I=1,9),TAUW1,TAUW2,(TINL(I),I=1,9),TAUT1,TAUT2 00000200
32  FORMAT (1H ,10X,6F12.4) 00000210
    MC=0 00000215
    TGL = T0 00000220
    TPU=T0 00000230
    DO 40 I=1,5 00000240
    TGU(I)=T0 00000250
    TT(I)=T0 00000260
    TGU2(I)=T0 00000265
    TT2(I)=T0 00000266
    TB2(I)=T0 00000267
40  TB(I)=T0 00000270
    DO 45 I=1,10 00000280
    TC2(I)=T0 00000285
45  TC(I)=T0 00000290
    DO 50 I=1,100 00000300

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	T2(I)=T0	00000305
50	T(I)=T0	00000310
	ONCE =0.	00000320
	TAUP =0.	00000330
	TAU=0.	00000340
	IFLOW = 0	00000345
	QF= PWR*FRAD/.5425	00000350
	VUP = 55.6/1728.	00000360
	VLP = 95.0/1728.	00000370
55	IF(0PTP) 60,60,57	00000380
60	IF(TAU-TAUP1) 62,62,64	00000390
62	PRATIO=P(1)+P(2)*TAU+P(3)*TAU**2	00000400
	GO TO 68	00000410
64	IF(TAU-TAUP2) 66,66,67	00000420
66	PRATIO=P(4)+P(5)*TAU+P(6)*TAU**2	00000430
	GO TO 68	00000440
67	PRATIO=P(7)+P(8)*TAU+P(9)*TAU**2	00000450
68	IF (TAU) 69,69,70	00000460
69	WRITE OUTPUT TAPE 6,29	00000470
29	FORMAT(27H1 TEMPERATURES AT ZERO TIME)	00000480
	WRITE OUTPUT TAPE 6,33,(TB(I),I=1,5),(T(I),I=1,95),(TT(I),I=1,5)	00000490
33	FORMAT (1H,5X,5F15.2)	00000500
	WRITE OUTPUT TAPE 6,352,(TC(I),I=1,10)	00000510
70	IF(0PTW) 71,71,901	00000520
71	IF(TAU-TAUW1) 72,72,74	00000525
72	WRATIO=W(1)+W(2)*TAU+W(3)*TAU**2	00000530
	GO TO 80	00000540
74	IF(TAU-TAUW2) 76,76,78	00000550
76	WRATIO=W(4)+W(5)*TAU+W(6)*TAU**2	00000560
	GO TO 80	00000570
78	WRATIO=W(7)+W(8)*TAU+W(9)*TAU**2	00000580
80	IF(TAU-TAUT1) 82,82,84	00000590
82	TIN=TINL(1)+TINL(2)*TAU+TINL(3)*TAU**2	00000600
	GO TO 88	00000610
84	IF(TAU-TAUT2) 86,86,87	00000620
86	TIN=TINL(4)+TINL(5)*TAU+TINL(6)*TAU**2	00000630
	GO TO 88	00000640
87	TIN=TINL(7)+TINL(8)*TAU+TINL(9)*TAU**2	00000650
88	IF(0PTH) 100,100,89	00000660

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89  WU=T(5)                                00000670
    D0 92 I=15,95,10                        00000680
    IF(T(I)-WU)92,92,90                     00000690
90  WU=T(I)                                00000700
92  CONTINUE                               00000710
    IF(WU-700.) 93,93,94                    00000720
93  WUX=0.83+.000653*WU-.488E-06*WU**2     00000730
    G0 T0 99                                00000740
94  IF(WU-850.)95,95,96                     00000750
95  WUX=0.83+.000307*WU                     00000760
    G0 T0 99                                00000770
96  IF(WU-1200.)97,97,98                    00000780
97  WUX=0.36+.000864*WU                     00000790
    G0 T0 99                                00000800
98  WUX=1.4                                 00000810
99  CRS =.0323/(.00362/WUX-.0008)          00000820

```

C

C

C

HEAT TRANSFER ROUTINE

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100 D0 115 N=1,5                            00000860
    DTC(1)= (DELTAU/CC)*(CRS*(T(5)-T C(1))+ FLOW*WRATIO*.21*(TIN -(TC(1)+TC(2))/2.))*54.75/(54.75-.00825*TC(1)) 00000870
1  J=15                                       00000880
    D0 105 I=2,9                             00000890
    DTC(I)= (DELTAU/CC)*(CRS*(T(J)- TC(I))+ FLOW*WRATIO*.21*(TC(I-1)-TC(I+1))/2.))*54.75/(54.75-.00825*TC(I)) 00000900
1  J = J+10                                  00000910
    DTC(10)= (DELTAU/CC)*(CRS*(T(95) -TC(10))+ FLOW*WRATIO*.21*(TC(9)-TC(10)))*54.75/(54.75-.00825*TC(10)) 00000920
1  J = J+10                                  00000930
    DTC(10)= (DELTAU/CC)*(CRS*(T(95) -TC(10))+ FLOW*WRATIO*.21*(TC(9)-TC(10)))*54.75/(54.75-.00825*TC(10)) 00000940
1  J = J+10                                  00000950
    D0 115 I=1,10                             00000960
115 TC(I)=TC(I)+ DTC(I)/5.                   00000970
    TOUT=0.5*(3.*TC(10)-TC(9))               00000980
117 IF(MC) 120,120,121                      00000990
120 CONNAK=28.5-3.*TPU/400.                  00001000
    H = 0.0748                               00001010
    PECN0=2.*37.*FLOW*WRATIO*.21/(3.1416*CONNAK*0.520) 00001020
    HTN0 = 5.8+.020*PECN0**0.8               00001030
    HC0EF=HTN0*CONNAK/(2.*H)                 00001040
    CAP=1./(626./HC0EF+.1812)

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121 D0 150 I=1,4                                00001050
      IF(I-1) 140,140,145                        00001060
140 Z=0.                                          00001070
      G0 T0 150                                  00001080
145 Z=1.                                          00001090
150 DTB(I)=(DELTAU/CE)*(CAE*(T(I)-TB(I))+Z*CRE(I-1)*(TB(I-1)-TB(I))- 00001100
      1 CRE(I)*(TB(I)-TB(I+1))+QE*PRATIO)        00001110
      DTB(5)=(DELTAU/CE)*(CAE*(T(5)-TB(5)) +CRE(4)*(TB(4)-TB(5))- CRES* 00001120
      1 (TB(5)-TIN) +QE*PRATIO)                  00001130
      J=91                                        00001140
      D0 170 I=1,4                                00001150
      IF(I-1) 160,160,165                        00001160
160 Z=0.                                          00001170
      G0 T0 169                                  00001180
165 Z=1.                                          00001190
169 DTT(I)=(DELTAU/CE)*(CAE*(T(J)-TT(I))+Z*CRE(I-1)*(TT(I-1)-TT(I))- 00001200
      1 CRE(I)*(TT(I)-TT(I+1))+CAG*(TGU(I)-TT(I))+QE*PRATIO)        00001210
      DTGU(I)=(DELTAU/CG)*(CAG*(TT(I)-TGU(I))+CAP*(TPU-TGU(I))+Z*CRG(I- 00001220
      1 1)*(TGU(I-1)-TGU(I))-CRG(I)*(TGU(I)-TGU(I+1))+QG*PRATIO)    00001230
170 J=J+1                                        00001240
180 DTT(5)=(DELTAU/CE)*(CAE*(T(95)-TT(5)) +CRE(4)*(TT(4)-TT(5))-CR 00001250
      1 ES*(TT(5)-TOUT)+CAG*(TGU(5)-TT(5))+QE*PRATIO)                00001260
      DTGU(5)=(DELTAU/CG)*(CAG*(TT(5)-TGU(5))+CAP*(TPU-TGU(5))+CRG(4)* 00001270
      1 (TGU(4)-TGU(5))+QG*PRATIO)                00001280
      C                                           00001290
      C TEMPERATURE CHANGES OF END-OF-FUEL NODES 00001300
      C                                           00001310
      D0 220 I=1,4                                00001320
      IF(I-1) 210,210,212                        00001330
210 Z=0.                                          00001340
      G0 T0 220                                  00001350
212 Z=1.                                          00001360
220 DT(I)=(DELTAU/CF)*(CA*(T(I+10)-T(I)) -CAE*(T(I)-TB(I)) +Z*CR(I 00001370
      1 -1)*(T(I-1)-T(I))-CR(I)*(T(I)-T(I+1)) +QF*FA(1)*PRATIO)    00001380
      2 *.15/(.0897+.0000469*T(I))              00001390
230 DT(5)=(DELTAU/CF)*(CA*(T(15)-T(5)) +CR(4)*(T(4)-T(5)) - CRS*(T 00001400
      1 5)-TC(1)) -CAE*(T(5)-TB(5))+ QF*FA(1)*PRATIO)              00001410
      2 *.15/(.0897+.0000469*T(5))              00001420
      J=1                                        00001430

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      DO 252 I= 91,94                                00001440
      IF(I-91) 240,240,242                             00001450
240   Z=0.                                             00001460
      GO TO 250                                         00001470
242   Z=1.                                             00001480
250   DT(I)= (DELTAU/CF)* (CA*(T(I-10)-T(I)) -CAE*(T(I)-TT(J)) +Z*CR(J
1     -1)*(T(I-1)-T(I)) -CR(J)*(T(I)-T(I+1)) +QF*FA(10)*PRATIO) 00001490
2     *.15/(.0897+.0000469*T(I))                    00001500
252   J=J+1                                           00001510
      DT(95)=(DELTAU/CF)* (CA*(T(85)- T(95)) -CAE*(T(95)-TT(5)) +CR(4)*00001520
1     (T(94)-T(95))-CRS*(T(95)-TC(10)) +QF*FA(10)*PRATIO) 00001530
2     *.15/(.0897+.0000469*T(95))                    00001540
C                                                     00001550
C     TEMPERATURE CHANGE OF FUEL NODES // THRU 85    00001560
C                                                     00001570
      J=2                                              00001580
      DO 270 I=11,81,10                              00001590
      DT(I)= (DELTAU/CF)* (CA*(T(I+10)+T(I-10)-2.*T(I)) - CR(1)*(T(I)-T(
1     I+1))+QF*FA(J)*PRATIO)*.15/(.0897+.0000469*T(I)) 00001600
270   J=J+1                                           00001610
      J=2                                              00001620
      DO 280 I=15,85,10                              00001630
275   DT(I)= (DELTAU/CF)* (CA*(T(I+10)+ T(I-10)-2.*T(I)) + CR(4)*(T(I-1
1     )-T(I))- CRS*(T(I)-TC(J)) + QF* FA(J)*PRATIO) 00001640
2     *.15/(.0897+.0000469*T(I))                    00001650
280   J=J+1                                           00001660
      J=12                                           00001670
      K=14                                           00001700
      L=2                                           00001710
290   N=2                                           00001720
      DO 295 I=J,K                                    00001730
      DT(I)=(DELTAU/CF)*(CA*(T(I-10)+ T(I+10)-2.*T(I))+CR(N-1)*(T(I-
1     1)-T(I))-CR(N)*(T(I)-T(I+1))+ QF*FA(L)*PRATIO) 00001740
2     *.15/(.0897+.0000469*T(I))                    00001750
295   N= N+1                                           00001760
      J=J+10                                           00001770
      K=K+10                                           00001780
      L=L+1                                           00001790
      IF(K-84) 290,290,312                            00001800

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312 CONTINUE                                00001830
    IF(ONCE) 305,305,309                    00001840
305 ONCE=1.                                00001850
    TAUP=TAU                                00001860
309 IF(MC)361,361,364                      00001866
361 IF(OTPT) 362,362,364                   00001870
362 TAU =TAU +DELTAU                       00001880
364 DO 370 I=1,5                           00001890
    TGU(I)=TGU(I)+DTGU(I)                  00001900
    TB(I)=TB(I)+ DTB(I)                    00001910
370 TT(I)=TT(I)+ DTT(I)                    00001920
    DO 380 I=1,95                           00001930
380 T(I)= T(I) + DT(I)                     00001940
    IF (MC) 381,381,353                     00001945
381 TPU=TPU+37.*FLOW*WRATIO*DELTAU*(TOUT-TPU)/(VUP*(54.75-.00825*
1 TOUT))                                   00001960
    TGL=TGL+37.*FLOW*WRATIO*DELTAU*(TIN-TGL)/(VLP*(54.75-.00825*TIN)) 00001970
353 SUMF=0.                                00001980
    J=1                                     00001990
    K=5                                     00002000
354 DO 356 I=J,K                           00002010
356 SUMF=SUMF+T(I)                          00002020
    J=J+10                                 00002030
    K=K+10                                 00002040
    IF(K-95) 354,354,357                   00002050
357 SUMC=0.                                00002060
    DO 358 I=1,10                          00002070
358 SUMC= SUMC + TC(I)                      00002080
    FTBAR=SUMF/50.                         00002090
    CTBAR=SUMC/10.                         00002100
C                                           00002120
C PERMANENT OUTPUT ROUTINE                00002130
C                                           00002140
    IF(TAU-TAUP) 307,300,300                00002150
300 WRITE OUTPUT TAPE 6,320,TAU,PRATIO,WRATIO,TIN 00002160
320 FORMAT (1H1,3X,5H TAU=E12.5,2X,8H PRATIO=,E12.5,2X,8H WRATIO=E12.
15,2X,5H TIN=E12.5)                        00002180
    IF (MC) 821,821,822                     00002181
821 WRITE OUTPUT TAPE 6,823,FRAD            00002182

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823 FORMAT (42HOFUEL ELEMENT NO 1, RADIAL POWER FACTOR=F8.4) 00002183
GO TO 330 00002184
822 WRITE OUTPUT TAPE 6,824,FRAD2 00002187
824 FORMAT (42HOFUEL ELEMENT NO 2, RADIAL POWER FACTOR=F8.4) 00002188
330 WRITE OUTPUT TAPE 6,340,(TB(I),I=1,5),(T(I),I=1,5),(T(I),I=11,15) 00002190
1,(T(I),I=21,25),(T(I),I=31,35),(T(I),I=41,45),(T(I),I=51,55),(T(I),I=61,65), 00002200
2,(T(I),I=71,75),(T(I),I=81,85),(T(I),I=91,95),(TT(I),I=100002210
3,5),(TGU(I),I=1,5) 00002220
340 FORMAT (21HLOWER END CAP TEMPS 5F10.2//21H FUEL TEMPS 1- 5 500002230
1F10.2/13X,8H 11-15 5F10.2/13X,8H 21-25 5F10.2/13X,8H 31-35 5F10.2/13X,8H 41-45 5F10.2/13X,8H 51-55 5F10.2/13X,8H 61-65 5F10.2/13X,8H 71-75 5F10.2/13X,8H 81-85 5F10.2/13X,8H 91-95 5F10.2//21H 000002240
2.2/13X,8H 11-15 5F10.2/13X,8H 21-25 5F10.2/13X,8H 31-35 5F10.2/13X,8H 41-45 5F10.2/13X,8H 51-55 5F10.2/13X,8H 61-65 5F10.2/13X,8H 71-75 5F10.2/13X,8H 81-85 5F10.2/13X,8H 91-95 5F10.2//21H 000002250
313X,8H 11-15 5F10.2/13X,8H 21-25 5F10.2/13X,8H 31-35 5F10.2/13X,8H 41-45 5F10.2/13X,8H 51-55 5F10.2/13X,8H 61-65 5F10.2/13X,8H 71-75 5F10.2/13X,8H 81-85 5F10.2/13X,8H 91-95 5F10.2//21H 000002260
4H UPPER END CAP TEMPS 5F10.2//21H UPPER GRID TEMPS 5F10.2) 00002270
350 WRITE OUTPUT TAPE 6,352,(TC(I), I=1,10) 00002280
352 FORMAT (1H0,21H COOLANT TEMPERATURES/(10X,5E16.8)) 00002290
WRITE OUTPUT TAPE 6,359,FTBAR,CTBAR,TOUT,TPU 00002300
359 FORMAT(16H0 AVG FUEL TEMP= F9.4,2X,14H AVG NAK TEMP=F9.4,2X, 6H T 00002310
1OUT=F9.4,2X,5H TPU=F9.4) 00002320
WRITE OUTPUT TAPE 6,722,TAU,ENN,HOTR,WUZ,U,FTBAR,TGUBAR,IPU,SUM, 00002321
1 (C(I),I=1,6) 00002322
IF(0PTG) 306,306,304 00002324
304 IF (MC) 307,307,306 00002325
306 TAUP = TAUP + PF 00002330
307 IF (TC(10)) 10,10,308 00002340
308 IF (0PTG) 390,390,800 00002345
390 IF (TC(10)-2000.) 400,10,10 00002350
400 IF (TT(5)-2000.) 410,10,10 00002360
410 IF(TT(5)) 10,10,420 00002370
420 IF(TAU-TAUL) 55,55,10 00002380
C 00002390
C 00002400
C 00002410
KINETICS 00002420
57 IF(TAU) 500,500,540 00002420
500 READ INPUT TAPE 5,12,SOURCE,STEP,STPA,FALPHA,GALPHA,RH00,DRH00 00002430
1 ,U,WUZ,CEXT 00002431
WRITE OUTPUT TAPE 6,512,SOURCE, STEP,STPA,FALPHA,GALPHA,RH00,DRH00 00002440
1 00 00002450
512 FORMAT (1H ,4X,E16.8) 00002460
BETA(1) = .038 00002470
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BETA(2) = .213	00002480
BETA(3) = .188	00002490
BETA(4) = .407	00002500
BETA(5) = .128	00002510
BETA(6) = .026	00002520
AMBDA(1) = 45.7	00002530
AMBDA(2) = 114.2	00002540
AMBDA(3) = 414.	00002550
AMBDA(4) = 1120.	00002560
AMBDA(5) = 5040.	00002570
AMBDA(6) = 13920.	00002580
TAUM=STEP	00002590
TAU=0.	00002600
SAVEN=1.	00002610
DTAU=DELTAU	00002611
FTBAR=T0	00002612
TGUBAR=T0	00002613
TIN=T0	00002614
IF(SOURCE)502,504,504	00002620
502 SOURCE=-SOURCE	00002621
ENN=CEXT*PWR/SOURCE	00002622
H0TR=0.	00002628
SUM=RH00+ENN*(1.-H0TR)	00002630
C(6)=ENN	00002632
D0 503 I=1,5	00002634
503 C(I)=(SUM-0.026*ENN)/0.974	00002636
INDEX=1	00002638
G0 T0 710	00002648
504 ENN=1.	00002660
D0 510 I=1,6	00002670
510 C(I)=1.	00002680
INDEX=0	00002700
G0 T0 628	00002710
540 SUMG=0	00002720
D0 550 I=1,5	00002730
550 SUMG=SUMG+ TGU(I)	00002740
TGUBAR=SUMG/5.	00002750
FALPHA=-.00074-3.3E-07*FTBAR	00002755
628 IF(INDEX) 506,506,507	00002756

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507 IF(TAU-TAUP1)508,506,506                                00002757
508 HØTR=0.                                                    00002758
    GØ TØ 630                                                  00002759
506 HØTR=WUZ+RHØØ+DRHØØ+FALPHA*(FTBAR-70.)+GALPHA*(TGUBAR+TIN-140.) 00002760
630 SUM =0.                                                    00002780
    DØ 640 I=1,6                                              00002790
640 SUM = SUM + BETA(I)*C(I)                                  00002800
    ENN=(-SUM+RHØØ)/(HØTR-1.)                                00002810
    DØ 650 I=1,5                                              00002820
650 C(I) =C(I)+ AMBDA(I)*(ENN -C(I)) *DTAU                  00002830
    C(6)=ENN                                                  00002840
    IF(ENN -SAVEN) 730,710,710                                00002850
710 SAVEN =1.1*ENN                                            00002860
    WRITE ØUTPUT TAPE 6,722,TAU,ENN,HØTR,WUZ,U,FTBAR,TGUBAR,TPU,SUM, 00002870
    1(C(I),I=1,6)                                             00002880
722 FØRMAT (1HØ,4X,15H KINETICS TAU=E12.5,2X,5H ENN=E12.5,2X,6H RHØT 00002890
    1=E12.5/18X,6E12.4/18X,6E12.4)                          00002900
730 TAU = TAU + DTAU                                          00002910
    IF(ENN-1.0E+14) 760,10,10                                00002920
760 IF(TAU-TAUL) 770,770,10                                  00002930
770 IF(TAU-TAUM) 780,610,610                                  00002940
610 U=U+STEPA                                                00002950
    TAUM =TAUM + STEP                                         00002960
    IF(U-30.)612,614,614                                      00002980
612 WUZ=.002*U-5.E-05*U**2+5.E-06*U**3                     00002990
    GØ TØ 628                                                  00003000
614 IF(U-50.) 616,616,618                                    00003010
616 WUZ=.33-.021*U+5.E-04*U**2                              00003020
    GØ TØ 628                                                  00003030
618 IF(U-70.) 620,620,622                                    00003040
620 WUZ=.576-.0334*U+6.5E-04*U**2                           00003050
    GØ TØ 628                                                  00003060
622 IF(U-95.) 624,624,626                                    00003070
624 WUZ= -2.892+.0616*U                                       00003080
    GØ TØ 628                                                  00003090
626 WUZ= -.05464*U+.001574*U**2-7.06E-06*U**3              00003100
    GØ TØ 628                                                  00003110
780 IF(ENN*SØURCE-.33)630,530,530                            00003120
530 PRATIO =ENN*SØURCE/PWR                                    00003130

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	G0 T0 70	00003140
C		00003970
C	TRANSFER ROUTINE - USED WHEN TWO FUEL ELEMENTS ARE RUN	00003980
C		00003990
	800 IF (MC) 801,801,802	00004000
	801 D0 803 I=1,100	00004010
	803 T1(I)=T(I)	00004020
	D0 805 I=1,10	00004030
	805 TC1(I)=TC(I)	00004040
	FTBAR1=FTBAR	00004041
	T0UT1=T0UT	00004042
	D0 807 I=1,5	00004050
	TB1(I)=TB(I)	00004060
	TT1(I)=TT(I)	00004070
	807 TGU1(I)=TGU(I)	00004080
	D0 809 I=1,100	00004090
	809 T(I)=T2(I)	00004100
	D0 811 I=1,10	00004110
	811 TC(I)=TC2(I)	00004120
	D0 813 I=1,5	00004130
	TB(I)=TB2(I)	00004140
	TT(I)=TT2(I)	00004150
	813 TGU(I)=TGU2(I)	00004160
	MC=1	00004170
	QF=PWR*FRAD2/.5425	00004180
	G0 T0 88	00004190
	802 D0 804 I=1,100	00004200
	804 T2(I)=T(I)	00004210
	D0 806 I=1,10	00004220
	806 TC2(I)=TC(I)	00004230
	D0 808 I=1,5	00004240
	TB2(I)=TB(I)	00004250
	TT2(I)=TT(I)	00004260
	808 TGU2(I)=TGU(I)	00004270
	D0 810 I=1,100	00004280
	810 T(I)=T1(I)	00004290
	D0 812 I=1,10	00004300
	812 TC(I)=TC1(I)	00004310
	D0 814 I=1,5	00004320

	TB(I)=TB1(I)	00004330
	TT(I)=TT1(I)	00004340
814	TGU(I)=TGU1(I)	00004350
	FTBAR=FTBAR1	00004351
	TOUT=TOUT1	00004352
	MC=0	00004360
	QF=PWR*FRAD/.5425	00004370
	G0 T0 390	00004380
C		00006010
C	THERMOELECTRIC PUMP ROUTINE - NO ONE	00006020
C		00006030
901	IF(IFLOW) 902,902,906	00006040
902	IFLOW=1	00006050
	N= 0	00006060
	TIN=TINL(1)	00006065
	ZR1 = 493.	00006070
	ZR2 = 123.	00006080
	ZR3 =2560.	00006090
	ZR4 = 833.	00006100
	ZR5 = 278.	00006110
	ZR6 = 182.	00006120
	ZR7 = 208.	00006130
	ZR8 = 251.	00006140
	ZR9 = 545.	00006150
	ZC2 = .01001	00006160
	ZC3 = .01645	00006170
	ZC4 = .02275	00006180
	ZC5 = .01827	00006190
	ZC6 = .0692	00006200
	ZC7 = .0769	00006210
	ZC8 = .0851	00006220
	ZC9 = .0786	00006230
	ZC10= .0420	00006240
	ZCAP1=2.91	00006241
	ZCAP2=2.38	00006242
	ZCAP3=0.48	00006243
	ZRAD10= 1.30 E-06	00006250
	ZRAD11= 1.58 E-06	00006260
	ZRAD12= 9.20 E-06	00006270

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ZRAD13= 1.172E-05      00006280
ZRAD14= 1.993E-05      00006290
ZRAD15= 3.75 E-05      00006300
ZRAD16= 5.30 E-05      00006310
ZSIG = 0.1713 E-08      00006320
ZLINE= 25000.           00006330
QTBAR=3413.*PWR/(1415.)**4 00006335
ZB = 0.4                00006340
ZL = 3.0                00006350
ZW = 1.0                00006360
ZKIN=0.4625            00006370
ZKFLOW=0.619           00006380
ZK1= 0.120 E-06        00006390
ZK2= 8.84 E-08          00006400
ZX3= 2.225              00006410
READ INPUT TAPE 5,12,ZFLOW,ZCUR,TSPACE,EFFP,EFFB,OLLOP,ZT2,ZT3,ZT4 00006420
1 ,ZT5,ZT6,ZT7,ZT8,ZT9,ZT10,TCUT 00006421
912 WRITE OUTPUT TAPE 6,904,ZFLOW,ZCUR,TSPACE,TPU,EFFP,EFFB,ZT2,ZT3, 00006438
1 ZT4,ZT5,ZT6,ZT7,ZT8,ZT9,ZT10 00006439
904 FORMAT (26H0 INITIAL PUMP PARAMETERS/6X,11H FLOWRATE =F8.4,19H LB00006440
1/SEC, CURRENT =F6.2,22H AMP, EQ SPACE TEMP =F8.3/6X,11H NAK TEMP00006450
2 =F8.3,7X,6H EFFP=F6.4,7X,6H EFFB=F6.4/6X,6F12.3/6X,3F12.3) 00006460
ZT11=TSPACE             00006470
TC11=TPU                00006561
TC12=TPU                00006562
TC13=TPU                00006563
ZDEN=(54.75-.00825*TPU)/1728. 00006570
ZV=ZFLOW/(12.*ZDEN*ZW*ZB) 00006580
ZDEL=3600.*DELTAU       00006590
→ 906 ZR10=1./((ZSIG*ZRAD10*((ZT4+459.69)**2+(ZT11+459.69)**2)*(ZT4+ZT11+00006610
1 919.38)) 00006620
ZR11=1./((ZSIG*ZRAD11*((ZT5+459.69)**2+(ZT11+459.69)**2)*(ZT5+ZT11+00006630
1 919.38)) 00006640
ZR12=1./((ZSIG*ZRAD12*((ZT6+459.69)**2+(ZT11+459.69)**2)*(ZT6+ZT11+00006650
1 919.38)) 00006660
ZR13=1./((ZSIG*ZRAD13*((ZT7+459.69)**2+(ZT11+459.69)**2)*(ZT7+ZT11+00006670
1 919.38)) 00006680
ZR14=1./((ZSIG*ZRAD14*((ZT8+459.69)**2+(ZT11+459.69)**2)*(ZT8+ZT11+00006690
1 919.38)) 00006700

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ZR15=1./((ZSIG*ZRAD15*((ZT9+459.69)**2+(ZT11+459.69)**2)*(ZT9+ZT11+00006710
1 919.38)) 00006720
ZR16=1./((ZSIG*ZRAD16*((ZT10+459.69)**2+(ZT11+459.69)**2)*(ZT10+ZT
1 11+919.38)) 00006730
ZT1=TPU 00006740
ZTTE=(ZT3+ZT4)/2. 00006750
ZPTE=(EXP(-.0025*ZTTE+5.66)+EXP(-.00143*ZTTE+6.84))/5080000. 00006780
YRTE=ZPTE*.182/2.67 00006790
ZPI=.000948*(ZTTE+459.7)*(1.2*ZTTE+60.)/1000000. 00006800
903 ZT2=ZT2+(ZT1/ZR1+ZT3/ZR2-ZT2*(1./ZR1+1./ZR2))*ZDEL/ZC2 00006810
ZT3=ZT3+(ZT2/ZR2+ZT4/ZR3-ZT3*(1./ZR2+1./ZR3)+.000948*.5*(ZCUR/2.)) 00006820
1 **2*YRTE-0.5*ZPI*ZCUR)*ZDEL/ZC3 00006830
ZT4=ZT4+(ZT3/ZR3+ZT5/ZR4+ZT11/ZR10-ZT4*(1./ZR3+1./ZR4+1./ZR10)+0.500006840
1 *.000948*(ZCUR/2.))*2*YRTE+ZPI*0.5*ZCUR)*ZDEL/ZC4 00006850
ZT5=ZT5+(ZT4/ZR4+ZT6/ZR5+ZT11/ZR11-ZT5*(1./ZR4+1./ZR5+1./ZR11))* 00006860
1 ZDEL/ZC5 00006870
ZT6=ZT6+(ZT5/ZR5+ZT7/ZR6+ZT11/ZR12-ZT6*(1./ZR5+1./ZR6+1./ZR12))* 00006880
1 ZDEL/ZC6 00006890
ZT7=ZT7+(ZT6/ZR6+ZT8/ZR7+ZT11/ZR13-ZT7*(1./ZR6+1./ZR7+1./ZR13))* 00006900
1 ZDEL/ZC7 00006910
ZT8=ZT8+(ZT7/ZR7+ZT9/ZR8+ZT11/ZR14-ZT8*(1./ZR7+1./ZR8+1./ZR14))* 00006920
1 ZDEL/ZC8 00006930
ZT9=ZT9+(ZT8/ZR8+ZT10/ZR9+ZT11/ZR15-ZT9*(1./ZR8+1./ZR9+1./ZR15))* 00006940
1 ZDEL/ZC9 00006950
ZT10=ZT10+(ZT9/ZR9+ZT11/ZR16-ZT10*(1./ZR9+1./ZR16))*ZDEL/ZC10 00006960
942 IF(ZT1-820.)945,945,946 00006970
945 ZPF=(30.8+.0284*ZT1)/1000000. 00006980
G0 T0 947 00006990
946 ZPF=(20.7+.0396*ZT1)/1000000. 00007000
947 IF(ZT2-540.)948,948,949 00007010
948 ZPW=(27.8+.0169*ZT2)/1000000. 00007020
G0 T0 960 00007030
949 ZPW=(30.4+.012*ZT2)/1000000. 00007040
960 ZPC=(0.53+.0007*(ZT2+ZT3))/1000000. 00007050
YRC=ZPC*0.78 00007060
ZTTE=(ZT3+ZT4)/2. 00007070
962 ZALPHA=(.20*ZTTE+60.)/1000000. 00007080
ZVTE=EFFP*ZALPHA*.985*(ZT3-ZT4)+.00185*EFFB 00007090
ZPTE=(EXP(-.0025*ZTTE+5.66)+EXP(-.00143*ZTTE+6.84))/5080000. 00007100

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YRTE=ZPTE*.182/2.67
ZX1=0.020*ZPW/(ZB*ZPF)
ZX2=0.020*ZPTE/(ZB*ZPF)
YRNAK=ZPF/1.2
YRWALL=8.83*ZPW
ZDEN=(54.75-.00825*ZT1)/1728.
ZRR=YRNAK*YRWALL/(YRNAK+YRWALL)
964 ZVOLT=ZVTE-ZCUR*YRC
ZDENOM=ZPW*ZW+0.182*ZPTE*(1.+2.*ZX1)/ZX3
DPUMP=ZL*(ZK2*ZVOLT*ZLINE-ZK1*ZK2*ZLINE**2*ZV*(0.364*ZX2/ZX3+ZW))/00007210
1 ZDENOM
ZACC=(DPUMP-ZKFLOW*(ABS(ZFLOW))**1.782)/ZKIN
ZFLOW=ZFLOW+0.5*ZACC*ZDEL
ZV=ZFLOW/(12.*ZDEN*ZW*ZB)
ZEX=ZK1*ZLINE*ZW*ZV
ZCUR=(ZVTE-ZEX+ZRR*ZEX/YRWALL)/(YRTE+ZRR+YRC)
IF(N) 965,965,966
965 N = 1
GO TO 964
966 N = 0
IF(TAU-TCUT)71,967,967
->967 WRATIO=3600.*ZFLOW/(37.*FLOW)
IF (TAU-TAUP) 994,909,909
909 WRITE OUTPUT TAPE 6,981,TAU,ZT1,ZT2,ZT3,ZT4,ZT5,ZT6,ZT7,ZT8,ZT9,
1 ZT10
981 FORMAT(22H0 THERMOELECTRIC PUMP/8H TIME =E12.5,9X,5F12.3
1 /23X,5F12.3)
ZMVTE=ZVTE*1000.
ZMFLOW=ZFLOW*60.
943 WRITE OUTPUT TAPE 6,944,ZMVTE,ZCUR,ZMFLOW,DPUMP
944 FORMAT (14H TE VOLTAGE =F6.2,14H MV, CURRENT =F6.2,17H AMP, FLOW
1 RATE =F6.2,30H LB/MIN, DEVELOPED PUMP HEAD =F8.4,4H PSI)
994 IF (OLLOP) 80,80,990
990 TIN=(1./(1./(TOUT+460.))**3+3.*QTBAR/(.21*37.*FLOW*WRATIO))**.3333
1 -460.
GO TO 88
END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)

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