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PERFORMANCE MODELING
OF THE
5-kwe REACTOR THERMOELECTRIC SYSTEM

AEC Research and Development Report

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DATE 5/15/73

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R. V. ANDERSON

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ABSTRACT

A time dependent model has been developed for the 5-Kwe Reactor TE System. This model incorporates bulk simulation of the TE modules and pump/piping system, with nodal modeling of the radiator subsystem. Temperature dependent degradation of the power and pump TE modules is provided for time dependent performance characteristics. The model is fully parametric and all pertinent variables may be externally controlled. The model may be used for system design specification and system performance mapping analyses. Assumptions incorporated into the model are discussed in this document.

Figure 1. Subsystem Diagram

I. INTRODUCTION

This performance model was developed to study time-dependent behavior of the 5 Kwe Reactor Thermoelectric System. The model is based on bulk operational approximations of the various component subsystems. All modeling has been parameterized for external specification, thus facilitating analysis of major system perturbations. The subsystem simulation approximations are discussed in the following sections, followed by the model program description. An example of the input and output of this program is presented in Section IV. A listing of the system modeling code appears in the Appendix.

The 5 Kwe Reactor Thermoelectric System was designed to provide electric power in a space environment for five years. The system utilizes a conical-cylindrical geometry with the following sequential major component placement; (1) ZrH reactor, (2) stainless steel gamma shield, (3) Lithium Hydride neutron shield, and (4) radiator. The radiator is an integral functional/structural component which provides the following; (1) total system and power conversion subsystem support during launch and operation, (2) power conversion system heat rejection surface, and (3) system to spacecraft mating interface.

Thermoelectric modules are utilized to convert the thermal energy to electrical energy. This energy is used to drive the system electromagnetic NaK pump and provide the necessary power at the mating plane. The 5 kwe system design was selected through an extensive series of analyses and trade studies (see reference 1). The system performance code was used in these studies to calculate the design statepoints and to scope the effects of component design modifications.

II. SYSTEM MODELING APPROACH

The 5 Kwe Reactor Thermoelectric System model is composed of a basic set of subsystem simulations. Figure 1 details the subsystems, with Figures 2 and 3 detailing the temperatures and thermal quantities which exist in the primary and secondary loops. The following subsections analyze the modeling approximations which are utilized for the subsystems.

Figure 2. Primary Loop Schematic

Figure 3. Secondary Loop Schematic

A. Reactor

The ZrH_x reactor is modeled as a single node device which supplies the thermal energy to the power conversion system. The reactor has been designed to deliver excess power during its nominal five year lifetime, and the subsystem model exists only as a simple heat source. Steady state operation is assumed to exist at each operational point. The heat losses from the core vessel are not included in this analysis, thus reactor power refers to that thermal energy deposited in the primary loop coolant. The pressure drop associated with the reactor core, plenums, gridplates, and nozzles is considered "lumped" with the piping subsystem modeling.

B. Thermoelectric Power Modules

Parametric data for the thermoelectric power conversion modules was supplied by Westinghouse Astronuclear Laboratory based on performance requirements established by Atomics International (see Reference 2). The modules are modeled as a single node device, in that the WANL supplied data is based on average operating temperatures only (hot clad and cold clad temperatures). Module degradation is assumed to effect the power output and overall efficiency, leaving the open circuit voltage undisturbed. This type of approximation is compatible with the theory that the degradation phenomenon is a diffusion of tellurium from the p-type washer to the n-type washer, resulting in an n-leg resistivity increase.

In addition, the effects of operating the module off matched load power transfer is included in the modeling of the efficiency. Thus, operation at a constant load voltage which results in off matched load conditions will effect the module conversion efficiency. Analyses by WANL were used to establish the necessary relations.

The NaK-to-clad film temperature drops associated with the primary and secondary annuli in the modules are approximated as constants. The values for these film drops are calculated for maximum heat throughput (i.e., end-of-life operation). Small variations in film drop are not considered during the system life. This approach is considered conservative.

The pressure drops associated with the primary and secondary module annuli are considered "lumped" with the piping subsystem model.

C. Thermoelectric Pump Modules

Parametric data for the thermoelectric pump modules was supplied by WANL based on performance requirements established by Atomics International (see reference 2). These modules are modeled similarly to the power conversion modules. The module power, efficiency, and open circuit voltage are considered a function of temperature, degradation, and interfacing to the pump (i.e., off matched load power transfer).

The NaK-to-clad film temperature drops associated with the pump module annuli are approximated as constants based on maximum thermal throughput (i.e., EOL operation).

The pressure drops associated with the primary and secondary pump module annuli are considered "lumped" with the piping subsystem model.

D. Electromagnetic NaK Pump

The pump model incorporates simulations of the primary throat, secondary throat, and copper busbar. Input data for the simulations includes dimensional parameters (throat, magnets, busbars), performance parameters (magnet field strength, busbar current, flowrates), and materials properties (NaK resistivity, NaK density, copper resistivity, etc.). The basic pump throat model calculates the developed pressure head and throat voltage drop for a given coolant flowrate and input electric current (see reference 3). The throat modeling includes all experimental-theoretical correlations.

The performance of each throat is subsequently matched to the requirements of its associated piping system (a subiteration is performed which matches the pressure/flow characteristics). The pump voltage requirements for a given electric current input are then matched to the pump

module capabilities (a subiteration is performed to match the current/voltage characteristics of these components).

Thus, the pump simulation modeling includes the effects of magnetic field strengths, pump throat design dimensions, and temperature dependent materials properties.

Variations of pump design parameters thus have the proper associated performance variation.

E. Piping Subsystems

The pressure versus flowrate characteristics of the primary and secondary piping subsystems are rigorously calculated for a specific system design (see reference 4). A functional relationship is established from this characterization which is utilized in the system performance model. The effects of temperature are not considered in the analysis because only minor variations in flowrate and pressure drop occur over the range of temperatures considered.

F. Radiator Subsystem

The radiator simulation is based on a five node model which incorporates all basic required analysis. The space system radiator heat rejection capability is calculated from the fin effectiveness model of Mackay (see reference 5). The calculation of the radiator fin effectiveness is based on a complicated set of correlations to experimental data. Fin effectiveness is a function of the specific radiating surface dimensions, temperature, emissivity, solar absorptivity, and environmental thermal input. The heat rejection is a function of area, fin effectiveness, and fourth-power absolute temperature. The equations are solved at each node, and the results integrated over the entire radiating surface. The axial temperature drop in the radiator is calculated from the loop flow requirements.

Two temperature drops exist between the coolant and the radiating fin surface. The coolant film drop is calculated based on the thermal throughput of each nodal section. The fin-tube bond temperature drop calculation is based on the thermal throughput of the section, and the available fin-tube bond area. Thus this calculation includes the effects of fin-tube bond degradation (effective reduction in thermal transfer area).

G. Thermal Loss Analysis

Three paths exist for thermal loss from the primary piping loop: (1) radiative losses from the reactor and shield (core and piping) to space; (2) radiative shunting from the internal primary piping to the radiator interior; and (3) conductive transfer from the primary to secondary pump throat (through the copper busbar). Detailed analyses were performed to calculate the heat loss magnitudes, and their functional dependence on temperature. The results of these analyses were incorporated into the system performance modeling through empirical correlations.

III. CALCULATIONAL METHODS

The system performance simulation model was programmed in Fortran IV for use on a Honeywell 600 Timesharing Computer System. The interactive nature of timesharing systems provides several advantages for simulation analysis. On-line communication with the computer code allows monitoring of specific output variables, thus not limiting the user to the batch-processing mode of analysis.

The simulation program was sectioned into several subroutines, with the overlay feature being used to minimize core storage requirements. The following sections will discuss the two major overlays; the pump simulation subroutines and the radiator simulation subroutines. A final section will discuss the integration of these routines into the main program, including calculation methods and flow diagrams.

Figure 4. PUMPSUB Overlay Logic Schematic

A. Pumping System Subroutines

The pumping subsystem simulation consists of four sequentially called subroutines: PMPSUB, PUMPA, DCPMP, and PARAT. A flow diagram for the subroutines appears as Figure 4. Input data for all subroutines is routed through the argument lists from the main subroutine system. Data is stored in disk files which are referenced by the main program and SYSTEM subroutine only. A listing of the PMPSUB overlay appears in the Appendix. Several comments are included in this listing to facilitate understanding of the logic flow.

Subroutine PARAT calculates temperature dependent materials properties for use in the DCPMP routine. The densities, resistivities, and permeabilities calculated are based on experimental data.

Subroutine DCPMP calculates the available pumping power for each throat. The pressure head and voltage drops of each throat are calculated from the input current and the flowrates. The total pump circuit voltage drop (primary throat + secondary throat + busbars) is additionally calculated. All analysis within this subroutine is based on the pump design equations of reference 3, and all latest experimental data.

Subroutine PUMPA integrates each throat to its respective piping loop. The pressure-flow characteristics for the piping subsystems are entered through the SYSTEM subroutine. These characteristics follow the familiar equation:

$$\Delta P = C \dot{m}^2$$

where ΔP = Loop Pressure Drop (psi)

C = Constant of Proportionality

$\dot{m}$ = Loop Flowrate (lb/sec)

Analyses were performed to scope the effects of including second-order terms in the above approximations. The effects were of negligible magnitude on system performance.

The PUMPA subroutine utilizes a two-variable iteration technique in which the DCPMP routine is repeatedly called. Flowrates are varied for a constant input current until the pump head is equal to the loop pressure drop.

Subroutine PMPSUB integrates the pump modules to the previously integrated pump-piping systems. Pump module performance characteristics are input to PMPSUB from the main SYSTEM subroutine. The module hot and cold clad temperatures are calculated in SYSTEM and used in PMPSUB, as is the module degradation. This subroutine iteratively calls the PUMPA subroutine to establish the necessary current-voltage operating point for the pumping system. This subroutine calculates the electrical operating characteristics of the pump modules, varying the pump input current to establish equal module output voltage and pump voltage drop. The pump module efficiency is subsequently calculated, with off-matched load effects incorporated in the analysis. The PMPSUB subroutine therefore provides the following functional relationship:

INPUT

Module Temperatures	Module Characteristics
Pump Throat Temperatures	Pump Design Characteristics
Pump Module Degradation	Piping Loop Characteristics

OUTPUT

Loop Flowrates	Loop Pressure Drops
Pump System Thermal Input	Pump Current Requirement
Pump Voltage Requirement	

The pumping/piping system is thus treated as a single calculation by the main SYSTEM subroutine.

B. Radiator Subroutines

The radiator simulation consists of three sequentially called subroutines: RDIATR, FINEFF, and EFFS. A fourth subroutine (POLY4) is used for data interpolation and curve fitting. A flow diagram for the subroutines appears as Figure 5. Input data for all subroutines is routed through the argument lists from the main subroutine, SYSTEM. A listing of the RDIATR overlay appears in the appendix. Several comments are included in this listing to facilitate understanding of the logic flow.

The following quantities are calculated in the RDIATR subroutine, and are used in the EFFS and FINEFF subroutines: (1) C_e (radiation constant); (2) C_∞ (environmental thermal input constant); (3) PN (fin profile number); and (4) EP (fin environmental parameter). These quantities are defined in reference 2 and are calculated from the fin geometry, surface properties, and orbit environment.

Subroutine EFFS is a compilation of equations which are equivalent to curves presented in reference 5. Subroutine EFFS calculates the fin effectiveness (Ω) for specific values of EP, PN, and geometrical hot-to-cold end thickness ratio. EFFS is essentially a curve searching routine.

Function FINEFF calculates the specific radiator fin effectiveness for a given profile number (PN), environmental parameter (EP), and thickness ratio. FINEFF repeatedly references the EFFS subroutine to establish a calculation range for EP and thickness ratio, with subsequent interpolation by POLY4.

Subroutine RDIATR calculates the radiator heat rejection capability, and specific temperature and flow conditions. Radiator fin geometry parameters, environmental thermal input parameters, and radiator surface coating properties are input to RDIATR through the main SYSTEM subroutine. RDIATR calculates the heat rejection capability of each of the five radiator nodal sections using the following relation:

Figure 5. RDIATR Overlay Logic Schematic

$$Q_{\text{rej}} = \epsilon A \sigma \Omega T_r^4$$

where

Q_{rej} = Thermal rejection

ϵ = Surface emissivity

A = Surface area

σ = Stefan-Boltzman constant

Ω = Fin effectiveness

T_r = Fin surface temperature (absolute)

The thermal rejection of the nodal sections is summed and the temperature profile is compared to that utilized in the rejection calculation. An iterative process is then used to establish the true temperature and rejection profiles. The RDIATR subroutine therefore provides the following functional relationship:

INPUT

Average Radiator Temperature	Radiator Geometry Characteristics
Radiator Flowrate	Environmental Parameters

OUTPUT

Radiator Thermal Rejection	Radiator Axial Temperature Drop
----------------------------	------------------------------------

The radiator system is thus treated as a single calculation by the main SYSTEM subroutine.

C. System Performance Computational Subroutines

The time dependent system performance calculations which allow for component degradation are made within the SYSTEM subroutine. A

dummy main program is used to call this subroutine, thereby allowing utilization of SYSTEM as a subsection of other programs. Four input data files (disk storage) are required to fully specify a performance simulation. Three of these files contain system design parameter information: (1)FTEMXX* for the power modules; (2) FTEPXX* for the pump modules; and (3) SSWDAT for all other components. A fourth file, SWDATX*, contains system performance parameters which are functions of the operating environment and the component design margins. These files are detailed in Section IV.A.

Assuming that data input has been completed, the SYSTEM subroutine can operate in several performance modes. These modes were included to allow flexibility during performance analyses. The six modes are listed in Table I.

TABLE I
SYSTEM PERFORMANCE MODES

Mode No.	Mode Description
0	Constant Reactor Outlet Temperature with Constant Voltage at the Baseplane
1	Constant Reactor Outlet Temperature with Power Modules Operated in Matched Load Condition
2	Constant Electrical Power and Voltage at the System Baseplane
3	Constant Electrical Power at the System Baseplane with Power Modules Operated in Matched Load Condition
4	Constant Electrical Power and Voltage with the Reactor Outlet Temperature Limited to a specified Value (a reduction in electrical power occurring after this limitation is reached).
5	Constant Electrical Power at Matched Load with the Reactor Outlet Temperature Limited to a Specified Value (a reduction in matched load power occurring after this limitation is reached).

* "X" indicates single digit integer

Two calculational procedures are employed in SYSTEM. The first procedure is utilized for performance at constant reactor outlet temperature (modes No. 0 and 1 throughout operation and modes No. 4 and 5 after the outlet temperature limitation is reached). The second procedure is utilized for performance at constant electrical power (modes No. 2 and 3 throughout operation and modes No. 4 and 5 prior to the outlet temperature limitation). Calculational schematic diagrams are presented for each of these modes in Figures 6 and 7.

Performance analysis is based on the assumption that a long-term transient can be simulated with several time-dependent steady-state simulations. Thus, SYSTEM performs a thermal and electrical balance at one-half year time steps through the desired simulation time. Investigations of the effects of increasing or decreasing this time-step length were made which indicated that one-half year steps offer the best compromise between computer running time and accuracy.

Component performance degradation is considered in two modes: (1) temperature independent degradation, and (2) temperature dependent degradation. The former is exhibited by the pump magnets, pump busbar-to-throat braze joints, AI-93 coating surface properties, and radiator fin-tube bond. The latter is exhibited by the power modules and pump modules (degradation in both efficiency and output electrical power). All temperature independent degradations are assumed to follow the relation:

$$S(t) = S(0) \times (1 - Dt)$$

where: $S(t)$ = Value of specific parameter at time t (years)

D = Degradation rate of specific parameter
(fraction/year) (constant)

All temperature dependent degradations are assumed to follow the relation (established by Westinghouse for the thermoelectric modules):

Figure 6. SYSTEM Calculational Schematic –
Constant Outlet Temperature

Figure 7. SYSTEM Calculational Schematic — Constant Electric Power

$$S(t) = S(0) \times (1 - D(T)t)$$

$$D(T) = A e^{-Q/RT} \text{ (fraction/year)}$$

where: $S(t)$ = value of specific parameter at time t (years)

$D(T)$ = Degradation rate of specific parameter at temperature T ($^{\circ}R$)

A = Frequency factor for degradation (inverse years)

Q = Activation energy of degradation phenomenon (Kcal/gm-mole)

R = Boltzman constant (Kcal/gm-mole- $^{\circ}R$)

T = Average hot clad temperature of module at time t ($^{\circ}R$)

During performance analysis, the module degradation rates are calculated from the average hot clad temperature of the previous time step.

Two modes of load regulation are available to the power modules: (1) a load requiring constant voltage; or (2) a load which follows the matched load (maximum power transfer) condition of the modules. Two distinct calculations are employed in each section of SYSTEM for these modes of operation.

The power and pump module performance data input is in tabular form (as a function of hot and cold junction temperatures). Two function subprograms are provided to interpolate within this data. FUNCT1 and FUNCT2 perform one and two dimensional three point lagrangian interpolation, and are utilized by SYSTEM.

It should be noted that in each of the calculational procedures, the primary and secondary loop temperature drops are assumed prior to the BOL calculation. These quantities are utilized to calculate the pump throat temperatures and the radiative thermal losses. The loop temperature drops are re-calculated during each iteration (at a given time step) with a required minimum of two iterations per calculation (assuring consistency of results). On time steps other than the first (BOL) the loop

temperature drops from the previous time step are assumed. Thus, the second-order effects associated with these temperature drops are included in the calculations.

Inspection of the logic schematics and the program listing (Appendix) is recommended for a complete understanding of the simulation calculations.

IV. OPERATION OF THE SYSTEM PROGRAM

A. Input Data Files

As indicated in Section III.C, four input data files are utilized by the SYSTEM subroutine. Samples of these data files appear in the Appendix.

1. FTEMXX Files

The FTEMXX file (X is a single integer) contains the power module performance data; (1) power per module, (2) module efficiency, and (3) module open circuit voltage. These quantities are presented in a two dimensional matrix form with respect to hot and cold clad temperatures. Interpolation routines are used for specific temperature values.

2. FTEPXX Files

The FTEPXX file (X is a single integer) contains the pump module performance data; (1) power per module, (2) module efficiency, and (3) module open circuit voltage. These quantities are presented in a matrixed format similar to that for the power module files.

3. SSWDAT File

The SSWDAT file contains performance data on the following components; (1) power modules (degradation parameters), (2) pump modules (degradation parameters), (3) electromagnetic NaK pump, and (4) radiator. The SYSTEM listing (see Appendix) contains comments which detail the SSWDAT file input requirements; however, these requirements will be explained below as an example of data input.

Table II details the SSWDAT file parameters. The indicated nominal values are those utilized in the listed SSWDAT file (see Appendix).

TABLE II
SSWDAT FILE REQUIREMENTS

Variable	Nominal Value	Description
FNPOWM	"FTEMO1"	Name of power module data file (alphanumeric)
FNPMPM	"FTEPO1"	Name of pump module data file (alphanumeric)
OFNAME	"SYSOUT"	Name of output data file (alphanumeric)
NMOD	16	Number of power conversion modules (integral)
NPMOD	3	Number of pump conversion modules (integral)
TOUTB	1200	Outlet temperature limit for modes No. 0, 1, 4 and 5 (°F)
VSYS	30.0	Voltage at baseplane for constant voltage modes (vdc)
QLM	2.38×10^{-13}	Equivalent factor for radiative losses from reactor and reactor piping ($\text{kwt}/^\circ\text{R}^4$)
QPM	6.66×10^{-13}	Equivalent factor for radiative shunting losses from primary loop piping ($\text{kwt}/^\circ\text{R}^4$)
QPMPM	2.06×10^{-3}	Equivalent factor for conductive shunting losses through pump throats ($\text{kwt}/^\circ\text{F}$)
THG	1100	Initial guess for hot clad temperature (°F)
TCG	500	Initial guess for cold clad temperature (°F)
DTPG	90	Initial guess for primary loop temperature rise (°F)
DTSG	140	Initial guess for secondary loop temperature drop (°F)
FLOWPG	4.7	Initial guess for primary loop flowrate (lb/sec)
FLOWSG	2.8	Initial guess for secondary loop flowrate (lb/sec)
QACTPO	31,000	Activation energy for power module degradation rate calculation (cal/gm-mole)
DGRMTR	1085	Temperature to which power module degradation rate is referenced for calculation (°F)

TABLE II
SSWDAT FILE REQUIREMENTS
(continued)

Variable	Nominal Value	Description
DTHC	12.5	Power module hot clad film temperature drop ($^{\circ}\text{F}$)
DTCC	5.0	Power module cold clad film temperature drop ($^{\circ}\text{F}$)
DTHCPM	24.5	Pump module hot clad film temperature drop ($^{\circ}\text{F}$)
DTCCPM	9.0	Pump module cold clad film temperature drop ($^{\circ}\text{F}$)
UAFINB	47.4	Heat transfer coefficient for radiator fin-tube bond ($\text{kwt}/^{\circ}\text{F}$)
UAFILM	18.9	NaK-tube film drop coefficient for radiator tubing ($\text{kwt}/^{\circ}\text{F}$)
TCONDB	127	Thermal conductivity of fin material at 0°F ($\text{Btu}/\text{sq ft}-^{\circ}\text{F}$)
TCONDS	.0576	Slope of fin material thermal conductivity ($\text{Btu}/\text{sq ft}-^{\circ}\text{F}^2$)
TNORM	0.945	Normalization correction factor on fin base thickness which correlates the five node calculation of RDLATR to the 25 node calculation performed by the radiator designer.
AREAS	38.24 (1) 52.91 (2) 67.58 (3) 54.04 (4) 54.04 (5)	Nodal areas of radiator from shield interface to baseplane: three conical nodes; two cylindrical nodes (sq ft)
FINLS	1.216 (1) 1.683 (2) 2.149 (3) 2.356 (4) 2.356 (5)	Average half-width of fin in nodal section (in)
FINTS	0.060 (1) 0.060 (2) 0.060 (3) 0.060 (4) 0.060 (5)	Fin thickness at fin centerline (maximum thickness - in.)

TABLE II
SSWDAT FILE REQUIREMENTS
(continued)

Variable	Nominal Value	Description
FETAPO	0.70	Fraction of power module matched load degradation (in power) which occurs in efficiency
		Power module axial temperature gradient degradation rate variation polynomial approximation factors:
AXDPO0	0.951	Zeroth-order coefficient (dimensionless)
AXDPO1	0.0	First-order coefficient (1/°F)
AXDPO2	4.9x10 ⁻⁶	Second-order coefficient (1/°F ²)
AXDPOS	1	Control for power module axial temperature gradient degradation rate variation: 0 = off; 1 = on
QACTPM	31,000	Activation energy for pump module degradation rate calculation (cal/gm-mole)
DGRPTR	1085	Temperature to which pump module degradation rate is referenced for calculation (°F)
FETAPM	0.83	Fraction of pump module matched load degradation (in power) which occurs in efficiency
		Pump module axial temperature gradient degradation rate variation polynomial approximation factors:
AXDPM0	0.951	Zeroth-order coefficient (dimensionless)
AXDPM1	0.0	First-order coefficient (1/°F)
AXDPM2	4.9x10 ⁻⁶	Second-order coefficient (1/°F ²)
AXDPMS	1.0	Control for pump module axial temperature gradient degradation rate variation; 0 = off; 1 = on
RMNBUS	0.00468	Resistance (at 600°F) of main power busbar (two-way resistance - ohms)
DGRMIN	0.0	Initial power module matched load power degradation fraction (for post-BOL calculations)
DGRPIN	0.0	Initial pump module matched load power degradation fraction (for post-BOL calculations)

TABLE II
SSWDAT FILE REQUIREMENTS
(continued)

Variable	Nominal Value	Description
FINRS	1.0 (1) 1.0 (2) 1.0 (3) 1.0 (4) 1.0 (5)	Fin centerline thickness to edge thickness ratio (unity for constant thickness fin)
		Power module efficiency multiplier polynomial for off-matched load operation:
EMULT0	0.5136	Zeroth-order coefficient (dimensionless)
EMULT1	0.2890	First-order coefficient (dimensionless)
EMULT2	0.6477	Second-order coefficient (dimensionless)
EMULT3	-.4503	Third-order coefficient (dimensionless)
IAEN2M	12	Integral iteration step maximum limit for constant electrical power hot clad tempera- ture loop
		Pump module efficiency multiplier polynomial for off-matched load operation:
EMM0	0.5136	Zeroth-order coefficient (dimensionless)
EMM1	0.2890	First-order coefficient (dimensionless)
EMM2	0.6477	Second-order coefficient (dimensionless)
EMM3	-.4503	Third-order coefficient (dimensionless)
T	0.028	Pump throat wall thickness (in)
T1	0.022	Pump throat splitter thickness (in)
Y	0.025	Pump throat edge to magnet face gap (in)
A	1.30	Pump throat height (in)
B	0.60	Pump throat width (in)
X	2.30	Effective pump throat length (in)
BLB	36.0	Effective busbar length (in)
BA	1.35	Effective busbar cross sectional area (sq in)
C9	0.22	Suction and discharge throat diffuser constants
D	2.50 (1) 1.88 (2)	Piping diameters which connect to pump (1) is suction/discharge for primary throat; (2) is suction/discharge for secondary throat

TABLE II
SSWDAT FILE REQUIREMENTS
(continued)

Variable	Nominal Value	Description
IPRINT	1 (1) 0 (2-5) 1 (6) 0 (7-10) 1 (11) 0 (12-21)	Dimensional integer array (21 entries) which specifies the time steps (ILIFE) at which the "SYSOUT" file is written. The first entry controls the entire printing: 0 = no print; 1 = print. The twenty succeeding entries control all other steps.

4. SWDATX Files

The SWDATX (X is a one digit integer) file contains parameters dependent upon the system environment and component design margins. The SSWDAT and SWDATX files contain similar types of information; however, SWDATX parameters are those most often changed when calculating system performance characterization mappings. These files were thus separated for convenience. The SYSTEM listing (see Appendix) includes comments which detail the SWDATX file input requirements; however, these requirements will be explained below as an example of data input.

Table III details the SWDATX file parameters. File SWDATO (see Appendix) parameters are indicated as nominal values. This file was used to predict system nominal performance.

TABLE III
SWDATX FILE REQUIREMENTS

Variable	Nominal Value	Description
POMPPM	1.0	Normalized multiplier for power module output power (dimensionless)
POMEFF	1.0	Normalized multiplier for power module efficiency (dimensionless)
POMDGB	0.01	Base power module degradation rate (matched load power degradation) at DGRMTR (fraction/year)
EPOWRS	5.0	System electrical power at baseplane for constant power operation (kwe)
PMMPPM	1.0	Normalized multiplier for pump module output power (dimensionless)
PMMEFF	1.0	Normalized multiplier for pump module efficiency (dimensionless)
PMMDGB	0.014	Base pump module degradation rate (matched load power degradation) at DGRPTR (fraction/year)
PTFSIN	2505	Initial primary pump throat magnet field strength (gauss)
PTFSDG	0.01	Primary pump throat magnet field strength degradation rate (fraction/year)
STFSIN	2000	Initial secondary pump throat effective magnet field strength (gauss)
STFSDG	0.01	Secondary pump throat magnet field strength degradation rate (fraction/year)
PBUSIN	1.0	Initial normalized pump busbar-to-throat braze joint resistivity multiplier (dimensionless)
PBUSDG	-.005	Pump busbar-to-throat braze joint resistivity degradation rate (fraction/year) (negative indicates increasing resistivity during operation)
PPIPFH	0.0468	Primary piping loop pressure-flow characteristics (psi/lb ² -sec ²)
SPIPFH	0.173	Secondary piping loop pressure-flow characteristics (psi/lb ² -sec ²)
REMMIN	0.90	Initial emissivity of Al-93 radiator surface coating (dimensionless)

TABLE III
SWDATX FILE REQUIREMENTS
(continued)

Variable	Nominal Value	Description
REMMDG	0.0	Degradation rate of emissivity for AI-93 radiator coating (fraction/year)
RABSIN	0.50	Initial absorptivity of AI-93 radiator surface coating (dimensional)
RABSDG	0.0	Degradation rate of absorptivity for AI-93 radiator coating (fraction/year)
RBNDIN	0.80	Initial normalized radiator fin-tube-bond area multiplier (dimensionless)
RBNDG	0.02	Degradation rate for radiator fin-tube-bond area (fraction/year)
RDIMTL	1.0	Normalized radiator fin root thickness multiplier (dimensionless)
DIRSOL	141.1	Direct solar flux impinging on radiator (Btu/sq-ft-hr) (orbit dependent)
ERTHRF	23.5	Earth reflected flux impinging on radiator (Btu/sq-ft-hr) (orbit dependent)
DIRERT	20.17	Direct earth flux impinging on radiator (Btu/sq-ft-hr) (orbit dependent)

B. Program Operation

The main system program was written in Fortran IV for use on a Honeywell 600 timesharing computer system. The system will operate in the "RUN" mode because the "overlay" option has been employed to reduce core storage requirements. When compiled, the system program requests the following information:

RUN FILE NUMBER = "X" Digit of "SWDATX" input file
 LCNTRL = Operational "MODE #" (0, 1, 2, 3, 4, 5)
 (see section III.C)
 LIFE = Operational Lifetime (years)

The SSWDAT file contains the input file numbers for the FTEMXX and FTEPXX files. The SSWDAT file is always read by the SYSTEM subroutine before a calculation is begun. An example of the above data requests is shown in the sample program run of Figure 8.

C. Program Output

The system program output occurs in two forms: (1) that associated with the running of the program, and (2) that written into the output data file SYSOUT (which is accessed and listed after completion of the program). The output file feature was employed to utilize the high-speed printing facility which is available at Rockwell International Corporation's Rocketdyne Division.

1. Run-Time Output

The run-time output occurs during and after the program is in the calculational mode. An example of this output appears as Figure 8, and the performance here described is that associated with the input file SWDATO (see Table III and Appendix). The program first requests data input as detailed in Section IV.B. During the calculation mode, the parameter ILIFE is printed specifying those time steps which have been completed ($ILIFE = 1$ is time zero). Thus a five year performance calculation will use eleven time steps. The output parameter ACHIEVABLE LIFE specifies the end-of-life of the system in years. Thus, this parameter is either equal to the requested total lifetime or the maximum time which the system can deliver electrical power. The latter condition occurs when components degrade severely and the system can no longer support operation.

The run-time output then details the time-dependence of several performance parameters (in one-half year time intervals). Table IV explains the nomenclature associated with this output. A summary of the SWDATX file input follows this tabulation. The latter is useful for record keeping purposes.

OSYSTW 08:04 NR T/S JAN 30, 1973

RUN FILE NUMBER ? 0

LIFE (YR),LCNTRL ? 5.,2

ILIFE=	1
ILIFE=	2
ILIFE=	3
ILIFE=	4
ILIFE=	5
ILIFE=	6
ILIFE=	7
ILIFE=	8
ILIFE=	9
ILIFE=	10
ILIFE=	11

ACHIEVABLE LIFE = 5.00 YEARS

(continued on following page

Figure 8. SYSTEM Run-Time Output Listing

TIME	EP0WER	T0UTLT	TH0TCL	PREACT	C0REDT	
0.0	5.00	1148.	1091.	95.62	88.7	
0.5	5.00	1152.	1095.	95.96	89.1	
1.0	5.00	1155.	1098.	96.37	89.5	
1.5	5.00	1159.	1102.	96.80	90.0	
2.0	5.00	1164.	1106.	97.27	90.5	
2.5	5.00	1168.	1110.	97.78	91.0	
3.0	5.00	1173.	1115.	98.34	91.6	
3.5	5.00	1179.	1120.	98.96	92.3	
4.0	5.00	1185.	1126.	99.66	93.0	
4.5	5.00	1192.	1133.	100.44	93.9	
5.0	5.00	1200.	1140.	101.34	94.8	
TIME	EFFP0M	TAVRAD	TC0LCL	PRADTR	DTRADT	
0.0	6.38	522.3	527.3	89.34	132.3	
0.5	6.36	523.3	528.3	89.69	133.0	
1.0	6.34	524.5	529.5	90.08	133.8	
1.5	6.31	525.7	530.7	90.50	134.7	
2.0	6.28	527.0	532.0	90.95	135.6	
2.5	6.25	528.5	533.5	91.45	136.7	
3.0	6.22	530.1	535.1	92.00	137.8	
3.5	6.19	531.8	536.8	92.60	139.0	
4.0	6.15	533.7	538.7	93.27	140.4	
4.5	6.10	535.9	540.9	94.03	141.9	
5.0	6.05	538.4	543.4	94.91	143.6	
TIME	EFFPMM	DGRP0M	DGRPMM	V0LTAG		
0.0	3.71	00.00	00.00	30.0		
0.5	3.69	0.53	0.65	30.0		
1.0	3.66	1.09	1.32	30.0		
1.5	3.64	1.67	2.03	30.0		
2.0	3.61	2.27	2.76	30.0		
2.5	3.59	2.90	3.53	30.0		
3.0	3.56	3.56	4.34	30.0		
3.5	3.52	4.27	5.20	30.0		
4.0	3.49	5.01	6.11	30.0		
4.5	3.45	5.81	7.08	30.0		
5.0	3.41	6.67	8.13	30.0		
P0MPPM	P0MEFF	P0MDGB	EP0WRS	PMPPM	PMMEFF	PMMDGB
1.00	1.00	1.00	5.00	1.00	1.00	1.40
PTFSIN	PTFSDG	STFSIN	STFSDG	PBUSIN	PBUSDG	
2505.	1.00	2000.	1.00	1.00	-.50	
PPIP FH	SPIP FH					
1.04683	0.17311					
REMMIN	REMDG	RAB SIN	RABSDG	RBNDIN	RBNDG	RDIMTL
0.900	00.00	0.500	00.00	0.80	2.00	1.00
DIRS0L	ERTHRF	DIRERT				
141.10	23.50	20.17				

Figure 8. SYSTEM Run-Time Output Listing (continued)

SYSOUT

CODE: 'SYSTW'

08:09 0N JAN 30, 1973

SPACE SYSTEM - AREA IS 266.8 SQ FT

PERFORMANCE SUMMARY @ 0.0 YEARS

REACTOR:						
POWER	T OUT	DEL T	FLOW	PRI PRES	Q LOSS	
95.6	1148.	88.7	4.87	1.11	1.27	
RADIATOR:						
POWER	T IN	DEL T	FLOW	SEC PRES	AVG TFIN	
89.3	589.	132.3	3.01	1.57	522.	
POWER MODULES:						
T HOT	T COLD	ETA	DEGRADE	Q IN	Q BUS	
1091.	527.	6.38	00.00	80.36	0.13	
# MOD	POW @M	VOC @M	POW @B	VLT @B		
16	5.13	57.97	5.00	30.00		
PUMP MODULES:						
T HOT	T COLD	ETA	DEGRADE	Q IN	POW OUT	
1079.	531.	3.71	00.00	9.77	0.362	
# MOD	VLTG	CURRENT	QSPUMP	QSPIPE		
3	0.210	1728.	0.97	3.24		

Figure 9. SYSOUT Output File Listing at BOL

TABLE IV
 RUN-TIME PROGRAM OUTPUT NOMENCLATURE
 (See Figure 8)

Parameter Name	Description
TIME	Time (years)
EPOWER	Electrical power at system baseplane (kwe)
TOUHLT	Reactor outlet temperature (°F)
THOTCL	Power module average hot clad temperature (°F)
PREACT	Reactor thermal power into the coolant (kwt)
COREDCT	Reactor core temperature rise (°F)
EFFPOM	Power module overall efficiency (%)
TAVRAD	Radiator average temperature (°F)
TCOLCL	Power module average cold clad temperature (°F)
PRADTR	Radiator thermal rejection (kwt)
DTRADT	Radiator axial temperature drop (°F)
EFFPMM	Pump module overall efficiency (%)
DGRPOM	Total power module degradation (% in matched load power)
DGRPMM	Total pump module degradation (% in matched load power)
VOLTAG	Voltage at system baseplane (vdc)

2. Data File Output

The SYSOUT data output file is written by the WRITER overlay at those time steps specified in the SSWDAT input data file. SYSOUT is a more detailed tabulation of the performance statepoint which occurs at a given time. Examples of SYSOUT files for BOL (time = 0 years) and EOL (time = 5 years) performance are shown in Figures 9 and 10. SYSOUT additionally contains the time and date for the calculation. Table V details the nomenclature employed in the SYSOUT listing.

SYSOUT CONTINUED

CODE: 'SYSTW'

08:28 ON JAN 30, 1973

SPACE SYSTEM - AREA IS 266.8 SQ FT

PERFORMANCE SUMMARY @ 5.0 YEARS

REACTOR:						
POWER	T OUT	DEL T	FLOW	PRI PRES	Q LOSS	
101.3	1200.	94.8	4.83	1.09	1.43	
RADIATOR:						
POWER	T IN	DEL T	FLOW	SEC PRES	AVG TFIN	
94.9	611.	143.6	2.94	1.50	538.	
POWER MODULES:						
T HOT	T COLD	ETA	DEGRADE	Q IN	Q BUS	
1140.	543.	6.05	6.67	84.79	0.13	
# MOD	POW OM	VOC OM	POW OB	VLT OB		
16	5.13	61.85	5.00	30.00		
PUMP MODULES:						
T HOT	T COLD	ETA	DEGRADE	Q IN	POW OUT	
1128.	547.	3.41	8.13	10.39	0.354	
# MOD	VLTG	CURRENT	QSPUMP	QSPIPE		
3	0.209	1691.	1.02	3.71		

Figure 10. SYSOUT Output File Listing at EOL

TABLE V
SYSOUT OUTPUT FILE NOMENCLATURE
(see Figures 9 and 10)

Parameter	Description
REACTOR:	
POWER	Thermal power to coolant (kwt)
T OUT	Outlet temperature (°F)
DEL T	Core temperature rise (°F)
FLOW	Primary loop flowrate (lb/sec)
PRI PRES	Primary loop pump pressure head (psi)
Q LOSS	Thermal losses from core and shield to space (kwt)
RADIATOR:	
POWER	Rejected thermal power (kwt)
T IN	Radiator coolant inlet temperature (°F)
DEL T	Radiator axial temperature drop (°F)
FLOW	Secondary loop flowrate (lb/sec)
SEC PRES	Secondary loop pump pressure head (psi)
AVG TFIN	Average fin temperature (°F)
POWER MODULES:	
T HOT	Average hot clad temperature (°F)
T COLD	Average cold clad temperature (°F)
ETA	Overall efficiency (%)
DEGRADE	Total matched load power degradation (%)
Q IN	Input thermal power (kwt)
Q BUS	Electrical busbar losses to baseplane (I^2R) (kwt)
# MOD	Number of power modules
POW @M	Electrical power at module connection rings (kwe)
VOC @M	Open circuit module voltage at connection rings (vdc)
POW @B	Electrical power at baseplane (kwe)
VLТ @B	Voltage at baseplane (vdc)

TABLE V
SYSOUT OUTPUT FILE NOMENCLATURE
(see Figures 9 and 10)
(continued)

Parameter	Description
PUMP MODULES:	
T HOT	Average hot clad temperature (°F)
T COLD	Average cold clad temperature (°F)
ETA	Overall efficiency (%)
DEGRADE	Total matched load power degradation (%)
Q IN	Input thermal power (kwt)
POW OUT	Electrical power into pump busbar (kwe)
# MOD	Number of pump modules
VLTG	Pump load voltage (vdc)
CURRENT	Pump current input (amperes)
QSPUMP	Thermal shunt losses from primary throat to secondary throat through pump busbar (kwt)
QSPIPE	Thermal shunt losses from primary piping loop radiating to radiator interior (kwt)

V. CONCLUSIONS

The system performance simulation program can be utilized to derive performance mappings for the 5 Kwe Reactor Thermoelectric System. The program accepts component design information through input data files. The performance calculations are discrete steady-state analyses of the long-term transient situation. Degradation in component performance is based on current correlations to experimental data. The program (as listed in the Appendix) is fully operative, with input file and output file examples.

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1. TI-652-640-001, R. V. Anderson, "5 Kwe Reactor Thermo-electric System Design Point Selection Summary," March 1, 1973.
2. TI-760-420-003, R. V. Anderson, "Thermoelectric Power and Pump Module Design and Performance Summary," to be released.
3. TSR-652-330-001, J. L. Johnson, "NaK Pump Performance Evaluation Trade Study," June 6, 1972.
4. TI-652-310-002, A. F. Lillie, "5 Kwe Reference Conceptual Design - System Hydraulics," September 25, 1972.
5. Mackay, Donald B., Design of Space Powerplants, Prentice-Hall, Inc., 1963. pg 331.

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APPENDIX

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1000$NDM                                SYSTEM Program (main)
1010$OVR,PMPSUB
1020$OVR,RDIATR
1030$OVR,WRITER
1040 REAL TIME(21),EPOWER(21),VOLTAG(21)
1050 REAL TOUTLT(21),PRACT(21),COREDT(21)
1060 REAL THOTCL(21),TCOLCL(21)
1070 REAL EFFPOM(21),DGRPOM(21)
1080 REAL EFFPMM(21),DGRPMM(21)
1090 REAL TAVRAD(21),PRADTR(21),DTRADT(21)
1100 REAL SDNAME(5)
1110 DATA SDNAME/"SWDAT0","SWDAT1","SWDAT2","SWDAT3","SWDAT4"/
1120 1 PRINT,*,* RUN FILE NUMBER ",*
1130 READ,NSRDAT
1140 CALL OPENF(1,SDNAME(NSRDAT+1))
1150C READ COMMENT AND BYPASS
1160 READ(1,)
1170 READ(1,),
1180& POMPPM,POMEFF,POMDGB,EPOWRS,PMPPPM,PMMEFF,PMMDGB,
1190& PTFSIN,PTFSDG,STFSIN,STFSDG,PBUSIN,PBUSDG,
1200& PPIPFH,SPIPFH,
1210& REMMIN,REMMDG,RABSIN,RABSDG,RBNDIN,RBNDG,RDIMTL,
1215& DIRSOL,ERTHRF,DIRERT
1220 CALL CLOSEF(1)
1230 5 PRINT,*,* LIFE (YR),LCNTRL ",*
1240 READ,YEARS,LCNTRL
1250 IF(YEARS.LT.0.0) GO TO 1
1260 NSTEPS=FIX(2.*YEARS+0.0001)
1270 CALL SYSTEM(POMPPM,POMEFF,POMDGB,
1280& EPOWRS,
1290& PMPPPM,PMMEFF,PMMDGB,
1300& PTFSIN,PTFSDG,STFSIN,STFSDG,PBUSIN,PBUSDG,
1310& PPIPFH,SPIPFH,
1320& REMMIN,REMMDG,RABSIN,RABSDG,RBNDIN,RBNDG,RDIMTL,
1325& DIRSOL,ERTHRF,DIRERT,
1330& NSTEPS,LCNTRL,KCNTRL,
1340& EPOWER,VOLTAG,FINTIM,
1350& TOUTLT,PRACT,COREDT,
1360& THOTCL,TCOLCL,
1370& EFFPOM,DGRPOM,EFFPMM,DGRPMM,
1380& TAVRAD,PRADTR,DTRADT)
1390 LIFE=NSTEPS+1
1400 IF(LIFE.EQ.0) GO TO 5
1410 PRINT 999,FINTIM
1420 999 FORMAT(// " ACHIEVABLE LIFE = ",F5.2," YEARS"//)
1430 DO 26 L=1,LIFE
1440 26 TIME(L)=0.5*FLOAT(L-1)
1450 PRINT 1000,(TIME(L),EPOWER(L),TOUTLT(L),THOTCL(L),
1460& PRACT(L),COREDT(L),L=1,LIFE)
1470 1000 FORMAT(/
1480& " TIME EPOWER TOUTLT THOTCL PRACT COREDT"/
1490& (1X,F10.1,F10.2,F10.0,F10.0,F10.2,F10.1))
1500 PRINT 1001,(TIME(L),EFFPOM(L),TAVRAD(L),TCOLCL(L),
1510& PRADTR(L),DTRADT(L),L=1,LIFE)
1520 1001 FORMAT(/
1530& " TIME EFFPOM TAVRAD TCOLCL PRADTR DTRADT"/
1540& (1X,F10.1,2PF10.2,0PF10.1,F10.1,F10.2,F10.1))
1550 PRINT 1002,(TIME(L),EFFPMM(L),DGRPOM(L),DGRPMM(L),
1560& VOLTAG(L),L=1,LIFE)
1570 1002 FORMAT(/

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1580&"      TIME      EFFPMM      DGRPOM      DGRPMM      VOLTAG"/
1590& (1X,0PF10.1,2P3F10.2,0PF10.1))
1600 PRINT 2000,
1610& POMPPM,POMEFF,POMDGB,EPOWRS,PMPPM,PMMEFF,PMMDGB,
1620& PTFSIN,PTFSDG,STFSIN,STFSDG,PBUSIN,PBUSDG,
1630& PPIPFH,SPIPFH,
1640& REMMIN,REMDG,RABSIN,RABSDG,RBNDIN,RBDDG,RDIMTL,
1645& DIRSOL,ERTHRF,DIRERT
1650 2000 FORMAT(//
1660&"      POMPPM      POMEFF      POMDGB      EPOWRS      PMPPM",
1670&"      PMMEFF      PMMDGB"/
1680& F10.2,F10.2,2PF10.2,0PF10.2,F10.2,F10.2,2PF10.2//
1690&"      PTFSIN      PTFSDG      STFSIN      STFSDG      PBUSIN      PBUSDG"/
1700& 0PF10.0,2PF10.2,0PF10.0,2PF10.2,0PF10.2,2PF10.2//
1710&"      PPIPFH      SPIPFH"/
1720& 0PF10.5,F10.5//
1730&"      REMMIN      REMDG      RABSIN      RABSDG      RBNDIN",
1740&"      RBDDG      RDIMTL"/
1750& F10.3,2PF10.2,0PF10.3,2PF10.2,0PF10.2,2PF10.2,0PF10.2//
1752&"      DIRSOL      ERTHRF      DIRERT"/
1754& 0P3F10.2//
1756&//)
1760 GO TO 5
1770 END
1780C
1790C
1800C
1810C
10000C  SYSTEM PERFORMANCE SIMULATION ROUTINE
10010  SUBROUTINE SYSTEM(POMPPM,POMEFF,POMDGB,
10020&      EPOWRS,
10030&      PMPPM,PMMEFF,PMMDGB,
10040&      PTFSIN,PTFSDG,
10050&      STFSIN,STFSDG,
10060&      PBUSIN,PBUSDG,
10070&      PPIPFH,SPIPFH,
10080&      REMMIN,REMDG,
10090&      RABSIN,RABSDG,
10100&      RBNDIN,RBDDG,
10110&      RDIMTL,
10115&      DIRSOL,ERTHRF,DIRERT,
10120&      NSTEPS,LCNTRL,KCNTRL,
10130&      EPOWER,VOLTAG,FINTIM,
10140&      TOUTLT,PReact,CORED,
10150&      THOTCL,TCOLCL,
10160&      EFFPOM,DGRPOM,
10170&      EFFPMM,DGRPMM,
10180&      TAVRAD,PRADTR,DTRADT)
10190C  INPUT PARAMETERS:
10200C  (ALL DEGRADATION RATES IN FRACTION/YEAR)
10210C  POMPPM = BASE POWER/MODULE (POWER MOD) (NORMALIZED)
10220C  POMEFF = BASE EFFICIENCY (POWER MOD) (NORMALIZED)
10230C  POMDGB = POWER DEGRADE RATE @ REF TEMP (POW MOD)
10240C  EPOWRS = ELECTRICAL POWER SOUGHT (KWE)
10250C  PMPPM = BASE POWER/MODULE (PUMP MOD) NORMALIZED)
10260C  PMMEFF = BASE EFFICIENCY (PUMP MOD) (NORMALIZED)
10270C  PMMDGB = POWER DEGRADE RATE @ REF TEMP (PMP MOD)
10280C  PTFSIN = INITIAL PRIMARY THROAT MAG FIELD STRENGTH
10290C  PTFSDG = PRIMARY THROAT MAG STRENGTH DEGRADATION RATE
10300C  STFSIN = INITIAL SECONDARY THROAT MAG FIELD STRENGTH

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10310C STFSDG = SEC THROAT MAG STRENGTH DEGRADATION RATE
 10320C PBUSIN = INITIAL PUMP BUS TOTAL RESISTENCE (NORMALIZED)
 10330C PRUSDG = PUMP BUS RESISTENCE DEGRADATION RATE
 10340C PPIPFH = PRIMARY LOOP FLOW/HEAD CHARACTERISTICS
 10350C SPIPFH = SEC LOOP FLOW/HEAD CHARACTERISTICS
 10360C REMMIN = INITIAL RADIATOR EMMISIVITY
 10370C REMMDG = RAD EMMISIVITY DEGRADATION RATE
 10380C RABSIN = INITIAL RADIATOR ABSORPTIVITY
 10390C RABSDG = RAD ABSORPTIVITY DEGRADATION RATE
 10400C RBNDIN = INITIAL NORMALIZED BOND AREA (FOR UA CALC)
 10410C RBNDG = RAD TUBE-FIN BND THERMAL RESIST. DEGRADE RATE
 10420C RDIMTL = NORMALIZED FIN THICKNESS MULTIPLIER
 10421C DIRSOL = DIRECT SOLAR ENVIORN INPUT
 10422C ERTHRF = EARTH REFLECTED ENVIORN INPUT
 10423C DIRERT = DIRECT EARTH ENVIORN INPUT
 10430C CONTROL PARAMETERS:
 10440C NSTEPS = # OF YEARS FOR CALCULATIONS
 10450C LCNTRL = LIFETIME MODEL CONTROLLER:
 10460C = 0 FOR CONST OUTLET TEMP AND VOLTAGE
 10470C = 1 FOR CONSTANT OUTLET TEMP @ MATCHED LOAD
 10480C = 2 FOR CONST ELECT POWER AND VOLTAGE
 10490C = 3 FOR CONST ELECT POWER @ MATCHED LOAD
 10500C = 4 FOR LIMITED TOUT AND CONST VOLTAGE
 10510C = 5 FOR LIMITED TOUT @ MATCHED LOAD
 10520C KCNTRL = INPUT FILE READ CONTROL
 10530C = 0 FOR READ (PRESET IN DATA STATEMENT)
 10540C = 1 FOR NO-READ (RESET IN READ SECTION)
 10550C OUTPUT ARRAYS (DIMENSIONED 21)
 10560C (BOL IS ENTRY 1 WITH SUCCESIVE YEARS FOLLOWING)
 10570C EPOWER = ELECTRICAL POWER TO BASEPLANE
 10580C VOLTAG = VOLTAGE DELIVERED TO BASEPLANE
 10590C FINTIM = LCNTRL:0,1 - ENDING TIME
 10600C = LCNTRL:2,3 - ENDING TIME OR MAX TIME @ POWER
 10610C = LCNTRL:4,5 - MAX TIME @ POWER OR TIME @ TOUTB
 10620C TOUTLT = REACTOR OUTLET TEMPERATURE
 10630C PREACT = REACTOR THERMAL POWER TO COOLANT
 10640C COREDT = REACTOR CORE TEMPERATURE RISE
 10650C THOTCL = HOT CLAD TEMP (POWER MODULES)
 10660C TCOLCL = COLD CLAD TEMP (POWER MODULES)
 10670C EFFPOM = EFFICIENCY (POWER MODULE)
 10680C DGRPOM = TOTAL DEGRADATION (POWER MODULE)
 10690C EFFPMM = EFFICIENCY (PUMP MODULE)
 10700C DGRPMM = TOTAL DEGRADATION (PUMP MODULE)
 10710C TAVRAD = AVERAGE RADIATOR TEMPERATURE
 10720C PRADTR = RADIATOR THERMAL POWER TO SPACE
 10730C DTRADT = RADIATOR COOLANT TEMP DROP
 10740C
 10750C
 10760C
 10770 REAL EPOWER(21),VOLTAG(21)
 10780 REAL TOUTLT(21),PREACT(21),COREDT(21)
 10790 REAL THOTCL(21),TCOLCL(21)
 10800 REAL EFFPOM(21),DGRPOM(21)
 10810 REAL EFFPMM(21),DGRPMM(21)
 10820 REAL TAVRAD(21),PRADTR(21),DTRADT(21)
 10830 DIMENSION THM(5),TCM(8),EFFTEM(5,8),PPM(5,8),VPM(5,8)
 10840 DIMENSION THP(6),TCP(7),EFFTEP(6,7),PPP(6,7),V(6,7)
 10850 REAL Q(2),G(2),D(2)
 10860 INTEGER IPRINT(21)
 10870 REAL AREAS(5),FINLS(5),FINTS(5),FINRS(5)

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10880 DATA DXINIT,DXMAX/0.01,0.10/
10890 DATA KCNTRL/0/
10900C
10910C
10920C
10930 IF(KCNTRL.NE.0) GO TO 2
10940C READ PARAMETERS ON FIRST CALL TO SYSTEM
10950 CALL OPENF(1,"SSWDAT")
10960 1002 FORMAT(A6,1X,A6,1X,A6)
10970C BYPASS DUMMY TITLE
10980 READ(1,)
10990C READ POW MOD,PMP MOD FILES, AND OUTPUT FILE NAME
11000 READ(1,1002),FNPOWM,FNPPMP,OFNAME
11010 READ(1,),
11020C # POW MOD,# PMP MOD,BASE TO,BASE VSYS
11030C NMOD,NPMD,TOUTB,VSYSS,
11040C HEAT LOSS AND SHUNT MULTIPLIERS
11050C QLM,QPM,QPPMP,
11060C FIRST GUESS FOR TEMPS AND DELTA TEMPS
11070C THG,TCG,DTPG,DTSG,
11080C LOOP FLOW GUESSES
11090C FLOWPG,FLOWSG,
11100C POW MOD ACTIVE ENERGY,REF TEMP,FRACTION EFFEC DEGRADE
11110C QACTPO,DGRMTR,FETAPO,
11120C POW MOD AXIAL TEMP DEGRADE PARAMETERS AND SWITCH
11130C AXDPOO,AXDPO1,AXDPO2,AXDPOS,
11140C PMP MOD ACTIVE ENERGY,REF TEMP,FRACTION EFFEC DEGRADE
11150C QACTPM,DGRPTR,FETAPM,
11160C PMP MOD AXIAL TEMP DEGRADE PARAMETERS AND SWITCH
11170C AXDPMO,AXDPM1,AXDPM2,AXDPM3,
11180C MAIN BUSS RESISTENCE
11190C RMNBUS,
11200C INITIAL POWER AND PUMP MODULE DEGRADATIONS
11210C DGRMIN,DGRPIN,
11220C POWER AND PUMP MODULE FILM TEMP DROPS
11230C DTHC,DTCC,DTHCPM,DTCCPM,
11240C RADIATOR: UA FOR FIN/TUBE AND NAK/TUBE
11250C UAFINB,UAFILM,
11260C RADIATOR:THERMAL COND BASE VALUE AND SLOPE
11270C TCONDB,TCONDS,
11280C RAD: NORM FACTOR FOR FIN THICKNESS
11290C TNORM,
11300C RADIATOR: FIVE SECTION PARAMETERS (TOP TO BOTTOM)
11310C AREAS (SQ FT)
11320C (AREAS(LLL),LLL=1,5),
11330C FIN HALF:WIDTHS (IN.)
11340C (FINLS(LLL),LLL=1,5),
11350C FIN THICKNESS (IN.)
11360C (FINTS(LLL),LLL=1,5),
11370C FIN THICKNESS RATIOS
11380C (FINRS(LLL),LLL=1,5),
11390C POWER MODULE OFF MATCHED LOAD EFFICIENCY COEFF
11400C EMULTO,EMULT1,EMULT2,EMULT3,
11410C ITERATION MAXIMUM FOR TH2 LOOP
11420C IAEN2M,
11430C PUMP SYSTEM PARAMETERS
11460C OFF-MATCHED LOAD EFFICIENCY POLYNOMIAL COEFFICIENTS
11470C EMMO,EMM1,EMM2,EMM3,
11480C PUMP BODY PARAMETERS
11530C THROAT WALL THICKNESS,SPLITTER THICKNESS,MAG GAP

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115408 T,T1,Y,
11550C THROAT: HEIGHT,WIDTH,LENGTH
115608 A,B,X,
11570C BASE BUSS LENGTH,BUSS AREA,DIFFUSSER CONST
115808 BLB,BA,C9,
11590C SUCTION/DISCHARGE PIPE SIZES
116008 D(1),D(2),
11610C TOTAL PRINT CONTROL (0/1) TO OFNAME
116208 IPRINT(1),
11630C PRINT (1)/NO PRINT (0) FOR ILIFE=2,21 (ILIFE=1 PRINTS)
116408 (IPRINT(LLL),LLL=2,21)
11650 CALL CLOSEF(1)
11660C READ POWER MODULE DATA FILE
11670 CALL OPENF(1,FNPOWM)
11680 READ(1,)
11690 READ(1,)
11700 READ(1,1000),((THM(I),TCM(J),PPM(I,J),EFFTEM(I,J),
117108 VPM(I,J),J=1,8),I=1,5)
11720 1000 FORMAT(2F7.1,2F8.5,F6.3)
11730 CALL CLOSEF(1)
11740C READ PUMP MODULE DATA FILE
11750 CALL OPENF(1,FNPPMP)
11760 READ(1,)
11770 READ(1,)
11780 READ(1,1001),((THP(I),TCP(J),PPP(I,J),EFFTEP(I,J),
117908 V(I,J),J=1,7),I=1,6)
11800 1001 FORMAI(2F7.1,2F8.5,F6.3)
11810 CALL CLOSEF(1)
11820 KCNTRL=1
11830C
11840C
11850C
11860 2 CONTINUE
11870 EPOWB=EPOWRS
11880 RNMOD=FLOAT(NMOD)
11890 RNPMOD=FLOAT(NPMOD)
11900C PRESET PUMP FLOWS
11910 Q(1)=FLOWPG
11920 Q(2)=FLOWSG
11930C PRESET LOOP TEMPERATURE DROPS
11940 DTP=DTPG
11950 DTS=DTSG
11960C PRESET TH2 LOOP BANDWIDTH MULTIPLIER
11970 DXMMLT=1.0
11980 FINTIM=0.0
11990 IECNTL=0
12000C PRESET TH2 LOOP ITERATION MAXIMUM
12010 IAEND2=IAEN2M
12020 NLIFE=NSTEPS+1
12030 DO 7000 ILIFE=1,NLIFE
12040 IF(ILIFE.GT.1) GO TO 11
12045 TIME=0.0
12050C CALCULATE FREQUENCY FACTORS FOR DEGRADATION
12060 FFDPOW=0.0
12070 IF(POMDGB.GT.0.) FFDPOW=POMDGB/EXP(-QACTPO/1.1038/
120808 (DGRMTR+460.))
12090 FFDPMP=0.0
12100 IF(PMMDGB.GT.0.) FFDPMP=PMMDGB/EXP(-QACTPM/1.1038/
121108 (DGRPTR+460.))
12120C PRESET INITIAL PARAMETER VALUES

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12130 DGRM=DGRMIN
12140 DGRP=DGRPIN
12150 G(1)=PTFSIN
12160 G(2)=STFSIN
12170 BL=BLB*PBUSIN
12180 EMISIV=REMMIN
12190 ABSORP=RABSIN
12200 RABND=RBNNDIN
12210 AREA=AREAS(1)+AREAS(2)+AREAS(3)+AREAS(4)+AREAS(5)
12220 GO TO 19
12230 11 CONTINUE
12240 TIME=0.5*FLOAT(ILIFE-1)
12250 DTIME=0.5
12260 12 CONTINUE
12270C   CALCULATE DEGRADATION EFFECTS
12280C   LOG-INVERSE-ABSOLUTE-TEMP DEGRADATION MODEL
12290 DGRMR=FFDPOW*EXP(-QACTPO/1.1038/(THOTCL(ILIFE-1)+460.))
12300C   AXIAL EFFECTS WITH SWITCH
12310 IF(AXDPOS.NE.0.) DGRMR=DGRMR*(AXDPO0+AXDPO1*CORED(T(ILIFE-1)+
12320 & AXDPO2*CORED(T(ILIFE-1)**2)
12330 DGRM=DGRPOM(ILIFE-1)+DTIME*DGRMR
12340C   LOG-INVERSE-ABSOLUTE-TEMP DEGRADATION MODEL
12350 DGRPR=FFDPMP*EXP(-QACTPM/1.1038/(THPMPP+460.))
12360C   AXIAL EFFECTS WITH SWITCH
12370 IF(AXDPMS.NE.0.) DGRPR=DGRPR*(AXDPM0+AXDPM1*CORED(T(ILIFE-1)+
12380 & AXDPM2*CORED(T(ILIFE-1)**2)
12390 DGRP=DGRPMM(ILIFE-1)+DTIME*DGRPR
12400C   ALL OTHER DEGRADATION ASSUMED LINEAR WITH TIME
12410 G(1)=PTFSIN*(1.-PTFSDG*TIME)
12420 G(2)=STFSIN*(1.-STFSDG*TIME)
12430 BL=BLB*PBUSIN*(1.-PBUSDG*TIME)
12440 EMISIV=REMMIN*(1.-REMDG*TIME)
12450 ABSORP=RABSIN*(1.-RABSDG*TIME)
12460 RABND=RBNNDIN*(1.-RBNDDG*TIME)
12470 19 CONTINUE
12480C   NEGATIVE LCNTRL INDICATES LCNTRL.GT.3
12490 IF(LCNTRL.GE.2) GO TO 9
12500C
12510C
12520C
12530C   TOUT ITERATION SECTION
12540 8 CONTINUE
12550 NLOC1=0
12560 X2A=TCG
12570 IF(ILIFE.GT.1) X2A=TCOLCL(ILIFE-1)
12580 X2B=THG
12590 IF(ILIFE.GT.1) X2B=THOTCL(ILIFE-1)
12600 YSA=RNMOD
12610 YSB=TOUTB
12620C   ENTER TC ITERATION - SEARCH ON # OF MODULES
12630 DELA=DXINIT*X2A
12640 DO 600 IA=1,11
12650 TC=X2A
12660C   ENTER TH ITERATION - SEARCH ON OUTLET TEMPERATURE
12670 DELB=DXINIT*X2B
12680 DO 400 IB=1,11
12690 TH=X2B
12700C   POWER MODULE CALCULATIONS
12710 POWMOD=FUNCT2(THM,TCM,PPM,5,8,5,TH,TC,NLOC1,2)
12720 POWMOD=POMPPM*POWMOD*(1.-DGRM)

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12730C  CALCULATE MODULE OPEN CIRCUIT VOLTAGE
12740  VOMOD=FUNCT2(THM,TCM,VPM,5,8,5,TH,TC,NLOC1,2)
12750C  CALCULATE MODULE RESISTENCE
12760  RMOD=(VOMOD/2.*RNMOD/2.)*2/(RNMOD*POWMOD*1000.)
12770C  MATCHED LOAD OR CONST VOLTAGE DECISION
12780  IF(LCNTRL/2*2.EQ.LCNTRL) GO TO 303
12790C  MATCHED LOAD CALCULATION
12800  EMULT=1.0
12810  PMULT=1.0
12820C  CALCULATE LOAD RESISTENCE (SAME AS MODULE RESISTENCE)
12830  RLOAD=RMOD
12840C  CALC VOLTAGE TO BASE PLANE
12850  VSYS=(RLOAD-RMNBUS)/RLOAD*(VOMOD/2.*RNMOD/2.)
12860C  CALCULATE POWER DISSIPATION IN MAIN BUSS
12870  QMNBUS=(VOMOD/2.*RNMOD/2./RLOAD)**2*RMNBUS/1000.
12880  GO TO 304
12890  303 CONTINUE
12900C  CONST VOLTAGE CALCULATION
12910C  SET VOLTAGE AT BASE PLANE
12920  VSYS=VSYS
12930C  CALCULATE BASE EQUIPMENT RESISTENCE
12940  REQUIP=(RMNBUS+RMOD)*VSYS/(VOMOD*RNMOD/2.-VSYS)
12950C  CALCULATE LOAD RESISTENCE
12960  RLOAD=REQUIP+RMNBUS
12970C  CALCULATE OFF MATCHED LOAD VOLTAGE FRACTION
12980  VF=2.*RLOAD/(RMOD+RLOAD)
12990C  CALCULATE OFF MATCHED LOAD EFFICIENCY MULTIPLIER
13000  EMULT=EMULT0+EMULT1*VF+EMULT2*VF*VF+EMULT3*VF*VF*VF
13010C  CALC POWER DISSIPATION IN MAIN BUSS
13020  QMNBUS=(VSYS/REQUIP)**2*RMNBUS/1000.
13030C  CALCULATE OFF MATCHED LOAD POWER FACTOR
13040  PMULT=4.*RMOD*RLOAD/(RMOD+RLOAD)**2
13050  304 CONTINUE
13060C  CALCULATE MODULE EFFICIENCY
13070  ETAM=POMEFF*FUNCT2(THM,TCM,EFFTEM,5,8,5,TH,TC,NLOC1,2)
13080C  MULT BY WANLEM TO CONVERT TO WESTINGHOUSE DATA
13090  ETAM=ETAM*(1.-FETAPO*DGRM)
13100C  MULT BY OFF MATCHED LOAD FACTOR
13110  ETAM=ETAM*EMULT
13120C  CALCULATE PUMP THROAT TEMPERATURES
13130  TIN=TH+DTHC-DTP/2.
13140  RTIN=TC-DTCC+DTS/2.
13150C  CALCULATE PUMP MODULE TEMPERATURES
13160  THPMP=TH+DTHC-DTHCPM
13170  TCPMP=TC-DTCC+DTCCPM
13180  NERR=0
13190C  CALL PUMP SIMULATION ROUTINE
13200  CALL LINK(4,"0PMPSU")
13210  CALL PMPSUB(THPMP,TCPMP,TIN,RTIN,DGRP,FETAPM,
13220& Q,PPIPFH,SPIPFH,G,
13230& CURRNT,VOLT,ETAP,THP,TCP,EFFTEP,PPP,V,
13240& PMPPPM,PMMEFF,RNPMOD,
13250& NERR,
13260& EMM0,EMM1,EMM2,EMM3,
13270& T,T1,Y,A,B,X,BL,BA,C9,D)
13280  IF(NERR.EQ.0) GO TO 307
13290C  EXIT LOOPS FOR PUMP ROUTINE ERROR
13300  NSTEPS=ILIFE-2
13310  RETURN
13320  307 CONTINUE

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13330 PEPUMP=VOLT*CURRNT/1000.
13340 QPUMP=PEPUMP/ETAP
13350C RADIATOR SIMULATION
13360 TRAD=TC-DTCC
13370 FLOWS=Q(2)
13380 CALL LINK(4,"ORDIAT")
13390 CALL RDIATR(TRAD,FLOWS,DTS,QRAD,
13400& EMISIV,ABSORP,UAFINB,UAFILM,RDIMTL,RABND,
13405& DIRSOL,ERTHRF,DIRERT,
13410& AREAS,AREA,FINLS,FINTS,FINRS,
13420& TCONDB,TCONDS,TNORM)
13430C CALCULATE QSPIPE,QSP,QSHUNT
13440 QSPIPE=QPM*((TH+DTHC+460.):**4-(RTIN-DTS/6.+460.):**4)
13450 QSP=QMPM*(TIN-RTIN)
13460 QSHUNT=QSPIPE+QSP
13470C CALC ELECT POWER BASED ON MODULE EFFICIENCY
13480 PELECT=(QRAD-QPUMP-QSHUNT-QMNBUS)*ETAM/(1.-ETAM)
13490 QCONV=PELECT/ETAM
13500C CALCULATE ELECT POWER TO BASE PLANE
13510 PELECT=PELECT-QMNBUS
13520C CALCULATE QLOSS
13540 QLOSS=QLM*(TIN+460.):**4
13550C CALCULATE REACTOR POWER
13560 QR=QCONV+QPUMP+QLOSS+QSHUNT
13570C CALCULATE PRIMARY TEMP RISE
13580 DTP=4.52*QR/Q(1)
13590C CALCULATE OUTLET TEMP
13600 TO=TH+DTHC+DTP/2.
13610 Y2B=TO
13620C MINIMUM TWO ITERATION REQUIREMENT
13630 IF(1B.EQ.1) GO TO 375
13640 YEPB=ABS((Y2B-YSB)/YSB)
13650 IF(YEPB.LE.0.0002) GO TO 425
13660 DELB=-(Y2B-YSB)/(Y2B-Y1B)*(X2B-X1B)
13670 DELB=SIGN(AMIN1(ABS(DELB),ABS(DXMAX*X2B)),DELB)
13680 375 X1B=X2B
13690 X2B=X2B+DELB
13700 400 Y1B=Y2B
13710 PRINT,2," MAX ITERATIONS IN TH1 LOOP",2
13720 NSTEPS=ILIFE-2
13730 RETURN
13740 425 CONTINUE
13750C CALCULATE NUMBER OF POWER MODULES TO DELIVER REQUIRED
13760C ELECT POWER TO TOTAL LOAD (EQUIP + BUSS)
13770 Y2A=(PELECT+QMNBUS)/POWMOD/PMULT
13780 YEPA=ABS((Y2A-YSA)/YSA)
13790 IF(YEPA.LE.0.0005) GO TO 625
13800 IF(1A.EQ.1) GO TO 575
13810 DELA=-(Y2A-YSA)/(Y2A-Y1A)*(X2A-X1A)
13820 DELA=SIGN(AMIN1(ABS(DELA),ABS(DXMAX*X2A)),DELA)
13830 575 X1A=X2A
13840 X2A=X2A+DELA
13850 600 Y1A=Y2A
13860 PRINT,2," MAX ITERATIONS IN TC1 LOOP",2
13870 NSTEPS=ILIFE-2
13880 RETURN
13890 625 CONTINUE
13900C SET OUTPUT VALUES
13910 FLOWP=Q(1)
13920 PPRES=PPIPFH*FLOWP*FLOWP

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13930 SPRES=SPIPFH*FLOWS*FLOWS
13940 EPOW=PFLECT
13950 EMDPOW=EPOW+QMNBUS
13960 VOC=RNMOD/2.*VOMOD
13970C   SFT PREVIOUS PUMP HOT CLAD VALUE
13980 THPMP=THPMP
13990 IF(LCNTRL.GE.0) FINTIM=TIME
14000 GO TO 6000
14010C
14020C
14030C
14040C   CONST POWER (& VOLTAGE) ITERATION SECTION
14050 9 CONTINUE
14060C   CALCULATE SYSTEM RESISTENCE (RSYS) IF NEEDED
14070 IF(LCNTRL/2*2.EQ.LCNTRL) RLOAD=VSYSS*VSYSS/EPOWB/1000. + RMNBUS
14080 NLOC1=0
14090 X2A=THG
14100 IF(ILIFE.GT.1) X2A=THOTCL(ILIFE-1)
14110 IF(IECNTRL.GE.1) X2A=THGG
14120 X2B=TCG
14130 IF(ILIFE.GT.1) X2B=TCOLCL(ILIFE-1)
14140 IF(IECNTRL.GE.1) X2B=TCGG
14150 YSA=EPOWB
14160 YSB=EPOWB
14170C   ENTER TH ITERATION - SEARCH ON FPOW
14180 DELA=DXINIT*X2A
14190 DO 1800 IA=1,IAEND2
14200 TH=X2A
14210C   ENTER TC ITERATION - SEARCH ON FPOW
14220 DELB=DXINIT*X2B
14230 DO 1600 IB=1,11
14240 TC=X2B
14250C   POWER MODULE CALCULATIONS
14260 POWMOD=FUNCT2(THM,TCM,PPM,5,8,5,TH,TC,NLOC1,2)
14270 POWMOD=POMPPM*POWMOD*(1.-DGRM)
14280 VOMOD=FUNCT2(THM,TCM,VPM,5,8,5,TH,TC,NLOC1,2)
14290C   PRFSET CONSTANTS TO MATCHED LOAD VALUES
14300 EMULT=1.0
14310 PMULT=1.0
14320 VSYS=RNMOD/2.*VOMOD/2.
14330C   CALCULATE VOLTAGE AT BASE PLANE
14340 VSYS=(VSYS+SQRT(VSYS*VSYS-4000.*EPOWB*RMNBUS))/2.
14350C   BYPASS OFF MATCHED LOAD CALC IF NOT NEEDED
14360 IF(LCNTRL/2*2.NE.LCNTRL) GO TO 1304
14370C   OFF MATCHED LOAD CALCULATION
14380C   CALCULATE OFF MATCHED LOAD POWER MULTIPLIER
14390C   CALCULATE MODULE RESISTENCE
14400 RMOD=(VOMOD/2.*RNMOD/2.)*2/(RNMOD*POWMOD*1000.)
14410 PMULT=4.*RMOD*RLOAD/(RMOD+RLOAD)*2
14420 VSYS=VSYSS
14430 VF=2.*RLOAD/(RMOD+RLOAD)
14440C   CALCULATE OFF MATCHED LOAD EFFICIENCY
14450 EMULT=EMULT0+EMULT1*VF+EMULT2*VF*VF+EMULT3*VF*VF*VF
14460 1304 CONTINUE
14470C   CALCULATE POWER DISSIPATED IN MAIN BUSBAR
14480 QMNBUS=(1000.*EPOWB/VSYS)*2*RMNBUS/1000.
14490C   CALCULATE ELECTRIC POWER BASED ON POWER PER MODULE
14500 PELCT1=RNMOD*POWMOD
14510 Y2B=PELCT1*PMULT-QMNBUS
14520 YEPB=ABS((Y2B-YSB)/YSB)

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14530 IF(YEPB.LE.0.0005) GO TO 1625
14540 IF(1B.EQ.1) GO TO 1575
14550 DELB=-(Y2B-YSB)/(Y2B-Y1B)*(X2B-X1B)
14560 DELB=SIGN(AMIN1(ABS(DELB),ABS(DXMAX*X2B)),DELB)
14570 1575 X1B=X2B
14580 X2B=X2B+DELB
14590 1600 Y1B=Y2B
14600 IF(DXMMLT.LE.0.9) GO TO 1611
14610C   RESET TH2 LOOP BANDWIDTH AND RETRY ITERATION
14620 DXMMLT=0.15
14630 GO TO 9
14640 1611 PRINT,12," MAX ITERATIONS IN TC2 LOOP: DXMMLT=0.1",12
14650 NSTEPS=ILIFE-2
14660 RETURN
14670 1625 CONTINUE
14680 ETAM=FUNCT2(THM,TCM,EFFTEM,5,8,5,TH,TC,NLOC1,2)
14690C   MULT BY WANLEM TO CONVERT TO WANL DATA
14700 ETAM=POMEFF*ETAM*(1.-FETAPO*DGRM)
14710C   CONVERT TO OFF MATCHED LOAD VALUE
14720 ETAM=ETAM*EMULT
14730C   CALCULATE PUMP THROAT TEMPERATURES
14740 TIN=TH+DTHC-DTP/2.
14750 RTIN=TC-DTCC+DTS/2.
14760C   CALCULATE PUMP MODULE TEMPERATURES
14770 THPMP=TH+DTHC-DTHCPM
14780 TCPMP=TC-DTCC+DTCCPM
14790 NERR=0
14800C   CALL PUMP SIMULATION ROUTINE
14810 CALL LINK(4,"QPMPUSU")
14820 CALL PMPSUB(THPMP,TCPMP,TIN,RTIN,DGRP,FETAPM,
148308 Q,PPIPFH,SPIPFH,G,
148408 CURRNT,VOLT,ETAP,THP,TCP,EFFTEP,PPP,V,
148508 PMMPPM,PMMEFF,RNPMOD,
148608 NERR,
148708 EMM0,EMM1,EMM2,EMM3,
148808 T,T1,Y,A,B,X,BL,BA,C9,D)
14890C   EXIT SUBROUTINE IF ERROR IN PUMP SIMULATION
14900 IF(NERR.EQ.0) GO TO 1307
14910 NSTEPS=ILIFE-2
14920 RETURN
14930 1307 CONTINUE
14940 PEPUMP=VOLT*CURRENT/1000.
14950 QPUMP=PEPUMP/ETAP
14960C   RADIATOR SIMULATION
14970 TRAD=TC-DTCC
14980 FLOWS=Q(2)
14990 CALL LINK(4,"ORDIAT")
15000 CALL RDIATR(TRAD,FLOWS,DTS,QRAD,
150108 EMISIV,ABSORP,UAFINB,UAFILM,RDIMTL,RABND,
150158 DIRSOL,ERTHRF,DIRERT,
150208 AREAS,AREA,FINLS,FINTS,FINRS,
150308 TCONDH,TCONDS,TNORM)
15040C   CALCULATE QSPIPE,QSP,QSHUNT
15050 QSPIPE=QPM*((TH+DTHC+460.)*4-(RTIN-DTS/6.+460.)*4)
15060 QSP=QMPM*(TIN-RTIN)
15070 QSHUNT=QSPIPE+QSP
15080C   CALCULATE LOAD POWER BASED ON MODULE EFFICIENCY
15090 PELECT=(QRAD-QPUMP-QSHUNT-QMNBUS)*ETAM/(1.-ETAM)
15100 OCONV=PELECT/ETAM
15110C   CALCULATE QLOSS

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15130 QLOSS=QLM*(TIN+460.)*.4
15140C  CALCULATE REACTOR POWER
15150 QR=QCONV+QPUMP+QSHUNT+QLOSS
15160C  CALCULATE PRIMARY LOOP TEMP DIFF
15170 DTP=4.52*QR/Q(1)
15180C  CALCULATE POWER TO BASE PLANE
15190 PELECT=PELECT-QMNBUS
15200 Y2A=PELECT
15210C  REQUIRE TWO-PASS MINIMUM FOR DTP & DTS CALC
15220 IF(IA.EQ.1) GO TO 1774
15230 YEPA=ABS((Y2A-YSA)/YSA)
15240 IF(YEPA.LE.0.0005) GO TO 1825
15250C  SEARCH FOR MAXIMUM VALUE OF Y2A FOR END-OF-LIFE CALC
15260 IF(Y2A.LE.YSA) Y2AM=AMAX1(Y2A,Y2AM)
15270 DELA=-(Y2A-YSA)/(Y2A-Y1A)*(X2A-X1A)
15280 DELA=SIGN(AMIN1(ABS(DELA),ABS(DXMAX*DXMMLT*X2A)),DELA)
15290 GO TO 1775
15300 1774 IF(Y2A.LE.YSA) Y2AM=Y2A
15310 1775 X1A=X2A
15320 X2A=X2A+DELA
15330 1800 Y1A=Y2A
15340 IF(IECNTL.GE.2) GO TO 1809
15350 IF(DXMMLT.LT.0.9) GO TO 1804
15360C  RESET THE LOOP BANDWIDTH FOR MAXIMUM SEARCH
15370 DXMMLT=0.15
15380 IAEND2=IAEN2M-2
15390 THGG=TH
15400 TCGG=TC
15410 IECNTL=1
15420 GO TO 9
15430 1804 CONTINUE
15440C  SET HALF-YEAR END-OF-LIFE POINTS
15450 TIME1=TIME
15460 ENDP01=Y2AM
15470 TIME=TIME+0.1
15480 DTIME=0.6
15490 DXMMLT=0.1
15500 IAEND2=IAEN2M-4
15510 THGG=TH
15520 TCGG=TC
15530 IECNTL=2
15540 GO TO 12
15550 1809 CONTINUE
15560C  SET 0.6 YEAR END-OF-LIFE POINTS
15570 TIME2=TIME
15580 ENDP02=Y2AM
15590C  LINEARLY EXTRAPOLATE BACK TO END-OF-LIFE POINT
15600 POWSLP=(ENDP01-ENDP02)/(TIME1-TIME2)
15610 TIME0=(YSA-ENDP01)/POWSLP+TIME1
15620 FINTIM=TIME0
15630 NSTEPS=ILIFE-2
15640 RETURN
15650 1825 CONTINUE
15660C  SET OUTPUT VALUES
15670 EPOW=EPOWB
15680 EMDPOW=EPOW+QMNBUS
15690 VOC=RNMOD/2.*VOMOD
15700 FINTIM=TIME
15710 FLOWP=Q(1)
15720 PPRES=PPIPFH*FLOWP*FLOWP

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15730 SPRES=SPIPFH*FLOWS*FLOWS
15740 TO=TH+DTHC+DTP/2.
15750C SET PREVIOUS PUMP HOT CLAD VALUE
15760 THPMPP=THPMP
15770 IF(LCNTRL.LT.4) GO TO 6000
15780 IF(TO.LT.TOUTB) GO TO 6000
15790C SET LCNTRL:-1,-2 FOR CONST TOUT CALC AND FLAG
15800 LCNTRL=LCNTRL-6
15810 IF(ILIFE.EQ.1) GO TO 8
15820C CALCULATE FINTIM FOR TOUTB INTERSECTION
15830 FINTIM=(TIME-DTIME)+(TOUTB-TOUTLT(ILIFE-1))*
15840& DTIME/(TO-TOUTLT(ILIFE-1))
15850 GO TO 8
15860C
15870C
15880C
15890 6000 CONTINUE
15900C WRITE TO OUTPUT FILE IF REQUIRED
15910 IF(IPRINT(1).NE.1) GO TO 6006
15920 IF(ILIFE.NE.1 .AND. IPRINT(ILIFE).NE.1) GO TO 6006
15930 CALL LINK(4,"OWRITE")
15940 CALL WRITER(ILIFE,AREA,OFNAME,XLINE,
15950& QR,TO,DTP,FLOWP,PPRES,QLOSS,
15960& QRAD,RTIN,DTS,FLOWS,SPRES,TRAD,
15970& TH,TC,ETAM,DGRM,QCONV,QMNBUS,
15980& NMOD,EMDPOW,VOC,EPOW,VSYS,
15990& THPMP,TCPMP,ETAP,DGRP,QPUMP,PEPUMP,
16000& NPMOD,VOLT,CURRNT,QSP,QSPIPE)
16010 6006 CONTINUE
16020C ASSIGN OUTPUT VALUES TO ARRAYS
16030 EPOWER(ILIFE)=EPOW
16040 VOLTAG(ILIFE)=VSYS
16050 TOUTLT(ILIFE)=TO
16060 PRACT(ILIFE)=QR
16070 COREDT(ILIFE)=DTP
16080 THOTCL(ILIFE)=TH
16090 TCOLCL(ILIFE)=TC
16100 EFFPOM(ILIFE)=ETAM
16110 DGRPOM(ILIFE)=DGRM
16120 EFFPMM(ILIFE)=ETAP
16130 DGRPMM(ILIFE)=DGRP
16140 TAVRAD(ILIFE)=TRAD
16150 PRADTR(ILIFE)=QRAD
16160 DTRADT(ILIFE)=DTS
16170C PRINT STEPS
16180 PRINT," ILIFE=",ILIFE
16190 7000 CONTINUE
16200 RETURN
16210 END
16220C
16230C
16240C
16250C
16260 FUNCTION FUNCT2(X1,X2,Z,NP1,NP2,LP1,XP1,XP2,IS,IC)
16270C
16280C FEBRUARY 4, 1972
16290C TWO-DIMENSIONAL LAGRANGIAN INTERPOLATION ROUTINE
16300C X1 = FIRST ABSCISSA ARRAY
16310C (MUST BE IN ASCENDING ORDER IN ARRAY)
16320C X2 = SECOND ABSCISSA ARRAY

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16330C      (MUST BE IN ASCENDING ORDER IN ARRAY)
16340C      Z = TWO-DIMENSIONAL ORDINATE ARRAY
16350C      NP1= LENGTH OF X1 ARRAY
16360C      NP2= LENGTH OF X2 ARRAY
16370C      LP1= TOTAL FIRST DIMENSIONAL STORAGE FOR Z ARRAY
16380C      XP1= VALUE OF FIRST ABSCISSA FOR INTERPOLATION
16390C      XP2= VALUE OF SECOND ABSCISSA FOR INTERPOLATION
16400C      IS  REMEMBERS PLACE IN TABLE (MUST BE SET EQUAL
16410C           TO ZERO BEFORE FIRST CALL TO FUNCTION)
16420C      IC  CONTROLS INTERPOLATION METHOD:
16430C           = 1 FOR LINEAR INTERPOLATION
16440C           = 2 FOR LAGRANGIAN INTERPOLATION
16450C      FUNCT2 SET TO CORRESPONDING ORDINATE VALUE
16460C      (FUNCT2 WILL EXTRAPOLATE)
16470C
16480      DIMENSION X1(1),X2(1),Z(LP1,NP2),Y(11)
16490      DIMENSION ED(3),XA(3),YA(3)
16500      EQUIVALENCE (ED(1),XA(1))
16510      NINT=3
16520      IS1=0
16530      IF(NP1.GE.3 .AND. IC.GE.2) GO TO 15
16540C      LINEAR INTERPOLATION
16550      NN=1
16560      I=0
16570      IF(NP1.LE.1) GO TO 38
16580      NINT=2
16590      15 NN=MAX0(2,NP1+2-NINT)
16600      XP=XP1
16610      NN1=2
16620      IF(IS.LE.1 .OR. IS.GE.NP1) GO TO 102
16630C      TEST WHICH DIRECTION TO SEARCH - MUST FIND THE SMALLEST
16640C      X1 GREATER THAN XP, BUT WITH I GREATER THAN 1 AND LESS
16650C      THAN NP1 (OR EQUAL TO NP1 FOR LINEAR INTERPOLATION)
16660      211 NN1=IS
16670      IF(XP.LT.X1(NN1)) GO TO 101
16680C      SEARCH UPWARD IN TABLE
16690      102 DO 20 I=NN1,NN
16700      IF(XP.LE.X1(I)) GO TO 10
16710      20 CONTINUE
16720      I=NN
16730      GO TO 10
16740C      SEARCH DOWNWARD IN TABLE
16750      101 DO 21 J=2,NN1
16760      I=NN1-J+1
16770      IF(XP.GT.X1(I)) GO TO 11
16780      21 CONTINUE
16790      I=1
16800      11 I=I+1
16810      10 SPAN=1.0E-06*XP
16820      NN=0
16830      DO 12 J=1,NINT
16840      NN1=I+J-2
16850      ED(J)=XP-X1(NN1)
16860      12 IF(ABS(ED(J)).LE.SPAN) NN=NN1
16870      IF(NN.EQ.0) GO TO 90
16880      38 DO 40 K=1,NP2
16890      40 Y(K)=Z(NN,K)
16900      FUNCT2=FUNCT1(X2,Y,NP2,XP2,IS1,IC)
16910      GO TO 80
16920      90 DO 93 J=1,NINT

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16930      NN1=I+J-2
16940      DO 92 K=1,NP2
16950 92 Y(K)=Z(NN1,K)
16960      YA(J)=FUNCT1(X2,Y,NP2,XP2,IS1,IC)
16970 93 XA(J)=X1(NN1)
16980      NN1=J
16990      IF(NINT.LT.3) NN1=2
17000      IS1=0
17010      FUNCT2=FUNCT1(XA,YA,NN1,XP,IS1,IC)
17020 80 IS=I
17030      RETURN
17040      END
17041C
17042C
17043C
17044C
17050      FUNCTION FUNCT1(X,Y,NP,XPI,IS,IC)
17060C
17070C      FEBRUARY 4, 1972
17080C      THREE POINT LANGRANGIAN INTERPOLATION
17090C          OR
17100C      TWO POINT LINEAR INTERPOLATION
17110C      X = ABSCISSA ARRAY
17120C          (MUST BE IN ASCENDING ORDER IN ARRAY)
17130C      Y = ORDINATE ARRAY
17140C      NP = LENGTH OF X & Y ARRAYS
17150C      XPI= VALUE OF ABSCISSA FOR INTERPOLATION
17160C      IS  REMEMBERS PLACE IN TABLE (MUST BE SET TO
17170C          ZERO BEFORE FIRST CALL TO FUNCTION)
17180C      IC  CONTROLS INTERPOLATION METHOD:
17190C          = 1 FOR LINEAR INTERPOLATION
17200C          = 2 FOR LAGRANGIAN INTERPOLATION
17210C      FUNCT1 SET TO CORRESPONDING ORDINATE VALUE
17220C      (FUNCT1 WILL EXTRAPOLATE)
17230C
17240      DIMENSION X(1), Y(1), ED(3)
17250      EQUIVALENCE (ED(1),E1), (ED(2),E2), (ED(3),E3)
17260      NINT=3
17270      IF(NP.GE.3 .AND. IC.GE.2) GO TO 15
17280C      LINEAR INTERPOLATION
17290      NN=1
17300      I=0
17310      IF(NP.LE.1) GO TO 38
17320      NINT=2
17330 15 NN=MAX0(2,NP+2-NINT)
17340      XP=XPI
17350      NN1=2
17360      IF(IS.LE.1 .OR. IS.GE.NP) GO TO 102
17370C      TEST WHICH DIRECTION TO SEARCH - MUST FIND THE SMALLEST
17380C      X GREATER THAN XP, BUT WITH I GREATER THAN 1 AND LESS
17390C      THAN NP (OR EQUAL TO NP FOR LINEAR INTERPOLATION)
17400 211 NN1=IS
17410      IF(XP.LT.X(NN1)) GO TO 101
17420C      SEARCH UPWARD IN TABLE
17430 102 DO 20 I=NN1,NN
17440      IF(XP.LE.X(I)) GO TO 10
17450 20 CONTINUE
17460      I=NN
17470      GO TO 10
17480C      SEARCH DOWNWARD IN TABLE

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17490 101 DO 21 J=2,NN1
17500      I=NN1-J+1
17510      IF(XP.GT.X(I)) GO TO 11
17520 21 CONTINUE
17530      I=1
17540 11 I=I+1
17550C      INTERPOLATE FOR FUNCT1 IN Y-TABLE CORRESPONDING TO
17560C      XP IN X-TABLE USING THREE POINT LAGRANGIAN
17570C      INTERPOLATION SCHEME
17580 10 SPAN=1.0E-06*XP
17590      NN=0
17600      DO 12 J=1,NINT
17610      NN1=I+J-2
17620      ED(J)=XP-X(NN1)
17630 12 IF(ABS(ED(J)).LE.SPAN) NN=NN1
17640      IF(NN.EQ.0) GO TO 90
17650 38 FUNCT1=Y(NN)
17660      GO TO 80
17670 90 E12=X(I-1)-X(I)
17680      IF(NINT.EQ.3) GO TO 360
17690      FUNCT1=Y(I)-(Y(I)-Y(I-1))*E2/E12
17700      GO TO 80
17710 360 E13=X(I-1)-X(I+1)
17720      E23=X(I)-X(I+1)
17730 36 FUNCT1=Y(I-1)*E2*E3/(E12*E13)
17740&      -Y(I) *E1*E3/(E12*E23)
17750&      +Y(I+1)*E1*E2/(E13*E23)
17760 80 IS=I
17770      RETURN
17780      END

```

PMPSUB Overlay

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20000 SUBROUTINE PMPSUB(TH,TC,TTP,TTS,DGRP,FETAPM,Q,CP,CS,G,
20010& I,VO,ETAP,THP,TCP,EFFTEP,PPP,V,
20020& PMMPPM,PMMEFF,RNPMOD,
20030& NERR,
20040& EMM0,EMM1,EMM2,EMM3,
20050& T,T1,Y,A,B,X,BL,BA,C9,D)
20060C SUBROUTINE SIMULATES EM PUMP OF GIVEN DESIGN
20070C INPUT: TH,TC,DGRP (HOT CLAD,COLD CLAD,DEGRADATION)
20080C INPUT: FLOW GUESSES AND PIPING FLOW/HEAD PARAM.
20090C CALCULATES OFF MATCHED LOAD OPERATION OF PUMP SYSTEM
20100C WHERE THE PUMP PROVIDES THE NECESSARY HEAD AND FLOW
20110C FOR THE PIPING SYSTEM SPECIFIED.
20120 REAL I,ICC,IML,Q(2),G(2),TT(2)
20130 REAL THP(6),TCP(7),EFFTEP(6,7),PPP(6,7),V(6,7)
20140 REAL D(2)
20150 NLOC1=0
20160 TT(1)=TTP
20170 TT(2)=TTS
20180C CALCULATE AS DESIGNED MODULE CHARACTERISTICS
20190C OPEN CIRCUIT VOLTAGE
20200 VOC=FUNCT2(THP,TCP,V,6,7,6,TH,TC,NLOC1,2)
20210C DEGRADATION DOES NOT EFFECT GENERATOR VOLTAGE
20220C MATCHED-LOAD POWER FOR RNPMOD MODULES
20230 PML=RNPMOD*FUNCT2(THP,TCP,PPP,6,7,6,TH,TC,NLOC1,2)
20240C INCLUDE DEGRADATION
20250 PML=PMMPPM*PML*(1.-DGRP)
20260C CALCULATE MATCHED LOAD VOLTAGE
20270 VML=VOC/2.
20280C CALCULATE MATCHED-LOAD CURRENT
20290 IML=1000.*PML/VML
20300C CALC SHORT CIRCUIT CURRENT
20310 ICC=2.*IML
20320C CALCULATE MODULE RESISTENCE
20330 RM=VML/IML
20340 RP=RM
20350 DO 100 K=1,25
20360 I=ICC*RM/(RM+RP)
20370 IF(I.GE.0.0) GO TO 49
20380 PRINT,*,2," NEGATIVE CURRENT IN PMPSUB",*,2
20390 NERR=1
20400 RETURN
20410 49 CONTINUE
20420 VO=VOC*RP/(RM+RP)
20430C CALL PUMP/PIPING SIMULATION ROUTINE
20440 CALL PUMPA(I,Q,CP,CS,G,TT,VN,RPN,
20450& NERR,
20460& T,T1,Y,A,B,X,BL,BA,C9,D)
20470 IF(NERR.EQ.1) RETURN
20480 DEL=ABS((VO-VN)/VO)
20490 IF(DEL.LE.0.0005) GO TO 200
20500 RP=RPN
20510 100 CONTINUE
20520 PRINT,*,2," MAX ITERATIONS IN PMPSUB",*,2
20530 NERR=1
20540 RETURN
20550 200 CONTINUE
20560 VO=VN
20570C CALCULATE PUMP CHARACTERISTIC EFFICIENCY
20580 ETAP=FUNCT2(THP,TCP,EFFTEP,6,7,6,TH,TC,NLOC1,2)
20590 ETAP=PMMEFF*ETAP*(1.-FETAPM*DGRP)

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20600C  CALCULATE VOLTAGE FRACTION
20610  VF=VO/VML
20620C  CALCULATE EFFICIENCY MULTIPLIER
20630  EM=EMM0+EMM1*VF+EMM2*VF*VF+EMM3*VF*VF*VF
20640  ETAP=ETAP*EM
20650  RETURN
20660  END
20670C
20680C
20690C
20700C
20710C
20720  SUBROUTINE PUMPA(I,Q,CP,CS,G,TT,VT,R,
20730& NERR,
20740& T,T1,Y,A,B,X,BL,BA,C9,D)
20750C  SIMULATES PUMP/PIPING INTERACTION
20760C  INPUT: CURRENT (I) AND FLOW PARAMETERS
20770C  CALCULATES PUMP VOLTAGE REQUIREMENT AND INTERNAL
20780C  RESISTENCE FOR A GIVEN PIPING SYSTEM LOAD AND
20790C  A GIVEN CURRENT INPUT.
20800  REAL I,Q(2),DP(2),DPN(2),TT(2)
20810  REAL G(2),V(2)
20820  REAL D(2)
20830  DP(1)=CP*Q(1)*Q(1)
20840  DP(2)=CS*Q(2)*Q(2)
20850  DO 100 K=1,25
20860C  CALL PUMP BODY SIMULATION ROUTINE
20870  CALL DCPMP(Q,I,TT,G,DPN,V,VB,
20880& T,T1,Y,A,B,X,BL,BA,C9,D)
20890  Y1=ABS((DP(1)-DPN(1))/DP(1))
20900  Y2=ABS((DP(2)-DPN(2))/DP(2))
20910  IF(Y1.LE.0.0005 .AND. Y2.LE.0.0005) GO TO 200
20920C  PRIMARY LOOP CHECK
20930  IF(Y1.LE.0.0005) GO TO 60
20940  IF(DPN(1).GT.0.0) GO TO 55
20950  Q(1)=0.95*Q(1)
20960  DP(1)=CP*Q(1)*Q(1)
20970  GO TO 60
20980  55 CONTINUE
20990  Q(1)=Q(1)*(DPN(1)/DP(1))**0.25
21000  DP(1)=CP*Q(1)*Q(1)
21010  60 CONTINUE
21020C  SECONDARY LOOP CHECK
21030  IF(Y2.LE.0.0005) GO TO 70
21040  IF(DPN(2).GT.0.0) GO TO 65
21050  Q(2)=0.95*Q(2)
21060  DP(2)=CS*Q(2)*Q(2)
21070  GO TO 70
21080  65 CONTINUE
21090  Q(2)=Q(2)*(DPN(2)/DP(2))**0.25
21100  DP(2)=CS*Q(2)*Q(2)
21110  70 CONTINUE
21120  100 CONTINUE
21130  PRINT,*,2," MAX ITERATIONS IN PUMPA LOOP",*,2
21140  NERR=1
21150  RETURN
21160  200 CONTINUE
21170C  CALCULATE TOTAL VOLTAGE DROP IN PUMP
21180  VT=V(1)+V(2)+VB
21190  R=VT/I

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21200 RETURN
21210 END
21220C
21230C
21240C
21250C
21260C
21270 SUBROUTINE DCPMP(Q,I,TT,G,
21280&          P1,V1,VB,
21310&          T,T1,Y,
21320&          A,B,X,
21330&          BL,BA,C9,
21340&          D)
21350C    DC TWO THROAT PUMP SUBROUTINE
21360C    2 DIMENSIONAL VARIABLES: 1 IS PRIMARY; 2 IS SECONDARY
21370C    INPUT PARAMETERS: Q,I,TT,G
21380C    Q = FLOW RATES (LB/SEC)
21390C    I = CURRENT (AMPS)
21400C    TT = THROAT TEMPERATURES
21410C    G = MAGNETIC FIELD STRENGTHS (GAUSS)
21420C    OUTPUT PARAMETERS: P1,V1
21430C    P1 = PUMP HEADS (PSI)
21440C    V1 = THROAT VOLTAGES (VOLTS)
21450C    VB = BUS VOLTAGE DROP (VOLTS)
21460C    PUMP PARAMETERS
21540C    T = THROAT WALL THICKNESS (IN.)
21550C    T1 = THROAT SPLITTER THICKNESS (IN.)
21580C    Y = MAGNET GAP
21590C    A = THROAT HEIGHT (IN)
21600C    B = THROAT WIDTH (IN)
21610C    X = THROAT LENGTH (IN)
21620C    BL = EFFECTIVE BUSBAR LENGTH (INCLUDING RINGS)
21630C    BA = BUSBAR CROSSECTION
21640C    C9 = DIFFUSER CONSTANT
21650C    D = PUMP SUCT/DISCH PIPE SIZES (2-DIMEN)
21660 REAL K
21670 REAL I,I1(2),I2(2),I3(2),I4(2),I5(2)
21680 REAL M1(2),M2(2),M3(2),M4
21690 REAL R1(2),R2(2),R3(2)
21700 REAL D(2),D5(2),U(2),S(2),C1(2)
21710 REAL Q(2),P1(2),V1(2)
21720 REAL TT(2),G(2)
21730 REAL L,L1,L2
21740 REAL N
21750C    INITIALIZE PUMP PARAMETERS FOR GIVEN TEMPS
21760 DO 100 J=1,2
21770 CALL PARAT(TT(1),TT(2),D5(J),U(J),R1(J),R2(J),R3(J),J)
21780C    CALCULATE PUMP HEAD FOR EACH THROAT
21790 K=3.0
21800 IF(A.LE.2.25) K=2.0
21810 IF(A.LE.1.50) K=1.0
21820 IF(A.LE.0.75) K=0.0
21830 I1(J)=R1(J)*(A-K*T1)/B/X
21840 I2(J)=R2(J)*(A+2.*T)/2./T/X
21850 I3(J)=R2(J)*(2.*T+K*T1)/B/X
21860 I4(J)=2.5*R1(J)/B
21870 I5(J)=I2(J)*I4(J)/(I2(J)+I4(J))
21880 M1(J)=5.714E-7*I5(J)/(8*(I1(J)+I5(J)))
21890 M2(J)=3.687E-14/(D5(J)*B*8*(I1(J)+I5(J)))
21900 M3(J)=0.26*3.687E-14/D5(J)/B/R1(J)

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21910 S(J)=4.0*A*B/FPI(D(J)*D(J))
21920 C1(J)=(0.02+C9*(1.-S(J))**2)*1.3E-3/(D5(J)*(A-K*T1)**2*B*B)
21930 100 CONTINUE
21940 DO 500 J=1,2
21950 N=8.64E4*Q(J)/U(J)/(A+B)
21960 IF(N.LE.2.3E3) F1=1.1*16.0/N
21970 IF(N.GT.2.3E3) F1=1.1*7.9E-2/N**0.25
21980 C2=2.*F1*(B+(A-K*T1))*X*1.3E-3/(D5(J)*B*B*B*(A-K*T1)**3)
21990 M4=C1(J)+C2
22000 B1=FPI(2.)*Q(J)*X*1.0E-9/(A*B*D5(J)*R1(J))
22010 Y1=EXP(B1)
22020 Y2=EXP(-B1)
22030 B6=(Y1+Y2)/(Y1-Y2)-1./B1
22040 Z2=(M1(J)/(4.*(M2(J)+M3(J))*Q(J))
22050 & -FPI(2.)*B6/10./B)*M1(J)
22060 B4=FPI(2.)*I*B6/10./G(J)/B
22070 B7=1.-B4
22080C   CALCULATE HEAD
22090 P1(J)=M1(J)*G(J)*I*B7-(M2(J)+M3(J))*G(J)*G(J)*Q(J)
22100 & -M4*Q(J)*Q(J)
22110 E1=6.452E-8*G(J)*Q(J)/D5(J)/B
22120C   CALCULATE VOLTAGE DROP IN THROAT
22130 V1(J)=I5(J)*(I*I1(J)+E1)/(I1(J)+I5(J))+I*I3(J)
22140 500 CONTINUE
22150C   CALCULATE BUS VOLTAGE DROP
22160 RBUS=R3(1)*BL/BA
22170 VB=RBUS*I
22180 RETURN
22190 END
22200C
22210C
22220C
22230C
22240C
22250 SUBROUTINE PARAT(TX1,TX2,D5,U,R1,R2,R3,ICNTL)
22260C   CALCULATES TEMPERATURE DEPENDENT PUMP PARAMETERS
22270 IF(ICNTL.EQ.2) GO TO 50
22280 T1=TX1
22290 T2=TX2
22300 GO TO 100
22310 50 T1=TX2
22320 T2=TX1
22330 100 CONTINUE
22340 R1=(13.49+7.463E-3*T1+7.205E-6*T1*T1)*1.0E-06
22350 R2=(27.+0.015*T1)*1.0E-6
22360 R3=(0.58+0.00148*(T1+T2)/2.)*1.0E-6
22370 D5=(54.27-0.008349*T1)/1728.
22380 T=T1+460.
22390 U=10.**((0.6663+(380.26/T)-0.4158*ALOG10(T))
22400 RETURN
22410 END

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RDIATR Overlay

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30000 SUBROUTINE RDIATR(TRA VG,FLORAT,TDROPG,QRAD,
30010& EMISIV,ABSORP,UAFINB,UAFILM,RDIMTL,RABND,
30015& DIRSOL,ERTHRF,DIRERT,
30020& A,AT,FL,FT,FR,
30030& TCONDB,TCONDS,TNORM)
30040C    RADIATOR SIMULATION
30050C    INPUTS: AVG TEMP,FLOWRATE,SURFACE PARAMETERS,GEOMETRY
30060C    TRA VG = LINEAR AVG RADIATOR TEMPERATURE (INPUT)
30070C    FLORAT = FLOWRATE IN RADIATOR (LB/SEC) (INPUT)
30080C    TDROPG = DT GUESS (INPUT), ACTUAL DT (OUTPUT)
30090C    QRAD = HEAT REJECTION (KWT) (OUTPUT)
30100C    EMISIV = EMMISIVITY OF RADIATOR
30110C    ABSORP = ABSORPTIVITY OF RADIATOR
30120C    UAFINB = EFFECTIVE UA OF FIN-TURE BOND (KWT/DEG F)
30130C    UAFILM = EFFECTIVE UA OF NAK-TUBE (KWT/DEG F)
30140C    RABND = NORMALIZED EFFECTIVE AREA OF TUBE-FIN BOND
30141C    DIRSOL = DIRECT SOLAR ENVIORNMENTAL INPUT
30142C    ERTHRF = EARTH REFLECTED ENVIORNMENTAL INPUT
30143C    DIRERT = DIRECT EARTH ENVIORNMENTAL INPUT
30150C    * 1,2,3,4,5 SUFFIX REFERS TO FIVE RAD SECTIONS *
30160C    AREAX = AREA OF SECTION (SQ FT)
30170C    FINLX = FIN MIDPLANE SPACING (AVG) ( IN)
30180C    FINTX = FIN HOT END THICKNESS (AVG) (IN)
30190C    FINRX = HOT-TO-COLD THICKNESS RATIO (AVG)
30200C    TCONDB = THERM COND OF MATL AT 0 DEG F (BTU/SQ-FT-DEG/F)
30210C    TCONDS = SLOPE OF THERM COND (LINEAR APPROX)
30220C    TNORM = NORMALIZER FOR FIN THICKNESSES
30230 DIMENSION A(5),FL(5),FT(5),FR(5)
30240 DATA QSGUES/20./
30250 DATA DXINIT,DXMAX/0.01,0.20/
30260C    ENTER FIRST ITERATION LOOP
30270C    ITERATE ON TEMP DROP TO GET CORRECT FLOWRATE
30280 YSA=FLORAT
30290 YSB=FLORAT
30300 X2A=TDROPG
30310 DELA=DXINIT*X2A
30320 DO 600 IA=1,25
30330 DT=X2A
30340C    CALCULATE RADIATOR NAK INLET TEMP
30350 TIN=TRA VG+DT/2.
30360 QTOT=0.0
30370 TINT=TIN
30380 C1=0.1713E-08*EMISIV
30390 C2=(DIRSOL+ERTHRF)*ABSORP+DIRERT*EMISIV
30400C    ENTER FIVE SECTION LOOP
30410 DO 500 IL=1,5
30420C    ENTER SECOND ITERATION LOOP
30430C    ITERATE ON SECTION TEMP DROP TO GET FLOWRATE
30440 X2B=TDROPG/5.
30450 DELB=DXINIT*X2B
30460 DO 400 IB=1,25
30470 DTS=X2B
30480 IF(18.EQ.1) QS=QSGUES
30490C    CALCULATE TEMP DROPS
30500 TDFINB=QS/(UAFINB*A(IL)/AT*RABND)
30510 TDFILM=QS/(UAFILM*A(IL)/AT)
30520C    CALCULATE ABSOLUTE SECTION TEMPERATURE (FIN FACE)
30530 TR=TINT-DTS/2.-TDFINB-TDFILM+460.
30540C    CALC TEMP DEPENDENT THERMAL CONDUCTIVITY
30550 TCOND=TCONDB+TCONDS*(TR-460.)

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30560C  CALC PROFILE NUMBER AND ENVIORNMENTAL PARAMETER
30570  PN=C1*TR**3*FL(IL)**2/(RDIMTL*TNORM*FT(IL))/TCOND/12.
30580  EP=C2/C1/TR/TR/TR/TR
30590C  CALCULATE FIN EFFECTIVENESS
30600  O=FINEFF(FR(IL),PN,EP)
30610C  CALCULATE HEAT REJECTION
30620  QS=EMISIV*O*A(IL)*0.1713E-08/3413.*(TR**4)
30630  Y2B=4.455*QS/DTS
30640  IF(1B.EQ.1) GO TO 375
30650  YEPB=ABS((Y2B-YSB)/YSB)
30660  IF(YEPB.LE.0.001) GO TO 425
30670  DELB=-(Y2B-YSB)/(Y2B-Y1B)*(X2B-X1B)
30680  DELB=SIGN(AMIN1(ABS(DELB),ABS(DXMAX*X2B/2.)),DELB)
30690  375  X1B=X2B
30700  X2B=X2B+DELB
30710  400  Y1B=Y2B
30720  PRINT,12," MAX ITER IN RAD SECTION FOR FLO",12
30730  QRAD=0.
30740  RETURN
30750  425  CONTINUE
30760C  RESET TEMPORARY SECTION INLET TEMP
30770  TINT=TINT-DTS
30780C  SUM HEAT REJECTION
30790  QTOT=QTOT+QS
30800  500  CONTINUE
30810  Y2A=4.455*QTOT/DT
30820  YEPA=ABS((Y2A-YSA)/YSA)
30830  IF(YEPA.LE.0.001) GO TO 625
30840  IF(1A.EQ.1) GO TO 575
30850  DELA=-(Y2A-YSA)/(Y2A-Y1A)*(X2A-X1A)
30860  DELA=SIGN(AMIN1(ABS(DELA),ABS(DXMAX*X2A)),DELA)
30870  575  X1A=X2A
30880  X2A=X2A+DELA
30890  600  Y1A=Y2A
30900  PRINT,12," MAX ITER IN RAD TOTAL FOR FLO",12
30910  QRAD=0.0
30920  RETURN
30930  625  CONTINUE
30940C  SET OUTPUT VALUES
30950  QRAD=QTOT
30960  TDROPG=DT
30970  RETURN
30980  END
30990C
31000C
31010C
31020C
31030C  ROUTINE SOLVES FOR FIN EFFECT. GIVEN THICK RATIO (TR)
31040C  PROFILE NUMBER (PN) AND ENVIORNMENTAL PARAMETER (EP)
31050C
31060  FUNCTIONFINEFF(TR,PN,EP)
31070  DIMENSIONEP1(4),XLMEP1(4),TR1(4),XLMTR1(4)
31080  NEP=EP*10.
31090  EP1(2)=FLOAT(NEP)/10.
31100  EP1(1)=EP1(2)-.1
31110  EP1(3)=EP1(2)+.1
31120  EP1(4)=EP1(3)+.1
31130  TR1(1)=.25
31140  TR1(2)=.5
31150  TR1(3)=.75

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31160 TR1(4)=1.
31170 IF(TR.GT..25)GOTO10
31180 TR1(1)=.01
31190 TR1(2)=.25
31200 TR1(3)=.50
31210 TR1(4)=.75
31220 10D050I=1,4
31230 D040J=1,4
31240 40CALLFFFS(TR1(I),PN,EP1(J),XLMEP1(J))
31250 CALLPOLY4(FP1,XLMEP1,EP,XLMTR1(I),DY)
31260 50CONTINUE
31270 CALLPOLY4(TR1,XLMTR1,TR,XLM,DY)
31280 FINEFF=XLM
31290 RETURN
31300 END
31310C
31320C
31330C
31340C
31350 SUBROUTINEEFFS(FRTIO,ZZ,C3E,EF)
31360 ZZ2=ZZ**2
31370 ZZ3=ZZ**3
31380 ZZ4=ZZ**4
31390 ZZ5=ZZ**5
31400 IF(FRTIO-1.)3601,3600,3683
31410 3601IF(FRTIO-.75)3603,3602,3683
31420 3603IF(FRTIO-.50)3605,3604,3683
31430 3605IF(FRTIO-.25)3607,3606,3683
31440 3607IF(FRTIO-.01)3683,3608,3683
31450 3683FRTIO=.01
31460 GOTO3608
31470 3600IF(ZZ-1.0)3650,3650,3665
31480 3650EP0=1.-1.262562*ZZ+1.887146*ZZ2-1.735795*ZZ3+.6448865*ZZ4
31490 FP1=.9-1.140328*ZZ+1.683534*ZZ2-1.537829*ZZ3+.569412*ZZ4
31500 EP2=.8-1.016279*ZZ+1.474814*ZZ2-1.322815*ZZ3+.4792801*ZZ4
31510 EP3=.7-.8927102*ZZ+1.281601*ZZ2-1.144517*ZZ3+.4156257*ZZ4
31520 EP4=.6-.7677726*ZZ+1.087437*ZZ2-.9604035*ZZ3+.3457387*ZZ4
31530 EP5=.5-.6422900*ZZ+.8996527*ZZ2-.7896137*ZZ3+.284251*ZZ4
31540 EP6=.4-.5138955*ZZ+.6973402*ZZ2-.5782825*ZZ3+.1898378*ZZ4
31550 EP7=.3-.3881648*ZZ+.5301611*ZZ2-.4555336*ZZ3+.1617304*ZZ4
31560 EP8=.2-.2586196*ZZ+.3404537*ZZ2-.2719214*ZZ3+.08508737*ZZ4
31570 EP9=.1-.1305437*ZZ+.1754656*ZZ2-.1505314*ZZ3+.05460955*ZZ4
31580 GOTO3700
31590 3684EF=0.
31600 RETURN
31610 3665IF(ZZ-3.2)3670,3670,3684
31620 3670EP0=.7757701-.3198802*ZZ+.0872388*ZZ2-.00949878*ZZ3
31630 EP1=.7038544-.3054176*ZZ+.08586906*ZZ2-.009551385*ZZ3
31640 EP2=.6070759-.2518273*ZZ+.06677432*ZZ2-.007047*ZZ3
31650 EP3=.5378824-.2362182*ZZ+.06538716*ZZ2-.00713444*ZZ3
31660 EP4=.4574065-.2021295*ZZ+.05570959*ZZ2-.00604585*ZZ3
31670 EP5=.3849067-.1782698*ZZ+.05101359*ZZ2-.005709398*ZZ3
31680 EP6=.2747747-.09967986*ZZ+.02178899*ZZ2-.001859083*ZZ3
31690 EP7=.2285584-.1078431*ZZ+.03086852*ZZ2-.003429516*ZZ3
31700 EP8=.1318693-.04501946*ZZ+.00881272*ZZ2-.0006344152*ZZ3
31710 EP9=.07896124-.04113519*ZZ+.01262526*ZZ2-.001476269*ZZ3
31720 GOTO3700
31730 3602IF(ZZ-1.)3640,3640,3666
31740 3640EP0=1.-1.335867*ZZ+2.070341*ZZ2-1.927851*ZZ3+.7171693*ZZ4
31750 EP1=.9-1.207947*ZZ+1.857098*ZZ2-1.729376*ZZ3+.6459525*ZZ4

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31760 EP2=.8-1.079416*ZZ+1.651198*ZZ2-1.548712*ZZ3+.5899295*ZZ4
31770 EP3=.7-.9492213*ZZ+1.442902*ZZ2-1.358585*ZZ3+.5249043*ZZ4
31780 EP4=.6-.8155273*ZZ+1.216008*ZZ2-1.117243*ZZ3+.4187663*ZZ4
31790 EP5=.5-.6827542*ZZ+1.009497*ZZ2-.9256834*ZZ3+.3489401*ZZ4
31800 EP6=.4-.5491958*ZZ+.8088220*ZZ2-.7472351*ZZ3+.2867089*ZZ4
31810 EP7=.3-.412255*ZZ+.5903902*ZZ2-.5205666*ZZ3+.1875009*ZZ4
31820 EP8=.2-.2940312*ZZ+.4329405*ZZ2-.3818678*ZZ3+.1359585*ZZ4
31830 EP9=.1-.1388308*ZZ+.1966445*ZZ2-.1742080*ZZ3+.06439428*ZZ4
31840 GOT03700
31850 36661F(ZZ-3.2)3641,3641,3684
31860 3641EP0=.7325675-.2591288*ZZ+.05389871*ZZ2-3.569779E-3*ZZ3
31870 EP1=.6923336-.3028001*ZZ+.08574299*ZZ2-9.584034E-3*ZZ3
31880 EP2=.6376183-.3053143*ZZ+.0910424*ZZ2-.01048478*ZZ3
31890 EP3=.5761279-.2986492*ZZ+.09336575*ZZ2-.01106601*ZZ3
31900 EP4=.4728776-.2331774*ZZ+.07034166*ZZ2-8.160483E-3*ZZ3
31910 EP5=.3987432-.2044435*ZZ+.06298206*ZZ2-7.397060E-3*ZZ3
31920 EP6=.3314806-.1836856*ZZ+.05922766*ZZ2-7.153621E-3*ZZ3
31930 EP7=.2243235-.1066364*ZZ+.03082724*ZZ2-3.453709E-3*ZZ3
31940 EP8=.1414196-.06451391*ZZ+.01814235*ZZ2-1.968459E-3*ZZ3
31950 EP9=.07764744-.04080494*ZZ+.01261357*ZZ2-1.479395E-3*ZZ3
31960 GOT03700
31970 36041F(ZZ-1.)3630,3630,3667
31980 3630EP0=1.-1.419051*ZZ+2.279145*ZZ2-2.157439*ZZ3+.8100526*ZZ4
31990 EP1=.9-1.282622*ZZ+2.036656*ZZ2-1.913415*ZZ3+.7146148*ZZ4
32000 EP2=.8-1.145255*ZZ+1.799773*ZZ2-1.680889*ZZ3+.6263710*ZZ4
32010 EP3=.7-1.007343*ZZ+1.572065*ZZ2-1.469559*ZZ3+.5528371*ZZ4
32020 EP4=.6-.8659147*ZZ+1.328053*ZZ2-1.214689*ZZ3+.4445508*ZZ4
32030 EP5=.5-.7248883*ZZ+1.099312*ZZ2-.9943335*ZZ3+.3599098*ZZ4
32040 EP6=.4-.5138955*ZZ+.6975402*ZZ2-.5782825*ZZ3+.1898378*ZZ4
32050 EP7=.3-.4392235*ZZ+.6548777*ZZ2-.5867130*ZZ3+.2126798*ZZ4
32060 EP8=.2-.2940312*ZZ+.4329405*ZZ2-.3818678*ZZ3+.1359585*ZZ4
32070 EP9=.1-.1472987*ZZ+.2117676*ZZ2-.1787227*ZZ3+.0592538*ZZ4
32080 GOT03700
32090 36671F(ZZ-3.2)3642,3642,3684
32100 3642EP0=.7517189-.3152291*ZZ+.08430097*ZZ2-8.396580E-3*ZZ3
32110 EP1=.676632-.296004*ZZ+.08396145*ZZ2-9.383384E-3*ZZ3
32120 EP2=.5991339-.2657965*ZZ+.07485574*ZZ2-8.261033E-3*ZZ3
32130 EP3=.5428751-.2669894*ZZ+.08156106*ZZ2-9.585416E-3*ZZ3
32140 EP4=.4417540-.2003986*ZZ+.05692503*ZZ2-6.320243E-3*ZZ3
32150 EP5=.3621664-.1631316*ZZ+.04599478*ZZ2-5.094662E-3*ZZ3
32160 EP6=.2935515-.1380147*ZZ+.03984790*ZZ2-4.465870E-3*ZZ3
32170 EP7=.2189595-.1043586*ZZ+.03041304*ZZ2-3.432674E-3*ZZ3
32180 EP8=.1441496-.0645139*ZZ+.01804235*ZZ2-1.968459E-3*ZZ3
32190 EP9=.06330937-.02281387*ZZ+.4.92543E-3*ZZ2-4.108926E-4*ZZ3
32200 GOT03700
32210 36061F(ZZ-1.)3620,3620,3668
32220 3620EP0=1.-1.541842*ZZ+2.640584*ZZ2-2.590399*ZZ3+.9920293*ZZ4
32230 EP1=.9-1.395863*ZZ+2.375164*ZZ2-2.326967*ZZ3+.8917568*ZZ4
32240 EP2=.8-1.247846*ZZ+2.109718*ZZ2-2.064751*ZZ3+.7928801*ZZ4
32250 EP3=.7-1.096189*ZZ+1.828237*ZZ2-1.761794*ZZ3+.664746*ZZ4
32260 EP4=.6-.9411451*ZZ+1.551385*ZZ2-1.492040*ZZ3+.5668007*ZZ4
32270 EP5=.5-.7928866*ZZ+1.309713*ZZ2-1.261295*ZZ3+.4794685*ZZ4
32280 EP6=.4-.6370859*ZZ+1.039991*ZZ2-.9980627*ZZ3+.3831580*ZZ4
32290 EP7=.3-.4776138*ZZ+.7563046*ZZ2-.6963899*ZZ3+.2554191*ZZ4
32300 EP8=.2-.3195394*ZZ+.4980944*ZZ2-.4481596*ZZ3+.1596046*ZZ4
32310 EP9=.1-.1601892*ZZ+.2441183*ZZ2-.2097517*ZZ3+.06882257*ZZ4
32320 GOT03700
32330 36681F(ZZ-3.2)3643,3643,3684
32340 3643EP0=.7432846-.3245687*ZZ+.09068971*ZZ2-9.446227E-3*ZZ3
32350 EP1=.6614814-.2910016*ZZ+.08280084*ZZ2-9.238809E-3*ZZ3

32360 EP2=.5855760-.2616799*ZZ+.07425487*ZZ2-8.224048E-3*ZZ3
32370 EP3=.4974506-.2153582*ZZ+.05935858*ZZ2-6.448077E-3*ZZ3
32380 EP4=.4310974-.1952906*ZZ+.05521895*ZZ2-6.076293E-3*ZZ3
32390 EP5=.3590722-.1668460*ZZ+.04807677*ZZ2-5.377573E-3*ZZ3
32400 EP6=.2998684-.1539176*ZZ+.04754946*ZZ2-5.584189E-3*ZZ3
32410 EP7=.2125494-.1011308*ZZ+.02961573*ZZ2-3.353561E-3*ZZ3
32420 EP8=.1344042-.05862245*ZZ+.01590582*ZZ2-1.694444E-3*ZZ3
32430 EP9=.05607560-.01465266*ZZ+1.546532E-3*ZZ2-5.307837E-5*ZZ3
32440 GOT03700
32450 3608IF(ZZ-1.)3610,3610,3669
32460 3610EP0=.9999936-1.797522*ZZ+4.052374*ZZ2-6.236334*ZZ3+
32470&5.215521*ZZ4-1.749732*ZZ5
32480 EP1=.9000782-1.565358*ZZ+3.055451*ZZ2-3.727843*ZZ3+
32490&2.313036*ZZ4-.5456319*ZZ5
32500 EP2=.7999615-1.4869213*ZZ+3.2018502*ZZ2-4.4704254*ZZ3+
32510&3.3231352*ZZ4-.99358975*ZZ5
32520 EP3=.7000037-1.286221*ZZ+2.864673*ZZ2-4.404467*ZZ3+
32530&3.699118*ZZ4-1.249106*ZZ5
32540 EP4=.6000804-1.042761*ZZ+1.867181*ZZ2-1.990334*ZZ3+
32550&8.9861449*ZZ4-.1445584*ZZ5
32560 EP5=.4999337-.9613845*ZZ+2.313228*ZZ2-3.932185*ZZ3+
32570&3.61904*ZZ4-1.312633*ZZ5
32580 EP6=.3999983-.7609123*ZZ+1.6272217*ZZ2-2.3341346*ZZ3+
32590&1.7766608*ZZ4-.52884616*ZZ5
32600 EP7=.2999344-.5113714*ZZ+.6617077*ZZ2+.00434428*ZZ3-
32610&8.8390895*ZZ4+.5179733*ZZ5
32620 EP8=.2000010-.3508254*ZZ+.540524*ZZ2-.3132728*ZZ3-
32630&8.1728608*ZZ4+.1845441*ZZ5
32640 EP9=.1000196-.1778996*ZZ+.2891058*ZZ2-.2229973*ZZ3+
32650&8.0037686*ZZ4+.05164025*ZZ5
32660 GOT03700
32670 3669IF(ZZ-3.2)3644,3644,3684
32680 3644EP0=.7320066-.3542916*ZZ+.1301737*ZZ2-.0254603*ZZ3
32690 EP1=.6335063-.2736811*ZZ+.07791312*ZZ2-.008754197*ZZ3
32700 EP2=.5571735-.2459316*ZZ+.07111858*ZZ2-.008089891*ZZ3
32710 EP3=.4894168-.2227472*ZZ+.06487390*ZZ2-.007347984*ZZ3
32720 EP4=.4222976-.2010661*ZZ+.06089664*ZZ2-.007141573*ZZ3
32730 EP5=.3414396-.1538677*ZZ+.04361350*ZZ2-.004804150*ZZ3
32740 EP6=.2780402-.1326730*ZZ+.03926314*ZZ2-.004473124*ZZ3
32750 EP7=.2065750-.1017284*ZZ+.03158822*ZZ2-.003783271*ZZ3
32760 EP8=.1300819-.05428682*ZZ+.01383862*ZZ2-.001373315*ZZ3
32770 EP9=.06748614-.03295503*ZZ+.01007373*ZZ2-.001189614*ZZ3
32780 3700IF(C3E)3705,3705,3720
32790 3705EF=EP0
32800 RETURN
32810 3720IF(C3E-.1)3730,3725,3740
32820 3725EF=EP1
32830 RETURN
32840 3730XX1=0.0
32850 YY1=EP0
32860 XX2=.1
32870 YY2=EP1
32880 GOT03950
32890 3740IF(C3E-.2)3750,3745,3760
32900 3745EF=EP2
32910 RETURN
32920 3750XX1=.1
32930 YY1=EP1
32940 XX2=.2
32950 YY2=EP2

32960 GOT03950
 32970 3760IF(C3E-.3)3770,3765,3780
 32980 3765EF=EP3
 32990 RETURN
 33000 3770XX1=.2
 33010 YY1=EP2
 33020 XX2=.3
 33030 YY2=EP3
 33040 GOT03950
 33050 3780IF(C3E-.4)3790,3785,3800
 33060 3785EF=EP4
 33070 RETURN
 33080 3790XX1=.3
 33090 YY1=EP3
 33100 XX2=.4
 33110 YY2=EP4
 33120 GOT03950
 33130 3800IF(C3E-.5)3810,3805,3820
 33140 3805EF=EP5
 33150 RETURN
 33160 3810XX1=.4
 33170 YY1=EP4
 33180 XX2=.5
 33190 YY2=EP5
 33200 GOT03950
 33210 3820IF(C3E-.6)3830,3825,3840
 33220 3825EF=EP6
 33230 RETURN
 33240 3830XX1=.5
 33250 YY1=EP5
 33260 XX2=.6
 33270 YY2=EP6
 33280 GOT03950
 33290 3840IF(C3E-.7)3850,3845,3860
 33300 3845EF=EP7
 33310 RETURN
 33320 3850XX1=.6
 33330 YY1=EP6
 33340 XX2=.7
 33350 YY2=EP7
 33360 GOT03950
 33370 3860IF(C3E-.8)3870,3865,3880
 33380 3865EF=EP8
 33390 RETURN
 33400 3870XX1=.7
 33410 YY1=EP7
 33420 XX2=.8
 33430 YY2=EP8
 33440 GOT03950
 33450 3880IF(C3E-.9)3890,3885,3900
 33460 3885EF=EP9
 33470 RETURN
 33480 3890XX1=.8
 33490 YY1=EP8
 33500 XX2=.9
 33510 YY2=EP9
 33520 GOT03950
 33530 3900IF(C3E-1.0)3910,3905,3905
 33540 3905EF=0.0
 33550 RETURN

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33560 3910XX1=.9
33570 YY1=EP9
33580 XX2=1.0
33590 YY2=0.0
33600 GOTO3950
33610 3950EF=YY1+(C3E-XX1)*(YY2-YY1)/(XX2-XX1)
33620 RETURN
33630 END
33640C
33650C
33660C
33670C
33680C   SUBROUTINE POLY4
33690C
33700C   THIS ROUTINE FITS A 4 POINT CURVE USING A CUBIC EQN BETWEEN
33710C   POINTS 2 & 3 AND QUADRATICS BETWEEN 1&2 AND 3&4
33720C
33730 SUBROUTINEPOLY4(X1,Y,XIN1,YOUT,DYDX)
33740 DIMENSIONX1(4),Y(4),X(4),XY(3)
33750 DO1I=2,4
33760 1X(I)=X1(I)-X1(1)+1.
33770 XIN=XIN1
33780 XIN=XIN-X1(1)+1
33790 X(1)=1.
33800C
33810C   DETERMINE SLOPES, ANGLES AND Y INTERCEPTS OF LINES JOINING POINTS
33820C
33830 SLO=(Y(1)-Y(2))/(X(1)-X(2))
33840 SLP=(Y(2)-Y(3))/(X(2)-X(3))
33850 SLQ=(Y(3)-Y(4))/(X(3)-X(4))
33860 SLR=(Y(1)-Y(3))/(X(1)-X(3))
33870 SLS=(Y(2)-Y(4))/(X(2)-X(4))
33880 PHI0=ATAN(SLO)/FPI(1.)*180.
33890 PHIP=ATAN(SLP)/FPI(1.)*180.
33900 PHIQ=ATAN(SLQ)/FPI(1.)*180.
33910 B0=Y(1)-SLO*X(1)
33920 BP=Y(2)-SLP*X(2)
33930 BQ=Y(3)-SLQ*X(3)
33940 BR=Y(1)-SLR*X(1)
33950 BS=Y(2)-SLS*X(2)
33960 IF(ABS(PHI0-PHIP).LE..005)GOTO5
33970 IF(ABS(PHIQ-PHIP).LE..005)GOTO5
33980 GOTO10
33990C
34000C   SPECIAL CASE 1 OR 1 - THREE POINTS IN STRAIGHT LINE
34010C
34020 5DYDX2=SLP
34030 DYDX3=SLP
34040 GOTO51
34050 10IF(ABS(PHI0-PHIQ).GT..005)GOTO20
34060C
34070C   SPECIAL CASE 3 - SLOPES 0 AND Q ARE PARALLEL
34080C
34090 15DYDX2=(SLO+SLS)/2.
34100 DYDX3=(SLO+SLR)/2.
34110 GOTO51
34120C
34130C   COMPUTE LINEAR EQNS TO DETERMINE TANGENT SLOPES
34140C
34150 20XL=(BQ-B0)/(SLO-SLQ)

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34160 XU=(BS-BR)/(SLR-SLS)
34170 YL=SL0*XL+B0
34180 YU=SLR*XU+BR
34190 IF(XU.EQ.XL)GOTO30
34200 T=(YU-YL)/(XU-XL)
34210 BT=YU-T*XU
34220 XM=(BT-BP)/(SLP-T)
34230 YM=SLP*XM+BP
34240 XLUR=ABS((XM-XU)/(XL-XU))
34250 XA=XL-XLUR*(XL-XU)
34260 YA=T*XA+BT
34270 GOTO40
34280 S0XA=XL
34290 YM=SLP*XA+BP
34300 YA=YL+YU-YM
34310 40DYDX2=(Y(2)-YA)/(X(2)-XA)
34320 DYDX3=(Y(3)-YA)/(X(3)-XA)
34330 50B2=Y(2)-DYDX2*X(2)
34340 B3=Y(3)-DYDX3*X(3)
34350 DY2S=DYDX2
34360 DY3S=DYDX3
34370C
34380C CHECK FOR PROPER TANGENT SLOPES. CORRECT TO NORMALS IF NEEDED
34390C
34400 IF(B0.GT.BP.AND.B2.GT.B0.OR.B0.GT.BP.AND.B2.LT.BP.OR.BP.GT.B0
344108 .AND.B2.GT.BP.OR.BP.GT.B0.AND.B2.LT.BP)DYDX2=-1./DYDX2
34420 IF(BQ.GT.BP.AND.B3.GT.BQ.OR.BQ.GT.BP.AND.B3.LT.BP.OR.BP.GT.BQ
344308 .AND.B3.GT.BP.OR.BP.GT.BQ.AND.B3.LT.BQ)DYDX3=-1./DYDX3
34440 IF(DY2S.NE.DYDX2.OR.DY3S.NE.DYDX3)GOTO15
34450C
34460C COMPUTE COEFF OF FIT EQNS
34470C
34480 51A1=(SL0-DYDX2)/(X(1)-X(2))
34490 B1=DYDX2-2.*A1*X(2)
34500 C1=Y(1)-B1*X(1)-A1*X(1)**2
34510 A2=(DYDX2+DYDX3-2.*SLP)/(X(3)-X(2))**2
34520 B2=(SLP-DYDX2)/(X(3)-X(2))-A2*(X(3)+2.*X(2))
34530 C2=SLP-A2*(X(2)**2+X(2)*X(3)+X(3)**2)-B2*(X(2)+X(3))
34540 D2=Y(2)-C2*X(2)-B2*X(2)**2-A2*X(2)**3
34550 A3=(SL0-DYDX3)/(X(4)-X(3))
34560 B3=DYDX3-2.*A3*X(3)
34570 C3=Y(3)-B3*X(3)-A3*X(3)**2
34580C
34590C LOCATE INPUT X, COMPUTE OUTPUT Y AND SLOPE
34600C
34610 60NX=1
34620 IF(XIN.GT.X(2).AND.XIN.LE.X(3))NX=2
34630 IF(XIN.GT.X(3))NX=3
34640 GOTO(70,80,90),NX
34650 70YOUT=A1*XIN**2+B1*XIN+C1
34660 DYDX=2.*A1*XIN+B1
34670 RETURN
34680 80YOUT=A2*XIN**3+B2*XIN**2+C2*XIN+D2
34690 DYDX=3.*A2*XIN**2+2.*B2*XIN+C2
34700 RETURN
34710 90YOUT=A3*XIN**2+B3*XIN+C3
34720 DYDX=2.*A3*XIN+B3
34730 RETURN
34740 END

```

WRITER Overlay

```

40000 SUBROUTINE WRITER(ILIFE,AREA,OFNAME,XLINE,
40010& QR,TO,DTP,FLOWP,PPRES,QLOSS,
40020& QRAD,RTIN,DTS,FLows,SPRES,TRAD,
40030& TH,TC,ETAM,DGRM,QCONV,QMNBUS,
40040& NMOD,EMDPOW,VOC,EPOW,VSYS,
40050& THPMP,TCPMP,ETAP,DGRP,QPUMP,PEPUMP,
40060& NPMOD,VOLT,CURRNT,QSP,QSPIPE)
40070 REAL DATE(3)
40080 IF(ILIFE.EQ.1) GO TO 200
40090 CALL OPENF(5,OFNAME)
40100 CALL SETSCT(5,XLINE)
40110 200 CONTINUE
40120 TIME=0.5*FLOAT(ILIFE-1)
40130 CALL DATIME(itime,tod,date)
40140 WRITE(5;1999),tod,date(1),date(2),date(3),area,time
40150 1999 FORMAT(//
40160& "          CODE: 'SYSTW'"/
40170&10X,A6," ON ",3A6//
40180& "          SPACE SYSTEM - AREA IS ",F5.1," SQ FT"/
40190& "          PERFORMANCE SUMMARY @ ",F5.1," YEARS"///)
40200 WRITE(5;2000)
40210& ,QR,TO,DTP,FLOWP,PPRES,QLOSS
40220& ,QRAD,RTIN,DTS,FLows,SPRES,TRAD
40230& ,TH,TC,ETAM,DGRM,QCONV,QMNBUS
40240& ,NMOD,EMDPOW,VOC,EPOW,VSYS
40250& ,THPMP,TCPMP,ETAP,DGRP,QPUMP,PEPUMP
40260& ,NPMOD,VOLT,CURRNT,QSP,QSPIPE
40270 2000 FORMAT(//
40280& "  REACTOR:"/
40290& "    POWER      T OUT      DEL T      FLOW  PRI PRES      Q LOSS"/
40300&F10.1,F10.0,F10.1,3F10.2//
40310& "  RADIATOR:"/
40320& "    POWER      T IN      DEL T      FLOW  SEC PRES  AVG TFIN"/
40330&F10.1,F10.0,F10.1,2F10.2,F10.0//
40340& "  POWER MODULES:"/
40350& "    T HOT      T COLD      ETA  DEGRADE      Q IN      Q BUS"/
40360&F10.0,F10.0,2PF10.2,2PF10.2,0PF10.2,F10.2/
40370& "    # MOD      POW @M      VOC @M      POW @B      VLT @B"/
40380&110,4F10.2//
40390& "  PUMP MODULES:"/
40400& "    T HOT      T COLD      ETA  DEGRADE      Q IN      POW OUT"/
40410&F10.0,F10.0,2PF10.2,2PF10.2,0PF10.2,F10.3/
40420& "    # MOD      VLTG      CURRENT      QSPUMP      QSPIPE"/
40430&110,F10.3,F10.0,2F10.2//
40440&/////////)
40450 CALL SAVSCT(5,XLINE)
40460 IF(ILIFE.EQ.1) CALL CLOSEF(5,OFNAME)
40470 IF(ILIFE.GT.1) CALL CLOSEF(5)
40480 RETURN
40490 END

```

FTEM01 Input Data File

00001	REF MOD	- 1.3 X	TEMX	- 12/18/72	FROM	WANL	- 7% DEGRADE	EOL
00002	TH	TC	POWMOD	ETA	VOC			
00003	1050.0	350.0	0.51619	0.07895	8.273			
00004	1050.0	400.0	0.44747	0.07420	7.844			
00005	1050.0	450.0	0.38062	0.06931	7.384			
00006	1050.0	500.0	0.31772	0.06374	6.943			
00007	1050.0	550.0	0.25889	0.05777	6.448			
00008	1050.0	600.0	0.20707	0.05161	5.933			
00009	1050.0	650.0	0.16040	0.04524	5.362			
00010	1050.0	700.0	0.12094	0.03977	4.698			
00011	1150.0	350.0	0.62793	0.08363	9.593			
00012	1150.0	400.0	0.55100	0.07915	9.199			
00013	1150.0	450.0	0.47812	0.07448	8.722			
00014	1150.0	500.0	0.40702	0.06891	8.273			
00015	1150.0	550.0	0.34304	0.06314	7.786			
00016	1150.0	600.0	0.28321	0.05718	7.253			
00017	1150.0	650.0	0.22942	0.05091	6.682			
00018	1150.0	700.0	0.18344	0.04529	6.045			
00019	1200.0	350.0	0.67738	0.08497	10.163			
00020	1200.0	400.0	0.59629	0.08054	9.785			
00021	1200.0	450.0	0.52074	0.07567	9.330			
00022	1200.0	500.0	0.44875	0.07020	8.900			
00023	1200.0	550.0	0.38170	0.06453	8.395			
00024	1200.0	600.0	0.31980	0.05867	7.852			
00025	1200.0	650.0	0.26393	0.05260	7.262			
00026	1200.0	700.0	0.21310	0.04705	6.639			
00027	1250.0	350.0	0.72178	0.08502	10.720			
00028	1250.0	400.0	0.63782	0.08054	10.556			
00029	1250.0	450.0	0.56237	0.07647	9.902			
00030	1250.0	500.0	0.48732	0.07110	9.452			
00031	1250.0	550.0	0.41819	0.06533	8.947			
00032	1250.0	600.0	0.35431	0.05926	8.395			
00033	1250.0	650.0	0.29538	0.05300	7.805			
00034	1250.0	700.0	0.24129	0.04728	7.164			
00035	1300.0	350.0	0.74759	0.08223	11.156			
00036	1300.0	400.0	0.66254	0.07776	10.744			
00037	1300.0	450.0	0.58472	0.07418	10.341			
00038	1300.0	500.0	0.50957	0.06841	9.874			
00039	1300.0	550.0	0.44163	0.06274	9.368			
00040	1300.0	600.0	0.37765	0.05678	8.815			
00041	1300.0	650.0	0.31772	0.05081	8.208			
00042	1300.0	700.0	0.26156	0.04425	7.590			

FTEPOL Input Data File

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00001 PUMP MOD - 1/29/73 - WANL - .201 V @ 564 A - 1128/550
00002 THOT TCOLD POW/MOD ETA OCV
00003 950.0 350.0 0.14367 0.04570 0.444
00004 950.0 499.0 0.08819 0.03421 0.362
00005 950.0 524.0 0.07823 0.03239 0.346
00006 950.0 549.0 0.06828 0.03030 0.327
00007 950.0 574.0 0.05832 0.02821 0.308
00008 950.0 599.0 0.03414 0.02625 0.295
00009 950.0 700.0 0.01422 0.01750 0.224
00010 1049.0 350.0 0.19773 0.05080 0.530
00011 1049.0 499.0 0.12591 0.03918 0.447
00012 1049.0 524.0 0.11389 0.03716 0.428
00013 1049.0 549.0 0.10240 0.03508 0.409
00014 1049.0 574.0 0.09148 0.03297 0.390
00015 1049.0 599.0 0.08104 0.03083 0.373
00016 1049.0 700.0 0.03769 0.02168 0.297
00017 1099.0 350.0 0.22476 0.05302 0.570
00018 1099.0 499.0 0.14482 0.04107 0.485
00019 1099.0 524.0 0.13188 0.03899 0.468
00020 1099.0 549.0 0.11946 0.03692 0.449
00021 1099.0 574.0 0.10760 0.03479 0.430
00022 1099.0 599.0 0.09620 0.03264 0.414
00023 1099.0 700.0 0.05121 0.02364 0.333
00024 1149.0 350.0 0.02504 0.05471 0.606
00025 1149.0 499.0 0.16358 0.04249 0.524
00026 1149.0 524.0 0.14980 0.04041 0.505
00027 1149.0 549.0 0.13650 0.03830 0.490
00028 1149.0 574.0 0.12376 0.03617 0.468
00029 1149.0 599.0 0.11153 0.03399 0.449
00030 1149.0 700.0 0.06544 0.02494 0.371
00031 1199.0 350.0 0.27169 0.05616 0.649
00032 1199.0 499.0 0.18199 0.04345 0.562
00033 1199.0 524.0 0.16740 0.04137 0.543
00034 1199.0 549.0 0.15340 0.03926 0.524
00035 1199.0 574.0 0.13980 0.03707 0.505
00036 1199.0 599.0 0.12678 0.03493 0.485
00037 1199.0 700.0 0.07966 0.02612 0.403
00038 1350.0 350.0 0.33286 0.05798 0.760
00039 1350.0 499.0 0.23329 0.04454 0.676
00040 1350.0 524.0 0.21763 0.04258 0.654
00041 1350.0 549.0 0.20199 0.04049 0.633
00042 1350.0 574.0 0.18634 0.03774 0.614
00043 1350.0 599.0 0.17070 0.03578 0.589
00044 1350.0 700.0 0.12376 0.02691 0.500

```

SSWDAT Input Data File

```

1000 INPUT PARAMETER FILE FOR "SYSTW" 12/19/72 RVA
1010 FTEM01 FTEPU1 SYSOUT
1020 16,3,1200.0,30.0,
1030 2.384E-13,6.660E-13,2.058E-03,
1040 1100.,500.,90.,140.,
1050 4.7,2.8,
1060 31000.,1085.,0.70,
1070 0.951,0.000,4.9E-06,
1080 1.0,
1090 31000.,1085.,0.83,
1100 0.951,0.000,4.9E-06,
1110 1.0,
1120 0.004680,
1130 0.0,0.0,
1140 12.5,5.0,24.5,9.0,
1150 47.35,18.94,
1160 127.03,-0.05755,
1170 0.945,
1180 38.24,52.91,67.58,54.04,54.04,
1190 1.216,1.683,2.149,2.356,2.356,
1200 0.060,0.060,0.060,0.060,0.060,
1210 1.0,1.0,1.0,1.0,1.0,
1220 0.5136,0.2890,0.6477,-0.4503,
1230 12,
1240 0.5136,0.2890,0.6477,-0.4503,
1250 0.028,0.022,0.025,
1260 1.30,0.60,2.30,
1270 36.00,1.35,0.22,
1280 2.50,1.875,
1290 1,
1300 0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,0,0,0,0,0,0

```

SWDATO Input Data File

1000 'REQ' 'SYSTW' PERFORMANCE (1200 DEG @ 5 YR) RVA 1/3/73
1010 1.0,
1020 1.0,
1030 0.010,
1040 5.0,
1050 1.0,
1060 1.0,
1070 0.014,
1080 2505.,
1090 0.01,
1100 2000.,
1110 0.01,
1120 1.0,
1130 -0.005,
1140 0.04683,
1150 0.17311,
1160 0.900,
1170 0.0,
1180 0.500,
1190 0.0,
1200 0.800,
1210 0.02,
1220 1.0,
1230 141.1,
1240 23.5,
1250 20.17

SWDAT1 Input Data File

1000 'NOM' 'SYSTW' PERFORMANCE (USES MARGINS) RVA 1/3/73
1010 1.0,
1020 1.0,
1030 0.010,
1040 5.0,
1050 1.0,
1060 1.0,
1070 0.014,
1080 2505.,
1090 0.01,
1100 2000.,
1110 0.01,
1120 1.000,
1130 -0.005,
1140 0.04072,
1150 0.15053,
1160 0.919,
1170 0.0,
1180 0.30,
1190 -0.13333,
1200 0.800,
1210 0.02,
1220 1.0,
1230 105.4,
1240 16.51,
1250 17.02