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AN UPDATE OF
INPUT INSTRUCTIONS TO TEMOD

Astronuclear Laboratory

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FORWARD

The work described herein was performed at the Westinghouse Astronuclear Laboratory under subcontract to the Atomics International Division of Rockwell International Corporation. The work was performed for the Space Nuclear Systems Division, a joint AEC-NASA office with project management provided by NASA-Lewis Research Center and the AEC-SNAP Project Office.

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AN UPDATE OF INPUT INSTRUCTIONS TO TEMOD

I. INTRODUCTION

The theory and operation of a Fortran IV computer code, designated as TEMOD*, used to calculate tubular thermoelectric generator performance is described in WANL-TME-1906. The original version of TEMOD was developed under AEC Contract AT(29-2)-2638 in 1969. This report which is written as Appendix D of WANL-TME-1906, describes additions to the mathematical model and an update of the input instructions to the code which have been developed under AEC Subcontract N854-0051, in the period 1969 - 1973.

Although the basic mathematical model described in WANL-TME-1906 has remained unchanged, a substantial number of input/output options have been added to allow completion of module performance parametrics as required in support of the Compact Thermoelectric Converter System Technology Program conducted at Westinghouse Astronuclear Laboratory. The report, then, basically replaces Section IV of WANL-TME-1906 entitled "Input to the TEMOD Code."

Section V of this report contains a Fortran listing of the code.

* C. M. Rose, "A Numerical Model for Tubular Thermoelectric Generator Performance Analysis", WANL-TME-1906, April 1969.

II. BASIC DESCRIPTION OF CODE SETUP

The TEMOD code consists of a main program, referred to as TEMOD, seven subroutines and three function subprograms. Although a complete Fortran listing of the code is given in Section V of this report, a brief discussion of the code sections is given below:

A. MAIN PROGRAM: TEMOD

Contains read statements for input quantities. Lists input parameters and module dimensions unless list is suppressed by input control parameter NZ(5). Also directs flow of logic between each of the individual subroutines and subprograms.

B. BLOCK DATA SUBPROGRAM

Contains compiled tables of all applicable material properties. Selections of thermoelectric material combinations, clad and conductor ring materials can be made by specification of control parameters at input.

C. PHONY SUBROUTINE

Assigns thermoelectric, clad and conductor ring properties as specified by input control parameters. Also adjusts thermoelectric material properties by percentages specified during input. Outputs all material properties used in each calculation unless output is suppressed by input control parameter NZ(5).

D. SUBROUTINE COUPLE

Performs heat balance/radial temperature profile/electrical output calculations for each thermoelectric couple. The mathematical model used for these calculations is discussed in WANL-TME-1906. A cross sectional view of a unit couple is shown in Figure 1.

E. SUBROUTINE OPTIM

Performs temperature, dimensional and load resistance incrementations specified. Also contains output statements which are restricted to one line of parameters for each set of conditions.

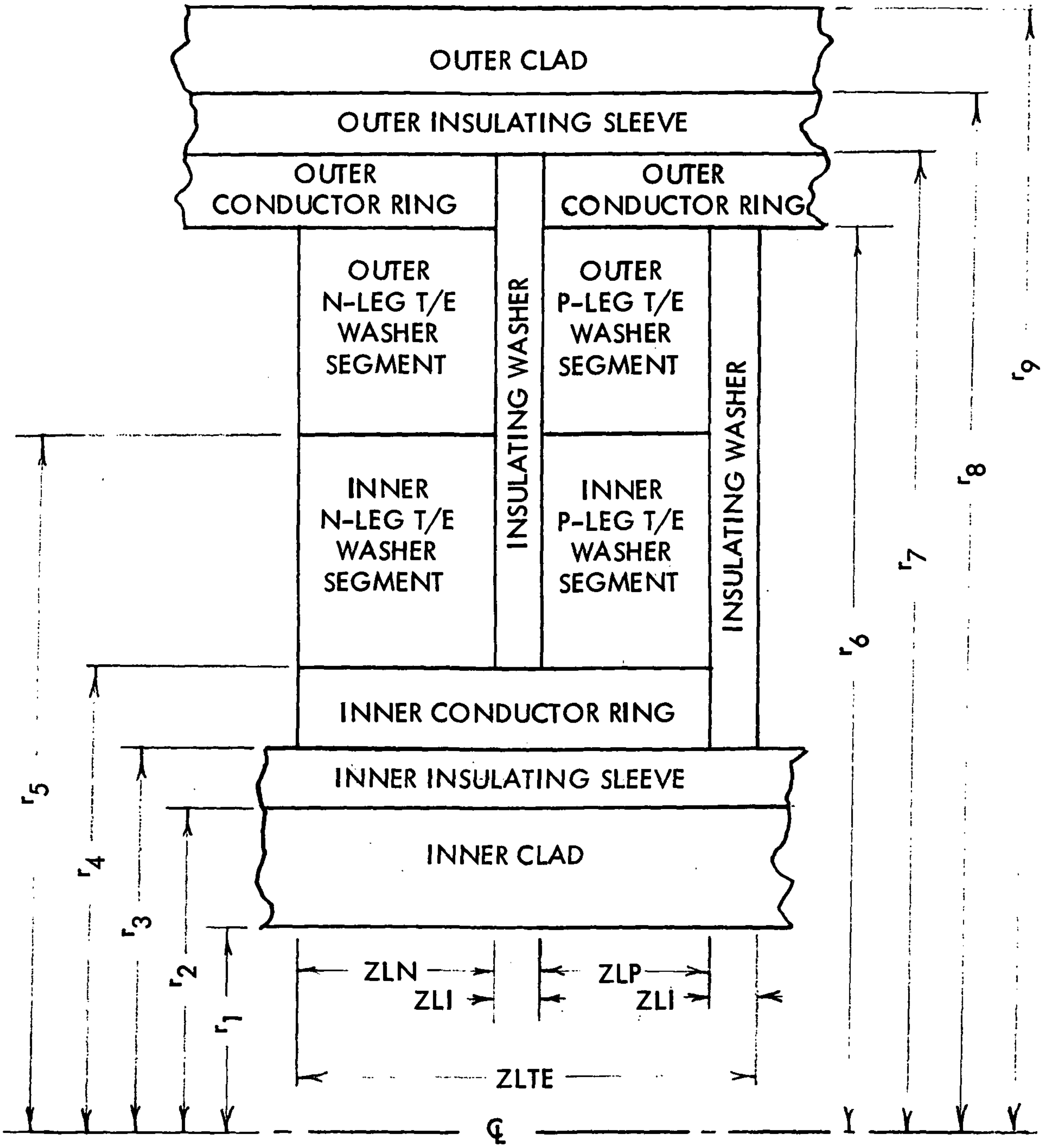

FIGURE 1. CROSS SECTIONAL VIEW OF A "UNIT" COUPLE

F. SUBROUTINE PUMP

Performs dimensional incrementations specified for pump module parametric calculations in which electrical power and required load voltage have been set.

G. SUBROUTINE LIFE

Performs performance as a function of time calculations in which operating conditions and degradation rates are specified.

H. SUBROUTINE RITE

Combines the results of the individual couple calculations to determine module performance for any specified number of couples (see NZ(10) below) operating in thermal parallel and electrical series. Also contains write statements to list results of module and individual couple calculations.

I. FUNCTION SUBPROGRAM SI

Performs all interpolation or extrapolation calculations. Primarily used to evaluate material properties which are contained in the program as temperature table values.

J. FUNCTION SUBPROGRAM DK2FK

Performs all temperature unit conversions. Performance calculations are done in Kelvin units, but input/output may be specified in either Fahrenheit or Kelvin units (see NZ(8)).

K. FUNCTION SUBPROGRAM WATE

Calculates module weight based on input module dimensions. Weight calculations will include contribution of end closures if appropriate entry is made in Z(61).

III. INPUT TO THE TEMOD CODE

A. GENERAL

There are four categories of input data required to operate the TEMOD code. The formats used to read these parameters have not been modified from the description given in WANL-TME-1906. The basic categories of input data are: (1) bulk material properties, (2) fixed point (integer) control constants; (3) floating point data, and (4) operating temperatures.

B. BULK MATERIALS PROPERTIES

Bulk materials properties include thermal conductivities and densities of all materials in the generator, Seebeck coefficients of all thermoelectric materials, and electrical resistivities of all materials in the electrical circuit. These properties with the exception of densities, are introduced as tables with the property evaluated at 50°K increments from 300°K up to 1000°K (15 values).

A listing of the material property subroutine, DATAIN, is given in Appendix A along with the complete program listing. Properties for six types of thermoelectric materials (TEGS-3N, TEGS-2N or GE-nl, TEGS-3P, TEGS-2P, ternary n-type, and ternary p-type) have been built into the code and calculations can be made using any combination of these materials by proper selection of the control constant, discussed below. In addition properties are entered for three types of cladding materials (stainless steel, inconel and tantalum) and three types of conductor ring materials (iron, tungsten, and molybdenum) are also entered and can be selected by an input control constant.

The sixteenth entry in the thermal conductivity table for each material in the DATAIN subroutine listed in Appendix A is the density of the material (in pounds per cubic inch). These densities are used in weight calculations.

Also note that Seebeck coefficients for all thermoelectrical materials are entered using absolute values. The negative Seebeck coefficients of n-type materials is handled internally by the program logic.

C. FIXED POINT CONTROL CONSTANTS

All fixed point data is read into a list called NZ. The list is dimensioned 50 although not all of the 50 locations are used. This list below gives the instructions that correspond to each location in the NZ array. The method of entering numbers into this array is unchanged from the procedures specified in WANL-TME-1906.

Table I lists fixed point control parameter definitions for each entry in the NZ array. As shown in the table, the first four entries in the NZ array refer to thermoelectric materials which must be specified for the inner and outer radial segments of both the n- and p-legs of the thermoelectric couples. A schematic of a "unit couple" is shown in Figure 1. This option allows performance calculations for modules incorporating radially segmented thermoelectric washers. By specifying the same thermoelectric material to the inner and outer segment of either leg, results will correspond to modules in which no radial segmenting has been incorporated.

As discussed above, property tables for six types of thermoelectric materials have been built into the code. By specifying an input control constant ranging from one to six, the material property tables for any of the six types of thermoelectric materials can be used in either radial segment of either leg.

All entries designated by an asterisk in Table 1 refer to parameters which are zeroed at the beginning of each calculational case to avoid potentially expensive (in terms of computer time) errors. If non-zero entries are desired in change cases for any of these parameters, the values must be reset in each change case. All other entries in the NZ array will maintain their previous values for all change case, unless changed by entering new values in subsequent cases.

TABLE 1

TEMOD INPUT FIXED POINT CONTROL PARAMETER DEFINITIONS

NƵ = J: The integer J specifies the material properties to be used for the inner n-leg thermoelectric washer segment (See Figure 1). The code numbers corresponding to each type of thermoelectric material whose properties are built into the code are as follows:

J = 1; TEGS-3N material.
J = 2; TEGS-2N material.
J = 3; TEGS-3P material.
J = 4; TEGS-2P material.
J = 5; Ternary n-type material.
J = 6; Ternary p-type material.

NƵ(2) = J: The integer J specifies the materials properties to be used for the outer n-leg T/E washer segment (J defined as for NƵ(1) above).

NƵ(3) = J: The integer J specifies the materials properties to be used for the inner p-leg T/E washer segment (J defined as above).

NƵ(4) = J: The intejer J specifies the materials properties to be used for the outer p-leg T/E washer segment of the P-leg (J defined as above).

NƵ(5) = IRITE: Output control parameter. Standard output format used except if:

IRITE = 1; NƵ and Ƶ array output suppressed.
IRITE = 2; Radial temperature profile and temperature drop which are standard output for non-parametric calculations, are suppressed.

TABLE 1 (Continued)

	IRITE = 3; NZ and Z array; Radial temperature output suppressed.
	IRITE = 4; Output restricted to one page of input temperatures and calculated parameters per case.
NZ(6) = NCLDH:	Parameter specifying inner clad material.
	NCLDH = 1; Stainless Steel 316 properties used.
	NCLDH = 2 or 0; Inconel 718 properties used.
	NCLDH = 3; Ta-10W properties used.
NZ(7) = NCLDC:	Parameter specifying outer clad material.
	NCLDC = 1 or 0; Stainless Steel 316 properties used.
	NCLDC = 2; Inconel 718 properties used.
NZ(8) = KFTEMP:	Parameter used to specify input and output temperature units.
	KFTEMP = 0; Temperatures specified and listed in °K.
	KFTEMP ≠ 0; Temperatures specified and listed in °F.
NZ(9) = IZ9:	Dimension input control parameter.
	IZ9 = 0; Module outer radius to be specified in Z(9) - See Table 2.
	IZ9 ≠ 0; Radial thickness of outer T/E washer segment (r_6 - r_5, in Figure 1) to be specified in Z(9) - See Table 2.
NZ(10) = NC:	Number of axial sections (complete unit couples as shown in Figure 1) in the module (300 maximum). NC = 1 for all parametric studies in which module performance is based on results of a unit couple operating at average clad temperature conditions.
NZ(11) = NGT1:	Parameter specifying type of calculations to be done.
	NGT1 = 0; Open circuit and matched load calculations for a module in which all axial sections (see NZ(10), above) are connected in electrical series and thermal parallel.

TABLE 1 (Continued)

NGT1 = 1; Open circuit calculations only for a module in which all axial sections (see NZ̸(10), above) are connected in electrical series and thermal parallel.

NGT1 = 2; Matched or fixed load calculations only for a module in which all axial sections (see NZ̸(10), above) are connected in electrical series and thermal parallel.

NGT1 = 3; Open circuit calculations made for each individual couple (axial section) with no electrical or thermal connections between couples.

NGT1 = 4; Matched load or fixed load (see Z̸(19) below) calculations made for each individual couple (axial section) with no electrical connections between couples.

NGT1 = 5; Matched or fixed load (see Z̸(19) below) and open circuit calculations made for each individual couple as in NGT1 = 3 and NGT1 = 4 above.

NGT1 = 6; Optimum load calculations (for maximum efficiency) made for each individual couple (axial section) with no electrical or thermal connections between couples.

NGT1 = 7, Optimum load and matched load calculations made for each individual couple as in NGT1 = 6 and NGT1 = 4 above.

NZ̸(12) = PCMULT: Number of couples in the module for which individual couple calculations have been specified (NZ̸(11) ≥ 3, above). Module performance is determined by multiplying appropriate parameters calculated for individual couples by PCMULT.

TABLE 1 (Continued)

		Results are strictly valid only for modules operating with uniform hot and cold clad temperatures.
NZ(13)	= INT:	Method by which hot and cold clad temperatures are to be read as input. INT = 0; Input hot and cold clad temperature pairs for each of the NC axial sections (see NZ(10) above). INT = 1; Axial hot and cold clad temperature profiles specified in previous case are used (for use in parametric studies). INT > 1; Input INT hot and cold clad thermocouple readings and interpolation will be performed based on axial locations (see NZ(14)) to determine hot and cold clad temperatures at the midpoints of each of the axial sections. This option can be used only if NZ(11) < 3.
NZ(14)	= INTTC:	Parameter specifying method of reading axial locations of thermocouples (used only if NZ(13) > 1). INTTC = 0 Input INT see (NZ(13)) hot and cold clad thermocouple readings. Individual thermocouples assumed to be uniformly spaced along circuit length of module with the first and last couples located at either end of the circuit. INTTC ≠ 0 Input an axial distance corresponding to each thermocouple pair. Axial distances to be entered as specified in Section E below.
NZ(15)	= ICRH:	Parameter specifying inner conductor ring material. ICRH = 1 Iron properties used. ICRH = 2; Tungsten properties used. ICRH ≠ 1 and ≠ 2: Molybdenum properties used.

TABLE I (Continued)

NZ(33) = IPUN:	Parameter specifying punched output in perturbation calculations. IPUN = 0; No punched output. IPUN = 1; A card of output parameters punched for each calculational case. Parameters listed are: Inner and outer diameters, average inner and outer clad temperatures, circuit length, load voltage, internal resistance, overall efficiency and power output in a 1X, 2F7.3, 2F7.1, 5E10.3 format.
NZ(34) = IPDWT:	Parameter specifying power density or weight calculation output in perturbation routine calculations. IPDWT = 0; Power density (watt/cc) calculations printed. IPDWT ≠ 0; Weight calculations printed.
NZ(35) = ITHQ:	Parameter specifying operating conditions for life test calculations (See Section IV). ITHQ = 0 or 1; Fixed inner (hot) clad temperature. ITHQ = 2; Fixed or decaying heat input.
NZ(36) = ITCR:	Parameter specifying heat rejection conditions for life test calculations (See Section IV). ITCR = 0 or 1; Fixed outer (cold) clad temperature. ITCR = 2; Fixed radiator.

TABLE 1 (Continued)

NƵ(16)	= ICRC	Parameter specifying outer conductor ring material. ICRC = 1 Iron properties used. ICRC = 2; Tungsten properties used. ICRC ≠ 1 and ≠ 2; Molybdenum properties used.
NƵ(17)		Not used.
NƵ(18)	= IPIN:	Parameter specifying material used for power lead pins (pins extending through retainer rings at each end of module, to which load circuit is connected). IPIN = 1; Iron properties used. IPIN = 2; Tungsten properties used. IPIN = 3; Molybdenum properties used. IPIN = 4 or 0; Nickel properties used.
NƵ(19), NƵ(20), NƵ(21)		Not used.
NƵ(22)*	= NODUMP:	Control parameter used to request intermediate calculated parameters as output. NODUMP = 0; No intermediate information printed out. NODUMP = 1; A page of intermediate parameters (interface resistances, Joule heat, etc.) printed out after each pass through subroutine couple. NODUMP = 2; Intermediate parameters are printed out after the final pass through subroutine couple for each axial section.
NƵ(23)	= MAXIND:	If module current closure is not obtained after MAXIND iterations, calculation will be terminated. If zero is entered, MAXIND is set equal to 10.

TABLE 1 (Continued)

NZ(24)	= MAXTEM:	If the criterion for temperature closure is not met for any couple after MAXTEM iterations, calculations will be terminated for this case and a dump of selected parameters will be given. If zero is entered, MAXTEM is set equal to 10.
NZ(25)*	= NPUMP:	Parameter used to specify pump module parametric calculations (See section IV).
NZ(26)*	= NPERT:	Increment on number of couples to be used in parametric calculations (See Section IV).
NZ(27)	= NR5ØPT	Parameter used to allow direct calculation of optimum T/E washer segmenting radius (r_5 in Figure 1) in parametric calculations.
NZ(28), NZ(29), NZ(30)		Not used.
NZ(31)*	= NOPTIM	Parameter used to specify temperature, load resistance, or geometry parametric calculations. (See Section IV). NOPTIM = 0 Perturbation subroutine (OPTIM) not entered. NOPTIM = 1 Standard value for perturbation calculations. One line of output listed for each set of temperatures, load resistance and dimensions. NOPTIM = 2 Used for T/E washer segmenting radius perturbations. Output listed only for optimum valve of r_5. NOPTIM = 3 Temperature derivative option (See Section IV).
NZ(32)	= DRINCR	Parameter specifying T/E washer segmenting radius perturbations. DRINCR corresponds to the increment to be applied to the inner segment thickness (in percent of the total specified T/E washer thickness).

D. FLOATING POINT INPUT PARAMETERS

All floating point input, except for axial temperatures, are read into a list labeled Z. Table 2 lists the parameter to be read into each location and the method of entering data into this array is given in the section entitled DATA CARDS. The radii (r's) and axial dimensions referred to in the table are shown in Figure 1.

All dimensions are in inches, resistances are in ohms and temperatures are in ^{o}K or ^{o}F depending on the value entered in NZ(8). Any exceptions are specified in Table 2.

All entries designated by an asterisk in Table 2 refer to parameters which are zeroed at the beginning of each calculational case to avoid potentially expensive (in terms of computer time) errors. If non-zero entries are desired in change cases for any of these parameters, the values must be reset in each change case. All other entries in the Z array will maintain their previous values for all change case, unless changed by entering new values in subsequent cases.

TABLE 2

TEMOD INPUT FLOATING POINT CONTROL PARAMETER DEFINITIONS

Ƶ(1)	= R(1)	Inside radius (r_1) - inches.
Ƶ(2)	= DR (1)	Radial thickness of inner clad (r_2 - r_1). See also Ƶ(24).
Ƶ(3)	= DR (2)	Radial thickness of inner insulating sleeve (r_3 - r_2).
Ƶ(4)	= DR(3)	Radial thickness of inner conductor ring (r_4 - r_3).
Ƶ(5)	= DR(4)	Radial thickness of inner T/E segment (r_5 - r_4).
Ƶ(6)	= DR(6)	Radial thickness of outer conductor ring (r_7 - r_6).
Ƶ(7)	= DR(7)	Radial thickness of outer insulating sleeve (r_8 - r_7).
Ƶ(8)	= DR(8)	Radial thickness of outer clad (r_9 - r_8). See also Ƶ(25).
Ƶ(9)	= R(9)	Outside radius r_9, if NZ(9) = 0.
	= DR(5)	Radial thickness of outer T/E segment, (r_6 - r_5), if NZ(9) ≠ 0.
Ƶ(10)	= ZLI	Axial length of insulating rings.
Ƶ(11)	= ZLN	Axial length of n-leg, T/E washer.
Ƶ(12)	= ZLP	Axial length of p-leg T/E washer. If zero is entered in this location, the axial length of the p-leg is calculated to optimize efficiency. See also Ƶ(29).
Ƶ(13)	= HH	Thermal contact coefficients of hot insulating sleeves interfaces (Typically zero).
Ƶ(14)	= HC	Thermal contact coefficients of cold insulating sleeves interfaces (Typically zero).
Ƶ(15)	= TOLTEM:	Tolerance to which temperatures must agree from one temperature iteration to the next to meet convergence requirement (TOLTEM = .001 if zero is entered) - See

TABLE 2 (Continued)

		Equation 41 of WANL-TME-1906.
Ƶ(16)	= TOLCUR:	Tolerance to which current must agree from one current iteration to the next to meet convergence requirement. (TOLCUR = .001 if zero is entered) - See Equation 45 of WANL-TME-1906.
Ƶ(17)	= TPIN:	Temperature at which electrical resistance of power lead pins (Ƶ(18)) has been evaluated. TPIN = 700°K (800°F) if Ƶ(18) = 0.
Ƶ(18)	= RPIN:	Electrical resistance of power lead pins connecting T/E circuit to external power leads.
Ƶ(19)*	= RLOAD:	Load resistance. RLOAD = Internal generator resistance, i.e., matched load, if zero is entered and load calculations are specified.
Ƶ(20)	= RECONC:	Contact resistivity coefficient of cold iron connector interfaces (See K_{INT} in Equation 1 of WANL-TME-1906). Typically RECONC = 0.
Ƶ(21)	= RECONH:	Contact resistivity coefficient of hot iron connector interfaces (See K_{INT} in Equation 1 of WANL-TME-1906). Typically RECONH = 0.
Ƶ(22)	= ZKEND:	Overall conductance of both module end closures (watts/°K if NZ(8) = 0; watts/°F if NZ(8) ≠ 0).
Ƶ(23)	= RRREF:	Inner-to-outer clad radius ratio (r_9/r_1) at which end closure conductance, ƵKEND, is evaluated. RRREF is used to scale ƵKEND in parametric analyses in which radial dimensions are varied.

TABLE 2 (Continued)

Ƶ(24)	= CID:	Ratio of inner clad thickness to module inner diameter. This parameter is used for parametric analyses in which the I.D. is being varied and is used to calculate DR(1) for each case. Ƶ(2) must be set equal to zero.
Ƶ(25)	= COD:	Ratio of outer clad thickness at module outer diameter. This parameter is used for parametric analyses in which the module O.D. is being varied and is used to calculate DR(8) for each case. Ƶ(8) must be set equal to zero.
Ƶ(26)	= ZNPERT:	Increment for the n-leg axial thickness, ƵLN, in parametric calculations (See Section IV).
Ƶ(27)	= ƵNMIN:	Minimum n-leg axial thickness, ƵLN, in parametric calculations (See Section IV).
Ƶ(28)*	= QREQ:	Required module heat input rate (watts) in parametric calculations in which total heat input is specified.
Ƶ(29)	= ƵLNLP	Specified ƵLN/ƵLP ratio, used only if Ƶ(12), ƵLP, is set equal to zero.
Ƶ(30)	= PEREQ:	Specified power output for parametric calculations (See Section IV).
Ƶ(31)	= VREQ:	Specified module load voltage for parametric calculations.
Ƶ(32)	= ZLREQ:	Specified total module length for parametric calculations. (Ƶ(32) = 0 if couple axial dimensions are specified).
Ƶ(33)	= THINC:	Increment for $\overline{T}_H$ in temperature perturbation calculations.
Ƶ(34)	= TCINC:	Increment for $\overline{T}_C$ in temperature perturbation calculations.

TABLE 2 (Continued)

Ƶ(35)	= THMAX:	Maximum $\overline{T}_H$ to be used in temperature perturbations.
Ƶ(36)	= TCMAX:	Maximum $\overline{T}_C$ to be used in temperature perturbations.
Ƶ(37)	= DTMIN:	Minimum radial temperature drop $(\overline{T}_H - \overline{T}_C)$ for which calculations are to be performed.
Ƶ(38)	= DRMIN:	Minimum T/E washer radial thickness for which calculations are to be performed.
Ƶ(39)	= RIINC:	Increment for module inner radius.
Ƶ(40)	= RØINC:	If NƵ(9) = 0, ROINC is the perturbation increment applied to the module outer radius, r_9. If NƵ(9) ≠ 0, ROINC is the perturbation increment applied to the outer T/E washer radial thickness, ΔR_5.
Ƶ(41)	= R1MAX:	Maximum module inner radius, r_1, for which calculations are to be performed.
Ƶ(42)	= R9MAX:	If NƵ(9) = 0, R9MAX is the maximum module outer radius, r_9, for which calculations are to be performed. If NƵ(9) ≠ 0, R9MAX is the maximum outer T/E washer radial thickness, ΔR_5, for which calculations are to be performed.
Ƶ(43)	= PWRDEN:	Fuel specific power density (watts/cc). Fuel is assumed to fill volume enclosed by the I.D. of the module inner clad. $\overline{T}_H$ will be calculated for cases in which PWRDEN > 0.
Ƶ(44)*	= QINPC:	Specified heat input rate (watts) for each couple. $\overline{T}_H$ will be calculated for cases in which QINPC > 0.

TABLE 2 (Continued)

Ƶ(45)	= QGAM:	Amount of gamma heat generated within the lead telluride of each couple in an internally fueled gamma emitting isotope configuration. This parameter must be determined by an independent gamma heat shielding analysis.
Ƶ(46)	= RLPERT:	Increment for load resistance (Ƶ(19) applied in perturbation subroutine. No perturbation performed if RLPERT = 0.
Ƶ(47)*	= RLMAX:	Maximum load resistance for which calculations are to be performed in load resistance perturbation subroutine.
Ƶ(48), Ƶ(49)		Not used.
Ƶ(50)*	= ƵLIBRH	Axial thickness of the tungsten foil diffusion barriers incorporated in the insulating washers in annulus D of Figure 1.
Ƶ(51)*	= ƵLIBRC	Axial thickness of the tungsten foil diffusion barriers incorporated in the insulating washers in annulus E of Figure 1.
Ƶ(52), Ƶ(55)		Not used.
Ƶ(56)	= HRINC:	Increment (hours) to be used in time increment calculations (See Section IV).
Ƶ(57)	= HRMAX:	Maximum time (hours) to be used in time increment calculations.
Ƶ(58)	= HFLF:	Half life (years) of isotope fuel in time increment calculations.
Ƶ(59)	= TREJ:	Ambient heat rejection temperature to be used in time increment calculations performed for fixed radiator configuration (See Section IV).
Ƶ(60)		Not used.

TABLE 2 (Continued)

Ƶ(61)	= WTCON:	Ratio of module end closure weight to cross sectional area of module (pounds per in^2).
Ƶ(62), Ƶ(70)		Not used.
Ƶ(70 + J)**		Percent increase desired in Seebeck coefficient of Jth thermoelectric material where J = 1 to 6 (See NƵ(1)).
Ƶ(80 + J)**		Percent increase desired in resistivity of the Jth thermoelectric material where J = 1 to 6 (See NƵ(1)).
Ƶ(90 = J)**		Percent increase desired in thermal conductivity of the Jth thermoelectric material where J = 1 to 6 (See NƵ(1)).

** These entries refer to percent increase per 1000 hours in life test calculations to account for module degradation as a function of time as discussed in Section IV of this report.

E. DATA CARDS, ORDER AND FORMATS

1. Comment Card

The first data card read into the program is a comment card. This comment should identify the case being run and will print out at the top of each page of output. The card is read using a 18A4 format so that the comment is restricted to a maximum of 72 spaces and should be centered in the 72 space field on the data card.

2. Fixed Point Data for NZ Array

Immediately after the comment card, fixed point data are read. A maximum of eleven (11) entries in the NZ (fixed point data)list may be made on one card. The format used in reading fixed point data is FORMAT (3I2, 11(3X, I3)).

The first two digit integer refers to the number of pieces of data given on the card. This must be a number form 0 to 11. Any entry other than zero in card columns 3 - 4 indicates that no more fixed point data will follow the card being processed. The two digit integer in card columns 5 - 6 indicates the NZ subscript of the first piece of data on the card being processed. The remaining input data centered on each card are entered sequentially into the NZ array.

3. Floating Point Data for Z Array

After processing a fixed point data card with an entry in card columns 3 - 4, the floating point data are read. A maximum of six (6) entries in the Z list (floating point data) may be made on one card. The format used to read this data is: FORMAT (3I2, 6F12.6). The first two digit integer refers to the number of pieces of data given on the card. This must be a number from 0 to 6. Any entry other than zero in card columns 3 - 4 indicates that no more floating point data is to be entered into the Z list after the present card is processed. The two digit integer in card columns 5 - 6 indicates the Z subscript of the first piece of data on the card being processed. The remaining data on the card are entered sequentially into the Z array.

4. Temperature Data

The method used to input clad temperature data is determined by the control variable entered in NZ(13). All temperatures must be entered in Kelvin units. Three options are available for specifying temperature data.

a. NZ(13) = 0. If NZ(13) has been set equal to 0, hot and cold clad temperature pairs for each axial section must appear immediately after the first floating point data card with a non-zero entry in card columns 3 - 4. The number of temperature pairs to be read is the number previously entered in NZ(10).

   Six temperatures pairs are read per card using a 12F6.5 Format. The first temperature of each pair must be the hot clad temperature. In the event that a zero is encountered in any of this temperature input data, an error message is printed and all calculations for the case are suppressed. Hence it is possible to make an input error for one case without affecting the following cases.

b. NZ(13) = 1. In the event that the effects of geometry variations are being investigated (as in parametric studies), it is often desired to run many cases using the same clad temperatures. If the number entered in NZ(13) is 1, no further data cards are read after the final card entering data in the Z array. The code uses the temperature data entered in the previous case.

c. NZ(13) > 1. This option is used to calculate the performance of a module for which experimental clad temperature measurements have been made at various locations along each clad. If NZ(13) has been assigned greater than 1, the computer will interpolate on input hot and cold clad thermocouple readings to determine the hot and cold clad temperatures of each axial section. The number entered in NZ(13) corresponds to the number of hot and cold clad thermocouple pairs (not to be confused with the number of thermoelectric couples in the module) to be read.

In order to perform the interpolation, of course, it is necessary to specify the axial location of each of the thermocouples. These locations are specified as the distance (in inches) from the leading edge of the first axial section of the module.

Since standard thermocouple instrumentation is used for most modules tested in the Compact Thermoelectric Converter program, the axial locations of these standard thermocouples are built into the code. By assigning NZ(14) = 0, the thermocouples are assumed to be uniformly spaced along the circuit length of the module with the first and last couples located at either end of the circuit. In this case, the first card (or set of cards) after the Z array data cards must contain the hot clad temperature data. The next card (or set of cards) must contain the cold clad temperature data. All of these cards use a 12F6.5 Format.
To specify externally the thermocouple locations, the number of thermocouple pairs must be the number entered in NZ (13). If NZ(14) has been assigned any value other than zero (and if NZ(13) has been assigned a number greater than 1) the computer will begin to read axial locations for each thermocouple pair immediately after reading the last floating point data card.

After reading the thermocouple locations, the computer will read INT (the number entered in NZ(13)) hot clad thermocouple temperatures and the INT cold clad temperatures. Each of the three lists begins on a new data card and each card uses a 12F6.5 Format.

A zero entry in either the hot or cold clad thermocouple data is used to indicate the absence of a thermocouple reading at a particular location. When performing the interpolation to determine the temperature at the mid-point of each axial section, all zero entries in the temperature lists are ignored.

5. Multiple Case Runs

Multiple runs can be made using TEMOD by simply stacking sets of input data. After reading all the input data for a given case, the calculations are performed and the output listed. The computer returns to input to search for another comment card. If none exists, calculations are terminated.

With the exceptions noted in Sections C and D above, entries in the Z array, NZ array and axial temperature profiles are not zeroed from one case to the next. Hence, it is normally not necessary to reread any data which has not changed from one case to the next. Only the parameters which are changed from the previous case need be read in.

Care must be taken, however, to include a comment card, at least one card with fixed point data and one with floating point data for each case. If, for example, no floating point parameters change from one case to the next, a dummy card with only an entry in card column 4 must be included in the data cards in place of the floating point data card.

IV. PARAMETRIC CALCULATIONS

A. GENERAL

The TEMOD code has been written to allow various type of parametric calculations to be performed. Incrementation of parameters (i.e. operating temperatures, load resistances and component geometries) is done automatically by the code eliminating the need for voluminous input data decks. In addition, the output for these types of calculations is restricted to one line per case. Provisions have been made to allow specifications of module operating parameters such as electrical power, voltage, and/or heat input to meet required module design operating conditions. These conditions are met internally using program logic to calculate the required number of thermoelectric couples and/or module circuit length.

In each case, the calculations are made on a unit couple (see Figure 1). Thus, in each parametric calculation case, the control parameter NZ(10) should be set equal to 1 and one set of temperature pairs should be entered.

The control parameters, geometry and operating temperatures for the first case of each parametric calculation must be set in accordance with instructions given in Section III of this report. The pertinent control parameters which must also be set for each type of parametric calculation is discussed below.

B. TEMPERATURE PARAMETRIC WITH SPECIFIED GEOMETRY

This option is normally used to determined performance of a specific type of module operating over a wide range of average hot and cold clad temperatures. In addition to the control parameters required to specify the module component materials and dimensions, the following entries are required to perform this type of parametric:

1. Set NZ(31) = 1.
2. Set Z(31) = Z(32) = 0.
3. Set Z(33) through Z(36) equal to the appropriate values as listed in Table 2.
4. Set the initial temperature pair at the lowest hot and cold clad levels of interest in the parametric.

C. LOAD RESISTANCE PARAMETRIC WITH SPECIFIED MODULE

This load is used to calculate load curve characteristics of a specific type of module at a specific set of operating temperatures. The results, of course, will show that the power output will approach zero as the load resistance approaches either limit (zero or infinity) and that maximum power occurs at the point where the load resistance very nearly equals the generator resistance, i.e. matched load. (For calculations performed at fixed hot and cold junction temperatures, maximum power would occur precisely at matched load. However since the module performance calculations are made at fixed clad temperatures and since the junction temperatures do vary as the load resistance varies, the maximum power point does not occur precisely at matched load. Since the deviation between matched load power and maximum power is extremely small, no distinction is made between the two and an option has been built into the code to allow a direct determination of the matched load performance eliminating the need for running a load parametric.)

The load parametric calculations will also indicate that the load resistance at which module efficiency is optimized (defined as "optimum load") is approximately 20 to 30 percent higher than the module internal resistance. An option has also been built into the code to allow a direct determination of optimum load performance without running a load parametric.

Load resistance parametrics may be specified over a narrow or a wide range of resistance values. A parametric with a step size and increment range resulting in more than 200 separate cases is considered a wide range parametric. In the wide range calculations, the increment size is increased by a factor of ten after every ten calculations. This allows the parametric to cover an extremely wide range of resistance with only ten calculations for each order of magnitude.

In addition to the control parameters and input data required to specify the module component materials and dimensions, the following entries are required to perform the two types of load resistance parametrics:

1. Narrow range parametric:
   a. Set NZ(31) = 1
   b. Set Z(19) equal to the initial (lowest) load resistance level.
   c. Set Z(46) and Z(47) equal to the appropriate values.
2. Wide range parametric: set all parameters as described in (1) above except Z(46) = 0.

D. TEMPERATURE PARAMETRIC WITH SPECIFIED VOLTAGE AND CIRCUIT LENGTH

This option allows parametric calculations to be performed to determine optimum module dimension for applications in which a load voltage and total circuit length has been prescribed. For these calculations, the number of thermoelectric couples required to meet the voltage specification at either matched or optimum load conditions is determined internally for each set of operating temperatures.

In addition to the control parameters and input data required to specify the module component material and dimensions, the following entries are required to perform this type of parametric:

1. Set NZ(11) = 4 or 6 (matched or optimum load calculations).
2. Set NZ(31) = 1
3. Set Z(12) = 0. to allow p-leg axial thickness to be optimized with respect to n-leg thickness for each set of operating temperatures.
4. Set Z(19) = 0. (A specification of load resistance, length, and voltage amounts to an overspecification of the module performance).
5. Set Z(31) through Z(36) equal to the appropriate values as listed in Table 2.

E. PARAMETRIC ON NUMBER OF COUPLES WITH SPECIFIED LOAD VOLTAGE AND CIRCUIT LENGTH

This type of parametric is very similar to D above, except the load voltage specification is met in each case by setting the load resistance equal to the appropriate value. This, of course, is done internally for each case by the program. This option is intended for use in applications where operating temperatures have been established by system operating constraints, hence, temperature parametrics should not be attempted.

1. Set NƵ(12) = 1 (the minimum number of couples required to achieve the specified lead voltage is determined by program logic).
2. Set NƵ(26) = 1 (the normal desired increment on the number of couples).
3. Set NƵ(31) = 1.
4. Set Ƶ(12) = 0. To allow p-leg axial thickness to be optimized with respect to n-leg thickness for each case.
5. Set Ƶ(27) equal to the minimum n-leg thickness to be considered (this corresponds to a specification of the maximum number of couples and determines when the parametric calculations will be terminated). Ƶ(27) = .020 inch if no value is input.
6. Set Ƶ(31) and Ƶ(32) equal to the appropriate values as specified in Table 2.
7. Set Ƶ(33) through Ƶ(36) equal to zero.

F. PARAMETRIC ON N-LEG/P-LEG AXIAL THICKNESS RATIO WITH SPECIFIED CIRCUIT LENGTH

The code has been written to allow a direct determination of the optimum n-leg/p-leg axial thickness ratio. This option, however, allows a determination of the effects of varying this ratio on module performance.

In addition to the control parameters and input data required to specify the module component materials and initial case dimensions, the following entries are required to perform this type of parametric:

1. Set NƵ(12) equal to the number of couples in the module.
2. Set NƵ(26) equal to the number of washer thickness perturbations required.
3. Set NƵ(31) = 1.
4. Set Ƶ(11) and Ƶ(12) equal to the initial n- and p-leg washer axial thicknesses
5. Set Ƶ(25) equal to the length by which the n-leg washer thickness is to be increased and the p-leg washer thickness decreased in each perturbation.

G. PARAMETRIC ON NUMBER OF COUPLES WITH SPECIFIED LOAD VOLTAGE HEAT INPUT OR POWER OUTPUT

In many module applications, system constraints govern the module voltage and heat input or power output requirements. For a given set of operating temperatures, the optimum module meeting these requirements can be determined using a parametric routine built into the code. In this routine, the number of couples in the module is increased from the minimum number required to produce an open circuit voltage greater than the required voltage to a maximum number which is determined primarily by fabrication limits (minimum thermoelectric washer thickness). The total thermoelectric circuit length is dictated, primarily, by the heat input or power output specification.

In addition to the control parameters and input data required to specify the module component materials and initial case dimensions, the following entries are required to perform this type of parametric:

1. Set NƵ(12) = 1 (the minimum number of couples required to achieve the specified load voltage is determined by program logic).
2. Set NƵ(26) = 1 (the normal desired increment on the number of couples).
3. Set NƵ(31) = 1.
4. Set Ƶ(12) = 0 to allow p-leg axial thickness to be optimized with respect to n-leg thickness for each case.
5. { Set Ƶ(28) equal to the desired module thermal power input, or
   Set Ƶ(30) equal to the required electrical power output.
6. Set Ƶ(31) equal to the desired load voltage.
7. Set Ƶ(32) through Ƶ(36) equal to zero.

H. PARAMETRIC TO DETERMINE OPTIMUM SEGMENTING RADIUS, r_5

For many applications, it is desirable to use radially segmented thermoelectric washers in either the p- or n-legs of the module. Thermoelectric materials can be doped at different levels to provide maximum conversion efficiency in different operating temperature ranges. Using a material doped for optimum performance at high temperatures in the inner segment of each thermoelectric washer, and an alternate material composition providing optimum performance at lower temperatures in the outer segment of each thermoelectric washers can provide efficiency improvements. Given two types of n-type and/or two types of p-type material, then, there is an optimum radius at which the materials can be segmented. An option has been provided to allow a determination of this optimum segmenting radius.

Since the optimum segmenting radius is a function of the module operating temperatures, this parametric option may be used in conjunction with the temperature parametric option discussed in (B) above.

In addition to the control parameters and input data required to specify the module component materials and initial case dimensions, the following entries are required to perform this type of parametric:

1. Set NƵ(31) = 0.
2. Set NƵ(32) equal to the increment to be applied to the inner segment thickness in percent of the total specified T/E washer thickness. Normally NƵ(32) = 5 provides adequate calculational resolution to determine the optimum segment radius.
3. Set Ƶ(5) = 0. This initializes the segmenting radius such that the radial thickness of the inner T/E washer segment is zero.
4. Set Ƶ(28) through Ƶ(32) equal to zero.
5. Set Ƶ(33) through Ƶ(36) equal to the appropriate values listed in Table 2 to allow operating temperature perturbations.
6. Set the initial temperature pair at the lowest hot and cold clad levels of interest in the parametric.

With this deck setup, a line of output will be listed for each segmenting radius. The first case (or line of output) for each temperature pair will correspond to a zero thickness outer T/E washer segment, i.e.

$$\frac{100(r_6 - r_5)}{r_6 - r_4} = 0 \text{ pct. (See Figure 1).}$$

or

$$\frac{100\,(r_5 - r_4)}{r_6 - r_4} = 100 \text{ pct.}$$

The final case for each temperature pair will correspond to a zero thickness inner T/E washer segment.

$$\frac{100\,(r_6 - r_5)}{r_6 - r_4} = 100 \text{ pct.}$$

or

$$\frac{100\,(r_5 - r_4)}{r_6 - r_4} = 0 \text{ pct.}$$

Since normally interest is restricted to the optimum segmenting radius only, an alternate form of this parametric can be used to reduce both the amount of output and the required computer time to perform the parametric. This option is specified in a manner identical to that discussed above except NZ(31) is set equal to 2. With this option incrementing of the inner washer thickness is performed until a maximum efficiency has been obtained, a line of calculated parameters corresponding to this optimum geometry is printed, and the temperatures are then incremented and the procedures repeated.

I. TEMPERATURE DERIVATIVE CALCULATIONS

During the course of reduction and analysis of experimental data from modules being tested, it has been found necessary to eliminate performance variations resulting from minor temperature fluctuations. For each experimental data set, it is desirable to determine analytically what the performance parameters would have been if the module had been operated at the exact prescribed operating temperatures.

This determination can be made by determining the derivatives of the primary performance parameters (i.e. effective Seebeck coefficient, $\bar{\alpha}$, internal resistance, Rg, and thermal impedance TI) with respect to hot and cold clad temperatures.

A routine has been provided in the code to allow this evaluation. Calculations are performed at 25°F increments on either side of the design hot $\bar{T}_H$, and cold $\bar{T}_C$, clad temperatures. The parameters

$$\left.\frac{\partial\ \bar{\alpha}}{\partial \bar{T}_H}\right)_{\bar{T}_C},\quad \left.\frac{\partial\ \bar{\alpha}}{\partial \bar{T}_C}\right)_{\bar{T}_H},\quad \left.\frac{\partial R_g}{\partial \bar{T}_H}\right)_{\bar{T}_C},\quad \left.\frac{\partial R_g}{\partial \bar{T}_C}\right)_{\bar{T}_H},\quad \left.\frac{\partial\ TI}{\partial \bar{T}_H}\right)_{\bar{T}_C} \text{ and } \left.\frac{\partial TI}{\partial \bar{T}_C}\right)_{\bar{T}_H}$$

are computed and listed on the basis of these calculations. In these expressions, the effective Seebeck coefficient is defined:

$$\bar{\alpha} = \frac{V_{oc}}{\bar{T}_H - \bar{T}_C},$$

where V_{oc} is the module open circuit voltage, and the thermal impedance is defined

$$TI = \frac{\bar{T}_H - \bar{T}_C}{Q},$$

where Q is the total module heat input.

In addition to the control parameters and input data required to specify the module component materials and initial case dimensions the following entries are required to perform this type of parametric:

1. Set NƵ(11) = 4. (The calculations are typically performed under matched load conditions except in the case of open circuit tests.)
2. Set NƵ(31) = 3.
3. Set Ƶ(28) through Ƶ(36) = 0.
4. Set the input temperatures at the design operating levels of the module.

J. RADIAL GEOMETRY PARAMETRICS

Quite often it is desired to perform any of the parametric options discussed above for a family of modules with varying overall radial geometries. For this reason an option is provided in the code to allow the radial geometry incrementation to be handled internally by the code.

Provisions have been made to allow perturbation of the module inner radius and module outer radius or lead telluride radial thickness. Both of these geometry incrementing options may be used in conjunction with any of the parametric routines discussed previously.

1. Inner Radius/Outer Radius Parameters

In addition to the control parameters and input data required to specify the module component materials and initial case dimensions, along with the entries to perform any of the previously discussed parametric calculations, the following entries are required to perform the radial geometry parametrics:

a. Set NƵ(9) = 0 (See Table 1).
b. Set Ƶ(1) equal to the smallest inner radius of interest.
c. Set Ƶ(2) = 0. Inner clad thickness should be scaled linearly with module inner radius as specified by Ƶ(24).
d. Set Ƶ(8) = 0. Outer clad thickness should be scaled linearly with module outer radius as specified by Ƶ(25).
e. Set Ƶ(9) equal to smallest outer radius of interest.
f. Set Ƶ(23) through Ƶ(25) equal to the appropriate values as specified in Table 2.
g. Set Ƶ(38) equal to the minimum T/E washer radial thickness for which calculations are to be performed. This is necessary since there may be r_1, r_9 combinations in the range of interest corresponding to negative or very small T/E washer thicknesses. A substantial amount of computer time may be required to achieve temperature convergence on these cases of little or no interest.
h. Set Ƶ(39) through Ƶ(42) equal to the appropriate values as specified in Table 2.
i. Set Ƶ(61) equal to the appropriate value as specified in Table 2.

2. Inner Radius/Thermoelectric Washer Radial Thickness Parametrics

This option is very similar to (1) above except that the outer radius of the module is controlled by the specified T/E washer thickness. All parameters should be set as discussed in (1) above except the following:

a. Set NƵ(9) = 1 (See Table 1).

b. Set Ƶ(9) equal to the smallest T/E washer radial thickness of interest.

c. Set Ƶ(38) = 0.

d. Set Ƶ(42) equal to the maximum T/E washer radial thickness of interest.

K. PUMP MODULE PARAMETRIC STUDIES

An option has been built into the TEMOD code to allow a determination optimum dimensions for tubular modules designed to provide electrical power for electromagnetic pumps. Since electromagnetic pumps require high current/low voltage power, typical pump modules have extremely low internal resistances. For this reason, inner and outer conductor ring radial thicknesses are very critical and optimum thicknesses must be determined parametrically.

The parametric routine included in the code requires a specification of required current and load voltage along with operating temperatures. The radial thicknesses of the inner and outer conductors and thermoelectric washers are each varied independently. Axial dimensions for each case are calculated on the basis of meeting the required current and voltage specifications.

In addition to the control parameters and input data required to specify the module component materials and initial case dimensions, the following entries are made to perform this type of parametric:

1. Set NƵ(9) = 0. (See Table 1).
2. Set NƵ(25) equal to the desired number of perturbations to be performed on each conductor and T/E washer radial thickness.
3. Set Ƶ(4), Ƶ(5), Ƶ(6) and Ƶ(9) equal to the appropriate minimum values of interest.

4. Set Ƶ(8) = 0. Since module outer radius will vary in parametric, outer clad thickness should be scaled linearly with r_9 as specified by Ƶ(25).
5. Set Ƶ(12) = 0. Program logic will determine the axial thickness of the T/E washers required to achieve voltage and current specifications for each case.
6. Set Ƶ(19) = 0. Although the input voltage and current specify a load resistance, this value is calculated internally.
7. Set Ƶ(23) and Ƶ(25) equal to the appropriate values as specified in Table 2.
8. Set Ƶ(30) equal to the specified power output (the product of the specified current and voltage).
9. Set Ƶ(31) equal to the specified voltage.
10. Set Ƶ(40) equal to the radial increment to be applied to the conductor rings. The T/E washer increment is half as large as the conductor ring increment.
11. Set Ƶ(61) equal to the appropriate value as specified in Table 2.

L. CALCULATION OF PERFORMANCE AS A FUNCTION OF TIME

During operation of thermoelectric generators various factors can produce performance variations as a function of time. Obviously, if the operating temperatures vary, the performance will be affected. These temperature variations can be caused by externally controlled modification or by a decay of the fuel in the case of an RTG application. In the latter case, the module cold clad temperature will vary as the amount of heat to be radiated is reduced.

In addition to operating condition variations, module performance is affected by a degradation process. The effects of this process can be simulated by modifying the thermoelectric material properties in the appropriate manner. In lead telluride generators these effects are simulated in increasing the resistivity of the n-type thermoelectric material to compensate for the diffusion of tellurium into the material. The rate at which the resistivity increases is a function of operating temperatures and washer axial thickness, and must be given as input to the calculations. Provisions are also included for modifying any of the other themoelectric properties in a similar manner.

In addition to the control parameters and input data required to specify the module component materials and dimensions, the following entries are required to perform this type of calculation.

1. *Set NƵ(35) equal to the appropriate value discussed in Table 1 to specify* either constant $\bar{T}_H$ or heat input conditions.
2. Set NƵ(36) equal to the appropriate value discussed in Table 1 to specify either constant $\bar{T}_C$ or fixed radiator calculations.
3. Set Ƶ(19) if fixed load resistance calculations are required (Ƶ(19) = 0 for matched load).
4. Set Ƶ(31) if fixed load voltage calculations are required.
5. Set Ƶ(56) equal to the desired time increment (in hours).
6. Set Ƶ(57) equal to the maximum time (hours).
7. Set Ƶ(58) equal to the isotope half life (in years) if heat decay calculations are desired.
8. Set Ƶ(59) equal to the heat sink temperature if fixed radiator calculations are desired.
9. Set Ƶ(71) through Ƶ(100) equal to the appropriate T/E material property rate of change as specified in Table 2. Rates of change to specified as percent change per 1000 hours.
10. Set temperatures at the beginning-of-life levels.

V. TEMOD FORTRAN PROGRAM LISTING

```
      PROGRAM TEMOD (INPUT,OUTPUT,PUNCH,TAPE 5=INPUT,TAPE 6=OUTPUT,
     1 TAPE 7=PUNCH)
C TEMOD...............CHARLES ROSE.............BLDG. 2.................
      DIMENSION NZ(50),Z(100),XTHERM(30),THERMC(30),THERMH(30),HD(6,8),
     1 HD1(8),HD2(8),HD3(16,2),ASTAR1(2),ZOPMAX(5), ZOPT(5),ZOPT1(5),
     2 CKF1(2),CKF2(2),TMKF(2)
      COMMON /TITLE/FETM(3),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMKF,
     1 CRMD(2,2),I3N,I2N,I3P,I2P
      COMMON /MDLIF/HRS,HRINC,HRMAX,HFLF,RADPCT,ITCR,ITHQ
      COMMON/TERIT/DTAV,OHM,OCV,RLOAD,QMOD,TCAV
      COMMON /MDCPOP/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
     1 QT(300),NOPTIM,VPC(300),RLPC(300),DTMOD(300),CUR(300),LNRAD(9),
     2 ZLP,ZLN,ZLI,ZLNLP,ZLPNI,ZLTE,NGT1,NGT2,ITPERT,PCMULT,NODUMP,IVD,
     3 QGEN,QGENL,QTE,QOUT,ZID,ZOD,ZKEND,ZK9,ZKR,RPPC,RPN,TOLTEM,TREJ,
     4 VREQ,PEREQ,ZLREQ,WTCON,ZLPN,IDUMZ,RN,DGRF,DGTRF,DGLRF,RADK,JDUMP,
     5 DP(30),NC
      COMMON /MODCPL/CURMOD(15),IT(300),DTTE,CONRN,CONRP,ZLIP,ZNC,
     1 ALR64,MAXTEM,QGAM,CGAM,INDI,RINT4,RINT6,RCON4,RCON6,C1FEH,C1FEC,
     2 CONST1,CONST2,CONST3,CONST4,CONST5,NR5OPT,SEGTE,ICRMDL,RADC
      COMMON/TEFO/NCLDC,NCLDH,ICRH,ICRC,IPIN,ZLIBRH,ZLIBRC,TPIN,RPIN
      COMMON /MODOPT/IPOWT, DR4,DRINCR,IRITE,DRTE,JOPTIM,IZ9,IENDK,IPUN,
     1 RIINC,ROINC,R1MAX,R9MAX,DTMIN,QREQ,THINC,TCINC,TCMAX,THMAX
     2,NPERT,ZNPERT,CKFP,CKFT,CTEOC,CTEIC,DELTL,RLPERT,RLMAX,ZNMIN,Z9SAV
      COMMON/TEPMP/NPUMP,DR8,COD2
      EQUIVALENCE (HD3(20),ASTAR1(1))
      DATA HD/4HINNE,4HR CL,4HAD   ,4H    ,4H    ,4H    ,
     1        4HINNE,4HR IN,4HSULA,4HTING,4H RIN,4HG   ,
     2        4HHOT ,4H SID,4HE CO,4HNDUC,4HTOR ,4HRING,
     3        4H    ,4HINNE,4HR T/,4HE WA,4HSHER,4HS   ,
     4        4H    ,4HOUTE,4HR T/,4HE WA,4HSHER,4HS   ,
     5        4HCOLD,4H SID,4HE CO,4HNDUC,4HTOR ,4HRING,
     6        4HOUTE,4HR IN,4HSULA,4HTING,4H RIN,4HG   ,
     7        4HOUTE,4HR CL,4HAD   ,1H ,1H ,1H /,TMKF/1HK,1HF/,KASE1/1/,
     8 HD1(2)/2HBN/,HD1(7)/2HBN/,HD2/3*1H ,2*1H-,3*1H /,HD3/20*1H ,1H*,
     9 6*1H ,2*1H*,3*1H /,NZ/50*0/,Z/100*0./,CKF1/0.,459.6/,CKF2/1.,1.8/
      REAL LNRAD
      FK2K(T)=(T+CKFP)/CKFT
      CID=CLOCK(CMT(21),CMT(22),CMT(23))
   93 READ (5,94)(CMT(K),K=3,20),ASTOP
   94 FORMAT(18A4,7X,A1)
      Z(19)=0.
      Z(28)=0.
      Z(44)=0.
```

```
      Z(45)=0.
      Z(47)=0.
      Z(50)=0.
      Z(51)=0.
      Z(62)=0.
      Z(67)=0.
      DO 90 I=70,100
   90 Z(I)=0.
      QGEN=0.
      ZKR=0.
      CURMOD(1)=0.
      NZ(20)=0
      NZ(22)=0
      NZ(25)=0
      NZ(26)=0
      NZ(31)=0
      ITPERT=0
      INDI=0
      LNDUMP=0
      IVD=1
      IF (ASTOP.NE.HD2(1)) STOP
C - READ FIXED POINT INPUT DATA
   95 READ (5,91) N,L,J, (IT(I),I=1,N)
   91 FORMAT (3I2,11(3X,I3))
      J=J-1
      DO 92 I=1,N
   92 NZ(I+J)=IT(I)
C - READ FLOATING POINT INPUT DATA
      IF (L.EQ.0.AND.N.NE.0) GO TO 95
    3 READ (5,2) N,L,J,(VPC(I),I=1,N)
    2 FORMAT (1X,I1,2I2,6E12.6)
      J=J-1
      DO 4 I =1,N
    4 Z(I+J)=VPC(I)
      IF (L.EQ.0.AND.N.NE.0) GO TO 3
C - DETERMINE TYPE OF MATERIAL SPECIFIED FOR EACH T/E SEGMENT
      I3N=NZ(1)
      I2N = NZ(2)
      I3P=NZ(3)
      I2P = NZ(4)
      IRITE=NZ(5)
      NCLDH=NZ(6)
      NCLDC=NZ(7)
      KFTEM=1
```

```
      IF (NZ(8).NE.0) KFTEM=2
      CKFP=CKF1(KFTEM)
      CKFT=CKF2(KFTEM)
      TEMKF=TMKF(KFTEM)
      IZ9=1
      IF (NZ(9).NE.0) IZ9=2
      NC=MAX0(NZ(10),1)
      ZNC = NC
      NGT1=NZ(11)
      PCMULT=AMAX0(NZ(12),1)
      IF (KASE1.EQ.1.AND.NZ(13).EQ.1) NZ(13)=0
      INT = NZ(13)
      INTTC=NZ(14)
      ICRH=NZ(15)
      ICRC=NZ(16)
      IPIN=MIN0(NZ(18),4)
      IF (IPIN.LE.0) IPIN=4
      NXTRP = MIN0(MAX0(NZ(19),1),5)
      SEGTE=10.
      IF (NZ(21).NE.0) SEGTE=NZ(21)
      NODUMP=NZ(22)
      JDUMP=NODUMP-1
      MAXIND=MAX0(NZ(23),10)
      MAXTEM=0
      IF (NZ(24).GT.10) MAXTEM=NZ(24)-10
      NPUMP=NZ(25)
      NPERT=NZ(26)
      NR5OPT=NZ(27)
      NOPTIM=NZ(31)
      IF (NOPTIM.GT.0) NC=1
      DRINCR=.01*FLOAT(NZ(32))
      IPUN=NZ(33)
      IF (NZ(34).NE.0) IPDWT=2
      ITHQ=MAX0(NZ(35),1)
      ITCR=MAX0(NZ(36),1)
      ICRMDL=NZ(50)
   32 JOPTIM=0
      ISECT=1
      IPDWT=1
      RAD(1)=Z(1)
      DR(1)=Z(2)
      DR(2)=Z(3)
      DR(3)=Z(4)
      DR(4)=Z(5)
```

```
      DR(6)=Z(6)
      DR(7)=Z(7)
      DR8=Z(8)
      Z9SAV=Z(9)
      ZLI=AMAX1(Z(10),1.0E-10)
      ZLN=Z(11)
      ZLP=Z(12)
      HH=Z(13)
      HC=Z(14)
      TOLTEM=AMAX1(Z(15),.001)
      IF (NGT1.EQ.2) TOLTEM=10.*TOLTEM
      TOLCUR=Z(16)
      IF (TOLCUR.LE.0.) TOLCUR=.001
      TPIN=FK2K(Z(17))
      IF (TPIN.LE.256.) TPIN=700.
      RPIN=Z(18)
      RLOAD=Z(19)
      RECONC=Z(20)
      RECONH=Z(21)
      ENDZK=Z(22)*CKFT
      RRREF=Z(23)
      CID2=2.0*Z(24)
      COD2=2.0*Z(25)
      ZNPERT=AMAX1(Z(26),.001)
      ZNMIN=AMAX1(Z(27),.020)
      QREQ=Z(28)
      ZLTE =ZLP+ZLI+ZLI+ZLN
      IDUMZ=1
      IF (ZLP.NE.0.) GO TO 15
      ZLTE=0.
      IDUMZ=2
      ZLNLP=Z(29)
      IF (ZLNLP.GT.0.) IDUMZ=3
   15 PEREQ=Z(30)
      VREQ=Z(31)
      ZLREQ=Z(32)
      THINC=Z(33)/CKFT
      TCINC=Z(34)/CKFT
      THMAX=1100.
      IF (THINC.GT.0.) THMAX=FK2K(Z(35))+0.5*THINC
      TCMAX=0.
      IF (TCINC.GT.0.) TCMAX=FK2K(Z(36))+.5*TCINC
      DTMIN=Z(37)/CKFT
      DRMIN=Z(38)
```

```
      RIINC=Z(39)
      ROINC=Z(40)
      R1MAX=0.
      IF (RIINC.GT.0.) R1MAX=Z(41)+0.5*RIINC
      R9MAX=0.
      IF (ROINC.GT.0.) R9MAX=Z(42)+0.5*ROINC
      PWRDEN=Z(43)
      QINPC=Z(44)
      QGAM=Z(45)
      RLPERT=Z(46)/PCMULT
      RLMAX=Z(47)/PCMULT
      IF (RLMAX.NE.0.) NOPTIM=1
      ZLIBRH=Z(50)/ZLI
      ZLIBRC=Z(51)/ZLI
      ZK9=Z(52)
      CTEIC=Z(53)*1.0E-06
      CTEOC=Z(54)*1.0E-06
      DELTL=Z(55)
      HRINC=Z(56)
      HRS=1000.
      IF (HRINC.LE.0.) GO TO 5
      HRS=0.
      IRITE=0
    5 HRMAX=Z(57)
      HFLF=Z(58)/7.907E-05
      TREJ=FK2K(Z(59))
      RADPCT=Z(60)
      WTCON=Z(61)
      DGRF=Z(62)
      DGTRF=FK2K(Z(63))
      DGLRF=.01*DGRF*Z(64)
      RADK=Z(65)/CKFT
      CIDP=Z(66)
      RADC=501.E-12*Z(67)*Z(68)*Z(69)
      DO 6 I=1,30
    6 DP(I)=Z(70+I)
      IF (KASE1.EQ.1.OR.(IRITE.NE.3.AND.IRITE.NE.4))
     1 CALL PHONY(DP,IPUN,HRS)
      KASE1=KASE1+1
      RLPC(1)=RLOAD
      YNC=ZNC
      IF (NGT1.GE.3) YNC=PCMULT
      DO 97 I=1,NC
   97 RLPC(I)=RLOAD/YNC
```

```
      ZCIR=YNC*ZLTE
      NGT2=2
      IF (RLOAD.EQ.0.) NGT2=3
      IF (NGT1.LE.1.OR.NGT1.EQ.3) NGT2=1
      IF (VREQ.GT.0..AND.NGT1.GE.4) NGT2=4
      IF (NGT1.GE.6) NGT2=5
      N=1
      IF (IRITE.EQ.1.OR.IRITE.GT.2) GO TO 11
      N=0
C - WRITE INPUT NZ AND Z ARRAYS IF SPECIFIED
      WRITE (6,100) (CMT(J),J=1,25)
  100 FORMAT (1H1,4X,2A4,1X,18A4,2H (,F2.0,2(1H/,F2.0),2H) ,2A4)
      WRITE (6,101)
  101 FORMAT (1H0/50X,10HINPUT DATA/)
      DO 103 I=1,10
  103 WRITE (6,104)  (J,NZ(J) ,J=I,50,10)
  104 FORMAT (2X,5(3HNZ(,I2,2H)=,I4,11X))
      WRITE (6,112)
      DO 105 I=1,20
  105 WRITE (6,106)  (J,Z(J),J=I,100,20)
  106 FORMAT (2X,4(3H Z(,I2,2H)=,G12.4,3X),2HZ(,I3,2H)=,G12.4)
CHECK TO SEE HOW TEMPERATURES ARE TO BE READ IN
   11 IF (NGT1.GE.3) GO TO 5080
      WRITE (6,100) (CMT(J),J=1,25)
      IF (INT.NE.1) GO TO 5070
      WRITE (6,5069)
 5069 FORMAT (1H0,25X,61H***** SAME AXIAL TEMPERATURES  USED AS IN PREVI
     1OUS CASE *****)
      KFTEM=1
      GO TO 123
 5070 THAV=0.
      TCAV=0.
      IF (INT.NE.0) GO TO 5072
      READ (5,5071) (TEMP(1,I),TEMP(9,I),I=1,NC)
 5071 FORMAT (12F6.2)
      IF (IRITE.LT.3) WRITE (6,5075) TEMKF
 5075 FORMAT (1H0,22X,62HHOT AND COLD CLAD TEMPERATURES OR EACH AXIAL SE
     1CTION IN DEGS. ,A1)
      GO TO 123
CALCULATION OF EQUI-SPACED (STANDARD) THERMOCOUPLE LOCATIONS
 5072 IF (INTTC.NE.0) GO TO 5083
      DTAV=ZCIR/(FLOAT(INT)-1.)
      XTHERM(1)=0.
      DO 5082 I=2,INT
```

```
 5082 XTHERM(I)=XTHERM(I-1)+DTAV
      GO TO 5084
 5083 READ (5,5071) (XTHERM(I),I=1,INT)
 5084 READ (5,5071) (THERMH(I),I=1,INT)
      READ (5,5071) (THERMC(I),I=1,INT)
      IF (ZLP .GT. 0.) GO TO 67
      WRITE (6,66)
   66 FORMAT (/////,7X,96HTEMPERATURES CAN NOT BE INTERPOLATED ON A RUN
     1OPTIMIZING AN AXIAL LENGTH, CALCULATIONS SUPRESSED)
      GO TO 93
C     CHECK FOR AND ELIMINATE ZERO THERMOCOUPLE INPUT TEMPERATURES
   67 J=0
      K=0
      DO 65 I=1,INT
      IF (THERMH(I).LE.0.) GO TO 63
      J=J+1
      VPC(J)=THERMH(I)
      VOC(J)=XTHERM(I)
   63 IF (THERMC(I).LE.0.) GO TO 65
      K=K+1
      PE(K)=THERMC(I)
      RPC(K)=XTHERM(I)
   65 CONTINUE
      DTAV=.5*ZLTE
      DO 81 I=1,NC
      TEMP(1,I)=SI(VOC,VPC,DTAV,J,IND,NXTRP,NXTRP)
      TEMP(9,I)=SI(RPC, PE,DTAV,K,IND,NXTRP,NXTRP)
   81 DTAV=DTAV+ZLTE
      WRITE (6,5074) TEMKF
 5074 FORMAT (1H0,27X,51HINPUT THERMOCOUPLE LOCATIONS AND READINGS IN DE
     1GS. ,A1)
      NKN=(INT+9)/10
      DO  73 K=1,NKN
      KNK=10*K
      KNNK=KNK-9
      IF (KNK.GT.INT) KNK=INT
      WRITE (6,108) (I,I=KNNK,KNK)
      WRITE (6,112) (XTHERM(I),I=KNNK,KNK)
  112 FORMAT (1X,F8.3,9F11.3)
      WRITE (6,112) (THERMH(I),I=KNNK,KNK)
   73 WRITE (6,112) (THERMC(I),I=KNNK,KNK)
      IF (IRITE.GE.3) GO TO 122
      WRITE (6,5076) TEMKF
 5076 FORMAT (1H0/21X,67HINTERPOLATED MID-POINT TEMPERATURES OR EACH AXI
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     1AL SECTION IN DEGS. ,A1)
 123 NKN=(NC+9)/10
     DO 111 K=1,NKN
     KNK=10*K
     KNNK=KNK-9
     IF (KNK.GT.NC) KNK=NC
     WRITE (6,108) (I,I=KNNK,KNK)
 108 FORMAT (1H0,3X,10(I3,8X))
     WRITE (6,112) (TEMP(1,I),I=KNNK,KNK)
 111 WRITE (6,112) (TEMP(9,I),I=KNNK,KNK)
 122 IF (INT.EQ.1) GO TO 5073
     DO 5077 I=1,NC
     TEMP(1,I)=FK2K(TEMP(1,I))
     TEMP(9,I)=FK2K(TEMP(9,I))
     THAV=THAV+TEMP(1,I)
5077 TCAV=TCAV+TEMP(9,I)
     THAV=THAV/ZNC
     TCAV=TCAV/ZNC
     DTAV=THAV-TCAV
     TMODAV=TCAV+0.5*DTAV
     THAVF=CKF2(2)*THAV-CKF1(2)
     TCAVF=CKF2(2)*TCAV-CKF1(2)
     TMODF=CKF2(2)*TMODAV-CKF1(2)
     DTAVF=CKF2(2)*DTAV
5073 WRITE (6,5078) THAV,THAVF,TCAV,TCAVF,DTAV,DTAVF,TMODAV,TMODF
5078 FORMAT (1H0/22X,30HAVERAGE HOT CLAD TEMPERATURE =,F9.3, 9H DEG.K
    1( ,F9.3,7H DEG.F)//21X,31HAVERAGE COLD CLAD TEMPERATURE =,F9.3,
    2 9H DEG.K  (,F9.3,7H DEG.F)//18X,34HAVERAGE RADIAL TEMPERATURE  DR
    3OP =,F9.3,9H DEG.K  (,F9.3,7H DEG.F)//24X,28HAVERAGE MODULE TEMPER
    4ATURE =,F9.3,9H DEG.K  (,F9.3,7H DEG.F))
     GO TO 119
5080 IF (INT.EQ.1) GO TO 119
     READ (5,5071) (TEMP(1,I),TEMP(9,I),I=1,NC)
     IF (N.EQ.0) WRITE (6,62) TEMKF,(TEMP(1,I),TEMP(9,I),I=1,NC)
  62 FORMAT (1H0/36H  INPUT TEMPERATURE PAIRS (IN DEGS. ,A1,1H)/
    1(6(2X,F7.2,1H-,F7.2,1H,)))
     IF (KFTEM.EQ.1) GO TO 119
     DO 5081 I=1,NC
     TEMP(1,I)=FK2K(TEMP(1,I))
5081 TEMP(9,I)=FK2K(TEMP(9,I))
 119 IF (RLOAD.GE.0.) GO TO 118
     READ (5,5071) (RLPC(I),I=1,NC)
     IF (N.EQ.0) WRITE (6,117) (RLPC(I),I=1,NC)
 117 FORMAT (74H INPUT LOAD RESISTANCE FOR EACH TEMPERATURE PAIR (IN MI
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     1LLIOHMS PER MODULE) /(2X,10(G10.2,1H,)))
      DO 116 I=1,NC
  116 RLPC(I)=.001*RLPC(I)/PCMULT
  118 DO 125 I=1,NC
      DTMOD(I)=TEMP(1,I)-TEMP(9,I)
      IF (DTMOD(I).NE.0.) GO TO 126
      TEMP(1,I)=TEMP(1,I)+.001
      DTMOD(I) = .001
  126 IF((TEMP(1,I).GT.0..AND.TEMP(9,I).GT.0.).OR.NGT1.GE.3) GO TO 125
      WRITE (6,121)
  121 FORMAT (1H0,/17X,80HNEGATIVE OR ZERO TEMPERATURE ENCOUNTERED - CAL
     1CULATION SUPRESSED FOR THIS CASE     )
      GO TO 93
  125 IT(I)=0
  127 CONTINUE
C - ESTABLISH MODULE RADIAL DIMENSIONS FROM INPUT DATA
 3061 IF (Z(2).LE.0.) DR(1)=CID2*RAD(1)+CIDP
      RAD(2)=RAD(1)+DR(1)
      RAD(3)=RAD(2)+DR(2)
      RAD(4)=RAD(3)+DR(3)
      RAD(5)=RAD(4)+DR(4)
      IF (IZ9.EQ.1) GO TO 3068
      DR(5)=Z9SAV
 3059 RAD(6)=RAD(5)+DR(5)
      RAD(7)=RAD(6)+DR(6)
      RAD(8)=RAD(7)+DR(7)
      IF (DR8.LE.0.) GO TO 3067
      DR(8)=DR8
      RAD(9)=RAD(8)+DR(8)
      GO TO 3066
 3067 IF (COD2.EQ.1.) GO TO 1996
      RAD(9)=RAD(8)/(1.0-COD2)
      DR(8)=RAD(9)-RAD(8)
      GO TO 3066
 3068 RAD(9)=Z9SAV
 3070 DR(8)=DR8
      IF (DR8.LE.0.) DR(8)=COD2*RAD(9)
      RAD(8)=RAD(9)-DR(8)
      RAD(7)=RAD(8)-DR(7)
      RAD(6)=RAD(7)-DR(6)
      DR(5)=RAD(6)-RAD(5)
 3066 ZOD=2.0*RAD(9)
      ZID=2.0*RAD(1)
      IF (RRREF.LE.0.) RRREF=ZOD/ZID
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```
      IENDK=1
      IF (ENDZK.GT.0.) IENDK=2
      QGENL=51.48*PWRDEN*RAD(1)*RAD(1)
      QGEN=QGENL*ZLTE
      IF (IDUMZ.NE.1) QGEN=QGENL*2.*(ZLN+ZLI)
      IF (QINPC.GT.0.) QGEN=QINPC
      IF (IRITE.GT.3) GO TO 4004
C - WRITE RADIAL AND AXIAL DIMENSIONS IF SPECIFIED (NZ(5) .EQ. 0,1,2)
      WRITE (6,100) (CMT(J),J=1,25)
      HD1(1)=SSIN(NCLDH)
      HD1(3)=FETM(ICRH)
      HD1(4)=CASCAD(I3N,2)
      HD(1,4)=CASCAD(I3P,2)
      HD1(5)=CASCAD(I2N,2)
      HD(1,5)=CASCAD(I2P,2)
      HD1(6)=FETM(ICRC)
      HD1(8)=SSIN(NCLDC)
      WRITE (6,2017)
 2017 FORMAT (1H0//,10X,17HRADIAL DIMENSIONS,13X,18HRADIAL THICKNESSES,
     1 7X, 9HCOMPONENT,/)
      I=1
      IF (NOPTIM.NE.0.AND.DRINCR.GT.0.) I=2
      DO 2019  J=1,8
 2019 WRITE (6,2018) J,RAD(J),HD3(J,I),J,DR(J),HD3(J+8,I),HD1(J),HD2(J),
     1 (HD(K,J),K=1,6)
 2018 FORMAT (10X,4HRAD(,I1,3H) =,F10.6,5H IN. ,A1/40X,3HDR(,I1,3H) =,
     1 F10.6,4H IN.,A1,3X,A3,A1,6A4)
      J=9
      WRITE (6,2018) J, RAD(J)
      J1=1
      IF (NOPTIM.NE.0.AND.VREQ.GT.0..AND.(ZLREQ.GT.0..OR.PEREQ.GT.0.))
     1 J1=2
      J =(J1+IDUMZ+1)/2
      WRITE (6,2021) ZLN,ASTAR1(J1),ZLP,ASTAR1(J), ZLI,ZLTE,ASTAR1(J)
 2021 FORMAT (1H0//46X,18HAXIAL DIMENSIONS  ,///10X,8HZLN    =,F9.5,
     1 23H IN.    (N-TYPE WASHER),A2//10X,8HZLP    =,F9.5,23H IN.    (P-
     2TYPE WASHER)A2//10X,8HZLI    =,F9.5,24H IN.    (MICA THICKNESS)//
     3 10X,8HZLTE   =,F9.5,32H IN.    (TOTAL COUPLE THICKNESS),A2)
      IF (J.EQ.1) WRITE (6,2023) ZCIR,YNC
 2023 FORMAT (1H0, 9X,8HZCIR   =,F9.5,30H IN.    (TOTAL CIRCUIT LENGTH,,
     1 F4.0,9H COUPLES))
      IF (J.EQ.2.OR.I.EQ.2) WRITE (6,2022)
 2022 FORMAT (1H0,50X,51H* THIS DIMENSION OPTIMIZED OR CALCULATED INTERN
     1ALLY)
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```
 4004 DR4=DR(4)
      DRTE=RAD(6)-RAD(4)
      IF (DRTE.LT.DRMIN.AND.(NOPTIM.GT.0.OR.NCLAD.GT.0)) GO TO 1996
 3016 IF (RAD(1).LE.0..OR.ZLI.LE.0.) GO TO 1996
      DO 31 J=1,8
      J1=J+1
      IF (RAD(J1).LE. 0.) GO TO 1996
      LNRAD(J)=ALOG(RAD(J1) /RAD(J))
   31 IF (J/2.NE.2.AND.LNRAD(J).LE.0.) GO TO 1991
      ISECT=1
      GO TO 1999
 1991 CONTINUE
      IF (NOPTIM.EQ.0.OR.RDINC.EQ.0.) GO TO 1996
      ISECT=3
      GO TO 1999
 1996 WRITE (6,1992)
 1992 FORMAT (1H0,21X,68HERROR IN DIMENSIONS SPECIFIED - CALCULATIONS SU
     1PRESSED FOR THIS CASE)
      GO TO 93
 1999 ZKEND=ENDZK*ALOG(RRREF)/ALOG(ZOD/ZID)
      IF (NOPTIM.EQ.0) GO TO 4002
      CALL OPTIM(ISECT,J)
      GO TO (4002,4002,4002,3059,4002,3070,3061), J
CALCULATE ALL RECURRING PRODUCTS
 4002 ALR64 = LNRAD(5)+LNRAD(4)
      CGAM=.5/ALR64-1./(EXP(2.*ALR64)-1.)
      CONST1=.062659*ALR64
      CONRN=CONST1/ZLN
      RCON4  = RECONH/(40.5366*ZLN*RAD(4))
      RCON6 = RECONC/(40.5366*ZLN*RAD(6))
CHECK FOR THERMAL CONTACT COEFFICIENTS EQUAL ZERO
      CONST3=0.
      CONST4=0.
      IF (HH.NE.0.) CONST3=.3937*(1.0/RAD(2)+1.0/RAD(3))/(LNRAD(2)*HH)
      IF (HC.NE.0.) CONST4=.3937*(1.0/RAD(7)+1.0/RAD(8))/(LNRAD(7)*HC)
CHECK TO SEE IF P-LEG AXIAL LENGTH IS TO BE OPTIMIZED
      IF (IDUMZ.GT.1) GO TO 78
CALCULATE RECURRING PRODUCTS IF P-LEG IS NOT TO BE OPTIMIZED
      ZLPN=ZLP+ZLN
      ZLPNI=ZLPN+ZLI
      ZLTE=ZLPNI+ZLI
      ZLNLP=ZLN/ZLP
      CONST5=15.9593*ZLP
      ZLIP=2.0*ZLI/ZLP
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```
      CONST2=15.9593*ZLTE
      RINT4=RCON4*ZLPN/ZLP
      RINT6=RCON6*ZLPN/ZLP
      CONRP=CONST1/ZLP
      IF (ICRMDL .NE. 0) GO TO 4005
      C1FEH=15.9593*DR(3)*(RAD(3)+RAD(4))/ZLTE
      C1FEC=15.9593*DR(6)*(RAD(6)+RAD(7))/ZLTE
      GO TO 78
CALCULATE RADIUS OF CIRCULAR CONDUCTOR RING ELECTRICAL STREAMLINE
 4005 RCHOT=AMIN1(DR(3),ZLN,ZLP)
      RCOLD=AMIN1(DR(6),ZLN,ZLP)
      C1FEH=5.08*RAD(4)*ALOG(3.14159*RCHOT/ZLI+1.0)
      C1FEC=5.08*RAD(6)*ALOG(3.14159*RCOLD/ZLI+1.0)
   78 INDI=INDI+1
C - ENTER SUBROUTINE COUPLE
      CALL COUPLE
      IF (NODUMP.EQ.5) GO TO 93
C - ENTER SUBROUTINE LIFE, IF SPECIFIED
      IF (HRINC.LE.0) GO TO 3052
      CALL LIFE(DAPERT)
      IF (JOPTIM.LT.0) GO TO 93
      GO TO 78
 3052 IF (NOPTIM.EQ.0) GO TO 3051
C - ENTER SUBROUTINE OPTIM FOR THOT, TCOLD, PCT2N PERTURBATION
      CALL OPTIM(2,J)
      DTMOD(1)=TEMP(1,1)-TEMP(9,1)
      GO TO (93,4002,78,3059,78,3070,3061), J
 3051 IF (NPUMP.LE.0) GO TO 3053
      CALL PUMP(J)
      GO TO (4002,3061,93),J
 3053 IF (NODUMP.EQ.3) GO TO 93
      IF (NGT1.GE.3) GO TO 79
CALCULATE MODULE VOLTAGE AND RESISTANCE FOR CURRENT CONVERGENCE CHECK
      OCV=0.
      OHM=0.
      QMOD=0.
      DO 36 I=1,NC
      OCV=OCV+VOC(I)
      OHM=OHM+RPC(I)
   36 QMOD=QMOD+QT(I)
      J=INDI+1
      IF (NGT2-2) 79,37,22
   22 RLOAD=OHM
CHECK FOR CONVERGENCE ON MODULE CURRENT
```

```
   37 CURMOD(J) =  OCV/(OHM+RLOAD)
      IF (ABS(1.0-CURMOD(INDI)/CURMOD(J)).LE.TOLCUR.AND.INDI.GT.2)GOTO79
      IF (INDI.EQ.2) TOLTEM=0.1*TOLTEM
      IF (INDI .LT. MAXIND) GO TO 78
      WRITE (6,43) MAXIND, (J,CURMOD(J),J=1,INDI)
   43 FORMAT (///,27X,37H***CURRENT CLOSURE NOT OBTAINED AFTER,I5,  14H
     1ITERATIONS***,//,22X,65HMODULE CURRENT CALCULATED ON EACH PASS THR
     2OUGH SUBROUTINE COUPLE  ,///,42X,9HITERATION,7X,7HCURRENT,/,
     3(1H0,44X,I3,1H.,7X,1PE12.5,/))
   79 CALL RITE
      IF (NGT1.EQ.5.AND.NGT2.EQ.3) GO TO 2060
      IF (NGT1.NE.0) GO TO 2059
      INDI=1
      NGT1=2
      TOLTEM=10.*TOLTEM
      IF(RLOAD.GT.0.) GO TO 2053
      CURMOD(2)=0.50*OCV/OHM
      NGT2=3
      GO TO 78
 2053 NGT2=2
      RLPC(1)=RLOAD/ZNC
      DO 2054 I=1,NC
 2054 RLPC (I)=RLPC(1)
      CURMOD(2)=OCV/(OHM+RLOAD)
      GO TO 78
 2059 IF (NGT1.NE.5) GO TO 2061
 2060 CURMOD(2)=0.
      INDI=1
      NGT2=1
      NGT1=3
      DTTE=TEMP(4,1)-TEMP(6,1)
      GO TO 78
 2061 IF (NGT1.NE.7) GO TO 93
      NGT1=4
      IRITE=4
      INT=1
      GO TO 32
      END
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```
      SUBROUTINE RITE
      DIMENSION TAVG(300),ETAC(300),DTMF(300),TF(9,300),TICUP(300),
     1 DTF(9,300),CPMD(12,2),ALPCUP(300),ETA(300)
      COMMON/TERIT/DTAV,OHM,OCV,RLOAD,QMOD,TCAV
      COMMON /MDCPOP/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
     1 QT(300),NOPTIM,VPC(300),RLPC(300),DTMOD(300),CUR(300),LNRAD(9),
     2 ZLP,ZLN,ZLI,ZLNLP,ZLPNI,ZLTE,NGT1,NGT2,ITPERT,PCMULT,NODUMP,IVD,
     3 QGEN,QGENL,QTE,QOUT,ZID,ZOD,ZKEND,ZK9,ZKR,RPPC,RPN,TOLTEM,TREJ,
     4 VREQ,PEREQ,ZLREQ,WTCON,ZLPN,IDUMZ,RN,DGRF,DGTRF,DGLRF,RADK,JDUMP,
     5 DP(30),NC
      COMMON /MODCPL/CURMOD(15),IT(300),DTTE,CONRN,CONRP,ZLIP,ZNC,
     1 ALR64,MAXTEM,QGAM,CGAM,INDI,RINT4,RINT6,RCON4,RCON6,C1FEH,C1FEC,
     2 CONST1,CONST2,CONST3,CONST4,CONST5,NR5OPT,SEGTE,ICRMDL,RADC
      COMMON /MODOPT/IPOWT, DR4,DRINCR,IRITE,DRTE,JOPTIM,IZ9,IENDK,IPUN,
     1 RIINC,ROINC,R1MAX,R9MAX,DTMIN,QREQ,THINC,TCINC,TCMAX,THMAX
     2,NPERT,ZNPERT,CKFP,CKFT,CTEOC,CTEIC,DELTL,RLPERT,RLMAX,ZNMIN,Z9SAV
      COMMON /TITLE/FETM(3),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMKF,
     1 CRMD(2,2),I3N,I2N,I3P,I2P
      COMMON /CPLRIT/DT(8,300),OPTZLP(300),OPTCPL(300)
      DATA CPMD/4H CIR,4HCUIT,4H  CA,4HRNOT,4H CUR,4HRENT,4H EFF,4H (AM,
     1 4HPS) ,4H PCT,1H.,4H.    ,4H  MO,4HDULE,4H AVE,4HRAGE,4H R-L,
     2 4HOAD ,4HTEMP,4H(M-O,4HHMS),4HDEG.,4HMOHM,1HS/
      CPMD(1,2)=CRMD(1,1)
      CPMD(2,2)=CRMD(2,1)
      WRITE (6,100) (CMT(J),J=1,25)
  100 FORMAT (1H1,4X,2A4,1X,18A4,2H (,F2.0,2(1H/,F2.0),2H) ,2A4)
      IF (ZKEND.LE.0.) GO TO 11
      CPMD(1,2)=CRMD(1,2)
      CPMD(2,2)=CRMD(2,2)
   11 IF (NGT1.LT.3.AND.IRITE.GT.2) GO TO 2005
      DO 2001 I=1,NC
      P=TEMP(9,I)+0.5*DTMOD(I)
      TAVG(I)=DK2FK(P)
      ETAC(I)=100.*DTMOD(I)/TEMP(1,I)
      DTMF(I)=CKFT*DTMOD(I)
      TF(9,I)=DK2FK(TEMP(9,I))
      TICUP(I)=DTMF(I)/QT(I)
      ALPCUP(I)=VOC(I)/DTMF(I)
      ETA(I)=PE(I)/QT(I)
      DO 2001 J=1,8
      DTF(J,I)=CKFT*DT(J,I)
 2001 TF(J,I)=DK2FK(TEMP(J,I))
 2006 IF (IRITE.GT.2) GO TO 2007
```

```
 1994 WRITE (6,1998) (COND(J,NGT2),J=1,3),TEMKF,(J,J=1,9),
     1 (I,(TF(J,I),J=1,9),I=1,NC)
 1998 FORMAT (1H0,10X,58HRADIAL TEMPERATURE PROFILE FOR EACH COUPLE CALC
     1ULATED FOR ,3A4,19H CONDITIONS (DEGS. ,A1,1H)/8H0 COUPLE,6X,
     2 9(1HT,I1,9X)/(3H0  ,I3,1H.,F11.2,8F11.2))
      IF (NC.GT.7) WRITE (6,100) (CMT(J),J=1,25)
      WRITE (6,2009) TEMKF,(I,(DTF(J,I),J=1,8),I=1,NC)
 2009 FORMAT (1H0,21X,64HRADIAL TEMPERATURE DROP ACROSS COMPONENTS FOR E
     1ACH COUPLE (DEG. ,A1,1H)//8H  COUPLE,10X,28HINNER        BORON
     2 INNER,28X,26HOUTER       BORON      OUTER/19X,81HCLAD       NITRIDE
     3  CONDUCTOR      T/E1        T/E2      CONDUCTOR    NITRIDE     CLAD/
     4(1H0,I5,2H. ,F16.3,7F11.3))
      WRITE (6,100) (CMT(J),J=1,25)
 2007 WRITE (6,2002) (COND(J,NGT2),J=1,3)
 2002 FORMAT (1H0,12X,61HCALCULATED PARAMETERS FOR INDIVIDUAL COUPLES OP
     1ERATING UNDER ,3A4,11H CONDITIONS)
C - WRITE INDIVIDUAL COUPLE PARAMETERS
      WRITE (6,13)  (CPMD(J,1),J=1,7),TEMKF,CPMD(8,1),CPMD(9,1),TEMKF,
     1 TEMKF,CPMD(10,1),CPMD(11,1)
   13 FORMAT (1H0,12X,18H*****VOLTAGES*****12X,50HINTERNAL    POWER
     1 HEAT     THERMAL   EFFECTIVE ,2A4,1X,2A4/33H    TH / TC       VOC
     2  V-LOAD  ,2A4,63H RESISTANCE  OUTPUT     INPUT   IMPEDANCE  SEEBE
     3CK      EFF.     ,A4,1H./8H    (DEG.,A1,24H)      (VOLTS)    (VOLTS)  ,
     4 2A4,35H  (M-OHMS)    (WATTS)    (WATTS)  (D-,A1,12H/KW)   (MV/D-,
     5 A1,14H)      (PCT.)   (,A4,A1,1H))
      WRITE (6,14) (TF(1,I),TF(9,I),VOC(I),VPC(I),CUR(I),RPC(I),PE(I),
     1 QT(I),TICUP(I),ALPCUP(I),ETA(I),ETAC(I),I=1,NC)
   14 FORMAT (1H0,F5.0,1H/,F4.0,2F10.5,F10.3,3PF10.4,0PF10.4,F10.2,
     1 3PF10.2,3PF10.4,2PF10.3,0PF9.2)
C - WRITE CALCULATED AXIAL LENGTHS IF ZLP HAS BEEN OPTIMIZED
 2062 IF (IDUMZ.EQ.1) GO TO 2061
      IF (NC.GT.7) WRITE (6,100) (CMT(J),J=1,25)
      WRITE(6,2052) (I,ZLN,OPTZLP(I),ZLI,OPTCPL(I),OPTCPL(I+100),I=1,NC)
 2052 FORMAT (1H0//  14X, 6HCOUPLE,18X,52HAXIAL THICKNESSES CALCULATED I
     1N OPTIMIZATION ROUTINE/14X,6HNUMBER,11X,5HN-LEG,10X,5HP-LEG,7X,12H
     2MICA WASHERS,6X,6HCOUPLE,8X,7HCIRCUIT/(1H0,13X,I4,4H)    ,5F15.5))
 2061 IF (NGT1.LT.3) GO TO 2005
      IF (NC.GT.7.OR.IDUMZ.EQ.2) WRITE(6,100) (CMT(J),J=1,25)
      WRITE (6,2042) PCMULT,(COND(J,NGT2),J=1,3)
 2042 FORMAT (//   F7.0,32H COUPLE MODULES OPERATING UNDER ,3A4,55H COND
     1ITIONS WITH UNIFORM HOT AND COLD CLAD TEMPERATURES)
      RLD=0.
      WRITE (6,13) (CPMD(J,2),J=1,7),TEMKF,CPMD(8,2),CPMD(9,2),TEMKF,
     1 TEMKF,CPMD(10,2),TEMKF
```

```
      DO 57 I=1,NC
      OCV = PCMULT*VOC(I)
      VLD = PCMULT*VPC(I)
      IF (NGT2.NE.1) RLD=1000.*PCMULT*RLPC(I)
      OHM=PCMULT*RPC(I)
      P = PCMULT*PE(I)
      QMOD=PCMULT*QT(I)+ZKEND*DTMOD(I)
      SEB=PCMULT*ALPCUP(I)
      ETAO=P/QMOD
      TIO=DTMF(I)/QMOD
   57 WRITE (6,14) TF(1,I),TF(9,I),OCV,VLD,RLD,OHM,P,QMOD,TIO,SEB,ETAO,
     1 TAVG(I)
      GO TO 2221
 2005 WRITE (6,2059)
 2059 FORMAT (1H0///43X,24HOVERALL MODULE OPERATION)
      WRITE(6,13) (CPMD(J,2),J=1,2),(CPMD(J,2),J=5,6),(CPMD(J,1),J=5,6),
     1CPMD(12,1),TEMKF,(CPMD(J,1),J=8,9),TEMKF,TEMKF,(CPMD(J,2),J=11,12)
C - CALCULATE MODULE PARAMETERS
      TAVG(2)=DK2FK(TCAV)
      TAVG(1)=TAVG(2)+CKFT*DTAV
      VLD=OCV-CURMOD(INDI)*OHM
      RLD=1000.*VLD/CURMOD(INDI)
      P=VLD*CURMOD(INDI)
      QMOD=QMOD+ZKEND*DTAV
      SEB=OCV/(DTAV*CKFT)
      ETAO=P/QMOD
      TIO=DTAV*CKFT/QMOD
      WRITE (6,14) TAVG(1),TAVG(2),OCV,VLD,CURMOD(INDI),OHM,P,QMOD,TIO,
     1 SEB,ETAO,RLD
      WRITE (6,2011) INDI
 2011 FORMAT(1H0,////,30X,I2,37H ITERATIONS TAKEN FOR CURRENT CLOSURE)
 2221 WRITE (6,2016) (IT(I),I=1,NC)
 2016 FORMAT(1H0// 38HONUMBER OF ITERATIONS FOR EACH COUPLE-/(5X,25I4)/
     1 1H0,22(5H*****))
      RETURN
      END
```

```
      SUBROUTINE PHONY(DP,IPUN,HRS)
      DIMENSION FM3N(15),FM2N(15),FM3P(15),FM2P(15),DP(30)
      COMMON /TITLE/FETM(3),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMKF,
     1 CRMD(2,2),I3N,I2N,I3P,I2P
      COMMON /DATIN/TTT(15),ZKMIC1(15),ZKMIC2(15), ZKSS(15),ZKBN(16),
     1  ZKIN(15),Z2NA(15),Z2NR(15),Z2NK(15),Z2PA(15),Z2PR(15),Z2PK(15),
     2Z2NRK(15),Z2PRK(15),Z3NA(15),Z3NR(15),Z3NK(15),Z3NRK(15),Z3PA(15),
     3 Z3PR(15),Z3PK(15),Z3PRK(15),ZKCRH(15),ZKCRC(15),RCRH(15),RCRC(15)
     4,RHP(15),RPRHO
      COMMON /FODAT/ALPHA(15,8),RHO(15,8),ZKON(16,8),ZKSSIN(16,3),
     1 RFETM(15,4),ZKFETM(16,3),ZKMICA(16)
      COMMON /FOWT/DEN(8),DENI,DEN3N,DEN2N,DEN3P,DEN2P,DCRH,DCRC
      COMMON/TEFO/NCLDC,NCLDH,ICRH,ICRC,IPIN,ZLIBRH,ZLIBRC,TPIN,RPIN
      DATA HOT/4HHOT /,COLD/4HCOLD/,NNAME/2HN-/,PNAME/2HP-/
      IF (NCLDH.NE.1.AND.NCLDH.NE.3) NCLDH=2
      IF (NCLDC.NE.2.AND.NCLDC.NE.3) NCLDC=1
      IF (ICRH.NE.2.AND.ICRH.NE.1) ICRH=3
      IF (ICRC.NE.2.AND.ICRC.NE.1) ICRC=3
      IF (I3N.LT.10) GO TO 301
      I3N=I3N-10
      READ (5,3001) (ALPHA(I,I3N),I=1,15),(RHO(I,I3N),I=1,15),
     1 (ZKON(I,I3N),I=1,16),CASCAD(I3N,1),CASCAD(I3N,2)
 3001 FORMAT (8F9.2/7F9.2/8F9.2/7F9.2/8F9.2/8F9.2,1X,2A4)
      IF (IPUN.GT.0) WRITE (7,401) (CASCAD(I3N,I),I=1,2),(ALPHA(I,I3N),
     1 I=1,15), (CASCAD(I3N,I),I=1,2),(RHO  (I,I3N),I=1,15),
     2 (CASCAD(I3N,I),I=1,2),(ZKON (I,I3N),I=1,16)
  401 FORMAT (25HC SEEBECK COEFFICIENT OF ,2A4,23H MATERIAL (VOLTS/DEG.K
     1),5X,1H1,10X,5(E9.3,1H,)/5X,1H2,10X,5(E9.3,1H,)/5X,1H3,10X,5(E9.3,
     2 1H,)/17HC RESISTIVITY OF ,2A4,19H MATERIAL (OHM*CM.)/5X,1H1,10X,
     3 5(E9.3,1H,)/5X,1H2,10X,5(E9.3,1H,)/5X,1H3,10X,5(E9.3,1H,)/
     4 26HC THERMAL CONDUCTIVITY OF ,2A4,27H MATERIAL (WATTS/CM./DEG.K)/
     5 5X,1H110X,5(E9.3,1H,)/5X,1H210X,5(E9.3,1H,)/5X,1H3,6(E9.3,1H,))
  301 IF (I2N.LT.10) GO TO 302
      I2N=I2N-10
      READ (5,3001) (ALPHA(I,I2N),I=1,15),(RHO(I,I2N),I=1,15),
     1 (ZKON(I,I2N),I=1,16),CASCAD(I2N,1),CASCAD(I2N,2)
      IF (IPUN.GT.0) WRITE (7,401) (CASCAD(I2N,I),I=1,2),(ALPHA(I,I2N),
     1 I=1,15), (CASCAD(I2N,I),I=1,2),(RHO  (I,I2N),I=1,15),
     2 (CASCAD(I2N,I),I=1,2),(ZKON (I,I2N),I=1,16)
  302 IF (I3P.LT.10) GO TO 303
      I3P=I3P-10
      READ (5,3001) (ALPHA(I,I3P),I=1,15),(RHO(I,I3P),I=1,15),
     1 (ZKON(I,I3P),I=1,16),CASCAD(I3P,1),CASCAD(I3P,2)
```

```
      IF (IPUN.GT.0) WRITE (7,401) (CASCAD(I3P,I),I=1,2),(ALPHA(I,I3P),
     1 I=1,15), (CASCAD(I3P,I),I=1,2),(RHO  (I,I3P),I=1,15),
     2 (CASCAD(I3P,I),I=1,2),(ZKON (I,I3P),I=1,16)
  303 IF (I2P.LT.10) GO TO 304
      I2P=I2P-10
      READ (5,3001) (ALPHA(I,I2P),I=1,15),(RHO(I,I2P),I=1,15),
     1 (ZKON(I,I2P),I=1,16),CASCAD(I2P,1),CASCAD(I2P,2)
      IF (IPUN.GT.0) WRITE (7,401) (CASCAD(I2P,I),I=1,2),(ALPHA(I,I2P),
     1 I=1,15), (CASCAD(I2P,I),I=1,2),(RHO  (I,I2P),I=1,15),
     2 (CASCAD(I2P,I),I=1,2),(ZKON (I,I2P),I=1,16)
  304 ZLIBH1=1.0-ZLIBRH
      ZLIBC1=1.0-ZLIBRC
      PN3N = 1.0
      PN2N = 1.0
      IF (I3N.EQ.I3P) PN3N=-1.0
      IF (I2N.EQ.I2P) PN2N=-1.0
      HRP=1.0E-5*HRS
      DZ3NA=(1.+HRP*DP(I3N))*PN3N
      DZ2NA=(1.+HRP*DP(I2N))*PN2N
      DZ3PA=1.0+HRP*DP(I3P)
      DZ2PA=1.0+HRP*DP(I2P)
      DZ3NR=1.0+HRP*DP(I3N+10)
      DZ2NR=1.0+HRP*DP(I2N+10)
      DZ3PR=1.0+HRP*DP(I3P+10)
      DZ2PR=1.0+HRP*DP(I2P+10)
      HRP=.01
      DZ3NK=1.0+HRP*DP(I3N+20)
      DZ2NK=1.0+HRP*DP(I2N+20)
      DZ3PK=1.0+HRP*DP(I3P+20)
      DZ2PK=1.0+HRP*DP(I2P+20)
      I=16
      DEN(1)=ZKSSIN(I,NCLDH)
      DEN(2)=ZKBN(I)
      DEN(7)=ZKBN(I)
      DEN(8)=ZKSSIN(I,NCLDC)
      DENI=ZKMICA(I)
      DCRH=ZKFETM(I,ICRH)
      DCRC=ZKFETM(I,ICRC)
      DEN3N=ZKON(I,I3N)
      DEN2N=ZKON(I,I2N)
      DEN3P=ZKON(I,I3P)
      DEN2P=ZKON(I,I2P)
      DO 249 I=1,15
      RHP(I)=RFETM(I,IPIN)
```

```
      ZKMIC1(I)=ZLIBH1*ZKMICA(I)+ZLIBRH*ZKFETM(I,2)
      ZKMIC2(I)=ZLIBC1*ZKMICA(I)+ZLIBRC*ZKFETM(I,2)
      RCRH(I)=RFETM(I,ICRH)
      RCRC(I)=RFETM(I,ICRC)
      ZKCRH(I)=ZKFETM(I,ICRH)
      ZKCRC(I)=ZKFETM(I,ICRC)
      ZKIN(I)=ZKSSIN(I,NCLDH)
      ZKSS(I)=ZKSSIN(I,NCLDC)
      Z3NA(I)=DZ3NA*ALPHA(I,I3N)
      Z2NA(I)=DZ2NA*ALPHA(I,I2N)
      Z3PA(I)=DZ3PA*ALPHA(I,I3P)
      Z2PA(I)=DZ2PA*ALPHA(I,I2P)
      Z3NR(I)=DZ3NR*RHO(I,I3N)
      Z2NR(I)=DZ2NR*RHO(I,I2N)
      Z3PR(I)=DZ3PR*RHO(I,I3P)
      Z2PR(I)=DZ2PR*RHO(I,I2P)
      Z3NK(I)=DZ3NK*ZKON(I,I3N)
      Z2NK(I)=DZ2NK*ZKON(I,I2N)
      Z3PK(I)=DZ3PK*ZKON(I,I3P)
      Z2PK(I)=DZ2PK*ZKON(I,I2P)
      Z2NRK(I)          = Z2NR(I)*   Z2NK(I)
      Z2PRK(I)          = Z2PR(I)*   Z2PK(I)
      Z3NRK(I)          = Z3NR(I)*   Z3NK(I)
  249 Z3PRK(I)=Z3PR(I)*Z3PK(I)
      RPRHO=RPIN/SI(TTT,RHP,TPIN,15,IND,1,1)
      IF (IPUN.LT.0) RETURN
      WRITE (6,100) (CMT(J),J=1,25)
  100 FORMAT (1H1,4X,2A4,1X,18A4,2H (,F2.0,2(1H/,F2.0),2H) ,2A4/
     1 //38X,33HINPUT MATERIALS PROPERTIES TABLES)
      WRITE (6,281) HOT,NNAME,(CASCAD(I3N,I),I=1,2),HOT,PNAME,(CASCAD
     1 (I3P,I),I=1,2)
  281 FORMAT (1H0,/16X,2(A4,6H SIDE ,A2,13HLEG WASHER - ,2A4,9H MATERIAL
     1,3X)/16X,2(42H******************************************,3X))
      WRITE (6,282)
  282 FORMAT (8X,5HTEMP.,6X,2(39HSEEBECK      RESISTIVITY   CONDUCTIVITY
     1,6X))
      WRITE (6,283)
  283 FORMAT (7X,6HDEG. K,3X,2(45H(VOLT/DEG K)      (OHM*CM)        (WATT/C
     1M/K)    ) )
      WRITE (6,253) (TTT(I),Z3NA(I),Z3NR(I),Z3NK(I),Z3PA(I),Z3PR(I),
     1Z3PK(I),I=1,15)
  253 FORMAT (1H0,6X,F6.1,6G15.5)
      WRITE (6,100) (CMT(J),J=1,25)
      WRITE (6,281) COLD,NNAME,(CASCAD(I2N,I),I=1,2),COLD,PNAME,(CASCAD
```

```
      1 (I2P,I),I=1,2)
       WRITE (6,282)
       WRITE (6,283)
       WRITE (6,253) (TTT(I),Z2NA(I),Z2NR(I),Z2NK(I),Z2PA(I),Z2PR(I),
      1Z2PK(I),I=1,15)
       WRITE (6,100) (CMT(J),J=1,25)
       WRITE (6,285)
  285 FORMAT (1H0,/16X,4(12HFIG-OF-MERIT,3X),2(12HCONDUCTIVITY,3X),/8X,
      1 5HTEMP.,2(7X,5HN-LEG,10X,5HP-LEG,3X),3X,27HBN INSULATOR   INTER-C
      2OUPLE,/7X,6HDEG. K,5X,2(9HHOT  SIDE,6X),2(9HCOLD SIDE,6X),24H SLEF
      3VES      INSULATORS/12X,4(6X,9H(1/DEG.K)),1X,2(4X,11H(WATT/CM/K)))
       DO 250 I=1,15
       FM3N(I)=Z3NA(I)*Z3NA(I)/Z3NRK(I)
       FM2N(I)=Z2NA(I)*Z2NA(I)/Z2NRK(I)
       FM3P(I)=Z3PA(I)*Z3PA(I)/Z3PRK(I)
  250 FM2P(I)=Z2PA(I)*Z2PA(I)/Z2PRK(I)
       WRITE (6,253) (TTT(I),FM3N(I),FM3P(I),FM2N(I),FM2P(I),ZKBN(I),
      1 ZKMIC1(I),I=1,15)
       WRITE (6,100) (CMT(J),J=1,25)
       WRITE (6,286) HOT,COLD,SSIN(NCLDH),SSIN(NCLDC),FETM(ICRH),
      1 FETM(ICRH),FETM(ICRC),FETM(ICRC)
  286 FORMAT (1H0,/17X,25HINNER CLAD      OUTER CLAD,5X,2(A4,21H SIDE CON
      1DUCTOR RINGS,5X)/8X,5HTEMP.,7X,6(1H(,A2,1H),11X),/7X,6HDEG. K,
      2 2(15H   CONDUCTIVITY),2(30H   CONDUCTIVITY    RESISTIVITY)/
      3 13X,2(15H     (WATT/CM/K)),2(28H    (WATT/CM/K)      (OHM*CM),2X))
       WRITE (6,253) (TTT(I),ZKIN(I),ZKSS(I),ZKCRH(I),RCRH(I),ZKCRC(I),
      1 RCRC(I),I=1,15)
       RETURN
       END
```

```
 SUBROUTINE COUPLE
 COMMON /MDCPOP/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
1 QT(300),NOPTIM,VPC(300),RLPC(300),DTMOD(300),CUR(300),LNRAD(9),
2 ZLP,ZLN,ZLI,ZLNLP,ZLPNI,ZLTE,NGT1,NGT2,ITPERT,PCMULT,NODUMP,IVD,
3 QGEN,QGENL,QTE,QOUT,ZID,ZOD,ZKEND,ZK9,ZKR,RPPC,RPN,TOLTEM,TREJ,
4 VREQ,PEREQ,ZLREQ,WTCON,ZLPN,IDUMZ,RN,DGRF,DGTRF,DGLRF,RADK,JDUMP,
5 DP(30),NC
 COMMON /MODCPL/CURMOD(15),IT(300),DTTE,CONRN,CONRP,ZLIP,ZNC,
1 ALR64,MAXTEM,QGAM,CGAM,INDI,RINT4,RINT6,RCON4,RCON6,C1FEH,C1FEC,
2 CONST1,CONST2,CONST3,CONST4,CONST5,NR5OPT,SEGTE,ICRMDL,RADC
 COMMON /DATIN/TTT(15),ZKMIC1(15),ZKMIC2(15), ZKSS(15),ZKBN(16),
1  ZKIN(15),Z2NA(15),Z2NR(15),Z2NK(15),Z2PA(15),Z2PR(15),Z2PK(15),
2Z2NRK(15),Z2PRK(15),Z3NA(15),Z3NR(15),Z3NK(15),Z3NRK(15),Z3PA(15),
3 Z3PR(15),Z3PK(15),Z3PRK(15),ZKCRH(15),ZKCRC(15),RCRH(15),RCRC(15)
4,RHP(15),RPRHO
 COMMON /TITLE/FETM(3),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMKF,
1 CRMD(2,2),I3N,I2N,I3P,I2P
 COMMON /CPLRIT/DT(8,300),DPTZLP(300),DPTCPL(300)
 DIMENSION XZK(9),ZK(9),TCON(11),ZKEQ(8),B(100)
 REAL LNRAD
 DATA XZK/9*0./,LNDUMP/0/,ZKTEP/0./,ZKTEN/0./,T5OP/670./,ZKEQ/8*0./
 DATA  B/ 6HTFEH  ,6HZKP1  ,6HRINT4 ,6HZKDT  ,6HTFEC  ,6HZKP2  ,
16HRINT6 ,6HQSAVE ,6HFERH  ,6HZKN1  ,6HTCLDH ,6HQGEN  ,6HFERC  ,
26HZKN2  ,6HTCLDC ,6HQGAM  ,6HALP1  ,6HZKI1  ,6HTBNH  ,6HQTOMP1,
36HALP2  ,6HZKI2  ,6HTBNC  ,6HQTOMP2,6HALN1  ,6HZKTEP ,6HDTMOD ,
46HQTOMN1,6HALN2  ,6HZKTEN ,6HDTTE  ,6HQTOMN2,6HZKR   ,6HZKTE  ,
56HTOLTEM,6HQTOM  ,6HRHOP1 ,6HZKTEQ ,6HTCON  ,6HQC    ,6HRHOP2 ,
66HZKECPC,6HALT1  ,6HQP    ,6HRHON1 ,6HZLP   ,6HALT2  ,6HQJ    ,
76HRHON2 ,6HZLN   ,6HALNH1 ,6HQIN   ,6HRHOP  ,6HZLTE  ,6HALNH2 ,
86HQOUT  ,6HRHON  ,6HRP    ,6HALNC1 ,6HVPC   ,6HCONST1,6HRN    ,
96HALNC2 ,6HRPC   ,6HCONST2,6HRFEH  ,6HALPH1 ,6HVOC   ,6HCONST3,
A6HRFEC  ,6HALPH2 ,6HCUR   ,6HCONST4,6HRINTFH,6HALPC1 ,6HPE    ,
16HZKHOT ,6HRINTFC,6HALPC2 ,6HQTE   ,6HZKCOLD,6HRPPC  ,6HRLPC  ,
26HQT    ,6HQEOL  ,6HQBOL  ,6HTREOL ,6HTRBOL ,6HPCMULT/
 TOLTEM=AMAX1(TOLTEM,.001)
 NSEG=SEGTE
 YNC=ZNC
 IF (NGT1.GE.3) YNC=PCMULT
 ZKECPC=ZKEND/YNC
 CONST6=0.5*ZLREQ/(ZLI*YNC)-1.0
 DO 6010 I=1,NC
 QSAVE=0.
 ITNOW=0
```

```
C INITIALIZE RADIAL TEMPERATURES
      IF (INDI.GT.1) GO TO 4053
      IF (I.EQ.1) GO TO 4045
      I1=I-1
      IF (QGEN.LE.0.) GO TO 5005
      DTMOD(I)=DTMOD(I1)
      TEMP(1,I)=TEMP(9,I)+DTMOD(I)
 5005 DTMODR=DTMOD(I)/DTMOD(I1)
      DT(1,I)=DT(1,I1)*DTMODR
      DO 4041 J=1,7
      J9=J+1
      TEMP(J9,I)=TEMP(J,I)-DT(J,I)
 4041 DT(J9,I)=DT(J9,I1)*DTMODR
      GO TO 4040
 4045 IF (QGEN.LE.0.) GO TO 5004
      DTMOD(I)=0.5*QGEN*CONRN/SI(TTT,Z2NK,TEMP(9,I),15,IND,1,1)
      TEMP(1,I)=TEMP(9,I)+DTMOD(I)
 5004 TEMP(5,I)=TEMP(1,I)-LNRAD(4)*DTMOD(I)/ALR64
      DO 4051 J=2,4
      TEMP(J,I)=TEMP(1,I)
 4051 TEMP(J+4,I)=TEMP(9,I)
      DO 4052 J=1,8
 4052 DT(J,I)=TEMP(J,I)-TEMP(J+1,I)
      GO TO 4040
 4053 IF (NGT1.LT.3.OR.ITPERT.GT.1) GO TO 4040
      IF (ITPERT.EQ.0) GO TO 4055
      ITPERT=0
      DTMOD(1)=TEMP(1,1)-TEMP(9,1)
      DTMODR=DTMOD(1)/DTMOD(3)
      DO 6013 J1=1,NC
      DO 4054 J=1,7
      DT(J,J1)=DT(J,J1)*DTMODR
 4054 TEMP(J+1,J1)=TEMP(J,J1)-DT(J,J1)
 6013 DT(8,J1)=DTMODR*DT(8,J1)
 4040 DTTE=TEMP(4,I)-TEMP(6,I)
      IF (DTTE.GT.DTMOD(I)) DTTE = DTMOD(I)
      IF (NR5OPT.EQ.0) GO TO 4060
      TEMP(5,I)=AMIN1(AMAX1(T5OP,TEMP(4,I)),TEMP(5,I))
      DT(4,I)=TEMP(4,I)-TEMP(5,I)
      DT(5,I)=TEMP(5,I)-TEMP(6,I)
 4060 DELT1=DT(4,I)/SEGTE
      DELT2=DT(5,I)/SEGTE
      TT1 = TEMP(5,I) + .5*DELT1
      TT2 = TEMP(6,I) + .5*DELT2
```

```
      ALP1 = 0.
      ALP2 = 0.
      RKP1 = 0.
      RKN1 = 0.
      RKP2 = 0.
      RKN2 = 0.
      ZKP1 = 0.
      ZKP2 = 0.
      ALN1 = 0.
      ALN2 = 0.
      ZKN1 = 0.
      ZKN2 = 0.
      ZKI1=0.
      ZKI2=0.
      DO 20 J=1,NSEG
      ALP1 = ALP1       + SI(TTT,Z3PA,TT1,15,IND,1,1)
      ALP2 = ALP2       + SI(TTT,Z2PA,TT2,15,IND,1,1)
      RKP1 = RKP1       + SI(TTT,Z3PRK,TT1,15,IND,1,1)
      RKP2 = RKP2       + SI(TTT,Z2PRK,TT2,15,IND,1,1)
      ZKP1 = ZKP1       + SI(TTT,Z3PK ,TT1,15,IND,1,1)
      ZKP2 = ZKP2       + SI(TTT,Z2PK ,TT2,15,IND,1,1)
      ALN1 = ALN1       + SI(TTT,Z3NA ,TT1,15,IND,1,1)
      ALN2 = ALN2       + SI(TTT,Z2NA ,TT2,15,IND,1,1)
      RKN1 = RKN1       + SI(TTT,Z3NRK,TT1,15,IND,1,1)
      RKN2 = RKN2       + SI(TTT,Z2NRK,TT2,15,IND,1,1)
      ZKN1 = ZKN1       + SI(TTT,Z3NK ,TT1,15,IND,1,1)
      ZKN2 = ZKN2       + SI(TTT,Z2NK ,TT2,15,IND,1,1)
      ZKI1=ZKI1+SI(TTT,ZKMIC1,TT1,15,IND,1,1)
      ZKI2=ZKI2+SI(TTT,ZKMIC2,TT2,15,IND,1,1)
      TT1 = TT1 + DELT1
   20 TT2 = TT2 + DELT2
      ALP1=ALP1/SEGTE
      ALP2=ALP2/SEGTE
      ALN1=ALN1/SEGTE
      ALN2=ALN2/SEGTE
      ZKP1=ZKP1/SEGTE
      ZKP2=ZKP2/SEGTE
      ZKN1=ZKN1/SEGTE
      ZKN2=ZKN2/SEGTE
      RKP1=RKP1/SEGTE
      RKP2=RKP2/SEGTE
      RKN1=RKN1/SEGTE
      RKN2=RKN2/SEGTE
      ZKI1=ZKI1/SEGTE
```

```
      ZKI2=ZKI2/SEGTE
      RHOP1=RKP1/ZKP1
      RHOP2=RKP2/ZKP2
      RHON1=RKN1/ZKN1
      RHON2=RKN2/ZKN2
 4055 ALPH1 =   SI(TTT,Z3PA,TEMP(4,I),15,IND,1,1)
      ALNH1 =   SI(TTT,Z3NA,TEMP(4,I),15,IND,1,1)
      ALPH2 =   SI(TTT,Z2PA,TEMP(5,I),15,IND,1,1)
      ALNH2 =   SI(TTT,Z2NA,TEMP(5,I),15,IND,1,1)
      ALPC1=SI(TTT,Z3PA,TEMP(5,I),15,IND,1,1)
      ALNC1=SI(TTT,Z3NA,TEMP(5,I),15,IND,1,1)
      ALPC2=SI(TTT,Z2PA,TEMP(6,I),15,IND,1,1)
      ALNC2=SI(TTT,Z2NA,TEMP(6,I),15,IND,1,1)
      QP=TEMP(4,I)*(ALPH1+ALNH1)+TEMP(5,I)*(ALPH2+ALNH2-ALPC1-ALNC1)
CALCULATE OPTIMUM SEGMENTING RADIUS, RAD(5), IF SPECIFIED
      IF (NR5OPT.EQ.0) GO TO 4061
      RAD(5)=RAD(6)
      IF (DT(5,I).LE.0.) GO TO 4062
      TT1=ZKN1*DT(4,I)/(ZKN2*DT(5,I))
      TT2=1.0/(TT1+1.0)
      RAD(5)=(RAD(6)**(TT1*TT2))*(RAD(4)**TT2)
      IF (RAD(5).LT.RAD(4).OR.RAD(5).GT.RAD(6)) GO TO 4063
 4062 LNRAD(4)=ALOG(RAD(5)/RAD(4))
      LNRAD(5)=ALOG(RAD(6)/RAD(5))
 4061 RHOP = (LNRAD(5)*RHOP2 + LNRAD(4)*RHOP1)/ALR64
      RHON = (LNRAD(5)*RHON2 + LNRAD(4)*RHON1)/ALR64
      ZKTEP = ALR64/(LNRAD(5)/ZKP2 + LNRAD(4)/ZKP1)
      ZKTEN = ALR64/(LNRAD(5)/ZKN2 + LNRAD(4)/ZKN1)
CALCULATE OPTIMUM ZLP IF NO VALUE HAS BEEN READ INTO Z(12)
      GO TO (4042,4001,4002), IDUMZ
 4001 TT2=RHON*ZKTEP/(RHOP*ZKTEN)
      IF (TT2.GE.0.) GO TO 1096
 4063 INDI=0
      NODUMP=5
      GO TO 3112
 1096 ZLNLP=SQRT(TT2)
 4002 IF (IVD.NE.2) GO TO 1097
      ZKI=ALR64/(LNRAD(5)/ZKI2+LNRAD(4)/ZKI1)
      ZLNLP=ZLNLP*SQRT((CONST6-ZKI/ZKTEN)/(CONST6-ZKI/ZKTEP))
      ZLN=ZLI*CONST6/(.5+.5/ZLNLP)
 1097 ZLP=ZLN/ZLNLP
      ZLIP=2.0*ZLI/ZLP
      CONST5=15.9593*ZLP
      ZLPN=  ZLN+ZLP
```

```
      ZLPNI=ZLPN+ZLI
      ZLTE=ZLPNI+ZLI
      QGEN=QGENL*ZLTE
      CONST2=15.9593*ZLTE
      OPTZLP(I)=ZLP
      OPTCPL(I)=ZLTE
      OPTCPL(I+100)=YNC*ZLTE
      RINT4=RCON4*ZLPN/ZLP
      RINT6=RCON6*ZLPN/ZLP
      CONRP=CONST1/ZLP
      IF (ICRMDL .NE. 0) GO TO 4005
      C1FEH=15.9593*DR(3)*(RAD(3)+RAD(4))/ZLTE
      C1FEC=15.9593*DR(6)*(RAD(6)+RAD(7))/ZLTE
      GO TO 4042
C     CALCULATE RADIUS OF CIRCULAR CONDUCTOR RING ELECTRICAL STREAMLINE
 4005 RCHOT=AMIN1(DR(3),ZLN,ZLP)
      RCOLD=AMIN1(DR(6),ZLN,ZLP)
      C1FEH=5.08*RAD(4)*ALOG(3.14159*RCHOT/ZLI+1.0)
      C1FEC=5.08*RAD(6)*ALOG(3.14159*RCOLD/ZLI+1.0)
C     CALCULATE COUPLE RESISTANCE
 4042 RINTFH=RINT4*TEMP(4,I)*TEMP(4,I)
      RINTFC=RINT6*TEMP(6,I)*TEMP(6,I)
      TFEC = TEMP(7,I) + .5*DT(6,I)
      TFEH = TEMP(4,I) + .5*DT(3,I)
      FERC = SI(TTT,RCRC,TFEC,15,IND,1,1)
      FERH = SI(TTT,RCRH,TFEH,15,IND,1,1)
      RFEH=FERH/C1FEH
      RFEC=FERC/C1FEC
      RN = CONRN*RHON
      RP = CONRP*RHOP
      RPN=RP+RN
      TTE=.5*(TEMP(4,I)+TEMP(6,I))
      RPPC=RPRHO*SI(TTT,RHP,TTE,15,IND,1,1)/YNC
      QJ=RFEH+RINTFH+.5*RPN
      RPC(I)=QJ+.5*RPN+RFEC+RINTFC+RPPC
C     CALCULATION OF THERMAL CONDUCTANCES
      TBNH= TEMP(3,I) +.5*DT(2,I)
      TBNC= TEMP(8,I) +.5*DT(7,I)
      TCLDH = TEMP(2,I) +.5*DT(1,I)
      TCLDC = TEMP(9,I) +.5*DT(8,I)
      XZK(1) = SI(TTT,ZKIN,TCLDH,15,IND,1,1)
      XZK(8)=SI(TTT,ZKSS,TCLDC,15,IND,1,1)
      XZK(2)= SI(TTT,ZKBN,TBNH,15,IND,1,1)
      XZK(7)= SI(TTT,ZKBN,TBNC,15,IND,1,1)
```

```
      XZK(3)=(SI(TTT,ZKCRH,TFEH,15,IND,1,1)*ZLPNI+SI(TTT,ZKMIC1,TFEH,
     1  15,IND,1,1)*ZLI)/ZLTE
      XZK(6)=(SI(TTT,ZKCRC,TFEC,15,IND,1,1)*ZLPNI+SI(TTT,ZKMIC2,TFEC,
     1  15,IND,1,1)*ZLI)/ZLTE
      ZK(1)=CONST2*XZK(1)/LNRAD(1)
      ZK(2)=CONST2*XZK(2)/(LNRAD(2)*(1.0+XZK(2)*CONST3))
      ZK(3)=CONST2*XZK(3)/LNRAD(3)
      ZK(4)=CONST5*(ZLNLP*ZKN1+ZKP1+ZLIP*ZKI1)/LNRAD(4)
      IF (LNRAD(4) .LE.0.) ZK(4)=1.0E30
      ZK(5)=CONST5*(ZLNLP*ZKN2+ZKP2+ZLIP*ZKI2)/LNRAD(5)
      IF (LNRAD(5).LE.0.) ZK(5)=1.0E30
      ZKTE =  ZK(4)*ZK(5)/(ZK(4)+ZK(5))
      ZK(6)=CONST2*XZK(6)/LNRAD(6)
      ZK(7)=CONST2*XZK(7)/(LNRAD(7)*(1.0+XZK(7)*CONST4))
      ZK(8)=CONST2*XZK(8)/LNRAD(8)
      IF (ZK9.GT.0.) ZK(8)=ZK(8)*ZK9*ZLTE/(ZK(8)+ZK9*ZLTE)
      ALT1 = ALP1+ALN1
      ALT2 = ALP2+ALN2
C CALCULATION OF VOLTAGES AND CURRENT
      VOC(I) = DT(4,I)*ALT1+DT(5,I)*ALT2
      IT(I)=IT(I)+1
      ITNOW=ITNOW+1
      ITCON=ITNOW-MAXTEM
      ITCON=MAX0(ITCON,1)
      QC=DTTE*ZKTE
      QEND=ZKECPC*DTMOD(I)
      GO TO (4047,4048,4049,4044,4050), NGT2
 4047 CUR(I)=0.
      GO TO 4046
 4049 RLPC(I)=RPC(I)
      GO TO 4048
 4050 RLPC(I)=RPC(I)*SQRT(1.+VOC(I)*(QP-VOC(I)*QJ/RPC(I))/(RPC(I)*(QC+
     1 QEND)))
      GO TO 4048
 4044 QTE=PCMULT*VOC(I)-VREQ
      RLPC(I)=1.0E30
      IF (QTE.GT.0.) RLPC(I)=VREQ*RPC(I)/QTE
 4048 CUR(I)=CURMOD(INDI)
      IF (NGT1.GE.3.OR.INDI.EQ.1) CUR(I)=VOC(I)/(RPC(I)+RLPC(I))
 4046 VPC(I)=VOC(I)-CUR(I)*RPC(I)
C CALCULATE ENERGY TERMS
      QTOMP1=CUR(I)*(ALPH1*TEMP(4,I)-ALPC1*TEMP(5,I)-ALP1*DT(4,I))
      QTOMN1=CUR(I)*(ALNH1*TEMP(4,I)-ALNC1*TEMP(5,I)-ALN1*DT(4,I))
      QTOMP2=CUR(I)*(ALPH2*TEMP(5,I)-ALPC2*TEMP(6,I)-ALP2*DT(5,I))
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      QTOMN2=CUR(I)*(ALNH2*TEMP(5,I)-ALNC2*TEMP(6,I)-ALN2*DT(5,I))
      QTOM=QTOMN1+QTOMN2+QTOMP1+QTOMP2
      IF (QTOM.GT.0.) QTOM=.5*QTOM
      QP=CUR(I)*QP
      QJ=CUR(I)*CUR(I)*QJ
      QTE=QP-QJ-QTOM-QGAM*CGAM
      QIN=QC+QTE
      PE(I) = VPC(I)*CUR(I)
C     CALCULATE EFFICIENCY
      QT(I)=QIN+QGAM
      QOUT=QT(I)-PE(I)
      ZKHOT=1.0/(1./ZK(1)+1./ZK(2)+1./ZK(3))
      ZKCOLD=1./(1./ZK(6)+1./ZK(7)+1./ZK(8))
      IF (QGEN.GT.0..AND.VREQ.GT.0..AND.DGRF.EQ.0.) QIN=.5*(QGEN-QEND
     1 +QIN)
C     CALCULATE TEMPERATURE DROPS AND NEW RADIAL TEMP. PROFILE
      ZKDT=QIN/QC
      ZKTEQ=ZKTE*ZKDT
      ZKEQ(1)=ZK(1)
      ZKEQ(2)=ZK(2)
      ZKEQ(3)=ZK(3)
      ZKEQ(4)=ZK(4)*ZKDT
      ZKEQ(5)=ZK(5)*ZKDT
      ZKDT=QIN/QOUT
      ZKEQ(6)=ZK(6)*ZKDT
      ZKEQ(7)=ZK(7)*ZKDT
      ZKEQ(8)=ZK(8)*ZKDT
      IF (ZKR.GT.0.) TEMP(9,I)=(ZKR*TREJ+QOUT+ZKECPC*TEMP(1,I))/
     1 (ZKR+ZKECPC)
      IF (RADC.LE.0..OR.INDI.EQ.1.OR.NOPTIM.LT.4) GO TO 5008
 5008 IF (QGEN.GT.0.) GO TO 5001
      ZKDT=DTMOD(I)/(1.0/ZKHOT +1.0/ZKTEQ+QOUT/(QIN*ZKCOLD))
      DT(1,I)=ZKDT/ZKEQ(1)
      DO 5006 J=2,8
      J1=J-1
      TEMP(J,I)=TEMP(J1,I)-DT(J1,I)
 5006 DT(J,I)=ZKDT/ZKEQ(J)
      TCON(ITCON)=ABS(1.-QSAVE/QT(I))
      QSAVE=QT(I)
      GO TO 5007
```

```
C     CALCULATE HOT CLAD TEMPERATURE IF HEAT GENERATION RATE IS SPECIFIED
 5001 ZKDT=QGEN-QEND
      DO 5002 J=1,8
      J9=9-J
      DT(J9,I)=ZKDT/ZKEQ(J9)
 5002 TEMP(J9,I)=TEMP(J9+1,I)+DT(J9,I)
      TCON(ITCON)=2.*ABS(1.-QSAVE/TEMP(1,I))
      QSAVE=TEMP(1,I)
      DTMOD(I)=QSAVE-TEMP(9,I)
 5007 IF (NODUMP.EQ.0.OR.NODUMP.EQ.2) GO TO 3007
 3112 WRITE (6,100) (CMT(J),J=1,25),INDI,IT(I),I
  100 FORMAT (1H1,4X,2A4,1X,18A4,2H (,F2.0,2(1H/,F2.0),2H) ,2A4//
     1          20X,19H  CURRENT ITERATION,I5,23H, TEMPERATURE ITERATION,
     1  I5,11H, ON COUPLE,I5//11X,3HRAD,11X,4HTEMP,12X,2HDT,12X,3HXZK,
     2 13X,2HZK,12X,4HZKEQ,13X,5HLNRAD)
      WRITE (6,3002) (J,RAD(J),TEMP(J,I),DT(J,I),XZK(J),ZK(J),ZKEQ(J),
     1 LNRAD(J),J=1,8)
 3002 FORMAT (I3,1H.,7G15.5)
      J=9
      WRITE (6,3003) J,RAD(J),TEMP(J,I),DTMOD(I),ZK9,PCMULT,ALR64
 3003 FORMAT (I3,1H.,3G15.5,15X,3G15.5//)
      WRITE (6,3004) B(1),TFEH,B(2),ZKP1,B(3),RINT4,B(4),ZKDT
      WRITE (6,3004) B(5),TFEC,B(6),ZKP2,B(7),RINT6,B(8),QSAVE
      WRITE (6,3004) B(9),FERH,B(10),ZKN1,B(11),TCLDH,B(12),QGEN
      WRITE (6,3004) B(13),FERC,B(14),ZKN2,B(15),TCLDC,B(16),QGAM
      WRITE (6,3004) B(17),ALP1,B(18),ZKI1,B(19),TBNH,B(20),QTOMP1
      WRITE (6,3004) B(21),ALP2,B(22),ZKI2,B(23),TBNC,B(24),QTOMP2
      WRITE (6,3004) B(25),ALN1,B(26),ZKTEP,B(27),DTMOD(I),B(28),QTOMN1
      WRITE (6,3004) B(29),ALN2,B(30),ZKTEN,B(31),DTTE,B(32),QTOMN2
      WRITE (6,3004) B(33),ZKR    ,B(34),ZKTE,B(35),TOLTEM,B(36),QTOM
      WRITE (6,3004) B(37),RHOP1,B(38),ZKTEQ,B(39),TCON(ITCON),B(40),QC
      WRITE (6,3004) B(41),RHOP2,B(42),ZKECPC,B(43),ALT1,B(44),QP
      WRITE (6,3004) B(45),RHON1,B(46),ZLP,B(47),ALT2,B(48),QJ
      WRITE (6,3004) B(49),RHON2,B(50),ZLN,B(51),ALNH1,B(52),QIN
      WRITE (6,3004) B(53),RHOP,B(54),ZLTE,B(55),ALNH2,B(56),QOUT
      WRITE (6,3004) B(57),RHON,B(58),RP,B(59),ALNC1,B(60),VPC(I)
      WRITE (6,3004) B(61),CONST1,B(62),RN,B(63),ALNC2,B(64),RPC(I)
      WRITE (6,3004) B(65),CONST2,B(66),RFEH,B(67),ALPH1,B(68),VDC(I)
      WRITE (6,3004) B(69),CONST3,B(70),RFEC,B(71),ALPH2,B(72),CUR(I)
      WRITE (6,3004) B(73),CONST4,B(74),RINTFH,B(75),ALPC1,B(76),PE(I)
      WRITE (6,3004) B(77),ZKHOT,B(78),RINTFC,B(79),ALPC2,B(80),QTE
      WRITE (6,3004) B(81),ZKCOLD,B(82),RPPC,B(83),RLPC(I),B(84),QT(I)
 3004 FORMAT (2X,4(A6,1H=,G12.5,10X))
      IF (INDI.EQ.0) WRITE (6,3006)
```

```
3006 FORMAT (1H0,21X,66HTHIS CASE DUMPED, THEN SUPPRESSED BECAUSE OPTIM
    1UM ZLP IS IMAGINARY)
     IF (NODUMP.EQ.1.AND.ITCON.LT.11) GO TO 3007
     WRITE (6,3008) (TCON(J),J=1,ITCON)
3008 FORMAT (10H0  TCON = ,10(F9.6,1H,))
     GO TO 4000
3007 IF (TCON(ITCON).GT.TOLTEM) GO TO 3009
     IF (NODUMP.EQ.2) GO TO 3112
     GO TO 4000
3009 IF (ITCON.LE.10) GO TO 4040
     GO TO 3112
4000 IF (NOPTIM.NE.5.OR.I.NE.1) GO TO 6010
C - SET UP B.O.L. PARAMETERS FOR CURIUM MISSION CALCULATIONS
     IDUMZ=1
     QGEN=1.211*(QT(1)+QEND)
     IF (INDI.EQ.1) GO TO 6010
     NGT2=4
     QEOL=PCMULT*(QOUT+QEND)
     QBOL=PCMULT*(QGEN-PE(2))
     ZKDT=QBOL/QEOL
     TREOL=TEMP(9,1)-RADK
     TRBOL=(ZKDT*TREOL**4-(ZKDT-1.)*TREJ)**.25
     TEMP(9,3)=TEMP(9,2)
     TEMP(9,2)=TRBOL+ZKDT*RADK
     ZKDT=TEMP(9,2)-TEMP(9,3)
     DO 6012 J=1,8
6012 TEMP(J,2)=TEMP(J,2)+ZKDT
     IF (NODUMP.EQ.0) GO TO 6011
     WRITE (6,3004) B(85),QEOL,B(86),QBOL,B(87),TREOL,B(88),TRBOL
     WRITE (6,3004) B(89),PCMULT
6011 CALL PHONY(DP,JDUMP,0.)
6010 CONTINUE
     RETURN
     END
```

```
      BLOCK DATA
      COMMON /DATIN/TTT(15),ZKMIC1(15),ZKMIC2(15), ZKSS(15),ZKBN(16),
     1  ZKIN(15),Z2NA(15),Z2NR(15),Z2NK(15),Z2PA(15),Z2PR(15),Z2PK(15),
     2Z2NRK(15),Z2PRK(15),Z3NA(15),Z3NR(15),Z3NK(15),Z3NRK(15),Z3PA(15),
     3 Z3PR(15),Z3PK(15),Z3PRK(15),ZKCRH(15),ZKCRC(15),RCRH(15),RCRC(15)
     4,RHP(15),RPRHO
      COMMON /FODAT/ALPHA(15,8),RHO(15,8),ZKON(16,8),ZKSSIN(16,3),
     1 RFETM(15,4),ZKFETM(16,3),ZKMICA(16)
      COMMON /TITLE/FETM(3),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMKF,
     1 CRMD(2,2),I3N,I2N,I3P,I2P
C TEMPERATURE AT WHICH EACH PARAMETER IS EVALUATED (DEG.K)
      DATA  TTT            /300.,350.,400.,450.,500.,550.,600.,650.,700.,
     1       750.,800.,850.,900.,950.,1000./
C SEEBECK COEFFICIENT OF TEGS-3N MATERIAL (VOLTS/DEG.K)
      DATA ALPHA/ 8.526E-05,1.058E-04,1.254E-04,1.411E-04,1.656E-04,
     2            1.803E-04,1.960E-04,2.097E-04,2.205E-04,2.254E-04,
     3            2.254E-04,2.185E-04,2.009E-04,1.735E-04,1.303E-04,
C SEEBECK COEFFICIENT OF TEGS-2N AND GE-NL MATERIAL (VOLTS/DEG.K)
     1            1.150E-04,1.369E-04,1.587E-04,1.806E-04,2.005E-04,
     1            2.176E-04,2.338E-04,2.452E-04,2.509E-04,2.490E-04,
     1            2.386E-04,2.205E-04,1.977E-04,1.730E-04,1.464E-04,
C SEEBECK COEFFICIENT OF TEGS-3P MATERIAL (VOLTS/DEG.K)
     1            5.015E-05,5.807E-05,8.974E-05,1.140E-04,1.394E-04,
     1            1.668E-04,1.911E-04,2.122E-04,2.281E-04,2.407E-04,
     1            2.502E-04,2.555E-04,2.544E-04,2.460E-04,2.281E-04,
C SEEBECK COEFFICIENT OF TEGS-2P MATERIAL (VOLTS/DEG.K)
     1            4.940E-05,7.980E-05,1.102E-04,1.387E-04,1.748E-04,
     1            2.090E-04,2.375E-04,2.594E-04,2.698E-04,2.726E-04,
     1            2.708E-04,2.660E-04,2.594E-04,2.508E-04,2.394E-04,
C SEEBECK COEFFICIENT OF RCA-NB   MATERIAL (VOLTS/DEG.K)
     1          1.030E-04,1.210E-04,1.410E-04,1.610E-04,1.820E-04,
     2          2.020E-04,2.230E-04,2.450E-04,2.600E-04,2.660E-04,
     3          2.620E-04,2.530E-04,2.430E-04,2.300E-04,2.140E-04,
C SEEBECK COEFFICIENT OF RCA GE-TE P-TYPE MATERIAL (VOLTS/DEG.K)
     1            0.52E-04,0.78E-04,1.05E-04,1.35E-04,1.73E-04,2.05E-04,
     1            2.38E-04,2.66E-04,2.83E-04,2.98E-04,3.11E-04,
     1            3.09E-04,3.00E-04,2.19E-04,.48E-4/
C RESISTIVITY OF TEGS-3N MATERIAL (OHM-CM)
      DATA RHO  /  .0002628, .0003623, .0004967, .0006722, .0008992,
     1             .0011785, .0015277, .0019206, .0023658, .0028198,
     1             .0032476, .0035880, .0037714, .0037452, .0036142,
C RESISTIVITY OF TEGS-2N AND GE-NL MATERIAL (OHM-CM)
     1             .0004132, .0005932, .0008393, .0011702, .0015737,
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     1                 .0020822, .0026552, .0032685, .0038738, .0043984,
     1                 .0046728, .0047615, .0046082, .0042209, .0037124,
C RESISTIVITY OF TEGS-3P MATERIAL (OHM-CM)
     1                 .0009940, .0010799, .0012395, .0014972, .0018408,
     1                 .0022090, .0026753, .0031539, .0036939, .0043811,
     1                 .0051542, .0057310, .0061360, .0063814, .0064428,
C RESISTIVITY OF TEGS-2P MATERIAL (OHM-CM)
     1                 .0004031, .0005493, .0007445, .0009987, .0013165,
     1                 .0017342, .0022517, .0028237, .0035227, .0042400,
     1                 .0049482, .0055656, .0059923, .0061739, .0059469,
C RESISTIVITY OF RCA-NB   MATERIAL (OHM-CM.)
     1              4.750E-04,6.300E-04,8.250E-04,1.070E-03,1.390E-03,
     2              1.820E-03,2.360E-03,3.040E-03,3.800E-03,4.570E-03,
     3              5.300E-03,6.000E-03,6.450E-03,6.800E-03,6.750E-03,
C RESISTIVITY OF RCA GE-TE P-TYPE MATERIAL (OHM*CM)
     1                3.7E-04,4.8E-04,6.8E-04,9.7E-04,13.8E-04,19.4E-04,
     1                25.5E-04,32.8E-04,40.5E-04,48.5E-04,58.0E-04,67.0E-04,
     1                77.5E-04,86.0E-04,98.0E-04/
C THERMAL CONDUCTIVITY OF TEGS-3N  MATERIAL (WATTS/CM./DEG.K)
      DATA ZKON /  .0428220, .0375516, .0332035, .0289872, .0250344,
     1                 .0213451, .0181829, .0162065, .0148889, .0150206,
     1                 .0162065, .0176558, .0191052, .0210816, .023058,.298,
C THERMAL CONDUCTIVITY OF TEGS-2N AND GE-NL MATERIAL (WATTS/CM/DEG.K)
     1                 .0286942, .0244433, .0208299, .0180668, .0157287,
     1                 .0139220, .0127530, .0122216, .0128593, .0141346,
     1                 .0159412, .0178542, .0204048, .0233805,.0260374,.298,
C THERMAL CONDUCTIVITY OF TEGS-3P  MATERIAL (WATTS/CM./DEG.K)
     1                 .0375000, .0305000, .0246000, .0199000, .0160000,
     1                 .0130000, .0114000, .0110000, .0112000, .0119000,
     1                 .0135000, .0166000, .0206000, .0265000, .035000,.298,
C THERMAL CONDUCTIVITY OF TEGS-2P  MATERIAL (WATTS/CM./DEG.K)
     1                 .0428878, .0348821, .0281344, .0227591, .0182988,
     1                 .0148678, .0130379, .0125804, .0128092, .0136097,
     1                 .0154396, .0189850, .0235597, .0303074,.0400286,.298,
C THERMAL CONDUCTIVITY OF RCA-N(A) MATERIAL (WATTS/CM./DEG.K)
     1   .0200,.0179,.0161,.0143,.0127,.0111,.0101,.00971,.00974,.0101,
     2 .0106,.0113,.0122,.0133,.0147,.296,
C THERMAL CONDUCTIVITY OF RCA-P(A) MATERIAL (WATTS/CM./DEG.K)
     1   .0345,.0270,.0222,.0189,.0156,.0135,.0118,.0108,.0103,.0103,
     2   .0109,.0128,.0181,.0303,.0653,.298/
C THERMAL CONDUCTIVITY OF BORON NITRIDE (WATT/CM/DEG.K)
      DATA  ZKBN           /.303,.301,.299,.296,.294,.291,.289,.286,.284
     1     ,.282,.279,.277,.274,.272,.270,.081/
C THERMAL CONDUCTIVITY OF IRON (WATT/CM/DEG.K)
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      DATA  ZKFETM         /.725,.696,.664,.635,.608,.574,.540,.510,.479
     1       ,.449,.420,.390,.360,.335,.313,.280,
C THERMAL CONDUCTIVITY OF TUNGSTEN (WATT/CM/DEG.K) - TPRC DATA
     2                         1.78,1.70,1.62,1.56,1.51,1.46,1.41,1.37,1.34
     3       ,1.31,1.29,1.26,1.24,1.22,1.20,.700,
C THERMAL CONDUCTIVITY OF MOLYBDENUM (WATT/CM/DEG.K) - TPRC DATA
     4                         1.37,1.35,1.33,1.31,1.30,1.27,1.26,1.24,1.22
     5       ,1.20,1.19,1.17,1.15,1.14,1.13,.368/
C RESISTIVITY OF IRON (OHM*CM)
      DATA  RFETM          /1.15E-5,1.40E-5,1.73E-5,2.08E-5,2.52E-5,
     1      2.97E-5,3.52E-5,4.12E-5,4.88E-5,5.60E-5,6.34E-5,7.10E-5,
     2      7.91E-5,8.80E-5,9.82E-5,
C RESISTIVITY OF TUNGSTEN (OHM*CM)                    TPRC DATA
     3      5.00E-6,6.25E-6,7.50E-6,8.70E-6,1.00E-5,1.12E-5,1.25E-5,1.38
     4      E-5,1.53E-5,1.67E-5,1.82E-5,1.98E-5,2.15E-5,2.29E-5,2.43E-5,
C RESISTIVITY OF MOLYBDENUM (OHM*CM)                  TPRC DATA
     5      5.50E-6,6.50E-6,7.50E-6,8.50E-6,9.50E-6,1.04E-5,1.13E-5,1.25
     6      E-5,1.37E-5,1.47E-5,1.58E-5,1.69E-5,1.80E-5,1.90E-5,2.00E-5,
C RESISTIVITY OF NICKEL (OHM*CM)
     7       .000011,.000013,.000015,.0000173,.0000198,.0000226,.0000257,
     8 .000029,.0000319,.0000346,.000037,.0000392,.000041,.0000427,
     9 .000044/
C THERMAL CONDUCTIVITY OF STAINLESS STEEL (WATT/CM/DEG.K)
      DATA  ZKSSIN         /.145,.157,.165,.172,.179,.184,.192,.198,.205
     1       ,.212,.219,.225,.232,.239,.246,.283,
C THERMAL CONDUCTIVITY OF INCONNEL (WATT/CM/DEG.K)
     3                          .117,.126,.135,.143,.152,.161,.170,.179,.188
     1       ,.197,.205,.215,.223,.230,.240,.296,
C THERMAL CONDUCTIVITY OF T-111 (TPRC PURDUE UNIV.)
     1       .418,.431,.439,.452,.464,.481,.490,.502,.515,.527,.540,.552,
     2       .565,.577,.586,.600/
C THERMAL CONDUCTIVITY OF MICA (WATT/CM/DEG.K)
      DATA ZKMICA /.0290,.0310,.0330,.0342,.0336,.0306,.0282,.0268,.0262
     1 ,.0262,.0268,.0268,.0268,.0268,.0268,.105/
      DATA CASCAD/4HTEGS,4H GE ,2*4HTEGS,2*4HRCA-,2*1H ,4H 3N ,4H NL ,
     1 4H 3P ,4H 2P ,4H  N ,4H  P ,2*1H /,COND/4HOPEN,4H CIR,4HCUIT,
     2 4H FIX,4HED L,4HOAD ,4HMATC,4HHED ,4HLOAD,4HFIXE,4HD V-,4HLOAD,
     3 4HOPTI,4HMUM ,4HLOAD/,FETM/2HFE,1HW,2HMO/,SSIN/2HSS,2HIN,2HTA/,
     4 CMT/25*4H****/,CRMD/4H CIR,4HCUIT,4H MOD,4HULE /
      END
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      SUBROUTINE OPTIM(ISECT,IRTRN)
      DIMENSION VPL(4,5),OMHD(4),DRCP(2,2),PDWT(2,4),VPL1(3),PWCT(4)
     1 ,VRL(5),DRCP1(2),SKP(12)
      COMMON /MODOPT/IPDWT, DR4,DRINCR,IRITE,DRTE,JOPTIM,IZ9,IENDK,IPUN,
     1 RIINC,ROINC,R1MAX,R9MAX,DTMIN,QREQ,THINC,TCINC,TCMAX,THMAX
     2,NPERT,ZNPERT,CKFP,CKFT,CTEOC,CTEIC,DELTL,RLPERT,RLMAX,ZNMIN,Z9SAV
      COMMON /TITLE/FETM(3),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMKF,
     1 CRMD(2,2),I3N,I2N,I3P,I2P
      COMMON /MDCPOP/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
     1 QT(300),NOPTIM,VPC(300),RLPC(300),DTMOD(300),CUR(300),LNRAD(9),
     2 ZLP,ZLN,ZLI,ZLNLP,ZLPNI,ZLTE,NGT1,NGT2,ITPERT,PCMULT,NODUMP,IVD,
     3 QGEN,QGENL,QTE,QOUT,ZID,ZOD,ZKEND,ZK9,ZKR,RPPC,RPN,TOLTEM,TREJ,
     4 VREQ,PEREQ,ZLREQ,WTCON,ZLPN,IDUMZ,RN,DGRF,DGTRF,DGLRF,RADK,JDUMP,
     5 DP(30),NC
      DATA VPL/4H   V,4HOC  ,4H (VO,4HLTS),4H CUR,4HRENT,4H (AM,4HPS) ,
     1 4HCKT.,4HLEN.,4H  (I,4HN.) ,4H  RL,4HOAD ,4H (OH,4HMS) ,4H  RL,
     2 4HOAD ,4H(M-O,4HHMS)/,PDWT/4HPDEN,4HW/CC,4H WT.,4HLBS.,4H CUR,4HA
     3MPS,4H TS ,4HDEG./,OMHD/3H M-,1H ,1HC,1HH/,DRCP/4H DR5,4HDRTE,
     4 4H NO.,4HCPLS/,SKP/1H ,1HO,8*1H ,1H*,1H*/
      EQUIVALENCE (VPL1(1),OCV),(VPL1(3),ZCIR)
      REAL LNRAD
      IF (ISECT.EQ.2) GO TO 3051
C - INITIALIZE VARIABLES USED IN OPTIMZATION ROUTINE
      IRTRN=1
      IF (JOPTIM.NE.0) GO TO 4014
      JOPTIM=1
      IPERT=0
      PCPERT=NPERT
      PCSAV=PCMULT
      RLOAD=PCMULT*RLPC(1)
      IRITE=4
C     IVD=1, TEMPERATURE PARAMETRIC WITH SPECIFIED GEOMETRY
C     IVD=2, TEMPERATURE PARAMETRIC WITH SPECIFIED LENGTH AND VOLTAGE
C     IVD=3, TEMP. PARAMETRIC WITH SPECIFIED LENGTH AND NO. OF COUPLES
C     IVD=4, PARAMETRIC ON NO. COUPLES WITH SPECIFIED VLOAD AND LENGTH
C     IVD=5, PARAMETRIC ON NO. COUPLES WITH SPECIFIED VLOAD AND POWER
      RLOM=1000.
      IDRCP=2
      IPDWT=1
      ISKP=2
      ZCIR=PCMULT*ZLTE
C - INITIALIZE PARAMETERS FOR CURIUM STUDY CALCULATIONS
      NOP2=NOPTIM/2
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      IF (NDP2.NE.2) GO TO 6000
      DCV=0.
      Q=0.
      IF (NOPTIM.EQ.5) NC=2
      IVPL=3
      IVRL=1
      TREJ=TREJ*TREJ*TREJ*TREJ
      DGTRF=1./DGTRF
      TEMP(1,2)=TEMP(1,1)
      TEMP(9,2)=TEMP(9,1)
      ISKP=2
      IPDWT=2
      GO TO 4009
C - INITIALIZE PARAMETERS FOR LOAD CURVE CALCULATIONS
 6000 IF (RLMAX.LE.0.) GO TO 4000
      IRML=1
      ISKP=1
      RLSAV=RLPC(1)
      IVPL=1
      IVRL=5
      IF (RLOAD.LT.1.) GO TO 3999
      RLOM=1.0
      IVRL=4
 3999 IPDWT=3
      IRLP=1
      IF (RLPERT.LE.0.) RLPERT=RLSAV
      IF ((RLMAX-RLSAV)/RLPERT.GT.200.) GO TO 4009
      IRLP=0
      GO TO 4009
 4000 IF (ZLREQ.LE.0.) GO TO 3998
      ZLN=.5*ZLREQ/PCMULT-ZLI
      ZLP=ZLN
      IVD=3
      ZCIR=ZLTE
 3998 IF (VREQ.LE.0.) GO TO 4002
      IVD=2
      RLPC(1)=0.
      IF (NPERT.LE.0) GO TO 4002
      NGT1=4
      NGT2=4
      IVD=4
      IPDWT=3
      RLPC(1)=1.0E10
      IF (PEREQ.LE.0..AND.QREQ.LE.0.) GO TO 4002
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      IVD=5
      PCPERT=1.
      CUREQ=PEREQ/VREQ
 4002 IVRL=1
      IF (NGT2.GE.4) IVRL=5
      IVPL=1
      IF (IVRL.EQ.1) IVPL=2
      IR5PRT=2
      IF (DRINCR.LE.0.) GO TO 4004
      IF (NOPTIM.NE.2) IR5PRT=1
      IPDWT=4
      IDRCP=1
      GO TO 4009
 4004 IF (NOPTIM.NE.3) GO TO 4009
C - INITIALIZE VARIABLES FOR TEMPERATURE DERIVATIVE CALCULATIONS
      TCINC=13.89
      THINC=TCINC
      THMAX=TEMP(1,1)+THINC
      TCMAX=TEMP(9,1)+TCINC
      TEMP(1,1)=TEMP(1,1)-THINC
      TEMP(9,1)=TEMP(9,1)-TCINC
 4009 T1HOT=TEMP(1,1)
      T1COLD=TEMP(9,1)
      IF (IPUN.EQ.1) WRITE (7,101) (CMT(J),J=3,23)
  101 FORMAT (17A4,A2,1X,F2.0,2(1H/,F2.0))
      J=38
      IF (THMAX.EQ.0) GO TO 4038
      I=(THMAX-T1HOT)/THINC+1.
      IF (NOPTIM.GT.3) I=2*I
      J=(39/I)*I
 4038 LCNTM=AMAX0(2,J)
      ZLNSAV=ZLN
      ZLPSAV=ZLP
C - INCREMENT O.D. IF INITIAL VALUE VIOLATES MINIMUM T/E THICKNESS
 4014 IF (ISECT.EQ.3) GO TO 4023
      WRITE (6,100) (CMT(J),J=1,25),CASCAD(I3N,2),CASCAD(I2N,2),
     1 CASCAD(I3P,2),CASCAD(I2P,2)
  100 FORMAT (1H1,4X,2A4,1X,18A4,2H (,F2.0,2(1H/,F2.0),2H) ,2A4/
     1 47X,1H(,A3,1H-,A3,1H,,A3,1H-,A3,1H))
      WRITE(6,4010) ZIO,ZOD,DR(1),DRTE,DR(8)
 4010 FORMAT      (13X,4HI.D.,8X,1H=,F8.4,4H IN.,45X,4HO.D.,8X,1H=,F8.4,
     14H IN./26H    INNER CLAD THICKNESS =,F8.4,4H IN.,9X,6HDRTE =,F7.4,
     2  4H IN.,10X,22HOUTER CLAD THICKNESS = F8.4,4H IN. )
      IF (ZCIR.LE.0.) GO TO 4061
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      ZLPNI=ZLP+ZLN+ZLI
      WT=WATE(P)
      J=1
      IF (WTCON.GT.0.) J=2
      IF (NGT2.NE.2.OR.RLPERT.GT.0.) GO TO 4040
      I=2
      IF (RLOAD.GE.1.) GO TO 4045
      RLOAD=1000.*RLOAD
      I=1
 4045 WRITE (6,4041) ZCIR,RLOAD,OMHD(I),CRMD(1,J),CRMD(2,J),WT
 4041 FORMAT (10X,16HCIRCUIT LENGTH =,F8.3,4H IN.,6X,7HRLOAD =,F9.3,
     1 A3,4HOHMS,11X,2A4,9H WEIGHT =,F8.3,5H LBS.)
      GO TO 4042
 4040 WRITE (6,4043) ZCIR,(COND(I,NGT2),I=1,3),CRMD(1,J),CRMD(2,J),WT
 4043 FORMAT (10X,16HCIRCUIT LENGTH =,F8.4,4H IN.,11X,3A4,18X,2A4,
     1 9H WEIGHT =,F8.3,5H LBS.)
      GO TO 4042
 4061 IVPL=3
      WRITE (6,4063) (COND(I,NGT2),I=1,3)
 4063 FORMAT (49X,3A4)
 4042 WRITE (6,4044) DRCP(1,IDRCP),(VPL(I,IVPL),I=1,2),(VPL(I,IVRL),
     1 I=1,2),(CRMD(1,IENDK),I=1,2),PDWT(1,IPDWT),TEMKF,TEMKF,DRCP(2,
     2  IDRCP),(VPL(I,IVPL),I=3,4),(VPL(I,IVRL),I=3,4),PDWT(2,IPDWT)
 4044 FORMAT (17HO    THOT     TCOLD,4X,A4,14H    ZLN      ZLP,4X,2A4,2X,
     1 2A4,4X,30HRGEN        VLOAD     P-OUT      Q, A4,5X,3HETA,A2,6X,A4/
     2 2(7H   (DEG.,A1,1H)),3X,A4,18H   (IN.)    (IN.)    ,2A4,2X,2A4,
     3 54H  (M-OHMS)   (VOLTS)  (WATTS)   (WATTS)    (PCT.)    (,A4,1H))
      LCNT=0
      IZLP=1
      ITHINC=1
      ITCINC=0
      ETAMAX=0.
      RETURN
 3051 IF (NOP2.NE.2) GO TO 6001
      ITPERT=2
C - ITERATE ON NO. OF COUPLES AND ZLN FOR CURIUM MISSION CALCULATIONS
      IDUMZ=2
      NGT2=5
      QGEN=0.
      IRTRN=2
      P=PCMULT*PE(1)
      VLD=PCMULT*VPC(1)
      IF ((ABS(1.-OCV/VLD)+ABS(1.-Q/P)).LT..01.OR.IPERT.GT.10) GOTO 4001
      IPERT=IPERT+1
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      PCMULT=IFIX(VREQ/VPC(1))+1
      ZLN=(PEREQ*ZLPN/(PE(1)*PCMULT*(1.+1./ZLNLP))+ZLN)*.5
      OCV=VLD
      Q=P
      IF (NOPTIM.EQ.4) TEMP(1,2)=TEMP(1,1)+20.
      D=DGLRF*EXP(16616.*(DGTRF-1./TEMP(1,2)))/ZLN
      D=AMIN1(D,.75)
      DP(12)=D*(RPC(NC)+DP(12)*(RPC(NC)-RN))/(RN*(1.-D))
      IF (NOPTIM.EQ.5) DP(12)=0.
      CALL PHONY (DP,JDUMP,100000.)
      RETURN
 6001 OCV=PCMULT*VOC(1)
      IF (IVD.EQ.1) GO TO 4001
      IF (IZLP.NE.2) GO TO 4035
      TOLTEM=10.*TOLTEM
      GO TO 4001
 4035 TOLTEM=0.1*TOLTEM
      IZLP=2
      IRTRN=2
      IF (IVD.EQ.2) GO TO 4028
 4027 IF (PEREQ.LE.0.) GO TO 4018
      IF (OCV.LE.VREQ) GO TO 4029
      ZLN=ZLN/(1.+(VOC(1)-VREQ/PCMULT-CUREQ*RPC(1))/(CUREQ*RPN))
      IF (ZLN.GT.0.) RETURN
      PCMULT=PCMULT+1
      GO TO 4037
 4018 IF (QREQ.GT.0.) ZLREQ=(QREQ-ZKEND*DTMOD(1))*ZLTE/QT(1)
      ZLN=(ZLREQ/PCMULT-2.0*ZLI)/(1.0+1.0/ZLNLP)
 4020 IF (VREQ.LE.0.) RETURN
CALCULATE MINIMUM NO. OF COUPLES TO ACHIEVE SPECIFIED LOAD VOLTAGE
      P=OCV-VREQ
      IF (P.LE.0.) GO TO 4029
      RLPC(1)=VREQ*RPC(1)*ZLP*ZLNLP/(P*ZLN)
      RETURN
 4029 PCMULT=IFIX(VREQ/VOC(1)+2.0)
      TOLTEM=10.*TOLTEM
      IZLP=1
      RPPC=RPPC/PCMULT
      RPC(1)=RPC(1)-RPPC*PCMULT+RPPC
 4037 OCV=PCMULT*VOC(1)
      PE(1)=VREQ*(OCV-VREQ)/(PCMULT*PCMULT*RPC(1))
      RLPC(1)=VREQ/(PCMULT*CUREQ)
      GO TO 4027
CALCULATE NO. OF COUPLES TO ACHIEVE SPECIFIED LOAD VOLTAGE
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 4028 PCMULT=IFIX(VREQ/VPC(1)+1.0)
      ZLN=(ZLREQ/PCMULT-2.0*ZLI)/(1.0+1.0/ZLNLP)
      RETURN
 4001 TEMPHF=DK2FK(TEMP(1,1))
      TEMPCF=DK2FK(TEMP(9,1))
      IF (IZLP.EQ.2.OR.DELTL.EQ.0.) GO TO 4064
CALCULATE TOTAL LENGTH TO ACHIEVE SPECIFIED CLAD MIS-MATCH
      IZLP=2
      IRTRN=2
      ZCIR= DELTL/(CTEIC*(TEMPHF-70.)-CTEOC*(TEMPCF-70.))
      IF (ZLREQ.GT.0.) ZCIR=ZLREQ
      PCMULT=IFIX(ZCIR/(ZLNSAV*(1.0+1.0/ZLNLP)+2.0*ZLI))+1
      ZLN=(ZCIR/PCMULT-2.0*ZLI)/(1.0+1.0/ZLNLP)
      RETURN
 4064 ETAO=PE(1)/(QT(1)+ZKEND*DTMOD(1)/PCMULT)
      IF (ETAO.LT.ETAMAX) GO TO 4015
      ZCIR=ZLTE*PCMULT
      RLOAD=PCMULT*RLPC(1)
      VRL(IVRL)=RLOM*RLOAD
      VRL(1)=PCMULT*VOC(1)
      DRCP1(1)=100.*DR(5)/DRTE
      DRCP1(2)=PCMULT
      VOL1 = 51.48*ZCIR*RAD(1)*RAD(1)
      VLD=PCMULT*VPC(1)
      OHM=PCMULT*RPC(1)
      P=PCMULT*PE(1)
      Q=PCMULT*QT(1)
      VPL1(2)=CUR(1)
      IF (IPOWT.EQ.2) PWCT(IPOWT)=WATE(QMOD)
      PWCT(3)=CUR(1)
      PWCT(4)=DK2FK(TEMP(5,1))
      IF (NOPTIM.NE.2) GO TO 4003
      ETAMAX=ETAO
      QMOD=ZLP
      PWCT(1)=ZLN
      GO TO 4017
 4015 ZLP=QMOD
      ZLN=PWCT(1)
      ETAO=ETAMAX
 4003 QMOD=Q+ZKEND*DTMOD(1)
      PWCT(1)=QMOD/VOL1
      IF (IPUN.EQ.3) WRITE (7,4055) TEMPHF,TEMPCF,QMOD,DCV,VLD,CUR(1),Q,
     1 (CMT(J),J=21,23)
 4055 FORMAT (7HREF MOD,12X,2F7.1,F8.2,3F8.4,F8.2,3A2/1H )
```

```
      IF (IPUN.EQ.1) WRITE (7,4050) ZID,ZOD,TEMPHF,TEMPCF,ZCIR,VLD,OHM,
     1 ETAO,P
 4050 FORMAT (1X,2F7.3,2F7.1,5E10.3)
      IF (NOPTIM.NE.3) GO TO 4031
      JOPTIM=JOPTIM+1
      VOC(JOPTIM)=OCV/(DTMOD(1)*CKFT)
      RPC(JOPTIM)=OHM
      QT(JOPTIM)=DTMOD(1)*CKFT/QMOD
 4031 LCNT=LCNT+ISKP
      IF (LCNT.LE.LCNTM) GO TO 4033
      WRITE (6,100) (CMT(J),J=1,25),CASCAD(I3N,2),CASCAD(I2N,2),
     1 CASCAD(I3P,2),CASCAD(I2P,2)
      WRITE(6,4010) ZID,ZOD,DR(1),DRTE,DR(8)
      IF (RLOAD.LT.1.) GO TO 4034
      RLOM=1.0
      IVRL=4
      VRL(4)=RLOAD
 4034 WRITE (6,4044) DRCP(1,IDRCP),(VPL(I,IVPL),I=1,2),(VPL(I,IVRL),
     1 I=1,2),(CRMD(1,IENDK),I=1,2),PDWT(1,IPDWT),TEMKF,TEMKF,DRCP(2,
     2  IDRCP),(VPL(I,IVPL),I=3,4),(VPL(I,IVRL),I=3,4),PDWT(2,IPDWT)
      PCPERT=2.0*PCPERT
 4033 WRITE (6,4011) SKP(ISKP),TEMPHF,TEMPCF,DRCP1(IDRCP),ZLN,ZLP,
     1 VPL1(IVPL),VRL(IVRL),OHM,VLD,P,QMOD,ETAO,PWCT(IPDWT)
 4011 FORMAT (A1,F7.1,F9.1,F7.0,2F8.4,2F10.3,3PF10.3,2(0PF10.3),
     1 F10.1,2PF10.4,0PF10.3)
      LCNT=2
      GO TO (6005,4016,4025,6006,6002),NOPTIM
C - WRITE B.O.L. PARAMETERS FOR CURIUM MISSION CALCULATIONS
 6002 WRITE (7,4050) ZID,ZOD,TEMPHF,TEMPCF,ZCIR,VLD,PWCT(2),ETAO,P
      TEMPHF=DK2FK(TEMP(1,2))
      TEMPCF=DK2FK(TEMP(9,2))
      OCV=PCMULT*VOC(2)
      OHM=1000.*PCMULT*RPC(2)
      VLD=PCMULT*VPC(2)
      P=PCMULT*PE(2)
      QMOD=PCMULT*QT(2)+ZKEND*DTMOD(2)
      ETAO=P/QMOD
      Q=QMOD/VOL1
      WRITE (6,6003) SKP(IPERT),TEMPHF,TEMPCF,D,Q,PWCT(2),OCV,OHM,VLD,
     1 P,QMOD,ETAO,IPERT
 6003 FORMAT (1X,A1,F11.1,F9.1,2PF6.1,0PF8.2,F9.2,F10.3,F9.1,F10.2,
     6 F10.1,F11.1,2PF9.3,I6)
      LCNT=LCNT+1
      CALL PHONY(DP,JDUMP,100000.)
```

```
      IPERT=0
      GO TO 4025
 6006 WRITE (6,6008) D,PWCT(1),PWCT(2),IPERT
 6008 FORMAT (22X,2PF6.1,0PF8.2,F9.2,59X,I6)
      IPERT=0
      GO TO 4025
 6005 IF (RLMAX.LE.0.) GO TO 4017
C - INCREMENT LOAD RESISTANCE, IF SPECIFIED (Z(47).GT.0.)
      RLPC(1)=RLPC(1)+RLPERT
      IRTRN=5
      ITHINC=1
      GO TO (5001,5002,5003), IRML
 5001 IF (RLPC(1).LT.RPC(1)) GO TO 5003
      IRML=2
      RSAV=RLPC(1)
      NGT2=3
      RETURN
 5002 IRML=3
      NGT2=2
      RLPC(1)=RSAV
 5003 P=9.99*RLPERT
      IF (IRLP.EQ.1.AND.RLPC(1).GE.P) RLPERT=10.*RLPERT
      IF (RLPC(1).LE.RLMAX) RETURN
      RLPC(1)=RLSAV
      LCNT=50
      RLOM=1000.
      IVRL=5
      IRML=1
      IF (IRLP.EQ.1) RLPERT=RLSAV
      GO TO 4025
 4017 IF (DRINCR.LE.0.) GO TO 4021
C - INCREMENT DR(4) IF SPECIFIED (NZ(32).GT.0)
      DR(4)=DR(4)+ DRINCR*DRTE
      RAD(5)=RAD(4)+DR(4)
      DR(5)=RAD(6)-RAD(5)
      IRTRN=3
      IF (DR(4).GT.DRTE) GO TO 4008
      LNRAD(4)=ALOG(RAD(5)/RAD(4))
      LNRAD(5)=ALOG(RAD(6)/RAD(5))
      RETURN
 4008 IF (NOPTIM.EQ.2) GO TO 4003
      WRITE (6,4011) SKP(2)
      LCNT=LCNT+1
 4016 DR(4)=DR4
```

```
      RAD(5)=RAD(4)+DR(4)
      DR(5)=RAD(6)-RAD(5)
      ETAMAX=0.
 4021 IZLP=1
      IF (NPERT.LE.0.) GO TO 4025
C - INCREMENT AXIAL DIMENSIONS, IF SPECIFIED (NZ(26).GT.0)
      IF (PCSAV.GT.1) GO TO 4051
C - INCREMENT NUMBER OF COUPLES IF PCMULT (NZ(12)).LE.1)
      IF (IPUN.EQ.2) WRITE (7,817) (CMT(J),J=3,15),PCMULT,PCMULT,ZLN,ZLP
  817 FORMAT (13A4,1H,F4.0,8H COUPLES/6H 1 112,F6.0/6H 2 111,2G12.5)
      PCMULT=PCMULT+PCPERT
      IF (ZLN.GE.ZNMIN.AND.PEREQ.LE.0.) GO TO 4026
      IPERT=IPERT+1
      IF (CUREQ.GT.0.) RLPC(1)=VREQ/(PCMULT*CUREQ)
      IF (IVD.GT.4.AND.IPERT.LE.NPERT) GO TO 4036
      IPERT=0
      PCMULT=PCSAV
      WRITE (6,4011) SKP(2)
      GO TO 4025
 4026 P=1./(1.+QTE*ZLTE*RLPC(1)*PCPERT/(RPC(1)*PCMULT*(ZLTE*QT(1)-2.*ZLI
     1*(QT(1)-QTE))))
      ZLN=P*ZLN
 4036 IZLP=1
      IRTRN=2
      RETURN
C - INCREMENT ZLN, IF SPECIFIED
 4051 IF (IPERT.LE.NPERT) GO TO 4052
      IPERT=0
      ZLN=ZLNSAV
      ZLP=ZLPSAV
      WRITE (6,4011)
      GO TO 4025
 4052 IPERT=IPERT+1
      ZLN=ZLN+ZNPERT
      ZLP=ZLP-ZNPERT
      IF (ZLP.LE.0.) GO TO 4023
      IRTRN=2
      RETURN
 4025 ITPERT=1
      DTMOD(3)=DTMOD(1)
      IRTRN=3
      IF (THINC.LE.0.) GO TO 6004
C - INCREMENT HOT CLAD TEMPERATURE, IF SPECIFIED
 6009 TEMP(1,1)=TEMP(1,1)+THINC
```

```
      ISKP=1
      IF (TEMP(1,1).LE.THMAX) RETURN
      TEMP(1,1)=T1HOT
      ISKP=2
      ZCIR=0.
 6004 IF (TCINC.LE.0.) GO TO 4023
C - INCREMENT COLD CLAD TEMPERATURE, IF SPECIFIED
      TEMP(9,1)=TEMP(9,1)+TCINC
      IF (TEMP(9,1).GT.TCMAX) GO TO 6007
      IF ((TEMP(1,1)-TEMP(9,1)).GT.DTMIN) RETURN
      IF ((THMAX-TEMP(9,1)).GT.DTMIN) GO TO 6009
 6007 TEMP(9,1)=T1COLD
      ZCIR=0.
C - INCREMENT OUTER T/E WASHER THICKNESS
 4023 IF (TEMP(1,1).GT.THMAX) GO TO 3062
      IF (IZ9.EQ.1) GO TO 4019
      DR(5)=DR(5)+ROINC
      IF (DR(5).GT.R9MAX) GO TO 3062
      IRTRN=4
      RETURN
C - INCREMENT OUTER DIAMETER
 4019 RAD(9)=RAD(9)+ROINC
      IF (RAD(9).GT.R9MAX) GO TO 3062
      IRTRN=6
      RETURN
C - INCREMENT INNER DIAMETER
 3062 RAD(1)=RAD(1)+RIINC
      IF (RAD(1).GT.R1MAX) GO TO 4024
      IRTRN=7
      RETURN
 4024 IF (NOPTIM.NE.3) GO TO 4030
CALCULATE AND WRITE TEMPERATURE DERIVATIVES, IF SPECIFIED
      P=27.78*CKFT
      VOC(2)=(VOC(7)-VOC(5))/P
      VOC(4)=(VOC(9)-VOC(3))/P
      RPC(2)=(RPC(7)-RPC(5))/P
      RPC(4)=(RPC(9)-RPC(3))/P
      QT(2)=(QT(7)-QT(5))/P
      QT(4)=(QT(9)-QT(3))/P
      WRITE (6,4074)
 4074 FORMAT (1H0/36X,34HCALCULATED TEMPERATURE DERIVATIVES)
      WRITE (6,4071) OMHD(4),VOC(2),TEMKF,TEMKF
 4071 FORMAT(1H033X,6H@AL/@T,A1,2H =,E13.4,12H  VOLTS/DEG.,A1,5H/DEG.A1)
      WRITE (6,4071) OMHD(3),VOC(4),TEMKF,TEMKF
```

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      WRITE (6,4072) OMHD(4),RPC(2),TEMKF
 4072 FORMAT(1H033X,6H@RG/@T,A1,2H =,E13.4,11H  OHMS/DEG.,A1)
      WRITE(6,4072) OMHD(3),RPC(4),TEMKF
      WRITE (6,4073) OMHD(4),QT(2),TEMKF,TEMKF
 4073 FORMAT(1H033X,6H@TI/@T,A1,2H =,E13.4,6H  DEG.,A1,10H/WATT/DEG.,A1)
      WRITE (6,4073) OMHD(3),QT(4),TEMKF,TEMKF
      TEMP(1,1)=TEMP(1,1)+THINC
      TEMP(9,1)=TEMP(9,1)+TCINC
 4030 IRTRN=1
      RETURN
      END
```

```
      SUBROUTINE LIFE(DP)
      COMMON /MDCPOP/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
     1 QT(300),NOPTIM,VPC(300),RLPC(300),DTMOD(300),CUR(300),LNRAD(9),
     2 ZLP,ZLN,ZLI,ZLNLP,ZLPNI,ZLTE,NGT1,NGT2,ITPERT,PCMULT,NODUMP,IVD,
     3 QGEN,QGENL,QTE,QOUT,ZID,ZOD,ZKEND,ZK9,ZKR,RPPC,RPN,TOLTEM,TREJ,
     4 VREQ,PEREQ,ZLREQ,WTCON,ZLPN,IDUMZ,RN,DGRF,DGTRF,DGLRF,RADK,JDUMP,
     5 DP(30),NC
      COMMON /MODCPL/CURMOD(15),IT(300),DTTE,CONRN,CONRP,ZLIP,ZNC,
     1 ALR64,MAXTEM,QGAM,CGQM,INDI,RINT4,RINT6,RCON4,RCON6,C1FEH,C1FEC,
     2 CONST1,CONST2,CONST3,CONST4,CONST5,NR5OPT,SEGTE,ICRMDL,RADC
      COMMON /MODOPT/IPOWT, DR4,DRINCR,IRITE,DRTE,JOPTIM,IZ9,IENDK,IPUN,
     1 RIINC,ROINC,R1MAX,R9MAX,DTMIN,QREQ,THINC,TCINC,TCMAX,THMAX
     2,NPERT,ZNPERT,CKFP,CKFT,CTEOC,CTEIC,DELTL,RLPERT,RLMAX,ZNMIN,Z9SAV
      COMMON /TITLE/FETM(3),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMKF,
     1 CRMD(2,2),I3N,I2N,I3P,I2P
      COMMON /MOLIF/HRS,HRINC,HRMAX,HFLF,RADPCT,ITCR,ITHQ
      DIMENSION CIRMOD(2)
      DATA CIRMOD/4HCIR ,4HMOD /
      QEPC=ZKEND * DTMOD(1)/PCMULT
      IF (JOPTIM.NE.0) GO TO 110
      JOPTIM=1
      THSAV=TEMP(1,1)
      TCSAV=TEMP(9,1)
      WRITE (6,100) (CMT(J),J=1,25)
  100 FORMAT (1H1,4X,2A4,1X,18A4,2H (,F2.0,2(1H/,F2.0),2H) ,2A4)
      WRITE (6,101) CIRMOD(IENDK),CIRMOD(IENDK),TEMKF,TEMKF
  101 FORMAT (//92H0           TIME      THOT       TCOLD      RLOAD     RGEN
     1   VOC       VLOAD    CURRENT    POWER      Q-,A4,7H   ETA-,A1/
     2 9X,5HHOURS,2(8H     DEG.,A1),2(9H    M-OHMS),2(9H      VOLTS),
     3  9H     AMPS ,2(9H     WATTS),9H      PCT./)
      QBOL=0.
      IF (ITHQ.EQ.1.AND.HFLF.EQ.0.) GO TO 102
      QBOL=QT(1)+QEPC
      QGEN=QBOL
  102 IF (ITCR.NE.1) ZKR=(QOUT+QEPC)/(TEMP(9,1)-TREJ)
  110 TEMPHF=DK2FK(TEMP(1,1))
      TEMPCF=DK2FK(TEMP(9,1))
      RLOAD=PCMULT*RLPC(1)
      OHM=PCMULT*RPC(1)
      C=CUR(1)
      OCV=PCMULT*VOC(1)
      VLD=PCMULT*VPC(1)
      P=PCMULT*PE(1)
```

```
      Q=PCMULT*(QT(1)+QEPC)
      E=P/Q
      WRITE (6,111) HRS,TEMPHF,TEMPCF,RLOAD,OHM,OCV,VLD,CUR(1),P,Q,E    ,
     1 IT(1)
  111 FORMAT (1X,F13.0,2F9.1,3P2F9.3,0P4F9.3,F9.1,2PF9.3,I10)
      JOPTIM=JOPTIM+1
      PE(JOPTIM)=P
      VOC(JOPTIM)=HRS
      HRS=HRS+HRINC
      IF (HRS.GT.HRMAX) GO TO 112
      IF (HFLF.GT.0.) QGEN=QBOL*EXP(-HRS/HFLF)
      CALL PHONY(DP,JDUMP,HRS)
      RETURN
  112 JOPTIM=-2
      IF (RADPCT.EQ.0.) RETURN
      Q=1.0E6*(1.-PE(3)/PE(2))/VOC(3)
      E=1.0E6*(1.-PE(7)/PE(2))/VOC(7)
      WRITE (6,201) VOC(3),Q,VOC(7),E
  201 FORMAT (1H0//25X,F10.0,25H HOUR POWER DEGRADATION =,F8.3,
     1 22H PCT. PER 10,000 HOURS)
      TEMP(1,1)=THSAV
      TEMP(9,1)=TCSAV
      RETURN
      END
```

```
      SUBROUTINE PUMP(IRTRN)
      COMMON /MODOPT/IPOWT, DR4,DRINCR,IRITE,DRTE,JOPTIM,IZ9,IENDK,IPUN,
     1 RIINC,ROINC,R1MAX,R9MAX,DTMIN,QREQ,THINC,TCINC,TCMAX,THMAX
     2,NPERT,ZNPERT,CKFP,CKFT,CTEOC,CTEIC,DELTL,RLPERT,RLMAX,ZNMIN,Z9SAV
      COMMON /MDCPOP/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
     1 QT(300),NOPTIM,VPC(300),RLPC(300),DTMOD(300),CUR(300),LNRAD(9),
     2 ZLP,ZLN,ZLI,ZLNLP,ZLPNI,ZLTE,NGT1,NGT2,ITPERT,PCMULT,NODUMP,IVD,
     3 QGEN,QGENL,QTE,QOUT,ZID,ZOD,ZKEND,ZK9,ZKR,RPPC,RPN,TOLTEM,TREJ,
     4 VREQ,PEREQ,ZLREQ,WTCON,ZLPN,IDUMZ,RN,DGRF,DGTRF,DGLRF,RADK,JDUMP,
     5 DP(30),NC
      COMMON /TITLE/FETM(3),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMKF,
     1 CRMD(2,2),I3N,I2N,I3P,I2P
      COMMON/TEPMP/NPUMP,DR8,COD2
      IF (JOPTIM-1) 102,103,201
C - INITIALIZE VARIABLES
  102 JOPTIM=1
      INC3=1
      TEMPHF=DK2FK(TEMP(1,1))
      TEMPCF=DK2FK(TEMP(9,1))
      IRITE=4
      COD2=DR(8)/RAD(9)
      COD=.5*COD2
      DR8=0.
      IF (PEREQ.GT.0..AND.VREQ.GT.0.) GO TO 105
      IRTRN=3
      WRITE (6,106)
  106 FORMAT (1H//100H VOLTAGE AND POWER MUST BE SPECIFIED IN PUMP MODUL
     1E PARAMETRIC CALCULATIONS, CALCULATIONS SUPPRESSED)
      RETURN
  105 CUREQ=PEREQ/VREQ
      RLPC(1)=VREQ/CUREQ
      IZ9=2
      Z9SAV=DR(5)
      P=ROINC*FLOAT(NPUMP)
      R9MAX=Z9SAV+0.5*P
      DR3SAV=DR(3)
      DR6SAV=DR(6)
      DR3MAX=DR3SAV+P
      DR6MAX=DR6SAV+P
  103 WRITE (6,100) (CMT(J),J=1,25)
  100 FORMAT (1H1,4X,2A4,1X,18A4,2H (,F2.0,2(1H/,F2.0),2H) ,2A4)
      WRITE (6,101) TEMPHF,TEMKF,TEMPCF,TEMKF,ZID,DRTE,DR(1),PCMULT,COD
  101 FORMAT (26H  AVERAGE HOT CLAD TEMP. =,F8.1,6H DEG. ,A1,30X,25HAVER
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     1AGE COLD CLAD TEMP. =,F8.1,6H DEG. ,A1/10X,16HINNER DIAMETER =,
     2 F8.4,4H IN.,36X,22HT/E RADIAL THICKNESS =,F8.4,4H IN./26H    INNE
     3R CLAD THICKNESS =,F8.4,4H IN.,8X,16HNO. OF COUPLES =,F3.0,4X,
     4 27HCLAD THICKNESS/O.D. RATIO =,F8.5)
      J=1
      IF (WTCON.GT.0.) J=2
      WRITE (6,104) CRMD(1,IENDK),CRMD(1,IENDK),CRMD(1,J)
  104 FORMAT  (95H0     DR(3)    DR(6)      O.D.       ZLN       ZLP      RGEN
     1     VOC       VLOAD   CURRENT    POWER    QA4,5X,3HETAA2,3X,A4,3HWT.
     2/119H        (IN.)    (IN.)    (IN.)      (IN.)     (IN.)  (M-OHMS)  (VOLT
     3S)    (VOLTS)    (AMPS)   (WATTS)  (WATTS)    (PCT.)    (LBS.))
  201 JOPTIM=JOPTIM+1
      IRTRN=1
      IF  (ABS(CUREQ-CUR(1))/CUREQ.LE.TOLTEM.OR.JOPTIM.GT.10) GO TO 210
      RCPC=(VOC(1)-VREQ/PCMULT)/CUREQ-RPPC
      RCOND=RPC(1)-RPPC-RPN
      P=RCPC*RCPC-4.*RPN*RCOND
      IF (P.LT.0.) GO TO 209
      ZLN=.5*ZLN*(RCPC-SQRT(P))/RCOND
      RETURN
  209 ZLN=ZLN*SQRT(RPN/RCOND)
      JOPTIM=10
      RETURN
  210 OHM=PCMULT*RPC(1)
      WT=WATE(P)
      OCV=PCMULT*VOC(1)
      VLD=PCMULT*VPC(1)
      P=VLD*CUR(1)
      Q=PCMULT*QT(1)+ZKEND*DTMOD(1)
      E=P/Q
      IF (INC3.EQ.0) GO TO 212
      WRITE (6,211) DR(3),DR(6),ZOD,ZLN,ZLP,OHM,OCV,VLD,CUR(1),P,Q,E,WT
  211 FORMAT (2H0 ,3F8.4,2F9.4,3PF9.4,0P2F10.4,F9.2,F9.3,F9.1,2PF10.4,
     1 0PF9.3)
      INC3=0
      GO TO 214
  212 WRITE (6,213) DR(6),ZOD,ZLN,ZLP,OHM,OCV,VLD,CUR(1),P,Q,E,WT
  213 FORMAT (10X,2F8.4,2F9.4,3PF9.4,0P2F10.4,F9.2,F9.3,F9.1,2PF10.4,
     1 0PF9.3)
C - INCREMENT OUTER CONDUCTOR RADIAL THICKNESS
  214 JOPTIM=2
      IRTRN=2
      DR(6)=DR(6)+ROINC
      IF (DR(6).LE.DR6MAX) RETURN
```

```
      INC3=1
      DR(6)=DR6SAV
C- INCREMENT INNER CONDUCTOR RADIAL THICKNESS
      DR(3)=DR(3)+ROINC
      IF (DR(3).LE.DR3MAX) RETURN
      JOPTIM=1
      DR(3)=DR3SAV
C- INCREMENT T/E WASHER RADIAL THICKNESS
      Z9SAV=Z9SAV+0.25*ROINC
      DR(4)=DR(4)+0.25*ROINC
      IF (Z9SAV.LE.R9MAX) RETURN
      IRTRN=3
      RETURN
      END

      FUNCTION WATE(WTPC)
      COMMON /MDCPOP/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
     1 QT(300),NOPTIM,VPC(300),RLPC(300),DTMOD(300),CUR(300),LNRAD(9),
     2 ZLP,ZLN,ZLI,ZLNLP,ZLPNI,ZLTE,NGT1,NGT2,ITPERT,PCMULT,NODUMP,IVD,
     3 QGEN,QGENL,QTE,QOUT,ZID,ZOD,ZKEND,ZK9,ZKR,RPPC,RPN,TOLTEM,TREJ,
     4 VREQ,PEREQ,ZLREQ,WTCON,ZLPN,IDUMZ,RN,DGRF,DGTRF,DGLRF,RADK,JDUMP
     5 DP(30),NC
      COMMON /MODCPL/CURMOD(15),IT(300),DTTE,CONRN,CONRP,ZLIP,ZNC,
     1 ALR64,MAXTEM,QGAM,CGAM,INDI,RINT4,RINT6,RCON4,RCON6,C1FEH,C1FEC,
     2 CONST1,CONST2,CONST3,CONST4,CONST5,NR5OPT,SEGTE,ICRMDL,RADC
      COMMON /FOWT/DEN(8),DENI,DEN3N,DEN2N,DEN3P,DEN2P,DCRH,DCRC
      ZLM=ZLI+.001
      PIL=3.14159*ZLTE
      DEN(3)=(ZLPNI*DCRH+ZLM*DENI)/ZLTE
      DEN(4)=(ZLN*DEN3N+ZLP*DEN3P+2.*ZLM*DENI)/ZLTE
      DEN(5)=(ZLN*DEN2N+ZLP*DEN2P+2.*ZLM*DENI)/ZLTE
      DEN(6)=(ZLPNI*DCRC+ZLM*DENI)/ZLTE
CALCULATE WEIGHT OF ONE COUPLE
      WTPC=0.
      DO 10 I=1,8
   10 WTPC=WTPC+PIL*DR(I)*(RAD(I)+RAD(I+1))*DEN(I)
CALCULATE TOTAL MODULE WEIGHT
      WATE=WTCON*(RAD(9)+RAD(1))*(RAD(9)-RAD(1))+PCMULT*WTPC
      RETURN
      END

      FUNCTION DK2FK(T)
      COMMON /MODOPT/IPDWT, DR4,DRINCR,IRITE,DRTE,JOPTIM,IZ9,IENDK,IPUN,
     1 RIINC,ROINC,R1MAX,R9MAX,DTMIN,QREQ,THINC,TCINC,TCMAX,THMAX
     2,NPERT,ZNPERT,CKFP,CKFT,CTEOC,CTEIC,DELTL,RLPERT,RLMAX,ZNMIN,Z9SAV
CONVERTS KELVIN TO FAHRENHEIT DEGREES (IF NZ(O)=1)
      DK2FK=T*CKFT-CKFP
      RETURN
      END
```

```
      FUNCTION SI(XTBL,YTBL,XX,NN,IND,INDLE,INDUE)
      DIMENSION XTBL(2),YTBL(2)
      X=XX
      N=NN
C
C     IND   = INDICATES TYPE-OF-EXTRAPOLATION THAT WAS USED   (IF ANY)
C             (IND=0 INDICATES NO EXTRAPOLATION WAS NEEDED ON X)
C             (IND=1 INDICATES LOWER EXTRAPOLATION WAS NEEDED ON X)
C             (IND=2 INDICATES UPPER EXTRAPOLATION WAS NEEDED ON X)
C     INDLE = INDICATES TYPE-OF-LOWER-EXTRAPOLATION TO BE USED ON X
C             (INDLE=1 INDICATES LOWER EXTRAP. ON X IS TO BE LINEAR)
C             (INDLE=2 INDICATES LOWER EXTRAP. ON X IS TO BE PARABOLIC)
C             (INDLE=3 INDICATES LOWER-LINEAR EXTRAP. ON X AND ERROR PRI
C             (INDLE=4 INDICATES LOWER-PARABOLIC EXTR. ON X AND ERROR PR
C             (INDLE=5 INDICATES LOWER EXTRAP. ON X IS TO BE FIRST TABLE
C     INDUE = INDICATES TYPE-OF-UPPER-EXTRAPOLATION TO BE USED ON X
C             (INDUE=1 INDICATES UPPER EXTRAP. ON X IS TO BE LINEAR)
C             (INDUE=2 INDICATES UPPER EXTRAP. ON X IS TO BE PARABOLIC)
C             (INDUE=3 INDICATES UPPER-LINEAR EXTRAP. ON X AND ERROR PRI
C             (INDUE=4 INDICATES UPPER-PARABOLIC EXTR. ON X AND ERROR PR
C             (INDUE=5 INDICATES UPPER EXTRAP. ON X IS TO BE LAST TABLE
C     XTBL  = NAME OF INDEPENDENT VARIABLE TABLES
C     YTBL  = NAME OF DEPENDENT VARIABLE TABLES
C     N     = NUMBER-OF-POINTS IN EACH TABLE
C     X     = PARTICULAR VALUE OF INDEPENDENT VARIABLE
      SI=YTBL(1)
      IND=0
      IF(NN.LE.1) RETURN
C     CHECK TO SEE IF LOWER OUT-OF-RANGE EXTRAPOLATION WILL BE NEEDED
      IF (X-XTBL(1)) 120, 130, 150
C     LOWER OUT-OF-RANGE EXTRAPOLATION WAS FOUND NECESSARY  (SET IND=1)
  120 IND=1
      IF (INDLE .EQ. 5) RETURN
  130 II=2
      GO TO 254
C     CHECK TO SEE IF UPPER OUT-OF-RANGE EXTRAPOLATION WILL BE NEEDED
  150 IF(X.LT.XTBL(N)) GO TO 210
C     UPPER OUT-OF-RANGE EXTRAPOLATION WAS FOUND NECESSARY  (SET IND=2)
      IND=2
      II=N
      GO TO (254,180,254,180,131),INDUE
  131 SI=YTBL(N)
      RETURN
```

```
 180   II=N-1
       GO TO 254
C
C      (X IS IN-RANGE     MAKE A POINT SEARCH ON X TO OBTAIN II)
 210   NM1=N-1
       DO 220 IK=2,NM1
       II=IK
       IF(XTBL(IK)-X)220,254,254
 220   CONTINUE
C
 254   X1=XTBL(II-1)
       X2=XTBL(II)
       Y1=YTBL(II-1)
       Y2=YTBL(II)
C
C      CHECK IF (UPPER OR LOWER) EXTRAPOLATION WAS FOUND TO BE NECESSARY
       IF(IND-1)259,257,258
C
C      LOWER EXTRAPOLATION IS NEEDED - CHECK INDLE FOR TYPE TO BE USED
 257   GO TO (270,259,370,359),INDLE
C
C      UPPER EXTRAPOLATION IS NEEDED - CHECK INDUE FOR TYPE TO BE USED
 258   GO TO (270,259,370,359),INDUE
C
C      ERROR PRINTOUT
 359   CALL ERROR(33H TABLE EXTRAPOLATED PARABOLICALLY)
C
  259 IF (NN.LE.2) GO TO 270
       X3=XTBL(II+1)
       Y3=YTBL(II+1)
C
C      PARABOLIC INTERPOLATION OR EXTRAPOLATION
 260   SI=Y1+(1.+(X2-X)/(X3-X1))*(Y2-Y1)*(X-X1)/(X2-X1)-(X2-X)/(X3-X1)*(
      1X-X1)/(X3-X2)*(Y3-Y2)
       GO TO 300
C
C      ERROR PRINTOUT
 370   CALL ERROR(28H TABLE EXTRAPOLATED LINEARLY)
C
C      LINEAR EXTRAPOLATION
 270   SI=Y1+(Y2-Y1)*(X-X1)/(X2-X1)
 300   RETURN
       END
```