AN UPDATE OF
INPUT INSTRUCTIONS TO TEMOD
AN UPDATE OF INPUT INSTRUCTIONS TO TEMOD

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INFORMATION CATEGORY
"UNCLASSIFIED"

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Authorized Classifier Date
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.

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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 N2(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 500 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**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_2 = J$:</td>
<td>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:</td>
</tr>
<tr>
<td></td>
<td>$J = 1$; TEGS-3N material.</td>
</tr>
<tr>
<td></td>
<td>$J = 2$; TEGS-2N material.</td>
</tr>
<tr>
<td></td>
<td>$J = 3$; TEGS-3P material.</td>
</tr>
<tr>
<td></td>
<td>$J = 4$; TEGS-2P material.</td>
</tr>
<tr>
<td></td>
<td>$J = 5$; Ternary n-type material.</td>
</tr>
<tr>
<td></td>
<td>$J = 6$; Ternary p-type material.</td>
</tr>
<tr>
<td>$N_2(2) = J$:</td>
<td>The integer $J$ specifies the materials properties to be used for the outer n-leg T/E washer segment ($J$ defined as for $N_2(1)$ above).</td>
</tr>
<tr>
<td>$N_2(3) = J$:</td>
<td>The integer $J$ specifies the materials properties to be used for the inner p-leg T/E washer segment ($J$ defined as above).</td>
</tr>
<tr>
<td>$N_2(4) = J$:</td>
<td>The integer $J$ specifies the materials properties to be used for the outer p-leg T/E washer segment of the P-leg ($J$ defined as above).</td>
</tr>
<tr>
<td>$N_2(5) = IRITE$:</td>
<td>Output control parameter. Standard output format used except if:</td>
</tr>
<tr>
<td></td>
<td>$IRITE = 1$; $N_2$ and $Z$ array output suppressed.</td>
</tr>
<tr>
<td></td>
<td>$IRITE = 2$; Radial temperature profile and temperature drop which are standard output for non-parametric calculations, are suppressed.</td>
</tr>
</tbody>
</table>
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 (r₆ - r₅ 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 NZ₁(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 NZ₁(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 Z₁(19) below) calculations made for each individual couple (axial section) with no electrical connections between couples.

NGT₁ = 5; Matched or fixed load (see Z₁(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.

NZ₁(12) = PCMULT:

Number of couples in the module for which individual couple calculations have been specified (NZ₁(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.

\[ \text{NZ}(13) = \text{INT}: \]
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 \(\text{NZ}(10)\) 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 \(\text{NZ}(14)\)) to determine hot and cold clad temperatures at the midpoints of each of the axial sections. This option can be used only if \(\text{NZ}(11) < 3\).

\[ \text{NZ}(14) = \text{INTTC}: \]
Parameter specifying method of reading axial locations of thermocouples (used only if \(\text{NZ}(13) > 1\)).

- 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 \(\neq 0\) Input an axial distance corresponding to each thermocouple pair. Axial distances to be entered as specified in Section E below.

\[ \text{NZ}(15) = \text{ICRH}: \]
Parameter specifying inner conductor ring material.

- ICRH = 1 Iron properties used.
- ICRH = 2; Tungsten properties used.
- ICRH \(\neq 1\) and \(\neq 2\); 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)

<table>
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<th>NZ(16) = ICRC</th>
<th>Parameter specifying outer conductor ring material.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRC = 1</td>
<td>Iron properties used.</td>
</tr>
<tr>
<td>ICRC = 2;</td>
<td>Tungsten properties used.</td>
</tr>
<tr>
<td>ICRC ≠ 1 and ≠ 2;</td>
<td>Molybdenum properties used.</td>
</tr>
<tr>
<td>NŽ(17)</td>
<td>Not used.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NŽ(18) = IPIN:</th>
<th>Parameter specifying material used for power lead pins (pins extending through retainer rings at each end of module, to which load circuit is connected).</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPIN = 1;</td>
<td>Iron properties used.</td>
</tr>
<tr>
<td>IPIN = 2;</td>
<td>Tungsten properties used.</td>
</tr>
<tr>
<td>IPIN = 3;</td>
<td>Molybdenum properties used.</td>
</tr>
<tr>
<td>IPIN = 4 or 0;</td>
<td>Nickel properties used.</td>
</tr>
</tbody>
</table>

| NŽ(19), NŽ(20), NŽ(21) | Not used. |

<table>
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<th>NŽ(22)* = NODUMP:</th>
<th>Control parameter used to request intermediate calculated parameters as output.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODUMP = 0;</td>
<td>No intermediate information printed out.</td>
</tr>
<tr>
<td>NODUMP = 1;</td>
<td>A page of intermediate parameters (interface resistances, Joule heat, etc.) printed out after each pass through subroutine couple.</td>
</tr>
<tr>
<td>NODUMP = 2;</td>
<td>Intermediate parameters are printed out after the final pass through subroutine couple for each axial section.</td>
</tr>
</tbody>
</table>

| NŽ(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. |

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TABLE I (Continued)

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<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NZ(24) = MAXTEM:</td>
<td>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.</td>
</tr>
<tr>
<td>NZ(25)* = NPUMP:</td>
<td>Parameter used to specify pump module parametric calculations (See section IV).</td>
</tr>
<tr>
<td>NZ(26)* = NPERT:</td>
<td>Increment on number of couples to be used in parametric calculations (See Section IV).</td>
</tr>
<tr>
<td>NZ(27) = N5OPT</td>
<td>Parameter used to allow direct calculation of optimum T/E washer segmenting radius ($r_5$ in Figure 1) in parametric calculations.</td>
</tr>
<tr>
<td>NZ(28), NZ(29), NZ(30)</td>
<td>Not used.</td>
</tr>
<tr>
<td>NZ(31)* = NOPTIM</td>
<td>Parameter used to specify temperature, load resistance, or geometry parametric calculations. (See Section IV).</td>
</tr>
<tr>
<td>NOPTIM = 0</td>
<td>Perturbation subroutine (OPTIM) not entered.</td>
</tr>
<tr>
<td>NOPTIM = 1</td>
<td>Standard value for perturbation calculations. One line of output listed for each set of temperatures, load resistance and dimensions.</td>
</tr>
<tr>
<td>NOPTIM = 2</td>
<td>Used for T/E washer segmenting radius perturbations. Output listed only for optimum value of $r_5$.</td>
</tr>
<tr>
<td>NOPTIM = 3</td>
<td>Temperature derivative option (See Section IV).</td>
</tr>
<tr>
<td>NZ(32) = DRINCR</td>
<td>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).</td>
</tr>
</tbody>
</table>
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 °K or °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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(z(1))</td>
<td>Inside radius ((r_1)) - inches.</td>
</tr>
<tr>
<td>(z(2))</td>
<td>Radial thickness of inner clad ((r_2 - r_1)). See also (z(24)).</td>
</tr>
<tr>
<td>(z(3))</td>
<td>Radial thickness of inner insulating sleeve ((r_3 - r_2)).</td>
</tr>
<tr>
<td>(z(4))</td>
<td>Radial thickness of inner conductor ring ((r_4 - r_3)).</td>
</tr>
<tr>
<td>(z(5))</td>
<td>Radial thickness of inner T/E segment ((r_5 - r_4)).</td>
</tr>
<tr>
<td>(z(6))</td>
<td>Radial thickness of outer conductor ring ((r_7 - r_6)).</td>
</tr>
<tr>
<td>(z(7))</td>
<td>Radial thickness of outer insulating sleeve ((r_8 - r_7)).</td>
</tr>
<tr>
<td>(z(8))</td>
<td>Radial thickness of outer clad ((r_9 - r_8)). See also (z(25)).</td>
</tr>
<tr>
<td>(z(9))</td>
<td>Outside radius (r_9) if (NZ(9) = 0). (z(9)) is defined as (R(9)) or (DR(5)) depending on whether (NZ(9)) is zero or non-zero, respectively.</td>
</tr>
<tr>
<td>(z(10))</td>
<td>Axial length of insulating rings.</td>
</tr>
<tr>
<td>(z(11))</td>
<td>Axial length of n-leg T/E washer.</td>
</tr>
<tr>
<td>(z(12))</td>
<td>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 (z(29)).</td>
</tr>
<tr>
<td>(z(13))</td>
<td>Thermal contact coefficients of hot insulating sleeves interfaces (Typically zero).</td>
</tr>
<tr>
<td>(z(14))</td>
<td>Thermal contact coefficients of cold insulating sleeves interfaces (Typically zero).</td>
</tr>
<tr>
<td>(z(15))</td>
<td>Tolerance to which temperatures must agree from one temperature iteration to the next to meet convergence requirement ((TOLTEM = .001) if zero is entered). - See</td>
</tr>
<tr>
<td>( Z(16) )</td>
<td>TOLCUR:</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>( Z(17) )</td>
<td>TPIN:</td>
</tr>
<tr>
<td>( Z(18) )</td>
<td>RPIN:</td>
</tr>
<tr>
<td>( Z(19)* )</td>
<td>RLOAD:</td>
</tr>
<tr>
<td>( Z(20) )</td>
<td>RECONC:</td>
</tr>
<tr>
<td>( Z(21) )</td>
<td>RECONH:</td>
</tr>
<tr>
<td>( Z(22) )</td>
<td>ZKEND:</td>
</tr>
<tr>
<td>( Z(23) )</td>
<td>RRREF:</td>
</tr>
</tbody>
</table>
TABLE 2 (Continued)

\[ \mathcal{Z}(24) = \text{CID:} \]
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. \( \mathcal{Z}(2) \) must be set equal to zero.

\[ \mathcal{Z}(25) = \text{COD:} \]
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. \( \mathcal{Z}(8) \) must be set equal to zero.

\[ \mathcal{Z}(26) = \text{ZNPERT:} \]
Increment for the n-leg axial thickness, \( ZLN \), in parametric  
calculations (See Section IV).

\[ \mathcal{Z}(27) = \text{ZMIN:} \]
Minimum n-leg axial thickness, \( ZLN \), in parametric calcula-  
tions (See Section IV).

\[ \mathcal{Z}(28)^* = \text{QREQ:} \]
Required module heat input rate (watts) in parametric  
calculations in which total heat input is specified.

\[ \mathcal{Z}(29) = \text{ZLNLP} \]
Specified \( ZLN/ZLP \) ratio, used only if \( \mathcal{Z}(12), ZLP \), is  
set equal to zero.

\[ \mathcal{Z}(30) = \text{PEREQ:} \]
Specified power output for parametric calculations (See  
Section IV).

\[ \mathcal{Z}(31) = \text{VREQ:} \]
Specified module load voltage for parametric calculations.

\[ \mathcal{Z}(32) = \text{ZLREQ:} \]
Specified total module length for parametric calculations.  
\( (\mathcal{Z}(32) = 0 \text{ if couple axial dimensions are specified}) \).

\[ \mathcal{Z}(33) = \text{THINC:} \]
Increment for \( \overline{T}_H \) in temperature perturbation calculations.

\[ \mathcal{Z}(34) = \text{TCINC:} \]
Increment for \( \overline{T}_C \) in temperature perturbation calculations.
TABLE 2 (Continued)

\( z(35) = \) THMAX: Maximum \( \bar{T}_H \) to be used in temperature perturbations.

\( z(36) = \) TCMAX: Maximum \( \bar{T}_C \) to be used in temperature perturbations.

\( z(37) = \) DTMIN: Minimum radial temperature drop \( \left( \bar{T}_H - \bar{T}_C \right) \) for which calculations are to be performed.

\( z(38) = \) DRMIN: Minimum T/E washer radial thickness for which calculations are to be performed.

\( z(39) = \) R1INC: Increment for module inner radius.

\( z(40) = \) RØINC: If \( NZ(9) = 0 \), ROINC is the perturbation increment applied to the module outer radius, \( r_\gamma \).

If \( NZ(9) \neq 0 \), ROINC is the perturbation increment applied to the outer T/E washer radial thickness, \( \Delta R_\gamma \).

\( z(41) = \) R1MAX: Maximum module inner radius, \( r_1 \), for which calculations are to be performed.

\( z(42) = \) R9MAX: If \( NZ(9) = 0 \), R9MAX is the maximum module outer radius, \( r_\gamma \) for which calculations are to be performed.

If \( NZ(9) \neq 0 \), R9MAX is the maximum outer T/E washer radial thickness, \( \Delta R_\gamma \) for which calculations are to be performed.

\( z(43) = \) PWRDEN: Fuel specific power density (watts/cc). Fuel is assumed to fill volume enclosed by the I.D. of the module inner clad. \( \bar{T}_H \) will be calculated for cases in which \( \text{PWRDEN} > 0 \).

\( z(44)^* = \) QINPC: Specified heat input rate (watts) for each couple. \( \bar{T}_H \) will be calculated for cases in which \( \text{QINPC} > 0 \).
### TABLE 2 (Continued)

| \(Z(45)\) | \(= \) 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. |
| \(Z(46)\) | \(= \) RLPERT: | Increment for load resistance (\(Z(19)\)) applied in perturbation subroutine. No perturbation performed if RLPERT = 0. |
| \(Z(47)\)* | \(= \) RLMAX: | Maximum load resistance for which calculations are to be performed in load resistance perturbation subroutine. |
| \(Z(48), Z(49)\) | | Not used. |
| \(Z(50)\)* | \(= \) ZLIBRH | Axial thickness of the tungsten foil diffusion barriers incorporated in the insulating washers in annulus D of Figure 1. |
| \(Z(51)\)* | \(= \) ZLIBRC | Axial thickness of the tungsten foil diffusion barriers incorporated in the insulating washers in annulus E of Figure 1. |
| \(Z(52), Z(55)\) | | Not used. |
| \(Z(56)\) | \(= \) HRINC: | Increment (hours) to be used in time increment calculations (See Section IV). |
| \(Z(57)\) | \(= \) HRMAX: | Maximum time (hours) to be used in time increment calculations. |
| \(Z(58)\) | \(= \) HFLF: | Half life (years) of isotope fuel in time increment calculations. |
| \(Z(59)\) | \(= \) TREJ: | Ambient heat rejection temperature to be used in time increment calculations performed for fixed radiator configuration (See Section IV). |
| \(Z(60)\) | | Not used. |
TABLE 2 (Continued)

<table>
<thead>
<tr>
<th>Definition</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z(61)$ = WTCN:</td>
<td>Ratio of module end closure weight to cross sectional area of module (pounds per in$^2$).</td>
</tr>
<tr>
<td>$Z(62)$, $Z(70)$</td>
<td>Not used.</td>
</tr>
<tr>
<td>$Z(70 + J)^{**}$</td>
<td>Percent increase desired in Seebeck coefficient of Jth thermoelectric material where $J = 1$ to $6$ (See $N(1)$).</td>
</tr>
<tr>
<td>$Z(80 + J)^{**}$</td>
<td>Percent increase desired in resistivity of the Jth thermoelectric material where $J = 1$ to $6$ (See $N(1)$).</td>
</tr>
<tr>
<td>$Z(90 = J)^{**}$</td>
<td>Percent increase desired in thermal conductivity of the Jth thermoelectric material where $J = 1$ to $6$ (See $N(1)$).</td>
</tr>
</tbody>
</table>

** 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 (312, 11(3X, 13)).
   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 (312, 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 NZ(12) = 1 (the minimum number of couples required to achieve the specified lead voltage is determined by program logic).
2. Set NZ(26) = 1 (the normal desired increment on the number of couples).
3. Set NZ(31) = 1.
4. Set Z(12) = 0. To allow p-leg axial thickness to be optimized with respect to n-leg thickness for each case.
5. Set Z(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). Z(27) = .020 inch if no value is input.
6. Set Z(31) and Z(32) equal to the appropriate values as specified in Table 2.
7. Set Z(33) through Z(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 NZ(12) equal to the number of couples in the module.
2. Set NZ(26) equal to the number of washer thickness perturbations required.
3. Set NZ(31) = 1.
4. Set Z(11) and Z(12) equal to the initial n- and p-leg washer axial thicknesses.
5. Set Z(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 NZ(12) = 1 (the minimum number of couples required to achieve the specified load voltage is determined by program logic).
2. Set NZ(26) = 1 (the normal desired increment on the number of couples).
3. Set NZ(31) = 1.
4. Set Z(12) = 0 to allow p-leg axial thickness to be optimized with respect to n-leg thickness for each case.
5. \( \left\{ \begin{align*}
\text{Set } Z(28) \text{ equal to the desired module thermal power input, or } \\
\text{Set } Z(30) \text{ equal to the required electrical power output.}
\end{align*} \right. \\
6. Set Z(31) equal to the desired load voltage.
7. Set Z(32) through Z(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 thermo-electric 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 N2(31) = 0.
2. Set N2(32) equal to the increment to be applied to the inner segment thickness in percent of the total specified T/E washer thickness. Normally N2(32) = 5 provides adequate calculational resolution to determine the optimum segment radius.
3. Set Z(5) = 0. This initializes the segmenting radius such that the radial thickness of the inner T/E washer segment is zero.
4. Set Z(28) through Z(32) equal to zero.
5. Set Z(33) through Z(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.

\[
\frac{100(r_6 - r_5)}{r_6 - r_4} = 0 \text{ pct. (See Figure 1).}
\]
The final case for each temperature pair will correspond to a zero thickness inner T/E washer segment.

\[
\frac{100 (r_5 - r_4)}{r_6 - r_4} = 100 \text{pct.}
\]

or

\[
\frac{100 (r_6 - r_5)}{r_6 - r_4} = 100 \text{pct.}
\]

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 \(N_5(31)\) 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, \(R_g\), and thermal impedance \(T_1\)) 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 $T_H$ and cold $T_C$ clad temperatures. The parameters

$$\frac{\partial \bar{\alpha}}{\partial T_H} \bigg|_{T_C} \quad \frac{\partial \bar{\alpha}}{\partial T_C} \bigg|_{T_H} \quad \frac{\partial R}{\partial T_H} \bigg|_{T_C} \quad \frac{\partial R}{\partial T_C} \bigg|_{T_H} \quad \frac{\partial T_I}{\partial T_H} \bigg|_{T_C} \quad \text{and} \quad \frac{\partial T_I}{\partial T_C} \bigg|_{T_H}$$

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

$$\bar{\alpha} = \frac{V_{oc}}{T_H - T_C},$$

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

$$T_I = \frac{T_H - T_C}{Q},$$

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 $N(11) = 4$. (The calculations are typically performed under matched load conditions except in the case of open circuit tests.)
2. Set $N(31) = 3$.
3. Set $Z(28)$ through $Z(36) = 0$.
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 $N \Xi(9) = 0$ (See Table 1).

   b. Set $\Xi(1)$ equal to the smallest inner radius of interest.

   c. Set $\Xi(2) = 0$. Inner clad thickness should be scaled linearly with module inner radius as specified by $\Xi(24)$.

   d. Set $\Xi(8) = 0$. Outer clad thickness should be scaled linearly with module outer radius as specified by $\Xi(25)$.

   e. Set $\Xi(9)$ equal to smallest outer radius of interest.

   f. Set $\Xi(23)$ through $\Xi(25)$ equal to the appropriate values as specified in Table 2.

   g. Set $\Xi(38)$ 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 $\Xi(39)$ through $\Xi(42)$ equal to the appropriate values as specified in Table 2.

   i. Set $\Xi(61)$ 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 N_Z(9) = 1 (See Table 1).
   
   b. Set \( Z(9) \) equal to the smallest T/E washer radial thickness of interest.
   
   c. Set \( Z(38) = 0 \).
   
   d. Set \( Z(42) \) 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 N_Z(9) = 0. (See Table 1).
   
   2. Set N_Z(25) equal to the desired number of perturbations to be performed on each conductor and T/E washer radial thickness.
   
   3. Set \( Z(4), Z(5), Z(6) \) and \( Z(9) \) equal to the appropriate minimum values of interest.
4. Set \( Z(8) = 0 \). Since module outer radius will vary in parametric, outer clad thickness should be scaled linearly with \( r_o \) as specified by \( Z(25) \).

5. Set \( Z(12) = 0 \). Program logic will determine the axial thickness of the T/E washers required to achieve voltage and current specifications for each case.

6. Set \( Z(19) = 0 \). Although the input voltage and current specify a load resistance, this value is calculated internally.

7. Set \( Z(23) \) and \( Z(25) \) equal to the appropriate values as specified in Table 2.

8. Set \( Z(30) \) equal to the specified power output (the product of the specified current and voltage).

9. Set \( Z(31) \) equal to the specified voltage.

10. Set \( Z(40) \) 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 \( Z(61) \) 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 thermoelectric 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 NZ(35) equal to the appropriate value discussed in Table 1 to specify either constant $T_H$ or heat input conditions.
2. Set NZ(36) equal to the appropriate value discussed in Table 1 to specify either constant $T_C$ or fixed radiator calculations.
3. Set Z(19) if fixed load resistance calculations are required ($Z(19) = 0$ for matched load).
4. Set Z(31) if fixed load voltage calculations are required.
5. Set Z(56) equal to the desired time increment (in hours).
6. Set Z(57) equal to the maximum time (hours).
7. Set Z(58) equal to the isotope half life (in years) if heat decay calculations are desired.
8. Set Z(59) equal to the heat sink temperature if fixed radiator calculations are desired.
9. Set Z(71) through Z(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), XHERM(30), THERM(30), THERMH(30), MD(6,8),
1 H01(8), H02(8), H03(16,2), ASTAR1(2), ZOPMAX(5), ZOPT(5), ZOPT1(5),
2 CKF1(2), CKF2(2), TMKF(2)
COMMON /TITLE/FTEM(3), CASCADE(8,2), SSIN(3), CMT(25), COND(3,5), TEMKF,
1 CRMD(2,2), I3N, I2N, I3P, I2P
COMMON /MODIF/HKS, HRINC, HRMAX, HFLF, RADPCT, ITCR, ITHQ
COMMON /TERIT/DTAV, DHM, QCV, RLOAD, QMOD, TCAV
COMMON /MODPOP/RAD(9), DR(8), TEMP(9,300), VOC(300), RPC(300), PE(300),
1 Q1T(300), NOPTIM, VPC(300), RLP(300), DTMOD(300), CUR(300), LRNRA(9),
2 ZLP, ZLN, ZLNP, ZLPN, ZLTE, NCR(T), NGT(2), ITPERT, PCMULT, NODUMP, VDO,
3 QGEN, QGENL, QTE, QOUT, ZID, ZOD, ZKEND, ZK9, ZKR, RPPC, RPN, TOLTEM, TREQ,
4 VREQ, PEREQ, ZLREQ, WTCON, ZLPN, I0UMZ, RN, DGRF, DGTRF, DGLRF, RADK, JDUMP,
5 DP(30), NC
COMMON /MODCPL/CURMOD(15), IT(300), DTTE, CONRN, CONRP, ZLIP, ZNC,
1 ALR64, MAXTM, QGAM, CGAM, INDI, RINT4, RINT6, RCON4, RCON6, CIFEM, CIFEC,
2 CONST1, CONST2, CONST3, CONST4, NRSOPT, SEGTE, ICRMDL, RADC
COMMON /TEF/NCDC, NCCL, ICRH, ICRC, IPIN, ZLIBRH, ZLIBRC, TCPIN, RPIN
COMMON /MDOPT/IPW, DR4, DRINC, RITE, DITE, DTMOD, Z9, ITENDK, IPUN,
1 RIINC, ROINC, RMAX, RMAT, DTIN, DREQ, THINC, TCINC, TCMAX, THMAX
2, NPERT, ZNPERT, CKFP, CKFT, CTEOC, CTEIC, DELT, RLPERT, RLMAX, ZNMIN, Z9SAV
COMMON /TEMPP/NCDC, NCPL, DR4, C002
EQUIVALENCE (HD3(20), ASTAR1(1))
DATA H0/4HNNE, 4HR CL, 4HAD, 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H,
1 4HNIN, 4HR IN, 4HSULA, 4HTING, 4HR IN, 4HR IN, 4HR IN, 4HR IN, 4HR IN,
2 4HHOT, 4HD SID, 4HE CO, 4HNDC, 4HTOR, 4HRING, 4HRING, 4HRING,
3 4H, 4HINNE, 4HR T, 4HE WA, 4HEWA, 4HEWA, 4HEWA, 4HEWA,
4 4H, 4HOUTE, 4HR IN, 4HSULA, 4HTING, 4HR IN, 4HR IN, 4HR IN,
5 4HCOLD, 4H SID, 4HE CO, 4HNDC, 4HTOR, 4HRING, 4HRING,
6 4HOUTE, 4HR IN, 4HSULA, 4HTING, 4HR IN, 4HR IN, 4HR IN,
7 4HOUTE, 4HR IN, 4HR CL, 4HAD, 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H, 4H,
8 MD1(2)/2HBN/, MD1(7)/2HBN/, MD2/3*1H, 2*1H, 3*1H, MD3/20*1H, 1H*,
9 6*1H, 2*1H*, 3*1H /, N2/50*0/, Z/100*0/, /, CKF1/0, /, 459.6/, /, CKF2/1, /, 1.8/
REAL LNRA
FK2K(T)=(T+CKFP)/CKFT
CID=CLOCK(CMT(21), CMT(22), CMT(23))
93 READ (5, 94) (CMT(K), K=3, 20), ASTNP
94 FORMAT(18A4, 7X, A1)
Z(19)=0.
Z(28)=0.
Z(44)=0.
DO 90 I=70,100
90 Z(I)=0.
UGEN=0.
ZKR=0.
CURMOD(I)=0.
NZ(20)=0
NZ(22)=0
NZ(25)=0
NZ(26)=0
NZ(31)=0
ITPER=0
INDI=0
LNDUMP=0
IVD=1
IF (ASTOP.NE.HD2(I)) STOP
C - READ FIXED POINT INPUT DATA
95 READ (5,91) N,L,J, (IT(I)),I=1,N
91 FORMAT (3I2,11(3X,13))
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
13N=NZ(1)
12N = NZ(2)
13P=NZ(3)
12P = NZ(4)
IRITE=NZ(5)
NCLDHNZ(6)
NCLUDC=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=MAXO(NZ(10),1)
ZNC = NC
NGTI=NZ(11)
PCMULT=AMAXO(NZ(12),1)
IF (KASE1.EQ.1,AND.,NZ(13).EQ.1) NZ(13)=0
INT = NZ(13)
INTTC=NZ(14)
ICRM=NZ(15)
ICRC=NZ(16)
IPIN=MNO(NZ(18),4)
IF (IPIN.LE.0) IPIN=4
NXTWP = MNO(MAXO(NZ(19),1),5)
SEGTE=10.
IF (NZ(21).NE.0) SEGTE=NZ(21)
NODUMP=NZ(22)
JDUMP=NODUMP=1
MAXIND=MAXO(NZ(23),10)
MAXTEM=0
IF (NZ(24).GT.10) MAXTEM=NZ(24)=10
NPUMP=NZ(25)
NPERT=NZ(26)
NR50PT=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=MAXO(NZ(35),1)
ITCR=MAXO(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)
UR8=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)
PEREQ=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=1.00.
IF (THINC.GT.0.) THMAX=FK2K(Z(35))+0.5*THINC
TMAX=0.
IF (TCINC.GT.0.) TCMAX=FK2K(Z(36))+0.5*TCINC
DTMIN=Z(37)/CKFT
DRMIN=Z(38)

D-40
RIINC = Z(39)
ROINC = Z(40)
RMAX = 0.
IF (RIINC.GT.0.) RMAX = 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
RMAX = Z(47)/PCMULT
IF (RMAX.NE.0.) NOPTIM = 1
ZLIBRH = Z(50)/ZL1
ZLIBRC = Z(51)/ZL1
ZK9 = Z(52)
CTEIC = Z(53)*1.0E-06
CTEOC = Z(54)*1.0E-06
DETL = 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-10*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 (1HO/50X,10HINPUT DATA/)
DO 103 I=1,10
103 WRITE (6,104) (J,NZ(J),J=I,50,10)
104 FORMAT (2X,5(3HNZ(,12,2H)*,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(3HZ(,12,2H) = ,G12.4,3X) ,2HZ(,13,2H) = ,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 (1HO, 25X, 61H***** SAME AXIAL TEMPERATURES USED AS IN PREVIOUS CASE *****)
KFTEM=1
GO TO 123
5070 TAV=0.
TCAV=0.
IF (INT.NE.0) GO TO 5072
READ (5,5071) (TEMP(I,1),TEMP(9,I),I=1,NC)
5071 FORMAT (12F6.2)
IF (IRITE.LT.3) WRITE (6,5075) TEMKF
5075 FORMAT (1HO,22X,62HMUT AND COLD CLAD TEMPERATURES OR EACH AXIAL SECTION IN DEGS.,/A1)
GO TO 123
CALCULATION OF EQUI-SPACED (STANDARD) THERMOCOUPLE LOCATIONS
5072 IF (INTC.NE.0) GO TO 5083
DTAV=ZCIR/(FLOAT(INT)-1.)
XTERM(1)=0.
DO 5082 I=2,INT
5082 X THERM(I) = X THERM(I-1) + DTAV
GO TO 5084
5083 READ (5,5071) (XTHERM(I), I=1, INT)
5084 READ (5,5071) (THERM(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 SUPPRESSED)
GO TO 93
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 (1HO, 27X, 51HINPUT THERMOCOUPLE LOCATIONS AND READINGS IN DE
1GS. , A1)
NKN=(INT+9)/10
DO 73 K=1, NKN
KNK=10*K
KNK=KNK-9
IF (KNK, GT, INT) KNK=INT
WRITE (6,108) (I, I=KNNK, KNK)
WRITE (6,112) (XTHERM(I), I=KNNK, KNK)
73 FORMAT (1X, F8.3, 9F11.3)
WRITE (6,112) (THERMH(I), I=KNNK, KNK)
WRITE (6,112) (THERMC(I), I=KNNK, KNK)
IF (WRITE, GE, 3) GO TO 122
WRITE (6,5076) TEMKF
5076 FORMAT (1HO/21X, 67HINTERPOLATED MID-POINT TEMPERATURES OR EACH AXI
IAL SECTION IN DEGS., A1)

123 NKN=(NC+9)/10

DO 111 K=1,NKN

KNNK=K*N

IF (KNNK.GT.NC) KNNK=NC

WRITE (6,108) (I,I=KNNK,KNNK)

108 FORMAT (1HO,3X,10(I3,8X))

WRITE (6,112) (TEMP(1,I),I=KNNK,KNNK)

111 WRITE (6,112) (TEMP(9,I),I=KNNK,KNNK)

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)

TCAV=TCAV+TEMP(9,I)

TCAV=TCAV/ZNC

THAV=THAV/ZNC

TMODAV=TCAV+0.5*DTAV

THAVF=CKF2(2)*THAV-CKF1(2)

TCAVF=CKF2(2)*TCAV-CKF1(2)

TMODAVF=CKF2(2)*TMODAV-CKF1(2)

DTAVF=CKF2(2)*DTAV

5073 WRITE (6,5078) THAV,THAVF,TCAV,TCAVF,DTAV,DTAVF,TMODAV,TMODOE

5078 FORMAT (1HO/22X,30H AVERAGE HOT CLAD TEMPERATURE =F9.3, 9H DEG,K

1/(F9.3,7H DEG,F)//21X,31H AVERAGE COLD CLAD TEMPERATURE =F9.3,

2 9H DEG,K (F9.3,7H DEG,F)//18X,34H AVERAGE RADIAL TEMPERATURE OR

3UP =F9.3,9H DEG,K (F9.3,7H DEG,F)//24X,28H AVERAGE MODULE TEMPE

4RATURE =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 (NC.EQ.0) WRITE (6,62) TEMKF,(TEMP(1,I),TEMP(9,I),I=1,NC)

62 FORMAT (1HO/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))

TEMP(9,I)=FK2K(TEMP(9,I))

119 IF (RLOAD.GE.0.) GO TO 118

READ (5,5071) (R LPC(I),I=1,NC)

IF (NC.EQ.0) WRITE (6,117) (RLPC(I),I=1,NC)

117 FORMAT (74H INPUT LOAD RESISTANCE FOR EACH TEMPERATURE PAIR (IN MI
116 RLP(I) = .001*RLPC(I)/PCMUL
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. NGT1.6E3) GO TO 125
   WRITE (6,121)
   FORMAT (1HO,/17X,80HNEGATIVE OR ZERO TEMPERATURE ENCOUNTERED - CAL-
   ICULATION SUPPRESSED 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.NEG.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 (C0D2.NEG.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)
HD(1) = SSIN(NCLOH)
HD(3) = FETM(ICRH)
HD(4) = CASCAD(I3N, 2)
HD(1, 4) = CASCAD(I3P, 2)
HD(5) = CASCAD(I2N, 2)
HD(1, 5) = CASCAD(I2P, 2)
HD(6) = FETM(ICRC)
HD(8) = SSIN(NCLUC)
WRITE (6, 2017)
2017 FORMAT (1HO///, 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, OR(J), HD3(J + 8, I), HD1(J), HD2(J),
1 CHD(K, J), K = 1, 6)
2018 FORMAT (10X, 4HRAD, 11, 3H), F10.6, 5H IN., A1/40X, 3HDR, 11, 3H, F10.6
4H IN., A3, A3, A3, A3, A3, A3, A3
WRITE (6, 2018) J, RAD(J)
J = 9
WRITE (6, 2018) J, RAD(J)
J = 1
IF (NOPTIM .NE. 0. AND. VREQ .GT. 0. AND. (ZLREQ .GT. 0., OR. PEREQ .GT. 0.,)
1 J = 2
J = (J + IDUMZ) / 2
WRITE (6, 2021) ZLN, ASTAR1(J), ZLP, ASTAR1(J), ZLI, ZLTE, ASTAR1(J)
2021 FORMAT (1HO///46X, 18AXIAL DIMENSIONS, ///10X, 8HZLN =, F9.5,
1 23H IN., (N=TYPE WASHER), A2///10X, 8HZL =, 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 (1HO, 9X, 8HZCIR =, F9.5, 30H IN., (TOTAL CIRCUIT LENGTH,
1 4F, 9.9 COUPLES))
IF (J .EQ. 2. OR. I .EQ. 2) WRITE (6, 2022)
2022 FORMAT (1HO, 50X, 51H* THIS DIMENSION OPTIMIZED OR CALCULATED INTERN
1ALLY)
4004 DR4=DR(4)
   DRT=E=RAD(6)-RAD(4)
   IF (DRT.LT.DRM1N.AND.(NOPTIM.GT.0.OR.NCLAD.GT.0)) GO TO 1996
3016 IF (RAD(J1).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
   LNRA0(J)=ALOG(RAD(J1)/RAD(J))
31 IF (J/2.NE.2,AND.LNRA(J).LE.0.) ISECT=1
   GO TO 1999
1991 CONTINUE
   IF (NOPTIM.EQ.0.OR.R0INC.EQ.0.) GO TO 1996
   ISECT=3
   GO TO 1999
1996 WRITE (6,1992)
1992 FORMAT (1HO,21X,68HERRUR IN DIMENSIONS SPECIFIED - CALCULATIONS SU
1PRESSED FOR THIS CASE)
   GO TO 93
1999 ZKN=ZKEND*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 = LNRA0(5)+LNRA0(4)
   CGAM5=.5/ALR64=1./(EXP(2.*ALR64)-1.)
   CONST0=.02659*ALR64
   CONRN=CONST1/ZLN
   RCON4 = RECON/(40.5366*ZLN*RA0(4))
   RCON6 = RECON/(40.5366*ZLN*RA0(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))/(LNRA0(2)*HH)
   IF (HC.NE.0.) CONST4=3937*(1.0/RAD(7)+1.0/RAD(8))/(LNRA0(7)*HC)
CHECK TO SEE IF P-LEG AXIAL LENGTH IS TO BE OPTIMIZED
   IF (IDUMZ.GT.1) GO TO 78
   CALL RECURRING PRODUCTS IF P-LEG IS NOT TO BE OPTIMIZED
   ZLPNZLP+ZLN
   ZLPNZLPNZL
   ZLTEZLPNZLI
   ZLNLPZLN/ZLP
   CONST5=15.9593*ZLP
   ZLIP=2.0*ZLI/ZLP
CONST2*15.9593*ZLTE

RINT4=RCON4*ZLPN/ZLP

RINT6=RCUN6*ZLPN/ZLP

CONRP=CONST1/ZLP

IF (ICRMDL .NE. 0) GO TO 4005

C1FEH=15.9593*DR(3)*RAD(3)/ZLTE

C1FE=15.9593*DR(6)*RAD(6)/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)

C1FE=5.08*RAD(6)*ALOG(3.14159*RCOLD/ZLI+1,0)

78 INDI=INDI+1

C - ENTER SUBROUTINE COUPLE

CALL COUPLE

IF (NONUMP,EQ.5) GO TO 93

C - ENTER SUBROUTINE LIFE, IF SPECIFIED

IF (HRINC.LE.0) GO TO 3052

CALL LIFE(DAPENT)

IF (JOPTIM.LT.0) GO TO 93

GO TO 78

3052 IF (NOPUMP,EQ.0) GO TO 3051

C - ENTER SUBROUTINE OPTIM FOR THOT, TCOLD, PCT2N PERTURBATION

CALL OPTIM(2,J)

DTM0D(1)=TEMP(1,1)-TEMP(9,1)

GO TO (93,4002,78,3059,78,3070,3061), J

3051 IF (NONUMP,EQ.0) GO TO 3053

CALL PUMP(J)

GO TO (4002,3061,93), J

3053 IF (NONUMP,EQ.3) GO TO 93

IF (NGT1.GE.3) GO TO 79

CALCULATE MODULE VOLTAGE AND RESISTANCE FOR CURRENT CONVERGENCE CHECK

UCV=0.

OHM=0.

QMOD=0.

DO 36 J=1,NC

UCV=UCV+VOC(J)

OHM=OHM+RPC(J)

36 QMOD=QMOD+QT(J)

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) GOTO 79
    IF (INDI.EQ.2) TOLTEM=0.1*TOLTEM
    IF (INDI.LT.MAXIND) GOTO 78
    WRITE (6, 43) MAXIND, (J, CURMOD(J), J=1, INDI)
43  FORMAT (///,27X,37H***CURRENT CLOSURE NOT OBTAINED AFTER,IS, 14H
     ITERATIONS***,///,22X,65HMODULE CURRENT CALCULATED ON EACH PASS THR
     2OUGH SUBROUTINE COUPLE ,///,42X,9HITERATION,7X,7HCURRENT,///,
     3(1HO,44X,13,1H.,7X,1PE12,5,/) )
79  CALL RITE
    IF (NGT1.EQ.5.AND.NGT2.EQ.3) GOTO 2060
    IF (NGT1.NE.0) GOTO 2059
    INDI=1
    NGT1=2
    TOLTEM=10.*TOLTEM
    IF(RLOAD.GT.0.) GOTO 2053
    CURMOD(2)=0.50*OCV/OHM
    NGT2=3
    GOTO 78
2053  NGT2=2
    RLCPC(I)=RLOAD/ZNC
    GOTO 2054 I=1,NC
2054  RLCPC(I)=RLPC(1)
    CURMOD(2)=OCV/(OHM+RLOAD)
    GOTO 78
2059  IF (NGT1.NE.5) GOTO 2061
2060  CURMOD(2)=0.
    INDI=1
    NGT2=1
    NGT1=3
    DTTE=TEMP(4,1)-TEMP(6,1)
    GOTO 78
2061  IF (NGT1.NE.7) GOTO 93
    NGT1=4
    IRITE=4
    INT=1
    GOTO 32
END
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, DTM, OCV, RLDO, QMOD, TCAV
COMMON /MDCPOP/RAD(9), OR(8), TEMP(9,300), VNC(300), RPC(300), PE(300),
1 GT(300), NOPTIM, VPC(300), RLPC(300), DTMOD(300), CUR(300), LNRAD(9),
2 ZLP, ZLN, ZLI, ZLNL, ZLPN, ZLTE, NGT1, NGT2, ITPERT, PCMULT, NODUMP, IV0,
3 QGEN, QGENL, QTE, QUT, Z10, Z9D, ZKEND, ZK9, ZKR, RPPC, RPN, TOLTEM, TREQ,
4 VREQ, PEREQ, ZLREQ, WTCON, ZLPN, IDUMZ, RN, DGRF, DGTRF, DGLRF, RAKD, JDUMP,
5 OP(30), NC

COMMON /MODCPL/CURMOD(15), IT(300), DTTE, CONRN, CONRP, ZLIP, ZNC,
1 ALR04, MAXTEM, QGAM, AGAM, INDI, RINT4, RINT6, RCON4, RCON6, C1FEH, C1FEC,
2 CONST1, CONST2, CONST3, CONST4, CONST5, NR5OPT, SEGTE, ICRMDL, RADC
COMMON /MODOPT/IPOPT, OR4, DRINCR, IRITE, JOPTIM, I9Z, TENOK, IPUN,
1 RIINC, RQINC, RMAX, R9MAX, DTMIN, QREQ, THINC, TCINC, TMAX, THMAX
2, NPERT, ZNPERT, CKPF, CKFT, CTEC, CTEIC, DELTL, RLPERT, RLMAX, ZNMIN, Z9SA
COMMON /TITLE/FETH(3), CASCAD(8,2), SSIN(3), CMT(25), CONO(3,5), TEMKF,
1 CRMD(2,2), I3N, I9N, I3P, I12P
COMMON /CPLRIT/DT(8,300), OPTZLP(300), OPTCPL(300)
DATA CPMD/4H CIR, 4H CUR, 4H CA, 4H RNS, 4H RNS, 4H EFF, 4H (AM, 1
4HPS), 4H PCT, 1H, 4H, 4H MD, 4H MD, 4H AVE, 4H RNS, 4H R-L,
2 4HAD, 4H TEMP, 4H HM0, 4H HMH, 4H DEG, 4H MDHM, 1H S/
CPMD(1,2) = CRMD(1,1)
CPMD(2,2) = CRMD(2,2)
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(1)
TAVG(I) = DK2FK(P)
ETAC(I) = 100. * DTMOD(1) / TEMP(1, I)
DTMF(I) = CKFT * DTMOD(I)
TF(9, I) = DK2FK(TEMP(9, I))
TICUP(I) = DTMF(I) / QT(I)
ALPCUP(I) = VNC(I) / DTMF(I)
ETA(I) = PE(I) / QT(I)
DO 2001 J = 1, 8
DTF(J, I) = CKFT * QT(J, I)
2001 TF(J, I) = DK2FK(TEMP(J, I))
2006 IF (IRITE .GT. 2) GO TO 2007

D-50
1994 WRITE (6,1998) (COND(J,NGT2),J=1,3),TEMKF,(J,J=1,9),
1 ((TF(J,I),J=1,9),I=1,NC)
1998 FORMAT (1HO,10X,58HRADIAL TEMPERATURE PROFILE FOR EACH COUPLE CALC
1 ULATED FOR 3A4,19H CONDITIONS (DEGS. ,A1,1H)/8H COUPLE,6X,
2 9(IHT,I,19X)/(3HO ,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 (1HO,21X,64HRADIAL TEMPERATURE DROP ACROSS COMPONENTS FOR E
1 EACH COUPLE (DEG. ,A1,1H)//8H COUPLE,10X,28H BORON
2 INNER,28X,26H OUTER BORON OUTER/19X,81H CLAD NITRIDE
3 CONDUCTOR T/E1 T/E2 CONDUCTOR NITRIDE CLAD/
4(1HO,15,2H, ,F16,3,7F11,3))
WRITE (6,100) (CMT(J),J=1,25)
2007 WRITE (6,2002) (COND(J,NGT2),J=1,3)
2002 FORMAT (1HO,12X,61HCALCULATED PARAMETERS FOR INDIVIDUAL COUPLES OPER
1 ERATING UNDER 3A4,11H CONDITIONS)
C - WRITE INDIVIDUAL COUPLES 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 (1HO,12X,18H VOLTAGES****12X,50H INTERNAL POWER
1 HEAT EFF. ,A4,1H//8H (DEG. ,A1,1H)/TH / TC VOC
2 V-LOAD 2A4,63H RESISTANCE OUTPUT IMPEDANCE SEEBE
3 CK EFF. ,A4,1H//8H (DEG. ,A1,1H)/(VOLTS) (VOLTS) (VOLTS) (VOLTS) /
4 2A4,35H (M=OHMS) (WATT) (WATT) (D=.A1,12H/KW) (MV/D-,
5 A1,14H) (PCT.) (,A1,14H)
WRITE (6,14) (TF(I),I),TF(9,I),VOC(I),VPC(I),CUR(I),RPC(I),PE(I),
1 QT(I),TICUP(I),ALPCU(I),ETA(I),ETAC(I),I=1,NC)
14 FORMAT (1HO,F5,0,1H/,F4,0,2F10,5,F10,3,3PF10,4,3PF10,4,F10,2,
1 3PF10,2,3PF10,4,3PF10,3,3PF10,2)
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,OPTCL(I),OPTCPL(I+100),I=1,NC)
2052 FORMAT (1HO/ 14X, 6HCouPLE,18X,52HAXIAL THICKNESSES CALCULATED IN
1 OPTIMIZATION ROUTINE/14X,6HNUMBER,11X,5H=LEG,10X,5H=LEG,7X,12H
2MICA WASHERS,6X,6HCouPL,8X,7HCouPL/CIRCUIT/(1HO,13X,14,4H) ,5F15,5))
2061 IF (NGT,J,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 CONDITIONS WITH
1 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
DCV = PCMULT*VDC(I)
VLD = PCMULT*VPC(I)
IF (NGT2.NE.1) RLO=1000,PCMULT*RLPC(I)
OMH=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),DCV,VLD,RLD,OMH,P,QMOD,TIO,SEB,ETAO,
1 TAVG(I)
GO TO 2221
2005 WRITE (6,2059)
2059 FORMAT (1HO///43X,24H OVERALL 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)*OMH
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),DCV,VLD,CURMOD(INDI),OMH,P,QMOD,TIO,
1 SEB,ETAO,RLD
WRITE (6,2011) INDI
2011 FORMAT (1HO///,30X,I2,37H ITERATIONS TAKEN FOR CURRENT CLOSURE)
2221 WRITE (6,2016) (IT(I),I=1,NC)
2016 FORMAT (1HO/// 38H NUMBER OF ITERATIONS FOR EACH COUPLE=(5X,2SI4)/
1 1HO,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),TEHK,F
1 CRMD(2,2),I3N,I2N,I3P,I2P
COMMON /DATIN/TTT(15),ZKMIC1(15),ZKMIC2(15),ZKSS(15),ZKBN(16),
1 ZKN(15),Z2NA(15),Z2NR(15),Z2NK(15),Z2PA(15),Z2PK(15),
2 Z2NRK(15),Z2PRK(15),Z3NA(15),Z3NK(15),Z3PK(15),Z3PA(15),
3 Z3PR(15),Z3PK(15),Z3PRK(15),ZKCRH(15),ZKCRC(15),RCHR(15),RCR(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),ZKMIC1(16)
COMMON /FODT/DEN(8),DENI,DEN3N,DEN2N,DEN3P,DEN2P,DCRH,DCRC
COMMON/TEFO/NLDC,NLDM,ICRH,ICRC,IPIN,LIBRM,LIBRC,TPIN,RPIN
DATA HOT/4HHOT/,COLD/4HCOLD/,NNAME/2HN-,PNAME/2HP-/
IF (NCLDH.NE.1.AND.NCLOH.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)
IF (IPUN.GT.0) WRITE (7,401) (CASCAD(I3N,I),I=1,2),(ALPHA(I,I3N),
1 I=1,15), (CASCAD(I3N,1),I=1,2),(RHO (I,I3N),I=1,15),
2 (CASCAD(I3N,1),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(E9.3,1H),
2 1H),7HC RESISTIVITY OF ,2A4,19H MATERIAL (OHM*CM.),5X,1H1,10X,5
3 S(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,1),I=1,2),(RHO (I,I2N),I=1,15),
2 (CASCAD(I2N,1),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=1,15),(ALPHA(I,I3P),
1 I=1,15),(CASCAD(I3P,I),I=1,15),(RHO(I,I3P),I=1,15),
2 (CASCAD(I3P,I),I=1,15),(ZKUN(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 (ZKUN(I,I2P),I=1,16),CASCAD(I2P,1),CASCAD(I2P,2)
IF (IPUN.GT.0) WRITE (7,401) (CASCAD(I2P,I),I=1,15),(ALPHA(I,I2P),
1 I=1,15),(CASCAD(I2P,I),I=1,15),(RHO(I,I2P),I=1,15),
2 (CASCAD(I2P,I),I=1,15),(ZKUN(I,I2P),I=1,16)
304 ZLIBR1=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=1.0*5*HR8
DZ3N=1.0+HRP*DP(I3N)*PN3N
DZ2N=1.0+HRP*DP(I2N)*PN2N
DZ3PA=1.0+HRP*DP(I3P)
DZ2PA=1.0+HRP*DP(I2P)
DZ3NH=1.0+HRP*DP(I3N+10)
DZ2NH=1.0+HRP*DP(I2N+10)
DZ3PK=1.0+HRP*DP(I3P+10)
DZ2PK=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)=ZKSN(I,NCLHD)
DEN(2)=ZKBN(I)
DEN(7)=ZKB8(I)
DEN(8)=ZKSN(I,NCLDC)
DEN=ZKMICA(I)
DCRH=ZKF7EM(I,ICRH)
DRCR=ZKF7EM(I,ICRC)
DEN3=ZKUN(I,I3N)
DEN2=ZKUN(I,I2N)
DEN3=ZKUN(I,I3P)
DEN2=ZKUN(I,I2P)
DO 249 I=1,15
RHP(I)=RFETM(I,IPIN)
WRITE (6,282)
WRITE (6,283)
WRITE (6,253) (TTT(I), Z2NA(I), Z2NR(I), Z2NK(I), Z2PA(I), Z2PR(I),
1 Z2PK(I), I=1,15)
WRITE (6,100) (CMT(J), J=1,25)
WRITE (6,285)
285 FORMAT (1HO, /16X, 4(12HFIG=OF=MERIT, 3X), 2(12HCONDUCTIVITY, 3X), /8X,
1 5HTEMP., 2(7X, 5HN=LEG, 10X, 5MP=LEG, 3X), 3X, 27HBN INSULATOR INTER-C
20UPLE, /7X, 6HDEG. K, 5X, 2(9H HOT SIDE, 6X), 2(9HCOLD SIDE, 6X), 24H SELF
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)
FM2P(I)=Z2PA(I)*Z2PA(I)/Z2PRK(I)
250 FM2P(I)=Z2PA(I)*Z2PA(I)/Z2PRK(I)
WRITE (6,253) (TTT(I), FM3N(I), FM3P(I), FM2N(I), FM2P(I), ZKB(N(I),
1 ZKMIC(i), I=1,15)
WRITE (6,100) (CMT(J), J=1,25)
WRITE (6,286) HOT, COLD, SSIN(NCLOH), SSIN(NCLOC), FETM(ICRH),
1 FETM(ICRC), FETM(ICCR), FETM(ICRC)
286 FORMAT (1HO, /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), ZK1N(I), ZK1S(I), ZKCRH(I), RCRH(I), ZKCRC(I),
1 RCRC(I), I=1, 15)
RETURN
END
SUBROUTINE COUPLE

COMMON /MDCP0P/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
1 QT(300),N0PTIM,VPC(300),RLPC(300),DTM0D(300),CUR(300),LNRAD(9),
2 ZLP,ZLN,ZNLP,ZNPLI,ZNTE,NGT1,NGT2,ITPERT,PCMULT,ND0UMP,IVO,
3 OGEN,GENL,QTE,QOUT,ZID,Z00,ZKEND,ZK8,ZK8,RP8,RP8,T0LTEM,TEJ,
4 VRE8,PEREQ,ZLREQ,WTC0N,ZLIP,INDM,ZN,GR8,GR8,DLR,DGLR,RADK,JD0UMP,
5 DP(30),NC

COMMON /MDCP0L/CURMOD(15),IT(300),OTT8,CONRN,CONRP,ZLP,ZNC,
1 AL84,MXTEM,GGAM,CGAM,INDI,INT4,INT6,RC0N4,RC0N6,C1FE8,C1FE8,
2 CON8t,CONST2,CONST3,CONST4,CONST5,NR5OPT,SEGTE,ICRM0L,RA0C

COMMON /DATIN/TT8(15),ZKMC1(15),ZKMC2(15),ZKSS(15),ZKBN(16),
1 ZKIN(15),ZN0(15),ZN0R(15),ZN8A(15),ZN8P(15),ZN8P(15),
2 ZN0R(15),ZN8PR(15),Z3NA(15),Z3NA(15),Z3R1(15),Z3PA(15),
3 Z3PR(15),Z3PK(15),Z3PK(15),ZKCRH(15),ZKCRH(15),
4 RHP(15),RPR8H0

COMMON /TITLE/ETM(3),CASCAD(8,2),SSINC3),CMT(25),COND(3,5),TEMKF,
1 CRM(2,2),IN,IZN,IZP,1P

COMMON /CPLRIT/DT(8,300),OPTZLP(300),OPTCPL(300)

DIMENSION XZK(9),Z0K(9),TCON(11),ZKEQ(8),B(100)

REAL LNRAD

 DATA X2K/9*0,/,LNDUMP/0/,ZKTEP/0,/,ZKTE0/0,/,TS0P/670,/,ZKEQ/8*0,/
 DATA B/ ,6HTFEH, ,6HZKPI, ,6HRT4, ,6H2K0T, ,6HTFEH, ,6HZKPI, ,
 16HRTN6, ,6H0SAVE, ,6HERH, ,6HZKNI, ,6HTC0LH, ,6H0GEn, ,6HFERC,
 26HZ2K12, ,6HTC0LC, ,6H0GAM, ,6H0LP1, ,6HZKII, ,6HT0N, ,6H0T0M1, ,
 36H0LP2, ,6HZKI2, ,6HTBCO, ,6H0T0M2, ,6HALN1, ,6HZKTP, ,6HT0M0D,
 46Hz0T0M1, ,6HALN2, ,6HZK0N, ,6H0T8, ,6H0T0M2, ,6HZKR, ,6HZKTE,
 56H0T0M, ,6H0T8, ,6H0HP1, ,6HZKETQ, ,6H0CON, ,6H0C, ,6H0HP0,
 66HZKE0PC, ,6HALT1, ,6H0P, ,6HRH0N1, ,6HZLP, ,6MAT2, ,6HQJ,
 76HRH0N2, ,6HZLN, ,6HALM1, ,6H0Q0, ,6HRH0P, ,6HZLT8, ,6HALM2,
 86H0Q0, ,6HRH0N, ,6HRP, ,6HALNC, ,6H0VC, ,6H0ST1, ,6HRN,
 96HALNC2, ,6HRPC, ,6H0ST2, ,6H0FEH, ,6HALPH1, ,6H0V0C, ,6H0ST3,
 A6HRFEC, ,6HALPH2, ,6HCUR, ,6H0ST4, ,6H0T8FH, ,6HALP1, ,6HPE,
 16HZK0HOT, ,6HRT0FC, ,6HALPC2, ,6H0TE, ,6HZK0LD, ,6HRPC, ,6HRPC,
 26HQT, ,6H0G0L, ,6H0B0L, ,6HTER0L, ,6HT0B0L, ,6H0CMULT/

T0LTEM=AMAX1(T0LTEM, .001)

NSEG=SEGTE  
YNCT2ZNC

IF (NGT1.GE.3) YNC=PCMULT

ZK0E0PC=ZKEND/YNCT

CONST6=0.5*ZLREQ/(ZL1*YNCT)-1.0

DO 6010 I=1,NC

Q30AVE=0.

ITNOW=0
C INITIALIZE RADIAL TEMPERATURES
IF (IND1,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*CONNR/SI(TT1,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)
J = J + 1,8
4052 DT(J,I) = TEMP(J,I) - TEMP(J+1,I)
DO 4054 J = 1,7
DO 4054 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) = AMIN(AMAX(TSUP,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)/SEGT
DELT2 = DT(5,I)/SEGT
TT1 = TEMP(5,I) + .5*DELT1
TT2 = TEMP(6,I) + .5*DELT2
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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
   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

20
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,Z3PA,TEMP(5,I),15,IND,1,1)
        ALNH2  = SI(TTT,Z3NA,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,Z3PA,TEMP(6,I),15,IND,1,1)
        ALNC2  = SI(TTT,Z3NA,TEMP(6,I),15,IND,1,1)

        QP=TEMP(4,I)*(ALPH1+ALNH1)+TEMP(5,I)*(ALPH2+ALNH2-ALPC1-ALNC1)

CUTIMATE OPTIMUM SEGMENTING RADIUS, RA0, IF SPECIFIED

        IF (NRSQPT.EQ.0) GO TO 4061
        RAD(5)=RAD(6)
        IF (OT(5,I).LE.0.) GO TO 4062
        TT2=1.0/(TTT+1.0)
        RAD(5)=RAD(6)**(TT1*TT2)**TT2)
        IF (HAD(5).LT.RAO(a),OR
        RAD(5).GT.RAD(b))
        4062  LNRAD(4)=ALOG(RAD(5)/RAD(4))
        LNRAD(5)=ALOG(RAD(5)/RAD(4))

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)

CUTIMATE 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
4002  IF (IVD.NE.2) GO TO 1097
        ZKI=ALR64/(LNRAD(5)/ZKI+LNRAD(4)/ZKI)
        ZLNLP=ZLNLPSQRT((CONST6-ZKI/ZKTEP)/(CONST6-ZKI/ZKTEP))
        ZLN=ZLI*CONST6/(ZLNLP+ZLNLP)
1097  ZLP=ZLN/ZLNLP
        ZLP=2.0*ZLI/ZLP
        CONST5=15.9593*ZLP
        ZLPN= ZLN+ZLP

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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 (ICRMDC,NE.,0) GO TO 4005
C1FEH=15.9593*DR(3)*(RAD(3)+RAD(4))/ZLTE
C1FEC=15.9593*OR(6)*(RAD(6)+RAD(7))/ZLTE
GO TO 4042
CALCULATE RADIUS OF CIRCULAR CONDUCTOR RING ELECTRICAL STREAMLINE
4005 RCHOT=AMIN1(DR(3),ZLN,ZLP)
RCHOT=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*RCHOT/ZLI+1,0)
CALCULATE COUPLE RESISTANCE
4042 RINTFH=RINT4*TEMP(4,I)*TEMP(4,I)
RINTFH=RINT6*TEMP(6,I)*TEMP(6,I)
TFEC = TEMP(7,I) + .5*DT(6,I)
TFEC = TEMP(6,I) + .5*DT(6,I)
FERC = SI(TTT,RCRC,TFEC,15,IND,1,1)
FERC = SI(TTT,RCRC,TFEC,15,IND,1,1)
RFEC=RFHC/C1FEH
RFEC=RFHC/C1FEC
RN = CONRN*RHON
RP = CONRP*RHOP
RPN=RP*RN
TTE=.5*(TEMP(4,I)+TEMP(6,I))
RPC=RP*RH0*SI(TTT,RH0,TTE,15,IND,1,1)/YNC
QJ*RFHC+RINTFH+.5*RPN
RPC(I)=QJ+.5*RPN+RFHC+RINTFC+RPC
CALCULATION OF THERMAL CONDUCTANCES
TBNC= TEMP(3,I) +.5*DT(2,I)
TBNC= TEMP(8,I) +.5*DT(7,I)
TCLDH = TEMP(2,I) +.5*DT(1,I)
TCLDH = 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,TBNC,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,115,IND,1,1)*ZLI)/ZLTE
XZK(6)=(SI(TTT,ZKCRH,TFEC,15,IND,1,1)ZLPNI+SI(TTT,ZKMIC2,TFEC,115,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) <= 0.0) ZK(4)=1.0E30
ZK(5)=CONST5*(ZLNLP*ZKN2+ZKP2+ZLIP*ZKI2)/LNRAD(5)
IF (LNRAD(5) <= 0.0) ZK(5)=1.0E30
ZK(10)=ZK(4)*ZK(5)/ZK(a)*ZK(5)/ZLTE/(ZK(8)+ZK9*ZLTE)

CALCULATION OF VOLTAGES AND CURRENT

VGC(I) = DT(4,I)*ALT1+DT(5,I)*ALT2
IT(1)=T(1)+1
ITNOW=ITNOW+1
ITCON=ITNOW=MAXTEM
ITCON=MAXO(ITCON,1)
QC=DTE*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)*SQR(T(1)+VOC(I)*(QP-VOC(I)*QJ/RLPC(I)))/(RPC(I)*(QC+1 QEND))
GO TO 4048
4044 QTE=PCMULT*VOC(I)=VREG
RLPC(I)=1.0E30
IF (QTE.GE.0.0) RLPC(I)=VREG*RPC(I)/QTE
4048 CUR(I)=CURMOD(INDI)
IF (NGT1.GE.3*DI,INDI,EQ.1) CUR(I)=VOC(I)/(RPC(I)+RLPC(I))
4046 VPC(I)=VOC(I)*CUR(I)*RPC(I)

CALCULATE ENERGY TERMS

QTOMP1=CUR(I)*(ALPH1*TEMP(4,I)-ALPC1*TEMP(5,I)-ALP1*DT(4,I))
QTOMP1=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)

CALCULATE EFFICIENCY
QT(I) = QIN + QGAM
QOUT = QT(I) * PE(I)
ZKHOT = 1.0 / (1./ZK(1) + 1./ZK(2) + 1./ZK(3))
ZKCOLD = 1.0 / (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)

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
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 (RAPC 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
TEMP(J, I) = TEMP(J1, I) = DT(J1, I)
5006 DT(J, I) = ZKDT / ZKEQ(J)
TCON = TCON + ABS(1. - QSAVE / QT(I))
QSAVE = QT(I)
GO TO 5007
CALCULATE HOT CLAD TEMPERATURE IF HEAT GENERATION RATE IS SPECIFIED

5001 ZKDT=QGEN-QEND
5002 J=1,8
J9=9-J
DT(J9,I)=ZKDT/ZKEQ(J9)
5002 TEMP(J9,I)=TEMP(J9+1,I)+DT(J9,I)
TCP=1(1)=2,QSAV=1(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) (CUT (J), J=1,25), INDJ, IT(I), I
100 FORMAT (1H1,4X,2A4,1X,18A4,2H (, F2,0,2(1H/,F2,0),2H), 2A4//
1 20X, 19H CURRENT ITERATION,15, 23H, TEMPERATURE ITERATION,
1 I5,11H, ON COUPLE,15/11X,3HRAD,11X,4HTEMP,12X,2HDT,12X,3HZK,9,
2 13X, 2HZK, 12X, 4HZKEQ, 13X, 5HLNRAD)
WRITE (6,3002) (J),RAD(J),TEMP(J,I),DT(J,I),ZK(J),ZKEQ(J),I
1 LNRAD(J=100),I=1,8
3002 FORMAT (I3,1H,/,7G15.5)
3003 J=I
WRITE (6,3003) J,INDJ,IT(I),DTMOD(I),ZK9,PCMULT,ALR64
3003 FORMAT (I3,1H,/,7G15.5,15X,7G15.5//)
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),FEC,B(14),ZKN2,B(15),TCLDC,B(16),OGAM
WRITE (6,3004) B(17),ALP1,B(18),ZKI1,B(19),TBHM,B(20),QTOMP1
WRITE (6,3004) B(21),ALP2,B(22),ZKI2,B(23),TBHC,B(24),QTOMP2
WRITE (6,3004) B(25),ALN1,B(26),ZKTEP,B(27),DTMOD(I),B(28),QTOMP1
WRITE (6,3004) B(29),ALN2,B(30),ZKTEM,B(31),DTT,E,B(32),QTOMP2
WRITE (6,3004) B(33),ZKR,B(34),ZKTE,B(35),TOLFH,B(36),QTOM
WRITE (6,3004) B(37),RHOP1,B(38),ZKTEO,B(39),TCON1TCON1,B(40),WC
WRITE (6,3004) B(41),RHOP2,B(42),ZKEPC,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,R(62),R(N,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),PET(I)
WRITE (6,3004) B(77),ZKMDT,B(78),RINTFC,B(79),ALPC2,B(80),QTE
WRITE (6,3004) B(81),ZKCOLD,B(82),RPPC,B(83),RLPC(I),B(84),QI
3004 FORMAT (2X,4(G6.1H=,6G15.5,10X))
IF (INDI,EQ.0) WRITE (6,3006)
3006 FORMAT (1HO, 21X, 66H This case dumped, then suppressed because optimum ZLP is imaginary)
   IF (NODUMP.EQ.1. AND. ITCON.LT.11) GO TO 3007
WRITE (6, 3008) ( TCON(J), J=1, ITCON)
3008 FORMAT (10HO TCON = , 10(F9.6, 1H))
   GO TO 4000
3007 IF (ITCON(ITCON).GT.TOLTEM) GO TO 3009
   IF (NODUMP.EQ.2) GO TO 3112
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/TIT(15),ZKMIC1(15),ZKMIC2(15), ZKSS(15),ZKBN(16),
1 ZKN(15),Z2NA(15),Z2NR(15),Z2NK(15),Z2PA(15),Z2PK(15),
2Z2NRK(15),Z2PRK(15),Z3NA(15),Z3NR(15),Z3NK(15),Z3NKK(15),Z3PA(15),
3 Z3PR(15),Z3PK(15),Z3PRK(15),ZKCRH(15),ZKCR(15),RHR(15),RPRH
COMMON /FDDAT/ALPHA(15,8),RHO(15,8),ZKDN(16,8),ZKSSIN(16,3),
1 RFETM(15,4),ZKFETM(16,3),ZKMIC(16)
COMMON /TITLE/FETM(5),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMF,1
1 CRMN(2,2),13N,12N,13P,12P
C TEMPERATURE AT WHICH EACH PARAMETER IS EVALUATED (DEG.K)
DATA TIT /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,
1 1.803E-04,1.960E-04,2.097E-04,2.205E-04,2.254E-04,
2 2.254E-04,2.185E-04,2.009E-04,1.735E-04,1.303E-04,
3 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-04,2.336E-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-04,2.694E-04,2.508E-04,2.394E-04,
C SEEBECK COEFFICIENT OF RCA-N8 MATERIAL (VOLTS/DEG.K)
1 1.030E-04,1.210E-04,1.480E-04,1.610E-04,1.820E-04,
1 2.020E-04,2.230E-04,2.450E-04,2.600E-04,2.660E-04,
1 2.620E-04,2.530E-04,2.430E-04,2.300E-04,2.140E-04,
C SEEBECK COEFFICIENT OF RCA GST-E 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-04,3.04E-04,2.19E-04,4.86E-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, .0037710, .0039870, .0041930,
C RESISTIVITY OF TEGS-2N AND GE-NL MATERIAL (OHM-CM)
1 .0004132, .0005932, .0008393, .0011702, .0015737,
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<th>Material Type</th>
<th>Conductivity Data (Watts/cm/°C)</th>
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<td>TEGS-3P</td>
<td>0.0375000, 0.0305000, 0.0246000, 0.0190000, 0.0160000, 0.0130000, 0.0114000, 0.0110000, 0.0112000, 0.0119000, 0.0135000, 0.0160000, 0.0206000, 0.0265000, 0.0350000, 0.298</td>
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<td>TEGS-2P</td>
<td>0.0428878, 0.0348821, 0.0281344, 0.0227591, 0.0182988, 0.0148678, 0.0135000, 0.0118000, 0.0108000, 0.0103000, 0.0103000, 0.0109000, 0.0128000, 0.0130000, 0.0130000, 0.0130000, 0.298</td>
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<td>RCA-NB</td>
<td>0.02000, 0.01799, 0.01610, 0.01430, 0.01270, 0.01110, 0.01010, 0.00971, 0.00974, 0.01010, 0.01060, 0.01130, 0.01220, 0.01330, 0.01470, 0.296</td>
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<td>RCA-P(A)</td>
<td>0.03450, 0.02700, 0.02220, 0.01890, 0.01560, 0.01350, 0.01180, 0.01080, 0.01030, 0.01030, 0.01090, 0.01280, 0.01810, 0.03030, 0.0653, 0.298</td>
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<td>60RON Nitride</td>
<td>0.02820, 0.02790, 0.02770, 0.02740, 0.02720, 0.02700, 0.02700, 0.02700, 0.298</td>
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<td>Iron</td>
<td>0.0250, 0.0150, 0.0130, 0.0120, 0.0110, 0.0101, 0.0101, 0.0101, 0.0101, 0.0101, 0.0101, 0.0101, 0.0101, 0.0101, 0.0101, 0.0101</td>
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<tr>
<td>RCA-TE P-type</td>
<td>0.3030, 0.3010, 0.2990, 0.2960, 0.2940, 0.2910, 0.2890, 0.2860, 0.2840</td>
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C Resistivity of TEGS-3P Material (Ohm-cm): 1 0.0032652, 0.0038738, 0.0043984, 0.0049828, 0.0055656, 0.0061739, 0.0067889, 0.0074129, 0.0080599, 0.0087219, 0.0094001, 0.0101061, 0.0108311, 0.0115751, 0.0123391, 0.0131241

C Resistivity of TEGS-2P Material (Ohm-cm): 1 0.0026552, 0.0032652, 0.0038738, 0.0044982, 0.0051542, 0.0057310, 0.0063078, 0.0068946, 0.0074814, 0.0080682, 0.0086550, 0.0092418, 0.0098286, 0.0104154, 0.0109722, 0.0115642

C Resistivity of RCA-NB Material (Ohm-cm): 1 0.0009940, 0.0010799, 0.0012395, 0.0014972, 0.0018408, 0.0022090, 0.0026753, 0.0031539, 0.0036939, 0.0042400, 0.0047615, 0.0053486, 0.0059357, 0.0065228, 0.0071099, 0.0076970

C Resistivity of RCA-TE P-type Material (Ohm-cm): 1 0.0004031, 0.0005493, 0.0007445, 0.0009987, 0.0013165, 0.0017342, 0.0022517, 0.0028237, 0.0035227, 0.0042400, 0.0046728, 0.0050048, 0.0053368, 0.0056688, 0.0060008, 0.0063328

C Resistivity of RCA-N(A) Material (Ohm-cm): 1 0.0000208, 0.0002655, 0.0003265, 0.0003874, 0.0004398, 0.0004983, 0.0005566, 0.0006174, 0.0006789, 0.0007413, 0.0008060, 0.0008722, 0.0009400, 0.0010106, 0.0010831, 0.0011575, 0.0012339, 0.0013124

C Resistivity of RCA-P(A) Material (Ohm-cm): 1 0.0009940, 0.0010799, 0.0012395, 0.0014972, 0.0018408, 0.0022090, 0.0026753, 0.0031539, 0.0036939, 0.0042400, 0.0047615, 0.0053486, 0.0059357, 0.0065228, 0.0071099, 0.0076970
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</table>
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 /MODLOPT/IPDWT, DR4, DRINC, IRITE, DRTE, JOPTIM, IZ9, IENOK, IPUN,
1 RINIC, RINC, R1MAX, R9MAX, DIMIN, OREQ, THINC, TCINC, TCMAX, TMAX
2, NPERT, ZNPERT, CKFP, CKFT, CITEOC, CTEIC, CETLIL, RELPRT, RLMAX, ZNMIN, Z9SAV
COMMON /TITLE/FETM(3), CASCAD(8,2), SSIN(3), CMT(25), COND(3,3), TEMKF,
1 CRMO(2,2), I3N, I2N, I3P, I2P
COMMON /MDCPOP/RAD(9), DR(8), TEMP(9,300), VDC(300), RPC(300), PE(300),
1 QT(300), NOPTIM, VPC(300), RLPC(300), DTMOD(300), CUR(300), LNRAK(9),
2 ZLP, ZLN, ZLITA, ZLPNI, ZRTE, ZT1, ZT2, ITPERT, PCMULT, NODUMP, IVD,
3 QGEN, QGENL, QTE, QOUT, ZID, ZOD, ZKEND, ZK9, ZKR, RPPC, RPM, TOLTEM, TRED,
4 VREQ, PERRQ, ZLR, VTMON, ZLPN, I3UMZ, 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 4HCYK, 4HLEN, 4H (I, 4HN.), 4H RL, 4HLOAD, 4H (OH, 4HMS), 4H RL,
2 4HLOAD, 4H (M=O, 4HMS) /, POFT/4HDPEN, 4H/WCC, 4H WT, 4HLS, 4H CUR, 4H
3MPS, 4H TS, 4HDEG, /, OMD(3) M=1H, 1HC, 1HH/ , DRCP/4H DR5, 4H DRT8,
4 4H NO, 4HCPESLS, SKP1/1H, 1H0, 8H1H, 1H* /,
EQUIVALENCE (VPL1(1), OCV) , (VPL1(3), ZLIR)
REAL LNRAD
IF (ISECT.EQ.2) GO TO 3051
C - INITIALIZE VARIABLES USED IN OPTIMIZATION ROUTINE
IRTRN=1
IF (JOPTIM.NE.0) GO TO 4014
JOPTIM=1
IPERT=0
PCPERT=NPERT
PCSAV=PCMULT
RLOAD=PCMULT*RLPC(1)
IRIT=4
C IV0=1, TEMPERATURE PARAMETRIC WITH SPECIFIED GEOMETRY
C IV0=2, TEMPERATURE PARAMETRIC WITH SPECIFIED LENGTH AND VOLTAGE
C IV0=3, TEMP, PARAMETRIC WITH SPECIFIED LENGTH AND NO. OF COUPLES
C IV0=4, PARAMETRIC ON NO. COUPLES WITH SPECIFIED VLOAD AND LENGTH
C IV0=5, PARAMETRIC ON NO. COUPLES WITH SPECIFIED VLOAD AND POWER
RLOM=1000.
IDRCP=2
IPDWT=1
ISKP=2
ZLIR=PCMULT*ZLITE
C - INITIALIZE PARAMETERS FOR CURIUM STUDY CALCULATIONS
NPO2=NOPTIM/2
D-69
IF (NOP2.NE.2) GO TO 6000
QCv=0.
Q=0.
IF (NOPTIM.EQ.5) NC=2
IVPL=3
IVRL=1
TREJ=TREJ*TREJ*TREJ*TREJ*TREJ
DGTRF=1./DGTRF
TEMP(1,2)=TEMP(1,1)
TEMP(9,2)=TEMP(9,1)
ISKP=2
IPDNT=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 (RLHAD.LT.1.) GO TO 3999
RLOM=1.0
IVRL=4
3999 IPDNT=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/PCHLT=ZL1
ZLP=ZLN
IVD=3
ZCIR=ZLTE
3998 IF (VREQ.LE.0.) GO TO 4002
IVD=2
RLPC(1)=0.
IF (NPFR.T.E.0) GO TO 4002
NGT1=4
NGT2=4
IVD=4
IPDNT=3
RLPC(1)=1.0E10
IF (PERQ.E.0. AND. NREQ.E.0.) GO TO 4002
IVD=5
PCPERT=1.
CUREQ=PEREQ/VREQ

4002  IVRL=1
    IF (NGT2.GE.4) IVRL=5
    IVPL=1
    IF (IVRL.EQ.1) IVPL=2
    IRSRIPRT=2
    IF (DRINCR.LE.0.) GO TO 4004
    IF (NOPTIM.NE.2) IRSRIPRT=1
    IPDWTL=4
    IDRCPR=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)/THING+1.
      IF (NOPTIM.GT.3) I=2*1
      J=(39/I)*I

4038  LCNTM=AMAXO(2,J)
      ZLNSAV=ZLN
      ZLPSAV=ZLP
C - INCREMENT 0.0, 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))
      WRITE(6,4010) ZIO,ZOO,DR(1),DRTE,DR(8)
      4010 FORMAT (13X,4H1.0,,8X,1H=,F8.4,4H IN.,45X,4H0.0,,8X,1H=,F8.4,
      14H IN.,/26H INNER CLAD THICKNESS =,F8.4,4H IN.,9X,6HORTE =,F7.4,
      2 4H IN.,/10X,22HOUTER CLAD THICKNESS = F8.4,4H IN. )
      IF (ZCIR.LE.0.) GO TO 4061
ZLPNI=ZLP+ZLN+ZLI
WT=WTATE(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 1A3,4HOMHS,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 19H 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(1,1DRCP),(VPL(I,IVPL),I=1,2),(VPL(I,IVRL), 1 I=1,2),(CRMD(1,1ENDK),I=1,2),PDWT(1,1PDWT),TEMKF,TEMKF,DRCP(2, 2 1DRCP),(VPL(I,IVPL),I=3,4),(VPL(I,IVRL),I=3,4),PDWT(2,1PDWT)
4044 FORMAT (17HO THOT TCDLD,4X,A4,14H ZLN ZLP,4X,2A4,2X, 1 2A4,4X,3OHREX 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))
LCNTS=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.
ITRTRN=2
P=PCMUL*PE(1)
VLD=PCMUL*VPC(1)
IF (((ABS(1.,OCV/VLD)+ABS(1.,-V/P)),LT.,01.OR.IPERT.GT.10) GOTO 4001
IPERT=IPERT+1
PCMULT = IFIX(VREQ/VPC(1)) + 1
ZLN = (P*VREQ/ZLN)/(PE(1)*PCMULT*(1.0 + ZLN/ZLNLP)) + ZLN*5
OCV = VLD
Q = P
IF (NOPTIM.EQ.4) TEMP(1, 2) = TEMP(1, 1) + 20.
D = DLRF*EXP(16616.0*(DGTRF - 1.0 TEMP(1, 2)))/ZLN
D = MIN(D, 75)
DP(12) = D*(RPC(NC) + DP(12)*(RPC(NC) - RNP)/(RNP*(1.0 - D))
IF (NOPTIM.EQ.5) DP(12) = 0.
CALL PHONIX(DP, JDUMP, 100000.)
RETURN

6001 OCV = PCMULT*VOC(1)
IF (IVD.EQ.1) GO TO 4001
IF (IZLP.NE.2) GO TO 4035
TOLTEM = 10.0*TOLTEM
GO TO 4001

4035 TOLTEM = 1.0*TOLTEM
IZLP = 2
IRTRN = 2
IF (IVD.EQ.2) GO TO 4028

4027 IF (PEREQ.LT.0.0) GO TO 4018
IF (OCV.LE.VREQ) GO TO 4029
ZLN = ZLN/(1.0 + VOC(1) - VREQ/PCMULT - CUREQ*RPC(1))/(CUREQ*RNP))
IF (ZLN.GT.0.) RETURN
PCMULT = PCMULT + 1
GO TO 4037

4018 IF (QREG.GT.0.0) ZLREQ = (QREG = ZKEND*DTMOD(1)) ZLTE/GT(1)
ZLN = (ZLREQ/PCMULT = 2.0*ZLI)/1.0 + 1.0/ZLNLP)
4020 IF (VREQ.LE.0.0) RETURN
CALCULATE MINIMUM NO. OF COUPLES TO ACHIEVE SPECIFIED LOAD VOLTAGE
P = OCV = VREQ
IF (P.LE.0.0) GO TO 4029
RLPC(1) = VREQ/RPC(1)*ZLP*ZLNLP/(P*ZLN)
RETURN

4029 PCMULT = IFIX(VREQ/VOC(1) + 2.0)
TOLTEM = 10.0*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
4026 PCMULT = IFIX(VREF/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=70.0)-CTEUC*(TEMPCF=70.0))
IF (ZLREQ.GT.0.) ZCIR=ZLREW
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*QMOD(1)/PCMULT)
IF (ETAO.LT.ETAMAX) GO TO 4015
ZCIR=ZLTE*PCMULT
RLLOAD=PCMULT*RLPC(1)
VRL=VRLM*RLLOAD
VRL(1)=PCMULT*VOC(1)
DRCP1(1)=100.0*DR(5)/DRTE
DRCP1(2)=PCMULT
VOL1=51.48*ZCIR*RDL(1)*RDL(1)
VLD=PCMULT*VPC(1)
OHM=PCMULT*RPC(1)
P=PCMULT*PE(1)
Q=PCMULT*QT(1)
VPL1(2)=CUR(1)
IF (IPDMT.EQ.2) PWCT(IPDMT)=WATE(QMOD)
PWCT(3)=CUR(1)
PWCT(4)=DK2FK(TEMP(5,1))
IF (NOPTIM.NE.2) GO TO 4003
ETAMAX=ETA0
QMOD=ZLP
PWCT(1)=ZLN
GO TO 4017

4015 ZLP=QMOD
ZLN=PWCT(1)
ETA0=ETAMAX

4003 QMOD=Q+ZKEND*QMOD(1)
PWCT(1)=QMOD/VOL1
IF (IPUN.EQ.3) WRITE (/4055) TEMPHF,TEMPCF,QMOD,OCV,VLD,CUR(1),0,
1 (CMT(J),J=21,23)
4055 FORMAT (THREF MOD,12X,2F7.1,F8.2,3F8.4,F8.2,3A2/1H )
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IF (IPUN.EQ.1) WRITE (7,4050) ZID,ZOD,TEMPHF,TEMPCF,ZCIR,VLD,OHM,1 ETAO,P
4050 FORMAT (1X,2F7.3,2F7.1,1E10.3)
IF (NOPTIM.NE.3) GO TO 4031
JQPTIM=JQPTIM+1
VOC(JQPTIM)=OCV/(DTMOD(1)*CKFT)
RPC(JQPTIM)=OHM
QT(JQPTIM)=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) ZIO,ZOO,DR(1),DRTE,OR(8)
IF (RLOAD.LT.1.) GO TO 4034
RLOM=1.0
IVRL=4
VRL(4)=RLOAD
4034 WRITE (6,4044) DRCP(1,1),DRCP(1,1),VPL(1,IVPL),I=1,2,
1 I=1,2),(1MD(1,1),1=1,2),PDWT(1,IPDWT),TEMKF,TEMKF,DRCP(2,2)
IDRCP(1),VPL(1,IVPL),I=1,3,4),(VPL(1,IVRL),I=1,3,4),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 (1X,1F7.1,F9.1,2F6.1,2F8.1,10F3.1,2F10.4,10F3.1)
CALL PHONY(OP,JOUMP,100000.)
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IPERT=0
GO TO 4025
6006 WRITE (6,6008) D,PWCT(1),PWCT(2),IPERT
6008 FORMAT (22X,2PF6.1,1PF8.2,F9.2,59X,16)
   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 (5001,50Q«?,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
   RLUM=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*ORTE
   RAD(5)=RAD(4)+DR(4)
   DR(5)=RAD(6)-RAD(5)
   IRTRN=3
   IF (DR(4).GT.,ORTE) GO TO 4008
   LRAD(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) 3KP(2)
4016 DR(4)=DR4

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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 2 111,2612.5)
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.*ZL1
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=ZLN+ZLP
ZLP=ZLP
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 HIC 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/F WASHER THICKNESS
4023 IF (TEMP(1,1).GT.THMAX) GO TO 3062
   IF (IZ9.EQ.1) GO TO 4019
   DR(5)=DR(5)+RDINC
   IF (DR(5).GT.R9MAX) GO TO 3062
   ITRN=4
   RETURN
C - INCREMENT OUTER DIAMETER
4019 RAD(9)=RAD(9)+RDINC
   IF (RAD(9).GT.R9MAX) GO TO 3062
   ITRN=6
   RETURN
C - INCREMENT INNER DIAMETER
3062 RAD(1)=RAD(1)+RIINC
   IF (RAD(1).GT.R1MAX) GO TO 4024
   ITRN=7
   RETURN
4024 IF (NOPT1M.NE.3) GO TO 4030
C - INCREMENT OUTER DIAMETER
C - INCREMENT INNER DIAMETER
CALCULATE AND WRITE TEMPERATURE DERIVATIVES, IF SPECIFIED
P=.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 (1HO/36X,34HCALCULATED TEMPERATURE DERIVATIVES)
WRITE (6,4071) OMHD(3),VOC(4),TEMKF,TEMKF
4071 FORMAT (1HO33X,6H#AL/8T,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(OP)
COMMON /MDCPOP/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
1 QT(300),NOPTIM,VPC(300),RLPC(300),DMOD(300),CVR(300),LNRAD(9),
2 ZLP,ZLN,ZLPN,ZLTP,LTEN,LTGZ,ITPRT,PCMULT,NDUMP,IVD,
3 UGEN,GENL,GEQ,GEOUT,GEZD,GEZD,GEKND,GEK,RCPC,RPNC,TOL,TEN,TREJ,
4 VREQ,PEREQ,ZLREQ,WTCON,ZLPC,ITUMZ,RN,DRF,DRG,DRG,DRF,DRK,JUMP,
5 DP(30),NC
COMMON /MODCPL/CURMOD(15),IT(300),DTTE,CUNRN,CONRP,ZLP,ZNC,
1 ALR64,MAXTE,QGAM,CGQM,INDI,RTN4,RTN6,RCON4,RCON6,C1FEC,C1FEC,
2 CONST1,CONST2,CONST3,CONST4,CONST5,NRSOPT,SEGTE,ICRDL,RADC
COMMON /MODOPT/IPOPT,DR4,DRINC,IKITE,DRTE,JOPTIM,IZ9,EMD,IPUN,
1 RIINC,RIINC,RIINC,RIINC,RIINC,RIINC,RIINC,RIINC,RIINC,RIINC,
2,NRPTZP,NPPERT,CNTF,CKFT,CNTF,CNTF,CNTF,DLT,RLPC,RLMAX,ZNMIN,Z9SAV
COMMON /TITLE/FETM(3),CASCAD(8,2),SSIN(3),CMT(25),COND(3,5),TEMKF,
1 CRMD(2,2),I3N,I3N,I3P,I3P
COMMON /MDLIF/HRS,HRINC,HRMAX,HFLF,RADPCT,ITCR,ITHQ
DIMENSION CIRMODC2)
DATA CIRMOQ/4HCIR ,aHM()D /
QEPC = ZKEND * PCLMODU)/PCMUIT
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(JH/,F2.0),2H),2A4)
WRITE (6,101) CIRMOD(IENDK),CIRMOD(IENDK),TEMKF,TEMKF
101 FORMAT (//92HO TIME THOT TCOLO RLOAD R6EN RGEN
1 VOC VLOAD CURRENT POWER N-,A4,7H ETA-,A1/
2 9X,5MHOURS,2(8H DEG.,A1),2(9H M=OHMS),2(9H WATTS),
3 9H AMPS ,2(9H WATTS),9H PCT.,/
QBOL=0.
IF (ITHQ,NE.1) ZKRA=0OUT+QEOC/((TEMP(9,1)-TREJ)
102 IF (ICTR,NE.1) ZKRA=GOUT+QEOC/((TEMP(9,1)-TREJ)
110 TEMPHF=DK2FK(TEMP(1,1))
2PCDCF=DK2FK(TEMP(9,1))
RLOAD=CMULT*RLPC(1)
UH=CMULT*RPC(1)
C=CMlK(1)
OCV=CMULT*VOC(1)
VOD=CMULT*VPC(1)
P=CMULT*PE(1)
Q=PCMULT*(GT(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=QBO*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 (140//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/IPDW, DR4, DRINCR, IRITE, DRT, JOPTIM, IZ9, IENDK, IPUN,
1 RIINC, ROINC, R1MAX, R9MAX, DMIN, QREG, THINC, TCINC, TCMAX, THMAX
2, NPERT, ZNPERT, CKFP, CKFT, CTEIC, CTEIC, DELTL, RLPERT, RLMAX, ZNMIN, Z9SAV
COMMON /MDCPOP/RAD(9), DR(8), TEMP(9, 300), VMC(300), RPC(300), PE(300),
1 QT(300), NRPTE, VPC(300), RLP(300), DNTM(300), CUR(300), LRLRT(9),
2 ZLP, ZLN, ZLI, ZLNP, ZLNI, ZLNI, NGT1, NGT2, ITPERT, PCMUL, NDUMP, IVD,
3 QGEN, QGEN, QTE, QOUT, ZID, ZOD, ZKEND, ZK9, ZKR, RPPC, RPN, TOLTEM, TREF,
4 VREQ, PEREQ, ZLREQ, WCON, ZLNP, IDUMZ, RN, DGRF, DGLRF, DGLRF, RAKD, JDUMP,
5 DP(30), NC
COMMON /TITLE/FETM(3), CASCAD(8, 2), SSIN(3), CMT(25), COND(3, 5), TEMKF,
1 CRMDO(2, 2), I3N, IZ2N, I3P, I2P
COMMON /TEPM/HPUMP, DR8, COD2
IF (JOPTIM = 1) 102, 103, 201

102 JOPTIM = 1
INC3 = 1
TEMPHF = DK2FK(TEMP(1, 1))
TEMPCF = DK2FK(TEMP(9, 1))
IRITE = 4
COD2 = DR(8) / RAD(9)
COUT = .5 * COD2
DR = 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 MODU
1E PARAMETRIC CALCULATIONS, CALCULATIONS SUPPRESSED)
RETURN

105 CUREQ = PEREQ / VREQ
RLPC(1) = VREQ / CUREQ
IZ9 = 2
Z9SAV = DR(5)
P = RINCR * 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, TEMPCEF, TEMKF, ZID, DRT, DR(1), PCMUL, COD
101 FORMAT (26H AVERAGE HOT CLAD TEMP. =, F8.1, 6H DEG., A1, 30X, 25HAYER

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AGE COLD CLAD TEMP. = F8.1,6H DEG. , A1/10X, 16H INNER DIAMETER =
2 F8.4,4H IN. , 36X, 22HT/E RADIAL THICKNESS = F8.4,4H IN. , 26H INNE
3R CLAD THICKNESS = F8.4,4H IN. , 16H MON. OF COUPLES = F3.0,4X,
4 27HC1AD THICKNESS/0.0. RATIO = F8.5
J=1
IF (WTCON.GT.0.0.) J=2
WRITE (6,104) CRMD(1,IENDK), CRMD(1,IENDK), CRMD(1,J)
104 FORMAT (95HO DR(3) DR(6) 0.0, ZLN ZLP RGEN
1 VOC VLOAD CURRENT POWER QA4,5X,3HETA2,3X,4,3HMLT,
2/119H (IN.) (IN.) (IN.) (IN.) (IN.) (IN.) (IN.) (IN.) (IN.) (M=OHMS) (VOLT
3S) (VOLTS) (AMPS) (WATTS) (WATTS) (PCT.) (LBS.))
201 JOPTIM=JOPTIM+1
IRTRN=1
IF (ABS(CUREO-CUR(1))/CUREO.LE.TOLTEM.OR.JOPTIM.GT.10) GO TO 210
RCPC=(VOC(1)-VREQ/PCMULT)/CUREO"RPPC
RCOND=RPC(1)-RPPC-"RPN
P=RCPC*RCPC-4*"RPN*RCOND
IF (P.LT.O.) 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 (2HO , 3F8.4,2F9.4,3PF9.4,4,0PF210.4,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,2F8.4,2F9.4,3PF9.4,4,0PF210.4,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)+DRINC
IF (DR(6).LE.DR6MAX) RETURN

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FUNCTION WATE(WTPC)
  COMMON /MDCPOP/RAD(9),DR(8),TEMP(9,300),VOC(300),RPC(300),PE(300),
  QT(300),NOPTIM,VPC(300),RLPC(300),DTMOD(300),CUR(300),LNRAD(9),
  ZLP,ZLN,ZLPN,TLTE,NGT1,NGT2,ITPERT,PCHULT,NOOUMP,IVD,
  QGEN,QGENL,QTE,QOUT,ZID,ZOD,ZEND,ZK9,ZKR,RPNC,RPC,RTEM,TEM,TREJ,
  RPM,VREQ,PEREQ,VLREQ,WTCON,ZLPN,INDUM,ZN,GRF,GRF,GRF,GRF,GRF,GRF,GRF,GRF
  COMMON /MODCPL/CURMOD(15),IT(300),DTTE,CONRN,CONRP,QLIP,ZNC,
  1 ALR64,MXTEM,UGAM,CGAM,INDI,RINT4,RINT6,RCON4,RCON6,CIFEM,CIFEC,
  2 CONST1,CONST2,CONST3,CONST4,CONST5,MR5OPT,SEGTE,ICRMDL,RADC
  COMMON /FWIT/DEN(8),DENI,DEN3N,DEN2N,DEN3P,DEN2P,DCRH,DCRC
  ZLM=ZLI+.001
  PIL=3.14159*ZLTE
  DEN(3)=(ZLPN*DCRH+ZLM*DENI)/ZLTE
  DEN(4)=(ZLN*ZNP3+ZLP*DEN3P+ZLM*DENI)/ZLTE
  DEN(5)=(ZLN*ZNP2+ZLP*DEN2P+ZLM*DENI)/ZLTE
  DEN(6)=(ZLPN*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*D)*DENCI)
  CALCULATE TOTAL MODULE WEIGHT
  WATE=WTCON*(RAD(9)+RAD(I))*PCML*(RAD(9)-RAD(I)) +WTPC
  RETURN
END

FUNCTION DK2FK(I)
  COMMON /MODOPT/IPDMT,DR4,DRINCR,IRITE,DRTE,JOPTIM,IZ9,IENDK,IPUN,
  IRIINC,ROINC,RMAX,R9MAX,MINQ,THINC,TCINC,TCMAX,THMAX
  NPERT,ZNPERT,CKFP,CKFT,CTEC,CTEC,DELTL,RLPERT,RMAX,ZNMIN,Z9SAV
  CONVERTS KELVIN TO FAHRENHEIT DEGREES (IF NZ(0)=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

IND = INDICATES TYPE-OF-EXTRAPOLATION THAT WAS USED  (IF ANY)
  (IND=0 INDICATES NO EXTRAPOLATION WAS NEEDED ON X)
  (IND=1 INDICATES LOWER EXTRAPOLATION WAS NEEDED ON X)
  (IND=2 INDICATES UPPER EXTRAPOLATION WAS NEEDED ON X)
INDLE = INDICATES TYPE-OF-LOWER-EXTRAPOLATION TO BE USED ON X
  (INDLE=1 INDICATES LOWER EXTRAP. ON X IS TO BE LINEAR)
  (INDLE=2 INDICATES LOWER EXTRAP. ON X IS TO BE PARABOLIC)
  (INDLE=3 INDICATES LOWER-LINEAR EXTRAP. ON X AND ERROR PRI
  (INDLE=4 INDICATES LOWER-PARABOLIC EXTR. ON X AND ERROR PR
  (INDLE=5 INDICATES LOWER EXTRAP. ON X IS TO BE FIRST TABLE
INDUE = INDICATES TYPE-OF-UPPER-EXTRAPOLATION TO BE USED ON X
  (INDUE=1 INDICATES UPPER EXTRAP. ON X IS TO BE LINEAR)
  (INDUE=2 INDICATES UPPER EXTRAP. ON X IS TO BE PARABOLIC)
  (INDUE=3 INDICATES UPPER-LINEAR EXTRAP. ON X AND ERROR PRI
  (INDUE=4 INDICATES UPPER-PARABOLIC EXTR. ON X AND ERROR PR
  (INDUE=5 INDICATES UPPER EXTRAP. ON X IS TO BE LAST TABLE
XTBL = NAME OF INDEPENDENT VARIABLE TABLES
YTBL = NAME OF DEPENDENT VARIABLE TABLES
N = NUMBER-OF-POINTS IN EACH TABLE
X = PARTICULAR VALUE OF INDEPENDENT VARIABLE
SI=YTBL(1)
IND=0
IF(NN.LE.1) RETURN

CHECK TO SEE IF LOWER OUT-OF-RANGE EXTRAPOLATION WILL BE NEEDED
IF (X.XTBL(1)) 120, 130, 150
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

CHECK TO SEE IF UPPER OUT-OF-RANGE EXTRAPOLATION WILL BE NEEDED
150 IF(X.LT.XTBL(N)) GO TO 210
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

D-85
II = N - 1
GO TO 254

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
CHECK IF (UPPER OR LOWER) EXTRAPOLATION WAS FOUND TO BE NECESSARY
IF (IND = 1) 259, 257, 258

C
LOWER EXTRAPOLATION IS NEEDED - CHECK INOLE FOR TYPE TO BE USED
257 GO TO (270, 259, 370, 359), INOLE

C
UPPER EXTRAPOLATION IS NEEDED - CHECK INDUE FOR TYPE TO BE USED
258 GO TO (270, 259, 370, 359), INDUE

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
PARABOLIC INTERPOLATION OR EXTRAPOLATION
260 SI = Y1 + (1.0 - (X2 - X) / (X3 - X1)) * (Y2 - Y1) * (X - X1) / (X2 - X1) - (X2 - X) / (X3 - X1) * (1X - X1) / (X3 - X2) * (Y3 - Y2)
GO TO 300

C
ERROR PRINTOUT
370 CALL ERROR (28H TABLE EXTRAPOLATED LINEARLY)

C
LINEAR EXTRAPOLATION
270 SI = Y1 + (Y2 - Y1) * (X - X1) / (X2 - X1)
300 RETURN
END