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THERMAL ANALYSIS OF A MATERIALS PROCESSING FURNACE BEING DEVELOPED FOR USE WITH HEAT PIPES

FINAL REPORT

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by

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1. INTRODUCTION AND SUMMARY

A special materials processing furnace is being developed by NASA-MSFC for use in forthcoming Spacelab missions to study the solidification under closely controlled conditions of various sample materials in the absence of gravity. The samples are to be rod shaped and will be subjected to both heating and cooling simultaneously with the heating and cooling distributed along the length of the rod by annular heat pipes concentric with the sample rod. The heat pipes will serve to maintain near-uniform temperature distributions along the hot and cold sections of the rod with a very steep temperature gradient in between.

The thermal model is based on a Lockheed-Huntsville developed Thermal Analyzer computer program. The model was developed to be very general to enable the simulation of variations in the furnace design and, hence, serve as an aid in finalizing the design.

The thermal model is described in Section 2, with a user's guide given in Section 3. Some preliminary results obtained in testing the model are given in Section 4.

2. THERMAL MODEL

The thermal model for the furnace was based on a number of preliminary design drawings and sketches provided by NASA-MSFC. A simplified schematic of the furnace is shown in Fig. 1. We concentrated our detailed thermal modeling efforts in the inner core region, including the sample, heat pipes, core tube (heating elements) and heat sink. Some of the outer region was not modeled exactly, since this would introduce considerable complexity into the model without significantly enhancing accuracy.

In modeling the furnace, we divided the overall model into three regions. The center section contains the core tube, hot heat pipe and surrounding insulation and housing and is labeled as Region 1. The end section opposite to the cold heat pipe and heat sink contains primarily structural stiffeners and insulation and is labeled Region 2. The end section containing the cold heat pipe and heat sink is labeled Region 3.

Heat is generated in the core tube and is distributed to the sample rod after being transferred through the muffle and hot heat pipe. Some heat is lost by conduction through the multilayer insulation to the external housing, where it is collected in a cooling jacket. The heat flowing through the sample into the cold heat pipe and heat sink is collected and removed through the heat sink.

A detailed schematic of the Region 1 nodal network is given in Fig. 2 with a table of conductors. In this configuration, the sample rod is fully extended into the heated region. The position of the sample can be altered to simulate translation from the heated region into the cooled region. We assumed that the heat pipe is an infinite conductor and, hence, is isothermal. The region within the muffle is partially pressurized by helium to enhance heat transfer by conduction. We modeled heat transfer in the radial direction

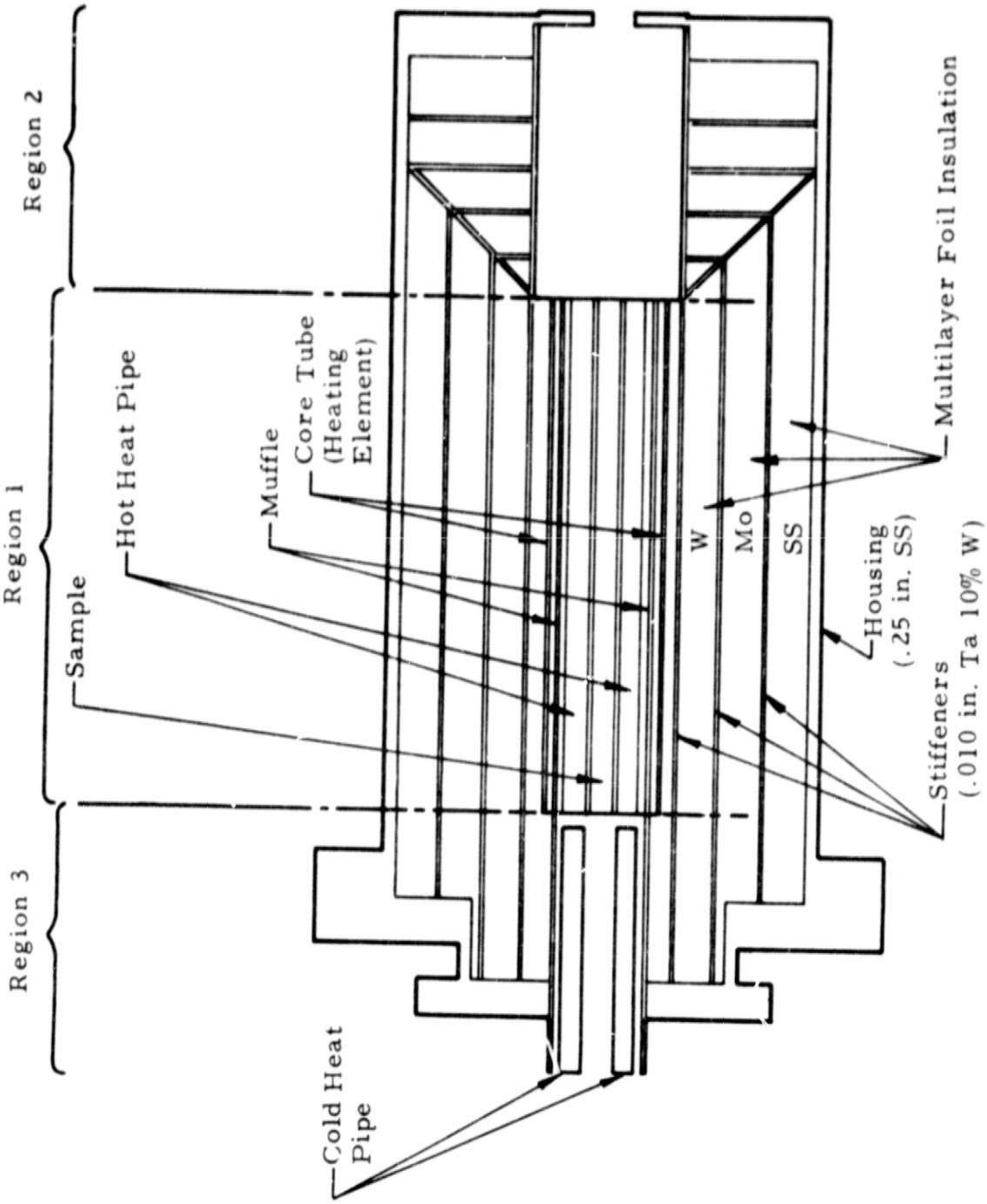

Fig. 1 - Schematic of Materials Processing Furnace

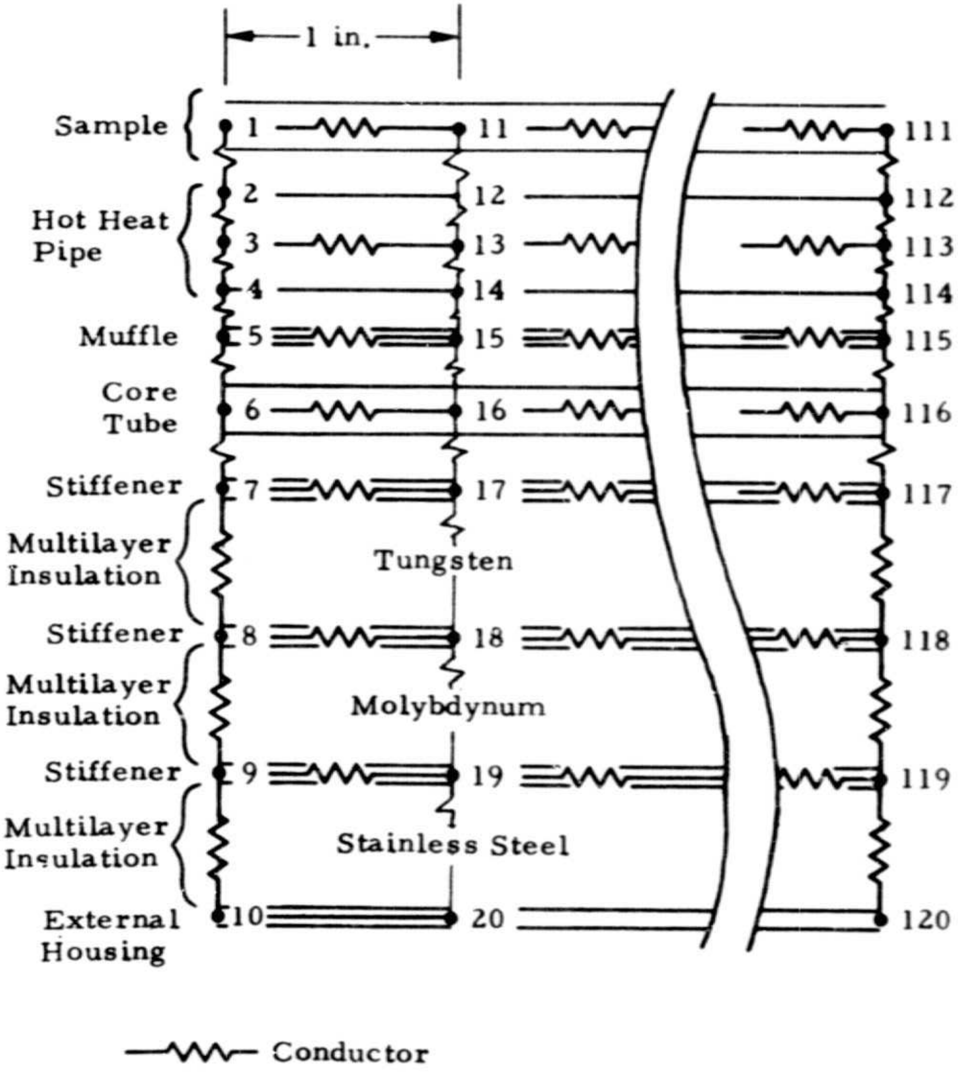

TABLE OF CONDUCTORS

Node Pair	Conductor	Type
1-2	1	Rad. & Cond.
2-3	2	Isothermal
3-4	3	Isothermal
4-5	4	Rad. & Cond.
⋮	⋮	⋮
9-10	9	Radiation
11-12	11	⋮
12-13	12	
⋮	⋮	
19-20	19	
21-22	21	
⋮	⋮	
119-120	119	
1-11	120	Conduction
3-13	122	Isothermal
5-15	124	⋮
⋮		
11-21	130	
13-23	132	
⋮	⋮	
⋮	⋮	
101-111	220	
103-113	222	
105-115	224	
⋮	⋮	

Fig. 2 - Schematic of Region 1 Nodal Network and Table of Conductors

within the muffle by a combination of conduction through the helium gas medium and radiation across the gaps separating the sample, heat pipe and muffle. Outside of the muffle, we modeled heat transfer in the radial direction by radiation only. Radiation through the multilayer foil is given by

$$q = \frac{\epsilon}{(2-\epsilon)n} (T_1^4 - T_2^4) \qquad (1)$$

where q is the radiant heat flux, ϵ is the emissivity of the foil, n is the number of foil layers and T_1 and T_2 are the temperatures on the surfaces bounding the n foil layers.

Heat transfer in the axial direction was modeled by conduction along the structural elements.

A detailed schematic of the Region 2 nodal network and conductors is given in Fig. 3. The configuration of stiffeners and multilayer insulation which we modeled in Region 2 is a simplification of the actual design shown in Fig. 1. This simplification was made to facilitate the modeling of heat transfer in this region without unduly sacrificing accuracy. Heat transfer was modeled by conduction along the stiffeners and radiation through the multilayer insulation.

The Region 3 nodal network and conductors is shown in Fig. 4. The sample is thermally connected to the cold heat pipe only if it is translated into the cooled region. As in Region 1, heat transfer within the muffle is by a combination of conduction through the helium gas and radiation between structural members. Outside the muffle, radial heat transfer is by radiation only, and axial heat transfer is by conduction along structural members. The cold heat pipe, like the hot heat pipe, is assumed isothermal.

In Regions 1, 2 and 3, the external housing is maintained at a constant temperature by a cooling jacket. The furnace is assumed to be controlled by maintaining the four core tube sections at fixed temperatures. The cold heat pipe is maintained at a fixed temperature by cooling from some arbitrary heat sink.

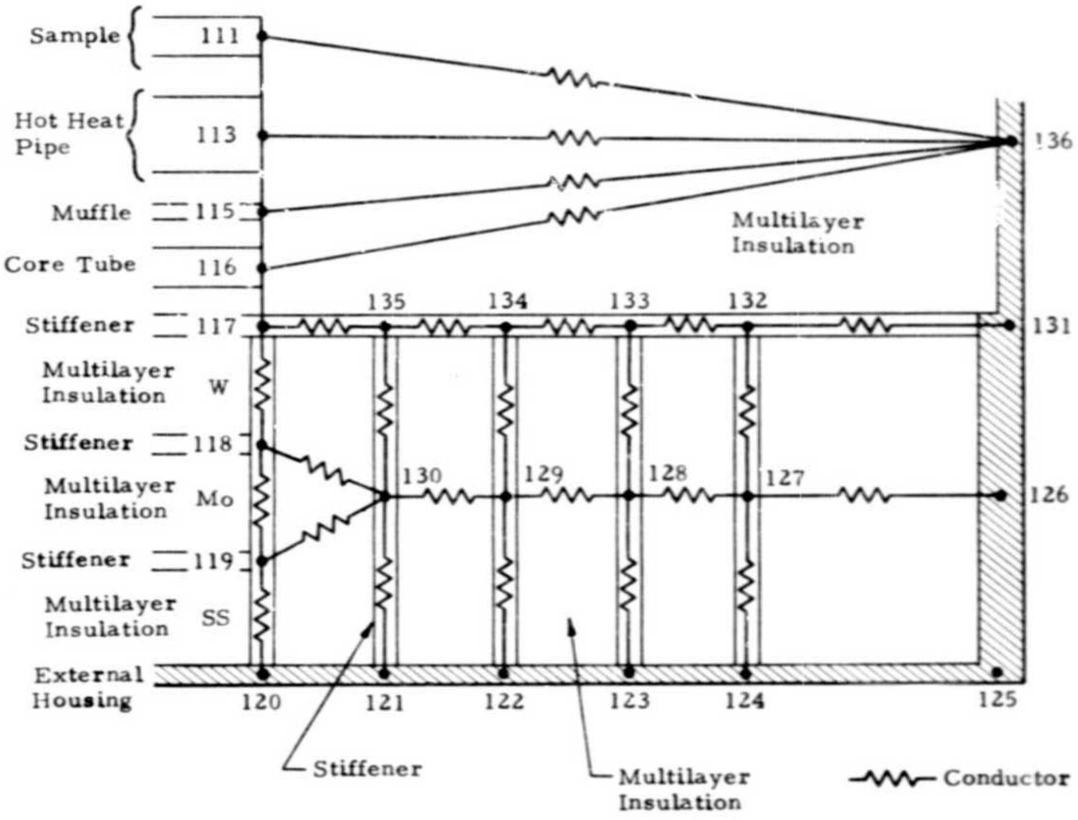

TABLE OF CONDUCTORS

Node Pair	Conductor	Type
126-127	236	Radiation
127-128	237	
128-129	238	
129-130	239	
131-132	241	Conduction
132-133	242	
133-134	243	
134-135	244	
117-118	245	
118-119	246	
119-120	247	
117-135	248	
118-130	249	Radiation
119-130	250	Radiation
135-130	251	Conduction
130-121	252	
134-129	253	
129-122	254	
133-128	255	
128-123	256	
132-127	257	
127-124	258	
116-136	261	Radiation
115-136	262	
113-136	263	
111-136	264	

Fig. 3 - Schematic of Region 2 Nodal Network and Table of Conductors

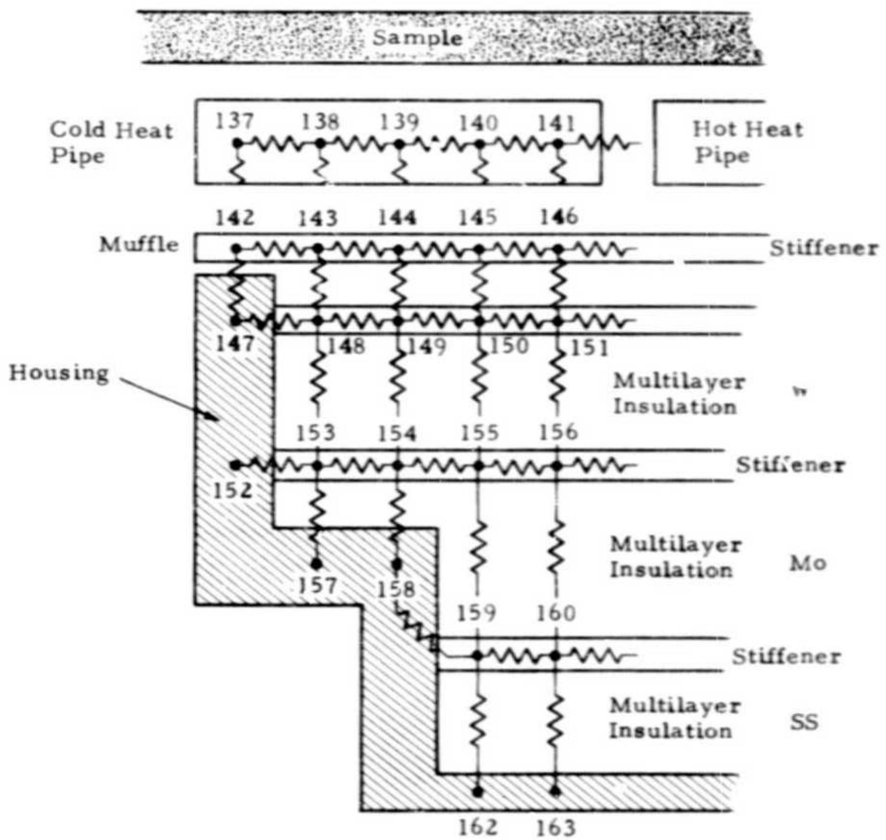

TABLE OF CONDUCTORS

Node Pair	Conductor	Type
137-138	265	Conduction
138-139	266	
139-140	267	
140-141	268	
142-143	270	
143-144	271	
144-145	272	
145-146	273	
147-148	275	
148-149	276	
149-150	277	
150-150	278	
152-153	280	
153-154	281	
154-155	282	
155-156	283	
158-159	286	
159-160	287	
137-142	290	Cond. & Rad.
138-143	291	
139-144	292	
140-145	293	
141-146	294	
142-147	295	Radiation
143-148	296	
144-149	297	
145-150	298	
146-151	299	
148-153	301	
149-154	302	
150-155	303	
151-156	304	
153-157	306	
154-158	307	
155-159	308	
156-160	309	
158-161	310	Conduction
159-162	311	Radiation
160-163	312	Radiation
146-5	313	Conduction
151-7	314	Conduction
156-8	315	Conduction
160-9	316	Conduction

Figure 4 - Schematic of Region 3 Nodal Network and Table of Conductors

3. COMPUTER PROGRAM

A complete listing of the computer program for the thermal model is given in Appendix A. The program is coded in FORTRAN V language for the NASA-MSFC Univac 1108 computer. The program can be run for various core tube temperatures and sample translations with various heat sink and cooling jacket temperatures by varying the program inputs. The thermal model can be changed to simulate furnace design changes by modifying the program.

The main program contains the thermal analyzer coding, but calls subroutines for defining initial conditions, nodal networks, capacitances and conductances. Initial conditions for the temperatures are computed in subroutine CONI. The initial temperatures in Region 1 are computed based on fixed core tube and housing temperatures assuming radial conduction at equilibrium. The initial temperatures interior to the core tube in Region 1 are made equal to the core tube temperatures. The temperatures in Regions 2 and 3 are initialized at the cooling jacket, heat sink or some other temperature near a Region 1 temperature. The idea is to start the program calculations at initial temperatures as near as possible to the actual equilibrium temperatures. This approach to initializing temperatures reduces the required program run time.

The linking between nodes in the nodal network is defined in subroutine LINKUP, and conductances for each link are defined in subroutine COND. In COND, there are basically three kinds of conductances considered: (1) radiation, (2) solid conduction, and (3) helium conduction. The radiant conductance, CD, for a single gap is given by

$$CD = \frac{1}{1/\epsilon_1 + 1/\epsilon_2 - 1} \sigma(T_1^2 + T_2^2)(T_1 + T_2) A$$

where ϵ_1 and ϵ_2 are the emissivities and T_1 and T_2 are the temperatures of the two surfaces, σ is the Stephan-Boltzmann constant, and A is the area. The conductance for multilayer insulation is given by the same expression divided by the number of foil layers.

The conductance of solid conductors is given by

$$C_D = \frac{K}{\Delta X} A$$

where K is conductivity, ΔX is thickness and A is cross-sectional area. The K values are read into the program in table form in subroutine DATA as a function of temperature. The tabular data is interpolated in subroutine INTP. Provision is made for 16 tables in the program giving conductivity and specific heat for stainless steel, alumina, tungsten, molybdenum and tantalum alloy. In addition, tables are set aside for the sample material and the hot and cold heat pipes. The tables are described in the listing of COND in Appendix A.

Conductances are also calculated for helium conduction in the region contained within the muffle. These calculations are noted by comments in the program listing.

Since the program computes an equilibrium solution, the values of the capacitances are not significant to the final solution except when used to flag nodes where temperatures are held constant. When the value of the capacitance is -1, the node is flagged as a constant temperature node. This is done in subroutine CAP. Subroutine HTRT is provided for defining heat generation rates. In our case, however, we set all heat rates Q equal to zero and, instead, use constant temperature nodes at points of heat generation or loss.

The time step in the numerical solution is recomputed to ensure stability at each step in the solution. This is done in subroutine TSTP.

The program inputs and their formats are given in Table 1.

Table 1

COMPUTER PROGRAM INPUT DATA

Card	Column	Format	Variable	Description
1	1-10	E10.0	PRIN	Arbitrarily set equal to 100
1	11-15	I5	NPR1	Number of iterations between printouts
1	16-20	I5	NEXCT	Arbitrarily set equal to 100
1	21-30	E10.0	TSCON	Maximum stable time step divided by this number to assure stability
1	31-40	E10.0	TMAX	Program run time
1	41-50	E10.0	TCASE	Cooling jacket temperature, R
1	51-60	E10.0	TCOOL	Heat sink temperature, R
2	1-10	E10.0	TCORE(1)	Core tube temperature, R
2	11-20	E10.0	TCORE(2)	↓
2	21-30	E10.0	TCORE(3)	↓
2	31-40	E10.0	TCORE(4)	↓
3	1-5	I5	NTRANS	Sample translation distance, in.
4	1-5	I5	N	Table number
4	2-10	I5	J	Number of values in table
5	1-10	E10.0	A	Temperature, R
5	11-20	E10.0	B	Table value (conductivity or capacitance)
5	21-80	–	–	Comment

(Repeat card 5 J times)
(Repeat cards 4 and 5 sequence for each table. End with blank card).

The program output lists the program input data, the conductors and their nodal end points, the nodes and the connecting nodes and conductors, and the tables of material properties prior to entering the thermal analyzer loop. After entering the thermal analyzer loop, a listing is made of temperatures, heat rates and conductance values at specified intervals. After completion of a run, totals are made of heat transferred to the cooling jacket (QCASE) and to the cold heat pipe heat sink (QCOOL). The sum of these heat flow rates is the furnace requirement (POWER). The heat flow rates QCASE and QCOOL are printed out in units of kcal/sec, and the power level POWER is printed out in kilowatts.

4. SAMPLE PROBLEM

A sample case was run for a tungsten sample rod translated 5 in. into the cooled region. The four core tube temperatures were assumed to be 838 C (2000 R), with the external housing and cold heat pipe cooled to 27 C (540 R). The input cards for this case are listed in Appendix B. The values of PRIN and NEXCT are not significant to our model and were arbitrarily set equal to 100. NPR1 was set equal to 50 to print data every 50 iterations. TSCON was set equal to 2 to assure a stable solution. TMAX was set equal to 100, since we found by experience that equilibrium is reached by that time.

The calculated temperatures at equilibrium are plotted in Fig. 5 along a radius at the midpoint of the core tube. The calculated sample temperatures are plotted in Fig. 6 along the sample length. The total heat lost to the external housing cooling jacket QCASE was found to be 146 kcal/hr, and the heat flow to the cold heat pipe was found to be 255 kcal/hr. This corresponds to a total power level for the core tube of .47 kW.

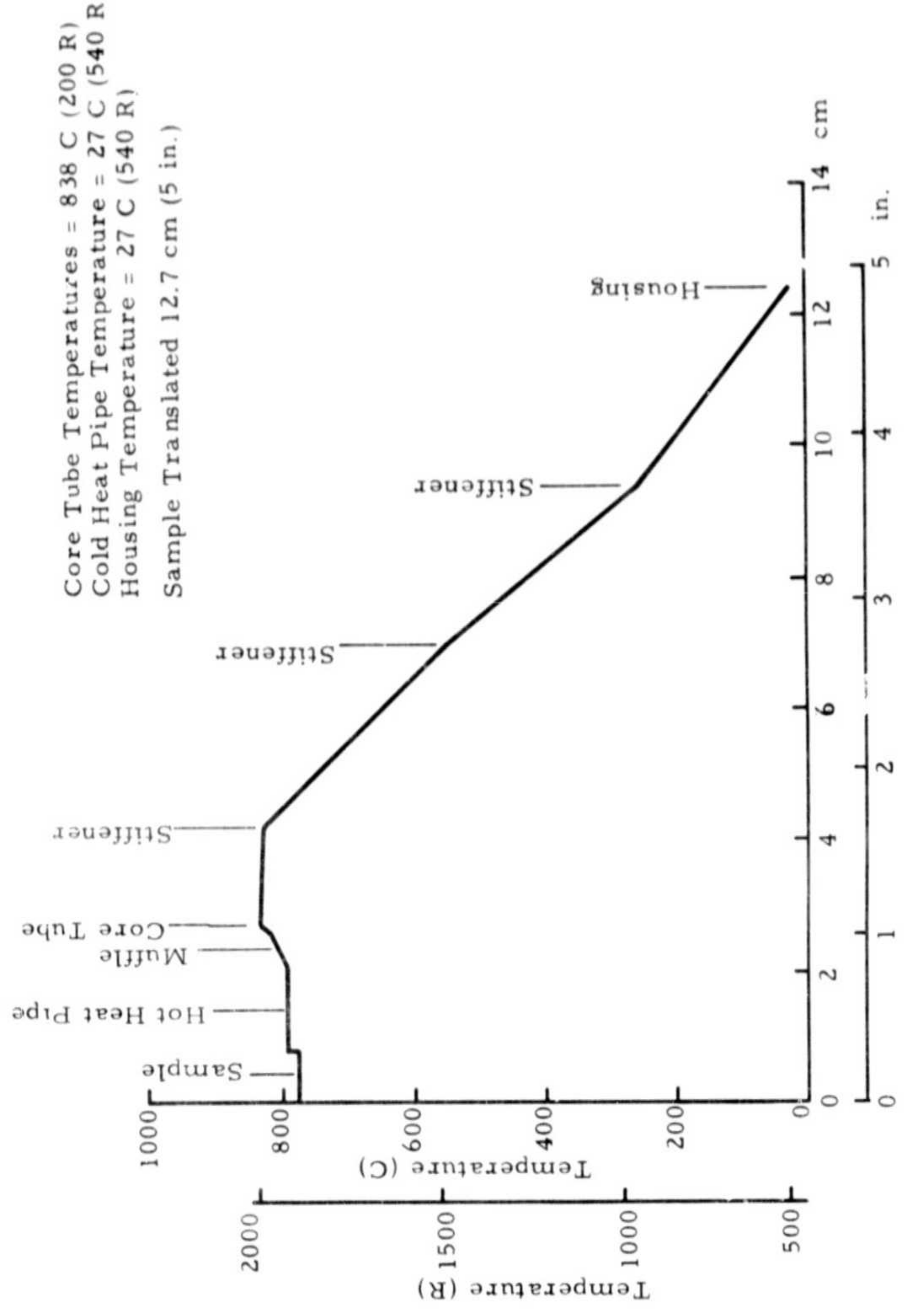

Fig. 5 - Temperature Distribution along Furnace Radius Bisecting Core Tube

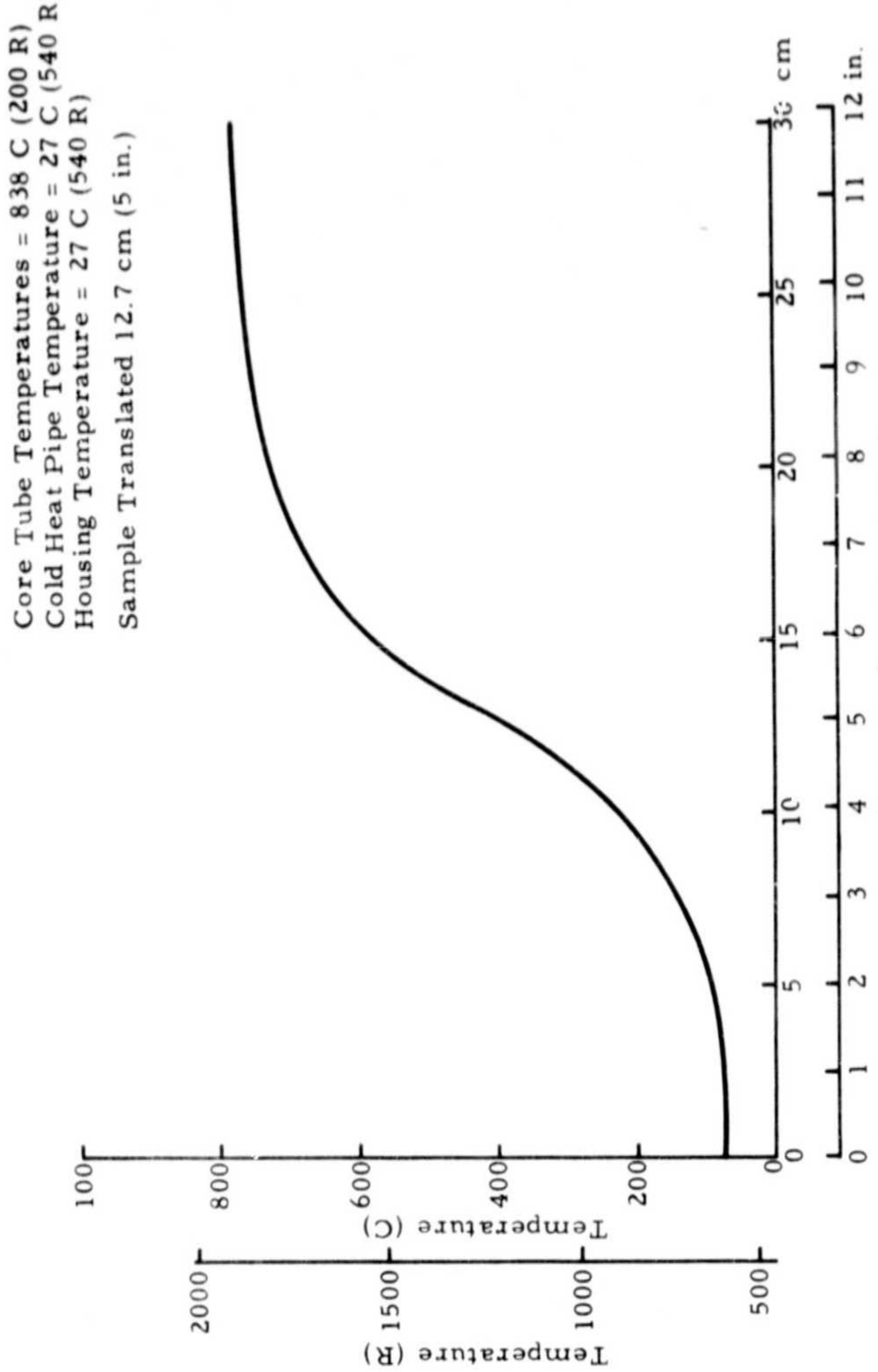

Fig. 6 - Temperature Distribution along Tungsten Sample Rod

5. CONCLUDING REMARKS

The thermal model developed during this effort accurately simulates heat transfer in the baseline furnace design, and is sufficiently general to model a broad range of design modifications. The model can be utilized to perform heat transfer analyses for various anticipated test conditions to determine required furnace power levels, cooling rates and sample temperature distributions.

It is recommended that experimental data be obtained on the conductance of the multilayer foil insulation. This updated data can be incorporated into the present thermal model with little difficulty.

Appendix A

LISTING OF COMPUTER PROGRAM FOR SPECIAL MATERIALS PROCESSING FURNACE THERMAL MODEL

```
C********
      COMMON/TRANS/NTRANS
      COMMON/XINIT/ICONI,CD67,CD78,CD89,CD910
C                 T H E R M A L   A N A L Y S E R      BY JOHN POND
C********
      DIMENSION T(200),C(200),CD(500),Q(200),TO(200)
      DIMENSION L(500,2),M(200,15)
      DIMENSION TCORE(4)
  701 FORMAT(2I5,E10.0)
  702 FORMAT (4I5)
  703 FORMAT(E10.0,2I5,4E10.0)
  704 FORMAT(4E10.0)
  705 FORMAT(1H1,'PRIN=',F10.0,2X,'NPRI=',I5,2X,'NEXCT=',I5,2X,'TSCON=',
     $ F10.1,2X,'TMAX=-,F10.0)
  706 FORMAT(1H0,'TCASE=',F10.0,2X,'TCOOL=',F10.0,2X,4('TCORE(',I1,')=',
     $ F10.0,2X,))
  707 FORMAT(1H0,'NTRANS=',I2)
     1                           I5,3X,6HNIT = ,I5)
     $ F10.0,2X,))
  707 FORMAT(1H0,'NTRANS=',I2)
     1                           I5,3X,6HNIT = ,I5)
  711 FORMAT(1H ,(2HT(,I5,2H)=,2X,E10.4,3X,
     1              2HT(,I5,2H)=,2X,E10.4,3X,
     2              2HT(,I5,2H)=,2X,E10.4,3X,
     3              2HT(,I5,2H)=,2X,E10.4,3X,
     4              2HT(,I5,2H)=,2X,E10.4,3X))
  712 FORMAT(1H ,(2HC(,I5,2H)=,2X,F8.3,3X,
     1              2HC(,I5,2H)=,2X,F8.3,3X,
     2              2HC(,I5,2H)=,2X,F8.3,3X,
     3              2HC(,I5,2H)=,2X,F8.3,3X,
     4              2HC(,I5,2H)=,2X,F8.3,3X))
  713 FORMAT(1H ,(2HK(,I5,2H)=,2X,E10.4,3X,
     1              2HK(,I5,2H)=,2X,E10.4,3X,
     2              2HK(,I5,2H)=,2X,E10.4,3X,
     3              2HK(,I5,2H)=,2X,E10.4,3X,
     4              2HK(,I5,2H)=,2X,E10.4,3X))
  714 FORMAT(1H ,(2HQ(,I5,2H)=,2X,E10.4,3X,
     1              2HQ(,I5,2H)=,2X,E10.4,3X,
     2              2HQ(,I5,2H)=,2X,E10.4,3X,
     3              2HQ(,I5,2H)=,2X,E10.4,3X,
     4              2HQ(,I5,2H)=,2X,E10.4,3X))
  715 FORMAT(1H0,3I5)
  716 FORMAT(1H0,2I5/(1H ,20I5))
  717 FORMAT(1H1,24HCONDUCTOR  NODE-1 NODE-2)
  718 FORMAT(1H1,25HNODE  NUMBER OF RESISTORS,//
     1         1H ,10HNODE--CON.,5X,10HNODE--CON.,5X,
     2         1H ,10HNODE--CON.,5X,10HNODE--CON.,5X,
     3         1H ,10HNODE--CON.,5X,10HNODE--CON.,5X,
     4         1H ,10HNODE--CON.,5X,10HNODE--CON.,5X)
```

```
  720 FORMAT(//5X,18HMAX TEMP CHANGE = ,F10.5,3X,9HAT NODE  ,I5,
     1       26HSUM OF ABS TEMP CHANGES = ,E15.6)
  730 FORMAT(1H ,(5HQDOT(,I5,2H)=,2X,E12.4,3X,
     1               5HQDOT(,I5,2H)=,2X,E12.4,3X,
     2               5HQDOT(,I5,2H)=,2X,E12.4,3X,
     3               5HQDOT(,I5,2H)=,2X,E12.4,3X))
 2000 CONTINUE
      READ(5,703) PRIN,NPRI,NEXCT,TSCON,TMAX,TCASE,TCOOL

      READ(5,704)(TCORE(I),I=1,4)
      READ(5,702)NTRANS
      WRITE(6,705)PRIN,NPRI,NEXCT,TSCON,TMAX
      WRITE(6,706)TCASE,TCOOL,(I,TCORE(I),I=1,4)
      WRITE(6,707)NTRANS
C
C********
      IF (PRIN.EQ.0.0) GO TO 4000
      NNDS=163
      NCDS=347
      KKFLG=100
      CALL CONI(T,TCORE,TCASE,TCOOL,CD,L)
      CALL LINKUP(L)
C********
C     SORT OUT CONDUCTORS AND ADJACENT NODES
C
C********
      DO 606 IN = 1,NNDS
      NR = 0
      DO 607 IR = 1,NCDS
      IF(L(IR,1).NE.IN) GO TO 608
      NR = NR + 1
      I1 = NR*2
      I2 = NR*2+1
      M(IN,I1) = L(IR,2)
      M(IN,I2) = IR
      GO TO 609
  608 CONTINUE
      IF(L(IR,2).NE.IN) GO TO 609
      NR = NR + 1
      I1 = NR*2
      I2 = NR*2+1
      M(IN,I1) = L(IR,1)
      M(IN,I2) = IR
  609 CONTINUE
  607 CONTINUE
      M(IN,1) = NR
  606 CONTINUE
C***********
C
C     PRINT OUT INITIAL INFORMATION
C
```

ORIGINAL PAGE IS OF POOR QUALITY

```
C***********
C       WRITE(6,717)
C       DO 502 I = 1,NCDS
C       WRITE(6,715)I,L(I,1),L(I,2)
C502   CONTINUE
        WRITE(6,718)
        DO 500 I=1,NNDS
        IN=M(I,1)*2+1
        WRITE(6,716)I,(M (I,J),J=1,IN)
  500   CONTINUE
        TIM = 0.0
        NIT = 0
        IPT=1
        NPR = 0
        DT = 0.0
        NCTRL = 0

        MAXTND = 0
        TMAXCG = 0.0
        TSMCG = 0.0
C
C        READ IN TABULAR DATA
C
        CALL DATA
C********
C                           START LOOP
        DO 1012 I=1,NNDS
        C(I)=2.0
 1012 CONTINUE
 1000 CONTINUE
        CALL CAP(C,T)
        CALL COND(CD,L,T)
C
C********
C
C       COMPUTE HEAT RATES
        CALL HTRT(T,TIM,DT,NNDS,Q)
  152 CONTINUE
C
C********
C
C       PRINT OUT RESULTS
C********
        IF(NPR1*(NPR/NPR1).NE.NPR) GO TO 160
        WRITE(6,710) TIM,DT,NCTRL,NIT
        WRITE(6,720) TMAXCG,MAXTND,TSMCG
        WRITE(6,711)(N,T(N),N=1,NNDS)
        WRITE(6,714)(N,Q(N),N=1,NNDS)
        WRITE(6,713)(N,CD(N),N=1,NCDS)
```

```
  160 CONTINUE
      NPR = NPR + 1
  150 CONTINUE
C
C********
C
C     COMPUTE TIME STEP
      CALL TSTP(C,CD,NCTRL,M,NNDS,NPR,PRIN,TIM,IPT,TSCON,DT)
C
C********
      MAXTND = 0.0
      TMAXCG = 0.0
      TSMCG = 0.0
      TIM = TIM + DT
      NIT=NIT+1
      DO 800 I =1,NNDS
      TCG = ABS(T(I)-TO(I))
      IF(TCG.LT.TMAXCG) GO TO 945
      MAXTND = I
      TMAXCG = TCG
  945 CONTINUE
      TSMCG=TSMCG+TCG
      TO(I) = T(I)
  800 CONTINUE
C********
C
C     COMPUTE NEW TEMPERATURES
C
C********
      DO 900 I = 1,NNDS
      IF(C(I))903,902,901
C
C     TRANSIENT CALCULATION
C
  901 CONTINUE
      NADJ = M(I,1)
      F1 = 0
      F2 = 0
      DO 803 J = 1,NADJ
      NR1 = J*2
      NR2 = J*2+1
      JN = M(I,NR1)
      JC = M(I,NR2)
      F1 = F1 + TO(JN)*CD(JC)
      F2 = F2 + TO(I)*CD(JC)
  803 CONTINUE
      T(I) = TO(I)+(F1-F2+Q(I))*DT/C(I)
      GO TO 900
```

```
C
C      STEADY STATE CALCULATION
C
  902 CONTINUE
      NADJ = M(I,1)
      F1 = 0
      F2 = 0
      DO 804 J = 1,NADJ
      NR1 = J*2
      NR2 = J*2+1
      JN = M(I,NR1)
      JC = M(I,NR2)
      F1=F1+TO(JN)*CD(JC)
      F2 = F2 + CD(JC)
  804 CONTINUE
      T(I)=(F1+Q(I))/F2
  903 CONTINUE
  900 CONTINUE
C
C      HOT HEAT PIPE TEMPERATURE ASSUMING INFINITE CONDUCTOR
C
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      IMAX=12-NTRANS
      DO 290 I=1,IMAX
      K=1+10*(I-1)
      SUM1=SUM1+T(K)*CD(K)
      SUM2=SUM2+CD(K)
  290 CONTINUE
      DO 291 I=1,12
      K=4+10*(I-1)
      SUM3=SUM3+T(K+1)*CD(K)
      SUM4=SUM4+CD(K)
  291 CONTINUE

      SUM3=SUM3+T(141)*CD(347)
      SUM4=SUM4+CD(347)
      T(3)=(SUM1+SUM3)/(SUM2+SUM4)
      DO 300 I=2,112,10
      T(I)=T(3)
      T(I+1)=T(3)
      T(I+2)=T(3)
  300 CONTINUE
      IF(TIM.LE.TMAX) GO TO 1000
      NPTS=NPR
C
```

```
C       HEAT RATES
C
        QCASE=0.
        DO 320 I=9,119,10
        QCASE=QCASE+CD(I)*(T(I)-TCASE)
  320 CONTINUE
        QCASE=QCASE+CD(247)*(T(119)-T(120))
        QCASE=QCASE+CD(252)*(T(130)-T(121))
        QCASE=QCASE+CD(254)*(T(129)-T(122))
        QCASE=QCASE+CD(256)*(T(128)-T(123))
        QCASE=QCASE+CD(258)*(T(127)-T(124))
        QCASE=QCASE+CD(236)*(T(127)-T(126))
        QCASE=QCASE+CD(241)*(T(132)-T(131))
        QCASE=QCASE+CD(311)*(T(159)-T(162))
        QCASE=QCASE+CD(312)*(T(160)-T(163))
        QCASE=QCASE+CD(286)*(T(159)-T(158))
        QCASE=QCASE+CD(307)*(T(154)-T(158))
        QCASE=QCASE+CD(306)*(T(153)-T(157))
        QCASE=QCASE+CD(280)*(T(153)-T(152))
        QCASE=QCASE+CD(275)*(T(148)-T(147))
        QCASE=QCASE+CD(295)*(T(142)-T(147))
        QCOOL=0.
        DO 330 I=1,5
        QCOOL=QCOOL+(CD(289+I)+CD(341+I))*(T(141-I)-TCOOL)
  330 CONTINUE
        QCOOL=QCOOL+CD(347)*(T(3)-T(141))
        IF(NTRANS.EQ.0) GO TO 340
        DO 335 I=1,NTRANS
        K1=1+10*(11+I-NTRANS)
        K2=329-NTRANS+I
        J=1+10*(I-1)
        QCOOL=QCOOL+(CD(K1)+CD(K2))*(T(J)-TCOOL)
  335 CONTINUE
  340 CONTINUE
        QCASE=QCASE*(.252/3600.)
        QCOOL=QCOOL*(.252/3600.)
        POWER=(QCASE+QCOOL)*4.186
        WRITE(6,350)QCASE,QCOOL,POWER
  350 FORMAT(1H0,'QCASE=',E10.3,' KCAL/SEC',2X,'QCOOL='E10.3,
      $ ' KCAL/SEC',
      $ 2X,'POWER=',E10.3,' KW')
        GO TO 2000
 4000 STOP
        END
```

```
      SUBROUTINE CONI(T,TCORE,TCASE,TCOOL,CD,L)
      COMMON/TRANS/NTRANS
      COMMON/XINIT/ICONI,CD67,CD78,CD89,CD910
      DIMENSION T(200),TCORE(4),CD(500),L(500,2)
C
C     INITIAL TEMPERATURES,REGION 1.
C
      ICONI=0
      CALL COND(CD,L,T)
      ICONI=1
      DO 10 I=6,116,10
      J=(I-6)/30+1
      T(I)=TCORE(J)
      T(I+4)=TCASE
      QCONST=(T(I)**4-T(I+1)**4)/(1./CD67+1./CD78+1./CD89+1./CD910)
      T(I+1)=(T(I   )**4-QCONST/CD67)**.25
      T(I+2)=(T(I+1)**4-QCONST/CD78)**.25
      T(I+3)=(T(I+2)**4-QCONST/CD89)**.25
      T(I-1)=T(I)
      T(I-2)=T(I)
      T(I-3)=T(I)
      T(I-4)=T(I)
      K=I-5+NTRANS
      IF(K.GT.111)GO TO 10
      T(K)=T(I)
   10 CONTINUE
C
C     INITIAL TEMPERATURES, REGION 2.
C
      DO 20 I=121,126
      T(I)=TCASE
   20 CONTINUE
      T(131)=TCASE
      T(136)=TCASE
      T(135)=T(118)
      T(134)=T(119)
      T(133)=TCASE
      T(132)=TCASE
      T(127)=TCASE
      T(128)=TCASE
      T(129)=0.5*(T(134)+TCASE)
      T(130)=0.5*(T(135)+TCASE)
C
C     INITIAL TEMPERATURES,REGION 3.
C
      DO 30 I=137,141
      T(I)=TCOOL
   30 CONTINUE
      DO 40 I=142,163
      T(I)=TCASE
```

```
40 CONTINUE
   IF(NTRANS.EQ.0) GO TO 50
   DO 45 I=1,NTRANS
45 T(I)=TCOOL
50 CONTINUE
   RETURN
   END

   SUBROUTINE HTRT(T,TIM,DT,NNDS,Q)
   DIMENSION T(200),Q(200)
   DO 1 I=1,NNDS
   Q(I)=0.
 1 CONTINUE
   RETURN
   END

   SUBROUTINE CAP(C,T)
   DIMENSION T(200),C(200)
   DO 5 I=6,116,10
   C(I)=-1.0
 5 CONTINUE
   DO 2 I=137,141
   C(I)=-1.00
 2 CONTINUE
   DO 3 I=10,120,10
   C(I)=-1.00
 3 CONTINUE
   DO 4 I=121,126
   C(I)=-1.0
 4 CONTINUE
   C(131)=-1.00
   C(136)=-1.00
   C(162)=-1.00
   C(163)=-1.00
   C(161)=-1.00
   C(158)=-1.00
   C(157)=-1.00
   C(152)=-1.00
   C(142)=-1.0
   C(147)=-1.0
   RETURN
   END
```

```
      SUBROUTINE LINKUP(L)
      COMMON/TRANS/NTRANS
      DIMENSION L(500,2),LL(500,2)
      DATA(LL(J,1),J=245,264)/
     1     117,118,119,117,118,119,135,130,134,129,
     2     133,128,132,127,126,131,116,115,113,111/
      DATA(LL(J,2),J=245,264)/
     1     118,119,120,135,130,130,130,121,129,122,
     2     128,123,127,124,131,136,136,136,136,136/
      DATA(LL(J,1),J=305,317)/
     1     152,153,154,155,156,158,159,160,146,151,156,160,163/
      DATA(LL(J,2),J=305,317)/
     1     157,157,158,159,160,161,162,163,5,7,8,9,10/
C
C     CONDUCTOR HOOK-UPS FOR REGION 1
C
      DO 100 J=1,119
      L(J,1)=J
      L(J,2)=J+1
  100 CONTINUE
      DO 200 J=120,229
      JJ=J-119
      L(J,1)=JJ
      L(J,2)=JJ+10
  200 CONTINUE
C     RADIATION BETWEEN SAMPLE AND HOT HEAT PIPE
      IMAX=12-NTRANS
      DO 110 I=1,IMAX
      K=1+10*(I-1)
      L(K,1)=K+NTRANS*10
      L(K,2)=K+1
C     HE CONDUCTION BETWEEN SAMPLE AND HOT HEAT PIPE
      J=317+I
      L(J,1)=K+NTRANS*10
      L(J,2)=K+1
  110 CONTINUE
      DO 111 I=1,12
C     RADIATION BETWEEN HOT HEAT PIPE AND MUFFLE
      K=4+10*(I-1)
      L(K,1)=K
      L(K,2)=K+1
C     HE CONDUCTION BETWEEN HOT HEAT PIPE AND MUFFLE
      J=329+I
      L(J,1)=K
      L(J,2)=K+1
  111 CONTINUE
C
C     CONDUCTOR HOOK-UPS FOR REGION 2
C
```

```
      DO 300 J=230,244
      JJ=J-110
      L(J,1)=JJ
      L(J,2)=JJ+1
  300 CONTINUE
C
C     CONDUCTOR HOOK-UPS FOR REGION 3
C
      DO 400 J=265,290
      JJ=J-128
      L(J,1)=JJ
      L(J,2)=JJ+1
  400 CONTINUE
      DO 500 J=290,304
      JJ=J-153
      L(J,1)=JJ
      L(J,2)=JJ+5
  500 CONTINUE
      DO 700 J=245,264
      L(J,1)=LL(J,1)
      L(J,2)=LL(J,2)
 700  CONTINUE
      DO 800 J=305,317
      L(J,1)=LL(J,1)
      L(J,2)=LL(J,2)
 800  CONTINUE
      IF(NTRANS.EQ.0)GO TO 850
      DO 845 I=1,NTRANS
C     RADIATION BETWEEN SAMPLE AND COLD HEAT PIPE
      K=1+10*(11+I-NTRANS)
      L(K,1)=(I-1)*10+1
      L(K,2)=141-NTRANS+I
C     HE CONDUCTION BETWEEN SAMPLE AND COLD HEAT PIPE
      K=329-NTRANS+I
      L(K,1)=(I-1)*10+1
      L(K,2)=141-NTRANS+I
      K=343+I
      L(K,1)=I
      L(K,2)=141-NTRANS+I
  845 CONTINUE
  850 CONTINUE
      DO 846 I=1,5
C     HE CONDUCTION BETWEEN COLD HEAT PIPE AND MUFFLE
      J=341+I
      L(J,1)=136+I
      L(J,2)=141+I
  846 CONTINUE
C     CONDUCTION BETWEEN HOT AND COLD HEAT PIPES
      L(347,1)=3
      L(347,2)=141
      WRITE(6,600)(J,L(J,1),L(J,2),J=1,347)
 600  FORMAT(1X,3I5,5X,3I5,5X,3I5,5X,3I5,5X,3I5,5X,3I5)
      RETURN
      END
```

```
      SUBROUTINE COND(CD,L,T)
      COMMON/TRANS/NTRANS
      COMMON/XINIT/ICON1,CD67,CD78,CD89,CD910
      DIMENSION CD(500),L(500,2),T(200)
      DIMENSION R(10),XK(500,16),RR(10)
      DATA E1,E2,E4,E5,E6,E7,E8,E9,EW,EM,ES /.400,.2,.2,.328,.400,.328,
     $.328,.328,.4,.2,.500/
      DATA(RR(I),I=1,10)/.315,.330,.580,.830,1.007,1.170,1.650,2.750,
     $3.200,4.900/
      DATA THTR1,TSTF1,TWAL1,TMUF1,DELXX/.115,.010,.250,.015,1.0/
C
C     ASSUMPTIONS USED IN CALCULATING CONDUCTOR VALUES
C
C                   REGION 1
C     (1) .030 INCH CLEARANCE BETWEEN SAMPLE AND HEAT PIPE
C     (2) .340 INCH CLEARANCE BETWEEN HEAT PIPE AND MUFFLE
C     (3) .020 INCH CLEARANCE BETWEEN MUFFLE AND HEATING ELEMENT
C     (4) .480 INCH CLEARANCE BETWEEN HEATING ELEM+NT A-D FIRST STIFFNER
C     (5) . 010 STIFFNER THICKNESS
C
C
C     NSW,NSM,NSS ARE THE NUMBER OF LAYERS OF TUNGSTEN ,MOLY AND ST STEE
C
      SIGMA=1.714E-09
      NSW=30
      NSM=30
      NSS=30
C
C     THE UNITS ON R,DELX THTR,TSTF,TWAL,TMUF ARE FT. THE VALUES ARE
C     READ IN IN INCHES AND CONVERTED TO FT.
C     DELX IS AXIAL DISTANCE STEP SIZE
C     TMUF IS THE MUFFLE THICKNESS
C     THTR IS THE HEATER THICKNESS
C     TSTF IS THE STIFNER THICKNESS
C
C
C               TABLE NO.      MATERIAL       PROPERTY
C
C                   1          ST.STEEL          CP
C                   2          ST.STEEL           K
C                   3          ALUMINA           CP
C                   4          ALUMINA            K
C                   5          TUNGSTEN          CP
C                   6          TUNGSTEN           K
C                   7          MOLY              CP
C                   8          MOLY               K
C                   9          TA-U/W            CP
C                  10          TA-U/W             K
C                  11          SAMPLE            CP
C                  12          SAMPLE             K
C                  13          HEAT PIPE         CP
C                  14          HEAT PIPE          K
C                  15          COLD H.P.         CP
C                  16          COLD H.P.          K
```

```
C
      XKHE=0.063
      ECHP=.400
      DO 10 I=1,10




   10 R(I)=RR(I)/12.
      DELX=DELXX/12.
      THTR=THTR1/12.
      TSTF=TSTF1/12.
      TWAL=TWAL1/12.
      TMUF=TMUF1/12.
      PI=3.1415927
      A2=2.*PI*R(2)*DELX
      A3=2.*PI*R(3)*DELX
      A4=2.*PI*R(4)*DELX
      A5=2.*PI*R(5)*DELX
      A6=2.*PI*R(6)*DELX
      A7=2.*PI*R(7)*DELX
      A8=2.*PI*R(8)*DELX
      A9=2.*PI*R(9)*DELX
      A10=2.*PI*R(10)*DELX
      R125 = 5.*DELX
      R126 = 3.5*DELX
      R131 = R(7)
      AM235 = PI*(R125+R126)*DELX
      AM259 = PI*(R126+R131)*DELX
      F21=R(1)/R(2)
      F54=R(4)/R(5)
      F65=R(5)/R(6)
      F111=1.0
      F115=1.0
      F118=1.0
      F127=1.0
      F116=1.0
      F113=1.0
      F119=1.0
      F128=1.0
C
C     CALL INTERPOLATION ROUTINE WITH PREVIOUS TEMPERATURES TO DETERMINE
C     NEW CONDUCTIVITY
C
      DO 700 J=2,16,2
      DO 700 I=1,317
      N1=L(I,1)
      N2=L(I,2)
      TAVG=(T(N1)+T(N2))/2.0
      CALL INTP(TAVG,J,XKK)
      XK(I,J)=XKK
```

```
  700 CONTINUE
      CD21 = (1./(1./E2+1./E1-1.))*SIGMA*A2*F21
      CD32 = XK(1,14)*PI*(R(3)+R(2))/(R(3)-R(2))*DELX
      CD43 = XK(1,14) * PI*(R(4)+R(3))/(R(4)-R(3))*DELX
      CD54=(1./(1./E5+1./E4-1.))*SIGMA*A5*F54
      CD65 = (1./(1./E6+1./E5-1.))*SIGMA*A6*F65
      CD67 = (1./(1./E6+1./E7-1.))*SIGMA*A6
      CD78 = (EW/(2.-EW))/(NSW+(2.*EW)/(2.-EW)*(1./E7+1./EW-1.))*
     $         SIGMA*A7
      CD89 = (EM/(2.-EM))/(NSM+(2.*EM)/(2.-EM)*(1./E8+1./EM-1.)) *
     $          SIGMA*A8
      CD910 = (ES/(2.-ES))/(NSS+(2.*ES)/(2.-ES)*(1./E9+1./ES-1.)) *
     $          SIGMA*A9
      IF(ICONI.EQ.0)RETURN
      A237=PI*(R(10)**2-R(7)**2)


      CD237=CD78/A7*A237*F128
      CD261 = (1./(1./E6  ./E5))*SIGMA*PI
      CD290 = (1./(1./E5+1./ECHP))*SIGMA*A5*F54
      CD296 = (1./(1./E5+1./E7))*SIGMA*A7*R(5)/R(7)
      CD301 = CD78*A8/A7*R(7)/R(8)
      CD306 = CD89*A9/A8*R(8)/R(9)
      CD311 = CD910*A10/A9*R(9)/R(10)
      DO 100 I=1,111,10
      K=I+10*(I-1+NTRANS)
      IF(K.LE.111)
     $CD(I)=CD21*(T(K)**2+T(3)**2)*(T(K)+T(3)   )
      CD(I+1)=CD32*XK(I+1,14)/XK(1,14)
      CD(I+2)=CD43*XK(I+2,14)/XK(1,14)
      CD(I+3)=CD54*(T(I+3)**2+T(I+4)**2)*(T(I+3)+T(I+4))
      CD(I+4)=CD65*(T(I+4)**2+T(I+5)**2)*(T(I+4)+T(I+5))
      CD(I+5)=CD67*(T(I+5)**2+T(I+6)**2)*(T(I+5)+T(I+6))
      CD(I+6)=CD78*(T(I+6)**2+T(I+7)**2)*(T(I+6)+T(I+7))
      CD(I+7)=CD89*(T(I+7)**2+T(I+8)**2)*(T(I+7)+T(I+8))
      CD(I+8)=CD910*(T(I+8)**2+T(I+9)**2)*(T(I+8)+T(I+9))
  100 CONTINUE
      CD(120)=XK(120,12)*PI*R(1)**2/DELX
      CD(121)=0.0
      CD(122)=XK(122,14)*PI*(R(4)**2-R(3)**2)/DELX
      CD(123)=0.0
      CD(124)=XK(124,10)*PI*((R(5)+TMUF)**2-R(5)**2)/DELX
      CD(125)=XK(125,4)*PI*((R(6)+THTR)**2-R(6)**2)/DELX
      CD(126)=XK(126,10)*PI*((R(7)+TSTF)**2-R(7)**2)/DELX
      CD(127)=XK(127,10)*PI*((R(8)+TSTF)**2-R(8)**2)/DELX
      CD(128)=XK(128,10)*PI*((R(9)+TSTF)**2-R(9)**2)/DELX
      CD(129)=XK(129,2)*PI*((R(10)+TWAL)**2-R(10)**2)/DELX
      DO 200 I=120,210,10
      CD(I+10)=CD(120)*XK(I+10,12)/XK(120,12)
      CD(I+11)=0.0
      CD(I+12)=CD(122)*XK(I+12,14)/XK(122,14)
```

```
      CD(I+13)=0.0
      CD(I+14)=CD(124)*XK(I+14,10)/XK(124,10)
      CD(I+15)=CD(125)*XK(I+15,4 )/XK(125,4)
      CD(I+16)=CD(126)*XK(I+16,10)/XK(126,10)
      CD(I+17)=CD(127)*XK(I+17,10)/XK(127,10)
      CD(I+18)=CD(128)*XK(I+18,10)/XK(128,10)
      CD(I+19)=CD(129)*XK(I+19,2 )/XK(129,2)
  200 CONTINUE
C
C     CONDUCTOR VALUES FOR REGION 2
C
      CD(230) = XK(230,2)*PI*((R(10)+TWAL)**2-R(10)**2)/DELX
      CD(231)= CD(230)*XK(231,2)/XK(230,2)
      CD(232)= CD(230)*XK(232,2)/XK(230,2)
      CD(233)= CD(230)*XK(233,2)/XK(230,2)
      CD(234)= CD(230)*XK(234,2)/XK(230,2)
      CD(235) = XK(235,2)*AM235/(R125-R126)
      CD(236)=CD237*(T(126)**2+T(127)**2)*(T(126)+T(127))
      CD(237) = CD237*(T(128)**2+T(127)**2)*(T(128)+T(127))
      CD(238) = CD237*(T(129)**2+T(128)**2)*(T(129)+T(128))
      CD(239) = CD237*(T(130)**2+T(129)**2)*(T(130)+T(129))
      CD(240) = 0.0
      CD(241) = CD(126)/2.*XK(241,10)/XK(126,10)
      CD(242) = CD(126)/2.*XK(242,10)/XK(126,10)
      CD(243) = CD(126)/2.*XK(243,10)/XK(126,10)
      CD(244) = CD(126)/2.*XK(244,10)/XK(126,10)
      CD(245) = XK(245,10)*PI*(R(8)+R(7))*TSTF/(R(8)-R(7))
      CD(246) = XK(246,10)*PI*(R(9)+R(8))*TSTF/(R(9)-R(8))
      CD(247) = XK(247,10)*PI*(R(10)+R(9))*TSTF/(R(10)-R(9))
      CD(248) = CD(230)*XK(248,2)/XK(230,2)
      CD(249)=CD237/2.*(T(118)**2+T(130)**2)*(T(118)+T(130))*F118/F128
      CD(250) = CD237/2.*(T(119)**2+T(130)**2)*(T(119)+T(130))*F119/F128
      CD(251) = XK(251,10)*PI*(R126+R(7))*TSTF/(R126-R(7))
      CD(252) = XK(252,10)*PI*(R(10)+R126)*TSTF/(R(10)-R126)
      CD(253) = CD(251)*XK(253,10)/XK(251,10)
      CD(254) = CD(252)*XK(254,10)/XK(252,10)
      CD(255) = CD(251)*XK(255,10)/XK(251,10)
      CD(256) = CD(252)*XK(256,10)/XK(252,10)
      CD(257) = CD(251)*XK(257,10)/XK(251,10)
      CD(258) = CD(221)*XK(258,10)/XK(252,10)
      CD(259) = XK(259,2)*AM259/(R126-R131)
      CD(260) = XK(260,2)*PI*R131*.2*DELX/R131
      CD(261) = CD261*((R(6)+THTR)**2-R(6)**2)*F116*
     1         (T(116)**2+T(136)**2)*(T(116)+T(136))
      CD(262) = CD261*((R(5)+TMUF)**2-R(5)**2)*F115*
     1         (T(115)**2+T(136)**2)*(T(115)+T(136))
      CD(263) = CD261*(R(4)**2-R(2)**2)*F113*
     1         (T(113)**2+T(136)**2)*(T(113)*T(136))
      CD(264) = CD261*R(1)**2*F111*
     1         (T(111)**2+T(136)**2) *(T(111)*T(136))
      IF(NTRANS.GT.0)CD(264)=0.
```

```
C
C     CONDUCTORS FOR REGION 3
C
      CD(265)=XK(265,16)*PI*(R(4)+R(3))/DELX
      CD(266)=CD(265)*XK(266,16)/XK(265,16)
      CD(267)=CD(265)*XK(267,16)/XK(265,16)
      CD(268)=CD(265)*XK(268,16)/XK(265,16)
      CD(269)=0.0
      CD(270)=CD(124)*XK(270,10)/XK(124,10)
      CD(271)=CD(124)*XK(271,10)/XK(124,10)
      CD(272)=CD(124)*XK(272,10)/XK(124,10)
      CD(273)=CD(124)*XK(273,10)/XK(124,10)
      CD(274)=0.0
      CD(275)=CD(126)*XK(275,10)/XK(126,10)
      CD(276)=CD(126)*XK(276,10)/XK(126,10)
      CD(277)=CD(126)*XK(277,10)/XK(126,10)
      CD(278)=CD(126)*XK(278,10)/XK(126,10)
      CD(279)=0.0
      CD(280)=CD(127)*XK(280,10)/XK(127,10)
      CD(281)=CD(127)*XK(281,10)/XK(127,10)
      CD(282)=CD(127)*XK(282,10)/XK(127,10)
      CD(283)=CD(127)*XK(283,10)/XK(127,10)
      CD(284)=0.0
      CD(285)=1.89*XK(285,2)*PI*DELX
      CD(286)=CD(128)*XK(286,10)/XK(128,10)
      CD(287)=CD(128)*XK(287,10)/XK(128,10)
      CD(288)=0.0
      CD(289)=CD(129)*XK(289,2)/XK(129,2)
      CD(290) = CD290*(T(137)**2+T(142)**2)*(T(137)+T(142))
      CD(291) = CD290*(T(138)**2+T(143)**2)*(T(138)+T(143))
      CD(292) = CD290*(T(139)**2+T(144)**2)*(T(139)+T(144))
      CD(293) = CD290*(T(140)**2+T(145)**2)*(T(140)+T(145))
      CD(294) = CD290*(T(141)**2+T(146)**2)*(T(141)+T(146))
      CD(295)=XK(295,2)*PI*(R(7)+R(5))*DELX*.50/(R(7)+R(5))
      CD(296) = CD296*(T(143)**2+T(148)**2)*(T(143)+T(148))
      CD(297) = CD296*(T(144)**2+T(149)**2)*(T(144)+T(149))
      CD(298) = CD296*(T(145)**2+T(150)**2)*(T(145)+T(150))
      CD(299) = CD296*(T(146)**2+T(151)**2)*(T(146)+T(151))
      CD(300)=CD(295)*2.0*XK(300,2)/XK(295,2)
      CD(301) = CD301*(T(148)**2+T(153)**2)*(T(148)+T(153))
      CD(302) = CD301*(T(149)**2+T(154)**2)*(T(149)+T(154))
      CD(303) = CD301*(T(150)**2+T(155)**2)*(T(150)+T(155))
      CD(304) = CD301*(T(151)**2+T(156)**2)*(T(151)+T(156))
      CD(305)=CD(285)*XK(305,2)/XK(285,2)
      CD(306) = CD306*(T(153)**2+T(157)**2)*(T(153)+T(157))
      CD(307) = CD306*(T(154)**2+T(158)**2)*(T(154)+T(158))
      CD(308) = CD306*(T(155)**2+T(159)**2)*(T(155)+T(159))
      CD(309) = CD306*(T(156)**2+T(160)**2)*(T(156)+T(160))
      CD(310)=XK(310,2)*PI*(R(10)+R(9))*DELX/(R(10)+R(9))
      CD(311) = CD311*(T(159)**2+T(162)**2)*(T(159)+T(162))
      CD(312) = CD311*(T(160)**2+T(163)**2)*(T(160)+T(163))
```

```
      CD(313)=CD(124)*XK(313,10)/XK(124,10)
      CD(314)=CD(126)*XK(314,10)/XK(126,10)
      CD(315)=CD(127)*XK(315,10)/XK(127,10)
      CD(316)=CD(128)*XK(316,10)/XK(128,10)
      CD(317)=CD(129)*XK(317,2 )/XK(129,2 )
      CD(261)=0.0
      CD(262)=0.0
      CD(263)=0.0
      CD(264)=0.0
      IF(NTRANS.EQ.0) GO TO 250
      DO 245 I=1,NTRANS
      K=1+10*(11+I-NTRANS)
      J=1+10*(I-1)
      CD(K)=CD21*(T(J)**2+T(137)**2)*(T(J)+T(137))
  245 CONTINUE
  250 CONTINUE
C     THE FOLLOWING CONDUCTORS ARE FOR THE HELIUM GAS CONTAINED IN
C     THE MUFFLE
      A1=2.*PI*R(1)*DELX
      AVG1=(A1+A2)/2.
      XDIS1=R(2)-R(1)
      AVG2=(A4+A5)/2.
      XDIS2=R(5)-R(4)
      CONHE1=XKHE*AVG1/XDIS1
      CONHE2=XKHE*AVG2/XDIS2
      DO 2001 I=318,329
      CD(I)=CONHE1
 2001 CONTINUE
      DO 2002 I=330,346
      CD(I)=CONHE2
 2002 CONTINUE
C     CONDUCTION BETWEEN HOT AND COLD HEAT PIPES
      NLAYER=30
      ELAYER=EW
      CD(347)=PI*(R(4)**2-R(2)**2)*SIGMA*(ELAYER/(2.-ELAYER))/NLAYER*
     $ (T(3)**2+T(141)**2)*(T(3)+T(141))
      RETURN
      END
```

```
      SUBROUTINE TSIP(C,CD,NCTRL,M,NNDS,NPR,PRIN,TIM,IPT,TSCON,DT)
      DIMENSION C(200),CD(500),M(200,15)
      SMAL = 1.0E30
      DO 100 I = 1,NNDS
      CAP = C(I)
      IF(CAP) 100,100,400
  400 CONTINUE
      NCOND = M(I,1)
      CSUM = 0.0
      DO 200 J = 1,NCOND
      IC = J*2+1
      NC = M(I,IC)
      CSUM = CSUM + CD(NC)
  200 CONTINUE
      STEST = CAP/CSUM
      IF(STEST.GE.SMAL) GO TO 300
      SMAL = STEST
      NCTRL = I
  300 CONTINUE
  100 CONTINUE
      DT = SMAL/TSCON
      TPR = FLOAT(NPR)*PRIN
      TT1 = TIM+DT
      IPT = 0
      IF(TPR.GT.TT1) GO TO 500
      DT = TPR-TIM
      IPT = 1
  500 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INTP(X,N,Y)
      COMMON/DTA/CC(40,51)
      J = CC(N,1)
      J1 = J*2
      XLST = CC(N,2)
      XHST = CC(N,J1)
      IF(X.EQ.XLST) GO TO 700
      IF(X.LT.XLST) GO TO 100
      IF(X.GT.XHST) GO TO 200
      JT = 4
  500 CONTINUE
      IF(CC(N,JT)-X)300,600,400
  300 CONTINUE
      JT = JT+2
      GO TO 500
  400 CONTINUE
      N1 = JT-2
      N2 = N1+1
      N3 = JT
      N4 = N3+1
      GO TO 900
  600 CONTINUE
      NT = JT+1
      Y = CC(N,NT)
      GO TO 1000
  700 CONTINUE
      Y = CC(N,3)
      GO TO 1000
  100 CONTINUE
      N1 = 2
      N2 = 3
      N3 = 4
      N4 = 5
      GO TO 900
  200 CONTINUE
      N1 = 2*J-2
      N2 = N1+1
      N3 = 2*J
      N4 = N3+1
  900 CONTINUE
      SL = (CC(N,N4)-CC(N,N2))/(CC(N,N3)-CC(N,N1))                      00
      Y = CC(N,N2)+SL*(X-CC(N,N1))
 1000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DATA
      COMMON/DTA/CC(40,51)
  701 FORMAT(2I5)
  702 FORMAT(2E10.0)
  703 FORMAT(1H1,10X,11HT A B L E S)
  704 FORMAT(1H0,5X,2I5)
  705 FORMAT(1H0,5X,2E12.5)
      WRITE(6,703)
  100 CONTINUE
      READ(5,701)N,J
      WRITE(6,704)N,J
      IF(N.EQ.0) GO TO 300
      CC(N,1) = J
      DO 200 I = 1,J
      READ(5,702) A,B
      WRITE(6,705)A,B
      K1 = I*2
      K2 = K1+1
      CC(N,K1) = A
      CC(N,K2) = B
  200 CONTINUE
      GO TO 100
  300 CONTINUE
      RETURN
      END
```

Appendix B
LISTING OF INPUT DATA CARDS FOR SAMPLE PROBLEM

```
        100.   50  100         2.0      100.         540.      540.
2000.       2000.       2000.       2000.
     5
     1     9
   0.0         .055       CP - STAINLESS STEEL
   250.        .085
   500.        .108
   750.        .123
  1000.        .133
  1500.        .142
  2000.        .152
  2500.        .164
  3000.        .177
     2     9
     0.0        4.8       K - STAINLESS STEEL
   250.         6.7
   500.         8.3
   750.         9.8
  1000.        11.[illegible]
  1500.        13.2
  2000.        15.2
  2500.        17.1
  3000.        19.0
     3    10
     0.0          .016    CP - ALUMINA
   200.           .022
   400.           .025
   600.           .027
   800.           .028
  1000.           .029
  1500.           .030
  2000.           .031
  2500.           .032
  3000.           .032
    13     2
   100.          .100     CP-HEAT PIPE
  4000.          .100
    14     2
   100.         1.0       K-HEAT PIPE
  4000.         1.0
    15     2
   100.          .100     CP-COLD HEAT PIPE
  4000.          .100
    16     2
   100.         1.0       K-COLD HEAT PIPE
  4000.         1.0
```

```
    4     10
   0.0         22.5      K - ALUMINA
  200.         17.8
  400.         12.8
  600.          9.3
  800.          7.2
 1000.          5.7
 1500.          3.9
 2000.          3.2
 2500.          3.2
 3000.          3.1
    5      2
  100.          .036     CP - TUNGSTEN
 3500.          .036
    6     10
  100.        220.0      K - TUNGSTEN
  200.        130.0
  300.        105.
  500.         93.
 1000.         79.
 1500.         73.
 2000.         68.
 2500.         65.
 3000.         62.
 3500.         59.5
    7     12
    0.          .046     CP - MOLY
  250.          .057
  500.          .062
  750.          .064
 1000.          .065
 1250.          .066
 1500.          .067
 2000.          .070
 2500.          .076
 3000.          .083
 3500.          .091
 4000.          .100
    8     12
   0.0         84.       K - MOLY
  250.         82.5
  500.         79.
  750.         76.5
 1000.         74.5
 1250.         72.5
 1500.         69.5
 2000.         63.5
 2500.         57.
 3000.         51.0
 3500.         45.5
 4000.         42.
```

```
   9      2
   0.0         .100   CP - TA-10W
4000.          .100
  10      5
   0.0        33,5    K - TA-10W
2400.          33.5
3200.          29.5
4000.          26.
4800.          22.5
  11      2
 100.          .036   CP - TUNGSTEN(SAMPLE)
3500.          .036
  12     10
 100.         220.0   K - TUNGSTEN
 200.         130.0
 300.         105.
 500.          93.
1000.          79.
1500.          73.
2000.          68.
2500.          65.
3000.          62.
3500.          59.5
```