APOLLO SYSTEMS DEPARTMENT
GENERAL ELECTRIC

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TIR 741-MED-4011			
FROM D. J. Grounds		TO J. A. Rummel, Ph.D./DB6	
DATE 7/17/74	WORK ORDER REF: DM-110T	WORK STATEMENT PARA: NAS9-12932	REFERENCE:
SUBJECT Transient Thermoregulatory Model with Graphics Output			

(NASA-CR-160217) TRANSIENT THERMOREGULATORY MODEL WITH GRAPHICS OUTPUT (General Electric Co.) 25 p HC A02/MF A01 CSCL 06P

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This report is a user's guide for the transient version of the thermoregulatory model of Stolwijk. The model is designed to simulate the transient response of the human thermoregulatory system to thermal inputs. The model consists of 41 compartments over which the terms of the heat balance are computed. The control mechanisms which are identified are sweating, shivering, vasoconstriction and vasodilation.

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Attachment

/db

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DISTRIBUTION NASA/JSC: Retha Shirkey, JM6 (1979 distribution) GE/TSSD: D.Fitzjerrell

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ASD 4028

PROGRAM DESCRIPTION

A. IDENTIFICATION

Program Name - Thermoregulatory Model of Stolwijk (Transient Version)

Bioengineer Contact - D. J. Grounds

Programmer - V. J. Marks

Date of Issue - June 30, 1974

B. GENERAL DESCRIPTION

This user's guide and program description updates and replaces TIR 741-MED-3011. The model is designed to simulate the transient response of the human thermoregulatory system to thermal inputs. The model consists of 41 compartments over which the terms of the heat balance are computed. The control mechanisms which are identified are sweating, shivering, vasoconstriction and vasodilation.

C. USAGE AND RESTRICTIONS

Machine and Compiler Required - Univac 1110 TSS and FORTRAN V

Peripheral Equipment Required - Time Sharing Terminal
- Tektronix 4010 Graphics Terminal

D. PARTICULAR DESCRIPTION

A detailed description of the basic model is given in references 1-5. The current modifications include an improved shivering mechanism and the introduction of a graphics output option.

The shivering mechanism which appeared in earlier versions was described by the following equation.

QSHIV = CCHIL*COLD (1) + SCHIL*COLDS + PCHIL*COLD (1) *COLDS.

But, since CCHIL = 0.0 and SCHIL = 0.0, the expanded equation becomes

$$QSHIV = 12.22\ (Tcore\ set - Tcore)\ head^*\ (\sum K(1)^*(Tset(1) - T(1))$$

where I equals all skin compartments and K(1's) are constants based on the weighted mass of each skin compartment. This equation was based on the widely accepted data of Benzinger and Kitzinger(6). However, the data are presented with average skin temperature as an independent variable. This does not allow verification of the model equation because of the introduction of set point temperatures for each skin compartment. The improved modeling of this mechanism is complicated by several factors. First, although the role of hypothalmic temperature signal and skin temperature signal has each been established as necessary for shivering, the functional relationship for the combined effect of skin receptor signal with hypothalmic signal is unknown for conditions other than uniform skin temperature. Further, the heat that is generated by chemical reactions as a response to cold, chemical thermogenesis is initiated by the same control signals and is therefore extremely difficult to separate from shivering thermogenesis. Shivering can also be initiated through the higher centers as a general sympathetic response. Also, there is considerable variation in the shivering responses between male and female subjects. These factors have contributed to the lack of an accepted control system model of the shivering mechanism.

In order to make the best use of available data without making assumptions which seriously limit the accuracy of the model, the approach chosen was to derive an empirical relationship from the experimental data. This approach was also taken by Riggs (7), but acceptable correspondence to the data could not be obtained using his equations. Although this approach seems to fulfill the requirements of the model, it should be reviewed whenever a more complete understanding of the mechanisms of this process is gained.

By using a combination of linear and parabolic regression schemes based on least squares criterion, a set of equations was found to approximate the curves of reference 6, page 649. These equations are:

$$XTC = TC - (.1\ ((37.0 - TC)\ 1.7)^2\ )\ /\ 10) \qquad (1)$$

$$RM = 22221. -614.2\ (XTC) + TS\ (-1933.2 + 53.66\ (XTC)\ ) \qquad (2)$$

$$+ TS^2\ (46.45 - 1.289\ (XTC)\ \ )$$

$$QSHIV = RMS\text{-}QBASAL \geq 0.0 \qquad (3)$$

where

QSHIV = Rate of heat produced by shivering BTU/HR

QBASAL = Basal Metabolic Rate BTU/HR

RM = Metabolic Rate CAL/SEC

RMX = Metabolic Rate BTU/HR

TC = Intercranial Temp. ^{o}C

TS = Average Skin Temp. ^{o}C

The fitted curves are shown in Figure 1 with corresponding experimental data.

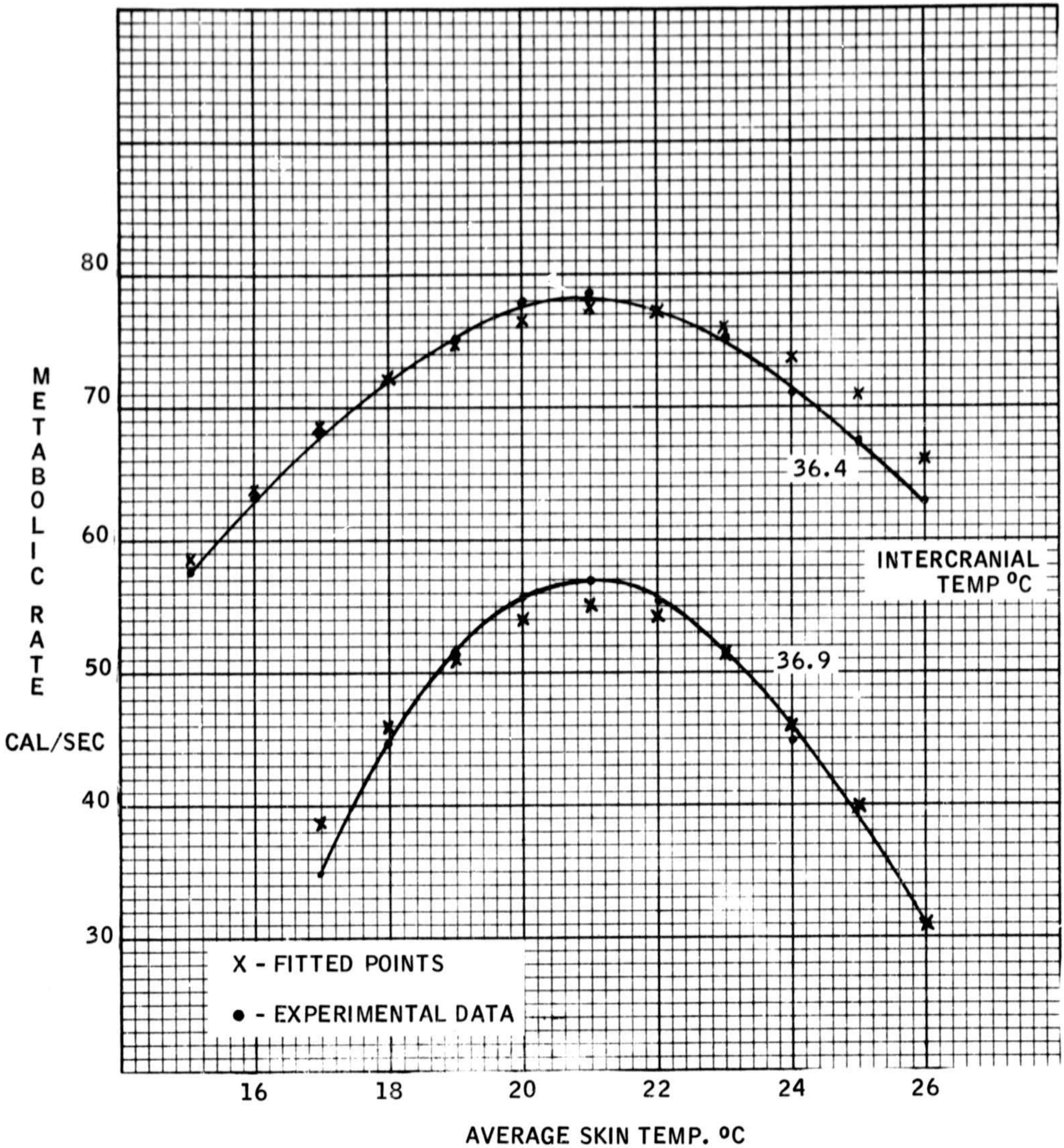


Fig. 1 COMPARISON OF EXPERIMENTAL DATA TO FITTED DATA

E. DESCRIPTION OF INPUT

The user must specify if the graphics output capability is required. If graphics is required, then a list of variables to plot is solicited. Upon completion of the list a name list input is requested. This request is answered as shown in the example of Appendix 2 by supplying the following values:

Col. 2

RM	Total Metabolic Rate	BTU/HR
QBS	Basal Metabolic Rate	BTU/HR
VEFF	Efficiency of useful work	%
AC	Surface Area for Convection	FT^2
AR	Surface Area for Radiation	FT^2
TCAB	Temperature of the Cabin	^oF
TW	Temperature of the Walls	^oF
TDEWC	Dew Point Temp. in Cabin	^oF
VCAB	Cabin Free Stream Velocity	FT^3/SEC
VEFF	Ventilation Efficiency	%
PCAB	Atmospheric Pressure in Cabin	PSIA
G	Gravity Normal to Earth	
CLOV	Clothing Thickness/Conductivity	$FT^2HR\ ^oF/BTU$
EUG	Emissivity of Undergarment	
CPG	Specific Heat of Gas	BTU/lb^oF
DT	Integration Step Size (.05)	MIN
PRINTI	Print Interval	MIN
SETI	Max Time/Run	MIN
MCASES	Number of Imposed Case	

MCASES = 0 Initial Conditions (Not plotted)
MCASES > 0 Imposed Case Using Final Values for Starting Point

To complete the namelist, input a $ END is entered beginning in column 2.

F. DESCRIPTION OF OUTPUT

See Appendix for example output. The graphics output option which has been added to the program is demonstrated in the example run shown. It includes some conversational input to specify the variables to plot and their ranges. There are 55 variables which can be used with the graphics option:

1-43		Temperatures of the T Array (See TIR 741-MED-3011)	^oF
44	TUGAV	Average Temperature of Undergarment	^oF
45	SQUG	Sum of Sensible Heat Transfer Rate	BTU/HR
46	QEVAP	Heat Transfer Rate of Evaporation from Surface	BTU/HR
47	TOTL	Total Latent Heat Transfer Rate	BTU/HR
48	TDEWC	Dew Point Temp. in Cabin	BTU/HR
49	WORK	The Metabolic Work Performed	^oF
50	QSHIV	Heat Produced by Shivering	BTU/HR
51	STORAT	The Rate of Heat Accumulation	BTU/HR

52	QSTOR	Total Heat Accumulated	BTU/HR
53	TCAB	Temperature of the Cabin	BTU
54	VPDEW	Vapor Pressure at Cabin Dew Point	^{o}F
55	U	Useful Work Performed	BTU/HR

G. INTERNAL CHECKS AND EXITS

The model will proceed until a steady-state condition is met (Storat - Oldstor/Storat) $\leq .01$ or until maximum time is exceeded whenever MCASES = 0. The model is then initialized with the steady-state values and thermal transients are then simulated for MCASES > 0.

H. INDEPENDENT SUBROUTINES

The Independent Subroutines are MANT, SHRT, VPT, CQSH, TCF, GVAR, and the Tektronix Plot Package. The Subroutines are listed in Appendix 1.

I. SYSTEM SUBROUTINES

No special system routines are required.

J. COMPLETION DATE

June 25, 1974

REFERENCES

1. "41-Node Transient Metabolic Man Program", LEC/672-23-030031, Lockheed Electronics Company, Houston Aerospace Systems Division.

2. "Simplification of 1108 Lockheed Version of Stolwijk Model and Incorporation of Improved Convective Heat Transfer Coefficient", TIR 750-MED-2002, General Electric Company, Space Division, Houston Programs and a revision, TIR 741-MED-2004.

3. "Incorporation of Basal Metabolic Rate as an Input Parameter", TIR 750-MED-2003, General Electric Company, Space Division, Houston Programs and a revision, TIR 750-MED-2005.

4. "Incorporation of Clothing Logic Contained in Stolwijk Amoeba Program into Simplified Lockheed Version of Stolwijk Model", TIR 750-MED-2006, General Electric Company, Space Division, Houston Programs.

5. "Steady State Version of Lockheed Program", TIR 741-MED-2011, General Electric Company, Space Division, Houston Programs.

6. Benzinger, T.H. and Kitzinger, C., "The Human Thermostat", Temperature Part 3 - Medicine and Biology, Reinholdt Publishing Corp., New York, 1963.

7. Riggs, D.S., Control Theory and Physiological Feedback Mechanisms Williams and Wilkins Co., Baltimore, Md., 1970, p. 388.

APPENDIX 1

PROGRAM LISTING

```
      END
C     STOLWIJK METABOLIC MAN TRANSIENT MODEL
      COMMON/NSHIV/TAVG,TC,RMX
      COMMON  T(43),TUGAV,SQUG,QEVAP,TOTL,TDEWC,WORK,QSHIV,
     & STORAT,QSTOR,TCAB,VPDEW,U,TUG(10),ACE(10),ARE(10),
     & PCAB,RM,QLCG,C(41),TSET(43),TW,EUG,CLO,CUG,VEFF,G,
     & VCAB,DTIME,QBASAL
      COMMON/DIAG/QCONV(40),QCOND(40),BF(40),QMET(40),TEST(41),WARM(41)
      DIMENSION SAVTUG(10),SAVT(43),PCA(10),PLT(55),NI(8)
      EQUIVALENCE (PLT(1),T(1))
      DATA PCA/.07,.3602,.06705,.06705,.1587,.1587,.025,.025,2*.0343/
      DATA(TSET(I),I=1,43)/98.6,97.6,97.0,96.6,98.8,98.3,95.9,94.4,96.1,
     *                     95.1,94.1,93.7,96.1,95.1,94.1,93.7,97.6,96.5,
     *                     95.1,94.5,97.6,96.5,95.1,94.5,95.9,95.7,95.6,
     *                     95.5,95.9,95.7,95.6,95.5,95.8,95.5,95.7,95.5,
     *                     95.8,95.5,95.7,95.5,98.5,95.,95./
      DATA C/6.67,1.488,0.496,0.535,20.9,34.9,9.42,2.69,1.382
     *                ,3.35,0.644,0.484,1.382,3.35,0.644,0.484,4.4,10.2
     *                ,1.58,1.192,4.4,10.2,1.58,1.192,0.1568,0.0738,
     *                 0.0992,0.184,0.1568,0.0738,0.0992,0.184,0.2645,
     *                 0.0738,0.148,0.247,0.2645,0.0738,0.148,0.247,
     *                 4.94/
      DATA KY,RQ/1HY,0.82/
C
C   DEFINITION OF BODY SEGMENT TEMPERATURE SUBSCRIPTS
C   T(1)  = HEAD CORE          T(2)  = HEAD MUSCLE        T(3)  = HEAD FAT
C   T(4)  = HEAD SKIN          T(5)  = TRUNK CORE         T(6)  = TRUNK MUSC
C   T(7)  = TRUNK FAT          T(8)  = TRUNK SKIN         T(9)  = RIGHT ARM
C   T(10) = RIGHT ARM MUSCLE   T(11) = RIGHT ARM FAT      T(12) = RIGHT ARM
C   T(13) = LEFT ARM CORE      T(14) = LEFT ARM MUSCLE    T(15) = LEFT ARM F
C   T(16) = LEFT ARM SKIN      T(17) = RIGHT LEG CORE     T(18) = RIGHT LEG
C   T(19) = RIGHT LEG FAT      T(20) = RIGHT LEG SKIN     T(21) = LEFT LEG C
C   T(22) = LEFT LEG MUSCLE    T(23) = LEFT LEG FAT       T(24) = LEFT LEG S
C   T(25) = RIGHT HAND CORE    T(26) = RIGHT HAND MUSCLET(27) = RIGHT HAND
C   T(28) = RIGHT HAND SKIN    T(29) = LEFT HAND CORE     T(30) = LEFT HAND
C   T(31) = LEFT HAND FAT      T(32) = LEFT HAND SKIN     T(33) = RIGHT FOOT
C   T(34) = RIGHT FOOT MUSCLE  T(35) = RIGHT FOOT FAT     T(36) = RIGHT FOOT
C   T(37) = LEFT FOOT CORE     T(38) = LEFT FOOT MUSCLE   T(39) = LEFT FOOT
C   T(40) = LEFT FOOT SKIN     T(41) = CENTRAL BLOOD      T(42) = AVERAGE SK
C   T(43) = AVERAGE MUSCLE
C
      NAMELIST/INPUT/RM,QBS,UEFF,AC,AR,TCAB,TW,TDE,C,VCAB,VEFF,PCAB
     &               ,G,CLOV,EUG,CPG,DT,PRINTI,SETI,MCASES
      COMMON/PLTBUF/NBUF,XBUF(181),YBUF(181,8),NA(8),KSTOPP,SETI,NN
      WRITE (6,10)
   10 FORMAT(/'0DO YOU WANT GRAPHIC INSTEAD OF TABULAR OUTPUT? (Y/N)')
      READ (5,15) KYY
   15 FORMAT(1A1)
      IF (KYY.EQ.KY) KPLT=1
      IF (KPLT.GT.0) CALL GVAR(NI,NA,NN)
   20 IF (KPLT.EQ.1 .AND. NBUF.GT.0) KSTOPP=1
      IF(ICOND.EQ.0)NKPLT=KPLT
      IF (KSTOPP.LT.1) GO TO 25
      CALL PLOTX
      KSTOPP=0
      NBUF=0
   25 WRITE(6,30)
```

```
   30 FORMAT(/'0INPUT DATA USING NAMELIST $INPUT'/,)
      READ(5,INPUT)
      QBASAL=QBS
      IF(QBASAL.LT.0.01) QBASAL=293.
      IF(QBASAL.GT.RM) QBASAL=RM
      WRITE(6,INPUT)
      IF (MCASES.EQ.0) WRITE (6,60)
   60 FORMAT (1H0,17X,18HINITIAL CONDITIONS//)
      IF (MCASES.NE.0) WRITE (6,80)
   80 FORMAT (1H0,17X,18HIMPOSED CONDITIONS//)
      DTIME=DT/60.
      SETX=SETI/60.
      IF(NKPLT.EQ.1.AND.MCASES.GT.0)KPLT=1
      SETT=SETX
      PRINT=PRINTI/60.
C*************************************************************************
C
C     INITIALIZATION
C
C*************************************************************************
      PRNOW=PRINT
      IF(MCASES.GT.0)GO TO 140
      IF (ICOND.EQ.1 .AND. MCASES.EQ.0) WRITE(6,654)
  654 FORMAT( ' NOT INITIALIZED AT STEADY STATE')
      KPLT=0
      ICOND=0
      KOUNT=0
      QLCG=0.
      SQUG=0.
      QEVAP=0.
      TOTL=0.
      QSHIV=0.
      QSTOR=0.
      STORAT=0.
      DO 100 I=1,43
  100 T(I)=TSET(I)
      TUGAV=T(42)
      DO 120 I=1,10
      J=4*I
  120 TUG(I)=T(J)
C*************************************************************************
  140 DO 160 I=1,10
      J=4*I
      ACE(I)=PCA(I)*AC
      ARE(I)=PCA(I)*AR
  160 CONTINUE
      STIME=STIME+TIME
      TIME=0.
      U=UEFF/100.*(RM-QBASAL)
      WORK=RM-QBASAL-U
      VPDEW=VPT(TDEWC)
      CLO=.88*CLOV
  180 CONTINUE
  200 FORMAT(125H1  TIME               TEMP    AV TEMP   TEMP        Q
     1Q EVAP  Q LATENT   HEAT    SHIVER    TOTAL  CABIN     DEW
     2    ,/ 125H     MIN              HEAD     SKIN,  UNDER-  SENSIBLE
     3BTU/HR    BTU/HR  STORAGE    RATE      HEAT  TEMP      POINT
```

```
     4      / 125H                          CORE        F     GARMENT     BTU/HR
     5                         RATE    BTU/HR     STORAGE  F           F
     6      /  98H                           F                    F
     7                        BTU/HR                    BTU//)
      LC=7
C*************************************************************************
      WRITE(6,789)
 789  FORMAT(1H ,3X,'TMINS',11X,'HEADCORE  AVGSKIN  TUGAV   BLOOD   QE
     CVAP   INSENS  STORAT          QSHIV   QSTOR   TCAB   TDEWC')
C     MAIN LOOP FOR SHIRTSLEEVE CASE
C*************************************************************************
  220 PTIM =TIME*60.
      IF (LC.GT.58) GO TO 180
      LC=LC+1
      IF(MCASES.EQ.0)GO TO 567
      NBUF=NBUF+1
      IF (NBUF.GT.181) NBUF=181
      XBUF(NBUF)=PTIM
      DO 230 I=1,NN
      NII=NI(I)
  230 YBUF(NBUF,I)=PLT(NII)
      IF (KPLT.GT.0) CALL PLOTX
      IF (KPLT.GT.0) GO TO 260
 567  CONTINUE
C     WRITE(6,2)TAVG,RMX,TC,QSHIV
  2   FORMAT(1H ,5X,'SKINT=',F11.5,5X,'MET RATE=',F11.5,
     &5X,'I-C TEMP=',F11.5,5X,'QSHIV=',F11.5)
C      DO887 IL=1,33,8
C887  WRITE(6,888)(QCONV(IL-1+ILL),ILL=1,8)
 888  FORMAT( 8F9.2)
      WRITE(6,240)PTIM,T(1),T(42),TUGAV,T(41),QEVAP,TOTL,STORAT,
     & QSHIV,QSTOR,TCAB,TDEWC
  240 FORMAT(F8.1,9X,11F9.2)
  260 OLDSTR = STORAT
C-------------------------------------------------------------------------
C
      CALL SHRT
C
C-------------------------------------------------------------------------
      TIME=TIME+DTIME
      IF (ABS(STORAT).GT.2.) GO TO 280
      IF (ABS((OLDSTR-STORAT)/STORAT).LT..001) GO TO 300
  280 IF (TIME.GE.SETT) GO TO 300
      IF(MCASES.EQ.0) GO TO 260
      IF (PRNOW.GT.TIME) GO TO 260
      PRNOW=PRNOW+PRINT
      GO TO 220
  300 PTIM=TIME*60.
      PRNOW=TIME+DTIME
      IF(MCASES.EQ.0)GO TO 568
      NBUF=NBUF+1
      IF (NBUF.GT.181) NBUF=181
      XBUF(NBUF)=PTIM
      DO 310 I=1,NN
      NII=NI(I)
  310 YBUF(NBUF,I)=PLT(NII)
      IF (KPLT.GT.0) CALL PLOTX
```

```
      IF (KPLT.GT.0) GO TO 315
  568 CONTINUE
      WRITE (6,240)PTIM,T(1),T(42),TUGAV,T(41),QEVAP,TOTL,STORAT,QSHIV,
     *QSTOR,TCAB,TDEWC
  315 KOUNT=KOUNT+1
      IF (ICOND.EQ.1.AND.KOUNT.LE.MCASES) GO TO 380
C     SAVE INITIAL CONDITION RESULTS TO START IMPOSED CONDITION CASES
  320 DO 340 I=1,43
      SAVT(I)=T(I)
  340 CONTINUE
      DO 360 I=1,10
      SAVTUG(I)=TUG(I)
  360 CONTINUE
      XTUGAV=TUGAV
      XSQUG=SQUG
      XQEVAP=QEVAP
      XTOTL=TOTL
      XSTRAT=STORAT
      XQSHIV=QSHIV
      XQSTOR=QSTOR
      ICOND=1
      GO TO 20
C
C     RESTORE INITIAL CONDITION RESULTS FOR NEXT CASE
C
  380 DO 400 I=1,43
      T(I)=SAVT(I)
  400 CONTINUE
      DO 420 I=1,10
      TUG(I)=SAVTUG(I)
  420 CONTINUE
      TUGAV=XTUGAV
      SQUG=XSQUG
      QEVAP=XQEVAP
      TOTL=XTOTL
      STORAT=XSTRAT
      QSHIV=XQSHIV
      QSTOR=XQSTOR
      GO TO 20
      END
      SUBROUTINE SHRT
      COMMON  T(43),TUGAV,SQUG,QEVAP,TOTL,TDEWC,WORK,QSHIV,
     & STORAT,QSTOR,TCAB,VPDEW,U,TUG(10),ACE(10),ARE(10),
     & PCAB,RM,QLCG,C(41),TSET(43),TW,EUG,CLO,CPG,VEFF,G,
     & VCAB,DTIME,QBASAL
      COMMON/SHRTMN/EMAX(10),QRSEN1,QRSEN2,QRSEN3,QRSEN5,QRSEN6,
     *                  QSEN(10),QRAD(10)
      DIMENSION H(10)
      DATA H/.033,.026,2*.036,2*.033,2*.04,2*.036/
      TWR=TW+460.
      SQUGA=0.0
      SQUGW=0.0
      SQW=0.0
      TAVSKN=(0.446*T(8)+0.0826*T(12)+0.0826*T(16)+0.1945*T(20)+0.1945*
     &T(24))/.9902
C**************************************************************************
C
```

```
C  CALCULATION OF Q-RADIATED(GRAD) AND Q-SENSIBLE(QSEN)
C
C••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
      DO 60 I=1,10
      J=4+I
      TUGR=TUG(I)+460.
      HC=H(I)*ACE(I)*SQRT(PCAB*VCAB)
      IF(G.LE.0.0)GO TO 10
      HC1=0.06*ACE(I)*(PCAB**2*G*ABS(TUG(I)-TCAB)).**.25
      IF(HC1.GT.HC)HC=HC1
10    HR=0.1713E-8*ARE(I)*EUG*(TUGR**3+TUGR**2*TWR+TUGR*TWR**2+
     $TWR**3)
      IF(I.LT.2.OR.I.GT.6)GO TO 20
      IF(CLO.LT.0.01)GO TO 20
      TUG(I)=(HR*TW+HC*TCAB+ACE(I)/CLO*T(J))/(HR+HC+ACE(I)/CLO)
      GO TO 40
   20 TUG(I)=T(J)
   40 QUGW=HR*(TUG(I)-TW)
      QUGA=HC*(TUG(I)-TCAB)
      SQUGW=SQUGW+QUGW
      SQUGA=SQUGA+QUGA
      QSEN(I)=QUGA
      QRAD(I)=QUGW
   60 CONTINUE
C••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C
C   CALCULATION OF RESPITORY SENSIBLE
C
C••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
      QRSEN1=0.5*0.0418*PCAB*144.0/(48.3*(TCAB+459.69))*RM*CPG*((0.385*T
     .(1)+0.086*T(2)+0.0287*T(3)+0.238*T(5)+0.2615*T(6))-TCAB)
      QRSEN2 = 0.172 * QRSEN1
      QRSEN3 = 0.0574 * QRSEN1
      QRSEN6 = 0.523 * QRSEN1
      QRSEN5 = 0.476 * QRSEN1
      QRSEN1=0.771*QRSEN1
C
C
      SQUG = SQUGA + SQUGW + SQW + QRSEN1 + QRSEN5 + QRSEN2 + QRSEN3 +
     .QRSEN6
      TUGAV=0.3317*TUG(2)+0.104*(TUG(3)+TUG(4))+0.23015*(TUG(5)+TUG(6))
C••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
C
C     CALCULATE MAXIMUM EVAPORATION RATE
C
C••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
      DO 80 I=1,10
      J=4+I
      VPTUG=VPT(TUG(I))
      HE=0.126*ACE(I)*(TCAB+460.)**1.04*VEFF/100.*SQRT(VCAB*PCAB)
      IF(G.LE.0.0)GO TO 65
      HE1=1.32*ACE(I)*(TCAB+460.)/PCAB*(PCAB*G*(ABS(.005*PCAB*TUG(I)-
     .TCAB)+1.02*(VPT(TUG(I))-VPDEW)))**.25
      IF(HE1 .GT. HE) HE=HE1
 65   IF(I .LT. 2 .OR. I .GT. 6) GO TO 70
      IF(CLO .LT. .01) GO TO 70
      HECL=22.36*ACE(I)*(T(J)+460.)**0.81/(CLO*PCAB)
```

```
      EMAX(I)=HE*HECL/(HE+HECL)*(VPT(T(J))-VPDEW)
      GO TO 75
   70 EMAX(I)=HE*(VPT(T(J))-VPDEW)
   75 IF(EMAX(I) .LT. 0.0) EMAX(I)=0.0
   80 CONTINUE
C-----------------------------------------------------------------------
C
      CALL MANT
C
C-----------------------------------------------------------------------
      QSTOR=0.
      DO 100 I=1,41
      QSTOR=QSTOR+C(I)*(T(I)-TSET(I))
  100 CONTINUE
      STORAT=RM-(SQUGA+SQUGW+SQW+TOTL+QRSEN1+QRSEN2+QRSEN3+QRSEN6+
     1     QRSEN5)-U+QSHIV
      SCABC = QRSEN1 + QRSEN5 + QRSEN2 + QRSEN3 + QRSEN6 + SQUGA
      SCAB1=SQUGA+SQUGW
      RETURN
      END
      SUBROUTINE MANT
      COMMON  T(43),TUGAV,SQUG,QEVAP,TOTL,TDEWC,WORK,QSHIV,
     & STORAT,QSTOR,TCAB,VPDEW,U,TUG(10),ACE(10),ARE(10),
     & PCAB,RM,QLCG,C(41),TSET(43),TW,EUG,CLO,CPG,VEFF,G,
     & VCAB,DTIME,QBASAL
      COMMON/SHRTMN/EMAX(10),QRSEN1,QRSEN2,QRSEN3,QRSEN5,QRSEN6,
     *              QSEN(10),QRAD(10)
      COMMON/DIAG/QCONV(40),QCOND(40),BF(40),QMET(40),TEST(41),WARM(41),
     *          COLD(41),QDIF(10),QLAT(10)
      DIMENSION  SWTFAC(10), FACTOR(40)
      DIMENSION BFB(40),QB(40),WORKM(10),CHILM(10),SKINV(10),SKINC(10),
     *          SKINS(10)
      DATA SWTFAC/0.6,0.05,0.05,0.08,0.08,0.01,0.01,0.01,0.01,00.1/
      DATA CSW,SSW,PSW,CDIL,SDIL,PDIL,CCON,SCON,PCON,CCHIL,SCHIL,PCHIL
     *   /705.0,63.9,0.0,143.,9.2,0.0,2.78,2.78,0.0,0.0,0.0,25./
      DATA BFB/105.6,0.594,0.264,3.7,510.0,14.08,5.06,4.62,0.759,1.364,
     *         0.352,0.55,0.759,1.364,0.352,0.55,2.32,4.07,0.88,3.135,
     *         2.32,4.07,0.88,3.135,0.11,0.055,0.055,2.2,0.11,0.055,
     *         0.055,2.2,0.165,0.033,0.088,3.3,0.165,0.033,0.088,3.3/
      DATA QB/.1604,.0039,.0018,.0009,.5622,.0914,.0335,.0044,.0049,
     *        .0089,.0023,.0008,.0049,.0089,.0023,.0008,.0160,.0265,
     *        .0057,.0019,.0160,.0265,.0057,.0019,.0006,.0002,.0004,
     *        .0003,.0006,.0002,.0004,.0003,.0010,.0002,.0005,.0004,
     *        .0010,.0002,.0005,.0004/
      DATA WORKM/0.0,0.3,0.04,0.04,0.3,0.3,0.005,0.005,0.005,0.005/
      DATA CHILM/0.023,0.948,0.00165,0.00165,0.0095,0.0095,0.00115,
     *          0.00115,0.00115,0.00115/
      DATA SKINV/0.132,0.322,0.0475,0.0475,0.115,0.115,0.061,0.061,
     *          0.05,0.05/
      DATA SKINC/0.05,0.15,0.025,0.025,0.025,0.025,0.175,0.175,0.175,
     *          0.175/
      DATA SKINS/0.081,0.482,2*0.077,2*0.1095,2*0.0155,2*0.0175/
      DATA FACTOR/8.85,12.82,22.60,0.0,3.09,10.70,28.05,0.0,3.18,8.32,
     *           22.80,0.0,3.18,8.32,22.80,0.0,5.75,18.70,33.50,0.0,
     *           5.75,18.70,33.50,0.0,4.50,8.32,9.41,0.0,4.50,8.32,
     *           9.41,0.0,5.54,13.36,11.93,0.0,5.54,13.36,11.93,0.0/
C***********************************************************************
```

```
C
C   SWEAT,SHIVER,CONSTRICTION,DILATION CALCULATIONS
C
C*************************************************************************
      DO 80 I=1,40
      TEST(I)=T(I)-TSET(I)
      WARM(I)=0.0
      COLD(I)=0.0
      IF (TEST(I)) 20,40,60
   20 COLD(I)=-TEST(I)
   40 GO TO 80
   60 WARM(I)=TEST(I)
   80 CONTINUE
C
      TAVSK=T(42)
      WARMS=0.0827*WARM(4)+0.587*WARM(8)+0.0411*WARM(12)+0.0411*WARM(16)
     *      +0.093*WARM(20)+0.093*WARM(24)+0.011075*WARM(28)+0.011075*
     *       WARM(32)+0.01995*WARM(36)+0.01995*WARM(40)
      COLDS=0.0827*COLD(4)+0.587*COLD(8)+0.0411*COLD(12)+0.0411*COLD(16)
     *      +0.093*COLD(20)+0.093*COLD(24)+0.011075*COLD(28)+0.011075*
     *       COLD(32)+0.01995*COLD(36)+0.01995*COLD(40)
      WARMM=0.417*WARM(6)+0.095*WARM(10)+0.095*WARM(14)+0.1965*WARM(18)+
     *       0.1965*WARM(22)
      COLDM=0.417*COLD(6)+0.095*COLD(10)+0.095*COLD(14)+0.1965*COLD(18)+
     *       0.1965*COLD(22)
      SWEAT=CSW*WARM(1)+SSW*WARMS+PSW*WARM(1)*WARMS
      DILAT=CDIL*WARM(1)+SDIL*WARMS+PDIL*WARM(1)*WARMS
      STRIC=CCON*COLD(1)+SCON*COLDS+PCON*COLD(1)*COLDS
      CALL QSH(T(1),QSHIV,TAVSK,QBASAL)
C*************************************************************************
C
C   CALCULATION OF RESPIRATORY LATENT
C
C*************************************************************************
      QLAT1=.5*0.0418*PCAB*144./(48.3*(TCAB+459.69))*RM*(VPT(0.385*
     *T(1)+0.086*T(2)+0.0287*T(3)+0.238*T(5)+0.2615*T(6))-0.8*VPDEW)
     **((18.0*1040.0)/(32.0*PCAB))
      QLAT2=0.172*QLAT1
      QLAT3=.0574*QLAT1
      QLAT5=0.476*QLAT1
      QLAT6=0.523*QLAT1
      QLAT1=0.771*QLAT1
      QR=QLAT1+QLAT2+QLAT3+QLAT5+QLAT6
C*************************************************************************
C
C   SKIN DIFFUSION
C
C*************************************************************************
      DO 100 I=1,10
      QDIF(I)=6.66*(VPT(TUG(I))-VPDEW)*ACE(I)
  100 CONTINUE
  120 CONTINUE
C*************************************************************************
C
C   QLATENT(QLAT) CALCULATIONS
C
C*************************************************************************
```

```
      DO 160 I=1,10
      J=4*I
      QLAT(I)=QDIF(I)+SKINS(I)*SWEAT*2.**((T(J)-TSET(J))/4.)
      IF (QLAT(I).GT.EMAX(I)) GO TO 140
      GO TO 160
  140 QLAT(I)=EMAX(I)
  160 CONTINUE
      QD=0.0
      TOTL=QR
      DO 180 I=1,10
      QD=QD+QDIF(I)
  180 TOTL=TOTL+QLAT(I)
      QEVAP=TOTL-QR-QD
C*************************************************************************
C  BLOOD FLOW CALCULATIONS
C*************************************************************************
      DO 200 I=1,10
      N=4*I-3
      BF(N)=BFB(N)
      QMET(N)=QB(N)*QBASAL
      QMET(N+1)=QB(N+1)*QBASAL+WORKM(I)*WORK+CHILM(I)*QSHIV
      BF(N+1)=BFB(N+1)+QMET(N+1)-QB(N+1)*QBASAL
      QMET(N+2)=QB(N+2)*QBASAL
      BF(N+2)=BFB(N+2)
      QMET(N+3)=QB(N+3)*QBASAL
      BF(N+3)=(BFB(N+3)+SKINV(I)*DILAT)/(1.0+SKINC(I)*STRIC)
  200 CONTINUE
      TSBF=BF(4)+BF(8)+BF(12)+BF(16)+BF(20)+BF(24)+BF(28)+BF(32)+BF(36)
     .             +BF(40)
C-------------------------------------------------------------------------
C  CHECK FOR NEGATIVE BLOOD FLOW
C-------------------------------------------------------------------------
      DO 220 I=1,40
  220 IF(BF(I).LT.0.0)BF(I)=0.0
C-------------------------------------------------------------------------
C     QCONV(I)=CONVECTION FROM BLOOD TO EACH NODE
C     QCOND(I)=CONDUCTION BETWEEN ADJACENT NODES
C-------------------------------------------------------------------------
      DO 240 I=1,40
      QCONV(I)=BF(I)*(T(41)-T(I))
      QCOND(I)=FACTOR(I)*(T(I)-T(I+1))
  240 CONTINUE
C*************************************************************************
C  TEMPERATURE CALCULATIONS
C*************************************************************************
C-------------------------------------------------------------------------
C  CALCULATE TEMP OF HEAD CORE,T(1), AND TRUNK CORE,T(5).
C-------------------------------------------------------------------------
      T(1)=T(1)+DTIME/C(1)*(QMET(1)-QLAT1+QCONV(1)-QCOND(1)-QRSEN1)
      T(5)=T(5)+DTIME/C(5)*(QMET(5)-QLAT5+QCONV(5)-QCOND(5)-QRSEN5)
C-------------------------------------------------------------------------
C  CALCULATE TEMPERATURES OF REMAINING CORES --ARM(9+13),LEG(17+21),
C                    HAND(25+29),AND FOOT(33+37)
C-------------------------------------------------------------------------
      DO 260 I=9,37,4
      T(I)=T(I)+DTIME/C(I)*(QMET(I)+QCONV(I)-QCOND(I))
  260 CONTINUE
```

```
C------------------------------------------------------------------------
C  CALCULATE THE TEMPERATURES OF THE MUSCLE --HEAD(2),TRUNK(6),ARM(10+
C              14),LEG(18+22),HAND(26+30),FOOT(34+38)
C------------------------------------------------------------------------
      T(2)=T(2)+DTIME/C(2)*(QCOND(1)+QMET(2)-QLAT2+QCONV(2)-QCOND(2)-
     *    QRSEN2)
      T(6)=T(6)+DTIME/C(6)*(QCOND(5)+QMET(6)-QLAT6+QCONV(6)-QCOND(6)-
     *    QRSEN6)
      DO 280 I=10,38,4
      T(I)=T(I)+DTIME/C(I)*(QCOND(I-1)+QMET(I)+QCONV(I)-QCOND(I))
  280 CONTINUE
C------------------------------------------------------------------------
C  CALCULATE TEMPERATURES OF THE FAT LAYER --HEAD(3),TRUNK(7),ARM(11+15)
C           LEG(19+23),HAND(27+31),FOOT(35+39)
C------------------------------------------------------------------------
      T(3)=T(3)+DTIME/C(3)*(QCOND(2)+QMET(3)-QLAT3+QCONV(3)-QCOND(3)-
     *    QRSEN3)
      DO 300 I=7,39,4
      T(I)=T(I)+DTIME/C(I)*(QCOND(I-1)+QMET(I)+QCONV(I)-QCOND(I))
  300 CONTINUE
C------------------------------------------------------------------------
C  CALCULATE TEMPERATURES OF THE SKIN --HEAD(4),TRUNK(8),ARM(12+16),
C           LEG(20+24),HAND(28+32),FOOT(36+40)
C------------------------------------------------------------------------
      DO 320 I=4,40,4
      J=I/4
      T(I)=T(I)+DTIME/C(I)*(QCOND(I-1)+QMET(I)-QLAT(J)+QCONV(I)
     *    -QSEN(J)-QRAD(J)-QLCG)
  320 CONTINUE
C------------------------------------------------------------------------
C  CALCULATE TEMP OF CENTRAL BLOOD --(41)
C------------------------------------------------------------------------
      SQCONV = 0.0
      DO 340 I=1,40
      SQCONV=SQCONV-QCONV(I)
  340 CONTINUE
      T(41)=T(41)+DTIME/C(41)*SQCONV
C------------------------------------------------------------------------
C     CALCULATE AVERAGE SKIN TEMPERATURE(42) BASED ON PERCENTAGE OF
C  TOTAL SKIN AREA FOR EACH SKIN NODE * THAT NODES TEMPERATURE
C------------------------------------------------------------------------
      T(42)=0.07*T(4)+0.3602*T(8)+0.06705*T(12)+0.06705*T(16)+0.1587*
     *      T(20)+0.1587*T(24)+0.025*T(28)+0.025*T(32)+0.0343*T(36)+
     *      0.0343*T(40)
      T(43)=0.02325*T(2)+0.549*T(6)+0.0527*T(10)+0.0527*T(14)+0.1592*
     *      T(18)+0.1592*T(22)+0.00115*T(26)+0.00115*T(30)+0.00115*
     *      T(34)+0.00115*T(38)
      TBF=0.0
      DO 360 I=1,40
  360 TBF=TBF+BF(I)
      PULSE=5.926*TBF/60.0
      RETURN
      END
      SUBROUTINE CQSH(TIC,QSHIV,TAVSK,QBASAL)
      COMMON/NSHIV/TAVG,TC,RMX
      CALL TCF(TC,TIC,0)
      CALL TCF(TAVG,TAVSK,0)
```

```
      TC=TC-(.1-(((37.0-TC)*1.7)**2.)/10.)
      RMX=22221.-614.2*(TC)+TAVG*(-1933.2+53.66*(TC))
     &+TAVG**2*(46.45-1.289*(TC))
C    CONVERTS METABOLIC RATE FROM CAL/SEC TO BTU/HR
      RMX=RMX*3.6*3.97
      QSHIV=RMX-QBASAL
      IF (QSHIV.LE.0.0)QSHIV=0.0
      RETURN
      END
      SUBROUTINE TCF (TC,TF,IFL)
      IF(IFL.NE.0)GO TO 65
      TC=(TF-32.)*5./9.
      RETURN
   65 TF=TC*9./5.+32
      RETURN
      END
      FUNCTION VPT(T)
C    FUNCTION TO CALCULATE VAPOR PRESSURE AT TEMP=T
      X=647.27-(T+460.)/1.8
      TEMP=X*1.8/(T+460.)*(3.244+5.868E-3*X+1.170E-8*X**3)
     & /(1.+2.188E-3*X)
      VPT=3207./10.**TEMP
      RETURN
      END
      SUBROUTINE GVAR(NI,NA,NN)
      DIMENSION NI(8),NA(8),KA(55)
      DATA (KA(I),I=1,5)/'  T(1)  T(2)  T(3)  T(4)  T(5)'/
      DATA (KA(I),I=6,10)/'  T(6)  T(7)  T(8)  T(9) T(10)'/
      DATA (KA(I),I=11,15)/' T(11) T(12) T(13) T(14) T(15)'/
      DATA (KA(I),I=16,20)/' T(16) T(17) T(18) T(19) T(20)'/
      DATA (KA(I),I=21,25)/' T(21) T(22) T(23) T(24) T(25)'/
      DATA (KA(I),I=26,30)/' T(26) T(27) T(28) T(29) T(30)'/
      DATA (KA(I),I=31,35)/' T(31) T(32) T(33) T(34) T(35)'/
      DATA (KA(I),I=36,40)/' T(36) T(37) T(38) T(39) T(40)'/
      DATA (KA(I),I=41,45)/' T(41) T(42) T(43) TUGAV  SQUG'/
      DATA (KA(I),I=46,50)/' QEVAP  TOTL TDEWC  WORK QSHIV'/
      DATA (KA(I),I=51,55)/'STORAT QSTOR  TCAB VPDEW     U'/
      WRITE(6,10)
   10 FORMAT(/'0PLEASE ENTER ITEMS TO BE PLOTTED BY INDEX NO. (I2)')
      DO 30 I=1,8
      GO TO 15
   13 WRITE(6,14)
   14 FORMAT(' ***** READ ERROR')
   15 READ (5,20,ERR=13) NI(I)
   20 FORMAT(I2)
      IF (NI(I).LT.1) GO TO 40
      IF (NI(I).GT.55) GO TO 13
      M=NI(I)
      NA(I)=KA(M)
      WRITE(6,25) NI(I),NA(I)
   25 FORMAT(' *****',I3,2X,A6)
   30 CONTINUE
   40 NN=I-1
      RETURN
      END

END ONSITE PRINTOUT ON JUNE 26, 1974 AT 15:50:10
```

ORIGINAL PAGE IS OF POOR QUALITY

APPENDIX 2

EXAMPLE RUN

```
@XQT RUN

 DO YOU WANT GRAPHIC INSTEAD OF TABULAR OUTPUT? (Y/N)
>Y

 PLEASE ENTER ITEMS TO BE PLOTTED BY INDEX NØ. (I2)
>Ø1
 ##### 1    T(1)
>42
 ##### 42   T(42)
>5Ø
 ##### 5Ø   QSHIV
>51
 ##### 51  STORAT
>52
 ##### 52   QSTOR
>

 INPUT DATA USING NAMELIST $INPUT

>@ADD TRDAT
> $END
```

```
$INPUT
RM       =      .27000000E+03
QBS      =      .27000000E+03
UEFF     =      .50000000E+01
AC       =      .19500000E+02
AR       =      .15500000E+02
TCAB     =      .80000000E+02
TW       =      .80000000E+02
TDEWC    =      .67000000E+02
VCAB     =      .50000000E+02
VEFF     =      .15000000E+02
PCAB     =      .14700000E+02
G        =      .10000000E+01
CLOV     =      .10000000E+01
EUG      =      .90000000E+00
CPG      =      .22000000E+00
DT       =      .50000000E-01
PRINTI   =      .20000000E+01
SETI     =      .24000000E+03
MCASES   =                 +0

$END
```

INITIAL CONDITIONS

```
   TMINS           HEADCORE   AVGSKIN   TUGAV     BLOOD     QEVAP    INSENS
STORAT       QSHIV    QSTOR      TCAB   TDEWC
      .0              98.60     95.00   95.00     98.50       .00       .00
     .00       .00      .00     80.00   67.00
   240.0              98.24     93.27   85.63     98.11      -.00     63.67
   -8.90       .00   -69.88     80.00   67.00
```

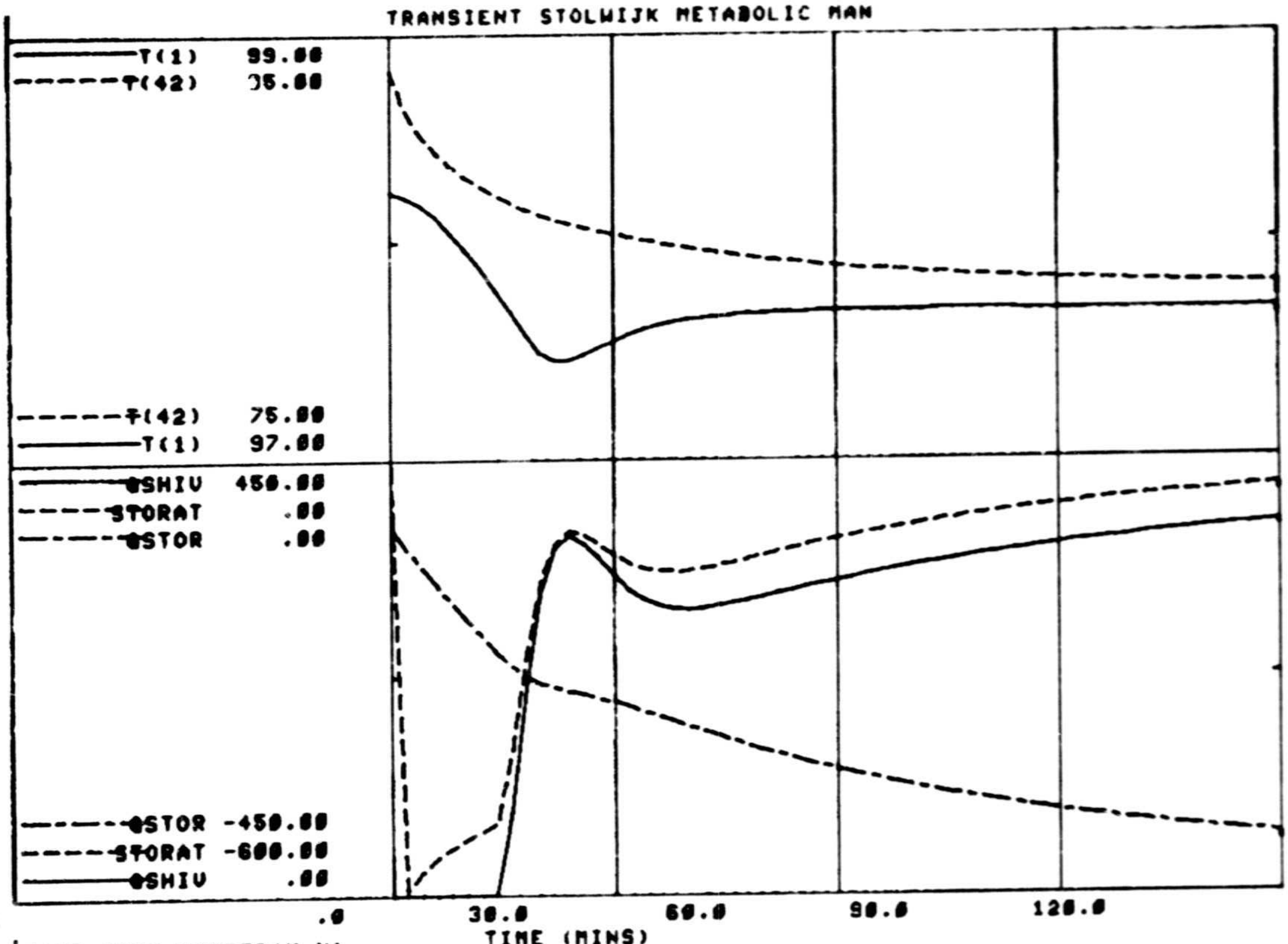
INPUT DATA USING NAMELIST $INPUT

```
 NCASES=1
> TCAB=40.
> TW=40.
> $END
 $INPUT
 RM       =     .27800000E+03
 QBS      =     .27800000E+03
 UEFF     =     .50000000E+01
 AC       =     .19500000E+02
 AR       =     .15500000E+02
 TCAB     =     .40000000E+02
 TW       =     .40000000E+02
 TDEWC    =     .67000000E+02
 VCAB     =     .50000000E+02
 VEFF     =     .15000000E+02
 PCAB     =     .14700000E+02
 G        =     .10000000E+01
 CLOV     =     .10000000E+01
 EVG      =     .90000000E+00
 CPG      =     .22000000E+00
 DT       =     .50000000E-01
 PRINTI   =     .20000000E+01
 SETI     =     .24000000E+03
 NCASES   =                +1

 $END
                    IMPOSED CONDITIONS

   TMINS            HEADCORE  AVGSKIN  TUGAV    BLOOD    QEVAP    INSENS
ISTORAT          QSHIV    QSTOR    TCAB   TDEWC
TYPE SHIFT-OUT (SO) AND RETURN-->
```

```
          GRAPHIC OUTPUT(Y,N,S),TIME INTERVALS,STARTX,STOPX,(A2,3F5.0)..
>Y 4.   0.   120.
  T(1)                Y SCALE   (A4,8X,F4.0,2F6.0)
 PLOT(Y,N,S) LOC HIGH  LOW    ...
>Y           1.  99.   97.
  T(42)               Y SCALE   (A4,8X,F4.0,2F6.0)
 PLOT(Y,N,S) LOC HIGH  LOW    ...
>Y           1.  95.   75.
  QSHIV               Y SCALE   (A4,8X,F4.0,2F6.0)
 PLOT(Y,N,S) LOC HIGH  LOW    ...
>Y           2.  450.  0.
 STORAT               Y SCALE   (A4,8X,F4.0,2F6.0)
 PLOT(Y,N,S) LOC HIGH  LOW    ...
>Y           2.  0.    -600.
  QSTOR               Y SCALE   (A4,8X,F4.0,2F6.0)
 PLOT(Y,N,S) LOC HIGH  LOW    ...
>Y           2.  0.    -450.
```



HARD COPY WANTED(Y,N)...
>