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Calculation of Time-Temperature History  
and Prediction of Injury to Skin Exposed  
to Thermal Radiation

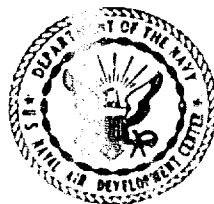
Naval Air Systems Command  
AirTask R360 FR102/2021/R01 101 01  
(RB-6-01)

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DEPARTMENT OF THE NAVY  
U. S. NAVAL AIR DEVELOPMENT CENTER  
JOHNSVILLE  
WARMINSTER, PA. 18974

Aerospace Medical Research Department

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## SUMMARY

This report gives a general description of a digital computer program used in connection with the study of injury of skin exposed to thermal energy. All of the information necessary for a detailed understanding of the program is included; however, the material is presented in a manner such that the novice in the field of computer science may make use of the program if he so desires. For this reason emphasis is placed on the operating instructions for the program. A short discussion of the pertinent theory and equations as they apply to the human skin is included at the beginning of this report.

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## INTRODUCTION

This report contains a description of a digital computer program that can be used to evaluate theoretical equations associated with the time-temperature histories of skin exposed to various levels of thermal radiation and to predict the injury due to such exposures (1). The program is written for a Control Data Corporation 3200 Computer System using the Fortran 3200 language. In the study of thermal tissue damage it is of interest to obtain the time-temperature history at some depth below the surface of the skin such as at the dermis-epidermis interface and also to obtain the time-temperature history at the surface of the skin. For this reason the computer program incorporates the feature of obtaining the time-temperature history at depth and at the surface.

## THEORY OF PROBLEM AND EQUATIONS

The time-temperature history of skin exposed to a square-wave pulse of thermal energy is characterized by a temperature rise from some initial temperature of the surrounding environment  $T_0$ , at time  $t=0$  when irradiation at a flux of magnitude,  $Q$ , begins. The temperature continues to rise to some peak temperature at time  $t = \tau$ , the time at which the radiation ceases. The temperature then drops, rapidly at first, then more slowly, approaching  $T_0$  as  $t$  approaches infinity. Figure 1 shows a typical example of a time-temperature history as computed for a specific exposure.

The following equation suggested by Buettner (2) describes the desired time-temperature history:

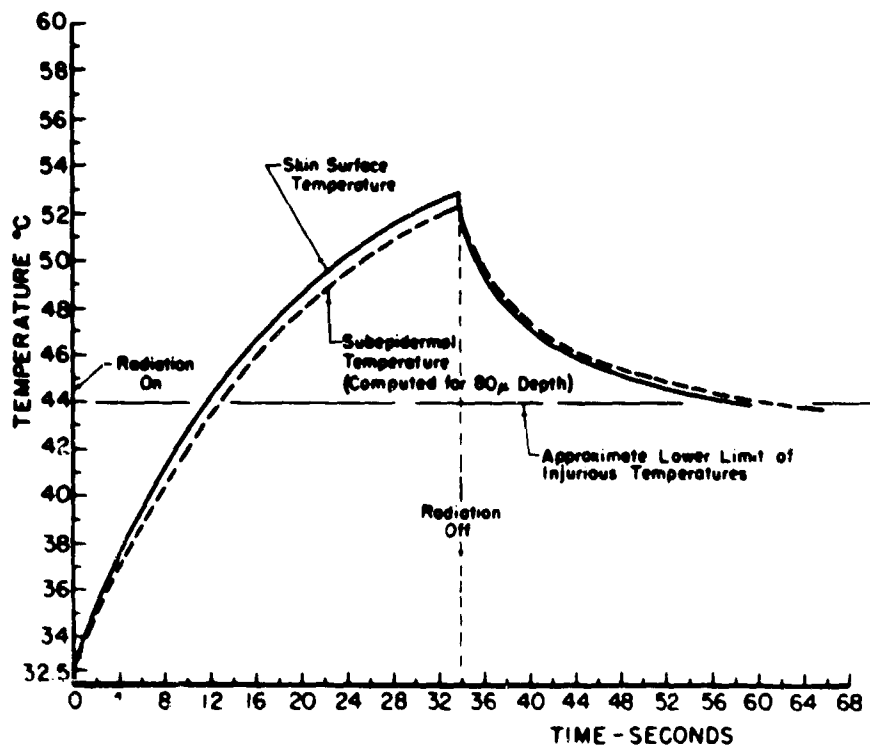


Figure 1. Typical Time - Temperature History of Skin Exposed to a Square-Wave Pulse of Thermal Energy.

$$T_x = \frac{Q}{k} \left[ \frac{2a\sqrt{t}}{\sqrt{\pi}} e^{-x^2/4a^2t} - x \left( 1 - \theta \left( \frac{x}{2a\sqrt{t}} \right) \right) \right] + T_0$$

$$- \frac{Q}{k} \left[ \frac{2a\sqrt{t-\tau}}{\sqrt{\pi}} e^{-x^2/4a^2(t-\tau)} - x \left( 1 - \theta \left( \frac{x}{2a\sqrt{t-\tau}} \right) \right) \right] \quad \text{Eq. 1}$$

where  $T_x$  = tissue temperature at depth  $x$  below the surface ( $^{\circ}\text{C}$ )

$Q$  = effective radiation on the surface of skin ( $\text{Cal}/\text{cm}^2 \text{ sec}$ )

$k$  = thermal conductivity ( $\text{Cal}/\text{cm sec } ^{\circ}\text{C}$ )

$\rho$  = density of skin ( $\text{g}/\text{cm}^3$ )

$c$  = specific heat ( $\text{Cal}/\text{g } ^{\circ}\text{C}$ )

$a^2 = k/\rho c =$  "temperature diffusivity" ( $\text{cm}^2/\text{sec}$ )

$t$  = time (sec)

$\tau$  = time at which thermal radiation ceases (exposure time) (sec)

$x$  = depth below the surface of the skin (cm)

$T_0$  = initial surrounding temperature ( $^{\circ}\text{C}$ )

$\theta(U) =$  integral of the probability curve =  $\frac{2}{\sqrt{\pi}} \int_0^U e^{-y^2} dy =$  Error Function

Equation 1 can be derived directly from the general differential equation for heat conduction in one dimension

$$\frac{\delta T}{\delta t} = a^2 \frac{\delta^2 T}{\delta x^2} \quad \text{Eq. 2}$$

assuming a constant heat flow and an initial isothermal condition (vertical temperature gradient equals zero) and the heat absorbed at the surface of the skin transferred inward by conduction.

Prediction of dermal injury resulting from exposure to thermal radiation of any given magnitude and duration depends entirely upon the resultant time-temperature history. Total tissue damage done during any given episode must



include the damage done during cooling after the radiation ceases as well as the damage done during heating. Equations 3 and 4 express damage as temporal integral of rates of tissue injury depending upon the tissue temperature, and increasing logarithmically with this temperature (3,4,5).

$$\Omega = \int_{t_1}^{\tau} \frac{d\Omega}{dt} dt + \int_{\tau}^{t_2} \frac{d\Omega}{dt} dt \quad \text{Eq. 3}$$

$$\Omega = \int_{t_1}^{\tau} P e^{-\Delta E/RT_x} dt + \int_{\tau}^{t_2} P e^{-\Delta E/RT_x} dt \quad \text{Eq. 4}$$

where  $\Omega$  = total tissue damage = 1.0 at point of complete transepidermal necrosis

$d\Omega/dt$  = damage rate at given temperature,  $T_x$

$dt$  = time interval for which given temperature prevailed (sec.)

$\tau$  = time at which thermal radiation ceases (exposure time)(sec.)

$t_1$  = time at which the injurious temperature level (44°C) is reached (sec.)

$t_2$  = time at which temperature falls below the injurious level (44°C) (sec.)

$P$  = constant of integration

$\Delta E$  = energy of inactivation

$R$  = gas constant

$T_x$  = tissue temperature at depth  $x$  in °K at time  $t$

The first term on the right hand side of Eq. 4 is the damage done during heating, hereafter designated  $\Omega_H$ ; the second term is the damage done during cooling, hereafter designated  $\Omega_C$ ; the sum of these two terms is the total damage done, hereafter designated  $\Omega_T$  and is equal to unity at the point of complete transepidermal necrosis.

## PROGRAM DESCRIPTION

The complete program can be roughly broken into seven parts. Figure 2 is a listing of the Fortran statements of the entire program.

The first part of the program reads into the computer the necessary data required for calculation of time-temperature histories. This includes data such as the number of time-temperature histories to be computed, various labels used on graph outputs, constants of integration, etc.

The second part of the program computes the individual time-temperature histories as arrays of time-temperature points. Each time point is stored in the array TIME(N) and the associated temperature point is stored in the array T(N). In addition, an array A(N) containing the square root of values of thermal conductivity is stored. Each of the three arrays has a maximum dimension of 200 floating point values. For each time-temperature history to be computed, a data card is read in containing the following variables:

- Q = effective radiation on the surface of the skin
- X = depth below the surface of skin (x = 0 at the surface)
- DT = time interval between points in the time-temperature history
- TAU = time at which thermal radiation ceases =  $\tau$  (exposure time)
- TIME(1) = initial starting point in time at which first temperature point is computed
- A1 = square root of value of thermal conductivity during heating phase
- A2 = square root of value of thermal conductivity used to compute first temperature point during the cooling phase.
- ZEROTEMP = initial surrounding temperature =  $T_0$
- PIESQRT =  $\sqrt{\pi} = 1.7724539$

```

PROGRAM PHOENIX
C CALCULATION OF TISSUE TEMPERATURE
DIMENSION LILY (12),ALILY (8),L1(2),L1(2),L1(2),L1(2),L1(2),L1(2)
DIMENSION T(200),TIME(200) SHRAU (60,1) L
1 FORMAT (13)
HEAD 200, LILY
200 FORMAT (12A6)
HEAD 200, U, M, C
209 FORMAT (1A1, 2A6)
HEAD (N0,110) M, P, Z, EN, F, H, Z
110 FORMAT (2E11.6) 2(FH,11)
LNU1 = 0M 15 LNU2 = 2M 1A1 LNU3 = 1M 1 LNU4 = 1M 1 LNU5 = 0M 11M
LNU6 = 0M 15 LNU7 = 0M 1.0
LNU8 = 0M 1A1 LNU9 = 0M 11M 1A1 LNU10 = 0M 1A1 LNU11 = 0M 1A1 LNU12 = 0M 1A1
C DATA AND EQUATION
10 HEAD (N0,10) U, A, OUT, TAU, TIME (1), A1, A2, Z, M, TEMP, P, I, SUMT
10 FORMAT (3H, 4, 2P, H, 1, 2P, 4, 5, F, 11.7)
A3 = A2
M = 0
N0 = 0 M1 = 0.0A1/MIESUMT SC1 = X/(2.0A1) S01 = C1°C1 SF10U/(A10A1)
15 N0 = 1 S0 = SUMT/(TIME(N)) S1F(TIME(N)-TAU)111112
11 T(N) = 10(N1)G0PAP (-01/11M (N1) - 10C1M0M (C1/6)) 2P MTEMP
A(N) = A1
GO TO 1111
12 M = SUMT/(TIME(N)-TAU)
M2 = 2.0A2/M1P SUMT SC2 = X/(2.0A2) S12 = C2°C2 S02 = U/(A20A2)
T(N) = 20(M2)G0PAP (-02/11M (N1) - M0EAP (-02/11M (N1)-TAU)) - X0(C0M
1E M (C2/6) - C0M0M (C2/M1)) 2P MTEMP
A(N) = A2
IF (M) 1001,1002
1002 M = M+1 STPM = T(N-1)
1001 A2 = A2-0.0001
IF (T(N)-00.0) 13,13,1111
1111 TIME(A+1) = TIME(N)+DT
GO TO 15
13 DO 1022 I=1,M
IF (T(I) .LT. 00.0) 1022,1004
1022 CONTINUE
1004 IF ((T(I)-00.0) .LT. (00.0-T(I-1))) 1004,1006
1006 I = I - 1
1005 NUBN = 1 + STMINUP = T(I) STMINUM = T(N) S1 = 1
GO TO (2001,5001)SSWTCMF(1)
C PRINT OUT
599 PRINT 20, N, A1, A3, TAU
20 FORMAT (41X, 4M = , F8.4, 2X, 7MA1 = , F9.5, 2X, 5MA2 = , F9.5, 2X,
16MTAU = , F8.3, //)
PRINT 5000
5000 FORMAT (7X, 4M TIME, 15X, 4M (A), 15X, 1MA, 24X, 4M TIME, 15X, 4M (A), 15X, 1MA
1//)
IF (N, E, U, (N/2+0.5)) 249,301
299 K=N/2
GO TO 300
301 K=N/2+1
T(20K) = 0.0 STIME(20K) = 0.0 SA(20K) = 0.0
300 DO 1130 I=1,K
K1=I+K
PRINT 30, TIME(I), T(I), A(I), TIME(K1), T(K1), A(K1)
30 FORMAT (5X, F8.4, 10X, F9.4, 8X, F8.5, 25X, F8.4, 10X, F9.4, 8X, F8.5)
1130 CONTINUE
2001 GO TO (2003,2002) SSWTCMF (5)
2002 GO TO (1009,1008) SLITETP(1)
1009 GO TO (1113,1112) SSWTCMF (1)
1112 PRINT 3001
3001 FORMAT (7//, 5X, 50M THE ABOVE TIME-TEMP. HISTORY IS FOR SURFACE TEMP
1.0)
PRINT 3000
1113 L=L-1
GO TO 236
1008 CALL SLITE(1)
LY = 14 SYL = 70.0
YDATE=72.50 SYU=71.25 SYA1=70.00 SYA2=68.75 SYTAU=67.50
NY=12
GO TO (2050,601) SSWTCMF (4)
2050 GO TO (2010,10) SLITETP (1)
2010 GO TO (2012,2011) SSWTCMF (1)
2011 PRINT 3001 SPPRINT 3000
2012 L=L-1 GO TO 605
2003 L = L-1
LY = 10 SYL = 50.0
YDATE=72.50 SYU=71.25 SYA1=70.00 SYA2=68.75 SYTAU=67.50
NY=N
601 GO TO (600,604)SSWTCMF (2)
C INTERNAL TISSUE DAMAGE INTERNAL
604 TEST=SUMZELH0=0. SCNF=1. STN0=2. SFIFU=50. SF0UM=0.
DO 22 J=1,N
IF (T(J)-F(F)) 111,112,112

```

Figure 2. Fortran Statement Listing of Program.

Continuation of Figure 2.

```

111 UOMM1=LEAP(-EM/(T(J)+273.))
    IF (TEST) S=113
112 UOMM2=LEAP(-EM/(T(J)+273.))
    GO TO 33
    5 IF (T(J)-TMIN) 117,32,33
117 PRINT 130.
118 FORMAT (//,14M ENHIN TMIN,1)
    GO TO 16
113 IF (T(J)-TMIN) 31,32,33
    31 PRINT 140.
    40 FORMAT (//,13M ENHIN TMINM)
    GO TO 16
12 UOMM3=UOMM1
    GO TO 116
13 UOMM4=UOMM2
116 SUMMIN=SUM
    IF (TEST=2) 111,14,21
119 PRINT 50.
    50 FORMAT (//,11M ENHIN TEST)
    GO TO 16
19 IF (T(J)-TPR) 22,23,24
    24 PRINT 40.
    40 FORMAT (//,10M ENHIN TPR)
    GO TO 16
23 MINISUM/1=0
    TEST=TEST+ONE
    SUM=0.
    GO TO 22
21 IF (T(J)-TMIN) 34,26,22
    14 PRINT 40.
    40 FORMAT (//,14M ENHIN TMIN,2)
    GO TO 16
26 LMINISUM/1=0
    FMIN=C
    SUM=0.
    TEST=0.
    PRINT 4.
    4 FORMAT (//,14M,1M,13A,2M,1,13A,3M,1,13A,2M,2,13A,3M,2,10A,2M,1,
    110A,2M,1,10A,2M,1)
    PRINT 70,0,0,1,FMIN,2,EN2,FMIN,C
    70 FORMAT (5F,7,3,5A,E12,0,5,1,FV,1,5A,E,12,0,5,1,FV,1,5A,F,0,5,1,
    17,0,5A,F,7,4)
    PRINT 2000,TPR,TMIN,U,TMIN,M
2000 FORMAT (8X,5MTPR =,FV,0,5R,4M TMIN,U =,FV,0,5R,0,4M TMIN,M =,FV,0,4)
22 CONTINUE
600 GO TO (01,0,15) SSWTCMF(1)
615 PRINT 3000.
3000 FORMAT (1M)
610 GO TO (003,002) SSWTCMF(3)
C
602 PUNCH 1012,11T,0,TMIN,U,TMIN,M,TPR,3
1012 FORMAT (F5,1,13,3F,7,3,F6,3)
    PUNCH ;007,(T(J),J,1,1)
1007 FORMAT (11F,7,3)
603 GO TO (104,005) SSWTCMF(4)
C
605 ATIC=TIME(1)/4.
    IF (ATIC.LT.0.5) 701,702
704 ATIC = 0.5
    AL = ATIC*10.
    GO TO 705
701 IF (ATIC.LT.0.25) 703,704
703 ATIC = 0.25
    AL = ATIC*10.
    GO TO 705
702 IX = ATIC
    IF (IX.EQ.ATIC) 2,3
    2 ATIC = IX
    GO TO 4
    3 ATIC = IX + ATIC*1.
    4 AL = ATIC*10.
705 DO 201 1=1,M
201 AL(1)=ATIC*1
    AL0 = -ATIC
203 IF (ABSXY(22,1,0,LY,ATIC,AL,VL,AL0,25,0,0,30,0,0)) 203,202
202 PAUSE 202 $GO TO 205
203 X = -19.*ATIC/20.
    IF (PLOTXY(X,52,0,0,0)) 206,207
207 PAUSE 207 $ GO TO 203
206 CALL LABEL (1,2,0,LND1)
    CALL LABEL (3,1,0,LND2)
211 X = -17.*ATIC/20.
    IF (PLOTXY(X,48,0,0,0)) 212,213
213 PAUSE 213 $GO TO 211
212 CALL LABEL (1,1,0,LND3)
214 X = -15.*ATIC/20.
    IF (PLOTXY(X,47,0,0,0)) 219,216
216 PAUSE 216 $GO TO 214
215 CALL LABEL (1,2,0,LND4)
    X = - ATIC/2.0
    Y = 30.0
    DO 220 I=1,NV
    Y = Y+.0
221 LIL = LILY(1)
    IF (PLOTXY(X,Y,0,0)) 220,222
222 PAUSE 222 $GO TO 221

```



It is necessary to use some value other than zero for TIME(1) in order that the value of the exponent containing TIME(N) as a divisor does not approach infinity since in this event an exponent overflow error would occur. Hence a value of TIME(1) very nearly equal to zero should be chosen so that the sum of TIME(1) plus some integer number times DT is very nearly equal to TAU. Again it is necessary that the sum of TIME(1) plus some integer number times DT does not exactly equal TAU in order to prevent error.

In solving Eq. 1 on the computer, the following approximation is used:

$$\rho c = 1 \quad \text{Eq. 5}$$

Hence  $a^2 = k$

or  $a = \sqrt{k}$  Eq. 6

The computation of the time-temperature history is divided into two intervals.  $0 < \text{TIME}(N) \leq \text{TAU}$  and  $\text{TIME}(N) > \text{TAU}$ , which correspond to the heating phase and cooling phase respectively. Before the calculation of each temperature point, a check is made to see if  $\text{TIME}(N) \leq \text{TAU}$ . If this is the case, Eq. 1 is solved for the first two terms on the right hand side, the third term being imaginary. When  $\text{TIME}(N)$  exceeds TAU in value (during the cooling phase), the entire equation is solved. During the heating phase a constant value of the square root of thermal conductivity, A1, is used; however, during the cooling phase the value of the square root of thermal conductivity, A2, is decremented by 0.0001 after the calculation of the first temperature point and is continually decremented for each temperature point thereafter.

The program uses an approximation formula to compute the value of the complementary Error Function,  $1 - \theta(U)$ . The approximation formula for the Error Function  $\theta(U)$  is given by Hastings (6).

$$\theta(U) = 1 - \frac{1}{[1 + a_1 U + a_2 U^2 + a_3 U^3 + a_4 U^4 + a_5 U^5 + a_6 U^6]^{16}} \quad \text{Eq. 7}$$

Since the complementary Error Function is equal to one minus the Error Function we have, Com.  $\theta(U) = 1 - \theta(U)$

$$\text{Com. } \theta(U) = \text{COMERF} = + \frac{1}{[1+a_1U+a_2U^2+a_3U^3+a_4U^4+a_5U^5+a_6U^6]^{16}} \quad \text{Eq. 8}$$

where

$a_1 = 0.0705230784$   
 $a_2 = 0.0422820123$   
 $a_3 = 0.0092705272$   
 $a_4 = 0.0001520143$   
 $a_5 = 0.0002765672$   
 $a_6 = 0.0000430638$

During and following calculation of the time-temperature history the following three specific values of  $T(N)$  are stored separately for later use:

TPK = peak temperature obtained

TMINUP = value of the temperature closest to 44°C (injurious temperature level) during the heating phase.

TMINDN = last value of temperature in the  $T(N)$  array.

Also the number of elements in the array  $T(N)$  between TMINUP and TMINDN inclusive is stored in NO for later use. Figure 3 is a flow chart of time-temperature history computation.

The last five parts of the program are essentially connected with output and are selected by means of sense switches located on the computer console. Thus any, all, or none of the five parts can be selected in turn. The operation of any one of the parts may be skipped in the program by setting the proper sense switch to the "ON" position. Briefly the five parts are concerned with:

- (1) printed output of the  $T(N)$ , Time(N), and A(N) arrays,
- (2) numerical solution

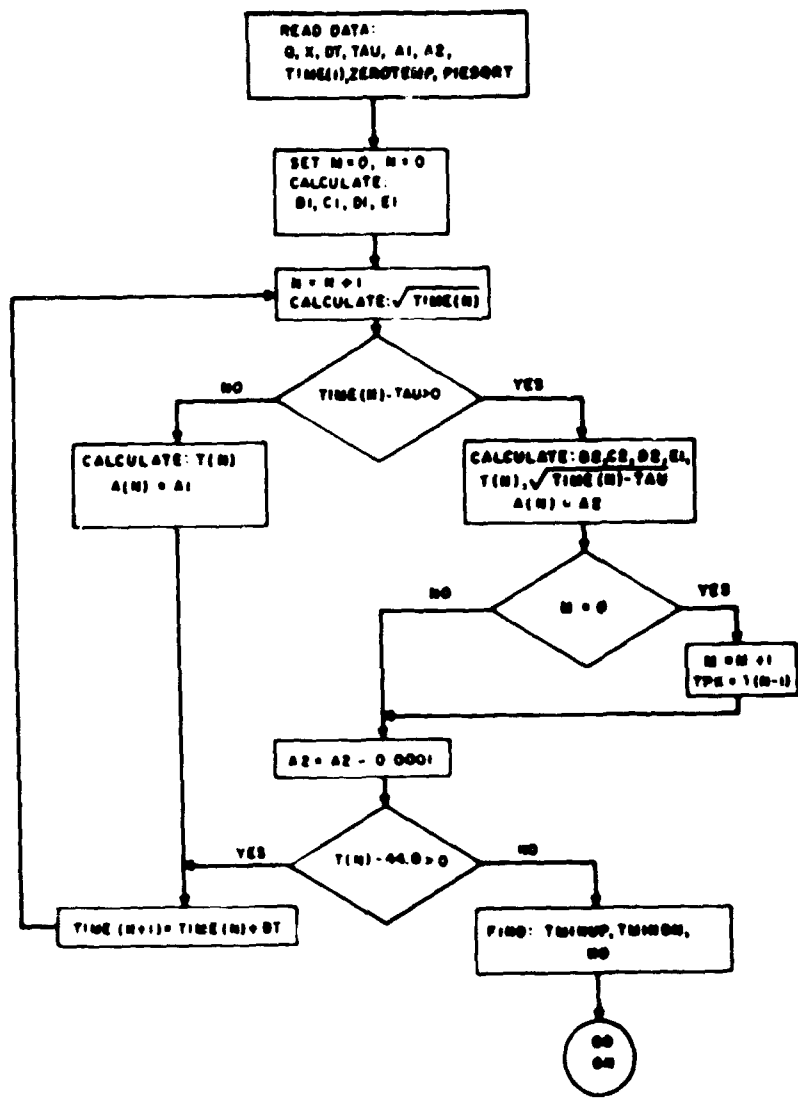


Figure 3. Flow Chart for Computation of Time - Temperature Histories.



of the thermal tissue damage integral and printed output of results, (3) card punch of time-temperature history just computed, (4) plot of time-temperature history just computed, and (5) plot of time-temperature history for surface temperatures ( $x = 0$ ). Here we discuss the numerical solution of the thermal tissue damage equation. The others are discussed under output in the Operating Instructions.

Equations 3 and 4 yield the following equation for tissue damage rates as a function of temperature  $T_x$ ,

$$\frac{d\Omega}{dt} = P e^{-\Delta E/RT_x} \quad \text{Eq. 9}$$

where the symbols have been previously defined. The values of  $P$ ,  $\Delta E$ , and  $R$  were determined as follows from the graph in Figure 4 (4);

$$P = P1 = 2.1850 \times 10^{+124}$$

and  $\Delta E/R = ER1 = 93,534.9$  for tissue temperature,  $T_x$ , less than  $50^\circ\text{C}$ , and

$$P = P2 = 1.8230 \times 10^{+51}$$

and  $\Delta E/R = ER2 = 39,109.8$  for tissue temperature,  $T_x$ , equal to or greater than  $50^\circ\text{C}$ .

The damage rate for each temperature value in the array  $T(N)$  between  $T_{MINUP}$  and  $T_{MINDN}$  is computed according to Eq. 9, depending on whether the value of the temperature is less than, greater than, or equal to  $50^\circ\text{C}$ . Values of temperature below  $T_{MINUP}$  do not make a significant contribution to the total damage integral. The heating damage integral (for values of temperature between  $T_{MINUP}$  and  $TPK$ ),  $HI$ , and the cooling damage integral (for values of temperature between  $TPK$  and  $T_{MINDN}$ ),  $CI$ , are computed according to the trapezoidal rule for integration;

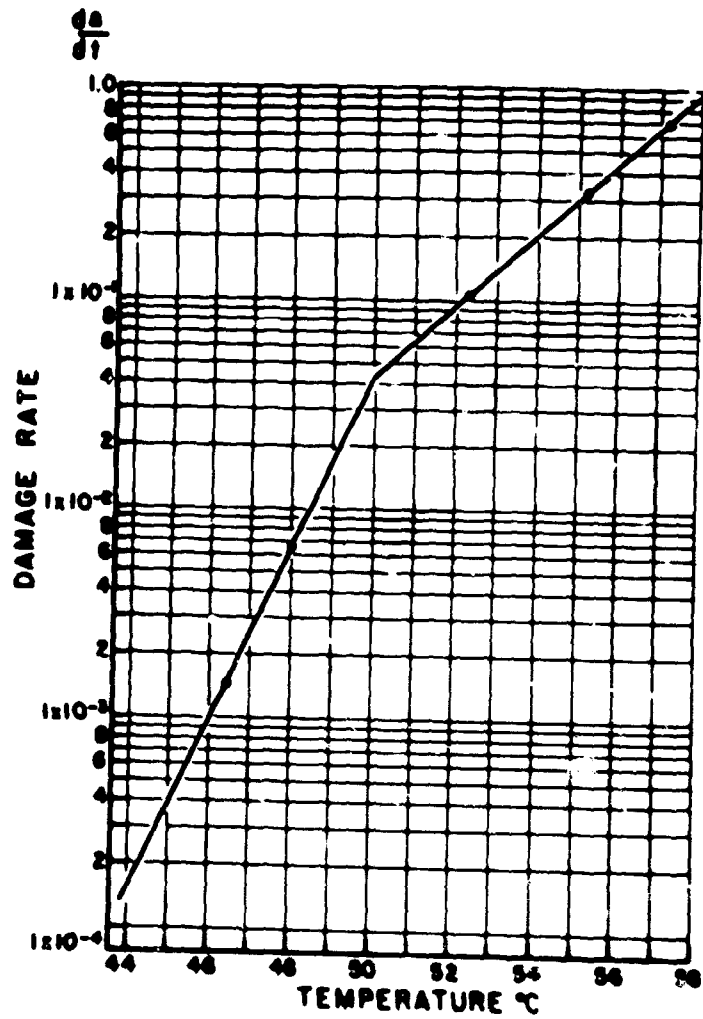


Figure 4. Damage Rates Derived from Radiative Data

$$\Omega = \frac{dt}{2} \left[ \frac{d\Omega}{dt_1} + 2\frac{d\Omega}{dt_2} + 2\frac{d\Omega}{dt_3} + \dots + 2\frac{d\Omega}{dt_{m-1}} + \frac{d\Omega}{dt_m} \right] \quad \text{Eq. 10}$$

where  $\Omega$  = damage integral

$dt = DT$  = time interval between temperature points

$d\Omega/dt_m$  = damage rate at given temperature

Following the computation of the damage integral during heating, HI, and CI, the integral during cooling, the sum HI + CI, the total damage is stored in FI. Figure 5 is a flow chart of the integral computation.

## OPERATING INSTRUCTIONS

### General

In addition to a deck of Hollerith cards containing all the Fortran statements, control cards are necessary for the operation of the program. However, since the number and format of the control cards may vary somewhat in different computer installations, they will not be considered here. Details on the appropriate control cards can be obtained at each installation. A binary deck containing the incremental plotter routine to operate the plotter (7,8) completes the card requirements.

Various modes of output may be selected by means of sense switches. The operation of each output is inhibited by placing the proper sense switch in the "ON" position. Figure 6 is a macro flow chart of the logic between various sections.

### Input

The first data card (Figure 7A) contains the variable L, the number of graphs to be plotted or the number of time-temperature histories to be computed.

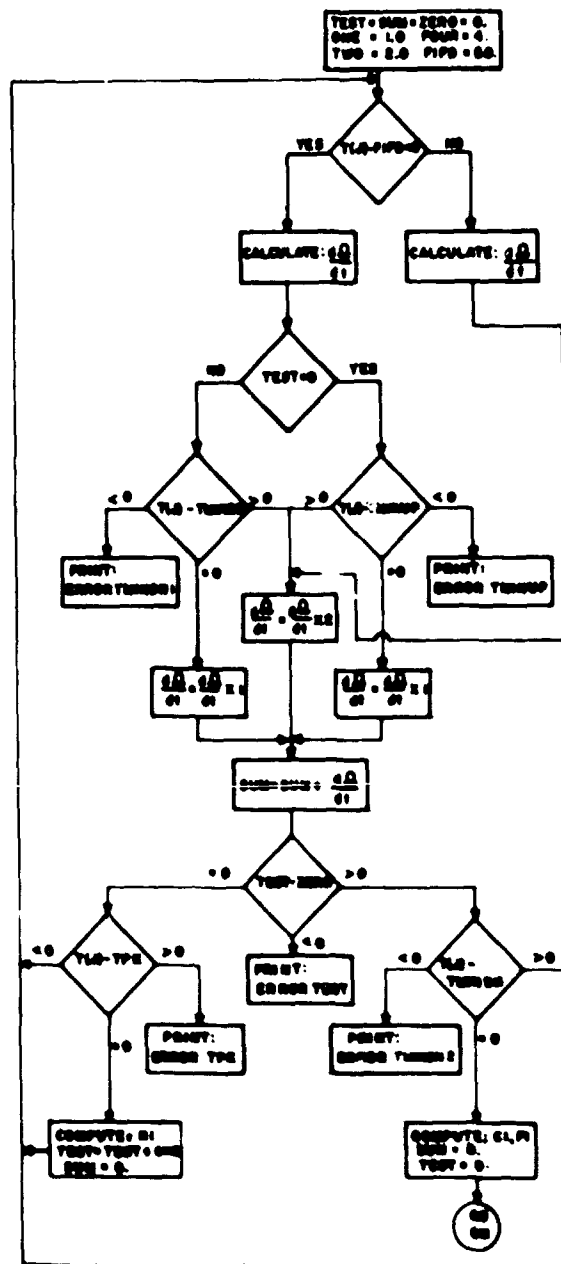


Figure 5. Flow Chart for Computation of the Thermal Tissue Damage Integral

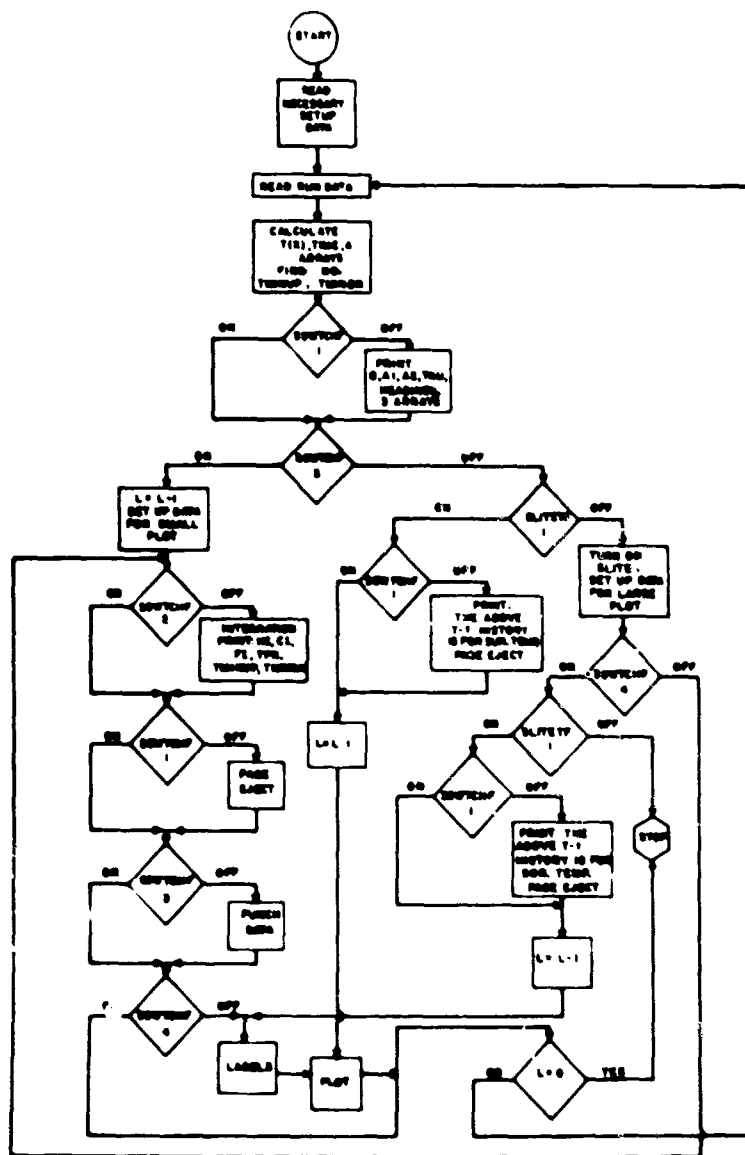


Figure 6. Macro Flow Chart of Logic.

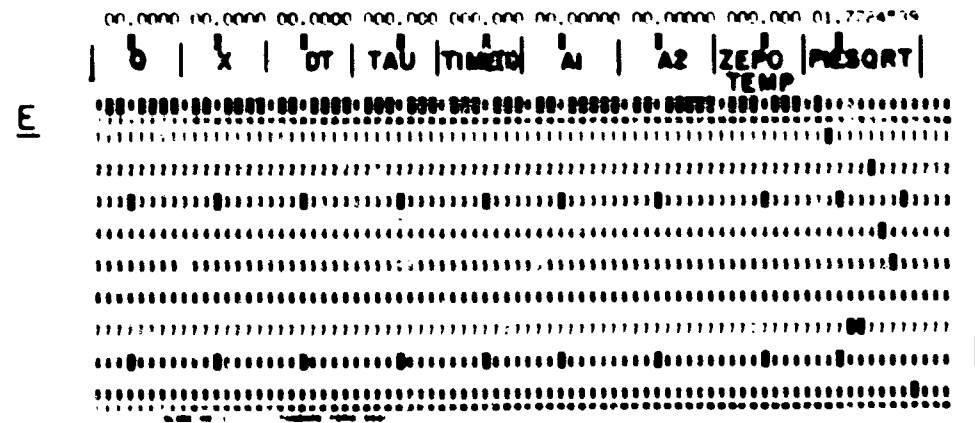
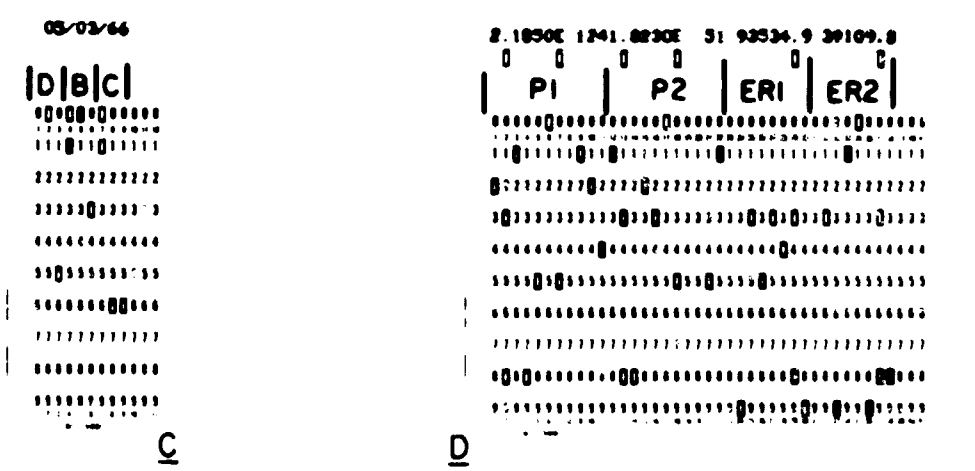
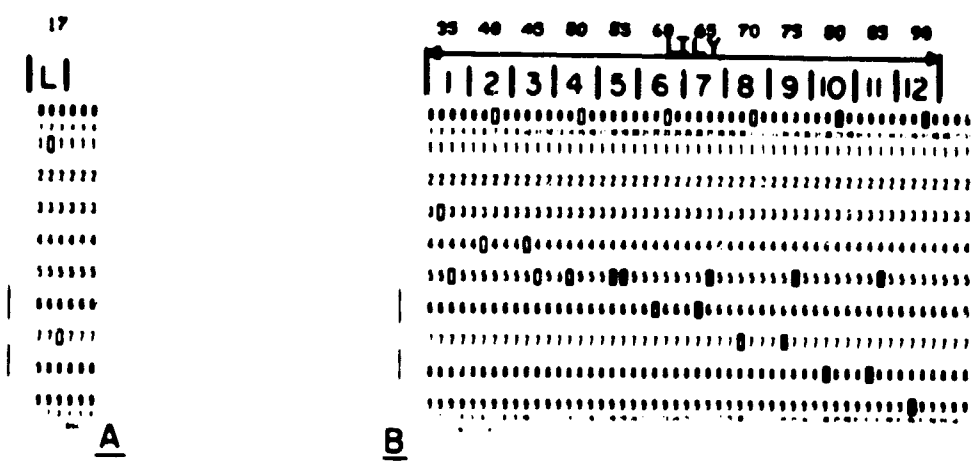


Figure 7. Examples of Input Data Cards.

L is a three-digit integer punched in columns 1-3 on the card and is read in I format. L is decremented by 1 after the computation of each history and tested for zero. When L=0 the program is terminated.

The second data card (Figure 7B) contains an array called LILY which has 12 four-digit labels used to label the ordinate axis of the graphed outputs. The first value, LILY(1), is punched in columns 1-4 on the card in the form .35, and is read in A format. Successive values of LILY are punched in successive columns of four, thus using columns 1 through 48 for the entire array.

The third data card (Figure 7C) contains three variables, D, B, C, used in labeling the graphed outputs. They are the date expressed in month, day, and year form, thus, 00/00/00. Each value is three digits in length and the three variables occupy columns 1 through 9 with the following form, D = .00, B=/00, and C=/00. The values are read in A format.

The fourth data card (Figure 7D) contains the values P1, P2, ER1, and ER2. P1 and P2 are punched in columns 1-11 and 12-22 respectively and read in E format. ER1 and ER2 are punched in columns 23-30 and 31-38 respectively and are read in F format.

The remaining data cards (Figure 7E) contain the values of Q, X, DT, TAU, TIME(1), A1, A2, ZEROTEMP, and PIESQRT. All the values are read in F format and occupy the following columns; Q in columns 1-8, X in columns 9-16, DT in columns 17-24, TAU in columns 25-32, TIME(1) in columns 33-40, A1 in columns 41-49, A2 in columns 50-58, ZEROTEMP in columns 59-66 and PIESQRT in columns 67-77. All values cover the expected range of the values with a sign position.

#### Output

The first part of the output, the printed output of the three arrays T(N), TIME(N), and A(N), is controlled by sense switch #1. Figure 8 is an

Q = .3760 A1 = .03740 A2 = .03450 TAU = 5.951

TIME	T(X)	A	TIME	T(X)	A
.3000	36.7984	.03740	7.3000	49.6900	.03390
.5500	48.9364	.03740	7.5500	49.1030	.03300
.8000	60.6400	.03740	7.8000	48.7200	.03270
1.0500	72.1402	.03740	8.0500	48.3150	.03246
1.3000	83.3475	.03740	8.3000	47.9424	.03250
1.5500	94.5170	.03740	8.5500	47.6023	.03340
1.8000	105.6659	.03740	8.8000	47.2902	.03330
2.0500	116.8024	.03740	9.0500	47.0023	.03320
2.3000	127.9392	.03740	9.3000	46.7356	.03310
2.5500	139.0758	.03740	9.5500	46.4877	.03300
2.8000	150.2124	.03740	9.8000	46.2564	.03290
3.0500	161.3490	.03740	10.0500	46.0401	.03270
3.3000	172.4856	.03740	10.3000	45.8371	.03260
3.5500	183.6222	.03740	10.5500	45.6443	.03250
3.8000	194.7588	.03740	10.8000	45.4666	.03240
4.0500	205.8954	.03740	11.0500	45.3000	.03230
4.3000	217.0320	.03740	11.3000	45.1463	.03220
4.5500	228.1686	.03740	11.5500	44.9842	.03210
4.8000	239.3052	.03740	11.8000	44.8398	.03200
5.0500	250.4418	.03740	12.0500	44.7027	.03190
5.3000	261.5784	.03740	12.3000	44.5722	.03180
5.5500	272.7150	.03740	12.5500	44.4479	.03170
5.8000	283.8516	.03450	12.8000	44.3294	.03160
6.0500	294.9882	.03440	13.0500	44.2162	.03160
6.3000	306.1248	.03430	13.3000	44.1081	.03150
6.5500	317.2614	.03420	13.5500	44.0047	.03140
6.8000	328.3980	.03410	13.8000	43.9057	.03130
7.0500	339.5346	.03400		0	0

Figure 8. Example of Array Printout.



example of the array printout. The values of Q, A1, A2, and TAU are printed at the top of the page for identification purposes, followed by the appropriate headings for each of the arrays. The arrays are each split in half and printed in six columns across the page. It will be noted that there is no variation in the value of the square root of thermal conductivity during the heating phase ( $0 < \text{TIME} \leq \text{TAU}$ ), while the square root of thermal conductivity during the cooling phase ( $\text{TIME} > \text{TAU}$ ) is continually decremented by 0.0001 at each time-temperature point as mentioned before.

The second part of the output, the printed output of the results of the numerical solution of the thermal tissue damage integral, is controlled by sense switch #2. Figure 9 is an example of the integration printout. The printout consists of the values of Q, P1, P2, ER1, ER2, TPK, TMINUP, and TMINDN for checking and identification purposes, along with the results of the integration FI, HI, and CI. It is seen that the integration printout directly follows the array printout. Since TPK should occur at  $\text{TIME} = \text{TAU}$ , TMINUP should be the value of temperature nearest to 44°C during the heating phase, and TMINDN should be the last value in the T(x) array, these values can easily be checked against the array printout.

The third part of the output punching the T(N) array on cards is controlled by sense switch #3. Figure 10 is an example of the punched data cards. Each array is preceded by a card containing the following data: DT in columns 1-5, NO in columns 6-8, TMINUP in columns 9-15, TMINDN in columns 16-22, TPK in columns 23-29, and Q in columns 30-35. (Figure 10A) The array from TMINUP to TMINDN inclusive is punched, eleven values of temperature per card, each value having a maximum of six digits and decimal point, three places to the

J = .1010 A1 = .03270 A2 = .03190 TAU = 21.001

TIME	T(X)	A	TIME	T(X)	A
.0270	50.7172	.03270	10.0229	52.3057	.03270
1.0007	50.5416	.03270	19.0096	52.7190	.03270
1.7554	51.6663	.03270	19.7563	53.0876	.03270
2.0221	50.0640	.03270	20.0230	53.4492	.03270
3.0008	48.0378	.03270	21.0097	53.8050	.03270
3.7555	46.9115	.03270	21.7564	51.6162	.03190
4.0222	41.7113	.03270	22.0231	50.3454	.03100
9.0009	42.0532	.03270	22.0096	48.0815	.03170
5.7556	43.1041	.03270	23.7565	48.2131	.03100
6.0223	43.8041	.03270	24.0232	48.7230	.03150
7.0010	44.4264	.03270	25.0099	47.7230	.03100
7.7557	45.0212	.03270	25.7566	47.2957	.03130
8.0224	45.5405	.03270	26.0233	46.9174	.03120
9.0011	46.1378	.03270	27.0000	46.5784	.03110
9.7558	46.6650	.03270	27.7567	46.2719	.03100
10.0225	47.1753	.03270	28.0234	45.9926	.03090
11.0012	47.6692	.03270	29.0001	45.7305	.03080
11.7559	48.1490	.03270	29.7568	45.5005	.03070
12.0226	48.6145	.03270	30.0235	45.2814	.03060
13.0013	49.0641	.03270	31.0002	45.0787	.03050
13.7560	49.5104	.03270	31.7569	44.8891	.03040
14.0227	49.9420	.03270	32.0236	44.7110	.03030
15.0014	50.3634	.03270	33.0003	44.5454	.03020
15.7561	50.7765	.03270	33.7570	44.3899	.03010
16.0228	51.1805	.03270	34.0237	44.2414	.03000
17.0015	51.5764	.03270	35.0004	44.1020	.02990
17.7562	51.9666	.03270	35.7571	43.9702	.02980

U .101 P1 2.1050E+124 P2 1.0230E+51 P3 30100.0 P4 .4500  
 P5 .03270 P6 .03190 P7 .03100 P8 .03150 P9 .03100 P10 .03170  
 P11 .03100 P12 .03150 P13 .03100 P14 .03170 P15 .03100 P16 .03150  
 P17 .03100 P18 .03170 P19 .03100 P20 .03150 P21 .03100 P22 .03170  
 P23 .03100 P24 .03150 P25 .03100 P26 .03170 P27 .03100 P28 .03150  
 P29 .03100 P30 .03170 P31 .03100 P32 .03150 P33 .03100 P34 .03170  
 P35 .03100 P36 .03150 P37 .03100 P38 .03170 P39 .03100 P40 .03150  
 P41 .03100 P42 .03170 P43 .03100 P44 .03150 P45 .03100 P46 .03170  
 P47 .03100 P48 .03150 P49 .03100 P50 .03170 P51 .03100 P52 .03150  
 P53 .03100 P54 .03170 P55 .03100 P56 .03150 P57 .03100 P58 .03170  
 P59 .03100 P60 .03150 P61 .03100 P62 .03170 P63 .03100 P64 .03150  
 P65 .03100 P66 .03170 P67 .03100 P68 .03150 P69 .03100 P70 .03170  
 P71 .03100 P72 .03150 P73 .03100 P74 .03170 P75 .03100 P76 .03150  
 P77 .03100 P78 .03170 P79 .03100 P80 .03150 P81 .03100 P82 .03170  
 P83 .03100 P84 .03150 P85 .03100 P86 .03170 P87 .03100 P88 .03150  
 P89 .03100 P90 .03170 P91 .03100 P92 .03150 P93 .03100 P94 .03170  
 P95 .03100 P96 .03150 P97 .03100 P98 .03170 P99 .03100 P100 .03150  
 P101 .03100 P102 .03170 P103 .03100 P104 .03150 P105 .03100 P106 .03170  
 P107 .03100 P108 .03150 P109 .03100 P110 .03170 P111 .03100 P112 .03150  
 P113 .03100 P114 .03170 P115 .03100 P116 .03150 P117 .03100 P118 .03170  
 P119 .03100 P120 .03150 P121 .03100 P122 .03170 P123 .03100 P124 .03150  
 P125 .03100 P126 .03170 P127 .03100 P128 .03150 P129 .03100 P130 .03170  
 P131 .03100 P132 .03150 P133 .03100 P134 .03170 P135 .03100 P136 .03150  
 P137 .03100 P138 .03170 P139 .03100 P140 .03150 P141 .03100 P142 .03170  
 P143 .03100 P144 .03150 P145 .03100 P146 .03170 P147 .03100 P148 .03150  
 P149 .03100 P150 .03170 P151 .03100 P152 .03150 P153 .03100 P154 .03170  
 P155 .03100 P156 .03150 P157 .03100 P158 .03170 P159 .03100 P160 .03150  
 P161 .03100 P162 .03170 P163 .03100 P164 .03150 P165 .03100 P166 .03170  
 P167 .03100 P168 .03150 P169 .03100 P170 .03170 P171 .03100 P172 .03150  
 P173 .03100 P174 .03170 P175 .03100 P176 .03150 P177 .03100 P178 .03170  
 P179 .03100 P180 .03150 P181 .03100 P182 .03170 P183 .03100 P184 .03150  
 P185 .03100 P186 .03170 P187 .03100 P188 .03150 P189 .03100 P190 .03170  
 P191 .03100 P192 .03150 P193 .03100 P194 .03170 P195 .03100 P196 .03150  
 P197 .03100 P198 .03170 P199 .03100 P200 .03150  
 P201 .03100 P202 .03170 P203 .03100 P204 .03150 P205 .03100 P206 .03170  
 P207 .03100 P208 .03150 P209 .03100 P210 .03170 P211 .03100 P212 .03150  
 P213 .03100 P214 .03170 P215 .03100 P216 .03150 P217 .03100 P218 .03170  
 P219 .03100 P220 .03150 P221 .03100 P222 .03170 P223 .03100 P224 .03150  
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 P231 .03100 P232 .03150 P233 .03100 P234 .03170 P235 .03100 P236 .03150  
 P237 .03100 P238 .03170 P239 .03100 P240 .03150 P241 .03100 P242 .03170  
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 P267 .03100 P268 .03150 P269 .03100 P270 .03170 P271 .03100 P272 .03150  
 P273 .03100 P274 .03170 P275 .03100 P276 .03150 P277 .03100 P278 .03170  
 P279 .03100 P280 .03150 P281 .03100 P282 .03170 P283 .03100 P284 .03150  
 P285 .03100 P286 .03170 P287 .03100 P288 .03150 P289 .03100 P290 .03170  
 P291 .03100 P292 .03150 P293 .03100 P294 .03170 P295 .03100 P296 .03150  
 P297 .03100 P298 .03170 P299 .03100 P300 .03150  
 P301 .03100 P302 .03170 P303 .03100 P304 .03150 P305 .03100 P306 .03170  
 P307 .03100 P308 .03150 P309 .03100 P310 .03170 P311 .03100 P312 .03150  
 P313 .03100 P314 .03170 P315 .03100 P316 .03150 P317 .03100 P318 .03170  
 P319 .03100 P320 .03150 P321 .03100 P322 .03170 P323 .03100 P324 .03150  
 P325 .03100 P326 .03170 P327 .03100 P328 .03150 P329 .03100 P330 .03170  
 P331 .03100 P332 .03150 P333 .03100 P334 .03170 P335 .03100 P336 .03150  
 P337 .03100 P338 .03170 P339 .03100 P340 .03150 P341 .03100 P342 .03170  
 P343 .03100 P344 .03150 P345 .03100 P346 .03170 P347 .03100 P348 .03150  
 P349 .03100 P350 .03170 P351 .03100 P352 .03150 P353 .03100 P354 .03170  
 P355 .03100 P356 .03150 P357 .03100 P358 .03170 P359 .03100 P360 .03150  
 P361 .03100 P362 .03170 P363 .03100 P364 .03150 P365 .03100 P366 .03170  
 P367 .03100 P368 .03150 P369 .03100 P370 .03170 P371 .03100 P372 .03150  
 P373 .03100 P374 .03170 P375 .03100 P376 .03150 P377 .03100 P378 .03170  
 P379 .03100 P380 .03150 P381 .03100 P382 .03170 P383 .03100 P384 .03150  
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 P397 .03100 P398 .03170 P399 .03100 P400 .03150  
 P401 .03100 P402 .03170 P403 .03100 P404 .03150 P405 .03100 P406 .03170  
 P407 .03100 P408 .03150 P409 .03100 P410 .03170 P411 .03100 P412 .03150  
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 P437 .03100 P438 .03170 P439 .03100 P440 .03150 P441 .03100 P442 .03170  
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 P461 .03100 P462 .03170 P463 .03100 P464 .03150 P465 .03100 P466 .03170  
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 P473 .03100 P474 .03170 P475 .03100 P476 .03150 P477 .03100 P478 .03170  
 P479 .03100 P480 .03150 P481 .03100 P482 .03170 P483 .03100 P484 .03150  
 P485 .03100 P486 .03170 P487 .03100 P488 .03150 P489 .03100 P490 .03170  
 P491 .03100 P492 .03150 P493 .03100 P494 .03170 P495 .03100 P496 .03150  
 P497 .03100 P498 .03170 P499 .03100 P500 .03150  
 P501 .03100 P502 .03170 P503 .03100 P504 .03150 P505 .03100 P506 .03170  
 P507 .03100 P508 .03150 P509 .03100 P510 .03170 P511 .03100 P512 .03150  
 P513 .03100 P514 .03170 P515 .03100 P516 .03150 P517 .03100 P518 .03170  
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 P525 .03100 P526 .03170 P527 .03100 P528 .03150 P529 .03100 P530 .03170  
 P531 .03100 P532 .03150 P533 .03100 P534 .03170 P535 .03100 P536 .03150  
 P537 .03100 P538 .03170 P539 .03100 P540 .03150 P541 .03100 P542 .03170  
 P543 .03100 P544 .03150 P545 .03100 P546 .03170 P547 .03100 P548 .03150  
 P549 .03100 P550 .03170 P551 .03100 P552 .03150 P553 .03100 P554 .03170  
 P555 .03100 P556 .03150 P557 .03100 P558 .03170 P559 .03100 P560 .03150  
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 P573 .03100 P574 .03170 P575 .03100 P576 .03150 P577 .03100 P578 .03170  
 P579 .03100 P580 .03150 P581 .03100 P582 .03170 P583 .03100 P584 .03150  
 P585 .03100 P586 .03170 P587 .03100 P588 .03150 P589 .03100 P590 .03170  
 P591 .03100 P592 .03150 P593 .03100 P594 .03170 P595 .03100 P596 .03150  
 P597 .03100 P598 .03170 P599 .03100 P600 .03150  
 P601 .03100 P602 .03170 P603 .03100 P604 .03150 P605 .03100 P606 .03170  
 P607 .03100 P608 .03150 P609 .03100 P610 .03170 P611 .03100 P612 .03150  
 P613 .03100 P614 .03170 P615 .03100 P616 .03150 P617 .03100 P618 .03170  
 P619 .03100 P620 .03150 P621 .03100 P622 .03170 P623 .03100 P624 .03150  
 P625 .03100 P626 .03170 P627 .03100 P628 .03150 P629 .03100 P630 .03170  
 P631 .03100 P632 .03150 P633 .03100 P634 .03170 P635 .03100 P636 .03150  
 P637 .03100 P638 .03170 P639 .03100 P640 .03150 P641 .03100 P642 .03170  
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 P701 .03100 P702 .03170 P703 .03100 P704 .03150 P705 .03100 P706 .03170  
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 P719 .03100 P720 .03150 P721 .03100 P722 .03170 P723 .03100 P724 .03150  
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 P731 .03100 P732 .03150 P733 .03100 P734 .03170 P735 .03100 P736 .03150  
 P737 .03100 P738 .03170 P739 .03100 P740 .03150 P741 .03100 P742 .03170  
 P743 .03100 P744 .03150 P745 .03100 P746 .03170 P747 .03100 P748 .03150  
 P749 .03100 P750 .03170 P751 .03100 P752 .03150 P753 .03100 P754 .03170  
 P755 .03100 P756 .03150 P757 .03100 P758 .03170 P759 .03100 P760 .03150  
 P761 .03100 P762 .03170 P763 .03100 P764 .03150 P765 .03100 P766 .03170  
 P767 .03100 P768 .03150 P769 .03100 P770 .03170 P771 .03100 P772 .03150  
 P773 .03100 P774 .03170 P775 .03100 P776 .03150 P777 .03100 P778 .03170  
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 P785 .03100 P786 .03170 P787 .03100 P788 .03150 P789 .03100 P790 .03170  
 P791 .03100 P792 .03150 P793 .03100 P794 .03170 P795 .03100 P796 .03150  
 P797 .03100 P798 .03170 P799 .03100 P800 .03150  
 P801 .03100 P802 .03170 P803 .03100 P804 .03150 P805 .03100 P806 .03170  
 P807 .03100 P808 .03150 P809 .03100 P810 .03170 P811 .03100 P812 .03150  
 P813 .03100 P814 .03170 P815 .03100 P816 .03150 P817 .03100 P818 .03170  
 P819 .03100 P820 .03150 P821 .03100 P822 .03170 P823 .03100 P824 .03150  
 P825 .03100 P826 .03170 P827 .03100 P828 .03150 P829 .03100 P830 .03170  
 P831 .03100 P832 .03150 P833 .03100 P834 .03170 P835 .03100 P836 .03150  
 P837 .03100 P838 .03170 P839 .03100 P840 .03150 P841 .03100 P842 .03170  
 P843 .03100 P844 .03150 P845 .03100 P846 .03170 P847 .03100 P848 .03150  
 P849 .03100 P850 .03170 P851 .03100 P852 .03150 P853 .03100 P854 .03170  
 P855 .03100 P856 .03150 P857 .03100 P858 .03170 P859 .03100 P860 .03150  
 P861 .03100 P862 .03170 P863 .03100 P864 .03150 P865 .03100 P866 .03170  
 P867 .03100 P868 .03150 P869 .03100 P870 .03170 P871 .03100 P872 .03150  
 P873 .03100 P874 .03170 P875 .03100 P876 .03150 P877 .03100 P878 .03170  
 P879 .03100 P880 .03150 P881 .03100 P882 .03170 P883 .03100 P884 .03150  
 P885 .03100 P886 .03170 P887 .03100 P888 .03150 P889 .03100 P890 .03170  
 P891 .03100 P892 .03150 P893 .03100 P894 .03170 P895 .03100 P896 .03150  
 P897 .03100 P898 .03170 P899 .03100 P900 .03150  
 P901 .03100 P902 .03170 P903 .03100 P904 .03150 P905 .03100 P906 .03170  
 P907 .03100 P908 .03150 P909 .03100 P910 .03170 P911 .03100 P912 .03150  
 P913 .03100 P914 .03170 P915 .03100 P916 .03150 P917 .03100 P918 .03170  
 P919 .03100 P920 .03150 P921 .03100 P922 .03170 P923 .03100 P924 .03150  
 P925 .03100 P926 .03170 P927 .03100 P928 .03150 P929 .03100 P930 .03170  
 P931 .03100 P932 .03150 P933 .03100 P934 .03170 P935 .03100 P936 .03150  
 P937 .03100 P938 .03170 P939 .03100 P940 .03150 P941 .03100 P942 .03170  
 P943 .03100 P944 .03150 P945 .03100 P946 .03170 P947 .03100 P948 .03150  
 P949 .03100 P950 .03170 P951 .03100 P952 .03150 P953 .03100 P954 .03170  
 P955 .03100 P956 .03150 P957 .03100 P958 .03170 P959 .03100 P960 .03150  
 P961 .03100 P962 .03170 P963 .03100 P964 .03150 P965 .03100 P966 .03170



right of the decimal point. (Figure 10B). This feature was originally included in the program to provide data output acceptable for use in another program.

The fourth part of the output, a plot of the entire tissue temperature array  $T(N)$  from  $T_0$  to  $TMINDN$  by means of an incremental plotter is controlled by sense switch #4. Figure 11 is an example of a tissue temperature plot. The ordinate of the plot is labeled  $T(x)$  and has a range from 25-75°C with the appropriate labeling. This graph procedure is used to plot time-temperature histories at a depth  $x$  below the surface where a TPK of less than 75°C is desirable. Hence, since the initial surrounding temperature ( $T_0$ ) is always 32.5°C, the range of the ordinate is sufficient to plot tissue temperatures at depth. The length of the abscissa is computed for each plot depending on the size of  $TIME(N)$ . If  $TIME(N)$  is less than 4.5 sec the length of the abscissa is 5.0 sec long; if  $TIME(N)$  is less than 2.25 sec the length of the abscissa is 2.5 sec long. If  $TIME(N)$  is greater than 4.5 sec, the length of the abscissa is equal to ten times the following truncated value:  $[(TIME(N)/9.)+1.]$  The abscissa is labeled  $TIME(sec.)$  and covers the appropriate range. The upper right hand corner of the plot contains the date of the plot and the values of  $Q$ ,  $A1$ ,  $A2$ , and  $TAU$  for identification purposes. One time-temperature history is plotted per each graph.

The fifth and last part of the output, a plot of surface time-temperature histories, is controlled by sense switch #5. The graph is exactly the same as that for tissue time-temperature histories except that the range of the ordinate is increased to 25-90°C to handle the higher TPK of the surface time-temperature histories.

Since there are five sense switches each with "ON" and "OFF" positions, there are thirty-two different modes of operation of the program. The program

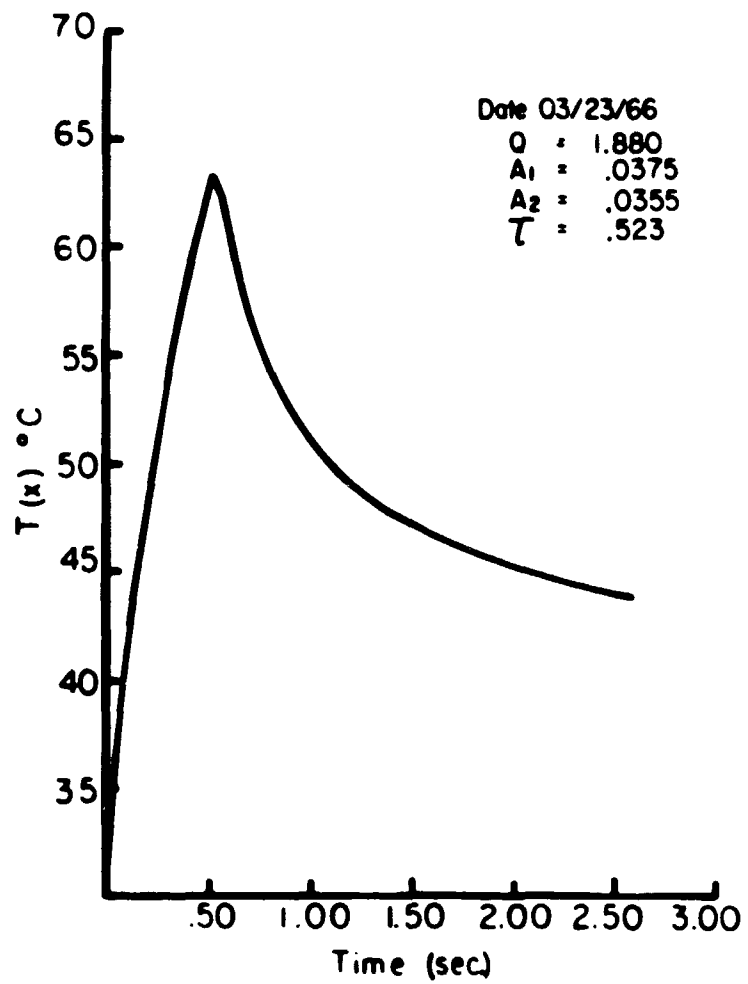


Figure 11. Example of Tissue Temperature Plot.

is designed to operate in each of the thirty-two modes; however only a few of the possible modes are used in actual practice. Some of these are briefly discussed because of their importance.

1. All sense switches in "OFF" position - normal mode of operation. The three arrays T(N), TIME(N), and A(N) are printed, followed by a printout of the results of the tissue damage integral as shown in Figure 9. The T(N) array is punched on cards according to the format shown in Figure 10 and a graph with increased ordinate size ( $25^{\circ}$ - $90^{\circ}$ C) is drawn containing both surface temperatures (the plot with the larger TPK) and tissue temperatures (the plot with the smaller TPK) as shown in Figure 12. Each surface time-temperature history is printed out as shown in Figure 13 with a label at the bottom identifying the history as a surface temperature history. The first four input data cards are arranged as mentioned before; however the remaining cards containing values of Q, X, DT, TAU, TIME(1), A1, A2, ZEROTEMP, and PIESQRT are arranged in the following order. Each card containing values of Q, X, DT, TAU, TIME(1), A1, A2, ZEROTEMP and PIESQRT for a time-temperature history at some depth x below the surface of the skin is immediately followed by a card containing exactly the same values except that the value of X is zero (0.0). Thus the value of L is equal to the number of such paired cards or the number of graphs drawn but equal to one-half the number of time-temperature histories computed.

2. Sense switch #3 in "ON" position, all the other switches in "OFF" position - Operation is exactly as in case 1 above except the punching of T(N) array is inhibited.

3. Sense switch #5 in "ON" position, all the other switches in "OFF" position - Operation is exactly as in Case 1 above except a graph with normal

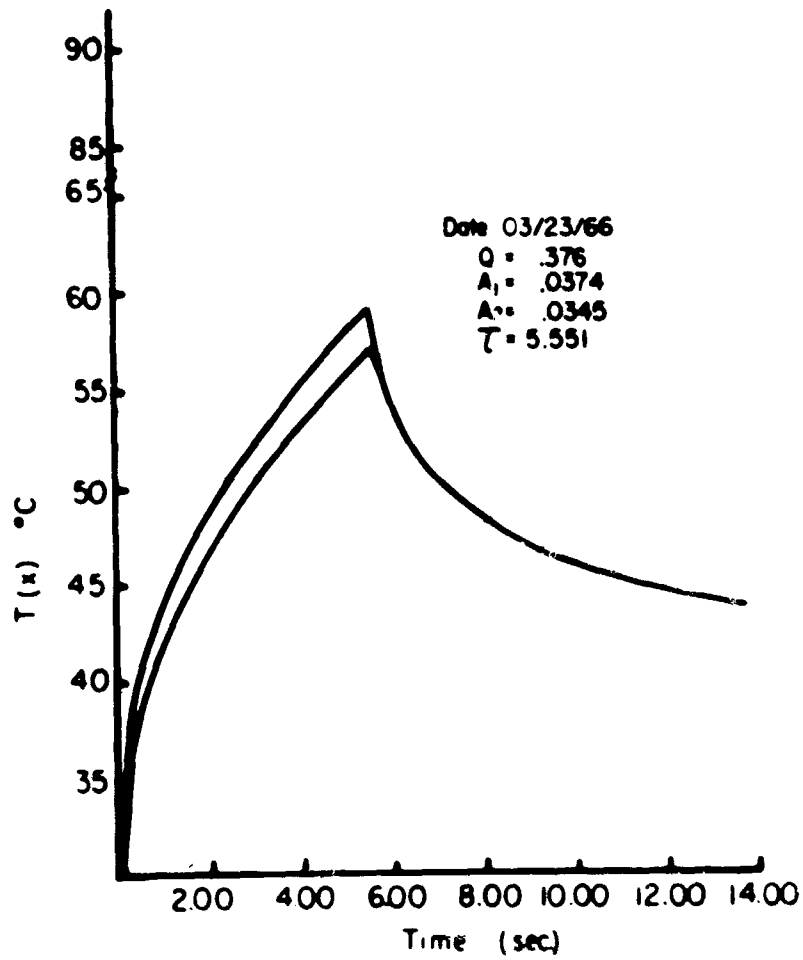


Figure 12. Example of Surface Temperature and Tissue Temperature Plot.

U = .2700 A1 = .03740 A2 = .03450 TAU = 5.551

TIME	TEMP	TEMP	TEMP	TEMP	TEMP
.3000	16.7136	.03740	7.3000	69.7631	.03390
.5000	69.9130	.03740	7.5000	69.8472	.03380
.8000	62.6665	.03740	7.8000	69.7997	.03370
1.0500	66.1262	.03740	8.0500	69.3651	.03360
1.3000	65.6443	.03740	8.3000	67.9004	.03350
1.5500	66.6433	.03740	8.5500	67.6451	.03340
1.8000	67.7198	.03740	8.8000	67.301	.03330
2.0500	68.7623	.03740	9.0500	67.0397	.03320
2.3000	69.7662	.03740	9.3000	66.7706	.03310
2.5500	70.6151	.03740	9.5500	66.5216	.03306
2.8000	71.6426	.03740	9.8000	66.2800	.03290
3.0500	72.3117	.03740	10.0500	66.0700	.03280
3.3000	73.1076	.03740	10.3000	65.8657	.03270
3.5500	73.6768	.03740	10.5500	65.6736	.03260
3.8000	74.6134	.03740	10.8000	65.4927	.03250
4.0500	75.3286	.03740	11.0500	65.3219	.03240
4.3000	76.0437	.03740	11.3000	65.1603	.03230
4.5500	76.6979	.03740	11.5500	65.0073	.03220
4.8000	77.3537	.03740	11.8000	64.8622	.03210
5.0500	77.9928	.03740	12.0500	64.7263	.03200
5.3000	78.6162	.03740	12.3000	64.5931	.03190
5.5500	79.2280	.03740	12.5500	64.4681	.03180
5.8000	79.9482	.03450	12.8000	64.3490	.03170
6.0500	80.1234	.03450	13.0500	64.2362	.03160
6.3000	82.0019	.03450	13.3000	64.1288	.03150
6.5500	81.6702	.03450	13.5500	64.0226	.03140
6.8000	81.5397	.03450	13.8000	63.9232	.03136
7.0500	80.3964	.03450			0

THE ABOVE TIME-TEMP. HISTORY IS FOR SURFACE TEMP.

Figure 13. Example of Surface Time-Temperature History Printout.



ordinate size ( $25^{\circ}$ - $75^{\circ}$ C) is drawn containing only one plot, that of a time-temperature history at depth  $x$  below the surface of the skin. The value of  $L$  is equal to number of data cards after the fourth one or the number of graphs drawn or the number of time-temperature histories computed.

4. Sense switch #4 in "ON" position, all other switches in "OFF" position. Only surface time-temperature histories are computed and printed out as shown in Figure 13. Integration and punching of surface time-temperature histories onto data cards are always automatically omitted whenever surface time-temperature histories are computed. In this case a large graph is drawn with one surface time-temperature history plotted per graph. The value of  $L$  is determined as in Case #3.

5. All sense switches except #2 in "ON" position, sense switch #2 in "OFF" position. The only operation performed is the evaluation of the thermal tissue damage integral, the results printed out one after another consecutively down the page.

The operational analysis of the other modes of operations can easily be understood by reference to the flow chart in Figure 6. It should be noted that the computer can distinguish between surface time-temperature history data ( $x=0.0$ ) and time-temperature history at depth data only by means of the sequencing called for in the program. Thus, for instance, if the operator loads in surface time-temperature history data and places sense switch #5 in the "ON" position the computer will treat the data as time-temperature history at depth data. It is the responsibility of the operator to make the input data consistent with what is called for by the sense switch settings.

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