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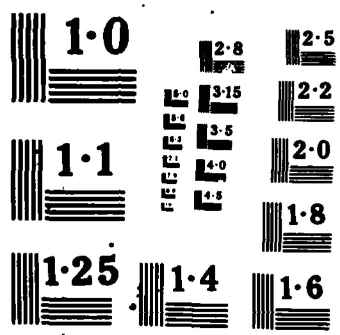

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Technical Note 4-86

FORTRAN PROGRAM TO PREDICT RECTAL TEMPERATURE AND HEART RATE RESPONSE OF A PERSON WORKING IN MOPP-4

Phillip G. Harnden

April 1986

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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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Heart Rate	MOPP (Mission Oriented Protective Posture)
Rectal Temperature	NBC (Nuclear Biological and Chemical Protective Uniform)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This FORTRAN program simulates multiple work and recovery cycles for a soldier wearing nuclear, biological, and chemical protective apparel (Mission-Oriented Protective Posture - Level 4 (MOPP-4)). The program predicts the soldier's rectal temperature and heart rate response to work performed in MOPP-4 for various climatic scenarios using formulas developed from previous human use studies (Berlin, Stoschein, & Goldman, 1975). The climatic parameters and the work and recovery cycle durations are user

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) inputs to the model. These inputs may be changed to produce variations in the rectal temperature and heart rate of the soldier. The model can be used to examine the duration of work and recovery time cycles. (Keywords:)

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CONTENTS

FORTRAN PROGRAM TO PREDICT RECTAL TEMPERATURE

AND HEART RATE RESPONSE OF A PERSON WORKING IN MOPP-4

INTRODUCTION

A computer program was developed to provide an analytical tool to assist in the structuring of work and recovery time cycles for a proposed Human Engineering Laboratory Forward Area Supply and Transfer (HELFAST) field study of ammunition handling operations to be conducted in Mission-Oriented Protective Posture - Level 4 (MOPP-4). The activities considered for investigation in this field study are those normally performed by a Direct Support Company operating an ammunition supply point (ASP). ASP operations are susceptible to degradation from extreme climatic conditions. This susceptibility may increase when handling operations are performed by personnel dressed in totally vapor-impermeable clothing (MOPP-4). This nuclear, biological, and chemical (NBC) protective uniform "poses a tolerance problem for the soldier for it encapsulates the wearer and interferes with the normal dissipation of body heat and can limit the time the wearer can work in a hot environment." (Goldman, 1963, p. 776)

BACKGROUND

From previous human use studies conducted at the U.S. Army Research Institute of Environmental Medicine, formulas have been developed to predict rectal temperature (Goldman & Givoni, 1972) and heart rate response (Goldman & Givoni, 1973) as a function of work, the environment, and the clothing properties of wearing apparel. Using these predictive formulas, Berlin, Stoschein, and Goldman (1975) developed a computer program for the HP-9810A programmable calculator which simulates rectal temperature and heart rate response based on a hypothetical situation of subjecting a nude man through a two-cycle work and recovery test. An analogous FORTRAN representation of their program, for use on the Human Engineering Laboratory's (HEL) VAX 11/780, was written for use by the Combat Service Support Directorate (CSSD) in preparation for field testing. Using the Berlin, Stoschein, and Goldman (1975) example as a standard, the FORTRAN program simulation predicts time patterns of rectal temperature and heart rate response that compare closely with it. The clothing insulation and evaporative impedance values demonstrated by Berlin, Stoschein, and Goldman (1975) have been changed to depict the same man dressed in NBC (MOPP-4) protective apparel.

THERMAL STRESS LIMITS

As a result of climatic chamber studies at Natick Laboratories, thermal stress limits were prescribed for the testing of human subjects (Iampietro & Goldman, 1965; Goldman, Green, & Iampietro, 1965). If, during testing, the rectal temperature equaled or exceeded 102.5 degrees Fahrenheit (°F), or the heart rate equaled or exceeded 180 beats per minute (bpm), the subject was removed from the study. For the Berlin, Stoschein, and Goldman (1975) example, time lengths were assigned to each work and recovery cycle. These time lengths were used as the determinants for the cessation of work and recovery. Using their simulation design, under certain environmental and clothing conditions, the predicted rectal temperature and heart rate during work may surpass these thermal stress limits before the duration of the cycle has completed. Therefore, the FORTRAN program simulations described will use the thermal stress limits mentioned as the determinants for the cessation of work. That is, the subject's rectal temperature and heart rate will dictate the length of the work cycle. Similarly, rectal temperature and heart rate will also determine the duration of recovery.

PROGRAM DESCRIPTION

Input Data

Two formatted data input files are used with the execution of the program. They are:

INITAL.DAT, which contains values for program variables that describe the subject, the rest, work, and recovery environments, and the clothing characteristics of the NBC protective uniform. The parametric values are identical to Berlin's except for the clothing parameters used to describe the NBC uniform. These parametric values remain unchanged for an entire test simulation. This file also contains values for the thermal stress limits, rectal temperature and heart rate, and determinant values for the cessation of recovery. (For an example, see Appendix A.)

CYCLE.DAT, which contains values for the program variables that identify the subject's metabolic rate and the environmental parameters, dry-bulb temperature and the relative humidity, for each cycle. (Appendix A)

Program

The computer program is written in FORTRAN 77 and runs on HEL's VAX 11/780. Program variable definitions are listed with the program code in Appendix B. The main program is in Appendix C.

The program simulates a multiple cycle work and recovery test for a hypothesized soldier wearing NBC protective apparel (MOPP-4). The length of the simulation test, or the number of work and recovery cycles simulated during program execution, is contingent on the data in CYCLE.DAT. At the start of the program run and before simulation of the test begins, the data in CYCLE.DAT is read and stored in the arrays MET, BULB, and HUMD. The arrays hold values for the soldier's metabolic rate (MET), the dry-bulb temperature (BULB), and the relative humidity (HUMD) present during each of the rest, work, and recovery time cycles. Before entering an activity cycle, either rest, work, or recovery, an element from each array is passed to the subroutine ENVIRN(MET,BULB,HUMD) which establishes the environment for the soldier throughout the duration of a cycle. The soldier's metabolic rate (MET) and the environmental parameters (BULB) and (HUMD) for the rest, work, and recovery activities may be varied by changing the data in CYCLE.DAT; although, variations of the metabolic rate are dependent on parametric data listed in INITAL.DAT. For the simulation examples described herein, the metabolic rate for work is an estimate of the rate expended for activities familiar to an ASP and were computed using the formula for the total metabolic rate (M) presented by Berlin, Stoschein, and Goldman (1975).

The predictive formulas for rectal temperature and heart rate for the rest, work, and recovery activities are located in separate subroutines. Rectal temperature, heart rate, cycle time, and simulation time are computed and printed every minute.

At the start of the simulation, the soldier is modeled as resting. The subroutine ENVIRN is called to set the environment for this rest period using elements from the array variables MET, BULB, and HUMD. This initial rest cycle lasts 30 minutes and acclimatizes the soldier to the testing environment. After this initial rest period, the soldier enters the first work cycle. At this time, situational parameters are changed to reflect the working posture and environment.

The work cycle continues until the soldier's predicted rectal temperature or heart rate reaches a thermal stress limit of 102.5 °F or 180 bpm. At this point, the program places the soldier into a recovery cycle. Again, situational parameters are changed to reflect the recovery posture, sitting or standing at ease, and environment. The soldier's metabolic rate, the dry-bulb temperature and relative humidity for this recovery cycle are passed to the subroutine ENVIRN where the recovery condition is computed. The test simulation continues, and the soldier remains in this recovery cycle until the predicted rectal temperature has fallen to 101 °F or the predicted heart rate has fallen to 100 bpm. At this point, the soldier begins the second work cycle. The test continues in this alternating work and recovery pattern. The duration of the simulation test is dependent on input from CYCLE.DAT and must conclude with a recovery period. The thermal stress limits and the cessation determinants for recovery listed in INITAL.DAT are adjustable.

A rectal temperature of 101 °F as a determinant for the end of a recovery period has been demonstrated in a previous investigation with human subjects using an analogous test design (Goldman, 1963). A heart rate of 100 bpm as a determinant for the cessation of recovery was a subjective choice whose validity has not been demonstrated in past tolerance studies. It was chosen because during example test simulations, as predicted by this program, it produced the optimal work time (in percent) with respect to the total testing time.

The cessation of the recovery periods is determined by the response pattern of the preceding work cycle. If, during work, the predicted rectal temperature reaches 102.5 °F before the predicted heart rate reaches

180 bpm, the following recovery cycle will continue until the predicted rectal temperature has fallen to 101 °F (Goldman, 1963). Similarly, if during work, the soldier's predicted heart rate reaches the thermal stress limit of 180 bpm before the predicted rectal temperature reaches 102.5 °F, the program places the soldier into a recovery posture until the predicted heart rate has fallen to 100 bpm.[1]

SIMULATION RESULTS

Two example test simulations are presented. Both simulated tests depict the rectal temperature and heart rate response for a person working in MOPP-4. The resulting response patterns are graphically displayed.

The first example is of a two-cycle work and recovery test. The test is simulated in an environment where the dry-bulb temperature is 77 °F, and the relative humidity is 75 percent. (Figure 1)

The second simulation is of a three-cycle work and recovery test. The test simulation occurs within an environment where the present dry-bulb temperature is 95 °F, and the relative humidity is 15 percent. (Figure 2)

SUMMARY

The purpose for developing this program was to find an analytical method that would assist the HELFAST Team of the Combat Service Support Directorate in the structuring of work and recovery time cycles for testing ammunition handling tasks of soldiers in MOPP-4. The replication of Berlin's test simulation example using this FORTRAN program was achieved, that is, agreement was demonstrated between the resulting predicted response patterns from Berlin and the predicted response patterns yielded from this program's simulation of his example. However, the reliability or validity of the predicted response patterns resulting from example simulations presented in this document is not intended to be conclusive. This program demonstrates an analytical procedure that allows the user to obtain data on the expected time constraints for work performed wearing such vapor-impermeable apparel.

[1]From preceding paragraph.

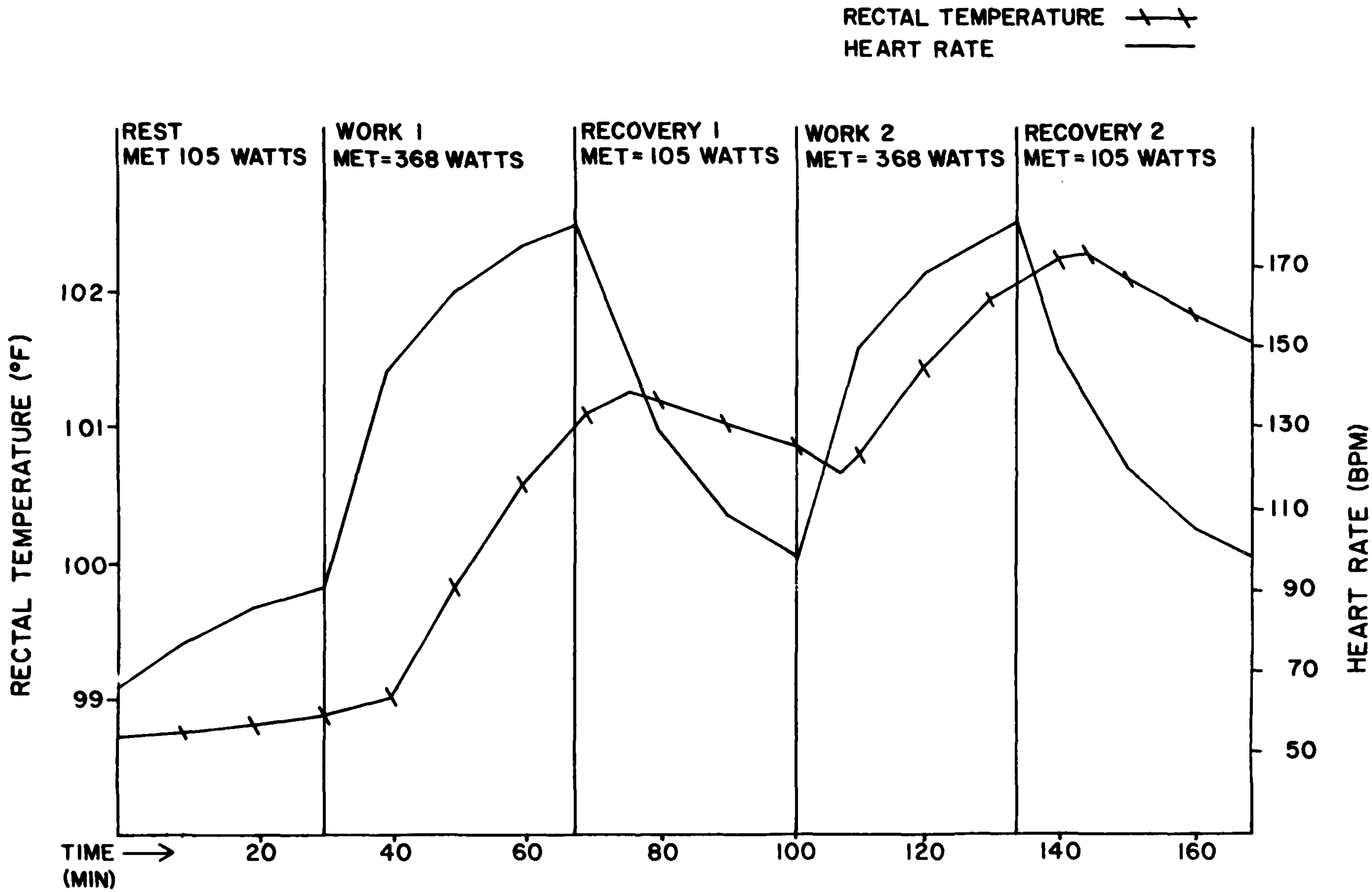

Figure 1. Two-cycle work and recovery test for a soldier in MOPP-4. Climatic parameters: Dry-bulb temperature is 77 °F. Relative humidity is 75%.

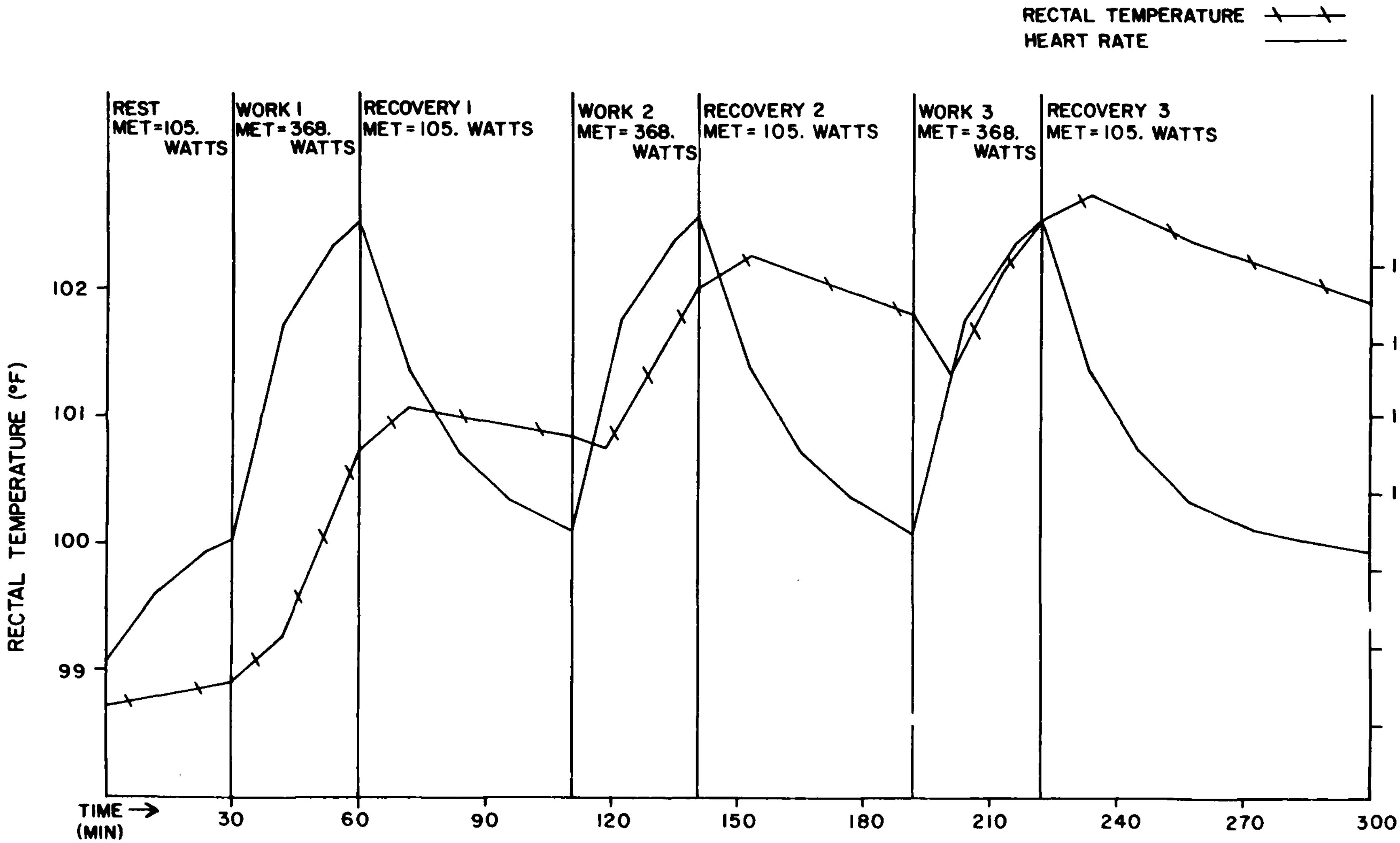

Figure 2. Three-cycle work and recovery test for a soldier in MOPP-4. Climatic parameters: Dry-bulb temperature is 95 °F. Relative humidity is 15%.

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APPENDIX A

VARIABLE VALUES FOR DATA INPUT FILES

VARIABLE VALUES FOR DATA INPUT FILES

Example input data for INITAL.DAT

HT	Subject's height, (cm)	171.45 cm
WT	Subject's weight including MOPP-4 ensemble, (kg)	68.04 kg
TOTSK	Total skin area, (sq m)	1.80 sq meters
EFFSK	Effective skin area, (sq m)	1.80 sq meters
IREC	Initial rectal temperature, (°C)	37.00 °C
IHR	Initial heart rate, (bpm)	65.00 bpm
SKTP	Skin temperature, (°C)	36.00 °C
HEAT	Days in heat	0.00 days
LOAD	Load, (kg)	0.00 kg
WALK	Walk speed, (m/s)	1.50 meters/second
GRADE	% grade	0.00 percent
TERR	Terrain coefficient[1]	1.10
CLO	Clothing insulation coefficient[2]	2.40
IMCLO	Permeability index ratio[2]	0.15
VELMOD	Velocity modifier	0.20
WIND	Wind speed, (m/s)	1.50 meters/second
IREST	Duration of initial rest/acclimatization period, (min)	30.00 min
HIGH	Thermal stress limit, rectal temperature, (°F)	102.50 °F
LOW	Recovery cessation determinant, rectal temperature, (°F)	101.00 °F
HRTHI	Thermal stress limit, heart rate, (bpm)	180.00 bpm
HRTLOW	Recovery cessation determinant, heart rate, (bpm)	100.00 bpm

Example input of a two-cycle work and recovery test for CYCLE.DAT.
Input data stored in array variables, MET, BULB, HUMD.

Rest period	MET(1)	105.	Metabolic rate, (watts)
	BULB(1)	30.	Dry-bulb temperature, (°C)
	HUMD(1)	.40	Relative humidity, (%)
1st work cycle	MET(2)	368.00	
	BULB(2)	30.	
	HUMD(2)	.40	
1st recovery cycle	MET(3)	105.	
	BULB(3)	30.	
	HUMD(3)	.40	
2nd work cycle	MET(4)	368.00	
	BULB(4)	30.	
	HUMD(4)	.40	
2nd recovery cycle	MET(5)	105.	
	BULB(5)	30.	
	HUMD(5)	.40	

[1] Soule, R. G., & Goldman, R. R. (1972). Terrain coefficients for energy cost prediction. Journal of Applied Physiology, 32, 706-708.
[2] Goldman, R. F. (1967). Systematic evaluation of thermal aspects of air crew protective systems. AGARD Conference Proceedings No. 25, Behavioral Problems in Aerospace Medicine, Rhode-Saint-Geneva, Belgium.

APPENDIX B

PROGRAM CODE AND VARIABLE DEFINITIONS

PROGRAM CODE AND VARIABLE DEFINITIONS

PROGRAM MOPP-4

Variable Definitions

Elements of array variable ENVIRN:

MET = an array which stores the subject's metabolic rate (watts) for each cycle

BULB = an array which stores the ambient dry-bulb temperature (°C) present during each cycle

HUMD = an array which stores the percentage saturation of the ambient air (relative humidity) present during each cycle (%)

Other array variables

TR = an array which stores a cycle time and the expected time lag for an induced rectal temperature change due to the transformation from one cycle to another (min)

TD = an array which stores the expected time lag for either a work or recovery induced rectal temperature change due to the transformation from one cycle to another (min)

TDREC = an array which stores the time lag of recovery (min)

Subject, Environmental, and Clothing attributes:

M = total metabolic rate (watts)

HT = height of subject (cm)

WT = weight of subject (kg)

TOTSK = total surface skin area of subject (sq meters)

EFFSK = effective skin area of subject (sq meters)

IREC = initial rectal temperature of subject (°C)

IHR = initial heart rate of subject (bpm)

SKTP = skin temperature of subject (°C)

HEAT = days in heat

LOAD = load (kg)

WALK = walk speed (meters/second)

GRADE = percent grade (%)

TERR = terrain coefficient

CLO = clothing insulation coefficient

IMCLO = permeability index ratio

VELMOD = velocity modifier (meters/second)

WIND = air speed (meters/second)

Variables used to describe rest, work, and recovery environments:

VEFF = effective air speed (meters/second)

CLO$ = effective clothing insulation coefficient

IMCLO$ = effective permeability index ratio

EREG = required evaporative cooling (watts)

PW = saturated vapor pressure of water at ambient air temperature (atmospheres)

EMAX = maximum evaporative capacity (watts)

TDX = time lag work induced (hr)

TDREC = time lag recovery (hr)

Clocks:

RECTIM = clock used in the prediction of rectal temperature response (min)

CYCTIM = clock used in the prediction of heart rate response (min)

Time Constants:

ALPHA = recovery time constant (hr)

TAU = work time constant (°C/hr)

Program flags and increments:

FIRST = variable used to designate a cycle change (logical)

NCYC = cycle number (integer)

INTV = time increment (min)

MODE = variable used to designate which limiting value has been reached (integer)

LIMIT = variable used to determine which rectal temperature and heart rate formulas are in use (logical)

CHANGE = variable used to designate the last heart rate prediction of a cycle (logical)

HLAST = variable used to signal heart rate as the cessation determinant for a recovery cycle (logical)

HIGH = thermal stress limit for rectal temperature (°F)

LOW = cessation determinant for recovery (°F)

HRTHI = thermal stress limit for heart rate (bpm)

HRTLOW = cessation determinant for recovery (bpm)

Variables pertaining to rectal temperature formulas:

TREF = the final equilibrium rectal temperature (°C)

TRET = a predicted rectal temperature (°C)

TREI = the initial rectal temperature at the beginning of a cycle (°C)

TREW = the rectal temperature at the beginning of decrease during a recovery cycle (°C)

TRER = the equilibrium resting rectal temperature during the recovery cycle (°C)

TDELTA = the difference of the final equilibrium rectal temperature (TREF) and the initial rectal temperature (TREI) found at the beginning of a cycle (°C)

Variables pertaining to heart rate formulas:

HRINDX = heart rate index

HRATE = a predicted heart rate (bpm)

HRDELT = the difference of the equilibrium heart rate for partially acclimatized subjects and the initial heart rate found at the beginning of a cycle (bpm)

HRIW = subject's heart rate at the beginning of work (bpm)

HRW = subject's heart rate at the end of work (bpm)

HRF = the equilibrium heart rate for fully acclimatized subjects due to the heart rate index (bpm)

HRFN = the equilibrium heart rate for partially acclimatized subjects (bpm)

HRACCL = heart rate response due to the acclimatization process (bpm)

APPENDIX C

MAIN PROGRAM

MAIN PROGRAM

VARIABLE DECLARATION

```
      IMPLICIT REAL (A-Z)
      REAL MET(30),BULB(30),HUMD(30),TR(30),TDREC(30)
      INTEGER NCYC, MODE, FIRST, LIMIT, CHANGE, HLAST
      COMMON /INIT/ HT,WT,TOTSK,EFFSK,IREC,IHR,SKTP,HEAT,LOAD
     1        WALK,GRADE,TERR,CLO,IMCLO,VELMOD,WIND,TDX,TDRECX,CP
      COMMON /TIMES/ TIME,RECTIM,CYCTIM,TR,TD,IREST
      COMMON /FLAGS/ NCYC,FIRST,INTV,LIMIT,CHANGE,MODE,LAST
      COMMON /TEMPS/ TRET,TREI,TREW,TRER,TREF,TDELTA,TEMP
      COMMON /CONST/ TAU,ALPHA
      COMMON /HEART/ HRINDX,HRATE,HRDELT,EMAX,HRIW,HRW,K,J,HRF
      COMMON /ELMNTS/ MET,BULB,HUMD
      COMMON /LIMITS/ HIGH, LOW, HRTHI, HRTLOW, HLAST
```

Assign output file for predicted rectal temperature and heart rate.

```
      CALL ASSIGN(1,'MOPP.OUT')
```

Read 'INITAL.DAT'. This file contains the initial values for the subject, environment, and clothing attributes.

```
      OPEN (UNIT=7, FILE='INITAL.DAT', STATUS='OLD')
10    READ(7,20,END=30)HT,WT,TOTSK,EFFSK,IREC,IHR,SKIP,HEAT,LOAD,
     1 WALK,GRADE,TERR,CLO,IMCLO,VELMOD,WIND,IREST,HIGH,LOW,HRTHI,
     1 HRTLOW

20    FORMAT(F8.4)
      GO TO 10

30    REWIND 7
```

Read 'CYCLE.DAT'. This file contains the metabolic rate, dry bulb temperature, and the relative humidity for each time cycle.

```
      OPEN (UNIT=8, FILE='CYCLE.DAT', STATUS='OLD')
         NCYC = 0
31       READ(8,40,END=41) A,B,C
40       FORMAT(F8.4)
         NCYC = NCYC + 1
         MET(NCYC) = A
         BULB(NCYC) = B
         HUMD(NCYC) = C
         GOTO 31

41    REWIND 8

         LAST = NCYC
```

Set time lags for work and recovery cycles.

```
     DO 200 I = 1, NCYC
        CALL ENVIRN(MET(I),BULB(I),HUMD(I))
        TD(I) = IFIX(TDX * 60.)
        TDREC(I) = IFIX(TDRECX * 60.)
200  CONTINUE
```

Store time lags into TD.

```
     DO 300 I = 3,NCYC, 2
          TD(I) = TDREC(I)

300  CONTINUE
```

Call INIT for variable initialization.

```
        CALL INIT
        CALL ENVIRN(MET(NCYC),BULB(NCYC),HUMD(NCYC))
        CALL HEADNG
        TRET = IREC
```

Last predictions of the test simulation?

```
400     IF(NCYC.EQ.LAST.AND.TEMP.LE.LOW.AND.
    1      MODE.EQ.1.OR.
    1      NCYC.EQ.LAST.AND.HRATE.LE.HRTLOW.AND.
    1      MODE.EQ.1) GOTO 999
```

Is the environment safe for work?

```
        IF(CP.LE.0.) GOTO 998
```

First predictions of new cycle?

```
        IF(FIRST)THEN
           CALL ENVIRN(MET(NCYC),BULB(NCYC),HUMD(NCYC))
           CALL HART
           TDELTA = TREF - TRET
           TAU = 0.5 + 1.5*EXP(-0.3*DELTA)
           TRER = TREF
           TREI = TRET
           TREW = TRET
           FIRST = FALSE
        ENDIF
```

Which cycle?

```
        IF(NCYC.EQ.1)CALL REST
        IF(NCYC.GT.1.AND.MOD(NCYC.2)EQ.0)THEN
         CALL WORK
        ELSE IF (NCYC.GT.1)THEN
         CALL RECOVR
        ENDIF
```

Print rectal temperature, heart rate, and time.

```
      TEMP = (9./5. * TRET) + 32.
      WRITE(1,60) TRET,TEMP,HRATE,CYCTIM,TIME
60    FORMAT(11X,F6.2,8X,F6.2,7X,F5.1,7X,F7.2,11X,F7.2)
```

Check if rectal temperature or heart rate has reached a stress limit?

```
      IF(LIMIT)THEN
       IF(TEMP.GE.HIGH.AND.MODE.EQ.1)THEN
         TR(NCYC)=TIME + TD(NCYC+1)
         LIMIT=.FALSE.
         CHANGE = .TRUE.
         MODE = 2
      ELSE IF(HRATE.GE.HRTHI)THEN
                TR(NCYC)=TIME + TD(NCYC+1)
                LIMIT=.FALSE.
                CHANGE = .TRUE.
                MODE = 3
                HLAST = .TRUE.
```

Has recovery ended?

```
      ELSE IF(TEMP.LE.LOW.AND.MODE.EQ.2)THEN
        TR(NCYC)=TIME + TD(NCYC+1)
        LIMIT=.FALSE.
        CHANGE = .TRUE.
        MODE = 1
      ELSE IF(HRATE.LE.HRTLOW.AND.MODE.EQ.3)THEN
        TR(NCYC)=TIME + TD(NCYC+1)
        LIMIT = .FALSE.
        CHANGE = .TRUE.
        MODE = 1
      ENDIF
    ENDIF
```

Increment clocks.

```
      CYCTIM = CYCTIM + INTV
      RECTIM = RECTIM + INTV
      TIME = TIME + INTV
```

If TIME has passed time lag, increment NCYC to initiate rectal temperature response to change in cycle.

```
      IF(ABS(TIME-TR(NCYC)).LT.INTV/2.)THEN
         RECTIM = IFIX(TD(NCYC+1))
         NCYC = NCYC + 1
         FIRST = .TRUE.
         LIMIT = .TRUE.
      ENDIF

      GOTO 400
```

```
   Do not work in this environment!

998        WRITE(1,45) CP
 45        FORMAT(2x,'**********    WARNING   ************',//2x,
   1 'The effective cooling power of the ',
   1 'environment is ',f6.2,'.',/3x,'This environment',
   1 'will not allow the body temperature to collapse.',/3x
   1 'That is, once the body temperature starts to rise it ',
   1 'will',/3x,'continue to rise even through recovery cycles',/)
999  STOP
     END

   ------------------------------------------------------------------------
   SUBROUTINE ENVIRN (MET,BULB,HUMD)

   This subroutine sets up the environmental conditions for each time cycle.

      IMPLICIT REAL (A-Z)
      COMMON /INIT/ HT,WT,TOTSK,EFFSK,IREC,IHR,SKTP,HEAT,LOAD,
   1         WALK,GRADE,TERR,CLO,IMCLO,VELMOD,WIND,TDX,TDRECX,CP
      COMMON /TEMPS/ TRET,TREI,TREW,TRER,TREF,TDELTA
      COMMON /CONST/ TAU,ALPHA
      COMMON /HEART/ HRINDX,HRATE,HRDELT,EMAX,HRIW,HRW,K,J,HRF

      DATA A,B,C,D /3.2437814, 5.86826E-3, 1.1702379E-8, 2.1878462E-3/

      VEFF = WIND + 0.004*(MET-105.)
      CLO$ = CLO*VEFF**(-VELMOD)
      IMCLO$ = IMCLO*VEFF**VELMOD
      EREQ = MET + ((6.47*TOTSK)/CLO$)*(BULB-SKTP)
      T = BULB + 273.16
      X = 647.27 - T
      XP = (X/T)*((A+(B*X)+C*(X**3.))/(1.+D*X))
      PW = (218.167*(10**(-XP))) * 760.
      EMAX = (14.2 * TOTSK) * (IMCLO$) * (44. - (HUMD * PW))
      TREF = 36.75 + 0.004*MET + ((0.014*TOTSK)/(CLO$))*(BULB-SKTP)+
   1  0.8*EXP(0.0047*( EREQ-EMAX))
      TDX = 58./MET
      CP = 0.15*TOTSK*IMCLO$*(44. -(HUMD*PW)) + ((0.097*TOTSK)/CLO$)*
   1  (SKTP-BULB)-1.57
      ALPHA = 1.5*(1.0-EXP(-1.5*CP))
      TDRECX = .25*EXP(-0.5*CP)

   The heart rate index is computed here

      HRINDX = 0.4*MET+(1.39*TOTSK/CLO$)*(BULB-SKTP)
   1                      +80.*EXP(.0047*(EREQ-EMAX))

      RETURN
      END
```

```
SUBROUTINE INIT

This subroutine is called for variable initialization.

IMPLICIT REAL (A-Z)
INTEGER NCYC, MODE, FIRST, LIMIT, CHANGE
REAL MET(30),BULB(30),HUMD(30),TR(30),TD(30),TDREC(30)
COMMON /TIMES/ TIME, RECTIM,CYCTIM,TR,TD,IREST
COMMON /FLAGS/ NCYC,FIRST,INTV,LIMIT,CHANGE,MODE

Initialize clocks, flags, and time increments.

RECTIM = 0
CYCTIM = 0
NCYC = 1
TIME = 0
INTV = 1.0
FIRST = .TRUE.
LIMIT = .FALSE.
CHANGE = .FALSE.
MODE = 1

TR(1) = IREST + TD(2)

RETURN
END


SUBROUTINE REST

This subroutine is called when the subject is in the rest cycle and is
called through the time lag for a work induced rectal temperature
response.

IMPLICIT REAL (A-Z)
REAL MET(30),BULB(30),HUMD(30),TR(30),TDREC(30)
INTEGER NCYC
COMMON /INIT/ HT,WT,TOTSK,EFFSK,IREC,IHR,SKIP,HEAT,LOAD,
1         WALK,GRADE,TERR,CLO,IMCLO,VELMOD,WIND,TDX,TDRECX,CP
COMMON /TIMES/ TIME,RECTIM,CYCTIM,TR,TD,IREST
COMMON /FLAGS/ NCYC,FIRST,INTV,LIMIT,CHANGE,MODE
COMMON /TEMPS/ TRET,TREI,TREW,TRER,TREF,TDELTA
COMMON /HEART/ HRINDX,HRATE,HRDELT,EMAX,HRIW,HRW,K,J,HRF
COMMON /ELMNTS/ MET,BULB,HUMD

Rest equation for rectal temperature prediction

      TRET = IREC + TDELTA *((0.1)**((0.4**(RECTIM/60.))))
```

Heart rate prediction -

```
      IF(RECTIM.LT.IREST)THEN
```

While resting

```
      HRATE = IHR + HRDELT*(1-EXP(-3.*CYCTIM/60.))

   ELSE IF(RECTIM.EQ.IREST)THEN
```

this is the last heart rate prediction of the rest cycle

```
      HRATE = IHR + HRDELT*(1-EXP(-3.*CYCTIM/60.))
      HRIW = HRATE
      IHR = HRATE
      CYCTIM = 0.
```

the subject is now entering the first work cycle

```
      CALL ENVIRN(MET(NCYC+1),BULB(NCYC+1),HUMD(NCYC+1))
      CALL HART
      CALL HEADNG

   ELSE
```

and while working we use the work equation for heart rate prediction

```
1     HRATE = HRIW + HRDELT*
              (1-(.8*EXP(-1*(6-.03*HRDELT)*CYCTIM/60.)))

   ENDIF

RETURN
END

SUBROUTINE WORK
```

This subroutine is called when the subject is in one of the work cycles and is called through the time lag for a recovery induced rectal temperature response.

```
IMPLICIT REAL (A-Z)
INTEGER NCYC, MODE, FIRST, LIMIT, CHANGE
REAL MET(30),BULB(30),HUMD(30),TR(30),TD(30),TDREC(30)
COMMON /INIT/ HT,WT,TOTSK,EFFSK,IREC,IHR,SKIP,HEAT,LOAD,
1      WALK,GRADE,TERR,CLO,IMCLO,VELMOD,WIND,TDX,TDRECX,CP
COMMON /TIMES/ TIME,RECTIM,CYCTIM,TR,TD,IREST
COMMON /FLAGS/ NCYC,FIRST,INTV,LIMIT,CHANGE,MODE
COMMON /TEMPS/ TRET,TREI,TREW,TRER,TREF,TDELTA
COMMON /CONST/ TAU,ALPHA
COMMON /HEART/ HRINDX,HRATE,HRDELT,EMAX,HRIW,HRW,K,J,HRF
COMMON /ELMNTS/ MET,BULB,HUMD
```

```
Equations for rectal temperature prediction -

   IF(LIMIT)THEN

work cycle here

   TRET = TREI + TDELTA*(1-EXP(TAU*(TD(NCYC)/60.-RECTIM/60.)))
   TLAST = TRET
     ELSE

recovery cycle here .....

   TRET=TREI+(TDELTA*(1-EXP(TAU *( TD(NCYC)/60.-RECTIM/60.))))/2.

      TMP = TREI + TDELTA*(1-EXP(TAU*(TD(NCYC)/60.-RECTIM/60.)))
      TRET = TLAST + (TMP - TLAST)/2.

      ENDIF

Heart rate prediction -

      IF(LIMIT)THEN

while working

      HRATE = HRIW + HRDELT*
1                     (1-(.8*EXP(-1*(6-.03*HRDELT)*CYCTIM/60.)))

ELSE IF(CHANGE)THEN

the last heart rate prediction during a work cycle is computed here.

   HRATE = HRIW + HRDELT*
1                  (1-(.8*EXP(-1*(6-.03*HRDELT)*CYCTIM/60.)))
   HRW = HRATE
   IHR = HRATE
   CYCTIM = 0

The subject is now entering a recovery cycle.....

   CALL ENVIRN(MET(NCYC+1),BULB(NCYC+1),HUMD(NCYC+1))
   CALL HART
   CALL HEADNG
   K = 2-0.01*(HRW-HRF)
   J = 2 + 12*(1-EXP(-0.3*CP))

   CHANGE = .FALSE.

ELSE
```

......and while in recovery this equation is used for heart rate prediction.

```
      HRATE = HRW - (HRW-HRF)*(1-EXP(-K*J*CYCTIM/60.))

     ENDIF
  RETURN
  END
```

SUBROUTINE RECOVR

This subroutine is called when the subject is in one of the recovery cycles and is called through the time lag for a work induced rectal temperature response.

```
      IMPLICIT REAL (A-Z)
      INTEGER NCYC, MODE, FIRST, LIMIT, CHANGE
      REAL MET(30),BULB(30),HUMD(30),TR(30),TD(30),TDREC(30)
      COMMON /INIT/ HT,WT,TOTSK,EFFSK,IREC,IHR,SKTP,HEAT,LOAD,
     1       WALK,GRADE,TERR,CLO,IMCLO,VELMOD,WIND,TDX,TDRECX,CP
      COMMON /TIMES/ TIME,RECTIM,CYCTIM,TR,TD,IREST
      COMMON /FLAGS/ NCYC,FIRST,INTV,LIMIT,CHANGE,MODE,LAST
      COMMON /TEMPS/ TRET,TREI,TREW,TRER,TREF,TDELTA
      COMMON /CONST/ TAU,ALPHA
      COMMON /HEART/ HRINDX,HRATE,HRDELT,EMAX,HRIW,HRW,K,J,HRF
      COMMON /ELMNTS/ MET,BULB,HUMD
```

Recovery equation for rectal temperature prediction.

```
         TRET = TREW -
     1           (TREW-TRER)*(1-EXP(ALPHA*(TD(NCYC)/60.-RECTIM/60.)))
```

Equations for heart rate prediction -

```
            IF(LIMIT)THEN
```

the subject is in recovery here

```
            HRATE = HRW - (HRW-HRF)*(1-EXP(-K*J*CYCTIM/60.))
```

has the end of the last recovery period of the test been reached?

```
            ELSE IF(CHANGE.AND.NCYC.EQ.LAST)THEN
                 RETURN

            ELSE IF(CHANGE)THEN
```

this is the last heart rate prediction of this recovery because ...

```
        HRATE = HRW - (HRW-HRF)*(1-EXP(-K*J*CYCTIM/60.))
          HRIW = HRATE
          IHR = HRATE
          CYCTIM = 0
```

.....the subject is entering a work cycle here

```
        CALL ENVIRN(MET(NCYC+1),BULB(NCYC+1),HUMD(NCYC+1))
        CALL HART
        CALL HEADNG
        CHANGE = .FALSE.

    ELSE
```

and while working we use this equation for heart rate prediction

```
        HRATE = HRIW + HRDELT*
1                (1-(.8*EXP(-1*(6-.03*HRDELT)*CYCTIM/60.)))

    ENDIF

RETURN
END
```

SUBROUTINE HART

This subroutine computes parametric values used in the formulas for heart rate prediction.

```
IMPLICIT REAL (A-Z)
COMMON /INIT/ HT,WT,TOTSK,EFFSK,IREC,IHR,SKTP,HEAT,LOAD,
1      WALK,GRADE,TERR,CLO,IMCLO,VELMOD,WIND,TDX,TDRECX,CP
COMMON /HEART/ HRINDX,HRATE,HRDELT,EMAX,HRIW,HRW,K,J,HRF

HEAT=0.
   IF(HRINDX.LE.225.)THEN
      HRF=65.+.35*(HRINDX-25.)
      HRACCL= 40.*(1-EXP(.04*(IHR-HRF)))*(1-EXP(-.005*EMAX))
      HRFN= HRF+HRACCL*EXP(-.3*HEAT)
      HRDELT = HRFN-IHR
   ELSE
      HRF= 135.+42.*(1-EXP(225.-HRINDX))
      HRACCL= 40.*(1-EXP(.04*(IHR-HRF)))*(1-EXP(-.005*EMAX))
      HRFN= HRF+HRACCL*EXP(-.3*HEAT)
      HRDELT = HRFN-IHR
   ENDIF
RETURN
END
```

```
      SUBROUTINE HEADNG

      This subroutine prints out program variables which describe subject, work,
      clothing, and environmental conditions.

      IMPLICIT REAL (A-Z)
      INTEGER NCYC, MODE, HLAST
      REAL MET(30),BULB(30),HUMD(30),TR(30),TD(30),TDREC(30)
      COMMON /INIT/ HT,WT,TOTSK,EFFSK,IREC,IHR,SKTP,HEAT,LOAD,
     1       WALK,GRADE,TERR,CLO,IMCLO,VELMOD,WIND,TDX,TDRECX,CP
      COMMON /HEART/ HRINDX,HRATE,HRDELT,EMAX,HRIW,HRW,K,J,HRF
      COMMON /TIMES/ TIME,RECTIM,CYCTIM,TR,TD,IREST
      COMMON /FLAGS/ NCYC,FIRST,INTV,LIMIT,CHANGE,MODE
      COMMON /ELMNTS/ MET,BULB,HUMD
      COMON /TEMPS/ TRET,TREI,TREW,TRER,TREF,TDELTA,TEMP
      COMMON /LIMITS/ HIGH, LOW, HRTHI, HRTLOW, HLAST

         IF(TIME.EQ.0.)THEN
           WRITE(1,47)
47         FORMAT(//5x,'Predicted rectal temperature and heart rate',
     1 'response to work, clothing, ',/2x,'and environment',
     1    'during various rest, work, and recovery time cycles.',/)

           TBULB = (9./5. * BULB(NCYC)) + 32.
           TIREC = (9./5. * IREC) + 32.
           TSKTP = (9./5. * SKTP) + 32.

      WRITE(1,48) HT,WT,TOTSK,EFFSK,TIREC,IHR,TSKTP,HEAT,LOAD,WALK,
     1  GRADE,TERR,CLO,IMCLO,VELMOD,WIND,EMAX,CP,TBULB,HUMD(NCYC)

48       FORMAT(/2X,
     1 'INITIAL VARIABLE ASSIGNMENTS:',//2X,
     1    'Subject height = ',F6.2,' cm.',/2X,
     1        'Subject weight = ',F6.2,' kg.',/2X,
     1 'Total skin area = ',F6.2,' sq. meters',/2X,
     1 'Effective skin area = ',F6.2,' sq. meters',/2X,
     1 'Initial rectal temperature = ',F6.2,' deg. fahrenheit',/2X,
     1    'Initial heart rate = ',F6.2,' bpm.',/2X,
     1 'Skin temperature = ',F6.2,' deg. fahrenheit',/2X,
     1 'Days in heat = ',F6.2,/2X,
     1 'Load = ',F6.2,' kg.',/2X,
     1 'Walk speed = ',F6.2,' meters/second',/2X,
     1 '% grade = ',F6.2,/2X,
     1 'Terrain coefficient = ',F6.2,/2X,
     1 'Clothing insulation coefficient = ',F6.2,/2X,
     1 'Permeability index ratio = ',F6.2,/2X,
     1 'Velocity modifier = ',F6.2,/2X,
     1 'Wind speed = ',F6.2,' meters/second',/2X,
     1 'Maximum evaporative capacity = ',F6.2,/2X,
     1 'Effective cooling power of the environment = ',F6.2,/2X,
     1 'Dry bulb temperature = ',F6.2,' deg. fahrenheit',/2X,
     1 'Relative humidity = ',F6.2,/2x,
     1 '--------------------------------------------------------',//)
```

```
      WRITE(1,49) IREST, MET(NCYC)
 49   FORMAT(2X,
     1 'Initial rest cycle = ',F6.2,' min.',/2X,
     1 'metabolic rate = ',F6.2,' watts',/,
     1    /11x,'TEMP(C)',6X,'TEMP(F)',
     1     5X,'HEART RATE',4X,'CYCLE TIME',4X,
     1     'SIMULATION TIME',/38X,'(bpm)',10X,'(min)',12X,'(min)')

      ENDIF

         TBULB = (9./5. * BULB(NCYC+1)) + 32.

      IF(TIME.GT.0.)THEN
         IF(NCYC.EQ.1)THEN
            WRITE(1,80)
 80         FORMAT(/2X,
     1      '******** cycle change *******',/2x,
     1      'End of acclimatization period',///2x,
     1      'WORK CYCLE')

         WRITE(1,50) TEMP,HRATE,MET(NCYC+1),TBULB,HUMD(NCYC+1),
     1         WIND,CP,EMAX

         ELSE IF(MOD(NCYC,2).EQ.0)THEN
                IF(TEMP.GE.HIGH)THEN
                   WRITE(1,60) HIGH
                ELSE
                   WRITE(1,61) HRTHI
                ENDIF

         WRITE(1,81)
 81      FORMAT(/2X,
     1      'RECOVERY CYCLE ')

      WRITE(1,50) TEMP,HRATE,MET(NCYC+1),TBULB,HUMD(NCYC+1),
     1         WIND,CP,EMAX

            ELSE IF(NCYC.GT.1)THEN
                IF(HLAST)THEN
                   WRITE(1,63) HRTLOW
                   HLAST = .FALSE.
                ELSE IF(TEMP.LE.LOW)THEN
                      WRITE(1,62) LOW
                ENDIF
```

```
      WRITE(1,82)
82    FORMAT(/2X,
  1       'WORK CYCLE ')

    WRITE(1,50) TEMP,HRATE,MET(NCYC+1),TBULB,HUMD(NCYC+1),
           WIND,CP,EMAX

         ENDIF
    ENDIF

50  FORMAT(//2X,
  1    'rectal temperature = ',f6.2,' deg. fahrenheit',/2x,
  1    'heart rate = ',f6.1,' bpm',/2x,
  1    'metabolic rate = ',f6.2,' watts',/2x,
  1    'Dry bulb temperature = ',F6.2,' deg. fahrenheit',/2X,
  1    'Relative humidity = ',F6.2,/2x,
  1    'Wind speed = ',F6.2,' meters/second',/2X,
  1    'Effective cooling power of the environment = ',F6.2,/2X,
  1    'Maximum evaporative capacity = ',f6.2,
  1       //11X,'TEMP(C)',6X,'TEMP(F)',
  1        5X,'HEART RATE',4X,'CYCLE TIME',4X,
  1       'SIMULATION TIME',/38X,'(bpm)',10X,'(min)',12X,'(min)')

60            FORMAT(/2X,
  1    '******* cycle change ********',/2x,
  1    'Rectal temperature has reached a thermal stress limit, ',
  1    f6.2,2x)

61            FORMAT(/2X,
  1    '******* cycle change ********',/2x,
  1    'Heart rate has reached a thermal stress limit, ',f6.1,/2x)

62            FORMAT(/2X,
  1    '******* cycle change *******',/2x,
  1    'Rectal temperature has reached a lower limit, ',f6.2,/2x)

63            FORMAT(/2X,
  1    '******* cycle change *******',/2x,
  1    'Heart rate has reached a lower limit, ',f6.1,/2x)

    RETURN
    END
```

END
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