53-54
177403
p 64

APPENDIX 3

Modifications to an interactive model of the human body during exercise: With special emphasis on thermoregulation

by

Megan Kay Scherb

A Creative Component Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF ENGINEERING

Department: Chemical Engineering
Major: Chemical Engineering

Iowa State University
Ames, Iowa

1992

TABLE OF CONTENTS

NOMENCLATURE

AGE	Age of the athlete, years
GAIN1	Gain constant based on level of training
GAIN2	Gain constant based on level of dehydration
HT	Height of the athlete, cm
MKG	Mass of the athlete, kg
Ts	Mean skin temperature
T_{head}	Temperature of the head
T_{arm}	Temperature of the arms
T_{hand}	Temperature of the hands
T_{ft}	Temperature of the feet
T_{leg}	Temperature of the legs
T_{th}	Temperature of the thighs
T_{tr}	Temperature of the trunk
VO2max	Maximum oxygen uptake

INTRODUCTION

Since 1988 an interactive computer model of the human body during exercise has been under development by a number of undergraduate students in the Department of Chemical Engineering at Iowa State University. The program, written under the direction of Dr. Richard C. Seagrave, uses physical characteristics of the user, environmental conditions and activity information to predict the onset of hypothermia, hyperthermia, dehydration, or exhaustion for various levels and durations of a specified exercise. The program, however, was severely limited in predicting the onset of dehydration due to the lack of sophistication with which the program predicted sweat rate and its relationship to sensible water loss, degree of acclimatization, and level of physical training. Additionally, it was not known whether sweat rate also depended on age and gender. For these reasons, the goal of this creative component was to modify the program in the above mentioned areas by applying known information and empirical relationships from literature. Furthermore, a secondary goal was to improve the consistency with which the program was written by modifying user input statements and improving the efficiency and logic of the program calculations.

Principle Mechanisms of Heat Transfer During Exercise

The human body exchanges heat with the environment by four basic mechanisms; radiation, conduction, convection, and evaporation. These mechanisms are the same whether heat is imposed to the body metabolically, as in exercise, or environmentally. Radiative heat transfer occurs by the transmission of electromagnetic heat waves between objects without the involvement of molecular contact. Heat transfer by radiation may result in either heat loss or gain depending on conditions in the environment. For example, when a person is cooler than the surroundings, he/she will absorb radiant heat energy. Conversely, when a person is warmer than the surroundings, he/she will lose heat to the environment.

Conductive heat transfer occurs when heat energy is transferred between objects by direct physical contact. Approximately three percent of a person's total heat loss at rest in a room temperature environment occurs via this mechanism (Brooks et al., 1987). Therefore, during exercise, heat loss by means of conduction is considered negligible. Conduction also occurs within the body itself as heat is conducted from the inner core to the skin or vice versa depending on the temperature gradient.

Convective heat transfer, a form of conduction of heat to a fluid, occurs via the circulation of air molecules adjacent to the skin. As air molecules are warmed, they become less dense, rise away from the body, and are displaced by cooler molecules. During exercise in air, heat loss due to convection is influenced by both the velocity of the athlete and the wind.

Finally, evaporative heat transfer occurs by way of the change of liquid water on the surface of the skin to gaseous water vapor in the environment. Evaporative heat transfer is the most important mechanism of heat transfer during exercise. In evaporation, heat is transferred from the body to water on the surface of the skin. When the water has gained sufficient energy, approximately 0.58 kilocalories per gram of water depending on the skin temperature, it vaporizes and heat is removed from the skin. It is important to note that unlike radiation, conduction, and convection which occur because of temperature gradients, evaporation is driven by a gradient in the vapor pressure. During exercise, this fact is especially salient in an environment where the ambient temperature and relative humidity are high. In this situation, the body gains heat by convection and radiation, and evaporation becomes the only mechanism by which the body can lose heat. However, when the relative humidity is high, temperature regulation becomes more difficult because the vapor pressure of the air is close to that of moist skin. Therefore, the rate of evaporation is greatly reduced. Sweating in these environments results in sensible water loss that can lead to dehydration without a cooling effect to the skin (McArdle, 1986).

In addition to the four basic mechanisms of heat transfer, heat loss via respiration (a combined mechanism) must also be considered during exercise. Respiratory energy losses occur via the evaporation of water in the lungs and respiratory tract as well as by the convective cooling effect of breathing.

Physiological Control of Heat Transfer During Exercise

There are two principle mechanisms by which the body can control the balance between heat production and heat loss during exercise. First, the body can change its surface temperature by altering blood flow to the skin. When blood vessels to the skin dilate (vasodilation), warm blood from the core of the body is brought to the surface where heat is lost via radiation and convection. Conversely, when these blood vessels constrict (vasoconstriction), heat is conserved in the inner core and less heat is lost to the surroundings. Second, the body can regulate the rate of sweating.

These physiological mechanisms are governed by the thermoregulatory center located in the hypothalamus. The hypothalamus functions as the body's thermostat by maintaining the body core temperature within a narrow range around its set-point of 37 degrees Celsius. When the core temperature increases above or decreases below this set-point, the hypothalamus initiates a response to increase or decrease heat production or facilitate heat loss.

The anterior hypothalamus reacts to increases in body heat, while the posterior hypothalamus is responsible for regulating reactions to a cold environment (Åstrand, 1986). Therefore, when the anterior hypothalamus senses an increase in core temperature above the set-point, it stimulates the sweat glands resulting in increased evaporative cooling. In addition, normal vasoconstriction is inhibited and blood flow to the skin is promoted. Conversely, when the posterior hypothalamus senses a decrease in core temperature below the set-point, the vasomotor center causes the peripheral blood vessels to constrict and, if the core temperature drops significantly, shivering commences.

LITERATURE REVIEW

Numerous reviews on the subject of exercise thermoregulation have been written in the past two and a half decades. For additional information on this subject, the reader is referred to two of the more recent reviews, Gisolfi et al. (1984) and Buskirk (1977).

Before specifically addressing the areas of interest of this work, it is necessary to provide background information regarding the relationships of physiological variables such as skin and core temperature to effector responses.

Since body tissue temperatures differ based on local rates of heat production and heat exchange as well as heat transfer between locations in the body, definitions are necessary to specify these variations. This paper will only consider the differences between core and skin temperatures.

Deep-body, or core temperature, is usually measured at one of three locations; rectum, esophagus or the tympanic membrane. These estimates of core temperature are not wholly equivalent to each other, but have been shown to vary in parallel and are thus effective measures of relative changes (Åstrand, 1986).

Skin temperature can be determined by assigning weights to specific skin temperature measurements at various locations on the body in proportion to the fraction of the body's total surface area represented by that location. The most commonly used formula which was developed by Hardy and Dubois follows (Åstrand, 1986):

$$Ts = 0.07\ T_{head} + 0.14\ T_{arm} + 0.05\ T_{hand} + 0.07\ T_{ft} + 0.13\ T_{leg} + 0.19\ T_{th} + 0.35\ T_{tr}$$

It is generally accepted that skin temperature is dependent on the environmental temperature surrounding the skin and is relatively independent of exercise load. Conversely, the core temperature is independent of the ambient temperature and is largely dependent on the relative exercise load, as expressed as a percentage of maximum oxygen uptake, $VO_{2\ max}$ (Åstrand, 1986). For example, if two people perform the same absolute work load but have different maximum oxygen uptakes, the person with the lower $VO_{2\ max}$ will experience a greater rise in core temperature. However, if the same two people exercise at the same percentage $VO_{2\ max}$, their core temperatures should increase by approximately the same amount.

In contrast, sweat rate is more closely related to the absolute work load than to relative work load (Buskirk, 1977). Furthermore, body core temperature can be as much as ten times more influential on sweat rate than skin temperature (Wyndham, 1965). Wyss et al. (1974) supported this finding by concluding that sweat rate was virtually independent of steady state skin temperature and that body core temperature was the dominant factor in skin blood flow, heart rate and sweat rate determination. Additionally, Davis et al. (1976) concluded that skin temperature was independent of evaporative sweat loss and relative exercise load.

Effects of Heat Acclimatization and Physical Training

Adaptations to sweating are typically caused by both an exercise and a heat effect (Nadel et al., 1974). However, it has been shown that these adaptations occur via two different mechanisms. Physical training results in enhanced sweating at a given level of central drive. The increased metabolic rate during training increases thermoregulatory demand and induces an increased peripheral sensitivity of the sweat glands (Nadel et al., 1974). In other words, physical training increases the slope of the sweat rate versus core temperature relationship. Nadel et al. (1974) noted an increase of 67 percent in this slope as a result of ten consecutive days of one hour exercise at a relative exercise intensity of 70 to 80 percent VO_{2max}.

In contrast to physical training, heat acclimatization lowers the threshold core temperature at which sweating starts, increases sweating capacity, decreases skin temperature, and reduces the heart rate (Nadel et al., 1974; Fortney and Senay, 1979; Frye and Kamon, 1981; Horstman and Christensen, 1982). Nadel et al. (1974) noted a 0.3 degree Celsius decrease in the threshold core temperature, while Brooks et al. (1987) noted a three fold increase in sweating capacity from 1.5 to 4 kilograms per hour as a result of heat acclimatization.

According to Bass (1963), the acclimatization process begins on the first day of exposure and is well developed in 4 - 7 days. It can be induced by short intermittent periods of work or exercise in the heat, and is retained during periods of no exposure for about two weeks. Additionally, persons in good physical condition tend to acclimatize more rapidly than unfit subjects. However, physical training cannot replace heat acclimatization (Strydom et al., 1966; Gisolfi and Cohen, 1979). Training results in partial acclimatization that may improve heat tolerance by up to 50 percent (Gisolfi and Cohen, 1979), but training alone cannot substitute for exercise in the heat.

Figure 1 of Appendix A illustrates schematically the effects on sweat rate of both heat acclimatization and physical training discussed above.

Effect of Dehydration

As noted previously, athletes who exercise for prolonged periods can lose up to four liters of body fluids in the form of sweat and can experience a total weight loss of seven to eight percent of body weight during an endurance event such as a marathon (Lamb, 1984). Since the body contains only 40 liters of fluid, of which 5 liters are blood, loss of a large portion of this fluid results in a decrease in blood volume, cardiac output, and blood pressure. A loss of two to three liters of body fluids during exercise causes a reduction in sweating which results in an increase in core temperature (Nadel, 1979). The data of Greenleaf and Castle (1971) show that at a level of dehydration equivalent to loss of fluid equal to about five percent body weight, core temperature increases significantly due to inadequate sweating. Nadel (1979) further postulates that dehydration causes a reduction in the sensitivity of the sweat rate. In other words, dehydration decreases the slope of the sweat rate versus core temperature relationship. Please refer to Figure 2 in Appendix A for a schematic illustration of this effect.

Effects of Age and Gender

Although the experimental data are limited, the evidence in literature suggests that there are few differences in the thermoregulatory responses which can be ascribed to age and gender (Davies, 1979). Studies by Drinkwater et al. (1982) show that the functional capacity of the sweating mechanism in healthy older women does not decrease with age. Additionally, no differences were reported between the sexes with respect to sweat rate or efficiency in dry heat, but women maintained a higher sweating efficiency in humid heat (Frye and Kamon, 1983). This increased efficiency allows women to conserve body water while maintaining a similar core temperature to that of men. In other words, for the same degree of evaporative cooling, women secrete less wasteful sweat. When men and women of similar fitness levels are compared, the previously reported gender differences with respect to heat exposure disappear (Avellini et al., 1980). Furthermore, Horstman and Christensen (1982) concluded that active men and women compared at the same level of relative exercise intensity performed exercise equally well in dry heat.

PROGRAM MODIFICATIONS

As many individuals had modified various parts of the program over the past four years, the program contained inconsistencies. Therefore, to improve the program two types of modifications were made; organizational changes and functional changes. Organizational changes involve modifications that changed the order in which the program performed specific operations. Functional changes are modifications that improved specific functions of the program, i.e. the consistency of wording in the user input statements, or changes to specific calculations.

In addition to the organizational and functional changes, specific modifications were made to the program as a result of information found in the literature. Modifications were made to account for the following effects; physical training, acclimatization to heat, and dehydration. Additionally, a modification was made to correct the program for its premature prediction of the onset of dehydration. Please refer to the program listing in Appendix C for an updated version of the program.

Organizational Changes

Modifications which improve the flow and efficiency of the program are described below. Please refer to the flow diagram in Figure 3 of Appendix A for more detailed information regarding the general organization of the program.

(1) The main program was divided into four sections: (a) user input, (b) calculation of constants and initial values, (c) calculation of material and energy balances, (d) calls for subroutines to calculate fuel usage, print summary information, and plot data.

(2) The section which prints summary information was rewritten as a subroutine (PRINTAB).

(3) The order of the user input statement was improved. The program now asks the user to input information in the following order; personal physical characteristics, environmental conditions and activity information.

(4) All format statements were moved to the end of the program or subroutine to which they apply.

Functional Changes

In order to improve the consistency of the program and the manner in which certain calculations are performed, the following modifications were made:

(1) The number of variables and constants defined within the program was increased.

(2) The language of the variable and constant definitions was improved to maintain consistent use of language throughout the list. Units of the variable or constant were also included in the definition.

(3) Additional tests were added in the user input section to ensure valid information is entered.

(4) Screen stops were added for all output printed to the screen.

(5) The consistency of the language in the user input section was improved.

(6) All FORTRAN 'print' statements were changed to 'write' statements to facilitate future modifications to input/output formats.

(7) A question regarding the user's gender was added to the input section.

(8) A subroutine PLOTDATA was added to plot program results versus time. These results include: core temperature, heat loss, body weight, and skin temperature.

(9) Revised expressions were added to calculate basal metabolic rate (Olson, 1992). The expressions follow:

Female: BASAL (kcal/day) = 655.1 + 9.563 MKG + 1.850 HT - 4.676 AGE

Male: BASAL (kcal/day) = 66.5 + 13.75 MKG + 5.003 HT - 6.775 AGE

Correction for Premature Prediction of Dehydration

Several simulations of the program at various levels and durations of exercise indicated that the program prematurely predicted the onset of dehydration. This occurred because the sweat rate equations estimate a high amount of sensible water loss as run-off. It is postulated by Seagrave that high quantities of run-off are estimated because Nielsen's (1969) sweat rate measurements were taken after steady state temperatures had been achieved. However, the program uses these sweat rate estimations in an unsteady state capacity. According to Kerslake (1963), loss of sweat by dripping does not begin until the sweat rate has reached one-third of the maximum evaporative capacity. Therefore, to improve the program, it is necessary to determine the point at which sweat run-off commences.

The program was modified by adding a statement to calculate one-third maximum evaporative capacity, the point at which sweating begins. If the sweat rate has not reached this point, the program uses the rate of evaporative mass transfer as an estimation of the water loss. However, if the sweat rate has reached one-third maximum evaporative capacity, the program uses the water loss calculated by the WATERLOSS subroutine.

Effect of Heat Acclimatization

Before any modifications could be made to the program, the existing sweat rate equations in the WATERLOSS subroutine had to be modified. These equations had been extrapolated by Woodard from data given in Nielson (1969). These relationships expressed sweat rate as a function of skin temperature at given metabolic rates and skin temperatures. These relationships were modified to express sweat rate as function of body core temperature, rather than skin temperature. To make this modification, core temperature, skin temperature and sweat rate data were generated using the program. Subsequently, linear regressions were performed on the data to generate equations which expressed sweat rate as a function of body core temperature for given skin temperatures and metabolic rates. Please see Table 1 in Appendix B for the revised sweat rate equations.

To account for heat acclimatization, two modifications were made. First, if the athlete is both acclimatized to heat and physically trained, the maximum sweat rate (MAXSR) is set to 4.0 kilograms per hour and the set-point of the body core temperature is lowered by 0.3 degrees Celsius to 36.7 degrees. However, if the athlete is not acclimated to heat, the maximum sweat rate is set to 1.5 kilograms per hour and the body core temperature is set to the standard set-point of 37 degrees Celsius.

Effect of Physical Training

To modify the program for the effect of physical training on sweat rate, statements were added to section 2 of the main program to change the slope of the sweat rate equations that appear in subroutine WATERLOSS. If an athlete is trained, GAIN1 is set to 1.65, or the slope of the sweat rate equation is increased by 65%. However, if the athlete is not trained, there is no change to the slope of the sweat rate equation and GAIN1 is set equal to 1.0.

Effect of Dehydration

To account for the effect of dehydration, statements were added to adjust the slope of the sweat rate equations in the WATERLOSS subroutine as dehydration progresses. The gain constants were chosen somewhat arbitrarily due to the lack of specific numerical information provided in the literature. However, statements were added in section 3 of the main program to adjust the slope of the sweat rate equations in the following manner; when the body is less than one percent dehydrated, no change is made to the slope of the sweat rate equation or GAIN2 is set to 1.0. When total dehydration is between one and two percent, the slope of the sweat rate equation is decreased by five percent or GAIN2 is set to 0.95. For increasing percentages of dehydration, the slope is decreased in ten percent increments to a maximum level of dehydration of five percent of the total body weight. At this level of dehydration, the slope of the sweat rate equation has been decreased a total of 35 percent.

RECOMMENDATIONS FOR FUTURE WORK

In order to improve the program the following recommendations are provided as areas of future work:

(1) Modify the program to account for partial acclimatization to heat.

(2) Modify the program to account for the fact that women are less wasteful sweaters.

(3) Add sweat rate equations for metabolic rates greater than 1700 kilocalories per hour.

(4) Further quantify the effect of dehydration on sweat rate.

(5) Determine the effect of cold acclimatization on exercise thermoregulation.

(6) Quantify the effect of transverse wind velocity on the total velocity.

(7) Quantify maximum glucose usage foe all exercises included in the program

LITERATURE CITED

Åstrand, P. O., K. Rodahl, 1986. Temperature Regulation. Pages 585 - 635, *Textbook of Work Physiology*. McGraw Hill, New York.

Avellini, B. A., E. Kamon, and J. T. Krajewski, 1980. Physiological responses of physically fit men and women to acclimatization to heat, *J. Appl. Physiol.*, 49(2):254.

Bass, E. E., 1963. Thermoregulatory and circulatory adjustments during acclimatization to heat in man. Pages 299 - 305 in J. D. Hardy (ed.), *Temperature: Its Measurement and Control in Science and Industry*, vol. 3, part 3, Reinhold Book Corporation, New York.

Buskirk, E. R., 1977. Temperature regulation with exercise, in R. Terjung (ed.), *Exercise Sport Sci. Rev.*, 5:45.

Brooks, G. A., T. D. Fahey, 1987. Temperature and exercise. Pages 264 - 285, *Fundamentals of Human Performance*, Macmillian Pub. Co., New York.

Davies, C. T. M., 1979. Thermoregulation during exercise in relation to sex and age, *Eur. J. Appl. Physiol.*, 42:71.

Davies, C. T. M., J. R. Brotherhood, and E. Zeidifard, 1976. Temperature regulation during severe exercise with some observation on effects of skin wetting, *J. Appl. Physiol.*, 41(5):772.

Drinkwater, B. L., J. F. Bedi, A. B. Louks, S. Rouche, and S. M. Horvath, 1982. Sweating sensitivity and capacity of women in relation to age, *J. Appl. Physiol.*, 53(3):671.

Fortney, S. M. and L. C. Senay, 1979. Effect of training and heat acclimation on exercise responses of sedentary females, *J. Appl. Physiol.*, 47(5):978.

Frye, A. J. and E. Kamon, 1983. Sweating efficiency in acclimated men and women exercising in humid and dry heat, *J. Appl. Physiol.*, 54(4):972.

Frye, A. J. and E. Kamon, 1981. Responses to dry heat of men and women with similar aerobic capacities, *J. Appl. Physiol.*, 50:65.

Gisolfi, C. V. and J. S. Cohen, 1979. Relationships among training, heat acclimation, and heat tolerance in men and women: The controversy revisited, *Med. Sci. Sports,* **11**:56.

Gisolfi, C. V. and C. B. Wegner, 1984. Temperature regulation during exercise: Old concepts, new ideas, in R. Terjung (ed.), *Exercise Sport Sci. Rev.,* **12**:339.

Greenleaf, J. E. and B. L. Castle, 1971. Exercise temperature regulation in man during hypohydration and hyperhydration, *J. Appl. Physiol.,* **30**(6):847.

Horstman, D. H. and E. Christensen, 1982. Acclimatization to dry heat: Active men vs. active women, *J. Appl. Physiol.,* **52**(4):825.

Kerslake, D. Mck., 1963. Errors arising from the use of mean heat exchange coefficients in calculation of the heat exchanges of a cylindrical body in a transverse wind. Pages 183 - 190 in J. D. Hardy (ed.), *Temperature: Its Measurement and Control in Science and Industry,* vol. 3, part 3, Reinhold Book Corporation, New York.

Lamb, D. R., 1984. Temperature regulation during exercise. Pages 221 - 238, Physiology of Exercise, Macmillian Pub. Co., New York.

McArdle, W.D., F. I. Katch, V. L. Katch, Exercise and Thermal Stress, 1986. Pages 441 - 466, *Exercise Physiology: Energy Nutrition and Human Performance,* Lea and Febiger, Philadelphia, PA.

Nadel, E. R., 1979. Control of sweating rate while exercising in the heat, *Med. Sci. Sports,* **11**(1):31.

Nadel, E. R., K. B. Pandolf, M. F. Roberts, and J. A. Stolwijk, 1974. Mechanisms of thermal acclimation to exercise and heat, *J. Appl. Physiol.,* 37(4):545.

Nielsen, B., 1969. Thermoregulation in rest and exercise, *Acta Physiol. Scand.* (Suppl. 323).

Olson, C. E., 1992. Integration of human material and energy balance in life support system descriptions, AeroE 499 Project, Iowa State University, Ames, IA.

Strydom, N. B., C. H. Wyndham, C. G. Williams, J. F. Morrison, G. A. G. Bredell, A. J. S. Benade, and M. von Rahden, 1966. Acclimatization to humid heat and the role of physical conditioning, *J. Appl. Physiol.,* **21**:636.

Woodard, L. K., 1988. Model of the human body during exercise, ChE 490 Project, Iowa State University, Ames, IA.

Wyndham, C. H., 1965. Role of skin and core temperature in man's temperature regulation, *J. Appl. Physiol.*, 20(1):31.

Wyss, C. R., G. L. Brengelmann, J. M. Johnson, L. B. Rowell, and M. Niederberger, 1974. Control of skin blood flow sweating, and heart rate: Role of skin vs. core temperature, *J. Appl. Physiol.*, 36(6):726.

ACKNOWLEDGMENTS

I would like to thank Dr. Richard C. Seagrave for his assistance and thought provoking advice during the period of this work. I would also like to thank Dr. Dean L. Ulrichson and Dr. Paula C. Morrow for serving on my committee.

Additionally, I would like to thank the NASA Advanced Life Support Division and Honeywell Foundation for the financial support provided throughout the duration of my graduate study at Iowa State University.

APPENDIX A:

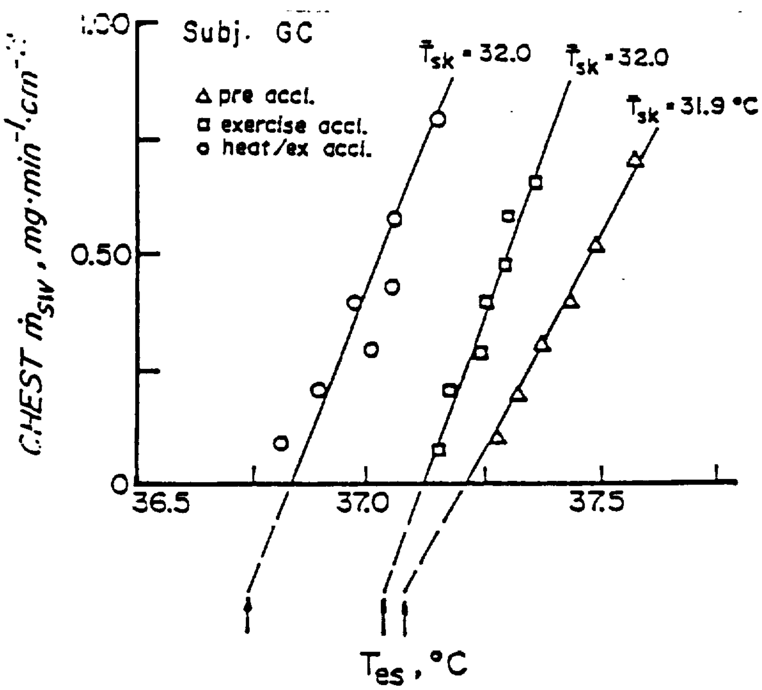


Figure 1: Chest sweating rate as a function of esophageal temperature prior to acclimatization, following 10 days of physical training and following 10 day of heat acclimatization. (Taken from Nadel, 1974)

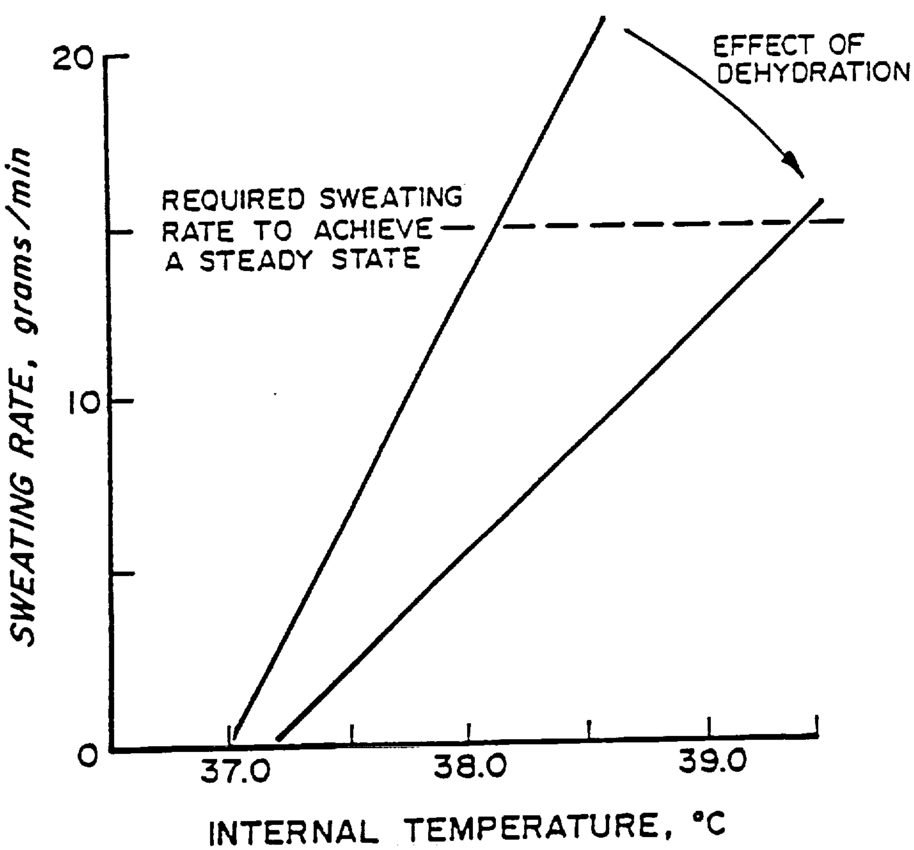


Figure 2: A schematic representation of one possible effect of dehydration on the sweating rate as a function of internal temperature. (Taken from Nadel, 1979)

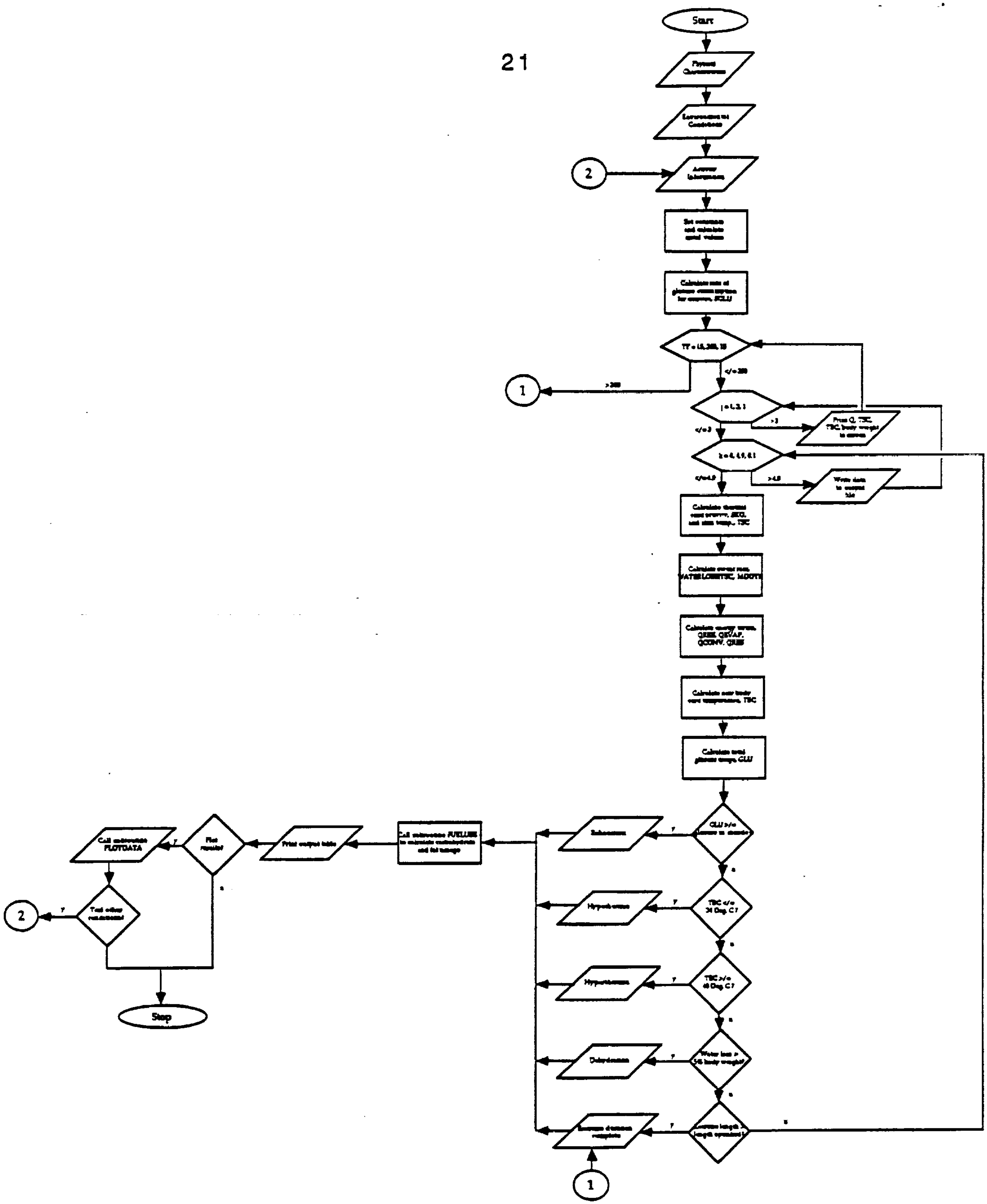


Figure 3: Flow Diagram of a *Model of the Human Body During Exercise*

APPENDIX B:

Table 1: Revised Sweat Rate Equations

Metabolic Rate (kcal/hour)	TSC Constraint(s) (Deg. C)	Regression Equation:
Less than 300	None	DSWEAT = 0.046122 TBC - 1.16399
301 - 500	</= 33.0	DSWEAT = 0.063091 TBC - 1.53415
	> 33.0	DSWEAT = 0.295611 TBC - 9.53531
501 - 700	</= 33.4	DSWEAT = 0.091916 TBC - 2.21063
	> 33.4	DSWEAT = 0.512109 TBC - 16.9846
701 - 900	</= 32.0	DSWEAT = 0.223172 TBC - 6.03852
	> 32.0	DSWEAT = 0.390976 TBC - 11.8576
901 - 1100	None	DSWEAT = 0.256577 TBC - 5.75055
1101 - 1300	</= 29.0	DSWEAT = 0.439115 TBC - 12.3871
	> 29.0	DSWEAT = 0.314289 TBC - 8.09200
1301 - 1500	</= 28.6	DSWEAT = 0.699080 TBC - 21.2381
	> 28.6	DSWEAT = 0.227225 TBC - 4.99327
1501 - 1700	None	DSWEAT = 0.053090 TBC + 1.639657

APPENDIX C: PROGRAM LISTING

```
********************************************************************************
*                                                                              *
*                  MODEL OF THE HUMAN BODY AND EXERCISE                        *
*                                                                              *
********************************************************************************

      REAL Y,N,WTLBS,MKG,TIC,WMPH,WMETPS,BASAL,GAIN1,GAIN2
      REAL RHUM,MDOT,VMPH,VMETPS,VELTOT,TBC,HV,PA,YA,AIRMOL
      REAL VAIRL,VOMAX,MILE,IPVO,PVO,SGLU,TSC,DSWEAT,PS,SWEAT,DTB
      REAL TSWEAT,DGLU,GLU,QRES,QEVAP,QCONV,QRAD,QTOT,CB,AC,HC,CA
      REAL KG,AV,AR,HR,TIF,VOL,LRA,CLO,K,YARRAY(40),WATERLOSS
      REAL CHFRAC,LFRAC,CHEQ,LIPEQ,TOTCAL,CHCAL,LIPCAL,CALEQ
      REAL LIPUSED,CHUSED,BCM,BCMB,QUAD,HAM,BICEP,TRICEP,CALF
      REAL HTVAP,EMAX,DRIP,MAXSR,TS

      CHARACTER ANS*4,C*1,WW*3,GENDER*1,ICASE*1
      CHARACTER NAME*50,EXDESC*50,CLOTHES*50,BOXANS*15,FRAME*15

      INTEGER TT,NUMDAT,ICLO,CHOICE,I,XARRAY(40)
      INTEGER AGE,FT,IN,MIN,SEC,TTMAX,ACTLEV,ACCLEV

      COMMON NAME,FT,IN,WTLBS,AGE,CLOTHES,MIN,SEC,ACTLEV,EXDESC
      COMMON MDOT,VOL,VMPH,TIF,RHUM,WMPH,TS,CBW,CBT,FTSC,TOTCAL
      COMMON CHCAL,LIPCAL,CHUSED,LIPUSED,TIME

      write(*,2) 'This program is designed to inform well trained'
      write(*,*) 'and novice athletes how long they may exercise at'
      write(*,*) 'a certain level before one of the following'
      write(*,*) 'conditons occur:'
      write(*,1)
      write(*,3) 'a) hyperthermia:  estimated core temperature'
      write(*,3) '   surpasses 40 Deg. C (104 Deg. F)'
      write(*,3) 'b) dehydration:  loss of body water exceeds 5%'
      write(*,3) '   of body weight'
      write(*,3) 'c) estimated muscle glycogen supply exceeded'
      write(*,3) 'd) hypothermia:  estimated core temperature'
      write(*,3) '   drops below 34 Deg. C (92 Deg. F)'
      write(*,1)

********************************************************************************
*                                                                              *
*                  PROGRAM VARIABLES/CONSTANTS                                 *
*                                                                              *
*     VARIABLE/CONSTANT              DESCRIPTION                               *
*                                                                              *
*     AC            Body area available for convection (94% total body         *
*                   area, m^2)                                                 *
*     ACCLEV        Level of acclimatization of user (heat, cold,              *
*                   unacclimatized)                                            *
*     ACTLEV        Activity level of user (trained/untrained)                 *
*     AGE           Age of the athlete (years)                                 *
```

```
*    AIRMOL    Air intake conversion (mol/hr)                              *
*    ANS       Answer to question (yes/no)                                 *
*    AR        Body area available for radiation (78% total body           *
*              area, m^2)                                                  *
*    AV        Body area available for evaporation (15% total body         *
*              area, m^2)                                                  *
*    BASAL     Basal metabolic rate (kcal/min)                             *
*    BCM       Volume of body (m^3)                                        *
*    BCMB      Volume of body taking into account body build (m^3)         *
*    HAM       Glycogen content in hamstrings (mmol)                       *
*    BICEP     Glycogen content in bicep (mmol)                            *
*    BSA       Surface area of body as a function of athlete               *
*              height and mass (m^2)                                       *
*    CA        Heat capacity of air (kcal/gmole*Deg. C)                    *
*    CALF      Glycogen content in calf (mmol)                             *
*    CB        Heat capacity of the body (kcal/kg*Deg. C)                  *
*    CBT       Current body temperature (Deg. F)                           *
*    CBW       Current body weight (lbs)                                   *
*    CLO       Clothing correction factor                                  *
*    CU        Carbohydrates used by muscle (grams)                        *
*    DGLU      Glucose used initially (grams)                              *
*    DRIP      One-third maximum evaporative capacity (kcal/min)           *
*    DSWEAT    Sweat rate as a function of skin temperature (kg/hr)        *
*    DTB       Body temperature change (Deg. C/6 sec)                      *
*    EMAX      Maximum evaporative capacity (kcal/6 sec)                   *
*    EXDESC    Type of exercise                                            *
*    FRAME     Body frame size of user (small/medium/large)                *
*    FT        Height of user (inches)                                     *
*    FTSC      Skin temperature (Deg. F)                                   *
*    GAIN1     Gain constant used in modifying sweat rate based on         *
*              level of training                                           *
*    GAIN2     Gain constant used in modifying sweat rate based on         *
*              level of dehydration                                        *
*    GENDER    Gender of the user (male/female)                            *
*    GLU       Glucose used (grams/6 sec)                                  *
*    HC        Convective heat transfer coef. (kcal/(m^2*hr*C))            *
*    HR        Radiative heat transfer coef. (kcal/(m^2*hr*C)              *
*    HD        Difference between heat generated and heat lost             *
*    HT        Height of user (cm)                                         *
*    HV        Heat transfer coefficient for vaporization                  *
*              (kcal/(m^2*hr*mmHg))                                        *
*    HVAP      Heat of vaporization of water @ 37 Deg. C (kcal/mol)        *
*    ICLO      Input indication of user clothing factor                    *
*    IOPTION   Program calculation option                                  *
*    KG        Mass transfer coefficient for evaporation of water          *
*              (kg/(hr*mmHg*m^2))                                          *
*    MAXSR     Maximum sweat rate depending on level of                    *
*              acclimatization (kg/hr)                                     *
*    MDOT      Metabolic energy rate (kcal/hr)                             *
*    MILE      Time of mile (min)                                          *
*    MIN       Time of mile (min)                                          *
```

```
*       MKG        Athlete's mass (kg)                                        *
*       N          No, answer to question                                     *
*       NAME       Name of program user                                       *
*       NUMDAT     Counter used to determine number of data points sent       *
*                  to output file                                             *
*       PA         Vapor pressure of water at ambient temperature             *
*                  using the Antoine equation (mmHg)                          *
*       PS         Vapor pressure of water at skin temperature                *
*                  using the Antoine equation (mmHg)                          *
*       PVO        Percent maximum oxygen capacity required for a             *
*                  certain level of exercise (%)                              *
*       QCONV      Heat transfer by convection (kcal/min)                     *
*       QEVAP      Heat transfer by evaporation (kcal/min)                    *
*       QRAD       Heat transfer by radiation (kcal/min)                      *
*       QRES       Energy lost in respiration (kcal/min)                      *
*       QTOT       Total heat transfer (kcal/min)                             *
*       QUAD       Glycogen content in quad (mmol)                            *
*       RHUM       Relative humidity                                          *
*       SEC        Time of mile (s)                                           *
*       SGLU       Rate of glucose consumption at a certain level             *
*                  of exercise (mmol/kg*min)                                  *
*       SKO        Thermal conductivity of skin at given body core            *
*                  temperature (kcal/(m*min*Deg. C))                          *
*       SWEAT      DSWEAT conversion (kg/6 sec)                               *
*       TBC        Body core temperature (Deg. C)                             *
*       TIC        Initial ambient temperature (Deg. C)                       *
*       TIF        Initial ambient temperature (Deg. F)                       *
*       TRICEP     Glycogen content in tricep (mmol)                          *
*       TSC        Relation for body skin temperature                         *
*       TSWEAT     Added water loss (kg)                                      *
*       TT         Time counter (min)                                         *
*       VAIRL      Rate of air intake for a particular exercise               *
*                  wrt MDOT (l/min)                                           *
*       VMETPS     Velocity created by the athlete (m/s)                      *
*       VMPH       Velocity created by the athlete (miles/hr)                 *
*       VELTOT     Total net velocity of the wind (created by the             *
*                  athlete and the environmental conditions)                  *
*       VOL        Required oxygen consumption for a particular               *
*                  exercise                                                   *
*       VOMAX      Variable for maximum oxygen capacity of a particular       *
*                  athlete                                                    *
*       WMETPS     Wind velocity (m/s)                                        *
*       WMPH       Wind velocity (miles/hr)                                   *
*       WTLBS      Athlete's weight (lbs)                                     *
*       WW         Response to wind direction question                        *
*       Y          Yes, answer to question                                    *
*       YA         Mole fraction of water in air                              *
*       Z          Rate of mass transfer by evaporation (kg/hr)               *
*                                                                             *
*******************************************************************************
```

```
*****************************************************************************
*                                                                           *
*       SECTION 1: This section asks the user to input their physical       *
*       characteristics, environmental conditions, and the desired type of  *
*       exercise.                                                           *
*                                                                           *
*****************************************************************************

C       -- Enter physical characteristics

        write(*,2) 'Please enter your name (50 character max): >'
        read(*,4) NAME

        write(*,2) 'Gender is used in calculating basal metabolic rate.'
        write(*,1)
9       write(*,*) 'If you are a female, please enter F;'
        write(*,*) 'if you are a male, please enter M: >'
        read (*,4) GENDER

        if ((GENDER .NE. 'F') .AND. (GENDER .NE. 'M')
   +    .AND. (GENDER .NE. 'f') .AND. (GENDER .NE. 'm')) then
          write(*,5)
         GOTO 9
        end if

10      write(*,2) 'This program is designed for athletes between'
        write(*,*) 'the ages of 18 and 75.'
        write(*,1)
        write(*,*) 'Please enter your age in years: >'
        read(*,*) AGE

        if ((AGE .LT. 18) .OR. (AGE .GT. 75)) then
          write(*,5)
         GOTO 10
        end if

11      write(*,2) 'Please enter your height (feet,inches): >'
        read(*,*) FT,IN

        if ((FT .LT. 0). OR. (IN .LT. 0) .OR. (IN .GT. 12)
   +    .OR. FT .GT. 7) then
          write(*,5)
         GOTO 11
        end if

12      write(*,2)'Please enter your body weight (60 - 300 lbs): >'
        read(*,*) WTLBS

        if ((WTLBS .LT. 60) .OR. (WTLBS .GT. 300)) then
          write(*,5)
```

```
      GOTO 12
     end if

13   write(*,2) 'Please enter your approximate muscular build:  >'
     write(*,*) '(small, medium, large)'
     read(*,4) FRAME

     if ((FRAME .NE. 'small') .AND. (FRAME .NE. 'large')
  +  .AND. (FRAME .NE. 'medium')) then
       write(*,5)
      GOTO 13
     end if

14   write(*,2) 'Enter the number which best corresponds to your'
     write(*,*) 'clothing (in addition to your shoes):  >'
     write(*,1)
     write(*,*) 'Shorts only, enter 1.'
     write(*,*) 'Shorts and short-sleeve shirt or singlet, enter 2.'
     write(*,*) 'Shorts and long-sleeve shirt, enter 3.'
     write(*,*) 'Legs covered and long-sleeve shirt, enter 4.'
     write(*,*) 'Legs, arms, hands, and head all covered, enter 5.'
     read(*,*) ICLO

     if (ICLO .NE. 1 .AND. ICLO .NE. 2 .AND. ICLO .NE. 3
  +  .AND. ICLO .NE. 4 .AND. ICLO .NE. 5) then
       write(*,5)
      GOTO 14
     end if

C    -- Environmental conditions

15   write(*,2) 'Please enter the air temperature (-40 to 120 Deg. F):  >'
     read(*,*) TIF

     if ((TIF .LT. -40.0) .OR. (TIF .GT. 120)) then
       write(*,5)
      GOTO 15
     end if

16   write(*,2) 'Please enter wind velocity (0 - 50 miles/hr):  >'
     read(*,*) WMPH

     if ((WMPH .GT. 50.0) .OR. (WMPH .LT. 0.0)) then
       write(*,5)
      GOTO 16
     end if

     if (WMPH .EQ. 0.0) then
      WMPH = WMPH + 1.0              ! Add 1 mph to account for free convection
      GOTO 17
     end if
```

```
25      write(*,1) 'On the average, is the wind opposing you (A) or'
        write(*,*) 'following you (F), or neither (N)?'
        write(*,*) 'Please enter either A, F, or N:  >'
        read(*,4)  WW

        if ((WW .NE. 'A') .AND. (WW .NE. 'a') .AND.
     +   (WW .NE. 'F') .AND. (WW .NE. 'f') .AND. (WW .NE. 'N') .AND. (WW .NE. 'n')) then
          write(*,5)
         GOTO 25
        end if

17      write(*,2) 'Please enter the relative humidity as a decimal:  >'
        read(*,*)  RHUM

        if ((RHUM .LT. 0.0) .OR. (RHUM .GT. 1.0)) then
          write(*,5)
         GOTO 17
        end if

C       -- Enter activity information (duration,level,type)

18      write(*,2) 'Would you like the program to:'
        write(*,3) '(1) recommend a duration of exercise?'
        write(*,3) '(2) allow you to choose a duration of exercise?'
        write(*,1)
        write(*,*) 'Please enter 1 or 2:  >'
        read(*,*)  IOPTION

        if (IOPTION .NE. 1 .AND. IOPTION .NE. 2) then
          write(*,5)
         GOTO 18
        end if

        if (IOPTION .EQ. 1) then
         TTMAX = 300
        else
19        write(*,2) 'Please enter the duration of exercise (1 - 300 min):  >'
          read(*,*) TTMAX
             if ((TTMAX .LE. 0) .OR. (TTMAX .GT. 300)) then
               write(*,5)
               GOTO 19
             end if
        end if

        if (TT .GT. 15) then                ! Bypass activity information that
         GOTO 41                            ! does not change during subsequent
        end if                              ! tests of exercise conditions.

C       -- The user's time for the mile run provides information about
C       maximal oxygen capacity and therefore maximal level of exercise
```

```
20      write(*,2) 'Do you know your best recent time for the mile?'
        write(*,*) 'If YES, please enter Y; if NO, please enter N:  >'
        read(*,4)  ANS

        if ((ANS .NE. 'Y') .AND. (ANS .NE. 'N') .AND. (ANS .NE. 'y')
     +  .AND. (ANS .NE. 'n')) then
          write(*,5)
         GOTO 20
        end if

        if ((ANS .EQ. 'Y') .OR. (ANS .EQ. 'y')) then
21        write(*,2) 'Please enter your time for the mile (min,sec):  >'
          read(*,*) MIN,SEC
           if ((MIN .LT. 4) .OR. (MIN .GT. 20) .OR. (SEC .GT. 60) .OR. (SEC .LT. 0)) then
             write(*,5)
             GOTO 21
          end if
        else
         MIN = 0
         SEC = 0
        end if

30      write(*,2) 'If best time for the mile is unknown, then maximum'
        write(*,*) 'oxygen capacity is based on age and activity level.'

39      write(*,2) 'Please select your normal level of activity:'
        write(*,3) '1) Active (well trained in distance sports)'
        write(*,3) '2) Inactive (no continuous training)'
        write(*,1)
        write(*,*) 'Please enter 1 or 2:  >'
        read(*,*)  ACTLEV

        if ((ACTLEV .NE. 1) .AND. (ACTLEV .NE. 2)) then
          write(*,5)
         GOTO 39
        end if

40      write(*,2) 'Please select level of acclimatization:'
        write(*,3) '1) Not acclimated to heat of cold'
        write(*,3) '2) Heat acclimated:'
        write(*,3) '   7-10 days training, 2-4 hrs/day, > 95 Deg. F
        write(*,3) '3) Cold acclimated'
        write(*,3) '   '
        write(*,1)
        write(*,*) 'Please enter 1, 2, or 3:  >'
        read(*,*)  ACCLEV

        if ((ACCLEV .NE. 1) .AND. (ACCLEV .NE. 2) .AND. ACCLEV .NE. 3) then
         write(*,5)
        GOTO 40
```

```
      end if

41    write(*,2) 'Please choose a type of exercise from the
     + list below:'
      write(*,1)
      write(*,*) 'Walking, running, cycling, skiing, basketball'
      write(*,*) 'boxing, soccer, rowing, tennis, circuit training,'
      write(*,*) 'field hockey, football, squash, or aerobics.'
      read(*,4) EXDESC

      if ((EXDESC .NE. 'running') .AND.
     + (EXDESC .NE. 'walking') .AND.
     + (EXDESC .NE. 'cycling') .AND.
     + (EXDESC .NE. 'skiing') .AND.
     + (EXDESC .NE. 'basketball') .AND.
     + (EXDESC .NE. 'boxing') .AND.
     + (EXDESC .NE. 'soccer') .AND.
     + (EXDESC .NE. 'rowing') .AND.
     + (EXDESC .NE. 'tennis') .AND.
     + (EXDESC .NE. 'circuit training') .AND.
     + (EXDESC .NE. 'field hockey') .AND.
     + (EXDESC .NE. 'football') .AND.
     + (EXDESC .NE. 'squash') .AND.
     + (EXDESC .NE. 'aerobics')) then
        write(*,5)
        GOTO 41
      end if

      if ((EXDESC .EQ. 'walking') .OR. (EXDESC .EQ. 'running')) then
42      write(*,2) 'Please enter your speed (1 - 16 miles/hr): >'
        read(*,*) VMPH
         if ((VMPH .LE. 0.0) .OR. (VMPH .GT. 16.0)) then
              write(*,5)
              GOTO 42
        end if
      else if (EXDESC .EQ. 'cycling') then
43      write(*,2) 'Please enter your speed (7 - 25 miles/hr): >'
        read(*,*) VMPH
         if ((VMPH .LT. 7.0) .OR. (VMPH .GT. 25.0)) then
              write(*,5)
              GOTO 43
        end if
      else if (EXDESC .EQ. 'skiing') then
44      write(*,2) 'Please enter your speed (2.5 - 8.8 miles/hr): >'
        read(*,*) VMPH
         if ((VMPH .LT. 2.5) .OR. (VMPH .GT. 8.8)) then
              write(*,5)
              GOTO 44
        end if
      else if (EXDESC .EQ. 'boxing') then
45      write(*,2) 'In a ring (ring) or sparring (spar)? >'
```

```
      read(*,4) BOXANS
        if ((BOXANS .NE. 'ring') .AND. (BOXANS .NE. 'spar')) then
             write(*,5)
             GOTO 45
        end if
      end if

************************************************************************************
*                                                                                  *
*       SECTION 2: This section defines/calculates constants and initial           *
*       values based on user input.                                                *
*                                                                                  *
************************************************************************************

      CA = 0.006949
      CB = 0.86
      GLU = 0.0
      HVAP = 10.39
      NUMDAT = 0
      TSWEAT = 0.0

C     — Calculate total height (cm); convert weight to kg, temperature
C     to Deg. C, wind velocity to m/s, and velocity created by user to m/s.

      HT = (12*FT + IN)*2.54
      MKG = WTLBS * 0.4536
      TIC = (TIF - 32.0)/1.8
      WMETPS = 0.447 * WMPH
      VMETPS = 0.447 * VMPH

C     — Calculate surface area of body used on various mechanisms of
C     heat transfer as a percentage of body surface area

      BSA = 0.00718 * (MKG**0.425) * (HT**0.725)
      AC = 0.94*BSA
      AR = 0.78*BSA
      AV = 0.15*BSA

      PA = PSAT(TIC)
      YA = RHUM * PA / 760.0
      PSI = PSAT(40)

C     — Calculate basal metabolism (kcal/day) based on gender,
C     age, weight, and height

      if ((GENDER .EQ. 'F') .OR. (GENDER .EQ. 'f')) then
       BASAL = 655.1 + 9.563*MKG + 1.850*HT - 4.676*AGE
      else if ((GENDER .EQ. 'M') .OR. (GENDER .EQ. 'm')) then
       BASAL = 66.5 + 13.75*MKG + 5.003*HT - 6.775*AGE
      end if
```

```
      BASAL = BASAL/(24.0 * 60.0)          ! Change units to kcal/min

C     — Initial values for energy loss terms based on basal metabolism

      QRES = 0.1*BASAL
      QRAD = 0.6*BASAL
      QEVAP = 0.1*BASAL
      QCONV = 0.2*BASAL

C     — Calculate initial skin temperature based on environmental
C     temperature and body core temperature

      TSCO = TBC - (TBC - TIC)/2.0

C     — Determine volume of the body in cubic meters taking body build
C     into account

      BCM = WTLBS * 0.07 / 154.0

      if (FRAME .EQ. 'small') then
       BCMB = BCM * 0.75
      else if (FRAME .EQ. 'medium') then
       BCMB = BCM * 1.00
      else if (FRAME .EQ. 'large') then
       BCMB = BCM * 1.25
      end if

C     — Determine clothing factor

      if (ICLO.EQ.1) then
       CLOTHES = 'Shorts only'
       CLO = 1.0
      else if (ICLO.EQ.2) then
       CLOTHES = 'Shorts and short-sleeve shirt or singlet'
       CLO = 0.70
      else if (ICLO.EQ.3) then
       CLOTHES = 'Shorts and long-sleeve shirt'
       CLO = 0.55
      else if (ICLO.EQ.4) then
       CLOTHES = 'Legs covered and long-sleeve shirt'
       CLO = 0.30
      else if (ICLO.EQ.5) then
       CLOTHES = 'Legs, arms, hands, and head all covered'
       CLO = 0.25
      end if

C     — Set gain in sweat rate equation based on level of training

      if (ACTLEV .EQ. 1) then
       GAIN1 = 1.65
      else
```

```
      GAIN1 = 1.0
      end if

C     — Define initial body core temperature (deg. C) and maximum sweat
C     rate (kg/hr) based on level of acclimatization

      if ((ACCLEV .EQ. 2) .AND. (ACTLEV .EQ. 1)) then
       MAXSR = 4.0
       TBC = 36.7
      else
       MAXSR = 1.5
       TBC = 37.0
      end if

C     — Calculate glycogen content in muscles in mmoles using typical
C     values for muscle distribution in the body and glycogen density
C     in the muscles.

      QUAD = (0.7 * 0.665 * 0.1101 * BCMB * 17750 * 5.5)
      HAM = (0.3 * 0.665 * 0.1101 * BCMB * 17750 * 5.5)
      BICEP = (0.5 * 0.0241 * 0.70 * BCMB * 17750 * 5.5)
      TRICEP = (0.5 * 0.70 * 0.0241 * BCMB * 17750 * 5.5)
      CALF = (0.046 * 0.55 * 0.6 * BCMB * 17750 * 5.5)

C     — Calculate metabolic rate for the type of exercise selected

      if ((EXDESC .EQ. 'walking') .OR. (EXDESC .EQ. 'running')) then
       if ((VMPH .GT. 0.0) .AND. (VMPH .LT. 2.0)) then
             MDOT = 125.0
       else if ((VMPH .GE. 2.0) .AND. (VMPH .LT. 3.0)) then
             MDOT = 151.0 + (VMPH - 2.0) * 82.0
       else if ((VMPH .GE. 3.0) .AND. (VMPH .LT. 4.0)) then
             MDOT = 233.0 + (VMPH - 3.0) * 133.0
       else if ((VMPH .GE. 4.0) .AND. (VMPH .LT. 5.0)) then
             MDOT = 366.0 + (VMPH - 4.0) * 210.0
       else if ((VMPH .GE. 5.0) .AND. (VMPH .LT. 6.0)) then
             MDOT = 576.0 + (VMPH - 5.0) * 46.0
       else if ((VMPH .GE. 6.0) .AND. (VMPH .LT. 8.0)) then
             MDOT = 622.0 + (VMPH - 6.0) * 43.5
       else if ((VMPH .GE. 8.0) .AND. (VMPH .LT. 10.0)) then
             MDOT = 709.0 + (VMPH - 8.0) * 172.5
       else if ((VMPH .GE. 10.0) .AND. (VMPH .LT. 12.0)) then
      end if

      MDOT = MDOT * WTLBS/154.0

      if (WMPH .EQ. 1.0) then
       VELTOT = VMETPS
      end if

      if ((WW .EQ. 'A') .OR. (WW .EQ. 'a')) then
```

```
          VELTOT = VMETPS + WMETPS
         else if ((WW .EQ. 'F') .OR. (WW .EQ. 'f')) then
          VELTOT = ABS(VMETPS - WMETPS)
         else if ((WW .EQ. 'N') .OR. (WW .EQ. 'n')) then
          VELTOT = VMETPS
         end if

C        —Calculate heat transfer coefficients for various mechanisms of
C        heat transfer based on the clothing factor and velocity

         HC = CLO*6.4*VELTOT**0.67
         HR = 4.3*CLO
         HV = 11.9*CLO*VELTOT**0.6
         KG = 0.0206332 * CLO*VELTOT**0.6

C        — Calculate rate of air intake (mole/hr), and rate of
C        oxygen required for exercise (l/min)


         VAIRL = 0.0264 * MDOT - 0.714
         AIRMOL = VAIRL * 60.0 / (0.08206 * (TIC + 273.15))
         VOL = 0.002768 * MDOT - 0.07164

C        — Calculate maximal oxygen capacity for users who do not know their
C        best recent time for the mile run. Calculation is based on user's
C        activity, age, and weight.

         if ((ANS .EQ. 'N') .OR. (ANS .EQ. 'n') .AND. ACTLEV .EQ. 1) then
          VOMAX = (59.943 - 0.346*AGE) * MKG/1000.0
         else if ((ANS .EQ. 'N') .OR. (ANS .EQ. 'n') .AND. ACTLEV .EQ. 2) then
          VOMAX = (103.43 - 1.257*AGE) * MKG/1000.0
         end if

         MILE = MIN + SEC/60.0
         VOMAX = (1608.0 + 30.0*MILE)/(5.0*(MILE + 1.0))*MKG/1000.0

C        — Calculate percent maximum oxygen capacity required for
C        level of exercise selected

         PVO = VOL / VOMAX * 100.0
         IPVO = PVO
         write(*,7) 'You are exercising at ',IPVO,' % of your capacity.'
         write(*,98)

C        — Calculate rate of glucose or carbohydrate consumption
C        at level of exercise selected

         SGLU = 0.005827*PVO+0.00004545*(PVO**2)+0.000001667*(PVO**3)

         if (ACTLEV .EQ. 1) SGLU = 0.75*SGLU
```

```
*******************************************************************************
*                                                                             *
*     SECTION 3: This section calculates change in body temperature,          *
*     weight loss, and carbohydrate usage with time. Data are written         *
*     to data files every 5 minutes and printed to the screen every 15        *
*     minutes.                                                                *
*                                                                             *
*******************************************************************************

      DO 150 TT = 15,300,15
       DO 111 j = 1,3
        DO 110 k = 0,4.9,0.1
            if (TT .EQ. 15 .AND. j .EQ. 1 .AND. k .EQ. 0) then
              TSC = TSCO
              TTSC = TSCO
            end if

C     — Calculate thermal conductivity as function of body temperature
C     to account for vasoconstriction (TBC < 37 Deg. C) or vasodilation
C     (TBC > 37 Deg. C)

            if (TBC .LT. 37.0) then
              SKO = 0.5*(1.0 - (37.0 - TBC)/6.0)
            else
              SKO = 0.5*(1.0 + (TBC - 37.0)/3.0)
            end if

C     — Calculate new skin temperatures

            TNSC = TBC - ((QRES + QEVAP + QCONV + QRAD)/10.0)/(1.8*SKO)

C     — Average last three skin temperatures

            TSC = (TSC + TTSC + TNSC)/3.0
            TTSC = TNSC

            TICL = TIC + 1.0
            TBCL = TBC - 0.5

C     — Skin temperature cannot be < 1 Deg. C more than
C     environmental temperature

            if (TSC .LT. TICL) TSC = TICL

C     — Skin temperature cannot be > 1/2 Deg. C less than body
C     core temperature

            if (TSC .GT. TBCL) TSC = TBCL

            PS = PSAT(TSC)
```

```
C       — Calculate rate of evaporative mass transfer

              Z = KG*AV*(PS - RHUM*PA)

C       — If core temperature < 37 Deg. C water loss is determined
C       by the rate of evaporation

              if (TBC .LT. 37.0) DSWEAT = Z

C       — Determine level of dehydration to modify slope of DWEAT vs. TBC
C       relationship used in determining sweat rate.  The gains
C       defined with respect to a given level of dehydration are NOT
C       specifically provided in literature, but have been arbitrarily
C       estimated using a hypothesized trend.

         if (TSWEAT .LT. 0.01*MKG) then
          GAIN2 = 1.0
         else if ((TSWEAT .GE. 0.01*MKG).AND.(TSWEAT .LT. 0.02*MKG)) then
          GAIN2 = 0.95
         else if ((TSWEAT .GE. 0.02*MKG).AND.(TSWEAT .LT. 0.03*MKG)) then
          GAIN2 = 0.85
         else if ((TSWEAT .GE. 0.03*MKG).AND.(TSWEAT .LT. 0.04*MKG)) then
          GAIN2 = 0.75
         else if ((TSWEAT .GE. 0.04*MKG).AND.(TSWEAT .LT. 0.05*MKG)) then
          GAIN2 = 0.65
         end if

C       — Call subroutine to calculate sweat rate (water loss rate)

         DSWEAT = WATERLOSS(TSC,TBC,MDOT,GAIN1,GAIN2)

         if (DSWEAT .GT. MAXSR) DSWEAT = MAXSR
         SWEAT = DSWEAT / 600.0            !Convert rate to kg/6 sec

C       — Calculate energy lost through respiration, evaporation,
C       convection and radiation

         PEXP = PSAT(TBC)
         YEXP = PEXP/760.0

         QRES = AIRMOL*(CA*(TBC - TIC) + HVAP*(YEXP - YA))/60.0
         QEVAP = HV*AV*(PS - RHUM*PA)/60.0
         QCONV = HC*AC*(TSC - TIC)/60.0
         QRAD = HR*AR*(TSC - TIC)/60.0
         QTOT = QRES + QEVAP + QCONV + QRAD - MDOT/60.0

         EMAX = QEVAP*0.1                  ! Convert rate to kcal/6 sec
         DRIP = EMAX/3.0                   ! Determine point at which run-off occurs
                                           ! (1/3 max evaporative capacity)

C       — Calculate body temperature change in 6 seconds by using
```

```
C       dividing new rate of heat loss and new body weight

          DTB = -(QTOT/10.0)/((MKG - TSWEAT)*CB)

C       -- Calculate new body core temperature

          TBC = TBC + DTB

C       -- Add water loss in current period to the previous water loss.
C       If the sweat rate is greater than or equal to 1/3 maximum evaporative
C       capacity then loss of sweat can occur by dripping. If the sweat rate
C       is less than 1/3 EMAX then loss of water occurs by evaporation.

        if (SWEAT .GE. DRIP) then
          TSWEAT = TSWEAT + SWEAT
        else
          TSWEAT = TSWEAT + Z/600.0
        end if

        if (j .eq. 1) then                    ! Time counter used in output
          TS = k+(TT-15.0)
        else if (j .eq. 2) then
          TS = (5.0 + k)+(TT-15.0)
        else if (j .eq. 3) then
          TS = (10.0 + k)+(TT-15.0)
        end if

C       -- Calculate the amount of glucose used in period

          DGLU = SGLU * 1.030 /10.0

C       -- Calculate total glucose usage

          GLU = GLU + DGLU

C       -- Determine whether maximum glucose usage has been surpassed

          if ((EXDESC .EQ. 'running') .OR. (EXDESC .EQ. 'walking')) then
             if (GLU .GE. CALF) then
               write(*,100)
               write(*,101)
               GOTO 275
             end if
             else if (EXDESC .EQ. 'cycling') then
                if ((GLU .GE. (0.7 * QUAD)) .OR.
   +    (GLU .GE. (0.3 * (BICEP + TRICEP)))) then
                  write(*,100)
                  write(*,101)
                  GOTO 275
                end if
             else if (EXDESC .EQ. 'rowing') then
```

```
            if ((GLU .GE. (0.5 * QUAD))
     +  .OR. (GLU .GE. (0.5 * BICEP))) then
              write(*,100)
              write(*,101)
              GOTO 275
            end if
          else if (EXDESC .EQ. 'circuit training') then
            if ((GLU .GE. (0.2 * QUAD)) .OR. (GLU .GE. (0.2 * BICEP))
     +  .OR. (GLU .GE. (0.2 * HAM)) .OR. (GLU .GE. (0.2 * TRICEP))
     +  .OR. (GLU .GE. (0.2 * CALF))) then
              write(*,100)
              write(*,101)
              GOTO 275
            end if
        else if (.NOT. ((EXDESC .EQ. 'running') .OR.
     +  (EXDESC .EQ. 'walking') .OR. (EXDESC .EQ. 'cycling')
     +  .OR. (EXDESC .EQ. 'rowing')
     +  .OR. (EXDESC .EQ. 'circuit training'))) then
            if (GLU .GE. 92.7) then
              write(*,100)
              write(*,101)
              GOTO 275
            end if
        end if

C     -- Determine if hypothermia has been achieved

        if (TBC .LE. 34.0) then
          write(*,1) 'HYPOTHERMIA!!!'
          write(*,*) 'Body core temperature has fallen below 92 Deg. F.'
          GOTO 275
        end if

C     -- Determine if hypothermia has been achieved

        if (TBC .GE. 40.0) then
          write(*,1) 'HYPERTHERMIA!!!'
          write(*,*) 'Body core temperature has exceeded 104 Deg. F.'
          GOTO 275
        end if

C     -- Determine if dehydration limit has been exceeded

        if (TSWEAT .GE. 0.05*MKG) then
          write(*,1) 'DEHYDRATION!!!'
          write(*,*) 'Loss of body water exceeds 5% total body weight.'
          GOTO 275
        end if

C     -- Determine if exercise duration has been exceeded
```

```
        if (TT .GT. TTMAX) then
          write(*,1) 'Exercise duration is complete!'
         GOTO 275
        end if

      T = TS + 0.1

110   CONTINUE

C     -- Write data to output file

      FTSC = 1.8 * TSC + 32.0
      CBT = 1.8 * TBC + 32.0
      HD = -QTOT
      CBW = (MKG - TSWEAT) * 2.2046
      CU = GLU * 100.0/92.7

      open (unit = 1,type = 'new',name = 'BODYTEMP.DAT')
      open (unit = 2,type = 'new',name = 'QTOT.DAT')
      open (unit = 3,type = 'new',name = 'BODYWT.DAT')
      open (unit = 4,type = 'new',name = 'SKINTEMP.DAT')

      write(1,99) T,CBT
      write(2,99) T,HD
      write(3,99) T,CBW
      write(4,99) T,FTSC

C     -- Count number of data pts.

      NUMDAT = NUMDAT + 1

111   CONTINUE

C     -- Print values to the screen every 15 min.

270   write(*,6) 'AFTER ',T,' MINUTES:'
      write(*,1)
      write(*,202) 'Rate of heat loss by respiration = ',QRES,' kcal/min'
      write(*,202) 'Rate of heat loss by evaporation = ',QEVAP,' kcal/min'
      write(*,202) 'Rate of heat loss by convection  = ',QCONV,' kcal/min'
      write(*,202) 'Rate of heat loss by radiation   = ',QRAD,' kcal/min'
      write(*,202) 'Heat accumulation in body        = ',HD,' kcal/min'
      write(*,1)
      write(*,201) 'Skin temperature         = ',FTSC,' Deg. F'
      write(*,201) 'Current body temperature = ',CBT,' Deg. F'
      write(*,201) 'Current body weight      = ',CBW,' lbs'
      write(*,269)
      read(*,*)

C     -- Continue simulation if hyperthermia, hypothermia, dehydration or
C     exhaustion have not been reached
```

```
150     CONTINUE

275     write(*,7) 'Total exercise duration = ',T,' min'
        write(*,269)
        read(*,*)

************************************************************************************
*                                                                                  *
*       SECTION 4: This section calls subroutines FUELUSE, PRINTAB, PLOTDATA       *
*       to estimate fuel usage, print a summary and plot data from the             *
*       simulation, respectively.                                                  *
*                                                                                  *
************************************************************************************

        CALL FUELUSE(TT,VOL,PVO,TOTCAL,CHCAL,LIPCAL,CHUSED,LIPUSED)

        CALL PRINTAB

        write(*,2) 'Would you like to plot any of the following results
   +from the simulation run?'
        write(*,1)
280     write(*,3) '1) Body Temperature vs. Time'
        write(*,3) '2) Heat Loss vs. Time '
        write(*,3) '3) Body Weight vs. Time'
        write(*,3) '4) Skin Temperature vs. Time'

285     write(*,1)
        write(*,*) 'If YES, please enter Y; if NO, please enter N:  >'
        read (*,4) ANS

        if ((ANS .NE. 'Y') .AND. (ANS .NE. 'N') .AND. (ANS .NE. 'y')
     +  .AND. (ANS .NE. 'n')) then
          write(*,5)
         GOTO 285
        end if

        if ((ANS .EQ. 'Y') .OR. (ANS .EQ. 'y')) then
         call PLOTDATA(NUMDAT)
        else
         GOTO 300
        end if

300     write(*,2) 'Would you like to test some other conditions?'
301     write(*,*) 'If YES, please enter Y; if NO, please enter N:  >'
        READ (*,4) ICASE

        if ((ICASE .NE. 'Y') .AND. (ICASE .NE. 'y') .AND.
     +  (ICASE .NE. 'N') .AND. (ICASE .NE. 'n')) then
         write(*,5)
         GOTO 301
```

```
      else if ((ICASE .EQ. 'Y') .OR. (ICASE .EQ. 'y')) then
       close (1)
       close (2)
       close (3)
       close (4)
       GOTO 14
      end if

1     format(/,1X,A)
2     format(//,1X,A)
3     format(1X,TR5,A)
4     format(A)
5     format(/,1X,'You have entered an invalid response,
   + please try again.',/)
6     format (/,1X,A,F5.1,A)
7     format (/,1X,A,F5.1,A)
98    format(1X,60('-'),/)
99    format (1X,F5.1,F10.2)
100   format(1X,'EXHAUSTION!!!')
101   format(1X,'You have depleted the carbohydrate stores in the
   + working muscle(s).')
201   format (1X,A,F7.1,A)
202   format (1X,A,F7.2,A)
269   format(//,1X,TR20,'Please press <RETURN> to continue.',///)

      STOP
      END

*********************************************************************************
*                                                                               *
*     This section contains FUNCTION and SUBROUTINE programs to print a         *
*     summary table, plot the data, calculate saturated water vapor             *
*     pressure, sweat rates, and fuel use.                                      *
*                                                                               *
*********************************************************************************

**************************************************************************
*------ SUBROUTINE PRINTAB prints a table of results after the -----------*
*--------------- simulation is complete. ---------------------------------*
**************************************************************************

      SUBROUTINE PRINTAB

      real    WTLBS,MKG,RHUM,MDOT,VMPH,TIF,CBW,CBT
      real    TOTCAL,CHCAL,LIPCAL,LIPUSED,CHUSED,FTSC,VOL

      character NAME*50,EXDESC*50,CLOTHES*50
      integer   AGE,FT,IN,MIN,SEC,TT,ACTLEV

      common NAME,FT,IN,WTLBS,AGE,CLOTHES,MIN,SEC,ACTLEV,EXDESC
      common MDOT,VOL,VMPH,TIF,RHUM,WMPH,TS,CBW,CBT,FTSC,TOTCAL
```

```
      common CHCAL,LIPCAL,CHUSED,LIPUSED

      write(*,9)
      write(*,*) 'SUMMARY OF EXERCISE SIMULATION FOR: >'
      write(*,*) NAME

      write(*,2) '— Characteristics of the Athlete'
      write(*,6) 'Height: ',FT,' ft. ',IN,' inches'
      write(*,4) 'Weight: ',WTLBS,' lbs.'
      write(*,6) 'Age:   ',AGE, ' years'
      write(*,*) 'Clothing:  ',CLOTHES
      write(*,1)
      write(*,6) 'Best recent time for the mile: ',MIN,' min ',SEC,' sec'
      write(*,*) 'Where:  0 - not available'
      write(*,1)
      write(*,8) 'Activity level = ',ACTLEV
      write(*,*) 'Where:  1 - Active, 2 - Inactive'
      write(*,10)
      read(*,*)


      write(*,2) '— Exercise Data'
      write(*,3) EXDESC
      write(*,1)
      write(*,4) 'Metabolic rate      = ',MDOT,' kcal/hr'
      write(*,4) 'Oxygen Consumption = ',VOL,' liters oxygen/min'
      write(*,4) 'Exercise Velocity  = ',VMPH,' miles/hr (0 = N/A)'
      write(*,2) '— Environmental Conditions'
      write(*,4) 'Air temperature    =  ',TIF,' Deg. F'
      write(*,5) 'Relative humidity =  ',RHUM
      write(*,4) 'Wind velocity      =  ',WMPH,' miles/hr'
      write(*,10)
      read(*,*)

      write(*,2) '— Final Simulation Values'
      write(*,7) 'Duration of Exercise =  ',TS,' min'
      write(*,4) 'Final body weight    =  ',CBW,' lbs'
      write(*,4) 'Final body temp.     =  ',CBT,' Deg. F
      write(*,4) 'Final skin temp.     =  ',FTSC,' Deg. F'

      write(*,2) '— Fuel Use'
      write(*,4) 'Total energy spent = ',TOTCAL,' kcal'
      write(*,4) '   - Carbohydrates = ',CHCAL,' kcal'
      write(*,4) '   - Fats          = ',LIPCAL,' kcal'
      write(*,1)
      write(*,4) 'Carbohydrates used: ',CHUSED,' grams'
      write(*,4) 'Fats used:          ',LIPUSED,' grams'
      write(*,10)
      read(*,*)

1     format(1X,/)
```

```
2       format (//,1X,A,/)
3       format (1X,TR5,A)
4       format (1X,A,F7.1,A)
5       format (1X,A,F7.2,A)
6       format (1X,A,I3,A,I3,A)
7       format (1X,A,TR2,F5.1,A)
8       format (1X,A,I2)
9       format (1X,60('-'),/)
10      format (//,1X,TR20,'Please press <Return> to continue.',/)

        RETURN
        END

************************************************************************
*—— SUBROUTINE PLOTDATA plots data calculated in the simulation. ————*
************************************************************************

        SUBROUTINE PLOTDATA(NUMDAT)

        real    LINE(0:100),STAR,SCALE,X(100),XMAX,XMIN
        real    Y(100),YMAX,YMIN
        integer CHOICE,NUMDAT,PF
        character FILENAME*15,PRINTFILE*15,YVAR*25,XVAR*15

290     write(*,1)
        read(*,*) CHOICE

        if (CHOICE .LE. 4 .AND. CHOICE .GE. 1) then
          XVAR = 'TIME (min)'
        else
          write(*,2)
         GOTO 290
        end if

        if (CHOICE .EQ. 1) then
         FILENAME = 'BODYTEMP.DAT'
         PRINTFILE = 'BODYTEMP.TXT'
         PF = 5
         YVAR = 'BODY TEMP. (Deg. F)'
        else if (CHOICE .EQ. 2) then
         FILENAME = 'QTOT.DAT'
         PRINTFILE = 'QTOT.TXT'
         PF = 6
         YVAR = 'HEAT LOSS (kcal/min)'
        else if (CHOICE .EQ. 3) then
         FILENAME = 'BODYWT.DAT'
         PRINTFILE = 'BODYWT.TXT'
         PF = 7
         YVAR = 'BODY WEIGHT (lbs)'
        else if (CHOICE .EQ. 4) then
         FILENAME = 'SKINTEMP.DAT'
```

```
        PRINTFILE = 'SKINTEMP.TXT'
        PF = 8
        YVAR = 'SKIN TEMP. (Deg. F)'
       end if

C      --- Input data

       open (unit = CHOICE, status = 'old', file = FILENAME)
       rewind (CHOICE)
       open (unit = PF, status = 'new', file = PRINTFILE)
       rewind (PF)

       do 6 i = 1,NUMDAT
        read (CHOICE,12) X(i), Y(i)
6      continue

       YMAX = Y(1)
       YMIN = Y(1)

       do 9 i = 1,NUMDAT
        if (Y(i) .LT. YMIN) YMIN = Y(i)
        if (Y(i) .GT. YMAX) YMAX = Y(i)
9      continue

       SCALE = YMAX - YMIN

       do 10 i = 0,55
        LINE(i) = ' '
10     continue

C      --- Plot data

       write(*,3) PRINTFILE
       write(PF,4) 'X','Y'
       write(*,4) 'X','Y'

       do k = 1,NUMDAT
        STAR = (Y(k) - YMIN)*55.0/SCALE
        LINE(STAR) = '*'
        write(PF,5) X(k),Y(k),(LINE(i),i = 0,55)
        write(*,5) X(k),Y(k),(LINE(i),i = 0,55)
        LINE(STAR) = ' '
       end do

       write(PF,13)
       write(*,13)
       write(PF,14) XVAR,YVAR
       write(*,14) XVAR,YVAR

       write(*,*) 'Would you like to plot some other data?'
295    write(*,*) 'If YES, please enter Y; if NO, please enter N:  >'
```

```
      READ (*,16) ICASE

      if ((ICASE .NE. 'Y') .AND. (ICASE .NE. 'y') .AND.
   +  (ICASE .NE. 'N') .AND. (ICASE .NE. 'n')) then
        write(*,5)
       GOTO 295
      end if

      if ((ICASE .EQ. 'N') .OR. (ICASE .EQ. 'n')) then
       RETURN
      else
       close (PF)
       write(*,11) '1) Body Temperature vs. Time'
       write(*,15) '2) Heat Loss vs. Time '
       write(*,15) '3) Body Weight vs. Time'
       write(*,15) '4) Skin Temperature vs. Time'
       GOTO 290
      end if

 1    format (/,1X,'Please enter 1, 2, 3, or 4:  >')
 2    format (1X,'You have entered an invalid response,
   + please try again.',/)
 3    format (//,1X,'The output file will be named ',A,/)
 4    format  (3X,A1,TR7,A1,TR8,56('-'))
 5    format  (1X,F5.1,F10.2,TR3,'|',56A1,'|')
 11   format (/,1X,A)
 12   format  (1X,F5.1,F10.2)
 13   format  (1X,TR19,56('-'),/)
 14   format (1X,'Where: ','X = ',A10,4X,'Y = ',A20,/)
 15   format  (1X,A)
 16   format  (A)

      RETURN
      END

***************************************************************************
*------ FUNCTION PSAT calculates saturated vapor pressure (mmHg) of --------*
*------ water at given temperatures using the Antoine equation. -----------*
***************************************************************************

      FUNCTION PSAT(T)

      real T,A,B,C

C     -- Antoine constants for water

      A = 8.10765
      B = 1750.286
      C = 235.0

      PSAT = 10**(A - B/(T+C))
```

```
      RETURN
      END

************************************************************************
*------ FUNCTION WATERLOSS calculates rate of water loss (evaporation ------*
*------ and runoff) for given skin temperatures and metabolic rates. ------------*
************************************************************************

      FUNCTION WATERLOSS(TSC,TBC,MDOT,GAIN1,GAIN2)

      real TBC,TSC,MDOT,GAIN1,GAIN2

      GAIN = GAIN1*GAIN2

      if (MDOT .LE. 300.0) then
       DSWEAT = 0.046122*GAIN*TBC - 1.16399
      else if (MDOT .LE. 500.0 .AND. MDOT .GT. 300.0) then
       if (TSC .LE. 33.0) then
        DSWEAT = 0.063091*GAIN*TBC - 1.53415
       else
        DSWEAT = 0.295611*GAIN*TBC - 9.53531
       end if
      else if (MDOT .LE. 700.0 .AND. MDOT .GT. 500.0) then
       if (TSC .LE. 33.4) then
        DSWEAT =  0.091916*GAIN*TBC - 2.21063
       else
        DSWEAT = 0.512109*GAIN*TBC - 16.9846
       end if
      else if (MDOT .LE. 900.0 .AND. MDOT .GT. 700.0) then
       if (TSC .LE. 32.0) then
        DSWEAT = 0.223172*GAIN*TBC - 6.03852
       else
        DSWEAT = 0.390976*GAIN*TBC - 11.8576
       end if
      else if (MDOT .LE. 1100.0 .AND. MDOT .GT. 900.0) then
       DSWEAT = 0.256577*GAIN*TBC - 5.75055
      else if (MDOT .LE. 1300.0 .AND. MDOT .GT. 1100.0) then
       if (TSC .LE. 29.0) then
        DSWEAT = 0.439115*GAIN*TBC - 12.3871
       else
        DSWEAT = 0.314289*GAIN*TBC - 8.09200
       end if
      else if (MDOT .LE. 1500.0 .AND. MDOT .GT. 1300.0) then
       if (TSC .LE. 28.6) then
        DSWEAT =  0.69908*GAIN*TBC - 21.2381
       else
        DSWEAT = 0.227225*GAIN*TBC - 4.99327
       end if
      else if (MDOT .LE. 1700.0 .AND. MDOT .GT. 1500.0) then
       DWEAT = 0.053090*GAIN*TBC + 1.639657
```

```
      end if

      WATERLOSS = DSWEAT

      RETURN
      END

*****************************************************************************
*------ SUBROUTINE FUELUSE calculates (using fuel consumption data) ---------*
*------ total energy spent (kcal) and amount (grams) of carbohydrates and ---------*
*------ lipids oxydized for a given duration and intensity of exercise.------------*
*****************************************************************************

      SUBROUTINE FUELUSE(TT,VOL,PVO,TOTCAL,CHCAL,LIPCAL,CHUSED,LIPUSED)

      real R,CALEQ,TOTVOL,TOTCAL,CHFRAC,CHCAL,PVO
      real VOL,LIPCAL,CHEQ,LIPEQ,CHUSED,LIPUSED
      integer TT

*****************************************************************************
*                                                                           *
*                       SUBROUTINE VARIABLES                                *
*                                                                           *
*     VARIABLE                  DESCRIPTION                                 *
*                                                                           *
*     CALEQ         Calorific equivalent of 1 liter of oxygen consumed      *
*     CHCAL         Calories derived from carbohydrates                     *
*     CHEQ          Equivalent carbohydrates oxydized (grams) per           *
*                   1 liter oxygen consumed                                 *
*     CHFRAC        Percentage calories derived from carbohydrates          *
*     CHUSED        Total carbohydrate oxydized (grams)                     *
*     LIPCAL        Calories derived from lipids                            *
*     LIPEQ         Equivalent lipids oxydized (grams) per                  *
*                   1 liter oxygen consumed                                 *
*     LIPUSED       Total lipids oxydized (grams)                           *
*     PVO           Athlete's percent maximal oxygen capacity at            *
*     R             Nonproteic respiratory quotient as function of PVO      *
*                   and duration of exercise                                *
*     TOTVOL        Total volume of oxygen consumed                         *
*     TOTCAL        Total kcal utilized                                     *
*     TT            Duration of exercise (min)                              *
*     VOL           Oxygen consumption at given metabolic rate              *
*     exercise level selected                                               *
*                                                                           *
*****************************************************************************

C     Determine the nonproteic repiratory quotient equation for the duration of
C     exercise. The equations for R are correspond to the following durations:
C     0 min. (ex. sprinters), 30 min., 60 min., 120 min., 180 min., 240 min. and
C     300 min.  For durations of exercise other than these values, R is
```

```
C       approximated using the equation defined at the nearest duration.

        if (TT .LE. 2)                              R = 0.0021*PVO + 0.765
        if (TT .GT. 2 .AND. TT .LE. 45)             R = 0.0021*PVO + 0.753
        if (TT .GT. 45 .AND. TT .LE. 90)            R = 0.0022*PVO + 0.737
        if (TT .GT. 90 .AND. TT .LE. 150)           R = 0.0020*PVO + 0.740
        if (TT .GT. 150 .AND. TT .LE. 210)          R = 0.0019*PVO + 0.735
        if (TT .GT. 210 .AND. TT .LE. 270)          R = 0.0020*PVO + 0.713
        if (TT .GT. 270)                            R = 0.0021*PVO + 0.769

        if (TT .GT. 300) then
          write(*,1) 'Maximum duration limit is 5 hours.'
          write(*,*) 'Percentages of carbohydrates and fats used will be '
          write(*,2) 'based on this duration of exercise.'
        end if

C       -- Calculate total energy expenditure.

        CALEQ  = 3.813 + 1.233*R
        TOTVOL = TT*VOL
        TOTCAL = TOTVOL*CALEQ

C       -- Calculate calories derived from each fuel

        CHFRAC = (-239.32 + 340.32*R)/100.0
        CHCAL  = CHFRAC*TOTCAL
        LIPCAL = (1.0 - CHFRAC)*TOTCAL

C       -- Calculate grams of carbohydrate and lipids oxydized

        CHEQ = -2.977 + 4.195*R
        CHUSED =  TOTVOL*CHEQ
        LIPEQ =  1.722 - 1.717*R
        LIPUSED =  TOTVOL*LIPEQ

1       format(/,1X,A)
2       format(1X,A,/)

        RETURN
        END
```

APPENDIX D: SAMPLE OUTPUT

```
This program is designed to inform well trained
and novice athletes how long they may exercise at
a certain level before one of the following
conditons occur:

      a) hyperthermia:  estimated core temperature
         surpasses 40 Deg. C (104 Deg. F)
      b) dehydration:  loss of body water exceeds 5%
         of body weight
      c) estimated muscle glycogen supply exceeded
      d) hypothermia:  estimated core temperature
         drops below 34 Deg. C (92 Deg. F)


 Please enter your name (50 character max):  >
Megan Scherb

 Gender is used in calculating basal metabolic rate.

 If you are a female, please enter F;
 if you are a male, please enter M:  >
f

 This program is designed for athletes between
 the ages of 18 and 75.

 Please enter your age in years:  >
   24

 Please enter your height (feet,inches):  >
    5.0  4.0

 Please enter your body weight (60 - 300 lbs):  >
  135.0

 Please enter your approximate muscular build:  >
 (small, medium, large)
medium

 Enter the number which best corresponds to your
 clothing (in addition to your shoes):  >

 Shorts only, enter 1.
 Shorts and short-sleeve shirt or singlet, enter 2.
 Shorts and long-sleeve shirt, enter 3.
 Legs covered and long-sleeve shirt, enter 4.
 Legs, arms, hands, and head all covered, enter 5.
    2

 Please enter the air temperature (-40 to 120 Deg. F):  >
   70.0
```

```
Please enter wind velocity (0 - 50 miles/hr):  >
   0.0

Please enter the relative humidity as a decimal:  >
   0.5

Would you like the program to:
      (1) recommend a duration of exercise?
      (2) allow you to choose a duration of exercise?

Please enter 1 or 2:  >
   1

Do you know your best recent time for the mile?
If YES, please enter Y; if NO, please enter N:  >
y

Please enter your time for the mile (min,sec):  >
   7.0 30.0

If best time for the mile is unknown, then maximum
oxygen capacity is based on age and activity level.

Please select your normal level of activity:
     1) Active (well trained in distance sports)
     2) Inactive (no continuous training)

Please enter 1 or 2:  >
   1

Please select level of acclimatization:
     1) Not acclimated to heat of cold
     2) Heat acclimated:
        7-10 days training, 2-4 hrs/day, > 95 Deg. F
     3) Cold acclimated

Please enter 1, 2, or 3:  >
   2

Please choose a type of exercise from the list below:

Walking, running, cycling, skiing, basketball
boxing, soccer, rowing, tennis, circuit training,
field hockey, football, squash, or aerobics.
running

Please enter your speed (1 - 16 miles/hr):  >
   7.5

You are exercising at  60.4 % of your capacity.
```

AFTER 15.0 MINUTES:

```
Rate of heat loss by respiration =    0.40 kcal/min
Rate of heat loss by evaporation =    2.60 kcal/min
Rate of heat loss by convection  =    4.03 kcal/min
Rate of heat loss by radiation   =    1.00 kcal/min
Heat accumulation in body        =    2.01 kcal/min

Skin temperature         =   97.8 Deg. F
Current body temperature =   99.2 Deg. F
Current body weight      =  134.9 lbs
```

Please press <RETURN> to continue.

AFTER 30.0 MINUTES:

```
Rate of heat loss by respiration =    0.42 kcal/min
Rate of heat loss by evaporation =    2.71 kcal/min
Rate of heat loss by convection  =    4.19 kcal/min
Rate of heat loss by radiation   =    1.04 kcal/min
Heat accumulation in body        =    1.69 kcal/min

Skin temperature         =   98.9 Deg. F
Current body temperature =  100.2 Deg. F
Current body weight      =  134.7 lbs
```

Please press <RETURN> to continue.

AFTER 45.0 MINUTES:

```
Rate of heat loss by respiration =    0.43 kcal/min
Rate of heat loss by evaporation =    2.80 kcal/min
Rate of heat loss by convection  =    4.32 kcal/min
Rate of heat loss by radiation   =    1.07 kcal/min
Heat accumulation in body        =    1.42 kcal/min

Skin temperature         =   99.8 Deg. F
Current body temperature =  101.0 Deg. F
Current body weight      =  134.5 lbs
```

Please press <RETURN> to continue.

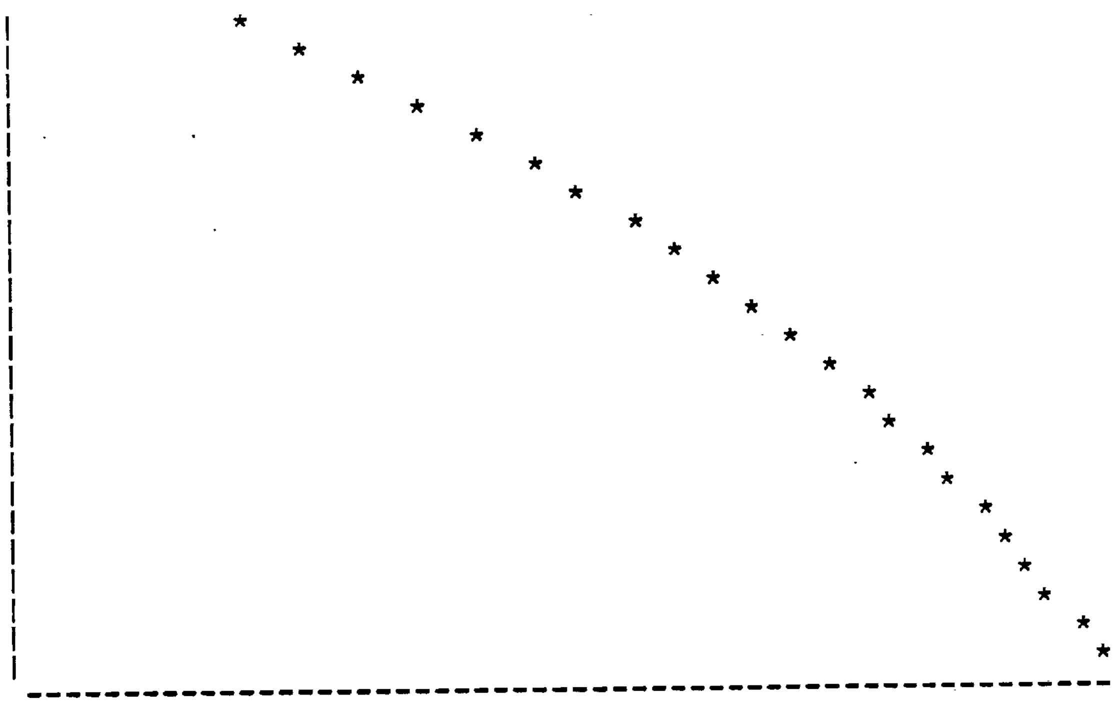
AFTER 60.0 MINUTES:

```
Rate of heat loss by respiration =    0.44 kcal/min
Rate of heat loss by evaporation =    2.88 kcal/min
Rate of heat loss by convection  =    4.42 kcal/min
Rate of heat loss by radiation   =    1.10 kcal/min
Heat accumulation in body        =    1.20 kcal/min

Skin temperature          =   100.5 Deg. F
Current body temperature  =   101.6 Deg. F
Current body weight       =   134.4 lbs

                    Please press <RETURN> to continue.


AFTER  75.0 MINUTES:

Rate of heat loss by respiration =    0.45 kcal/min
Rate of heat loss by evaporation =    2.95 kcal/min
Rate of heat loss by convection  =    4.51 kcal/min
Rate of heat loss by radiation   =    1.12 kcal/min
Heat accumulation in body        =    1.01 kcal/min

Skin temperature          =   101.1 Deg. F
Current body temperature  =   102.2 Deg. F
Current body weight       =   134.2 lbs

                    Please press <RETURN> to continue.


AFTER  90.0 MINUTES:

Rate of heat loss by respiration =    0.46 kcal/min
Rate of heat loss by evaporation =    3.00 kcal/min
Rate of heat loss by convection  =    4.59 kcal/min
Rate of heat loss by radiation   =    1.14 kcal/min
Heat accumulation in body        =    0.85 kcal/min

Skin temperature          =   101.6 Deg. F
Current body temperature  =   102.7 Deg. F
Current body weight       =   134.0 lbs

                    Please press <RETURN> to continue.


AFTER 105.0 MINUTES:

Rate of heat loss by respiration =    0.46 kcal/min
Rate of heat loss by evaporation =    3.05 kcal/min
Rate of heat loss by convection  =    4.65 kcal/min
Rate of heat loss by radiation   =    1.15 kcal/min
Heat accumulation in body        =    0.72 kcal/min
```

```
Skin temperature          =   102.1 Deg. F
Current body temperature  =   103.1 Deg. F
Current body weight       =   133.9 lbs

                    Please press <RETURN> to continue.


AFTER 120.0 MINUTES:

Rate of heat loss by respiration =     0.47 kcal/min
Rate of heat loss by evaporation =     3.09 kcal/min
Rate of heat loss by convection  =     4.71 kcal/min
Rate of heat loss by radiation   =     1.17 kcal/min
Heat accumulation in body        =     0.61 kcal/min

Skin temperature          =   102.4 Deg. F
Current body temperature  =   103.4 Deg. F
Current body weight       =   133.7 lbs

                    Please press <RETURN> to continue.


EXHAUSTION!!!
You have depleted the carbohydrate stores in the  working muscle(s).

Total exercise duration = 132.8 min

                    Please press <RETURN> to continue.

------------------------------------------------------------

SUMMARY OF EXERCISE SIMULATION FOR:  >
Megan Scherb

--- Characteristics of the Athlete

Height:  5.0 ft.  4.0 inches
Weight:   135.0 lbs.
Age:     24 years
Clothing:  Shorts and short-sleeve shirt or singlet

Best recent time for the mile:  7.0 min 30.0 sec
Where:  0 - not available

Activity level =  1
Where:  1 - Active, 2 - Inactive

                    Please press <Return> to continue.
```

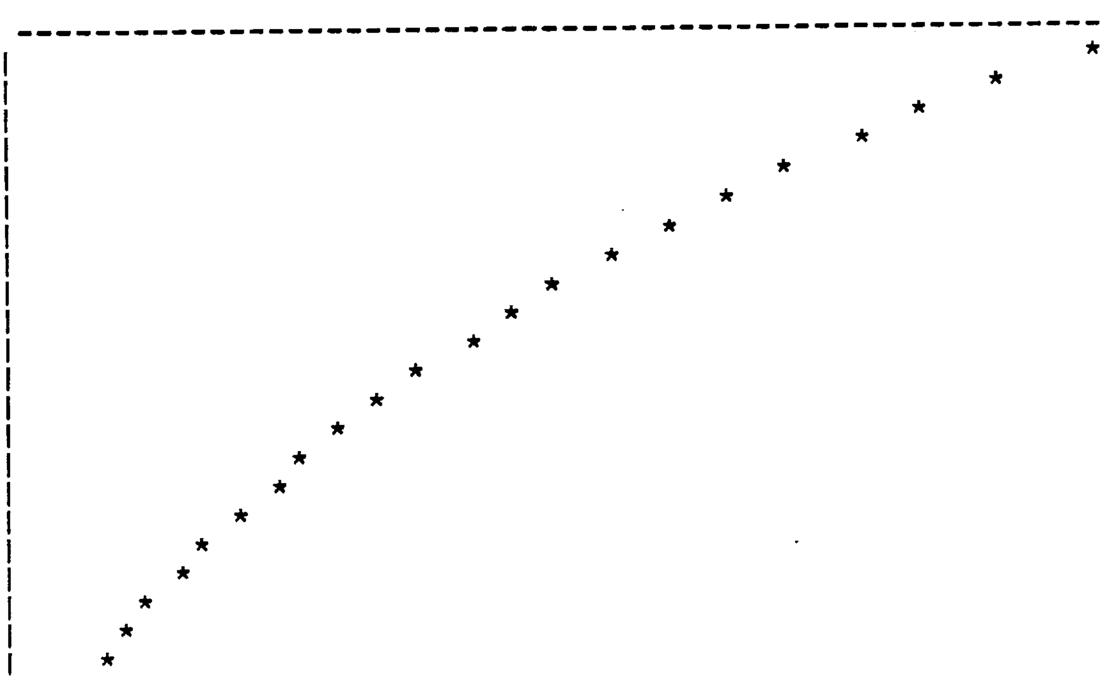
```
--- Exercise Data

     running

Metabolic rate       =   602.5 kcal/hr
Oxygen Consumption =       1.6 liters oxygen/min
Exercise Velocity    =     7.5 miles/hr (0 = N/A)

--- Environmental Conditions

Air temperature    =      70.0 Deg. F
Relative humidity =       0.50
Wind velocity       =      1.0 miles/hr

                     Please press <Return> to continue.

--- Final Simulation Values

Duration of Exercise =    132.8 min
Final body weight    =    133.6 lbs
Final body temp.     =    103.6 Deg. F
Final skin temp.     =    102.6 Deg. F

--- Fuel Use

Total energy spent =  1050.2 kcal
   - Carbohydrates =   563.4 kcal
   - Fats          =   486.8 kcal

Carbohydrates used:   136.7 grams
Fats used:             52.6 grams

                     Please press <Return> to continue.

Would you like to plot any of the following results from the simulation run?

      1) Body Temperature vs. Time
      2) Heat Loss vs. Time
      3) Body Weight vs. Time
      4) Skin Temperature vs. Time

If YES, please enter Y; if NO, please enter N:  >
Y
Please enter 1, 2, 3, or 4:  >
          1

The output file will be named BODYTEMP.TXT

   X       Y      --------------------------------------------------------
  5.0     98.49   |*                                                      |
 10.0     98.86   |   *                                                   |
 15.0     99.22   |       *                                               |
```

20.0	99.55
25.0	99.87
30.0	100.17
35.0	100.45
40.0	100.71
45.0	100.96
50.0	101.20
55.0	101.43
60.0	101.64
65.0	101.84
70.0	102.03
75.0	102.21
80.0	102.38
85.0	102.54
90.0	102.69
95.0	102.83
100.0	102.97
105.0	103.09
110.0	103.21
115.0	103.33
120.0	103.44
125.0	103.54
130.0	103.63



```
Where: X = TIME (min)     Y = BODY TEMP. (Deg. F)

Would you like to plot some other data?
If YES, please enter Y; if NO, please enter N:  >
y

1) Body Temperature vs. Time
2) Heat Loss vs. Time
3) Body Weight vs. Time
4) Skin Temperature vs. Time

Please enter 1, 2, 3, or 4:  >
        2


The output file will be named QTOT.TXT
```

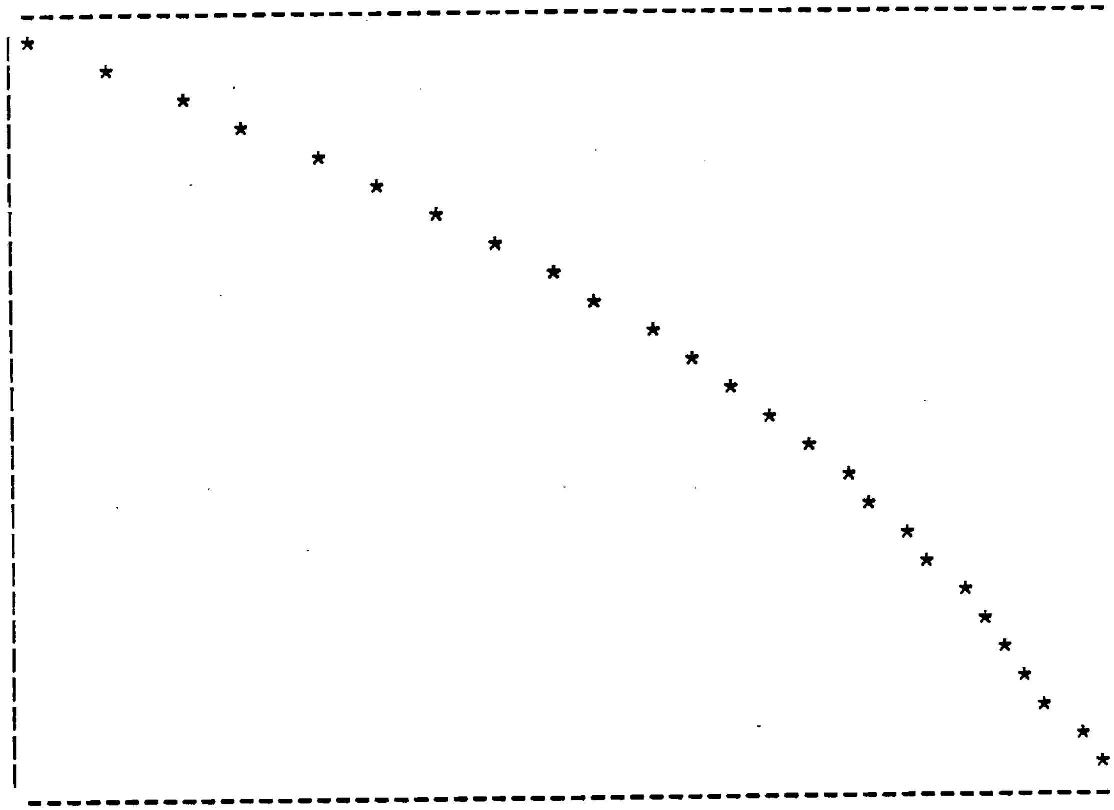
X	Y
5.0	2.27
10.0	2.14
15.0	2.01
20.0	1.90
25.0	1.79
30.0	1.69
35.0	1.60
40.0	1.51
45.0	1.42
50.0	1.34
55.0	1.27
60.0	1.20
65.0	1.13
70.0	1.07
75.0	1.01
80.0	0.96
85.0	0.90
90.0	0.85
95.0	0.81
100.0	0.76
105.0	0.72
110.0	0.68



```
120.0       0.61    |  *                                                       |
125.0       0.58    | *                                                        |
130.0       0.54    |*                                                         |
                     ----------------------------------------------------------

Where: X = TIME (min)     Y = HEAT LOSS (kcal/min)

Would you like to plot some other data?
If YES, please enter Y; if NO, please enter N:  >
Y

1) Body Temperature vs. Time
2) Heat Loss vs. Time
3) Body Weight vs. Time
4) Skin Temperature vs. Time

Please enter 1, 2, 3, or 4:  >
          3


The output file will be named BODYWT.TXT

  X        Y            ----------------------------------------------------------
  5.0    134.95     |                                                        *|
 10.0    134.91     |                                                      *  |
 15.0    134.86     |                                                    *    |
 20.0    134.81     |                                                  *      |
 25.0    134.76     |                                                *        |
 30.0    134.70     |                                              *          |
 35.0    134.65     |                                            *            |
 40.0    134.60     |                                          *              |
 45.0    134.55     |                                        *                |
 50.0    134.49     |                                     *                   |
 55.0    134.44     |                                   *                     |
 60.0    134.38     |                                 *                       |
 65.0    134.33     |                               *                         |
 70.0    134.27     |                            *                            |
 75.0    134.22     |                          *                              |
 80.0    134.16     |                        *                                |
 85.0    134.10     |                      *                                  |
 90.0    134.04     |                   *                                     |
 95.0    133.99     |                 *                                       |
100.0    133.93     |               *                                         |
105.0    133.87     |            *                                            |
110.0    133.81     |          *                                              |
115.0    133.75     |        *                                                |
120.0    133.69     |     *                                                   |
125.0    133.63     |   *                                                     |
130.0    133.57     |*                                                        |
                     ----------------------------------------------------------

Where: X = TIME (min)     Y = BODY WEIGHT (lbs)

Would you like to plot some other data?
If YES, please enter Y; if NO, please enter N:  >
Y

1) Body Temperature vs. Time
2) Heat Loss vs. Time
3) Body Weight vs. Time
4) Skin Temperature vs. Time

Please enter 1, 2, 3, or 4:  >
          4
```

```
The output file will be named SKINTEMP.TXT
```

X	Y
5.0	96.90
10.0	97.34
15.0	97.76
20.0	98.15
25.0	98.52
30.0	98.86
35.0	99.18
40.0	99.48
45.0	99.76
50.0	100.02
55.0	100.27
60.0	100.50
65.0	100.72
70.0	100.92
75.0	101.12
80.0	101.30
85.0	101.47
90.0	101.64
95.0	101.79
100.0	101.93
105.0	102.07
110.0	102.20
115.0	102.32
120.0	102.44
125.0	102.55
130.0	102.65



```
Where: X = TIME (min)      Y = SKIN TEMP. (Deg. F)

Would you like to plot some other data?
If YES, please enter Y; if NO, please enter N:   >
n

Would you like to test some other conditions?
If YES, please enter Y; if NO, please enter N:   >
n
```