Report No. CG-D-80-79

(11)

LEVEL IV

AD A081100

AN EVALUATION OF HUMAN THERMAL MODELS FOR THE STUDY OF IMMERSION HYPOTHERMIA PROTECTION EQUIPMENT

OCTOBER 1979

FINAL REPORT

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20590

80 2 22 005

18) USCG

(19)

Technical Report Documentation Page

1. Report No.
CG-D-80-79

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
(6) An Evaluation of Human Thermal Models for the Study of Immersion Hypothermia Protection Equipment

5. Report Date
October 12, 1979

6. Performing Organization Code

8. Performing Organization Report No.
(11) 12 Oct 79

7. Author(s)
~~E. R. Baker, IV, R. M. Harnett and J. L. Ringuest~~

9. Performing Organization Name and Address
Systems Engineering Program
Clemson University
Clemson, S. C. 29631

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
(15) DOT-CG-72074-A

13. Type of Report and Period Covered
(9) Final Report, (14)
Jan[redacted]78 [redacted] Aug[redacted]79

12. Sponsoring Agency Name and Address
U. S. Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, D. C. 20590

14. Sponsoring Agency Code
G-DSA

15. Supplementary Notes
This report summarizes work performed under Task Number 3 of subject contract and was technically monitored by LTjg Steven F. Wiker and Ens. John A. Budde.

(12) 108

16. Abstract
This report presents an evaluation of mathematical models of a man in a cold environment. The models are evaluated for their ability to predict the effectiveness of anti-exposure equipment used during cold water immersion. The evaluation is done by comparison of model results to those observed during in vivo cold immersions with a wide range of anti-exposure equipment. The models evaluated are those, available in the literature, which employ a metabolic rate control submodel. Model results obtained with modified and experimental submodels are discussed.

(10) R. Michael / Harnett E. R. / Baker, IV
Jeffrey L. / Ringuest

17. Key Words
Immersion hypothermia, hypothermia, equipment, models

18. Distribution Statement
Document is available to the public through the National Technical Information Service, Springfield, VA 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		102	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

409039

PREFACE

This report documents work conducted under Task Number 3 of Contract Number DOT-CG-72074-A from January 17, 1978 to August 21, 1979. The work was performed at Clemson University under the auspices of the U. S. Coast Guard, with LTjg Steven F. Wiker and Ens. John A. Budde serving as program technical monitors. The contract principal investigator was Dr. R. Michael Harnett. The leader of the part of the work addressed in this report was Dr. E. R. Baker, IV. The graduate assistant in this work was Jeffrey L. Ringuest.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

AN EVALUATION OF HUMAN THERMAL MODELS FOR THE STUDY OF IMMERSION HYPOTHERMIA PROTECTION EQUIPMENT

for

UNITED STATES COAST GUARD
U.S. Coast Guard Headquarters

Contract No. DOT-CG-72074-A
Task Number 3
Draft Final Report, Part III
from

Clemson University

by

E. R. Baker, IV, Ph.D., R. M. Harnett, Ph.D., J. L. Ringuest

August 21, 1979

1.0 INTRODUCTION

The use of human subjects for testing hypothermia protection devices is not without risk. Additionally, such in vivo tests can be used only to mild state of hypothermia (rectal temperatures not less than 35°C). A mathematical model capable of accurately simulating the thermal responses of a protected man in a cold environment would be an attractive alternative to human experimentation. In addition, the time required to perform the human experiments makes this alternative method of device evaluation extremely attractive.

1.1 Background

A variety of models have been proposed for the human thermal system. Some of the models have been established from experimentation while others have been constructed from the theories of thermodynamics and fluid mechanics. Some models predict the behavior of the whole body while others are specialized to a particular body segment. The interest in this research lies in models of the entire human body. Excellent reviews of the work in this field are available by Hardy (1972), Mitchell, et al. (1972), Shitzer (1972), Fan, et al. (1971), and Hwang and Konz (1977).

Mathematical models of the whole human body may be generally classified as single cylinder or multi-segment models. Further classification is accomplished by determining whether thermoregulation is internal or external to the model. Models with internal thermoregulation functions may be viewed as a composite of two submodels, one for the passive system (physical system) and one for the controlling system.

The complexity of models of the passive systems depends upon the number of body segments modeled, their geometries, the number of nodes and shells (layers of segment composition) attributed to each segment and the sophistication of the model circulatory system. The complexity of controller models range from simple function-evaluation types to those which compute error signals based on variables such as average skin temperature, core temperature and skin heat flux. All controllers determine metabolic rate and in some models, the control system also determines the sudometer (sweating) and vasometer (variable blood flow) responses.

The models are most generally expressed as a set of differential equations. Early models were solved using analog computers. The advent of larger, faster digital machines has resulted in most models now being programmed for digital computers. The solution methodology most often employed is that of finite differences.

1.2 Objectives

The objective of this research was to determine the feasibility of using an existing human thermal model in the evaluation of immersion hypothermia protection devices. To accomplish this task a review of the literature was conducted leading to the selection of candidate models representing the general types available. Computer codes for these models were obtained and modified as necessary to implement them on the computer system at Clemson University. These modifications of the computer-based models were not intended to accomplish basic structural changes to the models or to improve their intrinsic capabilities.

The selected candidate models were to be validated against the data collected from the human immersions discussed in Part I of this report, see Harnett, et al. (1979). Based on the results of these validations, recommendations were formulated regarding the potential usefulness of each selected model. Also, the most important areas for model improvement were determined and recommendations regarding their priorities were developed for consideration prior to undertaking any efforts aimed at improving the capabilities of a model.

1.3 Scope

The scope of this effort included only an evaluation of existing models. No new model development or modification of existing models was required. However, in the course of implementing the computer-based models and experimenting with them, it was also possible within project cost and schedule constraints to develop and implement a number of substantive model modifications. These modifications improved the performance of the affected models and in some cases were necessary in order to give the models any chance of performing as required for the evaluation of cold water protection equipment.

2.0 MODEL SELECTION

After a review of the literature it was decided that this investigation would be limited to non-steady state models containing controllers. This decision was predicated on two facts: (1) the human response to cold water immersion was unlikely to be steady state and (2) we would be unable to externally control the model since no experimental immersion data was available which correlated metabolic rate, vaso-constriction and surface blood flow to the physical parameters of the model such as core, skin and water temperatures.

References were found in the literature to but a few models fitting these criteria. Conversations and correspondence with the authors of these models revealed several other unpublished models. However, these models were all reported to be very similar to those found through the literature search. The following five models were obtained: Stolwijk, (1972); Montgomery, (1972); Gordon, (1972); Kuznet, (1974); and Winton and Linebarger, (1971). An additional model, without a controller, Wissler (1966) was requested from its author; but this request was not granted.

These models represented several different philosophies in the modeling of both the passive and control systems. Stolwijk's and Kuznet's models had been used primarily for investigation of hyperthermia. The applications were in support of the NASA manned space flight program. Both models were implemented on Clemson's IBM 370/165 and exercised with test data as specified by their authors. Neither model, however, was modified for further evaluation. Stolwijk's model was dropped from further investigation because Montgomery's model was determined to be an extension of it which had been used for diving studies. Kuznet's model was dropped because of its similarity to both the Gordon and Montgomery models. The three remaining models, Winton's, Montgomery's and Gordon's were chosen because of the contrasts among them in terms of their general approaches and complexity.

The Winton and Linebarger Model

The Winton and Linebarger (1971) model is the simplest of the models studied. This model was intended for study of both the steady-state and transient response of the human thermoregulation system to various degrees of internal and external thermal stress. Emphasis in this model was placed on the feedback structure and controller mechanisms involved in thermoregulation. This model has been exercised using both analog and digital simulation.

Winton and Linebarger represent the shape of the body as a cylinder having three concentric layers. The inner-most layer represents the core of the body, which is composed of the deep tissues and internal organs. Surrounding the inner core is a middle layer made up of muscle and fat. The skin comprises the outer layer of the cylinder. For purposes of analysis the thermal properties of the three-layer model are represented by an analogous electrical circuit. The thermal system and its electrical analog are governed by identical differential equations which form the basis of this model.

Three primary control mechanisms are included in this model: sudometer, vasometer and metabolic. These control mechanisms are incorporated into the model by varying the related parameters of the circuit analog in an appropriate manner. Physiological studies have shown the importance of both core and skin themperatures in thermoregulation. Based on these studies feedback signals from the core and skin have been included in this model.

The Montgomery Model

The Montgomery model is an extension of the Stolwijk (1970) model intended to allow investigation of heat loss/gain during underwater diving work. Its thermoregulatory system is divided into two distinct subsystems: the physical-controlled subsystem and the dynamic-controlling subsystem. The controlled subsystem consists of the physical portions of the body.

The controlling subsystem contains the central hypothalamic thermo-integrator, the central set point temperature and associated afferent and efferent signal pathways. The controlling subsystem receives afferent signals from all portions of the body, integrates the signals, compares the results to the central set point and distributes the appropriate effector command signals to all portions of the body.

The controlled subsystem, Figure III-1, consists of the head which is considered a sphere and cylinders representing the trunk, arms, hands, legs and feet. Both arms, hands, legs and feet are represented, because of symmetry, by one

FIGURE III-1
SCHEMATIC OF THE
MONTGOMERY CONTROLLED SYSTEM

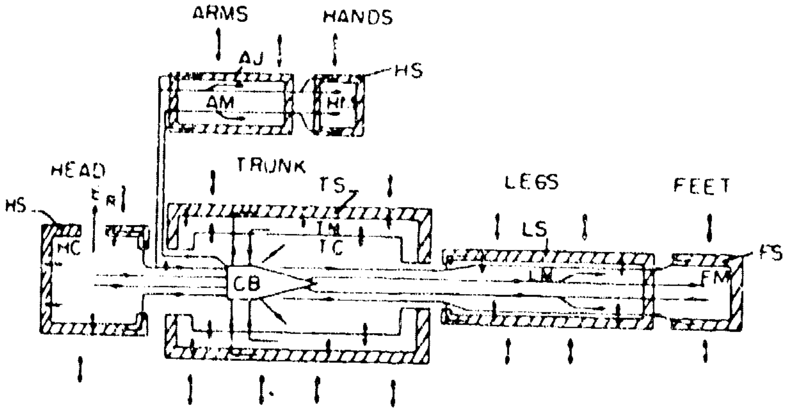
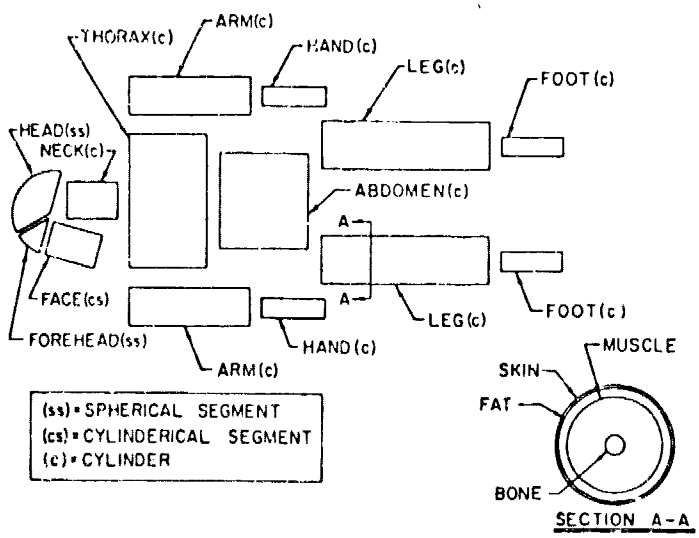


FIGURE III-2
SCHEMATIC OF THE
GORDON CONTROLLED SYSTEM



Body elements that comprise the passive system cylinder each. Each body segment is composed of eleven concentric layers: four representing the body core, four representing the muscle layer, and one each representing the body layers of fat and skin, and one representing the outer wet suit layer. A central blood compartment simulates the body's central blood pool which exchanges heat with all other body compartments, via convective heat transfer, through simulated blood flow to each compartment. Each of sixty-one body compartments is represented by a heat balance equation which accounts for internal heat generation, conductive heat transfer between adjacent compartments, and convective heat exchange with the central blood compartment. Where applicable, respiratory heat generation and heat loss are included in the body compartment heat equations. Additional heat balance equations represent a wet suit on the six body segments and include the effects of conductive heat transfer with the skin and conduction-convection with the ambient water. Each of the sixty-seven heat balance equations includes the thermal capacitance of the compartment enabling the transient response of the compartment to be simulated.

The Gordon Model

The Gordon model is the most complex of the three models examined. Gordon also divides the temperature regulatory system into two major subsystems: the passive subsystem and the control subsystem. The passive subsystem is divided into ten body segments. Cylinders are used to represent the neck, thorax, abdomen, arms, hands, legs and feet. A cylindrical segment represents the face and spherical segments represent the head and forehead. All segments consist of four concentric layers. Both the number of segments and the number of integration nodes per layer is variable. The model was implemented at Clemson with the segmentation described above and eleven nodes per segment. Both of these choices were used by Gordon in his initial validation of the model. They represent a logical balance between computational burden and numerical precision.

Since the body is modeled as concentric spherical or cylindrical shells, (Figure III-2) the governing equations were obtained by considering a shell of uniform properties. An energy balance equation is used for each shell. To complete the passive subsystem model, heat transfer involving the blood pool was modeled, including counter-current heat exchange between certain body elements and the blood pool. The partial differential equations (which from the energy balancing) are nonlinear and are solved by finite difference techniques.

The control subsystem in this model generates several "error signals" which are deviations of average skin heat flux, average skin temperature, and hypothalmus temperature from set-point values obtained passively during basal conditions (resting with no food in stomach). Combinations of these error signals are weighted to produce the control subsystem signal. The equations which describe this control signal make up the control system model. Although the original emphasis of this model was to simulate exposure to cold air, provisions were made for the future addition of a warm-environment controller. The computer code for the Gordon model was written in FORTRAN.

3.0 THERMAL TESTING PROCEDURE AND RESULTS

Any model to be used for evaluations of a cold-protection device must be provided a description of the thermal properties of the device. The models considered in this study were modified to accept, as input data, the thermal conductivity (resistivity) of the devices. Since this data was not available for many of the devices included in this study, it was necessary to determine them through experimentation. This chapter presents a brief description of the testing methodology and the results obtained with it. A detailed description of the methodology was given by Baker (1979).

Briefly, the procedure was to monitor the temperature in a bag of water (initially warm) which had been surrounded by the test material, while it was vigorously agitated in a large tank of colder water. From this data, the BTU loss could be calculated. Assuming linearity over a brief span (3-5 minutes) an estimate of the thermal resistance (R) of the material was calculated. Values obtained in this way are only approximations but were seen to compare well with published values obtained using the methodology of ASTM-C518-70.

Each device included in the cold-immersion test (except the PFD) was tested to determine its thermal resistance. A number of tests were performed on each device. Any test whose result was suspect due to obvious nonlinearity was discarded. This resulted in sample sizes ranging from three to five for individual protective devices. Table III-I presents thermal resistance values (R values) determined in this testing and coefficient of heat transfer values (U values).

The suits which relied upon Aramid underwear to provide thermal protection were tested with a swatch of it placed between the bag and the device being tested. These suits are identified in Table III-I with the comment (W/A). It was noted that in the case of the CWU-21/AP, the Arimid swatch was wet at the completion of each test. As was pointed out in Part I of this report, Harnett, et al. (1979), this suit was also observed to leak during its in vivo cold immersion testing.

The ILC Industries prototype and Dr. Rentsch's prototype rely mainly on an inflatable air bladder to provide thermal protection. The conductivity

TABLE III-I
RESULTS OF THERMAL TESTING

Test Article	THERMAL RESISTIVITY (°C·hr·m²/k cal)		HEAT TRANSFER COEFFICIENT (k cal/°C/hr/m²)
	Mean	Std. Dev.	
Bayley Exposure Suit (PVC foam)	0.1883	0.00654	5.309
Bayley WeatherMate Plus	0.09668	0.0210	10.343
Helly-Hansen Survival Suit (D-600-0)	0.1024	0.00876	9.765
Henderson Zip-On Exposure Suit (2080-4)	0.1222	0.03087	8.181
Henderson Prototype Jacket	0.1222	0.03087	8.181
*ILC Industries Prototype Survival Suit (W/A)	0.07189-0.51005	0.00664	13.910-1.96
Medalist Ski Shorty (7010)	0.0686	0.0026	14.575
Mustang U-VIC Thermofloat (1661)	0.1803	0.0665	5.545
NADC Goretex Experimental Coverall (W/A)	0.1023	0.00607	9.775
*Dr. S. B. Rentsch's Prototype Survival Suit (W/A)	0.02949-0.7572	0.00759	33.909-1.321
S.I.D.E.P. Seastep Survival Suit	0.1269	0.008	7.875
Stearns Windjammer Jacket (FJ-55)	0.2189	0.0708	4.567
Stearns Offshore Survival Jacket (FS-500)	0.1669	0.0368	5.989
Stearns Heavy-Duty Offshore Survival Suit (FS-71)	0.1058	0.00896	9.452
U.S. Air Force Modified Anti-Exposure Assembly(CWU-21/AP) (W/A)	0.0455	0.00607	21.99
Blue Denims (wet)	0.00673	0.000533	148.588

*First number is the value determined experimentally for the deflated suit.
The second number is the calculated value for the suit inflated.
No standard deviation is shown for the calculated value.

of these two devices could not be determined by direct tests as previously described. Instead, we measured the intrinsic conductivity of the suits deflated. These values along with the average thickness of the air space with the suit inflated were used to calculate an overall conductivity. The calculated values shown in Table III-I are actually the average of two calculated values. One value was calculated assuming that the air space was devoid of convection; the second assumed that the convection-conduction was equivalent to that between two smooth parallel plates. The first assumption leads to an optimistic value, the second to a pessimistic value. The average was taken with uniform weighting. This approximation is necessitated by the geometry of the problem which does not lend itself to solution by known techniques.

The accuracy of this method is unknown. It is suggested that in the future, conductivity tests be run using a heat balance system similar to that recommended in ASTM-C518-70 but adapted to testing in "the wet". For example, a brass sphere containing water and a heating coil could be covered with the material to be tested. By monitoring the temperature in the vessel during immersion, the power through the coil can be adjusted until a steady-state temperature is achieved within the vessel. The power being supplied to the coil is then directly related to the conductivity of the protective material.

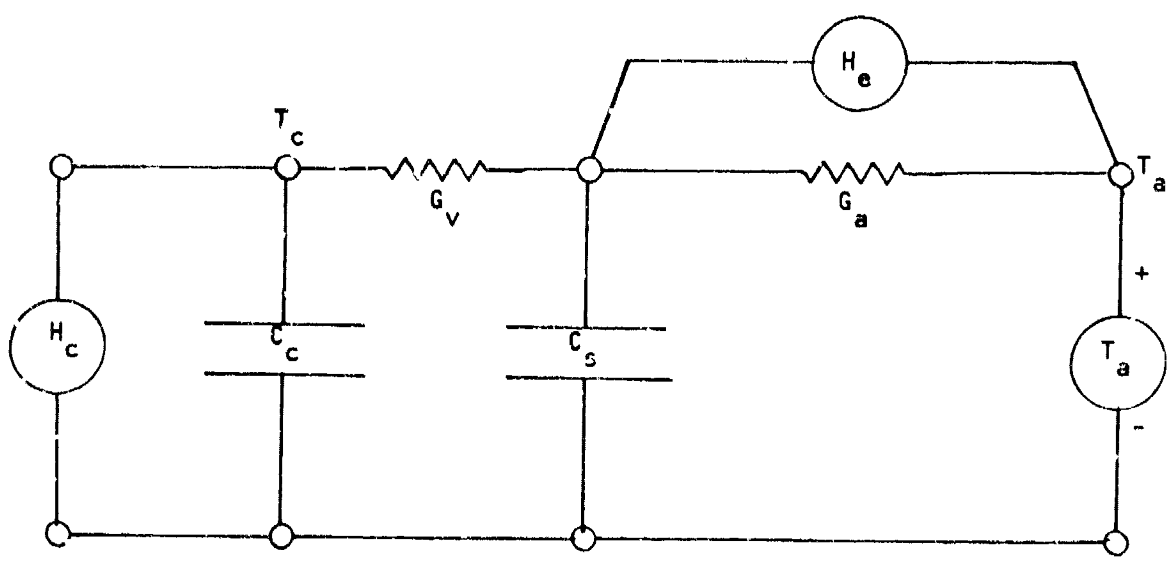
4.0 EVALUATION OF THE SELECTED MODELS

The models selected were modified to accept the inputs from the thermal testing described in the last chapter. This simplified the process of exercising the models for the variety of test articles considered in the study. It was also necessary to modify by adding a layer to represent the protection equipment. Further, it was necessary to modify the modeling of convective-conductive heat transfer at the interface with the environment to reflect the differences resulting from water as opposed to air immersion.

4.1 The Winton and Linebarger Model

The Winton and Linebarger model is the simplest of the three selected for evaluation. The three-layered cylinder used to model the body was represented by the electrical circuit analog shown in Figure III-3.

FIGURE III-3
WINTON-LINEBARGER 3-LAYER MODEL

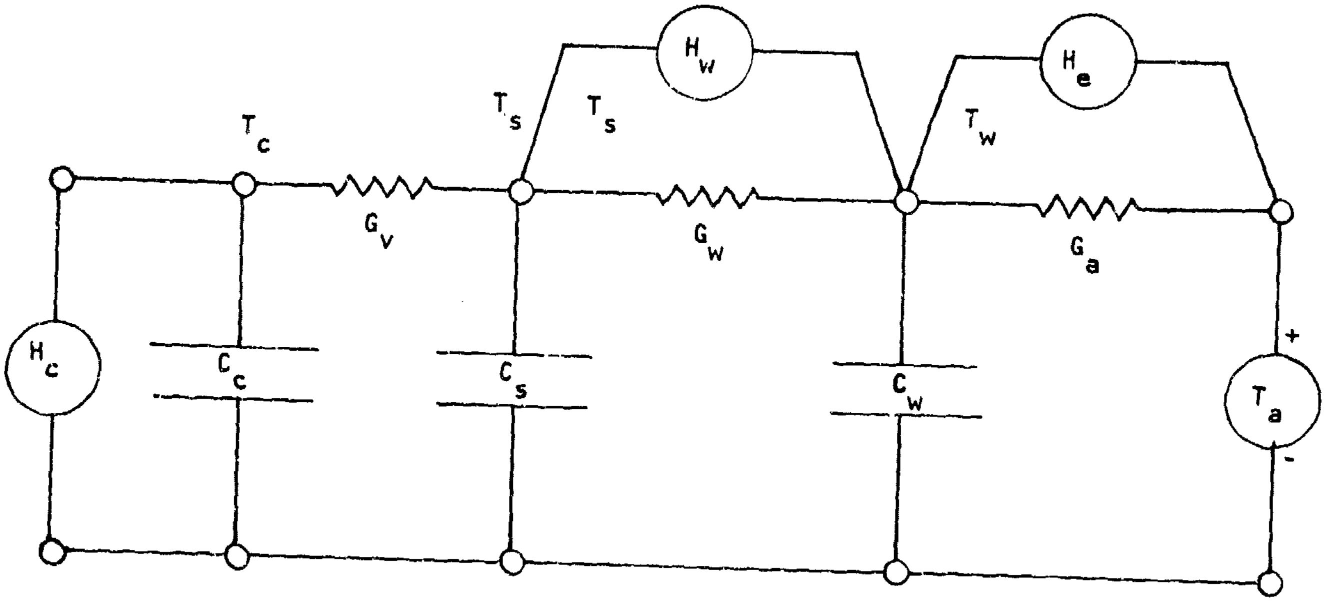


The model, originally implemented on an analog device was later written in CSMP. A CSMP version of the model was implemented and evaluated in this study.

In Figure III-3, H_c is a current source which represents basal metabolic thermogenesis, shivering thermogenesis and respiratory heat loss. G_v is a resistor representing the net heat conduction of the body tissues and G_a represents the net conduction from body to environment. C_c is a capacitor representing the heat capacitance of the body tissues except for the skin which is represented by C_s. H_e is a current source representing evaporative heat loss. T_a is a voltage source representing ambient environmental temperature and T_c and T_s represent core and skin temperatures, respectively.

To accommodate modeling of a thermal protective device it was necessary to modify the circuit in Figure III-3. Figure III-4 shows the modified model.

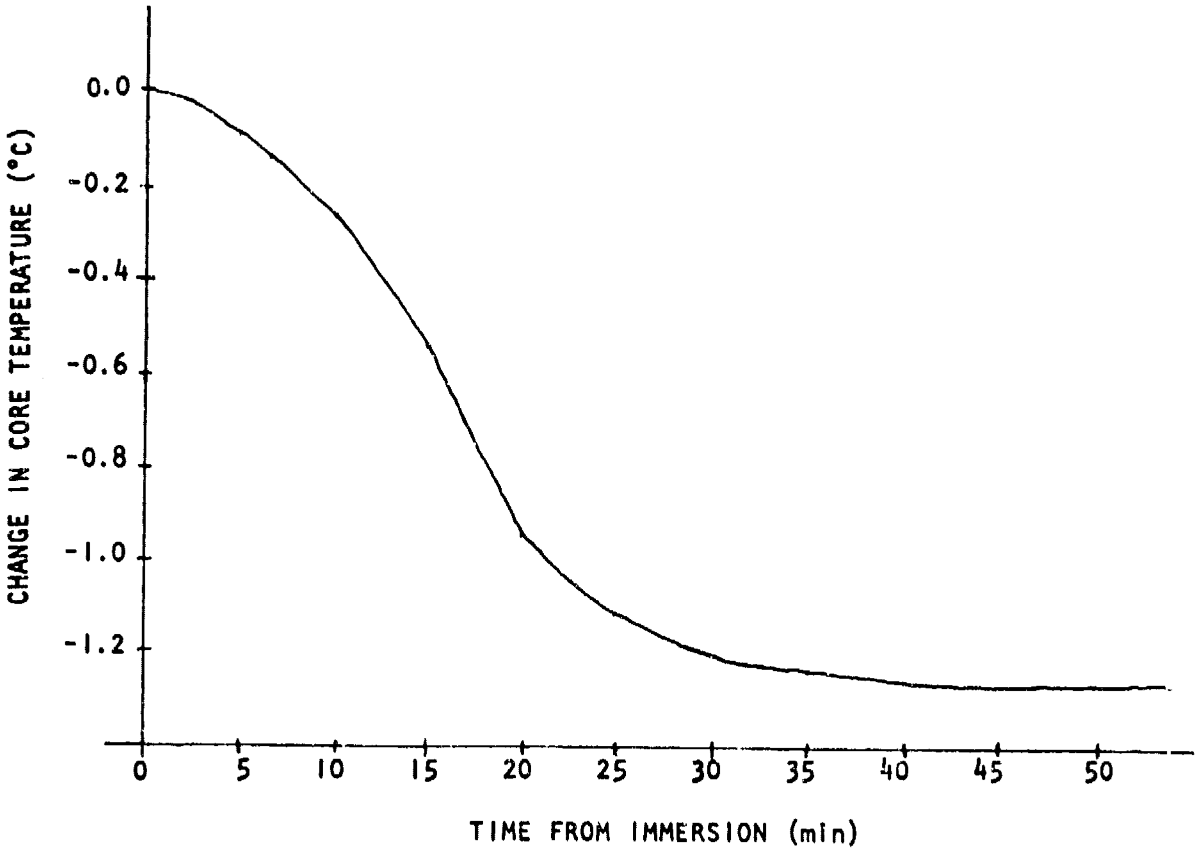
FIGURE III-4
MODIFIED WINTON-LINEBARGER MODEL



Here G_w represents the conductance of the protective device, and C_w its thermal capacitance. The current source, H_w, was included to allow the modeling of devices which, themselves, produce heat. T_w is the temperature of the protective device. For immersion simulation H_e is set for zero. All of the protective devices considered in this study are passive, so H_w was set to zero. A listing of the CSMP program used to implement the model in Figure III-4 is shown in Appendix A.

The model performed well considering its simplicity. Core temperature losses were of the same magnitude as those observed during a human immersion. The time trace itself however was not the same as is seen in Figure III-5. The model loses a significant amount of heat before the metabolic process can begin to compensate. The metabolic rate is driven as high as necessary to overcome the rate of heat loss and the model finally exhibits a plateauing.

FIGURE III-5
TIME-TEMPERATURE PROFILE
FROM WINTON'S MODEL



The initial large loss of heat, as reflected by a rapidly declining core temperature, is attributed in the main to the controllers inability to react to the high gradient experienced upon immersion. As with many models, Winton's was developed for use in estimating steady-state conditions. As a consequence, large continuing changes are required in core and skin temperatures before the metabolic rate becomes sufficiently elevated to overcome the rate of heat loss due to the immersion.

Making the model more useful for evaluating protective devices would require modification of the controlling subsystem. Because the model represents the surface of the subject as a single cylinder, it is applicable only to the study of full body protective devices. Some generalizations to this model are possible. With modification of the controller good estimates of cooling rate may be possible for full body suits. Since the model requires small amounts of both computer time and storage, there may be sufficient justification to warrant this modification effort.

4.2 The Gordon Model

As described in Chapter 2, Gordon represented the body by a set of spherical and cylindrical segments consisting of concentric layers. Each layer was subdivided to finally represent each segment as a set of partial differential equations across eleven nodes. Each node was centered in a shell of uniform material. The resulting equations are solved using finite difference techniques.

The addition of a protective device to this model required only two small changes to the model. An additional layer was modeled for each body segment covered by the device. Each segment originally had four layers. Because of the rapid transient temperatures to be experienced in this layer, it should be modeled with not less than two integration nodes, Wissler (1971). Thus, at a minimum, the model would consist of thirteen differential equations for each protected segment.

The second change required was in the control subsystem. In the original model, the controller is hooked to the last integration node, that of the skin. Since the model was built to accept a varying number of nodes per segment, the addition of the protective device would cause the controller to use as input temperatures and fluxes calculated for the furthest node from the segment core which would be protective device surface temperatures and fluxes. This is easily remedied in either of two manners. First, one may fix the number of nodes representing body in each segment thus affixing to the skin a constant node number. Alternatively the node number representing the skin may be calculated by including as input the number of nodes used to represent the protective device on each segment.

As mentioned above, the three models to be modified were first examined under conditions for which they had been designed. In this testing Gordon's model was found to be the best overall analog. Before modifications were made to model the protective device, the model was set up to simulate a nude cold immersion. As a result of these runs, a major problem was observed in the Gordon model. One would expect that, after an initial rise in core temperature, a decrease would occur which may or may not find an equilibrium level. The period of initial rise and the magnitude of the rise can vary. However, from experimental evidence one would expect the period to be relatively short with a magnitude of at most a few tenths of a degree celsius for a nude man in cold water. The Gordon model exhibited the initial increase upon immersion. However, the core temperature continued to climb as the simulated immersion continued. At the end of a 5-hour simulated immersion, the core temperature had reached approximately 42°C.

A re-examination of the model under the conditions for which it was validated by its author showed that the problem could have existed at that time. It was validated during relatively short (2 hour)simulations of exposure to cold air (5°C). Increasing core temperatures were expected during this period. Their appearance in the simulation results seemed to indicate that the model was working well. Unfortunately, the validations with cold air immersions did not extend into the time period when core cooling occurs. This problem was not observed in the initial testing at Clemson because the simulations were also of relatively short duration.

The Gordon model employs the most detailed modeling of the human physical structure of the three models examined. It was anticipated that it would prove to be the most accurate of the three selected models. For this reason, while it was not an objective of this effort to identify and correct modeling errors, an attempt to do so was made. The equations for the physical system were verified by rederivation. The coding was checked and several simplifications were made. However, the problem could not be identified. It was finally decided to terminate efforts to correct the Gordon computer code, in favor of concentrating on the Montgomery model.

4.3 The Montgomery Model

As suggested earlier, the Montgomery model is basically an adaptation of Stolwijk's model designed for use in evaluating the thermal aspects of diving activity. The model divides the body into ten compartments/segments. Each segment is subdivided into eleven concentric layers. Each compartment represents a lumped thermal capacitance with appropriate modes of heat production and heat transfer to other compartments. Each body layer generates metabolic heat at a basic rate and exchanges convective heat with the central blood pool. The eleven compartments of each segment exchange heat via conductive transfer with adjacent compartments as function of layer geometry and tissue thermal conductivity. Each wet suit segment exchanges heat with the environment as a function of wet suit properties and ambient water conditions.

The starting point in the development of the thermal network for a given subject is to estimate his percent body fat from his height and weight. His total surface area is also estimated from his height and weight. The surface area of each segment is then calculated from the total surface area.

The relative weights of the various segmental layers are calculated from the subject's total body weight and a percentage weight distribution. The various compartment weights, when multiplied by the corresponding specific heat value, yields the thermal capacitance value for each compartment. Since the core of each segment consists of both skeletal and visceral tissue which have different specific heat values, they must be treated separately and averaged.

The central blood compartment, representing the blood in the heart and the great vessels, is assumed to contain 2.5 liters of blood. The thermal capacitance of the central blood compartment is subtracted from the total thermal capacitance of the trunk core. The metabolic heat generation in each body compartment is calculated using the distribution given by Stolwijk and Hardy (1966).

The convective heat exchange that takes place between each body compartment and the central blood pool as a result of blood flow is calculated using the basal blood flow values for each compartment. The thermal conductances of each compartment are assumed to be uniform, concentrated at the compartment's center of mass and only dependent upon compartment temperature. Thermal conductance between layers is a function of the thermal conductivity of the material between compartments, the distance between compartments, the area of the heat transfer surface located at the mid-plane between compartments and the temperature of the two compartments.

The wet-suit-to-ambient-water heat transfer coefficients are dependent upon the geometric shape of the body segment, the ambient temperature and pressure; the viscosity, thermal conductivity, heat capacity and density of the surrounding water; and the water velocity relative to the body segment. Wet suit compartment thermal capacitance values are calculated as a function of wet suit specific heat and wet suit density for each segment.

The Stolwijk (1970) biothermal model was used to form a basis for the controlling subsystem. The first change that was made to the Stolwijk model was to provide more compartments to represent the core and muscle tissue of each body segment. Finite difference methods of solution using lumped nodes will produce errors when new gradients develop in the relatively thick muscle and core layers. This type of error may be decreased by introducing additional compartments in the core and muscle portions of the controlled subsystem. This method was used by Wissler (1964) to improve the simulated response to cold exposure.

The core and muscle portions of each segment were divided into four compartments, each having one-fourth of the core of muscle mass of the given segment. An additional compartment was also provided to represent the wet suit covering each body segment.

The effect of evaporative heat loss from the skin compartments is negligible under diving or totally immersed conditions. The evaporative heat loss from the trunk core is equal to that amount of heat that is carried away from the body during expiration of the respiratory gas. The quantity of heat loss from the respiratory tract for any gas mixture can be calculated from the physical properties of the gas mixture and the thermal and dynamic characteristics of the respiratory system. Respiratory heat loss is proportional to the respiratory minute volume, which is in turn related to the amount of oxygen required to provide energy for metabolic needs. The respiratory loss of heat is somewhat offset by the work of breathing. the net amount of evaporative heat loss from each of the trunk core compartments is taken to be one-fourth of the difference between the total respiratory heat loss and the total heat generation due to respiration.

Net heat flow into or from each compartment is then calculated. The skin compartment in each segment loses, through conduction to the wet suit, an amount of heat equal to the heat transfer coefficient multiplied by the temperature difference between the skin and wet suit compartments. Since a diver does not receive solar heat input and does not transfer radiant heat to his surroundings, the environmental heat transfer coefficients used by Stolwijk (1970) have been replaced by convective-conductive heat transfer coefficients between the wet suit and ambient water. The water-neoprene skin surface heat transfer coefficient is dependent upon the geometrical shape of the body segment; the ambient temperature and pressure; the viscosity, thermal conductivity, heat capacity and density of the surrounding water; and the water velocity relative to the body segment.

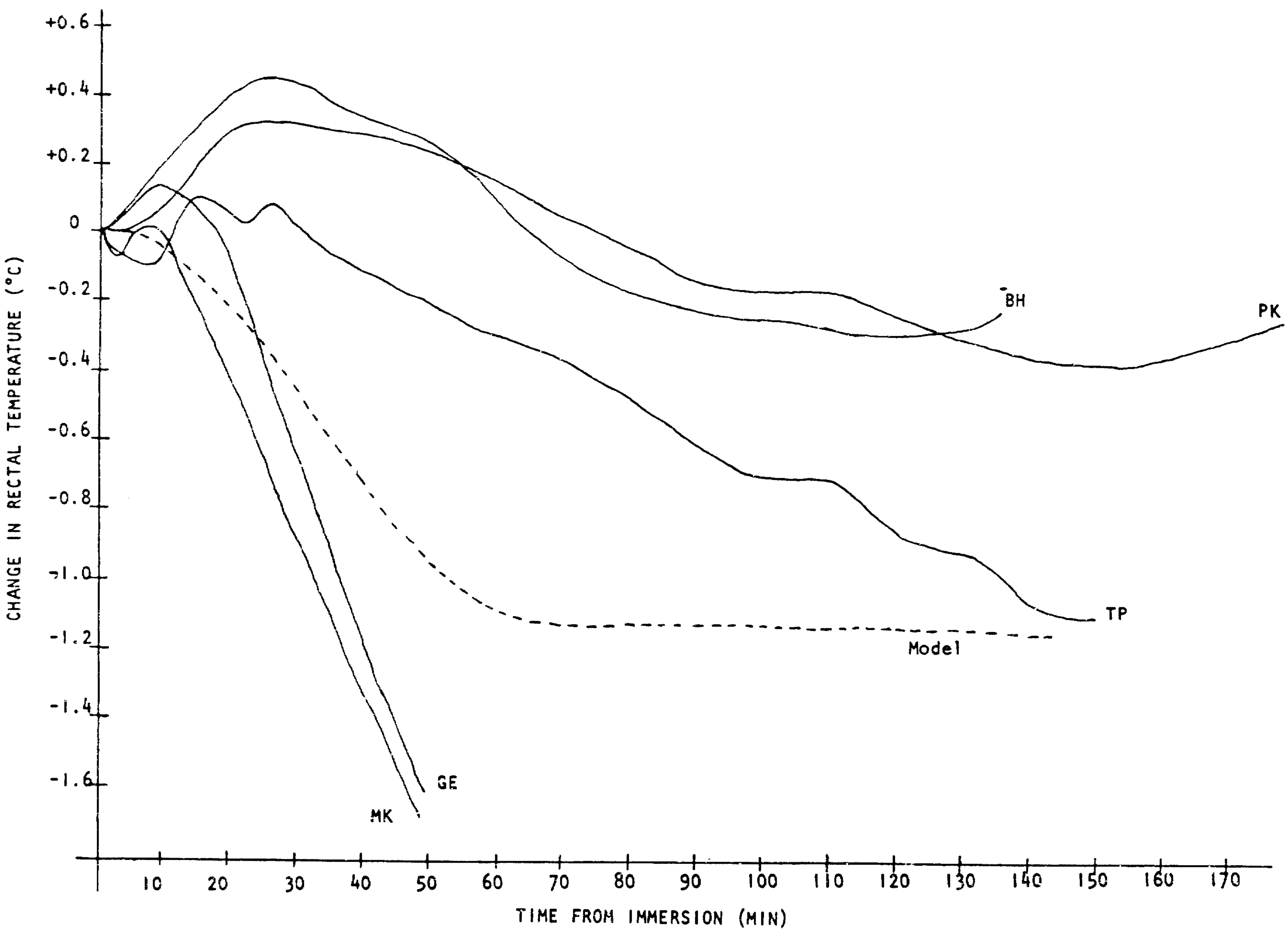
Little modification was necessary to the physical system of Montgomery's model since it already had provisions for an additional layer between the skin and environment. Initial modifications were directed toward increasing the flexibility of device modeling to allow simulation of other than full body suits. In addition, modifications suggested by Montgomery (personal communications) were implemented to simulate immersion of the body with the head and neck (modeled as a single segment) exposed to air. These changes were made in the WETMAN subroutine of the model computer code.

Typical Results with Montgomery's Model

Runs were made to simulate several of the devices included in the cold immersion test described in Part I of this report, Harnett et al. (1979). The results of one series of these simulations is shown in Figure III-6. The article modeled (WP3) was a jacket-type device providing protection basically to the trunk and arms. The figure presents the simulation results, for a man 172 cm tall weighing 74.4 kg, and the experimental observations for five volunteers testing this device.

Considerable variation in response is exhibited by the five experimental observations, largely due to somatotype differences among the subjects. None of the individual responses is represented well by the model results. The model's metabolic control subsystem initially fails to recognize the heat drain caused by the cold immersion. This results in a too slow increase in the rate of thermogenesis and a rapid cooling shortly after immersion.

FIGURE III-6
RESULTS WITH MONTGOMERY'S MODEL AND
FIVE COLD IMMERSIONS



When the metabolic controller does recognize the loss it elevates the metabolic rate by large steps to compensate for the decline in average skin* and head core temperature. The result is a complete stabilization of core temperature.

Montgomery's Metabolic Rate Controller

The controller for metabolic rate formulated by Stolwijk and used by Montgomery calculates changes in metabolic rate based upon the following formulation.

$$\Delta MR = C_c \cdot (\Delta T_c + R_c \cdot T_c') + C_s \cdot (\Delta T_s + R_s \cdot T_s') + C \cdot (\Delta T_c + R_c \cdot T_c') \cdot (\Delta T_s + R_s \cdot T_s')$$

where ΔMR = change in metabolic rate

C_c, C_s, C, R_c and R_s are weighting factors

ΔT_c = deviation of head core temperature from a set point value

T_c' = rate of change of head core temperature

ΔT_s = deviation of average skin temperature from a set point value

T_s' = rate of change of average skin temperature

The weighting factors (constants) are defined as follows.

$R_c = 0$

$R_s = 0.03$

$C_c = 0$

$C_s = 0$

$C = 21.0$

The definitions of C_c, C_s and C were used by Stolwijk based upon the experimental evidence of Benzinger, et al. (1963). With these definitions the metabolic rate controller simplifies to the following.

$$\Delta MR = 21 \cdot \Delta T_c \cdot (\Delta T_s + 0.03\, T_s')$$

*Average skin temperature is defined as the average of the outer surface temperatures of each compartment, weighted by their proportional amounts of surface.

This simplified model is completely insensitive to the rate of head core cooling and is not particularly sensitive to the rate of skin cooling. The model is largely based on the amounts of cooling in these two temperatures and places essentially equal emphasis on the two. Initially, there will be a rapid decrease in average skin temperature but very little change in core temperature. This implies that the product in the above equation will be small, resulting in small increases in the metabolic rate, until there has been a significant decrease in head core temperature.

This helps explain the behavior of the model as depicted in Figure III-6. It is obvious then that there is considerable room for improvement in modeling metabolic control. While not included in the scope of this project, the development of a new controller was seen to be essential to a positive finding that a model can serve the purpose addressed in this study.

The validity of Montgomery's (Stolwijk's) metabolic controller for certain conditions (e.g., a nude man in cold air) has been shown by many people including Stolwijk. It was, as stated above, based on experimental data. It was decided, therefore, to formulate a new controller for the immersion environment based on the data collected in the human immersion portion of this study summarized in Part I of this report.

<u>Improved Metabolic Controllers</u>

Relevant data available included rectal temperature at 15 cm, skin temperatures at the toe, thigh, forearm, bicep, groin and subscapular sites and periodic measurements of metabolic rate. The procedure used to develop the controller was to establish, through regression analysis, linear models relating changes in metabolic rate to changes in the rectal and skin temperatures. The basis of comparison for determining these changes were measurements made following a 30-minute rest period prior to commencing cold immersion.

The initial attempt was based upon regression analysis applied to the pooled sample of observations obtained in the laboratory. When the resulting metabolic controller was implemented in Montgomery's model, fair predictions of cooling rates resulted for most of the wet-mode suits but the predictions for the abandon-ship type dry suits were much worse.

The experimental data was then segregated in two subsets -- one obtained during immersion in 11.8°C water with wet-mode suits and one obtained during immersion in 1.7°C water with dry-mode suits. These data sets were analyzed separately to produce a metabolic controller for each condition. For the wet-mode suits the following model was obtained.

$$\Delta MR = 7.004 - 5.822 \cdot \Delta T_{th} - 2.407 \cdot \Delta T_{f} - 37.382 \cdot \Delta T_{r}$$

where ΔT_{th} = change in thigh temperature

ΔT_{f} = change in forearm temperature

ΔT_{r} = change in rectal temperature

This model had a correlation coefficient (R- value) of 0.77. The accuracy with which regression relations conform to the data is often expressed by "F test statistics". The significance of these statistics may be interpreted by the "level of significance" at which the hypothesis (that the observations follow the model) may be rejected. Small levels of significance indicate that the regression conforms well to the observations. The "level of significance" for this regression was 0.001.

The control model obtained from regression analysis of the data obtained with the dry-mode suits is the following.

$$\Delta MR = 1.987 - 2.654 \cdot \Delta T_{t} - 4.595 \cdot \Delta T_{th} -$$

$$5.361 \cdot \Delta T_{b} - 8.920 \cdot \Delta T_{r}$$

where ΔT_{t} = change in toe temperature

ΔT_{b} = change in bicep temperature

other symbols as previously defined

This model had a correlation coefficient of .85 and a "level of significance" of .0001.

These two relationships were implemented in the Montgomery model. It was necessary to accept some approximations in marrying the list of variables required by the controllers with those available in Montgomery's model. The variables were matched as follows.

Controller Variable	Model Variable
Toe temperature	Average foot temperature
Thigh temperature	Average leg temperature
Bicep temperature	Average arm temperature
Rectal temperature	Trunk core temperature

These approximations are unavoidable because of the simplifications involved in modeling the physical structure of the body in Montgomery's model.

Model Validation

The question of model validity is dependent upon the use to which the model is to be put. The objective in this case is to use the model rather than human experimentation as the basis to estimate the survival time associated with new developments in protection equipment. If one accepts the survival time model and prediction procedure presented in Part I, then all that is required of the model is a prediction of core cooling rate which may than be used to estimate survival time. This would relieve the need to be particularly concerned with absolute temperatures predicted by the model for various body sites or transient aspects of their profiles.

Based on this method for estimating survival time, model validity may be determined by establishing the accuracy of its predictions of the rate of core cooling. This may be done by performing statistical tests comparing the rates observed with the volunteer test subjects (Part I of this report) to corresponding rates predicted for them by the model. This data is naturally "paired" and so lends itself to paired analysis as a means of variance reduction. The "paired t test" described by Steel and Torrie (1960) was used for this purpose. The procedure is illustrated below. The test was run at the 0.05 level of significance with a two-tailed rejection region.

Null Hypothesis (H_o): There is no difference between mean simulated and mean experimentally observed cooling rates

Subject	Predicted Cooling Rate(°C/hr) Simulation	Experimental	Deviation (d) Simulation - Experimental
MK	1.037	2.510	-1.473
GE	1.472	1.800	-0.328
TP	1.100	0.556	0.544
BH	.697	0.391	0.30
PK	.621	0.244	0.376

$\Sigma d^2 = 2.808 \qquad \Sigma d = 0.575 \qquad n = 5$ (No. of pairs)

$$\bar{d} = d/n = 0.115$$

$$S_{\bar{d}}^2 = \frac{\Sigma d^2 - \frac{1}{n}(\Sigma d)^2}{n(n-1)} = 0.137$$

$$S_{\bar{d}} = 0.367$$

$$\text{t-test statistic} = \bar{d}/S_{\bar{d}} = 0.310$$

Critical value of t at 0.05 level of significance with
4 degrees of freedom = 2.776

Since the calculated statistic is less than the critical
value we cannot reject H_o.

A summary of these tests for each of the devices included in the cold immersion testing, except for the PFD is presented in Table III-2. From the table we observe that the model performed well for all of the wet-mode suits.

Those suits for which we must reject the hypothesis of sameness between model and observed average cooling rates are largely the abandon-ship suits. Reference to Figure I-1 in Part I of this report will help explain the models failure. The model "sees" all simulated immersions with the subject completely underwater from the neck down. As can be easily observed from the pictures of the flotation attitudes of these suits in Figure I-1, much of the upper surface areas covering the legs, arms and trunk of each of these suits is exposed to air. The heat transfer coefficient for air is much less than that of water. One would therefore expect the cooling rates predicted by the model for these devices to be greater than that observed in the

TABLE III-2
RESULTS OF PAIRED t TEST
WITH REGRESSION-BASED CONTROLLERS

TEST ARTICLES	Calculated Statistic	Critical Value @ 0.05 Level	Degrees of Freedom	Accept or Reject
Bayley Exposure Suit (PVC foam)	5.367	2.776	4	Reject
Bayley WeatherMate Plus	1.599	2.776	4	Accept
Helly-Hansen Survival Suit (D-600-0)	4.789	2.571	5	Reject
Henderson Zip-On Exposure Suit (2080-4)	5.237	2.776	4	Reject
Henderson Prototype Jacket	1.180	2.776	4	Reject
ILC Industries Prototype Survival Suit	0.387	2.776	4	Accept
Medalist Ski Shorty (7010)	8.172	2.776	4	Reject
Mustang U-VIC Thermofloat (1661)	0.009	2.776	4	Accept
NADC Goretex Experimental Coverall	9.102	2.571	5	Reject
Dr. S. B. Rentsch's Prototype Survival Suit (without respiratory heat reclamation)	1.289	2.776	4	Accept
S.I.D.E.P. Seastep Survival Suit	15.931	2.776	4	Reject
Stearns Windjammer Jacket (FJ-55)	0.416	2.776	4	Accept
Stearns Offshore Survival Jacket (FS-500)	1.823	2.571	5	Accept
Stearns Heavy-Duty Offshore Survival Suit (FS-71)	6.068	2.776	4	Reject
U.S. Air Force Modified Anti-Exposure Assembly (CWU-21/AP)	2.187	2.776	4	Accept

experimentation, as is the case.

The Stearns Heavy-Duty Offshore Survival Suit and the Henderson Zip-On Exposure Suit failed to pass the test. Reference to Figure I-I shows the same type of flotation attitude for these suits as for the abandon-ship suits. In addition to the above-stated reason, the inadequacy of the controller may be contributory to their failure.

Model results for two additional suits failed the paired t test. In both cases the model-predicted cooling rate was faster than that observed from our testing. Again reference to Figure I-I shows that both of these devices were tested with the subjects wearing a "water wings" type flotation device which exposed a significant amount of the trunk to the air. Additionally, the flotation device allowed the subjects to keep their arms and hands out of the water. Thus a faster predicted cooling rate from the model seems very reasonable.

Three suits passed the test which, by the above arguments, should have failed, the ILC prototype, Dr. Rentsch's prototype and the U. S. Air Force's CWU-21/AP. All three of these had simulation predicted cooling rates slower than we expected. For the ILC and Dr. Rentsch's prototypes this is most probably due to error in the estimation of their thermal conductivities. The estimated conductivities are, therefore, probably smaller than the reality. Thus while the model saw a completely submerged suit, it also saw a thermal resistance probably larger than reality. The combination of these two "errors" acted to cancel each other.

The average of the observed cooling rates was higher than the average of the model predictions for the CWU-21/AP. This suit, while ostensibly a dry suit, was observed to leak during testing, as noted in Part I and in Chapter 3 of this part of this report. Since the only thermal protection was the thin dry shell and arimid underwear, it is reasonable to assume that the major portion of the thermal protection offered by the underwear was lost when it became wet. Thus the model may have expected more thermal resistance than probably existed in the experimentation.

If one is concerned only with the prediction of cooling rates, the model, when used on suits that do not expose a great deal of body/device surface to air, appears acceptable. Overall, cooling rates predicted by the model are faster than observed. Thus, in general the cooling rate obtained by simulation will lead to conservative estimates of survival time when used with the survival-time prediction model presented in Part I of this report.

The failure of the model lies in its inability to accurately predict time traces of body temperatures. Figure III-7 shows a plot of rectal temperature as a function of time for two subjects wearing the U-VIC Thermofloat. The solid lines are plots from experimental data. Broken lines show the results obtained when the physical parameters of the two subjects were put into the model. Two important observations may be made. First, there is a complete absence in the simulation results of any initial rise in rectal temperature. Second, the average slopes of the observed and simulated rectal temperature traces (from maximal temperature to last observation) are very nearly equal. In fact, if the model traces are displaced to the right to coincide with the return of the experimental trace to entering temperature, the simulated and observed traces correspond very well. Since the slopes are approximately the same, the predicted cooling rates will be very simliar. Thus the model was able to pass the paired t test even though the predicted and observed rectal temperature behaviors varied notably.

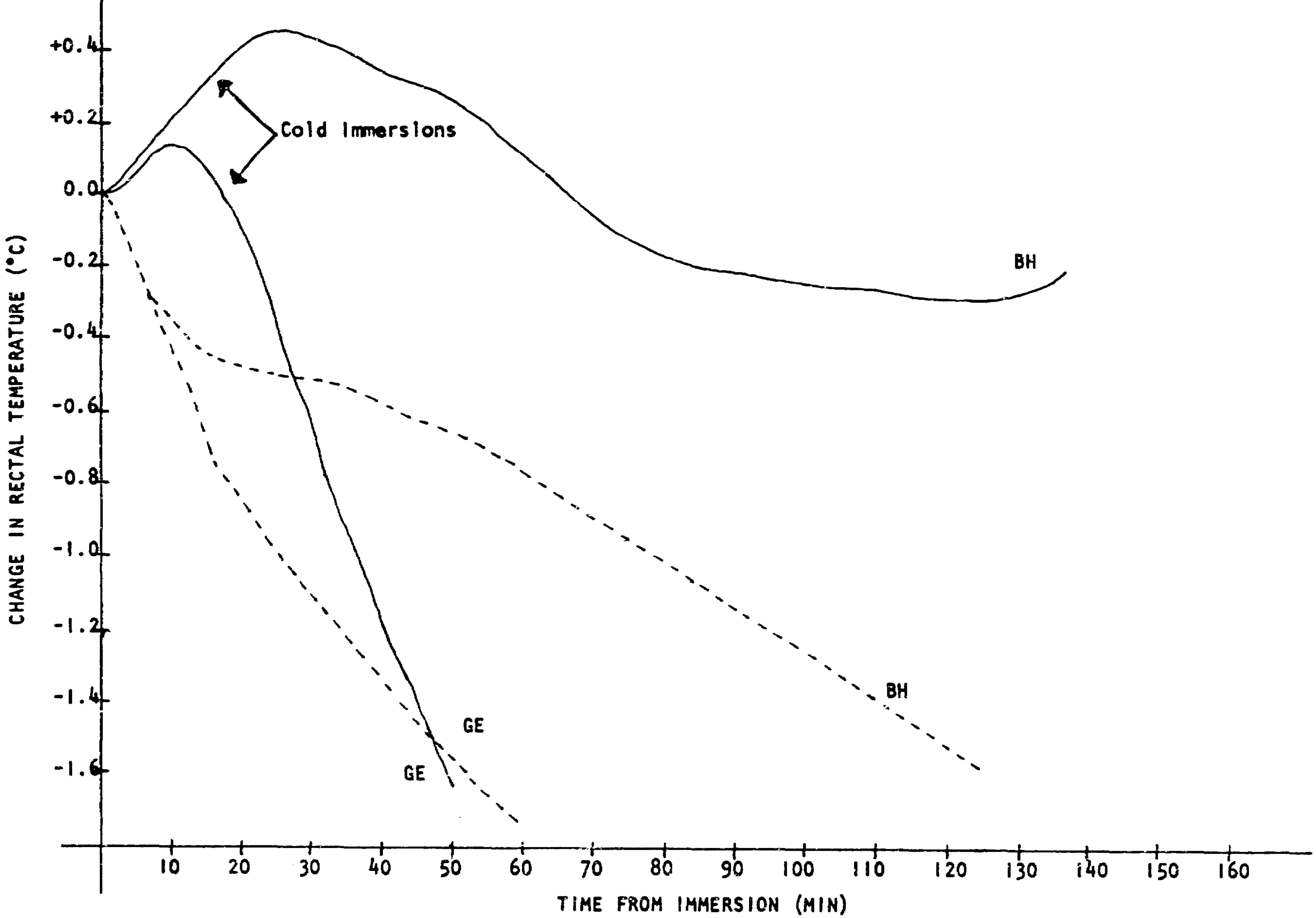
Tuning the Metabolic Controllers

As noted in Part I, for two of the human immersion tests we had the use of a Waters continuous reading oxygen consumption meter computer (MRM-I). The time profiles of metabolic rate observed using this device are seen in Figures I-4 and I-5 in Part I. It may be seen that immediately upon immersion the metabolic rate jumps by about 40 kcal/hr above a resting rate of approximately 70 kcal/hr. Since even the revised metabolic control models did not show this immediate increase, an experimental controller was constructed which included it as a constant. The resulting experimental controller for the wet-mode devices is the following.

$$\Delta MR = 40 + 1.237 - 5.339 \cdot \Delta T_{th} - 4.547 \cdot \Delta T_{f}$$

The last three terms of this experssion were obtained by regression and had an R-value of .69 and a level of significance of .04. For dry-mode suits tested in 1.7°C water, the 40 kcal/hr constant was added to the regression

FIGURE III-7
RESULTS WITH MONTGOMERY'S MODEL
(WITH MODIFIED METABOLIC CONTROLLER)
AND WITH TWO COLD IMMERSIONS



equations determined above for these suits.

Figure III-8, shows the profile of change in rectal temperature for two subjects wearing the U-VIC Thermofloat. The observations are shown as solid lines while the simulation results are represented by the broken lines. The agreement between observation and simulation is much improved over that depicted in Figure III-7 for the modified controller based solely on regression.

Table III-3 presents the results of paired t test carried out between the simulation predicted cooling rates using these experimental controllers and those observed experimentally. The results are much the same as those presented for the modified controllers in Table III-2. The notable changes are the ILC prototype and Rentsch's prototype which fail now, exhibiting slower predicted than observed cooling rates as would be expected with a higher average metabolic rate. The increase in metabolic rate also helped the S.I.D.E.P. Seastep and Stearns Heavy-Duty Offshore Survival suits to pass the test. Overall, while these controllers are not as firmly supported by experimentation, the results are subjectively more satisfying.

Figure III-8 presents the profiles of three skin temperatures predicted by the model for an "average" man, as described in Part I of this report, versus the average results obtained experimentally. The experimental points are bracketed by one standard deviation. The profiles show only the first fifty minutes of the immersions. This is necessitated by the removal of one of the subjects at that time.

The profile of leg temperature predicted by the model, as shown in Figure III-8(a), lies outside of the bounds of the experimental data. However, the temperature plotted for the model is an average leg temperature while that plotted from experimental data is a thigh temperature. One would certainly expect an average leg temperature to be lower than a thigh temperature.

The profile of arm temperature is shown in Figure III-8(b). The initial deviation is due most probably to the rapid decrease in skin temperatures when the protective device initially floods with water. The model does not see this flooding and the simulated temperatures drop more slowly. In the model heat must be lost through the simulated device to the water. The frequent movement of the subjects (e.g., shivering) during the immersion helps to maintain some continual flushing. Thus the average arm temperature from the model would be expected to be somewhat warmer than that observed.

FIGURE III-8
RESULTS WITH MONTGOMERY'S MODEL
(WITH EXPERIMENTAL METABOLIC CONTROLLER)
AND WITH TWO COLD IMMERSIONS

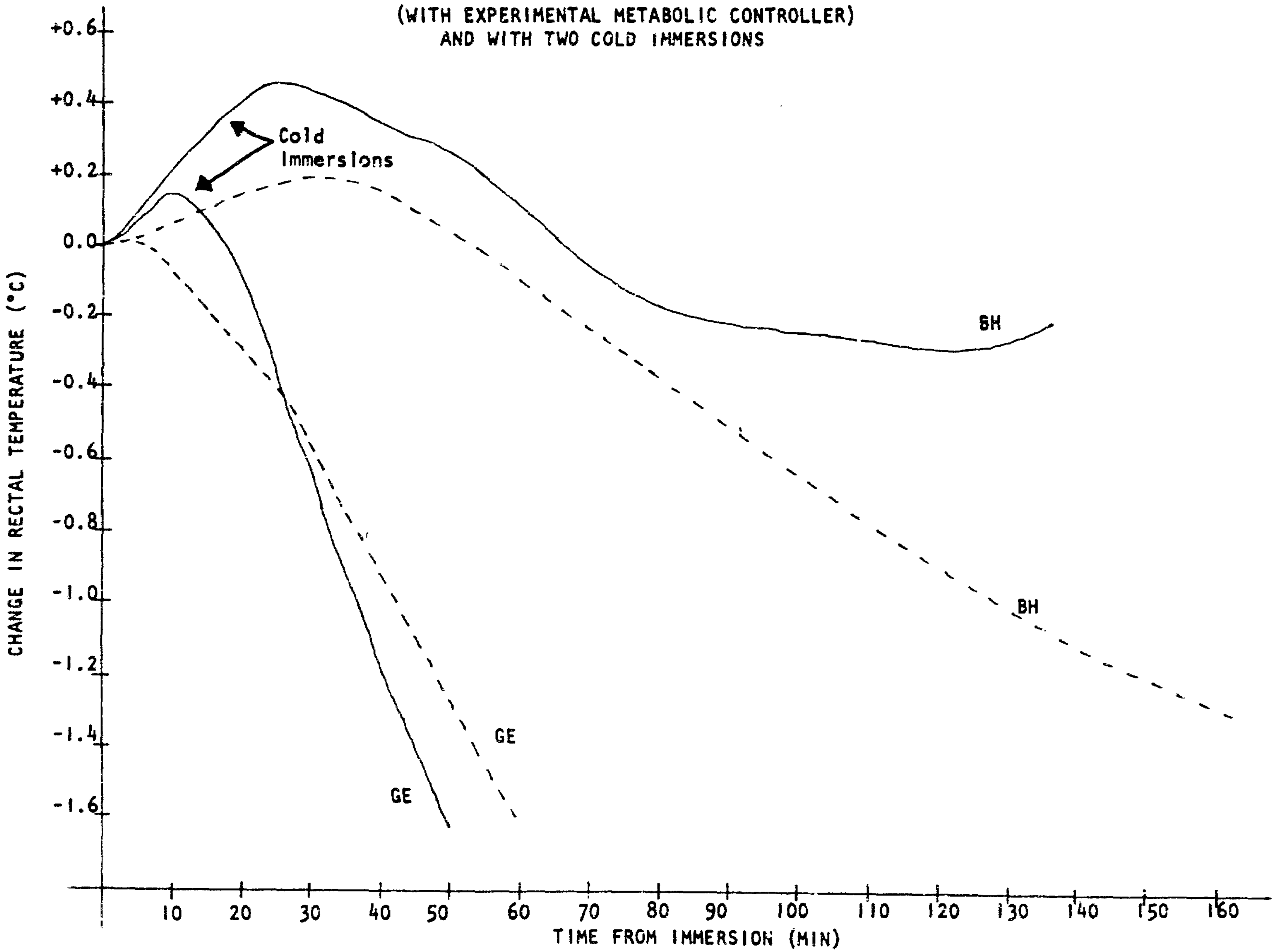


TABLE III-3
RESULTS OF PAIRED t TEST
WITH EXPERIMENTAL REGRESSION-BASED CONTROLLERS

TEST ARTICLES	Calculated Statistic	Critical Value @ 0.05 Level	Degrees of Freedom	Accept or Reject
Baylay Exposure Suit (PVC foam)	4.088	2.776	4	Reject
Bayley WeatherMate Plus	2.03	2.776	4	Accept
Helly-Hansen Survival Suit (D-600-0)	2.926	2.571	5	Reject
Henderson Zip-On Exposure Suit (2080-4)	4.552	2.776	4	Reject
Henderson Prototype Jacket	0.945	2.776	4	Accept
ILC Industries Prototype Survival Suit	4.750	2.776	4	Reject
Medalist Ski Shorty (7010) with Flight Suit	3.143	2.776	4	Reject
Mustang U-VIC Thermofloat (1661)	0.310	2.776	4	Accept
NADC Goretex Experimental Coverall	4.369	2.571	5	Reject
Dr. S. B. Rentsch's Prototype Survival Suit (without respiratory heat reclamation)	14.609	2.776	4	Reject
S.I.D.E.P. Seastep Survival Suit	2.597	2.776	4	Accept
Stearns Windjammer Jacket (FJ-55)	1.170	2.776	4	Accept
Stearns Offshore Survival Jacket (FS-500)	1.178	2.571	5	Accept
Stearns Heavy-Duty Offshore Survival Suit (FS-71)	1.706	2.776	4	Accept
U.S. Air Force Modified Anti-Exposure Assembly (CWU-21/AP)	1.323	2.776	4	Accept

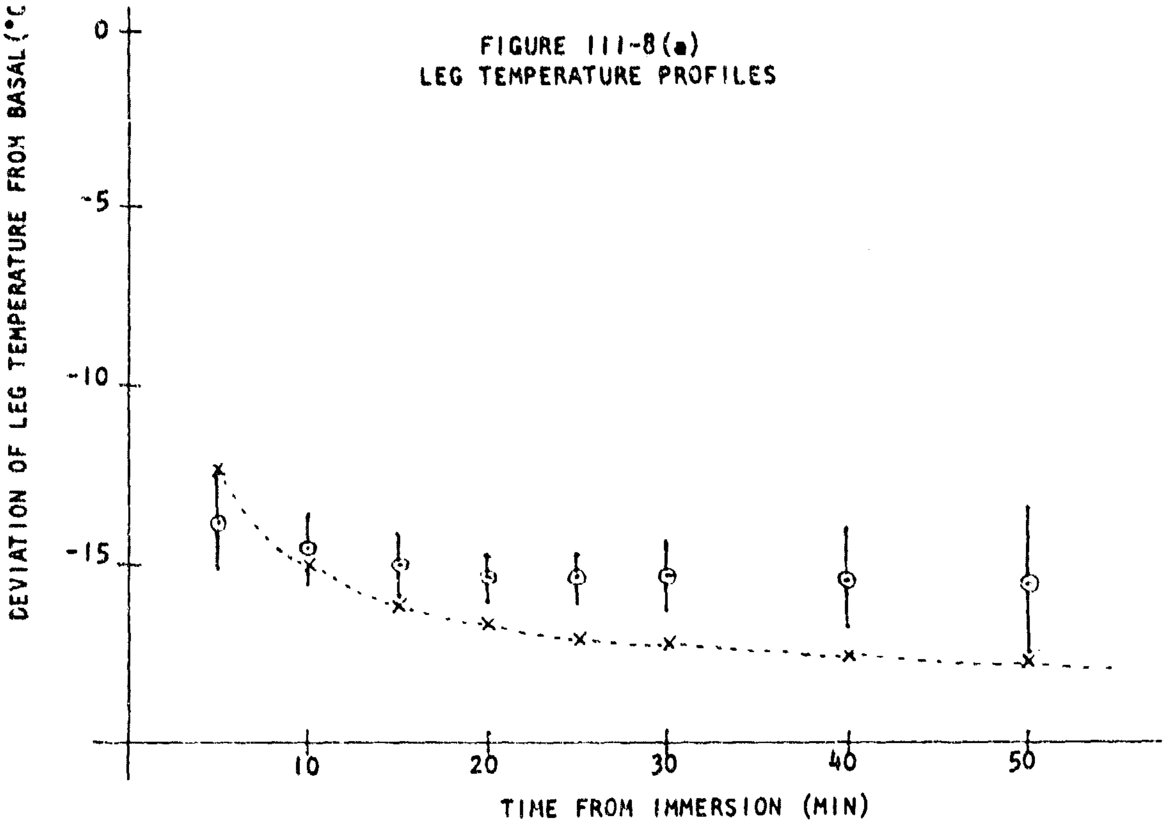


FIGURE III-8(a)
LEG TEMPERATURE PROFILES
DEVIATION OF LEG TEMPERATURE FROM BASAL (°C)
0
-5
-10
-15
10
20
30
40
50
TIME FROM IMMERSION (MIN)

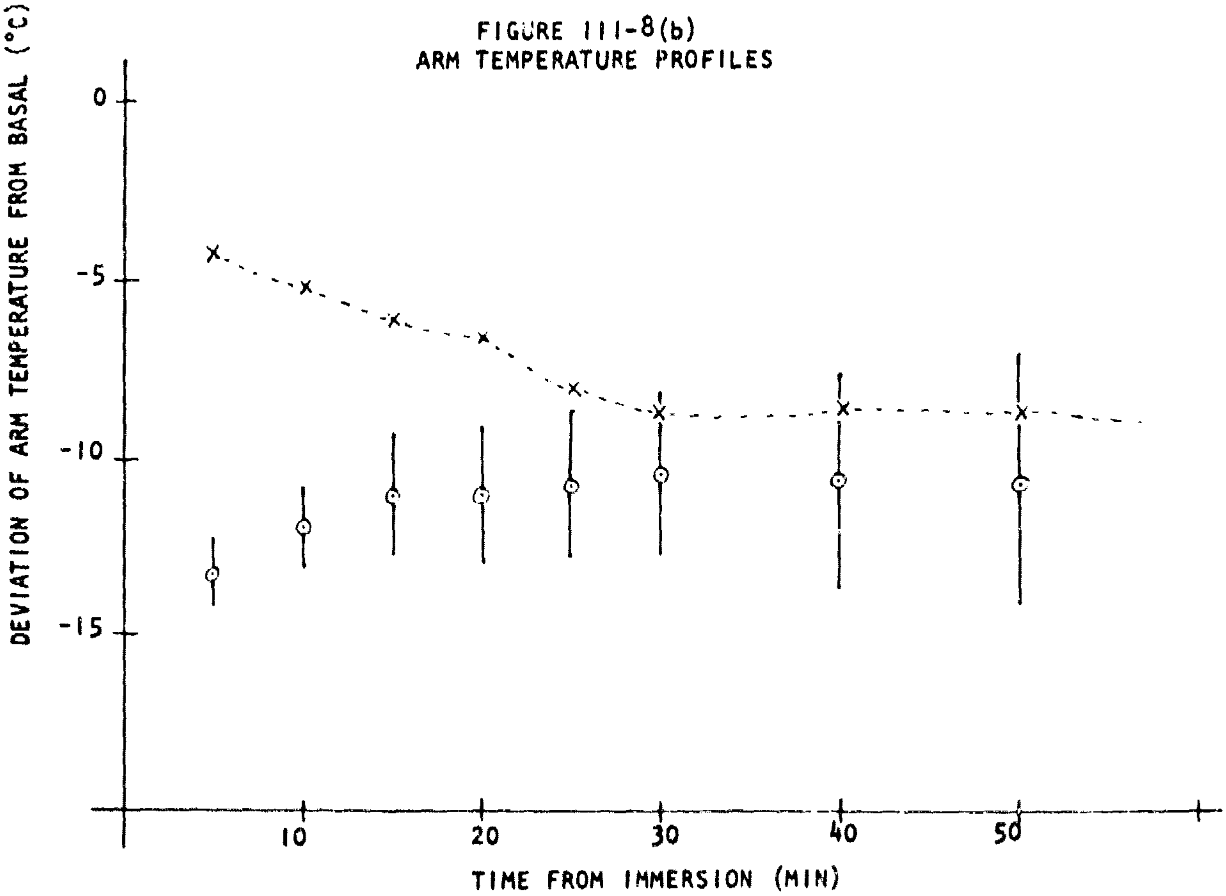


FIGURE III-8(b)
ARM TEMPERATURE PROFILES
DEVIATION OF ARM TEMPERATURE FROM BASAL (°C)
0
-5
-10
-15
10
20
30
40
50
TIME FROM IMMERSION (MIN)

FIGURE III-8(c)
TRUNK TEMPERATURE PROFILES

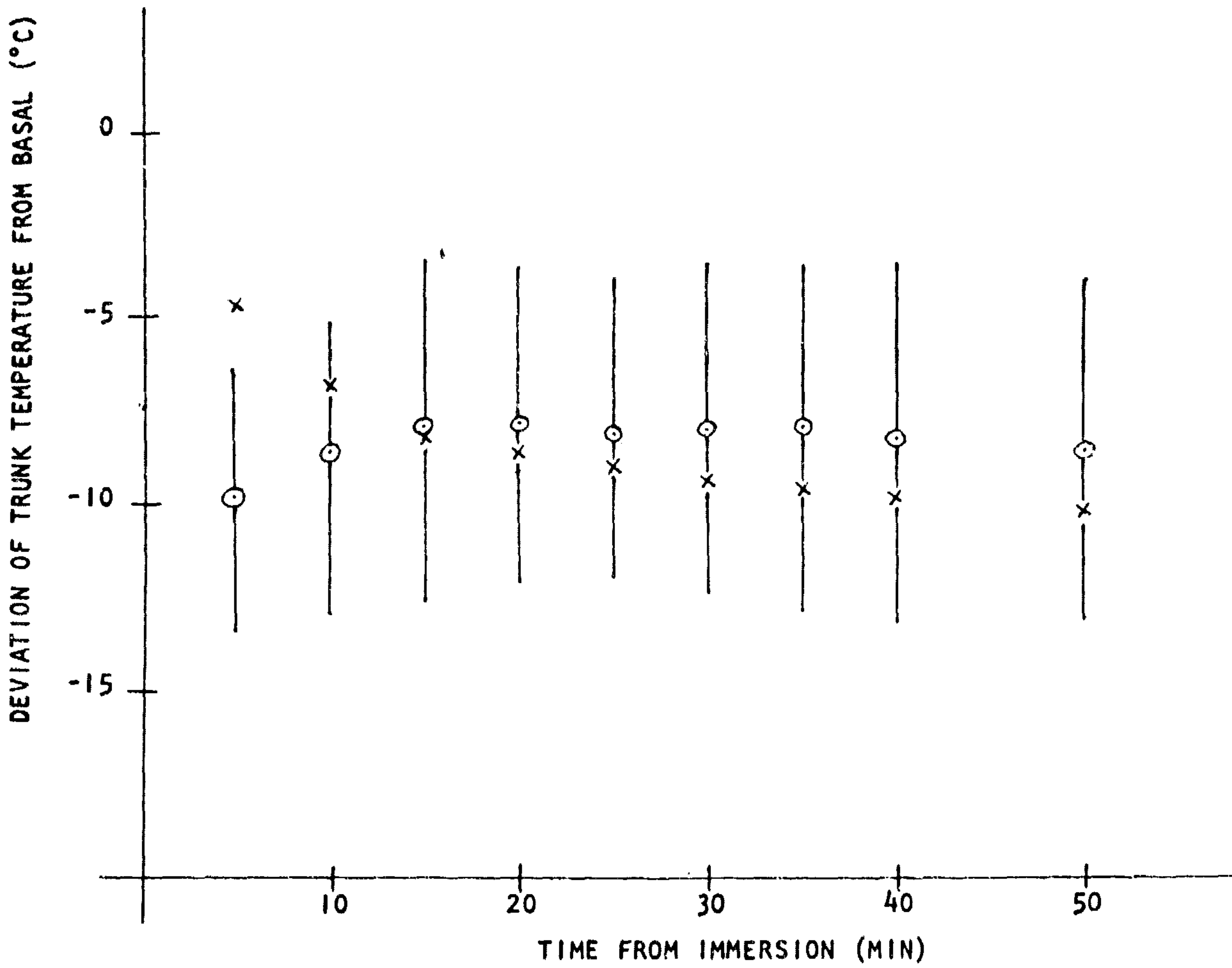


Figure III-8(c) shows the relationship between model predicted and observed temperatures for the trunk. Experimentally the trunk temperature was taken to be that monitored at the subscapular site. Again an initial deviation may be seen which is easily attributed to initial flooding of the suit. In the long run the experimental profile is at a slightly higher temperature level than the simulated one. The simulated data is for the average trunk temperature which might reasonably be expected to be cooler than the subscapular site.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The potential usefulness of a simulation model for evaluation of an immersion protective device is without question. In addition to eliminating the risk associated with human experimentation, there are economic advantages in conducting evaluations by simulation rather than by human experimentation. Furthermore, simulation of an immersion may be accomplished in a short time. The computer resources required by the model are small, most will run in under one minute of CPU time on an IBM 3033 and use less than 256k of core. The cost of a typical run made with Montgomery's model in this study was approximately $7.80. Obviously this is a much more economical approach than direct human experimentation.

An additional advantage lies in evaluation of new postulated designs. Currently, these designs must be fabricated and tested by human experimentation. Using a simulation model one need not physically construct the prototype. Rather, one need only describe it to the simulation model. Obviously, this approach would greatly increase the number of prototype devices which might be examined and the cost would be much reduced.

The modified Montgomery model, discussed in Chapter 4, represents a good start toward a useful model. One may be reasonably confident of survival times calculated from predicted cooling rates generated by this model. There is, however, some room for improvement. The major areas include: improvement of the controller, more detail in the physical model and improved methodology for the determination of protective device thermal properties.

The most immediate need is for an improved controller. Review of the literature has shown that all controllers presently in use were designed from data collected in low rate of heat loss experiments, generally nude cold air immersions. The validation of models with those controllers has been accomplished under the same conditions. There is no reason to expect that a controller thus developed will function correctly under the conditions one encounters during cold water immersions (e.g., high rates of heat loss).

As has been demonstrated, improved model performance may be obtained by using a controller developed from data collected during cold water immersions. The controllers investigated in this study were all based on simple deviations of temperatures at various body sites from predescribed resting temperatures for those sites. The behavior of the model, using a controller based solely on a linear regression of deviations in surface temperatures leaves much to be tried.

It was seen in Figure III-7 that a basic problem appears to be a too slow start of the metabolic furnace. That is, the simulated metabolic rate did not increase sufficiently, compared to the rate of heat loss, until a large rectal temperature drop occurs. This leads one to believe that controllers based on rate of heat loss, rate of change of various body site temperatures or whole or partial body heat flux may be required in order to obtain improved accuracy in temperature prediction from the model. One of the reasons Gordon's model was chosen for inclusion in this study was because its controller, unlike others, used whole body heat flux in determining deviation of metabolic rate from its basal level. Unfortunately, most of the experimental work has been carried out under low rate of heat loss conditions. That work which has been performed under conditions of high rates of heat loss has not been done with controller formulation in mind. One finds that metabolic rates were not always taken or if taken were taken at long intervals. Referring to Figure I-4 we observe a great deal of fluxation in metabolic rate as a function of time.

Improved controllers can certainly be developed with existing data. More human immersion work may need to be done continuously recording metabolic and temperature data in order to formulate an accurate controller. An attempt could then be made to correlate data collected in this fashion with data from low rate of heat loss work in order to develop a controller good for all modeling dealing with conditions of heat loss.

As was discussed in Chapter 4, most of the suits which failed the paired t test were believed to fail, at least in part, because of the model's inability to simulate the flotation attitude observed in the experimentation. The Montgomery model assumes immersion to the neck. Experimentally (Figure I-1) it was often seen that much of the trunk, legs and arms was exposed to air. Obviously, the model should and did predict higher than observed cooling rates. Therefore, to be applicable to the evaluation of suits of this type (basically abandon-ship suits) the model should be modified.

An additional problem encountered with Montgomery's model was the inability to properly describe some of the suits. The model represents the human body is composed of a complete head and trunk, complete arms, hands, legs and feet. There is no way to distinguish between thorax and abdomen, upper and lower arm or upper and lower legs. As a consequence, protective devices which only partially covered the extremities were modeled as not covering them at all (devices such as the Medalist Ski Shorty and U-VIC Thermofloat).

It is certainly possible to model this structure in more detail. As, for example, Gordon's model does. This affords one the capability to more accurately describe the physical structure of the device to be evaluated. One would expect this to lead to much more reliable predictions from the model.

No model thus far reviewed has the detail in the physical system to allow adequate description of flotation attitude. The inability is inherent in the modeling philosophy adapted by all authors. Specifically, each body element has been modeled as either a cylinder or a sphere. In order to derive the differential equations describing heat conduction within cylindrical body elements, a simplifying assumption has been made: all heat transfer is radial and uniform. To model an element partially exposed to air would necessitate consideration of longitudinal heat transfer. The derivation of model equations including this consideration would not be easy.

The changes necessary to give proper consideration to flotation attitude in the model may not be necessary. We have seen that parts of the legs, arms and trunk are exposed to air for some suits (Figure I-1). In rough sea or other open water conditions the continual washing of water over surfaces exposed to the air should result in a rate of heat loss very similar to that which would occur if the surface was continually covered by water. Under this assumption, the model's prediction of cooling rate may be very much in line with reality for these types of protection devices.

No method has been included in the modified Montgomery model for simulating flushing in wet-mode suits. Flushing is believe to do two things. First, it periodically places a large amount of cold water between suit and skin thus causing a rapid heat loss. Second, the water acts as additional insulation, once warmed, between the subject and his environment. Little is known of the dynamics of flushing and no attempt was made to include its effects in these simulations. In extremely rough water, flushing may play a significant role in increasing the rate of heat loss.

Finally, as was pointed out in Chapter 3, a more accurate, repeatable method for determining device conductivity should be developed. The method suggested in Chapter 3 has been seen to work well. It provides a direct measure of conductivity obtained by testing the devices in the wet. Testing the materials under dry conditions is not recommended as many devices contain in their composition porous materials whose thermal properties are different in water than in air.

While may refinements may and should be made to Montgomery's model, its ability to pass a significant number of the paired t tests indicates its potential usefulness for predicting cooling rates and thus survival times. The model could, with the present modified controller, perhaps be used in screening devices prior to in vivo tests. In the long term, a modified model with improved physical definition of the body, provisions for simulating flushing and a more accurate controller would be very useful in the suit design and evaluation process. The physical system modification can be accomplished easily. The modification of the controller may require additional human experimentation.

6.0 REFERENCES

Benzinger, T. H., C. Kitzinger and A. W. Pratt (1963), "The Human Thermostat", Temperature - Its Measurement and Control in Science and Industry, J. D. Hardy (Editor), Vol. 3, pp 637-665, Reinhold, New York.

Fan, L. T., F. T. Hsu and C. L. Hwang (1971), "A Review on Mathematical Models of the Human Thermal System", IEEE Transactions on Bio-Medical Engineering, Vol. BME-18, pp 218-34.

Gordon, R. G. (1972), The Response of a Human Temperature Regulatory System Model in the Cold, Ph.D. Dissertation, University of California, Santa Barbara.

Hardy, J. D. (1972), "Models of Temperature Regulation - A Review" in Essays on Temperature Regulation, Bligh, J. and R. E. Moore (Editors) North-Holland-Amsterdam, American Elseview-New York, pp 163-186.

Hwang, C. L. and S. A. Kong (1977), "Engineering Models of the Human Thermoregulatory System - A Review", IEEE Transactions on Bio-Medical Engineering, Vol. BME-24, pp 309-325.

Kuznetz, L. M. (1970), 41-Node Transient Metabolic Man Program, MSC Program Number J196, NASA Manned Spacecraft Center, Houston, Texas.

Mitchell, D., A. R. Atkins and G. H. Wyndham (1972), "Mathematical and Physical Models of Thermoregulation", in Essays on Temperature Regulation, Bligh, J. and R. E. Moore (Editors), North-Holland-Amsterdam, American Elsevier-New York, pp 37-54.

Montgomery, L. D. (1972), A Simulation of Heat Transfer in Man Under Immersed Conditions, Ph.D. Dissertation, University of California, Los Angeles.

Shitzer, A. (1972), "Mathematical Models of Thermoregulation and Heat Transfer in Mammals", NASA Technical Memorandum, NASA TMX-62, 172.

Steel, R. G. D. and J. H. Torrie (1960), Principles and Procedures of Statistics, pp 78-80, McGraw-Hill Co. Inc., New York.

Stolwijk, J. A. J. (1971), "A Mathematical Model of Physiological Temperature Regulation in Man", Contract Number NAS 9-9531, Report Number NASA CR-1855, NASA, Washington, D. C.

Wissler, E. H. (1966), "A Mathematical Model of the Human Thermal System", Mathematical Biophysics, pp 147-166.

Wissler, E. H. (1971), "Comparison of Computed Results Obtained from Two Mathematical Models - A Simple 14-Node Model and a Complex 250-Node Model", J. de Physiologie, pp 455-458.

APPENDIX A

THE WINTON MODEL

(MODIFIED)

This model is coded in CSMP, a FORTRAN-based, generalized, continuous-systems simulation language. The listing includes data required to simulate a "normal" man defined as 180.4 cm in height and weighing 73.4 kg with a surface area of 1.831 m^2. The model is set up to simulate immersion in a full body suit with thermal conductivity of 0.499 kcal/hr · m · °C and a thickness of 0.00631 m (1/4 in.). The following table identified the major variables of the model.

MAJOR VARIABLES OF THE WINTON MODEL

Symbol	Definition	Units
TC	Temperature of the core	°C
TW	Temperature of the water	°C
TS	Temperature of skin	°C
SKDEL	Deviation of skin temperature from set point	°C
HE	Evaporative heat loss	cal/sec
HW	Heat produced by the protective device (if applicable)	cal/sec
GA	Conductance of environment	cal/sec-°C
GW	Conductance of protective device	cal/sec-°C
TE	Environmental temperature	°C

A program listing follows with input data and output. The model is set-up to simulate a protective device 0.00631 m thick with a conductivity of 0.0499.

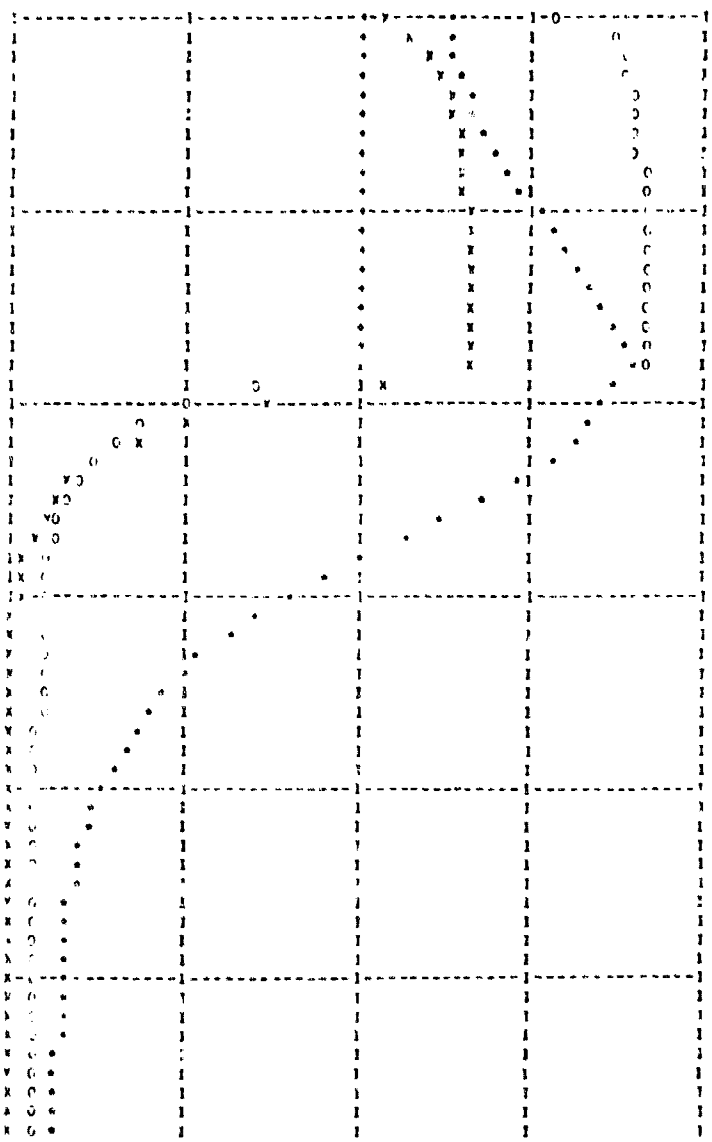
```
LABEL THERMOREGULATION MODEL
* THIS RUN TESTS WATER IMMERSION RESPONSE OF MODEL
* THERMAL ANALOG OF BODY
TC=INTGRL (ICTC,-(GV/CC)*(TC-TS)+(HC/CC))
TS=INTGRL (ICTS,-(GV/CS)*(TS-TC)-(GW/CS)*(TS-TW)-(HW/CS))
TW=INTGRL (ICTW,-(GW/CW)*(TW-TS)-(GA/CW)*(TW-TE)-(HE/CW)+(HW/CW))
* FEEDBACK STRUCTURE
SLIM=COMPAR(33.0,TS)
SKDEL=TS-33.0
W=LEDLAG(1400.,200.,SKDEL)
SKINFB=SGAIN*W*SLIM
COREFB=CGAIN*TC
TRA=TREF-SKINFB
ERROR=TRA-COREFB
* CONTROLLER FUNCTIONS
GV=AFGEN(CURVE2,ERROR)
HSH=AFGEN(CURVE3,ERROR)
HC=HSH
DB1=DEBUG(3,4000.)
DB2=DEBUG(3,6400.)
DB3=DEBUG(3,17000.)
* THIS CIRCUIT PROVIDES A STEP CHANGE IN TE AT 1800 SEC
Y=STEP(1800.)
TE=FCNSW(Y,37.,37.,1.8)
* DATA VALUES
* UNITS TIME IN SEC, TEMP IN DEG C, H IN CAL/SEC, C IN CAL/DEG C
* UNITS G,K,R IN CAL/SEC-DEG C, S IN DEG C/MM HG, V IN M/SEC
INCON ICTC=37.0,ICTS=33.0,ICTW=33.0
PARAM CC=58000.0,CS=3000.0,CW=535.0
PARAM SGAIN=0.025,CGAIN=1.0,TREF=37.1
PARAM HE=0.0,HW=0.0,GA=13.0,GW=15.23
AFGEN CURVE2=(-1000.,35.,-.5,35.,0.,5.,1000.,5.)
AFGEN CURVE3=(-1000.,18.,.6,18.,1.4,100.,1000.,100.)
METHOD RKS
TIMER DELT=0.1,FINTIM=9000.0,PRDEL=100.0,OUTDEL=100.0
PRTPLT TE(32.,42.,TC,TS,TW)
PRTPLT TE(32.,42.,HC,HE)
END
STOP

OUTPUT VARIABLE SEQUENCE
SKDEL  ZZ1006 W       SLIM    SKINFB TRA    COREFB ERROR  GV     HSH
HC     ZZ1001 TC      ZZ1003  TS     Y      TE     ZZ1005 TW     ZZ1007
DB1    DB2    DB3
```

```
      BLOCK DATA
      COMMON/ZZFDAT/F(    78)
     1 /ZZHIST/KEEP,NALARM,IZ0000,IZ0001,H(    15)
     2 /ZZISTO/I(    40)
      COMMON/ZZPOIN/NP(16)
      INTEGER NP/      4,      40,      15,      27,      37,      39,      54,      54
     1,     53,     53,     15,      3,      78,      0,      1,      4/
      COMMON/ZZSYMB/S11( 40)
      REAL*8 S11/                                                  'TIME   ZZ'
     1,'TIMEDELT',' ZZDELT','DELMINZZ','DELNFINT','IMZZFINT','PRDEL ZZ'
     1,'PRDEOUTD','ELZZOUTD','DELMAXZZ','DELXTC  ','  TS    ','TW     ZZ'
     1,'1007ZZ10','01ZZ1003','ZZ1005ZZ','1006ICTC','  ICTS  ','ICTW   ZZ'
     1,'1009CC  ','  CGAIN ','CS    CW','    GA  ','  GW    ','HE     HW'
     1,'    SSAI','N TREF  ','CURVE2CU','RVE3CORE','FBDB1   ','DB2    D3'
     1,'3   ERRO','R GV    ','HC    HS','H   SKDE','L SKINFB','SLIM   TE'
     1,'    TRA ','  W     ','Y       '
     1/
      END
```

```
      SUBROUTINE UPDATE
      COMMON  TIME
     1,ZZ0000,DELT  ,ZZDELT,DELMIN,ZZDELN,FINTIM,ZZFINT,PRDEL ,ZZPRDE
     1,OUTDEL,ZZOUTD,DELMAX,ZZDELX,TC     ,TS     ,TW     ,ZZ1007,ZZ1001
     1,ZZ1003,ZZ1005,ZZ1006,ICTC  ,ICTS  ,ICTW  ,ZZ1009,CC    ,CGAIN
     1,CS    ,CW    ,GA    ,GW    ,HE    ,HW    ,SGAIN ,TREF  ,CURVE2
     1,CURVE3,COREFB,DB1   ,DB2   ,DB3   ,ERROR ,GV    ,HC    ,HSH
     1,SKDEL ,SKINFB,SLIM  ,TE    ,TRA   ,W     ,Y
      COMMON/ZZHIST/KEEP,NALARM,IZ0000,IZ0001
      REAL    ICTC
     1,ICTS  ,ICTW
      REAL*8  ZZTIME
      EQUIVALENCE(ZZTIME,TIME   )
      GO TO(39995,39996,39997,39998),IZ0000
C     SYSTEM SEGMENT OF MODEL
39995 CONTINUE
      GO TO 39999
C    INITIAL SEGMENT OF MODEL
39996 CONTINUE
      GO TO 39999
C    DYNAMIC SEGMENT OF MODEL
39997 CONTINUE
      SKDEL=TS-33.0
      ZZ1006=(SKDEL-ZZ1007)/200.
      W=1400.*ZZ1006+ZZ1007
      SLIM=COMPAR(33.0,TS)
      SKINFB=SGAIN*W*SLIM
      TRA=TREF-SKINFB
      COREFB=CGAIN*TC
      ERROR=TRA-COREFB
      GV=AFGEN(       1,CURVE2,ERROR)
      HSH=AFGEN(       6,CURVE3,ERROR)
      HC=HSH
      ZZ1001         =-(GV/CC)*(TC-TS)+(HC/CC)
C     TC             =INTGRL       (ICTC          ,ZZ1001       )
      ZZ1003         =-(GV/CS)*(TS-TC)-(GW/CS)*(TS-TW)-(HW/CS)
C     TS             =INTGRL       (ICTS          ,ZZ1003       )
      Y=STEP(    14,1800.)
      TE=FCNSW(Y,37.,37.,1.8)
      ZZ1005         =-(GW/CW)*(TW-TS)-(GA/CW)*(TW-TE)-(HE/CW)+(HW/CW)
C     TW             =INTGRL       (ICTW          ,ZZ1005       )
C     ZZ1007         =INTGRL       (ZZ1009        ,ZZ1006       )
      DB1=DEBUG(      11,3,4000.)
      DB2=DEBUG(      12,3,6400.)
      DB3=DEBUG(      13,3,17000.)
      GO TO 39999
C  TERMINAL SEGMENT OF MODEL
39998 CONTINUE
```

THERMOREGULATION MODEL

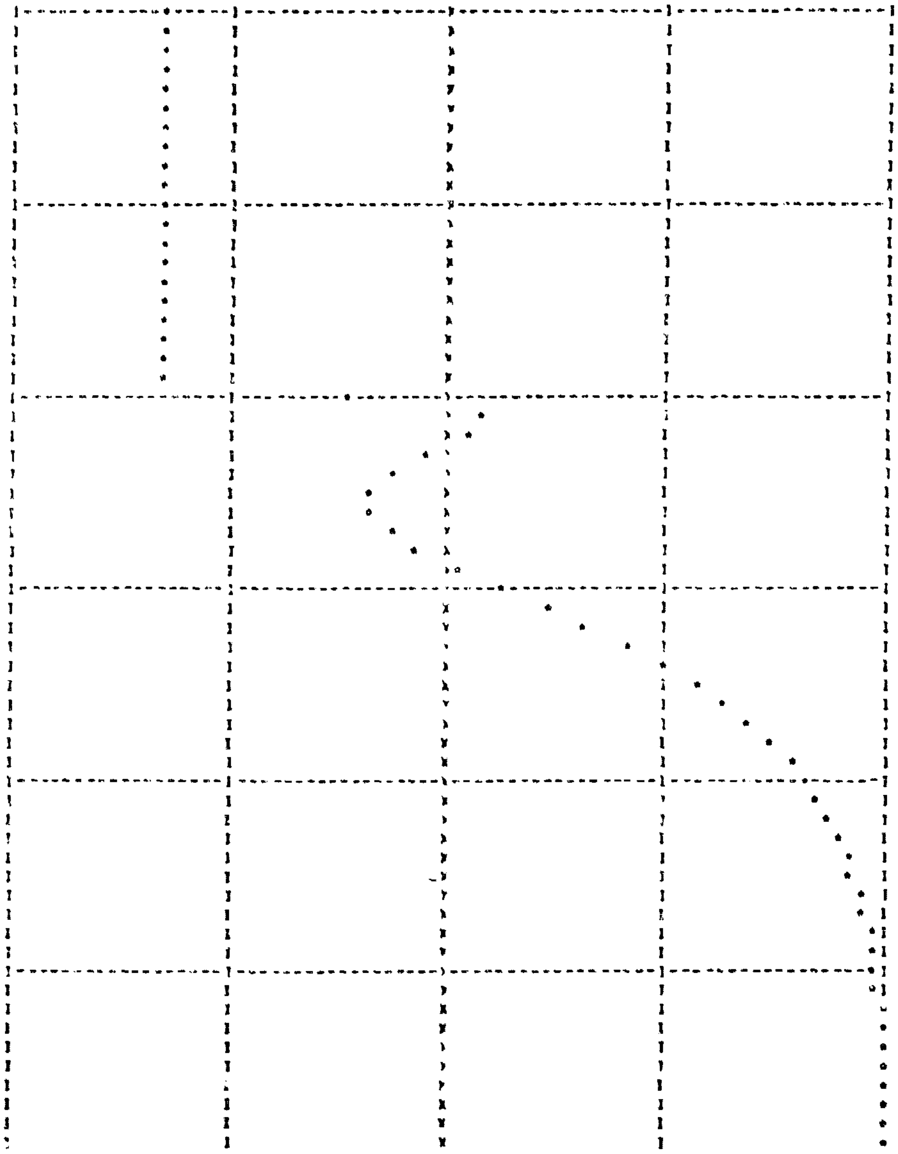
8.000	'O' =TW	40.00
16.00	'X' =TS	48.00
36.00	'*' =TC	37.60
32.00	'+' =TE	42.00



TIME	TE	TC	TS	TW
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	34.151	35.337
[illegible]	[illegible]	37.012	[illegible]	[illegible]
[illegible]	[illegible]	37.029	35.666	36.226
[illegible]	[illegible]	[illegible]	[illegible]	36.473
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	36.593	36.752
[illegible]	[illegible]	37.126	36.746	36.848
[illegible]	[illegible]	[illegible]	36.865	36.916
[illegible]	[illegible]	[illegible]	36.956	36.958
[illegible]	[illegible]	37.238	37.026	[illegible]
[illegible]	[illegible]	37.235	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	37.122	[illegible]
[illegible]	[illegible]	37.29	37.158	[illegible]
[illegible]	[illegible]	37.317	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	37.219	37.115
[illegible]	[illegible]	37.371	37.248	37.131
[illegible]	[illegible]	37.397	37.275	37.146
[illegible]	[illegible]	[illegible]	37.302	[illegible]
[illegible]	[illegible]	37.369	32.869	[illegible]
[illegible]	[illegible]	37.347	27.725	[illegible]
[illegible]	[illegible]	37.332	24.211	14.239
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	37.173	19.010	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	17.665	[illegible]
[illegible]	[illegible]	36.594	17.273	[illegible]
[illegible]	[illegible]	[illegible]	16.993	10.027
[illegible]	[illegible]	36.714	16.769	9.9655
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	36.563	[illegible]	9.7553
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	36.445	16.374	[illegible]
[illegible]	[illegible]	[illegible]	16.321	[illegible]
[illegible]	[illegible]	36.355	16.280	[illegible]
[illegible]	[illegible]	36.32	16.246	[illegible]
[illegible]	[illegible]	36.289	16.219	[illegible]
[illegible]	[illegible]	[illegible]	16.197	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	16.163	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	36.193	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	16.131	[illegible]
[illegible]	[illegible]	36.172	16.124	[illegible]
[illegible]	[illegible]	36.164	16.117	9.5267
[illegible]	[illegible]	[illegible]	16.112	9.5218
[illegible]	[illegible]	36.152	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	36.137	16.096	9.5129
[illegible]	[illegible]	[illegible]	[illegible]	9.5118
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	16.091	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

THERMOREGULATION MODEL

-1.200	'X' =HE	1.200
.0	'*' =HC	100.0
32.00	'+' =TE	42.00



TIME	TE	HC	HE
.	37.000	18.000	.0
100.00	37.000	18.000	.0
200.00	37.000	18.000	.0
300.00	37.000	18.000	.0
400.00	37.000	18.000	.0
500.00	37.000	18.000	.0
600.00	37.000	18.000	.0
700.00	37.000	18.000	.0
800.00	37.000	18.000	.0
900.00	37.000	18.000	.0
1000.0	37.000	18.000	.0
1100.0	37.000	18.000	.0
1200.0	37.000	18.000	.0
1300.0	37.000	18.000	.0
1400.0	37.000	18.000	.0
1500.0	37.000	18.000	.0
1600.0	37.000	18.000	.0
1700.0	37.000	18.000	.0
1800.0	1.8000	18.000	.0
1900.0	1.8000	18.000	.0
2000.0	1.8000	38.47[illegible]	.0
2100.0	1.8000	54.019	.0
2200.0	1.8000	53.12[illegible]	.0
2300.0	1.8000	47.72[illegible]	.0
2400.0	1.8000	42.973	.0
2500.0	1.8000	4[illegible].601	.0
2600.0	1.8000	40.774	.0
2700.0	1.8000	43.02[illegible]	.0
2800.0	1.8000	46.77[illegible]	.0
2900.0	1.8000	51.27[illegible]	.0
3000.0	1.8000	56.214	.0
3100.0	1.8000	61.191	.0
3200.0	1.8000	65.97[illegible]	.0
3300.0	1.8000	70.42[illegible]	.0
3400.0	1.8000	74.47[illegible]	.0
3500.0	1.8000	78.092	.0
3600.0	1.8000	81.281	.0
3700.0	1.8000	84.[illegible]54	.0
3800.0	1.8000	86.47[illegible]	.0
3900.0	1.8000	88.549	.0
4000.0	1.8000	90.32[illegible]	.0
4100.0	1.8000	91.[illegible]4[illegible]	.0
4200.0	1.8000	93.13[illegible]	.0
4300.0	1.8000	94.2[illegible]	.0
4400.0	1.8000	95.16[illegible]	.0
4500.0	1.8000	95.949	.0
4600.0	1.8000	96.613	.0
4700.0	1.8000	97.173	.0
4800.0	1.8000	97.64[illegible]	.0
4900.0	1.8000	98.046	.0
5000.0	1.8000	98.364	.0
5100.0	1.8000	98.66[illegible]	.0
5200.0	1.8000	98.908	.0
5300.0	1.8000	99.109	.0
5400.0	1.8000	99.280	.0
5500.0	1.8000	99.424	.0
5600.0	1.8000	99.544	.0
5700.0	1.8000	99.646	.0
5800.0	1.8000	99.734	.0
5900.0	1.8000	99.805	.0

APPENDIX B

THE GORDON MODEL

(UNMODIFIED)

This model is coded in standard FORTRAN and has been run on an IBM 370/168 and an IBM 3033. Run time on the IBM 3033 is about two CPU minutes for a simulated experiment of three hours length. As stated in the body of this report, the model never performed properly. The only modification appearing in the listing was made for ease of implementation. The following table lists the major variables of the model.

MAJOR VARIABLES OF THE GORDON MODEL

Symbol	Definition	Dimension
C (N)	Heat capacitance of compartment N	kcal . °C^{-1}
T (N)	Temperature of N	°C
F (N)	Rate of change of temperature in N	°C . h^{-1}
HF (N)	Rate of heat flow into or from N	kcal . h^{-1}
TC (N)	Thermal conductance between N and N + 1	kcal . h^{-1} . °C^{-1}
TD (N)	Conductive heat transfer between N and N+1	kcal . h^{-1}
QB (N)	Basal metabolic heat production in N	kcal . h^{-1}
Q (N)	Total metabolic heat production in N	kcal . h^{-1}
EB (N)	Basal evaporative heat loss from N	kcal . h^{-1}
E (N)	Total evaporative heat loss from N	kcal . h^{-1}
BFB (N)	Basal effective blood flow to N	l. h^{-1}
BF (N)	Total effective blood flow to N	l. h^{-1}
BC (N)	Convective heat transfer between central blood and N	kcal . h^{-1}
HC (I)	Convective and conductive heat transfer coefficient for Segment I	kcal . m^{-2} . h^{-1} . °C^{-1}
S (I)	Surface area of Segment I	m^{2}
HR (I)	Radiant heat transfer coeff. for Segment I	kcal . m^{-2}. h^{-1} . °C^{-1}
H (I)	Total environmental heat transfer coeff. for Segment I	kcal . h^{-1}. °C^{-1}
V	Air velocity	m . sec^{-1}
TAIR	Effective environmental temperature	°C
RH	Relative humidity in environment	———
TIME	Elapsed time	h
PAIR	Vapor pressure in environment	mm Hg
ITIME	Elapsed time	min
INT	Interval between outputs	min

Symbol	Definition	Dimension
DT	Integration step	h
P (I)	Vapor pressure table from 5 - 50°C	mm Hg
EMAX (I)	Calc. max. rate of evaporative heat loss from Segment I	kcal . h^{-1}
WORK	Total metabolic rate required by exercise	kcal . h^{-1}
PSKIN (I)	Saturated water vapor pressure at skin temp.	mm Hg
TSET (N)	"Set point" or reference point for receptors	°C
ERROR (N)	Output from thermoreceptors in compartment N	°C
RATE (N)	Dynamic sensitivity of thermoreceptors in N	h
COLD (N)	Output from cold receptors in N	°C
WARM (N)	Output from warm receptors in N	°C
COLDS	Integrated output from skin cold receptors	°C
WARMS	Integrated output from skin warm receptors	°C
SWEAT	Total efferent sweat command	kcal. h^{-1}
CHILL	Total efferent shivering command	kcal. h^{-1}
DILAT	Total efferent skin vasodilatation command	l . h^{-1}
STRIC	Total efferent skin vasoconstriction command	N. D.
SKINR (I)	Fraction of all skin receptors in Segment I	N. D.
SKINS (I)	Fraction of sweating command applicable to skin of Segment I	N. D.
SKINV (I)	Fraction of vasodilatation command applicable to skin of Segment I	N. D.
SKINC (I)	Fraction of vasoconstriction command applicable to skin of Segment I	N. D.
MWORK (I)	Fraction of total work done by muscles in Segment I	N. D.
MCHIL (I)	Fraction of total shivering occurring in muscles of Segment I	N. D.
CSW	Sweating from head core	kcal . h^{-1} .°C^{-1}
SSW	Sweating from skin	kcal . h^{-1}.°C^{-1}
CDIL	Vasodilatation from head core	l . h^{-1} .°C^{-1}
SDIL	Vasodilatation from skin	l . h^{-1} .°C^{-1}
CCON	Vasoconstriction from head core	°C^{-1}
SCON	Vasoconstriction from skin	°C^{-1}
CCHIL	Shivering from head core	kcal . h^{-1} .°C^{-1}
SCHIL	Shivering from skin	kcal . h^{-1}.°C^{-1}
PSW	Sweating from skin and head core	kcal . h^{-1}.°C^{-2}

Symbol	Definition	Dimension
PDIL	Vasodilatation from skin and head core	$l \cdot h^{-1} \cdot °C^{-2}$
PCON	Vasoconstriction from skin and head core	$°C^{-2}$
PCHIL	Shivering from skin and head core	$°C^{-2}$
BULL	Factor determining temperature sensitivity of sweat gland response	$°C^{-1}$

```
C
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C  <>                                                            <>
C  <>                 *     *     *     *  *     *               <>
C  <>                 **   **    * *    *  **    *               <>
C  <>                 *  *  *   *   *   *  *  *  *               <>
C  <>                 *     *   *****   *  *   **               <>
C  <>                 *     *   *   *   *  *     *               <>
C  <>                                                            <>
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION SOUT(300,14),FO(300,13),IMIN(10),IMAX(10),
     *AT(34,21),IND(34),GEO(34,12),Y(714),YY(34,21),EPS(34
     *),PC(34,11),DR(34,9),R(34,21),V(34,20),VT(34,9),AC(3
     *4),RHO(34,9),C(34,9),AK(34,9),BM(34,20),CMET(34,9),V
     *EB(34,9),TAR(34),A(34,20),B(34,20),D(34,20),E(34,20)
     *,T(34,21),ID(126),TVEN(34),UA(34),VELB(34),IA(126),
     * ENGR(34,7),EBT(34),QB(34,9),BFB(34,9),TV(34),WARM(3
     *4),COLD(34),FLUX(34),ERROR(34),SKINR(34),SKINS(34),S
     *KINV(34),SKINC(34),WORKM(34),CHILM(34),EB(34),FSET(3
     *4),PSKIN(34),TO(34,21),RATE(34),TOLD(34),EE(34),EMAX
     *(34),ANAME(34,3),ISK(34),IMU(34),FWARM(34),FCOLD(34)
      COMMON/ENV/BC/LDR/DR/LR/R/LV/V/LVT/VT/LAC/AC/LRHO/RH
     *O/LC/C/LAK/AK/LBM/BM/LCMET/CMET/LVEB/VEB/LTAR/TAR/LR
     *HOB/RHOB,CB,TAFF/COA/A/COB/B/COD/D/COE/E/LT/T/LID/NUM
     *,ISPHER,NUMS,ISS,NOP,ID/LTVEN/TVEN/LUA/UA/LVELB/VELB
     */LIA/IA/LENGR/ENGR/LEBT/EBT/LQB/QB/LBFB/BFB/LTIME/CO
     *,FTIME,EWRITE/LTV/TV/LTOT/TOTV,TOTA/LWARM/WARM/LCOLD
     */COLD/LF/F/LERROR/ERROR/LSKINR/SKINR/LSKINS/SKINS/LS
     *KINV/SKINV/LSKINC/SKINC/LWORKM/WORKM/LCHILM/CHILM/LE
     *B/EB/LHR/HR/LHC/HC/LPSKIN/PSKIN/LTO/TO/LRATE/RATE/LT
     *OLD/TOLD/LEE/EE/LEMAX/EMAX/LIMU/IMU/LFLUX/FLUX/STOLW
     *X/TAIR,VL,EH,WORK,FCMET,CTOLD/LNAME/ANAME/LISK/ISK/L
     *STOL/CSW,SSW,PSW,CDIL,SDIL,PDIL,CCON,SCON,PCON,CCHIL
     *,SCHIL,PCHIL,BULL,ABL,PCO/LQTEN/QTEN/LFSET/FSET/LFWA
     *RM/FWARM/LFCOLD/FCOLD/LQTBL/QTBL/LSTOP/STOPIT/LMUS/M
     *US
      LOGICAL ASYFL
C
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C  <>                                                            <>
C  <>    INPUT AND OUTPUT OF MODEL SIZE, MATERIAL, AND           <>
C  <>    NODAL CONFIGURATION.                                    <>
C  <>                                                            <>
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      DATA TIME,IZ,VB,IQ,JT,IDA/0.00000,2,0.0,0,0.0,0/
      READ(5,61)TIMST,ISPHER,MUS
   61 FORMAT(F10.7,2I5)
      WRITE(3,31)TIMST,NUM,ISPHER,MUS
   31 FORMAT('1',T20,'EXPERIMENT DURATION =',F10.7,'  HOURS'
     *//T20,'TOTAL NUMBER OF BODY ELEMENTS EQUALS :',I5//T20
```

```
     *,'TOTAL NUMBER OF SPHERICAL ELEMENTS EQUALS :',I5//T20
     *,'EXTREMITIES START WITH BODY ELEMENT :',I5//)
      READ(1,32)(IA(M),M=1,34)
   32 FORMAT(40I2)
      READ(1,33)(ID(M),M=1,34)
   33 FORMAT(6I9)
      DO 25 M=1,NUM
      IF(IA(M).NE.0) NOP=M
   25 CONTINUE
      READ(1,62)(UA(M),M=1,34)
      READ(1,133)(IMU(M),M=1,34)
  133 FORMAT(16I5)
      READ(1,35)((ANAME(M,K),K=1,3),M=1,34)
   35 FORMAT(18A4)
      WRITE(3,34)(M,IA(M),ID(M),ANAME(M,1),ANAME(M,2),ANAME(
     *M,3),UA(M),IMU(M),M=1,34)
   34 FORMAT(T20,'ELEMENT  SYMMETRICAL    NODE',10X,'ANATO',
     *'MICAL      CCHE (KCAL/HR/DEG)    MUSCLE'/T22,'NO.    ',
     *'  ELEMENT    DISTRIBUTION       NAME            COEFF',
     *13X,'DISTRIBUTION'//34(T22,I2,T33,I2,T40,I10,T57,3A4,T
     *76,F5.2,T96,I4/))
C
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C  <>                                                          <>
C  <>   INPUT AND OUTPUT OF GEOMETRIC SIZES, BASAL BODY        <>
C  <>   PARAMETERS, AND BOUNDRY CONDITIONS.                    <>
C  <>                                                          <>
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      CALL GEOMRG(GEO,NUM,*2)
      WRITE(3,66)
   66 FORMAT('1',T20,'BC(11) = CONVECTIVE H.T. COEFF. (CAL',
     *'/SQ.CM/HR/DEG)'/T20,'EPS = EMISSIVITY*SHAPE-FACTOR ',
     *'(N.D.)'/T20,'BC(3) = TEMPERATURE OF CONVECTIVE ENVI',
     *'RONMENT (DEG CENTIGRADE)'/T20,'BC(4) = TEMPERATURE ',
     *'OF RADIATIVE ENVIRONMENT (DEG CENTIGRADE)'/T20,'BC(',
     *'7) = INITIAL TEMPERATURE CHANGE PERMISSIBLE AT END ',
     *'OF ITERATION (DEG CENTIGRADE)'//T7,'ELEMENT    BC(1',
     *'1)     EPS       BC(3)      BC(4)       BC(7)')
      DO 20 M=1,NOP
      IF(ASYFL(M)) GO TO 20
      READ(1,67)BC(M,11),EPS(M),BC(M,3),BC(M,4),BC(M,7)
   67 FORMAT(4F10.5,1X,F10.9)
      WRITE(3,64)ANAME(M,1),ANAME(M,2),ANAME(M,3),BC(M,11),E
     *PS(M),BC(M,3),BC(M,4),BC(M,7)
   64 FORMAT(1X,3A4,1X,5F10.5)
      BC(M,3)=BC(M,3)+273.16
      BC(M,4)=BC(M,4)+273.16
   20 CONTINUE
      WRITE(3,65)
   65 FORMAT(///T10,'RHO = DENSITY (GM/CUBIC CM)'/T10,'C =',
     *' SPECIFIC HEAT (CAL/GM/DEG)'/T10,'AK = CONDUCTIVE H',
     *'.T. COEFFICIENT (CAL/CM/HR/DEG)'/T10,'EMET = BASAL ',
     *'METABOLISM (CAL/HR)'/T10,'VEB = BASAL BLOOD FLOW (M',
```

```
     *'L/HR)'///T6,'ELEMENT    MATL NO.      RHO',12X,'C',12X,
     *'AK',10X,'CMET',10X,'VEB')
      RHOCPV=0.0
      DO 12 M=1,NOP
      UA(M)=UA(M)*1000.
      IF(ASYFL(M)) GO TO 12
      CALL DEFSRG(M,LMAT,NODE,IZ)
      IND(M)=NODE
      ISK(M)=LMAT
      SIGEP=EPS(M)*4.8756E-9
      BC(M,2)=SIGEP*AC(M)
      DO 11 J=1,LMAT
      READ(1,62)RHO(M,J),C(M,J),AK(M,J),CMET(M,J),VEB(M,J)
      RHOCPV=RHOCPV+RHO(M,J)*C(M,J)*VT(M,J)
   62 FORMAT(5F12.5)
      EFB(M,J)=VEB(M,J)
      QB(M,J)=CMET(M,J)
      WT=WT+RHO(M,J)*VT(M,J)/1000.001
   11 WRITE(3,63)ANAME(M,1),ANAME(M,2),ANAME(M,3),J,RHO(M,J)
     *,C(M,J),AK(M,J),CMET(M,J),VEF(M,J)
   63 FORMAT(1X,3A4,4X,I2,2X,5(1X,F12.5,1X))
      IF(M.GT.ISPHER) GO TO 10
      ABR=R(M,NODE)+DR(M,LMAT)
      ABRR=R(M,NODE)+DR(M,LMAT)/2.
      BC(M,9)=-DR(M,LMAT)/AK(M,LMAT)/AC(M)*ABR*ABR/ABRR/ABRR
      GO TO 12
   10 ABC=AC(M)/R(M,NODE)
      BC(M,9)=-DR(M,LMAT)/(R(M,NODE)+DR(M,LMAT)/2.)/ABC/AK(M
     *,LMAT)
   12 CONTINUE
      WRITE(3,74) WT
   74 FORMAT(///T20,'THE TOTAL BODY WEIGHT'/T20,'EQUALS ==>'
     *,F10.5,' (KG)'//)
C
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C   <>                                                            <>
C   <>   CALCULATION OF COEFFICIENTS FOR ITERATIVE ROUTINE        <>
C   <>                                                            <>
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      CALL COEFRG
      READ(1,102)(EB(IM),IM=1,NUMS)
  102 FORMAT(16F5.0)
      READ(1,150) TAIR,VL,RH,WORK,DINT
  150 FORMAT(3F10.5,F20.5,F10.8,2I2)
      IM=0
      DO 302 M=1,NOP
      IF(ASYFL(M)) GO TO 302
      IM=IM+1
      BC(M,8)=RH
      BC(M,5)=DINT
      BC(M,1)=BC(M,11)*AC(M)
  302 CONTINUE
C
```

```
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C   <>                                                                  <>
C   <>     STEADY STATE TEMPERATURE DISTRIBUTION AND BODY               <>
C   <>     PARAMETERS ARE CALCULATED AND PRINTED.                       <>
C   <>                                                                  <>
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      CALL STEPRG(YY,Y)
      WRITE(3,73)
   73 FORMAT(//1X,' THE ARTERIAL BLOOD TEMPERATURES ARE A',
     *'S FOLLOWS:'//)
C
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C   <>                                                                  <>
C   <>          INPUT AND OUTPUT OF CONTROL COEFFICIENTS                <>
C   <>                                                                  <>
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      IM=0
      DO 15 M=1,NOP
      IF(ASYFL(M)) GO TO 15
      IM=IM+1
      LSK=ISK(M)
      L=IND(M)+1
      FSET(IM)=FLUX(IM)
      DO 5 N=1,L
    5 TO(M,N)=T(M,N)
      TOLD(IM)=T(M,L-1)
      VB=VB+VT(M,LSK)
      AT(1,IM)=TAR(M)-273.16
   15 CONTINUE
      CTOLD=T(1,1)
      WRITE(3,62)(AT(1,IM),IM=1,NUMS)
      READ(1,103) STOPIT
      WRITE(3,24) STOPIT
   24 FORMAT(//T20,'SUCCESSIVE ITERATIVE TEST EQUALS ==>',F5
     *.4)
  103 FORMAT(16F5.4)
      READ(1,103)(SKINR(IM),IM=1,NUMS)
      READ(1,103)(SKINS(IM),IM=1,NUMS)
      READ(1,103)(SKINV(IM),IM=1,NUMS)
      READ(1,103)(SKINC(IM),IM=1,NUMS)
      READ(1,103)(WORKM(IM),IM=1,NUMS)
      READ(1,103)(CHILM(IM),IM=1,NUMS)
      WRITE(3,104)
  104 FORMAT('1'//'  EB=CAL/HR'/'  FLUX=CAL/HR/SQ.CM '//T20,
     *'ENVIRONMENTAL COEFF.',T30,'WEIGHTING  COEFFICIENTS'//
     *6X,'ELEMENT            SKINR  SKINS  SKINV  SKINC  WOR',
     *'KM  CHILM',10X,'FLUX',11X,'EB')
      IM=0
      DO 105 M=1,NOP
      IF(ASYFL(M)) GO TO 105
      IM=IM+1
      WRITE(3,107)ANAME(M,1),ANAME(M,2),ANAME(M,3),SKINR(IM)
```

```
     *,SKINS(IM),SKINV(IM),SKINC(IM),WORKM(IM),CHILM(IM),FLU
     *X(IM),EB(IM)
  135 CONTINUE
  107 FORMAT(1X,3A4,8X,6F7.4,E20.8,F7.0)
      READ(1,110)CSW,SSW,PSW,CDIL,SDIL,PDIL,CCON,SCON,PCON,C
     *CHIL,SCHIL,PCHIL,BULL,ABL,QTEN,QTBL,PCO
  110 FORMAT(6F9.3)
      WRITE(3,112)CSW,SSW,PSW,CDIL,SDIL,PDIL,CCON,SCON,PCON,
     *CCHIL,SCHIL,PCHIL,BULL,ABL,QTEN,QTBL,PCO
  112 FORMAT(15(/),1X,T20,'CONTROLLER COEFFICIENTS    '///T25,
     *'CSW=',F9.4,'  KCAL/HR/DEG'/T25,'SSW=',F9.4,'  SQ.M'/T
     *22,'   PSW=',F9.4,'  LITER-SQ.M/KCAL'/T25,'CDIL=',F9.4
     *,'  LITER/HR/DEG'/T25,'SDIL=',F9.4,'  LITER-SQ.M/KCA',
     *'L'/T25,'PDIL=',F9.4,'  LITER-SQ.M/KCAL'/T25,'CCON=',F
     *9.4,'  1/DEG'/T25,'SCON=',F9.4,'  LITER-SQ.M/KCAL'/T25
     *,'PCON=',F9.4,'  LITER-SQ.M/KCAL'/T25,'CCHIL=',F9.4,2X
     *,'KCAL/HR/DEG'/T25,'SCHIL=',F9.4,'  SQ.M'/T25,'PCHIL='
     *,F9.4,'  KCAL/HR/SQ.DEG'/T25,'BULL=',F9.4,'  1/DEG'/T2
     *5,'ABL=',F9.3,'  LITER/DEG/HR'/T25,'QTEN=',F9.4,'  1',
     *'/DEG'/T25,'QTBL=',F9.4,' 1/DEG'/T25,'PCO=',F9.4,' M',
     *'L/CAL'///)
       CSW=CSW*1000.
       SSW=SSW*10000.
       PSW=PSW*10000.
       CDIL=CDIL*1000.
       SDIL=SDIL*10000.
       PDIL=PDIL*10000.
       SCON=SCON*10000.
       PCON=PCON*10000.
       CCHIL=CCHIL*1000.
       SCHIL=SCHIL*10000.
       PCHIL=PCHIL*1000.
       ABL=ABL*1000.
       GO TO 44
   90 CONTINUE
C
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C   <>                                                            <>
C   <>              INPUT AND OUTPUT OF TRANSIENT                 <>
C   <>              BOUNDRY CONDITIONS.                           <>
C   <>                                                            <>
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      READ(1,150) TAIR,VL,RH,WORK,DINT,IBC,IDA
      DO 202 M=1,NOP
      IF(ASYFL(M)) GO TO 202
      IF(IBC.NE.1) GO TO 22
      IF(IDA.EQ.0) GO TO 23
      READ(1,13)EPS(M),BC(M,3),BC(M,11),BC(M,8),BC(M,10)
   13 FORMAT(F5.4,F5.2,F8.4,F6.4,F8.4)
      BC(M,2)=EPS(M)*AC(M)*4.8756E-9
      BC(M,3)=BC(M,3)+273.16
      GO TO 23
```

```
   22 BC(M,8)=RH
      BC(M,3)=TAIR+273.16
      BC(M,10)=VL
   23 BC(M,7)=1.000000000001
      BC(M,5)=DINT
      BC(M,4)=BC(M,3)
      BC(M,1)=BC(M,11)*AC(M)*(BC(M,10)/.10)**0.5
  202 CONTINUE
C
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C  <>                                                                  <>
C  <>        TRANSIENT DETERMINATION OF TEMPERATURE                    <>
C  <>        DISTRIBUTION AND PHYSIOLOGICAL PARAMETERS                 <>
C  <>                                                                  <>
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      CALL STEPRG(YY,Y)
      TIME=TIME+BC(1,5)
   44 IQ=IQ+1
      IF(TIME.GE.TIMST) GO TO 82
      ETIME=TIME*60.00001
      TPOOL=TARP-273.16
C
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C  <>                                                                  <>
C  <>             OUTPUT OF TRANSIENT PHYSIOLOGICAL                    <>
C  <>             PARAMETERS FOR EACH TIME STEP                        <>
C  <>                                                                  <>
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      WRITE(3,40) ETIME,TPOOL,ECMET
   40 FORMAT(//1X,'TIME EQUALS  ',F5.1,' MINUTES'/1X,'ARTE
     *'RIAL POOL TEMPERATURE EQUALS  ',F6.3,'  DEG'/1X,'RE
     *'SPIRATORY LOSSES EQUALS  ',-3PF6.3,'  KCAL/HR'/)
      WRITE(3,42)
   42 FORMAT(8X,'ELEM    TCORE   TSKIN   INBAL    RBEC   BLHTR
     *'  MET     CONV     RAD     EVAP     SBF     TBF      QCC
     *'TAR     FLUX     FOT      FOOL')
      SOUT(IQ,1)=ETIME
      SOUT(IQ,13)=0.0
      EWET=0.0
      SOUT(IQ,12)=0.0
      SOUT(IQ,3)=ECMET
      SOUT(IQ,4)=ECMET
      SOUT(IQ,6)=0.0
      SOUT(IQ,5)=0.0
      SOUT(IQ,11)=0.0
      SOUT(IQ,12)=C0
      EO(IQ,1)=0.
      EO(IQ,2)=0.
      EO(IQ,3)=0.
      EO(IQ,4)=0.
      EO(IQ,5)=0.
      EO(IQ,6)=0.
```

```
      EO(IQ,7)=0.
      EO(IQ,8)=0.
      EO(IQ,9)=ECMET/1000.
      EO(IQ,10)=TAIR
      EO(IQ,11)=VL
      EO(IQ,12)=RH
      EO(IQ,13)=WORK/1000.
      CTOLD=T(1,1)
      IM=0
      DO 30 M=1,NOP
      IF(ASYFL(M)) GO TO 30
      L=IND(M)+1
      LSTOP=IND(M)
      IM=IM+1
      TOLD(IM)=T(M,L-1)
      ATAR=TAR(M)-273.16
      QCC=UA(M)*(TARP-TAR(M))
      EO(IQ,1)=EO(IQ,1)+EBT(M)/1000.001
      EO(IQ,2)=EO(IQ,2)+ENGR(M,7)/1000.001
      EO(IQ,3)=EO(IQ,3)+ENGR(M,1)/1000.001
      EO(IQ,4)=EO(IQ,4)+ENGR(M,2)/1000.001
      EO(IQ,5)=EO(IQ,5)+ENGR(M,3)/1000.001
      EO(IQ,6)=EO(IQ,6)+ENGR(M,4)/1000.001
      EO(IQ,7)=EO(IQ,7)+ENGR(M,5)/1000.001
      EO(IQ,8)=EO(IQ,8)+ENGR(M,6)/1000.001
      AT(IM,11)=T(M,L)-273.16
      AT(IM,2)=T(M,1)-273.16
      LSK=ISK(M)
      SOUT(IQ,6)=SOUT(IQ,6)+(T(M,L)-273.16)*VT(M,LSK)/VR
      EWET=EWET+EE(IM)/EMAX(IM)*AC(M)/TOTA/1.00001E04
      SOUT(IQ,4)=SOUT(IQ,4)+EE(IM)
      TBLF=0.0
      SKBF=0.0
      J=1
      CALL DEFRG(M,IMIN,IMAX,LMAT,NODE)
      DO 801 N=1,LSTOP
      IF(N.GT.IMAX(J)) J=J+1
      AQTEN=BM(M,N)**(QTEN/QTBL)
      VS=VEB(M,J)*V(M,N)/VT(M,J)
      CM=CMET(M,J)*V(M,N)/VT(M,J)
      IF(J.NE.LSK) GO TO 4
      SKBF=SKBF+VS*AQTEN
    4 SOUT(IQ,3)=SOUT(IQ,3)+CM*BM(M,N)
  801 TBLF=TBLF+VS*AQTEN
      SOUT(IQ,11)=SOUT(IQ,11)+SKBF/60000.01
      FOOL=FCOLD(IM)*SKINR(IM)
      FOT=FWARM(IM)*SKINR(IM)
      WRITE(3,43)ANAME(M,1),ANAME(M,2),ANAME(M,3),AT(IM,2),A
     *T(IM,11),EBT(M),ENGR(M,1),ENGR(M,2),ENGR(M,3),ENGR(M,4
     *),ENGR(M,5),ENGR(M,6),SKBF,TBLF,QCC,ATAR,FLUX(IM),FOT,
     *FOOL
   43 FORMAT(1X,3A4,0P2F7.2,-3P10F7.2,0P1F7.2,0P3F7.2)
   30 CONTINUE
      IF(IDA.EQ.0) GO TO 36
      WRITE(3,37)
```

```
 37 FORMAT(/1X,125('X')/T30,'**  WARNING  **'/T20,'BOUND',
   *'RY CONDITIONS HAVE BEEN CHANGED'/7X,'ELEM   EPS(M) ',
   *2X,'BC(M,11)    BC(M,8)    BC(M,10)'/)
    DO 38 M=1,NOP
    IF(ASYFL(M)) GO TO 38
    BCDUM=BC(M,3)-273.16
    WRITE(3,39)ANAME(M,1),ANAME(M,2),ANAME(M,3),EPS(M),BCD
   *UM,BC(M,11),BC(M,8),BC(M,10)
 39 FORMAT(1X,3A4,2X,F5.4,4X,F5.2,5X,F8.4,3X,F6.4,4X,F8.4)
 38 CONTINUE
C
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C   <>                                                            <>
C   <>   STORAGE OF PHYSIOLOGICAL DATA INTO SUMMARY ARRAYS       <>
C   <>                                                            <>
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
 36 EO(IQ,5)=EO(IQ,5)+EO(IQ,9)
    SOUT(IQ,4)=SOUT(IQ,4)/TOTA/1000.001
    SOUT(IQ,3)=SOUT(IQ,3)/TOTA/1000.001
    SOUT(IQ,2)=EO(IQ,3)/TOTA
    SOUT(IQ,13)=(SOUT(IQ,3)-ECMET/TOTA/1000.001-SOUT(IQ,2)
   *)/(TARP-273.16-SOUT(IQ,6))
    SOUT(IQ,5)=EO(IQ,2)*1000.001/RHOCPV
    SOUT(IQ,10)=T(7,2)-273.16
    SOUT(IQ,9)=T(2,2)-273.16
    SOUT(IQ,8)=TARP-273.16
    SOUT(IQ,7)=T(1,2)-273.16
    SOUT(IQ,12)=SOUT(IQ,12)/60000.01
    SOUT(IQ,14)=100.*EWET
    GO TO 90
C
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C   <>                                                            <>
C   <>   OUTPUT OF SUMMARY ARRAYS FOR TRANSIENT RESPONSE         <>
C   <>                                                            <>
C   <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
 32 K=60
    L=1
    LX=IQ-1
 77 WRITE(3,75)
    IF(LX.LT.60) K=K-60+LX
 75 FORMAT('1',' TIME  HFLOW     HP      EV      TR      TS     ',
   *' TH      TO      TR      TM      SBF      CO      COND     PWET')
    WRITE(3,76)((SOUT(II,JJ),JJ=1,14),II=L,K)
 76 FORMAT(1X,F5.1,3F7.2,6F6.2,2F7.3,2F7.2)
    IF(LX.LE.60) GO TO 78
    LX=LX-60
    L=L+60
    K=K+60
    GO TO 77
 78 K=60
    L=1
```

```
      LX=IQ-1
   87 WRITE(3,85)
      IF(LX.LT.60) K=K-60+LX
   85 FORMAT('1','ALL UNITS IN KCAL/HR EXCEPT TIME = MIN.,',
     *' TAIR = DEG-C,VEL =  M/SEC, AND RH IS NON-DIMENSION',
     *'AL'//1X,' TIME    INBAL        BEC         RBFC        BLHTR ',
     *'    MET        CONV         RAD        EVAP        RESP       TAI',
     *'R       VEL          RH       WORK')
      WRITE(3,86)(SOUT(II,1),(EO(II,JJ),JJ=1,13),II=L,K)
   86 FORMAT(1X,F5.1,13F9.3)
      IF(LX.LE.60) GO TO 88
      LX=LX-60
      L=L+60
      K=K+60
      GO TO 87
   88 CONTINUE
      STOP
      END
C
C <><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C <>                                                    <>
C <>           ****   *       ***    ***   *   *        <>
C <>           *   *  *      *   *  *   *  *  *         <>
C <>           ****   *      *   *  *      ***          <>
C <>           *   *  *      *   *  *   *  *  *         <>
C <>           ****   *****   ***    ***   *   *        <>
C <>                                                    <>
C <>                *****     *   *****   *              <>
C <>                *   *   * *    *    * *             <>
C <>                *   *  *   *   *   *   *            <>
C <>                *   *  *****   *   *****            <>
C <>                ****   *   *   *   *   *            <>
C <>                                                    <>
C <><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      BLOCK DATA
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION BC(34,11),DR(34,9),R(34,21),V(34,20),VT(34,9
     *),AC(34),RHO(34,9),C(34,9),AK(34,9),BM(34,20),CMET(34,
     *9),VEB(34,9),TAR(34),A(34,20),B(34,20),D(34,20),E(34,2
     *0),T(34,21),ID(126),TVEN(34),UA(34),VELB(34),IA(126),E
     *NGR(34,7),EBT(34),QB(34,9),BFB(34,9),TV(34),WARM(34),C
     *OLD(34),FLUX(34),ERROR(34),SKINR(34),SKINS(34),SKINV(3
     *4),SKINC(34),WORKM(34),CHILM(34),FF(34),FSET(34),FSKIN
     *(34),TO(34,21),RATE(34),TOLD(34),EF(34),EMAX(34),ANAMF
     *(34,3),ISK(34),IMU(34),FWARM(34),FCOLD(34)
      COMMON/ENV/BC/LDR/DR/LR/R/LV/V/LVT/VT/LAC/AC/LRHO/RHO/
     *LC/C/LAK/AK/LBM/BM/LCMET/CMET/LVEB/VEB/LTAR/TAR/LBLD/R
     *HOB,CB,TARP/COA/A/COB/B/COD/D/COE/E/LT/T/LID/NUM,ISPHE
     *R,NUMS,ISS,NOP,ID/LTVEN/TVEN/LUA/UA/LVELB/VELB/LIA/IA/
     *LENGR/ENGR/LEBT/EBT/LQB/QB/LBFB/BFB/LTIME/CO,ETIME,EWR
     *ITE/LTV/TV/LTOT/TOTV,TOTA/LWARM/WARM/LCOLD/COLD/LF/F/L
     *ERROR/ERROR/LSKINR/SKINR/LSKINS/SKINS/LSKINV/SKINV/LSK
     *INC/SKINC/LWORKM/WORKM/LCHILM/CHILM/LEB/EB/LHR/HR/LHC/
```

```
     *HC/LPSKIN/PSKIN/LTO/TO/LRATE/RATE/LTOLD/TOLD/LEE/EE/LE
     *MAX/EMAX/LIMU/IMU/LFLUX/FLUX/STOLWX/TAIR,VL,RH,WORK,EC
     *MET,CTOLD/LNAME/ANAME/LISK/ISK/LSTOL/CSW,SSW,PSW,CDIL,
     *SDIL,PDIL,CCON,SCON,PCON,CCHIL,SCHIL,PCHIL,BULL,ABL,PC
     *O/LQTEN/QTEN/LFSET/FSET/LFWARM/FWARM/LFCOLD/FCOLD/LQTB
     *L/QTBL/LSTOP/STOPIT/LMUS/MUS
      LOGICAL ASYFL
      DATA CSW,SSW,PSW,CDIL,SDIL,PDIL,CCON,SCON,PCON,CCHIL,S
     *CHIL,PCHIL,BULL,ABL,PCO/12*0.0,2*1000000.,1.0/,QTEN/10
     *00000./,QTBL/1000000./,STOPIT/.001/,T/714*309./,IA/1,2
     *,4,3,6,5,8,7,10,9,116*0/,BC/374*0.0/,ENGR/238*0.0/,EBT
     */34*0.0/,NUM,ISPHER,ISS,ID/34,1,1,10*1111,116*0/,CO,ET
     *IME,EWRITE/300000.,2*0.0/,TAR/34*309.93637/,RHOB,CB/1.
     *08,0.92/,TARP/309.93637/,TO/714*309.0/,TAIR,VL,RH,WORK
     */29.45,0.10,0.3,0.0/,RATE/34*0.0/,UA/34*0./,SKINR/34*0
     *.0/,SKINS/34*0.0/,SKINV/34*0.0/,SKINC/34*0.0/,WORKM/34
     **0.0/,CHILM/34*0.0/,FLUX/34*0.0/,FSET/34*0.0/,BFB/136*
     *0./,QB/136*0./,BM/680*1.0/
      END
C
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C  <>                                                        <>
C  <>            *****  *****    ***   *   *   *****         <>
C  <>            *      *       *   *  **  *     *           <>
C  <>            *****  *       *   *  * * *     *           <>
C  <>                *  *       *   *  *  **     *           <>
C  <>            *****  *****    ***   *   *     *           <>
C  <>                                                        <>
C  <><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
C
      SUBROUTINE SCONT
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION TS(11),P(11)
      DIMENSIONBC(1),VT(1),AC(1),BM(1),CMET(1),VEB(1),T(1),I
     *D(1),ENGR(1),QB(1),BFB(1),IMU(1),AK(1),R(1),FSET(1),FW
     *ARM(1),FCOLD(1),WARM(1),COLD(1),FLUX(1),ERROR(1),SKINR
     *(1),SKINS(1),SKINV(1),SKINC(1),WORKM(1),CHILM(1),EB(1)
     *,PSKIN(1),TO(1),RATE(1),TOLD(1),EE(1),EMAX(1),ANAME(1)
     *,ISK(1)
      COMMON/ENV/BC/LVT/VT/LAC/AC/LBM/BM/LCMET/CMET/LVEB/VEB
     */LT/T/LAK/AK/LID/NUM,ISPHER,NUMS,ISS,NOP,ID/LQB/QB/LBF
     *B/BFB/LIMU/IMU/LTIME/CO,ETIME,EWRITE/LR/R/LWARM/WARM/L
     *COLD/COLD/LF/F/LERROR/ERROR/LSKINR/SKINR/LSKINS/SKINS/
     *LSKINV/SKINV/LSKINC/SKINC/LWORKM/WORKM/LCHILM/CHILM/LE
     *B/EB/LPSKIN/PSKIN/LFLUX/FLUX/LTO/TO/LRATE/RATE/LTOLD/T
     *OLD/LEE/EE/LEMAX/EMAX/STOLWX/TAIR,VL,RH,WORK,ECMET,CTO
     *LD/LNAME/ANAME/LISK/ISK/LSTOL/CSW,SSW,PSW,CDIL,SDIL,PD
     *IL,CCON,SCON,PCON,CCHIL,SCHIL,PCHIL,BULL,ABL,PCO/LQTEN
     */QTEN/LFSET/FSET/LFWARM/FWARM/LFCOLD/FCOLD/LQTBL/QTBL/
     *LMUS/MUS
      LOGICAL ASYFL
      DATA TS/0.0,5.,10.,15.,20.,25.,30.,35.,40.,45.,50./
      DATA P/4.579,6.543,9.209,12.788,17.535,23.756,31.824,4
     *2.175,55.324,71.88,92.51/
```

```
      DATA IZ/2/
      RATES=0.0
      AGO=1.
      SUMT=0.0
      WARMS=0.0
      FWARMS=0.0
      COLDS=0.0
      FCOLDS=0.0
      CWARM=0.0
      CCOLD=0.0
      CRATE=(T(1)-CTOLD)/BC(137)
      IF(WORK.GT.71732.) GO TO 105
      WORKI=0.0
      GO TO 106
  105 WORKI=(WORK-71732.)*0.78
  106 IM=0
  301 DO 302 M=1,NCP
      IF(NSYFL(M)) GO TO 302
      IM=IM+1
      CALL DEFSRG(M,LMAT,NODE,IZ)
      L=M+NUM*(NODE-1)
      LL=M+NUM*(NODE-2)
      FLUX(IM)=(T(LL)-T(L))*AK(M+NUM*(LMAT-1))/(R(LL)-R(L))
      RATE(IM)=(T(L)-TOLD(IM))/BC(M+NUM*4)
      RATES=RATES+RATE(IM)*SKINR(IM)
      DO 306 N=1,NODE
      JN=M+NUM*(N-1)
  306 BM(JN)=2.**((T(JN)-TO(JN))/QTEN)
      WARM(IM)=0.0
      FWARM(IM)=0.0
      COLD(IM)=0.0
      FCOLD(IM)=0.0
      MSK=M+NUM*(NODE-1)
  310 ERROR(IM)=T(MSK)-TO(MSK)
      FERROR=FLUX(IM)-FSET(IM)
      IF(ERROR(IM).GT.0.0) GO TO 304
      IF(ERROR(IM).EQ.0.0) GO TO 307
      COLD(IM)=-ERROR(IM)
      COLDS=COLDS+COLD(IM)*SKINR(IM)
      SUMT=SUMT+(TO(MSK)-273.16)*SKINR(IM)
      GO TO 307
  304 WARM(IM)=ERROR(IM)
      WARMS=WARMS+WARM(IM)*SKINR(IM)
  307 IF(FERROR.GT.0.0) GO TO 308
      IF(FERROR.EQ.0.0) GO TO 302
      FCOLD(IM)=-FERROR
      FCOLDS=FCOLDS+FCOLD(IM)*SKINR(IM)
      GO TO 302
  308 FWARM(IM)=FERROR
      FWARMS=FWARMS+FWARM(IM)*SKINR(IM)
  302 CONTINUE
      TCOLD=COLDS-SUMT+28.5
      CERROR=T(1)-TO(1)
      IF(CERROR.LT.0.0) GO TO 303
```

```
      CWARM=CERROR
      FCCOLD=-CERROR
      GO TO 305
  303 CCOLD=-CERROR
      FCCOLD=-CERROR
  305 SWEAT=CSW*CWARM+SSW*FWARMS
      DILAT=CDIL*CWARM+SDIL*FWARMS
      STRIC=CCON*CCOLD+SCON*FCOLDS+PCON*COLDS
      IF(TCOLD.LT.0.0) AGO=0.
      CHILL=CCHIL*FCCOLD+SCHIL*FCOLDS+PCHIL*TCOLD*AGO
      IF(SWEAT.GE.0.0) GO TO 312
      SWEAT=0.0
  312 IF(DILAT.GE.0.0) GO TO 314
      DILAT=0.0
  314 IF(STRIC.GE.0.0) GO TO 316
      STRIC=0.0
  316 IF(CHILL.GE.0.0) GO TO 318
      CHILL=0.0
  318 IM=0
  400 DO 401 M=1,NOP
      IF(ASYFL(M)) GO TO 401
      IM=IM+1
      L=ISK(M)
      CUS=0.0
      IF(M.GE.MUS) CUS=(ABL*COLDS+PDIL*FCOLDS)*CHILM(IM)
      CALL MUSCLE(M,INUM,KA,KB,KC)
      IF(INUM.LE.0) GO TO 503
      GO TO (510,520,530),INUM
  530 NC=M+NUM*KC
      NB=M+NUM*KB
      NA=M+NUM*KA
      VM=VT(NC)+VT(NB)+VT(NA)
      CMET(NC)=QB(NC)+(WORKM(IM)*WORKI+CHILM(IM)*CHILL)*VT(N
     *C)/VM
      VEB(NC)=BFB(NC)+(WORKM(IM)*WORKI+CHILM(IM)*CHILL)*VT(N
     *C)/VM*PCO-CUS
      IF(VEB(NC).LE.0.005*BFB(NC)) VEB(NC)=.005*BFB(NC)
      GO TO 525
  520 NB=M+NUM*KB
      NA=M+NUM*KA
      VM=VT(NB)+VT(NA)
  525 CMET(NB)=QB(NB)+(WORKM(IM)*WORKI+CHILM(IM)*CHILL)*VT(N
     *B)/VM
      VEB(NB)=BFB(NB)+(WORKM(IM)*WORKI+CHILM(IM)*CHILL)*VT(N
     *B)/VM*PCO-CUS
      IF(VEB(NB).LE.0.005*BFB(NB)) VEB(NB)=.005*BFB(NB)
      GO TO 515
  510 NA=M+NUM*KA
      VM=VT(NA)
  515 CMET(NA)=QB(NA)+(WORKM(IM)*WORKI+CHILM(IM)*CHILL)*VT(N
     *A)/VM
      VEB(NA)=BFB(NA)+(WORKM(IM)*WORKI+CHILM(IM)*CHILL)*VT(N
     *A)/VM*PCO-CUS
      IF(VEB(NA).LE.0.005*BFB(NA)) VEB(NA)=.005*BFB(NA)
```

```
503 NJ=M+NUM*(L-1)
    VEB(NJ)=BFB(NJ)-STRIC*SKINC(IM)+DILAT*SKINV(IM)
    IF(VEB(NJ).LE.0.005*BFB(NJ)) VEB(NJ)=.005*BFB(NJ)
501 EE(IM)=(EB(IM)+SKINS(IM)*SWEAT)*2.0**(ERROR(IM)/BULL)
    CALL DEFSPG(M,LMAT,NODE,IZ)
    TZ=BC(M+NUM*2)-273.16
    CALL TERPRG(TS,P,TZ,PAIR,11)
    PAIR=PAIR*BC(M+NUM*7)
    NU=NODE+1
    TSK=T(M+NUM*(NU-1))-273.16
    CALL TERPRG(TS,P,TSK,PSKIN(IM),11)
    EMAX(IM)=(PSKIN(IM)-PAIR)*2.2*BC(M)
    IF(EE(IM).LE.EMAX(IM)) GO TO 403
    EE(IM)=EMAX(IM)
403 BC(M+NUM*5)=EE(IM)*T(M+NUM*(NU-1))
401 CONTINUE
    ECMET=(71732.+WORKI/.78+CHILL)*0.0023*(44.0-PAIR)
    CMET(3)=QB(3)-ECMET*.2
    CMET(38)=QB(38)-ECMET*.1
    CMET(71)=QB(71)-ECMET*.7
    VEB(5)=CO+BFB(5)
    VEB(6)=BFB(6)-PSW*FWARMS
    RETURN
    END
    SUBROUTINE COEFRG
    IMPLICIT REAL*8(A-H,O-Z)
    DIMENSION IMIN(10),IMAX(10)
    DIMENSION DR(1),R(1),VT(1),TAR(1),RHO(1),C(1),AK(1),BM(1),
   $CMET(1),VEB(1),A(1),B(1),D(1),E(1),ID(1),QB(1),BFB(1)
    COMMON/LDR/DR/LR/R/LVT/VT/LRHO/RHO/LC/C/LAK/AK/LBM/BM
    COMMON/LCMET/CMET/LVEB/VEB/LTAR/TAR/LBLP/RHOB,CB,TARP/COA/A/COB/B
    COMMON/COD/D/COE/E/LID/NUM,ISPHER,NUMS,ISS,NOP,ID
    COMMON/LQB/QB/LBFB/BFB
    COMMON/LQTEN/QTEN
    COMMON/LQTBL/QTBL
    LOGICAL ASYFL
    IGO=1
    ISP=1
    DO 99 I=1,NOP
    IF(I.GT.ISPHER) ISP=2
    ICEN=1
    IF(ASYFL(I)) GO TO 99
    CALL DEFRG(I,IMIN,IMAX,LMAT,NODE)
    K=1
    IF(IMIN(K).EQ.IMAX(K)) K=2
    GO TO (23,24),K
 24 ICEN=2
 23 BB=AK(I+NUM*(K-1))/DR(I+NUM*(K-1))/4.
    DO 80 N=2,NODE
    MP=I+NUM*K
    MM=I+NUM*(K-1)
    MN=I+NUM*(N-1)
    IF(IMIN(K).EQ.IMAX(K)) GO TO 14
    IF(N.EQ.IMIN(K)) GO TO 6
```

```
      IF(N.LT.IMAX(K)) GO TO 5
    4 IFLOW=1
      IF(N.EQ.NODE) GO TO 12
      AA=BB
      RP=DR(MM)+DR(MP)
      BB=(AK(MM)*DR(MM)+AK(MP)*DR(MP))/RP/RP/2.
      IGO=2
      GO TO 40
    6 IF(N.EQ.2) GO TO 16
      AA=BB
      BB=AK(MM)/DR(MM)/4.
      GO TO 40
    8 AA=BB
      GO TO 40
   19 IFLOW=2
   12 AA=BB
      GO TO (46,47),ISP
   46 BB=AK(MM)/DR(MM)/2.
      GO TO 48
   47 BBT=R(MN)/DR(MM)
      BB=AK(MM)*(BBT+.5)/(2.*BBT+1.)/DR(MM)
   48 GO TO (40,17),IFLOW
   14 IF(N.EQ.NODE) GO TO 19
      RP=DR(MM)+DR(MP)
      BB=(AK(MM)*DR(MM)+AK(MP)*DR(MP))/RP/RP/2.
      IGO=2
      GO TO 17
   16 BB=AK(MM)/DR(MM)/4.
   17 RP=DR(MM)+DR(I+NUM*(K-2))
      AA=(AK(MM)*DR(MM)+AK(I+NUM*(K-2))*DR(I+NUM*(K-2)))/RP/RP/2.
   40 AQTEN=BM(MN)**(QTEN/QTBL)
   10 CM=CMET(MM)/VT(MM)
      VB=VEB(MM)/VT(MM)
    9 GO TO (43,44),ISP
   43 AP=.75*(R(MN)+R(I+NUM*N))**2/(3.*DR(MM)*R(MN)**2+DR(MM)**3)
      AM=.75*(R(MN)+R(I+NUM*(N-2)))**2/(3.*DR(MM)*R(MN)**2+DR(MM)**3)
      GO TO 45
   44 AP=(1.+R(I+NUM*N)/R(MN))/2./DR(MM)
      AM=(1.+R(I+NUM*(N-2))/R(MN))/2./DR(MM)
   45 GO TO (27,28),ISS
   27 RC=1.
      GO TO 51
   28 RC=RHO(MM)*C(MM)
   51 A(MN)=(-RHOB*CB*VB*AQTEN-AA*AM-BB*AP)/RC
      B(MN)=AA*AM/RC
      D(MN)=BB*AP/RC
      E(MN)=(CM*BM(MN)+RHOB*CB*VB*AQTEN*TAR(I))/RC
      GO TO (80,18),IGO
   18 K=K+1
      IGO=1
   80 CONTINUE
      DUN=DR(I)*2.
      GO TO (33,34),ICEN
   33 AKBOB=AK(I)
```

```
      GO TO (49,50),ISP
   34 AKBOB=(AK(I)*DR(I)+AK(I+NUM)*DR(I+NUM))/(DR(I)+DR(I+NUM))
      GO TO (49,50),ISP
   49 ASP=6.
      GO TO 35
   50 ASP=4.
   35 GO TO (25,26),ISS
   25 RC=1.
      GO TO 52
   26 RC=RHO(I)*C(I)
   52 A(I)=(-ASP*AKBOB/DUN/DUN-RHOB*CB*VEB(I)/VT(I)*BM(I)**(QTEN/QTBL))/
     *RC
      B(I)=0.0
      D(I)=ASP*AKBOB/RC/DUN/DUN
      E(I)=(CMET(I)/VT(I)*BM(I)+RHOB*CB*VEB(I)/VT(I)*TAR(I)*BM(I)**(QTEN
     */QTBL))/RC
      ISP=1
   90 CONTINUE
      RETURN
      END
      SUBROUTINE EBAL(K,TT)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION IMIN(10),IMAX(10)
      DIMENSION BC(1),DR(1),R(1),V(1),VT(1),AC(1),RHO(1),C(1),AK(1),
     $BM(1),CMET(1),VEB(1),TAR(1),ID(1),ENGR(1),EBT(1),T(1),TT(1),QB(1),
     $BFB(1)
      COMMON/LBC/BC/LDR/DR/LR/R/LV/V/LVT/VT/LAC/AC/LRHO/RHO/LC/C/LAK/AK
      COMMON/LBM/BM/LCMET/CMET/LVEB/VEB/LTAR/TAR/LBLD/RHOB,CB/LT/T
      COMMON/LID/NUM,ISPHER,NUMS,N,NOP,ID/LENGR/ENGR/LEBT/EBT/LBFB/BFB
      COMMON/LQTEN/QTEN/LQTBL/QTBL/LQB/QB
   17 SUM=0.
      STOR=0.
      BEC=0.
      GEN=0.
      I=1
      CALL DEFRG(K,IMIN,IMAX,LMAT,NODE)
      NA=K+NUM*NODE
      DO 30 J=1,NODE
      IF(J.GT.IMAX(I)) I=I+1
      MN=K+NUM*(J-1)
      M=K+NUM*(I-1)
      AQTEN=BM(MN)**(QTEN/QTBL)
   10 CM=CMET(M)*V(MN)/VT(M)
      VB=VEB(M)*V(MN)/VT(M)
   16 STOR=STOR+RHO(M)*C(M)*V(MN)*(T(MN)-TT(MN))/BC(K+NUM*4)
      BEC=BEC+RHO(M)*C(M)*V(MN)*(T(MN)-273.16)
      ENGR(K+NUM*6)=BEC
      ENGR(K)=STOR
   15 SUM=SUM+RHOB*CB*VB*(T(MN)-TAR(K))*AQTEN
      ENGR(K+NUM)=SUM
   30 GEN=GEN+CM*BM(MN)
      ENGR(K+NUM*2)=GEN
      OUTA=BC(K)*(T(NA)-BC(K+NUM*2))
      ENGR(K+NUM*3)=OUTA
```

```
      OUTB=BC(K+NUM)*(T(NA)**4-BC(K+NUM*3)**4)
      ENGR(K+NUM*4)=OUTB
      OUTC=BC(K+NUM*5)/T(NA)
      ENGR(K+NUM*5)=OUTC
      OUT=OUTA+OUTB+OUTC
   18 GO TO (13,14),N
   13 EBT(K)=OUT-GEN+SUM
      RETURN
   14 EBT(K)=OUT-GEN+SUM+STOR
   20 RETURN
      END
      SUBROUTINE BLTPRG
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION IMIN(10),IMAX(10),DELT(126)
      DIMENSION V(1),VT(1),BM(1),BFB(1)
      DIMENSION VEB(1),TAR(1),T(1),ID(1),TVEN(1),UA(1),VELB(1)
      COMMON/LV/V/LVT/VT/LBFB/BFB
      COMMON/LVEB/VEB/LTAR/TAR/LBLD/RHOB,CB,TARP/LT/T/LBM/BM
      COMMON/LID/NUM,ISPHER,NUMS,ISS,NOP,ID/LTVEN/TVEN/LUA/UA/LVELB/VELB
      COMMON/LTIME/CO,ETIME,FWRITE
      COMMON/LQTEN/QTEN
      COMMON/LQTBL/QTBL
      LOGICAL ASYFL
      SUMB=0.
      SUMC=0.
      DO 5 I=1,NOP
      IF(ASYFL(I)) GO TO 5
      SUMA=0.
      VELB(I)=0.
      CALL DEFRG(I,IMIN,IMAX,LMAT,NODE)
      J=1
      DO 15 K=1,NODE
      MAT=I+NUM*(J-1)
      KN=I+NUM*(K-1)
      AQTEN=BM(KN)**(QTEN/QTBL)
    4 VB=VEB(MAT)*V(KN)/VT(MAT)
   10 VELB(I)=VELB(I)+VB*AQTEN
   25 SUMA=SUMA+T(KN)*VB*AQTEN
      IF(K.EQ.IMAX(J)) J=J+1
   15 CONTINUE
      TVEN(I)=SUMA/VELB(I)
    5 CONTINUE
      DO 45 I=1,NOP
      IF(ASYFL(I)) GO TO 45
   35 DELT(I)=TARP-TAR(I)
      TVEN(I)=TVEN(I)+DELT(I)
   40 SUMC=SUMC+VELB(I)*TVEN(I)
      SUMB=SUMB+VELB(I)
   45 CONTINUE
      CO=SUMB-CO
      TARP=SUMC/SUMB
      DO 50 I=1,NOP
      IF(ASYFL(I)) GO TO 50
   55 ALAM=UA(I)/VELB(I)/RHOB/CB
```

```
      TAR(I)=(TARP+ALAM*TVEN(I))/(ALAM+1.)
   50 CONTINUE
  400 RETURN
      END
      SUBROUTINE STEPRG(TT,DD)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION XAT(21)
      DIMENSION DD(1),TAR(1),EBT(1),ENGP(1),ANAME(1)
      DIMENSION A(1),B(1),D(1),E(1),BC(1),T(1),ID(1),TT(1),AT(1)
      COMMON/LTAR/TAR/LEBT/EBT/LENGR/ENGR
      COMMON/ENV/BC/COAY/A/COB/B/COD/D/COE/E/LT/T
      COMMON/LTIME/CO,ETIME,EWRITE/LNAME/ANAME/LID/NUM,ISPHER,NUMS,ISS,N
     $OP,ID
      COMMON/LSTOP/STOPIT
      IA=0
      LOGICAL ASYFL
      IT=1
      IL=0
      CALL SCONT
   53 IZ=2
      DO 90 K=1,NOP
      XBC=BC(1+NUM*6)
      IF(ASYFL(K)) GO TO 90
      DD(K)=TAR(K)
      CALL DEFSRG(K,LMAT,NODE,IZ)
      NN=K+NUM*NODE
      NU=NODE+1
   12 DO 30 I=1,NU
      N=K+NUM*(I-1)
      XAT(I)=T(N)
      GO TO (31,30),IT
   31 TT(N)=T(N)
   30 CONTINUE
   52 IF(ISS.NE.1) GO TO 20
      T(K)=-D(K)/A(K)*T(K+NUM)-E(K)/A(K)
      TT(K)=T(K)
      DO 6 I=2,NODE
      N=K+NUM*(I-1)
      T(N)=-B(N)/A(N)*T(K+NUM*(I-2))-D(N)/A(N)*T(K+NUM*I)-E(N)/A(N)
    6 TT(N)=T(N)
      T(NN)=BC(K+NUM*8)*(BC(K)*(T(NN)-BC(K+NUM*2))+BC(K+NUM)*(T(NN)**4-
     $BC(K+NUM*3)**4)+BC(K+NUM*5)/T(NN))+T(K+NUM*(NODE-1))
      GO TO 41
   20 T(K)=(-D(K)*BC(K+NUM*4)*T(K+NUM)-BC(K+NUM*4)*E(K)-TT(K))/(A(K)*BC(
     $K+NUM*4)-1.)
      DO 40 I=2,NODE
      N=K+NUM*(I-1)
   40 T(N)=(-BC(K+NUM*4)*(B(N)*T(K+NUM*(I-2))+D(N)*T(K+NUM*I))-BC(K+NUM*
     $4)*E(N)-TT(N))/(BC(K+NUM*4)*A(N)-1.)
      T(NN)=-BC(K+NUM*8)*(BC(K)*(BC(K+NUM*2)-TT(NN))+BC(K+NUM)*(BC(K+NUM
     $*3)**4-TT(NN)**4)-BC(K+NUM*5)/TT(NN))+T(K+NUM*(NODE-1))
   41 DO 51 J=1,NU
      N=K+NUM*(J-1)
      TEST=DABS(XAT(J)-T(N))
```

```
      XAT(J)=T(N)
      IF(TEST.GE.XBC) GO TO 52
   51 CONTINUE
   90 CONTINUE
      IT=2
      IL=IL+1
   35 CALL BLTPRG
      IAD=1
      ENERGY=0.
      EMAT=0.
      DO 73 I=1,NOP
      IF(ASYFL(I)) GO TO 73
      ETEST=DABS(DD(I)-TAR(I))
      DD(I)=TAR(I)
      IF(ETEST.GE.BC(I+NUM*6)) IAD=2
      CALL EBAL(I,TT)
      ENERGY=ENERGY+EBT(I)
      EMAT=EMAT+ENGR(I+NUM*2)
   73 CONTINUE
      CALL SCONT
      CALL COEFRG
      GO TO (74,53),IAD
   74 IF(BC(1+NUM*6).LE.STOPIT) GO TO 77
      DO 75 I=1,NOP
   75 BC(I+NUM*6)=BC(I+NUM*6)/10.
      GO TO 53
   77 EMAT=.05*EMAT
      IF(DABS(ENERGY).LT.EMAT) GO TO 70
   78 WRITE(3,79)
   79 FORMAT(/1X,'  CAUTION THE ENERGY BALANCE HAS NOT MET CRITERIA')
   70 IF(ISS.NE.1) GO TO 95
      WRITE(3,72) IL
      DO 10 K=1,NOP
      IF(ASYFL(K)) GO TO 10
      CALL DEFSRG(K,LMAT,NODE,IZ)
      NU=NODE+1
      DO 11 I=1,NU
      N=K+NUM*(I-1)
   11 TT(N)=T(N)-273.16
      WRITE(3,71)ANAME(K),ANAME(K+NUM),ANAME(K+NUM*2),(TT(K+NUM*(I-1)),I
     $=1,NU)
   10 CONTINUE
   71 FORMAT(1X,3A4,1X,2(T15,11F10.5/))
   72 FORMAT(/1X,'  STEADY STATE CONDITIONS HAVE BEEN REACHED.......THE
     $NUMBER OF ITERATIONS EXECUTED ==>',I10//1X,'THE STEADY STATE TEMPE
     $RATURE DISTRIBUTION FOLLOWS,'/1X,'STARTING FROM THE CENTER NODE TO
     $ THE SURFACE NODE ==>'/)
      ISS=2
   95 RETURN
      END
      SUBROUTINE GEOMRG(GEO,NUT,NOB)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION GEO(NUT,NOB),IMIN(10),IMAX(10),D(10)
      DIMENSION DR(1),R(1),V(1),VT(1),AC(1),ID(1),TV(1),ANAME(1)
```

```
      COMMON/LDR/DR/LR/R/LV/V/LVT/VT/LAC/AC/LID/NUM,ISPHER,NUMS,ISS,NOP,
     $ID
      COMMON/LTV/TV/LTOT/TOTV,TOTA/LNAME/ANAME
      LOGICAL ASYFL
      DATA PI/3.141592/
      TOTV=0.
      TOTA=0.0
      WRITE(3,68)
   68 FORMAT('1',T26,'SKIN     SUBCUT     DIA      DIA      DIA       DIA
     $DIA      DIA      DIA     SPHERE'/T7,'ELEMENT    CIRCUM    FOLD     FOLD
     $        RATIO    RATIO'   RATIO    RATIO    RATIO    RATIO    RATIO ANG(RA
     $D)    SEGMENT'/T18,'(CM)       THICK     THICK       MATL      MATL      MATL
     $    MATL      MATL      MATL      MATL    LENGTH      ANGLE'/T27, '(CM)
     $(CM)        3-4       4-5       5-6       6-7       7-8       8-9       9-10
     $(CM)        (RAD)')
      NUMS=NOP
      DO 31 I=1,NOP
      ISEG=2
      IF(ASYFL(I)) GO TO 30
      TV(I)=0.0
      READ(1,61)(GEO(I,J),J=1,12)
   61 FORMAT(F10.6,1X,F6.5,1X,F6.4,7F5.3,F8.4,F10.7)
      WRITE(3,62)ANAME(I),ANAME(I+NUM),ANAME(I+NUM*2),(GEO(I,J),J=1,12)
   62 FORMAT(1X,3A4,1X,F10.6,1X,F6.5,1X,F6.5,1X,8F8.4,1X,F10.7)
      CALL DEFRG(I,IMIN,IMAX,LMAT,NODE)
      NU=NODE+1
      DA=GEO(I,1)/PI
      D(3)=DA-GEO(I,3)
      K=LMAT+1
      DO 15 J=4,10
      D(J)=D(J-1)*GEO(I,J)
      N=K-J+1
      IF(J.EQ.K) GO TO 17
   15 DR(I+NUM*(N-1))=(D(J-1)-D(J))/4./DFLOAT(IMAX(N)-IMIN(N)+1)
   17 IE=2*(IMAX(N)-IMIN(N)+1)-1
      DR(I+NUM*(N-1))=(D(J-1)-D(J))/2./DFLOAT(IE)
      DR(I+NUM*(LMAT-2))=(GEO(I,3)-GEO(I,2))/4./DFLOAT(IMAX(LMAT-1)-IMIN
     $(LMAT-1)+1)
      DR(I+NUM*(LMAT-1))=GEO(I,2)/4./DFLOAT(IMAX(LMAT)-IMIN(LMAT)+1)
      SEG=GEO(I,12)/2./PI
      K=1
      VT(I+NUM*(K-1))=0.
      R(I)=0.
      R(I+NUM*(NU-1))=DA/2.
      DO 10 N=2,NODE
      IF(N.GE.IMIN(K).AND.N.LE.IMAX(K)) DD=2.*DR(I+NUM*(K-1))
      IF(N.GT.IMAX(K)) GO TO 11
   12 R(I+NUM*(N-1))=R(I+NUM*(N-2))+DD
      IF(I.GT.ISPHER) GO TO 33
      ISEG=1
      SEG=GEO(I,12)*PI*(1.-DCOS(GEO(I,11)*PI))
      V(I+NUM*(N-1))=((R(I+NUM*(N-1))+DR(I+NUM*(K-1)))**3-(R(I+NUM*(N-1)
     $)-DR(I+NUM*(K-1)))**3)*SEG/3.
      GO TO 34
```

```
33 V(I+NUM*(N-1))=PI*((R(I+NUM*(N-1))+DR(I+NUM*(K-1)))**2-(R(I+NUM*(N
  $-1))-DR(I+NUM*(K-1)))**2)*GEO(I,11)*SEG
34 VT(I+NUM*(K-1))=VT(I+NUM*(K-1))+V(I+NUM*(N-1))
   TV(I)=TV(I)+V(I+NUM*(N-1))
   GO TO 10
11 K=K+1
   DD=DR(I+NUM*(K-1))+DR(I+NUM*(K-2))
   VT(I+NUM*(K-1))=0.
   GO TO 12
10 CONTINUE
   GO TO (35,36),ISEG
36 V(I)=PI*DR(I)*DR(I)*GEO(I,11)*SEG
   AC(I)=GEO(I,1)*GEO(I,11)*SEG
   GO TO 37
35 V(I)=DR(I)*DR(I)*DR(I)*SEG/3.
   AC(I)=R(I+NUM*NODE)**2*SEG
37 VT(I)=VT(I)+V(I)
   TV(I)=TV(I)+V(I)
   GO TO 31
30 NUMS=NUMS-1
31 CONTINUE
   DO 70 N=1,NOP
   IF(ASYFL(N)) GO TO 70
   CALL DEFSRG(N,LMAT,NODE,2)
   NU=NODE+1
   WRITE(3,63)N,ANAME(N),ANAME(N+NUM),ANAME(N+NUM*2),AC(N),TV(N)
   WRITE(3,64)(VT(N+NUM*(K-1)),K=1,LMAT)
   WRITE(3,65)(DR(N+NUM*(K-1)),K=1,LMAT)
   WRITE(3,66)(R(N+NUM*(K-1)),K=1,NU)
   WRITE(3,67)(V(N+NUM*(K-1)),K=1,NODE)
   TOTV=TOTV+TV(N)
   TOTA=TOTA+AC(N)
70 CONTINUE
63 FORMAT(//T10,'DATA FOR BODY ELEMENT',I6,2X,3A4/T10,'SURFACE AREA (
  $SQ.CM)',2X,F10.3,T65,'TOTAL VOLUME (CUBIC-CM)',4X,F10.3/)
64 FORMAT(3X,'VT (CUBIC-CM)',2X,(T20,10F10.3))
65 FORMAT(3X,'DR (CM)',2X,(T20,10F10.3))
66 FORMAT(1X,'RADIUS (CM)',2X,(T20,10F10.4))
67 FORMAT(1X,'VOLUME (CUBIC-CM)',2X,(T20,10F10.3))
   TOTA=TOTA/10000.001
   WRITE(3,69)TOTV,TOTA
69 FORMAT(///1X,'TOTAL BODY VOLUME==>',F10.3,' (CUBIC CM)',T60,'TOTAL
  $ BODY AREA ==>',F10.3,' (SQUARE METERS)'/)
   RETURN
   END
   SUBROUTINE DEFRG(LSEC,IMIN,IMAX,LMAT,NODE)
   IMPLICIT REAL*8(A-H,O-Z)
   DIMENSION IMIN(10), IMAX(10),ID(126)
   COMMON/LID/NUM,ISPHER,NUMS,ISS,NOP,ID
   I7=1
   ENTRY DEFSEG(LSEC,LMAT,NODE,I7)
   NO=ID(LSEC)
   NODE=0
   DO 15 I=1,10
```

```
      NE=NO/10
      ICC=NO-NE*10
      NO=NE
      IF(ICC.EQ.0) GO TO 18
      IMIN(I)=ICC
   15 NODE=NODE+ICC
      I=I+1
   18 J=I-1
      LMAT=J
      GO TO (20,30),IZ
   30 RETURN
   20 ISTOR=IMIN(1)
      IMIN(1)=1
      IMAX(1)=ISTOR
      DO 16 K=2,J
      ISTOR=IMIN(K)
      IMIN(K)=IMAX(K-1)+1
   16 IMAX(K)=IMIN(K)+ISTOR-1
      RETURN
      END
      LOGICAL FUNCTION ASYFL(I)
      COMMON/LIA/IA(1)
      IF(I.NE.IA(I)) GO TO 5
      ASYFL=.FALSE.
      RETURN
    5 IF(I.GT.IA(I)) GO TO 6
      ASYFL=.FALSE.
      RETURN
    6 ASYFL=.TRUE.
      RETURN
      END
      SUBROUTINE MUSCLE(I,J,K,L,M)
      DIMENSION IMU(1)
      COMMON/LIMU/IMU
      J=IMU(I)-(IMU(I)/10)*10
      K=(IMU(I)-(IMU(I)/100)*100)/10-1
      L=(IMU(I)-(IMU(I)/1000)*1000)/100-1
      M=IMU(I)/1000-1
      RETURN
      END
      SUBROUTINE TERPNG(TABLE,COTAB,GIVE,WANT,INDEX)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION TABLE(INDEX),COTAB(INDEX)
      IF(GIVE.LT.TABLE(1)) GO TO 15
      IF(GIVE.GT.TABLE(INDEX)) GO TO 35
      IF(INDEX.GT.10) GO TO 40
      L=1
      WANT=COTAB(L)
      PROD=1.
      IND=INDEX-1
      GO TO 18
   40 DO 13 ILA=1,INDEX
      LA=ILA
      IF(TABLE(LA).GE.GIVE) GO TO45
```

```
   13 CONTINUE
   45 IF(TABLE(LA).EQ.GIVE) GO TO 60
      IF(LA.LE.10) IND=10
      IF(LA.GT.10) IND=LA
      L=IND-9
      WANT=COTAB(L)
      PROD=1.
   16 DO 10 I=L,IND
      PROD=PROD*(GIVE-TABLE(I))
      DIVDIF=0.
      IA=I+1
      DO 30 K=L,IA
      DPROD=1.
      DO 25 J=L,IA
      IF(J.EQ.K) GO TO 25
      DPROD=DPROD*(TABLE(K)-TABLE(J))
   25 CONTINUE
   30 DIVDIF=DIVDIF+COTAB(K)/DPROD
   10 WANT=WANT+PROD*DIVDIF
      RETURN
   15 WANT=COTAB(1)
      WRITE(3,50)GIVE
      RETURN
   35 WANT=COTAB(INDEX)
      WRITE(3,50)GIVE
   50 FORMAT(1X,'THE VALUE BEING INTERPOLATED (',E16.8,') EXCEEDS TABLE
     $RANGE, STANDARD FIXUP TAKEN')
      RETURN
   60 WANT=COTAB(LA)
      RETURN
      END
```

```
3.000          2    7
1 2 3 4 5 5 6 710 912111413 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    2111       2111      21111      2111      21111      21111      2111      2111
    2111       2111       2111      2111       2111       2111         0         0
       0          0          0         0          0          0         0         0
       0          0          0         0          0          0         0         0
       0          0          0         0          0          0         0         0
    0.0           0.0            0.0            0.14055       0.0
    0.0           0.80784        0.80784        1.00980       1.00980
    1.77131       1.77181        2.12617        2.12617       0.0
    0.0           0.0            0.0            0.0           0.0
    0.0           0.0            0.0            0.0           0.0
    0.0           0.0            0.0            0.0           0.0
    0.0           0.0            0.0            0.0           0.0
  0     0   312    21    31    31    21    21    21    21    21    21    21    21     0     0
  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
```

```
          HEAD      FOREHEAD          FACE            NECK         THORAX      ABDOMEN
          ARMS          ARMS         HANDS           HANDS           LEGS         LEGS
          FEET          FEET      NOT USED        NOT USED       NOT USED     NOT USED
      NOT USED      NOT USED      NOT USED        NOT USED       NOT USED     NOT USED
      NOT USED      NOT USED      NOT USED        NOT USED       NOT USED     NOT USED
      NOT USED      NOT USED      NOT USED        NOT USED       NOT USED     NOT USED
65.676020 .40001   .8160 .856 .0    .0      .0    .0    .0   .0   1.00    .8568969
65.676020 .40001   .8160 .856 .0    .0      .0    .0    .0   .0   1.00    .1431030
49.008470 .40001  1.9735 .796 .495  .0      .0    .0    .0   .0   9.8425 3.6041049
35.604717 .21623  0.8161 .495 .0    .0      .0    .0    .0   .0   8.4258 6.2831850
80.842249 .44488  3.1421 .789 .867  .0      .0    .0    .0   .0  28.5788 6.2831850
79.193402 .33028  4.1832 .793 .938  .0      .0    .0    .0   .0  55.1564 6.2831850
26.269337 .34      .9018 .395 .0    .0      .0    .0    .0   .0 127.4443 6.2831850
14.207163 .44     1.4393 .649 .0    .0      .0    .0    .0   .0  62.0224 6.2831850
35.968834 .60     2.1265 .515 .0    .0      .0    .0    .0   .0 139.3424 6.2831850
22.604526 .48     2.3457 .735 .0    .0      .0    .0    .0   .0  48.3591 6.2831850
   .20001   0.8      29.45      29.45    .09999999
   .26501   1.0      29.45      29.45    .09999999
   .31001   1.0      29.45      29.45    .09999999
   .32201    .6933   29.45      29.45    .09999999
   .11001   0.7735   29.45      29.450   .09999999
   .15801   0.7105   29.45      29.450   .09999999
   .32001   0.6774   29.45      29.45    .09999999
   .14301   0.7785   29.45      29.45    .09999999
   .23001   0.6129   29.45      29.45    .09999999
   .18301   0.9346   29.45      29.45    .09999999
    1.05        .883      4.536    13095.     41610.
    1.50        .5256    10.000        0.         0.
    0.85        .640      1.376        0.34       1.55
    1.00        .9269     1.797      100.      2960.
    1.05        .883      4.536     2190.      6950.
    1.50        .5256    10.000        0.         0.
    0.85        .640      1.376        0.06       0.26
    1.00        .9269     1.797       17.       494.
    1.05        .9269     3.612       80.       250.
    1.50        .5256    10.000        0.         0.
    1.05        .9269     3.612      180.       600.
    0.85        .640      1.376        0.6        2.71
    1.00        .9269     1.797       50.      2320.
    1.30        .5256     5.004        0.         0.
    1.05        .9269     3.612      340.         0.
    0.85        .640      1.376        0.25    1090.
    1.00        .9269     1.797       30.         1.16
    0.55        .9269     2.425     1700.       335.
    1.30        .5256     5.004        0.      4760.
    1.05        .9269     3.612     2630.         0.
    0.85        .640      1.376        8.59    8560.
    1.00        .9269     1.797      440.        39.01
    1.05        .883      4.700    36670.      1970.
    1.30        .5256     5.004        0.    165000.
    1.05        .9269     3.612     4320.         0.
    0.85        .640      1.376       22.7    14070.
    1.00        .9269     1.797      620.       103.1
    1.70        .5256    19.608        0.      3724.
                                                  0.
```

```
     1.05            .9269        3.612     2660.         9300.
     0.85            .640         1.376       2.58          11.7
     1.00            .9269        1.797      480.         2608.
     1.70            .5256       19.608        0.            0.
     1.05            .9269        3.612      160.          530.
     0.85            .640         1.376       1.03           4.69
     1.00            .9269        1.797      160.         2216.
     1.70            .5256       19.608        0.            0.
     1.05            .9269        3.612     4240.        13830.
     0.85            .640         1.376      11.4           51.8
     1.00            .9269        1.797      850.         4203.
     1.70            .5256       19.608        0.            0.
     1.05            .9269        3.612      250.          810.
     0.85            .640         1.376       2.43          11.03
     1.00            .9269        1.797      220.         1880.
 393.  66. 184. 200.1509.2843.1607. 603.3816. 830.
  29.4501     0.1        0.3                       0.0     9.9
.01
.0324.0054.0152.0165.1711.3224.0686.1845.1505.0334
.0377.0063.0177.0193.1668.3142.1540.0310.2180.0350
.0615.0103.0289.0314.1117.2103.0950.1210.2300.1000
.1131.0152.1414.0082.0008.0008.2700.1911.2104.2961
.0000.0000.0000.0000.1135.1865.0800.0100.6000.0100
.0000.0000.0339.0436.4414.4611.0076.0004.0113.0007
    0.0       0.1        0.0       0.0        0.5       4.0
    0.0       0.141       .030   300.0        1.35     75.0
 9999.99     33.0       10.       10.         1.5
  28.5001     0.1        0.3                       0.0     .16666666  0 0
  28.5001     0.1        0.3                       0.0     .16666666  0 0
  28.5001     0.1        0.3                       0.0     .16666666  0 0
   4.7001     0.1        0.3                       0.0     .00333333  0 0
   4.7001     0.1        0.3                       0.0     .00333333  0 0
   4.7001     0.1        0.3                       0.0     .00333333  0 0
   4.7001     0.1        0.3                       0.0     .00333333  0 0
   4.7001     0.1        0.3                       0.0     .00333333  0 0
   4.7001     0.1        0.3                       0.0     .00833333  0 0
   4.7001     0.1        0.3                       0.0     .00833333  0 0
   4.7001     0.1        0.3                       0.0     .00833333  0 0
   4.7001     0.1        0.3                       0.0     .00833333  0 0
   4.7001     0.1        0.3                       0.0     .00833333  0 0
   4.7001     0.1        0.3                       0.0     .00833333  0 0
   4.7001     0.1        0.3                       0.0     .00833333  0 0
   4.7001     0.1        0.3                       0.0     .00833333  0 0
   4.7001     0.1        0.3                       0.0     .01666666  0 0
   4.7001     0.1        0.3                       0.0     .01666666  0 0
   4.7001     0.1        0.3                       0.0     .01666666  0 0
   4.7001     0.1        0.3                       0.0     .01666666  0 0
   4.7001     0.1        0.3                       0.0     .01666666  0 0
   4.7001     0.1        0.3                       0.0     .01666666  0 0
   4.7001     0.1        0.3                       0.0     .01666666  0 0
   4.7001     0.1        0.3                       0.0     .01666666    0
   4.7001     0.1        0.3                       0.0     .01666666  0 0
   4.7001     0.1        0.3                       0.0     .01666666  0 0
   4.7001     0.1        0.3                       0.0     .04166666  0 0
```

4.7001	0.1	0.3	0.0	.04166666	0	0
4.7001	0.1	0.3	0.0	.04166666	0	0
4.7001	0.1	0.3	0.0	.04166666	0	0
4.7001	0.1	0.3	0.0	.04166666	0	0
4.7001	0.1	0.3	0.0	.04166666	0	0
4.7001	0.1	0.3	0.0	.08333333	0	0
4.7001	0.1	0.3	0.0	.08333333	0	0
4.7001	0.1	0.3	0.0	.08333333	0	0
4.7001	0.1	0.3	0.0	.08333333	0	0
4.7001	0.1	0.3	0.0	.08333333	0	0
4.7001	0.1	0.3	0.0	.08333333	0	0
4.7001	0.1	0.3	0.0	.16666666	0	0
4.7001	0.1	0.3	0.0	.16666666	0	0
4.7001	0.1	0.3	0.0	.16666666	0	0
4.7001	0.1	0.3	0.0	.25000000	0	0
4.7001	0.1	0.3	0.0	.25000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	-0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.50000000	0	0
4.7001	0.1	0.3	0.0	.25000000	0	0
4.7001	0.1	0.3	0.0	.25000000	0	0
4.7001	0.1	0.3	0.0	.25000000	0	0
4.7001	0.1	0.3	0.0	.25000000	0	0
4.7001	0.1	0.3	0.0	.25000000	0	0
4.7001	0.1	0.3	0.0	.25000000	0	0

APPENDIX C

THE MONTGOMERY MODEL
(MODIFIED)

The Montgomery model was implemented as a FORTRAN program. It has run on both an IBM 370/168 and an IBM 3033. On the IBM 3033 a ninety-minute simulation requires approximately twenty-eight CPU seconds. The following table lists the major variables of this model. Following the listing of the model, its input data and a typical output, there are instructions for using it.

MAJOR VARIABLES OF THE MONTGOMERY MODEL

Symbol	Definition	Units
A(N)	Area of the mid-plane between compartment N and N+1	M^2
AL(I)	Wet suit half-thickness covering segment I	M
AT	Adipose tissue weight	KG
BFB(N)	Basal blood flow to compartment N	L/HR
BFWT	Body fat weight	GM
BM	Diver's basal matabolic rate	$\frac{KCAL}{M^2-HR}$
C(N)	Thermal capacitance of compartment N	KCAL/^oC
CM(N)	Radius to the center of mass of compartment N	M
DO(I)	Outside diameter of Segment I	M
HAR	Height of arms segment	M
HF	Height of feet segment	M
HHA	Height of hands segment	M
HL	Height of legs segment	M
HSS(I)	Thermal conductance between skin and wet suit of segment I	KCAL/HR-^oC
HT	Diver's height	CM
HTR	Height of trunk segment	M
K(L)	Thermal conductivity values of different materials	$\frac{KCAL}{M-HR-^oC}$
LBWT	Lean body weight	GM
NAT	Non-adipose tissue weight	KG

Symbol	Definition	Units
PBF	Diver's percent body fat	N.D.
QB(N)	Basal metabolism of compartment N	KCAL/HR
QC	Total basal metabolism of body core excluding head and trunk core	KCAL/HR
QM	Total basal metabolism of muscle	KCAL/HR
QSF	Total basal metabolism of skin plus fat	KCAL/HR
R(N)	Radius of compartment N	M
RMP(N)	Radius to the mid-plane between compartment N and N+1	M
S(I)	Outside surface area of segment I	M^2
SA	Total body surface area	CM^2
SG	Specific gravity of diver	N.D.
SWT(N)	Body compartment (N) weight	KG
TC(N)	Thermal conductance between compartment N and N+1	KCAL/HR-°C
THWS(I)	Wet suit thickness covering segment I	M
VAR	Volume of arms segment	M^3
VF	Volume of feet segment	M^3
VHA	Volume of hands segment	M^3
VL	Volume of legs segment	M^3
VTR	Volume of trunk segment	M^3
WC	Weight of body core	KG
WM	Total weight of muscle	KG
WSCP	Wet suit specific heat	$\frac{KCAL}{KG\text{-}^{\circ}C}$
WSD	Wet suit density	KG/M^3
WSF	Total weight of skin plus fat	KG
WT	Diver's weight	GM
X(N)	Heat transfer length between compartment N and N+1	M

Symbol	Definition	Units
COND3	Total body heat loss to ambient water	$\frac{KCAL}{M^2-HR}$
DEN	Density of ambient water	KG/M^3
DILAT	Total efferent skin vasodilation command	$\frac{L}{HR}$
DT	Integration step	HR
E(N)	Total evaporative heat loss from N	$\frac{KCAL}{HR}$
EB(N)	Basal evaporative heat loss from N	KCAL/HR
EE	Total respiratory heat loss	$\frac{KCAL}{HR}$
ERROR(N)	Output from thermoreceptors in compartment N	^oC
EV	Total evaporative heat loss	$\frac{KCAL}{M^2-HR}$
F(N)	Rate of change of temperature in N	$^oC/HR$
H(I)	Total environmental heat transfer coefficient for Segment I	$\frac{KCAL}{M^2-HR-^oC}$
HF(N)	Rate of heat flow into or from N	$\frac{KCAL}{HR}$
HFLOW	Total rate of heat flow to or from the body	$\frac{KCAL}{M^2-HR}$
HO(I)	Water-wet suit surface heat transfer coefficient for Segment I	$\frac{KCAL}{M^2-HR-^oC}$
HP	Total metabolic heat production	$\frac{KCAL}{M^2-HR}$
HTBAL	Total body heat balance	$\frac{KCAL}{M^2-HR}$

Symbol	Definition	Units
H2OOUT	Total water loss rate in expiratory gas	$\frac{GM}{HR}$
INT	Interval between outputs	MIN.
ITIME	Elapsed time	MIN.
JTIME	Elapsed time	MIN.
M	Metabolic heat production = HP (Print out label)	$\frac{KCAL}{M^2 \cdot HR}$
MU	Dynamic viscosity of water	$\frac{KG}{HR-M}$
P(I)	Water vapor pressure table from 0-50°C	mm Hg
PAIR	Vapor pressure of environmental air	mm Hg
PIN	Saturated water vapor pressure of inspired air	mm Hg
POUT	Saturated water vapor pressure of expired air	mm Hg
PR	Prandtl Number of environmental water	N.D.
Q(N)	Total metabolic heat production in N	$\frac{KCAL}{HR}$
RATE(N)	Dynamic sensitivity of thermo-receptors in N	HR
RE(I)	Reynolds' Number of body Segment I	N.D.
RHEAT	Respiratory heat generation rate	$\frac{CAL}{MIN}$
RHL	Respiratory heat loss rate	$\frac{KCAL}{HR}$
S	Rate of body heat storage = HFLOW (Print out label)	$\frac{KCAL}{M^2-HR}$
S(I)	Surface area of Segment I	M^2

Symbol	Definition	Units
SA	Total skin surface area	M^2
SBF	Total skin blood flow	$\frac{L}{MIN}$
SKINC(I)	Fraction of vasoconstriction command applicable to skin of Segment I	N.D.
SKINR(I)	Fraction of all skin receptors in Segment I	N.D.
SKINS(I)	Fraction of sweating command applicable to skin of Segment I	N.D.
SKINV(I)	Fraction of vasodilation command applicable to skin of Segment I	N.D.
STRIC	Total efferent skin vasoconstriction command	N.D.
SV	Specific volume of water	M^3/KG
SWEAT	Total efferent sweat command	$\frac{KCAL}{HR}$
T(N)	Temperature of N	^oC
TB	Mean weighted body temperature	^oC
TD(N)	Conductive heat transfer between N and N+1	$\frac{KCAL}{HR}$
TE	Absolute temperature of expiratory gas	^oK
TH	Temperature of the head core, representing the hypothalamic temperature = T(1) (Print out label)	^oC
TI	Absolute temperature of inspiratory gas	^oK
TIME	Elapsed time	MIN.
TM	Temperature of muscle compartment in the leg = T(47) (Print out label)	^oC

Symbol	Definition	Units
TO	Temperature of the central blood compartment, representing esophageal temperature = T(61) (Print out label)	°C
TR	Trunk core temperature representing rectal temperature = T(11) (Print out label)	°C
TS	Mean weighted skin temperature	°C
TSET(N)	"Set point" or reference point for receptors in compartment N	°C
U(I)	Overall body Segment I wet suit-water heat transfer coefficient	$\frac{KCAL}{M^2\text{-}HR\text{-}°C}$
VE	Respiratory gas expiration rate	$\frac{L}{HR}$
VEMIN	Respiratory gas expiratory minute volume	$\frac{L}{MIN}$
WARM(N)	Output from warm receptors in N	°C
WARMS	Integrated output from skin warm receptors	°C
WORKM(I)	Fraction of total work done by muscles in Segment I	N.D.
BULL	Factor determining temperature sensitivity of sweat gland response	1/°C
CCHIL	Shivering from head core	KCAL/HR-°C
CCON	Vasoconstriction from head core	1/°C
CDIL	Vasodilation from head core	L/HR-°C
CSW	Sweating from head core	KCAL/HR-°C
SCHIL	Shivering from skin	KCAL/HR-°C
SCON	Vasoconstriction from skin	1/°C
SDIL	Vasodilation from skin	L/HR-°C
SSW	Sweating from skin	KCAL/HR-°C

Symbol	Definition	Units
PCHIL	Shivering from skin and head core	$1/°C^2$
PCON	Vasoconstriction from skin and head core	$1/°C^2$
PDIL	Vasodilation from skin and head core	$L/HR\text{-}°C^2$
PSW	Sweating from skin and head core	$KCAL/HR\text{-}°C$

```
      COMMON/PASS/AL(6),DO(6),HSS(6),S(6),TC(60),QB(60),BFB(60)
     *,C(67),CS(1),CH(1),RK(6)
      CALL SIZE
      CALL WETMAN
      STOP
      END
      SUBROUTINE SIZE
C THIS PROGRAM IS FOR A FULL WET SUIT HEAD OUT
      REAL NAT,K
      DIMENSION K(3)
      DIMENSION X(60),RMP(60),A(60)
      DIMENSION THWS(6),R(66),CM(66),H(6)
      DIMENSION SWT(61)
      COMMON/PASS/AL(6),DO(6),HSS(6),S(6),TC(60),QB(60),BFB(60)
     *,C(67),CS(1),CB(1),RK(6)
      DATA WSCP/0.25/,WSD/241.0/,SG/0.0/
      DATA THWS/0.006312,0.006312,0.006312,0.006312,0.006312,0.006312/
      DATA K/0.3193,0.1419,0.046/
      DATA RK/0.03711,0.03711,0.03711,0.03711,0.03711,0.03711/
      READ(1,3)HT,WT
3     FORMAT(2F10.5)
      READ(1,7)BM
7     FORMAT(F10.5)
      IF(SG.GT.0.0)GO TO 5
      SG=0.8*((HT**0.242)/(WT**0.1))+0.162
5     PBF=(5.548/SG)-5.044
      BFWT=PBF*WT
      LBWT=WT-BFWT
      SA=71.84*((WT/1000)**0.425)*(HT**0.725)
      S(1)=0.07*SA*0.0001
      S(2)=0.3602*SA*0.0001
      S(3)=0.1341*SA*0.0001
      S(4)=0.05*SA*0.0001
      S(5)=0.3174*SA*0.0001
      S(6)=0.0686*SA*0.0001
      AT=BFWT*0.001
      NAT=LBWT*0.001
      DO 2 I=1,4
2     SWT(I)=(0.0164/(0.85*4.0))*NAT+(0.024/(0.85*4.0))*NAT
      DO 4 I=5,8
4     SWT(I)=(0.005/(0.85*4.0))*NAT
      SWT(9)=(0.005/0.15)*AT
      SWT(10)=(0.0036/0.85)*NAT
      DO 6 I=11,14
6     SWT(I)=(0.038/(0.85*4.0))*NAT+(0.159/(0.85*4.0))*NAT
      DO 8 I=15,18
8     SWT(I)=(0.2409/(0.85*4.0))*NAT
      SWT(19)=(0.095/0.15)*AT
```

```
      SWT(20)=(0.0181/0.85)*NAT
      DO 10 I=21,24
10    SWT(I)=(0.0202/(0.85*4.0))*NAT+(0.01/(0.85*4.0))*NAT
      DO 12 I=25,28
12    SWT(I)=(0.0453/(0.85*4.0))*NAT
      SWT(29)=(0.013/0.15)*AT
      SWT(30)=(0.0065/0.85)*NAT
      DO 14 I=31,34
14    SWT(I)=(0.0031/(0.85*4.0))*NAT+(0.0004/(0.85*4.0))*NAT
      DO 16 I=35,38
16    SWT(I)=(0.001/(0.85*4.0))*NAT
      SWT(39)=(0.002/0.15)*AT
      SWT(40)=(0.0025/0.85)*NAT
      DO 180 I=41,44
180   SWT(I)=(0.0673/(0.85*4.0))*NAT+(0.0258/(0.85*4.0))*NAT
      DO 200 I=45,48
200   SWT(I)=(0.1368/(0.85*4.0))*NAT
      SWT(49)=(0.032/0.15)*AT
      SWT(50)=(0.0161/0.85)*NAT
      DO 22 I=51,54
22    SWT(I)=(0.005/(0.85*4.0))*NAT+(0.0008/(0.85*4.0))*NAT
      DO 24 I=55,58
24    SWT(I)=(0.001/(0.85*4.0))*NAT
      SWT(59)=(0.003/0.15)*AT
      SWT(60)=(0.0032/0.85)*NAT
      SWT(61)=2.50
      DO 26 I=1,4
26    C(I)=(0.5*(0.0164/0.85)*NAT+0.9*(0.024/0.85)*NAT)/4.0
      DO 28 I=5,8
28    C(I)=0.9*SWT(I)
      C(9)=0.6*SWT(9)
      C(10)=0.9*SWT(10)
      DO 300 I=11,14
300   C(I)=(0.5*(0.038/0.85)*NAT+0.9*(0.159/0.85)*NAT)/4.0
      DO 320 I=15,18
320   C(I)=0.9*SWT(I)
      C(19)=0.6*SWT(19)
      C(20)=0.9*SWT(20)
      DO 340 I=21,24
340   C(I)=(0.5*(0.0202/0.85)*NAT+0.9*(0.01/0.85)*NAT)/4.0
      DO 36 I=25,28
36    C(I)=0.9*SWT(I)
      C(29)=0.6*SWT(29)
      C(30)=0.9*SWT(30)
      DO 38 I=31,34
38    C(I)=(0.5*(0.0031/0.85)*NAT+0.9*(0.0004/0.85)*NAT)/4.0
      DO 40 I=35,38
40    C(I)=0.9*SWT(I)
      C(39)=0.6*SWT(39)
      C(40)=0.9*SWT(40)
      DO 42 I=41,44
42    C(I)=(0.5*(0.0673/0.85)*NAT+0.9*(0.0258/0.85)*NAT)/4.0
      DO 44 I=45,48
44    C(I)=0.9*SWT(I)
```

```
      C(49)=0.6*SWT(49)
      C(50)=0.9*SWT(50)
      DO 46 I=51,54
46    C(I)=(0.5*(0.005/0.85)*NAT+0.9*(0.0008/0.85)*NAT)/4.0
      DO 48 I=55,58
48    C(I)=0.9*SWT(I)
      C(59)=0.6*SWT(59)
      C(60)=0.9*SWT(60)
      C(61)=0.9*SWT(61)
      DO 50 I=11,14
50    C(I)=C(I)-C(61)/4.0
      CS(1)=C(10)+C(20)+C(30)+C(40)+C(50)+C(60)
      CB(1)=0.0
      DO 52 I=1,61
      CB(1)=CB(1)+C(I)
52    CONTINUE
      QSF=0.3*(0.05882*NAT+1.0*AT)
      QM=(0.18*(BM*SA/10000))-QSF
      QC=0.10*(BM*SA/10000)
      WSF=0.05882*NAT+1.0*AT
      WM=0.5059*NAT
      WC=0.1765*NAT+0.2588*NAT
      DO 54 I=1,4
54    QB(I)=SWT(I)*QC/WC+0.04*(BM*SA/10000)
      DO 56 I=5,8
56    QB(I)=SWT(I)*QM/WM
      QB(9)=SWT(9)*QSF/WSF
      QB(10)=SWT(10)*QSF/WSF
      DO 58 I=11,14
58    QB(I)=SWT(I)*QC/WC+0.14*(BM*SA/10000)
      DO 60 I=15,18
60    QB(I)=SWT(I)*QM/WM
      QB(19)=SWT(19)*QSF/WSF
      QB(20)=SWT(20)*QSF/WSF
      DO 62 I=21,24
62    QB(I)=SWT(I)*QC/WC
      DO 64 I=25,28
64    QB(I)=SWT(I)*QM/WM
      DO 66 I=29,30
66    QB(I)=SWT(I)*QSF/WSF
      DO 68 I=31,34
68    QB(I)=SWT(I)*QC/WC
      DO 70 I=35,38
70    QB(I)=SWT(I)*QM/WM
      DO 72 I=39,40
72    QB(I)=SWT(I)*QSF/WSF
      DO 74 I=41,44
74    QB(I)=SWT(I)*QC/WC
      DO 76 I=45,48
76    QB(I)=SWT(I)*QM/WM
      DO 78 I=49,50
78    QB(I)=SWT(I)*QSF/WSF
      DO 80 I=51,54
80    QB(I)=SWT(I)*QC/WC
```

```
      DO 82 I=55,58
82    QB(I)=SWT(I)*QM/WM
      DO 84 I=59,60
84    QB(I)=SWT(I)*QSF/WSF
      DO 86 I=1,60
86    BFB(I)=1.2*QB(I)
      DO 88 I=1,4
88    BFB(I)=11.25
      DO 90 I=11,14
90    BFB(I)=52.5
      BFB(10)=5.34*SWT(10)
      BFB(20)=1.56*SWT(20)
      BFB(30)=1.35*SWT(30)
      BFB(40)=5.58*SWT(40)
      BFB(50)=0.84*SWT(50)
      BFB(60)=2.34*SWT(60)
      R(1)=(((0.003*SWT(1))/12.56)**0.333)
      DO 92 I=2,10
92    R(I)=((R(I-1)**3.0)+((0.003*SWT(I))/12.56))**0.333
      R(61)=R(10)+THWS(1)
      VTR=0.0
      DO 94 I=11,20
94    VTR=VTR+SWT(I)*0.001
      HTR=(S(2)**2.0)/(12.56*VTR)
C*****CHANGE A TO AA.   A IS PREVIOUSLY DIMENSIONED.*****
      AA=0.001
      R(20)=(2*VTR)/S(2)
      DO 96 I=1,9
      J=21-I
      R(J-1)=((R(J)**2)-((AA*SWT(J))/(3.14*HTR)))**0.5
96    CONTINUE
      R(62)=R(20)+THWS(2)
      VAR=0.0
      DO 98 I=21,30
98    VAR=VAR+SWT(I)*0.001
      HAR=(S(3)**2.0)/(12.56*VAR)
      R(30)=(2.0*VAR)/S(3)
      DO 100 I=1,9
      J=31-I
      R(J-1)=((R(J)**2)-((AA*SWT(J))/(3.14*HAR)))**0.5
100   CONTINUE
      R(63)=R(30)+THWS(3)
      VHA=0.0
      DO 102 I=31,40
102   VHA=VHA+SWT(I)*0.001
      HHA=(S(4)**2.0)/(12.56*VHA)
      R(40)=(2.0*VHA)/S(4)
      DO 104 I=1,9
      J=41-I
      R(J-1)=((R(J)**2)-((AA*SWT(J))/(3.14*HHA)))**0.5
104   CONTINUE
      R(64)=R(40)+THWS(4)
      VL=0.0
      DO 106 I=41,50
```

```
106   VL=VL+SWT(I)*0.001
      HL=(S(5)**2.0)/(12.56*VL)
      R(50)=(2.0*VL)/S(5)
      DO 108 I=1,9
      J=51-I
      R(J-1)=((R(J)**2)-((AA*SWT(J))/(3.14*HL)))**0.5
108   CONTINUE
      R(65)=R(50)+THWS(5)
      VF=0.0
      DO 110 I=51,60
110   VF=VF+SWT(I)*0.001
      HF=(S(6)**2.0)/(12.56*VF)
      R(60)=(2.0*VF)/S(6)
      DO 112 I=1,9
      J=61-I
      R(J-1)=((R(J)**2)-((AA*SWT(J))/(3.14*HF)))**0.5
112   CONTINUE
      R(66)=R(60)+THWS(6)
      CM(1)=0.7937*R(1)
      DO 114 I=2,10
114   CM(I)=0.7937*((R(I-1)**3)+(R(I)**3))**0.333
      CM(61)=0.7937*((R(10)**3)+(R(61)**3))**0.333
      CM(11)=0.7071*R(11)
      DO 116 I=12,20
116   CM(I)=0.7071*((R(I-1)**2)+(R(I)**2))**0.5
      CM(62)=0.7071*((R(20)**2)+(R(62)**2))**0.5
      CM(21)=0.7071*R(21)
      DO 118 I=22,30
118   CM(I)=0.7071*((R(I-1)**2)+(R(I)**2))**0.5
      CM(63)=0.7071*((R(30)**2)+(R(63)**2))**0.5
      CM(31)=0.7071*R(31)
      DO 120 I=32,40
120   CM(I)=0.7071*((R(I-1)**2)+(R(I)**2))**0.5
      CM(64)=0.7071*((R(40)**2)+(R(64)**2))**0.5
      CM(41)=0.7071*R(41)
      DO 122 I=42,50
122   CM(I)=0.7071*((R(I-1)**2)+(R(I)**2))**0.5
      CM(65)=0.7071*((R(50)**2)+(R(65)**2))**0.5
      CM(51)=0.7071*R(51)
      DO 124 I=52,60
124   CM(I)=0.7071*((R(I-1)**2)+(R(I)**2))**0.5
      CM(66)=0.7071*((R(60)**2)+(R(66)**2))**0.5
      DO 126 I=1,60
126   X(I)=CM(I+1)-CM(I)
      DO 128 I=1,6
128   X(10*I)=CM(I+60)-CM(10*I)
      DO 130 I=1,60
130   RMP(I)=CM(I)+X(I)/2.0
      DO 132 I=1,10
132   A(I)=12.56*(RMP(I)**2)
      DO 134 I=11,20
134   A(I)=6.28*RMP(I)*HTR
      DO 136 I=21,30
136   A(I)=6.28*RMP(I)*HAR
```

```
      DO 138 I=31,40
138   A(I)=6.28*RMP(I)*HHA
      DO 140 I=41,50
140   A(I)=6.28*RMP(I)*HL
      DO 142 I=51,60
142   A(I)=6.28*RMP(I)*HF
      DO 144 I=1,60
144   TC(I)=(K(1)*A(I))/X(I)
      RMPA=CM(8)+((R(8)-CM(8))/2.0)
      AA=12.56*(RMPA**2)
      XA=R(8)-CM(8)
      YA=(K(1)*AA)/XA
      RMPB=R(8)+((CM(9)-R(8))/2.0)
      AB=12.56*(RMPB**2)
      XB=CM(9)-R(8)
      YB=(K(2)*AB)/XB
      TC(8)=(YA*YB)/(YA+YB)
      DO 146 I=1,6
146   TC(10*I)=0.0
      DO 148 I=1,6
148   TC(10*I-1)=(K(2)*A(10*I-1))/X(10*I-1)
      H(1)=0.0
      H(2)=HTR
      H(3)=HAR
      H(4)=HHA
      H(5)=HL
      H(6)=HF
      DO 150 I=2,6
      RMPA1=CM(10*I-2)+((R(10*I-2)-CM(10*I-2))/2.0)
      AA1=6.28*RMPA1*H(I)
      XA1=R(10*I-2)-CM(10*I-2)
      YA1=(K(1)*AA1)/XA1
      RMPB1=R(10*I-2)+((CM(10*I-1)-R(10*I-2))/2.0)
      AB1=6.28*RMPB1*H(I)
      XB1=CM(10*I-1)-R(10*I-2)
      YB1=(K(2)*AB1)/XB1
      TC(10*I-2)=(YA1*YB1)/(YA1+YB1)
150   CONTINUE
      SMPR=CM(10)+((R(10)-CM(10))/2)
      SMPA=12.56*(SMPR**2)
      SX=R(10)-CM(10)
      SY=(K(2)*SMPA)/SX
      WSMPR=R(10)+((CM(61)-R(10))/2)
      WSMPA=12.56*(WSMPR**2)
      WSX=CM(61)-R(10)
      WSY=(K(3)*WSMPA)/WSX
      HSS(1)=(SY*WSY)/(SY+WSY)
      DO 152 I=2,6
      SMPRI=CM(10*I)+((R(10*I)-CM(10*I))/2)
      SMPA1=6.28*SMPRI*H(I)
      SX1=R(10*I)-CM(10*I)
      SY1=(K(2)*SMPA1)/SX
      WSMPR1=R(10*I)+((CM(I+60)-R(10*I))/2.0)
      WSMPA1=6.28*WSMPR1*H(I)
```

```
      WSX1=CM(I+60)-R(10*I)
      WSY1=(K(3)*WSMPA1)/WSX1
      HSS(I)=(SY1*WSY1)/(SY1+WSY1)
152   CONTINUE
      DO 154 I=1,6
154   AL(I)=R(I+60)-CM(I+60)
      DO 156 I=1,6
156   DO(I)=2.0*R(I+60)
      S(1)=12.56*(R(61)**2)
      DO 158 I=2,6
158   S(I)=6.28*R(I+60)*H(I)
      C(62)=WSCP*WSD*1.333*3.14*((R(61)**3)-(R(10)**3))
      DO 160 I=2,6
160   C(I+61)=WSCP*WSD*((R(I+60)**2)-(R(10*I)**2))*H(I)*3.14
      SAA=SA/10000.0
      VHEAD=0.0
      DO 162 I=1,10
162   VHEAD=VHEAD+SWT(I)*0.001
      WRITE(3,361)SG,PBF,SAA
361   FORMAT(1X,'BODY S.G.=',F7.5,2X,'% BODY FAT=',F7.4,
     &2X,'SURFACE AREA=',F7.4,'SQ M')
      WRITE(3,37)AT,NAT
37    FORMAT(/,1X,'ADIPOSE TISSUE WT.=',F7.4,1X,'KG',2X,
     &'NON-ADIPOSE TISSUE WT.=',F7.4,1X,'KG')
      WRITE(3,30)R(10),VHEAD
30    FORMAT(/,1X,'HEAD RADIUS=',F7.4,1X,'M',T30,'HEAD VOL.=',
     &F7.4,1X,'M CUBE')
      WRITE(3,31)HTR,VTR
31    FORMAT(1X,'TRUNK LENGTH=',F7.4,1X,'M',T30,'TRUNK VOL.=',
     &F7.4,1X,'M CUBE')
      WRITE(3,32)HAR,VAR
32    FORMAT(1X,'ARM LENGTH=',F7.4,1X,'M',T30,'ARM VOL.=',
     & F7.4,1X,'M CUBE')
      WRITE(3,33)HHA,VHA
33    FORMAT(1X,'HAND LENGTH=',F7.4,1X,'M',T30,'HAND VOL.=',
     & F7.4,1X,'M CUBE')
      WRITE(3,34)HL,VL
34    FORMAT(1X,'LEG LENGTH=',F7.4,1X,'M',T30,'LEG VOL.=',
     & F7.4,1X,'M CUBE')
      WRITE(3,35)HF,VF
35    FORMAT(1X,'FOOT LENGTH=',F7.4,1X,'M',T30,'FOOT VOL.=',
     & F7.4,1X,'M CUBE')
      WRITE(3,181)
181   FORMAT(/,' FOLLOWING ARE S(I) VALUES IN SQ M')
      WRITE(3,51)(S(I),I=1,6)
51    FORMAT(1(6F8.4,/))
      WRITE(3,183)
183   FORMAT(/,' FOLLOWING ARE AL(I) VALUES IN M')
      WRITE(3,19)(AL(I),I=1,6)
19    FORMAT(1(6F8.4,/))
      WRITE(3,185)
185   FORMAT(/,' FOLLOWING ARE DO(I) VALUES IN M')
      WRITE(3,20)(DO(I),I=1,6)
20    FORMAT(1(6F8.4,/))
```

```
      WRITE(3,187)
187   FORMAT(/,' FOLLOWING ARE HSS(I) VALUES IN KCAL/HR/DEG C')
      WRITE(3,18)(HSS(I),I=1,6)
18    FORMAT(1(6F8.4,/))
      WRITE(3,189)
189   FORMAT(/,' FOLLOWING ARE TC(I) VALUES IN KCAL/HR DEG C')
      WRITE(3,17)(TC(I),I=1,60)
17    FORMAT(6(10F7.2,/))
      WRITE(3,191)
191   FORMAT(/,' FOLLOWING ARE A(I) VALUES IN SQ M')
      WRITE(3,163)(A(I),I=1,60)
163   FORMAT(6(10F7.2,/))
      WRITE(3,193)
193   FORMAT(/,' FOLLOWING ARE RMP(I) VALIES IN M')
      WRITE(3,164)(RMP(I),I=1,60)
164   FORMAT(7(10F7.4,/))
      WRITE(3,195)
195   FORMAT(/,' FOLLOWING ARE X(I) VALUES IN M')
      WRITE(3,165)(X(I),I=1,60)
165   FORMAT(7(10F7.4,/))
      WRITE(3,197)
197   FORMAT(/,' FOLLOWING ARE THE VALUES OF CS(1) AND CB(1)')
      WRITE(3,47)CS(1),CB(1)
47    FORMAT(1X,'CS(1)=',F7.3,T30,'CB(1)=',F7.3)
      WRITE(3,199)
199   FORMAT(/,' FOLLOWING ARE C(I) VALUES IN KCAL/DEG-C')
      WRITE(3,167)(C(I),I=1,66)
167   FORMAT(7(10F7.3,/))
      WRITE(3,201)
201   FORMAT(/,' FOLLOWING ARE QB(I) VALUES IN KCAL/HR')
      WRITE(3,169)(QB(I),I=1,60)
169   FORMAT(7(10F7.3,/))
      WRITE(3,203)
203   FORMAT(/,' FOLLOWING ARE BFB(I) VALUES IN L/HR')
      WRITE(3,171)(BFB(I),I=1,60)
171   FORMAT(7(10F7.3,/))
      WRITE(3,205)
205   FORMAT(/,' FOLLOWING ARE R(I) VALUES IN M')
      WRITE(3,173)(R(I),I=1,66)
173   FORMAT(7(10F7.3,/))
      WRITE(3,207)
207   FORMAT(/,' FOLLOWING ARE CM(I) VALUES IN M')
      WRITE(3,175)(CM(I),I=1,66)
175   FORMAT(7(10F7.4,/))
      WRITE(3,209)
209   FORMAT(/,' FOLLOWING ARE SWT(I) VALUES IN KG')
      WRITE(3,177)(SWT(I),I=1,61)
177   FORMAT(7(10F7.3,/))
      RETURN
      END
```

```
      SUBROUTINE WFTMAN
      REAL MU
      DIMENSION T(67),TSET(61),RATE(61),F(67)
      DIMENSION WARM(61),COLD(61),HF(67),ERROR(61)
      DIMENSION EB(60),Q(60),E(60),BF(60)
      DIMENSION TD(60),BC(60)
      DIMENSION P(11),SKINS(6),SKINV(6),SKINC(6)
      DIMENSION RF(6),HO(6),U(6)
      DIMENSION SKINR(6)
      DIMENSION WORKM(6),CHILM(6),H(6),PSKIN(6),EMAX(6)
      DIMENSION ATIME(9),ATAIR(9),AV(9),ARH(9),AWORK(9)
      DIMENSION A(288),B(288)
      COMMON/PASS/AL(6),DO(6),HSS(6),S(6),TC(60),QB(60),BFP(60)
     *,C(67),CS(1),CB(1),RK(6)
      DATA ATIME/0.,30.,60.,90.,120.,150.,180.,210.,250./
      DATA ATAIR/1.7,1.7,1.7,1.7,1.7,1.7,1.7,1.7,1.7/
C     DATA ATAIR/11.8,11.8,11.8,11.8,11.8,11.8,11.8,11.8,11.8/
      DATA AV/122.,122.,122.,122.,122.,122.,122.,122.,122./
      DATA ARH/0.3,0.3,0.3,0.3,0.3,0.3,0.3,0.3,0.3/
      DATA AWORK/0.,0.,0.,0.,0.,0.,0.,0.,0./
      DATA P/4.579,6.543,9.209,12.788,17.535,23.756,31.824,42.175,
     & 55.324,71.88,92.51/
      DATA TSET/36.96,36.96,36.96,36.96,35.07,35.07,35.07,35.07,
     & 34.81,34.58,36.89,36.89,36.89,36.89,36.28,36.28,36.28,36.28,
     & 34.53,33.62,35.53,35.53,35.53,35.53,34.12,34.12,34.12,34.12,
     & 33.59,33.25,35.41,35.41,35.41,35.41,35.38,35.38,35.38,35.38,
     & 35.30,35.22,35.81,35.81,35.81,35.81,35.3,35.3,35.3,35.3,35.31,
     & 34.10,35.14,35.14,35.14,35.14,35.03,35.03,35.03,35.03,35.11,
     & 35.04,36.71/
      DATA EB/60*0./,RATE/61*0./
      DATA SKINR/0.0695,0.4935,0.0686,0.1845,0.1505,0.0334/
      DATA SKINS/0.081,0.481,0.154,0.031,0.218,0.035/
      DATA SKINV/0.132,0.322,0.095,0.121,0.230,0.10/
      DATA SKINC/0.05,0.15,0.05,0.35,0.05,0.35/
      DATA WORKM/0.0,0.075,0.02,0.0025,0.15,0.0025/
      DATA CHILM/0.005,0.2125,0.0125,0.0,0.0175,0.0/
      DATA CSW/320.0/,SSW/29.0/,PSW/0.0/
      DATA CDIL/117.0/,SDIL/7.5/,PDIL/0.0/
      DATA CCHIL/0.0/,SCHIL/0.0/,PCHIL/21.0/
      DATA CCON/5.0/,SCON/5.0/,PCON/0.0/
      DATA BULL/10.0/
      DATA T/37.7,37.7,37.7,37.7,37.,37.,37.,37.,36.,35.3,
     & 37.7,37.7,37.7,37.7,36.,36.,36.,36.,36.,35.3,
     & 35.,35.,35.,35.,35.,35.,35.,34.,34.,34.,
     & 35.,35.,35.,35.,35.,35.,35.,35.,35.,34.5,
     & 35.81,35.81,35.81,35.81,35.3,35.3,35.3,35.3,35.31,34.1,
     & 35.,35.,35.,35.,35.,35.,35.,35.,35.,32.8,36.71,
     & 34.58,33.,33.,33.,34.,32./
      DATA BM/39.4/
      KK=
      JJ=48
      DO 99 I=1,6
99    RATE(10*I)=0.03
      READ(1,5)PR,MU,SV,COND
```

```
5       FORMAT(4F10.5)
        READ(1,6)TAM,PRA,MUA,SVA,CONDA
6       FORMAT(5F10.5)
        SA=0.0
        DO 110 K=1,6
110     SA=SA+S(K)
        TIME=0.0
        INT=5
        ITIME=0
        JTIME=0
        DO 102 N=1,61
        F(N)=0.0
102     CONTINUE
        L=1
199     IF(ITIME.LT.ATIME(L+1)) GO TO 189
        L=L+1
        GO TO 199
189     TAIR=ATAIR(L)
        V=AV(L)
        RH=ARH(L)
        WORK=AWORK(L)
        IF(WORK-(BM*SA)) 104,104,105
104     WORKI=0.0
        GO TO 106
105     WORKI=(WORK-(BM*SA))*0.78
106     CONTINUE
        DENA=1.0/SVA
        RE(1)=((DENA*V*DO(1))/MUA)
        HO(1)=(CONDA/DO(1))*(0.97+0.68*(RE(1)**0.5))*(PRA**0.31)
        DO 2 I=2,6
        DEN=1.0/SV
        RE(I)=((DEN*V*DO(I))/MU)
        HO(I)=(COND/DO(I))*(0.60*(RE(I)**0.50)*(PR**0.31))
2       CONTINUE
        HO(1)=(COND/DO(1))*(0.97+0.68*(RE(1)**0.5))*(PR**0.3)
        U(1)=1.0/((1.0/HO(1))+(AL(1)/RK(1))
        U(2)=1.0/((1.0/HO(2))+(AL(2)/RK(2))
        U(3)=1.0/((1.0/HO(3))+(AL(3)/RK(3))
        U(4)=1.0/((1.0/HO(4))+(AL(4)/RK(4))
        U(5)=1.0/((1.0/HO(5))+(AL(5)/RK(5))
        U(6)=1.0/((1.0/HO(6))+(AL(6)/RK(6))
        DO 4 I=1,6
        H(I)=U(I)*S(I)
4       CONTINUE
        I=(TAM/5)+1.0
        PIN=P(I)+(P(I+1)-P(I))*(TAM-5*(I-1))/5.0
        PAIR=RH*PIN
        K=(T(11)/5)+1.0
        POUT=P(K)+(P(K+1)-P(K))*(T(11)-5*(K-1))/5
301     CONTINUE
        DO 302 N=1,61
        WARM(N)=0.0
        COLD(N)=0.0
        IF (F(N)) 310,311,311
```

```
311     F(N)=0.0
310     CONTINUE
        ERROR(N)=T(N)-TSET(N)+RATE(N)*F(N)
        IF (ERROR(N)) 303,302,304
303     COLD(N)=-ERROR(N)
        GO TO 302
304     WARM(N)=ERROR(N)
302     CONTINUE
        WARMS=0.0
        COLDS=0.0
        DO 305 I=1,6
        K=10*I
        WARMS=WARMS+WARM(K)*SKINR(I)
        COLDS=COLDS+COLD(K)*SKINR(I)
305     CONTINUE
        SWEAT=CSW*ERROR(1)+SSW*(WARMS-COLDS)+PSW*WARM(1)*WARMS
        DILAT=CDIL*ERROR(1)+SDIL*(WARMS-COLDS)+PDIL*WARM(1)*WARMS
        STRIC=-CCON*ERROR(1)-SCON*(WARMS-COLDS)+PCON*COLD(1)*COLDS
C THIS CONTROLLER BASED ON FULL SUIT DATA
C       CHILL=BM+1.98703250-8.92395166*(T(11)-TSET(11))
C      $-2.65356692*(T(60)-TSET(60))-4.59453410*(T(50)-TSET(50))
C      $-5.36126819*(T(30)-TSET(30))
C THIS CONTROLLER BASED ON PRELIMINARY DATA
        CHILL=7.001-5.822*(T(50)-TSET(50))-2.407*(T(30)-TSET(30))
       $-37.338*(T(11)-TSET(11))
        IF(SWEAT) 309,312,312
309     SWEAT=0.0
312     IF(DILAT) 313,314,314
313     DILAT=0.0
314     IF(STRIC) 315,316,316
315     STRIC=0.0
316     IF(CHIL) 317,318,318
317     CHILL=0.0
318     CONTINUE
400     CONTINUE
        DO 401 I=1,6
        N=10*I-9
        Q(N)=QB(N)
        BF(N)=BFB(N)
        E(N)=0.0
        Q(N+1)=QB(N+1)
        BF(N+1)=BFB(N+1)
        E(N+1)=0.0
        Q(N+2)=QB(N+2)
        BF(N+2)=BFB(N+2)
        E(N+2)=0.0
        Q(N+3)=QB(N+3)
        BF(N+3)=BFB(N+3)
        E(N+3)=0.0
        Q(N+4)=QB(N+4)+WORKM(I)*WORKI+CHILM(I)*CHILL
        BF(N+4)=BFB(N+4)+Q(N+4)-QB(N+4)
        E(N+4)=0.0
        Q(N+5)=QB(N+5)+WORKM(I)*WORKI+CHILM(I)*CHILL
        BF(N+5)=BFB(N+5)+Q(N+5)-QB(N+5)
```

```
      E(N+5)=0.0
      Q(N+6)=QB(N+6)+WORKM(I)*WORKI+CHILM(I)*CHILL
      BF(N+6)=BFB(N+6)+Q(N+6)-QB(N+6)
      E(N+6)=0.0
      Q(N+7)=QB(N+7)+WORKM(I)*WORKI+CHILM(I)*CHILL
      BF(N+7)=BFB(N+7)+Q(N+7)-QB(N+7)
      E(N+7)=0.0
      Q(N+8)=QB(N+8)
      BF(N+8)=BFB(N+8)
      E(N+8)=0.0
      Q(N+9)=QB(N+9)
      BF(N+9)=((BFB(N+9)+SKINV(I)*DILAT)/(1.0+SKINC(I)*
     & STRIC))*2.0**(ERROR(N+9)/6.0)
      E(N+9)=0.0
401   CONTINUE
      IF(AWORK(L)-(SA*BM)) 14,14,15
14    BWORK=SA*BM
      GO TO 16
15    BWORK=AWORK(L)
16    CONTINUE
      VE=(22.0*BWORK)/4.83
      VEMIN=VE/60
      BP=760.0
      TI=TAIR+273.0
      TE=T(11)+273.0
      AIRDCP=(0.2905*(BP/760)*(293/TE))/1000
      H2OOUT=VE*((BP*99.962)/(62.4*TE))*(POUT/(BP-POUT))*
     & (18.01534/99.962)
      RHEAT=(6.7E-3*(VEMIN**2))+(6.2E-5*(VEMIN**3))
      RHL=(VE*AIRDCP*(TE-TI))+(0.58*H2OOUT)
      DO 602 I=11,14
      E(I)=(RHL-0.06*RHEAT)/4.0
602   CONTINUE
      DO 500 K=1,60
      BC(K)=BF(K)*(T(K)-T(61))
      TD(K)=TC(K)*(T(K)-T(K+1))
500   CONTINUE
      DO 501 I=1,6
      K=10*I-9
      HF(K)=Q(K)-E(K)-BC(K)-TD(K)
      HF(K+1)=Q(K+1)-E(K+1)-BC(K+1)-TD(K+1)+TD(K)
      HF(K+2)=Q(K+2)-E(K+2)-BC(K+2)-TD(K+2)+TD(K+1)
      HF(K+3)=Q(K+3)-E(K+3)-BC(K+3)-TD(K+3)+TD(K+2)
      HF(K+4)=Q(K+4)-E(K+4)-BC(K+4)-TD(K+4)+TD(K+3)
      HF(K+5)=Q(K+5)-E(K+5)-BC(K+5)-TD(K+5)+TD(K+4)
      HF(K+6)=Q(K+6)-E(K+6)-BC(K+6)-TD(K+6)+TD(K+5)
      HF(K+7)=Q(K+7)-E(K+7)-BC(K+7)-TD(K+7)+TD(K+6)
      HF(K+8)=Q(K+8)-E(K+8)-BC(K+8)-TD(K+8)+TD(K+7)
      HF(K+9)=Q(K+9)-E(K+9)-BC(K+9)+TD(K+8)-HSS(I)*(T(K+9)-T(I+61))
      HF(I+61)=HSS(I)*(T(K+9)-T(I+61))-H(I)*(T(I+61)-TAIR)
501   CONTINUE
      HF(61)=0.0
      DO 502 K=1,60
      HF(61)=HF(61)+BC(K)
502   CONTINUE
```

```
      DT=0.0166666666667
      DO 600 K=1,67
      F(K)=HF(K)/C(K)
      AU=ABS(F(K))
      IF(AU*DT-0.1) 600,600,601
  601 DT=0.1/AU
  600 CONTINUE
      DO 700 K=1,67
      T(K)=T(K)+F(K)*DT
  700 CONTINUE
      TIME=TIME+DT
      LTIME=60.*TIME
      IF(LTIME-INT-ITIME) 301,701,701
  701 CONTINUE
      ITIME=ITIME+INT
      CO=0.0
      HP=0.0
      EV=0.0
      TS=0.0
      TB=0.0
      HFLOW=0.0
      SBF=0.0
      DO 800 N=1,67
      CO=CO+BF(N)/60.0
      HP=HP+Q(N)
      EV=EV+E(N)
  800 CONTINUE
      DO 802 I=1,6
      SBF=SBF+BF(10*I)/60.0
      TS=TS+T(10*I)*C(10*I)/CS(1)
  802 CONTINUE
      DO 801 N=1,61
      TB=TB+T(N)*C(N)/C9(1)
      HFLOW=HFLOW+HF(N)
  801 CONTINUE
      EV=EV/SA
      HP=HP/SA
      HFLOW=HFLOW/SA
      FE=E(11)+E(12)+E(13)+E(14)
      COND2=(HP-FE/SA-HFLOW)/(T(61)-TS)
      IF(ITIME-INT) 910,910,911
  910 WRITE(3,999)
  999 FORMAT('1',10X,'HAYLEY PVC   C.R.')
      WRITE(3,912)
  912 FORMAT(' ',1X,'T',4X,'TW',2X,'HFLW',2X,'M',5X,'EV',3X,'TB',4X,'TS'
     &,4X,'TH',4X,'TC',4X,'TP',4X,'TM',3X,'SBF',3X,'CO',2X,'CCND',2X,
     &'TLEG',2X,'TARM',2X,'TTRNK')
      NN=0
  911 WRITE(3,915)ITIME,TAIR,HFLOW,HP,EV,TB,TS,T(1),T(61),T(11),
     & T(47),SBF,CO,COND2,T(50),T(30),T(20)
  915 FORMAT(' ',I3,F5.1,3F6.1,6F6.2,F5.2,2F5.1,3F6.2)
      COND3=0.0
      DO 250 I=1,6
```

```
      COND3=COND3+H(I)*(T(I+61)-TAIR)
2050  CONTINUE
      COND3=COND3/SA
      HTBAL=HP-HFLOW-FE/SA-COND3
      NN=NN+1
C1100 KK=KK+1
C     A(KK)=ITIME
C     A(JJ+KK)=TAIR
C     A(2*JJ+KK)=T(11)
C     A(3*JJ+KK)=TS
C     A(4*JJ+KK)=T(1)
C     B(KK)=ITIME
C     B(JJ+KK)=TAIR
C     B(2*JJ+KK)=HP
C     B(3*JJ+KK)=SBF
C     B(4*JJ+KK)=CO
      JTIME=JTIME+INT
      IF(JTIME-30) 301,1101,1101
1101  JTIME=0
      IF(ITIME-90)102,1102,1102
C1102 CALL PLOTEE(1,A,48,5,48,0)
C     WRITE (3,3001)
C3001 FORMAT('-',10X,'1=TWTR',5X,'2=TR',5X,'3=TS',5X,'4=TH')
C     CALL PLOTEE(2,B,48,5,48,0)
C     WRITE (3,3002)
C3002 FORMAT('-',10X,'1=TWTR',5X,'2=M',5X,'3=SBF',5X,'4=CO')
1102  RETURN
      END
```

```
180.4000069300.0000
 39.40000
  9.55000     4.70800     0.00100     0.48400
 21.00000     0.71000     0.06580     0.81620     0.35120
```

BODY S.G.=1.08462 % BODY FAT= 0.0711 SURFACE AREA= 1.6613SQ M

ADIPOSE TISSUE WT.= 4.9297 KG NON-ADIPOSE TISSUE WT.=64.3700 KG

HEAD RADIUS= 0.0992 M HEAD VOL.= 0.0039 M CUBE
TRUNK LENGTH= 0.9709 M TRUNK VOL.= 0.0377 M CUBE
ARM LENGTH= 0.7635 M ARM VOL.= 0.0066 M CUBE
HAND LENGTH= 1.1823 M HAND VOL.= 0.0006 M CUBE
LEG LENGTH= 1.4424 M LEG VOL.= 0.0197 M CUBE
FOOT LENGTH= 1.5493 M FOOT VOL.= 0.0039 M CUBE

FOLLOWING ARE S(I) VALUES IN SQ M

0.1398	0.7161	0.2825	0.1409	0.6543	0.1905

FOLLOWING ARE AL(I) VALUES IN M

0.0025	0.0031	0.0031	0.0028	0.0031	0.0029

FOLLOWING ARE DO(I) VALUES IN M

0.2110	0.2349	0.1179	0.0380	0.1445	0.0392

FOLLOWING ARE HSS(I) VALUES IN KCAL/HR/DEG C

1.5438	8.9372	3.3309	1.2735	7.8793	1.7441

FOLLOWING ARE TC(I) VALUES IN KCAL/HR DEG C

0.61	1.68	2.92	6.99	30.33	31.63	32.93	13.73	8.06	0.0
3.63	7.56	11.60	14.14	16.57	20.48	24.38	22.29	27.61	0.0
2.86	6.03	9.12	10.05	11.17	14.25	17.32	19.08	18.23	0.0
4.42	9.33	14.12	28.13	71.10	75.84	80.59	20.15	7.19	0.0
5.40	11.39	17.23	19.18	21.43	27.24	33.04	40.11	41.88	0.0
5.80	12.23	18.51	40.14	150.35	156.56	162.78	27.71	10.48	0.0

FOLLOWING ARE A(I) VALUES IN SQ M

0.04	0.06	0.08	0.10	0.11	0.11	0.11	0.11	0.12	0.13
0.21	0.30	0.37	0.43	0.49	0.54	0.59	0.63	0.66	0.68
0.07	0.10	0.13	0.15	0.17	0.20	0.22	0.23	0.24	0.26
0.03	0.04	0.05	0.06	0.06	0.07	0.07	0.07	0.08	0.10
0.17	0.25	0.31	0.36	0.42	0.47	0.52	0.56	0.58	0.61
0.04	0.06	0.08	0.09	0.09	0.10	0.10	0.10	0.11	0.14

FOLLOWING ARE RMP(I) VALIES IN M

0.0553	0.0715	0.0822	0.0891	0.0920	0.0931	0.0942	0.0954	0.0971	0.1004
0.0338	0.0491	0.0604	0.0703	0.0798	0.0887	0.0968	0.1037	0.1084	0.1122
0.0149	0.0217	0.0267	0.0313	0.0361	0.0408	0.0450	0.0464	0.0507	0.0537
0.0041	0.0059	0.0073	0.0083	0.0087	0.0090	0.0093	0.0097	0.0108	0.0139
0.0191	0.0277	0.0340	0.0399	0.0460	0.0519	0.0571	0.0613	0.0639	0.0670
0.0046	0.0067	0.0082	0.0092	0.0097	0.0099	0.0101	0.0105	0.0115	0.0145

FOLLOWING ARE X(I) VALUES IN M

0.0202	0.0122	0.0093	0.0046	0.0011	0.0011	0.0011	0.0014	0.0021	0.0045
0.0181	0.0125	0.0101	0.0097	0.0094	0.0084	0.0077	0.0061	0.0034	0.0042
0.0060	0.0055	0.0045	0.0048	0.0050	0.0044	0.0040	0.0028	0.0019	0.0042
0.0022	0.0015	0.0012	0.0007	0.0003	0.0003	0.0003	0.0006	0.0016	0.0045
0.0102	0.0070	0.0057	0.0060	0.0062	0.0055	0.0050	0.0033	0.0020	0.0043
0.0025	0.0017	0.0014	0.0007	0.0002	0.0002	0.0002	0.0006	0.0015	0.0044

FOLLOWING ARE THE VALUES OF CS(1) AND CB(1)

CS(1) = 3.408 , CB(1) = 56.347

FOLLOWING ARE C(I) VALUES IN KCAL/DEG-C

0.564	0.564	0.564	0.564	0.085	0.085	0.085	0.085	0.099	0.245
2.506	2.506	2.506	2.506	4.105	4.105	4.105	4.105	1.873	1.234
0.362	0.362	0.362	0.362	0.772	0.772	0.772	0.772	0.256	0.443
0.036	0.036	0.036	0.036	0.017	0.017	0.017	0.017	0.039	0.170
1.077	1.077	1.077	1.077	2.331	2.331	2.331	2.331	0.631	1.097
0.061	0.061	0.061	0.061	0.017	0.017	0.017	0.017	0.059	0.218
2.250	0.050	0.265	0.102	0.045	0.238				

FOLLOWING ARE QB(I) VALUES IN KCAL/HR

3.167	3.167	3.167	3.167	0.031	0.031	0.031	0.031	0.049	0.082
11.364	11.364	11.364	11.364	1.502	1.502	1.502	1.502	0.937	0.411
0.151	0.151	0.151	0.151	0.283	0.283	0.283	0.283	0.128	0.148
0.018	0.018	0.018	0.018	0.006	0.006	0.006	0.006	0.020	0.057
0.466	0.466	0.466	0.466	0.853	0.853	0.853	0.853	0.315	0.366
0.029	0.029	0.029	0.029	0.006	0.006	0.006	0.006	0.030	0.073

FOLLOWING ARE BFB(I) VALUES IN L/HR

11.250	11.250	11.250	11.250	0.037	0.037	0.037	0.037	0.059	1.456
52.500	52.500	52.500	52.500	1.803	1.803	1.803	1.803	1.124	2.138
0.181	0.181	0.181	0.181	0.339	0.339	0.339	0.339	0.154	0.665
0.021	0.021	0.021	0.021	0.007	0.007	0.007	0.007	0.024	1.056
0.560	0.560	0.560	0.560	1.024	1.024	1.024	1.024	0.379	1.024
0.035	0.035	0.035	0.035	0.007	0.007	0.007	0.007	0.035	0.567

FOLLOWING ARE R(I) VALUES IN M

0.057	0.072	0.082	0.091	0.092	0.093	0.094	0.095	0.097	0.099
0.035	0.049	0.061	0.070	0.080	0.089	0.097	0.104	0.109	0.111
0.015	0.022	0.027	0.031	0.036	0.041	0.045	0.049	0.051	0.053
0.004	0.006	0.007	0.008	0.009	0.009	0.009	0.010	0.010	0.013
0.020	0.028	0.034	0.039	0.046	0.052	0.057	0.062	0.064	0.066
0.005	0.007	0.008	0.010	0.010	0.010	0.010	0.010	0.011	0.013
0.105	0.117	0.059	0.019	0.072	0.020				

FOLLOWING ARE CM(I) VALUES IN M

0.0452	0.0654	0.0776	0.0868	0.0914	0.0925	0.0936	0.0947	0.0961	0.0982
0.0247	0.0428	0.0553	0.0654	0.0751	0.0845	0.0929	0.1006	0.1067	0.1101
0.0109	0.0189	0.0244	0.0289	0.0337	0.0386	0.0430	0.0470	0.0497	0.0516
0.0030	0.0052	0.0067	0.0079	0.0086	0.0089	0.0092	0.0094	0.0100	0.0116
0.0139	0.0242	0.0312	0.0369	0.0429	0.0491	0.0546	0.0597	0.0629	0.0649
0.0034	0.0058	0.0075	0.0089	0.0096	0.0098	0.0100	0.0102	0.0108	0.0123
0.1026	0.1143	0.0559	0.0161	0.0691	0.0167				

FOLLOWING ARE SWT(I) VALUES IN KG

0.765	0.765	0.765	0.765	0.095	0.095	0.095	0.095	0.164	0.273
3.730	3.730	3.730	3.730	4.561	4.561	4.561	4.561	3.122	1.371
0.572	0.572	0.572	0.572	0.858	0.858	0.858	0.858	0.427	0.492
0.066	0.066	0.066	0.066	0.019	0.019	0.019	0.019	0.066	0.189
1.763	1.763	1.763	1.763	2.590	2.590	2.590	2.590	1.052	1.219
0.110	0.110	0.110	0.110	0.019	0.019	0.019	0.019	0.099	0.242
2.500									

BAYLEY PVC C.R.

T	TW	HFLW	M	EV	TB	TS	TH	TC	TR	TM	SBF	CO	COND	FLES	TARM	TTANK
5	1.7	-145.5	43.8	6.8	35.62	31.29	37.32	36.93	37.20	35.15	0.08	4.9	32.4	31.12	30.55	31.39
10	1.7	-119.1	55.9	6.3	35.21	28.86	37.13	36.72	36.99	34.56	0.02	5.3	21.4	28.89	28.41	28.87
15	1.7	-101.7	64.4	6.8	34.86	27.43	36.90	36.49	36.76	33.88	0.01	5.6	17.6	27.57	27.30	27.52
20	1.7	-88.5	71.3	6.8	34.55	26.46	36.69	36.28	36.55	33.27	0.01	5.8	15.6	26.85	26.59	26.72
25	1.7	-78.1	77.0	6.3	34.29	25.76	36.48	36.08	36.34	32.75	0.01	6.0	14.4	26.24	26.12	26.23
30	1.7	-69.6	82.0	6.3	34.05	25.23	36.29	35.90	36.15	32.32	0.01	6.2	13.6	25.77	25.79	25.91
35	1.7	-62.1	86.3	6.4	33.84	24.82	36.11	35.73	35.98	31.97	0.01	6.4	13.0	25.40	25.56	25.71
40	1.7	-55.0	90.1	6.4	33.65	24.50	35.95	35.57	35.81	31.67	0.01	6.5	12.6	25.10	25.40	25.58
45	1.7	-50.7	93.7	6.4	33.48	24.24	35.79	35.42	35.66	31.41	0.01	6.6	12.3	24.86	25.29	25.48
50	1.7	-46.0	96.8	6.3	33.33	24.02	35.64	35.28	35.51	31.20	0.01	6.7	12.1	24.65	25.21	25.40
55	1.7	-41.9	99.7	6.3	33.19	23.84	35.50	35.15	35.37	31.01	0.01	6.9	12.0	24.48	25.15	25.33
60	1.7	-38.2	102.4	6.3	33.05	23.69	35.37	35.02	35.24	30.86	0.01	6.9	11.8	24.34	25.10	25.27
65	1.7	-34.6	104.8	6.1	32.94	23.56	35.26	34.91	35.13	30.72	0.01	7.0	11.7	24.22	25.07	25.21
70	1.7	-31.6	107.0	6.1	32.83	23.44	35.15	34.80	35.02	30.60	0.01	7.1	11.7	24.12	25.05	25.16
75	1.7	-29.0	109.0	6.1	32.72	23.33	35.03	34.70	34.90	30.49	0.01	7.2	11.6	24.02	25.03	25.10
80	1.7	-26.4	110.9	6.1	32.64	23.25	34.95	34.62	34.82	30.41	0.01	7.2	11.6	23.95	25.01	25.06
85	1.7	-24.1	112.7	6.1	32.55	23.18	34.86	34.53	34.73	30.32	0.01	7.3	11.5	23.88	24.99	25.01
90	1.7	-22.0	114.3	6.1	32.48	23.11	34.78	34.45	34.65	30.25	0.01	7.4	11.5	23.82	24.98	24.97

To Run the Model

1. Specific gravity of the simulate subject may be entered by data statement. If SG=0 the program will calculate SG based on subject's height and weight.
2. Protective device thickness (THWS) in meters is entered by data statement.
3. Protective device thermal conductivity for each body segment (RK(N)) is entered by data statement.
4. Water temperature (ATAIR) is entered by data statement.
5. Subject height and weight are read from the first data card.
6. The output may be labeled by simulated experiment by altering the hollerith stream in format statement 999.

* U.S.G.P.O. 620-039/1302-774