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# $P^2NBC^2$ Heat Strain Decision Aid

# USERS' GUIDE

**(Version 2.0)**

Science Applications International Corporation
An Employee-Owned Company


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This guide is designed to provide information for the straightforward manipulation of the $P^2NBC^2$ Heat Strain Decision Aid computer program. This version of the guide replaces previous documentation. It is suggested that users read the guide in its entirety before using the Heat Strain Decision Aid program.

## ACKNOWLEDGMENTS

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The US Army Physiological and Psychological Effects of the NBC Environment and Sustained Operations on Systems in Combat ($P^2NBC^2$) Program Office for its guidance and support.

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Funding for the development of the Heat Strain Decision Aid program was provided by the US Army $P^2NBC^2$ Program Office.

## NOTES TO THE USER

### ■ ADVISORY

The $P^2NBC^2$ Heat Strain Decision Aid program is a developmental analytical tool which has not yet been determined unequivocably safe or suitable for use in making decisions which could affect the health and safety of personnel.

At this writing, the program and the algorithms embedded within it remain in the evaluation/validation process. For guidance in this matter, contact:

Commander, US Army Research Institute for Environmental Medicine
ATTN: SGRD-UE-2A, Natick, MA 01760
508/651-4848
DSN 256-4811

Also, the user should understand that casualty predictions are based on a limited data set, and should be interpreted with that in mind.

### ■ OPERATION OF THE PROGRAM

- HARDWARE REQUIREMENTS

  - IBM PC and 100% compatible systems
  - DOS 3.0 or greater
  - minimum of 470K available RAM, hard disk
  - VGA or EGA graphics board
  - math coprocessor [*The program will perform without a math coprocessor; however, in the absence of a coprocessor, processing speed will significantly decrease.*]

- The $P^2NBC^2$ Heat Strain Decision Aid program requires most of the standard 640K random access memory (RAM) that IBM PC compatibles possess. If you have memory-resident programs loaded on your PC that occupy more space than the Heat Strain Decision Aid program leaves available, *the Heat Strain Decision Aid program will not run*. Instead, this message will appear when you attempt to execute the program:

**EXCEPTION NEVER HANDLED: STORAGE ERROR**

To correct the problem, download memory-resident programs as necessary. (Most memory-resident programs are initiated from the "AUTOEXEC.BAT" or "CONFIG.SYS" files, usually found in the root directory.)

## USE OF THE ESCAPE KEY

- If you have chosen a command or a menu selection and wish to cancel the effects of this command/selection, strike the **ESCAPE** key. This will return you to the previous menu.

- The program contains several warning messages (e.g., you are alerted if you have indicated a user-defined value that is outside of the predefined range of values for that parameter). To continue in the program, strike the **ESCAPE** key.

- Finally, if you choose to enter user-defined values for a particular input parameter, strike the **ESCAPE** key to complete your selection and continue.

## USE OF THE USERS' GUIDE

### ORGANIZATION OF THE USERS' GUIDE

The Users' Guide is organized into three main sections, which are followed by references and two appendixes. Sections 1 and 2 are primarily descriptive, Section 3 instructive. In Section 1, "Background," the history of the $P^2NBC^2$ Heat Strain Decision Aid program is related; in Section 2, "Introduction to the Program," the characteristics, uses, and flow of the program are presented. Section 3 is the meat of the manual. In this section, the features of the program are listed and directions for their operation given, from the program's start to finish. (For detail, see the Table of Contents, p. v.)

### BOLDFACE TYPE

In an effort toward user-friendliness, the authors have employed, throughout this users' guide, boldface type to highlight words that represent key features/functions of the program. Boldface type, uppercase, is used as follows:

- **MAIN MENU**
- **MAIN DISPLAY**
- **MAIN GRAPH**
- **PATH**
- **BINARY FILES**
- Commands (e.g., **FILE, INPUT, GET FILE**)
- Names of keys (e.g., **ENTER, ESCAPE, PAGE-UP, ARROW**)

## ■ CUSTOMER SUPPORT

A great deal of effort was expended in an attempt to produce both a superior program and an excellent users' guide; nonetheless, we recognize that no product is problem-free. In the event that you discover problems with the program or guide, we request that you contact us:


Science Applications International Corporation
626 Towne Center Drive, Suite 205
Joppa, MD 21085
ATTN: Richard McNally *or* Maureen Stark
410/679-9800 FAX: 410/679-3705


In addition, we encourage you to communicate to us your suggestions or requests for program modifications.

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DRAFT

# $P^2NBC^2$ Heat Strain Decision Aid

# Users' Guide

# (Version 2.0)

## 1. BACKGROUND

During the past two decades, the US Army Research Institute for Environmental Medicine (USARIEM) has established a database with an associated series of predictive equations for the core temperatures, heart rates, and water requirements of soldiers performing physical work in various environmental conditions and clothing configurations. Employing the database and equations, USARIEM personnel developed a Hewlett-Packard 41-CV handheld calculator implementation, which predicts the amounts of heat strain that soldiers would experience in given sets of conditions and determines appropriate work/recovery and water intake regimens.

## 2. INTRODUCTION TO THE $P^2NBC^2$ HEAT STRAIN DECISION AID PROGRAM

During the past two years--over the course of several intermediate program stages--the algorithms used in the calculator-operated heat strain prediction model have been translated to a portable, high-level programming language. Version 2 of the program, the "$P^2NBC^2$ Heat Strain Decision Aid," is written in "Ada," for operation on a personal computer, and includes a graphical user interface.

### 2.1 OVERVIEW OF THE PROGRAM

The $P^2NBC^2$ Heat Strain Decision Aid is designed to provide information to military decision-makers regarding the prevention of heat strain among soldiers in the field. The program incorporates the algorithms employed in the HP41-CV model. Included as well are equations that modify some of the parameters of the HP41-CV model. These modifying factors are the heights and weights, the dehydration statuses and the states of heat acclimatization of soldiers. Based on the inputs, Version 2 of the program calculates two physiological responses--core temperature and water requirements--which serve as indicators of heat strain. These calculations drive the program's outputs, which are predictions of (1) work/recovery final core temperatures; (2) work/recovery cycles; (3) work/recovery water requirements; (4) maximum work times, and (5) probability of thermal casualties. These outputs include three values not displayed by the calculator model: work/recovery final core temperature and the probability of thermal casualties. In addition, the Heat Stain Decision Aid incorporates an algorithm for tracking an individual's core temperature as a function of time.

Designed for user-friendliness, the Heat Strain Decision Aid is an interactive, menu-driven program. Operational improvements over the calculator model include pull-down menus, the ability to use multiple data sets for individual input variables, graphic display of data, and automatic file-saving.

## 2.2 PROGRAM FLOW

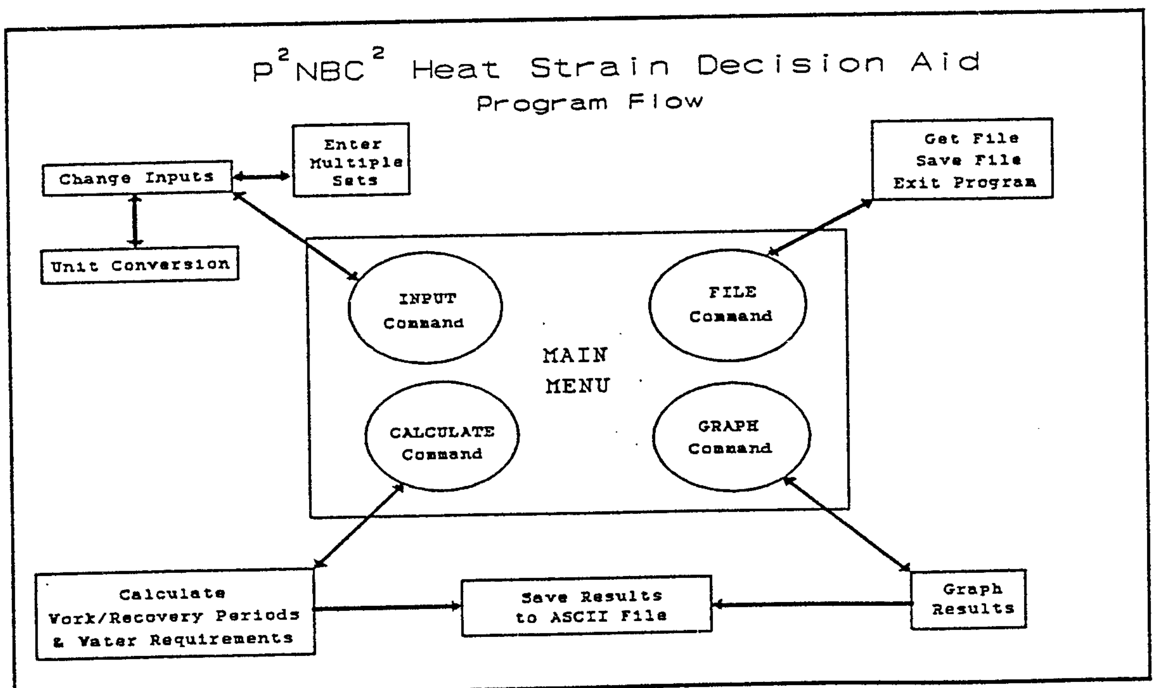


**Figure 1.** $P^2NBC^2$ Heat Strain Decision Aid program flow.

When entering the program, the user is presented with a **MAIN MENU**, which displays default values for input parameters and the result categories for the program's calculations.[1] The user may modify input values, custom-designing thermal and clothing parameters, work activity, soldier attributes, and acceptable casualty risk. The program calculates work/recovery final core temperatures, work/recovery cycles, work/recovery water requirements, maximum work times, and the probability of casualties for the conditions specified. The program allows the user to graph results and to perform heat strain sensitivity analyses. Finally, the user is given the opportunity to save data in a DOS text format.

## ■ MAIN MENU COMMANDS

The **MAIN MENU** (see Figure 1) serves as the hub of user activity. Four commands[2] are available to the user from this menu: **FILE**, **INPUT**, **CALCULATE**, and **GRAPH**.

- **FILE** allows the user to
  - -save a set of inputs
  - -retrieve saved inputs
  - -exit the program.

- **INPUT** allows the user to enter input mode, where input parameters can be altered.

- **CALCULATE** causes the current set of inputs to be used to determine heat strain predictions.

  - if a single set of inputs has been specified, the results of calculations will be displayed on the **MAIN DISPLAY**.

  - if multiple sets of inputs have been specified, the results of calculations will be written onto a **BINARY FILE**; from the **BINARY FILE**, these results can later be retrieved by the program's graphing routines *[Notes: 1. Multiple-input results are not displayed on the MAIN DISPLAY. 2. Multiple-input sets can be written to a text file (discussed in the section, "CALCULATE," page 19).]*

---

1 A list of initial default settings, plus ranges for input variables, appears as Appendix A.

2 An annotated list of commands appears as Appendix B.

- **GRAPH** - queries user as to which type of graph is to be displayed

  - displays user's selections on screen, with accompanying legend, as appropriate.

After the indicated action has been completed, the user, in order to continue, returns to the **MAIN MENU**.

## ■ BINARY FILES

The program uses three binary files:

- **HSPM.OLD** This file contains a binary record of the last set of inputs used by program.

- **HSPM_SET.OUT** This file contains a series of binary records, each of which contains a single input set and the matching program results.

  This file is read by the **GRAPH** command and is the source file for converting the binary data to ASCII format with the **F3** key.

- **AXISDATA** This file contains a binary record to keep track of the current X and Y values for graphing.

You can also specify various file names for storing data. From the **FILE** menu, you can specify the name of a file in which to store the current inputs (as an alternative to using **HSPM.OLD**, which will be overwritten at the end of every session). You should be aware that the file that you name will be a **BINARY FILE**, which can be read by the program when the next session is begun.

You can also specify the name of a file in which to store program results. This file is in ASCII format and, accordingly can be printed and/or viewed in a word processor.

## 3. USING THE PROGRAM

In this section, step-by-step instructions for using the Heat Strain Decision Aid program are presented.

### 3.1 PROGRAM WALK-THROUGH

■ **INSTALLING THE PROGRAM**

• To install the $P^2NBC^2$ Heat Strain Decision Aid on your hard drive:

▪ Using the DOS **MKDIR** command, create a new directory on the hard drive. Name this directory. If you were installing your program on drive C, you would enter

**MKDIR C:P2NBC2**

▪ Place the installation diskette into Drive A and change the root directory to Drive A. Enter

**A:**

▪ Copy all of the files from the installation diskette to the directory that you have created on Drive C, using either the **COPY** command or the **XCOPY** command.

**XCOPY *.* C:\P2NBC2**

• To execute the program, enter the name of the program (without the **EXE** extension):

**HSDA**

*[Note: If you wish to use the program in a directory other than $P^2NBC^2$, you must alter the PATH.]*

The program uses various files to save user inputs and to store the results of calculations; space for these files should be reserved. Depending on the number of cases run, reserve from 5-35 kilobytes.

■ **USING THE MAIN MENU**

• **BASIC OPERATION**

To execute the program, type in the root name, **HSDA**. After two introductory screens are presented, the **MAIN MENU** is displayed (see Figure 2). Four command options appear on the

**MAIN MENU: FILE, INPUT, CALCULATE,** and **GRAPH.** To select a command, either (1) highlight the selected command with the **ARROW** key and strike the **ENTER** key, *or* (2) strike the beginning letter of the command (e.g., "F" for **FILE**, "I" for **INPUT**).

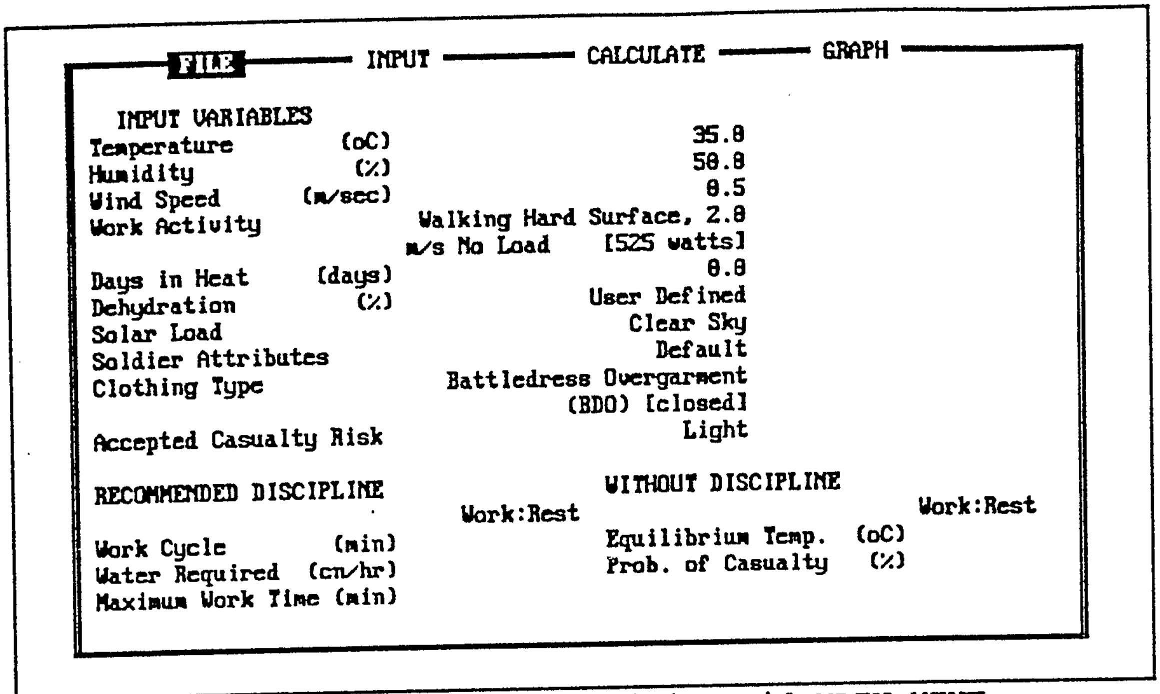


Figure 2. $P^2NBC^2$ Heat Strain Decision Aid **MAIN MENU.**

- **MAIN MENU DISPLAY**

The **MAIN MENU** display shows both inputs and outputs. (1) Inputs: All of the current selections for input parameters are displayed. If multiple selections have been made for an item or if user-defined values have been specified, the **MAIN MENU** display will indicate this with the message "Multiple Selections" or "User-Defined," respectively. (2) Outputs: If a single set of data has been specified and **CALCULATE** or **GRAPH** has been selected subsequent to any input values having been altered, program predictions will be displayed on the **MAIN DISPLAY.** Each program prediction is described below.

"Equilibrium Temperature" displays the predicted equilibrium core temperature (in degrees Celsius) for an individual during work/recovery for the inputs specified. The work value shows what the individual's equilibrium core temperature is if no recovery period is allowed, while the recovery value shows the individual's equilibrium core temperature under the given conditions if the individual remains at rest.

"Work Cycle" displays suggested work/recovery times (in minutes) calculated to limit casualties at the user-specified level.

"Water Required" indicates the number of canteens of water required per hour to sustain the specified work/recovery cycle.

"Maximum Work Time" indicates the maximum single-exposure time (in minutes) for an individual to work in the given conditions. It assumes no recovery period and is intended to guide the soldier in determining how long a period he can safely (within the specified casualty level) work. After this work period, a prolonged recovery would be required before another period of work.

"Probability of Casualty" is based on the "Equilibrium Work Temperature" displayed above. The value displayed on the **MAIN DISPLAY** reflects the probability of casualties resulting from continuous work.

## ■ USING COMMANDS

*Note: The ESCAPE key is used in these ways:*

- *If you have chosen a command or a menu selection and wish to cancel the effect, strike the ESCAPE key. This will return you to the previous menu).*
- *The program contains several warning messages (e.g., you are alerted if you have indicated a user-defined value that is outside of the predefined range of values for that parameter; to continue in the program, strike the ESCAPE key.*
- *Finally, if you choose to enter User-defined values for a particular input parameter, strike the ESCAPE key to complete you selection and continue.*

### • FILE COMMAND

When **FILE** is selected, a list of commands is displayed (see Figure 3). To select a command, highlight the selected command with the **ARROW** key, then strike the **ENTER** key. Three selections are available from the **FILE** menu: **GET FILE**, **SAVE FILE**, and **EXIT**.

#### ■ GET FILE

The **GET FILE** command allows you to access inputs used for the program's calculations in a previous working session. When **GET FILE** is selected, you are queried for the name of the file that you wish to retrieve. Type in any valid DOS file name and strike the **ENTER** key. If the program is unable to find the file that you have specified, you are given the opportunity to re-enter a file name.

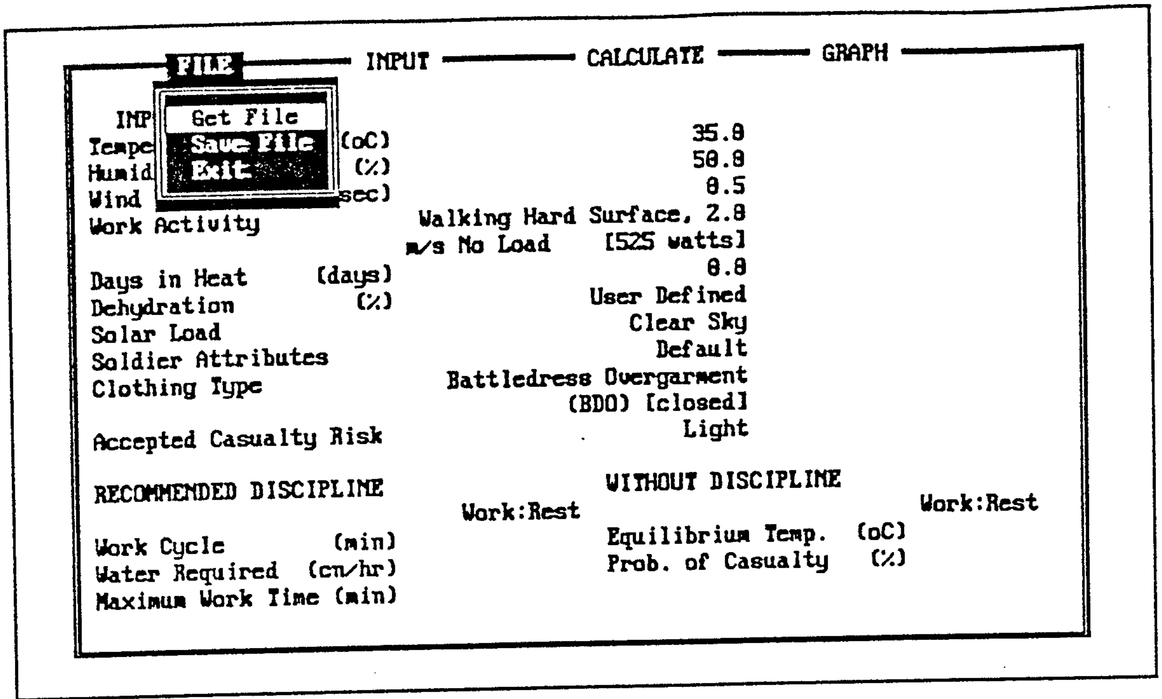

Figure 3. FILE menu.

- SAVE FILE

**SAVE FILE** enables you to save the current set of inputs. The data is saved on a binary file, and, although any legal DOS file name may be used for this file, the file will be readable by the Heat Strain Decision Aid program only. When **SAVE FILE** is selected, you are queried for the name of the file that you wish to save. Type in a file name. If a file by this name exists, you are asked if the file should be overwritten. If you do not want to overwrite an existing file, you are given the opportunity to enter a new name for the file.

- EXIT

The **EXIT** command is used to exit the program. If you have altered the inputs and have not saved these inputs, you are asked whether you want to exit without saving. If you answer "No" (by entering "N" or "n"), you are returned to the **MAIN MENU**. If you answer "Yes" (by entering "Y" or "y"), you exit the program. *[Note: Even if you choose not to save the current inputs, these values are saved on a file in the current directory called HSPM.OLD. This feature is intended to provide protection to the user.]*

When a user next enters the program, the data stored in **HSPM.OLD** is read and displayed. This feature enables a user to pick up where the program left off. If an **HSPM.OLD** file does not exist (because the program has never been run from the directory being used or because the file has been deleted), the program-defined defaults for the various input variables will be displayed on the **MAIN MENU**.

- **INPUT COMMAND**

### Basic Operation

Selecting **INPUT** allows you to edit the displayed values for input parameters. These parameters are ambient temperature, humidity, wind speed, work activity, days in heat (acclimatization), dehydration level, solar load, soldier attributes, clothing type, and accepted casualty risk.

### Entering Multiple-Input Commands

You may specify multiple values for a single input parameter (e.g., in order to evaluate the impact of these values on program predictions). However, once multiple data has been selected for any *one* parameter, multiple data for no other parameter may be simultaneously selected. This limitation should not be prohibitive, given that calculations or graphing can be done by first examining the impact of various selections of a given parameter, saving these results and--in a subsequent run--altering the inputs to examine the effects of multiple values of a second parameter with a single value for the first parameter.

This process can be repeated for as many parameters as you wish. For example, up to eight values may be entered for temperature. Let's say that you enter six temperature values, then enter a single value for humidity, wind speed, and so on. You run the program, save the temperature results, then--in a subsequent run--you enter a single value for temperature, six values for humidity, a single value for wind speed, and so on. You run program, and save humidity results. And so you continue on down the list of parameters...

### Types of Input Values

The program parameters fall into three categories, in terms of how they are input to the program: scalar values, predefined sets of values, and user-defined sets of values.

#### Scalar Values

Temperature, humidity, wind speed, and days in heat are considered scalar inputs. Data for these parameters is entered as a single decimal value, as a discrete list of values, or as a data range. The program does not require that your style of including or not including decimal points or 0's before or after decimal point be consistent (e.g., the program will accept all of these entries: 2, 20, .2, 0.2). Any input characters other than digits, decimal points, or signs (e.g., "-" or "+") will cause the program to stop reading characters (e.g., if you enter "12a.5," your entry will be read as "12").

Discrete lists of values (up to eight) may be specified for any of the scalar parameters by entering the desired values separated by commas. Allowance is made for desired values to be entered into 26 character positions. If you attempt to enter 27 or more characters, the final character position is continuously overwritten with the last digit entered. [*Note: This feature was incorporated in order to allow the capability for two-column input in a future upgrade of the program. The authors suggest that data ranges, described next, may serve as alternative selections when the 26-character quota is not practicable.*]

Data ranges can be specified for scalar parameters only. A data range consists of three values: an initial value, a subsequent value, and a maximum value for the parameter. For example, for temperature, you might enter:

**20,22..30**

This data range tells the program to use 20°, 22°, 24°, 26°, 28°, and 30° for ambient temperature [*Note: Units were not specified in the preceding list because the user can indicate degrees Celsius or degrees Farenheit by using the UNIT-CONVERSION key later in the Section, "Unit Conversion," page 17. The default unit for ambient temperature is degrees Celsius.*] The first two values determine the increment for subsequent values. The third value is an upper limit for the data range. If more than eight values are specified in the data range, the list is truncated. If the increment specified does not result in a final value equal to the maximum value specified, the closest value less than the maximum is used. For example, specifying 20,22..29 would result in the following list: 20, 22, 24, 26, 28.

| Table 1. Acceptable inputs for scalar-value parameters.* | |
|---|---|
| USER INPUT | INPUT TYPE |
| 20<br>20.<br>20.0<br>+20.0 | Single Value |
| 20,21,33,40<br>20.,21.,33.,40.<br>20.0,21.0,33.0,40.0<br>20,21.,33.0,40 | Discrete List |
| 20,22..30<br>20.,22...30.<br>20.0,22.0..30.0<br>20,22...30.0<br>20.,22..30. | Data Range |
| * Scalar-value inputs: temperature, humidity, wind speed, days in heat. | |

Table 1 illustrates examples of acceptable inputs for scalar values. Note that the table contains entries for each type of acceptable input (i.e., single value, discrete list, data range).

To ensure that data is reasonable, each value is checked against predefined minimum and maximum acceptable values. (See Appendix B for list of minimum and maximum values.) In the event that your value does not fall within the allowable range, a warning message is displayed. With that message on the screen, you can continue only by hitting the **ESCAPE** key.

- **Predefined Values**

All nonscalar input parameters (work activity, dehydration, solar load, clothing type, and casualty risk) can be selected by choosing the desired parameter accepted from a predefined menu. To display a predefined menu, highlight the desired parameter with an **ARROW** key, then hit the **ENTER** key. You are asked whether your current selection is to be added to your previous selection(s) or whether this selection should replace the current selection(s). Highlight the desired response and strike the **ENTER** key. If a different item has multiple values specified, you may not add to that list of values. As with any menu, you may abort this operation by hitting the **ESCAPE** key at any time.

All predefined menus can be scanned by using one of the following keys: **PAGE-UP, PAGE-DOWN, HOME, END**, or any of the other cursor keys (**UP, DOWN, LEFT** or **RIGHT ARROWS**).

Figures 4-8 show the program's predefined menus. The Work Activity and Clothing Type menu are too lengthy to be displayed on the screen in their entirety; to peruse these menus, strike the control keys specified above.

Note that each menu provides a choice called "User-Defined," which allows you to specify values for each of the variables underlying the parameter used in the program. User-Defined values will be discussed in the next section.

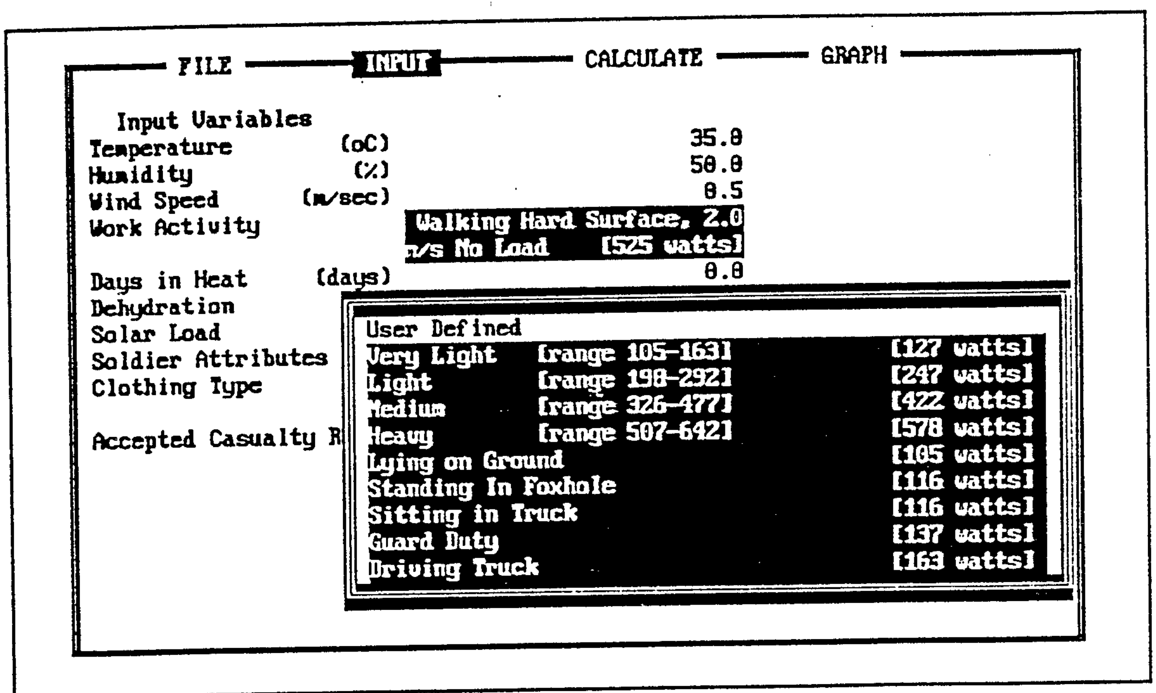


Figure 4. Work Activity menu.

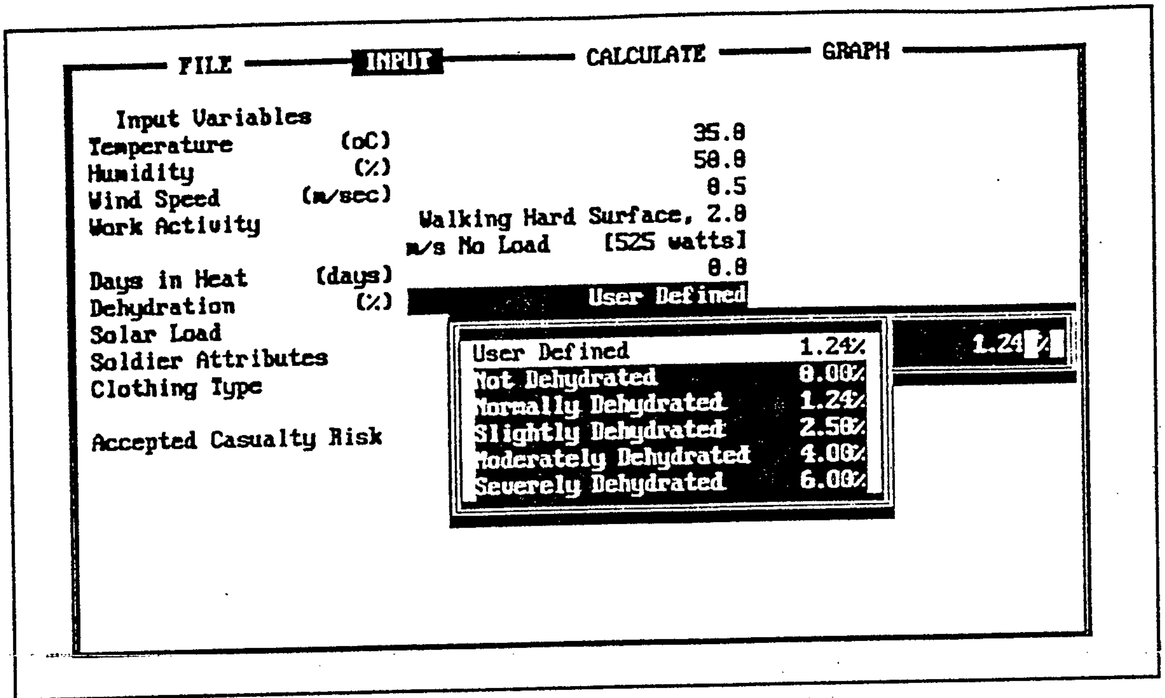


Figure 5. Dehydration menu.

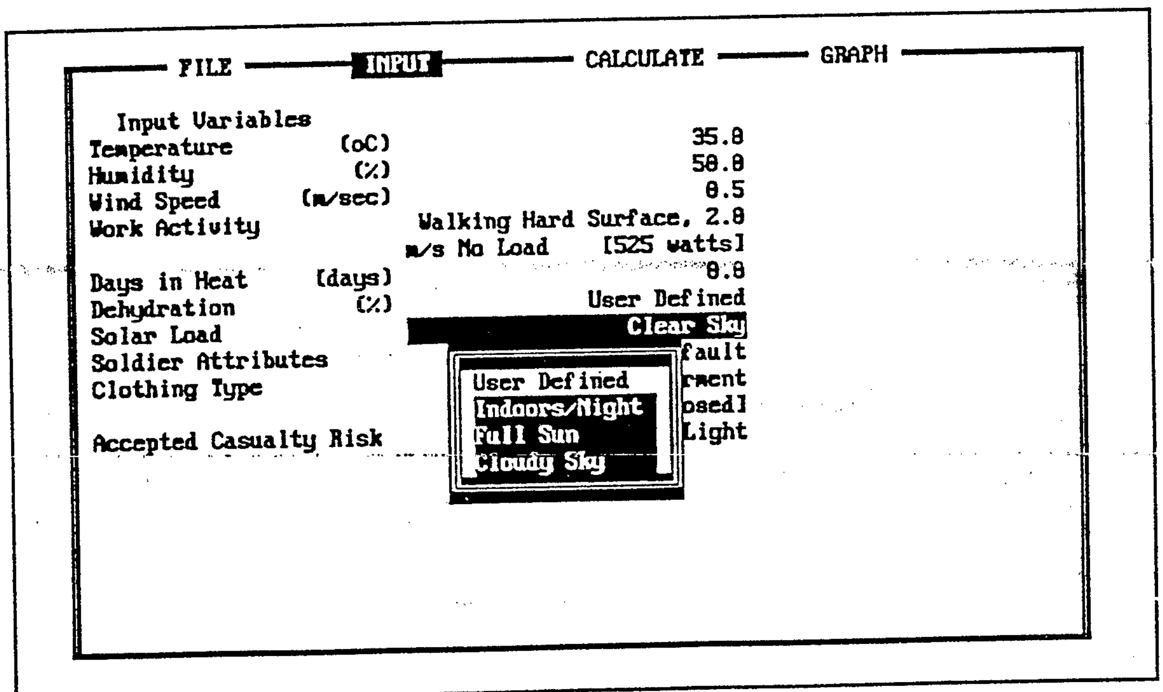


Figure 6. Solar Load menu.

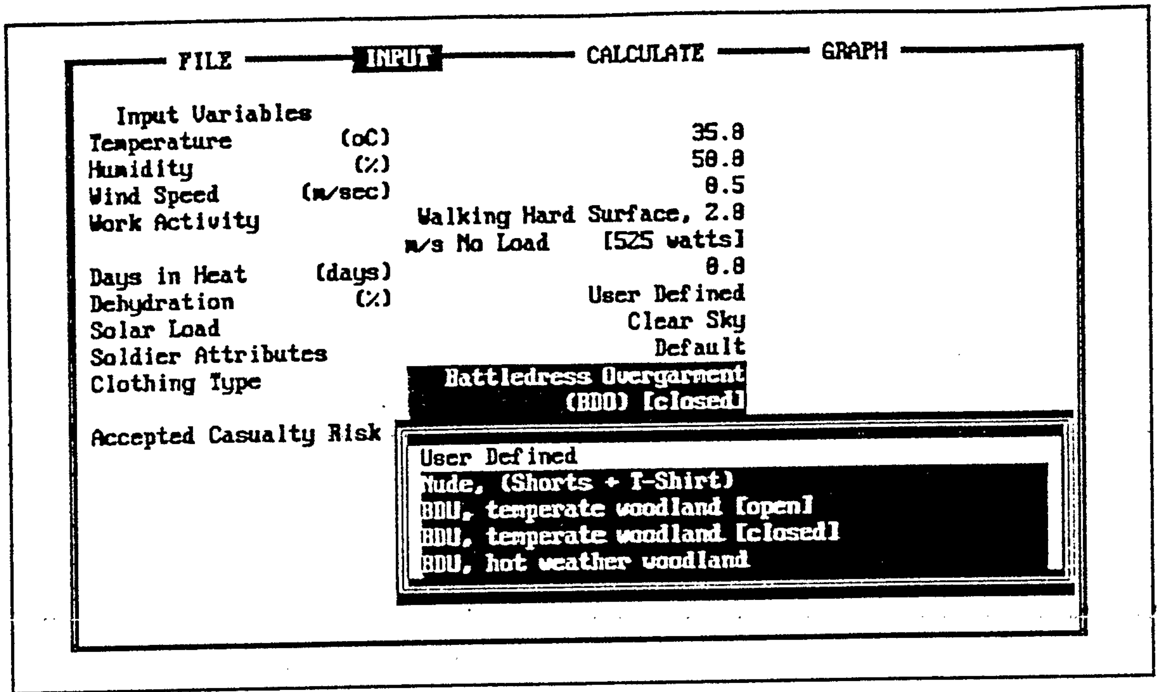


Figure 7. Clothing Type menu.

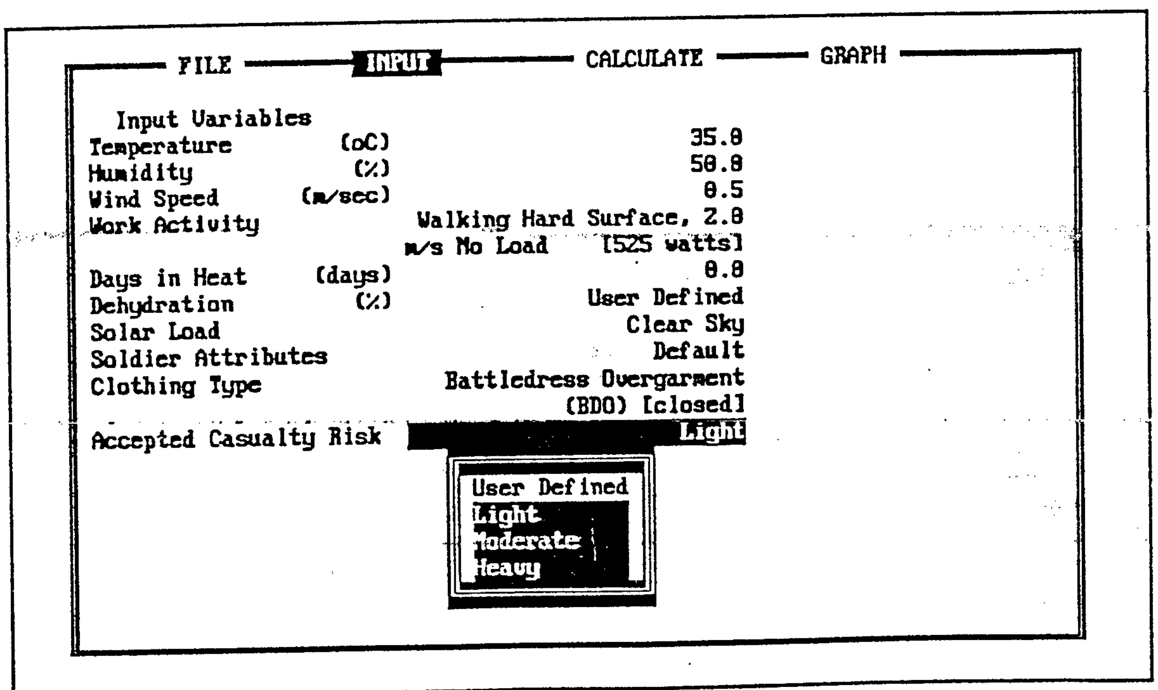


Figure 8. Casualty Risk menu.

- **User-Defined Values**

For soldier attributes, and for each of the predefined input parameters (work activity, dehydration, solar load, clothing type, casualty risk), you may enter your own values for the variables used by the program to define the input parameters.

The Soldier Attributes menu appears as Figure 9, and the variables underlying parameters are listed in Table 2.

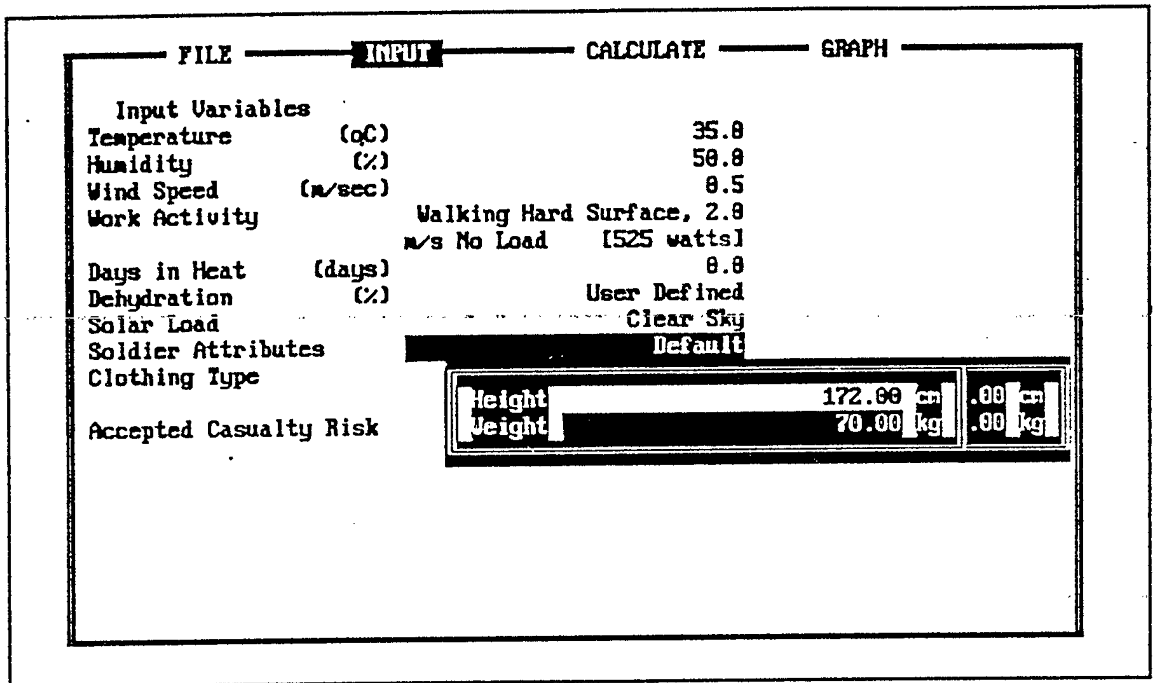


Figure 9. Soldier Attributes menu.

An example of using the user-defined value option: If you wish to select your own values for one or both of the variables underlying the "work activity" parameter, place the highlight bar on "work activity" and strike the **ENTER** key. The predefined menu of work activity choices will be displayed. Then, select "User-Defined" by highlighting this choice and striking the **ENTER** key again. A menu arranged like that shown in Figure 10 for Work Activity will come up, at which point, you may enter the desired values for metabolic rate, external work rate, or both. To incorporate your selection(s), strike the **ESCAPE** key. Before returning to the main **INPUT** menu, you are asked whether to add the selection(s) that you just make to the current list or to replace the current selection(s) with yours. Highlight your response and strike the **ENTER** key.

Table 2. **User-defined** selections for input parameters.

| Input Parameter | User-Defined Variables |
|---|---|
| Work Activity | Working Metabolic Rate<br>External Work |
| Dehydration | Level of Dehydration |
| Solar Load | Solar Factor<br>Cloud Factor |
| Casualty Risk | Skin Temperature<br>Single-Exposure Maximum Temperature Limit<br>Maximum Cyclic Temperature Limit<br>Maximum Sustained Temperature Limit |
| Soldier Attributes | Height<br>Weight |
| Clothing Type | Clothing Insulation (Clo)<br>Im/Clo Permeability (Im/Clo)<br>Gamma for Clo (GammaC)<br>Gamma for Im/Clo (GammaI) |

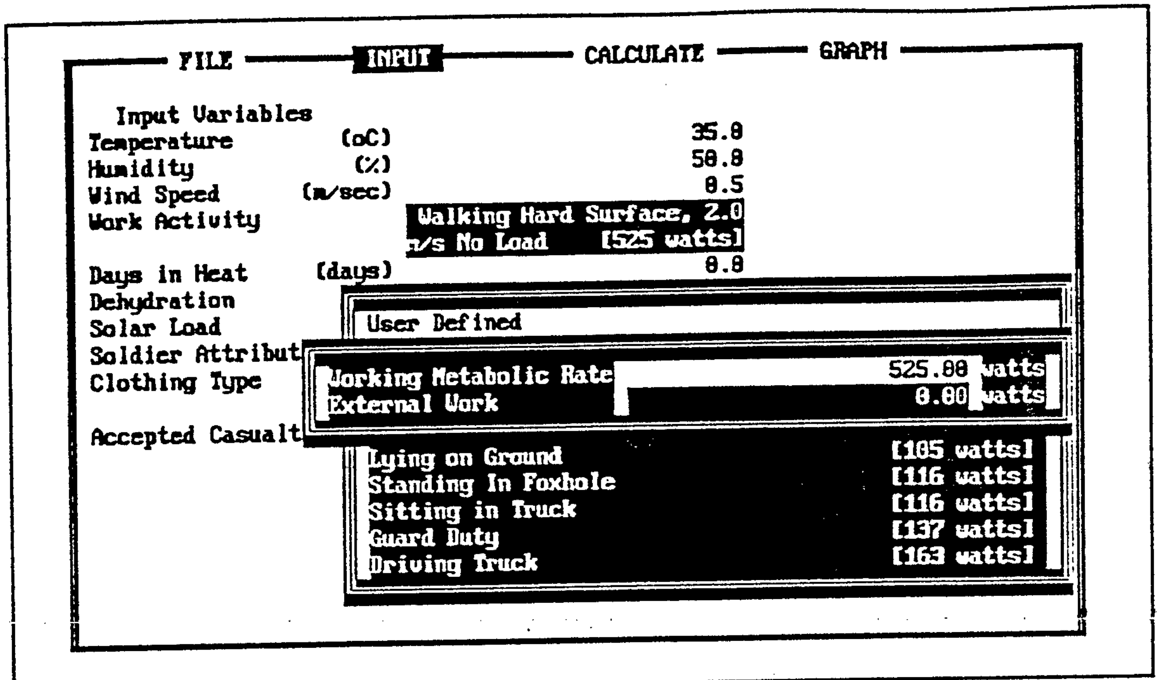


Figure 10. User-Defined Work Activity menu.

- **Display of Inputs**

- Display of User-Defined Values

When you are on a given input parameter menu (e.g., Work Activity), if you select a user-defined set of values--and if you have *not* selected multiple values--the text "User-Defined" will appear next to the parameter. When this item is highlighted in the **MAIN INPUT** menu, a pop-up window will appear displaying the currently selected user-defined parameters. This display enables you to view your selections to date. If you wish to add values or to change these values, strike the **ENTER** key to pull down the predefined menu.

- Display of Multiple-Input Selections

When multiple selections have been made for nonscalar input parameters, these selections are displayed whenever the input parameter is highlighted on the **MAIN INPUT** menu. Current selections are displayed in a pop-up window. Since, in almost all cases, the data associated with multiple selections of nonscalar data does not fit on the display, it is likely that only the beginning of each data entry will be displayed. You may shift the data display to the left and right by using the **LEFT** and **RIGHT ARROW** keys. Each entry displays a text string used to describe the parameter, followed by a list of the values used to define the parameter. The user may add to the list of parameter or replace the list by striking the **ENTER** key and selecting from a predefined menu. Moving the highlight bar to another input variable causes display of the list of multiple selections to disappear.

- **Unit Conversion**

A **UNIT-CONVERSION** feature may be utilized which allows values to be displayed in one of several measurement scales (see Appendix A for list). To bring up the menu which lists alternative measurement scales, strike the **F2** function key. A menu arranged like that shown in Figure 11 for Humidity will be displayed, at which point you may enter the desired measurement scale. Table 3 lists the available units for input parameters.

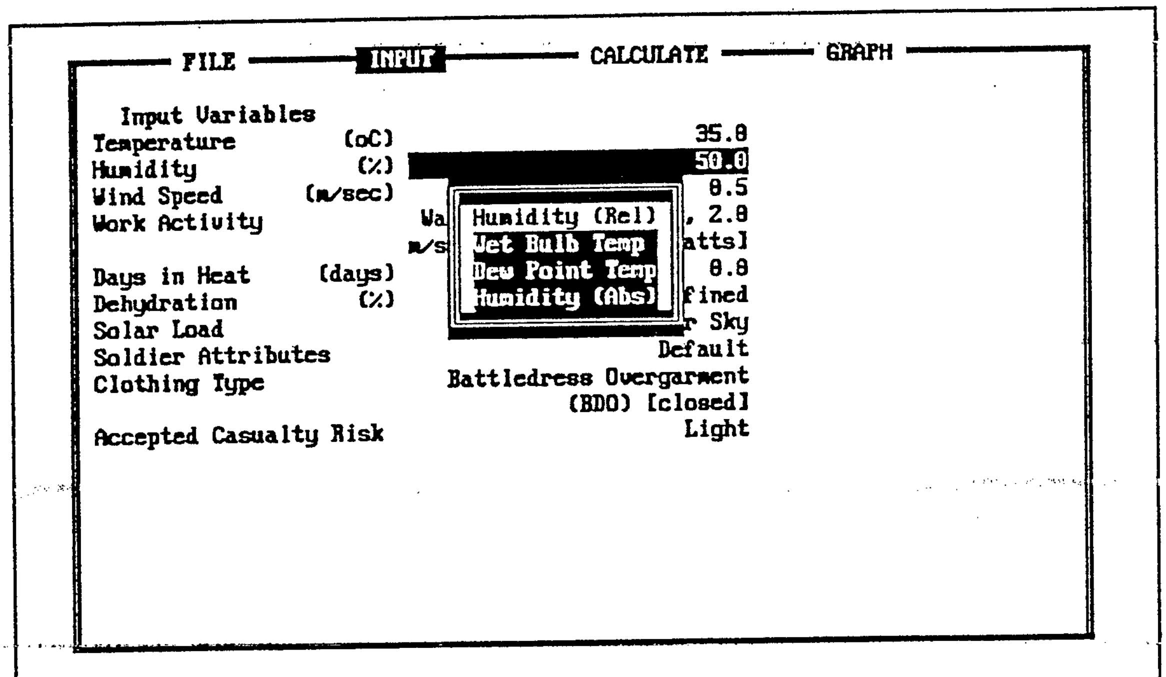


Figure 11. Conversion menu for Humidity.

| Table 3. Units of measurement allowed for input parameters. | |
|---|---|
| **Input Parameters** | **Units** |
| Temperature | Degrees Celsius (default)<br>Degrees Farenheit |
| Humidity | Relative (default)<br>Wet-Bulb Temperature[1]<br>Dew-Point Temperature[1]<br>Absolute |
| Wind Speed | Meters/Second (default)<br>Kilometers/Hour<br>Miles/Hour<br>Knots |
| Working Metabolic Rate<br>External Work | Watts (default)<br>British Thermal Units<br>Kilocalories/Hour<br>MET |
| Height | Centimeters (default)<br>Inches<br>Feet |
| Weight | Kilograms (default)<br>Pounds |

[1] Wet-bulb and dew-point temperatures may be entered in degrees Celsius or degrees Farenheit. Both of these conversions take ambient temperature into consideration. The user should be aware that if multiple temperatures have been selected, the first of the temperatures entered will be used to convert humidity to either wet-bulb or dew-point temperature.

## C. CALCULATE Command

When the **CALCULATE** command is selected, the program takes the selected input values and uses them in the heat strain prediction algorithms.

The **CALCULATE** command causes input values and resulting program predictions to be written onto an internal, binary file called **HSPM_SET.OUT**, which is read by the program when **GRAPH** is selected (see "GRAPH," page 20). This file is stored in the current working directory and is readable only by the program. You need not be concerned with this file other than to ensure that there is enough room on the disk for it.

- **Display of Results**

If a single set of inputs has been selected, the results of these calculations are displayed on the **MAIN DISPLAY**. If multiple inputs have been selected, results may be written to a DOS text file as described below.

- **Saving Data in Text Format**

When multiple inputs are selected, results are not displayed on the main display. These results can, however, be written to an ASCII file by striking the **F3** key immediately after using the **CALCULATE** command. If you strike the **F3** key at this point, you will be asked for a file name for the ASCII file. The file contains a list of the current inputs and the resulting program predictions.

- **GRAPH COMMAND**

The **GRAPH** Command allows you to graph the program's predictions, thereby enabling you to gauge the sensitivity of the program to various parameters. If the **CALCULATE** command has not been selected prior to the **GRAPH** command, calculations are done and written to the internal, binary file known as **HSPM_SET.OUT** (see "CALCULATE COMMAND," page 19). This file is then read by the graph routines to produce the various results graphs.

If a single set of inputs has been specified you will be presented with an optional Thermal Discipline menu, as shown in Figure 12. If two sets of inputs have been specified, you will be presented with the menu shown in Figure 13. In either case, to select the desired graph, highlight your choice on the menu (using the **ARROW** keys), and striking the **ENTER** key. In the case of two inputs, if you select the core temperature graph, you will be presented with the optional Work Discipline menu, as shown in Figure 14.

If more than two input sets have been specified, you will be given the graphing options shown in the menu in Figure 15. Note that the only difference between the menu shown in Figure 13 and that in Figure 15 is the option to plot core temperature versus time in Figure 13.

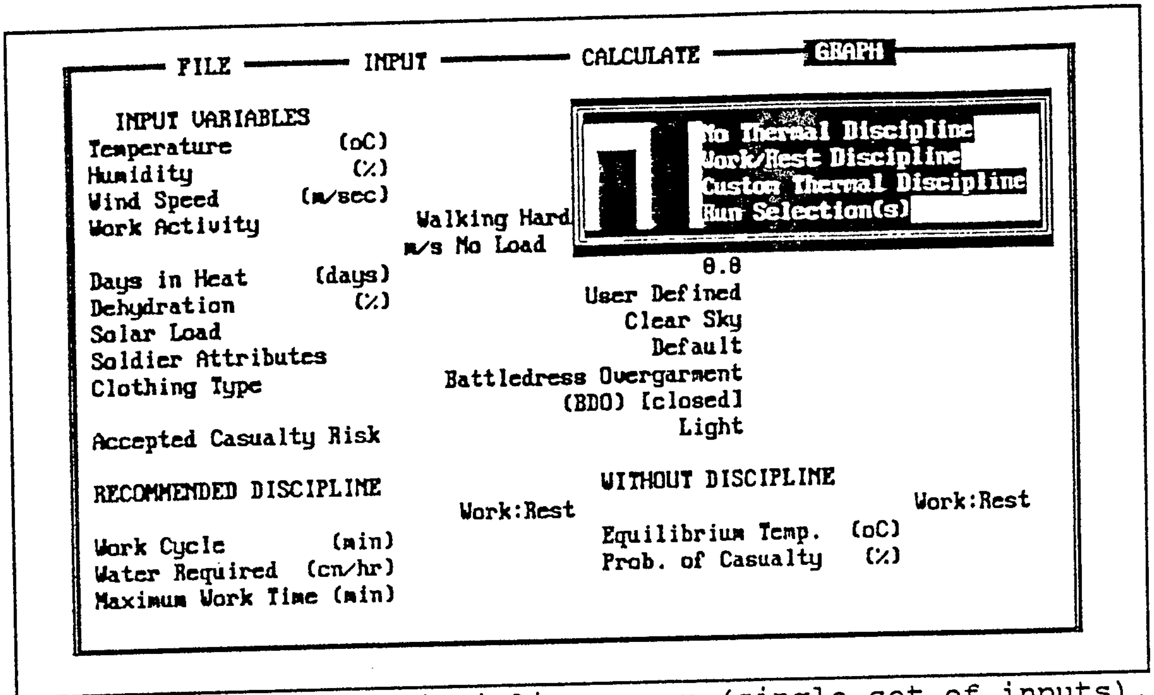


Figure 12. Thermal Disciplines menu (single set of inputs).

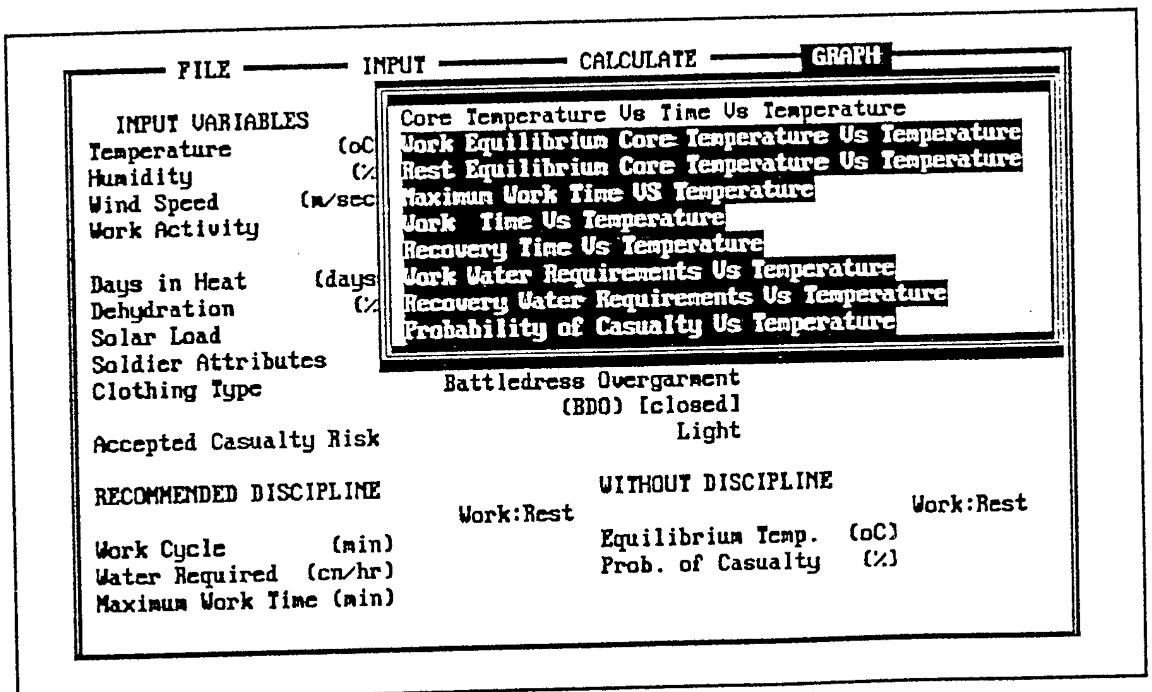


Figure 13. GRAPH menu (two sets of inputs).

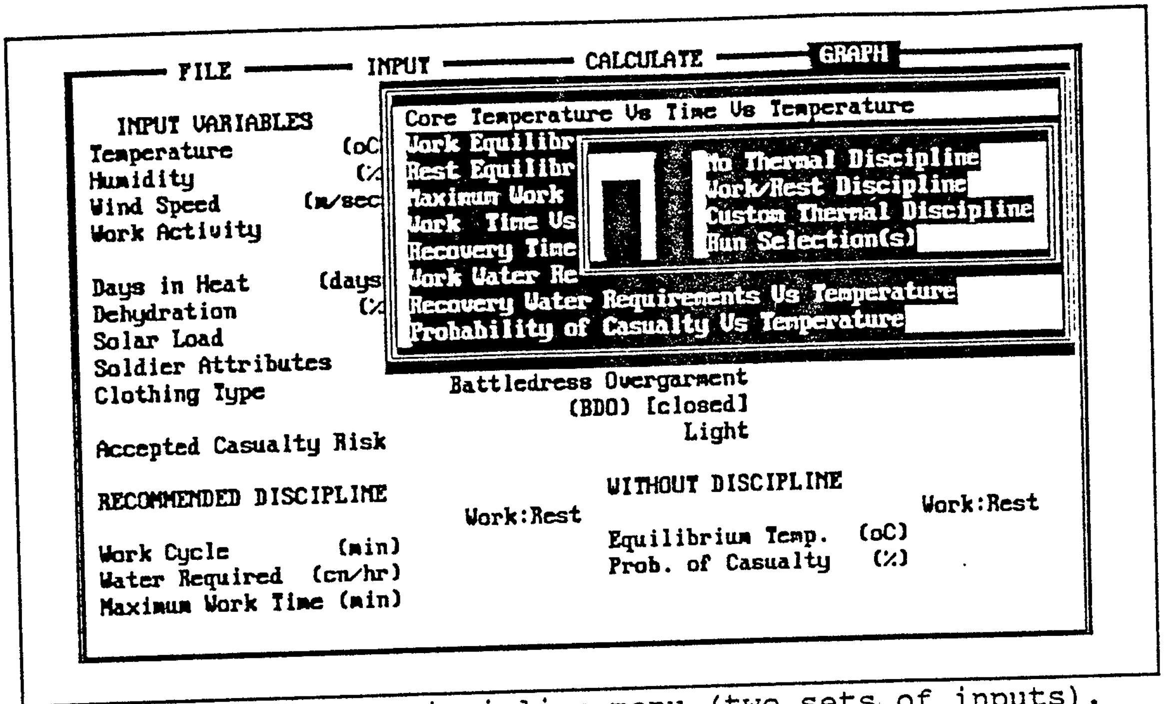


Figure 14. Thermal Discipline menu (two sets of inputs).

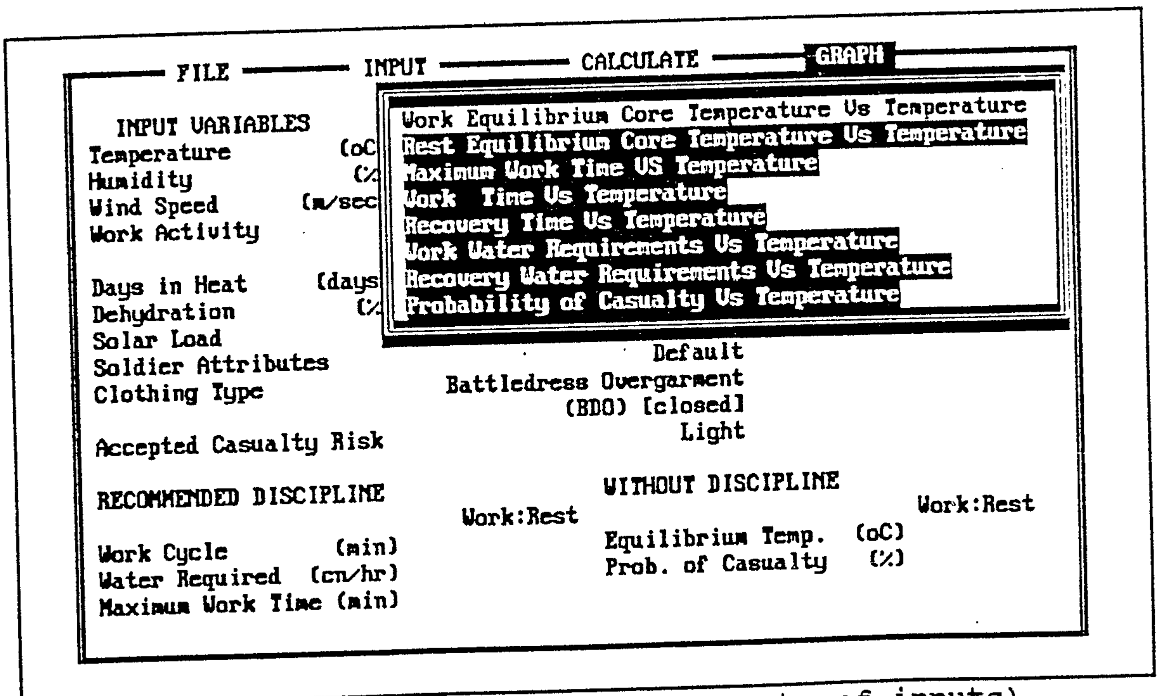


Figure 15. GRAPH menu (more than two sets of inputs).

## ■ GRAPH COMMAND SELECTIONS

### • Core Temperature Versus Time

This graph, also known as a "temperature time series," is available for up to two input sets only. If you choose this option, the menu presenting optional work disciplines is presented. This menu, as shown in Figure 14, allows you to specify the type of work discipline to be applied when values for the time series are calculated.

"No Thermal Discipline" means that no work/recovery cycles or other thermal discipline are used for the purpose of preventing heat strain casualties. The "Work/Recovery Discipline" selection allows you to view the time series after the work/recovery times predicted by the program have been applied. "Custom Work Discipline" allows you to specify work/recovery times. If you choose "Custom Work Discipline," you will be presented with a final menu, which displays the work/recovery times calculated by the program and gives you the opportunity to enter your own work/recovery times.

You may enter work/recovery times for each of the input sets (also referred to as "cases"). Data is entered onto this menu by a method similar to that used for scalar values (**INPUT** command see pages 9-10). That is, single values may be entered if a single input set has been specified (e.g. 30); a discrete list of values may be entered by separating the values with commas (e.g. 20,25,30); or a data range may be specified (e.g. 20,25..40).

In any event, the number of values entered on the Custom Thermal Discipline menu should be equal to the number of input sets selected. Any discrete list or data range which includes too many values will be truncated. Furthermore, if the number of work or recovery times entered is less than the current number of input sets, the last custom value that you have specified will be used for the rest of the values. If no value is given for either Custom Work Time or Custom Recovery Time, the values predicted by the program will be used.

To exit the menu after having specified custom work/recovery times, strike **ESCAPE**. This will bring you back to the original Thermal Discipline menu. To view the selected graphs, highlight "Run Selections" and strike the **ENTER** key. Figures 16, 17, and 18 illustrate the program flow for the **GRAPH** command.

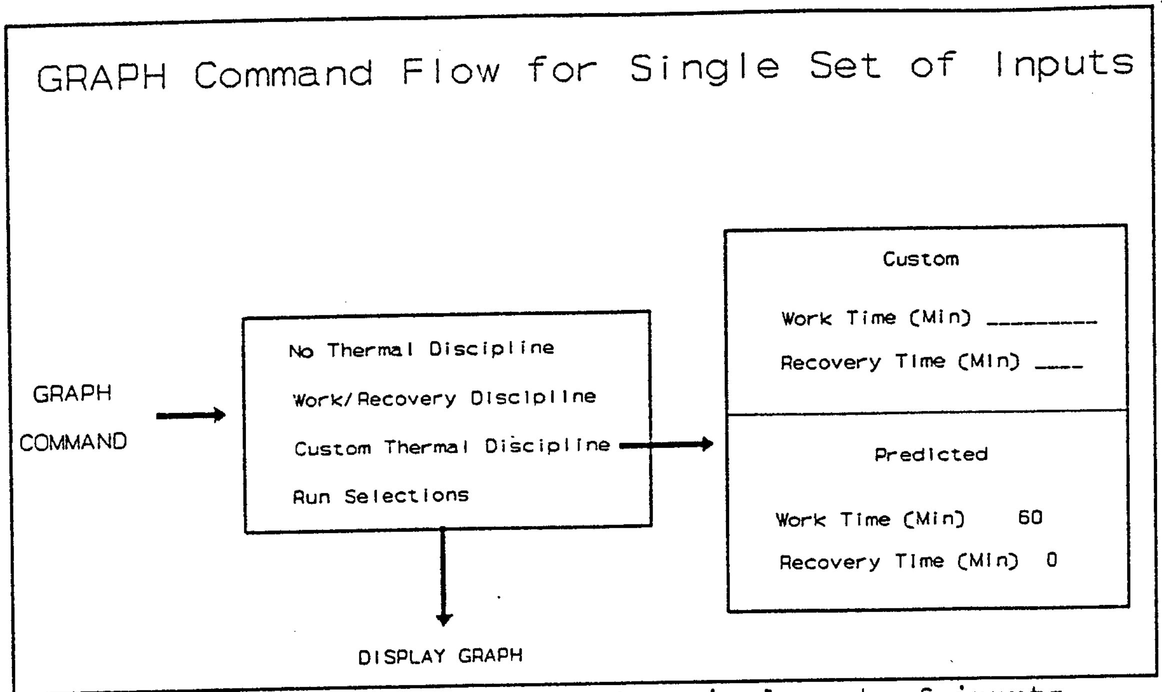


Figure 16. **GRAPH** command flow for single set of inputs.

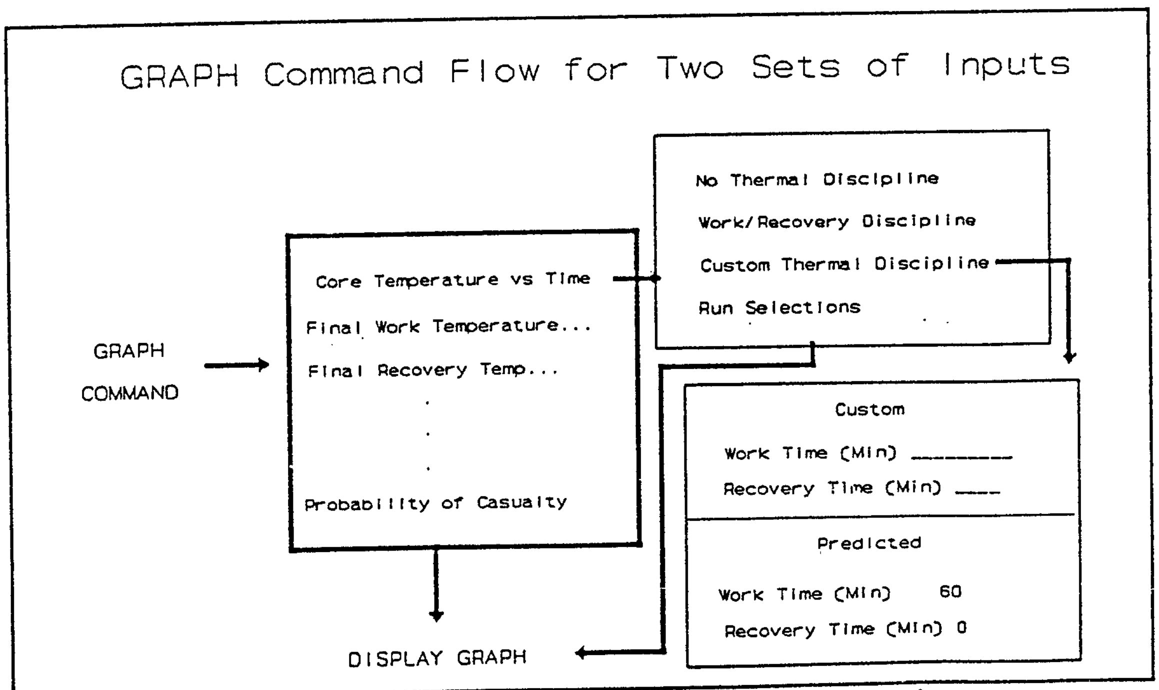


Figure 17. **GRAPH** command flow for two sets of inputs.

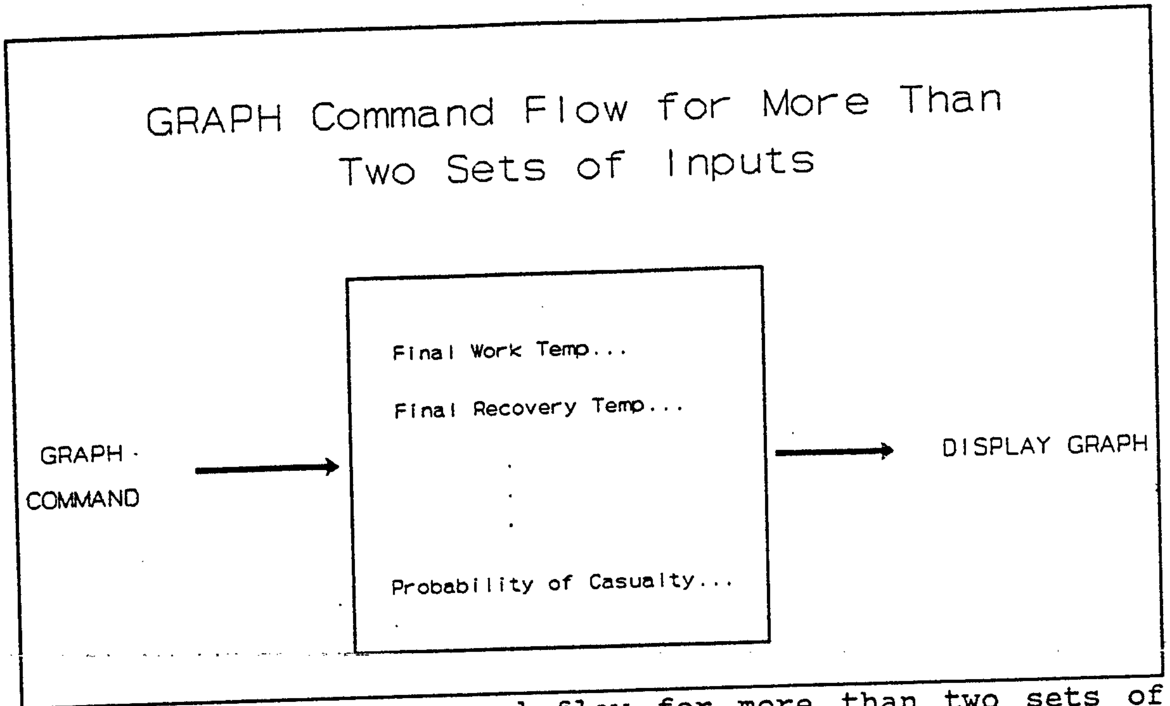


Figure 18. **GRAPH** command flow for more than two sets of inputs.

- **Other Graph Selections**

The other options available from the **MAIN GRAPH** menu (as shown in Figure 15) are graphs of final work temperatures, final recovery temperatures, predicted work times, predicted recovery times, predicted maximum work times and probability of casualties for each of the inputs specified. To select an option, highlight the desired graph and strike the **ENTER** key.

- **Interpreting Graph Display**

Line graphs are used for all core temperature plots (as illustrated in Figure 19) and for scalar values when more than six inputs have been selected. (Recall, scalar values are temperature, humidity, wind speed and days in heat).

The **GRAPH DISPLAY** page shows the desired graph in the upper right section of the screen, with a list of the inputs used for the current plot in the upper left corner. If multiple values for a nonscalar input parameter have been specified, that input parameter is omitted from the list of inputs. It can, instead, be viewed by invoking the legend for the graph. To display the legend, strike the **F4** key in **GRAPH MODE**. **F4** will also display a legend for core temperature graphs.

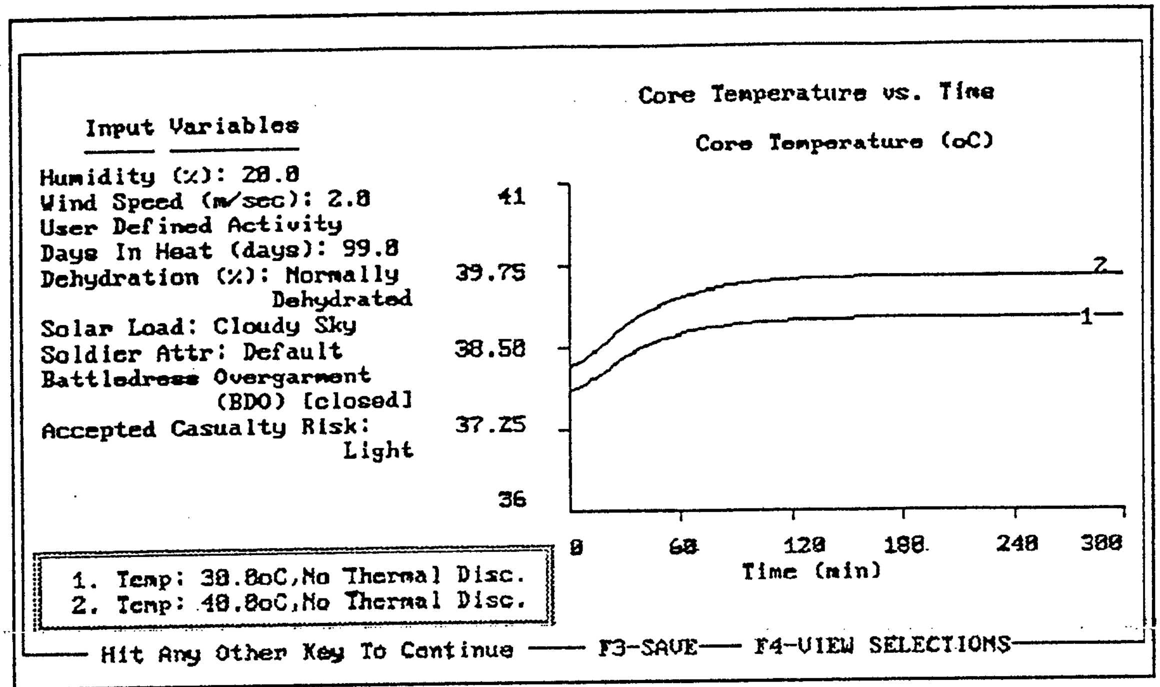


Figure 19. Core Temperature versus time graph.

The legend for each graph is displayed in the lower left corner of the screen. Since space on the graph display is at a premium, the legend text is truncated. You can, however, view the entire list by using the **LEFT** and **RIGHT ARROW** keys to shift the display from left to right. To redraw the graph without the legend, strike the **ESCAPE** key.

All other graphs are bar graphs. Figure 20 shows a bar graph used to compare maximum work times as a function of ambient temperature. Note that the X-axis values correspond to the selected temperatures and that these values are also included in the input list in the upper left corner of the display.

- **Saving Data in Text Format**

Input data and program results are stored in a binary file for use by the graph routines within the program. The **F3** key, used from the **GRAPH DISPLAY** screen, enables you to save the current data to an ASCII file. When you strike the key, you are asked to supply a file name; this file already exists you are warned and given the chance to enter a new name. Using "Save" option returns you to the **MAIN MENU DISPLAY.**

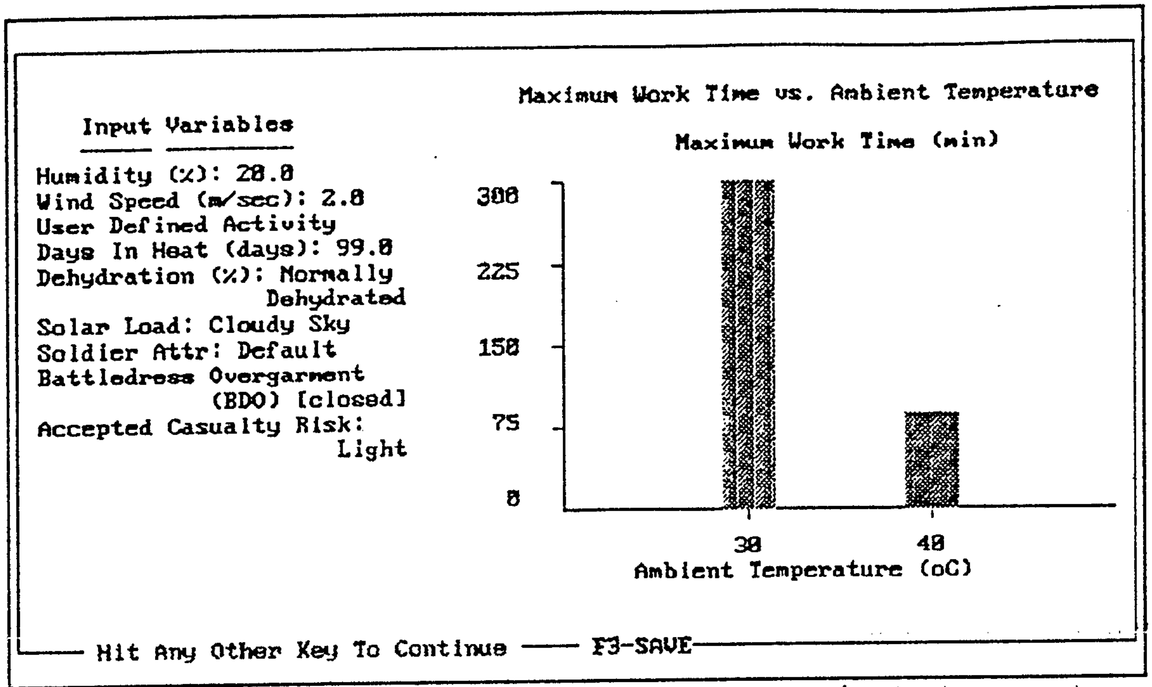


Figure 20. Maximum work time versus ambient temperature resulting from multiple inputs.

## REFERENCES


McNally, R.E., M.M. Stark, and D.T. Ellzy (1990). *Verfication and Usage of the Goldman-Givoni Model: Predicting Core Temperature and Casualty Generation in Thermally Stressful Environments*, Contract No. MDA903-88-D-1000, Science Applications International Corporation, Joppa, Maryland.

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Pandolf, K.B., L.A. Stroschein, L.L. Drolet, R.R. Gonzales, and M. Sawka (1986). Prediction modeling of physiological responses and human performance in the heat. *Comput. Bul. Med. 16*, Great Britain.

Passmore, R., and J.V.G.A. Durnin (1955). Human energy expenditure. *Physiol. Rev. 35*.

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# APPENDIX A

## INPUT Section Descriptions with Default Values and Ranges

## APPENDIX A

### INPUT Section Descriptions with Default Values and Ranges

The **INPUT** section of the **MAIN MENU** allows the user to change the environmental and soldier settings to variables that best approximate desired parameters. This appendix will discuss, in detail, each of the settings along with the allowable range designations.

**TEMPERATURE:** Temperature is the dry-bulb temperature of the air (ambient temperature). The default setting is 35°C. The allowable range is 10.0°C (min) to 65.0°C (max). To convert to °F, hit the **F2** function key. The program will convert the temperature to display in °F. Please note that the program displays the °F value only --°C is the internal computational value used in generating the results.

**HUMIDITY:** In general, humidity is defined as the measurable amount of moisture in the atmosphere. The default setting is 10.0%. The allowable range is 0-100%. By hitting the **F2** key, the user is presented with four alternative choices for input:

Relative Humidity: Relative humidity is the ratio of the water vapor present in the ambient air to the water vapor present in saturated air at the same temperature and pressure. The default setting is 10%. The allowable range is 0-100%.

Wet-Bulb Temperature: The lowest temperature that can be obtained on a wet-bulb thermometer in any given sample of air, by evaporation of water (or ice) from a muslin wick; used in computing dew point and relative humidity.

Dew-Point Temperature: The temperature at which water vapor in the air first starts to condense. The dew-point temperature is a measure of the actual water vapor content in the atmosphere. The water vapor content is constant for any dew-point temperature regardless of the dry-bulb or wet-bulb temperature. The allowable range is -273.15°C (min) to 37.77°C (max).

Absolute Humidity: The mass of water vapor present in a unit volume of the atmosphere, usually measured as grams per cubic meter. Absolute humidity may also be expressed in terms of the actual pressure of the water vapor present. The allowable range is 0.00 mm of Hg (min) to 42.18 mm of Hg (max).

**WIND SPEED:** The default setting is 0.5 meters/sec. The allowable range is 0.3 m/sec (min) to 20.0 m/sec (max). By hitting the **F2** key, the user is allowed to convert to alternative measurement scales (kilometers/hour, miles/hour, or knots).

**WORK ACTIVITY:** The user is presented with a list of 28 work activity choices presented in three submenus. Each work activity is further defined as either very light (VL), light (L), moderate (M), or heavy (H). The user highlights the appropriate work activity and hits the **RETURN** key. By hitting the F2 key, the user is allowed to convert to alternative measurement scales and to include units available (British Thermal Units/hour, Kilocalories/hour met).

If the user chooses the "User-Defined" list, specific rates can be set to the following limitations:

Work Metabolic Rate (in Watts): Work Metabolic Rate refers to the energy demand to continue an activity in which an individual is currently engaged. The default setting is 350.0 Watts. The allowable range is 75-800 Watts.

External Work (in Watts): External Work is the amount of physical work an individual is capable of conducting for the given metabolic rate at which he is currently working. The default setting is 0.0 Watts. The allowable range is 0-800 Watts.

**DAYS IN HEAT:** The default setting is 99 days. The allowable range is 0-99 days.

**DEHYDRATION:** The user may select four levels of hydration (User-Defined, Fully Hydrated, Normally Hydrated and Severely Dehydrated). If User-Defined is selected, the user may enter a specific level of dehydration. The default setting is 1.24%. The allowable range is 0 (min) to 20% (max).

**SOLAR LOAD:** The user may select four environments (User-Defined, Indoors, Clear Sky, or Cloudy Sky). If User Defined is selected, specific solar and cloud factors may be used:

Solar Factor: Solar Factor is the intensity of solar radiation on skin and/or clothing. The default setting is 0.0. The allowable range is 0.0 (min) to 300.0 (max).

Cloud Factor: Cloud Factor is an empirical factor, which, when combined with the Solar Factor, generates radiative solar transfer to the individual. The default setting is 4.0. The allowable range is 0.0 (min) to 5.0 (max).

**CASUALTY RISK:** The user may select from four casualty risk levels (User-Defined, Light, Moderate, or Heavy). If User-Defined is selected, specific values may be used:

Single Exposure Maximum Temperature Limit: Single-Exposure Maximum Temperature Limit refers to the temperature limit that someone can work to until maximum exertion is reached. The default setting is 39°C. The allowable range is 0.0°C (min) to 500.0°C (max).

Maximum Cyclic Temperature Limit: Maximum Cyclic Temperature Limit, combined with Work/Recovry values, refers to how high an individual's core temperature may reach before the individual must stop and rest. The default setting is 38.5°C. The allowable range is 0.0°C (min) to 500.0°C (max).

Maximum Sustained Temperature Limit: Maximum Sustained Temperature Limit is the core temperature of an individual working indefinitely under a specific temperature. The default setting is 38.5°C. The allowable range is 0.0°C (min) to 500.0°C (max).

Skin Temperature: The default setting is 36.5°C. The allowable range is 0.0°C (min) to 500.0°C (max).

**CLOTHING TYPE:** The user is presented with a list of clothing configurations. If User-Defined is selected, specific data may be used to further define clothing parameters if the listed configurations are not applicable:

Clothing Insulation: The default setting is 2.09 Clo. The allowable range is 0.4 (min) to 3.0 (max).

Im/Clo Permeability: The default setting is 0.16. The allowable range is 0.09 (min) to 2.0 (max).

Gamma for Clo: The default setting is -0.15. The allowable range is -0.5 (min) to -0.1 (max).

Gamma for Im/Clo: The default setting is 0.20. The allowable range is 0.1 (min) to 0.6 (max).

# APPENDIX B

## $P^2NBC^2$ Heat Strain Decision Aid List of Commands

APPENDIX B

## $P^2NBC^2$ Heat Strain Decision Aid
## List of Commands

### MAIN MENU COMMANDS

FILE - Invoked by hitting F or by highlighting **FILE** on the **MAIN MENU** and hitting the **ENTER** key. This command pulls down the file commands for saving the current set of inputs.

INPUT - Invoked by hitting I or by highlighting **INPUT** on the **MAIN MENU** and hitting the **ENTER** key. This command puts the user in **INPUT** Mode.

CALCULATE - Invoked by hitting C or by highlighting **CALCULATE** on the **MAIN MENU** and hitting the **ENTER** key. This command creates a binary file of **INPUT** sets and results. It can be used by the **GRAPH** routines and/or saved as ASCII text by hitting F3 immediately after selecting **CALCULATE**. Results are displayed on the **MAIN MENU DISPLAY** if a single set of inputs has been specified.

GRAPH - Invoked by hitting G or by highlighting **GRAPH** on the **MAIN MENU** and hitting the **ENTER** key. This command pulls down the graph choices menu.

F3 key - Used immediately after invoking the **CALCULATE** command; allows the user to specify the name of a file in which to store program results in ASCII format.

### FILE COMMANDS

GET FILE - Invoked by hitting G or by highlighting **GET FILE** and hitting the **ENTER** key. This command asks the user for the name of a file previously saved with the **SAVE FILE** command. This file is only readable by the program.

SAVE FILE - Invoked by hitting S or by highlighting **SAVE FILE** and hitting the **ENTER** key. This command asks the user for the name of a file in which to save the current inputs. This file can be retrieved by the program with the **GET FILE** command.

EXIT - Invoked by hitting E or X or by highlighting EXIT and hitting the ENTER key. This command is used to exit the program. If inputs have not been saved, the user will be given a chance to save the current inputs. If the user chooses not to save the current inputs, the program saves them in a file called "HSPM.OLD," which is used to start the next session.

ESCAPE - Hitting ESCAPE returns the user to the MAIN MENU.

INPUT COMMANDS

ENTER - The ENTER key is used to select an item from the predefined menus or to indicate entry of user-defined values or scalar values is complete.

ESCAPE - The ESCAPE key is used to request several somewhat related actions. If the user is in a predefined pull-down menu, ESCAPE is used to exit that menu and return to the MAIN INPUT menu without altering the previous inputs. ESCAPE is also used to continue after certain warning messages are displayed (especially those about inputs being outside the predefined minimum and maximums for the particular parameter). Finally, ESCAPE is used to return to the MAIN MENU DISPLAY.

F2 - The F2 key can be used to invoke unit conversion for a particular input parameter (if that parameter has alternative measurement units defined). F2 can be invoked after a scalar value or user-defined value has been entered and before ENTER has been hit, or it can be invoked when the item is highlighted.

PAGE UP
PAGE DOWN
UP
DOWN
HOME
END - These keys are used to traverse predefined menus or the **MAIN INPUT** menu.

RIGHT
LEFT - These keys are used to shift the screen display to the left or right when the multiple text selection menus are displayed.

GRAPH COMMANDS

ENTER - The **ENTER** key is used to select an item from the **GRAPH** menus. It is also used to terminate data input for Custom Thermal Discipline work/recovery cycles. **ENTER** is also used to select highlighted graph types on the Core Temperature menu. **ENTER** must be hit when the "Run Selections" option is highlighted on the Core Temperature submenu in order to display the selected graphs.

F4 - The F4 key can be used from the **MAIN GRAPH DISPLAY** page to bring up the legend for the current graph.

ESCAPE - The **ESCAPE** key is used to erase the legend displayed with F4.

F3 - The F3 key can be used from the **MAIN GRAPH DISPLAY** page to save current data to an ASCII text file. This action will also return the user to the **MAIN MENU DISPLAY.**

# Use of Sleep Disciplines to Mitigate Thermal Hazards to Operations in Southwest Asia

Contract # DAAL02-90-C-0071
Task Order No. 0001AD

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## ABSTRACT

The recent Desert Shield/Storm operation brought to light the necessity for a rigorous level of intense military effectiveness in a thermally stressful environment. Our combat personnel must be able to maintain an effective balance between sleep requirements and military effectiveness in order to perform continuous operations.

This report focuses on the impact of using sleep disciplines to mitigate the impacts of working in extremely hot environments. A Headquarters and Headquarters Battery for a Field Artillery Battalion, 155mm Self-Propelled Heavy Division, was modeled and used to illustrate the potential advantage of sleeping during the hot periods of the day and completing operations during the cooler nighttime periods. The study reported here was completed in two phases: Phase I illustrates the use of sleep as a thermal discipline, while Phase II shows the impact of various sleep disciplines over a 20-day period.

The results indicate that optimal thermal discipline, such as that modeled for this analysis, can extend effective performance in the most demanding thermal environment and prevent thermal casualties; less than optimal hydration demonstrates the mass casualty potential of failing to heed the tenets of thermal discipline; sleep deprivation can have catastrophic consequences on unit performance; appropriate sleep discipline and thermal discipline can maintain effective unit performance indefinitely; and that sleep during the day in the thermally intense environment of Southwest Asia is an effective adjunct to effective thermal discipline in maximizing unit effectiveness.

FIGURES

## TABLES

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# 1. INTRODUCTION

"Continuous operations," as defined in U.S. Army Field Manual 22-9, is continuous land combat with some opportunity for sleep, although this sleep may be brief or fragmented. The successful development and application of a doctrine for managing sleep and alertness in continuous operations is essential to success on the battlefield. The potential technological advantages of night vision and electro-optical devices for all weather operations increase the potential for continuous operations.

The Soviet soldier and his unit have planned continuous operations in a 2-3 day surge period with no opportunity to sleep. After this surge, the soldier and his unit are rotated from the action for a specific time frame to rest, reorganize, and resupply while, in its place, another unit conducts the operation. The U.S. Army cannot conduct continuous operations by rotating personnel in shifts (in part because of the inability to rotate crews or teams efficiently). The U.S. Army cannot conduct continuous operations by fighting soldiers and units to exhaustion and replacing them with fresh personnel because of the numerical superiority of the Soviet Union and its allies in men and material (WRAIR Technical Report No. BB-87-1).

The combat unit must maintain an efficient balance of sleep and work in order to sustain high levels of performance in continuous operations. Ideally, every individual would receive adequate sleep to maintain effective performance on a daily basis; this performance must be maintained in all activities during the day. Nominally, the amount of sleep necessary to do this depends on the individual and the tasks to be performed. Continuous operations are routinely conducted by U.S. Navy, U.S. Air Force, and U.S. Army aviation units with 6-8 hours of sleep in every 24-hour period. It is difficult and potentially dangerous to conduct unit level exercises to evaluate the long-term impact of the continuous operations with different sleep disciplines. Laboratory measurements of effectiveness on experimental tasks do not readily translate into performance of tasks necessary to maintain operational effectiveness. As a step to examine the implication of different sleep disciplines, an effort was undertaken to define, develop, test, and evaluate a methodology to incorporate sleep into the Army Unit Resiliency Analysis (AURA) model. This effort was completed in October 1989 (McNally *et al.*, 1989).

Operation Desert Shield/Storm highlighted the need for a robust doctrine for conducting military operations in hot environments. The desert terrain and the intense thermal environment found in Southwest Asia forces soldiers to drastically alter their mode of operations. Heat stress and dehydration become real threats to the ability of troops to operate. An evaluation of alternative work disciplines in hot environments and the resulting impact of these disciplines on unit performance were completed in October of 1990 (McNally *et al.*, 1991)

There is a potential advantage to considering alternative sleep regimens in concert with effective thermal disciplines in order to develop an interdisciplinary approach to minimize thermal stress in hot environments. If soldiers sleep during the hot periods of the day, they may be able to avoid heat stress and, thus, maximize their effectiveness in hot environments. This study examined both the effects of sleep deprivation on unit performance and the use of sleep as a thermal discipline.

In the course of this study, we modeled the combined impact of sleep deprivation and thermal stress in a hot environment (e.g., Southwest Asia). Of primary interest was the potential advantage the unit might gain by adopting a sleep regimen which allowed them to sleep during the hot periods of the day. Assuming soldiers could successfully adapt to daytime sleep, this approach could potentially prevent otherwise unavoidable heat casualties and provide soldiers with needed rest to effectively perform assigned duties/tasks.

We examined individual variations of sleep requirements to determine the unit's sleep requirements. Sleep requirements were specified as a normal distribution with a mean of 6 hours and a standard deviation of 45 minutes. Sleep regimens studied included 4, 8, and 12 hours of sleep in each 24-hour period; unit performance was assessed over a period of 20 days under each regimen.

## 2. STUDY OBJECTIVE

The objective of this study was two-fold: to determine the impact of alternative sleep regimens on an Army unit performing primarily cognitive tasks and to evaluate the use of sleep as a thermal discipline. Earlier studies were performed using an M109 Artillery Battery to illustrate the impact of sleep deprivation on unit performance (McNally *et al.*, 1989). The greatest impact of sleep deprivation, however, is evident in soldiers performing cognitive tasks as opposed to those performing strictly labor-intensive tasks. Using a cognitive unit for this analysis gives a "worst case" view at the effects of sleep deprivation.

## 3. STUDY APPROACH

The AURA methodology, as developed by Dr. J.T. Klopcic of the U.S. Army Ballistic Research Laboratory (BRL), was used to measure the impact of sleep deprivation and thermal stress on a unit's performance. The unit chosen for this analysis was a Headquarters Unit for an M109 Artillery Brigade. The Headquarters Unit performs tasks which can be classified as almost entirely cognitive in nature.

The AURA model determines, for a given unit under a given set of conditions, unit effectiveness in performing a pre-specified mission. This effectiveness value was used as a measure of performance for the current study and a basis of comparison for the cases studied.

## 4. SLEEP METHODOLOGY

The sleep methodology within AURA has been documented in an earlier report (McNally *et al.*, 1989). A discussion of this methodology and of the modifications made to the methodology during the course of this study will be included in this report.

In the sleep methodology used for the previously referenced studies, there were six key variables to identify the sleep cycle within AURA. These variables included the definition of the unit of effective sleep, the maximum allowable accumulation of these effective sleep units, the level of sleep units which are equivalent to 100% effective performance, and the use rate of effective sleep units during work activities. The final variable used in the methodology was the size of the reservoir of effective sleep units that can be saved for use at a later time. Three additional variables were developed for use during this analysis. These new variables included a parameter to specify a required work period. This variable allowed us to control sleep periods more easily and directly than did the previous methods of adjusting the minimum sleep units needed to remain awake. Two other variables were added to the AURA model to allow the representation of individual variations in required sleep. These will be discussed in detail in the section on the AURA methodology.

### 4.1 SLEEP ACCUMULATION FUNCTION

The basic sleep accumulation function is constructed in four segments (see Figure 1). For the first 10 minutes, no "minutes of effective sleep" are generated; for minutes 10 through 30, a person is given half-credit for the amount of time asleep (i.e., 10 minutes). So a person at 30 minutes into their sleep period will have accumulated 10 "minutes of effective sleep," reflecting the fact that individuals do not start deriving full benefit from sleep until 30 minutes after they have fallen asleep. From 30 minutes until the point where they have made up 80% of the difference between where they started at the beginning of the sleep period and maximum extent of their reservoir (that level defining full restedness), a person is able to accumulate effective sleep on a one-to-one basis one minute of effective sleep for each minute asleep. After replenishing 80% of the deficit, a person only accumulates half of a minute of effective sleep for every minute the person sleeps. For example, the benefit to be derived from six hours of rest is calculated by solving the following set of simultaneous equations:

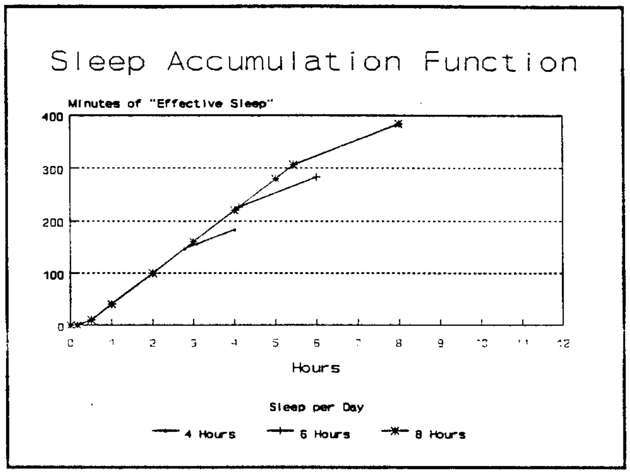


**Figure 1.** Sleep Accumulation Function

$$10 + x*1 + (330 - x) * \frac{1}{2} = Total\ Slunits (Eq.1)$$

$$10 + x*1 = 0.8 * Total\ Slunits \quad (Eq.2)$$

where, X is the number of minutes of sleep and a ***Slunit*** represents a minute of "effective sleep."

If a person is in balance working 18 hours and sleeping 6 hours, during that 6-hour sleep period he would accumulate 283 1/3 effective minutes of sleep and be at maximum sleep accumulation at the end of the sleep period. If a person was very tired, having worked more than 18 hours, then a 6-hour sleep period could potentially yield 340 "minutes of effective sleep" in a 6-hour period because the reservoir remained below the 80% threshold of diminishing returns. Finally, once a person sleeps sufficiently long to reach the maximum of their reservoir, further sleep accrues no further benefit to the sleep accumulation function.

## 4.2 WORK DEGRADATION FUNCTION

The rate at which sleep units are used is based on the observations of degradations in performance in individuals deprived of sleep over extended periods. The Department of Behavioral Biology of the Walter Reed Army Institute of Research has observed that the maximum time that a person can work without effective rest is 4 days. Measures of a variety of mental (cognitive) tasks indicate that the rate of correct performance declines an average of 25% per day.

It has also been observed that a person in their normal sleep cycle (where they are in balance) will be able to retain 100% performance in their every day of work in that environment. A person that has a nominal sleep requirement of 6 hours of sleep/18 hours of work will still perform at 100% of their capability at the end of the 18-hour work period. With these limits in mind, assuming work is to continue, we modeled a linear drop in the effectiveness at which they were able to perform their job. For this analysis, all jobs were considered to be cognitive and, therefore, subject to a performance degradation of 25% per day without effective rest.

## 4.3 SLEEP REQUIREMENTS DISTRIBUTION

In order to model individual variations in sleep requirements, the differences in sleep balance points for individuals were assigned according to an approximate normal distribution of requirements. The distribution of sleep requirements was categorized into four classes (see Figure 2).

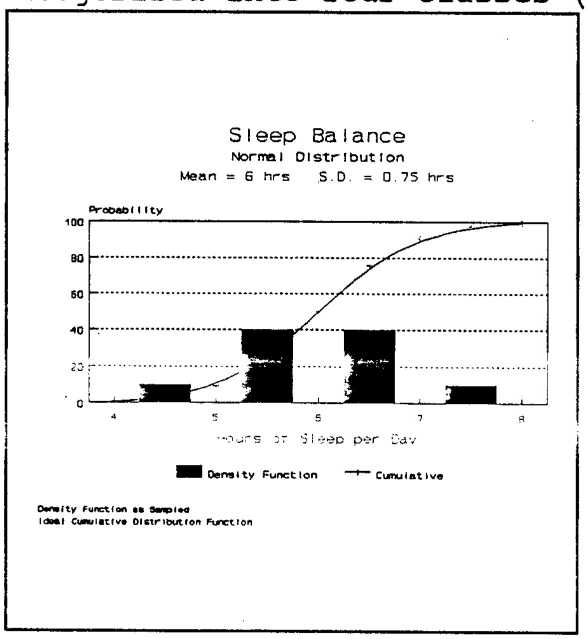


**Figure 2.** Sleep Requirements Distribution

- 10% of the unit was assumed to require 7.5 hours of sleep

- 40% of the unit required 6.5 hours of sleep

- another 40% of the unit required 5.5 hours of sleep

- 10% of the unit required 4.5 hours of sleep

The above factors resulted in an approximation to the normal distribution with a mean of 6 hours and a standard deviation of 45 minutes. The differences in sleep balance point required an adjustment to the size of the reservoir for individuals performing different jobs. The absolute rate at which "minutes of effective sleep" were used was individualized to reflect both the rate of use imposed by the job and the adjusted size of the reservoir for the individual.

# 5. THERMAL FACTORS

## 5.1 THE GOLDMAN-GIVONI MODEL

The Goldman-Givoni Model was used to predict core temperature and probability of casualty for soldiers operating in the thermally stressful environments expected in Southwest Asia. The Goldman-Givoni model is based on equations generated by work conducted at the U.S. Army Research Institute of Environmental Medicine (USARIEM) during the late 1960s and early 1970s by Baruch Givoni and Ralph Goldman. Currently, three implementations of this model are being used for different purposes in different organizations. The implementation used for this study was originally coded by Dr. Klopcic at BRL for use in AURA (the combat simulation model) and subsequently modified by analysts at Science Applications International Corporation.

The BRL implementation of the Goldman-Givoni model is written in FORTRAN 77. The foundation for the BRL implementation was the stand-alone FORTRAN model known as TCORE, described by Berlin *et al.* (1975). Initially, TCORE was used, as a member of the AURA family of models, to produce coefficients which were used as input values to AURA. TCORE has subsequently been modified and is now incorporated directly into the AURA model. This modified code has come to be called the BRL implementation of the Goldman-Givoni model. A verification of the model and a demonstration of its used was completed in April, 1990 (McNally *et al.*, 1990).

The Goldman-Givoni model accepts inputs describing the meteorological conditions, working metabolic rate, clothing worn, initial skin temperature, level of acclimatization, and level of dehydration being considered. The model then uses these inputs to determine the expected equilibrium core temperature of an individual and the resulting probability of casualty. The BRL implementation also produces a distribution of the times at which the casualties are expected to occur.

The Goldman-Givoni algorithms have recently been translated from the Hewlett Packard CV-41 calculator language to ADA as part of Contract No. DAAL02-90-C-0071, Task Order No. 0001AA. The new model is known as the USARIEM Heat Strain Prediction Model. This new model is currently being enhanced as part of Contract No. DAAL02-90-C-0071, Task Order No. 0001AE. These enhancements will include a new user-interface and a graphics capability.

## 5.2 METEOROLOGICAL CONDITIONS IN SOUTHWEST ASIA

Meteorological data collected in Dhahran, Saudi Arabia in July, 1989 was used for this analysis and is shown in Table 1 (Matthew, 1989). Meteorological conditions change over the course of the day and, as such, five time periods are outlined in the table for use in the study, with the most severe conditions prevailing between 1100 and 1500 hours. Some variations on these meteorologic data were used in the analysis to represent the differing conditions found in coastal and inland regions. These will be discussed in the section on the AURA model which follows.

**Table 1. Average Meteorological Data for Dhahran, Saudi Arabia in July, 1989**

| LOCAL TIME | WINDSPEED M/S | WET BULB °C | DRY BULB °C | WBGT °C | SOLAR WATTS |
|---|---|---|---|---|---|
| 0000-0700 | 2.9 | 21.5 | 31.1 | 24.6 | 0 |
| 0700-1100 | 4.6 | 21.5 | 35.6 | 27.3 | 516 |
| 1100-1500 | 6.4 | 22.6 | 40.9 | 29.6 | 519 |
| 1500-1900 | 6.1 | 23.0 | 39.1 | 28.7 | 361 |
| 1900-2300 | 3.3 | 23.1 | 34.5 | 26.6 | 0 |
| 2300-2400 | 2.9 | 21.5 | 31.1 | 24.6 | 0 |

## 5.3 METABOLIC LIMIT AS A WORK DISCIPLINE

In a previous study, various work disciplines were examined and evaluated as to their effectiveness in avoiding casualties while maximizing unit performance (Stark *et al.*, 1991). One such discipline was referred to as a "metabolic limit discipline." This work discipline allowed soldiers to pace themselves over the course of the day, taking care not to allow their core temperatures to exceed a pre-determined level. The results of these studies showed a metabolic limit discipline at 39°C provided the greatest payoff in unit performance with relatively few (at most 20%) casualties. This work discipline was used in this analysis.

# 6. UNIT PERFORMANCE

## 6.1 THE AURA MODEL

The AURA methodology was developed to represent a unit's mission effectiveness. AURA considers the combination of the assets available to a unit and the individual jobs which must be done correctly in a time sequence to appropriately complete a mission segment. The assets of a unit are selected based on the table of organization and equipment (TOE) while the jobs are based upon the Army Training Evaluation Program (ARTEP) standards for essential tasks and the performance measure to be gained from the proper execution of the job.

## 6.2 THE HEADQUARTERS UNIT

The unit chosen to study in this analysis was a Headquarters and Headquarters Battery for a Field Artillery Battalion, 155mm Self-Propelled Heavy Division. This unit was initially modeled by analysts at BRL and documented in November, 1988 (Roach, 1989). Although these original inputs were used for this study, they were modified significantly during the course of the analysis. Some modifications were limited to minor changes in how assets were portrayed in order to correctly use the sleep and thermal methodologies. However, a major overhaul of the parameters used to describe each job and what combinations of jobs were required was done to eliminate weaknesses in the original unit description.

The Headquarters Unit is very personnel-intensive. In all, the unit has 209 personnel assets and 77 individual pieces of equipment. The mission selected for the unit in the original BRL study was for the unit to be able to perform 26 fire support tasks per hour. This rather broad mission statement was meant to be all-inclusive, reflecting many of the types of tasks performed by such a unit. Appendix A contains both an input listing from the original BRL study, showing the parameters used to describe each required job and a graphical representation of the unit's functional structure, e.g., the organization of jobs required to perform the units mission.

Of high concern to us during this analysis was the organization of jobs in the original BRL inputs. Specifically, many of our initial runs highlighted the seemingly exaggerated importance of the Fire Direction Officer and those jobs related to fire direction. The original unit structure was designed in such a way as to bring the unit's effectiveness to 0% if the Fire Direction Officer's job or any related jobs were unable to be performed (due to unavailability of personnel to do the job because of sleep or heat stress). Concern over this portion of the original inputs prompted a set of working sessions with Major Andrew Ellis and SSGT Faisson, both experienced Field Artillery soldiers stationed at the BRL. They were tremendously helpful in assisting us with redefining the structure of the Headquarters Unit. The major changes included: providing an alternate pathway for performing the mission in the absence of the unit's fire direction capability, modifying the contribution of various components in the unit and revamping the substitution matrix. These new inputs are included in Appendix B.

### 6.3 MODELING OF SLEEP IN AURA

The AURA Sleep Methodology has undergone numerous modifications during the course of the studies performed by SAIC analysts. In the past, a series of 20 separate AURA runs were required to examine the effects of sleep deprivation over a 20-day period (thereby ensuring that the long-term effects of sleep deprivation would not be missed). Separate runs were mandatory due to the limited number of time points allowed in AURA at the time (approximately 49). In order to overcome this limitation, a set of cyclic procedures was developed to run AURA, capture key output values and, subsequently use them to generate a new input set. Once the new inputs were generated, AURA was run again. This cycle continued until 20 runs were completed, each tracking the effects for a single day.

The sleep methodology which existed in AURA prior to this study provided only limited control over when assets were allowed to go to sleep. As a result, two variables, known as MIN and MAX, were adjusted between each run to ensure the unit would maintain the specified sleep discipline. An additional AURA input variable was introduced during the course of this study which provided more control over when soldiers were allowed to sleep.

The introduction of thermal considerations into this sleep analysis forced us to implement some changes in how we used AURA, and, in fact, in AURA itself. While the sleep routines within AURA are not stochastic in nature, the thermal routines are. Therefore, it was desirable to use one AURA run to show thermal and sleep effects. Stochastically, the critical core temperature to become a thermal casualty is drawn at the beginning of each simulation and is compaired to the core temperature developed during the run. A single run over the 20-day period was the only way to insure that the some personnel have thermal casualties. Twenty separate runs would generate 20 different patterns of thermal casualties for each replication. This requirement led to an increase in the number of reconstitution times allowed in AURA.

The modeling of individual variations of sleep requirements prompted the last set of modifications to the AURA model. The AURA model provides for two parameters which are job-related and specify at what rate a particular job tires the worker and when job performance starts to degrade due to sleep deprivation. In past studies, we used these parameters to model individual variations which are inherently asset-related, and not job-related. To illustrate the difference between these two concepts, consider the soldier who requires 4.5 hours of sleep--it is not the job being performed that makes him a 4.5 hour sleeper; but, instead, has to do with his own requirement for sleep regardless of the job he actually performs. While this distinction was not a problem in past studies (due to the nature of how the units were organized), in the current study it was essential to have some method to relate these factors to an individual, independent of the job he was required to perform. The details of these modifications are included in Appendix C. Table 2 lists the key parameters used in modeling sleep deprivation for this study. Appendix D contains the algorithms and computations used to develop the parameters shown in Table 2.

Table 2. Values Used for Modeling Sleep in AURA

| Required Sleep (Hrs) | Desired Slunit Usage Rate (Sl/Min) | Desired Threshold (Slunits) | Slunits Gained (Slunits) | Asset Inputs | | Job Inputs | |
|---|---|---|---|---|---|---|---|
| | | | | MUL | TMUL | Fatigue Rate (Sl/Min) | Threshold (Slunits) |
| 4.5 | 0.21368 | 980.77 | 250 | 0.67876 | 0.66568 | 0.31481 | 1473.33 |
| 5.5 | 0.27928 | 1298.65 | 310 | 0.88714 | 0.88144 | 0.31481 | 1473.33 |
| 6.5 | 0.35238 | 1659.71 | 370 | 1.11934 | 1.1265 | 0.31481 | 1473.33 |
| 7.5 | 0.43434 | 2071.82 | 430 | 1.37969 | 1.40622 | 0.31481 | 1473.33 |

In modeling sleep within AURA, we needed to be very careful in our choice of reconstitution points, that is, the times at which AURA is called upon to evaluate the unit's ability to perform its mission(s). Within AURA, sleep can begin or end at a reconstitution point but not in between points. Thus, inappropriate choices for these time points could result in assets being worked longer than desired or in assets being allowed to sleep for longer periods than desired.

## 6.4 MODELING OF THERMAL EFFECTS IN AURA

The meteorological conditions presented in Table 1 were used for this study with some modifications. Meteorological conditions in that area of the world vary greatly and depend largely on an individual's proximity to coastal regions. Humidity variations can be as low as 20% humidity for inland regions as opposed to 80% humidity for coastal regions. The resulting impact on predicted casualties greatly affects unit performance.

In order to provide a representative overview of expected thermal casualties and their impact on unit performance, three thermal environments were modeled. The environment found in air-conditioned tents or buildings provided a "best-case" scenario for evaluating sleep deprivation in the absence of any thermal casualties. The other two environments modeled reflected those found in inland and coastal regions. Inland and coastal meteorological conditions varied only in anticipated humidity. Humidity in inland regions was estimated at 20%, while humidity on the coast was set at 80%.

The windspeed shown in Table 1 was used during daytime hours, but was limited to 0.5 meters/second at night in all cases to reflect having tent flaps closed at that time.

Those personnel who directly contributed to completing the unit's mission were assigned a working metabolic rate of 150 watts; 150 watts is reasonable for personnel performing cognitive jobs which do not require much physical labor. Unassigned assets were assumed to be at rest and, therefore, were assigned a metabolic rate of 105 watts. Sleeping personnel were given a metabolic rate of 75 watts.

Finally, soldiers were considered to be wearing the standard battle dress uniform (BDU) and to be fully acclimated to the environment. Three levels of dehydration were considered: 0, 2, and 4% dehydration.

Table 3 summarizes the key thermal parameters used for this study.

| Table 3. Values Used for Modeling Thermal in AURA | | | |
|---|---|---|---|
| AURA Parameter | Thermal Environment | | |
| | Air Conditioning | Inland Region | Coastal Region |
| Ambient Temperature (°C) | 25 | ----- [1] | ----- [1] |
| Humidity (%) | 30 | 20 | 80 |
| Wind Speed (m/s) | 0.5 | ----- [2] | ----- [2] |
| Working Metabolic Rate (watts) | 150 | 150 | 150 |
| Level of Dehydration (%) | 0,2,4 | 0,2,4 | 0,2,4 |
| Skin Temperature (°C) | 37 | 37 | 37 |
| Days of Acclimatization | 12 | 12 | 12 |
| Clothing | BDU[3] | BDU[3] | BDU[3] |

[1]Varies during the day according to values shown in Table 1.
[2]Varies during the day according to values shown in Table 1. During night hours, wind speed was set at 0.5 m/s to reflect closed tent flaps.
[3]Battle dress uniform.

As discussed above, a work discipline (referred to as the metabolic limit discipline) was modeled. This discipline reflects an individual's ability to pace themselves in hot environments. By limiting the intensity of work to a predefined level, individuals are able to avoid large levels of heat stress casualties. Of course, restricting work intensity has the net result of reducing an individual's ability to perform. Previous studies have examined the impact of implementing this discipline and have determined that establishing a core temperature limit of 39°C results in an acceptable level of casualties (at most 20%) with the highest payoff in terms of unit performance (Stark *et al.*, 1991). This metabolic limit of 39°C was used for this analysis.

The Goldman-Givoni model was used to provide the inputs to the AURA model required for modeling this work discipline. Prior to running the AURA model, each set of thermal conditions were input to the Goldman-Givoni model. The 39°C core temperature limit was then specified. The Goldman-Givoni model subsequently generated a metabolic rate which would keep an individual's equilibrium core temperature from exceeding 39°C. This metabolic rate was then used within AURA to limit an individual's metabolic rate during the extremely hot portions of the day. At the same time, degradation factors were generated for use in AURA. These degradation factors accounted for the performance decrement resulting from restricting work intensity during those hot periods.

After running all the different sets of conditions through the Goldman-Givoni model, only the coastal conditions produced metabolic rates above the original estimated working metabolic rate of 150 Watts for the unit. Thus, performance degradation during hot periods was only evident in those runs reflecting coastal degradation. Table 4 shows both the metabolic limits required for individuals to keep their core temperature under 39°C and the resulting degradation factors. Metabolic rates were only limited during the two extremely hot parts of the day: between 1100 and 1500 hours and between 1500 and 1900 hours.

Table 4. Metabolic Limits and Degradation Factors for Personnel Operating in Southwest Asia Coastal Regions

| Level of Dehydration | 1100 - 1500 hours<br>Ambient Temperature: 40.9°C<br>Wind Speed: 6.4 m/s<br>Humidity: 80% | | 1500 - 1900 hours<br>Ambient Temperature: 39.1°C<br>Wind Speed: 6.1 m/s<br>Humidity: 80% | |
|---|---|---|---|---|
| | Metabolic Limit (Watts) | Degradation Factor | Metabolic Limit (Watts) | Degradatio Factor |
| 0% | 130 | 0.56 | ------[1] | 1 |
| 2% | 101 | 0 | ------[1] | 1 |
| 4% | 68 | 0 | 125 | 0.44 |

1. Working metabolic rate sufficient to keep core temperature below 39°C.

The AURA implementation of Goldman-Givoni requires the AURA analyst to carefully select reconstitution points (those time points at which AURA is queried as to how effective the unit can operate). In order to assure that all thermal casualties will be correctly assessed, AURA requires the analyst to allow sufficient time for an individual to reach their equilibrium core temperature. Allowing four hours between reconstitution points assured that all thermal casualties would be correctly assessed.

## 7. FINDINGS

The results of this study focused on two areas: the effectiveness of using sleep as a thermal discipline and the impact of alternate sleep disciplines in hot environments. Phase I evaluated the potential benefit of sleeping troops during the day to minimize the otherwise unavoidable consequences of working in extreme hot environments. In theory, daytime sleep routines are attractive because they enable troops to get their required rest during what would be potentially unproductive and possibly health-threatening hours of the day. Daytime sleep regimens, however, assume that troops can successfully fall asleep during daytime hours and still achieve "effective rest".

Sleeping soldiers during the cooler nighttime hours provides the same sleep benefit (if the above assumption regarding the effectiveness of daytime sleep is true) but does not take advantage of these cooler temperatures to complete work which is severely restricted during the hot periods of the day. Of key interest was the potential payoff to be achieved by minimizing thermal casualties and maximizing performance by getting rest during the most thermally-stressed periods of the day.

The thermal model in AURA assumes that once a given soldier is exposed to a particular thermal environment and has survived it, he is likely to survive that same environment in the future. Thus, given that thermal conditions specified for the first day repeated for all subsequent days, the thermal impact of daytime sleep and nighttime sleep was evident by the end of the first day of the scenario.

The full impact of sleep deprivation on a unit is not evident until 10 days have past. Thus, Phase II examined the effects of sleep deprivation over a 20-day period, and also included thermal effects.

### 7.1 PHASE I: SLEEP AS A THERMAL DISCIPLINE

Figure 3 shows the percent of thermal casualties for the Headquarters Unit operating in air-conditioned tents or deployed either inland or in coastal regions in Saudi Arabia. Note that these results are for fully acclimatized, fully hydrated individuals dressed in BDUs. Under these sets of conditions, casualties are only expected in coastal regions. If the unit sleeps during the night hours (and, thus, works during the hot periods of the day) approximately 12% casualties are predicted. Recall, also, that a metabolic limit discipline is being modeled. These results indicate that even when trying to limit activities, troops can be expected to see some thermal casualties. Minimal to no casualties can be expected if soldiers are allowed to sleep during the hot periods of the day.

It should also be noted that, in fact, AURA was only run once to show the impact of working in air-conditioned tents. Since air-conditioning did not result in any casualties, it was unnecessary to run AURA for each sleep discipline In this environment.

Figure 4 shows the impact of these casualties and of setting a metabolic limit for troops operating during the hot periods on unit performance. Note that the effectiveness shown is the "average effectiveness" for the first day of the scenario. Recall that all thermal casualties are realized by the end of the first day given that the thermal conditions on subsequent days are repeated. For those environments in which no casualties are taken, the only lost effectiveness results from lack of performance during sleep. The values shown for night sleep on the coast reflect both thermal casualties and degraded performance during the hot periods of the day. The Headquarters Unit is a brittle unit in that few casualties result in large losses in effectiveness.

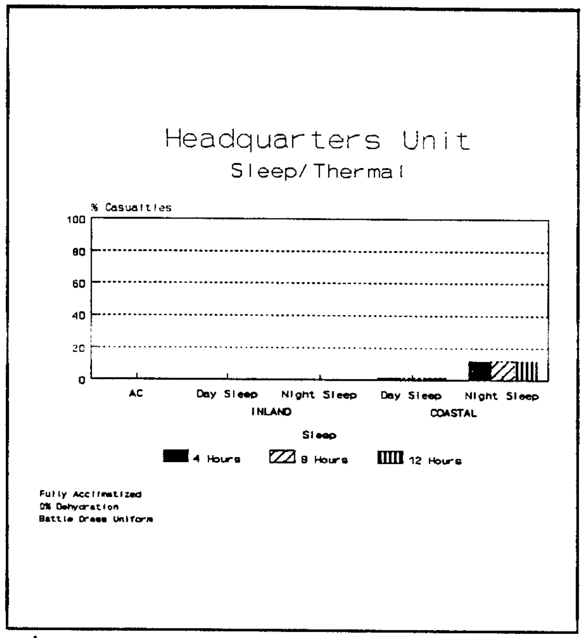


**Figure 3.** Percent Casualties for Headquarters Unit, 0% Dehydration

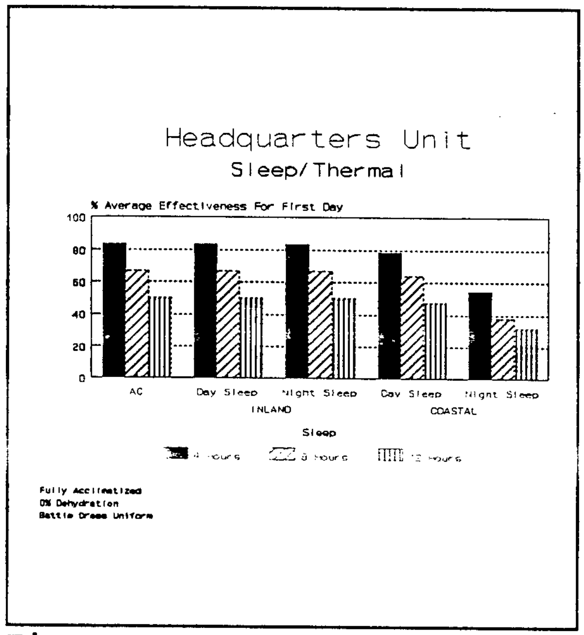


**Figure 4.** Percent Average Effectiveness for First Day, Headquarters Unit, 0% Dehydration

Figures 5 and 6 show predicted thermal casualties and the resulting impact on unit performance for soldiers 4% dehydrated. Casualties in this case exceed the 20% maximum established for using the 39°C core temperature limit as discussed above. Close examination of Table 4 will reveal why casualties exceed this pre-determined limit. During the hottest period of the day, a soldier would have to limit his metabolic rate to 68 watts. Since 105 watts represents a resting metabolic rate and 75 watts estimates an individual's metabolic rate during sleep, it is physically impossible for an individual to limit his efforts to 68 watts. Thus, the desired ceiling of 20% casualties was exceeded.

As shown in Figure 3, even day sleep is insufficient in preventing all thermal casualties if individuals are very dehydrated. Still, the predicted level of casualties for day sleep is less than half that associated with night sleep (working during the hot periods of the day).

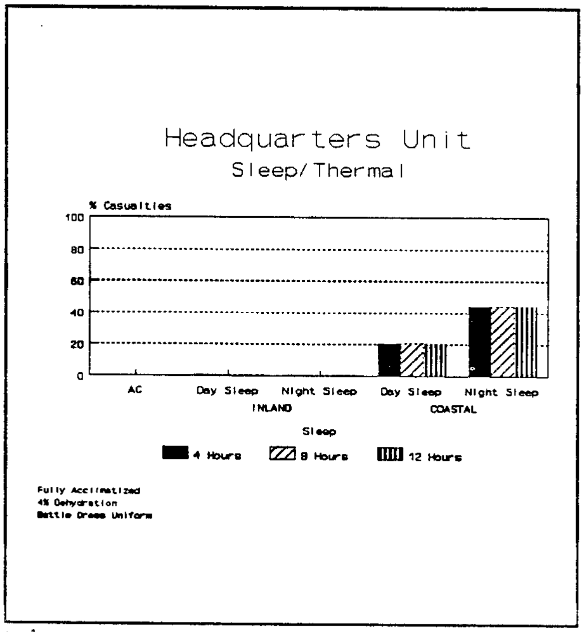


**Figure 5.** Percent Casualties, Headquarters Unit, 4% Dehydration

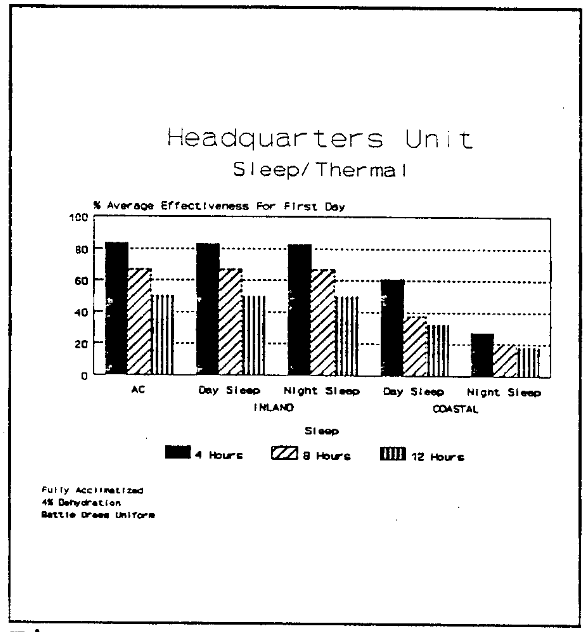


**Figure 6.** Percent Average Effectiveness for First Day, Headquarters Unit, 4% Dehydration

An 8-hour sleep regimen allows individuals to maintain maximum performance during work periods and, as such, allows us to see the impact of the thermal environment without having to consider the effects of sleep deprivation. Figures 7 and 8 illustrate the impact of differing levels of dehydration on unit casualties and unit performance. Increasing levels of dehydration can dramatically increase thermal casualties and result in a significant drop in unit performance.

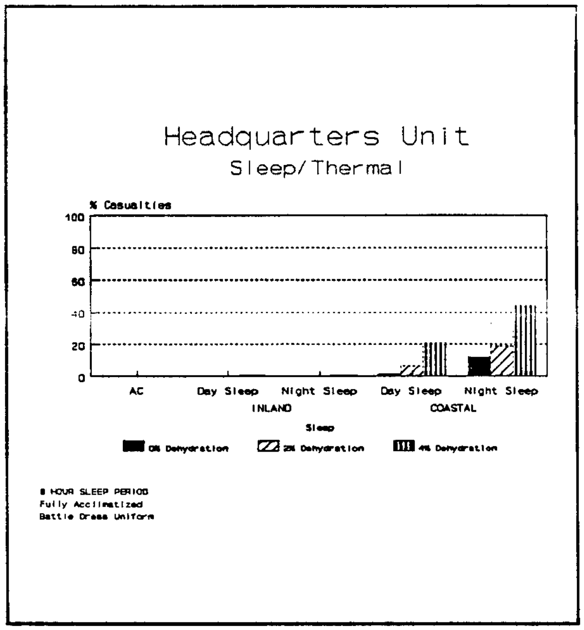


**Figure 7.** Percent Casualties, Headquarters Unit, Fully Acclimatized

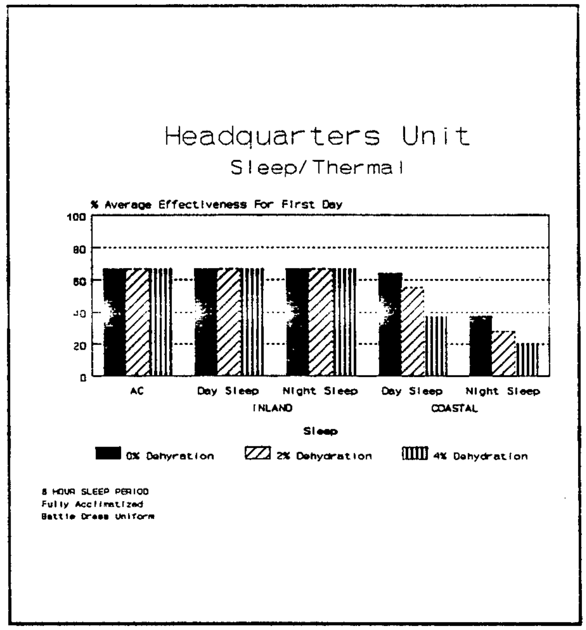


**Figure 8.** Percent Average Effectiveness for First Day, Headquarters Unit, Fully Acclimatized

Finally, while 12 hours of sleep per day may seem like an attractive option, the results clearly show that while 12 hours of sleep prevents sleep deprivation effects troops are also unavailable for longer periods of each day. This results in a lower overall unit performance than either the 8 hour or 4 hour sleep discipline.

## 7.2 PHASE II: IMPACT OF ALTERNATE SLEEP DISCIPLINES IN HOT ENVIRONMENTS

While the mitigation of thermal effects resulting from different sleep disciplines was shown in Phase I of this study, the long-term effects of sleep deprivation were not evident. Phase II examined the impact of 4 different sleep regimens; 4, 6, 8, and 10 hours of sleep per day. For this portion of the analysis, troops were considered to be fully acclimatized and fully hydrated. This enabled us to examine the impact of sleep deprivation under optimal thermal conditions. For the same reasons, only daytime sleep was modeled with the exception of the 8 hour runs. Here, nighttime sleep was modeled to enable us to define the relevant band of effects for the two disciplines.

Figures 9 through 11 show the impact of sleep deprivation coupled with limited thermal casualties for a twenty day period for each of the environments considered. Recall that the unit is required to perform 26 fire support tasks per hour. Thus, the Y-axis illustrates the number of fire support tasks completed per day for each of the different sleep regimens. In all cases, the effects of sleep deprivation clearly drive the unit's ability to complete its mission over the 20 day period. The coastal results differ from the inland and air-conditioned results in the first few days of the analysis due to thermal casualties resulting from the more extreme conditions. Also, as noted in discussing the results of Phase I, since no thermal casualties were evident in the air-conditioned and inland runs, air-conditioning was only run for the 4 and 6 hour sleep regimens. This allowed us to see the impact of sleep deprivation for these regimens. It was unnecessary to run these two sets of conditions for the 8 and 10 hour regimens since these regimens were sufficient to prevent sleep deprivation effects.

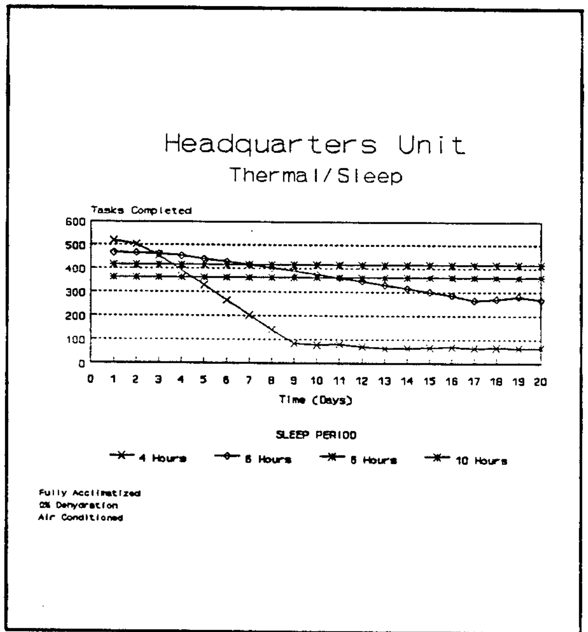


**Figure 9.** Tasks Completed, Headquarters Unit, 0% Dehydration, Air Conditioned

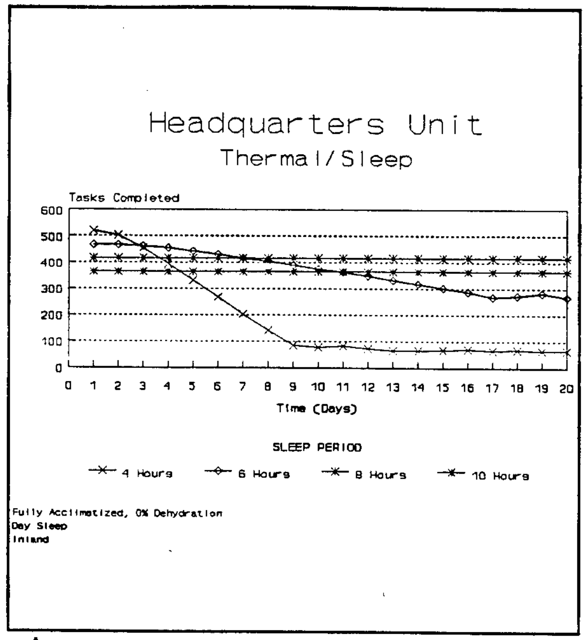


**Figure 10.** Tasks Completed, Headquarters Unit, 0% Dehydration, Inland Region

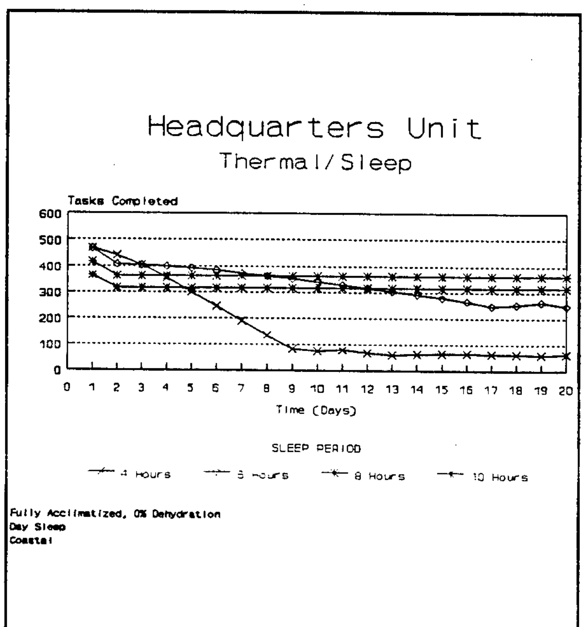


**Figure 11.** Tasks Completed, Headquarters Unit, 0% Dehydration, Coastal Region

In each of these figures (9 through 11), a suspicious anomaly appeared in the results between days 17 and 20. After investigation, it was discovered that by day 17 several of the 7.5 hour sleepers (those who required 7.5 hours of sleep per day) had become so degraded that they were allowed to go to sleep before the rest of the unit and remain asleep for longer periods of times than initially intended. Although the inputs could have been manipulated to prevent this, in fact, by day 17 in the scenario, it is not unreasonable to assume that the 7.5 hour sleepers would be so tired as to have lost their original sleep discipline. In any event, the predominant effects of sleep deprivation are clear from the first 17 days.

Figure 12 shows a comparison of daytime sleep versus nighttime sleep over the twenty day period. Note that the 8 hour sleep regimen was used in order to eliminate the effects of sleep deprivation. Unit productivity is dramatically reduced with night sleep as a result of increased thermal casualties and the impact of restricting work during the hot periods of the day. These results illustrate daytime sleep as an effective thermal discipline.

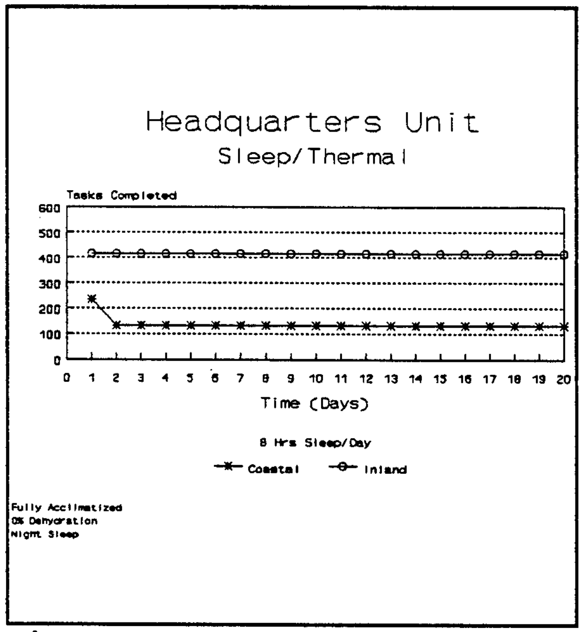


**Figure 12.** Tasks Completed, Headquarters Unit, 0% Dehydration, Fully Acclimatized, Night Sleep

Figures 13 through 15 graphically illustrate the impact of various sleep disciplines on the Headquarters Unit. Note also that, in the case of the coastal conditions, thermal casualties also impact these results. These results show that the 4 and 6 hour sleep regimens are insufficient in preventing sleep deprivation effects on unit performance. While the 10 hour sleep regimen provides optimal performance during work periods, the 8 hour regimen provides the greatest performance over the 20 day period.

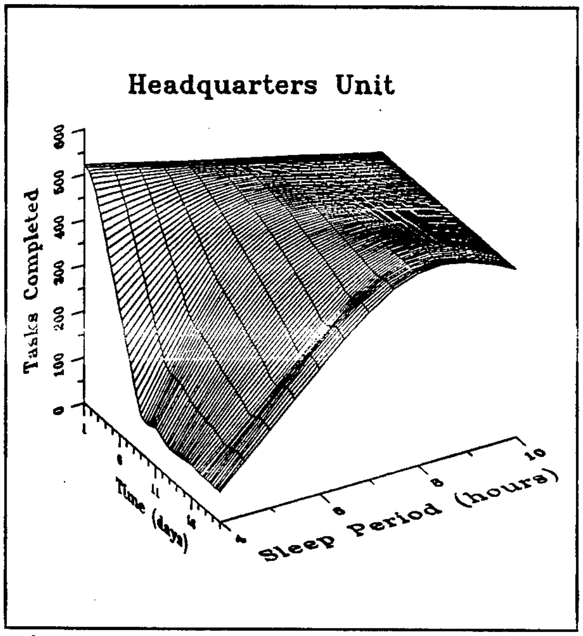


**Figure 13.** Productivity of Headquarters Unit, Air Conditioned

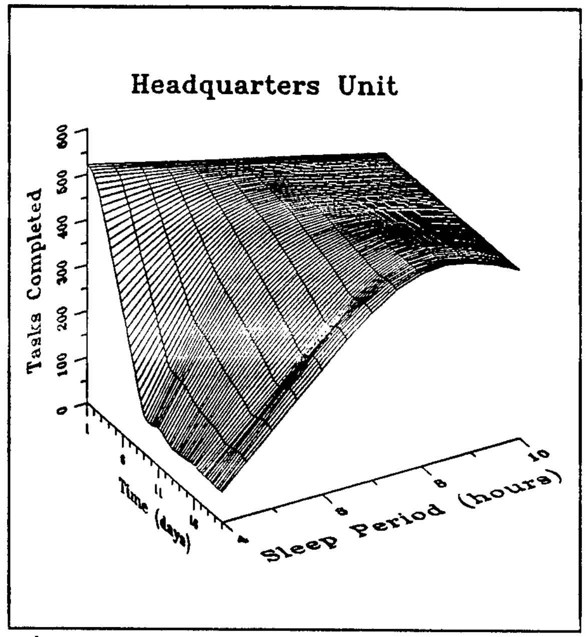


**Figure 14.** Productivity of Headquarters Unit, Inland Region

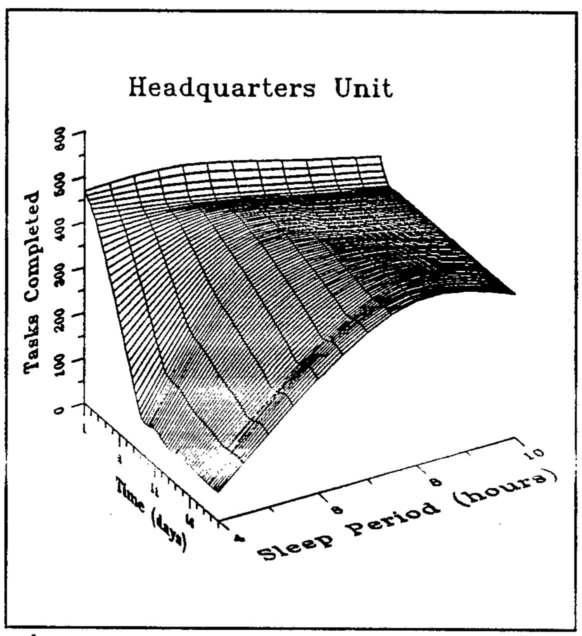


**Figure 15.** Productivity of Headquarters Unit, Coastal Region

## 8. CONCLUSIONS

Based on the results presented here, we conclude that:

1. Optimal thermal discipline, such as the metabolic limit discipline modeled for this analysis, can extend effective performance in the most demanding thermal environment and prevent thermal casualties.

2. Less than optimal hydration demonstrates the mass casualty potential of failing to heed the tenets of thermal discipline.

3. Even with optimal thermal discipline, sleep deprivation can have catastrophic consequences on unit performance.

4. Appropriate sleep discipline and thermal discipline can maintain effective unit performance indefinitely.

5. Sleep during the day in the thermally intense environment of Southwest Asia is an effective adjunct to effective thermal discipline in maximizing unit effectiveness.

## 9. RECOMMENDATIONS

For this study, we assumed that there was no interaction between sleep deprivation and heat strain tolerance. In fact, anecdotal evidence suggests that thermal stress makes it more difficult to effectively rest. In addition, increasing levels of dehydration are likely to prevent effective sleep. The interaction between sleep deprivation and thermal sensitivity should be represented in a future analysis.

Finally, this type of analysis should be expanded to include other, less optimal thermal disciplines. Hydration status is only one of several ways to compromise thermal discipline. Less effective thermal disciplines may have a tremendous impact on the effectiveness of sleep as a thermal discipline.

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Stark, M.M., R.E. McNally, D.E. Lee, and A. M. Machovec (1991). The Evaluation of Thermal Disciplines to Minimize Casualties for Operations in Southwest Asia. Contract No. MDA903-88-D-1000, Science Applications International Corporation, Joppa, Maryland.

Tables of Organization and Equipment, Number 06366J410, HHB FA BN 155 SP HVY DIV.

# APPENDIX A

The following is a partial listing of the original AURA inputs used for the Headquarters Unit. Since this is an unmodified input listing, a brief explanation of the data format is included.

| | | |
|---|---|---|
| LINKS | ----> | indicates job description information follows |
| GRANULARITY,1. | ----> | specifies maximum amount of an asset to assign to any one job |
| JOB NAME,2. | ----> | specifies 2 assets are required for 100% effectiveness of job |
| [$M,90] | ----> | optional parameter indicating the minimum capability (in percent) for this job |

| | | |
|---|---|---|
| [$Sub 1, Sub 2 ..... ] | ---> | Substitute for job |
| [$T,Time 1, Time 2 ......] | | Time needed for substitution |
| [$E,Eff 1, Eff 2 .... ] | | Effectiveness of substitute in job |

Note: The # symbol is used as a comment marker in AURA. Since substitutions were not modeled for this analysis, all substitution information was commented out but included here for completeness.

The other AURA input sections are also included for completeness. These sections (SUBCHAIN, COMPOUND LINKS, and CHAINS) tell AURA how to combine the jobs listed in the LINKS section to complete the given mission(s). The reader is referred to the AURA input manual for a more detailed description of these inputs.

[redacted]

[redacted]RIGINAL LINKS AND CHAINS FOR HEADQUARTERS UNIT

```
[redacted]NKS
[redacted]ANULARITY,1.
[redacted]PER CP DRIVER,1.
$M,90
[redacted]MM DRIVER,1.
[redacted],90
[redacted]E FS OFCR,1.
BDE SGT,1.
BDE FS SPEC,1.
[redacted]E CP DRIVER,1.
[redacted],90
[redacted]E CARRIER CP,1.
BDE FS RADIO,2.
$M,85
[redacted]E FS HMMWV,1.
[redacted] FS OFCR,3.
[redacted] FS SGT,3.
BN FS SPEC,3.
BN FS CP DRIVER,3.
[redacted],90
[redacted] FS RADIO,6.
[redacted],85
BN FS HMMWV,3.
[redacted] CO,1.                    #BN HQ
[redacted],85
[redacted]XO,BTRY CO, S2/S3, S4, PLANS/OPER OFCR, FIRE DIR OFCR
#$T, 10.,30.,15.,15.,10.,30.
#$E, .85,.70,.70,.70,.80,.60
[redacted],1.
[redacted],85
[redacted]BTRY CO, S2/S3, S4, PLANS/OPER OFCR, FIRE DIR OFCR
#$T, 30.,15.,15.,30.,30.
#$E,.85,.85,.85,.85,.85
[redacted]/S3, 2.
[redacted],85
[redacted]XO,PLANS/OPER OFCR
#$T,10.,15.
#$E,.90,.80
[redacted] STAFF OFCR,1.
[redacted],85
[redacted]TAC COMM CHF
#T,30.
[redacted],.80
[redacted]TOR OFCR,1.
[redacted],85
[redacted]MAINT SGT
#$T,30.
[redacted]E,.70
[redacted],1.
[redacted],85
S4,1.
$M,95
[redacted]XO
[redacted]T,10.
[redacted]E,.90
CMD SGT MAJOR,1.
$M,85
[redacted]FIRST SGT,OPNS SGT,INTEL SGT, TAC COMM CHF
[redacted]T,30.,30.,30.,30.
#$E,.75,.75,.75,.75
BN DRIVER 1,1.
[redacted],85
[redacted]DRIVER
[redacted]T,30.
#$E,1.
BN RADIO,2.
[redacted],85
[redacted] HMMWV,2.
```



[redacted]

[redacted],85
[redacted]MMWV
[redacted],30.
$E,.90
BTRY CO,1. #BTRY HQ
[redacted],85
[redacted]FIRST SGT,FOOD SGT,SPLY SGT
[redacted]T,10.,10.,10.
#$E,.80,.70,.70
[redacted]RST SGT,1.
[redacted],90
[redacted]FOOD SGT,SPLY SGT
#$T,10.,10.
#$E,.85,.85
[redacted]OD SGT,1.
[redacted],90
[redacted]COOK
#$T,20.
#$E,.80
[redacted]LY SGT,1.
[redacted],90
[redacted]SPLY SPEC/ARMORER
#$T,10.
#$E,.85
[redacted]LY SPEC/ARMORER,2.
[redacted],90
[redacted]OK,6.
$M,90
[redacted]RY DRIVER,1.
[redacted],85
[redacted]DRIVER
#$T,10.
#$E,1.
[redacted]RY GEN5,1.
[redacted],90
[redacted]ELD KITCHEN,1.
$M,90
BTRY HMMWV,1.
[redacted],85
[redacted]MMWV
[redacted],30.
$E,1.
BTRY TRAILER1.5,1.
[redacted],85
[redacted]RY TRUCK2.5,1.
[redacted],85
PLANS/OPER OFCR, 1. #OPS/INTEL PLT HQ
[redacted]CHEM OFCR, OPNS SGT
[redacted]T,10.,10.
[redacted]E,.90,.75
CHEM OFCR,1.
#$OPNS SGT
[redacted]T,10.
[redacted]E,.80
[redacted]NS SGT, 1.
#$FIRE CONTROL NCO
#$T,10.
[redacted]E,.90
[redacted]RE CONTROL NCO,1.
[redacted]C NCO,1.
OPHQ CLERK,1.
$M,90
[redacted]HQ CP DRIVER,1.
[redacted],90
[redacted]OPNS SPEC
#$T,10.
[redacted]E,.95
[redacted]NS SPEC,1.
[redacted]HQ DRIVER,1.
$M,90
#$DRIVER
[redacted]T,30.
[redacted]E,1.

[redacted]

[redacted]HQ CARRIER CP,1.
[redacted]HQ RADIO,3.
[redacted]HQ HMMWV,1.
$HMMWV
$T,30.
[redacted],1.
[redacted]TEL HMMWV, 1.
[redacted]RE DIR OFCR,1. #OPERATIONS-FD SECTION
TF COMP OPER,1.
#$TF EQUIP SPEC,TF OPER SPEC
[redacted]T,10.,10.
[redacted]E,.90,.80
[redacted] EQUIP SPEC,2.
#$TF OPER SPEC
[redacted]T,10.
[redacted]E,.90
[redacted] OPER SPEC,2.
OPER FDC,1.
$M,90
[redacted]ER SINCGAR,2.
[redacted],90
[redacted]ER TRUCK5,2.
$M,90
OPER CP-HMMWV,1.
[redacted],90
[redacted]RGETING OFCR,1. #INTELLIGENCE SECTION
[redacted]INTEL OFCR,INTEL SGT
#$T,10.,10.
[redacted]E,.90,.75
[redacted]TEL OFCR,1.
[redacted]INTEL SGT
[redacted]T,10.
#$E,.85
[redacted]TEL SGT,1.
[redacted],90
[redacted]INTEL ANAL
#$T,10.
#$E,.80
[redacted]TEL ANAL,1.
[redacted]TEL CP DRIVER,1.
[redacted],90
INTEL CARRIER CP,1.
INTEL VRC-90,1.
[redacted]CON OFCR,1. #SURVEY PLT HQ
[redacted]CHF SURVEYOR
[redacted],10.
#$E,.85
CHF SURVEYOR,1.
[redacted]RVHQ DRIVER,1.
[redacted],90
[redacted]RVHQ VRC-89,1.
SURVHQ LASER SET,2.
[redacted]RVHQ HMMWV,1.
[redacted]MWV
[redacted]30.
$E,1.
CONVL SEC CHF,1. #CONVL SURVEY SECTION
[redacted]URVEY COMPUTER,INSTR OPER,RODMAN/SURV REC
[redacted],10.,10.,10.
[redacted],.90,.80,.80
SURVEY COMPUTER,1.
#$INSTR OPER,RODMAN/SURV REC
[redacted],10.,10.
[redacted],.90,.90
[redacted]STR OPER,1.
#$RODMAN/SURV REC
[redacted],10.
[redacted],.90
[redacted]MAN/SURV REC,2.
[redacted]INSTR OPER
#$T,10.
[redacted],.90
[redacted]VL VRC-88,2.



[redacted]

[redacted]

```
[redacted]ONVL HMMWV,2.
[redacted]HMMWV
[redacted]T,30.
$E,1.
PADS SEC CHF,2.                         #PADS SURVEY SECTION
[redacted]$PADS DRIVER
[redacted]$T,10.
#$E,.70
PADS DRIVER,2.
$M,90
[redacted]ADS VRC-90,2.
[redacted]ADS HMMWV,2.
$HMMWV
$T,30.
[redacted]E,1.
[redacted]ADS,2.
[redacted]OMM PLT LDR,1.                #COMM PLT HQ
#$TAC COMM CHF
#$T,10.
[redacted]$E,.85
[redacted]AC COMM CHF,1.
[redacted]$TAC COMM SYS SUPV
#$T,10.
#$E,.90
[redacted]OMSEC CLERK,1.
[redacted]M,90
[redacted]AC COMM SYS SUPV,2.
#$TAC COMM MECH
[redacted]T,30.
[redacted]E,.80
[redacted]C COMM MECH,5.
$M,90
#$DRIVER
[redacted]T,30.
[redacted]E,1.
[redacted]OMM GEN1.5,1.
$M,.80
COMM RADIO,3.
[redacted]OMM HMMWV,2.
[redacted]HMMWV
[redacted],30.
$E,1.
WIRE SEC CHF,1.                                 #WIRE SECTION
[redacted]WIRE TM CHF
[redacted]T,10.
[redacted]E,.90
WIRE TM CHF,5.
#$WIRE SWBD OPER, WIRE INSTL
[redacted]T,10.,30.
[redacted]E,.90,.70
WIRE SWBD OPER,2.
#$WIRE INSTL
[redacted]T,10.
[redacted]E,.90
[redacted]RE INSTL,12.
#$WIRE SWBD OPER
#$T,10.
[redacted]E,.90
[redacted]RE HMMWV,5.
[redacted]MMWV
$T,30.
$E,1.
[redacted]O TM CHF,1.                   #RADIO TT SECTION
[redacted]RDO TTY OPER
#$T,10.
#$E,.90
RDO TTY OPER,2.
[redacted]O GEN5,1.
[redacted]O TELETYPE-142,1.
RDO HMMWV,1.
$HMMWV
[redacted],30.
[redacted],1.
```



[redacted]

YS ASST,1. #MEDICAL SECTION
,70
D NCO,1.
#$EMER NCO
#$T,10.
E,.90
ER NCO,1.
MED AID-SPEC-DRIVER,BTRY AIDMAN
#$T,10.,10.
#$E,.85,.85
D AID-SPEC-DRIVER,6.
BTRY AIDMAN
#$T,10.
#$E,.90
RY AIDMAN,7.
MED AID-SPEC-DRIVER
T,10.
#$E,.90
MED AMBUL/HMMWV,3.
D TRUCK2.5,2.
C SUPV,1. #PERS/ADMIN CENTER
PER STAFF NCO
#$T,10.
#$E,.90
R STAFF NCO,1.
PER ADMIN SPEC
T,10.
#$E,.85
EGAL SPEC,1.
,90
R ADMIN SPEC,3.
CHAPEL SPEC,1.
$M,90
C CLERK,1.
C GEN5,1.
C VRC-90,1.
PAC HMMWV,2.
$HMMWV
,30.
,1.
C TRAILER.75,1.
$M,.80
PAC TRUCK2.5,1.
HQ FS TERM, 2. #AFATDS EQUIPMENT FOLLOWS
ER FS TERM, 2.
TEL FS TERM, 2.
BDE FS TERM, 2.
BN FS TERM, 2.
HQ PRG LD UNT, 1.
HQ ELEC PRINT, 1.
OPER FS COMP TERM, 1.
OPER PRG LD UNT, 1.
ER PWR CONV GRP, 1.
ER TAC DIS DEV, 1.
ER ELEC PRINT, 1.
OPER LOC AREANET, 1.
BDE FS COMP TERM, 1.
TEL PRG LD UNT, 1.
E FS TAC DIS DEV, 1.
E FS PWR CONV GRP, 1.
BDE FS LOC AREANET, 1.
INTEL ELEC PRINT, 1.
E FS ELEC PRINT, 1.
E FS PRG LD UNT, 1.
BN FS PRG LD UNT, 1.
BN FS ELEC PRINT, 1.
BN STAFF,1.
BTRY STAFF,1.
ADMIN, 1.
NO OPHQ, 1.
END
CHAINS
, FOOD SGT, COOK, FIELD KITCHEN, BTRY GEN5

, SPLY SGT, SPLY SPEC/ARMORER
, PLANS/OPER OFCR, CHEM OFCR, OPNS SGT, FIRE CONTROL NCO,
BC NCO, OPHQ CLERK, OPHQ CP DRIVER, OPNS SPEC, OPHQ DRIVER,
$OPHQ CARRIER CP, OPHQ RADIO, OPHQ HMMWV,OPHQ FS TERM, OPHQ PRG LD UNT,
$OPHQ ELEC PRINT
, FIRE DIR OFCR, TF COMP OPER, TF EQUIP SPEC, OPER CP DRIVER,
F OPER SPEC,OPER SINCGAR, OPER TRUCK5, OPER CP-HMMWV, OPER FDC,
OPER FS TERM, OPER FS COMP TERM, OPER PRG LD UNT, OPER PWR CONV GRP,
$OPER TAC DIS DEV, OPER ELEC PRINT, OPER LOC AREANET
*5, TARGETING OFCR, INTEL OFCR, INTEL SGT, INTEL ANAL,
NTEL CP DRIVER, INTEL CARRIER CP, INTEL VRC-90,
NTEL FS TERM, INTEL PRG LD UNT,INTEL ELEC PRINT
*6, RECON OFCR, CHF SURVEYOR, SURVHQ DRIVER, SURVHQ VRC-89,
$SURVHQ HMMWV, SURVHQ LASER SET
, CONVL SEC CHF, SURVEY COMPUTER, INSTR OPER, RODMAN/SURV REC,
ONVL VRC-88, CONVL HMMWV
, PADS SEC CHF, PADS DRIVER, PADS VRC-90, PADS HMMWV, PADS
*9, COMM PLT LDR, TAC COMM CHF, COMSEC CLERK, TAC COMM SYS SUPV,
$TAC COMM MECH, COMM DRIVER, COMM GEN1.5, COMM RADIO, COMM HMMWV
0, WIRE SEC CHF, WIRE TM CHF, WIRE SWBD OPER, WIRE INSTL, WIRE HMMWV
1, RDO TM CHF, RDO TTY OPER, RDO GEN5, RDO TELETYPE-142, RDO HMMWV
2, PHYS ASST, MED NCO, EMER NCO, MED AID-SPEC-DRIVER, BTRY AIDMAN,
$MED AMBUL/HMMWV, MED TRUCK2.5
*13, PAC SUPV, PER STAFF NCO, LEGAL SPEC, PER ADMIN SPEC,
HAPEL SPEC, PAC CLERK, PAC GEN5, PAC VRC-90, PAC HMMWV,
AC TRAILER.75, PAC TRUCK2.5
4,BN DRIVER 1,BN RADIO,BN HMMWV
*15,BDE FS OFCR,BDE SGT,BDE FS SPEC,BDE CP DRIVER,BDE CARRIER CP,
$BDE FS RADIO,BDE FS HMMWV,BDE FS TERM,BDE FS ELEC PRINT,BDE FS PRG LD UNT,
DE FS TAC DIS DEV, BDE FS PWR CONV GRP, BDE FS LOC AREANET,BDE FS COMP TERM
6, BN FS OFCR,BN FS SGT,BN FS SPEC,BN FS CP DRIVER,BN FS RADIO,
$,BN FS HMMWV,BN FS TERM, BN FS PRG LD UNT, BN FS ELEC PRINT
END
OMPOUND LINKS
TRY HQ
RST SGT,.35
*1,.25
*2,.25
RY DRIVER,.02
RY HMMWV,.01
RY TRAILER1.5,.01
BTRY TRUCK2.5,.01
NO BTRY STAFF,.10
N HQ
,.05
,.15
S4,.15
S2/S3,.30
STAFF OFCR,.15
TOR OFCR,.05
CMD SGT MAJOR,.05
*14,.05
BN STAFF,.05
ECON
,.4
*7,.3
*8,.3
OMMO
,.3
0,.3
*11,.4
!ADMIN
2,.05
3,.05
NO ADMIN,.90
!OPHQ
*3,.20
OPHQ,.80
VR GROUPS/INTEL
*5,.20
*15,.45
6,.35
D

```
AIN
 CO,!BN HQ,BTRY CO,!BTRY HQ,!RECON, !COMMO, !ADMIN, !OPHQ,
4, !MVR GROUPS/INTEL
END
```

IGINAL TASK STRUCTURE FOR HEADQUARTERS UNIT

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BN CO

 !!
 !!
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 !!          !!          !!          !!          !!          !!          !!          !!          !!
0.05        0.15        0.15        0.30        0.15        0.05        0.05        0.05        0.05
 !!          !!          !!          !!          !!          !!          !!          !!          !!
XO          S1          S4          S2/S3       CE STA      MOTOR       CMD SG      ******      NO BN
                                                FF OFC      OFCR        T MAJO       !!         STAFF
                                                R                       R           BN DRI
 !!          !!          !!          !!          !!          !!          !!         VER 1        !!
 !!          !!          !!          !!          !!          !!          !!                      !!
 !!          !!          !!          !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!         BN RAD       !!
 !!          !!          !!          !!          !!          !!          !!         IO           !!
 !!          !!          !!          !!          !!          !!          !!                      !!
 !!          !!          !!          !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!         BN HMM       !!
 !!          !!          !!          !!          !!          !!          !!         WV           !!
 !!          !!          !!          !!          !!          !!          !!                      !!
 !!          !!          !!          !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!         ******       !!
 !!          !!          !!          !!          !!          !!          !!          !!          !!
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 !!
 !!
TRY C

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!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
 !!          !!          !!          !!          !!          !!          !!          !!
0.35        0.25        0.25        0.02        0.01        0.01        0.01        0.10
 !!          !!          !!          !!          !!          !!          !!          !!
FIRST       ******      ******      BTRY D      BTRY H      BTRY T      BTRY T      NO BTR
GT           !!          !!         RIVER       MMWV        RAILER      RUCK2.      Y STAF
            FOOD S      SPLY S                              1.5         5           F
 !!         GT          GT           !!          !!          !!          !!          !!
 !!                                  !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!          !!
 !!         COOK        SPLY S       !!          !!          !!          !!          !!
 !!                     PEC/AR       !!          !!          !!          !!          !!
 !!                     MORER        !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!          !!
 !!          !!         ******       !!          !!          !!          !!          !!
 !!         FIELD        !!          !!          !!          !!          !!          !!
 !!         KITCHE       !!          !!          !!          !!          !!          !!
 !!         N            !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!          !!
 !!         BTRY G       !!          !!          !!          !!          !!          !!
 !!         EN5          !!          !!          !!          !!          !!          !!
 !!                      !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!          !!
 !!         ******       !!          !!          !!          !!          !!          !!
 !!          !!          !!          !!          !!          !!          !!          !!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
 !!
 !!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!
 !!          !!          !!
0.40        0.30        0.30
 !!          !!          !!
*****       ******      ******
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 !!          !!          !!
ECON        CONVL       PADS S
FCR         SEC CH      EC CHF
            F
 !!          !!          !!
 !!          !!          !!
HF SU       SURVEY      PADS D
VEYOR        COMPU      RIVER
            TER
 !!          !!          !!
 !!          !!          !!
URVHQ       INSTR       PADS V
DRIVE       OPER        RC-90
R
 !!          !!          !!
 !!          !!          !!
URVHQ       RODMAN      PADS H
VRC-8       /SURV       MMWV
9           REC
 !!          !!          !!
 !!          !!          !!
URVHQ       CONVL       PADS
HMMWV       VRC-88

 !!          !!          !!
 !!          !!         ******
URVHQ       CONVL        !!
LASER       HMMWV        !!
SET                      !!
 !!          !!          !!
*****       ******       !!
 !!          !!          !!
 !!!!!!!!!!!!!!!!!!!!!!!!!!
 !!
 !!
 !!!!!!!!!!!!!!!!!!!!!!!!!!
 !!          !!          !!
0.30        0.30        0.40
 !!          !!          !!
*****       ******      ******
 !!          !!          !!
COMM P      WIRE S      RDO TM
T LDR       EC CHF       CHF

 !!          !!          !!
 !!          !!          !!
TAC CO      WIRE T      RDO TT
M CHF       M CHF       Y OPER

 !!          !!          !!
 !!          !!          !!
COMSEC      WIRE S      RDO GE
LERK        WBD OP      N5
            ER
 !!          !!          !!
 !!          !!          !!
TAC CO      WIRE I      RDO TE
 SYS        NSTL        LETYPE
UPV                     -142
 !!          !!          !!
 !!          !!          !!
AC CO       WIRE H      RDO HM
 MEC        MMWV        MWV

 !!          !!          !!
 !!         ******      ******
MM D         !!          !!
VER          !!          !!
             !!          !!
 !!          !!          !!
 !!          !!          !!
MM G         !!          !!
1.5          !!          !!
```

```
             !!         !!
  !!         !!         !!
  !!         !!         !!
COMM R       !!         !!
ADIO         !!         !!
             !!         !!
  !!         !!         !!
  !!         !!         !!
COMM H       !!         !!
MMWV         !!         !!
             !!         !!
  !!         !!         !!
******       !!         !!
  !!         !!         !!
  !!!!!!!!!!!!!!!!!!!!!!!!!
  !!
  !!
  !!!!!!!!!!!!!!!!!!!!!!!!!
  !!         !!         !!
 0.05       0.05       0.90
  !!         !!         !!
******     ******     NO ADM
  !!         !!       IN
PHYS A     PAC SU
SST        PV           !!
                        !!
  !!         !!         !!
  !!         !!         !!
MED NC     PER ST       !!
O          AFF NC       !!
           O            !!
  !!         !!         !!
  !!         !!         !!
EMER N     LEGAL        !!
CO         SPEC         !!
                        !!
  !!         !!         !!
  !!         !!         !!
MED AI     PER AD       !!
D-SPEC     MIN SP       !!
-DRIVE     EC           !!
  !!         !!         !!
  !!         !!         !!
BTRY A     CHAPEL       !!
IDMAN       SPEC        !!
                        !!
  !!         !!         !!
  !!         !!         !!
MED AM     PAC CL       !!
BUL/HM     ERK          !!
MWV                     !!
  !!         !!         !!
  !!         !!         !!
MED TR     PAC GE       !!
UCK2.5     N5           !!
                        !!
  !!         !!         !!
******       !!         !!
  !!       PAC VR       !!
  !!       C-90         !!
  !!                    !!
  !!         !!         !!
  !!         !!         !!
  !!       PAC HM       !!
  !!       MWV          !!
  !!                    !!
  !!         !!         !!
  !!         !!         !!
  !!       PAC TR       !!
  !!       AILER.       !!
  !!       75           !!
  !!         !!         !!
  !!         !!         !!
```

```
  !!        PAC TR        !!
  !!        UCK2.5        !!
  !!                      !!
  !!          !!          !!
  !!        ******        !!
  !!          !!          !!
  !!!!!!!!!!!!!!!!!!!!!!!!!!
  !!
  !!
  !!!!!!!!!!!!!
  !!          !!
 .20         0.80
  !!          !!
******      NO OPH
  !!        Q
LANS/
PER O         !!
FCR           !!
  !!          !!
  !!          !!
HEM O         !!
CR            !!
              !!
  !!          !!
  !!          !!
PNS S         !!
GT            !!
              !!
  !!          !!
  !!          !!
IRE C         !!
ONTROL        !!
 NCO          !!
  !!          !!
  !!          !!
BC NC         !!
O             !!
              !!
  !!          !!
  !!          !!
PHQ C         !!
LERK          !!
              !!
  !!          !!
  !!          !!
PHQ C         !!
P DRIV        !!
R             !!
  !!          !!
  !!          !!
OPNS S        !!
PEC           !!
              !!
  !!          !!
  !!          !!
OPHQ D        !!
RIVER         !!
              !!
  !!          !!
  !!          !!
OPHQ C        !!
RRIER         !!
CP            !!
  !!          !!
  !!          !!
OPHQ R        !!
DIO           !!
              !!
  !!          !!
  !!          !!
OPHQ H        !!
MWV           !!
              !!
```

!! !!
!! !!
OPHQ F !!
S TERM !!
!!
!! !!
!! !!
OPHQ P !!
RG LD !!
UNT !!
!! !!
!! !!
OPHQ E !!
LEC PR !!
INT !!
!! !!
****** !!
!! !!
!!!!!!!!!!!!!!
!!
!!
******
!!
FIRE D
R OFC
!!
!!
TF COM
OPER
!!
!!
TF EQU
P SPE
!!
!!
PER C
DRIV
R
!!
!!
F OPE
SPEC
!!
!!
PER S
NCGAR
!!
!!
PER T
UCKS
!!
!!
PER C
-HMMW
V
!!
!!
PER F
DC
!!
!!
PER F
S TERM
!!
!!

PER F
COMP
TERM
!!
!!
PER P
G LD
UNT
!!
!!
PER P
R CON
V GRP
!!
!!
PER T
C DIS
DEV
!!
!!
PER E
EC PR
INT
!!
!!
PER L
OC ARE
ANET
!!
*****
!!
!!
!!!!!!!!!!!!!!!!!!!!!!!!!!

| | | |
|---|---|---|
| 0.20 | 0.45 | 0.35 |
| ****** | ****** | ****** |
| ARGET NG OF CR | BDE FS OFCR | BN FS OFCR |
| NTEL FCR | BDE SG T | BN FS SGT |
| NTEL GT | BDE FS SPEC | BN FS SPEC |
| NTEL NAL | BDE CP DRIVE R | BN FS CP DRI VER |
| NTEL CP DRI VER | BDE CA RRIER CP | BN FS RADIO |
| NTEL CARRIE R CP | BDE FS RADIO | BN FS HMMWV |
| NTEL VRC-90 | BDE FS HMMWV | BN FS TERM |

```
NTEL         BDE FS         BN FS
S TER         TERM          PRG LD
                             UNT
  !!           !!             !!
  !!           !!             !!
NTEL         BDE FS         BN FS
RG LD         ELEC          ELEC P
UNT          PRINT          RINT
  !!           !!             !!
  !!           !!           ******
NTEL         BDE FS           !!
LEC P         PRG L           !!
RINT         D UNT            !!
  !!           !!             !!
*****          !!             !!
  !!         BDE FS           !!
  !!          TAC D           !!
  !!         IS DEV           !!
  !!           !!             !!
  !!           !!             !!
  !!         BDE FS           !!
  !!          PWR C           !!
  !!         ONV GR           !!
  !!           !!             !!
  !!           !!             !!
  !!         BDE FS           !!
  !!          LOC A           !!
  !!         REANET           !!
  !!           !!             !!
  !!           !!             !!
  !!         BDE FS           !!
  !!          COMP            !!
  !!         TERM             !!
  !!           !!             !!
  !!         ******           !!
  !!           !!             !!
  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  !!
  !!
 *
tton>
```

**APPENDIX B**

The following is a partial listing of the original AURA inputs used for the Headquarters Unit. Since this is an unmodified input listing, a brief explanation of the data format is included.

| | | |
|---|---|---|
| LINKS | ----> | indicates job description information follows |
| GRANULARITY,1. | ----> | specifies maximum amount of an asset to assign to any one job |
| JOB NAME,2. | ----> | specifies 2 assets are required for 100% effectiveness of job |
| [$M,90] | ----> | optional parameter indicating the minimum capability (in percent) for this job |

| | | |
|---|---|---|
| [$Sub 1, Sub 2 ..... ] | ---> | Substitute for job |
| [$T,Time 1, Time 2 ......] | | Time needed for substitution |
| [$E,Eff 1, Eff 2 .... ] | | Effectiveness of substitute in job |

Note: The # symbol is used as a comment marker in AURA. Since substitutions were not modeled for this analysis, all substitution information was commented out but included here for completeness.

The other AURA input sections are also included for completeness. These sections (SUBCHAIN, COMPOUND LINKS, and CHAINS) tell AURA how to combine the jobs listed in the LINKS section to complete the given mission(s). The reader is referred to the AURA input manual for a more detailed description of these inputs.

VISED LINKS AND CHAINS FOR HEADQUARTERS UNIT

```
LINKS
OPER CP DRIVER,1.
,90
FD PERSONNEL,PERSONNEL
#$T,0.,30.
#$E,1.,1.
MM DRIVER,1.
,90
DRIVER
#$T,30.
#$E,1.
E FS OFCR,1.
E SGT,1.
E FS SPEC,1.
BDE CP DRIVER,1.
$M,90
E CARRIER CP,1.
E FS RADIO,2.
,85
BDE FS HMMWV,1.
BN FS OFCR,3.
N FS OFCR1,BN FS OFCR2,BN FS OFCR3
,1.,1.,1.
T,0.,0.,0.
BN FS SGT,3.
N FS SGT1,BN FS SGT2,BN FS SGT3
,1.,1.,1.
,0.,0.,0.
BN FS SPEC,3.
$BN FS SPEC1,BN FS SPEC2,BN FS SPEC3
,1.,1.,1.
,0.,0.,0.
 FS CP DRIVER,3.
$M,90
$BN FS CP DRIVER1,BN FS CP DRIVER2,BN FS CP DRIVER3
,1.,1.,1.
,0.,0.,0.
 FS RADIO,6.
$M,85
BN FS HMMWV,3.
 CO,1.                    #BN HQ
,85
#$XO,S3,PLANS/OPER OFCR,BTRY CO,S2,S4,FIRE DIR OFCR
#$T,30.,5.,5.,30.,5.,30.,5.
E,.85,.8,.8,.7,.7,.7,.7
,1.
,85
#$S4,S3,BTRY CO,S2,PLANS/OPER OFCR,FIRE DIR OFCR
#$T,5.,30.,30.,30.,30.,30.
E,.85,.85,.8,.8,.8,.8
,1.
,85
#$XO,PLANS/OPER OFCR,S2
#$T,30.,5.,5.
E,.9,.9,.8
,1.
,85
#$TARGETING OFCR,INTEL SGT
#$T,5.,5.
E,.9,.9
 STAFF OFCR,1.
$M,85
#$TAC COMM CHF
,30.
,.85
TOR OFCR,1.
$M,85
#$MAINT SGT
T,30.
E,.8
```

```
[redacted],1.
[redacted],85
[redacted]ER STAFF NCO,S4              #PAC NCO,S4
#$T,5.,5.
[redacted]E,.85,.85
[redacted],1.
[redacted],95
[redacted]SPLY SGT,XO
#$T,5.,5.
[redacted]E,.85,.90
[redacted] SGT MAJOR,1.
[redacted],85
#$FIRST SGT,TAC COMM CHF,OPNS SGT,INTEL SGT
#$T,30.,30.,30.,30.
[redacted]E,.75,.75,.75,.75
[redacted] DRIVER 1,1.
[redacted],85
#$DRIVER,PERSONNEL
#$T,30.,30.
[redacted]E,1.,1.
[redacted] RADIO,2.
[redacted],85
BN HMMWV,2.
$M,85
[redacted]MMWV
[redacted],30.
$E,.90
BTRY CO,1.                   #BTRY HQ
[redacted],85
[redacted]COMM PLT LDR,FIRST SGT,TAC COMM CHF
[redacted]T,40.,0.,40.
#$E,.75,1.,.95
FIRST SGT,1.
[redacted],90
[redacted]TAC COMM CHF,SPLY SGT
[redacted]T,40.,0.
#$E,.85,.8
FOOD SGT,1.
[redacted],90
[redacted]COOK
[redacted]T,0.
#$E,.80
SPLY SGT,1.
[redacted],90
[redacted]SPLY SPEC/ARMORER
#$T,0.
#$E,.85
[redacted]Y SPEC/ARMORER,2.
[redacted],90
[redacted]PLY SPEC/ARMORER1,SPLY SPEC/ARMORER2
$T,0.,0.
$E,1.,1.
[redacted]K,6.
[redacted],90
[redacted]OK1,COOK2,COOK3,COOK4,COOK5,COOK6
$T,0.,0.,0.,0.,0.,0.
$E,1.,1.,1.,1.,1.,1.
[redacted]Y DRIVER,1.
[redacted],85
[redacted]DRIVER,PERSONNEL
#$T,10.,30.
[redacted]E,1.,1.
[redacted]Y GEN5,1.
[redacted],90
FIELD KITCHEN,1.
$M,90
[redacted]Y HMMWV,1.
[redacted],85
[redacted]MMWV
$T,30.
$E,1.
[redacted]Y TRAILER1.5,1.
[redacted],85
```

```
[redacted]RY TRUCK2.5,1.
[redacted]85
[redacted]NS/OPER OFCR, 1.                    #OPS/INTEL PLT HQ
#$CHEM OFCR, OPNS SGT,S2
[redacted],0.,0.,0.
[redacted]E,.9,.75,.9
[redacted]EM OFCR,1.
$M,80
#$OPNS SGT ,NBC NCO
[redacted],0.,0.
[redacted]E,.80 ,.9
[redacted]S SGT, 1.
#$FIRE CONTROL NCO ,INTEL SGT
#$T,0.,0.
[redacted]E,.90,.9
[redacted]E CONTROL NCO,1.
[redacted]IRE DIR OFCR,TF COMP OPER
#$T,0.,0.
#$E,.85,.85
[redacted]C NCO,1.
[redacted]80
[redacted]CHEM OFCR,OPHQ CLERK
#$T,0.,0.
[redacted]E,1.,.8
[redacted]Q CP DRIVER,1.
[redacted]90
[redacted]OPNS SPEC,DRIVER,PERSONNEL
#$T,0.,30.,30.
[redacted]E,.95,.95,.95
[redacted]S SPEC,1.
[redacted]PS PERSONNEL
#$T,0.
#$E,.95
[redacted]Q DRIVER,1.
[redacted]90
[redacted]RIVER,PERSONNEL
#$T,30.,30.
#$E,1.,1.
[redacted]Q CARRIER CP,1.
[redacted]Q RADIO,3.
OPHQ HMMWV,1.
$HMMWV
[redacted]30.
[redacted]1.
[redacted]EL HMMWV, 1.
FIRE DIR OFCR,1.                        #OPERATIONS-FD SECTION
#$FIRE CONTROL NCO,TF COMP OPER,TF EQUIP SPEC
[redacted],0.,0.,0.
[redacted]E,.75,.6,.6
[redacted]COMP OPER,1.
#$TF EQUIP SPEC,FIRE CONTROL NCO,FIRE DIR OFCR,TF OPER SPEC
#$T,0.,0.,0.,0.
[redacted]E,.7,.9,.9,.85
[redacted]EQUIP SPEC,2.
[redacted]F EQUIP SPEC1,TF EQUIP SPEC2
$T,0.,0.
$E,1.,1.
[redacted]F OPER SPEC
[redacted],0.,0.
[redacted]E,.90,.7
TF OPER SPEC,2.
[redacted]F OPER SPEC1,TF OPER SPEC2
[redacted]0.,0.
[redacted]1.,1.
#$TF EQUIP SPEC,FIRE DIR OFCR,FIRE CONTROL NCO
#$T,0.,0.,0.
[redacted]E,.9,.8,.9
[redacted]R FDC,1.
[redacted]95
OPER SINCGAR,2.
$M,95
[redacted]R TRUCK5,2.
[redacted]95
```

```
ER CP-HMMWV,1.
,95
ARGETING OFCR,1.                          #INTELLIGENCE SECTION
#$INTEL OFCR,INTEL SGT
$T,0.,0.
E,.90,.9
TEL OFCR,1.
#$INTEL SGT ,TARGETING OFCR
#$T,0.,0.
E,.9,.9
TEL SGT,1.
,90
#$INTEL ANAL,INTEL OFCR,TARGETING OFCR
#$T,0.,0.,0.
E,.9,.9,.9
TEL ANAL,1.
$INTEL SGT,INTEL OFCR,TARGETING OFCR
#$T,0.,0.,0.
#$E,.9,.9,.9
TEL CP DRIVER,1.
,90
#$INTEL PERSONNEL,PERSONNEL
#$T,0.,30.
$E,1.,1.
TEL CARRIER CP,1.
TEL VRC-90,1.
RECON OFCR,1.                      #SURVEY PLT HQ
#$CHF SURVEYOR,CONVL SEC CHF
$T,40.,40.
$E,.9,.9
F SURVEYOR,1.
#$CONVL SEC CHF,RECON OFCR
#$T,40.,40.
$E,.9,.9
RVHQ DRIVER,1.
M,90
#$DRIVER,PERSONNEL
#$T,30.,30.
$E,1.,1.
RVHQ VRC-89,1.
SURVHQ LASER SET,2.
SURVHQ HMMWV,1.
HMMWV
T,30.
E,1.
CONVL SEC CHF,1.                               #CONVL SURVEY SECTION
#$SURVEY COMPUTER,INSTR OPER,RODMAN/SURV REC
$T,0.,0.,0.
$E,.90,.80,.5
RVEY COMPUTER,1.
#$INSTR OPER,RODMAN/SURV REC
#$T,0.,0.
$E,.90,.75
NSTR OPER,1.
#$RODMAN/SURV REC
#$T,0.,0.
#$E,.90,.9
DMAN/SURV REC,2.
RODMAN/SURV REC1,RODMAN/SURV REC2
$T,0.,0.
$E,1.,1.
$T,0.,0.
$E,.90,.9
ONVL VRC-88,2.
CONVL HMMWV,2.
$HMMWV
T,30.
E,1.
ADS SEC CHF,2.                        #PADS SURVEY SECTION
$PADS SEC CHF1,PADS SEC CHF2
$T,0.,0.
E,1.,1.
$PADS DRIVER
```

```
[redacted],0.
[redacted],.80
[redacted]S DRIVER,2.
$M,90
$P[redacted]DS DRIVER1,PADS DRIVER2
$[redacted]0.,0.
$[redacted]1.,1.
#$PADS PERSONNEL,PERSONNEL
#$T,0.,30.
[redacted],.9,.9
P[redacted]S VRC-90,2.
P[redacted]S HMMWV,2.
#$HMMWV
#$T,30.
[redacted],1.
P[redacted]S,2.
[redacted]M PLT LDR,1.                        #COMM PLT HQ
#$TAC COMM CHF,WIRE SEC CHF,RDO TM CHF
#$T,0.,30.,30.
[redacted],.95,.85,.85
[redacted] COMM CHF,1.
[redacted]AC COMM SYS SUPV,WIRE SEC CHF,RDO TM CHF
#$T,10.,30.,30.
[redacted],.90,.85,.85
[redacted]SEC CLERK,1.
[redacted]90
TAC COMM SYS SUPV,2.
$TAC COMM SYS SUPV1,TAC COMM SYS SUPV2
[redacted]0.,0.
[redacted]1.,1.
[redacted]AC COMM MECH
#$T,30.
#$E,.80
[redacted] COMM MECH,5.
[redacted]90
[redacted]C COMM MECH1,TAC COMM MECH2,TAC COMM MECH3,TAC COMM MECH4,TAC COMM MECH5
$T,0.,0.,0.,0.,0.
$E,1.,1.,1.,1.,1.
[redacted]RIVER
[redacted],30.
[redacted],1.
COMM RADIO,3.
COMM HMMWV,2.
[redacted]MWV
[redacted]30.
[redacted],1.
WIRE SEC CHF,1.                               #WIRE SECTION
[redacted]IRE TM CHF
[redacted],10.
[redacted],.90
WIRE TM CHF,5.
$WIRE TM CHF1,WIRE TM CHF2,WIRE TM CHF3,WIRE TM CHF4,WIRE TM CHF5
[redacted]0.,0.,0.,0.,0.
[redacted]1.,1.,1.,1.,1.
[redacted]IRE SWBD OPER, WIRE INSTL
#$T,30.,30.
#$E,.90,.70
[redacted]E SWBD OPER,2.
[redacted]RE SWBD OPER1,WIRE SWBD OPER2
[redacted],0.,0.
$E,1.,1.
[redacted]IRE INSTL
[redacted],30.
[redacted],.90
WIRE INSTL,12.
$WIRE INSTL1,WIRE INSTL2,WIRE INSTL3,WIRE INSTL4,WIRE INSTL5,WIRE INSTL6
[redacted]0.,0.,0.,0.,0.,0.
[redacted]1.,1.,1.,1.,1.,1.
[redacted]RE INSTL7,WIRE INSTL8,WIRE INSTL9,WIRE INSTL10,WIRE INSTL11,WIRE INSTL12
$T,0.,0.,0.,0.,0.,0.
$E,1.,1.,1.,1.,1.,1.
[redacted]IRE SWBD OPER
[redacted],30.,30.
```

```
E,.90,.9
RE HMMWV,5.
MMWV
$T,30.
,1.
O TM CHF,1.                          #RADIO TT SECTION
RDO TTY OPER
#$T,0.
#$E,.90
O TTY OPER,2.
DO TTY OPER1,RDO TTY OPER2
,0.,0.
$E,1.,1.
#$RDO TM CHF
T,0.
E,.9
O GEN5,1.
RDO TELETYPE-142,1.
RDO HMMWV,1.
MMWV
,30.
,1.
PHYS ASST,1.                              #MEDICAL SECTION
,70
D NCO,1.
EMER NCO
T,10.
#$E,.90
ER NCO,1.
MED AID-SPEC-DRIVER,BTRY AIDMAN
T,10.,10.
#$E,.85,.85
MED AID-SPEC-DRIVER,6.
ED AID-SPEC-DRVR1,MED AID-SPEC-DRVR2,MED AID-SPEC-DRVR3
,0.,0.,0.
,1.,1.,1.
$MED AID-SPEC-DRVR4,MED AID-SPEC-DRVR5,MED AID-SPEC-DRVR6
$T,0.,0.,0.
,1.,1.,1.
BTRY AIDMAN
T,10.
#$E,.90
RY AIDMAN,7.
TRY AIDMAN1,BTRY AIDMAN2,BTRY AIDMAN3,BTRY AIDMAN4
,0.,0.,0.,0.
E,1.,1.,1.,1.
$BTRY AIDMAN5,BTRY AIDMAN6,BTRY AIDMAN7
,0.,0.,0.
,1.,1.,1.
MED AID-SPEC-DRIVER
#$T,10.
#$E,.90
D AMBUL/HMMWV,3.
D TRUCK2.5,2.
C SUPV,1.                          #PERS/ADMIN CENTER
#$PER STAFF NCO,S1
T,0.,0.
E,.90,.9
R STAFF NCO,1.
PER ADMIN SPEC,PAC CLERK,LEGAL SPEC
#$T,0.,0.,0.,
E,.85,.85,.85
GAL SPEC,1.
,90
#$PAC SUPV,PER STAFF NCO,S1
#$T,0.,0.,0.
E,.9,.9,.9
R ADMIN SPEC,3.
,75
$PER ADMIN SPEC1,PER ADMIN SPEC2,PER ADMIN SPEC3
$T,0.,0.,0.
,1.,1.,1.
APEL SPEC,1.
```

```
[redacted],90
[redacted]C CLERK,1.
[redacted]AC GEN5,1.
PAC VRC-90,1.
PAC HMMWV,2.
[redacted]MMWV
[redacted],30.
[redacted]E,1.
PAC TRAILER.75,1.
[redacted],.80
[redacted]C TRUCK2.5,1.
[redacted]HQ FS TERM, 2.            #AFATDS EQUIPMENT FOLLOWS
OPER FS TERM, 2.
$M,95
[redacted]TEL FS TERM, 2.
[redacted]E FS TERM, 2.
[redacted] FS TERM, 2.
OPHQ PRG LD UNT, 1.
$M,95
[redacted]HQ ELEC PRINT, 1.
[redacted]ER FS COMP TERM, 1.
[redacted],95
OPER PRG LD UNT, 1.
OPER PWR CONV GRP, 1.
[redacted],95
[redacted]ER TAC DIS DEV, 1.
[redacted],95
OPER ELEC PRINT, 1.
[redacted],95
[redacted]ER LOC AREANET, 1.
[redacted],95
BDE FS COMP TERM, 1.
INTEL PRG LD UNT, 1.
[redacted]E FS TAC DIS DEV, 1.
[redacted]E FS PWR CONV GRP, 1.
[redacted]E FS LOC AREANET, 1.
INTEL ELEC PRINT, 1.
BDE FS ELEC PRINT, 1.
[redacted]E FS PRG LD UNT, 1.
[redacted] FS PRG LD UNT, 1.
[redacted] FS ELEC PRINT, 1.
NO BN STAFF,1.
[redacted],100
[redacted] BTRY STAFF,1.
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[redacted]NUAL FIRE DIR,1.
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[redacted]BCHAINS
*1, FOOD SGT, COOK, FIELD KITCHEN, BTRY GEN5
*2, SPLY SGT, SPLY SPEC/ARMORER
[redacted], PLANS/OPER OFCR, CHEM OFCR, OPNS SGT,
[redacted]BC NCO, OPHQ CP DRIVER, OPNS SPEC, OPHQ DRIVER,
[redacted]PHQ CARRIER CP, OPHQ RADIO, OPHQ HMMWV,OPHQ FS TERM, OPHQ PRG LD UNT,
$OPHQ ELEC PRINT
[redacted], FIRE DIR OFCR, FIRE CONTROL NCO,TF COMP OPER, TF EQUIP SPEC,
[redacted]PER CP DRIVER, TF OPER SPEC,OPER SINCGAR, OPER TRUCK5, OPER CP-HMMWV,
[redacted]PER FDC,OPER FS TERM, OPER FS COMP TERM, OPER PRG LD UNT,
$OPER PWR CONV GRP,OPER TAC DIS DEV, OPER ELEC PRINT, OPER LOC AREANET
*5, TARGETING OFCR, INTEL OFCR, INTEL SGT, INTEL ANAL,
[redacted]NTEL CP DRIVER, INTEL CARRIER CP, INTEL VRC-90,
[redacted]NTEL FS TERM, INTEL PRG LD UNT,INTEL ELEC PRINT
[redacted], RECON OFCR, CHF SURVEYOR, SURVHQ DRIVER, SURVHQ VRC-89,
$SURVHQ HMMWV, SURVHQ LASER SET
*7, CONVL SEC CHF, SURVEY COMPUTER, INSTR OPER, RODMAN/SURV REC,
[redacted]ONVL VRC-88, CONVL HMMWV
[redacted], PADS SEC CHF, PADS DRIVER, PADS VRC-90, PADS HMMWV, PADS
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*11, RDO TM CHF, RDO TTY OPER, RDO GEN5, RDO TELETYPE-142, RDO HMMWV
*12, PHYS ASST, MED NCO, EMER NCO, MED AID-SPEC-DRIVER, BTRY AIDMAN,
ED AMBUL/HMMWV, MED TRUCK2.5
3, PAC SUPV, PER STAFF NCO, LEGAL SPEC, PER ADMIN SPEC,
$CHAPEL SPEC, PAC CLERK, PAC GEN5, PAC VRC-90, PAC HMMWV,
$PAC TRAILER.75, PAC TRUCK2.5
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##$BDE FS TAC DIS DEV, BDE FS PWR CONV GRP, BDE FS LOC AREANET,BDE FS COMP TERM
#*16, BN FS OFCR,BN FS SGT,BN FS SPEC,BN FS CP DRIVER,BN FS RADIO,
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BTRY HMMWV,.01
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**APPENDIX C**

## MODIFICATIONS TO AURA'S SLEEP METHODOLOGY

The AURA model provides three main input sections for the control of the unit's sleep requirements: FATIGUE, TIREDNESS and REST (Klopcic, 1989; Klopcic *et al*., 1990). The FATIGUE option allows the AURA user to specify that different jobs may be more or less demanding than others, both in terms of the need for personnel to be rested and the drain upon personnel who are engaged in the job. Two parameters are provided for each job listed: first is the rate of fatigue for a particular job and second is the relative demand-for-stored-rest, also known as the threshold value for sleep degradation. Once a person performing a specified job reaches his threshold level of effective sleep units (referred to in AURA as SLUNITS), sleep deprivation starts to affect job performance. In past studies, these two parameters were used to represent the individual variations of required sleep. Recently, additional variables were added under the TIREDNESS option which allowed us to specify the same fatigue rate and threshold for each job and model the individual variations using these new TIREDNESS options.

The TIREDNESS option has a variety of input variables available to represent an individual's reservoir of effective sleep, when an individual is allowed to sleep and how long that person is allowed to sleep. Three new variables allow better control of when the unit was allowed to sleep (using a variable called UPTIME) and model individual variations (using two variables called MUL and TMUL).

The UPTIME parameter allows the AURA user to specify (in minutes) the amount of time the unit is expected to be working, starting a time zero. In past versions of AURA, the initiation of a sleep period was controlled by the MIN parameter. MIN specifies in effective sleep units (SLUNITS) the level below which assets are allowed to sleep. Using MIN to control sleep periods turned out to be clumsy, at best. The UPTIME parameter provided a much more direct method to control sleep periods.

While the UPTIME variable is fairly straightforward, use of the MUL and TMUL parameters requires some discussion. In developing values to represent individual variations in sleep requirements, we came upon a clear dichotomy in the way we intended to use the fatigue rate and how the AURA developers intended fatigue rate to be used. Specifically, fatigue rate was meant to show how tiring a particular job was regardless of who was doing it. Originally, however, we intended different fatigue rates to represent how tired an individual became regardless of the job he was assigned to perform. Originally, this did not present a problem as long as cross-training of personnel was not modeled. Consider a person requiring 4.5 hours of sleep each day. Prior to the introduction of MUL and TMUL, the only way to represent his sleep requirements was through the fatigue rate (therefore, he would tire more slowly than would a person requiring 7.5 hours of sleep). If substitution was allowed, however, a 7.5 hour man might be substituted for a job with a fatigue rate meant for a 4.5 hour man. This would clearly be flawed. This fundamental inconsistency prevented us from using AURA's ability to model personnel cross-training and substitution.

Another set of problems led to the introduction of two parameters, known as MUL and TMUL. When modeling sleep and thermal factors, AURA does well with groups of people no larger than one. In the area of sleep, if AURA encounters a group of people that are supposed to perform the same job, it only has one fatigue rate for that job--all personnel in the job are equally tired or equally rested (using fatigue rates to model individual variations). The solution is to represent each job requiring more than one asset as a set of jobs which all contribute to finishing the whole job. To do this correctly, two new controls were created: MUL and TMUL.

The AURA model provides for two parameters (Fatigue rate and Threshold) which are job-related and specify at what rate a particular job tires the worker and when job performance starts to degrade due to sleep deprivation of the worker. In past studies, we used these parameters to model individual variations which are inherently asset-related, not job-related. As mentioned above, this did not present a problem as long as cross-training and substitution were not being played. However, in the process of modifying the inputs to represent each individual (along with their own distinct sleep requirements and thermal sensitivities), it became imperative to have some way of associating tiredness with individual assets. Once again, consider the soldier who requires 4.5 hours of sleep. It is not the job being performed that makes him a 4.5 hour sleeper; but, instead, has to do with his own requirement for sleep regardless of the job he performs. While this distinction was not a problem in past studies (due to the nature of how the units were organized), in this study it was essential to have some way to relate these factors to an individual, independent of the job he was required to perform. Parameters were needed to relate variations on the rate at which sleep units (SLUNITS) were used to individual assets; MUL and TMUL provide the needed control over slunit usage. MUL allows the user to specify a real number for each asset which is used as a multiplier for the fatigue rate of the job the asset is performing. TMUL is also an asset-related parameter. Simply put, TMUL is used as a multiplier for the threshold value. Using these parameters, we were able to keep individual sleep requirements tied to assets as opposed to the jobs they perform.

APPENDIX D

## DERIVATIONS OF AURA SLEEP PARAMETERS

The AURA fatigue algorithms are documented in a BRL report (Klopcic, 1989). Excerpts from this report are included here for the benefit of the reader. Documentation of the calculations used for this study's sleep parameters are also included in this appendix.

Several assumptions were made in regards to an individual's sleep status:

1. An individual can maintain a performance equilibrium with 18 hours of work and 6 hours of sleep in each 24 hour period.

2. A fully rested individual can work 18 hours before his work begins to degrade due to fatigue, not exhaustion.

3. The performance of a fully rested individual performing cognitive tasks will go to zero in four days if he is not allowed to rest.

4. An individual gains 1 SLUNIT (SLeep UNIT) from one minute of *efficient* sleep.

The basic sleep accumulation function is constructed in four segments (see Figure 1). For the first 10 minutes, no "minutes of effective sleep" are generated; for minutes 10 through 30, the person is given half-credit for the amount of time asleep (i.e., 10 minutes). So a person at 30 minutes into their sleep period will have accumulated 10 "minutes of effective sleep," reflecting the fact that individuals do not start deriving full benefit from sleep until 30 minutes after they have fallen asleep. From 30 minutes until the point where they have made up 80% of the difference between where they started at the beginning of the sleep period and maximum extent of their reservoir (that level defining full restedness), a person is able to accumulate effective sleep on a one-to-one basis one minute of effective sleep for each minute asleep. After replenishing 80% of the deficit, a person only accumulates half of a minute of effective sleep for every minute the person sleeps. For example, the benefit to be derived from six hours of rest is calculated by solving the following set of simultaneous equations:

$$10 + x*1 + (330 - x) * \frac{1}{2} = Total\ Slunits (Eq.1)$$

$$10 + x*1 = 0.8 * Total\ Slunits \quad (Eq.2)$$

where, X is the number of minutes of sleep.

If a person is in balance in working 18 hours and is sleeping 6 hours, during that 6-hour sleep period he would accumulate 283 1/3 effective minutes of sleep and be at maximum sleep accumulation at the end of the sleep period. If a person was very tired, having worked more than 18 hours, then a 6-hour sleep period could potentially yield 340 "minutes of effective sleep" in a 6-hour period because the reservoir remained below the 80% threshold of diminishing returns. Finally, once a person sleeps sufficiently long to reach the maximum of their reservoir, further sleep accrues no further benefit to the sleep accumulation function.

In accordance with assumption 1, the effective sleep units gained in 6 hours are equal to those used in 18. Therefore, the default fatigue rate, *FR*, is given by

$$FR = \frac{285}{(18*60)} = 0.264\ SLUNITS/minute$$

"Full restedness" can be placed on an absolute SLUNIT scale through assumption 3. Since 4 days of work results in total depletion of SLUNITs, full restedness (known as the CEILING) must be:

$$CEILING = 4\,(days) * 1440\,(\min/day) * 0.264\,(SLUNITS/\min) = 1520\ SLUNI$$

Finally, using assumption 2, we can evaluate a default value for the threshold for degradation. Since the performance begins to degrade after 18 hours of work, the threshold for task degradation is given by

$$THRESHOLD = 1520 - 285 = 1235\ SLUNITS$$

This study examined the impact of individual variations of sleep requirements. The calculations above were used with one exception; soldiers were considered to be tired at the start of the scenario. Thus, a six hour sleep period resulted in a full 340 minutes of effective sleep (or 340 *Slunits*). Substituting 340 in the above equations (for 285) results in the values shown in Table 1 below. Individuals in each of the four groups modeled in the study (4.5, 5.5, 6.5 and 7.5 hour sleepers) were assumed to degrade to zero at the end of 4 days if not allowed to sleep.

Table 1. Values Used for Modeling Sleep in AURA

| Required Sleep (Hrs) | Desired Slunit Usage Rate (Sl/Min) | Desired Threshold (Slunits) | Slunits Gained (Slunits) |
|---|---|---|---|
| 4.5 | 0.21368 | 980.77 | 250 |
| 5.5 | 0.27928 | 1298.65 | 310 |
| 6 | 0.31481 | 1813.33 | 340 |
| 6.5 | 0.35238 | 1659.71 | 370 |
| 7.5 | 0.43434 | 2071.82 | 430 |