RISK ASSESSMENT OF PULMONARY EXPOSURE TO RESPIRABLE DUST WHILE WEARING DUST RESPIRATOR UNDER SIMULATED WORK CONDITIONS

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INTRODUCTION

One of the most serious problems influencing the effectiveness of respiratory protection in the workplace is the degree of fitness between worker's face and respirator mask. This problem has been the focus of several investigators, particularly during the past decade.[1,2,5-7,9-13] In spite of significant advancement in development of numerous types of respirator masks, difficulties are still encountered with respect to the ability of worker to obtain an efficient face seal with the mask of a "tight-fitting respirator." Despite the requirements for thorough qualitative and/or quantitative fit testing of tight-fitting respirators on workers in order to select the best fitted respirator mask, under actual working conditions the degree of assurance as to (1) how long a respirator mask will remain fit, (2) what factors affect the face-seal efficiency the most, and (3) what would be the potential exposure risk involved, are still uncertain. In addition to facial hair and morphology, which have been studied by several investigators in the past, factors such as repeated and prolonged head and body motion, rate of respiratory ventilation, respirator strap tension, temperature and humidity, etc. may affect the respirator fit resulting in increased exposure risk to air contaminants.

In our laboratory, we have developed a unique automated motion and breathing system that utilizes NIOSH-adopted dummy heads. These dummy heads have been used by NIOSH and other investigators for respirator bench test.

The purpose of this attempt was to develop a respirator testing system that simulates the actual working conditions. The prime objectives were: (1) to test the integrity of respirator masks, (2) to study the effects of dynamic factors that affect the respirator mask face seal such as head and body motion as well as breathing rate and frequency. Other factors that may also affect respirator seal, such as strap tension, temperature and humidity, can also be studied with this system.

INSTRUMENTS AND METHODS

System Components

The experimental system consists of a dummy, referred to as "Dusty", equipped with automated motion and breathing system. Dusty is installed inside a 1000-liter inhalation chamber and is connected to the motion and breathing systems outside the chamber by means of cables and tubings. The major components of the system are described below:

The chamber. The chamber is equipped with gas and vapor generation systems and a Wright dust feeder. Other commonly used aerosol systems such as DOP, mineral oil or salt aerosol can also be used to generate the desired concentration of aerosol. The aerosol concentration within the chamber is monitored by means of a light-scattering particulate counter. In case of use of gas or vapor for experiment, the concentration can be continuously monitored by means of an infrared gas spectrophotometer and strip chart recorder. The chamber is also equipped with a dynamic airflow system and necessary gauges for temperature, pressure and airflow control. An electrostatic precipitator followed by an absolute filter, continuously cleans the chamber air from air contaminants before discharging it to the environment. (Figure 1)

Human-form dummy (Dusty). Dusty comes in three different sizes: small, medium and large for use with various size respirator masks. Dusty's face is made out of soft and flexible plastic and approximates normal shape of human face. Similar dummies, as stated earlier, have been used by NIOSH Respiratory Research Section in Morgantown, WV, for primarily Bench Test.[2] (Figure 2)

Motor drive/indexers. The 3180-Pl Motor Drive/Indexers used in this system are line-operated, energy efficient motor drive modules. An integral power supply provides the necessary DC voltages required to operate the indexer and drive. The indexer/drive modules are capable of driving stepping motors allowing a wide range of functions. The indexers are also used for memory storage up to 400 lines of program in non-volatile memory.[3]

There are three drive indexers in this system: A, B and C. Each drive/indexer controls one motion of the dummy in two opposite directions. Drive/indexer A also controls the breathing system.

Stepping motors. There are three stepping motors in the system: 1, 2 and 3. These motors are controlled by motor/drive indexers, A, B and C, respectively. Each motor runs in two opposite directions: positive and negative. For

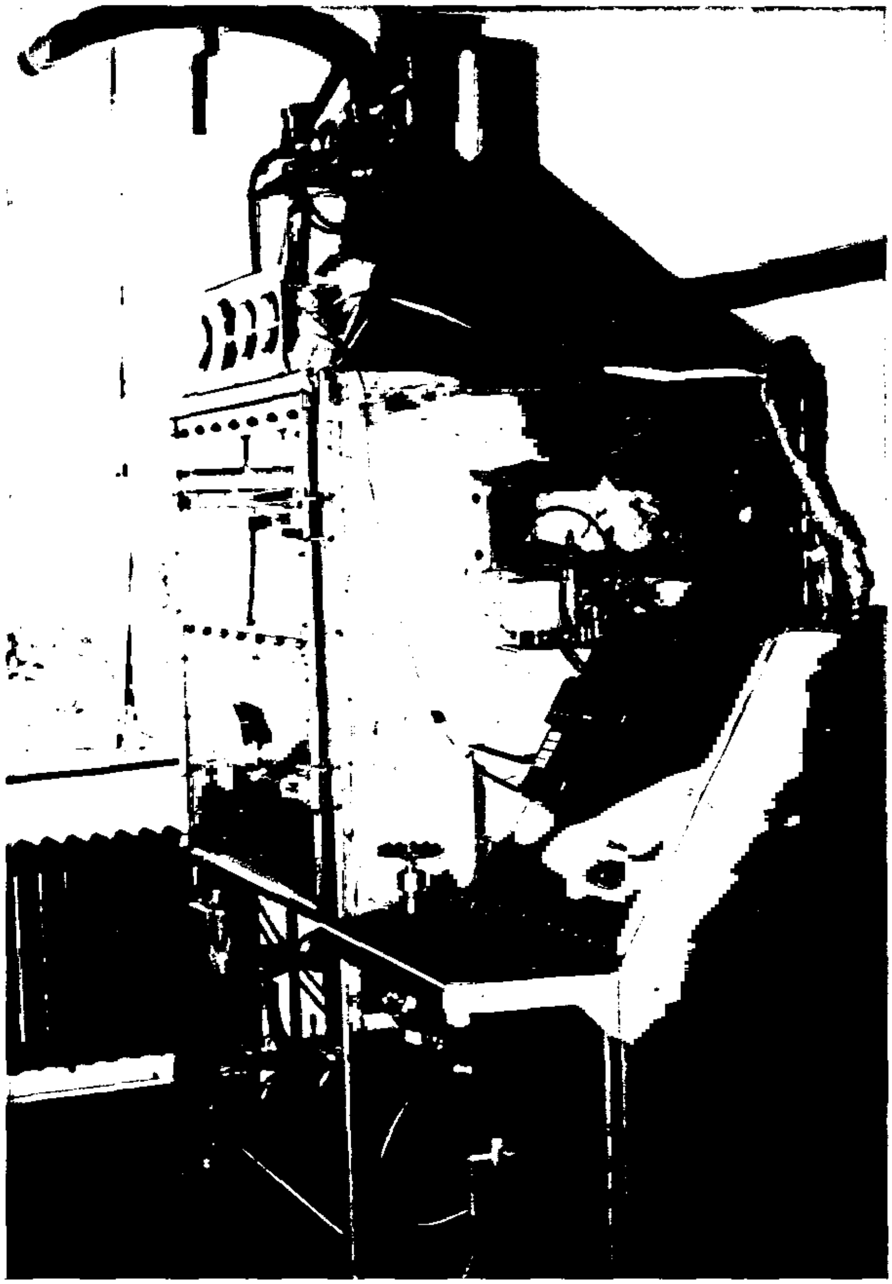

Figure 1. Inhalation chamber and automated motion and breathing simulators.

example, in vertical motion of Dusty, positive motion is "moving up" and negative motion is "moving down." In horizontal rotation (turning head) moving head to the left is positive and to the right is negative. In vertical translation (nodding head), forward head motion is positive and backward movement is negative.[3]

Indexer programmer. The SSP-500 indexer programmer is a dedicated programmer which is designed to be used with a variety of drive/indexers including the 3180-Pl used in this system. All functions, parameters, data, and commands for the microseries indexers can be easily entered, edited, uploaded and downloaded using this device. All information is clearly displayed on the two-line by 40-character liquid crystal display (LCD) panel. Seven function keys, Bi-Directional Cursor Locators, Numerical Keypad, Entry, and Mode keys provide easy and convenient data entry. All programming functions are menu-driven, and are presented in a clear, easy to follow sequence. The SSP-500 is designed to be either hand-held or affixed on an exterior surface.[4]

Breather. The Breather is a box containing a vacuum/compressor pump and two three-way selenoid valves which alternate the flow of air from and to the vacuum/compressor pump.

Figure 2. Human-form dummy (Dusty) used in the system.

The opening and closing of these valves are controlled by the Drive/Indexer "A". The frequency of opening and closing of valves (same as respiration frequency) can be changed by programming the Drive/Indexer through the Indexer Programmer. A breath warmer/humidifier is also used on the exhalation line. For inhalation, the computer opens up the two valves in direction from the Dusty's mouth toward the vacuum pump; as a result, Dusty inhales the contaminated air from the chamber through the respirator being worn. At the end of inhalation cycle, the computer reverses the direction of airflow by switching the two selenoid valves in the opposite direction, i.e., from the pump toward Dusty; as a result, room air is pushed through the warmer/humidifier and then into the Dusty's respirator cavity and out into the chamber through the respirator's exhalation valve. Volume and rate of breathing is adjustable through the indexer programmer. Therefore, increased rate of breathing can be set corresponding to the assumed rate of a worker's metabolic rate.

Portacount. Portacount is a highly versatile particle-counting instrument. It can accurately measure respirator fit factors, filter penetrations, and particle concentrations. Based on the technology of continuous flow condensation nucleus counters, the portacount counts individual airborne particles from variety of sources. The instrument has two modes: Count Mode and Fit-test Mode. In the Count Mode, the portacount measures the concentration of airborne particles, whereas in the Fit-test Mode, the instrument measures the concentrations of particles inside and outside a respirator and calculates the respirator penetration or protection factor.[8]

METHODS

The system can be used to conduct variety of experiments on respirators. For example, to assess the risk of dust exposure associated with a specific respirator fit under a certain head and body motion and/or breathing rate, the following procedure may be followed:

1. The "test respirator" is fit-tested on Dusty's face by means of the Portacount, until satisfactory fit is achieved.
2. The Chamber is set on desired flowrate and dust (or other aerosols) generation rates so that the desired concentration is achieved within a reasonable time, i.e., approximately 5 minutes.
3. Dusty's motion and breathing systems (as programmed) are activated to run for a pre-determined length of time.
4. Dust concentrations outside and inside respirator is recorded continuously throughout the experiment. The extent of dust penetration into the respirator either through the face seal or any other route is detected at any time during the experiment and recorded on the strip chart. Any fluctuations in dust penetration for example, can also be matched with the Dusty's motion and breathing pattern. Such experiment is expected to provide answers to questions such as: (1) how long the respirator mask remains fit before a dust leak occurs? (2) which movement disturbs the respirator face seal, and to what extent? (3) what would be the effect of inhalation (negative pressure inside respirator mask), exhalation and/or breathing rate on dust penetration through the respirator? and (4) what would be the estimated risk of dust exposure involved under a set of conditions.

Operating the Robotic Dusty

Programming and operating the motion/breathing system, as stated earlier, is done through the Indexer/Programmer (Figure 3). The following is an example of the many programs used in this system. In this example, Dusty will carry out a consecutive combination of head and body motions: i.e., turning head, pumping tire, jogging in place, bending, turning head while bending, and turning while nodding. These motions will be accompanied by breathing at a rate of 15 respirations per minute and approximately 750 mL of air per respiration.

When using this program, the first mode appearing on the display of the Indexer/Programmer is the "OPERATING MODE" (Figure 3). The function key beneath each lowercase word will act on that word. For example, f7 key activates the indexers. Pressing this key will bring the display in Figure 4 which is "SELECT FUNCTION". Pressing f7 key (motion) again will move the system to the "MOTION" options

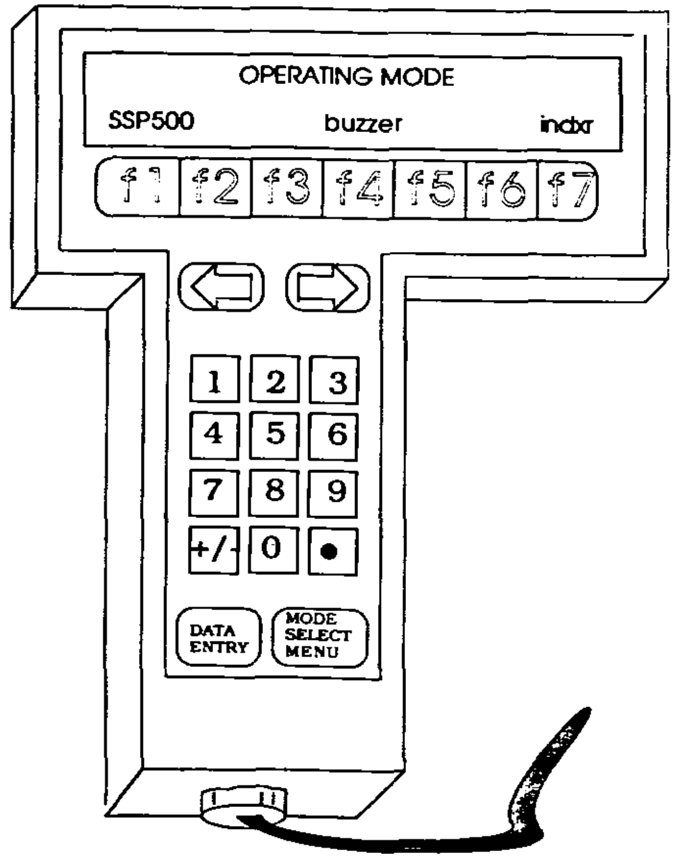

Figure 3.

(Figure 5). Here, the operator has several options; however, in this example, pressing f3 key (exec) would be the right choice. The next display (Figure 6) is "EXEC MOTION". Here again, several options are available; however, since the operator is asking Dusty to carry out all the motions, f4 key (all) should be pressed which will activate all indexers. This will take the operator to the last step of this program: "AUTO EXEC MOTION" (Figure 7). Out of several options available in this mode, pressing f1 key, CYCST (Cycle start) will start the system. Dusty will start the head and body motions, as stated earlier, in a consecutive fashion while breathing. Indexer/Programmer display during the operation would be "AUTO EXECUTING" (Figure 8). The system will continue to operate until the end of pre-set time on the program unless the operator wishes to stop the system at any time by pressing f1 key (stop). Pressing f4 (hold) may also be used should the system have to be stopped momentarily.

The robotic Dusty can also be run manually for each single motion by pressing f1 (man) in the "MOTION" mode (Figure 5). The next screen will show "ATT'N INDXR (01-99)" (Figure 9). The cursor on this screen will be flashing asking for the Drive/Indexer number of choice. Using the numeric key pad, one of the three indexers is activated by typing a zero and then the Indexer number: 01, 02 or 03. Once an Indexer is chosen, the "DATA ENTRY" key on the

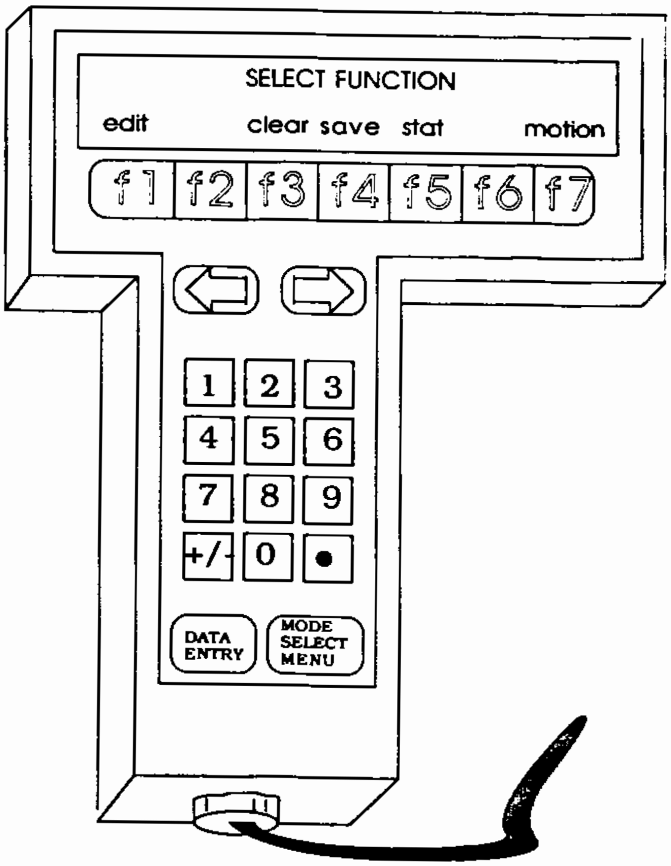

Figure 4.

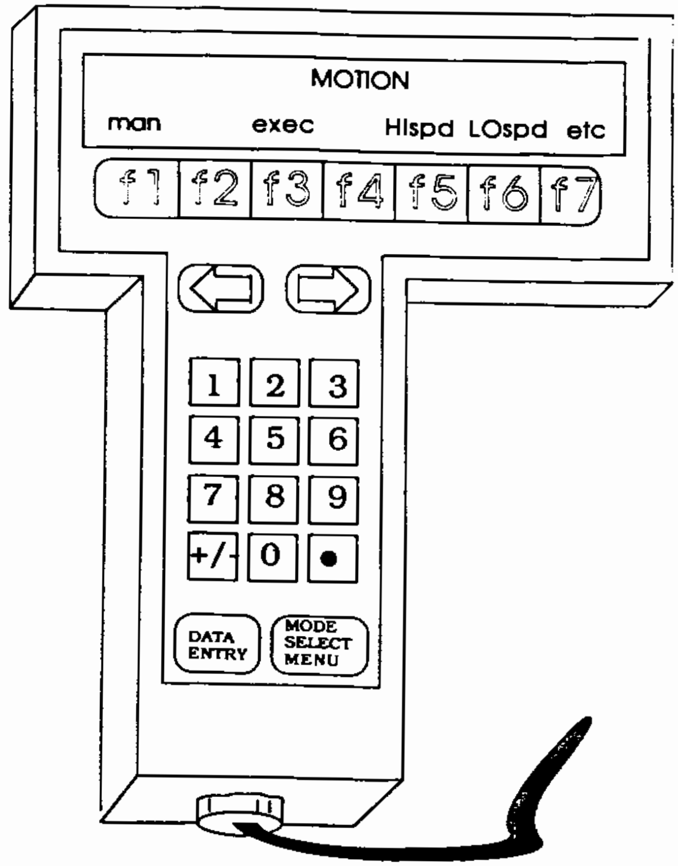

Figure 5.

Indexer/Programmer is pressed to activate the next screen of choice: "MANUAL MOTION" (Figure 10). The number in the upper left, here shown as "OX", will be the number of the indexer chosen. Several options are available on this screen. The one primarily used in manual control of the system is f2 (Jog). Pressing f2 will activate a continuous motion of the Dusty depending on the Indexer number chosen. The screen appearing during this operation will be "JOG MOTION".

In addition, the system can be programmed and executed to carry out varieties of desired motions or combination of motions (up to 999 choices). To execute the desired motion, f5 key (N) should be pressed during the AUTO EXEC MOTION (Figure 7). Using the numerical keypad, the desired motion number is then entered and followed by pressing "DATA ENTRY" key. The system is now ready to execute the desired motion indefinitely by pressing f1 key (Cycst).

If the system is stopped at any time during the operation, Dusty must be "returned" to its "electrical home" before a new cycle can be started. This is done by pressing f6 key (reh) in "MANUAL MOTION" mode (Figure 10).

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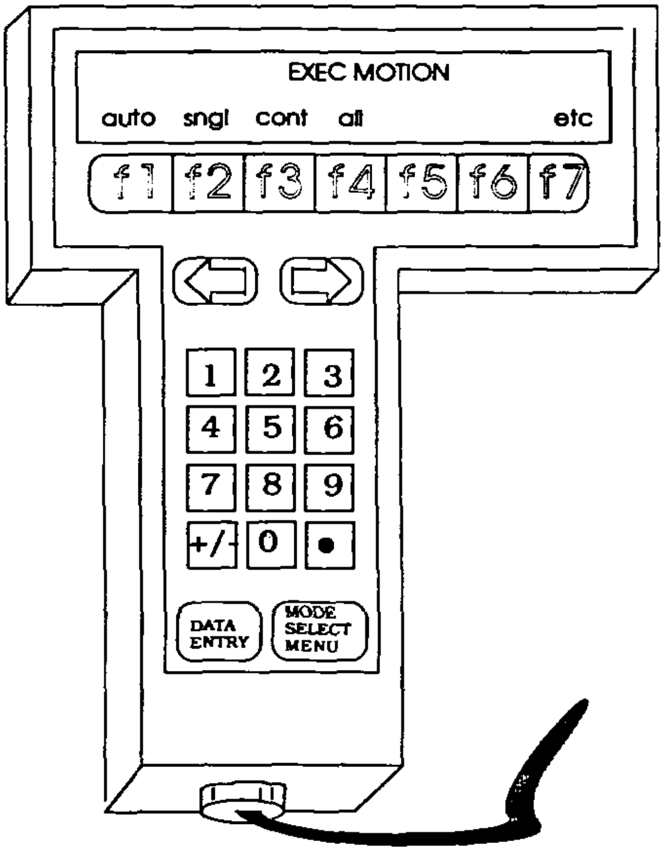

Figure 6.

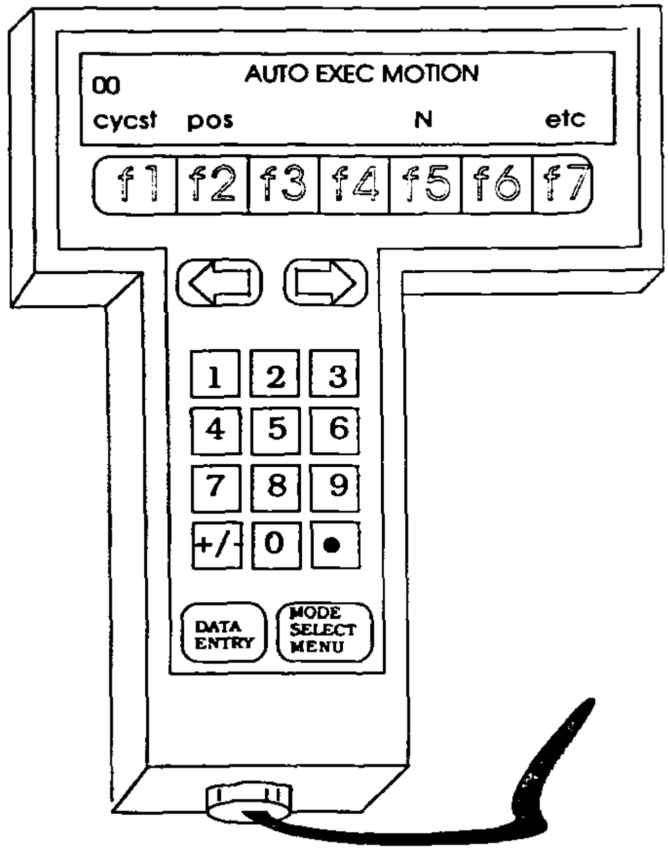

Figure 7.

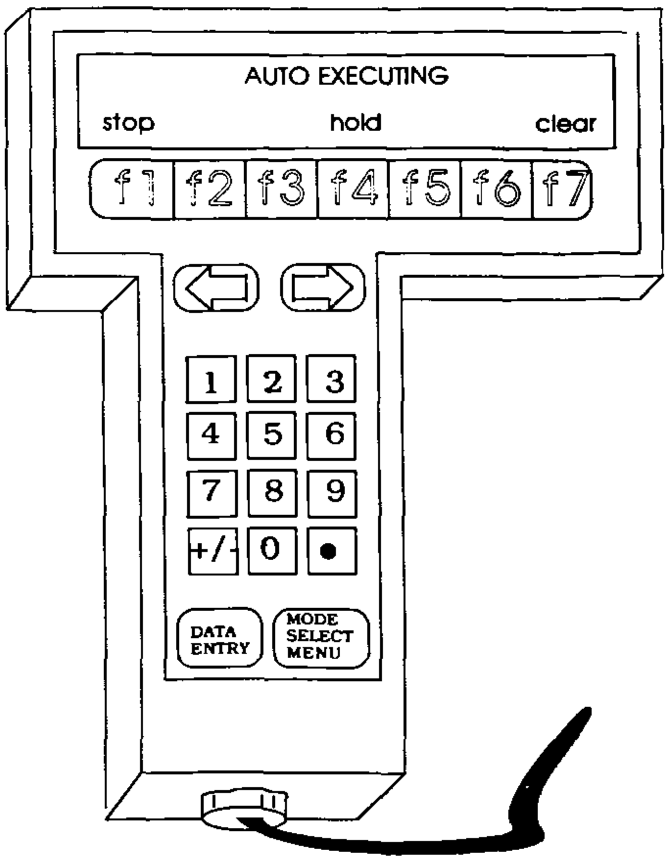

Figure 8.

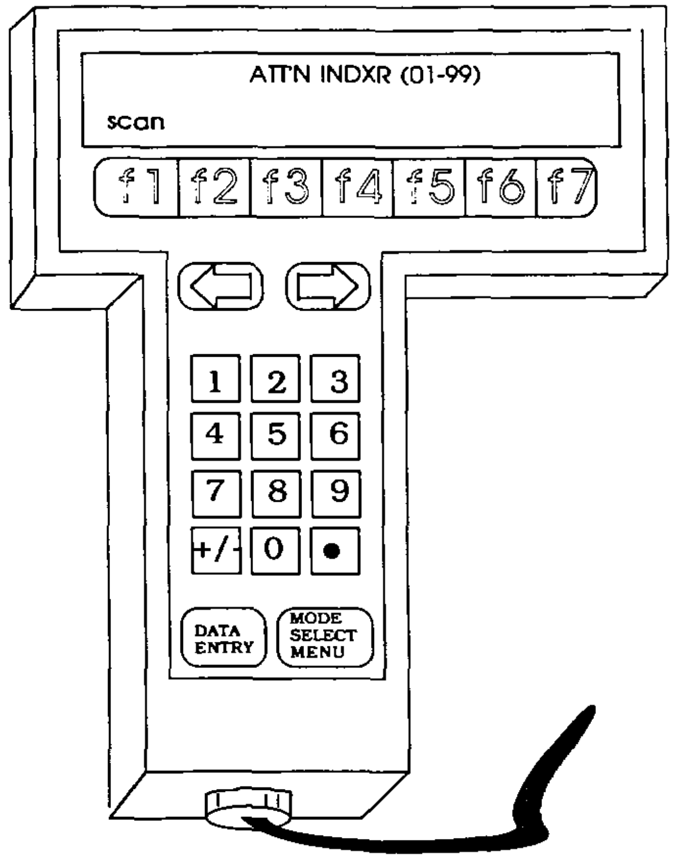

Figure 9.

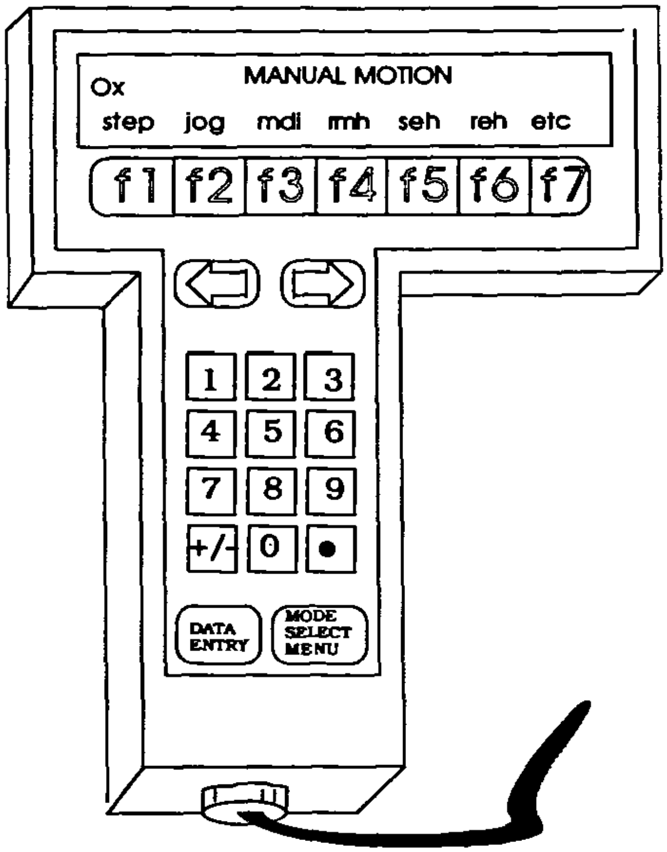
Ox
MANUAL MOTION
step jog mdi rmh seh reh etc
f1 f2 f3 f4 f5 f6 f7
1 2 3
4 5 6
7 8 9
+/- 0 •
DATA ENTRY
MODE SELECT MENU

Figure 10.

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Pittsburgh, Pennsylvania, USA—August 23-26, 1988
Pittsburgh, Pennsylvanie, Etats-Unis—23-26 août 1988
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November 1990

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DHHS (NIOSH) Publication No. 90-108 Part II