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DESIGN AND FABRICATION OF PROTOTYPE MODIFIED DEMILITARIZATION P--ETC(U)

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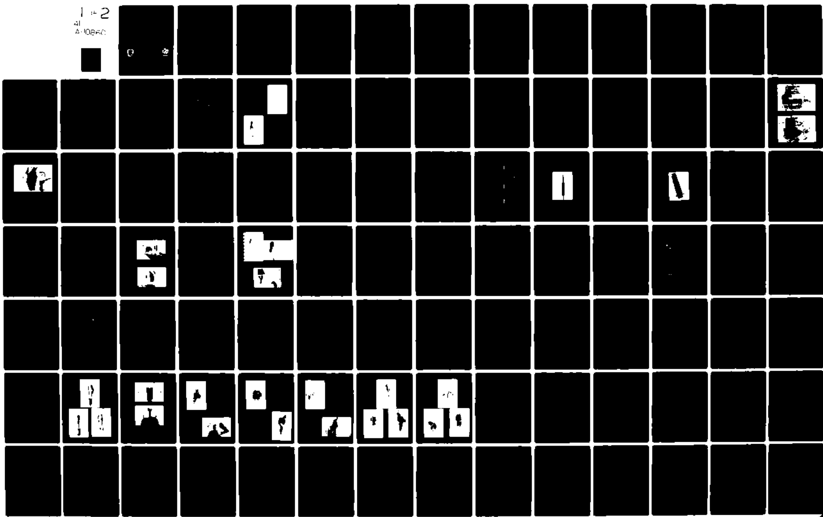

CHEMICAL SYSTEMS LABORATORY CONTRACTOR REPORT

ARCSL-CR-

DESIGN AND FABRICATION OF PROTOTYPE MODIFIED DEMILITARIZATION PROTECTIVE ENSEMBLES FOR 2 1/2 HOUR SELF-CONTAINED USE

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July 1981

Contract DAAK11 -80-C-0020

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
Chemical Systems Laboratory
Aberdeen Proving Ground, Maryland 21010

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARCSL-CR-	2. GOVT ACCESSION NO. AD-A110 860	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Design and Fabrication of Prototype Modified Demilitarization Protective Ensembles for 2½ hour self-contained use.		5. TYPE OF REPORT & PERIOD COVERED Final Report 3 March 80 - 1 June 81
		6. PERFORMING ORG. REPORT NUMBER DAAK11-80-C-0020-01
7. AUTHOR(s) Charles R. Sandy, Project Engineer Protective Equipment, ILC Dover		8. CONTRACT OR GRANT NUMBER(s) DAAK11-80-C-0020
9. PERFORMING ORGANIZATION NAME AND ADDRESS ILC Dover P.O. Box 266 Frederica, Delaware 19946		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS CDR, ARRADCOM CML/Ballistics Procurement, APG (Edgewood Area), MD 21010		12. REPORT DATE July 1981
		13. NUMBER OF PAGES ___ of ___
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Commander DCASMA - Philadelphia P.O. Box 7699 Philadelphia, PA 19101		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Outergarment	Pressurization System	Heat Removal
Cooling System	Endurance Testing	Expansion Gore
Rebreather	Heat Exchanger	Visor Fogging
DPE	Circulation System	Vol. Accumulator

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

A modified design of the Demilitarization Protective Ensemble for 2½ hr. self-contained operation was developed, fabricated and tested. A commercially available prototype rebreather was selected for use with the system. The ensemble includes a liquid cooled undergarment and active breathing air cooling. The Outergarment is designed to maintain positive suit pressure.
Two types of ensembles were developed; one made of CPE for use in ambient temperatures of 32°F to 100°F, and one made of butyl coated nylon for use in ambient temperatures of 0°F to 32°F. —> cont.

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Twenty four endurance tests have determined that the ensembles used in these temperature ranges meet all design criterion.

A one hour self-contained version was also developed. It includes a commercially available one hour rebreather, a liquid cooled body vest, active breathing air cooling, and positive suit pressure.

Prototype self-contained chemical protective ensembles for both 1 hr. and $2\frac{1}{2}$ hr. use were fabricated and delivered.

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FOREWARD

The work reported herein was conducted by ILC Dover, Frederica, Delaware, for ARRADCOM, CML/Ballistics Procurement, APG (Edgewood Area), Maryland in accordance with Contract DAAK11-80-C-0020. Mr. Donald R. Cohee was the Program Manager and Mr. Charles R. Sandy was Project Engineer for ILC Dover. Mr. Wayne Davis was the Contract Monitor for the Chemical Systems Laboratory. This work was accomplished between 3 March 1980 and 1 June 1981.

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1.0 INTRODUCTION

Various United States Government agencies are charged with responsibilities which require the handling, containment or disposal of articles and equipment which are contaminated with chemicals of a toxic or hazardous nature. In many cases these chemicals are harmful from both physical contact and vapor proximity exposure. The current available protective equipment often inhibits or restricts the capability of personnel to effectively perform their tasks.

The umbilical air supplied Demilitarization Protective Ensemble (DPE) developed by ILC and the Chemical System Laboratory (CSL) at Aberdeen Proving Ground for use in the Army's Chemical Agent Munitions Disposal Systems (CAMDS) operation at Tooele Army Depot in Tooele, Utah, represents the current state-of-the-art in personnel chemical protection. This suit, however, is not presently capable of being used at remote sites in a self-contained mode.

The Hazardous Chemical Protective Clothing Outfit (HCPCO) manufactured by ILC for the U.S. Coast Guard for use in hazardous chemical handling and clean-up operations is limited in the types of atmospheric environments in which it is effective. Since it uses a filtered ambient air supply, it is useless in an oxygen deficient environment and limited otherwise to environments which are compatible with the filter medium.

Due to these limitations, it is desirable to develop modifications to the DPE that will enable it to operate in a self-contained mode. The modifications would have to include a self-contained breathing air supply, body cooling and positive suit pressure.

An initial effort toward this goal was authorized under Contract DAAK11-79-C-0060. It included the development of an initial breadboard 2½ hr. self-contained breathing system, a cooling system concept that permits body cooling for the duration without excessive weight, and an outergarment design that provides the primary chemical barrier, and helps to maintain positive suit pressure. [See Design and Development of Initial Breadboard Units for a Self-Contained Life Support System.]

The work reported herein is the second step toward the ultimate goal of an approved, production ready, 2½ hr. self-contained chemical protective ensemble. The objective of this effort was to design and deliver prototype modified DPE's for 2½ hr. self-contained operation.

2.0 SUMMARY

Prototype modified DPE's were designed, fabricated and tested for 2½ hr. self-contained operation. All design criteria were met.

The breathing system prototype developed by U.S. Divers Co. was tested and passed all NIOSH requirements for closed circuit rebreathers. *The unit employs many redundant features, making it a more safety conscious design than any currently available. Pressure monitors, visual warnings, and audio alarms keep the user constantly aware of the systems' condition. The fully charged breathing system weighs 43.5 lbs. No other system can provide service time, suit pressurization capability, and emergency breathing capability in a comparable package.

The cooling system was expanded to include breathing air cooling as well as body cooling. The closed loop cooling circulation is driven by a backpack mounted battery driven pump, and includes an air heat exchanger, body cooling garment, water heat exchanger, and a sump.

Testing indicates that the system provides adequate body and breathing air cooling for use in ambient temperatures as high as 100°F.

The suit pressurization system was designed as a combination of an active pressurization system in the backpack, and an outergarment design that would minimize the use of the backpack pressurization system. Testing indicates

*NOTE: While the breathing system passed these tests at U.S. Divers Co., it is not yet a NIOSH approved system.

that as long as the outergarment develops no leak, the outergarment will maintain positive suit pressure without using the backpack pressurization system at all.

A butyl coated nylon version of the same outergarment was developed for use in cold temperatures as low as 0°F, since CPE does not have good low temperature flexibility. Testing indicates that the CPE outergarment can be used from 32°F to 100°F, and the butyl outergarment from 0°F to 32°F.

A manned endurance test program of 24 tests was conducted to verify the reliability of the ensemble, and to determine the optimum temperature range of each outergarment material. Tests were conducted at 0°F, from 22°F to 45°F, at room temperature, and at 100°F. All components of the system consistently performed to design criteria. The endurance test program also provided useful practical experience in using the system which resulted in a number of recommendations for improvements, included in this report.

To demonstrate the early feasibility of the self-contained concept, a one hour self-contained version was developed, fabricated, and tested. It incorporated a Biomarine 60 P one hour rebreather, a modified ILC cool vest expanded to include breathing air cooling, and an outergarment. Manned testing indicates this ensemble enables the user to work effectively in up to 100°F ambient temperatures. It was during this phase of the effort that the need for breathing air cooling was discovered, and the outergarment pressurization system was designed.

3.0 REQUIREMENTS

Design parameters and general performance specifications were established for each of the basic subsystems; breathing system, cooling system, and pressurization.

3.1 Breathing System

3.1.1 The breathing system should provide self-contained breathable air for two hours plus one-half hour for donn/doff modes.

3.1.2 There should be an emergency back-up capability for five minutes to enable emergency evacuations from a contaminated area.

3.2 Cooling System

3.2.1 The cooling system should provide internal suit cooling for operation of the modified DPE sufficient to maintain body core temperature at a safe level (102°F design goal).

3.2.2 The design point for environmental load extremes shall be as delineated.

3.2.2.1 Maximum temperature of 100°F in zero wind, full sun exposure.

3.2.2.2 Minimum temperature of 0°F during night operation.

3.2.2.3 All weather operation.

3.2.3 The cooling system must be designed to interface smoothly and without interference with the breathing system, pressurization system, and outergarment, and must not affect the wearer's protection from the toxic environment.

3.2.4 The cooling systems total weight must be kept low enough to be tolerable by the user.

3.2.5 The cooling system should not bring any material, liquid or solid, that has been contaminated inside the outergarment.

3.3 <u>Pressurization System</u>

3.3.1 The pressurization system shall provide continuous positive pressure within the suits for the two and one-half hour mission.

3.4 <u>Requirements for One Hour Self-Contained Modified DPE</u>

3.4.1 Breathing System

3.4.1.1 The breathing system should provide self-contained breathable air for one hour.

3.4.1.2 The breathing system shall be a commercially available, NIOSH approved, production unit.

3.4.2 Cooling System

3.4.2.1 The cooling system requirements for the one hour self-contained modified DPE shall be the same as the requirements for the 2½ hr. self-contained modified DPE. (see 3.2)

3.4.3 Pressurization System

3.4.3.1 The pressurization system shall provide continuous positive pressure within the outergarment for a one hour duration.

4.0 TECHNICAL DISCUSSION

4.1 Breathing System

4.1.1 ILC utilized the services of U.S. Divers, Survivair Division, Santa Ana, California, as subcontract supplier for the development and delivery of a prototype 2½ hour closed circuit life support system. See U.S. Divers' Final Report including Test Report and Outline for NIOSH Certification, Operating and Maintenance Instructions for the 2½ hour Prototype Rebreather/ Pressurization System, and Safety Assessment Report for the 2½ hour Closed Circuit Life Support System for documentation of this development effort. (Contract DAAK11-80-C-0059)

4.2 Cooling System

The preliminary design and feasibility study on the cooling system was accomplished under contract DAAK11-79-C-0060 (Refer to Final Report, Design and Development of Initial Breadboard Units for a Self-Contained Life Support System.)

The design concept which was developed is a closed loop cooling system, picking up body heat through a liquid cooled garment and transferring it to an ice pack that can be replaced when depleted. This enables the ice pack to be sized to a more convenient weight, while still cooling the man for the full 2½ hours. A number of softgoods heat exchangers were evaluated. The cooling garment concept was expanded from an ILC cool vest to a full coverall cooling garment. The circulating pump was a 12 VDC centrifugal pump.

The initial effort demonstrated the feasibility of providing cooling for a 2½ hour mission in a self-contained closed circuit system. The system, however, still had a number of difficulties which needed to be resolved:

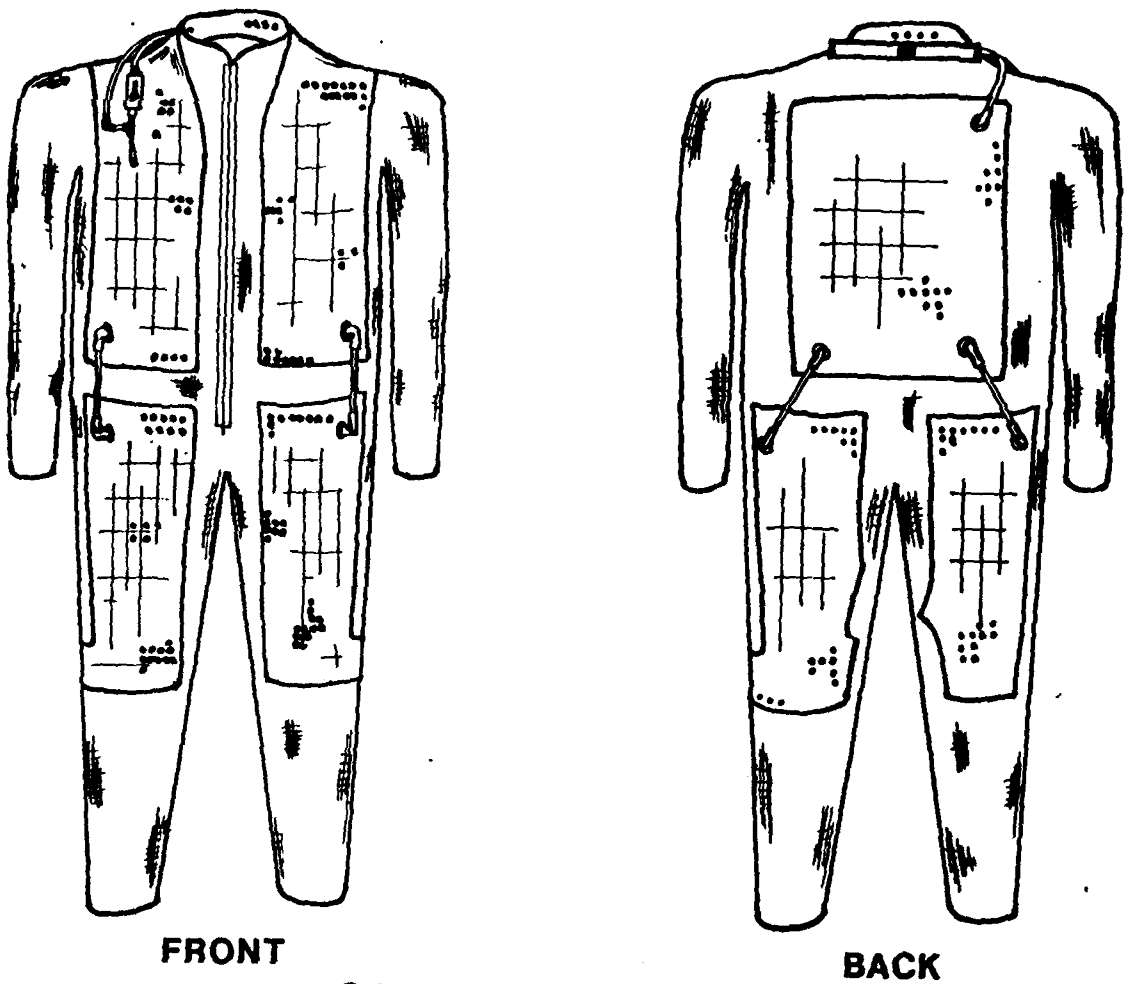
1. Water flow between front and back panels was difficult to interface with the spandex. The flow could be crimped off in usage.
2. The centrifugal pump requires a sump above it, so it was placed at the waist of the garment. This is an inconvenient location from a comfort and use standpoint.
3. The optimum softwear heat exchanger would be large, cumbersome, and difficult to arrange in the chest pouch so that repeated loading with ice would not damage it.

Each of these problems has been solved in the prototype system final design.

4.2.1 Cooling Garment

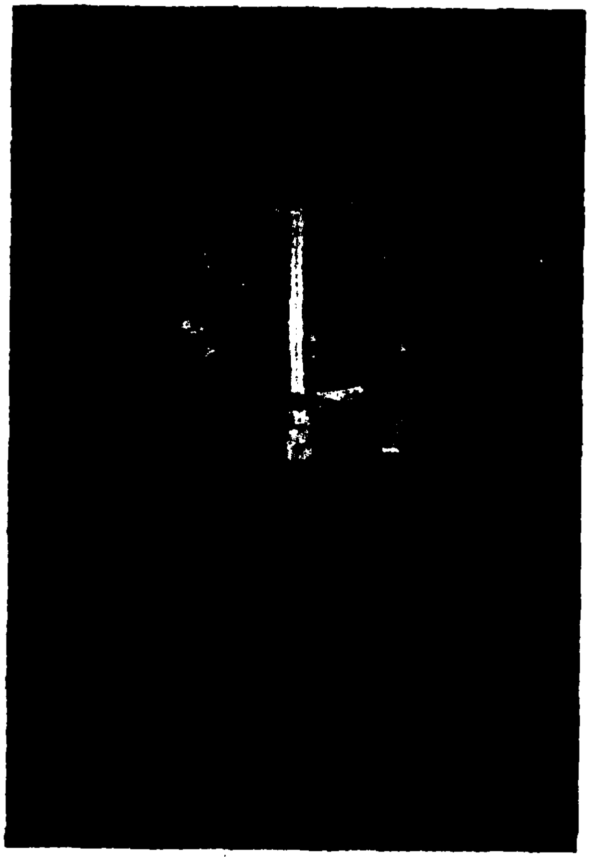
The full coverall cooling garment concept was kept, but the garment itself was reconfigured to eliminate any crimping problems. The garment developed includes neck, front torso, front thigh, back thigh, and back torso cooling. Each of these cooling panels are connected in series and are mounted on a spandex liner. (see Figure 1a and 1b)

Water enters the garment in the back of the collar. Here it splits into two parallel flows down either side of the front torso. It is carried through short vinyl tubes to front thigh panels. These panels are fashioned in a "wrap-around" manner so that they are integral with the rear thigh panels. Water continues through the rear thigh panels to short vinyl tubes leading



COOLING GARMENT

FIGURE 1a



FRONT

BACK

FIGURE 1b
COOLING GARMENT

to the rear torso panel. Here the two flows combine. The rear torso panel fills and water exits through a port in the upper right side.

This arrangement has the entry and exit ports located at the highest points in the garment to prevent large cooling panel areas from becoming air bound.

4.2.1.1 By-Pass Arrangement

Mounted directly to the entry and exit ports is a tubing and valve arrangement that permits flow control of water through the cooling garment. Flow can be controlled from full on to full off. (see Figure 2)

4.2.1.2 Sizing

The cooling garment prototype was sized to fit medium to large sized men. The spandex connecting the cooling garment panels permits a fairly large range of user sizes. Very small or very large sized men may require specially sized cooling garments, however.

4.2.2 Pump and Battery

An extensive survey of commercially available pumps and batteries was made to select the optimum combination of minimum weight and best performance. Pumps were evaluated on the basis of size, weight, pressure/flow characteristics, and current draw. It was determined that positive displacement pumps had significant advantages over centrifugal pumps as they were not as readily susceptible to air-lock and they could overcome a higher pressure drop for the same flow. The product survey revealed that weight and current draw considerations were not

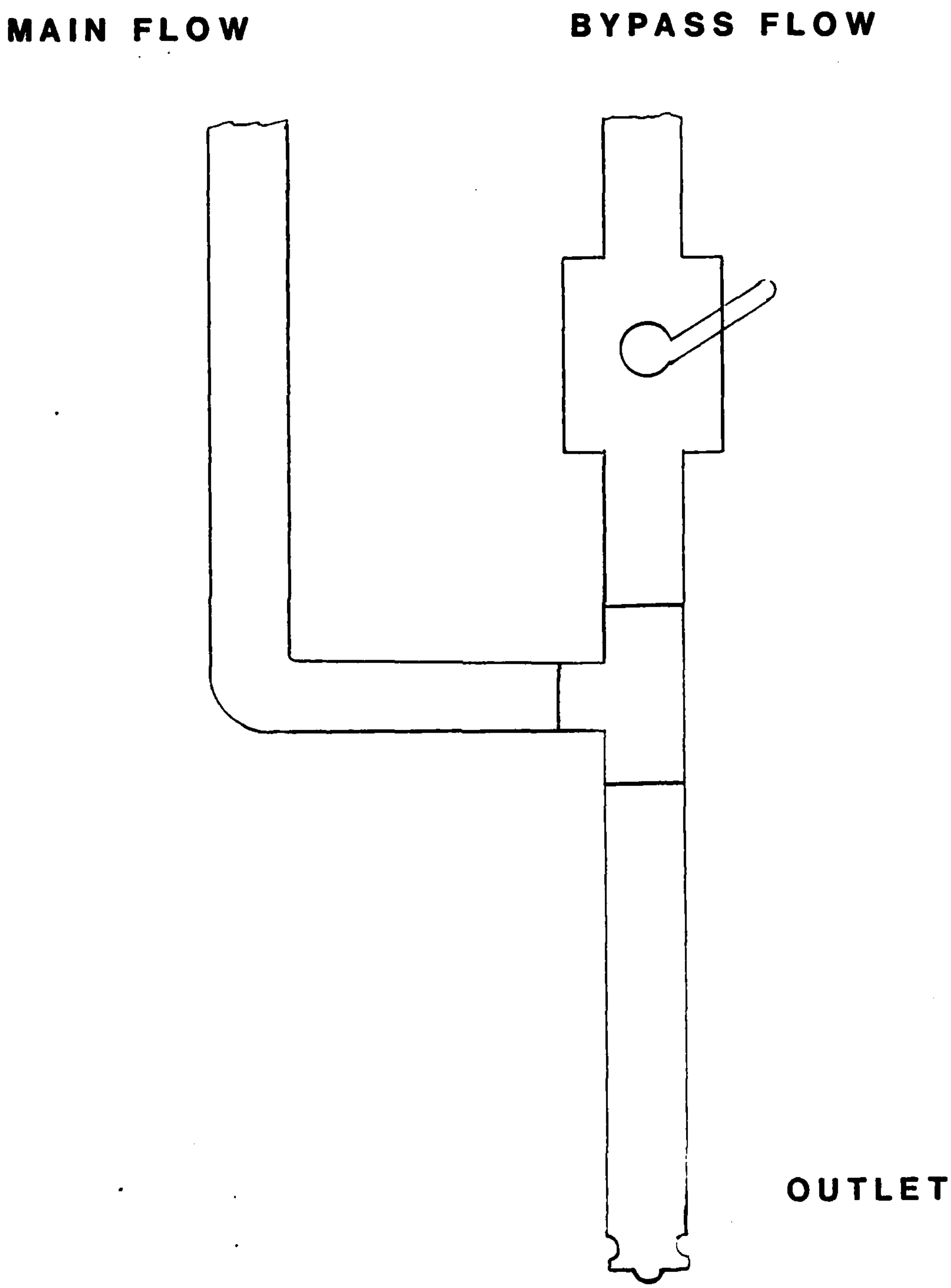


FIGURE 2

COOLING GARMENT BYPASS

compromised by these advantages, so a positive displacement pump was selected. Of the positive displacement pumps available in the size, weight, current draw, and flow ranges that were determined, the Tuthill Pump Model 9058-PT was selected as optimum. The unit uses 12 VDC, weighs 1.27 lbs. and was later determined to draw 1.5 amps when circulating water through the cooling system. It is a compact, reliable gear pump and was able to be located in the saddle of the U.S. Diver's backpack.

Batteries were evaluated on the basis of size, weight, voltage, amp-hour rating, and recharge cycle life. The main categories under consideration were lead-acid and Nickel-Cadmium batteries. The amp-hour rating required was a function of the current draw of the pump and the duration of each use:

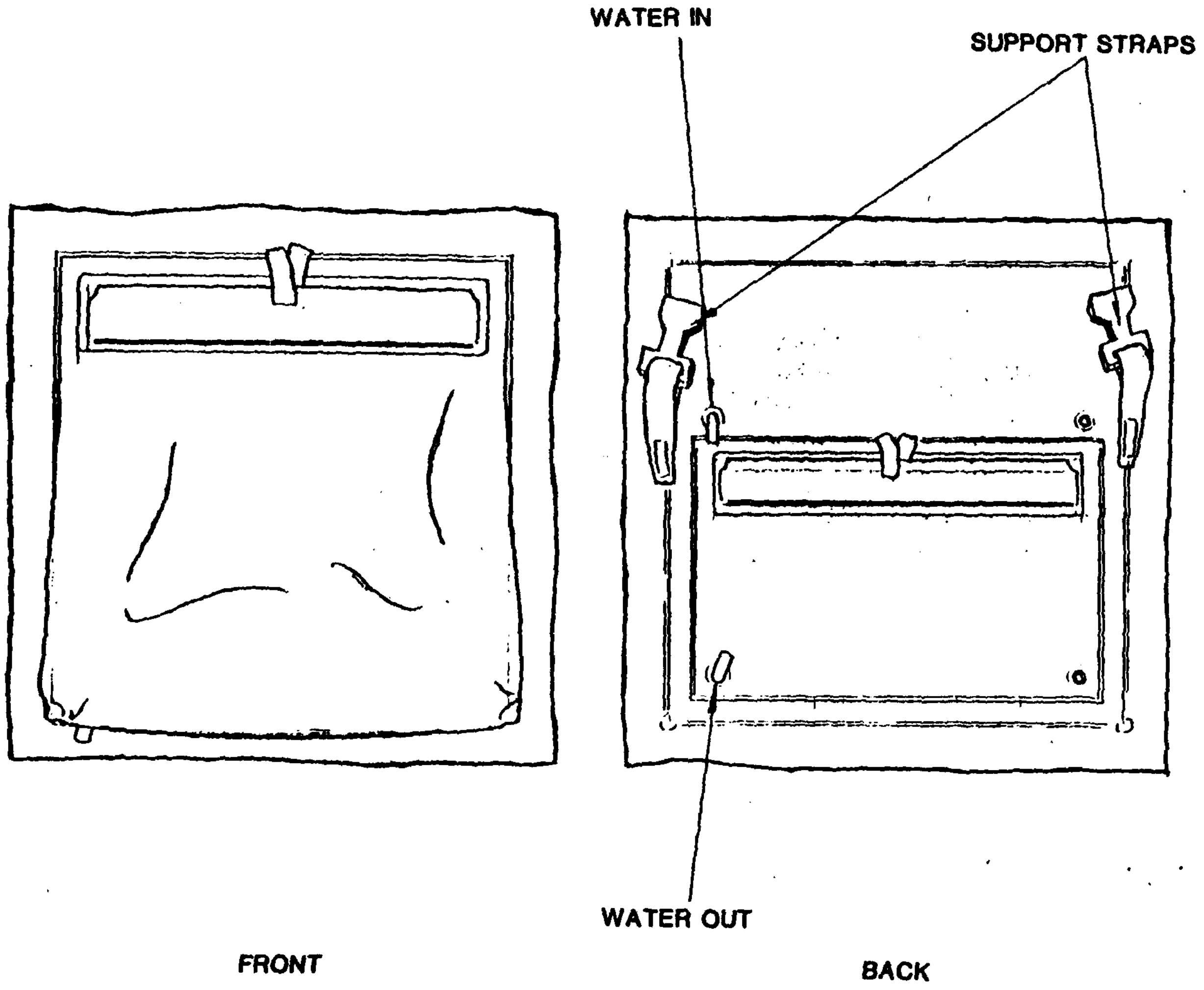
1.5 AMPS x 2.5 HOURS = 3.75 AMP-HOURS

Therefore, a 12 VDC battery of at least 3.75 amp-hour capacity was required.

The product survey revealed that Nickel-Cadmium batteries generally could deliver the required power for less weight than a lead-acid battery. The lowest weight NiCad available that met the voltage and power requirements was a custom made battery pack manufactured by Telecommunication Devices, Inc. It consists of 10 high energy density NiCad D-cells in two rows of 5 cells each. Each cell is 1.2 VDC, 4 amp-hours, and they are connected in series making the overall pack a 12 VDC, 4 amp-hour unit. They were received packed together in heat shrunk material. A durable ABS case for the unit was designed and fabricated. The total unit weight is 3.27 lbs. The battery pack is compact, durable, relatively lightweight, meets the voltage/power requirements and can be recharged hundreds of times. A recharging unit was also selected, purchased and delivered as part of this system.

4.2.3 Heat Exchanger

The heat exchanger which was designed for removing the heat from the water in the circulating system is a series flow copper tube submersed in an ice bath inside an insulated CPE pouch mounted on the front torso of the DPE. A hardware heat exchanger was chosen over softwear designs due to the greater heat transfer capacity of metal compared to plastic tubes, coated fabrics, or films. This approach had not been persued during the design and feasibility study because it was thought that the hardware/softwear interface could cause wear problems and that a hardware heat exchanger would be an expensive item to include as part of a one-time use outergarment. After initial calculations, however, it was evident that only a small amount of copper tubing (about five feet) would be required for the necessary heat transfer. This would enable the exchanger to be fabricated in a simple compact flat pattern that would be lightweight, inexpensive, and cause no interface difficulty with the softwear of the pouch or suit wall. (see Figure 3) This is the configuration as it was finalized and incorporated into the deliverable outergarments.

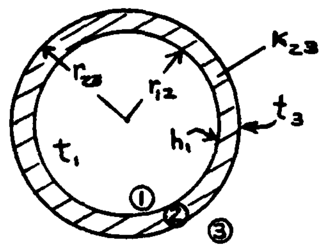


ICE POUCH/SUMP ASSY

FIGURE 3

4.2.3.1 <u>Heat Exchanger Design Calculations</u>

Heat transfer calculations were made for 3/8" copper tubing immersed in an ice water bath. Based on total heat removed per unit time in the case of the one hour suit, a minimum length was calculated:



Fluid outside does not move, therefore this is a conductive problem:

$$\frac{q}{L} = \frac{2\pi\,(t_3 - t_1)}{\frac{1}{r_{12}\,h_{12}} + \frac{\ln r_3/r_1}{k_{23}}}$$

[Reference: Heat Transfer]
[Chapman, p.66, eq. 3.4]

where

q = Heat transfer rate (Btu/hr)

L = tube length (ft)

t_3 = temperature at outside wall of tube (°F)

t_1 = temperature at inside wall of tube (°F)

r_{12} = inside tube radius (inches)

r_{23} = outside tube radius (inches)

k_{23} = thermal conductivity of copper (Btu/hr - ft - °F)

h_{12} = coefficient of convective heat (Btu/hr. - ft^2 - °F) transfer at inside wall

t_3 = 32°F

t_1 = 50°F (based on temperatures of coolant in one hour suit cooling system)

r_{12} = .01270"

r_{23} = .01565"

k_{23} = 233 Btu/hr. ft. - °F

h_{12} = 599 Btu/hr. - ft^2 - °F

$$\frac{q}{L} = \frac{2\pi\,(32 - 50)}{\frac{1}{.01270(599)} + \frac{\ln\,(.01565/.01270)}{233}}$$

$$\frac{q}{L} = -\,853.35$$

if q = 2400 Btu/hr,

L = 2.81 ft = 33.72"

This figure provided a basis for beginning empirical evaluations of heat exchanger designs. It could not be taken to be completely accurate due to the following assumption:

- 32°F at outside tube wall. This assumes perfect mixing of the ice/water solution.
- k_{23} = 233 $\frac{\text{Btu.}}{\text{hr-ft.}}$ This assumes a <u>pure</u> copper tube. Small amounts °F. of impurities or alloying elements rapidly reduce the thermal conductivity of copper.
- t = 50°F. This was an approximation based on temperatures of coolant in the one hour suit cooling system.
- q = 2400 Btu/hr. Again, an approximation based on one hour suit cool system results.

4.2.3.2 Heat Exchanger Testing

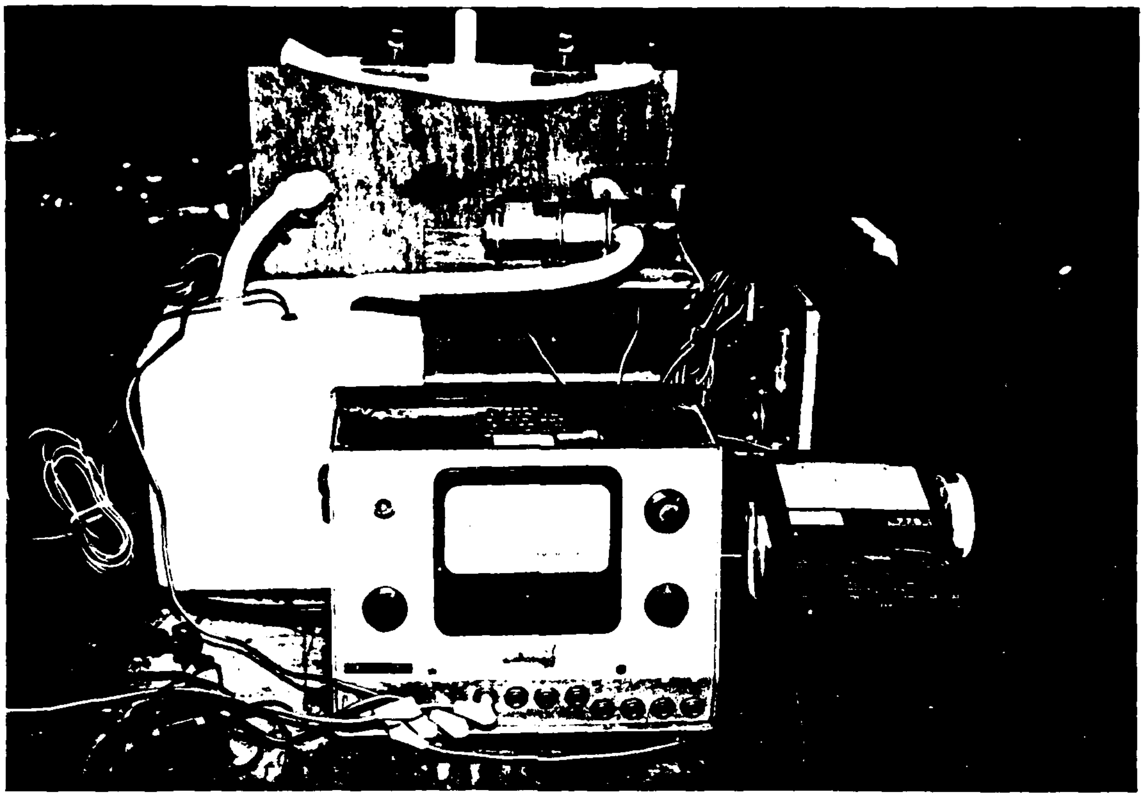
Based on the previous calculations, a 34" long copper tube was shaped in a 3 pass serpentine arrangement. Also, a 60" long tube was shaped in a 5 pass serpentine arrangement to determine if heat transfer is significantly improved or if 3 passes removes as much as possible for a 32°F heat sink, and is therefore optimal for size and weight considerations.

These two designs were tested in a calorimeter type test set-up, pictured in Figure 4 and diagrammed in Figure 5. In addition to comparing the 3 pass to the 5 pass heat exchangers, a comparison was made of performance at 12 volts and at 8 volts. The temperature vs. time plots generated for each combination are shown in Figures (6), (7), (8), (9).

Imposing the curves on top of each other indicated that:

1. The 5 pass, 60" long heat exchanger cools the circulating water significantly better than the 3 pass, 34" long version.
2. Reducing voltage from 12V to 8V has almost no effect on the heat exchanger performance.

Conclusion #1 led to the selection of the 5 pass heat exchanger. Conclusion #2 initially led to a reduction in pump voltage by reducing the number of cells from 10 to 6 (12 volts down to 7.2 volts). Later however, manned testing revealed that battery voltage dropped off earlier with the 7.2 arrangement and that it could not be used for a 2½ hour duration. The final design, therefore, uses the full 12 volt battery pack.



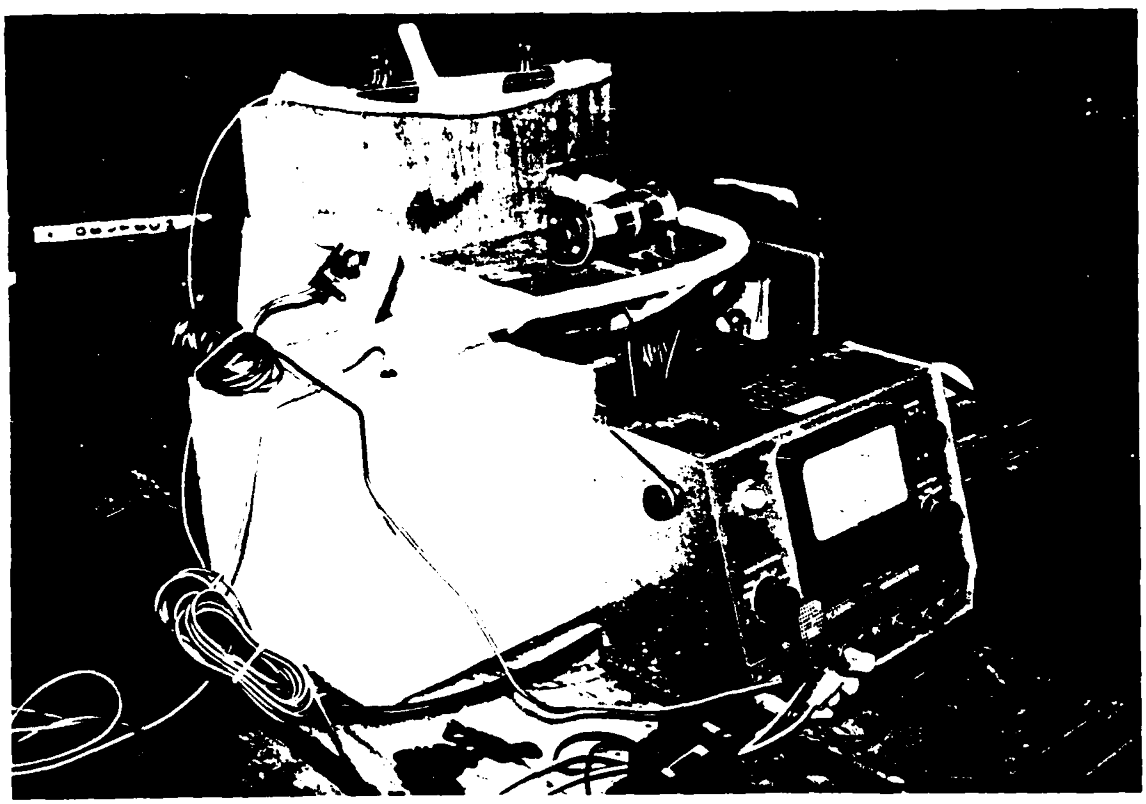


FIGURE 4 HEAT EXCHANGER BENCH TESTING

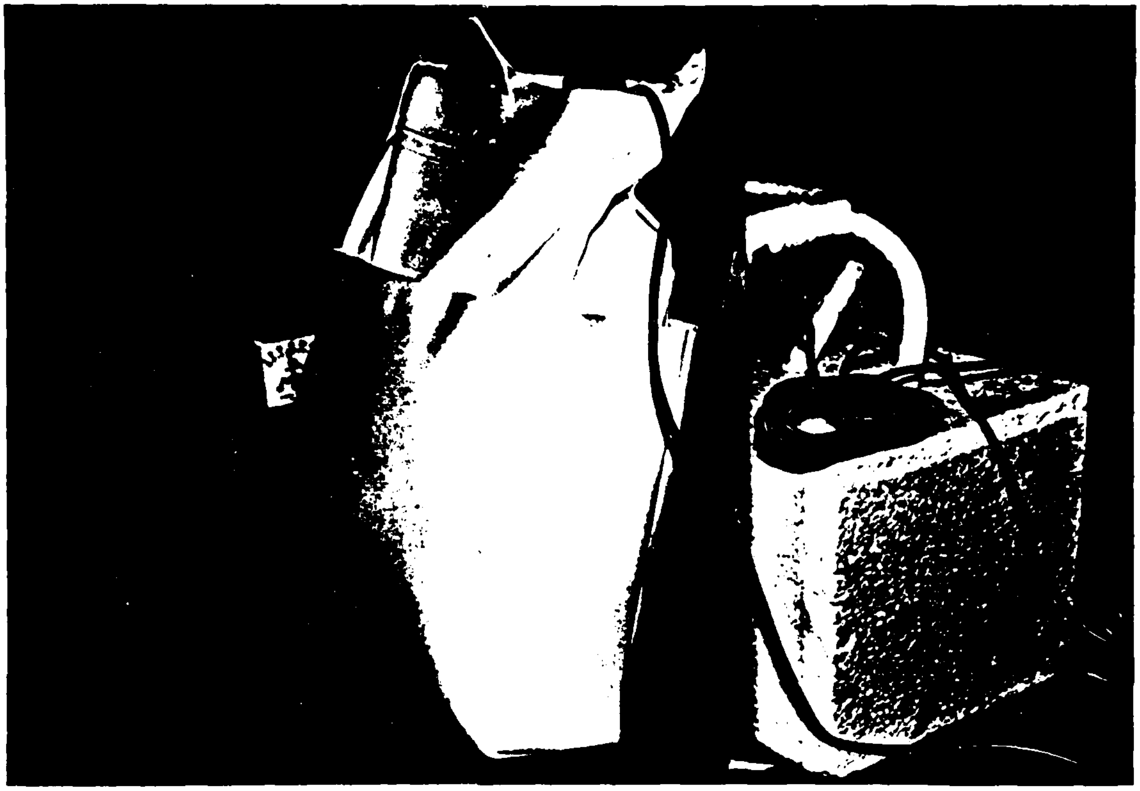


FIGURE 4 cont'd

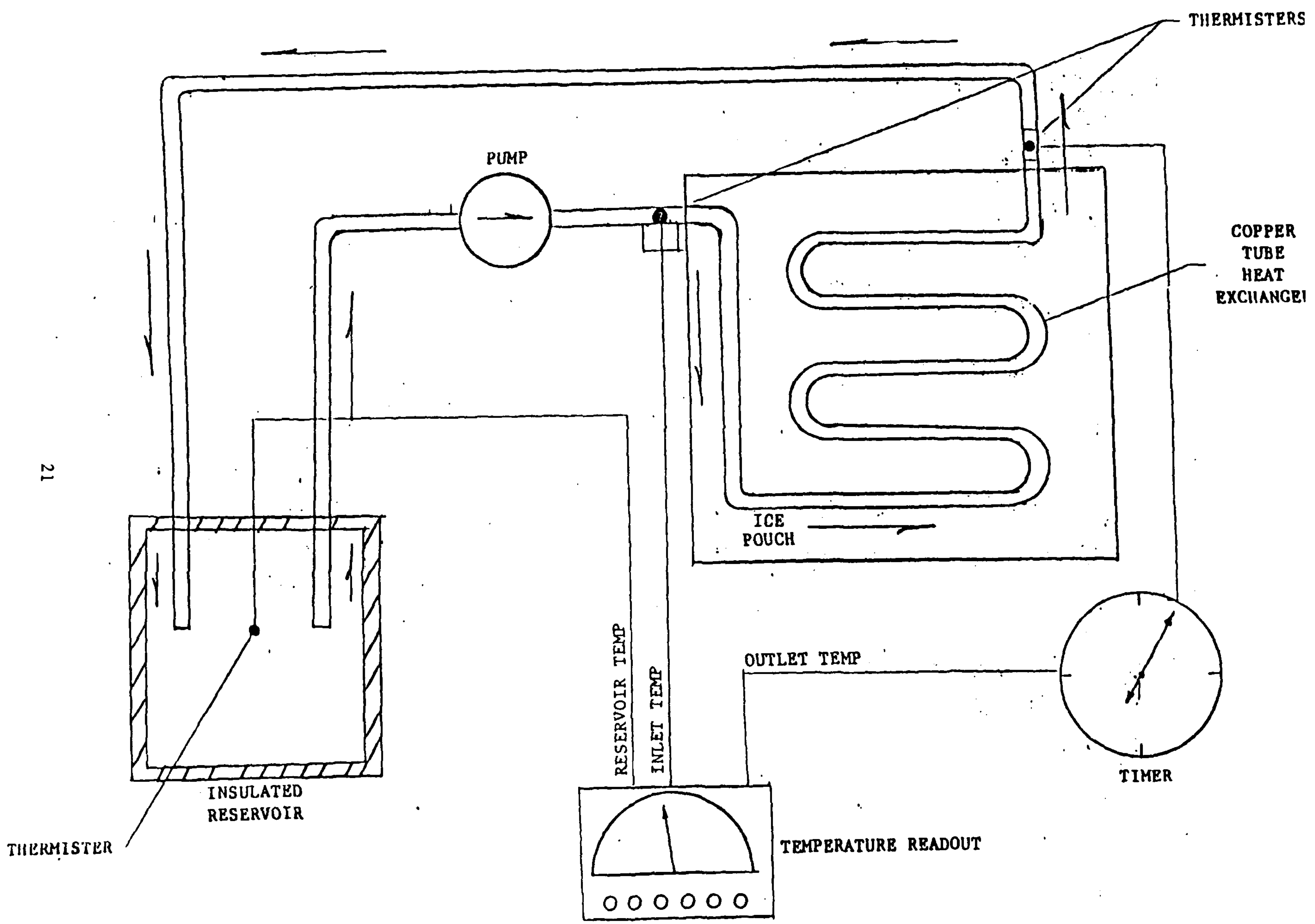


Figure 5
Calorimeter Schematic

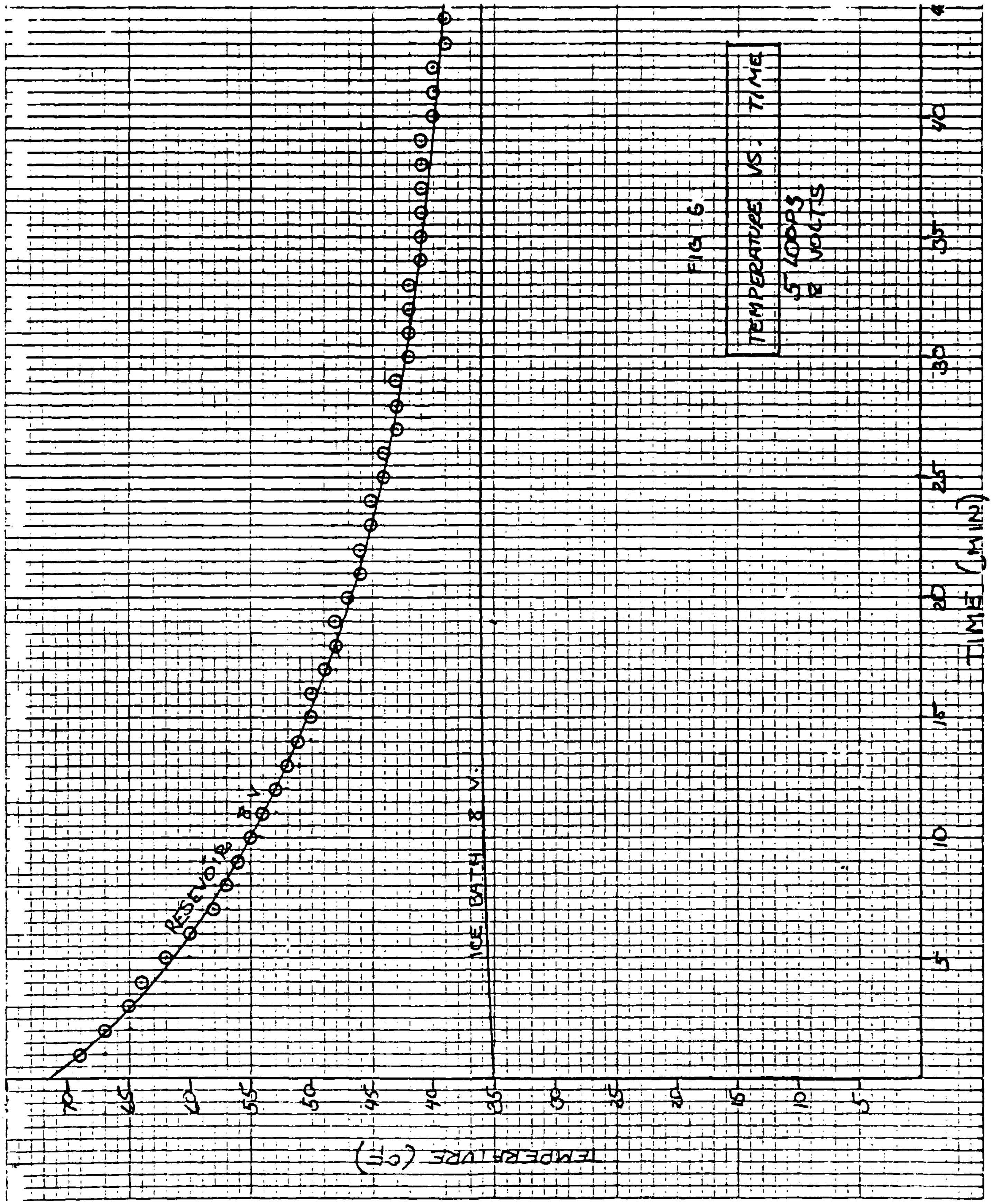


FIG 6
TEMPERATURE VS. TIME
5 LOOPS
8 VOLTS
RESEVOIR 8 V
ICE BATH 8 V.
TIME (MIN)
TEMPERATURE (C°)

FIGURE 6

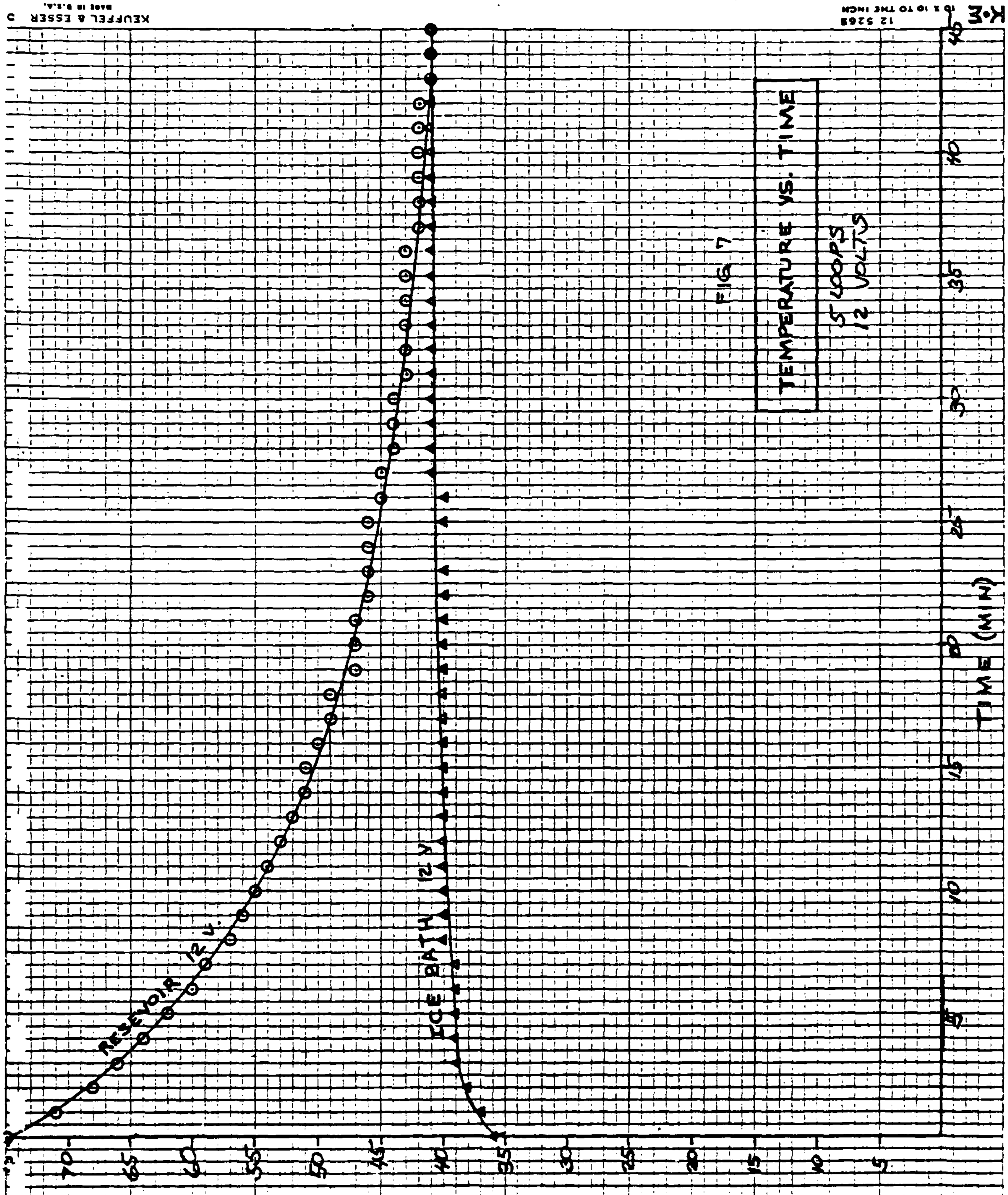

TEMPERATURE VS. TIME
FIG 7
5 LOOPS
12 VOLTS
RESEVOIR 12 V.
ICE BATH 12 V
TIME (MIN)
TEMPERATURE (°F)

FIGURE 7

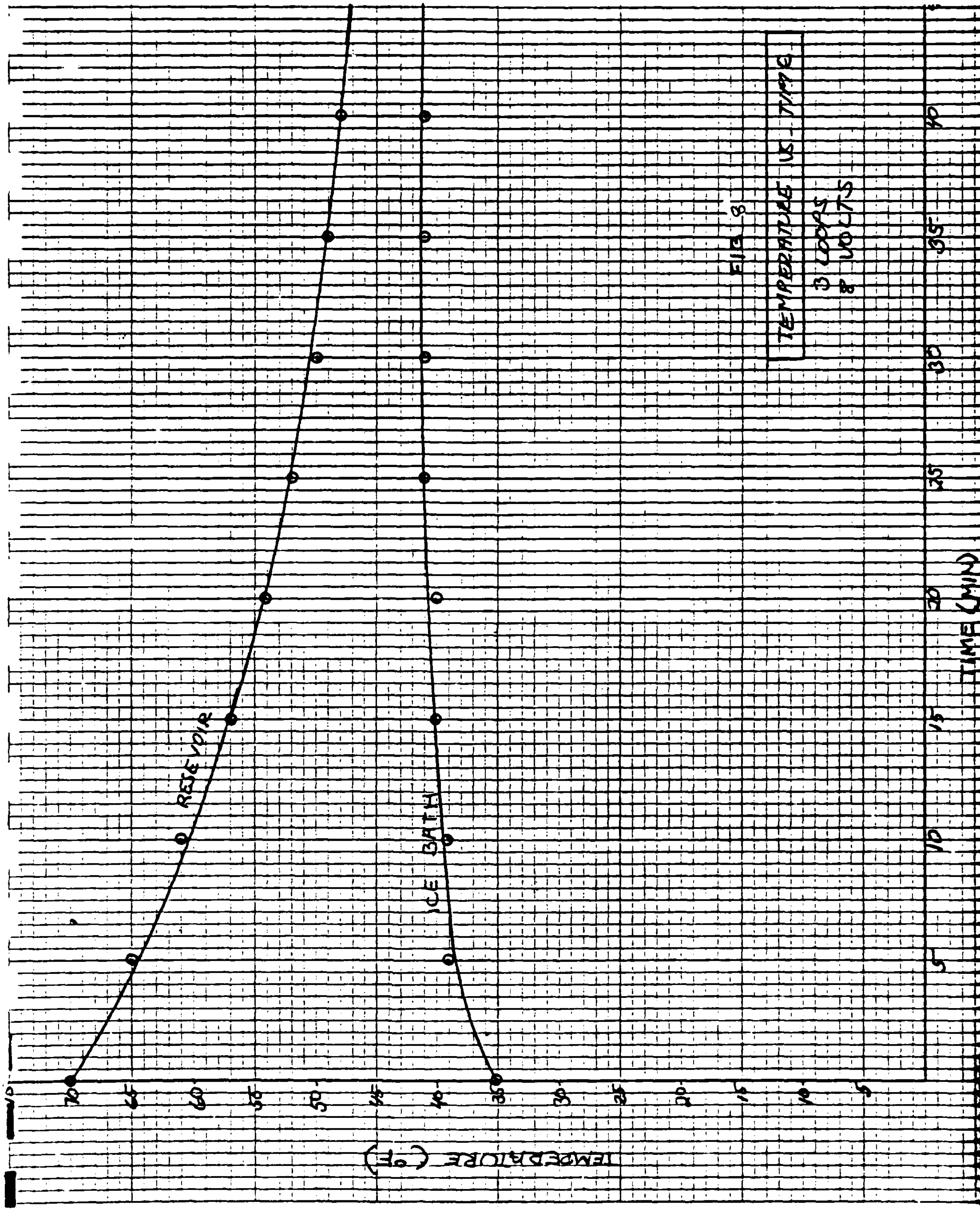


FIG 8
TEMPERATURE VS TIME
3 LOOPS
8 VOLTS
RESEVOIR
ICE BATH
TIME (MIN)
TEMPERATURE (°F)

FIGURE 8

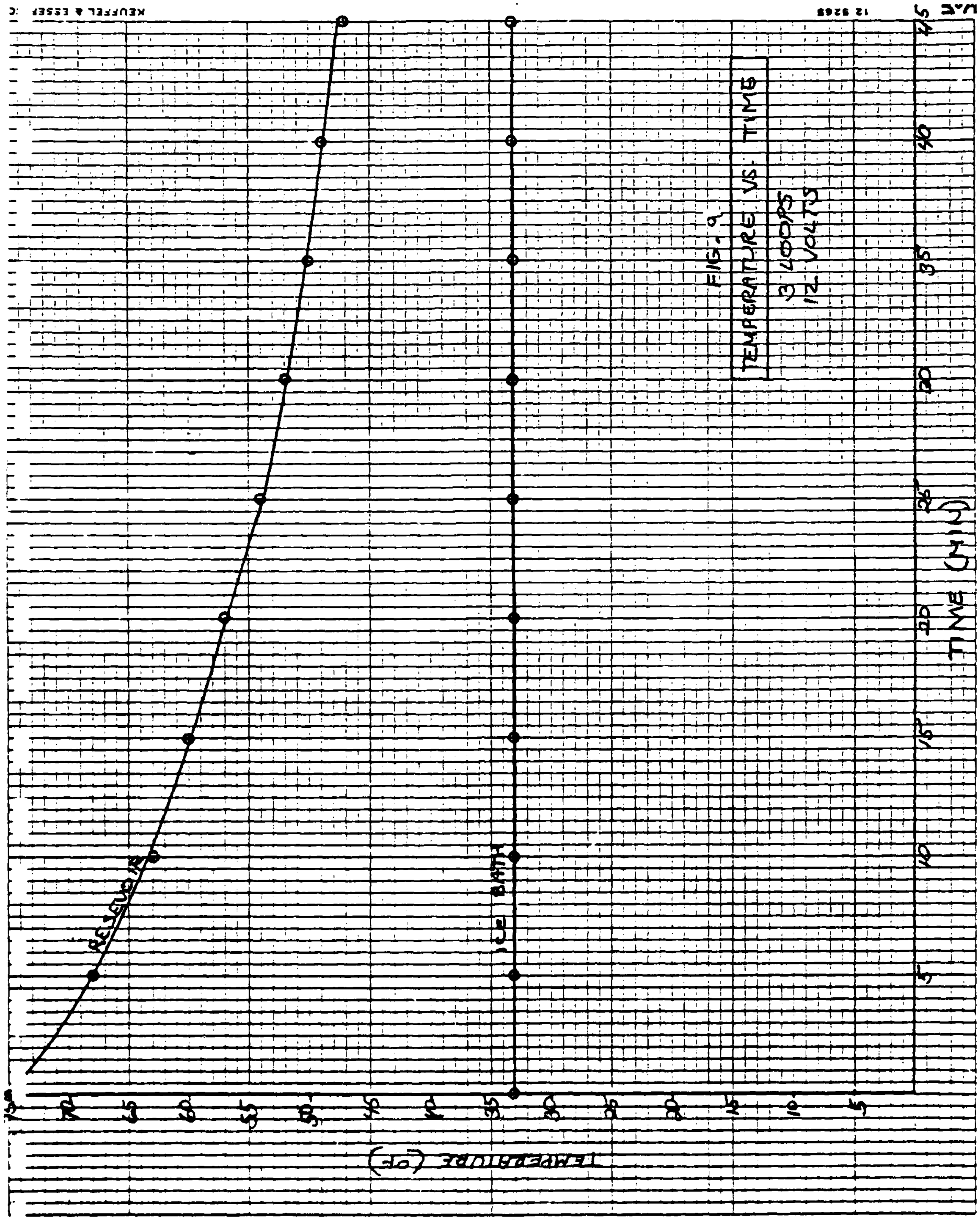


FIG. 9
TEMPERATURE VS. TIME
3 LOOPS
12 VOLTS
TIME (MIN)
TEMPERATURE (°F)
RESEVOIR
ICE BATH

FIGURE 9

4.2.4 Air Cooling

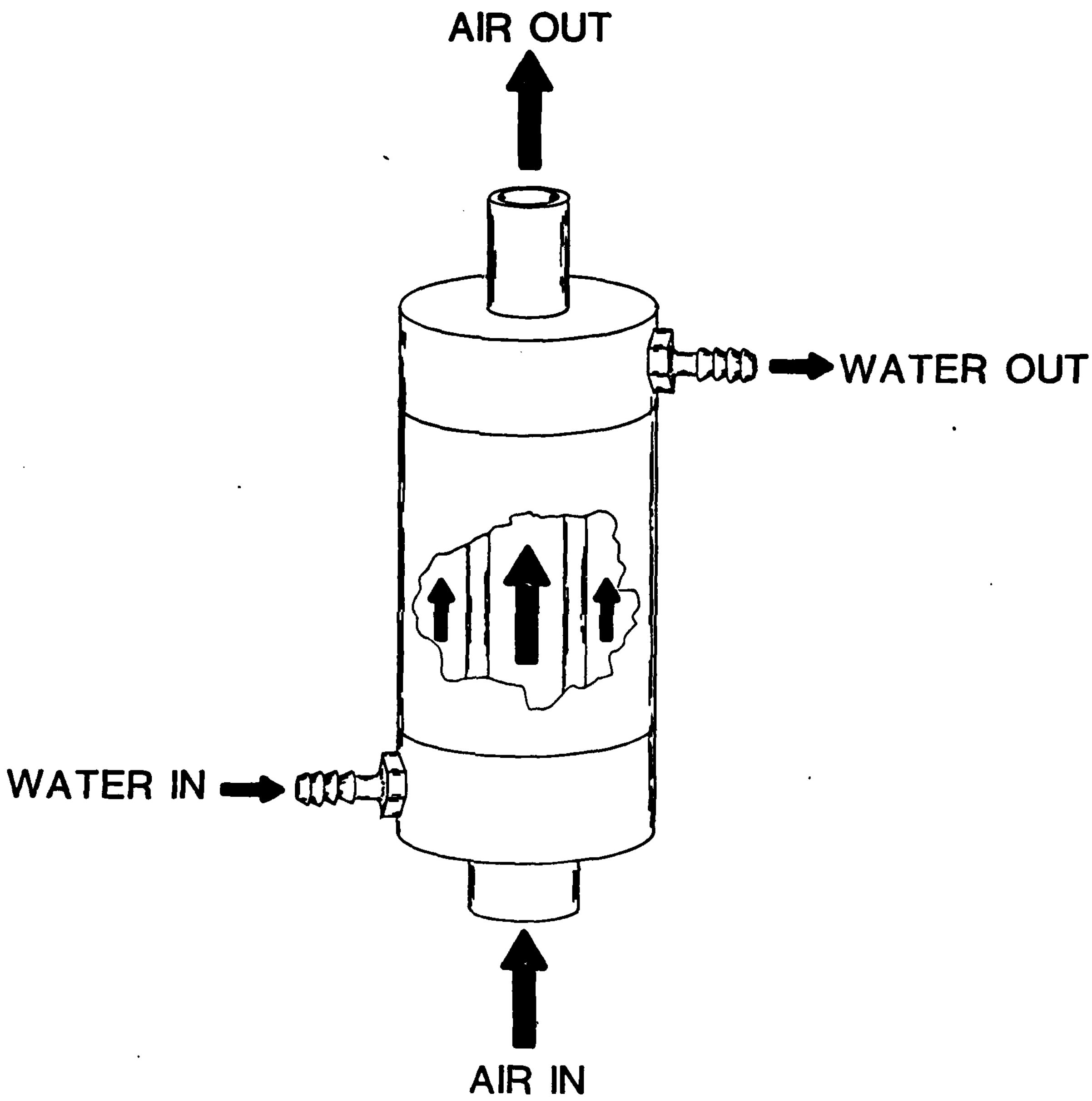
As a result of the development of the one-hour prototype modified DPE (see section 4.8), it was known that air cooling would be necessary in order to provide breathable air for the mission duration. The air heat problem is due mainly to the exothermic reaction that occurs when CO_2 is absorbed in the rebreather. When this condition is coupled with a 100°F ambient, the resulting heat stress is intolerable, even with body cooling. While breathing air temperatures were never observed to exceed NIOSH requirements, suit subjects were not able to continue after 15-20 minutes without active air cooling.

While the breathing air cooling in the one-hour suit was accomplished by a coated fabric sheath over the inlet hose, a more reliable hardware heat exchanger, integral with the backpack, was desired for the final 2½ hr. design. In the interest of program schedule, a parallel path program was followed. Two designs were developed, fabricated and tested simultaneously, and a final selection made on the basis of performance, weight, and impact on breathing resistance.

The first design was a concentric tube heat exchanger. The breathing air flows through the inner tube, while cooling water flows between the tubes, removing heat from the air. Based on initial calculations (section 4.2.4.1), a six inch concentric tube heat exchanger was fabricated.

The second design was a stack of 15 rectangular aluminum plates, machined with cavities, slots, and holes such that when assembled with a sealant adhesive, it formed alternating flow paths for the breathing air and cold water. The air enters at the bottom, divides into two flows traveling from left to right across the exchanger, separated by a channel containing the cold circulating water. The air returns, recombines, and exits, again always surrounded by water channels. The hot air and cold water are separated only by 1/32" wall of aluminum. The thin rectangular cross sections of the flow paths permitted a much greater surface area to volume ratio than the concentric tube design, enabling 4½ times the heat transfer area for only slightly greater overall dimensions. It was sized to fit in the horizontal indentation in the top of the 2½ hr. rebreather.

Prototypes of each design were fabricated and are pictured and illustrated in Figures 10 and 11.



AIR HEAT EXCHANGER

FIGURE 10a

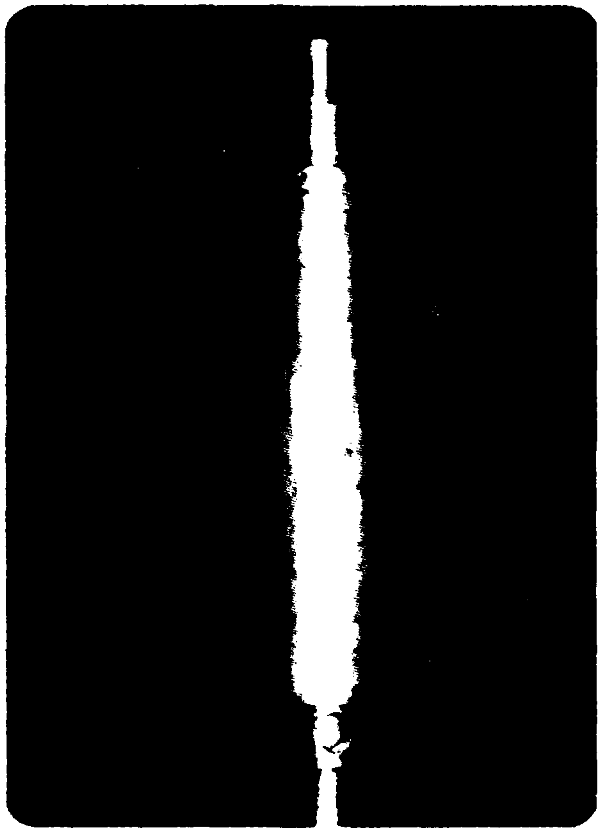


FIGURE 10b

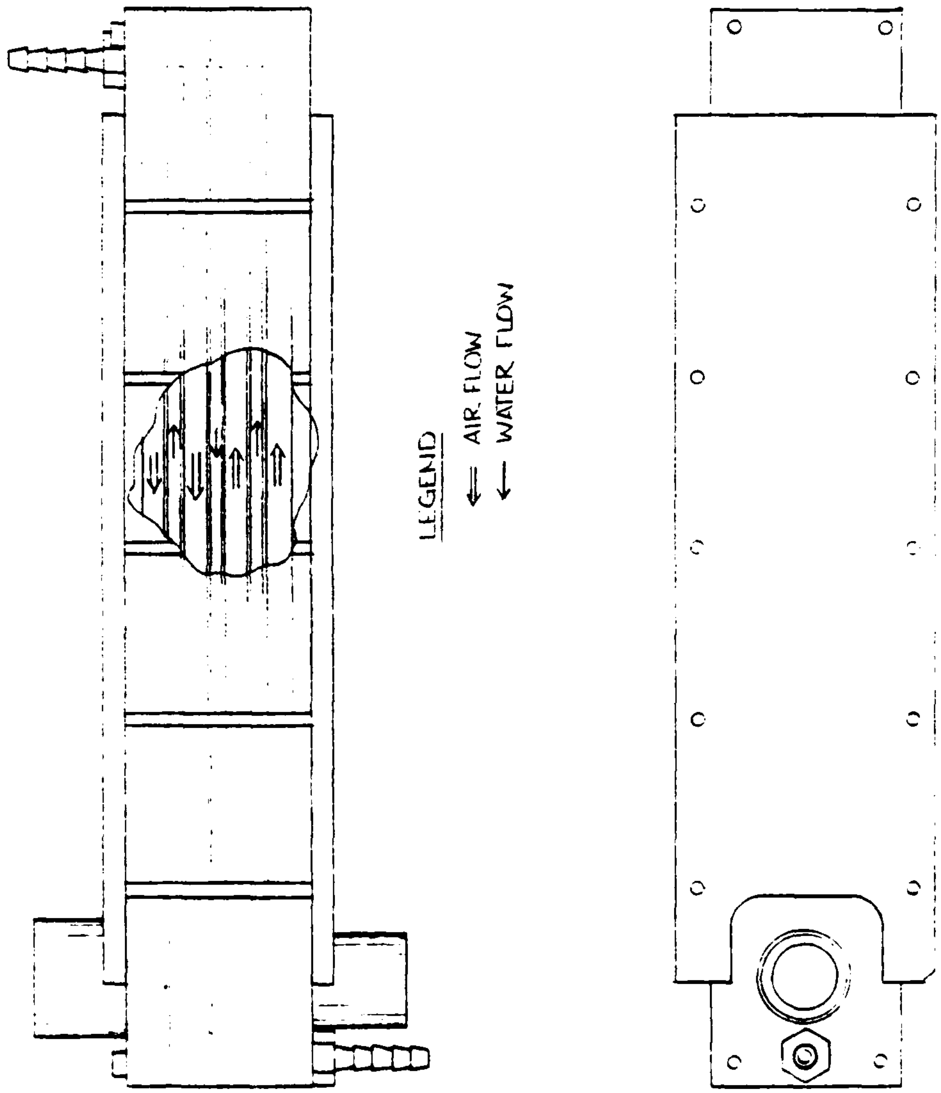


FIGURE 11a

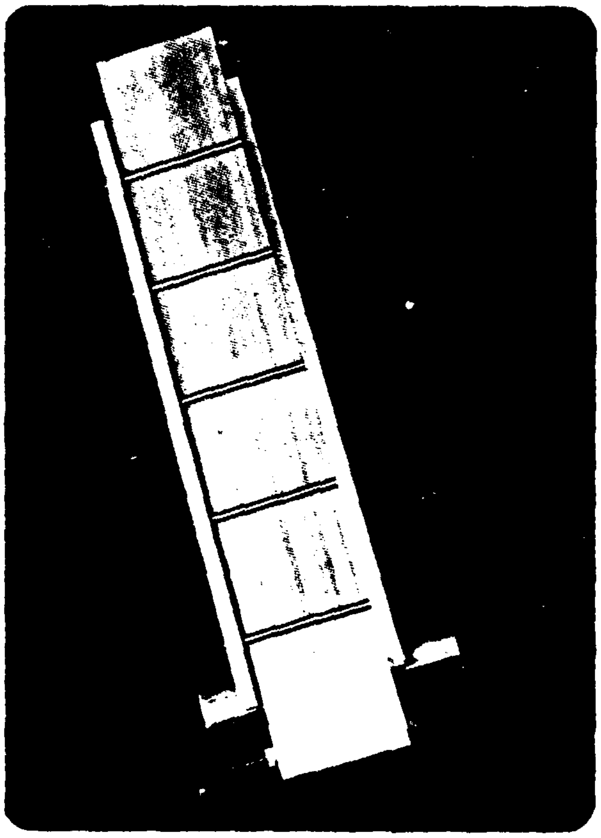
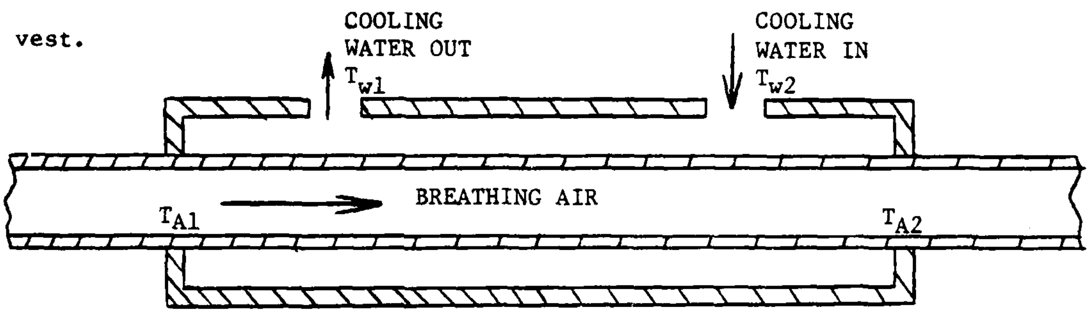


FIGURE 11b

4.2.4.1 Air Heat Transfer Calculations

Breathing Air Cooling

In order to cool the breathing air in the 2½ hour walkaround suit, the air from the rebreather is passed through a heat exchanger as shown below. The cooling medium in the heat exchanger is water that is bled off the cool vest.



Breathing Air Heat Exchanger

Test data from the 1-hour suit treadmill testing shows that the air temperature from the rebreather reaches a steady state temperature of 110°F after 20 minutes. The cooling water reaches a steady state temperature of 65°F after 5 minutes. Therefore, the cooling of the breathing air through the heat exchanger can be considered a steady state problem.

The mass flow rate of the breathing air is estimated to be 2.5 ft^3/min. (ref. Bio-Astronautics Data Book - breathing rate during moderate exercise). At 15 psia and 110°F the mass flow rate of the air is:

$$m_a = (.070\ \#/ft^3)\ (2.5\ ft^3.min)\ (60\ min/hr) = 10.5\ \#/hr$$

The specific heat of the air and water is:

$$C_{pa} = .24\ \text{BTU/\# - °F} \qquad C_{pw} = 1.0\ \text{BTU/\# - °F}$$

It is desired to reduce the temperature of the breathing air to a maximum of 85°F. The heat flow from the air to the water required for this is:

$$q = m_a C_{pa} \Delta T \quad q = (10.5\ \text{\#/hr})\ (.24\ \text{BTU/\# - °F})\ (110°\text{F} - 85°\text{F}) \quad q = 63\ \text{BTU/hr}$$

The increase in temperature of the cooling water in the heat exchanger is:

$$\Delta T = \frac{q}{m_w C_{pw}}$$

$$\Delta T = \frac{63\ \text{BTU/hr}}{(355\ \text{\#/hr})\ (1.0\ \text{BTU/\# - °F})} = .177°\text{F}$$

Due to the much larger mass flow rate and heat capacity of the water, the increase in water temperature through the heat exchangers is negligible.

The log-mean temperature difference across the heat exchanger is given by:

$$\Delta T_m = \frac{(T_{a1} - T_{w1}) - (T_{a2} - T_{w2})}{\ln((T_{a1} - T_{w1})/(T_{a2} - T_{w2}))}$$

$$\Delta T_m = \frac{(110 - 65) - (85 - 65)}{\ln((110 - 65)/(85 - 65))} = 30.8°\text{F}$$

The area required for the heat exchangers is found from:

$$q = UA\Delta T_m \quad \text{or} \quad A = \frac{q}{U\Delta T_m}$$

Where U is the overall heat-transfer coefficient for the heat exchanger, which is a function of the convective heat transfer coefficients of the breathing air and cooling water, the coefficient of thermal conductivity of the heat exchanger material, and the physical dimensions of the heat exchanger. Typical values for thin-walled aluminum tubing and PVC tubing are:

U_{al} = 32 BTU/hr - ft^2 - °F U_{pvc} = 4.5 BTU/hr - ft^2 - °F (Ref: Heat Transfer, J.P. Holman)

The area required for the heat exchanger is then:

$$A_{al} = \frac{63 \text{ BTU/hr}}{(32 \text{ BTU/hr - ft}^2 - °\text{F})\ (30.8°\text{F})} = .064 \text{ ft}^2$$

$$A_{pvc} = \frac{63}{(4.5)\ (30.8)} = .455 \text{ ft}^2$$

For .88 ID tubing, a 3.5 inch long aluminum or a 25 inch long PVC heat exchanger will give adequate cooling to the breathing air.

4.2.4.2 Air Heat Exchanger Bench Testing

Bench testing of the one-hour suit's air hose sheath exchanger and the 6" concentric tube air heat exchanger was conducted to establish a comparison between a design known to provide adequate cooling, and a new design. The test set-up was the same as the calorimeter arrangement used for evaluating water heat exchangers, expanded to include an air heat exchanger, and a heated air supply. (Figure 12) The air hose sheath heat exchanger produced an air temperature drop of 40°F to 49°F. The 6" concentric tube produced an air temperature drop averaging 11°F. The difference in ΔT performance of the sheaths versus tube exchangers was attributed to the vastly different heat transfer areas. Therefore the rectangular version was designed with a 450% increase in contact area over the 6" tube design.

In order to make the most accurate and realistic comparison of the two hardware heat exchanger designs, it was decided that manned testing would be required.

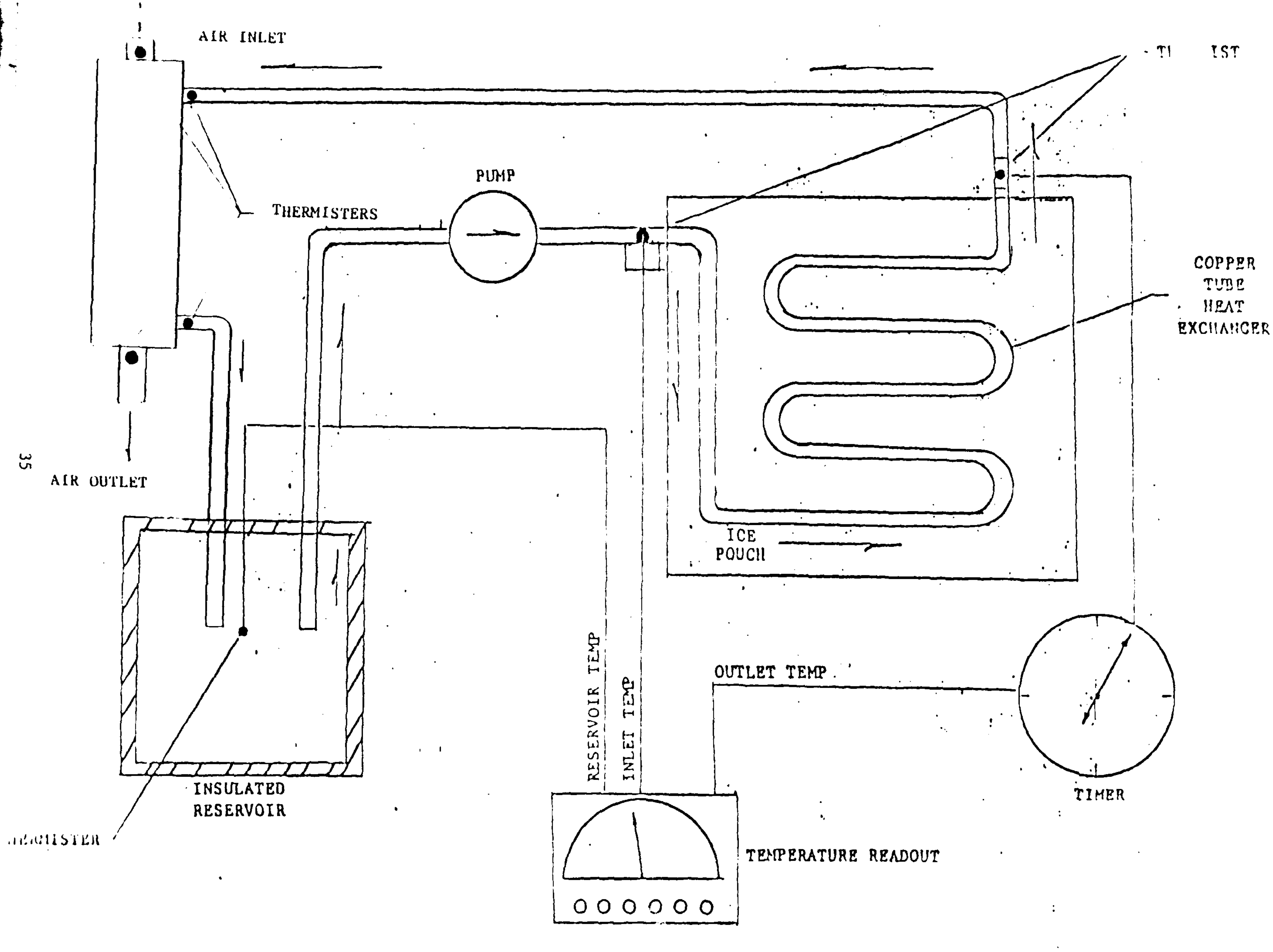
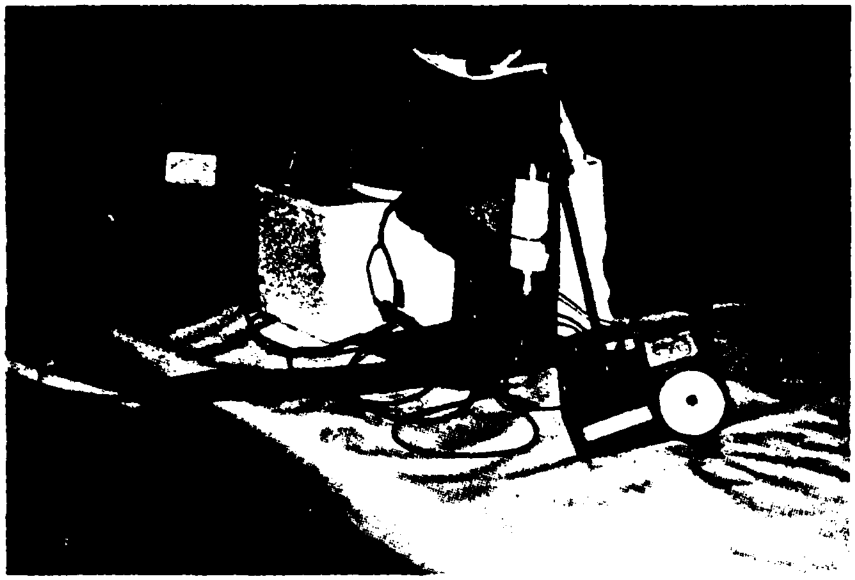


Figure 12a
Calorimeter Schematic



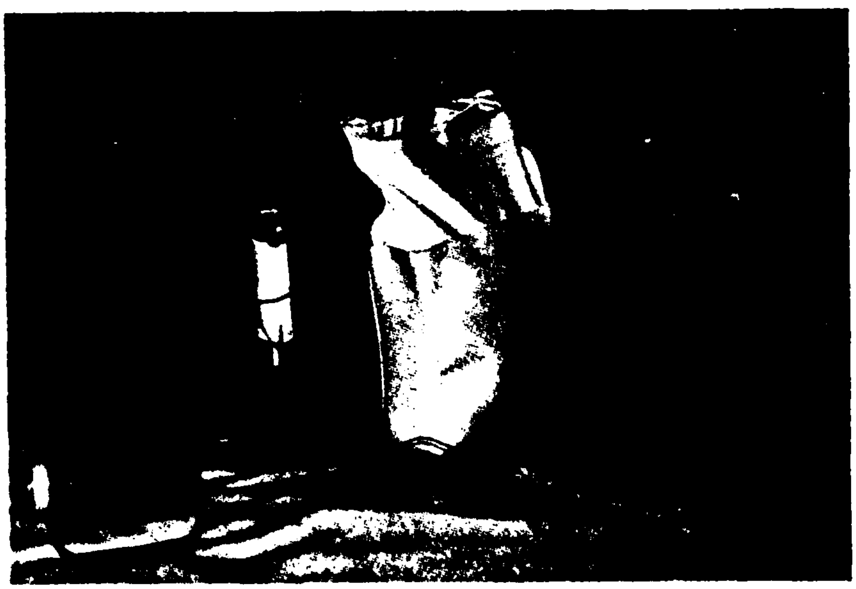


FIGURE 12b

4.2.4.3 Air Heat Exchanger Manned Testing

At the point in the program when this testing was needed, the U.S. Divers 2½ hour prototype self-contained breathing system was not yet available. As a result, a one-hour duration self-contained commercially available system was utilized in the interim. A Biopak 60P positive pressure rebreather was modified to include the pump, battery, and air heat exchanger being evaluated. The outergarment development at this point in the program already had a prototype available for use in this testing.

Manned testing was conducted in 100°F ambient temperature and simulated sun load by placing a treadmill in a temperature controlled room with a bank of four heat lamps on each side. (see Figure 13)

Manned test results indicated that the air heat exchanger did not extract sufficient heat from the breathing air. (see Attachment 1) After 30 minutes, the breathing air had risen to 92°F. The subject felt uncomfortably warm due to the hot air, and the test was terminated. Examination of the system after the test revealed that a leak had developed at the air heat exchanger inlet. As water had leaked out, air was introduced into the system. Since the air in the system could have reduced heat exchange from the breathing air, another test was required for a good evaluation.

To make the system less vulnerable to leaks, a small sump was added to the pump inlet to act as a collection point for any air that is introduced into the system, or is freed from the body panels of the cooling garment after initial charging.

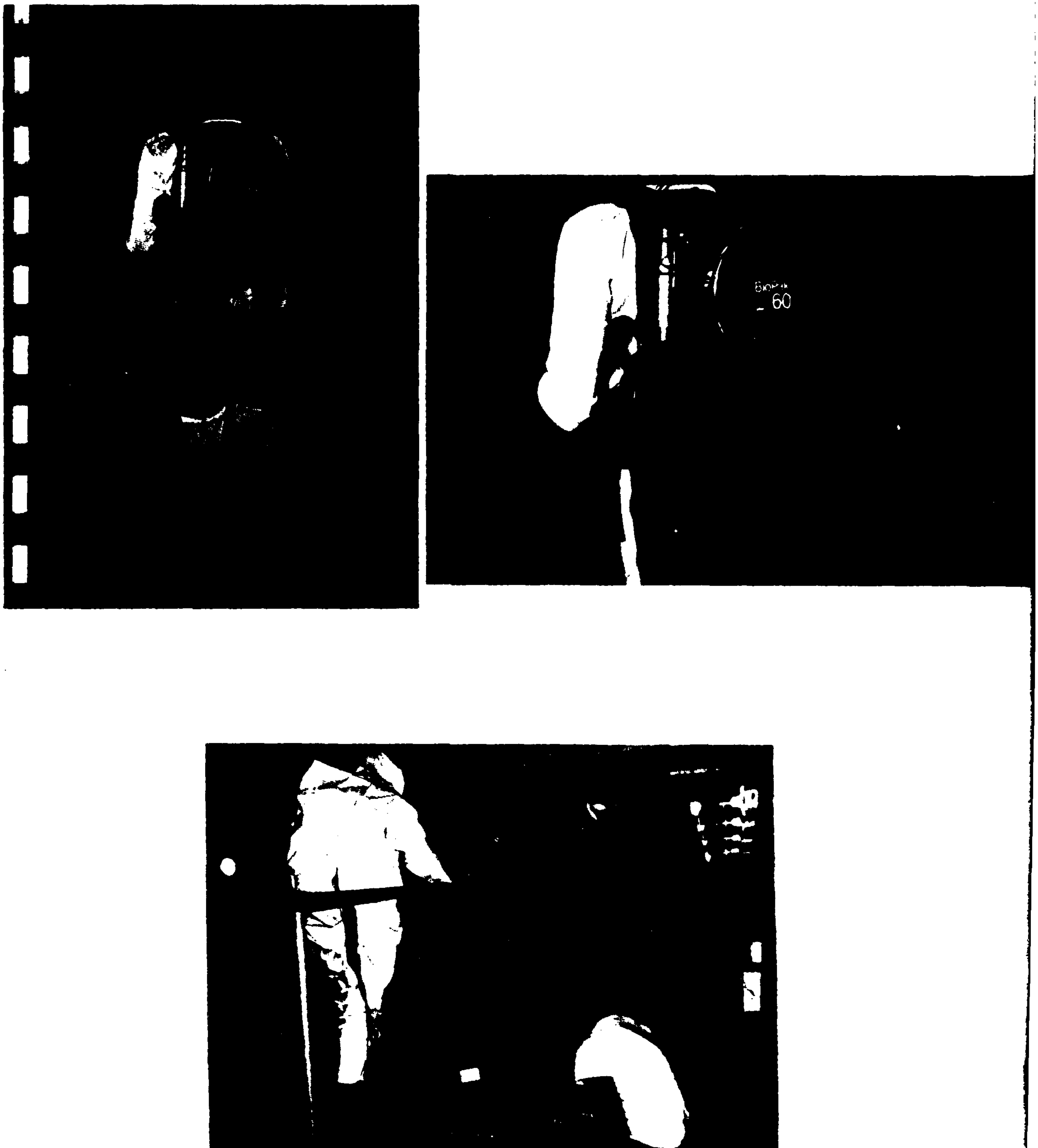


FIGURE 13

Another manned test was run on the treadmill at 100°F, simulated sun load. The sump successfully kept air out of the circulation system, but there was no significant improvement in the air heat exchanger performance. While the subject worked in the suit for 154 minutes, breathing air steadied out at 92°F. The subject reported the air to be unacceptably hot. (see Attachment 1)

The rectangular plate heat exchanger was mounted in place of the concentric tube on the Biopak 60P. Manned treadmill testing at 100°F, simulated sun load, was conducted to evaluate this design.

The test results indicate that the heat exchanger performed very well. (Attachment 1) The test was terminated at 72 minutes due to accidental damage to the sump. The air heat exchanger, however, was delivering from 68°F to 73°F breathing air. The subject reported no discomfort due to heat, either body or breathing air.

While the two previously discussed designs were being evaluated, U.S. Divers incorportated into their breathing system an air heat exchanger of the same configuration as the concentric tube exchanger, lengthened to 9 inches. Later manned testing would indicate that at the high temperature design point (100°F ambient), it would provide marginally acceptable air cooling, i.e., while subjects could tolerate the breating air and could work when subjected to it, they found it uncomfortable.

The rectangular heat exchanger was shown to U.S. Divers' engineering personnel, who indicated that it would almost surely introduce unacceptably high breathing resistance into the system. No breathing resistance tests were conducted on it, however. Also, its weight was prohibitively high. While improved fabrication techniques could lighten it, it would always be heavier than a comparably sized concentric tube design. Summarizing the two designs:

	Rectangular Plate	9" Concentric Tube
ADVANTAGES:	Removes breathing air heat excellently. Fits inside backpack.	Lightweight, Little added breathing resistance. Provides adequate cooling.
DISADVANTAGES:	Too heavy. Breathing resistance too high. Difficult and expensive to fabricate.	Will not fit inside backpack, must be side mounted. While cooling is adequate, it is marginal.

Taking all factors into consideration, including program schedule, the 9" concetric tube air heat exchanger was selected as the final design.

4.2.5 Cooling Evaluation

As a result of the manned testing conducted specifically to evaluate air heat exchanger designs, an initial evaluation of the entire system was made, both qualitative and quantitative.

In each test, the subject reported that the body cooling garment worked well. It was comfortable, did not interfere with any body motions, and provided the essential body cooling that enabled him to function in the suit in a 100°F ambient environment. At this temperature, ice had to be added every 20-25 minutes. The subject's response to the air temperature varied with the air heat exchanger used (see 4.2.4.3). Even with satisfactory air cooling, two hours of working at 100°F inside the suit was physically demanding. The suit subjects' qualitative assessment was that with the body and air cooling, he was warm, but not hot or uncomfortable due to heat. He felt fatigued after each test and required rest. The subject indicated that he felt capable of performing work activities for the two hours at that temperature, given the body and air cooling.

This report was considered a positive qualitative assessment of the cooling system performance.

4.2.5.1 Heat Removal Rate

The heat removal rate for the second manned test (6" concentric tube air heat exchanger with sump) was calculated from the temperature data. The flow for this system had previously been determined for a range of pump voltages. The voltage/flow curve in plotted in Figure 14.

The calculation is made by using the temperature difference across the cooling garment.

$$q = C_p \rho Q \Delta T$$

where: q = Heat flow, Btu/Hr.

C_p = Specific heat of fluid, Btu/lb. °F

ρ = Fluid density, lbs./ft^3

q = Fluid flow, ft^3/hr

ΔT = Temperature difference, °F

C_p (water) = 1.00 Btu/lbs °F

ρ (water) = 62.4 lbs/ft^3

Q = .55 gal/min = 4.42 ft^3/hr. (at 12 volts)

therefore:

q = (1.0) (62.4) (4.42) ΔT

Minimum Heat Removal Rate:

ΔT = .5 °F

q = 138 Btu/Hr.

Maximum Heat Removal Rate:

ΔT = 8.5 °F

q = 2344 Btu/Hr.

Average Heat Removal Rate:

ΔT ave = 2.32 °F

q ave = 640 Btu/Hr.

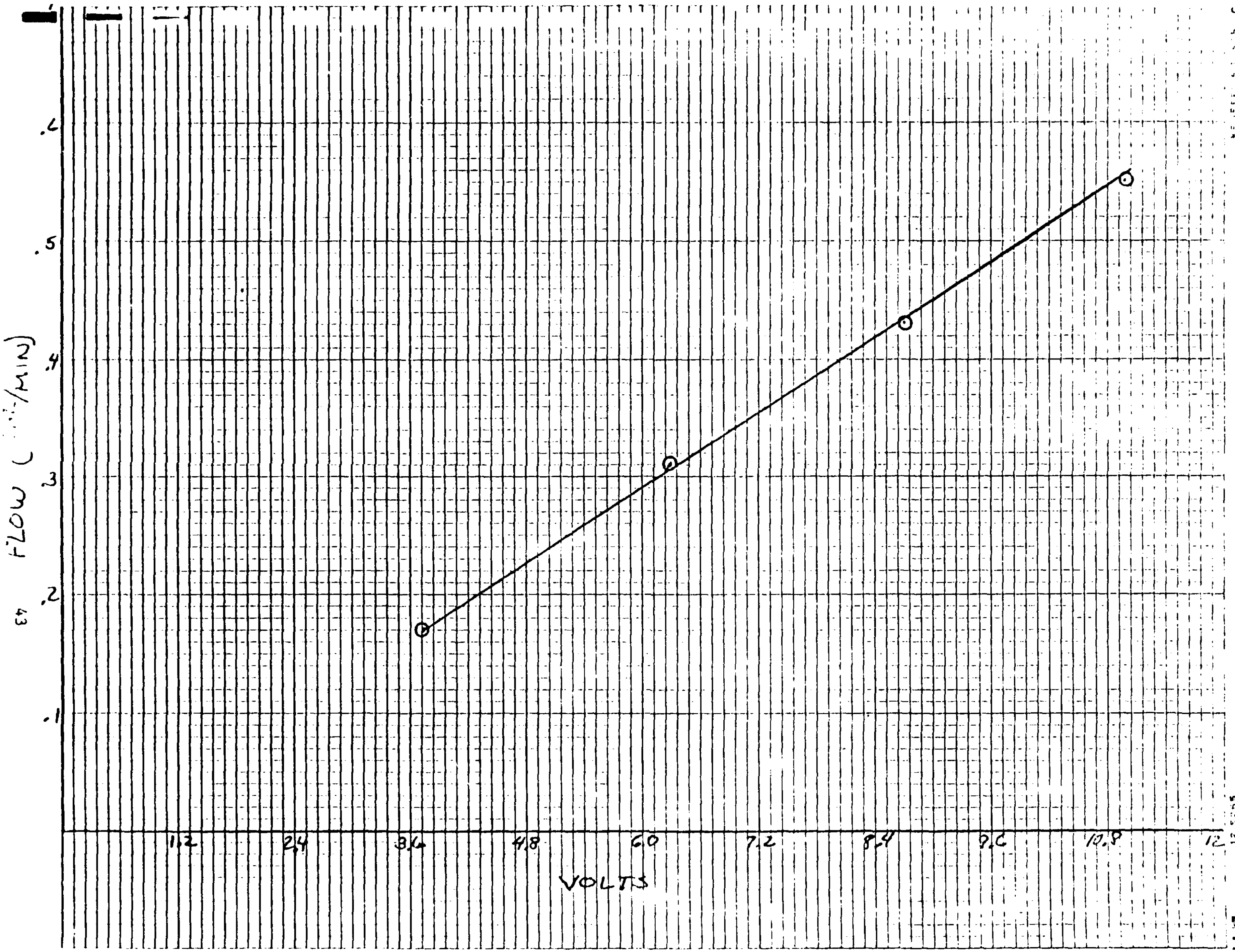


FIG. 14

4.2.6 Cooling System Specifications

The cooling system final design is illustrated in Figure 15. The specifications of this system are given below:

Weight	Lbs
Battery	3.27
Pump	1.27
Cooling garment	2.48
Heat Exchanger/Ice pouch/Sump Ass'y	1.98
Total (empty)	11.48
Water	10.42
Ice	4.20
Total (full)	26.10

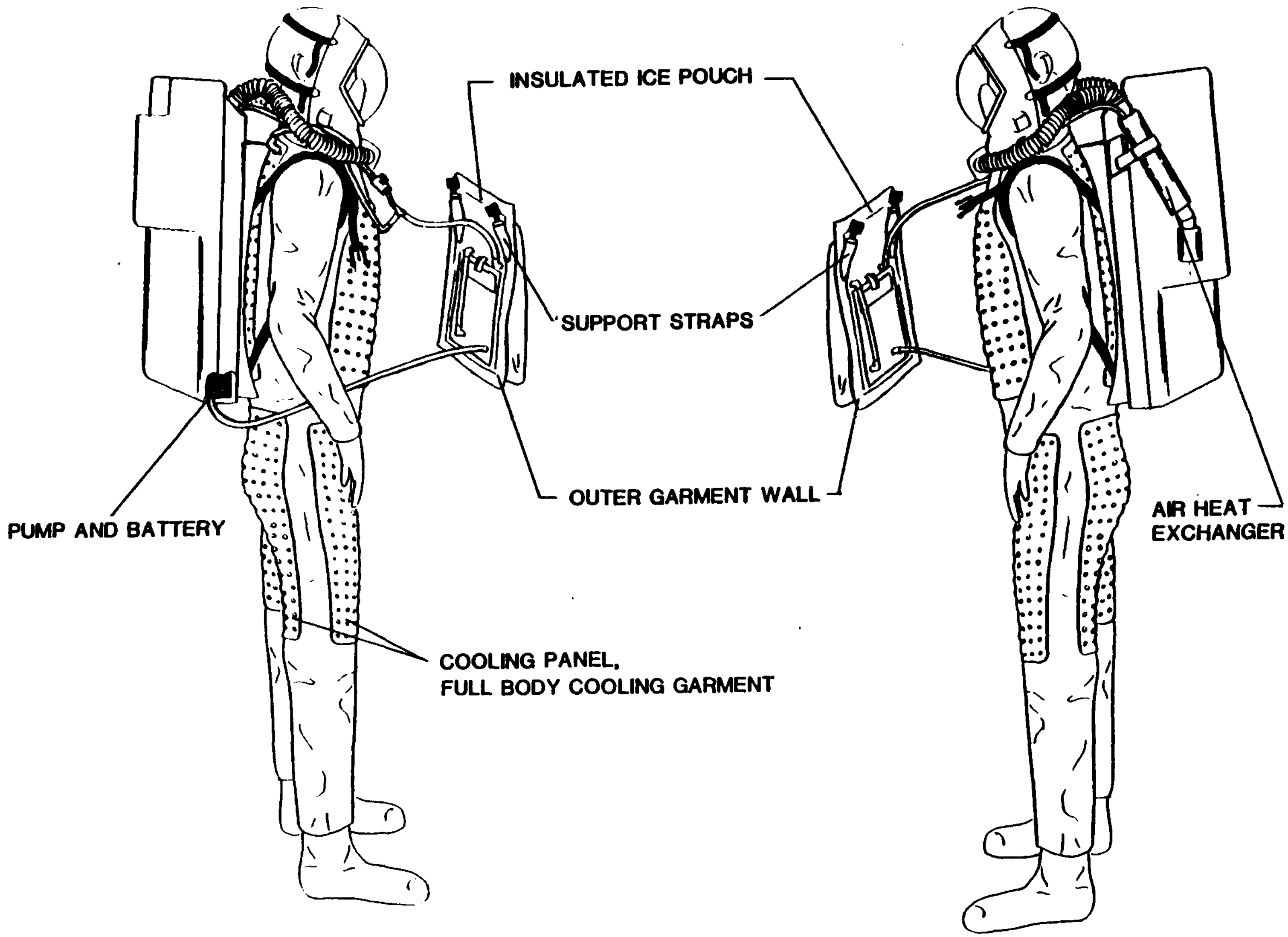
Battery: 12 VDC, 4 AMP-HR.

Pump: 12 VDC, .55 Gal/min, Positive displacement gear pump.

4.2.7 Accomplishments

This effort has developed an initial breadboard cooling system into a prototype working system that meets all of its design requirements. A full body cooling garment was developed. The optimum pump and battery for the system were selected. A hardware water heat exchanger was developed and tested. An air heat exchanger was developed to provide cooler breathing air. Using a modified commercial one hour rebreather, the system was tested and evaluated.

The sump unit that was added during manned testing was built into the final design as a small pouch on the inside wall of the suit, opposite the heat exchanger ice pouch. The sump then became part of that assembly.



COOLING SYSTEM

FIGURE 15

Both qualitative and quantitative analysis indicate that the system works effectively and can be successfully integrated into the final ensemble design.

4.3 PRESSURIZATION SYSTEM

A suit pressurization system was developed to provide continuous positive pressure within the outergarment for 2½ hours. The requirement for suit pressurization make-up may be caused by one of two things: 1) a leak which might develop in the suit due to a tear or puncture during use, and 2) a need to replenish air which is dumped through relief valves due to suit over pressure during constricting body motions.

The pressurization system concept developed during the design and feasibility study of this effort was a combination of 1) a compressed air supply inside the backpack, regulated to vent into the suit whenever the suit pressure dropped below a certain level, and 2) an outergarment design that would minimize the use of the suit make-up system due to air lost through relief valves during constricting body motions.

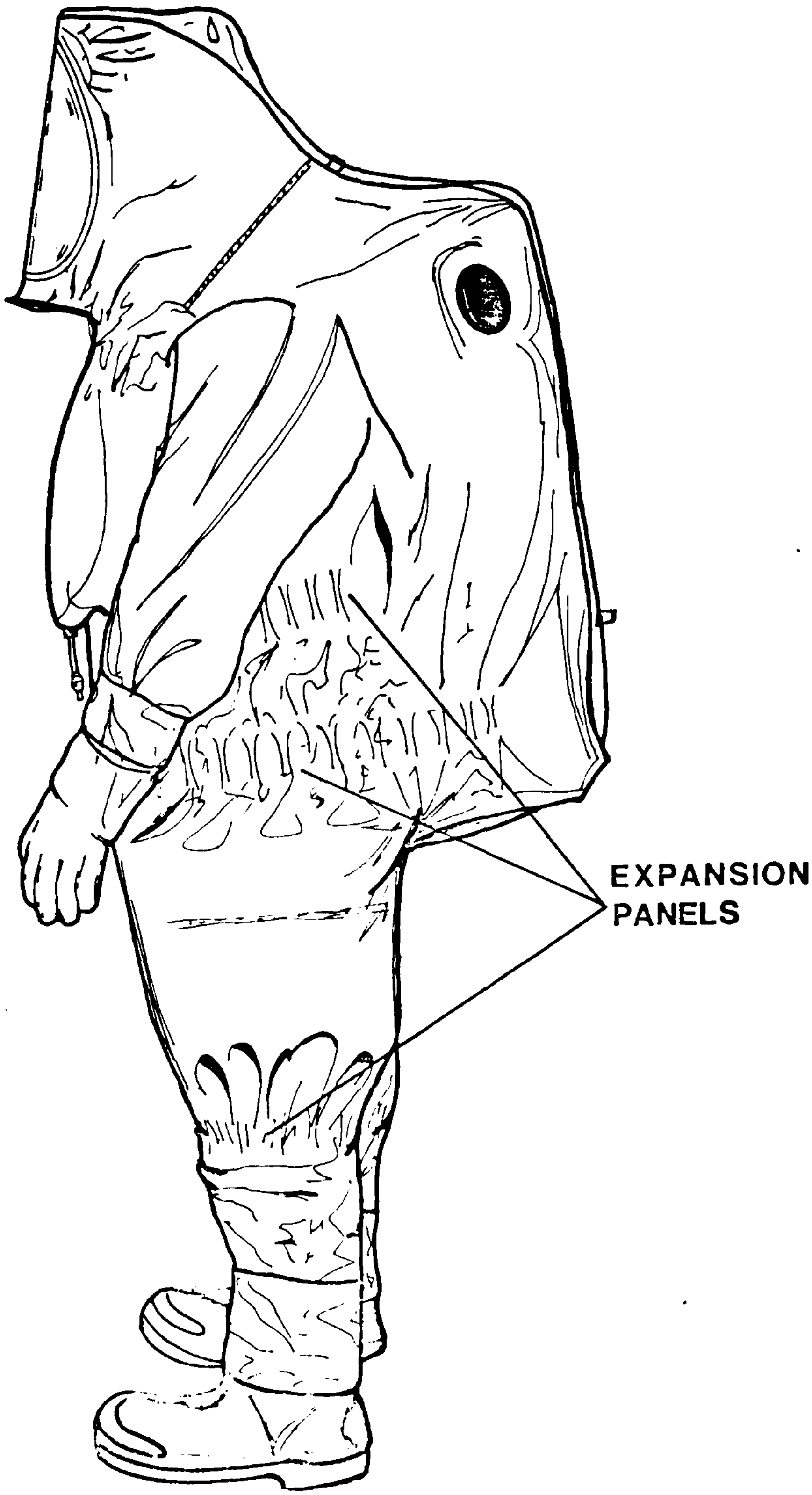
The suit make-up system is described in the U.S. Divers final report, Final Report Including Test Report and Outling for NIOSH Certification.

Two approaches to outergarment designs for minimizing suit make-up were developed during the design and feasibility study. Both were volume accumulators. A specific suit volume is allowed to expand to accommodate air forced from joints during movement. The accumulator is tensioned by an elastic restraint which collapses the accumulator when the constricting motion is reversed, thus returning the air to the main body of the suit. The accumulator is designed to expand completely under internal suit pressures that are less than the cracking pressure of the relief valves. Therefore, the relief valves open only after the accumulator is fully expanded. When the accumulator is sized correctly, this approach will maintain positve suit pressure even through the worst case body motion, i.e. rising rapidly from a ball squat to a standing position with arms extended . The first accumulator design was an expansion gore, where sections of suit wall were pleated by an elastic material. The second design was a multiple cell bellows which expanded outward perpendicular to the suit wall. Both were evaluated and found to work well.

4.3.1 Volume Accumulator

The approach that was selected for prototype design was the expansion gore accumulator. The bellows design was rejected because it provided a serious snag point which was not within the wearer's view. The outergarment design should be as smooth as possible, avoiding any 90° protruberences, particularly in the rear where the user cannot see to prevent it from being caught or snagged during use.

The expansion gore was relocated from the back to the suit sides. Three elastic panels are on each side of the suit: directly under the arms, in the area corresponding to the man's lower rib cage, and in the side of the thighs. These three areas were selected as areas that generally did not collapse during suit motions, and thus air flow into them would not be restricted. The back location had to be rejected because too many other components were being located there (such as the relief valve assembly, external pressure monitor assembly, and the EPC/zipper closure assembly). Each panel consists of a 2" wide white elastic sewn to a strip of vinyl coated fabric. The coated fabric is heat sealed directly to the inside walls of the suit. The outergarment is illustrated with these expansion panels in Figure 16.



OUTERGARMENT WITH EXPANSION PANELS
FIGURE 16

4.3.2 Exhaust Assembly

The exhaust assembly used in the 2½ hr. ensemble is identical to that developed for the one hour prototype. It consists of 4 Halkey-Roberts bulkhead relief valves (cracking pressure = 2.8 iwg) located under a single splash cover. Special polycarbonate caps were designed and fabricated to be threaded on the back of each valve. The cap prevents accidental opening of the valve by any motions of the man or backpack hitting the valve stem. The assembly is located in the rear of the suit.

The exhaust assembly works together with the volume accumulator. If there is any mask leakage, or after initial suit pressurization, a constricting suit motion can bottom out the accumulator. When this happens, pressure rises unitl it reaches 2.8 iwg when the relief valves open. Four valves were chosen as the minimum number required to achieved an acceptable exhaust flow rate. Trilok spacer material is placed inside the splash cover to prevent the cover from cutting off exhaust flow. The cover is tack heat sealed to retain the Trilok.

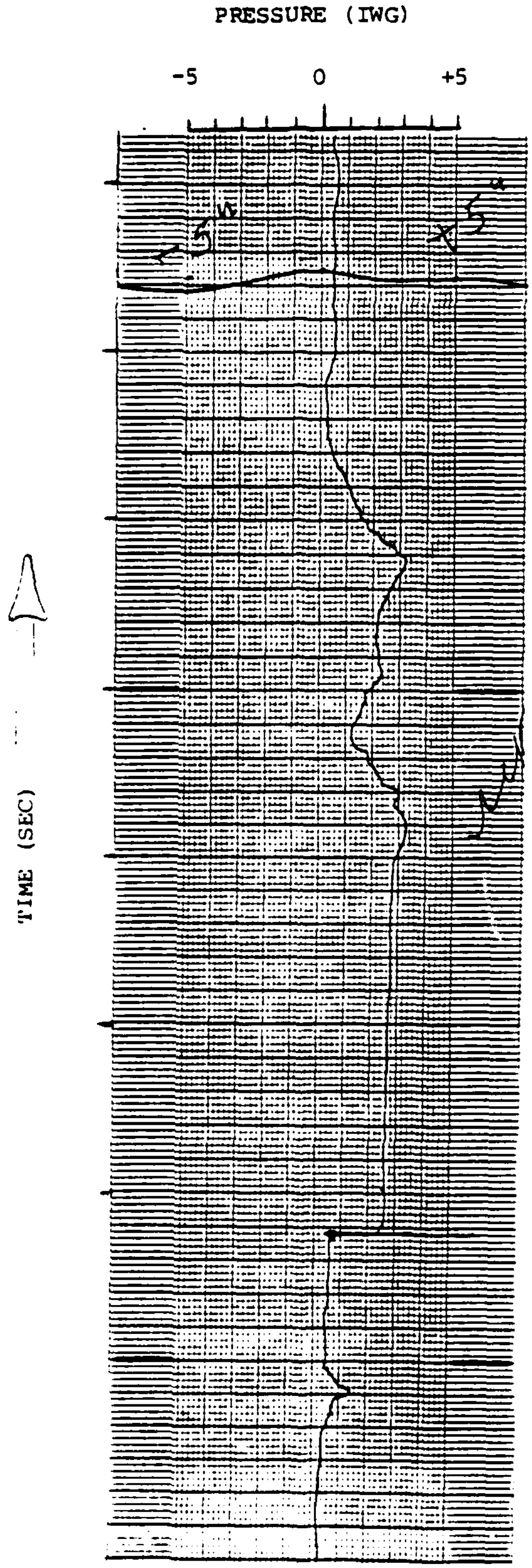
4.3.3 Test Results

Testing was conducted to determine how well the expansion gore design maintained positive suit pressure during extreme body motions. The development of the expansion gore acculuiator took place during the one-hour suit development.

The tests reported here were conducted using the one-hour suit outergarment. The same design was utilized in the 2½ hr. outergarment. Evaluation of pressurization performance in the 2½ hr. system was based on endurance test results. (see section 4.7.3)

The suit with the expansion gore accumulator was donned, and the subject went through a series of ball squats followed by rapidly standing up with arms extended. Internal suit pressure was monitored by sensitive pressure trace equipment. A typical result is shown in Fig. 17. Occasionally, a very small spike of negative pressure was detected, but this was attributed to pressure waves set up in the monitoring hose as it was shaken by the suit motion. This was definitely shown to be the case when an identical effect was made on the pressure trace when the hose was plugged and shaken in a like manner.

Testing, then, indicated that the expansion gore accumulator design would maintain positive suit pressure through any suit motion without requiring suit make-up air. The only need for the suit make-up air, then, is in the event of suit tear or puncture during use.



INTERNAL SUIT PRESSURE TRACE
FIGURE 17

4.3.4 External Pressure Monitor

In order for the suit make-up system in the backpack to function, it must monitor the pressure outside the suit. The internal suit pressure is then "compared" with the ambient to determine if the difference is less than the pre-set minimum (.6 iwg). The ambient air pressure cannot be measured directly, however, since it is contaminated, and cannot be brought inside the suit. An agent resistant diaphram, therefore, is needed at the suit wall, so that the external pressure can be sensed without exposing any backpack components to contamination. The diaphram and housing are shown in Fig. 18. The housing was 2 vacuum formed rigid PVC parts heat sealed together. It includes a recess in one part where the lip of a butyl diaphram is located. When the two halves are heat sealed together with the diaphram in place, the lip is sealed in compression. Holes in the outer half admit ambient air, and a standard heat sealed vinyl elbow connects to a tube leading to the backpack.

The diaphram was specified for this application by U.S. Divers Co. The diaphram design is a standard regulator diaphram, however a special run out of butyl rubber rather than the standard silicone had to be made since silicone is not agent resistant.

The external pressure monitor appeared to function well when tested at U.S. Diver's Co. There were difficulties with it, however, when tested at ILC Dover. During the first few endurance tests, the suit make-up system maintained too high an internal suit pressure. (1.5 - 2.0 iwg compared with a design value of .6 iwg)

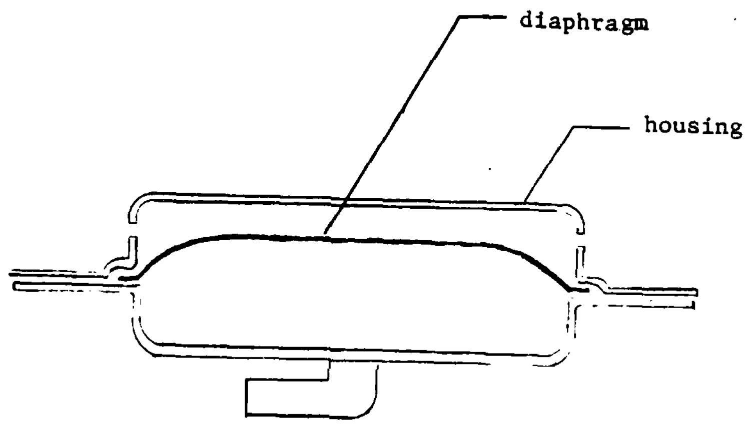


FIGURE 18
EXTERNAL PRESSURE MONITOR

At first thought to be caused by the suit make-up regulator being out of adjustment, U.S. Diver's determined that the problem was the relative insensitivity of the external pressure monitor diaphram. They recommended that either a thinner diaphram or a larger diameter diaphram be used to increase the sensitivity.

Schedule and funding did not permit these alternatives to be persued. While the diaphram problem was being investigated, endurance testing continued without the suit make-up system. The outergarment pressurization design consistently maintained positive pressure in the suit for the full duration with no suit make-up system.

4.3.5 Accomplishments

An outergarment pressurization system consisting of an integral volume accumulator and exhaust assembly was developed that maintains positive suit pressure for 2½ hours. The suit make-up system is needed only in the event of suit tear or puncture during use. Testing has verified the reliability of this design.

An external pressure monitor for use with suit make-up system was not entirely successful due to the relative insensitivity of the diaphram. The system meets all pressurization design requirements, however, without suit make-up.

4.4 OUTERGARMENT

The 2½ hour ensemble outergarment is a modified DPE. The configuration resembles the DPE Outergarment as much as possible. It is a 20 mil CPE heat sealed at all seams. The sleeve/glove assembly is identical to the DPE Outergarment. The legs were patterned to face the feet forward. The back was patterned to fit the U.S. Divers backpack as closely as possible. The helmet had to be patterned to allow easement for the facemask tee assembly. The ice pouch/sump assembly is located in the center chest area. The EPC/closure assembly is located on the left back. The exhaust assembly is on the right back. The air inlet valve (a standard bulkhead tire fitting) is on the lower right front torso. Two inch diameter reinforcing patches are located in numerous places in the suit, particularly backpack vertices and inside corners.

The visor is a 1/32" sheet of antifog treated polycarbonate. A special adhesive/ heat seal technique had to be developed to attach it to the CPE. Polycarbonate was required since vinyl is too heavily plasticized to retain the antifog treatment.

Straps of a heavy duty vinyl coated fabric were attached to the inside wall at the ice pouch/sump assembly. These attach to plastic clip fasteners. The mates to these fasteners are on webbing straps sewn to the backpack harness. When connected, this arrangement enables the weight of the ice pouch and sump to be transferred directly to the man's shoulders preventing the suit from sagging and pulling the helmet down.

The outergarment has arm and leg flanges for use with overgloves and boots, the same as with the DPE Outergarment.

The external pressure monitor is located on the left back.

Initial fit checks of the outergarment indicated that the O_2 pressure gauge mounted on the facemask tee would cause visor interference. The gauge was relocated to a pocket on the inside helmet and a small plastic bracket was fabricated that supported the gauge, and which slides into the pocket. This arrangement held the gauge securely while in use, and was easy to install and remove during donning and doffing. It successfully eliminated the visor interference problem, and suit subjects report the gauge is still easily seen in the new location.

4.4.1 Butyl Outergarment

The requirements for the 2½ hour system include a temperature range down to 0°F. It is known that CPE becomes noticeably stiffer at lower temperatures (about 40°F), and would be unusable at 0°F. Butyl rubber, however, maintains its flexibility at 0°F and is also agent resistant. It is not considered as good an overall suit material as CPE because of its poor abrasion resistance, and because the seams are not nearly as reliable as heat sealed CPE seams. It was, however, a solution to the low temperature requirement. Therefore, a butyl coated nylon version of the CPE 2½ hour modified DPE was developed.

Except for material changes and fabrication techniques, the design and configuration of the butyl and CPE Outergarments are identical. The butyl outergarment patterning is different insofar as all seams became lap rather than pinch construction. This requirement resulted in a configurational difference only in the boot of the garment. The visor, inlet valve, relief valves, and copper heat exchanger are the same as those used in the CPE Outergarment. The O_2 gauge support pocket remained the same, except that it was made of butyl coated nylon. The exhaust valve cover was patterned so that it could not interfere with exhaust flow, eliminating the need for the Trilok spacer material. It also was made of butyl coated nylon. The major differences, other than suit material, were in the ice pouch/sump assembly, the closure assembly, and the gloves and boots.

4.4.1.1 Ice Pouch/Sump Assembly for Butyl Outergarment

The ice pouch/sump assembly was not made of butyl coated nylon bacause its poor abrasion and wear characteristics would have resulted in early failure of this component. Instead, a urethane coated fabric (olive drab) was selected. It was chosen because:

1) It is a durable material.
2) It heat seals readily, forming strong, reliable seams.
3) While urethane does not offer good agent resistance, it is not needed in this componnet since the ice pouch is exposed inside and out during use anyway. The suit wall continues to be the chemical barrier.
4) It could be fastened to the suit using reliable pressure sealing compression fittings.

The ice pouch utilizes an extruded urethane closure corresponding to the extruded CPE closure on the CPE Outergarment's pouch. This closure heat seals directly to the inside walls of the pouch. Since the pouch is only for use in low temperature, the insulation used in the CPE pouch was not necessary. The sump on the opposite side of the suit wall has a similar construction, i.e. urethane coated fabric with an extruded urethane closure. They are fastened to the suit wall with a pair of brass compression fittings with female NPT through their centers. These fittings, then, not only support the ice pouch and sump, but provide the water inlets and outlets. Support straps of the same material as that used on the CPE suit have holes in them at the bottom and fit into the bulkhead fittings directly behind the suit wall, thus supporting the entire assembly by the brass fittings. Threaded plastic hose fittings lead to short lengths of vinyl tube that are clamped on the ends of the copper heat exchanger, connecting the water flow paths from brass fitting to the heat exchanger and back.

4.4.1.2 Butyl Closure Assembly

In order to provide a pressure sealing entry into the Butyl Outergarment, an extruded butyl closure was developed. It is of the same configuration as the CPE closure assembly. An extruded two track closure of butyl provides the pressure sealing while a mechanical zipper located behind it bears the mechanical load of closing. An extrusion supplier was subcontracted to develop the necessary butyl extrusion. Three attempts were made before the final extrusion was reached.

It was sewn and cemented into a closure assembly with the same mechanical zipper as that used in the CPE closure assembly. It was 36" long. The end stops were made by injecting butyl cement into the ends of the tracks and clamping a permanent matal clip over the ends. The entire assembly was then installed in the rear of the suit using a standard sew, cement, and tape procedure. Schedule and funding did not permit the development of pull tabs for the closure.

4.4.1.3 Butyl Outergarment Gloves and Boots

The vinyl gloves used in the CPE Outergarment could not be attached to the butyl sleeves, so thin butyl undergloves were selected for use with the butyl outergarment. It was decided that a stronger, more reliable glove to sleeve attachment could be made if rigid nylon cuff rings were used. Therefore, the butyl outergarments were fabricated with the cuff rings and butyl undergloves. Endurance testing indicated that the attachment is reliable, and that the cuff rings and butyl gloves work well, causing no interface or usage difficulties.

As previously mentioned, the integral boots of the butyl otuergarment had to be reconfigured due to the difference in seam construction. The new boot has a squared off toe, and angles down from a side view. It is a three dimensional rather than a flat pattern construction. Fit check indicates no fit or comfort problems when worn with an overboot, and endurance testing turned up no wear or comfort problems with this boot design.

4.5 SYSTEM INTEGRATION

A number of outergarment items described in the section 4.4 resulted from the need for smooth interface between the major subsystems. These included helmet patterning, back patterning, ice pouch/sump support straps, and the O_2 gauge support pocket inside the helmet.

In addition to these, vinyl tubing and disconnects were sized to interface the backpack air heat exchanger to the cooling garment, the cooling garment to the ice pouch/heat exchanger, and the sump to backpack return line. Also, the air line and disconnect joining the backpack to the external pressure monitor was added.

4.5.1 System Donning

The system as it is donned is pictured in Figures 19, 20, 21, 22, 23, 24, 25. The procedure is outlined as follows:

1) Donn cooling garment.

2) Donn backpack.

   a) Right shoulder strap must be fed through bypass hoses on cooling garment.

3) Connect water line from air heat exchanger to garment entry port, back of collar.

4) Donn outergarment to waist height.

   a) Insert legs in outergarment, leave arms free.

5) Connect ice pouch support straps.

6) Connect water line from cooling garment to ice pouch.

7) Connect water return line from sump to backpack.

8) Insert O_2 gauge/support bracket into helmet pocket.

9) Connect air line from backpack to external pressure monitor.

10) Fill resevoir with water.

11) Turn on pump.

12) Top off resevoir and close.

   a) Wait till air bubbles stop returning to sump, then top off.

13) Donn facemask.

14) Turn on primary and secondary breathing systems.

15) Complete donning outergarment.

   a) Insert arms in sleeves and head in helmet.

   b) Close rear EPC/closure assembly.

16) Pressurize outergarment.

   a) Use inlet fitting.

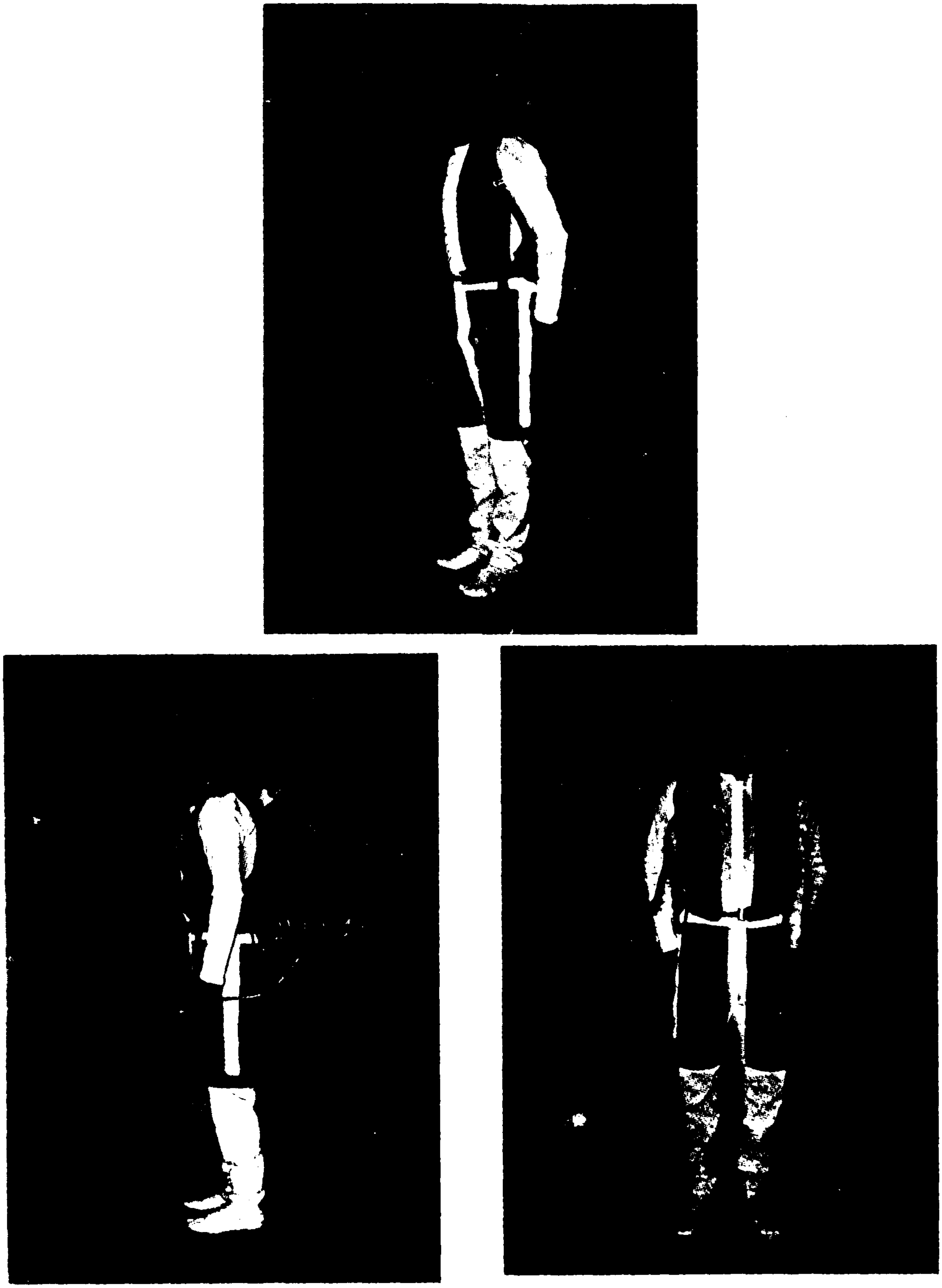
   b) Pressurize to approximately 1.0 iwg

17) Turn on SMR (suit make-up regulator)

    a) Activate SMR through wall of suit.

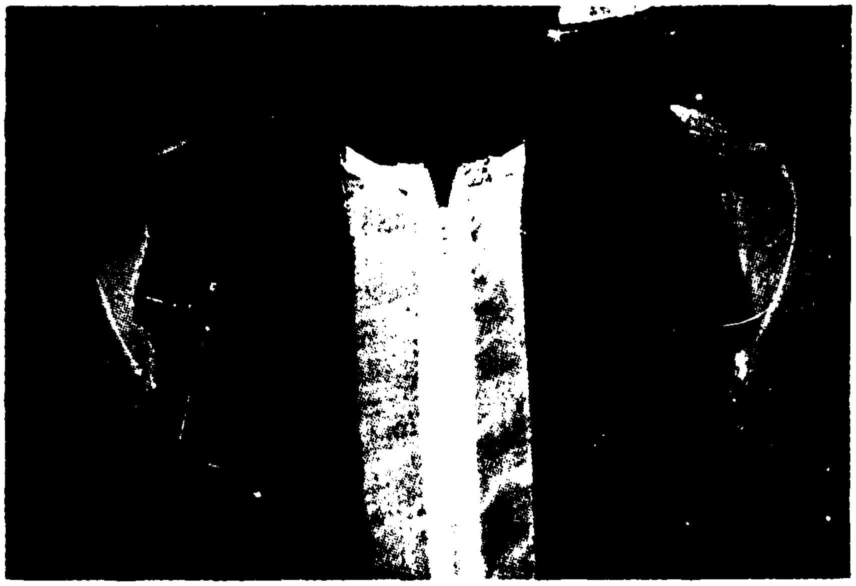
18) Squeeze suit wall once to lock up SMR.

19) Proceed with mission.



COOLING GARMENT WITH BACKPACK

FIGURE 19



CONNECTING ICE POUCH
SUPPORT STRAPS

FIGURE 20

OUTERGARMENT PARTIALLY DONNED

FILLING THE COOLING SYSTEM
WITH WATER THROUGH THE SUMP

FIGURE 21

FACE MASK DONNED AND CONNECTED

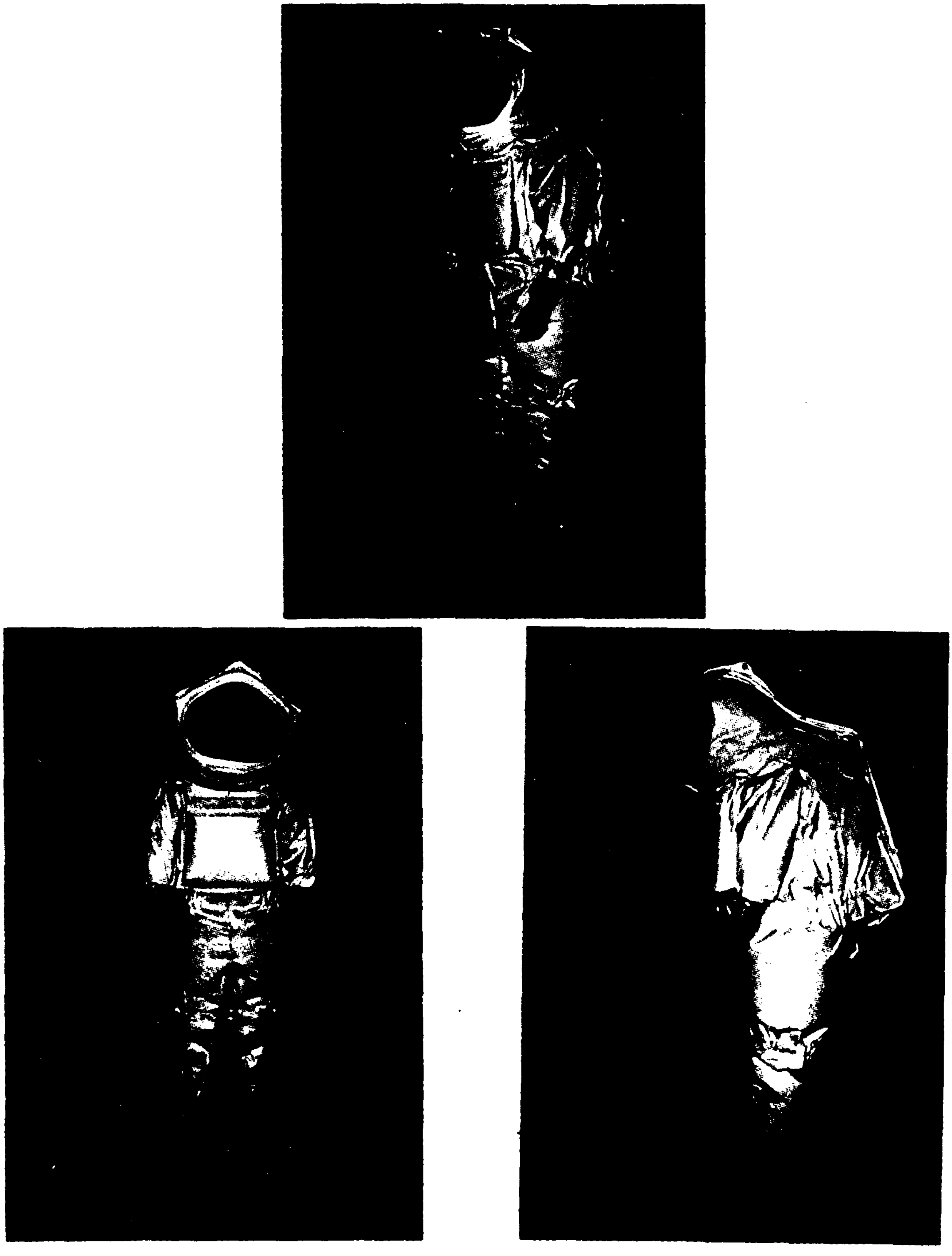
OUTERGARMENT CLOSED,
BEING PRESSURIZED

FIGURE 22

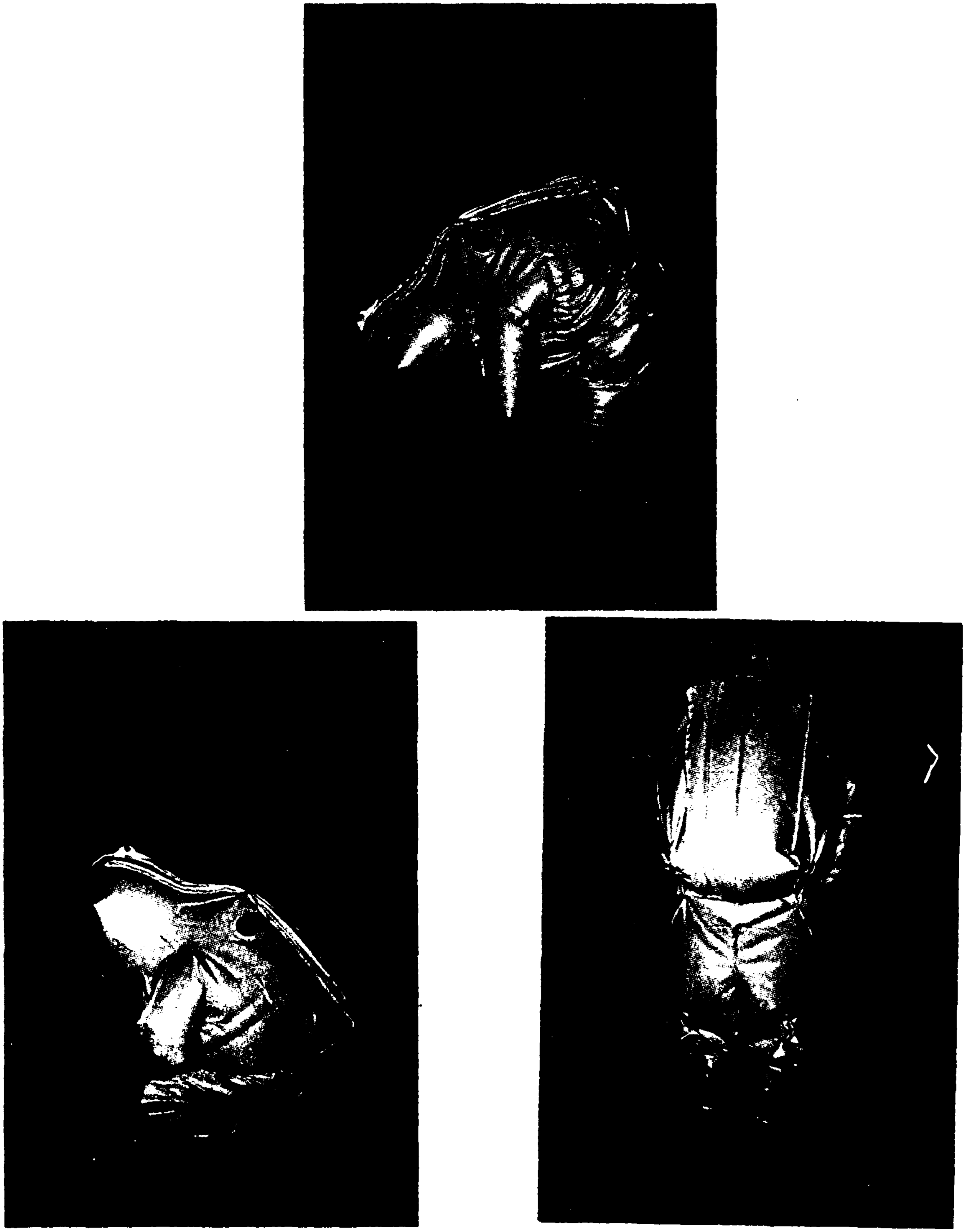
ADDING ICE TO CHEST POUCH

ADDING WATER TO CHEST POUCH

FIGURE 23



COMPLETE ENSEMBLE
FIGURE 24



COMPLETE ENSEMBLE
FIGURE 25

4.5.2 System Weight

In weights of the major system components as incorporated in the delivered prototype is given below:

Backpack (see next section for backpack weight breakdown)	43.28 lbs.
Cooling Garment, empty, including bypass arrangement	2.48 lbs.
CPE Outergarment, no water in sump or ice pouch	11.18 lbs.
Water in cooling system	6.25 lbs.
Water in ice pouch	4.17 lbs.
Ice	4.2 lbs.
Boots	5.64 lbs.
Gloves	.53 lbs.
System Total	77.73 lbs.

NOTE: Butyl Outergarment weights 10.15 lbs, making Butyl system total 76.70 lbs.

4.5.2.1 Backpack Weight

O_2 bottle	6.42 lbs.
Air bottle	6.42 lbs.
Scrubber Cannister	1.86 lbs.
LiOH	1.28 lbs.
Reg/Heat Ex/Water Trap	2.17 lbs.
Breathing Bag/Manifold	3.63 lbs.
Pump (no fittigns)	1.27 lbs.
Mask/Hose Assy.	2.21 lbs

Frame, etc.		7.25 lbs.
Shell, back		2.69 lbs.
Shell, Front (strap, beeper, pump switch & fittings)		4.81 lbs.
	Total	43.28 lbs.

4.5.3 Cost Estimate

Table of Operation for fabricating the body cooling garment, modified CPE DPE Outergarment, and modified butyl DPE Outergarment are included in Appendix A. Based on these operations for fabricating the prototypes as delivered, the follwing ROM cost estimate for each was made.

Body Cooling Garment	$ 292
Modified CPE DPE Outergarment	$ 429
Modified Butyl DPE Outergarment	$ 1,095

NOTE: These estimates assume a production quantity of 100 units.

4.6 ENDURANCE TESTING

In order to verify the reliability of the 2½ hour self-contained modified DPE, demonstrate that des[illegible] criteria are consistently met, and identify any unanticipated usage [illegible] twenty-four (24) two-hour manned endurance tests were conducted. The test program included tests spanning the design temperature limits:

1. 2 tests of the modified butyl DPE at 0°F.
2. 4 tests of the modified CPE-DPE at 100°F, simulated full sun load.

3. 9 tests of the modified CPE DPE at room temperature.

4. 9 tests of the modified CPE DPE to determine the lower limit operating temperature.

4.6.1 Endurance Test Plan

The activity schedule followed for each endurance is given below:

Definitions

1. Work Cycle

   a. Walk up and down stairs carrying tool kit.

   b. Coil and uncoil hose.

   c. Move full 55 gal. drum with hand truck 25 feet and return it.

   d. Turn overhead valve.

   e. Load 20 lb. boxes on platform and unload.

   f. Use wrench and screwdriver.

2. Exercise Cycle

   a. Extend arms straight outward. Pivot at waist back and forth.

   b. Extend arms overhead. Bend at elbows repeatedly.

   c. Bend forward at waist and return to erect position. Repeat.

   d. Duck Squat. Pivot on feet left and right. Stand up.

   e. Kneel down. Reach behind, left side and right side. Stand up.

3. Treadmill Cycle

   a. Walk on treadmill at 2 mph, 5° incline for prescribed time.

Activity Schedule

15 minutes - work cycle

5 minutes - rest

	15 minutes	- work cycle
	5 minutes	- rest
	15 minutes	- exercise cycle
	5 minutes	- rest
	15 minutes	- exercise cycle
	5 minutes	- rest
	40 minutes	- treadmill cycle, 2 minutes on, 2 minutes rest
Total	120 minutes	

While this outline was generally followed, the testing was altered at any time at the request of the subject, if he required additional rest, for example.

4.6.2 Endurance Test Set-up

A test facility was fabricated consisting of a large insulated room with space heaters capable of bringing the room to 110°F. A stairway/platform was built and the treadmill placed in the room along with all the necessary props to perform the work cycle.

Two test outergarments were fabricated. They included 1) a special bulkhead fitting fabricated to permit thermal sensor leads to pass through the suit wall without loss of suit pressure, 2) an oxygen concentration monitor mounted on the suit wall, and 3) an outside strap support for a small speaker box connected to a throat microphone which permitted communication between subjects and test conductors.

Test parameters measured during each test are listed below:

1. Core temperature.
2. Air temperature into air heat exchanger.
3. Air temperature out of air heat exchanger.
4. Exhalation air temperature.
5. Water temperature into cooling garment.
6. Water temperature out of cooling garment.
7. Battery voltage.
8. Bypass position.
9. Internal suit pressure
10. Ambient temperature.
11. Temperature of air inside suit.

Other parameters measured for safety purposes were blood pressure before and after test, weight before and after test, and heart rate measured throughout the test. Oxygen concentration was not able to be measured because the high humidity in the suit damaged the sensor, at first causing erratic readings and finally no readings at all.

The 100°F tests were conducted in the test room with heaters and heat lamps on. Room temperature tests were usually conducted in the daytime without heaters. Low temperature tests were conducted mostly at early morning hours because it was the only time of day these temperatures were reached. 0°F testing took place in a local cold storage facility. During low temperature and 0°F testing, the cooling garment was bypassed so that only breathing air was cooled.

4.6.3 Endurance Test Results

The endurance test data sheets are included in Attachment 2.

In some tests, the garment was not worn so that warmer clothes could be. In this case water went directly from the air heat exchanger to the ice pouch via a special length of tube made for this purpose.

4.6.3.1 100°F Testing (4 tests)

Heat Removal Rate

Average Maximum	1135 Btu/hr
Average Minimum	315 Btu/hr
Average	520 Btu/hr

Inhalation Air Temperature

Average	87 °F

Air ΔT Through Exchanger

Average Maximum	18 °F

Suit Temperature

Average	89 °F

Time Between Ice Changes

Average	20-25 Minutes

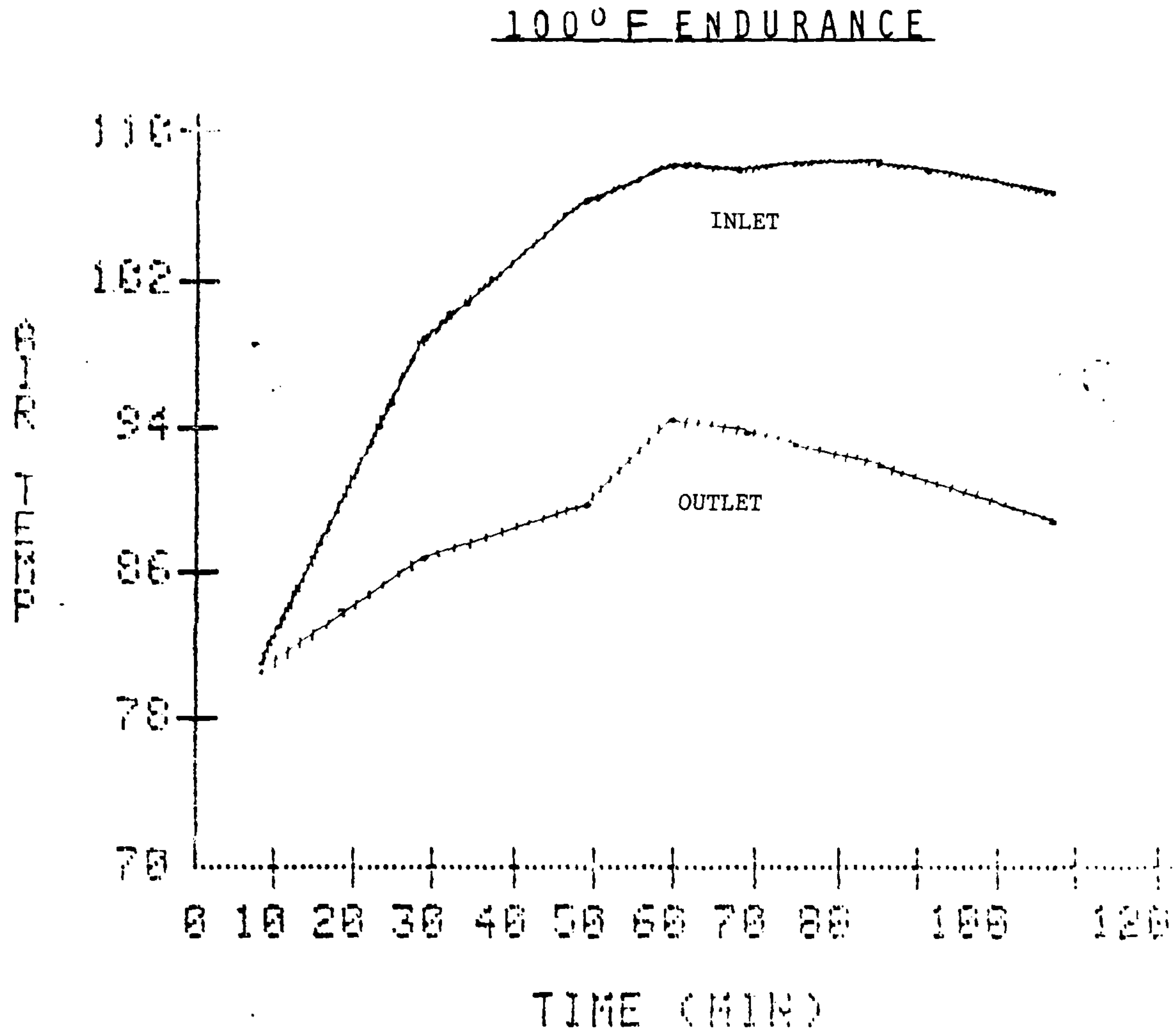
Suit Pressure

Positive, throughout test

Core Temperature — Steady, under design limit

Qualititve Assessment - Subjects report they were warm, but not uncomfortably hot. Anti-fogging was fairly effective. Subjects were very tired after each test.

Breathing air temperatures are plotted in Fig. 26 for a typical 100°F test.



100°F ENDURANCE
110
102
94
86
78
70
AIR TEMP
INLET
OUTLET
0 10 20 30 40 50 60 70 80 100 120
TIME (MIN)

FIGURE 26

4.6.3.2 Room Temperature Testing (9 tests)

Heat Removal Rate

Average Maximum	1775 Btu/hr
Average Minimum	1120 Btu/hr
Average	1388 Bty/hr

Inhalation Air Temperature

Average	79 °F

Air ΔT Through Exchanger

Average Maximum	18 °F

Suit Temperature

Average	68 °F

Time Between Ice Changes

Average	34 Minutes

Suit Pressure

Positive, throughout test

Core Temperature

Steady, under design limit

Qualitative Assessment - Subjects report they were warm, but not uncomfortably hot. Anti-fogging least effective at this temperature. Sometimes caused visual difficulty. Almost as tired after this test as 100°F tests. Fatigue due mainly to weight carried, level of activity, and 2 hour duration.

Breathing air temperatures are plotted in Fig. 27 for a typical room temperature test.

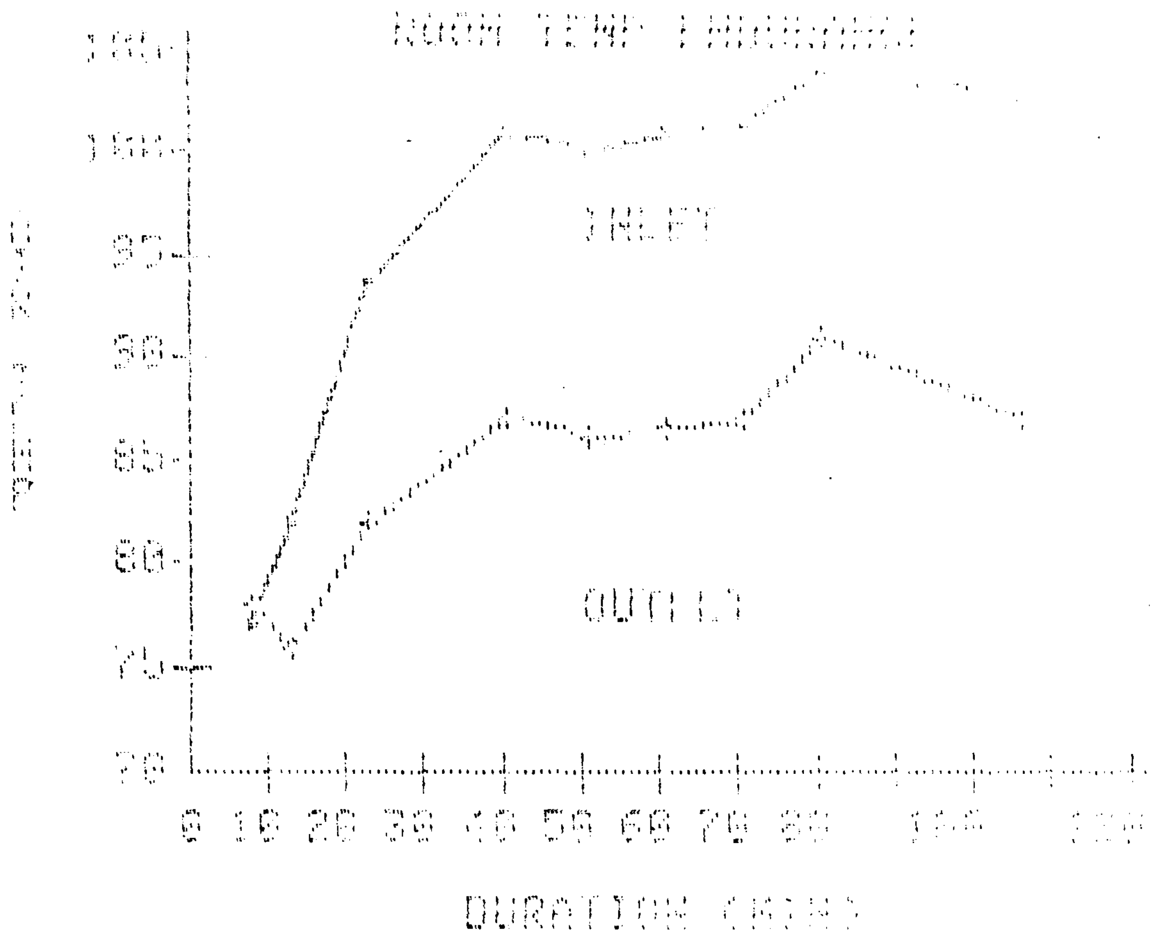

ROOM TEMP
INLET
OUTLET
95
90
85
80
75
70
0 10 20 30 50 60 70 80
DURATION

FIGURE 27

4.6.3.3 Low Temperature Testing (9 tests)

Inhalation Air Temperature

Average	76 °F

Air ΔT Through Exchanger

Average Maximum	21 °F

Suit Temperature

Average	55 °F

Suit Pressure

Positive, throughout test

Core Temperature — Steady, under design limit

Qualitative Assessment - Suit material failed at 22°F, did not at 35°F. Material was noticeably stiffer from 45° - 50° on down. The colder the temperature, the stiffer the material felt. At 22°F, stiffness was not only noticeable, but was resisting and interfering with suit motions. Anti-fog was more effective than at room temperature, but not as effective as at 100°F. Very comfortable from a temperature standpoint. Still fatigued at end of test, but not as much as at room temperature or 100°F.

NOTE: 32°F should be established as CPE lower operating limit.

Breathing air temperatures are plotted in Fig. 28 for a typical low temperature test.

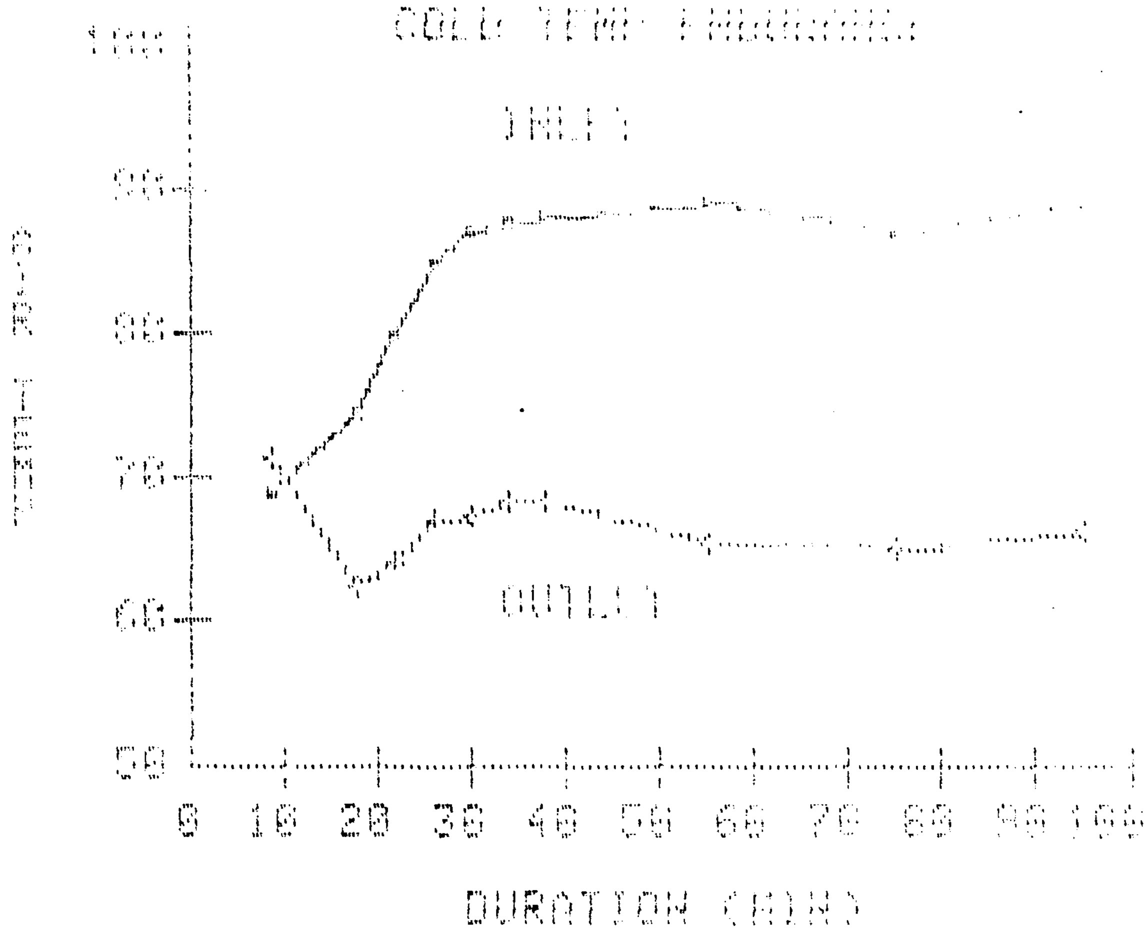

COLD TEMP
INLET
OUTLET
100
90
80
70
60
50
0
10
20
30
40
50
60
70
80
90
100
DURATION

FIGURE 28

4.6.3.4 0°F Testing (2 tests)

Inhalation Air Temperature

Average	62 °F

Air ΔT Through Exchanger

Average Maximum	18 °F

Suit Pressure

Positive, throughout test

Core Temperature — Steady, under design limit

Qualitative Assessment - Feet were cold, but not in pain. Breathing air and body temperature were very comfortable. The suit material felt fine, with no stiffness at all. There was no fogging in the facemask, but some was noted on the suit visor. When the condensation froze, it interfered with vision. The suit subject had to pull his hand in and wipe the visor off from inside about twice per test. The butyl closure became slightly more difficult to open. About the same level of fatigue was felt as with low temperataure tests. A layer of ice had formed on top of the water in the pouch by the end of test. CPE closure became more difficult to open due to increased stiffness.

Breathing air temperatures are plotted in Fig. 29 for a typical 0°F test.

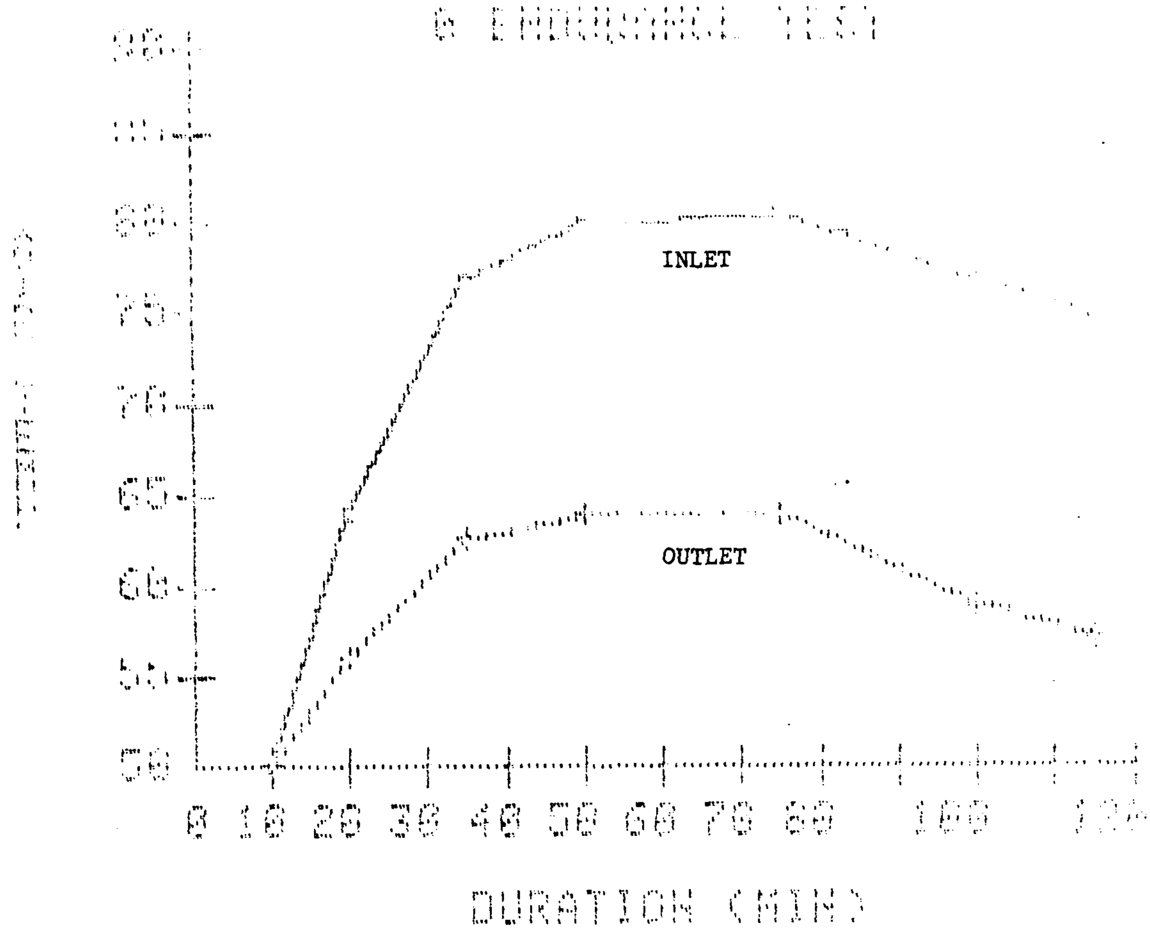

80
75
70
65
60
INLET
OUTLET
0 10 20 30 40 50 60 70 80 100
DURATION (MIN)

FIGURE 29

4.6.4 System Failures and Analysis

During the emdurance test program, a number of difficulties were encountered which resulted in a test delay or test termination. Each failure of a subsystem was either corrected, explained, or a recommendation for correction made.

4.6.4.1 LiOH Dusting

Initial tests were terminated because LiOH dust in the rebreather was getting past the cannister filters and causing respiratory irritation when inhaled. It was found that the dust was getting around the edges of the bottom filter. It was solved by blocking off the outer holes in the retainer ring behind the bottom filter. An annular vinyl disk was cemented to the retainer ring, covering only the outer circle of holes. When the filter is added, LiOH dust cannot circumvent both the filter and the vinyl ring. Thus, the air passing through the cannister is kept free of particulates.

4.6.4.2 Air Heat Exchanger/Regulator Support

The air heat exchanger/regulator/water trap assembly on the rebreather was fabricated so that the only support for it was the threaded coupling joining it to the breathing bag manifold. This resulted in large stresses on this coupling, not only from the assembly's weight, but also from any external loading on it during use. The coupling failed several times as a result, within the first few tests. The coupling's plastic center bushing was replaced with an aluminum bushing. In order to better support the air heat exchanger/regulator assembly, a support bracket mounted on the backpack bottom shell was designed and fabricated. The air heat exchanger is secured to it with a velcro strap. No further failures of the threaded coupling were noted after these measures were taken.

4.6.4.3 LiOH Cannister

The LiOH Cannister is a machined rigid polycarbonate cylinder. As the cap is screwed on, a cap gasket is compressed, loading the thin-walled cylinder radially. This loading resulted in stresses large enough to induce several cracks in the polycarbonate cylinder near the threads. The cylinder was cemented at these failure sites, and reinforced with plastic band clamps. The failure did not reoccur after these measures were taken. It is noted that the thin walled polycarbonate cannister was used for this prototype only, and a more durable material and cannister design would be used for the final production units.

4.6.4.4 Facemask Seal Leakage

Some endurance tests were terminated early due to oxygen depletion in the primary breathing system. It was determined that the cause of the unusually rapid depletion of O_2 was leakage around the faceseal of the facemask. Whenever the rapid O_2 depletion occurred, the subject reported that he could feel air escaping aroung the facemask seal each time he exhaled. As a result, the O_2 bottle had to be drained faster to make up for the lost volume. Thus, the primary system did not last the full two hours. The secondary system would engage, the alarm sounded, and the test aborted.

After subjects became more familiar with the mask and the best adjustment for their own faces, this problem stopped occurring.

4.6.4.5 Suit Make-up Regulator

Endurance tests in which the active pressurization system was employed had problems with suit overinflation. When engaged, the active pressurization system maintain suit pressure at approximately 2.0 iwg, compared with the design value of .6 iwg. The result was an overinflated suit that was difficult to operate in, and which vented heavily with each constricting suit motion. This caused the make-up regulator to make-up more suit air when the motion was reversed, until internal suit pressure was again as high as 2.0 iwg. This cycle quickly depleted the air cylinder until the pre-set cut-off was reached, corresponding to the minimum emergency egress capacity.

The cause of the overinflation was initially thought to be an incorrect adjustment of the Suit Make-up Regulator (SMR). U.S. Divers engineering personnel visited ILC Dover to correct the SMR problem. Closer examination and analysis revealed that the SMR was not out of adjustment, but that the external pressure sensing monitor was inducing a pressure lag between the ambient pressure and the line pressure transmitted to the SMR. It was not sensitive enough to the ambient pressure to provide a sufficiently accurate and responsive pressure reference to the SMR. U.S. Divers suggested two methods of improving the sensitivity of the diaphram assembly: 1) use a thinner, more flexible diaphram and, 2) use a larger diameter diaphram. Program schedule considerations did not permit these solutions to be persued. The balance of the endurance tests were conducted without engaging the active pressurization system. As noted previously, positive internal suit pressure was consistently maintained without it.

4.6.4.6 Ice Pouch Support Straps

The ice pouch support strap attachment heat seal is loaded both in shear and in peel. After several tests, this heat seal seam began to fail in the peel mode. This was corrected by reconfiguring the strap so that it widened at the end. The attachment seam is thus loaded over a larger area. This measure solved the problem, as no more failure of this kind were noted.

4.6.4.7 Suit Material

An endurance test conducted at 22°F experienced a suit material failure in the rear upper thigh area. A hole developed at the break line of this joint due to the repeated flexing of the CPE which was stiffer due to the lower temperature. This failure was taken as indication that 22°F is lower than the lower operating temperature limit of CPE. 32°F was finally determined to be the recommended lower operating temperature limit of the CPE Outergarment.

4.7 Conclusions/Recommendations

The prototype ensembles as delivered meet all design requirements as described in section 3.0. The breathing, cooling, pressurization, and outergarment systems interface smoothly to create a workable self-contained chemical protective ensemble providing a full 2 hour mission capability in temperatures ranging from 0°F to 100°F.

These prototypes demonstrate that a self-contained 2½ hour chemical protective capability is a feasible, practicle possibility whose production readiness is relatively near.

As a result of the experience with this system that was gained during the endurance test program, ILC Dover recommends a number of improvements that will make it easier to use and more comfortable without compromising the high safety standards to which it was designed.

4.7.1 Breathing System

The major elements of the breathing system that need improvement are the facemask, LiOH cannister, air heat exchanger, Secondary Breathing System, Support Harness, Backpack Cover, and overall component location.

The facemask needs to have a lower profile by rotating the check valve assembly downward. This would eliminate the front chin area interface problem with the suit that resulted in an awkward hood patterning to provide easement.

The LiOH cannister needs redesigned due to its thin wall cross section, fine threads, dust particle seepage around the ends of the filters, and excessive overall length. Changing the cannister material, redesigning the cannister spring, and bonded rings inside the cylinder could eliminate these problems.

The air heat exchanger needs redesigned because it provides only marginal cooling at elevated temperature and because it was mounted outside the backpack case and was subject to failure. An improved heat exchanger design would result in improved air cooling and locating it inside the backpack would eliminate the possibility of a snag with the Outergarment.

The Secondary Breathing System could be made simpler and more lightweight by the elimination of the suit make-up feature. Since it has been shown that the Outergarment pressurization design maintains positive internal suit pressure regardless of the operating position and without the suit make-up feature, ILC recommends that the suit make-up feature be eliminated. The direct bendfit is a weight reduction due to the decrease in the air bottle volume and the elimination of the suit make-up regulator hardware, including the pressure reference in the Outergarment wall. ILC also recommends eliminating the manual by-pass if NIOSH concurrence can be obtained since the rebreather has a separate emergency escape feature with automatic switch over. This deletion would also save weight.

The backpack support harness needs redesigned, since it is presently uncomfortable to wear for 2½ hours. ILC Dover recommends that the support harness be redesigned along the line of cross country backpacks where comfort for long durations is very important. A design that supports the backpack mainly through the hips rather than the shoulders is needed to improve comfort.

The backpack cover needs to be modified so that it is made of a more flexible material. The present rigid cover is not an optimum surface for interfacing with the Outergarment, since cuts in the Outergarment material occur more readily if the material is caught between two rigid surfaces. ILC recommends that the cover be redesigned and manufactured in a "soft" material such as a formable urethane foam.

ILC Dover recommends a component packaging redesign in order to simplify routine maintenance and refurbishment, and to lower the overall backpack profile. Relocation of the air and O_2 cylinders and slight rotation of the scrubble cannister can greatly improve the serviceability of the unit.

4.7.2 Cooling System

The cooling garment water outlet port needs to be relocated to eliminate an interface difficulty with the backpack straps. Shifting the outlet port slightly to the right will accomplish this. Also, the control valve assembly needs to be redesigned so that it won't be necessary to disconnect the right hand shoulder strap and feed it between the tubing during donning.

ILC also recommends that the garment be sized to include three ranges (small, medium, large) in order to fit from 5-95% percentile of the population.

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4.7.3 Outergarment

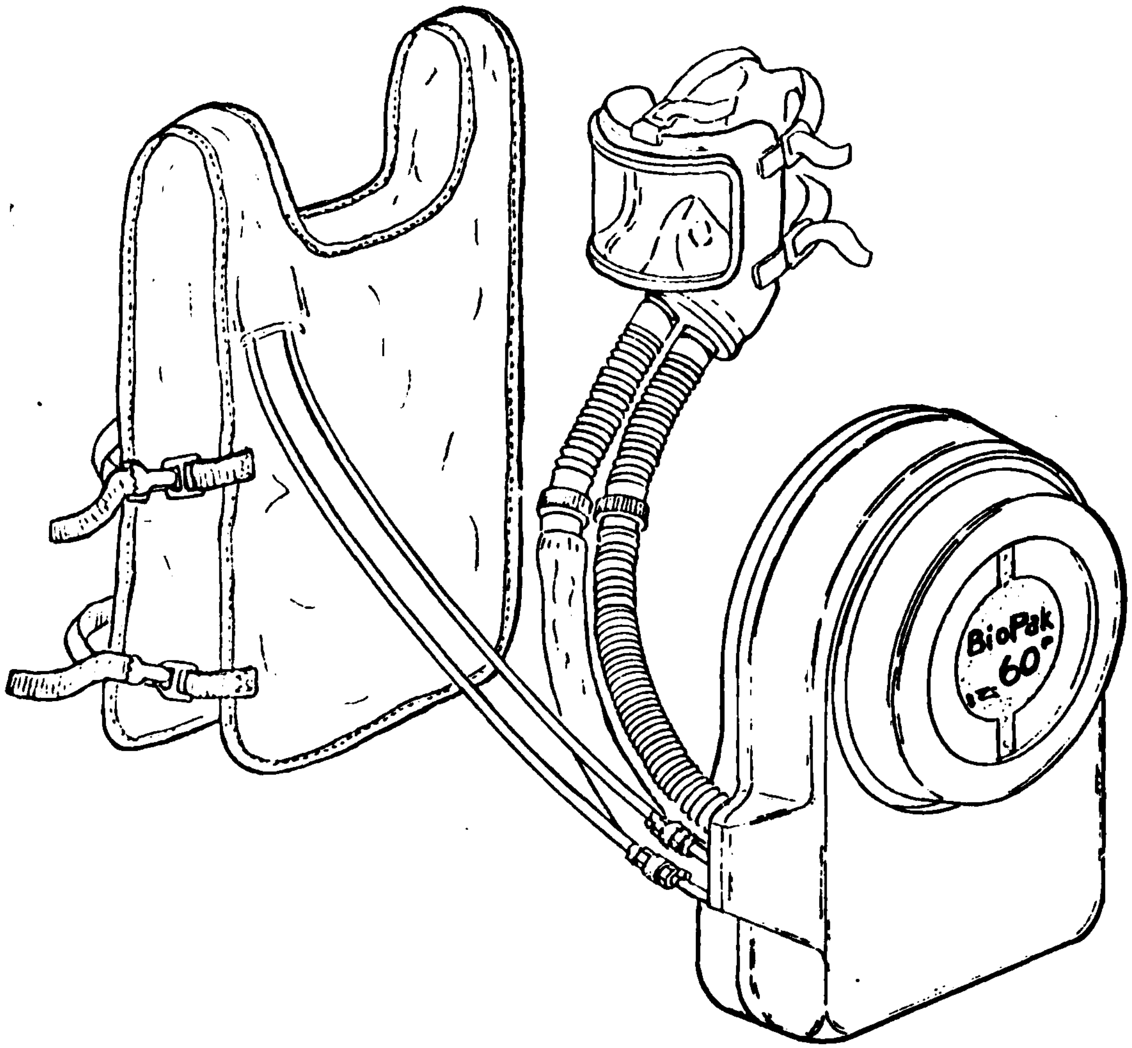
The back and facemask areas of the Outergarment will need repatterning if the previously recommended changes are made to the backpack and facemask. The suit could be made more conformal and lower in profile, assuming a backpack and facemask redesign. A sizing study may also be required to fit the 5-95% percentile of the population.

4.8 One Hour Self-Contained Chemical Protective Ensemble

A one hour self-contained chemical protective ensemble was developed prior to the 2½ hour system to demonstrate the early feasibility of the self-contained concept and to provide an interim solution to the self-contained chemical protective need in the community prior to the completion of the 2½ hour system. It incorporated a breathing system, a cooling system, and a pressurzation system as part of the Outergarment. Finally, manned testing was conducted to verify the design. It was during the development of the one-hour ensemble that the need for air cooling was recognized and the Outergarment pressurization system was developed.

4.8.1 Breathing System

The breathing apparatus used in this suit is a Biopack 60 (see Fig. 30). This system, manufactured by BioMarine Industries, Inc., is a 1 hour positive pressure rebreather. This NIOSH approved unit uses soda-sorb as the CO_2 absorbent. The total weight of this system including the 2250 psi O_2 cylinder and the mask and hoses, is 25 pounds.



ONE HOUR ENSEMBLE COOLING SYSTEM
FIGURE 30

4.8.2 Cooling System

The cooling system used for this suit consists of a modified ILC cool vest. This urethane coated nylon vest is a water cooling garment with cooling panels located on the chest and back. The water is pumped from an ice pouch in the front with an 8 VDC centrifugal pump. A conventional 8 VDC lead acid battery is used to supply this power. The amount of flow into the garment can be controlled by a 2 way ball valve. For this application two modifications were made to the standard garment. The conventional ice pouch was enlarged to accommodate one hour's worth of ice. In addition, the water flow Pattern is redirected with vinyl tubing through an inlet air cooling sheath before returning to the vest. This cooling sheath was needed to bring the temperature of the scrubbed air down to acceptable levels.

4.8.3 Pressurization System

The configuration of the volume accumulator and the exhaust assembly for the one hour suit are identical to those described in sections 4.3.1 and 4.3.2 of this report.

4.8.4 Outergarment

The one hour walkaround outergarment is basically a modified DPE. The material is 20 Mil CPE, and the configuration has the same general shape. The rear of the suit was patterned to closely conform to the Biopack 60 with a 36" EPC. Elastic accumulator panels are located on each side of the suit: directly under the arms, in the area corresponding to the man's lower rib cage, and in the side of the thighs. The exhaust assembly containing the four relief valves is located on the chest, and is covered with a CPE flap.

In addition, the visor was changed to a 1/32" polycarbonate antifog treated material.

4.8.5 <u>One Hour Ensemble Testing</u>

The testing program for the one hour suit consisted of 2 min. walking/ 2 min. rest cycles on a treadmill. Initially the tests were conducted without the use of an air heat exchanger. Due to the heat build up in the Biopack 60 the air inlet temperatures exceeded 100°F. This was unacceptable, and precipitated the design of an air heat exchanger sheath. Following this modification testing was resumed, and the maximum air inlet temperature was reduced to 85°F. With this change the suit subjects found the ensemble to be very comfortable.

In all tests a positive pressure was maintained, and the core temperature was found to be relatively constant and well below 102°F.

ATTACHMENT 1

Manned Test Results

BATTERY: 12 volt, 4 AH

PUMP: Positive displacement gear pump (Tuthill)

WATER HEAT EXCHANGER: 5 pass, 60" long, 3/8" copper tube

AIR HEAT EXCHANGER: 6" concentric tube prototype

SUMP: None

BODY COOLING: Full 2½ hour prototype body cooling garment

WORK CYCLE: 1 min. on, 1 min. off

TIME	AMBIENT AIR	AIR IN	AIR OUT	WATER IN	WATER OUT	CORE
0	99	82.5	78.0	82.5	66.0	100.0
2	95	83.0	75.0	79.0	61.0	100.0
4	99	82.5	75.0	78.5	60.0	100.0
6	101	85.0	77.0	76.0	61.0	100.0
8	103	86.0	78.0	74.5	58.0	100.0
10	104	85.5	78.5	77.0	60.0	100.0
12	106	88.0	78.5	79.0	57.0	100.0
14	107	91.0	82.0	80.0	63.5	100.0
16	106	90.0	81.0	80.0	57.0	100.0
18	106	93.5	85.0	81.0	57.0	100.0
20	ICE CHANGE					
22	99	96.0	86.0	84.0	59.0	100.5
24	98	97.5	87.0	86.0	53.0	101.0
25	100	100.0	92.0	90.0	54.0	101.0

Test terminated due to discomfort causes by high breathing air temperature.

Manned Test Results

BATTERY: 12 volt, 4 AH

PUMP: Positive displacement gear pump (Tuthill)

WATER HEAT EXCHANGER: 5 pass, 60" long, 3/8" copper tube

AIR HEAT EXCHANGER: 6" concentric tube prototype

SUMP: 1 pint

BODY COOLING: Full 2½ hour prototype body cooling garment

WORK CYCLE: 1 min. on, 2 min. off

TIME	AMBIENT AIR	AIR IN	AIR OUT	WATER IN	WATER OUT	CORE
0	101	72.5	68	68	64.5	98.0
1	98	74	68	65	65.5	97.5
4	100	75	70	65.5	67	96.0
7	100.5	77	72	66	68	95.0
10	101	79.5	74	67.5	69	92.0
13	102	83	76.5	69	72	90.5
16	101	84	78	70	72.5	86.0
19	101.5	86.5	80	71.5	73	87.5
	ICE CHANGE					
24	100.5	87.5	80	70	73	87.0
27	101	88.5	80.5	69.5	73	89.0
30	101	88.5	81.5	70	73	90.0
33	101.5	90.0	83.0	70	72	89.0
36	101.5	90.5	83.5	70	72.5	--
39	101.5	91.5	84.5	70	72.5	--
42	101.5	95.0	87.0	71	71.5	--
	ICE CHANGE					
47	100	95	88	70	72	--
50	101	95.5	88	70	72	--
53	101	96	88	71	72	--
56	101	98	91	71	72	--
59	101	98	91	72	72	--
62	101.5	99	92	73	73.5	--
65	100	98.5	92.5	73	74.5	--
	ICE CHANGE					
69	100	100	93.5	73.5	74	--
72	100	100	93.5	73	74	--
75	100	99	92	73	74	--
78	100	100	93.5	73.5	74	--
81	100	100	93	73.5	74	--
	O_2 BOTTLE CHANGED AND ICE CHANGE					

/continued

TIME	AMBIENT AIR	AIR IN	AIR OUT	WATER IN	WATER OUT	CORE
85	98.5	93	86	72	74	--
88	99	92	85.5	70.5	73.5	--
91	99	95.5	89	69	71	--
94	100	97	90	69	70	--
97	100.5	98	90.5	70	71	--
100	100	98	90.5	71.5	70.5	--
103	100.5	98.5	91.5	71.5	71	--
106	100	98	90.5	71	70.5	--
109	100	98	91	72	70	--
112	100.5	98.5	91.5	72	71	--
113	100.5	98.5	91.5	72.5	71.5	--
115	101	99	91.5	73	71.5	--
			ICE CHANGE			
119	98	99	90.5	72.5	72.5	--
122	99.5	99.5	90	72	73	--
125	100	100	90	72.5	73	--
128	99	99.5	90.5	72	74.5	--
131	99.5	99	91.5	72	75.0	--
134	100	99	92	71.5	76.0	--
137	100	98.5	91.5	72	76.5	--
140	100	98.5	91.5	72	78.0	--
143	100.5	99	92	72	79.5	--
146	100	99.5	92	72	80	--
			ICE CHANGE			
150	99	99.5	92	71.5	80	--
154	100	100	92	71.5	80	--

NOTE: Core temperature readings terminated when probe was determined to be faulty.

Manned Test Results

BATTERY: 12 volt, 4 AH

PUMP: Positive displacement gear pump (Tuthill)

WATER HEAT EXCHANGER: 5 pass, 60" long, 3/8" copper tube

AIR HEAT EXCHANGER: Rectangular aluminum plate prototype

SUMP: 1 pint

BODY COOLING: Full 2½ hour prototype body cooling garment

WORK CYCLE: 1 min. on, 2 min. off

TIME	AMBIENT AIR	AIR IN	AIR OUT	WATER IN	WATER OUT	CORE
0	96	79	77	77.5	69	99
1	98	78	72	74	67	99
3	98.5	77	70.5	72	67	99
4	99	78	70	71.5	66	99
6	99	78	69	70	66	99
7	98.5	79	68	70	66	99
9	98	79.5	68.5	70	68	99
10	99	81	68	70	65	99
12	99	82	68	69.5	67	99
13	99.5	83	68.5	70	65.5	99
ICE CHANGE						
15	100	84	68.5	70	64.5	99
AFTER 1 MINUTE WALKING, ONE MINUTE OF EXTRA REST						
17	100	84	67	69	63	99
19	100	83.5	66.5	68	64	98.8
20	100	85	66	68	63	98.8
22	101	85	66.5	67.5	64	98.1
23	100.5	85.5	66	68	63	98.1
25	101	86	66.5	68	64.5	98.5
26	101	87	67	68	64	98
28	101.5	87	67	68.5	65	98
29	102	88	67	69	64	98
31	101	87	68	69	66	98
32	100.5	88	68	69.5	65	98
34	101	89	68	70	63	98
ICE CHANGE						
36	100	90	67	69	63.5	98
38	101	89	67.5	69	65	98
39		91	68	70	64	98
41	101	90	68	70	66	98
42	101	92	68	70	64.5	98
44	101	92	68.5	71	66	98

/continued

TIME	AMBIENT AIR	AIR IN	AIR OUT	WATER IN	WATER OUT	CORE
45	101	93.5*	69	71	65.5	98.2
47	101.5	92.5	69	71	67	98
48	101.5	93	69	71.5	66	98
50	102	94	70	72	66	98
51	102	94.0	70	73	67	98
53	102	95	70.5	73	68	98
54	102	95	71	74	67	98
56	102.5	96	71	74.5	69	98
57	102	96	71	75	68	98
59	103	95	72	75	70	97.8
60	102.5	96	72	76	69	98
			O_2 BOTTLE CHANGED			
65	103	92	73	76.5	70	97.5
68	103	95	73	77	70.5	97.5

Test terminated due to leaking sump.

ATTACHMENT 2

DATA SUMMARY

Date: 4/16/81 Ambient Temp: 45°F Test Subject: Chris Lovelace

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
7-10	98.5	73.0	-	-	1.0"	67.0
10-25	98.5	70.0	-	-	.5"	51.0
30-45	98.0	70.5	-	-	.1"	49.0
50-65	98.0	75.0	-	-	0	50.0
70-85	98.0	77.0	16.5	-	0	51.0
Extra Rest Requested by Subject						
98-101 walk 101-103	98.0	80.0	-	-	0	61.0
103-106 106-108	98.0	82.5	14.5	-	0	61.0
108-111 111-113	98.0	85.5	-	-	0	62.0
113-116 116-119	98.5	88.0	-	-	0	63.5

DATA SUMMARY

Date: 3/12/81 Ambient Temp: 34°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
0.0	99.0	64.5	4.0	1965		57.0
15 min work 15 min rest	98.5	60.0	20.0	1872	1.0"	50.0
15 min work 5 rest	98.5	71.0	15.0	1123	.7"	50.0
15 min ex. 5 rest	98.5	70.5	19.0	923	.9"	50.0
15 min ex. 5 rest	97.5	72.5	17.0	972	.2"	50.5
82	98.0	76.0	13.5	1219	.3"	51.0
86	98.0	81.0	11.5	1268	.5"	51.0
			ICE CHANGE			
92	97.5	83.0	9.5	830	.4"	51.0
96	98.0	84.5	9.5	284	.5"	52.0
100	98.0	84.0	9.0	202	.5"	52.0
106	98.0	87.5	9.5	434	.7"	52.5

DATA SUMMARY

Date: 3/18/81 Ambient Temp: 22°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
0	98.5	66.5	6.0	3307	.85"	
15 min work 5 rest	99.0	66.0	25.5	3592	.80"	27.0
15 work 5 rest	99.0	69.5	25.5	3436	.70"	34.0
15 exer. 5 rest	97.0	62.5	25.0	3123	.80"	37.0
15 exer. 5 rest.	core out	65.0	22.5	2788	.20"	37.0
82		69.5	20.0	2918	*0	44.0
86		70.0	20.5	3071	0	45.0
90		72.0	20.0	-	0	47.0
94		70.5	19.5	-	0	47.0
98		73.0	19.5	-	0	48.0
102		73.0	19.0	-	0	48.5
108		75.5	18.5	-	0	48.5

*NOTE: Suit developed a hole which cause the loss in pressure.

DATA SUMMARY

Date: 3/19/81 Ambient Temp: 50°F Test Subject: Evan Hensley

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
0.0	99.5	81.5	6.5	-	1.0"	63.0
15 min work 5 rest	98.5	74.0	5.5	-	.9"	60.0
15 min work 5 rest	core out	76.5	16.0	-	.2"	60.5
			ICE CHANGE			
15 min ex. 5 rest		74.0	18.0	-	.4"	57.0
15 min ex. 5 rest		74.0	18.0	-	.9"	57.5
82		78.0	14.5	-	.4"	60.0
87		80.0	14.5	-	.3"	61.0
			ICE CHANGE			
92		79.5	16.5	-	.6"	60.0
97		80.0	16.0	-	.6"	59.0
102		79.0	17.0	-	.5"	60.0
107		81.0	16.0	-	.5"	60.5

DATA SUMMARY

Date: 3/18/81 | Ambient Temp: 48°F | Test Subject: Chuck Sandy

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
0	101	74	2	-	.6"	62
4	101	73	11	-	.6"	60
8	101	74	13	-	.4"	59
12	101	78	15	-	.6"	59
16	101	77	15	-	.6"	59
20	101	80	15	-	.6"	59
24	101	82	16	-	.6"	60
28	101	84	16	-	.6"	60
32	101	85	16	-	.6"	60
36	100.5	85	17	-	.5"	60
40	101	87	16	-	.6"	60
60				-		

Abort due to high core temperature for safety reasons.
Later determined subject has high average temperature.

DATA SUMMARY

Date: 4/07/81 Ambient Temp: 35°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
9	98.5	71.5	2.5	-	.2"	66.0
18	98.5	62.5	12.0	-	.4"	62.0
22	98.5	64.0	14.5	-	.05"	61.5
26	98.5	67.0	17.5	-	.5"	61.0
30	98.5	67.5	19.5	-	.6"	60.0
34	98.5	68.5	19.0	-	.5"	60.0
38	98.0	68.5	19.5	-	.1"	60.0
55-60	98.0	65.5	23.5	-	1.3"	51.0
75-80	98.0	65.0	22.0	-	.7"	52.5
95-100	98.0	66.5	22.5	-	1.3"	52.5
115-120						

DATA SUMMARY

Date: 3/07/81 Ambient Temp: 41°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
0	98.5	-	-			
15	99.0	70.0	-	-	.15"	-
35	99.0	70.0	-	-	.15"	-
55	99.0	75.5	-	-	0	-
75	98.5	83.0	-	-	0	-
82	85.0	85.0	-	-	0	-
86	core lost	88.0	-	-	0	-
90		89.5	-	-	0	-
94		90.0	-	-	0	-
98		91.0	-	-	0	-
104		93.5	-	-	0	-

DATA SUMMARY

Date: 3/11/81 Ambient Temp: 42°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
0.0	98.0	73.5	1.5	-	.80"	65.0
15 min work 5 rest	96.0	72.5	6.0	-	.20"	56.0
15 work 5 rest	-	70.5	19.0	-	.70"	54.0
15 ex. 5 rest	-	75.0	18.0	-	.80"	56.0
15 ex. 5 rest	-	78.5	17.0	-	.40"	57.5
82	-	81.0	15.0	-	.30"	59.0
86	-	81.5	15.0	-	.20"	59.5
90	-	83.5	14.0	-	.15"	60.0
94	-	84.0	14.0	-	.15"	60.0
98	-	85.0	13.5	-	.20"	60.5
102	-	87.5	12.5	-	.15"	61.0
108	-	92.0	10.0	-	.30"	61.0

DATA SUMMARY

Date: 3/24/81 | Ambient Temp: 35°F | Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
6.0	98.5	70.5	4.0	-	.70"	60.5
15 work 5 rest	97.5	63.0	26.0	-	.60"	46.0
15 ex. 5 rest	93.5	62.0	24.0	-	1.10"	44.5
15 work 5 rest	93.5	62.5	23.0	-	1.8"	44.5

Aborted due to loss of O_2
Check out of system revealed a crack in scrubber
cannister and crack in demand regulator connection.

DATA SUMMARY

Date: 4/14/81 Ambient Temp: -6°F Test Subject: Chris Lovelace

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
10	-	61.0	6.5	-	+	-
15 work 5 rest	97	69.0	16.5	-	+	-
15 work 5 rest	-	68.0	17.0	-	+	-
15 ex. 5 rest	-	73.0	14.0	-	+	-
15 ex. 5 rest	-	73.0	14.0	-	+	-
15 work 5 rest	~	75.-	12.0	-	+	-

DATA SUMMARY

Date: Ambient Temp: -6°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
10 min.	99	50	0.0	-	1.0"	-
20	100	56	8.0	-	.6"	-
35	100	62.5	14.5	-	+	-
50	100	64.0	16.0	-	+	-
75	100	64.0	16.5	-	+	-
100	100	59.0	18.0	-	+	-
115	99.5	57.0	18.0	-	+	-

DATA SUMMARY

Date: 3/06/81 Ambient Temp: 70°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
4	97.5	71.5	4.0	-	.40	-
8	97.5	73.0	9.0	-	.38	
12	97.5	76.0	12.0	-	.39	
16	97.5	78.5	14.0	-	.38	
20	97.5	79.5	15.0	-	.20	
24	97.0	81.0	15.5	-	.30	
28	97.0	81.5	15.5	-	.40	
32	96.0	83.0	16.0	-	1.20	
36	95.5	82.0	17.5	-	.20	
		ICE CHANGE, 2½ hr. water drained, 2 min. extra				
42	95.0	82.0	17.0	-	1.0	
64	81.0	78.0	20.5	-	.20	
1 hr. 20 min.	84.0	77.0	16.0	-	.30	

DATA SUMMARY

Date: 4/10/81 Ambient Temp: 74°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
8	-	78.0	1.0	1614	2.0"	79.0
13-18	-	76.0	6.0	1775	2.0"	78.5
23-28	-	82.0	11.5	1120	2.0"	78.5
			ICE CHANGE			
41-46	-	87.0	14.0	1270	2.0"	79.5
51-56	-	86.0	14.0	1260	1.0"	80.0
61-66	-	86.5	14.5	1260	1.4"	80.0
71-76	ICE CHANGE	87.0	14.5	1562	.9"	81.0
81-86	-	91.0	13.0	1239	2.0"	82.0
		End of 2 Treadmill cycles. Start work scenario at 85 min.				
15 min/ 5 rest						
106		87.0	16.0	-	1.9"	82.0

DATA SUMMARY

Date: 2/25/81 Ambient Temp: 71°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
6.0	96	73.5	0.5		-	-
9.5	95	72.5	2.5	85		
12.0	95					
14.0	95	75	10.0			
16.0	93	77	11.0	322		
18.0	92.5	76	15.0	766		
20.0	93	79	16.0	603		
22.0	93	77	16.0	714		
25.0	92.5	79	15.5	454		
27.0	92	78	17.5			
29.0	91	81.5	15.5	285		
31.3	90	79.5	17.5	335		
33.0	85	81.5	15.5	335		
37.0	89	79.5	16.5	478		
37-39	87	82	17.0	372		
41.0	89.5	79	18.0	319	-	-
43.0	86.0	81	17.5	212		
45.0	89	81	17.5	210		
47.0	88	83	16.0	15.8		
One hour suit - Change to endurance scenarios						
50.0	90	78	18.5	207		
Exercise segment begins						
69.0	81.5	83	16.0	98.5		

/continued

DATA SUMMARY

Date: 2/25/81 Ambient Temp: 71°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
73.0	ICE ADDED					
75.0	Work Scenario begins					
82.0						
90.0	500 psi remaining					
103	84.5	84	13.5	134		
108 + 12	Test terminated successfully.					

DATA SUMMARY

Date: 3/20/81 Ambient Temp: 60°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
6	99.5	78.0	0.0	-	.5"	69.0
15 min work 5 rest	99.0	80.5	11.5	-	.4"	67.5
15 work 5 rest	99.0	77.0	21.5	-	.4"	66.0
15 ex. 5 rest	core lost	75.0	24.5	-	.4"	58.5
15 min ex 5 rest	-	76.5	23.0	-	.3"	63.5
82		81.5	18.0	-	.2"	65.0
			ICE CHANGE			
87		80.0	20.0	-	1.0"	66.0
91		81.0	20.0	-	.4"	66.0
95		81.5	20.5	-	1.0"	66.0
99		81.5	19.5	-	.2"	67.0
103		82.5	20.0	-	.8"	66.5
107		83.0	19.5	-	.2"	67.0
111		83.5	19.5	-	.2"	67.5
115		84.0	19.5	-	.2"	68.0
Ice Change 140		77.0	25.0	-	.8"	60.0

DATA SUMMARY

Date: 3/26/81 Ambient Temp: 58°F Test Subject: Chris Lovelace

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
15	98.5	72	1	-	1.0	63
16	98	73	3	-	.4	65
19	98	77	7	-	.4	65
23	98	80	9	-	.4	65
Ice Change						
28	98	81	9	-	.4	66
32	98	81	11	-	.4	67
35	97	82	11	-	.4	66
38	97	83	10	-	.4	67
41	96.5	84	11	-	.4	66.5
61	96.5	78	11.5	-	.4	68
78	Abort due to suit subject exhaustion.					

DATA SUMMARY

Date: 02/26/81 Ambient Temp: 70°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
0	99	75	14	-	.2"	-
2.5	98	76.5	14.5	-	.2"	-
4.5	98	76	16	-	.2"	-
10	98	77	18	-	.2"	-
14	97.5	77	19	-	.15"	-
18	96.5	79	17	-	.15"	-
22	96.0	80	16	-	.2"	-
26	95.5	80	16.5	-	.2"	-
30	95	80	16	-	.2"	-
34	95	80	16	-	.2"	-
Ice Change 5 min. change and rest						
54	80	74	20	-	.2"	-

DATA SUMMARY

Date: 3/30/81 Ambient Temp: 62°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
13	-	79.5	1.5	-	2.0"	70.5
35	-	81.5	17	-	.4"	67.0
	Ice Change	77.5	16.5	-	1.8"	67.0
62	-	77.5	14.5	-	1.9"	67.5
67	Ice Change	80.0	15	-	.4"	67.0
72	-	80.5	15.5	-	.6"	67.0
77	-	82.0	16.5	-	1.0"	67.0
82	-	82.0	16.0	-	.3"	67.0
87	-	81.0	16.0	-	.6"	67.0
92	-					

DATA SUMMARY

Date: 4/15/81 Ambient Temp: 42°F Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
6-10	98.0	72.0	0.0	-	1.0"	68.0
15 min ex. 5 rest	99.0	73.5	-	-	.4"	54.0
15 min ex. 5 rest	98.0	73.5	-	-	-	52.0
15 min work 5 rest	98.5	74.0	18.0	-	.6"	52.0
15 min work 5 rest				-		
77-79 walk 79-81 off	97.5	75.0	16.0	-	.4"	61.0
81-83 83-85	98.0	77.5	15.5	-	-	62.0
85-87 87-89	98.0	77.5	15	-	.4"	63.0
		Subject requests extra 2 min. of rest				
91-96 96-101	98.0	82.5	13.5	-	.4"	64.0
101 +	98.0	76.0	17.0	-	-	64.5

DATA SUMMARY

Date: 4/01/81 | Ambient Temp: 97°F | Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
3	100.0	81.5	1	-	-	82.0
15 work 5 rest	99.5	81.0	13	318	1.3"	87.0
15 work 5 rest	99.5	83.0	16.5	781	1.3"	89.0
			ICE CHANGE			
15 ex. 5 rest	-	82.5	17.5	-	1.7"	85.0
15 ex. 5 rest	-	82.0	-	151	1.3"	83.0
			ICE CHANGE			
87	-	86.0	16	302	.2"	84.0
91	-	88.0	14.5	0	.2"	84.0
95	-	88.5	16.5	151	.2"	85.0
99	-	89.0	16	-		85.0
103	-	88.0	17	299	.4"	85.0
107	-	85.0	19	443	1.2"	87.5
111	-	85.0	17.5	443	.9"	88.0
115	-	85.5	16.5	289	.2"	88.0
119	-	81.5	16.5	281	.9"	89.0

DATA SUMMARY

Date: 4/07/81 Ambient Temp: 100°F Test Subject: Chris Lovelace

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
0.0	100	79	3	1640	+	87
20	99.5	77	4	0.0	+	90
40	99.5	85	15	158	+	94
60	100	87	17	307	+	95
80	200	88	17	299	+	94
90	99.5	85	18	588	+	93.5
94	99.5	88	15	578	+	93
98	100	91	12	0.0	+	93
102	99.5	91	13	260	+	92
106	100	94	14	999	+	93
110	100	94	14	710	+	93
114	100	87	14	687	+	93
120	100	87	14	655	+	93

DATA SUMMARY

Date: 4/08/81 | Ambient Temp: 100°F | Test Subject: Don Pommell

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
9	100.0	79.5	1.5	-	1.1"	-
15 min ex 5 rest	-	86.5	13	-	.7"	-
15 ex 5 rest	-	89.0	17	-	.4"	-
50-52 walk 52-56	Ice Change			-		-
58	-	94.0	14	-	.1"	-
		Extra rest requested by subject.				
66	-	93.0	14	-		-
			ICE CHANGE			
74	-	92.0	15.5	-	.3"	-
78	-	93.0	14.5	-	.3"	-
		Extra rest requested by subject.				
86	-	92.0	15	-	.6"	-
92	-	91.0	15.5	-	.3"	-
		Ice Change before work scenario.				
15 min work 5 rest	-					
110	-		17.5	-	1.0"	-
120	END					

DATA SUMMARY

Date: 4/02/81 Ambient Temp: 110°F Test Subject: Chris Lovelace

Time	Core Temp	Inhale Air	Δ Air	Ht Rmvl Rate	Suit Press	Suit Temp
0.0	100	78	1	-	.8"	88
20	100	84	12	984	.8"	90
40	100	87	16	635	.8"	91
60	99.5	88	15	-	+	93
80	99.5	87	14	-	+	90
83	98	90	13.5	_	+	90.5
			ICE ADDED			
92	97.5	92	14	-	+	92
96	98	92	12	-	+	93
101	Abort due to high breathing air temperature.					
END	97.5	93	11	-	+	95

APPENDIX A

TABLE OF OPERATIONS

FOR

BODY COOLING GARMENT

MODIFIED CPE DPE OUTERGARMENT

MODIFIED BUTYL DPE OUTERGARMENT

DISTRIBUTION LIST

	COPIES
DRDAR-CLW-CC	3
DTIC	2
DCASR, Phila.	11
ARRADCOM	2
DRDAR-CLJ-R	3
DRDAR-CLJ-L	3
DRDAR-CLF	1

DA
FILM

3 –