ADVANCED LIFE SUPPORT EQUIPMENT

FOR

NITROGEN TETROXIDE ENVIRONMENTS

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The present life support device for operating in NO_2 environments is the SCAPE (Self-Contained Atmospheric Protective Ensemble), used by both NASA and the Air Force, and also the French in French Guinea. The present suit material is butyl boated nomex per MIL-C-38149. Faceplates are either PVC or acrylic. Boots, gloves, faceplate seal, and cuffs are butyl. To date, there have been no documented exposures to concentrations exceeding TLVs in SCAPE at KSC. Of course, suits are not instrumented and occasionally workers have reported smelling propellants.

From references 4 and 5, tests show that 2/3 of subjects (N=42) tested can detect MMH at .2 ppm (TLV=.2 ppm) and 1/4 of subjects (N=59) tested can detect NO_2 at .9 ppm (TLV=5 ppm). With NO_2, 8 of 59 (13.6%) subjects experienced irritation of the nasal mucosa. Figures 1 and 2 show the effects of breathing NO_2 at .9 ppm or 18% of the present TLV. (So while 5 ppm is the present legal limit, NIOSH has recommended 1 ppm, and this should be the design goal of any SCAPE system.)

Figure 3 shows the locations on the Orbiter of the various fluid commodities. One (1) is N_2O_4; 123 gallons in the forward RCS tank, and in both aft RCS tanks, two 640 gallon OMS tanks for a total of 1650 gallons of N_2O_4. Seven (7) is MMH; 127 gallons in the forward RCS tank and in both aft RCS tanks, two 640 gallon OMS tanks for a total of 1661 gallons of MMH. Two (2) is hydrazine; three tanks for a total of 291 pounds. Three (3) is ammonia; 97.6 pounds, two tanks in the aft.

From the same source document, see Appendix 1, the hazards that personnel engaged in Orbiter crash/rescue operations may be exposed to are:

Unexpended pyrotechnic devices

Toxic fumes

Raw propellants (hydrazine, MMH, and N_2O_4)

Flash fires

High pressures

Hot brakes/wheels (fire/explosion)

Static discharge

Steam/hot water

Propellant (fuel/oxidizer) fires

The first personnel to approach the Orbiter after it has landed, provided it is not on fire, will be in SCAPE (see Figures 4 and 5). The present SCAPE was not designed as a body armor, nor a fire proximity suit, nor is the proposed SCAPE. SCAPE's primary function is to provide a protective envelope about its user that will prevent intrusion of toxic propellants, and maintain the suit interior at or below TLVs with as little inconvenience to the wearer as possible.

The problems of maintaining suit integrity are as follows:

1. Suit material permeability.
2. Sealing of all suit penetrations.
3. Maintaining a positive pressure within the suit, 14" H_2O for SCAPE.

The positive pressure is maintained by a two hour cryogenic backpack worn under the suit (Figure 6), that maintains a purge of approximately 1.4 scfm through three relief valves while recirculating the suit air at 12.7 scfm. The SCAPE leakage spec is 10,000 sccm at .4" H_2O with the relief valves taped off. The Apollo Space Suit leakage spec was 180 sccm at 3.75 psig. A good tight SCAPE has approximately a 2000 sccm leak rate. The reason for the disparity in leak rates is that the zipper (pressure sealing closure) is installed backwards, such that increasing pressure in the suit does not tend to tighten the sealing surfaces but to part them. The reason for the reversed installation was that of the zipper materials, those externally exposed parts, were nylon and brass, not hyper compatible. This fact has been brought out because, upstream diffusion studies (references 2 and 3) have shown that, depending on the flow rate, upstream diffusion is probable.

The problem of suit material permeability can best be illustrated by discussing a computer simulation based on the suit material permeability specification (.01 $mg/in^2/hr$), and a 100% NO_2 outside concentration. Ball park figures for suit area, 15.5 sq. ft., which represents 1/2 the surface area of a suit and assuming a spill only on one side of the worker, and suit free volume, 3 ft^3, have been used before. *Flow rate out of the suit is 1.4 scfm. In this simulation*, NO_2 exceeded TLV in four minutes, 10 seconds. Now, 100% NO_2 concentrations do not occur operationally. There is also a period of time where no permeation takes place. Estimated worst case concentration is 26% for eight minutes. However, the present material does not meet the permeability spec and is severely attacked by N_2O_4. The material permeates at 140-700 times the spec rate, depending on whether or not the material has been exposed to N_2O_4 before (see Figures 7 and 8). Additionally, the butyl coated nomex has such an electrostatic problem that prior to use, all suits have to be sprayed with Statikill. Statikill is a humectant, that is, it accumulates moisture, so that static charges will decay through the moisture. Moisture however, seriously increases the rate of chemical attack of N_2O_4 on the butyl coated nomex.

NASA is presently preparing to test the whole suit in a test chamber with a 26% NO_2 concentration. This type of test has not been performed before on the SCAPE suit.

In considering candidates for a less permeable material, additional design constraints are:

1. Chemical inertness to rocket propellants.
2. Impermeability (or less than .005 $mg/in^2/hr$ for 1/2 hr).
3. Tear resistance.
4. Inflammability or flame retardant material.
5. Abrasion resistance.
6. Resistivity less than 10" 's per square, or induced charge decay of at least 90% in one second.
7. Light in color (preferably white).

8. Flexibility, suppleness, or in the cant of the garment industry, "a good hand."
9. Bondable, either by heat sealing or with a adhesive that does not degrade in rocket propellants.

Chemical inertness is important for the life of the garment and is a necessary property as any type of chemical attack seriously increases permeability.

To achieve adequate tear resistance, a coating is generally applied to a fabric. Fabrics under consideration and in use in protective clothing are:

1. Cotton (Standard Safety Equipment Co.), PVC coated,used at WSTF.
2. Nomex (Arrowhead Products), butyl coated, SCAPE.
3. Teflon (DuPont), viton coated with FEP laminate, Boeing fluorine suit.
4. Beta Glass (Dodge Fluoroglass), teflon coated, JPL fluorine suit.
5. Kevlar (DuPont), citon coated, AF proximity suit.

To make an environmental barrier of a material found to have satisfactory chemical, mechanical, and permeability properties, it must be bondable to itself either through heat sealing, thermowelding (the preferred methods, since they are cheaper, labor wise) or with a chemically compatible adhesive.

Materials that have good chemical resistance to N_2O_4 are Kalrez, Teflon, PNF (Phosphonitrilic Fluoroelastomer), CR-39 for faceplates, Kydex for helmets. Kalrez cannot be bonded to itself, teflon coated on beta glass can be heat sealed with a teflon FEP film, but to get enough teflon onto a substrate to give sufficient impermeability it becomes too stiff. CR-39 is PPGs new allyl diglycol carbonate and is inert to rocket fuels and oxidizer and the present PVC and acrylic faceplates are not and it has higher impact and abrasion resistance. Kydex made by Rohm and Hass is an alloy of PVC and acrylic and an excellent helmet material. PNF, made by Firestone Rubber Company, is inert to N_2O_4 and rocket fuels, is coatable onto nomex, comes in any color, is bondable and will decay an induced charge to less than 10% in one second, so it will not hold a static charge like teflon, or the present SCAPE material.

From our present state of knowledge, of compatibility, permeability, and electrostatic testing, Firestone's PNF (phospho-nitrilic fluoroelastomer) looks like a very good candidate for the material for the next generation of SCAPE suits, that is coated onto nomex for the suit material, molded into gloves, boots, cuffs, and faceplate seals and for relief valve seals. For the faceplate, CR-39 is much better than the present materials.

The pressure sealing closure problem is unclosed at present. There is an OEB (omni environmental barrier) zipper manufactured by Talon Division of Textron that seals better than the present one, yet still has exterior metals; 12% nickle brass, that will have to be tested to determine if it represents a serious problem. Alternate closure methods are a waist roll cuff as is now used for the boots and gloves or a zip lock type closure. Resolution of the closure method should reduce suit leakage to less than 100 sccm.

Additional problems with the present SCAPE are as follows:

1. Reduced forward visual field due to the relief valve.
2. Inadequate ventilation.
3. Danger of frostbite from a cryo leak.

The relief valve can be moved to the side of the helmet, improving the visual field. This mod is still awaiting prototype testing to measure the effect of CO_2 concentration in the suit caused by repositioning the relief valve.

Per MIL-STD-1472B, recommended air flow into any personal enclosure is 30 scfm minimum, approximately 2/3 should be outside air. Total SCAPE flow is 12.7 scfm (41% of spec), with outside (fresh) air 1.54 scfm (7.7% of spec). If SCAPE had 30 scfm flow, it would be too noisy, and would increase backpack weight prohibitively. While some improvement is desired, by judicious conservation of energy, workers may avoid overheating their enclosures (See Appendix II).

With the present SCAPE the hazard exists of a failure in a cryo line in the backpack, from which the worker has no escape. The backpack can, itself, be self-contained and attached by umbilicals to the personal enclosure. This concept exists with the space suits and with Arrowhead Modular, Omni Environmental Protective Suit (See Appendix III).

In summary, pending NASA funding, suit improvements are:

1. PNF instead of Butyl for suit material, boots, gloves, cuffs, and faceplate seal.
2. CR-39 instead of PVC or acrylic for faceplate material.
3. OEB waist roll cuff or zip lock pressure sealing closure.
4. Relief valves with elastomeric, PNF, seals reducing back flow from 6.54 sccm to less than .10 sccm and longer vent ducts.
5. Improved visual field, by moving relief valve to the side of the helmet.
6. Reduced suit leakage.
7. No static charge problem.
8. Detachable backpack.

If NASA accepts all of these changes, we really ought to have a SCAPE suit that protects the worker in the spirit as well as the letter of the law for the first time.

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4. "Olfactory Response to 0.9 ppm by Volume Nitrogen Dioxide," TR-WSTF-146, September 12, 1977

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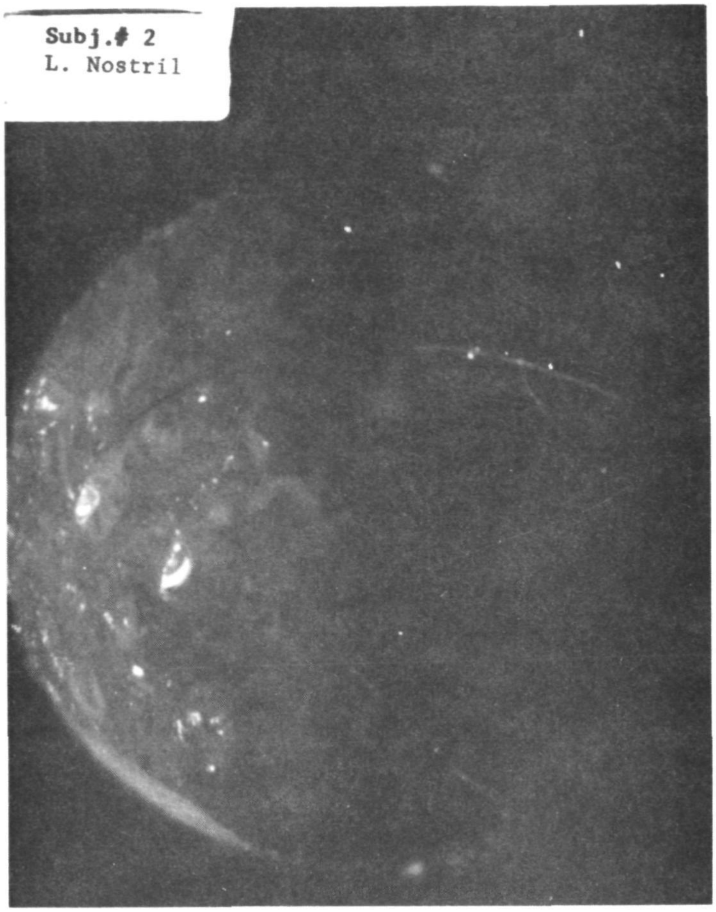
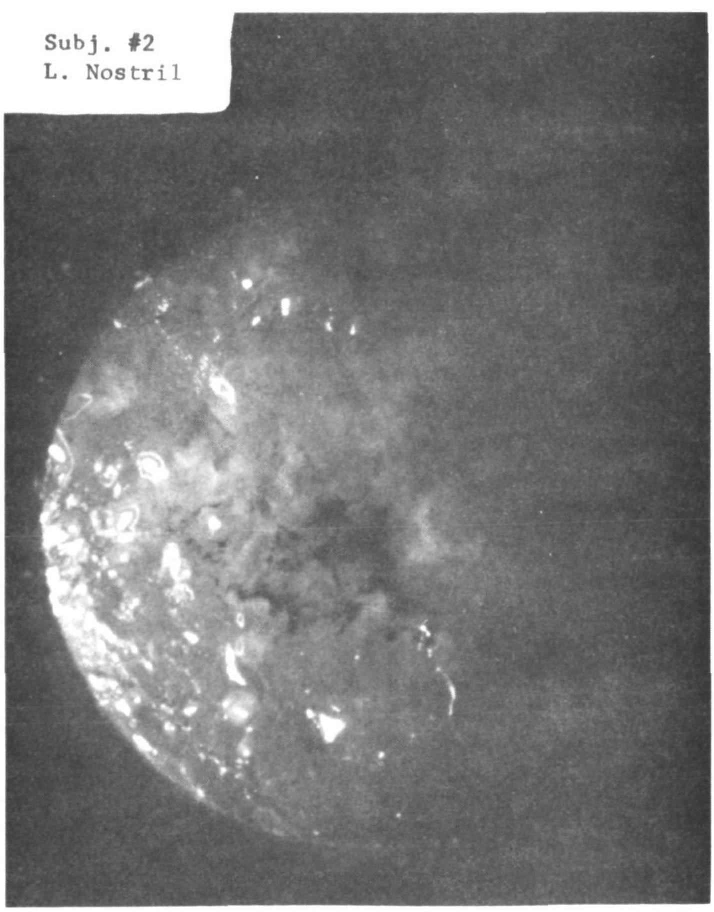
6. "Orbiter Crash and Rescue Information," V00000-9, SD77-0111, Rockwell International Space Division, August 1, 1977

7. MIL-STD-1472B, Military Standard Human Engineering Design Criteria for Military Systems, Equipment, and Facilities, December 31, 1974



PRETEST

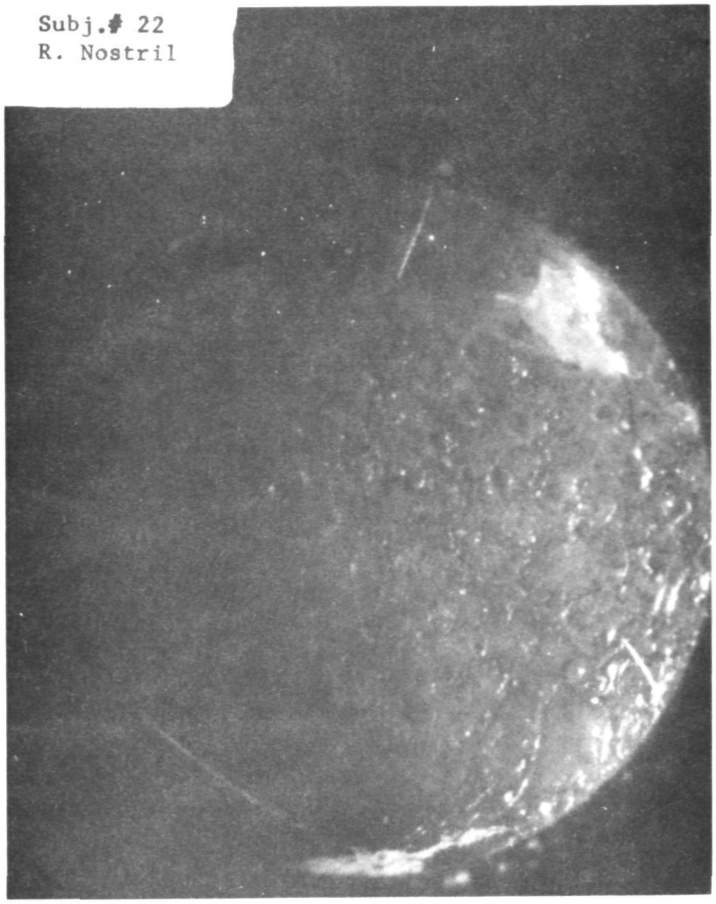
NORMAL NASAL MUCOSA



POST TEST

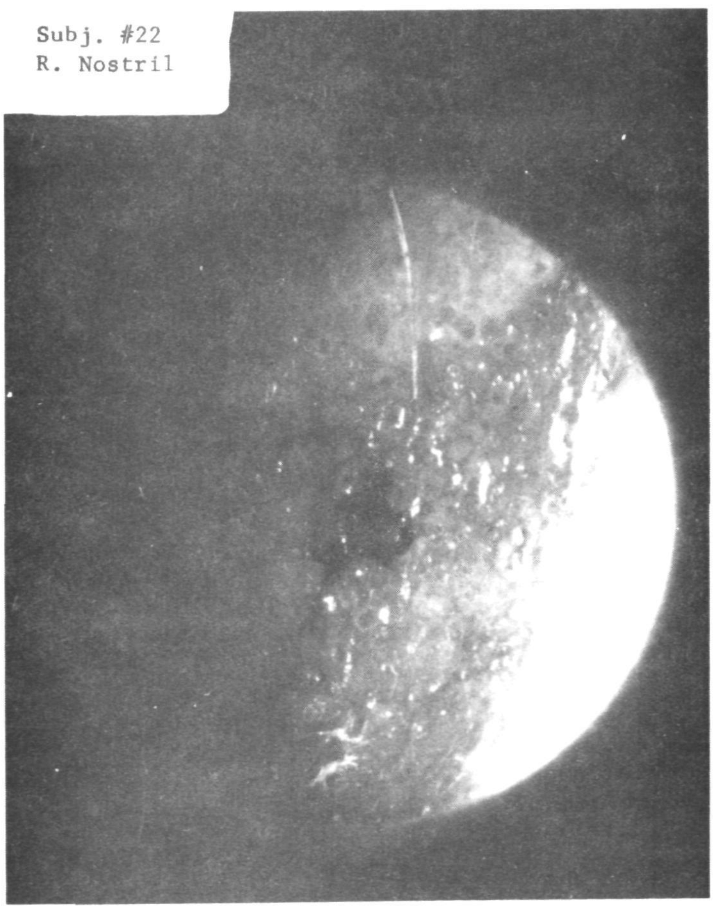
HEMORRHAGENOUS AREAS
AND BLISTERING

Figure 1



PRETEST

NORMAL NASAL MUCOSA

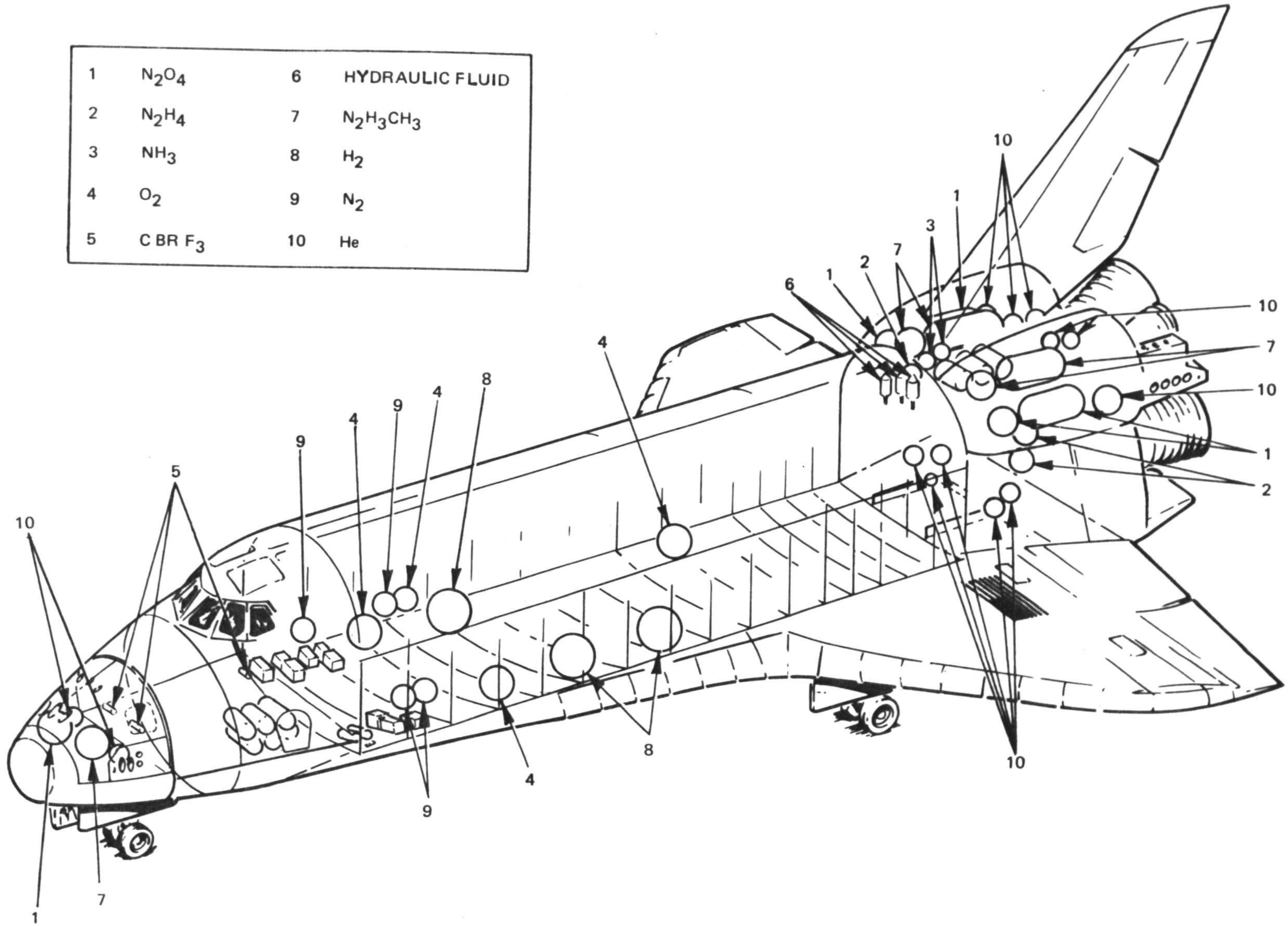


POST TEST

HEMORRHAGENOUS AREAS

AND BLISTERING

Figure 2



Fluids and Gases--Location

FIGURE 3

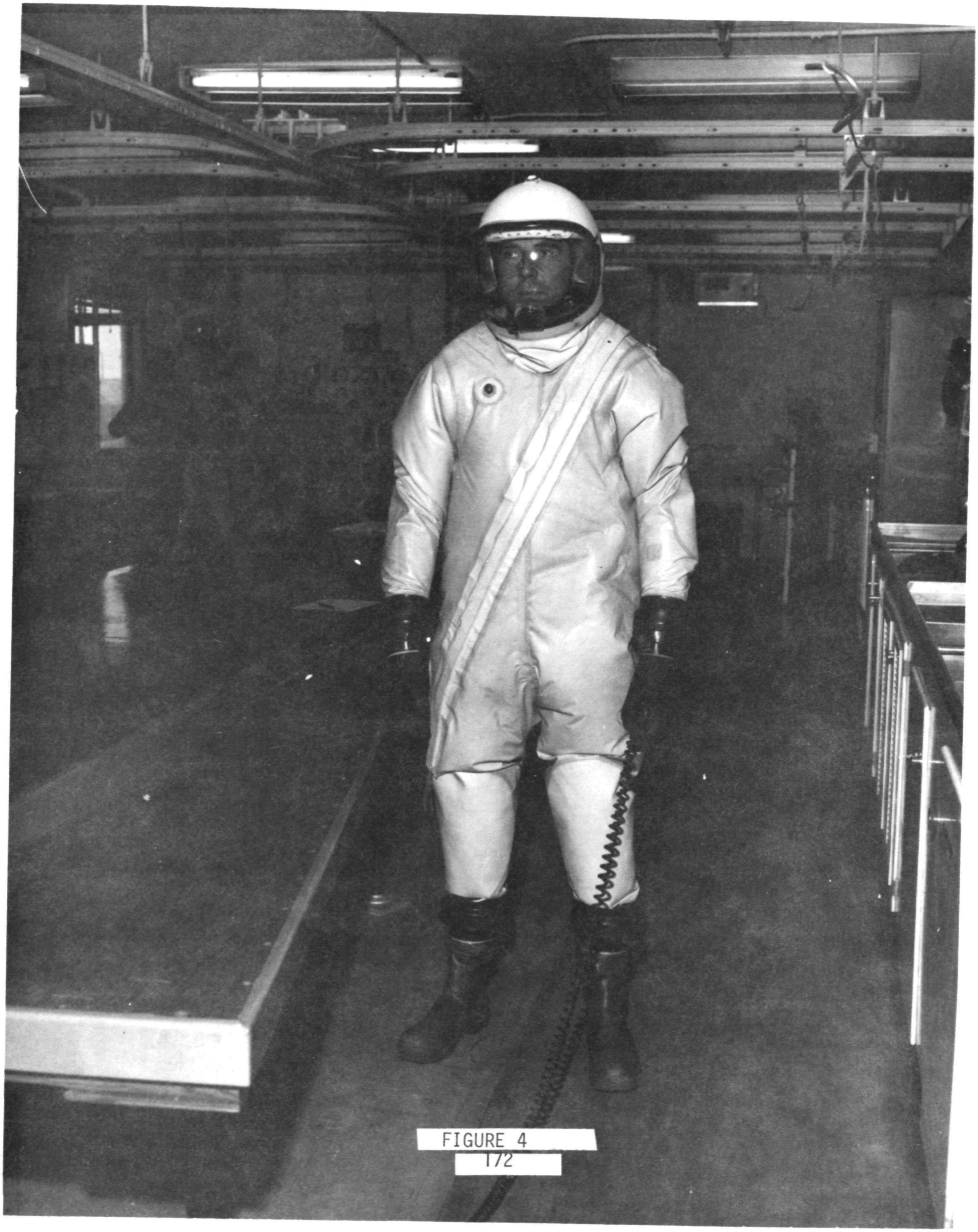


FIGURE 4

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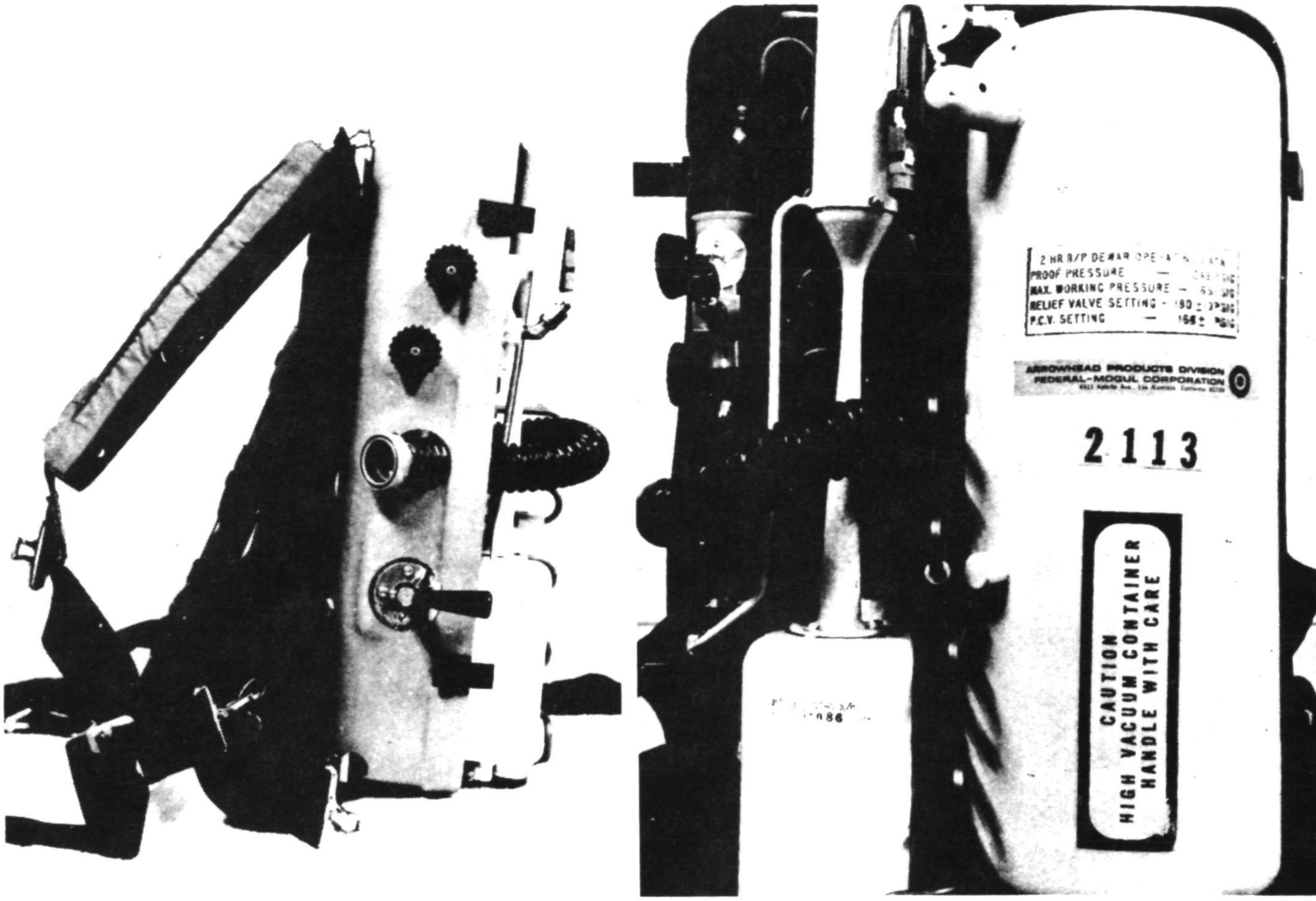
FIGURE 5



TWO-HOUR ENVIRONMENTAL CONTROL UNIT

DRAWING:	79K00962
USE:	To provide air for breathing and ventilation for wearers of toxic fuel handlers' coveralls.
MEDIUM:	Liquid air (7 liters).
DURATION:	2 hours at 11.7 scfm and 700 to 900 Btu/hr normal cooling.
WEIGHT:	34 lb (15.4 kg) fully charged; 18.8 lb (8.5 kg) empty.
FEATURE:	90 percent of the air output is recirculated air used in cooling the suit; approximately 10 percent is used for breathing.

This unit converts liquid air to gaseous air for breathing and ventilating when used with the coveralls (commonly called SCAPE SUIT) for toxic fuel handlers. It has a shelf life (standby time) of 16 hours when fully charged.

Figure 6

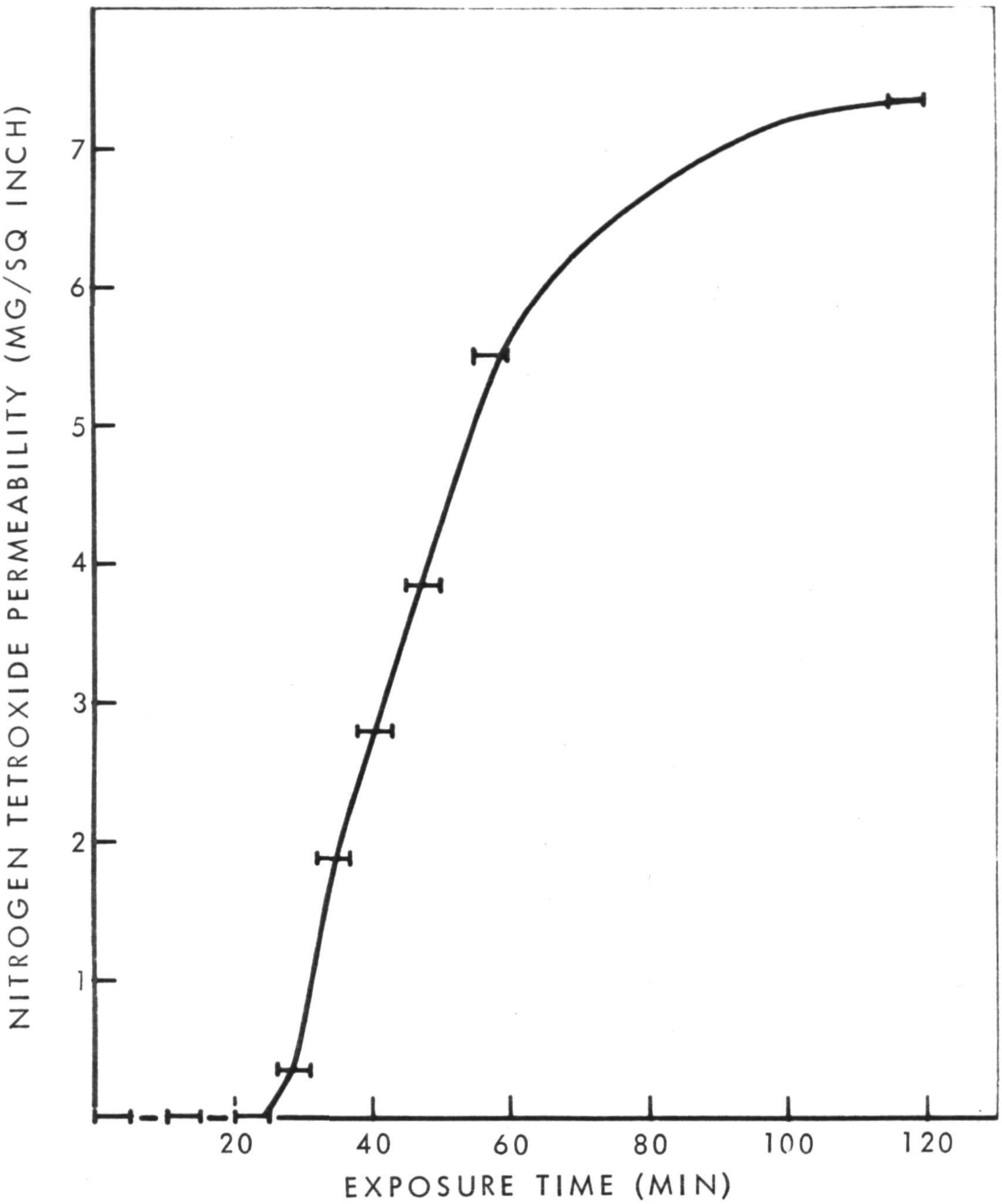


Figure 4: SAMPLE 5 PERMEABILITY CURVE
Preconditioned Plain (Unseamed)

FIGURE 7

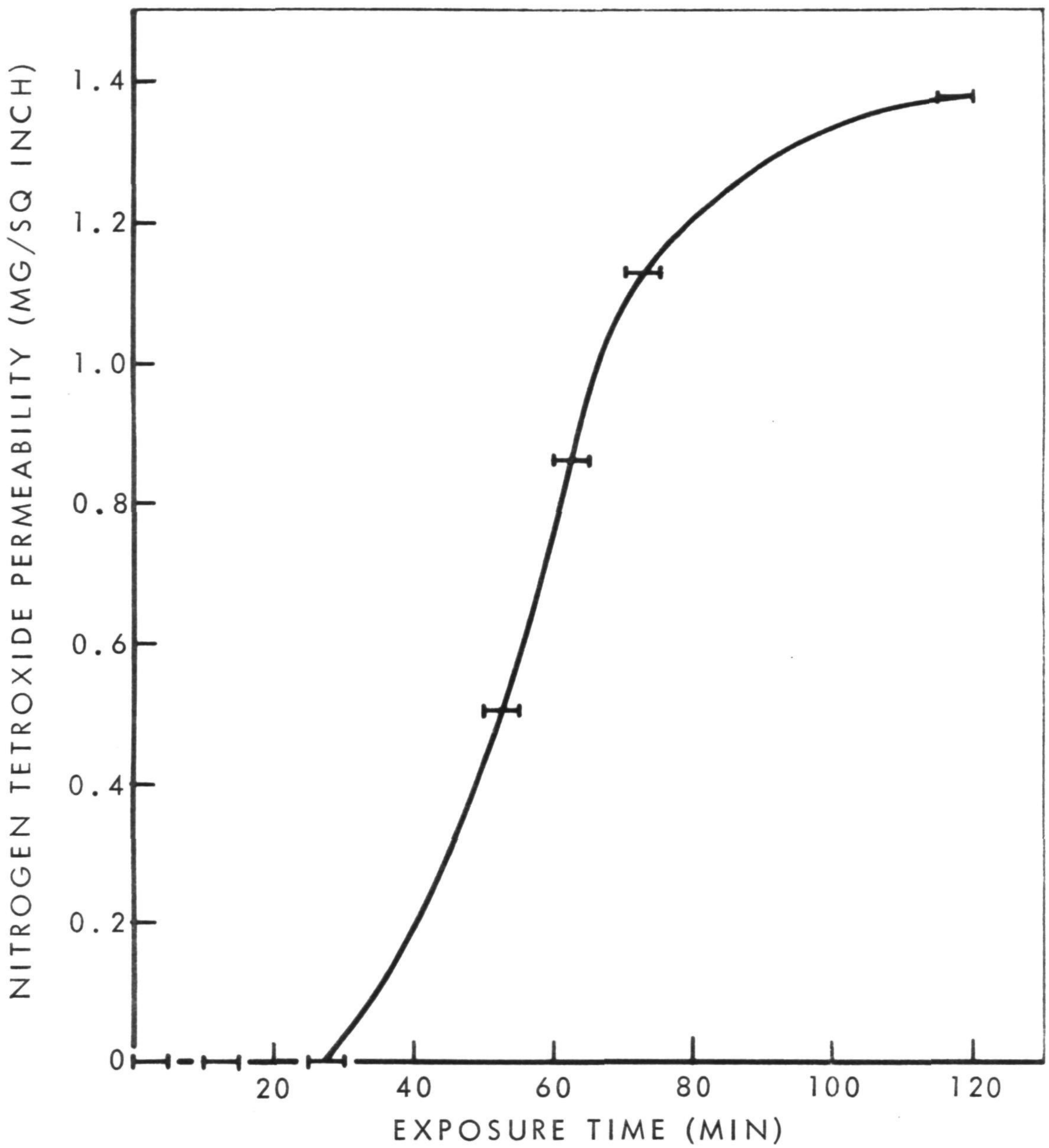


Figure 5: SAMPLE 6 PERMEABILITY CURVE
Unconditioned Plain (Unseamed)

FIGURE 8

SECTION II

2.0 HAZARDS AND SAFETY PRECAUTIONS

2.1 GENERAL. This section provides information on Orbiter hazards, their location, and first aid. Figure 2-1 shows the location of all the fluid and gas storage tanks. The quantities of fluid/gas listed in Table 2-1 will vary depending on whether the Orbiter completed the mission or the flight was aborted during launch. The quantities listed are with storage tanks full.

2.2 HAZARDS. Personnel engaged in Orbiter crash/rescue operations may be exposed to the following hazards:

- Unexpended pyrotechnic devices
- Toxic fumes
- Raw propellants (hydrazine and nitrogen tetroxide)
- Flash fires
- High pressures
- Hot brakes/wheels (fire/explosion)
- Static discharge
- Steam/hot water
- Propellant (fuel/oxidizer) fires

2.3 PROTECTIVE CLOTHING/BREATHING EQUIPMENT. Protective clothing and breathing equipment must be available for firefighter/rescue personnel. The chief officer shall determine the acceptable level of protection for his personnel after considering the hazards involved. Minimal levels of protection, for each hazard, will be described in this section when applicable.

2.4 MARKINGS, ACCESS PROVISIONS, AND EQUIPMENT LOCATION. Figures 2-2 through 2-15 illustrate the various access panels and doors, Orbiter structure, and components. The intent of these illustrations is to allow personnel to become familiar with the vehicle, its exterior markings, and equipment/component location.

2.5 PYROTECHNIC DEVICES. Pyrotechnic devices are provided for activation of the fire extinguisher system, emergency landing gear release system, and crew emergency escape system. With the exception of the ejection seats, the pyrotechnic devices will normally be disarmed by Contractor/NASA personnel. However, firefighter/rescue personnel must know their location. These devices are shown on Figures 2-16 through 2-18.

NOTE

For additional information on health, flammability, and reactivity codes used within this manual, refer to NFPA Manual, National Fire Codes, Volume 15, Standard 704M.

ECU DEFICIENCIES

"MIL-STD-1472B, Military Standard Human Engineering Design Criteria for Military Systems, Equipment and Facilities", page 137 recommends "a minimum of 30 cubic feet per minute per man into any personnel enclosure approximately two-thirds should be outside air".

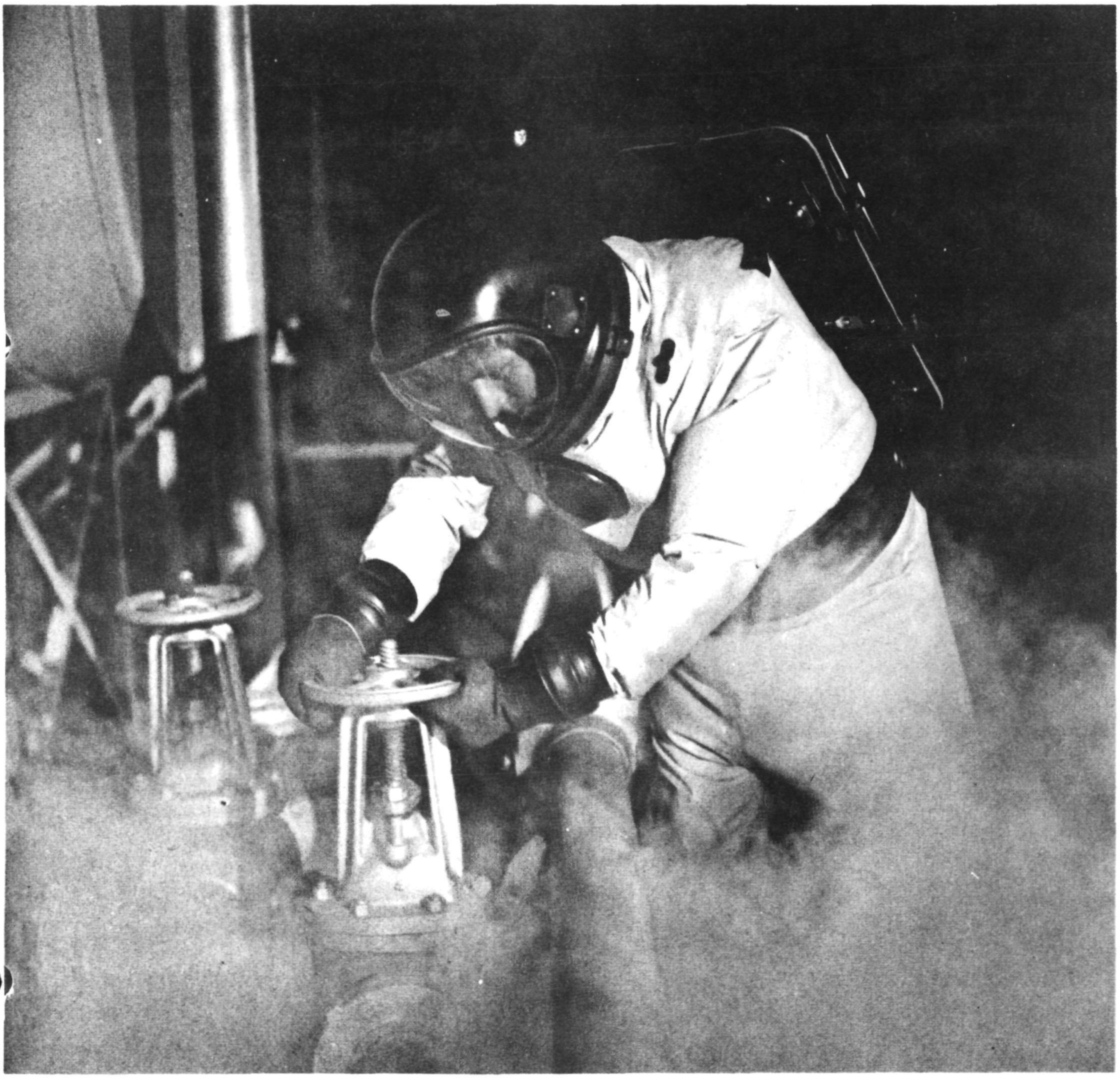
In SCAPE on maximum flow there is 12.3 SCFM (41% of optimum design). Fresh air is 1/8 of total ECU flow or 1.54 SCFM (7.7% of optimum design).

	MIL-STD-1472B	SCAPE ECU	PERCENT
Recommended flow	30 SCFM	12.7 SCFM max.	41%
Percent outside (fresh)	20 SCFM	1.54 SCFM max.	7.7%

Too much flow creates noise which interferes with communications. Tests could be run with a CAT IV suit to determine how many SCFM are an optimum compromise between recommended air flow and the maximum tolerable noise. Helmet modifications could be considered for noise reduction if the flow could be increased towards optimum design without reducing operating time.

ARROWHEAD PRODUCTS

Modular, Omni-Environmental Protective Suit



Modular, Omni-Environmental Protective Suit

■ MODULAR DESIGN ■ ALTERNATE AIR SYSTEMS ■ COMPLETE ISOLATION ■ IMPERMEABLE CONSTRUCTION ■ IMPACT, ABRASION RESISTANT ■ HIGH MOBILITY ■ INTEGRAL COMMUNICATIONS

General Description

The multi-hazard protective suit is designed to completely isolate a man from a variety of toxic or hazardous environments. The basic suit – consisting of coveralls, boots, gloves, and a helmet – is fabricated from a variety of impermeable and chemically resistant materials. These materials include coated fabric, stainless steel, laminated reinforced plastics, and special coatings of Teflon and Kynar.

All materials meet rigid permeability requirements and are effective against chemical and biological agents, nitrogen tetroxide, UDMH, hydrazine and other storable propellants.

Through integral connections, environmental control equipment, electronic detection and communications equipment, or emergency equipment may be introduced into the suit. Unique environmental hazards faced in various military and industrial operations can be met through appropriate component selection.

Coverall Design

The coveralls are two-piece, all bonded, with a sealed parting line at the waist. Knee and elbow areas feature external replaceable scuff pads and internal replaceable cushioning. A relief valve with a high dumping capacity is located under a cover on the chest. It is designed to maintain a positive pressure within the suit.

The ventilation system disconnect, mounted in the upper torso section of the suit, also functions as the gas distribution manifold and forms the upper structure of the environmental control unit (ECU) carrying frame. Ducts from this manifold carry air to the helmet and to the gloves and boots.

The ECU frame is fully adjustable for maximum wearer comfort. The entire assembly is readily decontaminated and resists decontamination agents. Acceptance testing includes soap bubble tests at 12-inches of water pressure to verify zero leakage through the seams of the suit or component materials.

Helmet Design

The helmet is of rigid shell construction with a replaceable visor. The size of the visor assures virtually unrestricted visibility. In the normal configuration soft foam earpads carry earphones and serve to stabilize the helmet. In addition to earphones, either a boom-type or a directly mounted microphone may be installed. Radio antennae may be built into the helmet for transceivers. Connections are available for radiac or electronic stethoscopes or for hardwire communications.

Helmet mounted filters with internal ducts and mouthpieces are available as emergency equipment. In cold weather, anti-fog agents or an exhaust deflecting mask may be used to reduce visor fogging. Glasses can be worn inside the helmet.

Component Attachment

All removable components of the suit are automatically sealed when connected. The molded butyl boot disconnect is bonded to the boot. Boots have non-skid sole treads and steel safety toes.

Two types of gloves are provided; inner and outer. The inner glove is very light weight and provides the dexterity required to manipulate small tools and make fine adjustments. The outer glove may be used alone when fine dexterity is not required. When both gloves are used, the outer one is removable without disturbing the inner glove seal.

The helmet disconnect consists of an aluminum ring and a butyl seal bonded to the helmet and a second aluminum ring bonded to the torso neck.

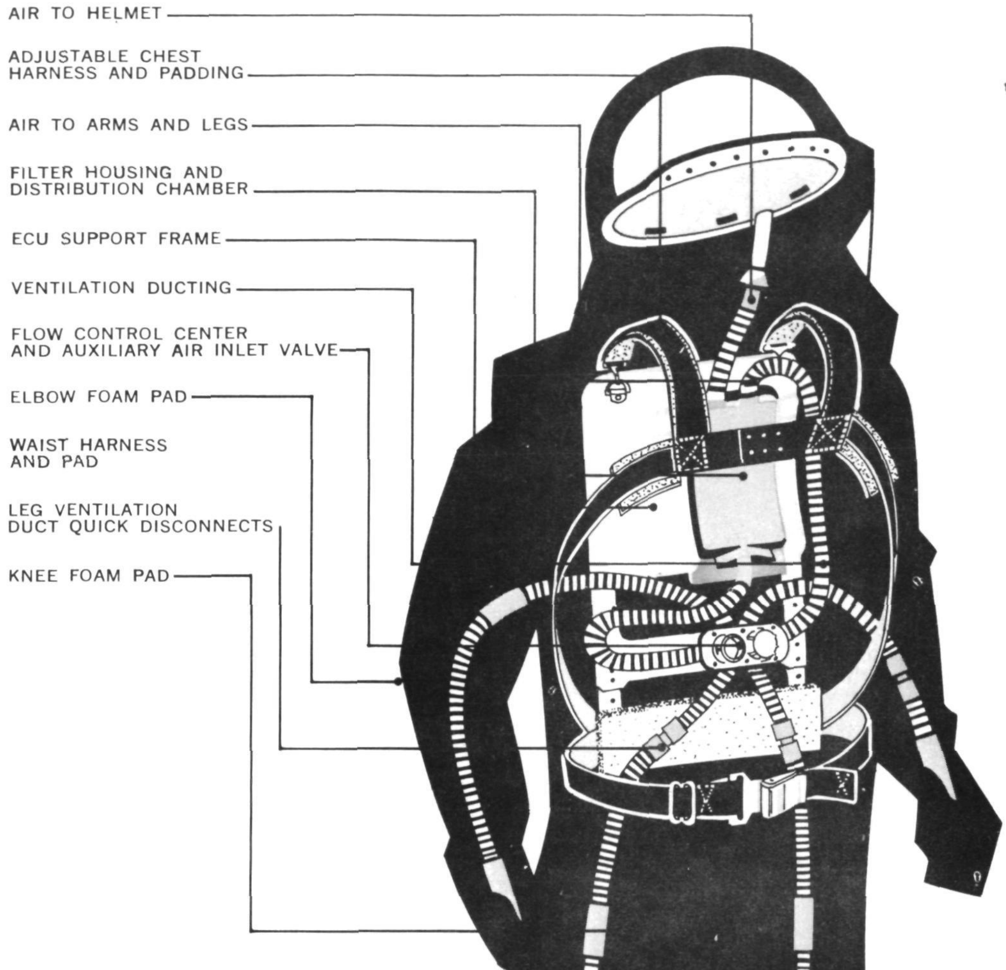
Air Supply Systems

Air supply systems provide disconnects that allow attachment or removal, even in a contaminated atmosphere, without allowing contaminants to enter the system. The primary air supply for breathing and ventilation is connected to the suit in the area between the shoulder blades.

For optimum cooling with complete mobility, liquid air evaporating packs are used. These may be back mounted or hand carried and connected to the suit via a double duct umbilical or even cart mounted for extended use. Fig. A.

When compressed air is available, simple ventilation or heating and cooling through the use of a vortex tube can be accomplished. Either portable compressors with appropriate filters or facility installed air lines may be used as the supply. Figure B.

Two-gas systems may also be used with the suit. For example: respiratory needs may be met by using a mask and a demand or closed loop oxygen system while cooling is provided by an evaporating liquid refrigerant.



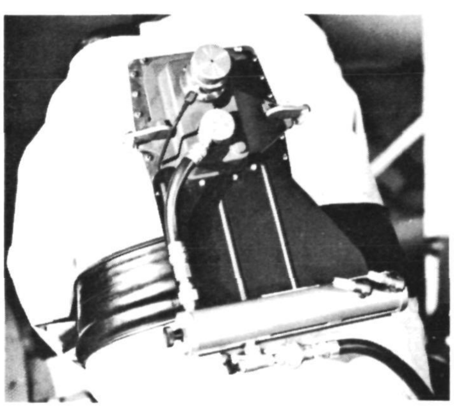


FIGURE B. COMPRESSED AIR WITH VORTEX TUBE

FIGURE A. LIQUID AIR PACK WITH UMBILICAL

Basic Ventilation System

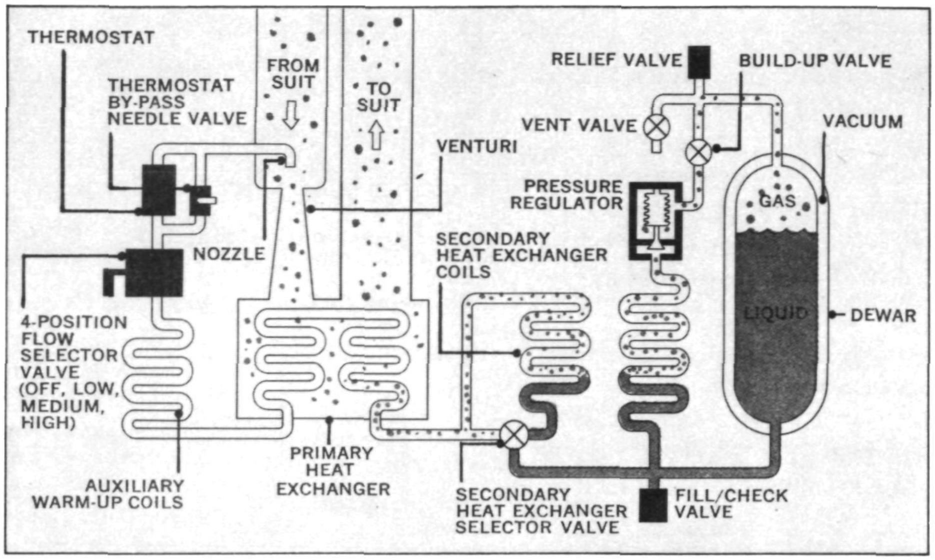
The basic environmental control unit (ECU) illustrated, provides a two to four hour supply of breathing and cooling air. Flow rate is wearer adjustable to control temperature, and match cooling capacity with metabolic demand. A thermostatic valve prevents freeze-up should the wearer set flow rate too high. The manifold in the suit-mounted portion of the disconnect divides the flow to the helmet and the extremities. Air to the helmet flows through a large duct to a disconnect which is an integral part of the neck ring. From this point, flow continues through a tube into the helmet distribution chamber between the helmet shell and its liner. A row of outlets provides an antifogging wash down across the visor.

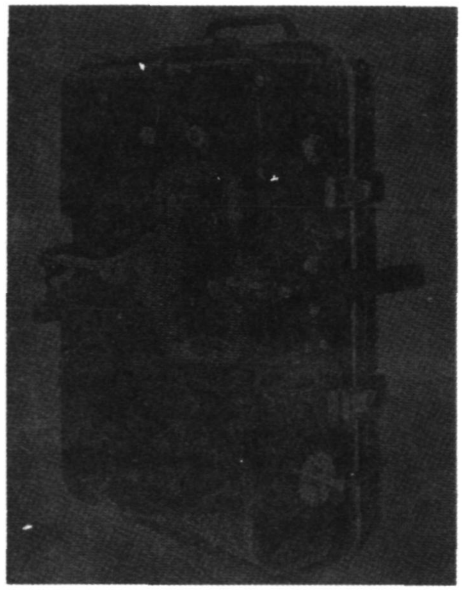
The chest mounted exhaust valve dumps suit air at a rate equal to the rate of evaporation of liquid air from the supply system.

Under emergency conditions the wearer may also use a compressed air supply. An attachment point is provided on the left chest.

Arrowhead Products has developed special test facilities for suit infiltration testing and for materials permeability tests. All suit materials have complete traceability. Tests have checked permeability at a sensitivity level of 1 part per billion of contaminants in air.

Tests use many procedures developed by Arrowhead Products, including a colorimetric procedure that provides accuracies an order of magnitude greater than procedures described in MIL-P-26359A for detecting N_2O_4. Suits also have been tested with, and are fully compatible with all common decontamination agents related to the toxic and contaminated environments with which the suits may be used.





Arrowhead Products has had extensive experience in protective ensembles for personnel working in hazardous environments. The SCAPE-Self Contained Atmosphere Protective Ensemble–used extensively by missile and rocket propellant handling crews is a development of Arrowhead Products.

BULLETIN NO. 62-169

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