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NASA *CR-66441*

GE DOCUMENT 67SD888

25 AUGUST 1967

A RESEARCH STUDY TO DEFINITIZE A BIO-ISOLATOR SUIT SYSTEM (BISS)

FINAL REPORT

GENERAL ELECTRIC

RE-ENTRY SYSTEMS DEPARTMENT

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A RESEARCH STUDY TO DEFINITIZE A BIO-ISOLATOR SUIT SYSTEM (BISS)

Prepared under Contract **No. NAS** 1-6537 **by**

GENERAL ELECTRIC

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for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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A RESEARCH STUDY TO DEFINITIZE A BIO-ISOLATOR SUIT SYSTEM (BISS)

FINAL REPORT

by

General Electric, Re-entry Systems Department

1.0 SUMMARY

This report covers the efforts and accomplishments of the General Electric Company, Re-entry Systems Department, in the conduct of a "Research Study to Definitize a Bio-Isolator Suit System (BISS)" for use in sterile spacecraft assembly facilities. This study, performed under Contract No. NAS 1-6537 from the Langley Research Center of the National Aeronautics and Space Administration, consisted of the following five tasks:

- TASK I. System Criteria
- TASK II. BISS Concept
- TASK III. Integrated Test Plan
- TASK IV. Materials Analysis
- TASK V. Mock-up Test Program

The objectives, accomplishments, and conclusions in each of these areas are described herein together with recommendations for further study to advance the developmental status of the BISS system.

2.0 INTRODUCTION

2.1 BACKGROUND

Programs for interplanetary missions such as Voyager require sterile flight vehicles if they are to enter the atmosphere or land on the surface of extra-terrestrial planets. Two basic concepts have been proposed for the achievement of the sterility of the spacecraft. These are called "Terminal Sterilization" and "Assembly/Sterilizer" processing.

Terminal sterilization refers to the concept in which a vehicle is assembled and check-out in a clean room, decontaminated with a gaseous biocidal agent (ETO), sealed in a canister, and then exposed to dry heat sterilization. Subsequent to sterilization, no access to the flight vehicle is possible without recontamination.

The Assembly/Sterilizer concept was developed by the General Electric Company and was first presented to NASA in the Mariner B and Voyager system design studies in 1963. The Assembly/Sterilizer is an ultra-bio-clean-room facility which permits decontamination and sterilization of disassembled spacecraft, and subsequent assembly, checkout, adjustment and if necessary, repair of the spacecraft in a sterile environment. Through the use of a Bio-Isolator Suit System, BISS, all human operators are topologically and biologically isolated from the spacecraft after sterilization operations have been initiated. The concept of the Assembly/Sterilizer facility layout is shown in Figure 1.

A study program to investigate the feasibility of the Assembly/Sterilizer concept was initiated by the General Electric Company on 21 July 1965 under NASA contract NAS 1-5381 from the Langley Research Center of the National Aeronautics and Space Administration and was completed on 21 February 1967.

On that program, the feasibility of the concept was established using a reduced scale analog of the full scale Assembly/Sterilizer. This analog is shown in Figures 2 and 3. The program effort and accomplishments are described in detail in GE Document No. 67SD604, "Assembly/Sterilizer Feasibility Program Final Report," dated 21 February 1967.

After establishment of the feasibility of the Assembly/Sterilizer with an analog model, the next logical step in the development was an investigation of the Bio-Isolator Suit System. A research study to definitize the Bio-Isolator Suit System was started by the General Electric Company on 28 July 1966 under NASA Contract NAS 1-6537 from the Langley Research Center of the National Aeronautics and Space Administration. This contract will be considered as completed upon approval

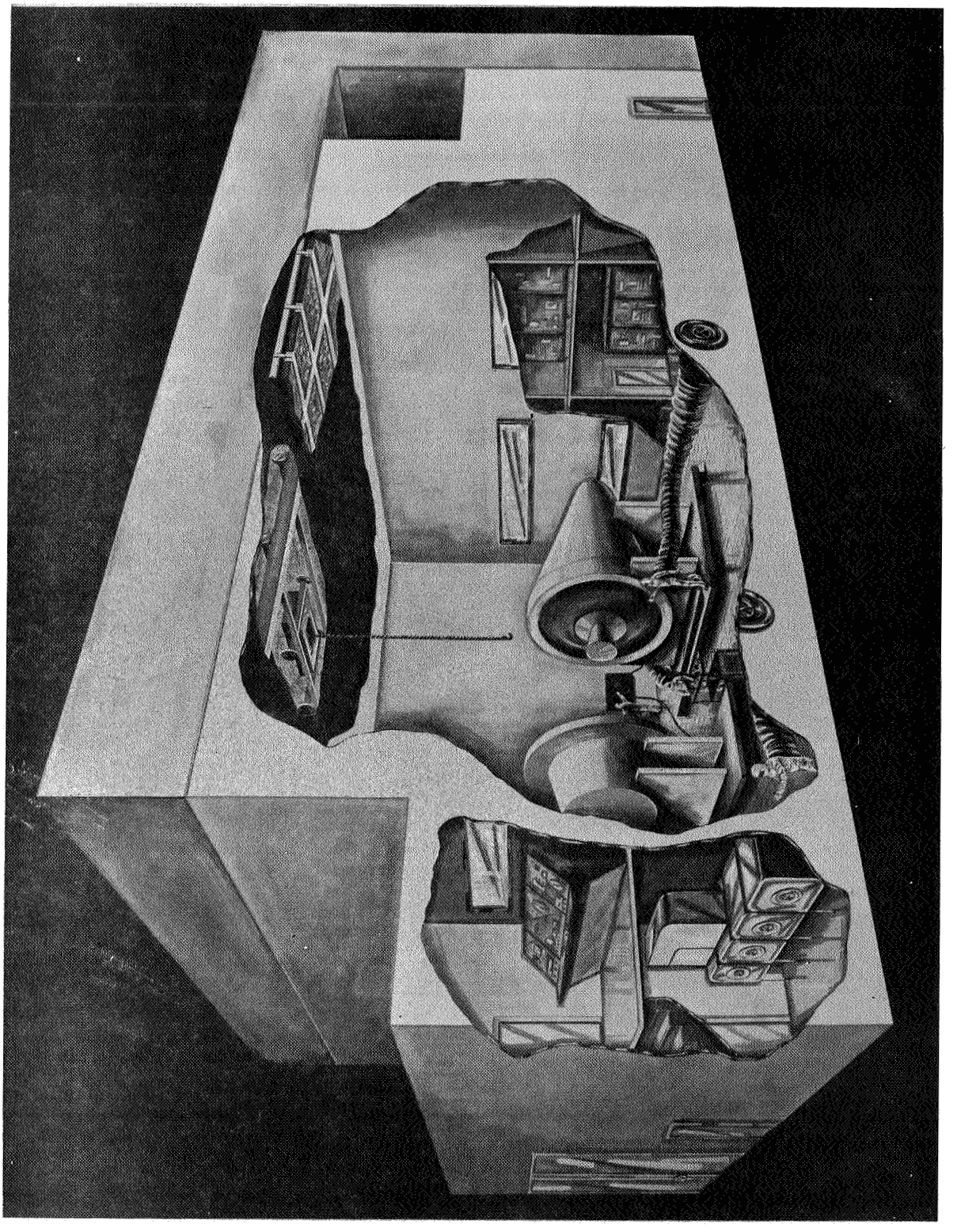

Figure 1. Assembly/Sterilizer Facility

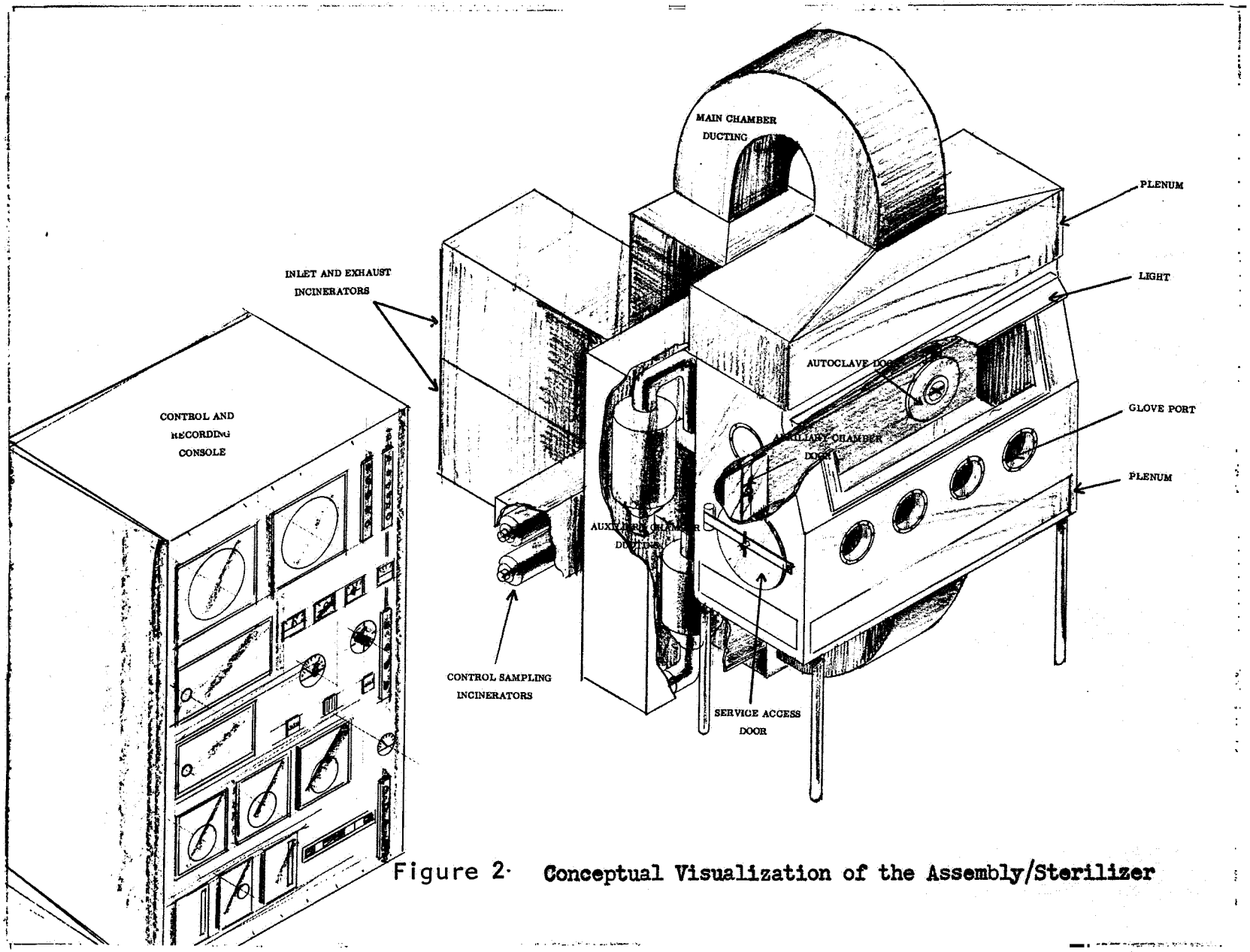

Figure 2. **Conceptual Visualization of the Assembly/Sterilizer**

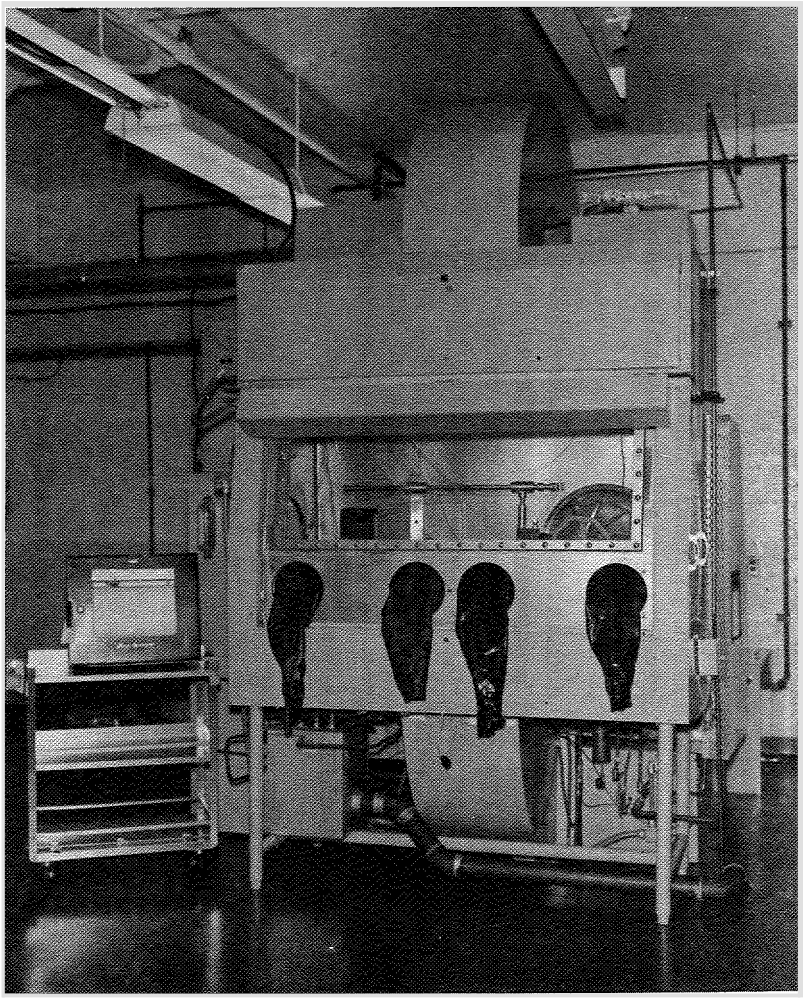

Figure 3A. Assembly Sterilizer Analog

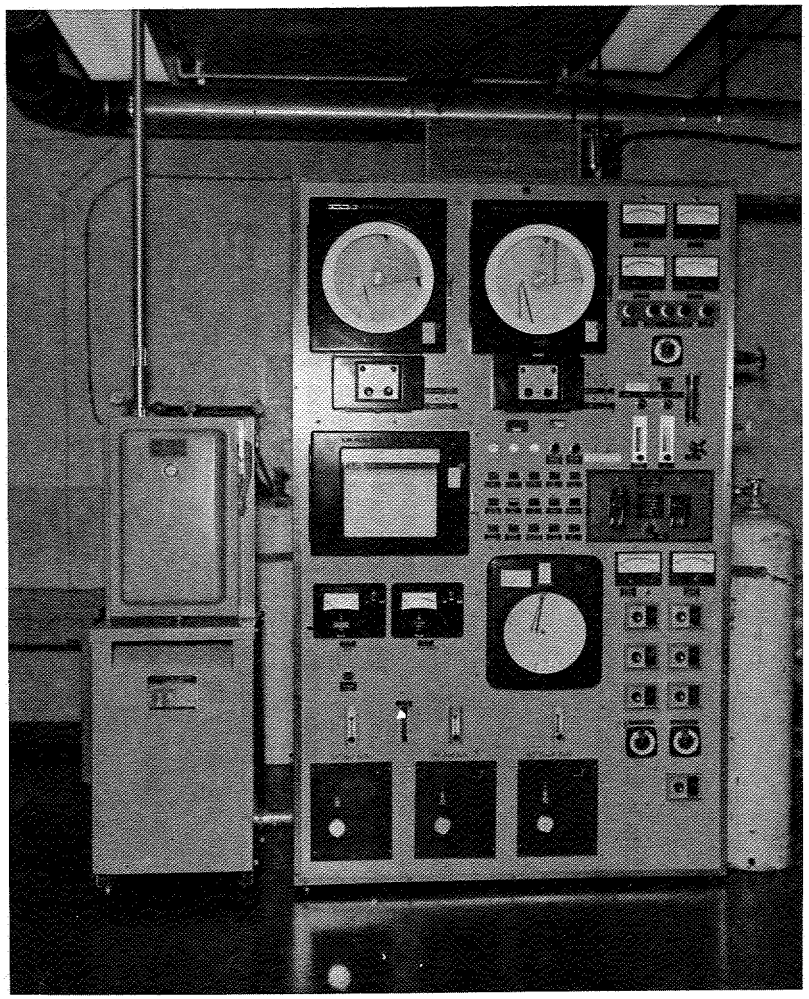

Figure 3B. Assembly Sterilizer Analog Control Station

by NASA of this Final Report. The efforts and accomplishments of this program are the subject of this document.

2.2 PROGRAM OBJECTIVES

It was the objective of this program to develop BISS functional requirements by investigating and defining system criteria, concepts, and materials. A laboratory test program was performed with functional mock-ups of BISS. Although these mock-ups were not intended to possess the environmental tolerance or bio-integrity of prime BISS systems, they did permit evaluation and development of the BISS concept and aided the functional definition of such a system. The program required the performance of five tasks to accomphish the objectives:

- TASK I. System Criteria
- TASK II. BISS Concept
- TASK III. Integrated Test Plan
- TASK IV. Materials Analysis
- TASK V. Mock-up Test Program

The objective of the system criteria task was to provide a quantitative description of the criteria in a form useable as definitive guide lines for the development of the BISS concept.

The BISS Concept task consisted of the investigation of design parameters and alternatives and man/machine interfaces to define design requirements for a BISS system satisfying the criteria. This task was closely related to the mock-up test program task which provided experimental evaluation and verification of the evolving concept. In addition to conceptual descriptions, the primary output of this task is the functional description of the BISS system and major elements thereof in the form of MIL type specifications.

The Integrated Test Plan task required the preparation and documentation of a coordinated plan for the laboratory investigations on the program and preparation of a plan for the test and demonstration of engineering models on a subsequent test program.

The objective of the Materials Analysis task was to identify and investigate candidate BISS suit materials by literature search, supplier conferences, and laboratory testing to determine their suitability for use

in the BISS program. Suitability was to be determined largely on four criteria:

- Bio-integrity
- Physical parameters
- Special environmental effects
- Effects of abrasion and other working conditions on the materials

The purpose of the Mock-up Test Program task was to provide basic experience with a mock-up suit and tunnel, entrance hatchway, life support equipment, and communications subsystem to support a suited worker. The suit and tunnel and life support and communications subsystems for the mock-up were to employ adaptations of available commercial equipment. The mock-up was to simulate BISS working conditions in a pressurized chamber to determine:

(1) Feasible means of access to and egress from the suit through the hatch and tunnel;

(2) Criteria for a man/machine interface which will provide a comfortable, hygienic working environment and permit the worker to accomplish the normal vehicle assembly and test tasks.

2.3 SUMMARY OF CONCLUSIONS

The outputs of the several program tasks have permitted the degree of definitization of the BISS system consistent with the fiscal and technical scope of the program. This definitization is documented in the form of specifications appended hereto and augmented by the technical discussions of this report.

The BISS suit concept has been fully developed and has been demonstrated in an essentially prime configuration mock-up. The mock-up suit and its associated helmet were fabricated in a more sophisticated configuration than the adaptations of a commercially available, special purpose, soft, industrial suit called for by the Statement of Work for the mock-up task. Very early in the concept development study and mock-up planning it was recognized that development of much of the detail necessary to specify an appropriate mock-up suit required experience with some form of tunnel-suit in a very similar environment and work situation. Since this experience was not available, it was determined that the most efficient course of action was to perform mock-up studies in two phases:

Phase I using a minimal adaptation of an inexpensive commercial suit, and Phase 11 employing a specially constructed mock-up of a refined design providing an excellent simulation of a prime **BISS** suit. This course of action was pursued with the result that the mock-up program demonstrated the feasibility and utility of a suit which configurationally requires only minor adaptation for prime **BISS** system definition. The helmet used with the Phase **II** suit is of prime system quality and would be useable in systems with a maximum exposure temperature of + 270°F. For higher temperatures an alternate design would be required.

The tunnel concept developed in Task **II** was realized in the mock-up and has been shown to be satisfactory. The basic ideas of supporting the tunnel by vertical stringers and reefing the tunnel Over a hard tube have also been satisfactorily demonstrated. A detailed study of mechanical systems for reefing and supporting the tunnel was beyond the scope of the program. However, the design problems associated with this ancillary equipment were investigated to the extent of identifying the major problems to be solved and recommending concepts for further investigation.

Any reefing mechanism must have means for positive attachment to the tunnel to apply driving forces. This requires not only a grasping device as part of the mechanism but also incorporation of graspable attachment points on the tunnel (or continuous grasping strips). Of necessity, therefore, the completion of tunnel definition must be concurrent with completion of a tunnel reefing mechanism definition.

The life support subsystem concept has been fully developed and reduced to breadboard equipment demonstrated in the mock-up testing. The life support equipment supplys conditioned air to a specially designed undersuit. The system gave excellent environment control for the **BISS** suit occupant and is directly applicable to a prime system with minor detail design changes.

A communications subsystem concept was developed and reduced to hardware for the mock-up testing. The majority of the subsystem is conventional in concept and implementation. The **BISS** occupant's communication equipment is unique. Transducers in the form of a microphone and small speakers are mounted on the upper chest of the occupant's undersuit permitting satisfactory two-way talk-at-will communications for the suited operator without encumbering him with a head-set or requiring that the transducers be able to withstand the severe environment which exists in the outer suit during sterilization.

Supporting studies have been performed in the areas of bio-integrity and leak detection, human factors, hygiene, maintenance, and safety. These studies played a two-fold role in the concept development: first they have provided inputs to the study and definition of the concepts for the BISS equipment; and secondly, they have provided one means of assessing the developed concepts against the prescribed system criteria. In this latter role, the supporting studies were augmented by a formal design review of the BISS concept. This review and the supporting studies assured that the results of the equipment concept study areas constituted a workable, integrated system satisfying the system criteria. The design review is not reported herein as a separate technical area because no non-compliant concept features or supporting study conclusions were identified. The design review did contribute significantly towards the crystalization of recommendations for future study, and this contribution is reflected in the recommendations section of this report.

The integrated test program was executed in accordance with the integrated test plan with some modifications to facilitate work, to improve experiment sensitivities, or to delete testing shown to be superfluous by early test results. Also, a preliminary test and demonstration plan for subsequent work was formulated. The work performed in the integrated test program consisted of physical and biological testing of candidate BISS materials and two phases of testing of mock-ups of the BISS system.

Testing of candidate materials was a part of the overall materials analysis task. In this task numerous candidate materials were screened for applicability in each of the following areas: outer suit and tunnel, gloves, boots, helmet, and undersuit. Candidate materials thus identified were subjected to biological and physical testing to augment published characteristics data. Based on these tests and the published data, recommended materials have been identified which satisfy the requirements in each of the areas. Following the identification of suitable materials, techniques of bonding materials were investigated with the objective of defining acceptable techniques for bonding in the fabrication of a prime BISS system.

In each of the areas investigated, bonding techniques were identified and tested with resultant demonstration of one or more techniques in each area with good mechanical properties. Subsequent micro-biological testing indicated permeability to micro-organisms either with a virgin bond or after stress treatments. Thus, this attempted advancement of the state-of-the-art, proving microbiological integrity of bonded materials, has not been accomplished within the scope of the present program. This is not felt to be an inherent limitation, but represents an area requiring further study and experimentation. Appropriate recommendations to this effect are contained herein.

In the mock-up testing, typical prime **BISS** system operations were investigated in a two-phased program. Phase **I,** employing a very elementary outer suit and tunnel, permitted early verification of the evolving system concept and provided information necessary for definition of a much more refined suit for the primary investigative efforts performed in Phase **11.** Through the use of a two-phased program, it has been possible to demonstrate, using a nearly prime configuration suit, the full operational feasibility of the **BISS** suit concept. Repeated successful cycles of entry and egress were accomplished with intermediate performance of a wide variety of simulated spacecraft assembly tasks. The primary emphasis in the mock-up testing was on ascertaining or verifying the man/machine interface in terms of criteria for a comfortable, hygienic work environment for a suited worker to accomplish normal flight vehicle assembly and test tasks. Throughout the test program personnel were observed to monitor their response to the environment and specific tests were performed to ascertain what physical limitations, if any, the BISS imposed on the suit occupant.

The mock-up program was highly successful. The test results show that occupant comfort can be maintained in a hygienic environment while performing a wide range of physical tasks. No significant decrement in performance capability, compared with normal operations, was noted beyond work shift duration limitations and manual dexterity reductions normally associated with gloved operations.

Although it was not the objective of this program to document a final detailed design of a prime **BISS** system, the degree of technical description in the resultant specifications is in some aspects less than anticipated at the outset of the program. This is due to the inherent nature of research programs of prescribed scope. In particular, when investigating a wholly new system the full degree of complexity of some of the systems interface problems and design details is usually not apparent prior to performance of the investigation; and secondly, accurate prediction of the effort required to satisfy new and unique requirements with existing techniques is impossible. These two difficulties have arisen in consideration of tunnel reefing and in the bonding investigation, respectively. The nature of these two problems has been discussed in the foregoing material. The effect is that further study is required to provide the desired degree of definition of tunnel interface with the reefing mechanism and **BISS** outer suit bonding techniques.

Recommendations for future work are provided in a separate section of this report. The recommendations fall into two basic categories: studies, development, and detailed design effort, beyond the scope of the present contract, required to advance the developmental state of the **BISS**

to that of a fully detailed design for a prime BISS system; and further operational support studies required to effect optimal integration of the prime BISS system into an Operational Assembly/Sterilizer facility. An example of the former is the extension of the tunnel reefing and support study. An example of the latter is the need to study the operational plans for processing specific flight systems through the facility, so that the communications subsystem concepts developed and demonstrated on the present program can be incorporated in an optimal communications system in the Assembly/Sterilizer.

3.0 SYSTEM DESCRIPTION

3.1 SYSTEM CONCEPT

The Bio-Isolator Suit System (BISS) is intended to be an integral part of the Assembly/Sterilizer facility for processing sterile interplanetary spacecraft. The Assembly/Sterilizer is a facility to permit sterilization of a partially assembled spacecraft, with subsequent access for checkout, repair, and final assembly under sterile conditions.

The function of the BISS in the Assembly/Sterilizer is a facility to permit a technician to work in a sterile chamber while maintaining an absolute biological and topological barrier between the technician and the environment. The barrier is provided by a suit connected to an outer wall of the sterile chamber by a tunnel. This concept is shown schematically in Figure 4. The analogy of the suit and tunnel to gloves used in glove-boxes in the biological and nuclear industries should be recognized.

In addition to the suit and tunnel, a complete BISS system requires equipment to maintain a proper environment for the suit occupant, to permit communication between the occupant and support and supervising personnel, to support and reef the tunnel, to assist occupant entry and egress, to monitor the occupants response to the environment, to monitor or check bio-integritg and to permit suit and tunnel maintenance and BISS occupant emergency rescue. These several functions are performed by BISS subsystems or ancillary equipment.

The BISS system complement of subsystems and ancillary equipment is provided in the following list.

BISS Subsystems

- Outersuit/Undersuit/Tunnel
- Life Support
- Communications

Ancillary Equipment

- Donning Rack
- Tunnel Support Boom Reefing Mechanisms and Equipment
- Hatch Assembly
- Medical monitoring equipment
- Leak Detection Equipment (Bio-integrity monitor)
- Antechamber

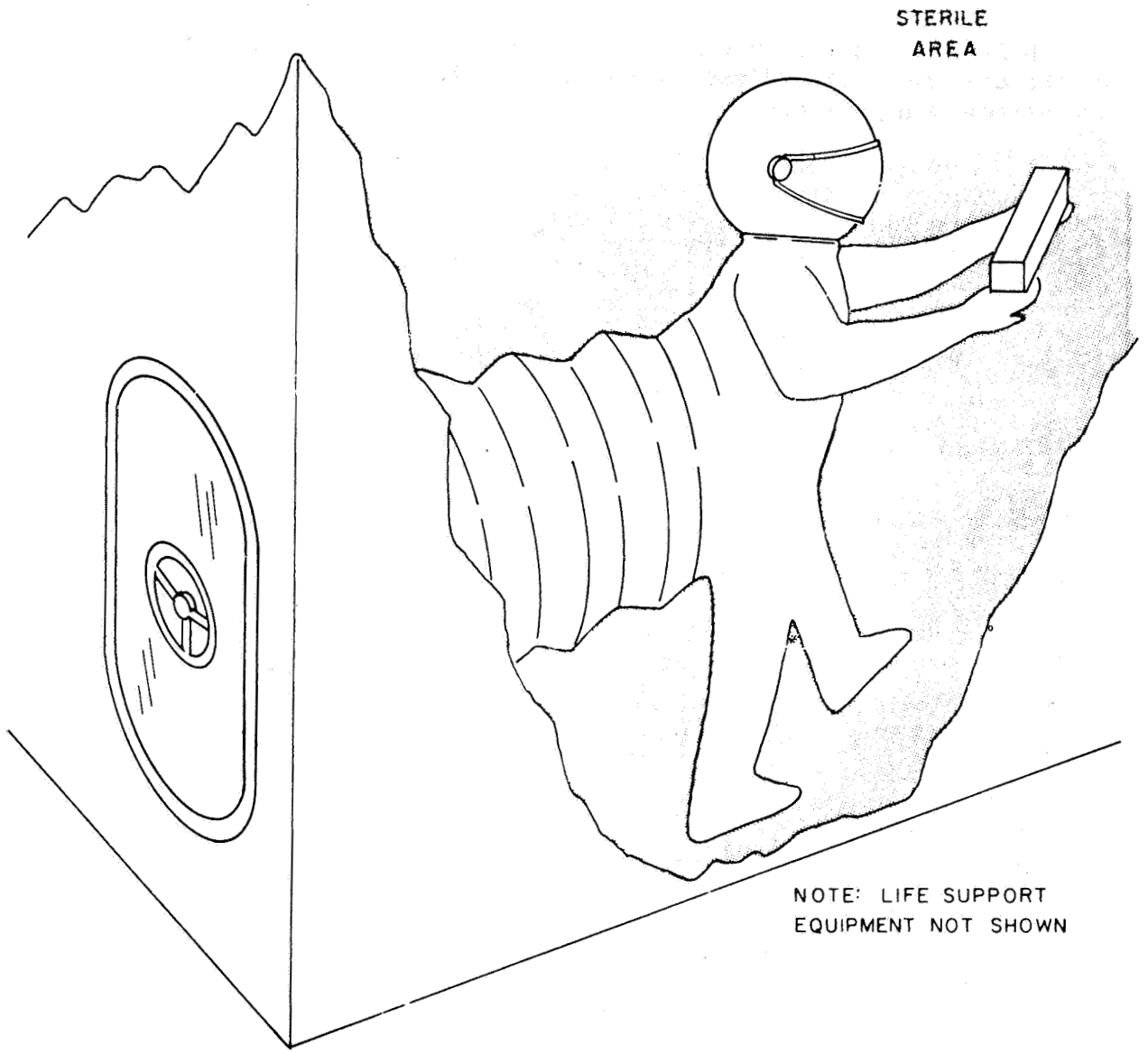

Figure 4 General BISS Configuration

3.2 SYSTEM CRITERIA

Definition of the system criteria was one of the five major tasks on the contract. The criteria establish the basic requirements for the system in nine areas:

1. Configuration
2. Bio-Integrity
3. Technician Environment'
4. Technician Safety
5. Human Factors
6. Hygiene
7. Equipment Environment
8. BISS Endurance
9. Sterile Maintenance

The system criteria were formulated during the first quarter of the program and served as a directive document for the development of the concept of the BISS system, subsystems, and ancillary equipment. Upon completion of the concept development and mock-up test program tasks of the contract, the criteria were reviewed and revised to maintain consistency with the evolving BISS system.

The revised system criteria are presented in Appendix A hereto.

3.3 SYSTEM OPERATION

Understanding of the BISS system concept and the role of each of the subsystems and items of ancillary equipment is aided by consideration of the employment of BISS in the Assembly/Sterilizer. The following discussion describes the BISS operations in part of a nominal flow and then covers one emergency condition and a maintenance procedure. The rationale behind each of the procedural steps should become clear after reading the detailed descriptions of the following sections.

3.3.1 BISS Operation in a Nominal Assembly/Sterilizer

Prior to the initiation of an Assembly/Sterilizer cycle, the BISS suit and tunnel would have been put in place, attached to the tunnel reefing and support equipment, and leak checked. The antechamber/main chamber door would be left open and the suit, tunnel, and tunnel mechanisms would then be decontaminated and sterilized along with the main chamber and its contents. During these treatments the tunnel is in a reefed condition and the suit is supported by the donning rack.

During the final phases of the post-sterilization cool down, **BISS** system operation is initiated. The life support and communications system are checked out, EKG electrodes are attached to the **BISS** technicians' torso, and the technicians suit-up in their undersuits. The undersuits are then connected to the life support and communications subsystems to complete entry preparations.

When the Assembly/Sterilizer chambers have reached ambient temperature, the **BISS** support personnel open the hatch to the tunnel and the technician climbs through the tunnel into the suit. This is made possible by a hard tube which runs the full length of the reefed tunnel from the hatch to the tunnel/suit interface. In climbing into the suit the technician first puts his feet down into the boots, then puts his head into the helmet and his arms into the sleeves. He is now prepared to disengage the suit from the donning rack and move into the chamber.

The technician moves out into the chamber, and the tunnel and support extends as he moves forward. As the technician moves away from the end of the hard tube, the tunnel collapses radially behind him. The technician is now free to move about in the main chamber and perform his assigned work tasks. The tunnel support and reefing mechanisms follow his movements.

While in the chamber, the technician can converse with his fellow workers or support and supervisory personnel by means of the communications system. His environment is continuously monitored and controlled by life support personnel, and his response to the environment is monitored by medical personnel.

At the completion of the required work, or the end of the work shift, the technician backs towards the antechamber and the tunnel is reefed. When he has reached the donning rack he attaches the suit to the rack and climbs out into the hard tunnel and then out through the hatch. Following each occupancy, the necessary suit disinfection procedures are performed prior to entry of the next technician.

3.3.2 Emergency Egress

If it becomes necessary for a technician to leave the suit immediately, he returns to the antechamber and climbs out of the suit. A disabled technician can be aided in the return to his antechamber by one or more other suited technicians in the chamber. Then personnel outside the chamber can aid the disabled occupant in getting out of the suit.

In extreme emergency conditions, either of the procedures can be followed: Support personnel can don air-packs, open emergency hatches to the main chamber, take an air-pack to the disabled occupant, cut him out of his suit, put the air-pack on him, and remove him from the chamber. Alternatively, the disabled BISS occupant could be returned to his antechamber by BISS suited personnel then the antechamber could be closed and the above procedure followed in the antechamber rather than in the main Assembly/Sterilizer chamber. Thus, the antechamber permits emergency rescue using most drastic techniques without compromising the sterility of the chamber and its contents.

3.3.3 BISS Suit Maintenance

In the event that a BISS suit is determined to be in need of repair or replacement while the main chamber is in a sterile condition, these operations can be performed without compromising the sterility of the main chamber. The antechamber is sealed off from the main chamber, then BISS support personnel can open a maintenance hatchway into the antechamber and effect any necessary repairs or replacement. Upon completion of these tasks, the antechamber maintenance hatchway is sealed and the antechamber and its contents are sterilized. Once sterility has been re-established, the antechamber door into the main chamber can be re-opened and the BISS suit can be put back into operation.

4.0 BISS SUBSYSTEMS AND ANCILLARY EQUIPMENT

4.1 SUIT AND TUNNEL

4.1.1 Configuration Selection

The selection of a suit employing a tunnel was made prior to the study under the subject contract. The following discussion gives the background on this selection.

The suit and tunnel are the heart of the BISS system and provide the physical envelope which forms the barrier between the technician and the sterile environment. The maintenance of an absolute biological barrier suggested the tunnel concept which achieves biological isolation through topological isolation.

Two fundamentally different suit system concepts are employed for isolation of a technician from an industrial or laboratory environment and were considered for possible application in the Assembly/Sterilizer, These are:

1) Free suit with life support back pack
2) Free suit with life lines (gas supply and exhaust)

Examples of the first class are the SCAPE* suit shown in Figure 5, used for rocket motor fueling and some fire fighting suits. Examples of the second class are deep diving suits, the INFAB** used for fabrication of specialty steels in an argon atmosphere at Universal Cyclops Specialty Steel Division, and a system used at Lobund Laboratory (Notre Dame) for gnotobiological experimentation.

Either one of two basic schemes can be used to introduce a man in either type of free suit into a special environment chamber. The first is the use of a special "lock" or antechamber. For the purposes of the Assembly/Sterilizer this scheme is not feasible because chemical sterilants (such as used at Notre Dame) are not sufficiently reliable and steam or dry heat sterilization treatments are not practicable for a suit with a man in it. In the second scheme part of the suit is integral with the wall or floor of the chamber. The technician enters

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* Self Contained Atmospheric Protective Ensemble
** Inert Fabrication

Figure 5. Scape Suit

this part of the suit, effects a seal to the rest of the suit, and then detaches the suit from the chamber surface. This scheme is akin to that used in table-top isolators for gnotobiological experimentation. A proposal for implementation of this basic scheme for a suit system has been made by Trexler*** This proposal does not appear to offer the reliability required for the **BISS** system.

Any free suit system has the inherent hazard that each introduction of a man into the chamber poses a threat to the sterility of the system and this threat is repeated at least twice per man during the normal eight hour work shift in an industrial application.

These factors lead to the selection of the general configuration of a suit with attached tunnel for the BISS.

4.1.2 Rigidity

Once the general **BISS** configuration of a suit and tunnel had been selected, it was necessary to determine the optimum degree of hardness for these two elements of the system. These were the first two trade-offs in the concept development under the subject contract. Since the suit and tunnel have different requirements, the hardness trade-offs were made separately.

4.1.2.1 Suit

Several different degrees of suit hardness can be defined ranging from a very light weight, flexible membrance envelope (monofilament less than 5 mils thick) to a completely rigid suit with articulated joints (e.g. a deep diving suit). For the purposes of a trade-off evaluation, three degrees of hardness were evaluated:

Soft - Flexible suit fabricated of reinforced or composite material.
Semirigid - Soft suit modified by the addition of rigid metal or plastic limb (and possiblytorso) sections bonded to the flexible shell.
Rigid - Hard Suit composed of rigid metal or plastic limb and torsa sections interconnected by articulated joints.

These three types of suits were judged to be equivalent in terms of hygiene interfaces with the tunnel and life support and communica-

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*** P.C. Trexler "The Detection and Elimination of Contamination from Germfree Operations", 1965 Proceedings of the Forth Annual Technical Meeting and Exhibit of the A262.

tions subsystems, and decontamination and sterilization compatibility. However, there are several important parameters for which the suits are not equivalent. The trade-off comparison based on these parameters is provided in Table I.

TABLE I. SUIT HARDNESS TRADE-OFF (NOTE 1)

PARAMETER	SOFT SUIT	SEMIRIGID	RIGID
Weight	1	2	3
Sizing Fit	1	2	3
Mobility	1	2	3
Ease of Entry and Egress	3	1	2
Physical Injury Protection	3	2	1
Emergency Egress	1	2	3
Joint Sealing	1	1	3
Joint Fatigue	1	2	3
Puncture Resistance	3	2	1
cost	1	2	3

Note (1) - Rating of 1 is best, 3 is worst

Selection of a suit type from Table I. could be made by assigning a weighting factor to each parameter and then deriving a rating score for each suit type. However, since the soft suit ranks first in all but three of the eleven parameters, a more direct approach is to tentatively select the soft suit and assess the significance of the last place rating in these three parameters.

Ease of entry and egress for the soft suit was evaluated in the mock-up test (See Section 8.0) and was found to be adequate. The entry and egress times are within the limits set by the system criteria.

Physical injury protection in an industrial environment is normally concerned primarily with the head, hands, and feet inasmuch as these are the three areas most subject to injury. Any reasonable BISS suit, will have a hard helmet and soft gloves; further, steel toe caps can

be incorporated in soft suit boots, Thus physical protection of the three most likely injury areas is essentially equivalent for all three suits. The semi-rigid and rigid suits do offer better protection of limbs and torso, but any deficiency of the soft suit in this respect can be minimized by proper work procedures. Also, the more mobile, soft suited worker can better avoid a potential injury situation.

Puncture resistance is an important factor in bio-integrity. The soft gloves common to all three suit types are the most likely site for occurence of a puncture, minimize the advantage in this respect of the semi-rigid or rigid suit. In the materials analysis effort on the contract (See Section 7.0) puncture resistance is one of the tests performed to select materials for a soft BISS suit. The results of this analysis indicate that a soft suit system with high puncture resistance is feasible.

The soft suit was selected for the BISS. None of the last place ratings for the soft suit in Table I. represents a major reason for selection of one of the other suits, and overall trade-off rating strongly favors the soft suit.

Any free suit system has the inherent hazard that each introduction of a man into the chamber poses a threat to the sterility of the system and this threat is repeated at least twice per man during the normal eight hour work shift in an industrial application.

These factors lead to the selection of the general configuration of a suit with attached tunnel for the BISS.

4.1.2.2 Tunnel

The optimum degree of rigidity for the tunnel requires a trade-off evaluation independent of the individual parameters of the suit rigidity trade-off, but not independent of the suit trade-off overall result. In particular, a tunnel of fixed cross section when used with a soft suit results in an unbalanced force tending to push the occupant back into the tunnel.*

* A positive, inward pressure gradient of up to four inches of water (gage) is maintained across the suit and tunnel outer surfaces. This results in an unbalanced force of 5.202 lbs per inch of water per square foot of tunnel-suit interface opening. Depending on the nature of the suit end tunnel and their interface, this force tends to collapse the tunnel axially and/or push the suit occupant into the tunnel.

Three degrees of tunnel hardness were considered:

Soft - Flexible tunnel fabricated of reinforced or composite material, supported vertically by an overhead load balancing device, and free to collapse axially and radially.

Semi-rigid - Soft tunnel modified by the addition of circumferential support rings and constant force axial extension aids.

Rigid - Articulated hard tunnel of fixed length and cross section supported vertically by casters or dollies on each tunnel section.

TABLE II. TUNNEL HARDNESS TRADE-OFF (NOTE 1)

PARAMETER	SOFT	SEMIRIGID	RIGID
Weight	1	2	3
Mobility Horiz.	1	2	3
Vert.	1	2	non-existent
Ease of Entry and Egress	2	1	3
Ease of Rescue	2	1	3
Unbalanced forces on Occupant	1	3	3
Obstruction of Working Space	1	2	3
Disruption of laminar gas flow (if used)	1	2	3
Vertical load balancing	3	3	1
Ease of Reefing	2	1	not possible
Joint Sealing	1	1	2
Joint Fatigue	1	2	3
Material fatigue due to reefing	3	2	not possible
Damage Resistance	2	2	1
Maintainability	1	1	

Note (1) Rating of 1 is best, 3 is worst.

A simple unweighted summation of the parameter ratings in Table II. indicates that the soft tunnel is most desirable and the rigid tunnel is least desirable. The two major parameters not covered in the table are cost and complexity. Meaningful evaluation of these parameters would have required a depth of design detail on each tunnel type inconsistent with the status of the concept development at the point at which the trade-off was made. However, thediffersnces in these parameters for the three tunnel types are felt to be small relative to the overall cost and complexity of the Assembly/Sterilizer facility of which the tunnel will be one element.

Also not shown explicitly in the table is the need for (or utility of) an antechamber for the three tunnel types. Of the three, only the rigid tunnel could not use an antechamber. Because it is not axially compressible, the rigid tunnel could not be withdrawn into an antechamber. Thus the features of suit-tunnel maintenance and drastic emergency procedures (cutting a man out of a suit) without contaminating the sterile Assembly/Sterilizer main chamber are not available for the rigid tunnel system.

Any reasonable weighting of the significance of the several trade-off parameters clearly favors the soft or semi-rigidtunnel over the rigid type. Further trade-off between these two is heavily dependent on two parameters: ease of reefing and unbalanced forces on the suit occupant. The reefing mechanism (See Section *4.3)* for either the soft or semirigid tunnel will be quite sophisticated, probably being more complex for the soft tunnel. Any advantage gained on this point for the semirigid tunnel is offset to some degree by the greater complexity of the tunnel itself in comparison with the soft tunnel.

The problem of force unbalance for the semi-rigid tunnel is significant. The unbalance for a 5 square foot tunnel-suit interface is on the order of 26 pounds per inch of water pressure differential across the suit and tunnel outer surfaces. The result is high local pressures on the suit occupant at the interface circumference in equilibrium with a low force distributed rather uniformly over the front of his body. The effect is to tend to push the occupant out through the tunnel. This would cause very exhausting and possibly injurious stress on the occupant. A body-contoured plate could be attached to the back of the occupant to equilibrate the forces without high local forces; however, such a plate would make entry and egress much more difficult and would very adversely affect occupant mobility and comfort.

In summary, the soft tunnel is the most desirable of the three types studied and was selected for the BISS. This tunnel concept has been shown in the mock-up tests (see Section 8.0) to be feasible.

4.1.3 Description

4.1.3.1 Suit

Upon selection of a soft suit, a trade-off was made to determine the optimum way of incorporating the life support functions and suit communications transducers in the suit. It was determined that a double suit concept was desirable employing an outer suit for the microbiological barrier and an undersuit as a personalized garment with life support and communications interfaces.

The outer suit is an anthropomorphically shaped, multi-layer plastic laminate garment which has attached to it relatively form-fitting gloves, semi-rigid boots (e.g. fireman's boots), and a fishbowl helmet and support harness (or yoke). Support rings flank the elbows and thighs. The outer suit interfaces with the tunnel by means of a 104" circumference opening in the back of the suit.

The undersuit is a multi-layer undergarment which permits air circulation for body cooling. An interface is provided on the undersuit for the life support subsystem plenums. The undersuit also provides two plates which serve as attachment points for the communications system transducers.

4.1.3.1.1 Undersuit - The primary functions of the undersuit are:

- To provide an interface for the life support supplies of breathing air and cooling medium.
- To provide body cooling capability.
- To provide mounting for the occupant's communications transducers.
- To act as a personal undergarment promoting good hygiene and containing personal bacteria.
- To relieve effects, such as chafing, resulting from compression of the soft outer suit against the occupant's body.
- To minimize the range of suit elements that must be designed to withstand sterilization.

The provision of body cooling cgpability is a particularly important function of the undersuit. To permit comfort and efficiency for extended operations in the BISS, it is necessary to remove excess body

heat. In providing a capability to do so, the undersuit acts as an adjunct to the life support subsystem.

Two types of cooling undersuits, liquid cooled and gas cooled, have been developed for space suit and other applications. Both types of undersuits were investigated by trade-off analysis and experimentation to select the optimum undersuit for the BISS. An air-cooled undersuit, designed by GE on the program was compared with a commercially available watercooled undersuit. The air-cooled suit was selected. The trade-offs and experimental results which lead to this selection are discussed in Sections 4.7.3.1 and 8.0 uespectively.

In the air cooled concept, the cooling air is ducted to the ankles and wrists of the undersuit, drawn through the limbs to the torso, across the torso, and is then exhausted from the back of the suit. This undersuit was originally conceived as an individually tailored garment with three bonded layers: a cotton inner layer to interface with the occupant's shin; an open cell foam, which would compress somewhat under pressure, but still permit air flow; and a layer sealing the outer face of the foam and channeling the cooling air flow. Practical difficulties of bonding a cotton fabric to open cell foam necessitated modification of this concept to permit a separate suit of long cotton underwear covered by the air channeling undersuit. This modification necessitated bonding a thin, highly-porous, low friction material to the foam inner surface to reduce friction between the foam and the cotton underwear.

Two versions of the undersuit were designed and fabricated for the mock-up tests described in Section 8.0. The first version consisted of a close fitting modified SCUBA diver's "wet suit" of closed-cell neoprene rubber with a layer of open-cell polyurethane foam bonded to the inner surfaces. This Phase I version of the undersuit is shown in Figure 6.

Additional development of the concept based on Phase I mock-up experience indicated that the neoprene outer layer of the undersuit should be replaced by a thin, low-friction material. It was found that the neoprene grabbed against the outer suit material and reduced the ease of operator entry and exit. It was also determined that the outer layer should be a lighter weight material and that the suit should be a relatively loose fit. A Phase II undersuit was designed and procured based on the experience with the Phase I undersuit. This undersuit is described by the following text and illustrations.

The undergarment is full length, covering the wearer's arms to the wrists and legs to the ankles. Figures 7, 8, 9 illustrate the overall appearance of the garment. The dimensions shown in these drawings

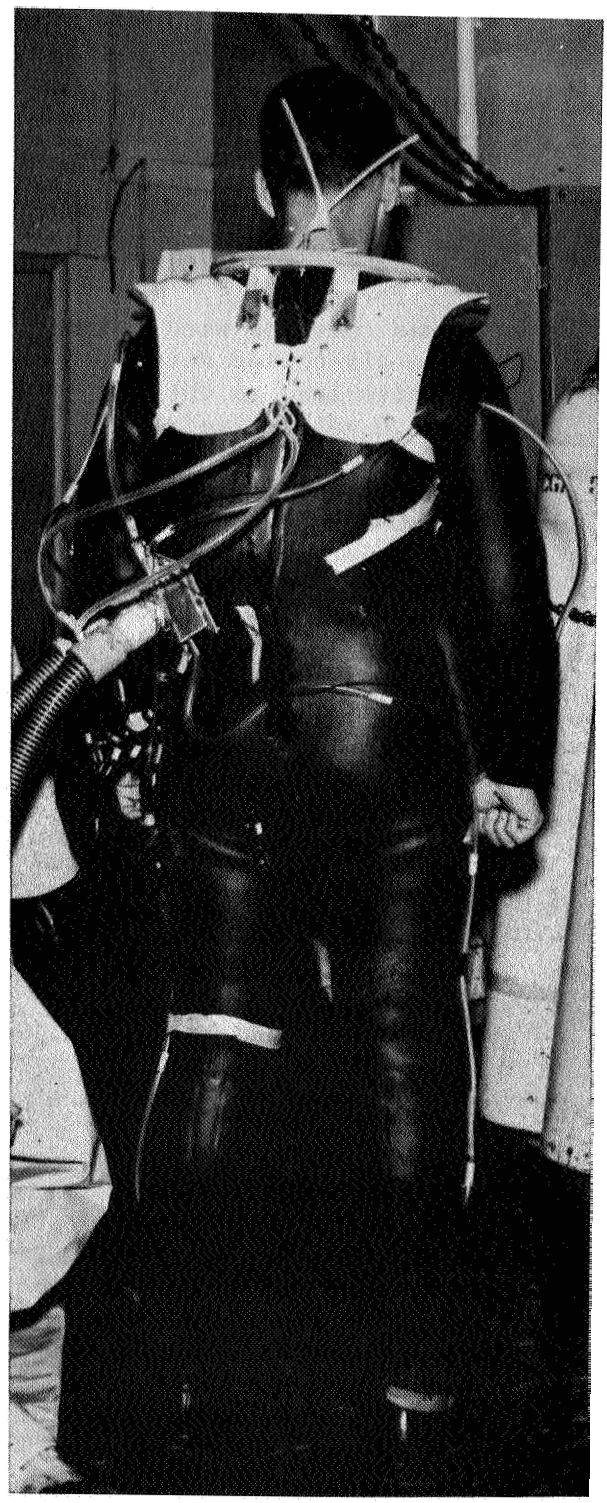


Figure 6. - BISS **Phase I Undersuit Rear View**

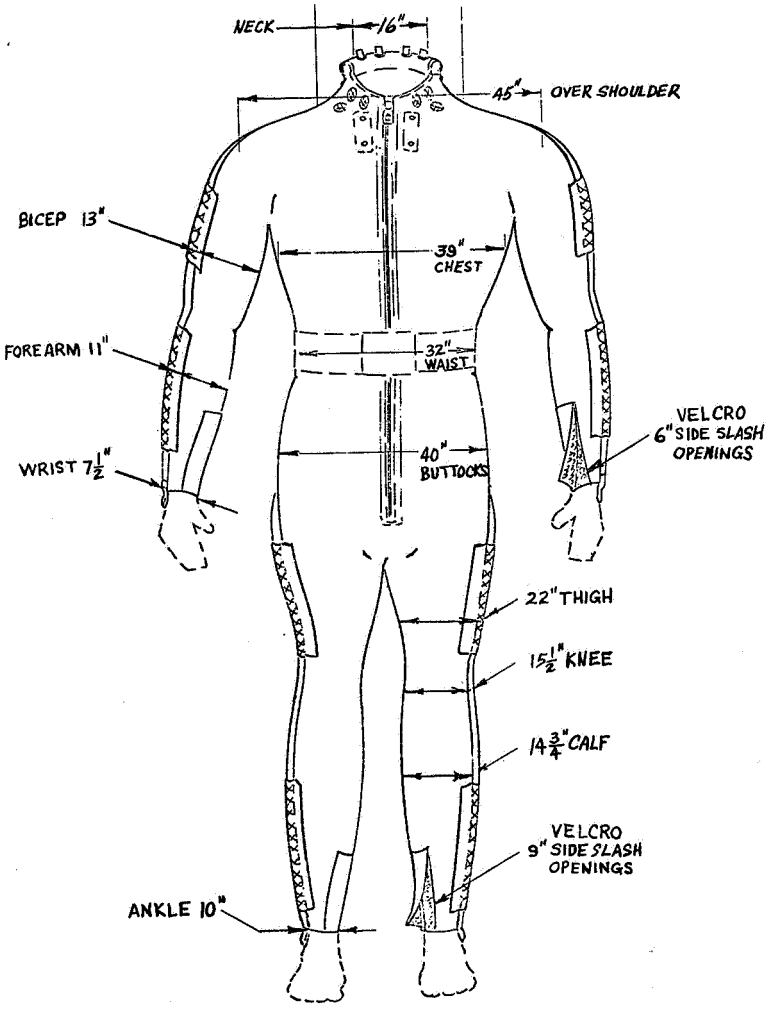


Figure 7. Phase II Undersuit Front View A

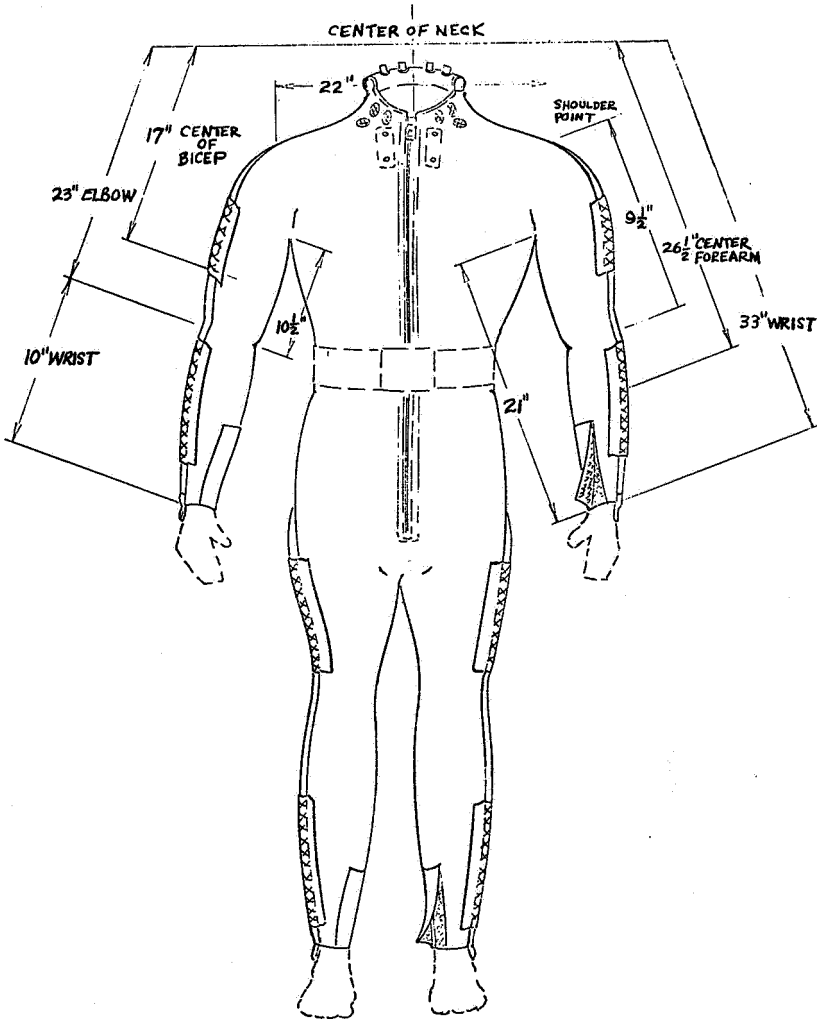


Figure 8. Phase II Underswit, Front View B

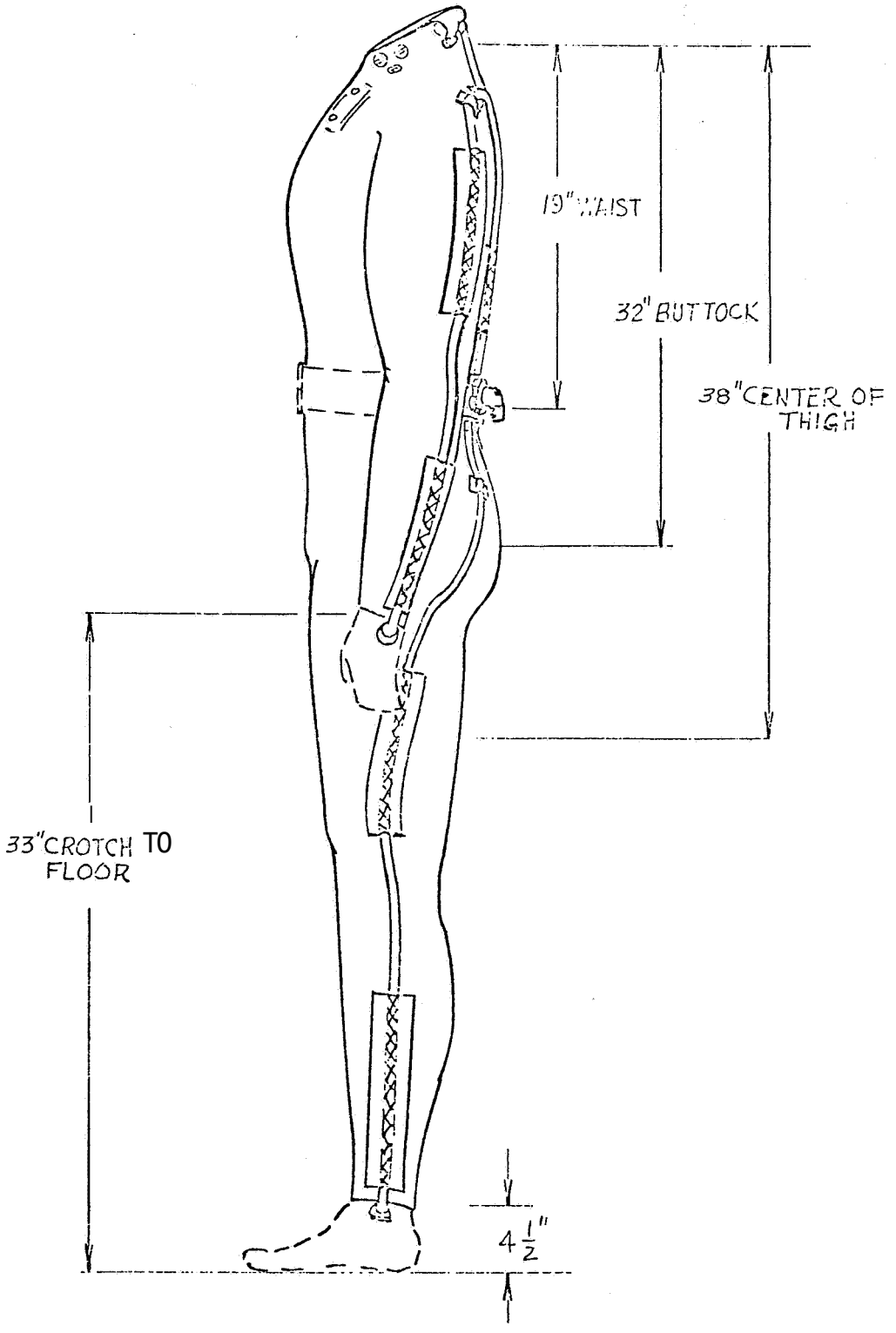


Figure 9. **Phase XI Undersuit** Side View

reflect the actual size of the wearer, therefore, the vendor was required to consider the thickness of the tri-layer material in developing final suit dimensions. In dimensioning the suit, the vendor was required to make it conform to body shape without being tight on any portion of the body. Particular emphasis was given to providing good limb mobility. The three layers were bonded together so that after repeated wearing and cleansing operations, the suit is still a unitary garment. The method of bonding the three layers of the suit together does not block a continuous flow path through the foam.

The material used for the outer layer is Fairprene neoprene sheet stock, of thickness 1/64" (nominal) by DuPont. The open cell foam layer is Scott foam with 10 pores per linear inch, 1/4 inch in thickness. The inner layer is nylon laminating scrim, 2/1 leno weave, style 38016, count 20 x 10 by J. P. Stevens & Co., N.Y. The main zipper on the chert of the subject is a B. F. Goodrich, or equivalent, air-tight type. Slash openings for the wrists are six inches in length. For the ankles, these openings are nine inches in length. All four slashopenings are closed with Velcro, allowing the inner foam to mate so that a continuous, porous foam layer is maintained.

In addition to the basic garment, the undersuit provides interfaces for the life support subsystem. These interfaces are shown in Figure 10. Air is brought to the suit from the life support subsystem by a hose which mates with the supply plenum. From the plenum, five tubes lead to the feet, hands, and to the helmet air distribution device. The air is drawn from the hands, feet and helmet through the foam layer. of the undersuit to theexhaust plenum, and is returned to the life support subsystem. The foam-exhaust plenum interface is shown in Figure 11. Figure 12 shows the helmet air distribution device, and Figure 13 shows the helmet exhaust parts and communications transducer mounting hard points. The actual undersuit is shown in Figure 14.

Although good experimental results were obtained with the Phase II undersuit, the experience gained in operating with this version of the suit suggested some further modifications to optimize the design. These modifications were made in specifying the final recommendations for an air cooled undersuit as reflected in the BISS Undersuit Specification 0230-00-0002 attached hereto as Appendix L. For easy reference the illustrations from the specification are presented here as Figures 15, 16, and 17.

The major change between the final undersuit concept and the garment used in PhaseII testing is the change in the design and location of the air distribution andexhaust plenums. As can be seen by examining Figure 16, the plenums are now located on top of one another, in the middle of the lower back. This permits interfacing with a larger

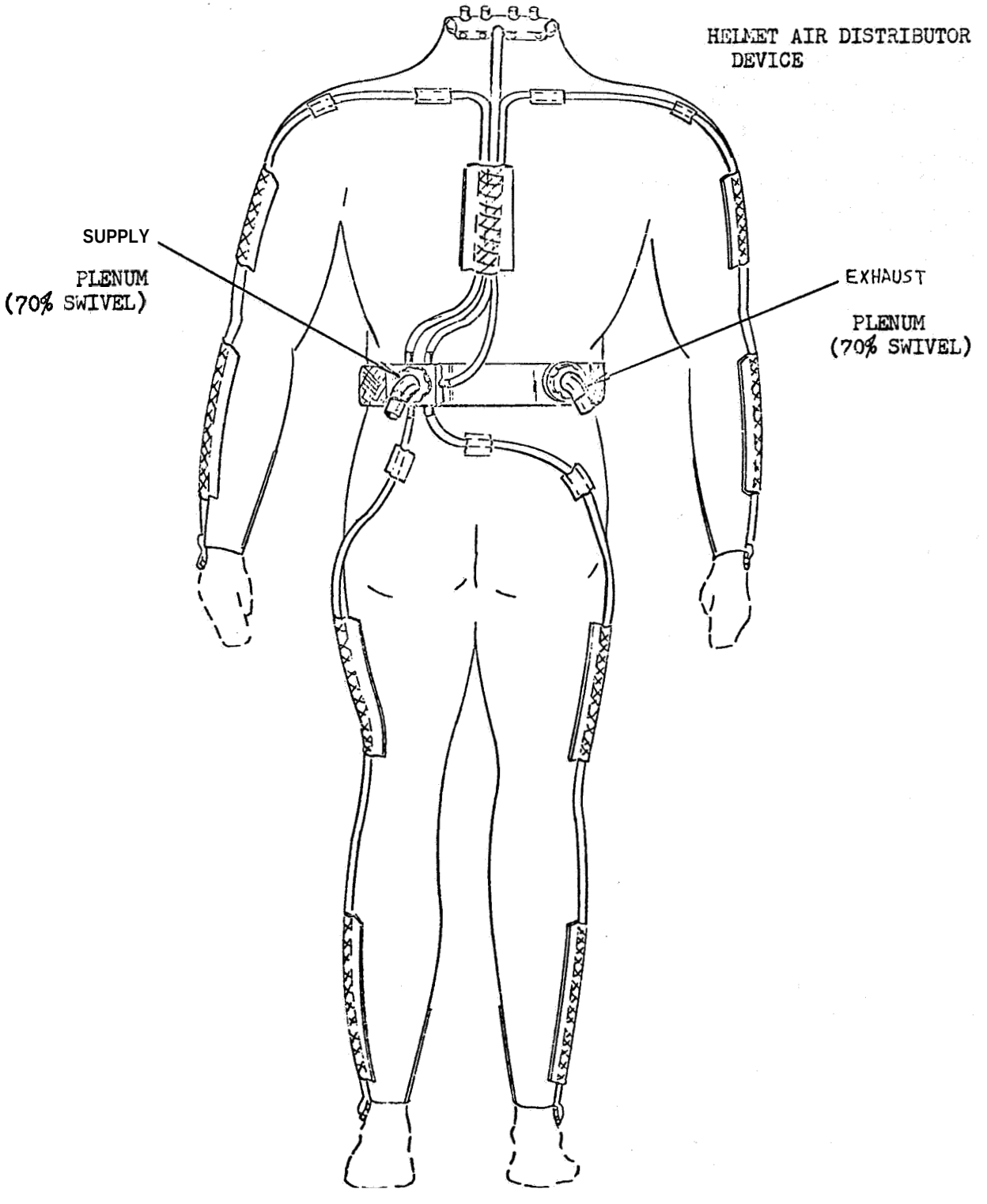


Figure 10-Life Support Plenum and Air Distribution System (Back of Phase II Suit)

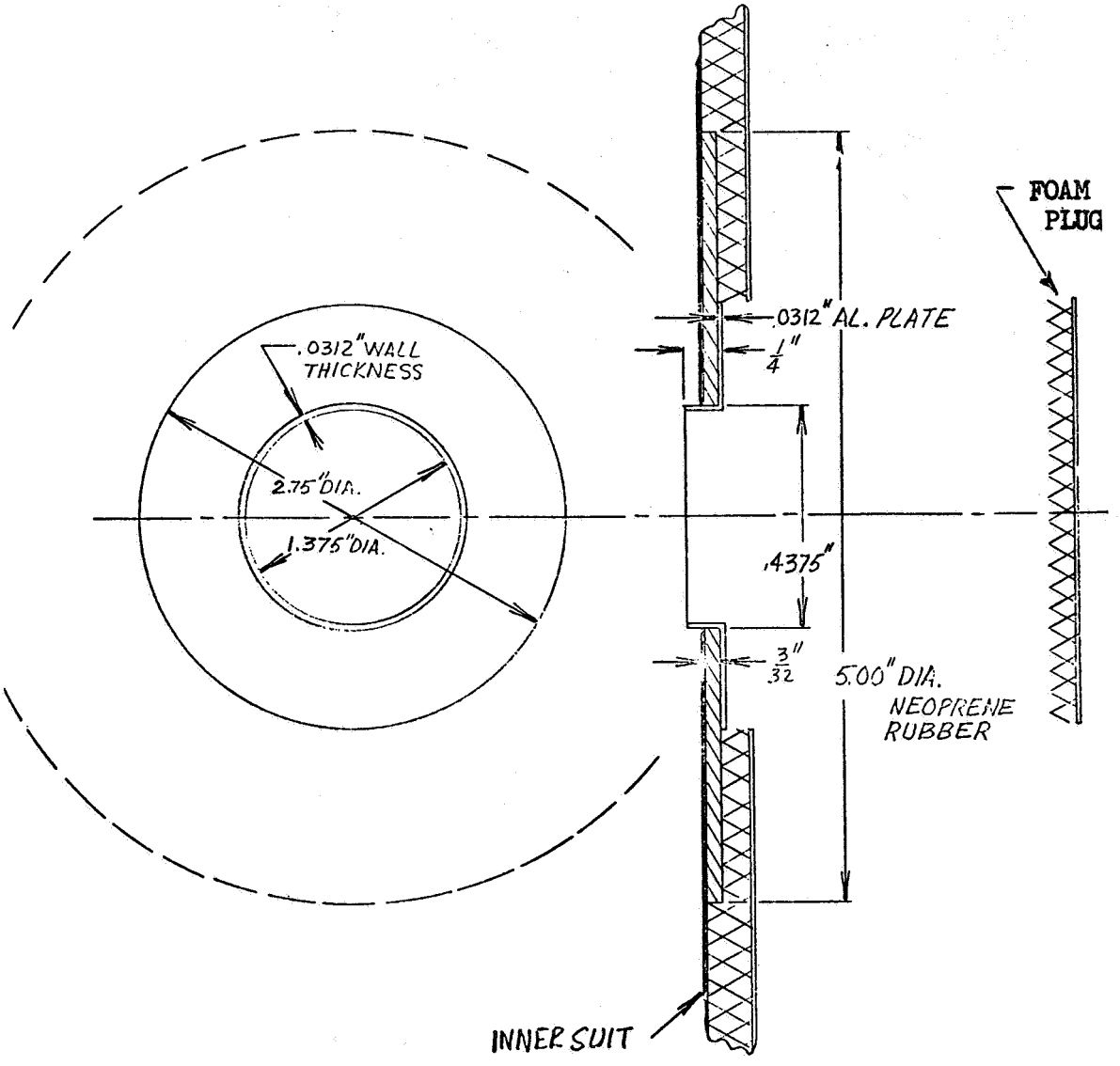


Figure 11. Phase II F Plenum tnterface

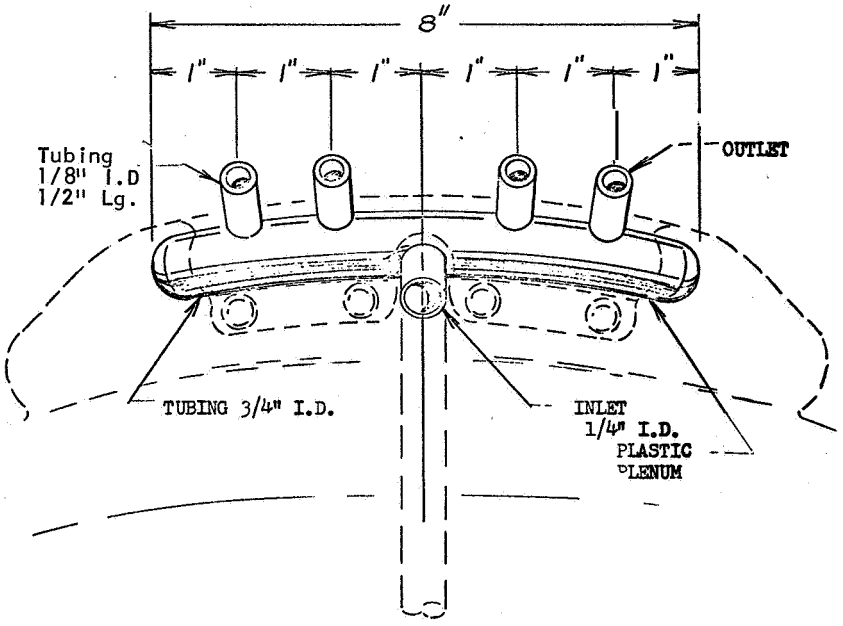


Figure 12. Phase II Helmet Air Distribution Device

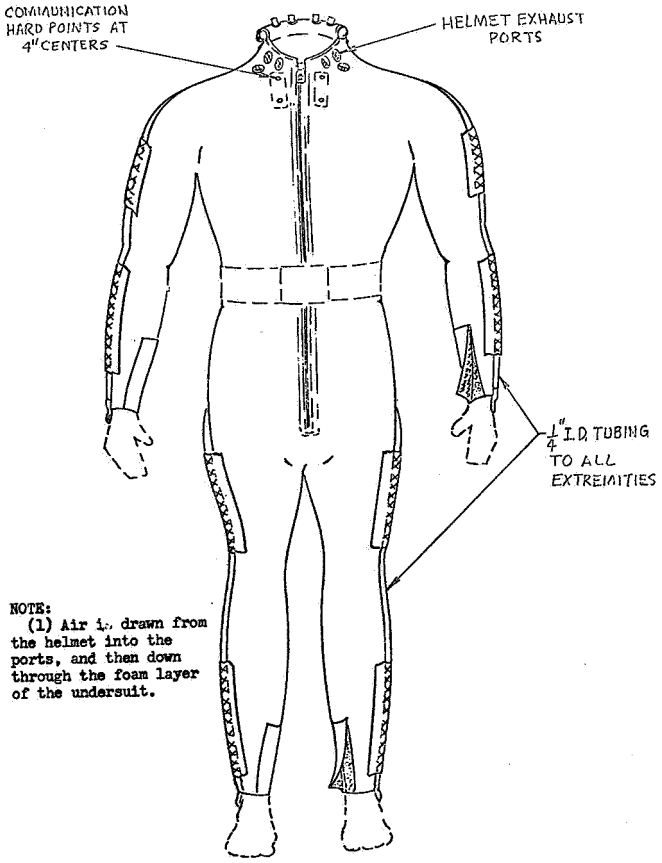


Figure 13. Helmet Exhaust Parts and Communication Hard Points (Phase II)

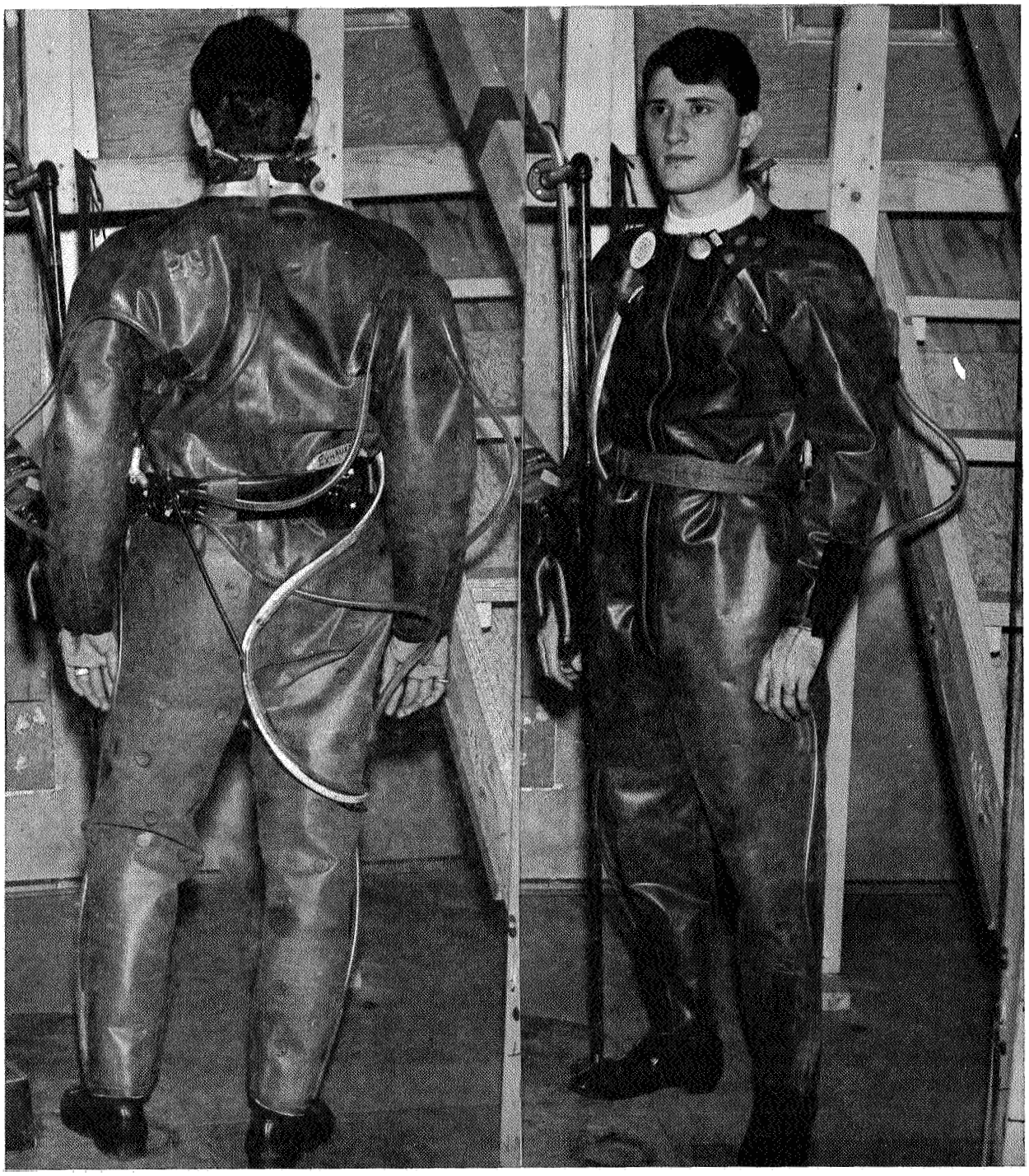


Figure *14.* - BISS **Phase** II **Undersuit**

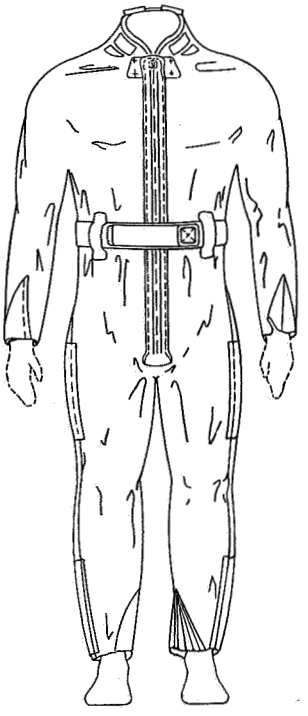


Figure 15. Final Undersuit Front View

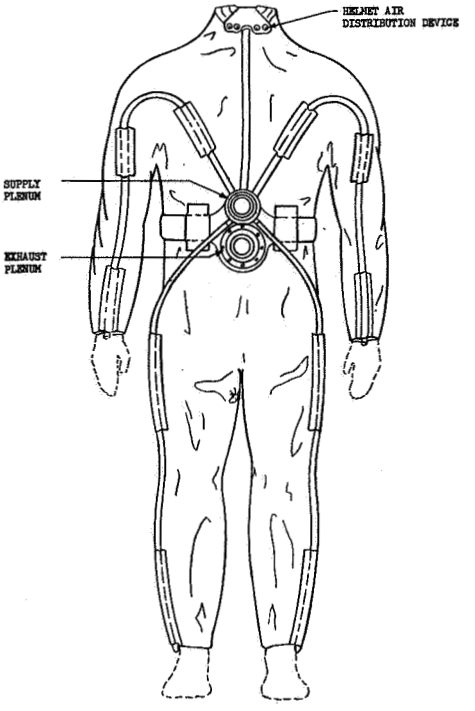


Figure 16. Final Undersuit' Rear View

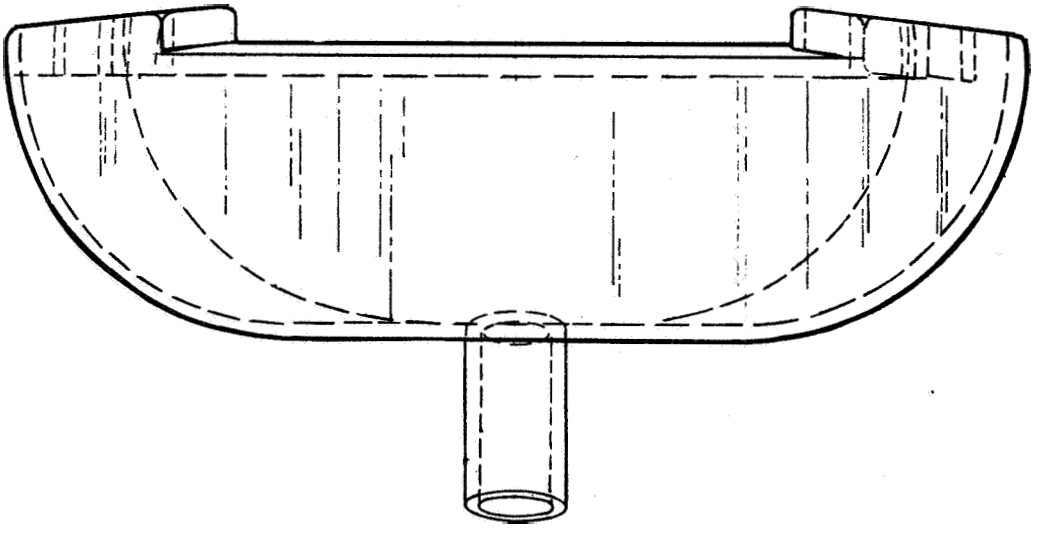


Figure 17. Final Helmet Air Distribution Device

area of foam for suit exhaust than did the previous approach. It also permits the air distribution tubes to be routed in a more direct manner to the extremities with a resultant reduction in the probability of the air distribution hoses being stressed. The other changes worthy of note are the design of the helmet air distribution device, Figure 17, the wrist and ankle fastenings, and the length of the zipper. The magnitude of the air distribution device redesign can be assessed by a comparison of Figures 12 and 17. The wrist and ankle fastenings for the final design Velcro flaps which are sewed down on one side of the slash openings with mating Velcro on the opposite side of the opening. The zipper has been shortened since it was found that getting the Phase II undersuit zipper started when it terminated between the subjects legs was difficult. Therefore, the zipper now ends on the front surface of the undersuit.

4.1.3.1.2 Outersuit

The outer suit serves one primary function: isolation of the BISS occupant from the sterile environment of the Assembly/Sterilizer main chamber. In addition, it serves several secondary functions such as physical protection of the occupant's feet and head and containment of a safe gas mixture for breathing. The outer suit consists of several integrated elements: suit shell (body and limbs), helmet, gloves, and boots. The helmet, gloves, and boots are bonded to the suit shell.

As with the undersuit, the outersuit concept has been developed in three stages, the first two being embodied in the Phase I and Phase II mock-ups and the last stage reflected in the final recommendations.

In recognition of the evolutionary nature of the concept development of the outer suit, the first generation suit was designed to be the simplest, least expensive garment possible consistent with functional requirements for mock-up experimentation. The resultant Phase I suit is shown in Figure 18. This suit is a loose fitting envelope of 20 mil polyvinylchloride (PVC) with integral foot shaped protrusion for boots, and with commercial neoprene rubber gloves and a cylindrical plexiglass helmet attached.

The concept of boots in the form of loose fitting envelopes of suit material with durable traction surfaces on the bottoms was also not optimum. This shell would have merely covered normal work shoes which the subject would wear in the suit. Foot support and toe protection were to be provided by the operator's work shoes. The concept developed to that of a relatively rigid boot with built in foot protection and

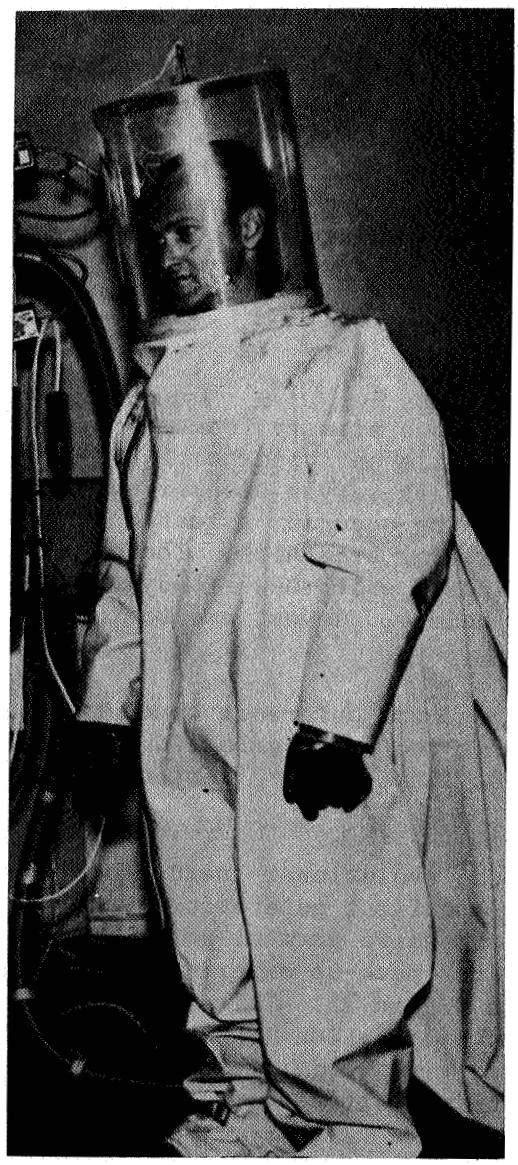


Figure 18. - BISS Phase I Outer Suit

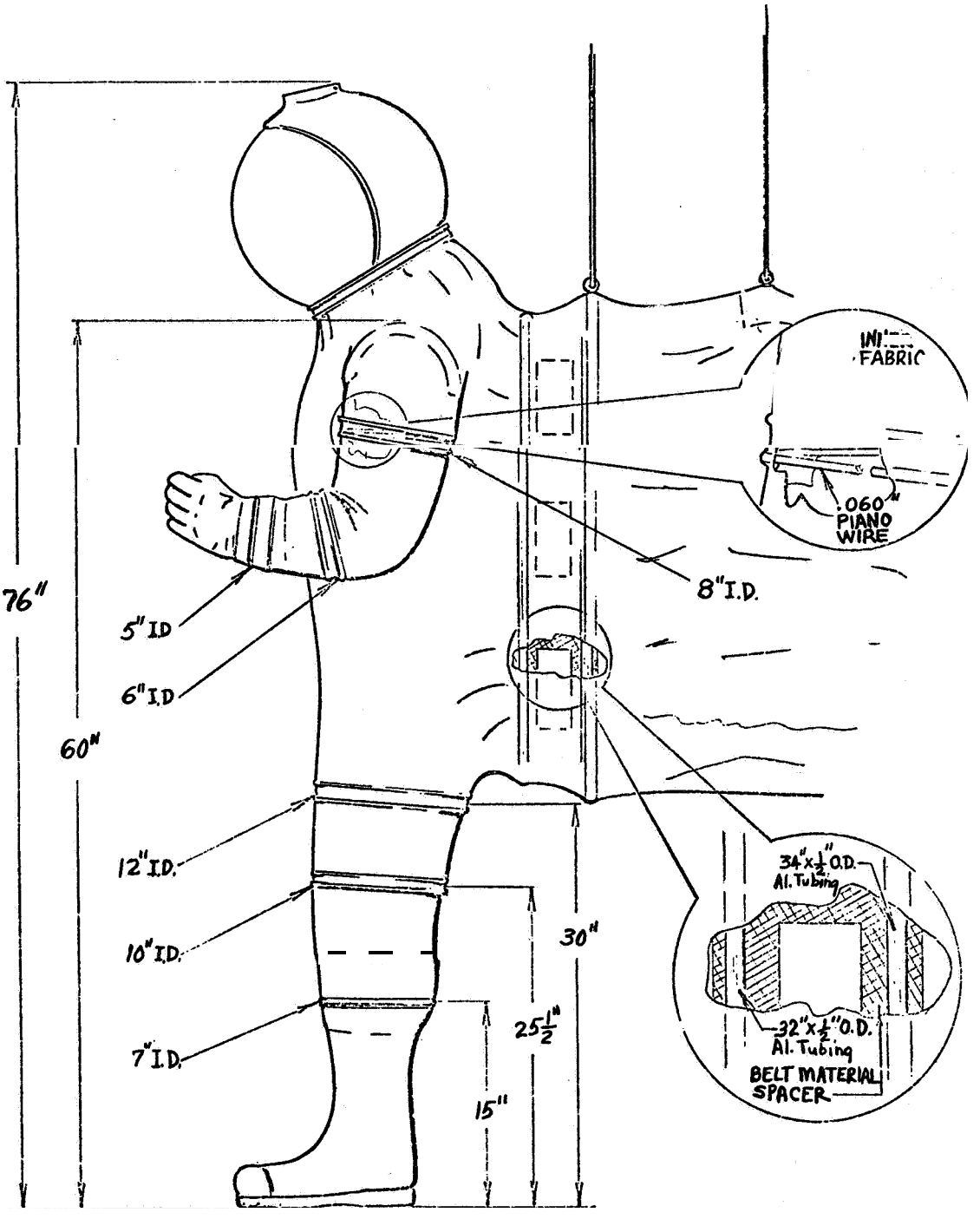
support. Since the boots are not changeable from individual to individual, personal inner socks or slippers are required for each operator to help maintain hygiene and to accommodate a range of foot sizes. Fireman's boots were adapted to the Phase I suit because of the deficiencies of the integral "bootie" design.

Experimentation of the cylindrical helmet and an Apollo-type helmet strongly suggested the appropriateness of 'a large "fish-bowl" or "bubble" type helmet. This was necessary because the helmet does not move with the operator's head, and contouring of the helmet in a conventional manner would interfere with the operator's head movement. A cotton cap will be worn by each operator to avoid smearing the helmet' with hair oils, etc. Unlike pressure suit helmets which derive physical support from the suit pressure, a means must be provided to support the BISS helmet in the overpressure environment. In the Phase I suit, the helmet was supported by a modified set of athletic shoulder pads. This concept was refined to the use of a molded shoulder yoke with elastic bands which go under the wearer's armpits. The yoke is permanently affixed to the helmet and is a part of the outer suit.

Surgeon's cotton skull caps will be worn by BISS operators inside the helmet to prevent contamination of the helmet with hair oils and to absorb operator perspiration. These caps will be procured in the sizes required for a given Assembly/Sterilizer operator population and will be laundered after each work session.

As a result of the testing performed on the Phase I outersuit, several deficiencies or areas for improvement were rated. The looseness and imprecise fit of the garment impeded occupant entry and egress under pressure because of folding and collapse of excess suit material. In addition to the need to make the outer suit fit more precise, the study indicated the need for two stiffening rings in both the arms and legs of the suit. These rings flank the elbows and thighs respectively and in no way hamper operator mobility. In conjunction with two large rings located at the suit-tunnel interface, and a donning rask which supports the suit in a proper donning attitude at the end of the hatch tube, the arm and leg rings greatly facilitate operator entry into the suit under the overpressure environment. The rings accomplish this by creating discernable openings, appropriately positioned, at which the operator can aim during the entry process. These features also aid in exit from the suit by reducing the amount of suit collapse on the limbs.

With the necessary design improvements defined, the Phase II outer suit was specified. This version of the suit is shown in Figures 19, 20, and 21. The suit body is illustrated in Figure 19. The garment is fabricated of AI,-160 by Cooley, Inc., Pawtucket, R.I., of weight 16 oz/yd in accordance with the dimensions shown. The color of the fabric



.Figure 19. Phase II **BISS** Outer Suit

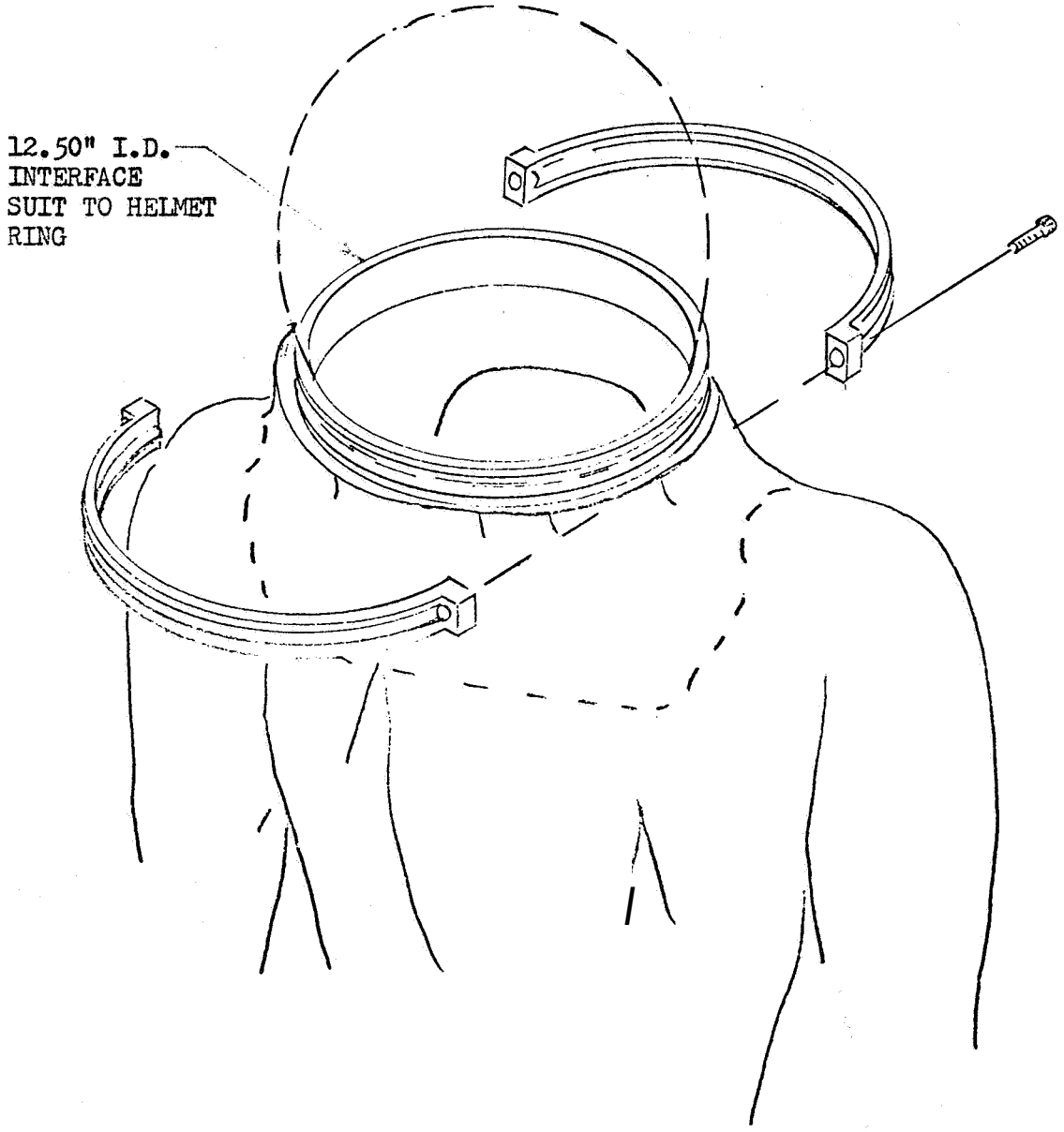


Figure 20. Phase II Helmet Neck Ring

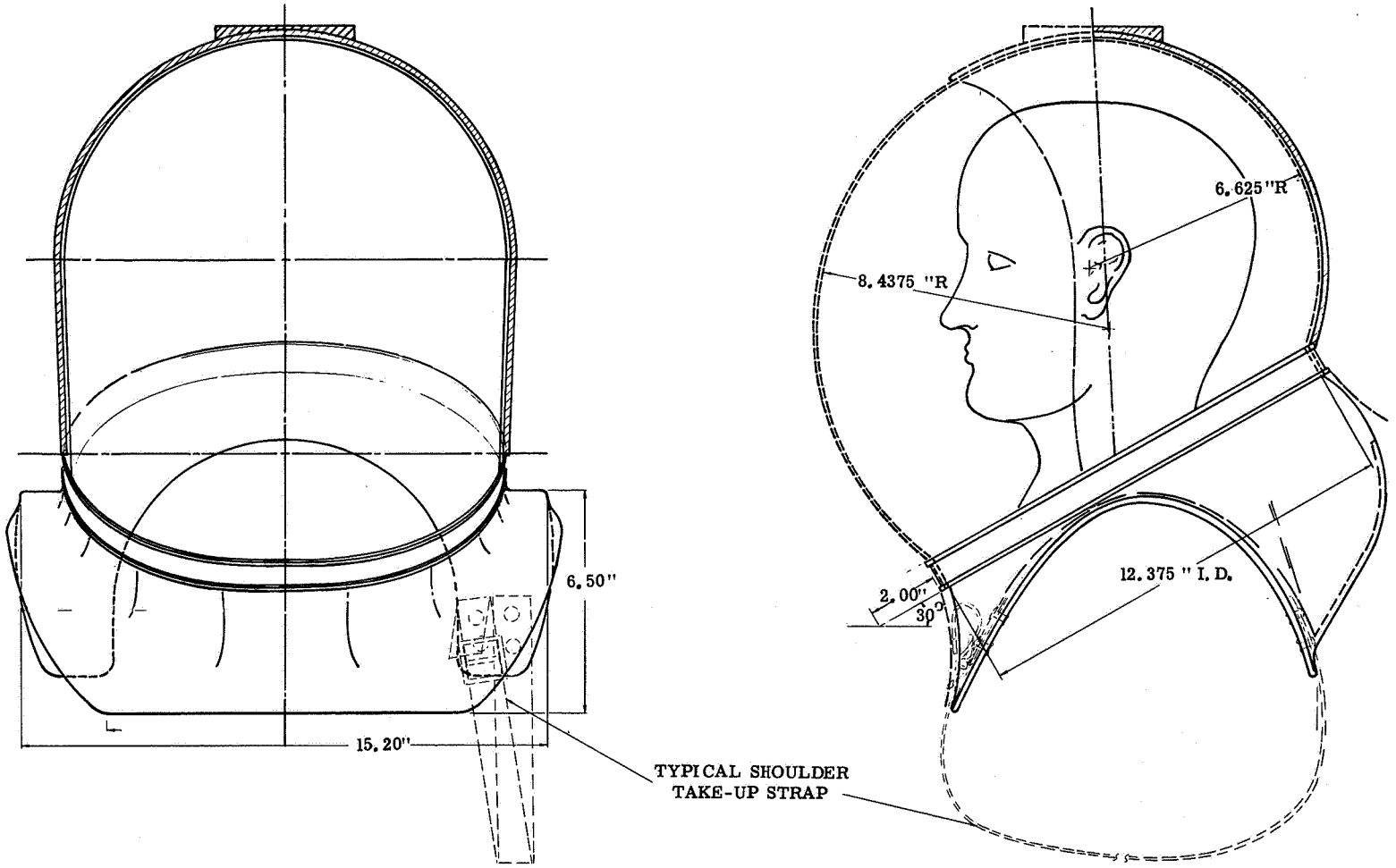


Figure 21. Phase II Helmet-Yoke Assembly Concept

is black and aluminum, with the aluminum on the exterior surfaces. The garment has a 100" circumference opening in the back of the suit for interface with the tunnel. A 12.5" diameter circular opening is provided for interfacing with the helmet and yoke assembly (See Figure 20 and 21). The support rings incorporated in the arms and legs of the outer suit are made of .060 rolled piano wire to the dimensions shown in Figure 19. These rings are necessary to assist the wearer in entering the suit under the overpressure environment, and are laminated to the interior of the suit material. Figure 22 shows three (3) adjustment straps on the exterior of the suit. The crotch strap is used to adjust the sizing in this area for different subjects. The two shoulder straps interface with the helmet support yoke as shown in Figures 21 and 22.

The helmet and yoke are shown in Figures 20 and 21. The helmet, manufactured by Airlock, Inc., was vacuum formed of GE Lexan polycarbonate. The yoke and a protective shield over the rear half of the helmet were fabricated of epoxy fiberglass and bonded to the clear Lexan. The yoke and the rear of the helmet were padded inside with polyurethane foam. The actual helmet is shown in Figures 23 and 24.

The interface between the suit and boots is shown in Figure 25. The boots used with the suit are relatively stiff and sized for a person who wears 10½ C shoes. These boots provide necessary foot support and are suitable for wearing over heavy socks or light booties. The boots are adaptations of commercially-available natural rubber boots. Figure 25 details the interface between the boots and the legs of the suit. The interface device provides a hard point at which the suit and boot materials may be bonded together. It also offers a surface against which maintenance personnel can cut when removing worn boots. Boots are replaceable by cutting away the old boot and bonding on a new one. The heels of the boots have a cutout to mate with the boot clamp of the donning rack.

The gloves used with the suit were 30 mil size 10 butasol (Charleston Rubber Company) gloves as used successfully in the Assembly/Sterilizer Analog Program.* The glove interface with the suit is shown in Figure 26. The gloves have curved fingers, are lined and have smooth inside and outside surfaces. Individual cotton undergloves are worn by the operator to absorb perspiration. The cotton undergloves are sized for each operator.

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* NASA contract NAS 1-5381, Final Report GE Document 67SD660 24 March 1967.

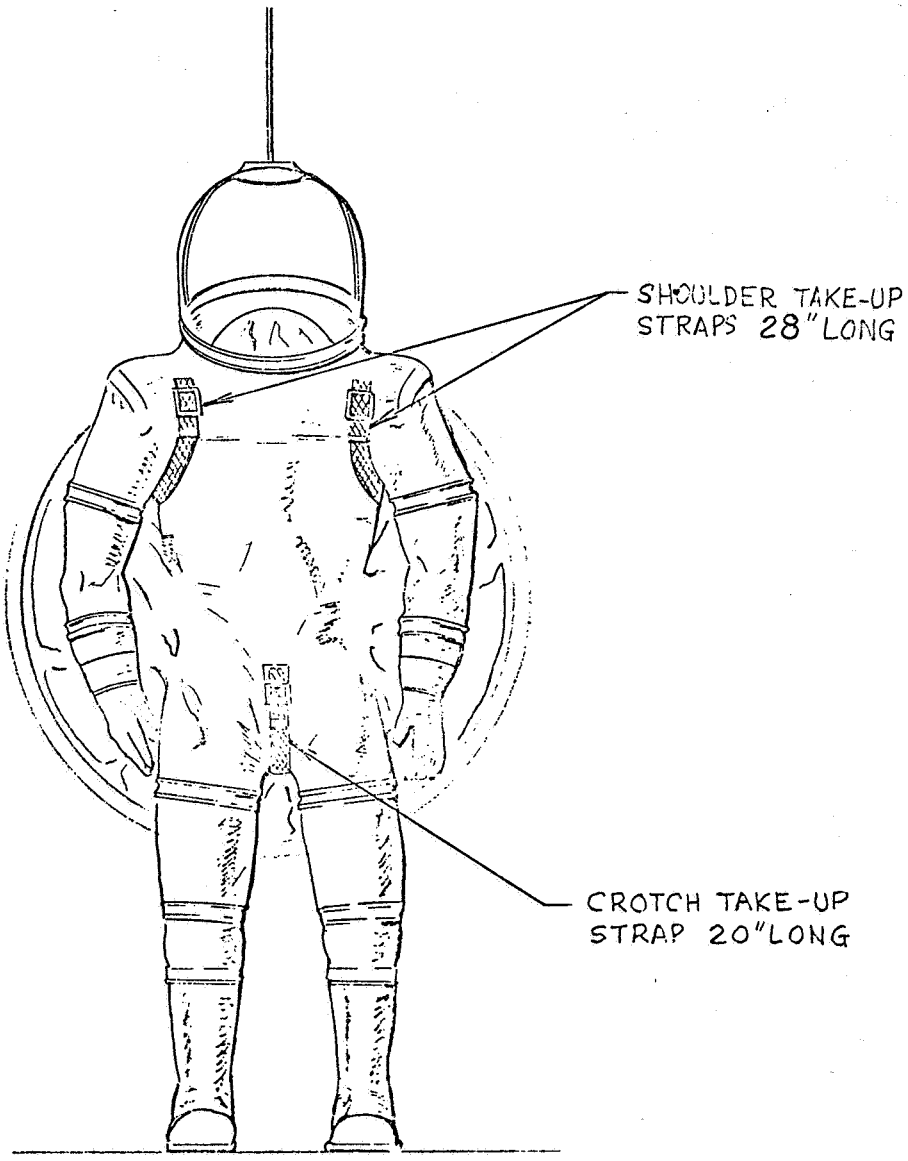


Figure 22. Phase II Suit Adjustment Straps

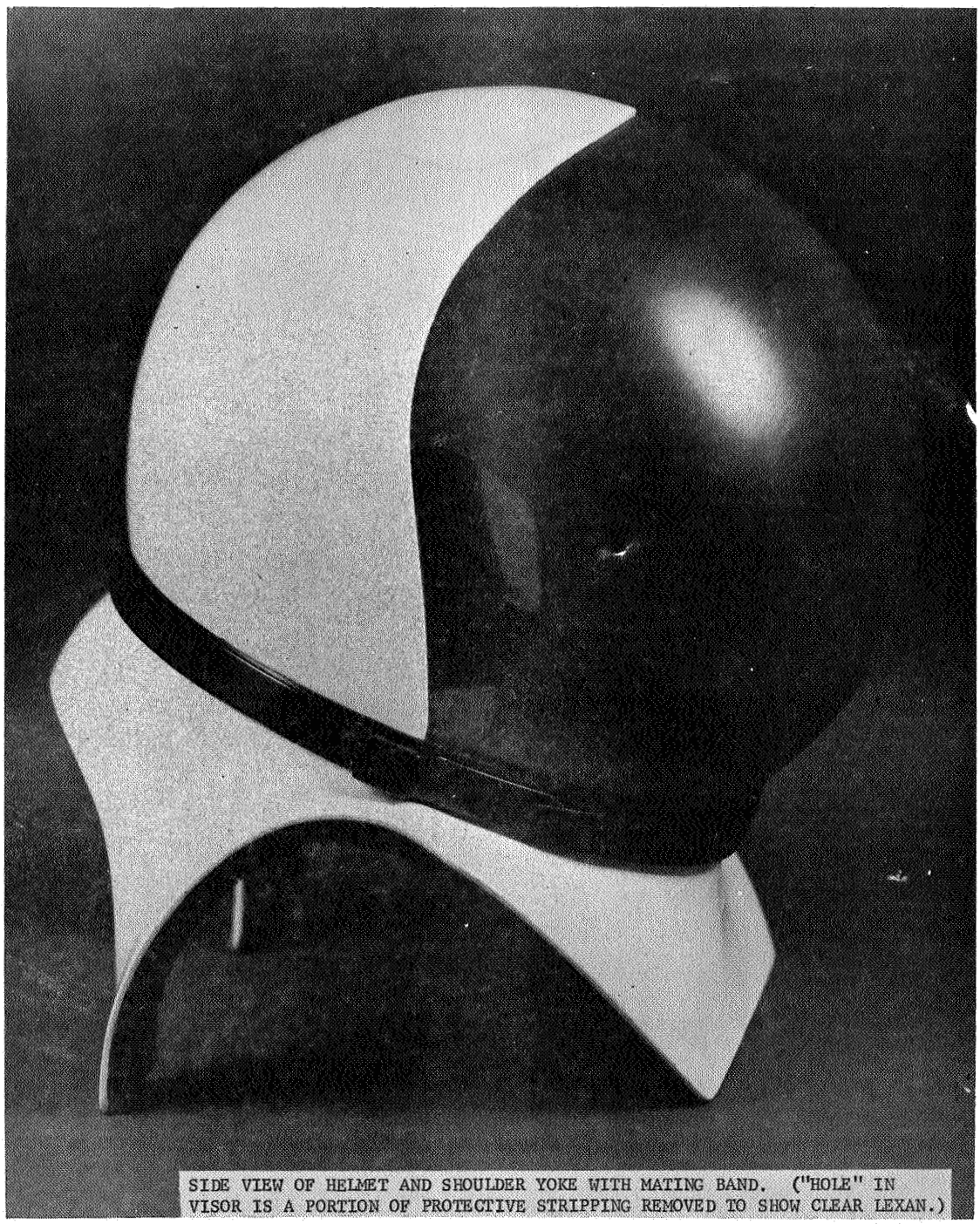
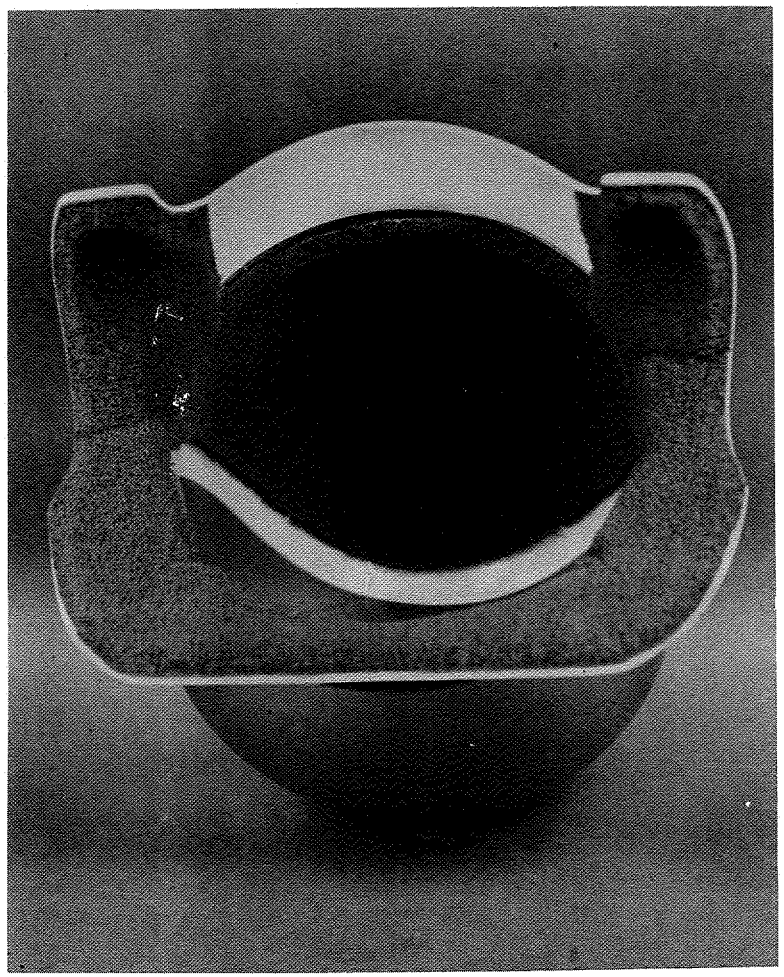


Figure 23. Phase II Helmet and Yoke Side View



NOTE: FOAM THICKNESS 1/2"
Figure 24. Phase II Helmet and Yoke Bottom View

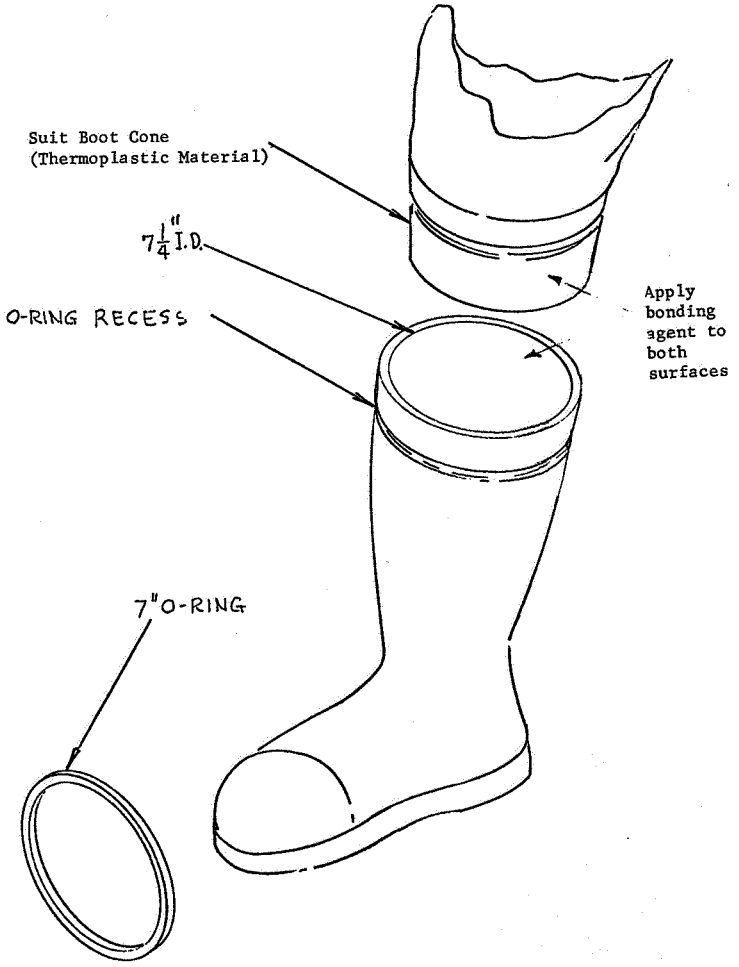


Figure 25. Phase II Suit Boot Interface

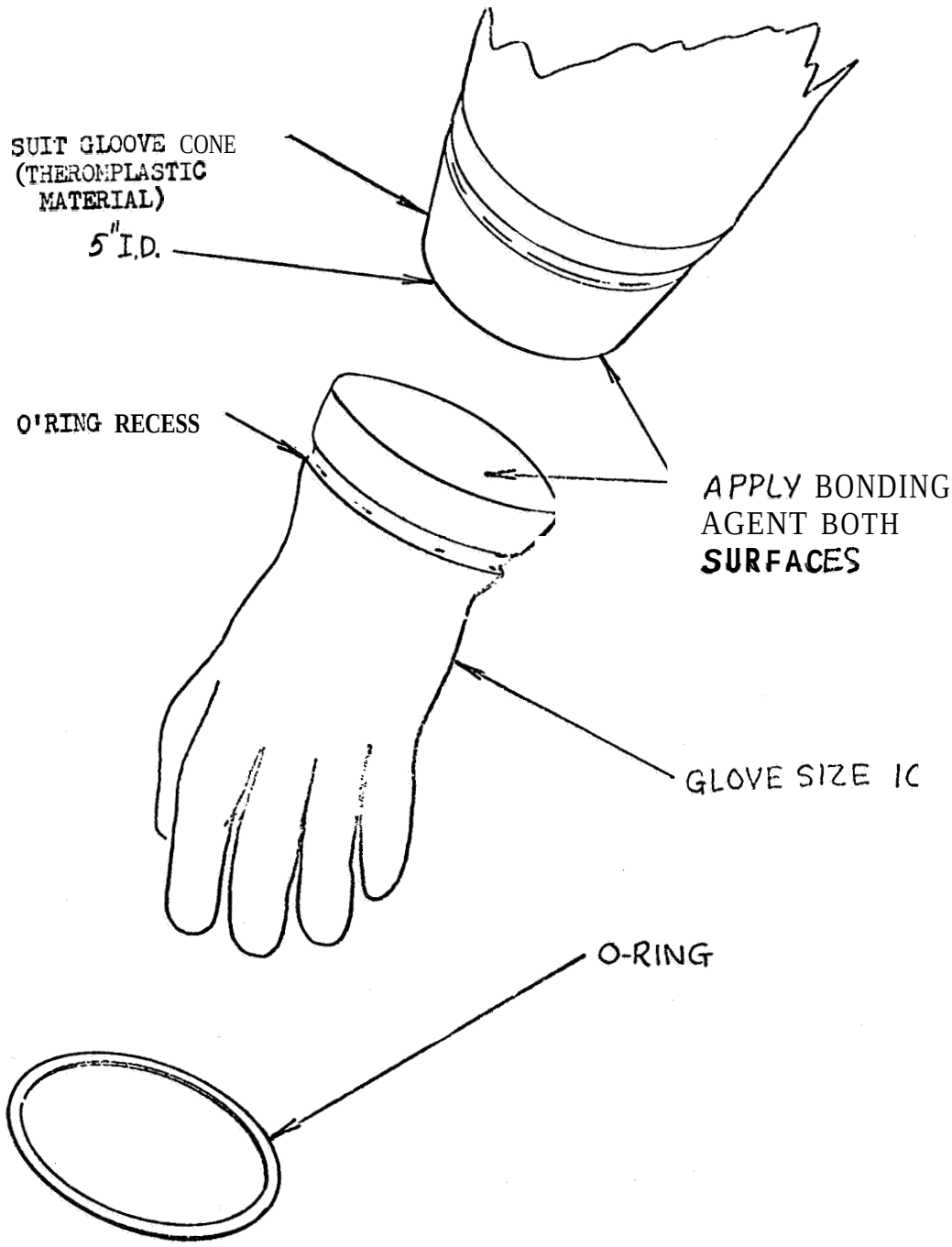


Figure 26. Phase II Suit Boot and Glove Interfaces

Although good experimental results were obtained with the Phase II outer suit, the experience gained in operating this version of the suit suggested further modifications to optimize the design. These modifications were made in specifying the final recommendations for the outersuit as reflected in the **BISS** Outer Suit and Tunnel Specification 0230-00-0001 attached hereto as Appendix K. For easy reference the illustrations from the specification are presented here as Figures 27, 27A, 28 and 29.

The major change for the final outer suit is removal of the hard. rings at the suit-tunnel interface. It was found that in the overpressure environment, the rings pressed against the occupant's back causing considerable discomfort, particularly when exercising. In place of the rings, stiffeners will be added by bonding heavy webbing at the interface.

The only other change of significance is in helmet position restraint. The two straps under the armpits of the Phase II suit were found to be unnecessary; the pressure differential across the outer suit tends to keep the helmet in place. There was some tendency of the helmet to pitch forward when the occupant bent over. Figure 29, illustrating the reconfigured helmet, shows the technique suggested for overcoming this. A "Y" strap adjusted for the individual occupant is attached to the two "D" rings on the helmet yoke before the occupant places his head in the helmet. After placing his head in the helmet, but before placing his arms in the sleeves, the occupant attaches the bottom of the "Y" strap to a ring at his waist in back. In addition to overcoming the tendency for the helmet to pitch forward, this also provides vertical support for part of the weight of the supply and exhaust plenums on the back of the undersuit.

Figure 29, also shows that the revised yoke design provides additional clearance for the communications transducers on the undersuit.

The final boot and glove configurations are shown in Figure 30 and 31 respectively.

4.1.3.2 Tunnel - The tunnel is a horizontal* tube interfacing at one

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* Late in the program, consideration was given to the possibility of using a vertical tunnel coming down from the ceiling rather than a horizontal tunnel from a chamber wall. The investigative effort in this area is reported in Appendix B. The concept is felt to be deserving of further investigation but is not, at this time, the recommended configuration.

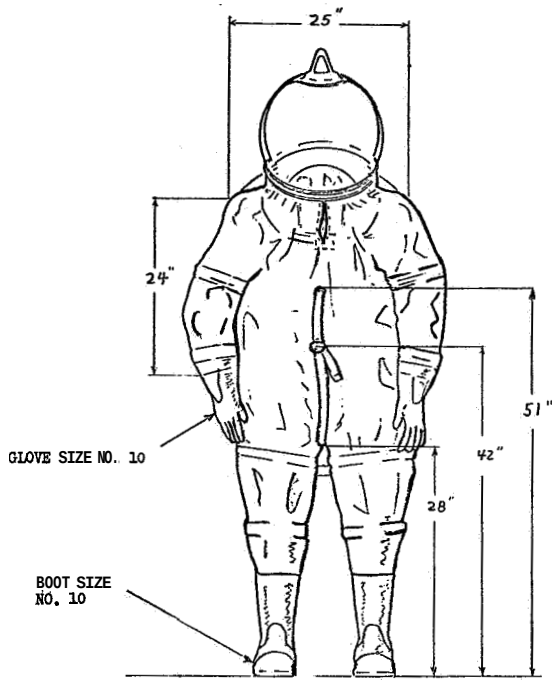

Figure 28 Front View of Final Outer Suit Showing Adjustment Strap.

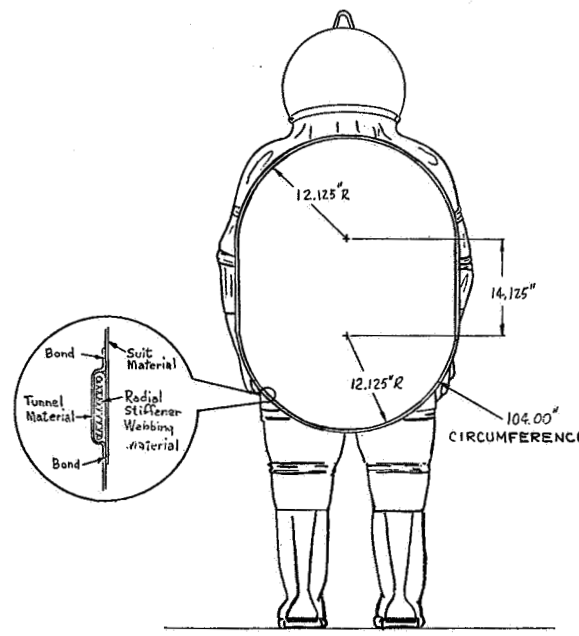

Figure 27A Final Suit Body Rear View

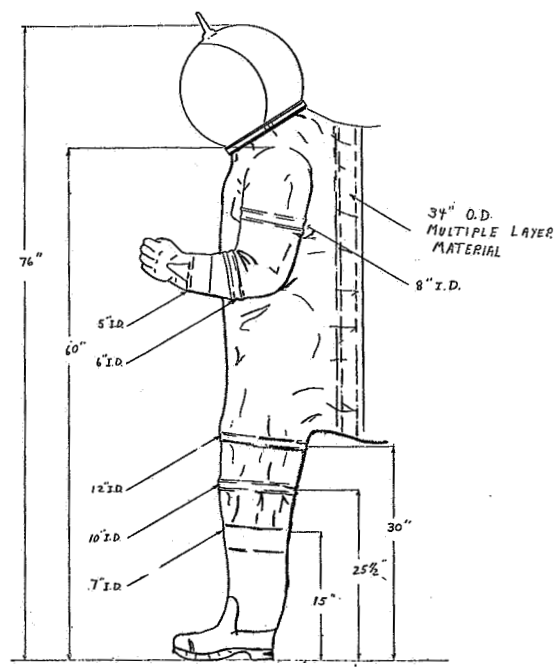

Figure 27 Final Suit Body-Side View

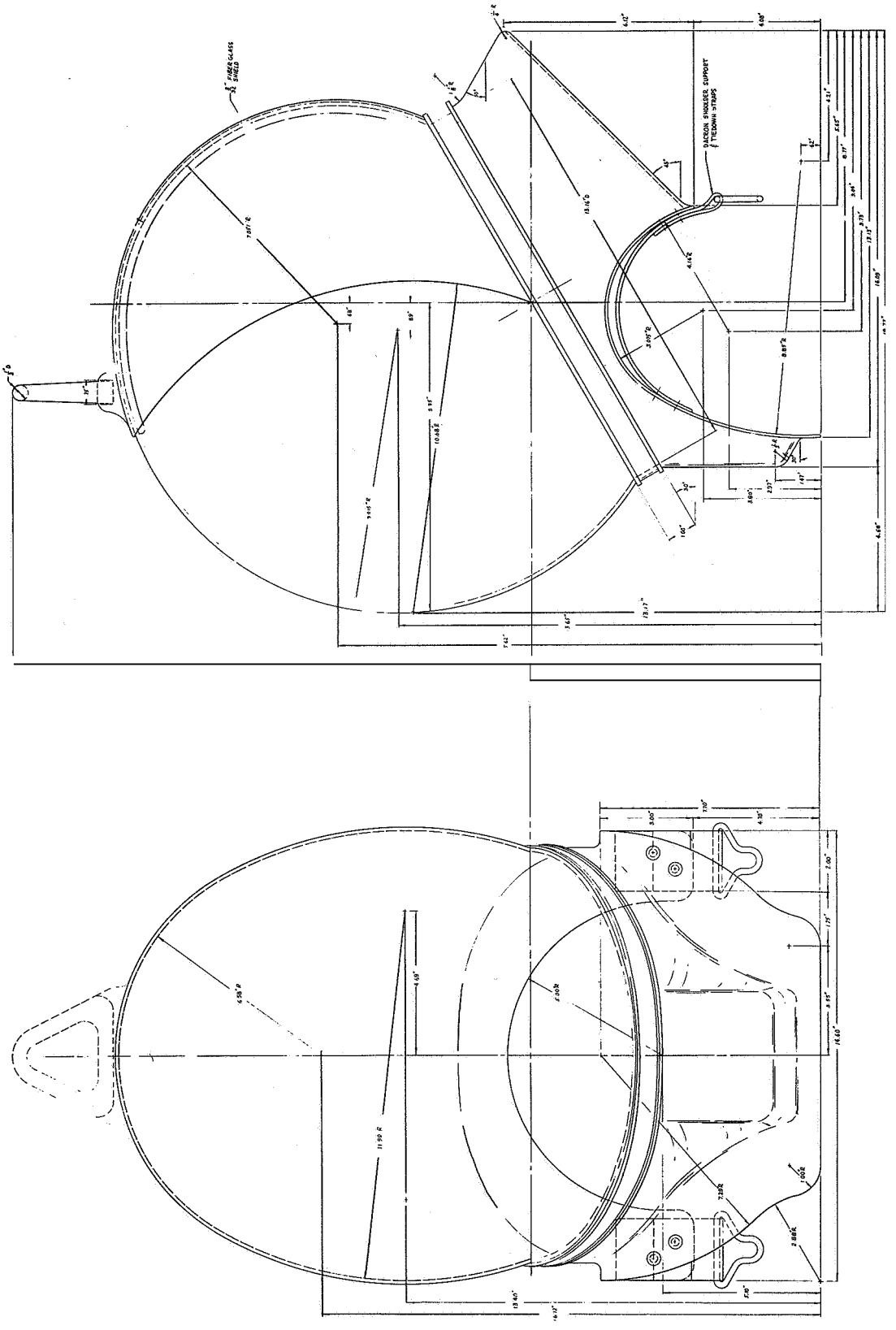

Figure 29 - Final Helmet and Yoke Assembly

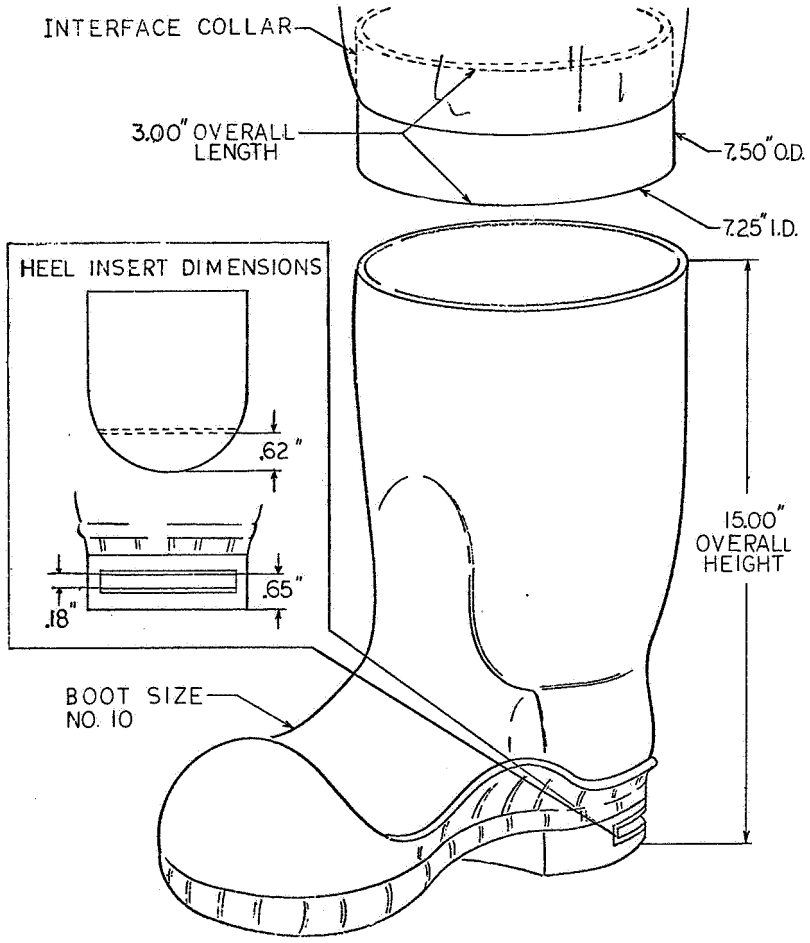

Figure 30 Final Boot and Interface

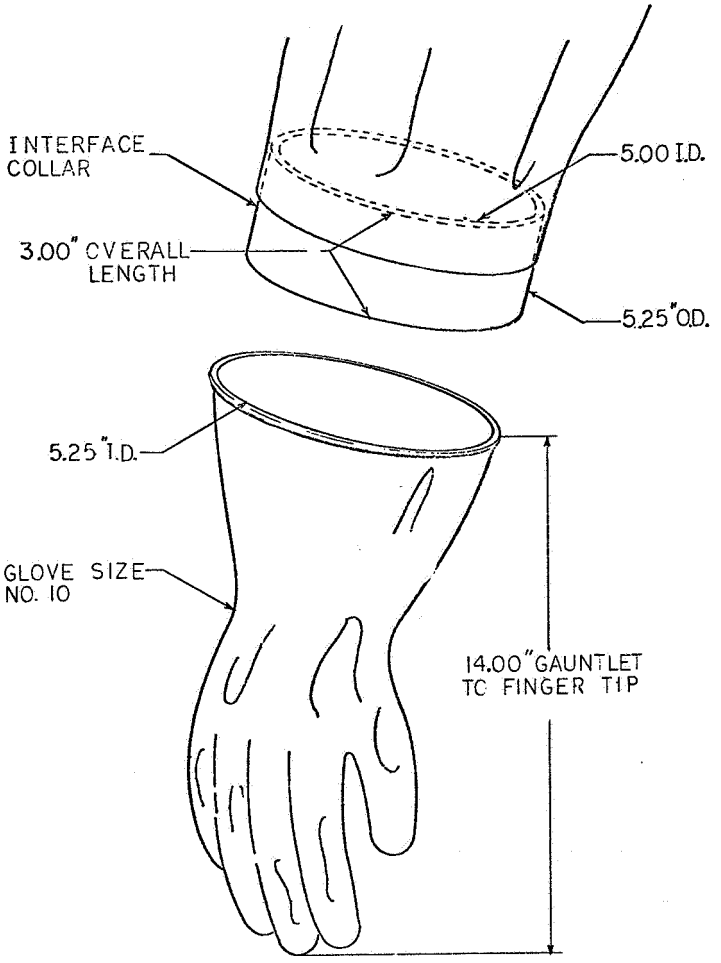

Figure 31 Final Glove and Interface

end with the back of the **BISS** outer suit and at the other end with the hatch on the Assembly/Sterilizer wall. At the wall end, the tunnel fits over a rigid tube extending into the chamber which is used for reefing. In the trade-off discussion of Section *4.2.2,* the selection of a soft tunnel was substantiated. The primary functional requirements of the tunnel are:

- Permit entry to, and egress from, the suit.
- Maintain an absolute barrier against micro-organisms.
- Support the life lines and communications lines between the suit occupant and the life support and communications subsystems respectively.
- Minimize constraints on suit occupant in moving about the chamber.

It is desirable to minimize tunnel size consistent with reasonable entry-egress complexity. A tunnel with a nominal circumference of 100 inches was tentatively selected during the early concept development efforts in the program and has been found in Phase **I** and Phase **II** of mock-up test program, Section 8.0, to be satisfactory.

The Phase **I** tunnel, like the Phase **I** outer suit, was designed to be of the simplest, least expensive form possible consistent with functional requirements for mock-up experimentation. **As** such, **it was** a simple tube of 20 mil polyvinyl chloride (PVC) zippered to the back of the suit with a 100 inch zipper. Experimentation with this tunnel confirmed several design constraints anticipated in the definition of this concept:

- Vertical tunnel support is necessary
- A soft tunnel is quite difficult to reef in an overpressure environment
- **A** soft tunnel tends to be pushed back into the open end of the hard tube by the overpressure environment.

These constraints are reflected in the requirement for a tunnel support mechanism, a tunnel reefing mechanism, and a mechanism to prevent the tunnel from pushing into the hard tube. These mechanisms are discussed in the following sections.

As a result of the tunnel hardness trade-off and the Phase I testing, the tunnel was conceived as being made of a relatively soft fabric similar in composition to the outer suit. The tunnel bridges the gap between the outer suit and the reefing tube through which the operator enters or leaves the suit when the tunnel is reefed over the tube. The tunnel carries the life support and communication lines to the suit occupant and is itself supported by stringers to an overhead boom. As the operator moves about in the chamber, the boom supports the tunnel and accommodates three dimensional movement, thus protecting the tunnel from abrasion and permitting it to remain radially collapsed under the overpressure.* Stiffening is required at the suit-tunnel interface to facilitate operator entry and exit.

This concept was embodied in the Phase II tunnel. The tunnel is a 20 foot long tapered tube of 32" diameter at the open end and 34" at the suit interface. The tunnel is made of the same material as the Phase II outer suit (AL-160 by Cooley, Inc.) and is sealed to the opening in the back of the suit. It is supported as shown in Figure 32. This Figureshows the support loops which are to be attached to the exterior of the tunnel. Stringers from the loops lead to an over head trolley line in the Phase II mock-up permitting full longitudinal movement along the hatch-hard tube axis and limited lateral movement.

Although good experiment results were obtained with the Phase II tunnel, the experience gained in operating this version of the tunnel suggested minor modifications to optimize the design. These modifications were made in specifying the final recommendations for a tunnel as reflected in the BISS Outer Suit and Tunnel Specification 0230-00-001 attached hereto as Appendix K. For easy reference, two of the illustrations from the specification are combined here as Figure 33. The changes are in the tunnel dimensions, hard tube shape, and support loop design.

The final tunnel will be fabricated from a single piece of soft material compatible with the outer suit body. The tunnel will be 60 to 100 feet long, with a 104-inch nominal circumference. The seam in the tunnel will be lengthwise, and bonded in to provide a permanent . absolute biological seal. The interfaces at the suit body and hard tube shall be capable of withstanding a direct pull of 700-pounds minimum without damaging seals.

Flexible stringers will be attached to the top of the tunnel spaced equidistantly along the entire tunnel length. They shall be secured

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* See footnote on overpressure effects.

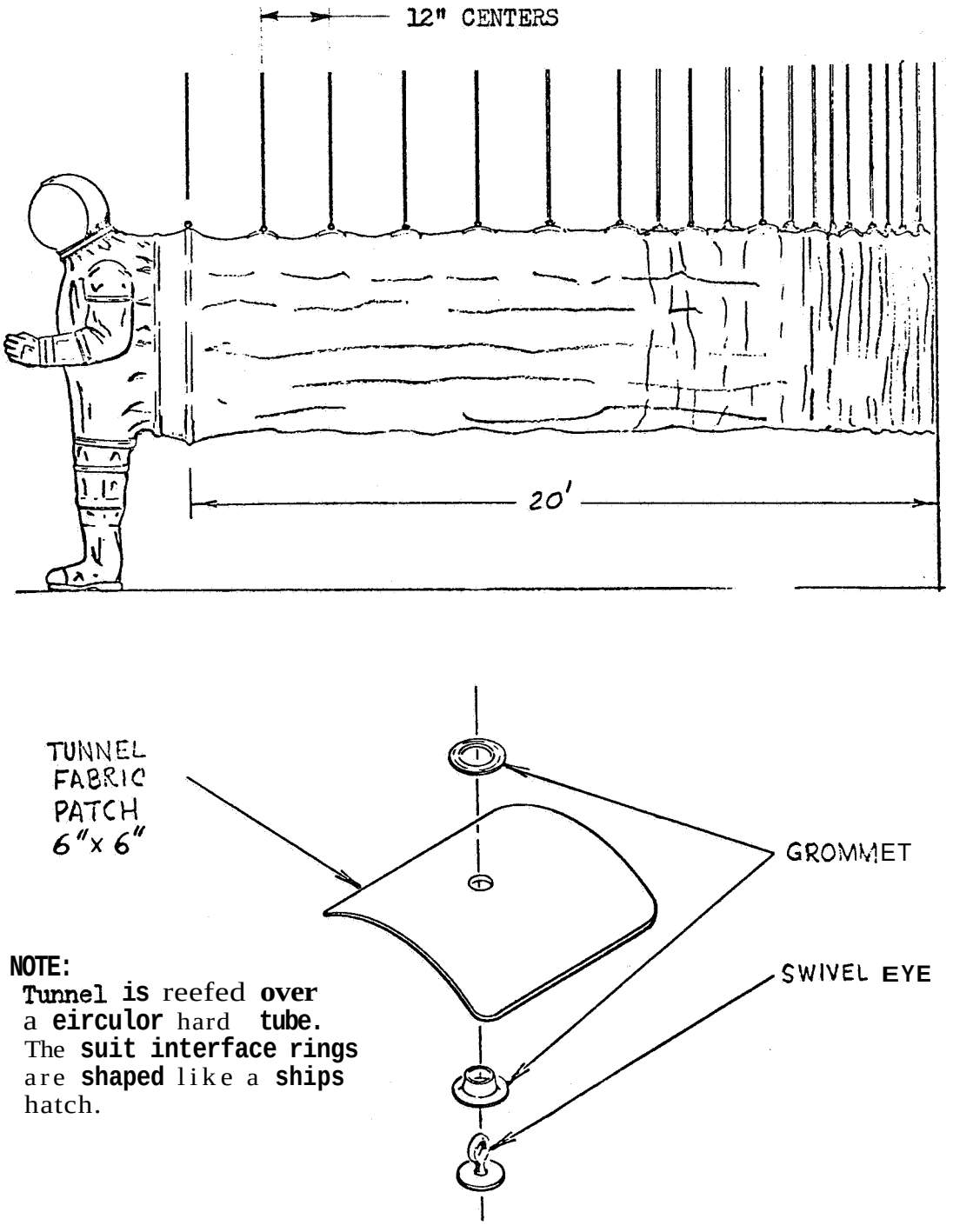
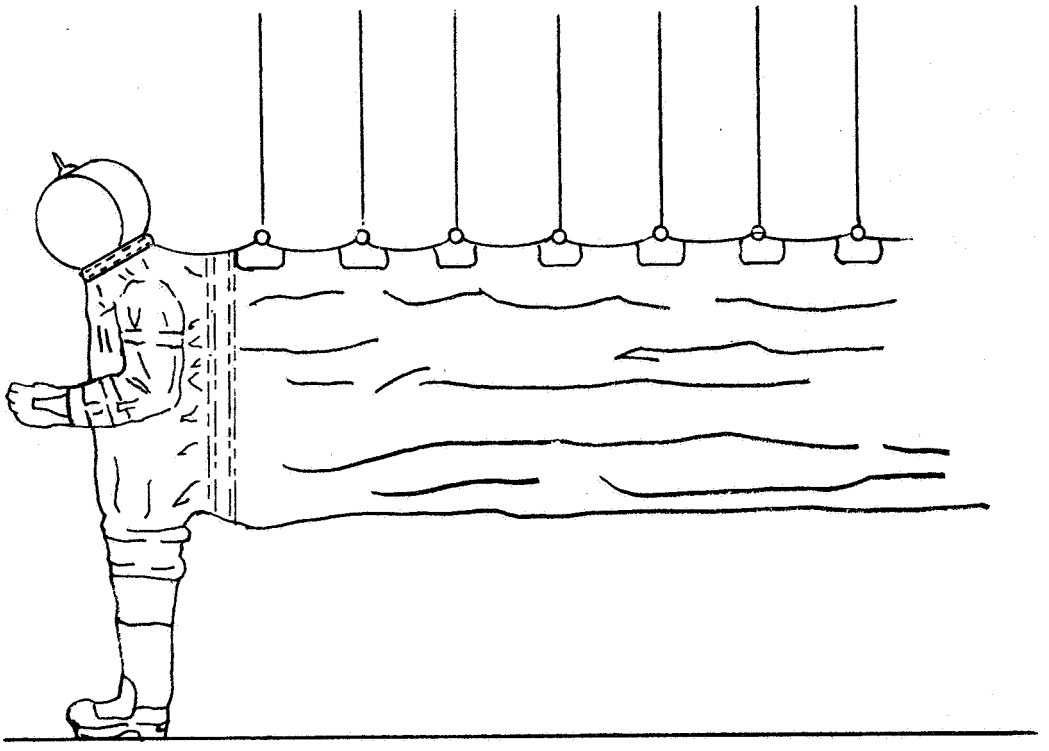


Figure 32- Tunnel for Phase II Biss Mock-up



NOTES:

Tunnel is reefed over a hard tunnel shaped like a ships hatch. Suit interface stiffoning is not rigid, so tunnel flattens at the interface.

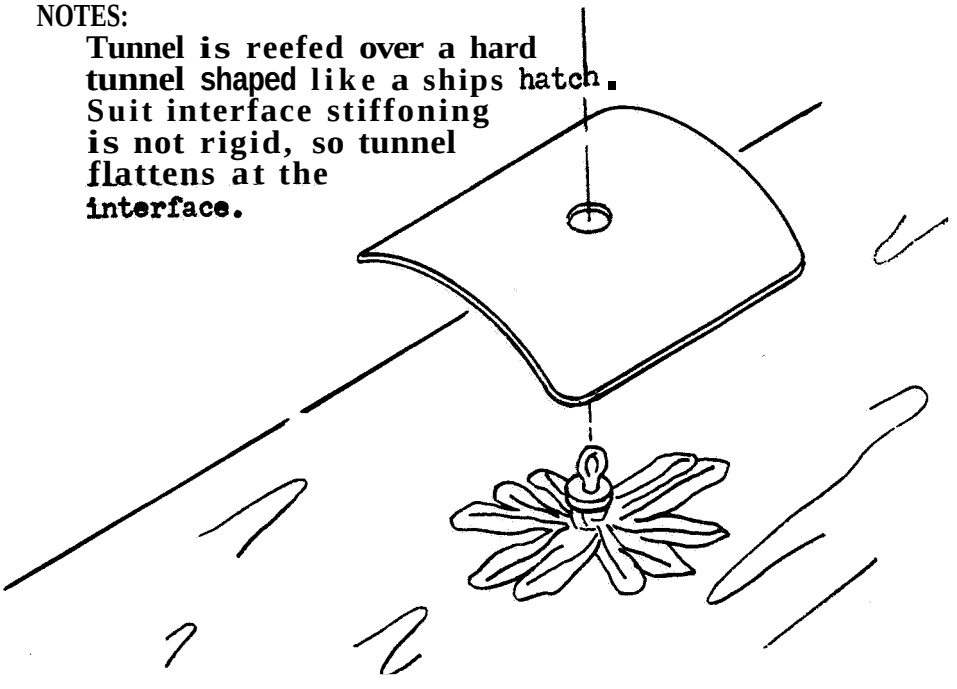


Figure 33 Tunnel and Detail of Swivel-Grommet Construction.

to the tunnel outer wall by a grommet and swivel eye attachment. A second short spider stringer from the grommet and swivel eye will be adhered to the tunnel outer wall. This stringer end will be formed in such a manner that the stress is distributed over a large area. A patch of tunnel material will cover the formed stringer to provide additional strain relief and security of stringer attachment.

The hard tube to be used for reefing will be shaped like a ship's hatch with a circumference of 100 inches maximum. Reefing attachments will be provided on the tunnel to form the interface between it and the reefing mechanism.

4.2 HATCH ASSEMBLY

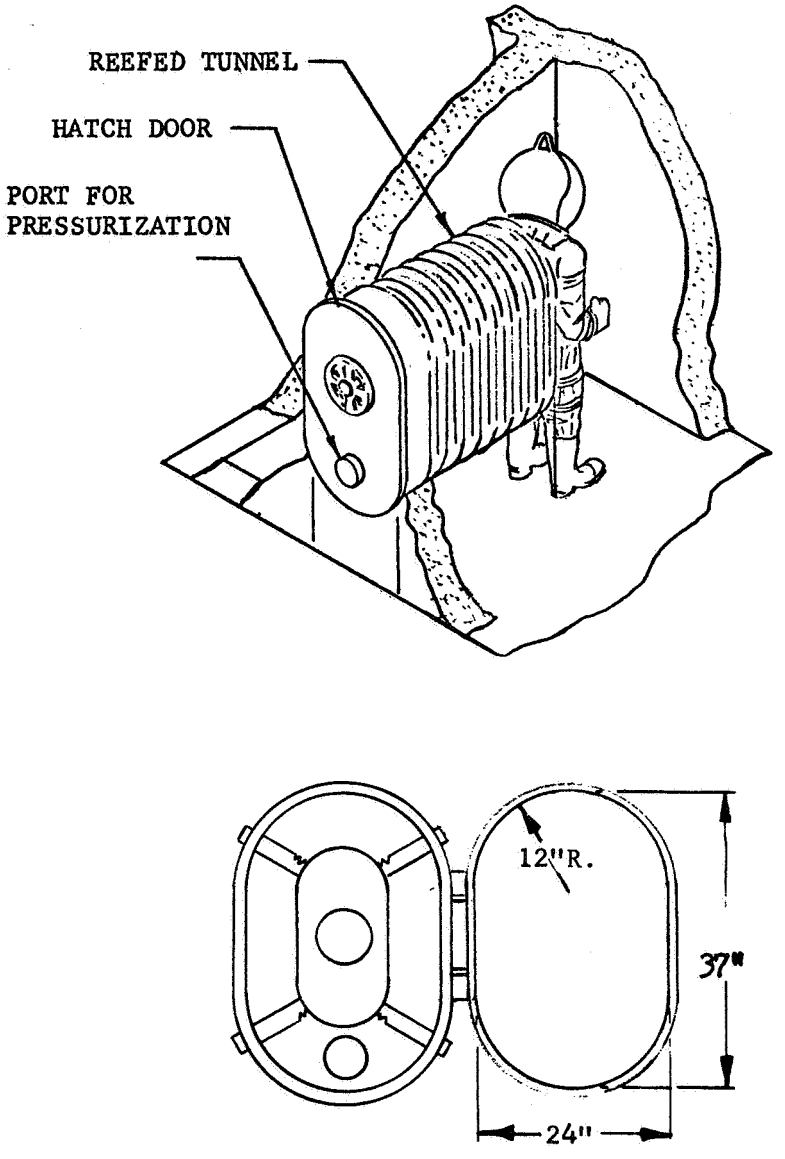
The function of the hatch assembly is to provide an interface between the **BISS** suit-tunnel, the sterile Assembly/Sterilizer Chamber and the non-sterile areas outside. The assembly consists of the hatchway, hatch door, and a hard tube used for tunnel reefing. The hatch assembly is shown in Figure *34*. The hatch and hard tube shape is a rectangle with semi-circular ends on the top and bottom sides. This is the shape of a normal ship's hatch and provides maximum ease of entry and egress for a given circumference.

Although the ship's hatch shape was envisioned in the earliest visualization of the **BISS** hatch; a circular hatch and cylindrical tube were used for the mock-up tests (Section 8.0) to minimize experimental costs. The circular cross section was found adequate, but was not optimum. For a given tunnel circumference a circular cross section results in significantly increased difficulty in ease of entry and egress.

The final recommendation is for a ship's hatch cross section for the hatch and hard tube with dimensions as shown in Figure *34*. The length of the hard tube is a function of tunnel lengths, fractional length of the reefed tunnel, and tube length allocation required for the reefing mechanism.

The normal mode of operation of the hatch assembly is with the door open when a man is in the suit and closed, but vented, when the suit is not occupied. .This mode of operation assures maintenance of a positive inward pressure gradient against the suit and tunnel outer surfaces by maintaining the chamber at a positive pressure relative to ambient.

The hatch door will have four locking bars driven by a hand wheel on the center of the door. The door or hatchway shall have a gasket so that when the door is closed and the locking bars are in place



HATCH OPENING
DIMENSIONS

Figure 34 Hatch **Assembly**

the door presents a leak tight biological barrier. This will permit use of sterile chamber with one or more suits removed and with the associated hatches sealed.

The door contains a sealable port which can be used for venting the suit and tunnel to maintain pressure gradient. The port also can be used to pressurize the suit with a tracer gas to make leak checks on the suit and tunnel in a non-sterile antechamber or main chamber. Conversely, if leak detection is to be performed by "spraying" a tracer gas over the outer surface of the unoccupied suit and tunnel, the port can be used for sampling the suit-tunnel gas. (This is generally a low sensitivity leak check scheme).

4.3 **TUNNEL** REEFING MECHANISM

The reefing of the BISS tunnel for entry and egress and disreefing to permit suited worker mobility present a mechanical design problem of considerable sophistication. The complexity of tunnel reefing is a function of the degree of tunnel hardness. The tunnel hardness trade-off is given in Section *4.2.2.* The reefing aspect of this trade-off is expanded somewhat here.

A rigid tunnel composed of articulated sections on casters or dollies does not permit reefing. This tunnel configuration was rejected for many reasons including mobility restrictions, entry-egress difficulty, and difficulty of emergency rescue. A semi-rigid tunnel consisting of a soft tunnel with radial support rings would probably be the easiest to reef and disreef since its fixed cross section would prevent it from collapsing over or into the hard reefing tube. However this configuration presents the difficulty of force-balancing and causes the tunnel rings at the suit interface to press against the back of the suit occupant. Thus, the soft tunnel, which allows the extended tunnel to collapse radially, was selected. While it is recognized that the selection of the soft tunnel complicated reefing, it was felt that the other problems associated with the semi-rigid configuration outweighted its advantage of easier reefing.

Several schemes for reefing the soft tunnel have been considered. Early mock-up tests indicated that pulling the tunnel through the hard reefing tube and attempting to lap it back over the hard tube outside the chamber was not feasible as a means of reefing. The in-chamber overpressure caused the tunnel to balloon out through the tube and prevented manual reefing operations. Subsequent in-chamber manual reefing (on the in-chamber projection of the hard tube) under two inches of water overpressure indicated that the amount of force necessary to overcome the pressure on the fabric is not excessive for manual reefing.

Manual reefing, drawing the tunnel fabric over the outside of the hard tube, was used throughout the mock-up test program. A dome shaped piston was inserted in the tube so that the dome extended out of the end of the tube away from the hatch. This aided reefing and disreefing by preventing the tunnel from collapsing back into to the tube. This is shown conceptually in the sketches of Figure 35. Openings are left in the piston for life support and communications lines to pass through. Even with the use of the piston, aided disreefing of the tunnel is necessary. Under two inches of water overpressure, the suit occupant is barely able to pull the tunnel off the reefing tube bywalking forward with considerable exertion.

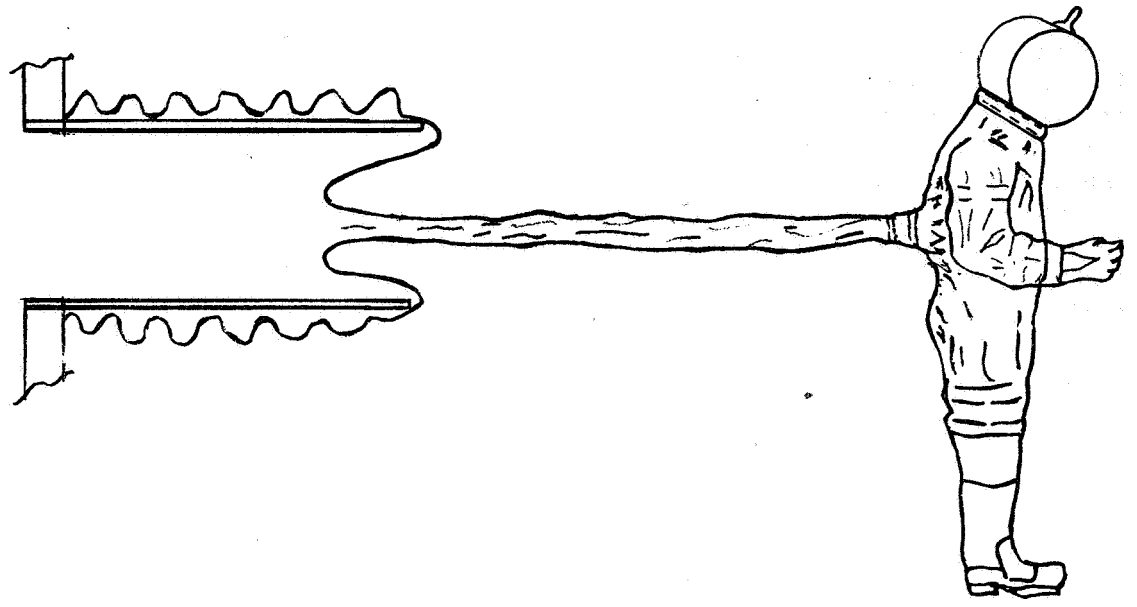
To perform manual reefing, personnel must stand in the chamber adjacent to the reefing tube. Thus, manual reefing is not acceptable for routine use in the Assembly/Sterilizer. A mechanical reefing technique is required. However, manual reefing may be satisfactory for emergency procedures in the event of malfunction of the mechanical reefing system. In fact any mchanical reefing system should be compatible with manual reefing by other suited chamber occupants to assist in emergency egress in the event of equipment malfunction.

A mechanical reefing and disreefing mechanism must be able to grasp the tunnel fabric and either push or pull the fabric onto the tube and must be able to reverse the process. This requires a device for "grasping" the tunnel fabric and a device for pulling or pushing the fabric over the tube either continuously or cyclicly.

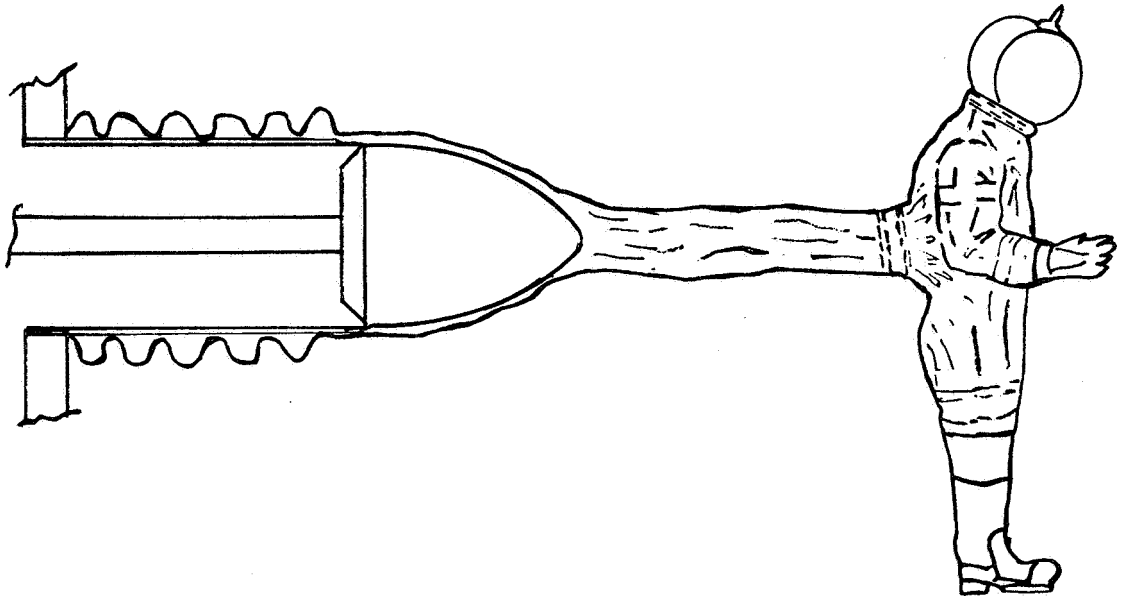
The major reefing mechanism requirements are that it must:

- Grasp the tunnel fabric
- Reef and disreef the tunnel over a rigid tube which is coaxial with the reefed tunnel.
- Provide uniform pull (or push) on the tunnel.
- Provide uniform displacement around the circumference of the tunnel as it reefs or disreefs the tunnel.
- Be compatible with manual emergency reefing.

Satisfaction of these requirements is complicated by (1) the fact that the extended tunnel requres vertical support (reefing mechanism and support stringers must not interfere), (2) it is desirable that the tunnel surfaces be smooth and slick to facilitate reefing over the hard tube and to minimize wear, and (3) the over-pressure environment.



WITHOUT PISTON, TUNNELL TENDS TO COLLAPSE BACK INTO HARD TUBE.



PISTON PREVENTS TUNNEL FKOM COLLAPSING INTO HARD TUBE.

Figure 35 Domed Piston Reefing Aid

Five of the mechanical reefing mechanisms which have been considered are shown in Figure 36. Although further study supported by experimentation is required to develop the optimum reefing mechanism, a brief discussion of some of the concepts involved in the mechanisms of Figure 36 is helpful in guiding future development and in appreciation of some of the problems to be encountered in realization of an optimum system.

Reefing mechanisms can be categorized in two broad classes; External and Internal. This classification refers to the position of the mechanism drive prime mover relative to the tunnel and hard tube. The external mechanism provides a system in which the majority of the equipment is outside of the tunnel and hard tube. This puts the equipment in the sterile chamber environment and minimizes any obstruction of the hard tube passage. The system has the disadvantages that:

(1) It is not possible to use a reefing device at the top center of the tunnel. (Any device in this location would interfere with the stringers which connect to the overhead boom to provide support of the tunnel).

(2) Any maintenance required on the mechanism must be performed in the sterile chamber or chamber sterility must be violated. (Even if an ante-chamber is employed this will in effect put one BISS suit location oat of operation for several work shifts).

(3) Support is required for the reefing devices in addition to the support required for the hard tube. The potential structural integrity of the tube is not well utilized in this respect.

The external reefing mechanism does have the following advantages: .The tunnel design can be such that the outer surfaces facilitate grasping of the tunnel fabric while the inner surfaces can be made smooth and slick to facilitate the slipping of the tunnel of the hard tube. . The reefing mechanism does not obstruct the hard tube passage.

The internal mechanism provides a system in which the majority of the equipment is inside the tunnel and hard tube. This concept appears to have only one major disadvantage in comparison with external mechanisms: The internal drive mechanism will cause some obstruction of the hard tube passage. This obstruction can be minimized by proper design. The internalmechanism appears to have the following distince advantages over the external mechanism:

- Provision for angular indexing of the tunnel on the hard tube can be readily incorporated in the disign of the tube. This is shown in view D of Figure 36.

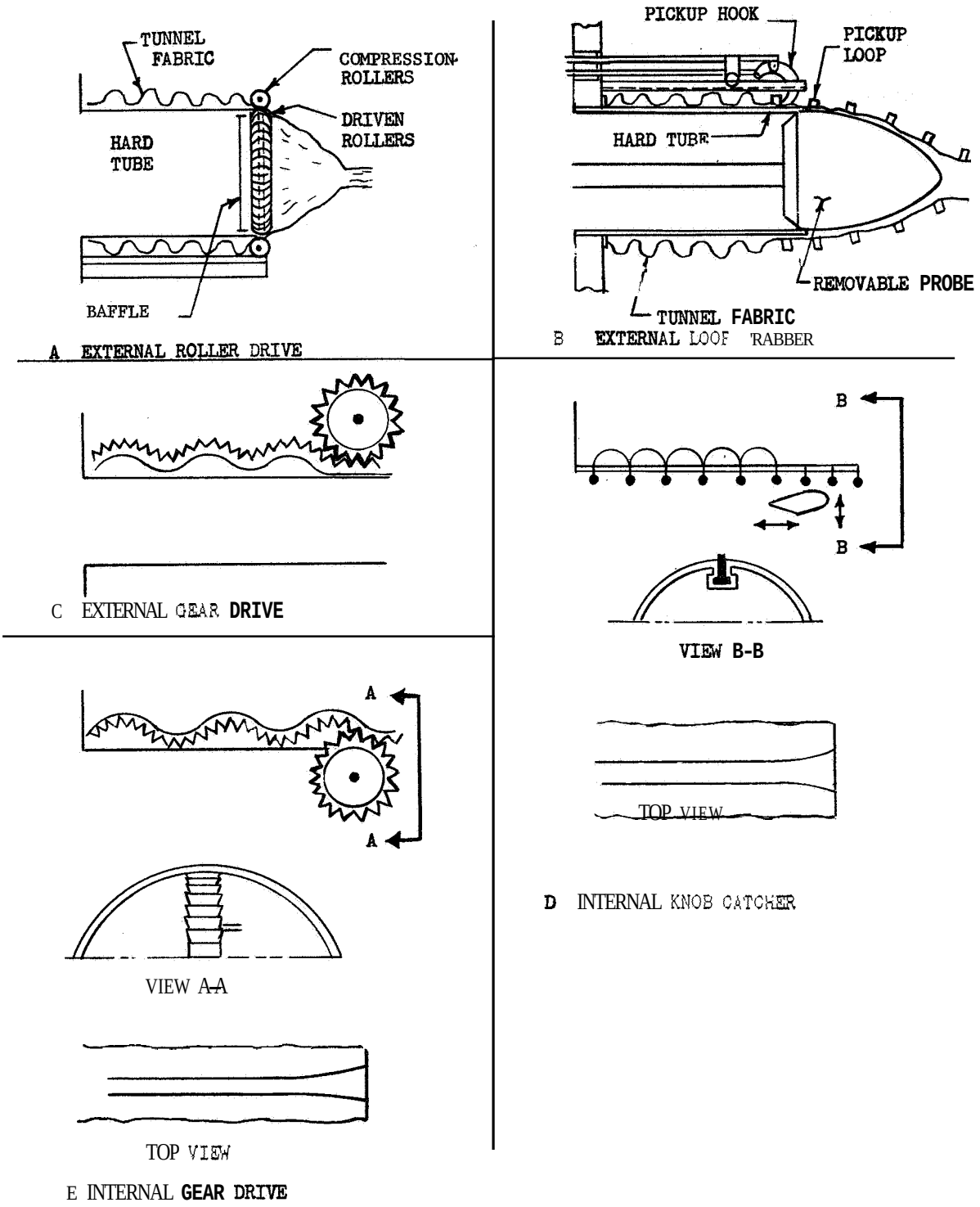


Figure 36 Possible Reefing Mechanisms

- The mechanism is on the non-sterile side of the tunnel and can, therefore, be worked on at any time except during a sterilization cycle. This also permits the utilization of maintenance personnel who do not have to be BISS trained and do not have to work in the BISS suits.

- By using devices such as long shafts or rods, the prime movers for the internal mechanisms can be located on the far side of the chamber wall near the opening of the hard tube. This would permit improved access for servicing and minimize obstruction of the hard tube.

The five devices shown in Figure 36 represent both internal and external mechanisms and employ three basically different concepts of driving tunnel material. These three concepts are continuous roller drive, continuous gear drive, and cyclic drive through attachments to the tunnel. Each of the mechanisms illustrated is a view of only one of several duplicate mechanisms that will be simultaneously required around the periphery of the tunnel to affect uniform driving force and uniform displacement. Some form of mechanical of electrical syncronizing will be required to assure syncronous operation of the multiple mechanisms.

Since the roller drive is not a positive drive mechanism a relatively sophisticated feed-back system employing a displacement follower would be required for each of the multiple mechanisms. Two possible examples of displacement followers would be a potentiometer driven by a wheel riding on the moving fabric or an optical sensor counting circumferential stripes painted on the tunnel. The other mechanisms shown in Figure 36 are all positive displacement devices and do not require this type of feed-back to assure uniform displacement.

The internal and external gear drive mechanisms would employ a flexible rack gear molded from a high-temperature material such as Teflon and bonded to the tunnel surface. These would require angular indexing of the tunnel material to assure that the drive gear remains in contact with the rack. A possible alternative to the drive gear would be use of Velcro strips on the tunnel with a Velcro covered drive wheel, but this does not appear to offer any advantage over a gear drive system.

The loop grabber mechanism shown in View B of Figure 36 employs cyclic driving of the tunnel material. In the cycle the mechanism attaches to the tunnel, pulls in a length of material, disengages, returns to the extended provision and repeats the cycle. The attachment hook would be designed in such a manner that it could dis-reef as well as reef. This mechanism has the disadvantage that the required angular indexing necessitates provision of some indexing feature on the tunnel in addition to the feed-back loops.

The internal knob-catcher mechanism shown in view D overcomes this difficulty by employing the drive knobs for indexing. This particular mechanism also has the advantage that the multi-point attachment ot the hard tube by means of the knobs tends to make the tunnel fold back in the desired manner as it is reefed.

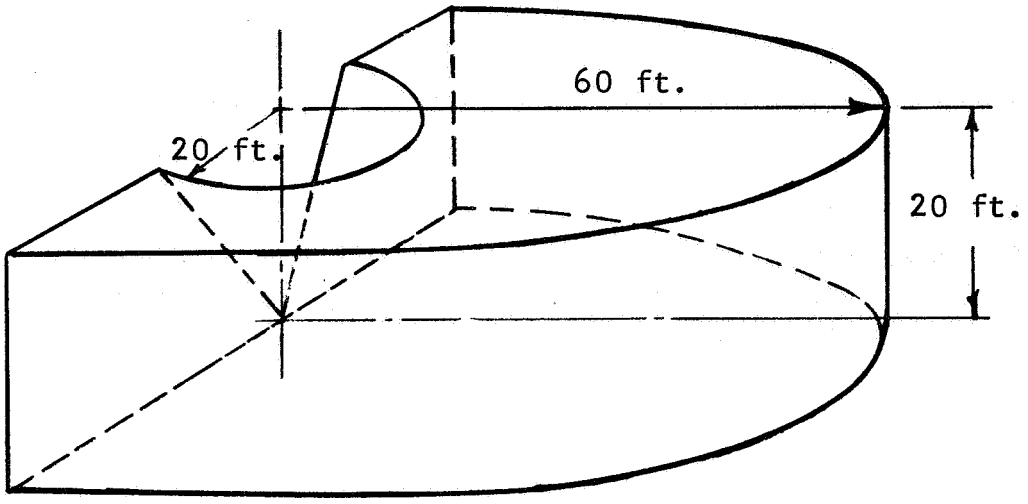
Providing that the knob-catcher drive mechanism can be made sufficiently small that the obstruction of the hard tube is tolerable, this mechanism appears to be superior to the other four mechanisms shown and to offer significant potential for further development. If the knob retention channels formed into the hard tube can be made sufficiently small, these channels may in turn prove advantageous to the overall BISS system. They can act as rails for small wheeled seats which can be used by the worker entering the BISS suit and by maintence personnel' to facilitate movement in the hard tube.

4.4 **TUNNEL** SUPPORT BOOM

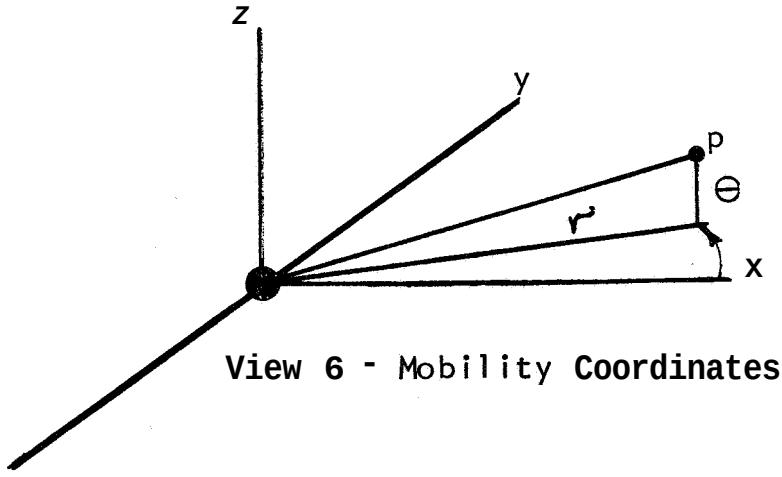
A boom is required to provide vertical support of the tunnel when it is fully or partially extended. The support will be provided by stringers from the boom to the tunnel. In addition to providing support, the boom must accomodate the movement of the BISS suit occupant within the main chamber. The mobility requirement for the BISS occupant is free movement throughout a semicylinder with a 60 foot radius and a 20 foot height except for a semiconical volume with a *45* degree half angle and a 20 foot radius. This volume is sketched in Figure **37.**

The mobility requirement results in a minimum of three dimensional motion. The coordinates of this motion are shown in view B of Figure **37.** The requirement is further complicated by the fact that a man in a BISS suit is not an isolated point but is connected to the **YZ** plane by the tunnel with the boom centerline above the tunnel centerline.

Figure **38** is presented to show the overlap of BISS worker mobility areas in a typical installation in an Assembly/Sterilizer main chamber with a floor of approximately 100 **x 75** feet. The three views of this figure show the overlap for 60, 80, and 100 feet radius work volumes. From consideration of these figures, it is seen that for achievement of the safety requirement of two men being able to assist any disabled operator a large number of BISS occupants must be present in the chamber at all times or the work volumes must have very large radii. Inferred in this figure, though not shown explicitly, is the fact that if the tunnel booms are of fixed length, tremendous difficulties will result from boom interference as the several occupants move about in the chamber.



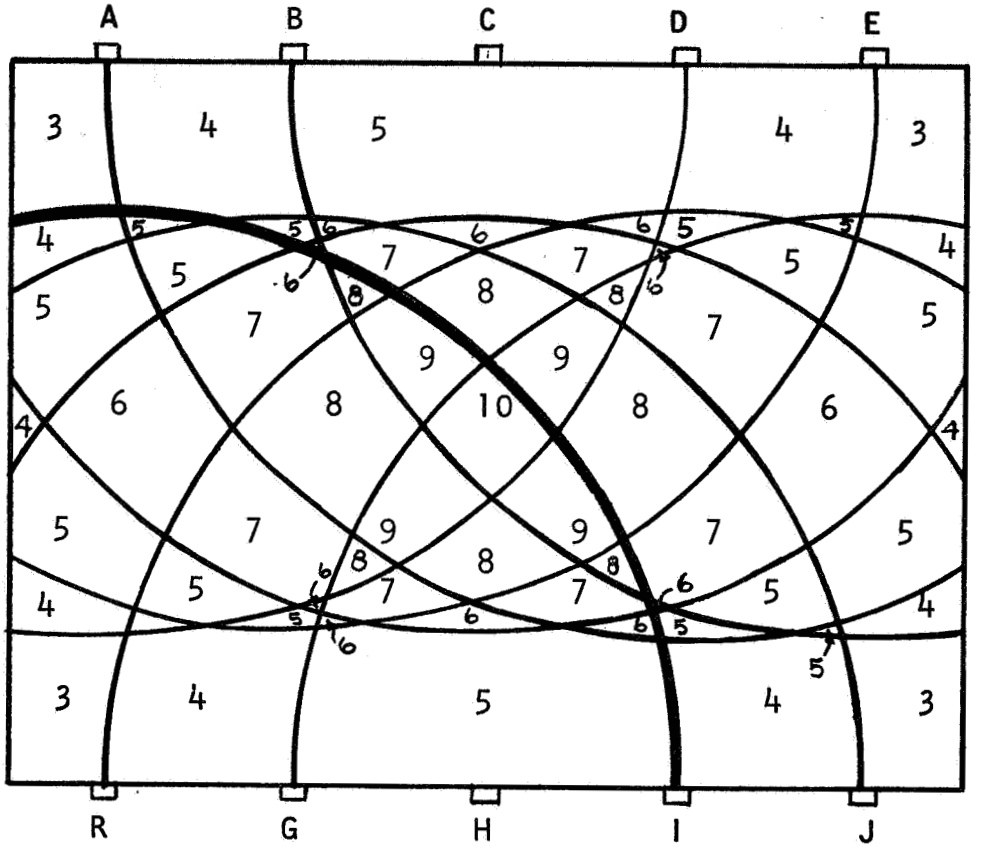
View A - Volume Definition Bottom Surface of Cylindrical Section in Plane of Floor. Flat Vertical Surface in Plane of Chamber Wall and (See View B) Coordinate r Plane xy Coincident with floor, Plane yz coincident with chamber wall.



View 6 - Mobility Coordinates.

Figure 37 Required Mobility Volume

Plan View of Assembly/Sterilizer Main Chamber

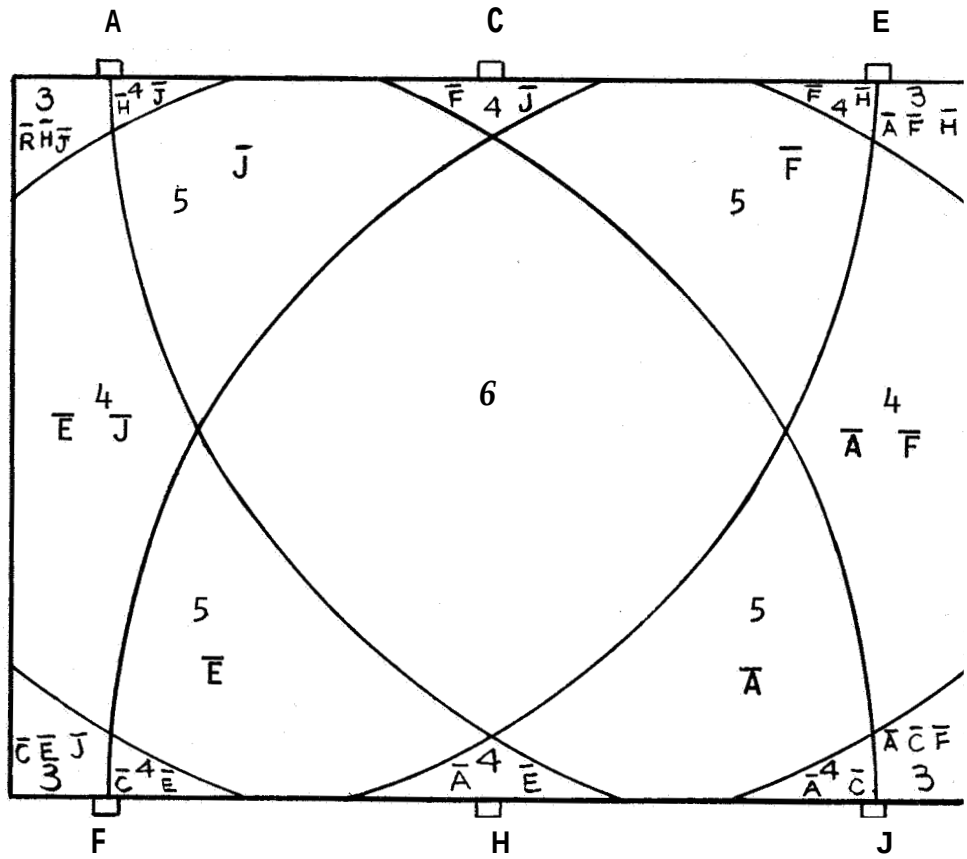


NOTES:

1. Numbers in floor area zones indicate the number of Biss occupants whose work volumes include the indicated zones.
2. Letters around periphery designate Biss suit interfaces with outside wall.
3. Letters in zones indicate Biss occupants whose work volumes do not include the indicated zone.

View A 60 Foot Radius Work Volume -10 Occupants

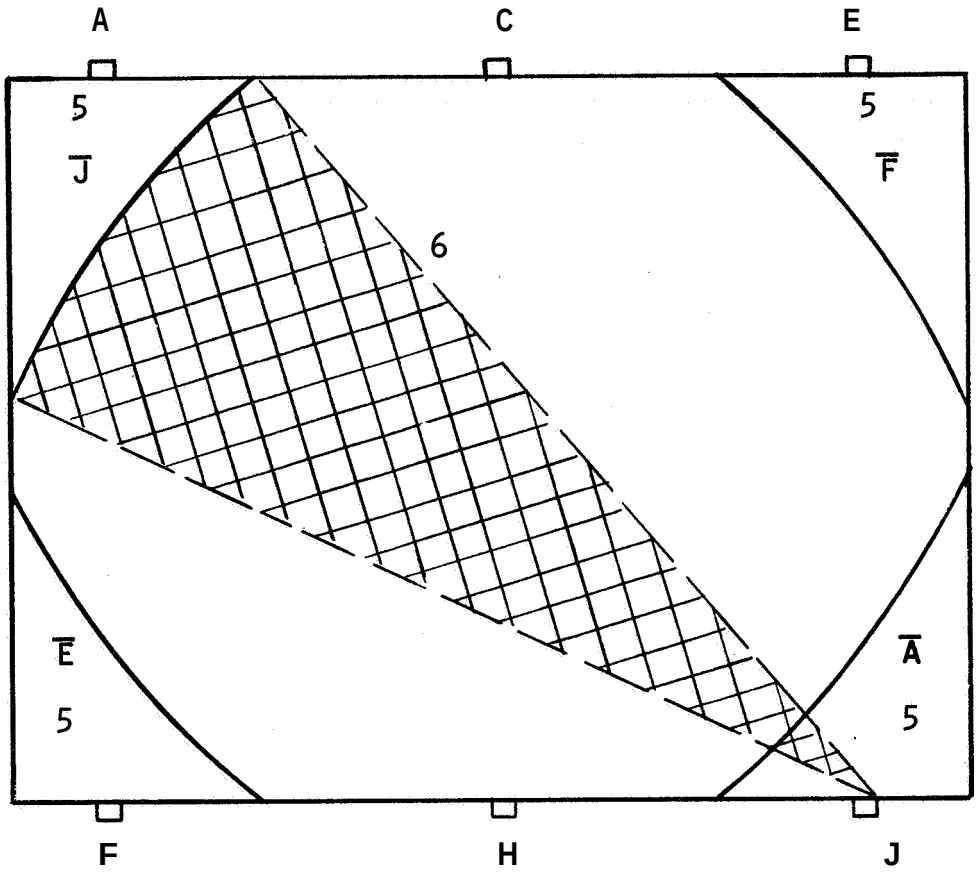
Figure 38 Overlap Of Working Volumes (Plan View)



View B

80 Foot Radius **Work Volume** -*6* Occupants

Figure 38 OVERLAP OF WORKING **VOLUMES** (VIEW B)



View C

1.00 Foot Radius Work Volume -6 Occupants-

SHADED AREA SHOWS LIMITATION ON MOVEMENT OF BISS OCCUPANT J IF BOOM LENGTH IS FIXED.

- Figure 38 Overlap of Working Volumes (view C)

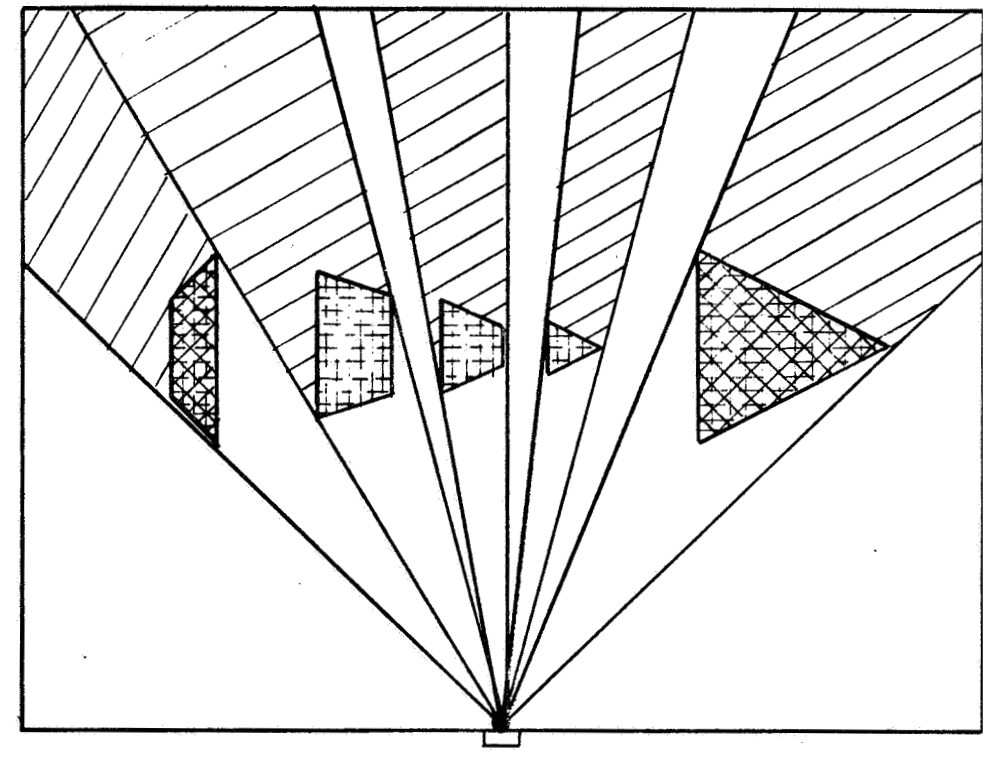
Also if the booms are of fixed length, not all occupants can cover their assigned work areas. This is shown in view C of Figure 38 where the limitations on horizontal mobility of one of the workers are shown for a fixed boom.

In the **BISS** mock-up, the boom was simulated by the simplest possible analog: a wire was strung across the chamber in a line directly above the centerline of the reefing tube. The tunnel was supported from this line by means of stringers attaahed to metal loops which were free to slide along the wire. This permits complete freedom of lonitudinal movement but very limited lateral movement.

The next step of sophistication beyond a simple horizontal wire would be a rigid boom pivoted on the chamber wall or at the end of the reefing tube. (If antechambers are employed, the boom pivot would be in the chamber wall; if antechambers are not employed, the boom pivot would be directly above the suit end of the reefing tube). This boom would have to contain some type of a track which would permit stringer supports to slide along the boom. As shown in the discussion of Figure **38,** the mobility attainable in the plane of the floor with this type of a boom is extremely limited. It appears, therefore, that the boom must be articulated in the horizontal plane or must have a telescoping capability. In the optimum sense, both of these capabilities are desirable. A telescoping feature would be easier to incorporate in a boom than would articulation. It would not, however, permit a **BISS** occupant to move around a large vehicle section. The full extent of the effect of the booms on horizontal mobility can only be appreciated by considering the effect that large vehicle sections on the work floor would have on the freedom of angular positioning of the booms.

Figure 39 shows the effects of vehicle sections on horizontal mobility when the boom has no horizontal articulation. The situation could be made to look better by showing only the areas inaccessible to any one of several **BISS** technicians operating from positions along both sides of the chamber; however, addition of a second vehicle, tool carts, etc. would significantly offset any such betterment of conditions.

To determine the optimum degree of horizontal articulation, a detailed work flow study of the processing of a sterile lander in the Assembly/Sterilizer would be required. As a minimum, however, it appears that at least one articulation joint near the end of the boom is necessary. It should be noted that without at least one horizontal articulation joint, in addition to the boom pivot at the chamber wall, a man whose hatch is at one end of the chamber side wall cannot be aided in emergencies by



Legend

Areas "blocked" by Vehicle Sections

Bio-Barrier

Vehicle Sections

Figure 39 Effects of Vehicle Sections On Mobility With Non-Articulated Boom (Telescoping Boom Only.

more than one man from his side of the chamber.

In addition to the problem of horizontal mobility, the defined work volume imposes the necessity of vertical mobility of the suit occupant. This requires either vertical articulation of the boom or a system whereby stringers from the tunnel to the boom are individually controllable with a horizontal boom adds considerable complexity to vertical mobility capability with a horizontal boom adds considerable complexity to the boom design. Such a concept requires individually controllable position servos on each of a number of tunnel support stringers. With this approach, the stringers would be shortened as the BISS worker climbed a work-stand to work on equipment not accessible from the floor of the chamber. This is shown in Figure 40. Each of the stringers from the boom to the inclined portion of the tunnel is of a different length.

Several constant force tensioning devices have been considered for incorporation in the stringers to provide the vertical movement freedom with a passive (non-servo) system. Examples of such devices are weights and pulleys or constant force springs (such as Negators). However, the dynamics of motion of the suit occupant will not result in constant tunnel forces which obviates the use of such devices. Any unbalance of the forces would cause vertical "bowing" of the tunnel and would result in the tunnel dragging on the floor or bowing upward, wither of which would complicate reefing. Tunnel dragging, of course, would be very undesirable. In addition to this problem, a pulley and weight system would be particularly disadvantageous because it would result in a significant increase in chamber height.*

Since a constant force system cannot be employed with a horizontal boom, a controlled displacement system (servos) would be required. With a servo drive system on the stringers, the amount of stringer shortening and the number of stringers to be shortened would be a function of the desired vertical ascent and the distance of the desired position from the chamber wall or reefing tube end. This would result in a quite sophisticated system.

As an alternative to stringer length adjustment, vertical articulation of the boom can be employed. As a minimum, this would require a 28.3 foot section of boom which could be elevated to 45^{o} to provide the 20 foot ascent capability. To minimize undesirable interaction between horizontal and vertical articulation and to optimize worker mobility, the boom should be articulated at two points in the vertical plane as well

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* A twenty foot ascent capability with pulley and weight support would require a pulley height of about fourty-five feet.

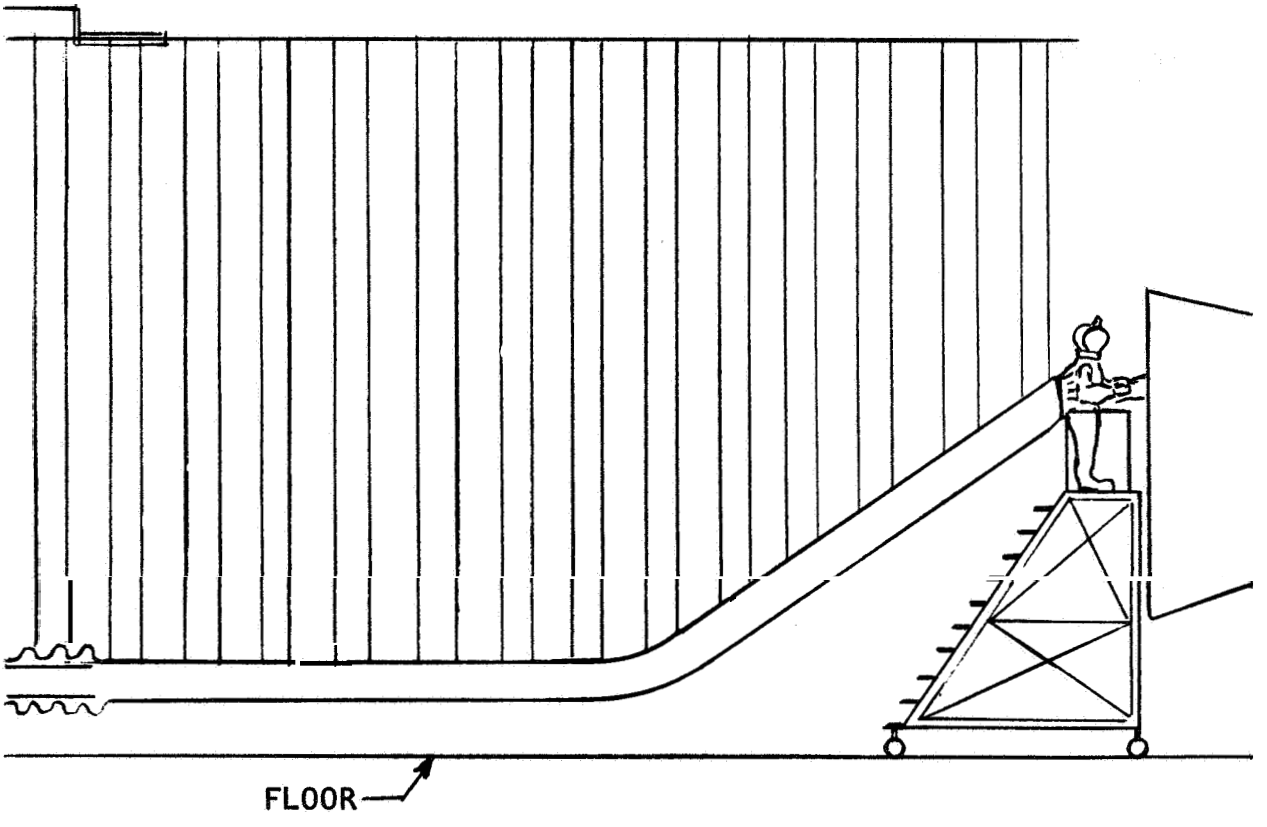
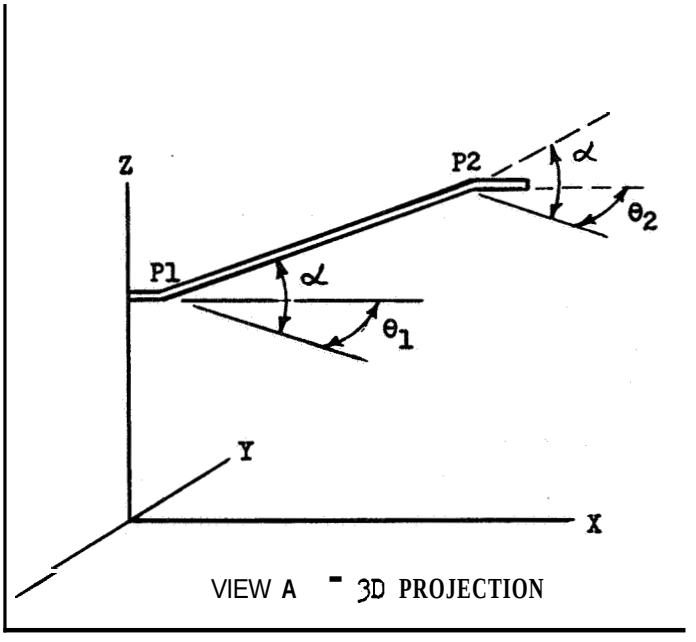


Figure 40 Vertical Ascent of BISS Worker



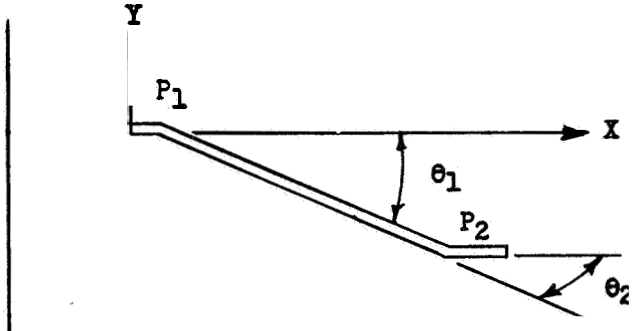
VIEW A - 3D PROJECTION

P1,P2 PIVOT POINTS

DISTANCE P1 P2 ADJUSTABLE BY TELESCOPING

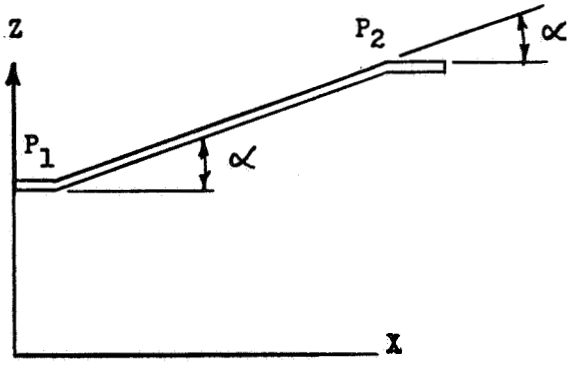
α ELEVATION ANGLE OF BOOM

θ_1, θ_2 HORIZONTAL ARTICULATION ANGLES



θ_1 and θ_2 INDEPENDENT

VIEW B - BOOM PROJECTION IN PLANE OF FLOOR



VIEW C BOOM PROJECTIOM IN XZ PLANE WITH θ_1 θ_2 0

Figure 41. Minimum Recommended Articulation of Tunnel Support Boom.

as in the horizontal plane. This combination is shown in Figure 41. The two joint articulation in the vertical plane would be coordinated to keep the outer end section of the boom horizontal. The horizontal articulation angles θ_1 and θ_2 would be independent to maximize mobility. The configuration shown here is the recommended minimum to permit reasonable mobility of the BISS occupant.

In considering the desired degree of boom articulation, one further system interaction should be noted: if the boom does not have two joint horizontal articulation, the location of the reefing tube has a very significant impact on the useable main chamber volume. This is shown in Figure 42.

4.5 REEFING/BOOM/BISS OCCUPANT INTERACTION

The preceeding discussions of tunnel reefing and tunnel support indicate the complexity of the individual reefing and boom design problems. These problems are further complicated by the need to coordinate these two major equipment items with each other and with the BISS occupants desired motions. For example, as the suit occupant moves away from the reefing tube, the reefing mechanism must play out the tunnel, the boom must extend, and the support stringers must be driven out on the boom. These machine functions must be accomplished in at least gross synchronism with the forward motion of the suit occupant. In essence the system design problem is one of a coordinated multidimensional servo system incorporating a human as a driving element.

As a minimum, the system involves 9 degrees of freedom as delineated below:

System Criteria	Degrees of Freedom
Tunnel Reefing - displacement	1
Boom - Extension	1
- Elevation	1
- Horizontal Motion	2
Suit Occupant - Position	4*
TOTAL	9

* Suit occupant position involves as a minimum, X, Y, and Y position and angle of body rotation about its axis. This does not include the differential displacements such as result from bending or squatting.

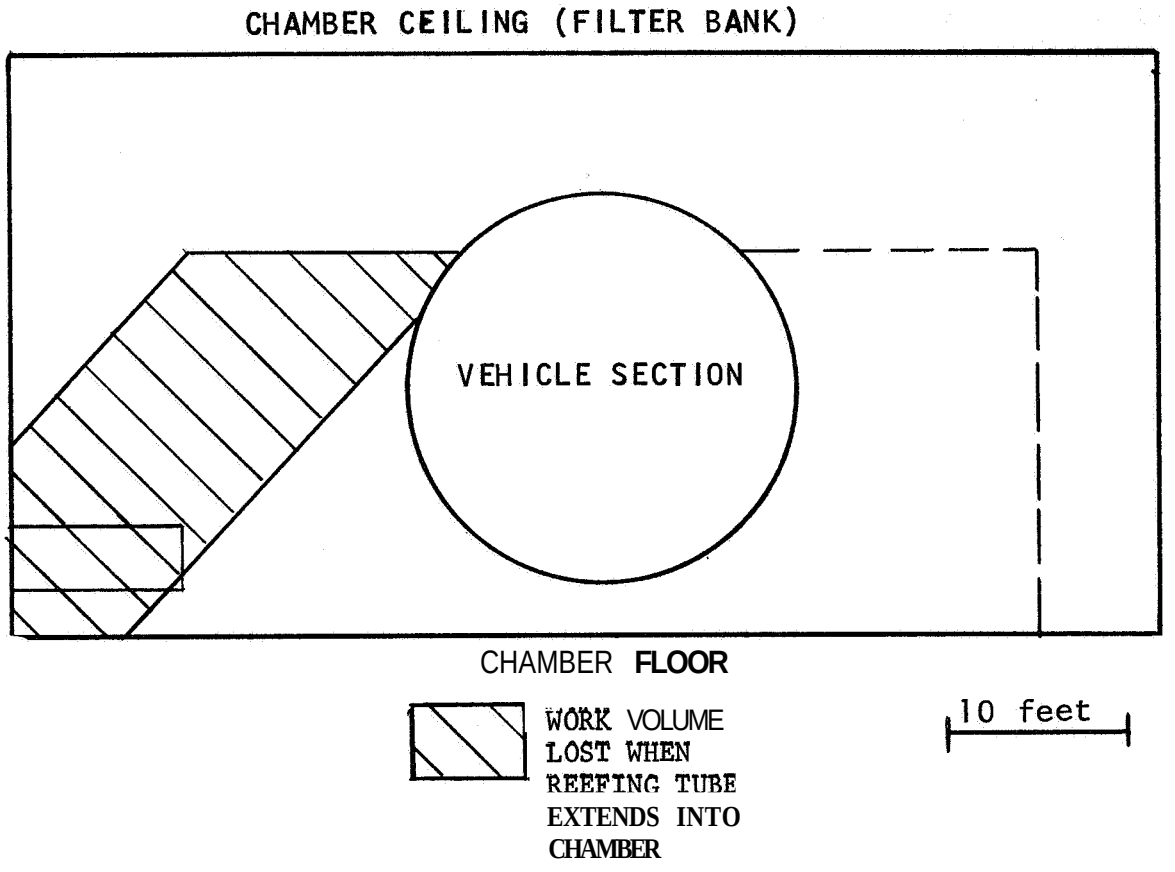


Figure 42 **Loss** of Work Volume **if** Reefing Tube Extends into Chamber and Boom Has Only **One** Horizontal Articulation Joint

To have a workable system, motion in all of these degrees of freedom must be coordinated and must be in response to the motion desired by the suit occupant. For optimum efficiency, the hardware whould be so designed that the system responds to the desires of the suit occupant in that his attempts to move are sensed and the system automatically aids this motion (as in automotive power steering).

It should be noted that the complexity of the required system is even greater than that suggested above because of two significant facts: (1) the coordination between system degrees of freedom involves non-linearities (e.g. tunnel reefing mechanism playout can be a function of the sine of angled; (2) the system must be able to adapt to different modes of operation depending upon the desired motion of the occupant (e.g. boom elevation and tunnel reefing are coordinated for vertical ascent, but no elevation is involved in moving about on the floor, though reefing is involved).

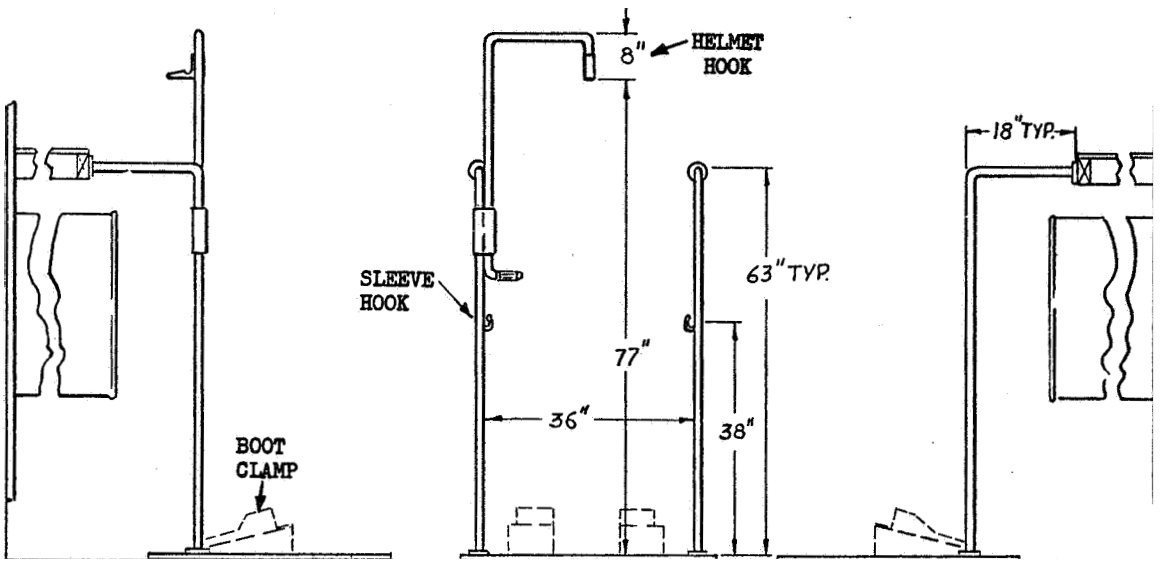
The design of a man/machine system of this complexity will require extensive systems and hardware analysis and design based on detailed work flow planning and supported by experimental verification of the evolving system. Such a design is beyond the scope of the present contract.

4.6 DONNING RACK

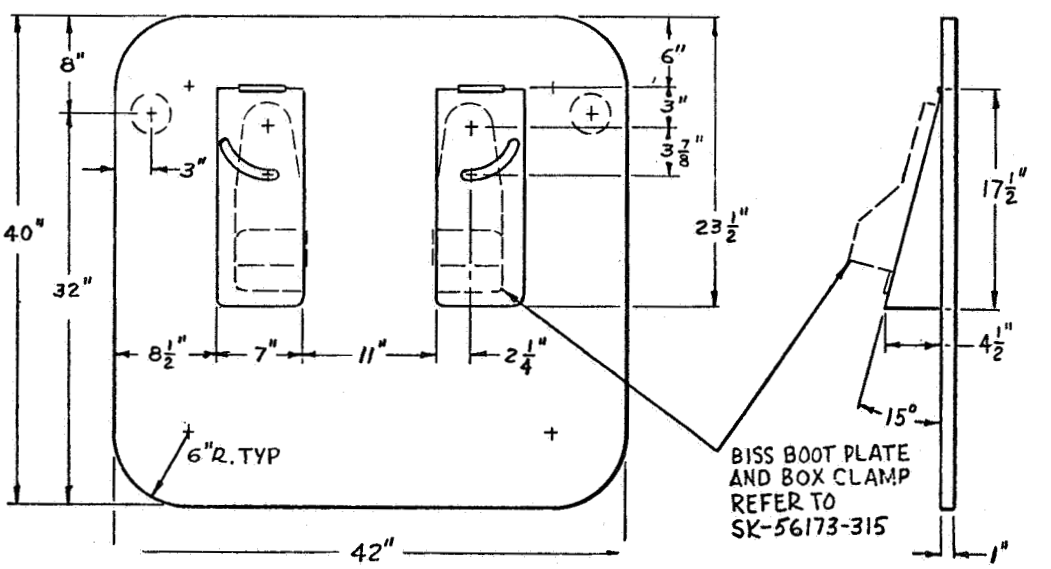
A means is required to support the BISS outer suit so that it holds its anthropomorphic shape during donning and doffing. Holding the suit in shape is a great aid to the man entering or leaving the suit. A donning rack has been designed for this purpose.

Early in the program, a rough wooden donning rack was used for the Phase I mock-up effort and as an experimental design tool for evolving a refined metal rack. The tubular metal rack which was evolved is shown in Figure *43.* The rack holds the helmet, boots, and suit sleeves while the man dons or doffs the suit. The helmet and suit sleeves are held by hooks, and the boots are held by special clamps. The details of the boot clamp are shown in Figures *44* and *45.*

The tubular donning rack was used extensively in the Phase II mock-up tests and was found satisfactory. Minor modifications are recommended in the sleeve holding feature to optimize the design.



DONNING RACK 1" TUBULAR FRAMING



DONNING RACY BASE - TOP & SIDE VIEWS

Figure 43 BISS Donning Rack

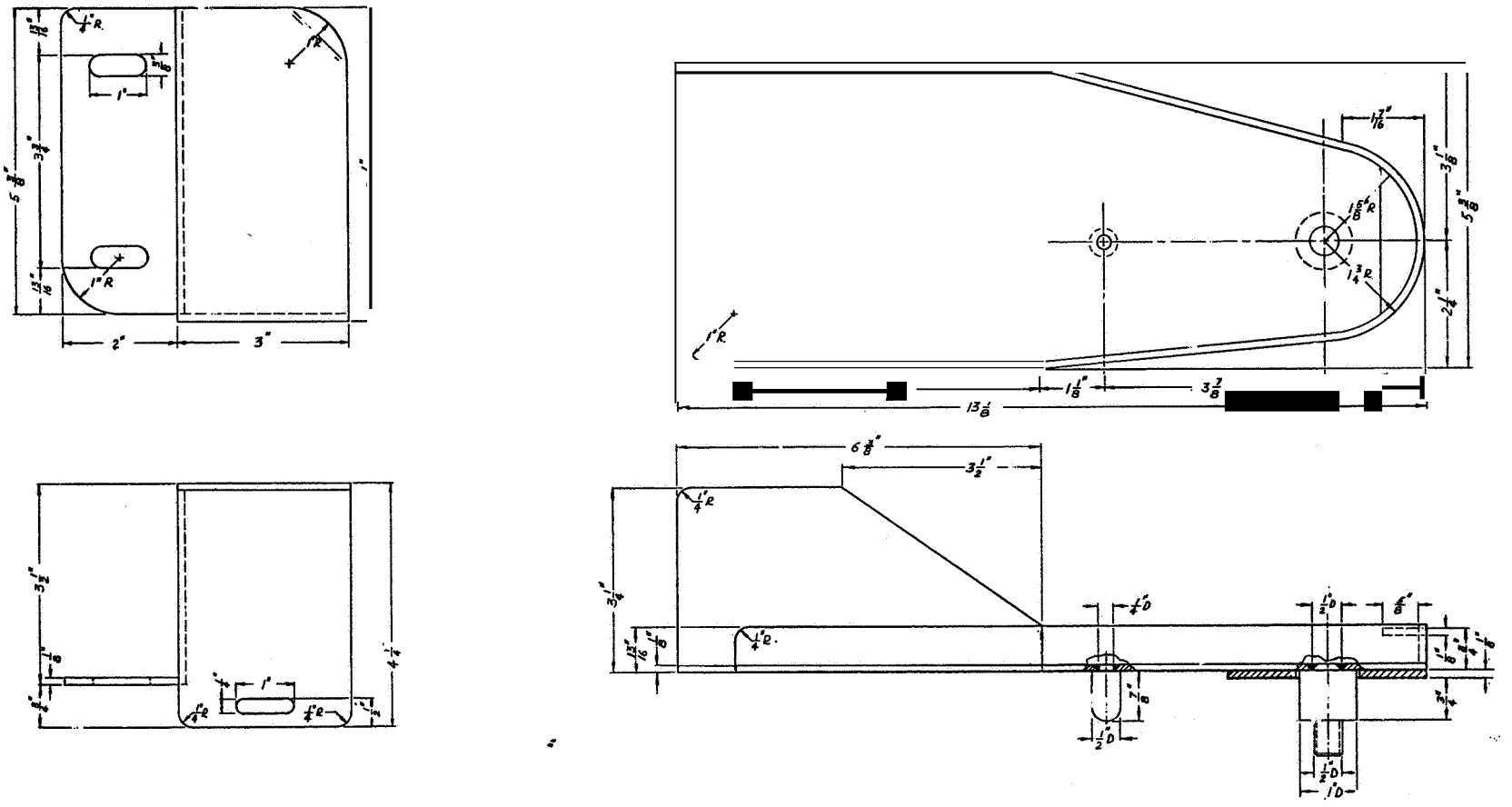


Figure 44 BISS Boot Plate and Box Clamp

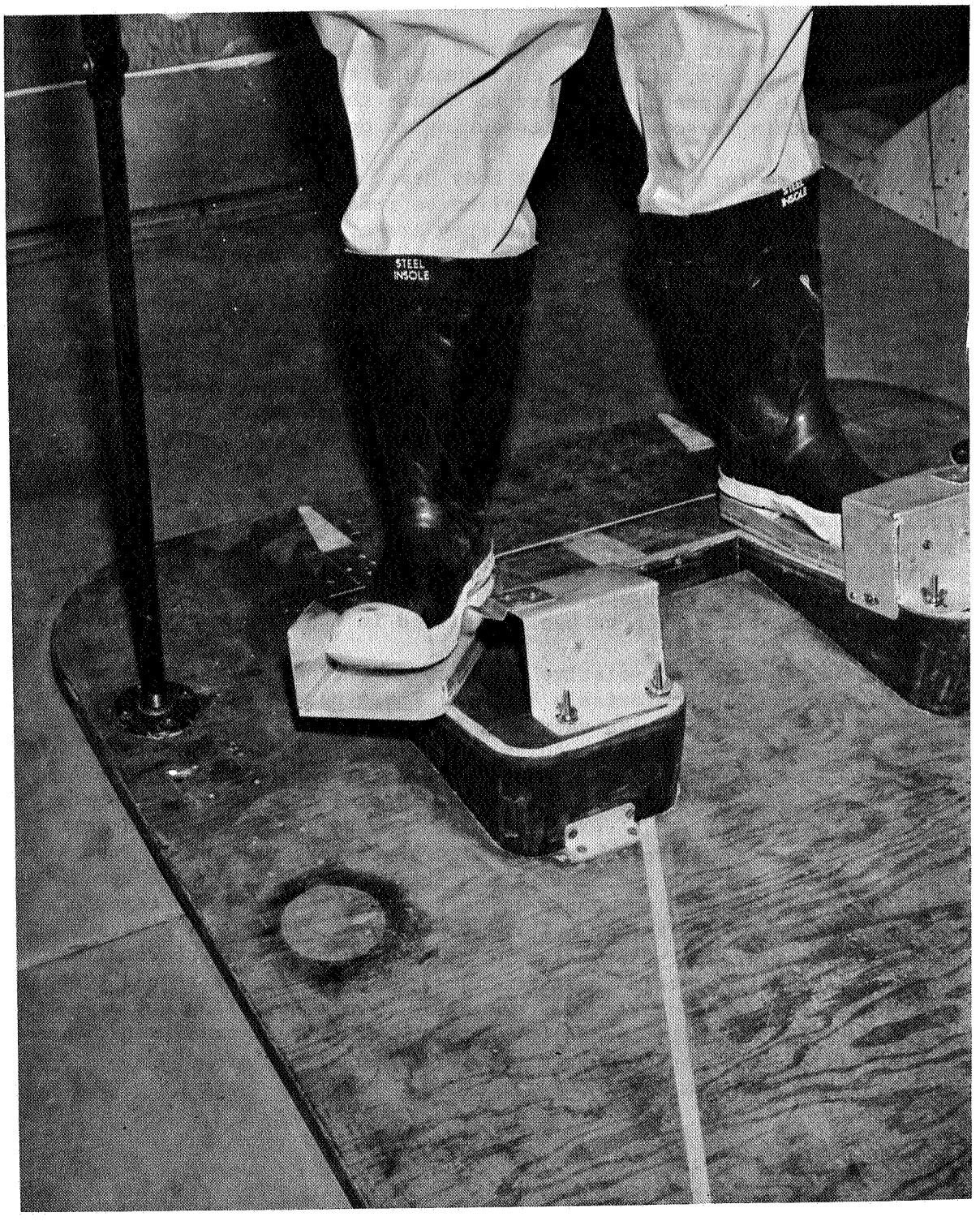


Figure 45 **BISS** Boot Clamp

4.7 LIFE SUPPORT

4.7.1 Requirements

The life support subsystem includes the equipment necessary to provide a comfortable, healthful environment within the outer suit and tunnel, and the equipment necessary to ensure that the environment is maintained within reasonable limits during an operating cycle.

Operator comfort requires that body heat, moisture, and waste gases resulting from the operator's metabolism be removed from the suit at approximately the same rate at which they are evolved, and that adequate amounts of oxygen be supplied for breathing. In the case of heat and water vapor removal, too rapid a removal rate would result in overcooling the operator; too slow a rate would cause overheating, discomfort, and could ultimately cause prostration of the operator. Failure to remove waste gases would result in a noxious or even a hazardous atmosphere in the suit. Improper removal rates would thus result in discomfort or danger to the operator and reduced operating efficiency.

The oxygen for breathing must be in sufficient quantity and in the proper dilution to maintain normal respiration at any given activity level. Insufficient oxygen or too low a partial pressure can result in dyspnea, discomfort, reduced work capacity, and could also cause eventual prostration. Too high a concentration can result in hyperventilation, apnea and alkylosis. For operator comfort and safety, sea level oxygen concentrations of 17-36% have been specified in the system criteria.

The temperature and relative humidity of the suit atmosphere must be maintained within comfortable limits. These parameters are interdependent and comfort levels vary with the individual operator. Generally speaking, however, relative humidity less than 30% will result in drying of the mucous membranes of nose and mouth, while r.h. higher than 80% will result in discomfort. Temperatures below 60°F will usually be uncomfortable while temperatures above 80°F promote perspiration and discomfort even at low activity levels. Acceptable ranges were originally identified as 65°F to 75°F for temperature and 40% to 50% for relative humidity. In experimentation with the Phase II mock-up system, dry bulb temperature of 68°F to 78°F with wet bulb temperature of 57°F to 64°F have been shown to be satisfactory for occupant comfort. This range of conditions is shown in a psychometric chart in Figure 46. The system should possess sufficient range and accuracy of control to permit establishment of temperature and humidity conditions within a relatively small region within this range to optimize comfort for personal differences and differences in occupant work load.

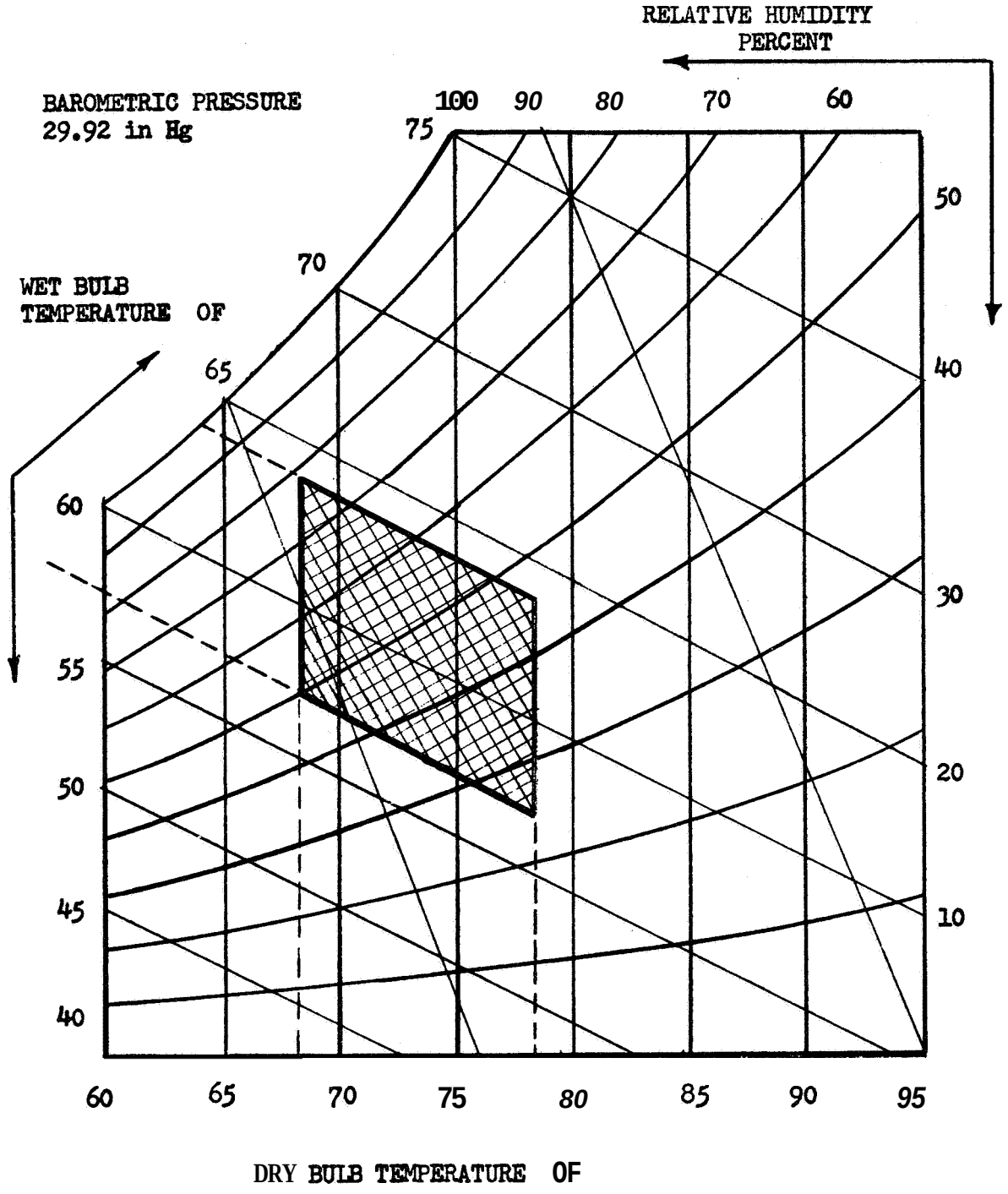


Figure 46 Life Support Gas Supply Operating Region

After a general survey of life support literature, the following values were established as subsystem design parameters*, to be validated by tests:

- Heat removal capacity - 1600 BTUH
- Helmet air flow rate - 2.5 CFM
- Moisture removal - 1 liter/hour maximum
- Temperature of suit atmosphere - 77°F
- Humidity of suit atmosphere - 40% r.h.

A few of the normal activities which can be expected to be performed by the suited operator during assembly operations of a large spacecraft structure are sitting at rest, standing at rest, performing manual operations while seated, walking with and without a load, and climbing stairways. From the literature, levels of heat production and air flow rates for operator comfort can be estimated. This data is presented in **Table III.**

TABLE **111.**

TYPICAL METABOLIC HEAT PRODUCTION AND AIR FLOW REQUIREMENTS FOR PHYSICAL ACTIVITY

ACTIVITY	HEAT PRODUCTION BTU/min	AIR **FLOW** cfm
Sitting at rest	8	10
Standing at rest	**10**	12
Manual operations seated	12	***14***
Walking - no load	13	15
Climbing stairway - no load	***34***	***41*****
Walking - ***44*** lb load	16.9	20**

* These values were abstracted from "Bioenergetics of Space Suits for Lunar Exploration", E. M. Roth M.D., 1966 (NASA SP *84).*

** These conditions represent extended high levels of physical activity that cannot be sustained for periods longer than 10 to 15 minutes without causing extreme fatigue. The conditions exceed physical stress levels which will be encountered in the Assembly/Sterilizer, and thus represent absolute ceilings on heat load and air flow requirements.

These data support the 1600 BTUH design value and are consistent with the 20 CFM air flow found experimentally in the mock-up tests to be an adequate upper limit for all expected suit occupant activities in **BISS.** The air flow rates, including safety margins, experimentally established for **BISS** suit operations are presented in Table IV.

TABLE IV

ACTIVITY AT REST	AIR FLOW
Sitting at rest	10 cfm
Standing at rest	12 cfm
Manual operators seated	14 cfm
Walking - no load	15 cfm
Walking - 40 lb load	20 cfm

The requirements for life support back-up and emergency equipment are discussed under Safety, Section 5.5.

4.7.2 Description

The BISS life support subsystem consists of a cooling unit, heater, humidifier, air cooled undersuit, supply and exhaust ducting and blowers, and monitoring instruments. A schematic block diagram of the subsystem is shown in Figure 47. All of the equipment except the undersuit and ducting, is located in a life support console.

Conditioned air from the facility is forced by the intake blower through a heat exchanger, where it is cooled to 50 to 60°F by means of a compressor thpe refrigeration unit. The cool air is passed through a flow meter, thermostatically controlled heater, humidifier, and supply ducting to the distribution (supply) manifold on the undersuit. Inlet temperature and humidity are monitored by sensors located just upstream of the manifold to provide data for making adjustments in the thermostat and the humidity control valve. The humidity control valve effects control by establishing the mixing rates for dehumidified and humidified air.

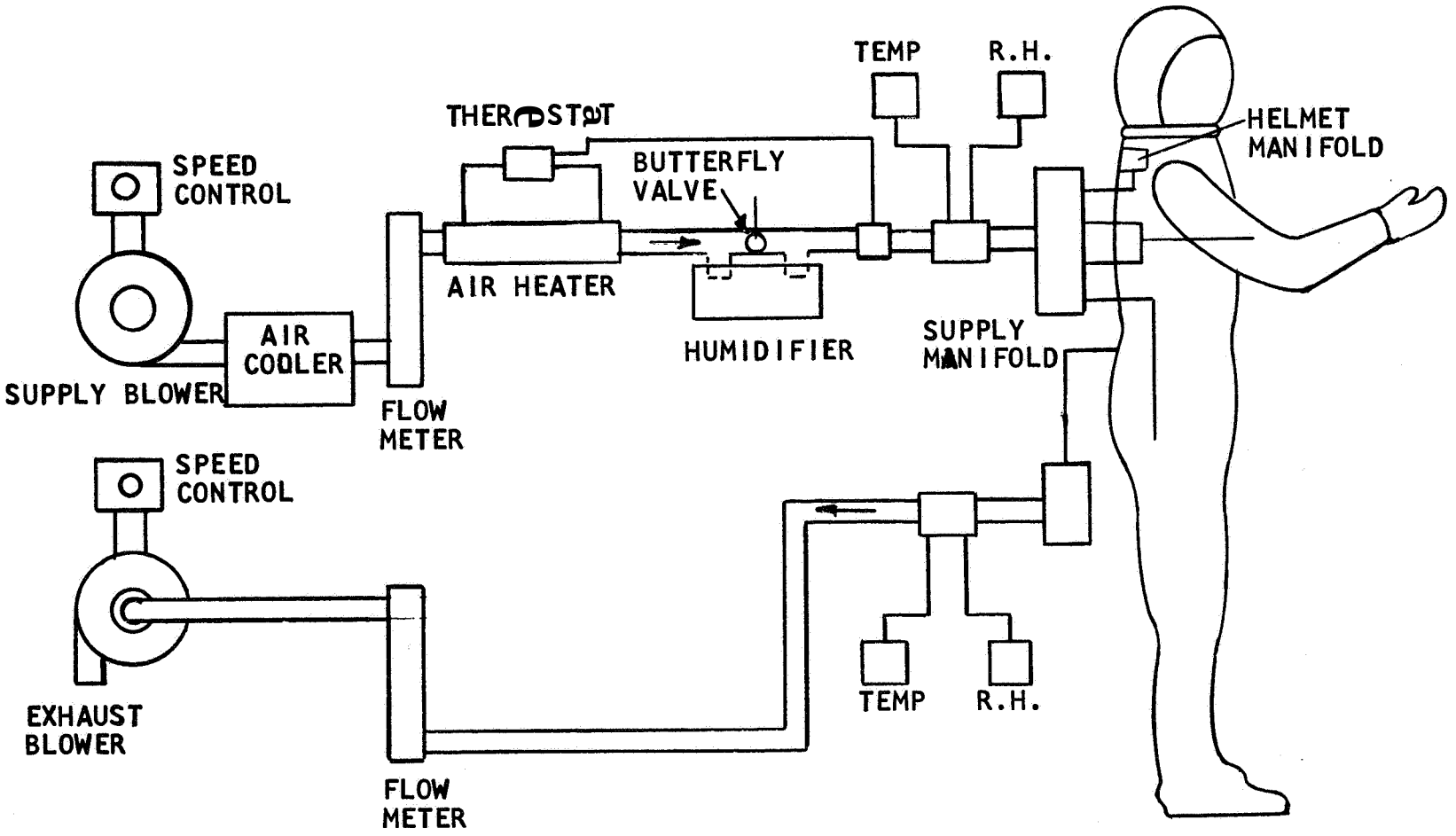


Figure 47 BISS Life Support Sub System Schematic Diagram

Air is distributed from the manifold to the extremities and helmet manifold by means of flexible tubing attached to the life support undersuit. Distributed air is directed into the gloves, boots, and helmet of the outer suit. The gas flow rate is controlled by adjusting the blower speed by means of an autotransformer. Air distribution is controlled by flow resistance in the distribution ducting.

The supply air to the helmet is directed by the helmet manifold onto the helmet rear inner surface and is then directed down over the operator's face by the helmet configuration. This flow pattern provides a sensation of coolness to the operator, prevents helmet fogging due to expired water vapor, and ensures that supply air will not be diluted by expired air from the operator's lungs. The downward curtain of air also prohibits infringement of noxious by-products of metabolism on the operator's olfactory receptors.

The air from the extremities is drawn through the open cell foam lining of the undersuit, passing over the body surfaces to the exhaust duct at the rear of the undersuit through which it is carried to a rotameter, and then to the exhaust blower and vented to atmosphere, The speed of the exhaust blower can be varied by means of an autotransformer to control exhaust flow and suit pressure precisely and to reduce back pressure in the supply lines. Exhaust temperature and relative humidity are monitored just downstream of the junction of the exhaust duct and the undersuit to provide data for adjustment of supply and exhaust blowers and the humidity control valve.

The selection of the basic subsystem concept is described in the trade-offs discussion which follows. The inatrument selection required the choice of gas flow meters, temperature indicators, and humidity indicators. A number of devices are available for measuring gas flow rates, including Hall effect generators, rotameters, hot wire flowmeters, turbine meters, and pitot tubes. Trade-offs of cost and complexity versus reliability and availability indicate that rotameters are desirable for the pressure and flow rates involved in the BISS life support. Gas temperature monitoring can be accomplished using thermometers, thermistors, or thermocouples with remote read-out. Cost factors traded off against reliability and convenience indicate that the thermistors are most desirable. Relative humidity monitoring is somewhat more difficult to accomplish. An electrical resistance type probe mounted as a printed circuit was selected on the basis of sensitivity, availability, and cost.

These instrument selections were biased to some extent by the fact that the life support system had to be realized in hardware for the mock-up test program. Consistent with the technical and fiscal scope of the program, simplicity and cost of the hardware took precedence over remote read-out and control and extreme accuracy. For example, a rotameter

represents an excellent instrument for flow rate measurement when life support control personnel are located with the air conditioning 2nd control equipment, but would not be satisfactory for use in a system where life support control personnel were located remotely as may be the case in a full scale Assembly/Sterilizer.

4.7.3 Design Trade-offs

Trade-off studies were performed to select the optimum solution to the life support subsystem suit temperature and moisture control design problem. These studies indicated that the most promising approach is to supply breathing and cooling air, conditioned by a facility mounted, compressor type cooler to a "semi-closed" life support undersuit separate from the bio-barrier outer suit. The separate trade-offs leading to this approach are presented in the following subsections.

4.7.3.1 Body Environment Control

In developing a solution to the temperature and moisture control problem, a trade-off of three classes of cooling systems was made. The systems which were evaluated were "open" and "closed" systems with air as the cooling medium and a "closed" system with a liquid as the coaling medium. In the closed system, a membrane is interposed between the cooling medium and the wearer's body. For the air-cooled system, this membrane was to be semipermeable and not susceptible to blockage caused by overpressure compression, thereby allowing the passage of moisture through it. The membrane for the liquid cooled suit was to be impermeable to the liquid. A trade-off comparison of these three basic systems is provided in Table V.

Based on the comparison of the three systems, it was concluded that conditioned air was the best cooling fluid primarily because of its superior moisture control properties and the relative simplicity of related hardware development. A further conclusion was to compromise with regard to the "open" or "closed" air system. The compromise was to use a permeable membrane to promote air flow under the overpressure environment, but not to completely seal the undersuit off as would be the case in a truly "closed" system.

Openings were located at the wrists, ankles and neck of the undersuit, which serve as entry ports for input air which is pulled through the suit's continuous membrane and exhausted from a plenum worn at the operator's waist. Input air is supplied to the extremities by means of separate ducting located on the exterior of the undersuit. It was further decided that the readily-available water cooled suit of B. Welson, Inc. should be empirically compared with the air-cooled suit developed by General Electric Company.

TABLE V BODY ENVIRONMENT CONTROL SYSTEM TRADE-OFF

AIR-COOLED "OPEN" SYSTEM	
ADVANTAGES	DISADVANTAGES
(a) Fair heat exchange medium	(a) Cooling air distribution may be less uniform than for a "closed" system.
(b) Non-toxic medium, leakage poses no problem.	(b) Large supply and exhaust ducts required.
(c) Excellent moisture control possible	(c) Moisture vapor loss in supply ducting would probably vary with ambient conditions, thereby making humidity control difficult.
(d) Ducting in suit is minimized.	
(e) Light weight medium and ducting.	
(f) Nominal amount of development work required.	
(g) Complexity of supply and control devices is no greater than that of similar industrial devices of proven reliability.	

TABLE V BODY ENVIRONMENT CONTROL SYSTEM TRADE-OFF (con'd)

AIR-COOLED "CLOSED" SYSTEM	
ADVANTAGES	DISADVANTAGES
(a) Most of the advantages of the "open" system would apply since the heat exchange medium is the same.	(a) Additional complexity, weight and cost are added to the undersuit by the addition of the membranous distribution ducting.
(b) Uniform distribution of the coolant under an overpressure environment.	(b) Supply and exhaust ducting problems are the same as for the "open" system.
(c) Several suitable membranes are available.	(c) Location and sizing of the distribution ducting would require considerable effort.

TABLE V BODY ENVIRONMENT CONTROL SYSTEM TRADE-OFF (con'd)

LIQUID COOLING* WITH DESICCANT CARTRIDGES FOR MOISTURE CONTROL	
ADVANTAGES	DISADVANTAGES
(a) A simple system using water as the heat exchange medium is available (B. Welson, Apolio-type system).	(a) Suitably locating the desiccant cartridge within the suit might prove difficult.
(b) More efficient heat exchange than with a gaseous medium	(b) Independent liquid input and output and breathing air input and output lines are required.
(c) Supply and return lines would be smaller than needed for a gaseous medium.	(c) Humidity control under varying conditions of activity would be poor.
(d) Suitable desiccants are commercially available and cartridges or bags	(d) Localized pressure of the cooling tubing can cause irritation.
	(e) Weight of liquid filled supply lines would be greater than larger gas filled lines.

* Liquids other than water were not considered since no major advantage was apparent, while such difficulties as toxicity, high cost, and chemical reaction with the undersuit and ducting could be foreseen.

Tests were performed to compare the first version of the General Electric Company developed air-cooled undersuit (Phase I mock-up) with the water cooled undersuit. The comparisons resulting from these tests are summarized in Table VI.

TABLE VI. UNDERSUIT TEST COMPARISON

GE DEVELOPED AIR-COOLED SUIT	WELSON WATER COOLED SUIT
ADVANTAGES	ADVANTAGES
(a) Good humidity and pollutant gas control of the suit atmosphere.	(a) The coolant has high heat capacity and so heat transfer is quite efficient.
(b) Light weight	(b) The suit does not restrict body movement.
(c) Good temperature control of the cooling	
(d) There is no restriction on the availability of breathing air.	
(e) Every point within the suit or tunnel can maintained at pressure below the chamber pressure.	
(f) System leakage within the suit creates no problem.	
DISADVANTAGES	DISADVANTAGES
(a) The undersuit construction is relatively bulky and somewhat restricting to the subject's arm and leg motions.	(a) A rather elaborate temperature control system is required because of the sensitivity of the system.
(b) Feed and exhaust hoses are large in cross section and therefore are rather cumbersome to manipulate.	(b) Separate breathing air supply and exhaust lines are required in addition to water supply and return lines.

TABLE VI. UNDERSUIT TEST COMPARISON (CONTINUED)

	DISADVANTAGES
	(c) The water cooled undersuit provides no positive humidity or noxious gas control. (d) Leakage and seepage might be a problem over a long period of operation.

Although both suits gave satisfactory performance in the experimental comparison, the enumeration of the advantages and disadvantages of each distinctly favors the air-cooled undersuit. The air-cooled undersuit was selected for BISS and in subsequent experimentation with a refined version of the suit (Phase II mock-up) the concept was verified. The aircooled undersuit gave excellent environment control with no difficulty beyond a minor limitation of mobility.

4.7.3.2 Air Supply Location.

A trade-off cornparision was made to select the location of the BISS suit air supply. Two locations were considered: a portable back pack in the suit, and a facility mounted supply. For a back pack the supply would be compressed gaseous or liquid air. For a facility mounted supply the nature of the supply was not restricted at this point in the trade-off analysis. The results of the comparison are shown in Table VII. From this table, it is seen that for normal operations the facility mounted air supply is superior, and this is supply location selected for the BISS.

Advantages of aback-pack supply under emergency conditions have been considered further in the safety analysis discussed in Section 5.5.

4.7.3.3 Separate Undersuit vs. Integrated Garment

The body environment control trade-off resulted in selection of conditioned air for removal of excess heat and humidity. A specialized undergarment is required to channel this air over the body of the suit occupant.

A trade-off was made between an independent, personnalized undergarment and a unitary **BISS** suit containing the undergarment as an integral part of the outer suit. The results of this trade-off are contained in Table VIII.

TABLE VII AIR SUPPLY LOCATION TRADE-OFF

BACK-PACK	
ADVANTAGES	DISADVANTAGES
(a) Requires no supply ducting	(a) An exhaust hose would still be required.
(b) Accidental blockage of the tunnel would not create a dangerous condition for the subject.	(b) A breathing air supply adequate for a 4-hour shift would be too heavy to carry about and periodic recharging of the supply bottles would be time consuming.
	(c) Carrying sufficient air to provide cooling to other than the facial areas would be prohibitive due to size and weight of the air bottles.
	(d) The back-pack would increase physical burden borne by the subject and tend to induce fatigue.
	(e) The presence of high pressure gas in the suit/tunnel introduces a danger of overpressurizing the suit in the event of an accident, or in case the tunnel exhaust route were cut off.

TABLE VII AIR SUPPLY LOCATION TRADE-OFF (CON'T)

FACILITY MOUNTED SYSTEM	
ADVANTAGES	DISADVANTAGES
(a) Size and weight of the supply equipment would not have any effect on the load borne by the subject, so that high capacity equipment could be used for long work periods.	(a) Life support ducting or hoses would be needed for both input and exhaust air. These would reduce the mobility of the subject slightly and complicate tunnel reefing.
(b) Capabilities for emergency air or oxygen, for other than a supply line blockage condition, could be incorporated into the system with no effect on the suit/ tunnel design. Redundant systems could be incorporated for increased reliability.	(b) Accidental blockage of the tunnel could cut off the suit air and coolant supply, creating a potentially hazardous condition for the subject
(c) A single life support system could suffice to supply more than one operator, so that the number of control and monitoring personnel and equipment could be minimized.	
(d) No high pressure gas would be required within the suit/tunnel for normal operational conditions.	

TABLE VIII SEPARATE UNDERSUIT/INTEGRATED SUIT TRADE-OFF

SEPARATE UNDERSUIT	INTEGRATED GARMENT
ADVANTAGES	ADVANTAGES
(a) The undersuit and life support equipment would not have to withstand sterilization temperatures. (b) Undersuit and support equipment could be tailored to fit each subject resulting in more efficient air channeling. (c) Individual undergarments significantly reduce the difficulty of maintaining a hygienic occupant environment. (d) Suit design and fabrication is easier.	(a) Subject's entrance into and egress from the suit may be easier.
DISADVANTAGES	DISADVANTAGES
(a) Entry and egress may be more difficult (b) Total equipment complement for the system is greater since each occupant has his own undersuit.	(a) All components would have to meet the same sterilization requirements as the suit/tunnel. (b) Sizing and adjustments required for individual operators would be difficult to make. (c) Cleaning of inner surfaces for hygienic purposes would be very difficult. (d) Achieving efficient air flow over the back of the suit occupant would be very difficult. (e) Suit fabrication is more complicated.

The trade-off comparison very clearly favors the use of a separate undersuit. Subsequent experimentation has shown that the separate undersuit provides good air channeling which in conjunction with properly conditioned air results in a comfortable environment for the occupant.

4.7.3.4 **Cool** Air Source

Two basic types of equipment were investigated for their applicability for cooling the air for breathing and body environment control for the **BISS** occupant. These equipments were a conventional compressor refrigeration, plant and a vortex' tube* heat exchanger (ENCON Mfg. Co., Houston, Tex.)

The two cool air sources were evaluated experimentally. The results of the evaluation are presented in table IX. The compressor air conditioner was selected because of large capacity, silent operation, ease of control, and the fact that no prior air processing is required. The vortex tube must be supplied by a man-rated air compressor.

*This device, also known as a Hilsh tube, provides simultaneous hot and cold air outputs when supplied with high ambient air, requires no power other than the air supply, and has no moving parts.

TABLE IX COOL AIR SOURCE TRADE-OFF

COMPRESSOR TYPE COOLER	
ADVANTAGES	DISADVANTGES
(a) Initial cost of an adequate unit (6000 BTUH) is relatively low.	(a) The unit is rather large-approximately 17 inches x 25 inches x 25 inches with plenum installed.
(b) Outlet air temperature can be easily controlled by thermostats.	(b) A means is required to evaporate or drain off water condensed by the unit.
(c) Operation is quiet and reliable.	
(d) Air flow rate and temperature can be controlled independently; cooling does not depend upon air flow rate.	
(f) A normal unit of this capacity can supply many times the 20 CFM maximum flow needed for suit operation.	
(g) Filtered outside air or room air can be used for both suit cooling and breathing air. No separate breathing air supply is required.	
(h) Humidity reduction is an integral feature of the system.	

TABLE IX COOL AIR SOURCE TRADE-OFF (CON'T)

VORTEX TUBE	
ADVANTAGES	DISADVANTAGES
(a) The vortex tube assembly is simple and reliable having no moving parts.	(a) One (or two) compressed air supplies are required.
(b) The vortex tube can be operated from shop air if it is available.	(b) Operation is quite noisy due to the high pressure air blast.
(c) No power is required for vortex tube operation other than compressed air.	(d) Adjustment of air temperatures directly affects flow rate and back pressure.
(d) The vortex tube is small and lightweight.	(e) Vortex tube capacity is limited to about 12 CFM which is marginal for this system.

4.8 COMMUNICATIONS SUBSYSTEM

4.8.1 Requirements

The communications subsystem must provide aural communication between suit occupants, between a suit occupant and control and support personnel, and between control and support personnel through the use of an electrical or electronic system. Any such system must be a wired system - the use of RF links is precluded by the potential presence of pyrotechnic components on-board spacecraft being assembled by BISS suit occupants.

The primary restriction on the subsystem are that it provide intelligible, convenient, reliable communication at all times between preselected stations with interstation connections being readily changeable under the direction of the facility supervisor or his designee for communications. Intelligibility requires establishment of appropriate volume levels while maintaining essentially distortion free operation.

Convenience requires a talk-at-will capability over established links. Reliability requires the simplest system consistent with operational requirements, employing well proven techniques and equipment.

In a full scale assembly sterilizer it is estimated that upwards of 30 personnel will be involved with the operation, supervision, and direct support of the assembly sterilizer main chamber. Desired communications patterns between these personnel will be continually varying as work progresses in the facility. The general requirements for the communications system have been interpreted as design constraints in the communications subsystem specification S1050-02-0001 in Appendix M. In addition to the performance specifications, several network design recommendations have been formulated. These are listed below.

Any suit occupant shall be able to communicate with any other occupant when necessary. Where there are three or less suit occupants, they shall be interconnected on a common talk-at-will net. When there are more than three men in the chamber, they shall be interconnected on two or more nets as work assignments indicate. A work supervisor outside the chamber will normally be associated with each net. The capability shall be provided to connect all suit occupants on a common net when coordinated effort of the entire team is required.

There shall be a life support communicator and medical monitor associated with each suit occupant net. These personnel will normally have only a listen capability on the net and will relay information to the occupants through the associated work supervisor. The work supervisor shall be able to connect these personnel to the net for two way communications whenever he deems it advisable. (Note that to permit efficient operations the life support communicators and medical monitors must be able to transfer control and observation of suit occupants to their counterparts for other nets as net assignments change - the advisability of this break in continuity requires further study).

Listen only stations shall be provided for visitors and shall permit switching to all currently operating nets.

A communications supervisor shall oversee the operation of the communications system. He shall be directly responsible to the operations supervisor of the facility and shall have complete overriding control over all communications system operation.

4.8.2 Design Trade-offs

Analytical comparisons were made in two areas to support the development of the communications concept. A summary of the results of these analyses follows.

4.8.2.1 **BISS** Operator's Communications Transducer Selection

The transducer configurations considered for use in the **BISS** were:

(a) Headset and throat microphone

(b) Headset and boom microphone

(c) Single suit-mounted speaker/microphone

(d) Separate suit-mounted speaker and microphone

Approaches (c) and (d) appeared to have the most promise in view of the potential impediment to suit entry and exit posed by head mounted transducers. Phase I mock-up experience ruled out (c) because switching is required and a single volume setting must be used for transmit and receive at both ends of the link. It became apparent that no single setting could be found which was satisfactory for both the **BISS** operator and the test conductor. Therefore, the concept employed on the present program was alternative (d) for a separate, suit-mounted microphone and speaker.

4.8.2.2 **BISS** Operator's Method of Actuating the Communications System

The following alternatives were considered:

(a) Push-to-talk

(b) Voice-actuated turn-on

(c) Talk when not receiving (outside switching required)

(d) Talk-at will

Alternatives (c) and (d) emerged from the analysis as having the greatest merit. The relative economy and simplicity of (c) dictated that it be tried first. The requirement for any switching on the part of either the test conductor or the suited operator was found undesirable, and voice actuated switching results in clipping of messages and abnormal speech patterns.

Further, open links in both directions permit instant alerting in either direction if a hazardous condition should arise. Therefore, alternative (d) (talk-at-will) is incorporated in the concept.

4.8.3 Description

Definition of an optimum communications system for the full scale Assembly/Sterilizer must be predicated on a detailed work flow description and task analysis of the facility operation.* The system designed on the present program was directed primarily towards use in the mock-up or similar facilities, with consideration of extension to a full scale facility.

The communications system is a talk-at-will network between the several BISS stations. The network as implemented in the mock-up test facility is shown in Figure *48.* A recommended extension of this network is described in the communications subsystem specification S0150-02-0001 in Appendix M. The basic concept of the system is similar to that of a **PBX** telephone system with additional provision for monitoring of lines by selected personnel who are unable to speak to both parties on the line. This feature was incorporated to minimize the number of speakers talking to the suit occupant so that he would receive instructions from only one source, the test director. Each microphone and speaker has an independent amplifier to assure adequate audio-power for all conditions and to permit flexibility in adjustment of signal levels. The transducers used in all locations are conventional devices used in a conventional manner except for the chamber horn and the transducers in the **BISS** suit.

The transducers in the suit consist of a small speaker and microphone located on the upper chest of the undersuit. This location shown in Figure **13,** was found to provide adequate communications and provide two advantages: the suit occupant was not encumbered by headsets and a boom, lip, or throat microphone; and mounting the transducers on the undersuit rather than the outer suit or helmet means that they are easily serviced and do not have to be able to withstand the severe environment of the sterilization cycle.

The chamber horn used on the present contract was a standard commercial unit. However, this unit remains in the chamber at all times and

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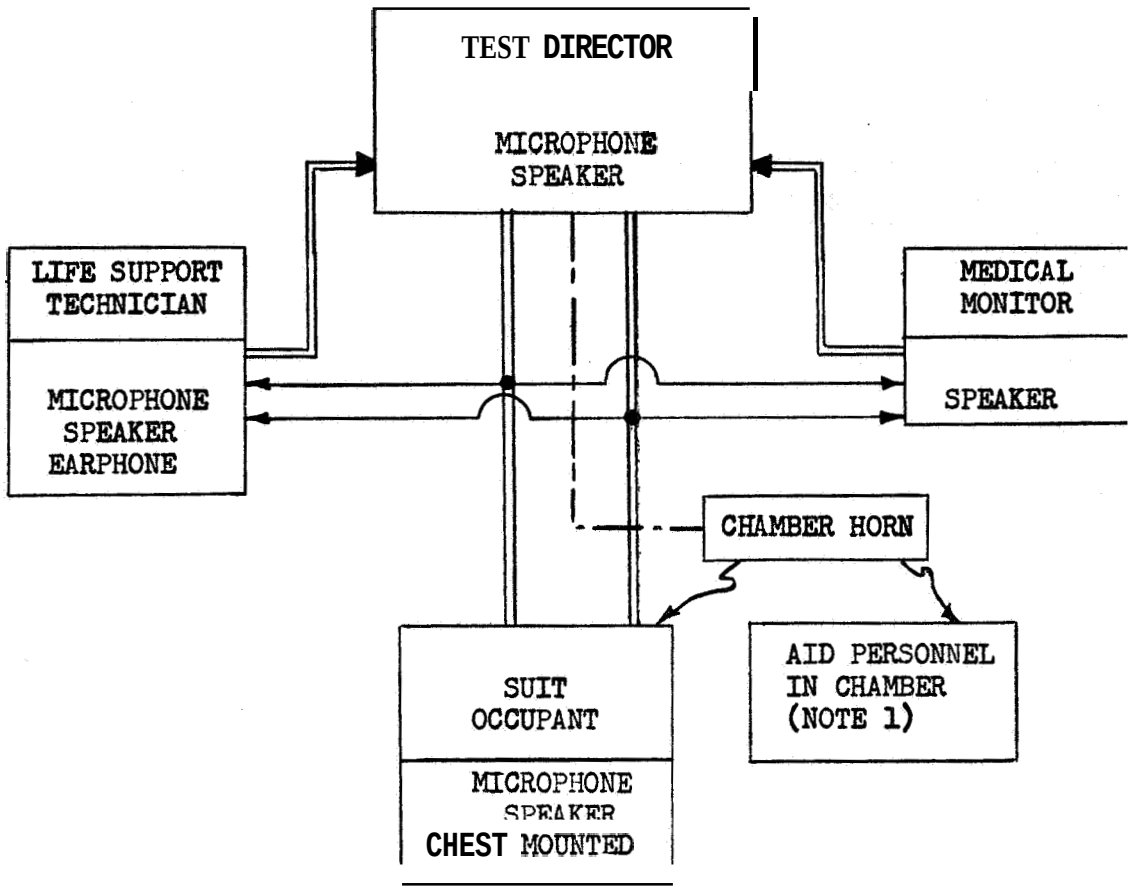
* Full definition of a communications system without this data would result in the communications system imposing restrictions on the work flow and personnel relationships rather than being designed to optimize the efficiency of the Assembly/Sterilizer system operation.



NOTES

(3.) These personnel were test support personnel who would not be *in* the chamber when operating under sterile conditions.

Figure 48 Minimum BISS Communications System As Implemented for BISS Phase II Mock-up.

would have to be redesigned to withstand decontamination and sterilization for use in an operating Assembly/Sterilizer.

Experience with this system in the mock-up program indicated that there was room for improvement. Two deficiencies in the system were noted: gains could not be increased to the desired levels without causing feedback, and gains were not well matched when signals from several persons were feeding a single speaker. The gain increase can be accomodated by a change in transducers and the signal level matching can be accomodated by a more flexible system.

In the system described above most stations used speakers as receiving transducers in a high ambient noise level. They also employed microphones, permitting two way talk-at-will transmission. As a result, when loop gains were adjusted sufficiently high to give good communications in the high noise environment, acoustic feedback caused oscillation in the net, and gains had to be reduced to a less than optimum level. This problem will be mitigated somewhat in a prime system by the fact that the majority of personnel can be expected to be working in areas with much lower noise levels than experienced in the mock-up test facility and can be eliminated by isolation of the receiving and transmitting transducers at each station.

Isolation of transducers can be achieved physically, acoustically, or electrically. The most efficient physical isolation results from the use of earphones and microphones. This also greatly reduces the effective noise level for reception. Acoustic isolation can be achieved by using highly directional microphones and speakers. This requires either that each communicator keep his head relatively stationary or that the transducers move with his head. The former being undesirable and the latter leading towards integrated head sets with earphone and microphones. Electrical isolation is achieved by a push-to-talk feature which disables reception during transmission. This is undesirable because of the inconvenience and the disruption of normal speech patterns. Thus it appears that integrated headsets for each communicator should be given serious further consideration.

In the trade-off study for transducers for the suit of the occupant, the integrated head set was felt to be less desirable than independent chest mounted transducers. This conclusion should be reevaluated. In particular, human factors experimentation should be performed to determine the degree of difficulty of suit entry and egress resulting from wearing a close fitting headset with earphones and a boom microphone, and the suit occupant discomfort resulting from extended wearing of the headset.

The problem of gain matching is common to all multi-station phone type networks. This problem is normally solved by employing signal mixers at each receiving station so that the level of each incoming signal can be adjusted to give a relatively uniform sound level from the speaker, or earphones, regardless of the signal source. These adjustments are done on a periodic basis at each station by a communications technician or supervisor. Because all the stations in the Assembly/Sterilizer communication subsystem will be located in a single building or small complex of buildings, all amplifier/mixers should be located in a single location for ease of system set-up; and tone generators would be used to provide gain balancing signals. This is standard communications practice. A receiving amplifier would be located at each station with a gain control which would permit adjustment of the combined signal to a comfortable level for the local communicator (the communicator would have no control over the gain of his microphone amplifier which would also be located locally).

The only other communications problem for the BISS and Assembly/ Sterilizer system is that caused by frequent changes in interconnections and number of stations on multi-station networks. Changes in connections result in changes in impedance matching and loading which in turn change loop gains. This phenomenon is experienced in telephone systems when more than two parties are in the network (e.g. party lines, extensions, or conference calls). There are several ways of minimizing or eliminating this problem. One such technique is to load each amplifier input or output with multiple dummy loads equivalent to the loads that would be imposed by the maximum number of input and output connections. When an input or output is connected, the respective dummy load is removed. This maintains constant loading regardless of the number of connections from none up to the maximum permissible. A similar though somewhat less effective result can be achieved by using T pads in all input and output lines on amplifiers.

4.9 MEDICAL MONITORING

The BISS places the suit occupant in a unique and potentially stressful environment. It was determined that it would be advisable to provide some means of real time monitoring of the physiological response of the occupant to this environment, in addition to careful medical selection and periodic medical examinations. The single equipment which provides the greatest information and least inconvenience to the worker is an electrocardiogram (EKG).

An EKG monitors the heart performance and thus indicates the phsiological response of the suit occupant to the physical and non-physical stresses of the environment. Also, changes or abnormalities in the EKG record can indicate the onset of pathological conditions within a short time after their occurence so that appropriate safety procedures can be

instituted with the least possible delay.

This degree of medical monitoring is usually only experienced in a laboratory situation, in treatment of patients with suspected cardiac abnormalities, or in medical examinations. Most industrial medical practive runs counter to this degree of medical monitoring. An excellent example is the "IN-FAB" facility operated by the Universa 1-Cyclops Steel Corporation at Bridgeville, Pa. This facility is an inert atmosphere rolling mill for speciality steel. The workers are employed at hard labor for a four hour shift in a "free suit" in an argon atmosphere and are connected to external life support equipment by hoses, resulting in an environment simular to BISS. No medical measurements are made on a routine basis which these workers are on the job. Universal-Cyclops has experienced no difficulties because of the lack of medicalmonitoring*

Medical monitoring was employed during the mock-up testing on the present program as discussed in Section *4.9.* The EKG records from this monitoring showed some unexpected responses to the environment. Subsequent discussions with an expert cardiologist experienced in medical monitoring of personnel in unusual environments indicated that responses of the type observed are not atypical and that they do not appear to represent cause for concern about the health of the suit occupants or the effects of the environment on their health. This subject is discussed in more detail in Appendix C.

The experience of Universa 1-Cyclops in the operation of "IN-FAB" and proper interpretation of GE's experience with the mock-up suggest that continued medical monitoring on future programs employing BISS is not essential. However, it is felt that the practice of monitoring with an EKG should be continued until a more complete history of physiological response to the environment is available on a wider range of personnel. The information thus obtained is derived at relatively small cost and offers several potential benefits: (1) it promises to be helpful in selecting personnel, (2) it may contribute to further investigation of optimum work shift duration, and (3) the data itself is of considerable scientific interest in that it augments the relatively limited information on cardiac response to unusual environments. Thus, it is recomended that EKG recording be continued in future BISS operations until definite, predictable patterns of EKG's are developed on a sufficiently wide base to indicate clearly that medical monitoring is not needed for personnel protection and that further monitoring would be of little scientific value.

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* Personal communication between Dr. W.S. Kip of General Electric Company and Mr.C.P. Mueller of Universal Cyclops

On the present program EKG's were taken using a Telemedics radiocardiogram feeding a GE EKG recorder. The result was a single channel EKG record distorted by significant amounts of electrical interference. In addition to the adverse effects of the electrical interference, the single channel nature of the system made some of the resultant records difficult to interpret. The dynamics of body movements during BISS operation and the dynamics of cardiac response to the environment are such that single channel data does not give an adequate picture of cardiac performance. It is recommended that EKG;s used for future medical monitoring in BISS operations be multichannel, or vector, EKG;s and that signal transmission be accomplished by shielded cables.

5.0 SUPPORTING STUDIES

5.1 BIO-INTEGRITY AND LEAK DETECTION

The bio-integrity of the Assembly/Sterilizer is a function of the achievement and maintenance of sterility of the inner surfaces of the chamber and its contents. It has been shown on a reduced scale analog of the Assembly/Sterilizer system that bio-integrity can be achieved and maintained.* While a logical extension can be made to infer the ability of a full scale facility to achieve and maintain biointegrity, the extension requires considerable support. The BISS suit and tunnel are of central importance in determining the bio-integrity of the Assembly/Sterilizer.**

While the present study does not involve a probabilistic examination of the bio-integrity of the Assembly/Sterilizer or the BISS, a brief review of the associated probabilities is useful to establish the framework for the discussion of the BISS bio-integrity. The present official NASA/JPL requirement is that the probability of a single organism on a supposedly sterile spacecraft be less than one in 10,000***. Allowing moderate conservatism, this means that the probability of the Assembly/Sterilizer maintaining sterility, once established, should be on the order of 3×10^{-5}, and the probability of the BISS permitting one or more viable organisms to penetrate the "skin" of the suit and tunnel should be on the order of 1×10^{-5} or less. In a practical sense this requires essentially absolute assurance of the integrity of the BISS suit and tunnel.

Based on present knowledge, the only way to assure than an organism will not penetrate a barrier is to assure that the barrier has no physical holes large enough to permit passage of an organism under conditions otherwise favorable to such a transfer.*+ The studies under the present

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* NASA Contract NAS 1-5381

** The other areas of concern in decreasing order of importance are latched closures (e.g. doors), bolted closures (e.g. windows), welded seams, wall plates.

*** NASA Position Paper, COSPAR 1966, "A Note on COSPAR Resolution 26.5"

* The question of an organism being able to penetrate by consumption of nutrient material is being answered by selection of non-nutrient materials (see fungus growth and mycelial penetration tests in Section 7.3).

\+ The results to be developed under current contracts NAS 1-7277 and NAS1-7166 may show that maintenance of a pressure gradient counter to the intended direction of organism transfer will prohibit such a transfer for some pressure/hole size regimes.

contract have concentrated on this aspect of bio-integrity assurance by examining techniques for detection of physical holes in the BISS suit and tunnel.

The hole sizes of concern are 0.2 micron diameter and larger for cylindrical holes. For practical suit and tunnel materials, this means a hole length to diameter ratio on the order of3808:1 or larger.* For other holes of simple geometry, the critical dimension is the linear dimension of the minimum cross sectional area of the hole (e.g. the width of a rectangle, the minor axis length of an ellipse, etc.). Better definition of hole dimensions of concern can only be validly based on a detailed study of the mechanics of failure of the material and interfaces to be employed in an actual system.

5.1.1 Detection of Holes by Physical Techniques

5.1.1.1 Basic Detection Techniques

Examination of the suit and tunnel for holes by microscopy** is barred by the very small hole sizes of concern relative to the large total surface area. Pressure leak-down techniques are barred because normal chamber and suit pressure fluctuations would completely mask the infintesimal changes that would result from leaks through a sub-micron hole. Thus any bio-integrity monitoring or checking system must employ a physical detection system using a tracer and a highly sensitive and selective detector.

The tracer could be gaseous, liquid, or a fine particle solid. Solids have been investigated in the form of fluorescein particles and found to be inapplicable to use in the BISS system. The technique was developed by McDonnell Aircraft for a double-walled asceptic assembly facility wherein an aerosol of micron sized particles of fluorescein is dispensed between the walls in gas at a pressure above both the internal and external pressures of the chamber. A leak in either wall would tend to carry the aerosol from the sterile interstice either into the chamber interior or into the room in which the chamber was housed. The particles escaping confinement would be detected by an optical device measuring their fluorescence. The chamber employs double surgical type gloves,

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* 0.2 micron = .0078 mil; typical suit thickness = 30 mils; 30 mils/.0078 mil = 3807

** Any such microscopy would have to be ultraviolet or electron microscopy because the limiting resolution of visible light is 0.2 microns.

one sealed into each wall of the interstice. The gloves attached to the outer wall have external ribbing to maintain an air space between the two gloves. The aerosol then permeates this space so that a leak in either glove can be detected. There is a significant time constant associated with this permeation and it is difficult to maintain an aerosol in the space between the two layers.

The significant factors associated with the application of this system to BISS leak detection are:

- Production and maintenance of the aerosol in a large space with one small dimension.
- Detectability of the aerosol in very large volumes of gas.
- The ability of the aerosol to transgress holes of small diameter.

Because of the large time constant associated with dissemination of the aerosol through spaces with one small dimension, and the hygroscopic nature of the aerosol particles, it appears that establishing and maintaining an aerosol between two layers of outer suit and tunnel material will not be possible. McDonnell personnel advised that it would be extremely difficult to achieve satisfactory aerosol distribution. In addition, the aerosol tends to deposit in an orifice and close it to further particle flow, thereby limiting the amount of available agent to be detected. This, coupled with the extremely large chamber volume, would reduce the sensitivity and reliability of this detection system to unacceptably low levels.

The system is not adaptable to application of the aerosol either to the internal chamber volume or to the suit interior. The former would result in removal of the aerosol by filtration and contamination of hardware, and the latter would result in widespread dissemination of the fluorescein to produce high backgrounds and general equipment and facility contamination.

Detectable liquids are employed for leak checking in some industrial applications. At least one manufacturer, Magnaflux, makes a fluorescent liquid for this purpose. For application in the BISS suit and tunnel, this liquid would be used in a manner similar to that described immediately above for fluorescein and would be subject to the same limitations. In addition, if any viable organisms were in the interstice, the liquid would encourage organism transfer by capillary action, and sterilizing a liquid in the interstice would present significant design problems. Thus the use of a liquid for leak detection is not felt to be feasible for the BISS.

Gas tracer leak detection systems are much more sensitive than liquid or solid systems and are recommended for use in the BISS system. Several possible gas leak detection systems are:

- Mass spectrometer - any gas with a distinct ion mass/charge ratio (e.g., helium)
- Halide detector - ionizable halides or hydrocarbons (e.g., dichlorodifluoromethane - Cl_2F_2C-Freon-12)
- Sonic detector - any gas
- Nuclear detector - any radioactive gas (e.g. krypton-85, carbon-14 dioxide)
- Gas Chromatograph
- Wet Chemistry
- Dry Chemistry
- Thermal Conductivity - any gas with specific heat significantly different from ambient
- Human Nose - any pungent gas (e.g. the mezcaptans)

Of these, the mass spectrometer and halide detector are probably the most commonly used, with the use of radioactive gas detection systems increasing significantly. These systems are quite sensitive and involve relatively straight-forward equipment. The halide detector is the simplest of the detectors but is less sensitive than the helium or radioactive gas systems.

5.1.1.2 Continuous vs. Periodic Monitoring

It is desirable that leak monitoring be continuous when the Assembly/Sterilizer - BISS system is in operation (i.e. sterile or decontaminated). Such detection has been called "real time", and "active". Neglecting the time delay required to accumulate a detectable concentration of tracer gas and the time to transport the gas to the detector, a continuous system may be regarded as real time in that it indicates the existence of a leak as soon as it becomes detectable. This offers the greatest possibility of correcting the problem which causes the leak before microbial penetration occurs. Continuous detection has been called active since its use is most beneficial when the Assembly/Sterilizer system is active. In general, continuous monitoring can be expected to require simultaneous use of multiple fixed sensors to achieve a useful system sensitivity.

Periodic monitoring can be employed alone or to augment continuous monitoring. Though by descriptive title periodic monitoring differs from continuous only in the sampling time base, it will in fact be expected to also differ in implementation. For example, periodic monitoring might use a leak detector to probe seams, thereby providing greater sensitivity than would be possible using the same system with a fixed detector probe for continuous monitoring.

A continuous leak detection system for the BISS suit and tunnel would use multiple detectors connected to specially designed detection volumes in the suit and tunnel. The complexity of the system would be considerable and the response time and sensitivity would be such as to mitigate strongly against the use of such a system. These problems are discussed in detail in Appendix D.

It is recommended that a periodic leak detection system be used for bio-integrity assurance. With a periodic system, leak checks would be performed before and after processing of a vehicle in the main chamber. The suit and tunnel would be inflated with a tracer gas and the outer seams and surfaces would be probed with a detector. If desired, checks could be made while maintaining sterility by using the antechamber for this purpose.

Depending on the decision policy ultimately developed for bio-integrity assurance, it may be possible to perform periodic leak checks of the suit and tunnel in the sterile main chamber. One logical decision basis would be: "If a physical leak is detected in the system at any time after sterilization, it will be presumed to indicate a biological violation of the system (i.e. contamination of chamber contents) and the chamber contents will be resterilized."* With such a policy, it should be permissible (and in fact desirable) to inflate the suit and tunnel in the main chamber any time that a leak is suspected, and have a BISS suited technician probe it for leaks. Although at first reading this sounds counter to bio-integrity objectives, it is very much in accord with these objectives and can save considerable waste effort.

The only reason for not operating the BISS suit and tunnel under positive pressure is to reduce the probability of passage of organisms through a small hole which may develop in the system. However, if the detection of such a hole is regarded as a violation of bio-integrity,

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* Data from contracts NAS **1-7277** and **NAS 1-7166** may indicate that a less conservative approach is justified if an inward pressure gradient is maintained on the suit and tunnel. Such a result would significantly alter the arguments of this discussion.

then the best course of action is one which permits its detection as early as possible so that appropriate action can be taken. Checking the suit and tunnel, as described, as frequently as possible consistent with overall operational efficiency would thus be a desirable course of action and pressurizing the suit and tunnel to do so would not impose a practical threat to the resultant inferred bio-integrity.

The halide detector appears to be particularly applicable to use for sterile in-chamber leak checking. This detector uses a hot cathode diode in air to detect the easily ionized halides and should be compatible with redesign to withstand dry heat sterilization much more readily than any other detector system.

It should be noted that if this absolutist policy is to be implemented its extension to positive pressure operation of the suit and tunnel has a very significant and beneficial effect on design of the BISS system. Reefing, for example, would be much simpler if the suit and tunnel were operated at positive pressure. The overall implications of positive pressure operation affect virtually every area of BISS system design.

5.1.2 Tentative Leak Check Procedures

Periodic leak checking would be done by probing the surfaces and seams of the BISS suit and tunnel with a helium mass spectrometer or a halide detector. The procedures tentatively recommended are:

1) Non-Sterile Check (e.g., At Suit Installation)*

   a. Extend the suit and tunnel its full length into the unsterile Assembly/Sterilizer main chamber.

   b. With the hatch closed, flush and pressurize the suit and tunnel tracer gas.

   c. Examine the entire suit and tunnel surface for leaks.

   d. Flush the tracer gas from the suit and tunnel.

   e. Reef the tunnel and close the antechamber.

* As discussed above, this same procedure may be applicable for a sterile check depending on the decision policy for directed action after detecting a leak.

2) Sterile Check (e.g., **gross** check between shifts of Suit Occupancy)

a. The worker departing from the suit will close the door between the main chamber and the antechamber, then exit from the suit.

b. Flush and pressurize the antechamber with sterile tracer gas.

c. Close the hatch.

d. Sample the atmosphere within the suit and tunnel periodically and analyze for tracer gas accumulation.

e. Flush the tracer gas from the suit and tunnel.

3) Nonsterile check without violating main chamber sterility (e.g, when a leak in a suit or tunnel is suspected).

a. Reef the suit and tunnel into the antechamber and close the door to the main chamber.

b. Flush and pressurize the suit and tunnel with tracer gas.

c. Enter the antechamber through service doors and examine suit and tunnel surfaces for leaks.

d. Flush tracer gas from suit and tunnel

e. Close antechamber service door, and resterilize antechamber and contents

f. Open door to main chamber.

4) Final Leak Check at Termination of Lander Bus Assembly

Procedures (1), (2), or **(3)** can be employed after final assembly and removal of the assembled lander bus in its bio-barrier.

5.2 HUMAN FACTORS AND MAN-MACHINE ANALYSIS

5.2.1 Entry and Egress

BISS mockup testing has indicated that unaided entry to, and egress from, the BISS suit through a hard tube is feasible for a technician clothed in the BISS undersuit. The technician will have his life support hoses attached to the plenums on the back of his undersuit, and his communications transducers in place on the upper chest of the undersuit,

and will be supported by breathing and cooling air as he passes through the tube. The tube will have parrallel sides and a semicircular top and bottom, (i.e., the shape of a commercial water-tight door in a ship) as shown previously in Figure *34.*

Although not used on the present program, it is recommended that a small dolly be employed in the reefing tube. Such a dolly would ride along the bottom of the reefing tube and would significantly aid the seated operator in moving along the tube. The interface with one possible reefing mechanism is discussed in Section *4.5.* In addition to its advantage in normal operations, the use of a dolly in the tube will prove very beneficial in aided egress of an operator under emergency conditions. To further facilitate movement small handholds along the tube should be employed.

The process of entry and egress requires a donning rack at the suit end of the hatchway. The donning rack holds the outer suit in position for facilitation of entry and egress. It attaches to the four extremeties and the helmet while the tunnel is reefed back on the outer surface of the hatchway. The operator enters the hatchway, and sitting upright, slides along the tube. Arriving at the suit, the operator sits at the lip of the tube and puts his feet into the boots. The operator then puts his hands through the arms into the gloves, simultaneously putting his shoulders into the yoke and his head into the helmet, so that he stands erect. The operator then detaches the arms from the donning rack, then the helmet, and finally the boots, Egress is a reversal of the progress.

5.2.2 work Shift Duration

It would be desirable for a BISS occupant to be able to work a normal 8 hour work shift. However, since the BISS environment is stressful, it is not to be expected that this goal is attainable. A four hour work shift is considered to be a more reasonable goal,* with personnel assigned to other duties outside the Assembly/Sterilizer main chamber when not working in the BISS suits. Such an outside assignment might be acting as BISS support personnel. This should result in considerable motivation to perform the support functions well.

The four hour work shift in the BISS suit has been selected as the goal. While it has been demonstrated in mock-up tests that personnel can work a four hour shift in the BISS suit with appropriate rest periods, further experimentation is required to make a definite recommendation for a prime BISS system. The limited experience gained to date suggests that the optimum work shift may be less than four hours. Several factors which will affect the optimum wbrk shift for a prime system are discussed below.

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* This is also the work shift duration in the "IN-FAB" facility - see Section 4.9 on Medical Monitoring.

5.2.2.1 Amount of Chamber Overpressure

As the chamber overpressure goes up, difficulty in chamber operations goes up significantly. The suit tends to cling and resist body movements.

5.2.2.2 Sophistication of Prime BISS Suit

In-chamber duration of operation will be a function of suit weight and material stiffness, both of which figure prominently in ease of body movement to operational efficiency. Suit fit, while important in a **gross** sense, is not specifically an inhibitor if the fit is generally adequate. Boot and glove fit appear to be more important than gross body fit, as factors in operational chamber duration.

5.2.2.3 Tunnel Length and Reefing Mechanism and Boom Sophistication

The tunnel length and sophistication of the reefing mechanism and boom directlyaffect the degree of exertion required by the BISS occupant to move about in the Assembly/Sterilizer main chamber and perform his assigned duties. If the occupant must exert significant forces to achieve these movements, the duration of his work shift must be correspondingly shortened.

5.2.2.4 Work Type Duration

The nature of the work the operator must do will affect his in-chamber duration. Extended requirements for walking, climbing, executing difficult body movements, or working in a cramped position will all tend to decrease in-chamber operational duration. Mockup experience has indicated the need for in-chamber tasks to be custom-adapted for BISS operations, rather than to require the suited operator to adapt to the task.

5.2.2.5 Planned Rest Cycles

The operator will have to have rest areas in which he can sit for planned periods in relative comfort. Due to the overpressure, the operator needs to shift suit weight and relieve pressure points to relieve muscular tension. It is estimated that for most light in-chamber work, the operator may need as much as a 10 minute break for each half hour of work.

5.2.2.6 Operator Orientation, Training and Physical Condition

The operator must have prior orientation with BISS, and training in overpressure conditions. The extent of training is yet to be determined, but it is safe to say that aside from technical in-chamber operations, the operator will require at least twelve hours of incremental suited operational training as well as additional hours to acquire intimate knowledge of the life support and communication system. This training will serve to orient the operator, determine his personal life support and communication needs, and provide for psychological preparation for extended in-chamber operations.

In addition to selecting healthy employees in good physical condition, it is advisable that personnel be motivated to maintain themselves in good condition. While it is unlikely that a rigid diet and physical exercise program will be readily accepted by the workmen, some dietary restrictions must be imposed (e.g., consumption of large quantities of liquids before a work shift is not compatible with extended isolation in the BISS suit) and recreational exercise should be encouraged. A reasonable approach to the definition of an exercise program would be to examine the program for the astronauts, probably the most rigorous occupational exercise program, and delete from it those elements not felt necessary for the BISS workers.

Since the BISS workers will not be able to work a full eight hour shift in the suits, an exercise period may be able to be worked conveniently into the work schedule with the strong motivational factor of being paid for the exercise period.

5.2.3 Occupant Comfort

Suit occupant comfort is a function of the degree of in-chamber overpressure and the design details of the BISS under and outer suits. Since the outer suit rests mainly on the shoulder yoke, this is the prime area for padding and support. The design of the undersuit plays an important role in occupant confort since it is closest to his body. It is important that the innermost lining fabric of the suit be smooth, "cool" fabric (in the acetate or nylon family) and sufficiently close knit to adequately cover the layer of foam. The inner suit must be roomy enough to preclude constriction or chafing spots, but not slack enough to provide for reduced cooling affects or folds which could produce chafing during movement of the wearer. When all of these factors have been adequately accounted for, the primary remaining factor in occupant comfort is net suit and equipment weight supported by the suit occupant. Increased weight plays a large role in decreasing comfort and in-chamber duration time.

While sensible air-flow in the helmet was shown in early BISS experimentation to be an important factor in psychological comfort, it has been found that as occupants gained additional experience in the suit this factor tended to be reduced in importance.

The helmet should not ordinarily touch the occupant's head while the head is held erect. However, for areas in which head contact is made (rear of helmet) a 1/4 inch of padding suffices for comfort and also provides a degree of sound absorption.

Care must be taken to provide for adequate air flow past the operator's wrists to the hands. Tha gloves must have sufficient gauntlet diameter to accommodate air-flow back to the inner suit for scavenging back to the exhaust hose. Similarly, the use of cotton undergloves insures comfort for the hands against the **"sticky"** feeling of elastic gloves.

5.2.4 Visibility

Vision accommodation in the helmet is dependent upon the quality of the material in the visor area, the extent of visor face area, and the degree of curvature of the visor. The helmet design shown previously in Figure 21 and 23 gave excellent vision. Care must be taken by the operator, however, to prevent ducking the helmet down close to the work, since mockup testing has shown that with good helmet vision, the operator tends to forget his helmet visor and scrapes the visor against the work object, producing scratches on the visor. If the occupant wears eyeglasses, the frames should be padded at the corners to prevent interior scratches, should the occupants glasses come into contact with the visor.

5.2.5 Mobility and Dexterity

Gross mobility in the Assembly/Sterilizer main chamber is directly dependent on the sophistication of the design of the reefing mechanism and tunnel support boom. This is discussed in detail in Sections 4.3, 4.4, and 4.5.

Operator mobility is promoted by the use of a soft suit with a minimum of reinforcement. The suit design is discussed in Section 4.1.3.1. All reinforcements (e.g., support rings) are located **so** that they do not restrict joint motion. The main impediment that the operator must contend with is a force of about 26 lbs/in. of water pressure which exists in those periods during which the tunnel is not fully collapsed. This condition occurs briefly during retraction for reefing or extension of the tunnel when the operator walks out into the chamber. However, once this brief period is concluded, operator mobility is vastly improved.

The BISS suit has been shown experimentally to promote good mobility and is satisfactory for any task requirements the wearer is likely to encounter. Care must be taken that the design of in-chamber work does not require the operator to lie on his back, as this is virtually impossible due to the life support hoses and tunnel.

5.2.6 Operator Population and Suit Team Composition

5.2.6.1 Population

Initially, it was intended that the BISS outer suit concept would accomodate the 30th to 80th percentile of male body sizes. Subsequent experience in the BISS mockup study has indicated that a suit which would accommodate an 80th percentile man was too large for the 30th percentile man because of overpressure effects. Overpressure folds the excess material down and requires that the operator pull against the compressed excess of material in moving his arms for work. Therefore, the sizing restrictions have been narrowed to the following:

Height: 50th - 80th percentile (69" - 71.4")*

Weight: 20th - 80th percentile (146 lb. - 195 lb.)*

Age: 25 - 34 years

Population factors other than size limitations are discussed under personnel selection and training.

5.2.6.2 Suit Team Composition

The BISS concept envisions a capability of deploying a maximum of ten operators in the Assembly/Sterilizer. The number of operators required at any one time in the chamber will be a function of the programmed task or tasks. The minimum number of operators who can work in the chamber at one time is 3, for reasons of safety. It is possible that small groups of 2 or 3 men will be deployed simultaneously to accomplish separate tasks in the chamber. For each such group or task, one of the suited operators will act as task leader. Due to the limited number of BISS personnel that can work in one area, the leaders will not just Oversee, but will actively contribute to task accomplishment.

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* These ranges refer to American males, (National Center of Health Statistics, U.S. Department of Health, Education, and Welfare, 1960-62 census)

A facility Operations Director will be located outside the Assembly/Sterilizer chamber and will have visual contact with activities within the chamber. He will be responsible for deploying a task-oriented work team and assuring the proper functioning of all BISS support activities such as operation of the life support and communications systems. The Operations Director also will have control of all safety and rescue operations.

The team of BISS operators will consist of mechanical and electronic technicians. Though more task definition of Assembly/Sterilizer activities is required before specific job skill requirements or work teams can be identified, a few general characteristics of the operational BISS team can be hypothesized safely. First, each man will be a highly competent technician with varied mechanical and electrical skills. Making the assumption that the interplanetary spacecraft which will be assembled and tested in the Assembly/Sterilizer will require system-specific skills, it is possible that each BISS operator will be trained as a specialist in one or more of these specific skills. If this approach is used, the especially-trained technician can act as team leader for those tasks in which he has received specific instruction. For other operations, he can serve as a worker under the leadership of another specialist. A flexible personnel assignment approach such as this should provide the necessary skills for interplanetary spacecraft assembly and checkout with a minimum number of personnel.

5.2.7 Personnel Selection and Training

Observation, measurement, and the subjective reports of the subjects themselves in the mockup test program indicated that operator selection and training will play a very important role in the success of a prime system employing BISS suits.

The prime limitations for selection of the suited-operator population will be in terms of size and age, technical capability, personality variables, and physical condition, in that order. That is, the first determination after size and age will be for appropriate mechanical and electrical capability, and from the selected candidates, selection will then be made on the other variables.

BISS suited operators will have to possess, in addition to basic required skills and technical experience, very acceptable personality traits and attitudes. Absence of any discernable phobic traits which would be triggered by the BISS environment must be a basic requirement, and tolerance to unusual and stressful environments for an extended period of time, while maintaining an interpersonal equilibrium, is particularly necessary.

An indication of appropriate medical and psychological selection criteria can be obtained from the six years of experience of the INFAB facility. INFAB selects its chamber operation on the basis of the following tests.

A. Mental Testing

1. PTI Verbal Test - (intelligence)

2. Bennett Mechanical Comprehension Test (Mechanical knowledge and tool use)

3. Comprehensive testing by a professional testing service

- Guilford-Zimmerman Aptitude survey
- General Reasoning Test (intelligence)
- Watson - Glaser Critical Thinking Appraisal (intelligence)
- Revised Minnesota Paper Form Board Test (3-D test of perception and form)
- Guilford-Zimmerman Aptitude Survey (perceptual speed)

B. Physical Examination (Plant and Hospital)

1. Age *(25 - 40)*

2. Weight (150 lb. minimum, 170 lb. maximum)

3. Height (5'6" to 5'11")

4. Vision

5. Heart

6. Blood Pressure

7. Reflexes

8. Hernia Check

9. Routine eyes, ears, nose, and throat

10. Urinanalysis

11. Chest x-ray (Frontal and side)

12. Blood analysis

13. Electrocardiogram

C. Personality Characteristics (Professional Service used)

1. Depth interview and appraisal

2. Personal history form analysis

3. Guilford-Zimmerman Temperament Survey

4. Edwards Personal Preference Schedule

5. Minnesota Multiphasic Personality Inventory

All of the tests above are preceded by an orientation to prepare examinees for the tests, to describe the purpose of testing, and to explain why they may be rejected, if they are so rejected. These tests imply a well-designed selection program, the physical part of which is followed-up every six months. Although not scheduled, it is probable that the personality tests may be repeated or supplemented at various intervals, at the recommendation of the program supervisor.

Details of a training program must be based on definition of qualitative and quantitative personnel requirements, which in-turn require a work flow analysis of chamber operations. However, it is known that in addition to specific technical training on the details of the spacecraft assembly and checkout techniques, the operators will require training in specific use and care of the suit, personal hygiene, safety, chamber operations, and communication rules and regulations. There will have to be team-type instructions, simulated and evaluated team activities, and a developmental training program to observe individual operators for team acceptance and particiaption, as well as technical know-how.

5.2.8 Special Tool Requirements

The need for unique tools for the suited operator is not anticipated. Mockup testing has indicated the need, however,, for hand tools with good gripping detail, i.e., corregated or fluted handles, absence of smooth grips, and more especially, the need for gripping or pincer-type tools if the gloved-suited operator is required to work with very small or fine hardware. Otherwise, it is anticipated that special jigs, fixtures, or tools will only be required for unique assembly tasks which would require similar aids for ungloved operations. The tool sterility study of the Assembly/Sterilizer Analog program, as desired in Appendix D of 67SD604, provides a more detailed discussion of hand tools for use by gloved technicians in the Assembly/Sterilizer.

5.2.9 Work-Team Planning

With the anticipated work limitation not exceeding four hours, it is important that the time period for a given team in a chamber be efficiently utilized. This criterion suggests the need for pre-determined work segments for each shift and a detailed break-down of each operator's contribution to the shift work goal. Preplanning will minimize necessary decisions within the chamber and excessive cross-talk among operators. A detailed visual projection of work order process can be made on an in-chamber screen or wall. This schedule can be remotely checked off and referred to by all personnel, In like manner, the projection method can be used for detailed schematics and other diagrammatic references.

5.3 HYGIENE

Provision of a safe, comfortable environment for the BISS occupant includes maintenance of hygienic conditions in the suit. This is accomplished by a combination of techniques:

- Medical selection and screening
- Partial isolation of personnel from the microbial flora of others
- Periodic sanitizing of critical areas in the BISS
- Insistence on good personal hygiene and appropriate prophylaxis

In addition to selection of personnel whose general medical condition is compatible with the BISS work environment, particular care must be taken to assure freedom from chronic infectious or contagious diseases. Diseases of the respiratory tract or skin are particularly important. The presence of acute symptoms of minor ailments will not preclude selection of personnel as BISS workers, but will preclude their employment in this capacity until the ailment is cured.

The primary bacteriological hazard to personnel exists in the form of vegetative organisms such as staphlococci, tubercule bacilli, and spores such as trichophyton (athletes foot). The vegetative organisms are common to the respiratory tracts and skin of all personnel. The tubercule bacilli are of significant concern but are not found in healthy persons, although early detection of tubercule diseases is not easy in a cursory examination. Spore infections are relatively common in otherwise healthy persons particularly in the feet and crotch and often on the hands.

From a purely hygienic standpoint it is desirable that the BISS suit and tunnel be completely free of any residual flora from the previous occupant when a worker enters the suit. Assurance of such an objective presents significant practical problems. Procedures for sanitizing the suit are discussed in Appendix E.

It has been concluded that routine sanitizing of the BISS suit should be concentrated on the helmet. The head of the BISS occupant is the only part of his anatomy which is not isolated from the BISS inner surfaces by personal under-garments in the form of an undersuit, gloves, and socks or booties as described in Section 4.1. These undergarments perform two hygienic functions in addition to their roles in the life support subsystem. They tend to contain the flora released by the body, limbs, hands, and feet of the occupant and to isolate them from any possible residual contamination from the previous occupant. This protection, in conjunction with medical selection and checking of personnel is felt to be adequate except for the head and respiratory tract.

The head and respiratory tract are completely exposed to the environment of the BISS helmet except for the slight protection given by the cotton skull cap worn inside the helmet. Thus physical and biological contamination of the helmet inner surfaces by the occupant is virtually unavoidable. Consecutive occupancy of the suit without an intermediate sanitizing procedure could result in a health hazard to the second occupant. Procedures for sanitizing the helmet between occupants are described in Appendix E. The tests performed to confirm these procedures have shown them to be effective.

In order for the helmet sanitizing and the partial isolation of personnel by the undersuits to constitute an effective means for protecting BISS personnel from the microbiological flora of each other, additional measures must be instituted. Cursory medical examinations should be performed on a daily basis before the work shift to assure absence of any readily detectable symptons of disease or infection. The hands, feet, and respiratory tracts are of particular importance in this examination since these are the areas of the person's system least isolated in the BISS suit. The daily medical examinations can be performed by *a* well trained paramedical technician or nurse* backed up by a doctor who is available to make decisions in questionable cases.

* Male technicians or nurses are preferrable for this function. Routine presence of female personnel in the BISS preparation area will adversely affect the freedom of operations in the area. Also, indifference to being regularly examined by a female would be a further and unnecessary restriction on personnel selection.

Periodic rigorous physical examinations will be performed by a physician to assure the exclusion of personnel who contract serious ailments not readily detected in the daily examination (e.g. tuberculosis).

BISS personnel will prepare for work in the suits in a special preparation area, They will doff their street clothes in an outer locker room, shower, be subjected to the daily medical examination, dress in BISS undersuits over long underwear, and proceed to their work areas. Appropriate intermediate garments such as robes, shorts, or wrap-around kilts; and slippers or scuffs will be provided to minimize social discomfort and optimize attainment of good hygiene.

Freshly laundered towels, wash cloths, and body contact garments shall be provided for BISS occupants daily. Regular cleaning and disinfection of the air-cooled undersuit is also required but a schedule has not been established. Experience with the mock-up suggests that the undersuit need not be cleaned more often than once per week, but forced air drying of the suit is recommended after each occupancy. Further experience with an operating system is necessary to establish an optimum schedule. In this regard, it is recommended that not less than three undersuits be provided for each occupant. This is a personnalized, semi-tailored garment. Unless the laundering procedure has a very short turn around time, it will be necessary to have one garment in use, one in stand-by, and one being laundered.

The maintenance of good personal hygiene is important to the attainment of the overall hygiene objectives for the BISS. In addition to expecting personnel to follow normal good personal hygiene practices, the showering and prophylaxis before each shift of work is very important. The showering will consist of a good overall cleansing with Phisohex prior to the medical examination, Following the examination, personnel will dress for BISS occupancy applying liberal quantities of prophylsctic powder such as Desenex or Asterol to the feet and socks or booties to be worn in the BISS as well as intermediate foot covering worn from the preparation area to the BISS hatch. Immediately prior to leaving the preparation area, the personnel shall again wash their hands with liberal quantities of Phisohex to provide a residual bacteriostatic deposit on the hands. Then they will put on cotton gloves and proceed to their work stations.

In addition to these medically recommended procedures, it is important that personnel use body deodorants and an effective deodorizing tooth paste or powder or mouth wash. In addition to being part of a program of good personal hygiene, elimination of offensive body and breath odors is psychologically significant to effective operation of the BISS system. Any given BISS outer suit will be occupied at times by several different personnel. Each of these personnel will want to feel that his predecessors did in fact practice good hygiene, and prevention of offensive odors is directed towards this end. This same observation extends to other matters of personal hygiene or habits.

5.4 MAINTENANCE

5.4.1 Maintenance Philosophy

The basic concepts for suit-tunnel maintenance are: total replacement of the suit-tunnel with repair of defects in a special maintenance area, or repair or replacement of suit-tunnel elements within antechambers.

The following list identifies some of the factors which must be considered in maintenance concept development.

- Time to reactivate work station
- Time, man hours, and equipment to perform in-line repairs
- Time, man hours, and equipment to perform repairs in special areas
- Time, man hours, and equipment to replace a suit-tunnel
- Impact on suit-tunnel design
- Impact on antechamber design
- Number of suit-tunnel subsystems which can support each work station
- Number of suit-tunnel subsystems extending from each antechamber

To the extent that it is possible to detail a maintenance concept for BISS at the present time, the following information is presented at the subsystem level.

5.4.1.1 Outer Suit and Tunnel Repair

Damage to the outer suit and tunnel will be replaced by patching the defective area or by replacing one or more of the following components:

A. Suit and Tunnel

(1) Repair - Tunnel and suit-shell repair is limited to patching minor defects, such as punctures or tears up to ½ inch in length.

(2) Replacement - Suit-tunnel replacement is performed if the defect exceeds the repair criteria or when an effective repair cannot be accomplished. The suit-tunnel is cut from its mounting rings and a replacement is bonded in its place. Replacement is also carried out when either the service life or endurance cycle limits have been reached.

B. Glove and Boot

(1) Repair - Glove and boot repair is limited to minor defects, such as punctures or tears up to ½ inch in length. The glove or boot may be repaired by bonding a patch of like material over the defective area providing it is not in a critical location (i.e., fingers of glove, etc.) where added thickness would adversely affect operator mobility or dexterity.

(2) Replacement - Glove or boot replacement is performed if the defect exceeds the repair criteria or when an effective repair cannot be accomplished. The item is cut from its mounting ring and a replacement is bonded in its place.

C. Helmet

(1) Repair - Helmet repair is limited to the replacement or resecuring of polyurethane foam padding bonded to the interior of the helmet.

(2) Replacement - Helmet replacement will be performed if the helmet is cracked, destroying its bio-integrity, or if the visor is scarred, thereby degrading its optical qualities. To accomplish helmet replacement, the helmet interface clamp is removed and the suit shell is cut from the helmet mounting ring. A replacement helmet is bonded to the suit shell and the helmet interface clamp is installed.

D. Maintenance Location

The major concept tradeoff in the area of maintenance of the BISS was that of considering the location for repair and/or replacement of BISS items. The competitive areas were:

(1) within the sterile chamber

(2) outside of the chamber (i.e. elsewhere in the facility)

(3) within an antechamber to the sterile chamber.

(1) Maintenance Within the Assembly/Sterilizer Main Chamber

Since preliminary maintenance generally occurs within the area of operation, performing maintenance in the Assembly/Sterilizer itself was considered as the first possibility. It was concluded that this approach was unacceptable because the rigid checkout testing contemplated to assure the integrity of the suit-tunnel subsystem could jeopardize the sterility of the main chamber. Specifically, any tracer gas used to pressurize the subsystem for post repair checkout purposes might leak into the Assembly/Sterilizer and also transport microbes, present in the suit interior, into the sterile chamber.* Further, maintenance in the main chamber would require that the work be performed by BISS suited personnel if sterility is to be maintained.

(2) Maintenance External to the Assembly/Sterilizer Main Chamber

Recognizing that the ideal maintenance location did not lie in the main chamber, the next step was to consider the area immediately outside the main chamber in which supporting subsystems are situated. Consideration of how suit-tunnel replacement might be effected indicated that chamber sterility would almost certainly be violated by this process when the suit-tunnel subsystem was replaced.

(3) Maintenance in an Antechamber

Just as bio-integrity will be maintained between an antechamber of the Assembly/Sterilizer, bio-integrity can be maintained between an antechamber and the Assembly/Sterilizer main chamber. Necessary maihtenance can be performed within the antechamber or exterior to it. Although antechamber sterility is lost in the proeess, it may be restored by means of dry heat sterilization. Thus the antechamber can be sealed off from the main chamber, required maintenance can be performed, the antechamber and its contents can be resterilized, and then the antechamber can be re-opened to to the main chamber.

* Ths significance of this factor is dependent upon the decision policy for the action upon detection of a leak (see Section 5.1 on Bio-Integrity).

These considerations lead to the recommendation for the use of antechambers in which repairs and leak checking can be performed with no compromise of the bio-integrity of the main chamber. This concept is not to the exclusion of the maintenance in the main chamber. For example, if a suit has been abraded with resultant visible degradation of suit material but without full penetration of the material, a patch covering the area could be applied in the main chamber with greatest efficiency and with a minimum of lost time. Such an operation would not threaten bio-integrity of the system.

The antechamber concept is shown in Figure *49.* The dimensions of the antechamber are given in part in Figure 50. The remaining dimensions are subject to further investigation. In particular, the height and the incremental length, X, are not known. The height of the antechamber will be primarily a function of the tunnel support boom design. The boom design problem is discussed in Section *4.4.* Since the tunnel support stringers from the boom will remain attached to the tunnel in a reefed condition, the boom or an overhead track interfacing with the boom at the chamber wall must extend backwards into the antechamber. The boom design and boom deployment system will determine the minimum overhead clearance required in the antechamber and the resultant antechamber height.

The incremental length, X, in Figure 50 is either the minimum reefed length of the tunnel or the minimum length of the tunnel for leak checking in the antechamber. It is presently presumed that these lengths will be roughly equivalent and will be one the order of one fifth of the maximum extended tunnel length.

The other measurements shown in the antechamber figure will permit adequate movement around the suited operator for emergency rescue and adequate movement for leak test and repair and/or replacement of the tunnel or suit. The door into the antechamber from the adjacent corridor is wider than an ordinary door (30"), so that the equipment for repairs or emergency rescue can be easily rolled into the antechamber.

5.5 SAFETY

The emphasis of the safety study has been on the identification of potential hazards in both the mock-up and final Assembly/Steriler system configurations. Potential safety problem areas which have been identified include the following:

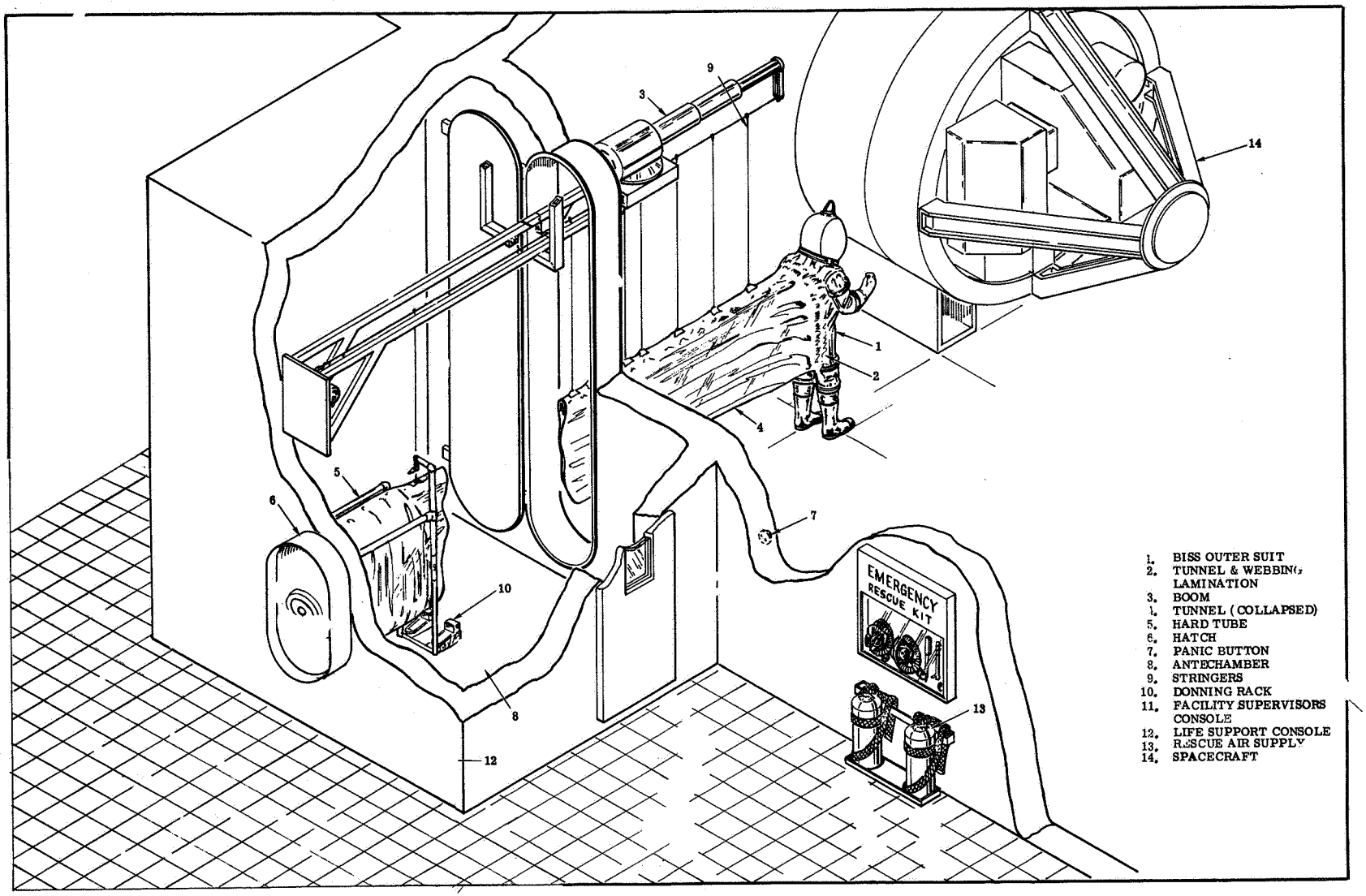

Figure 49 - BISS Assembly/Sterilizer Interface Concept

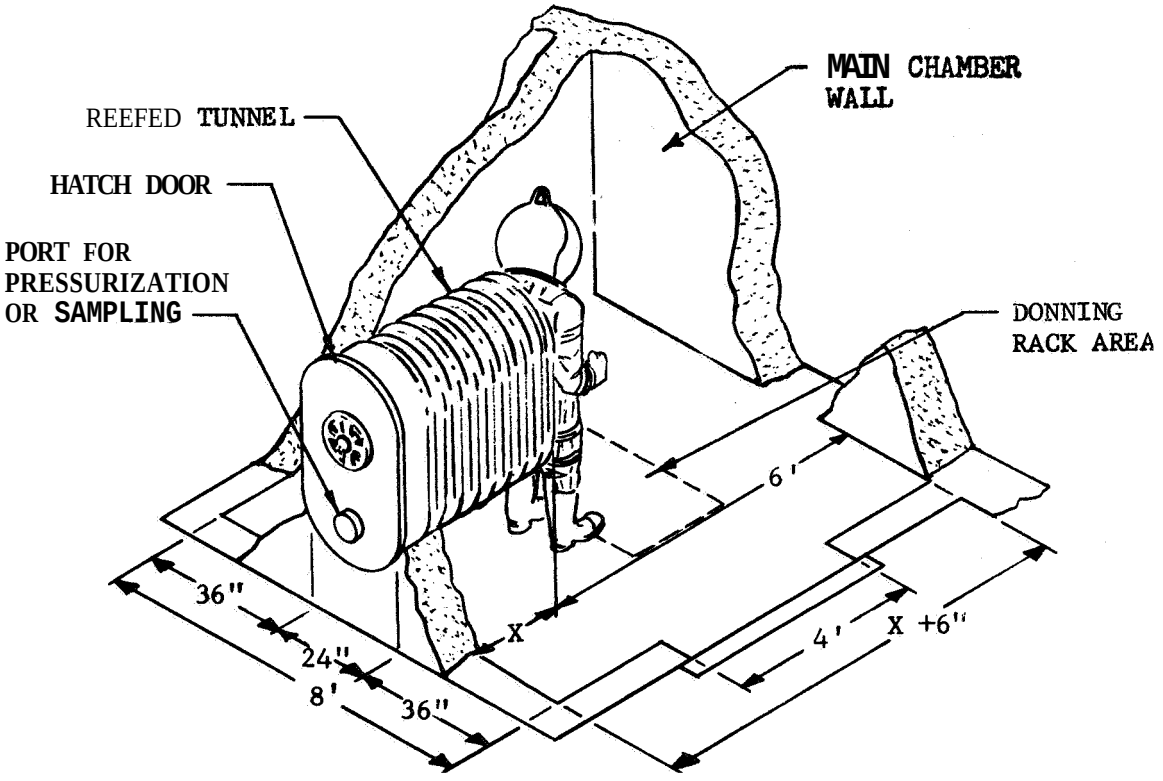

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Figure 50 Antechamber Dimensions

- Accidental loss of breathing air while working within an operating Assembly/Sterilizer,
- Failure to preclude presence of toxic or noxious contaminants from contact with BISS occupant.
- Accidental injury of BISS occupant while in the operating Assembly/Sterilizer.
- Isolation of BISS occupant from assistance in the event of illness or injury.

In addition to recommending solutions to these problems, the following discussion notes other recommended safety features which should be incorporated in the Assembly/Sterilizer and BISS.

5.5.1 Accidental Loss of Breathing Air

Although the life support system, which will provide the breathing air needed by the BISS occupant in the 100% nitrogen Assembly/Sterilizer environment, will be designed to be highly reliable, the possibility of a failure either within the Life Support System, BISS suit/distribution lines, or a facility power failure exists. If such an event should occur, the BISS occupant would be in a potentially hazardous condition.

In order to properly evaluate the preferred means for providing suitable safety to minimize this potential BISS occupant hazard, the various possible accident modes and resulting situations were identified. The following classes of accident modes and postulated conditions were established.

(1) Internal equipment failure of the Life Support system precluding the supply of breathing air to a BISS occupant without prior warning or external indication of occurrence. It is expected that a change in the operating characteristics of the Life Support Equipment would be noticed by the monitoring personnel. However, the BISS occupant's supply of breathing air could be seriously diminished causing physiological change such as dizzyness, and in an extreme case unconsciousness, before the completion of corrective action on the part of support personnel.

(2) Facility power failure during a BISS operation could create a serious safety problem for the BISS occupant. If all BISS life support systems, lighting, and communications are dependent on the primary facility power source, then effective egress from the Assembly/Sterilizer chamber would be extremely difficult for the BISS occupant. Since his breathing air supply would be terminated, he could hot safely remain stationary until the outage was corrected, and any movement within a darkened chamber could be hazardous due to the risk of falling or other injury producing accident.

(3) Breathing air supply line failure due to leakage, kinking, or breaking would create an immediate potential hazard to the BISS occupant which might not be observable to the external monitors. The worst case accident situation would be unlikely, but the possibility exists of complete severing of all life support lines leading to the BISS caused by a sharp edged falling object.

Various techniques for minimizing these potential hazards have been considered and evaluated. It appears that in all three postulated accident conditions, an emergency back-up supply of air for the BISS occupant is essential for use between the period of time when a physiological hazard begins and the occupant is removed to a life supporting environment. Alternate approaches to provision of a back-up air supply are described below, together with the appropriate trade-off considerations.

(2) Back-up supply provided as part of the life support system equipment. This would use the normal air supply lines to the BISS, but operate off of compressed air bottles to be independent of facility power or life support equipment failure. The back-up would be designed to operate automatically in the event that normal air supply pressure falls below a predetermined level.

Advantages

- Provides no weight or mobility penalty to BISS occupant.
- Economical to design, install and maintain
- High expected reliability.

Disadvantages

- Would not function properly in event of breathing air supply line or undersuit and helmet air distribution failure

(b) Portable emergency air supply carried internally in the BISS, and designed to be operated by either the BISS occupant or from outside the BISS. Ideally this internal supply would be designed to be very compact, and would be incorporated into the BISS design so as to provide minimal penalty on the BISS occupant.

Advantages

- Provides a positive emergency supply of breathing air to the BISS occupant under worst case accident modes, including failure of supply hose to BISS or intermal BISS distribution system.

Disadvantages

- Would require additional design and development effort to prove feasibility.
- Would provide weight and operability penalty in BISS design.
- Would provide a potential added safety problem in the event of failure of pressurized system (tubes or regulator) during normal BISS operation.

(c) Portable emergency air supply in Assembly/Sterilizer main chamber. This concept envisions the use of sterile, emergency, pressurized breathing air bottles strategically located inside the Assembly/Sterilizer chamber.

These bottles would be equipped with especially designed output-tube fittings which would permit connection into the BISS suit without loss of bio-integrity. Once connected, the bottle's valve could be opened, and air injected into the BISS suit to provide emergency breathing air to the occupant.

Sufficient numbers of sterilized bottles would be located within an operating Assembly/Sterilizer chamber to allow ready access by any BISS occupant. In the event of an emergency, the BISS occupant could walk to the closest bottle, make the BISS suit-air bottle connection, and open the valve to allow the air to

enter the suit. The BISS occupant would then be assured of at least 5 minutes of breathing air supply to safely complete his emergency egress from the Assembly/Sterilizer chamber while carrying the emergency air supply bottle with him.

In the event the BISS occupant is immobilized, or otherwise unable to perform this operation himself, it would be possible for another BISS operator to bring an air bottle to the incapacitated BISS occupant and connect it to his suit, thereby assuring an adequate breathing air supply during egress.

For this concept, a relatively small air bottle would be preferred to enable ease in carrying and storage.

Advantages

- Does not add any weight penalty to the BISS suit.

Disadvantages —

- Permits only a limited supply.
- Will require special sterilizable portable air supplies
- Will require development of a connection technique which will maintain bio-integrity.

It is recommended that both external back-up supply and the portable emergency air supply in the Assembly/Sterilizer main chamber be incorporated in the BISS operation concept. This would provide the maximum degree of safety with minimum potential risk of compromizing the Assembly/Sterilizer main chamber bio-integrity. Unless the breathing air supply line is cut or blocked, the portable supply in the BISS would not be used.

The requirement for a back up life support system was substantiated by failures of power to life support equipment which occurred during Phase II testing. The Occurrence of these power failures showed that an occupant could be removed from the chamber within a two minute period in the mock-up system. This was proven in two cases, and the operator was capable of exiting under his **own** power.

5.5.2 Noxious Toxic Contamination of Internal BISS Suit

If the BISS is ETO decontaminated, it will be necessary to assure that no ETO permeated into the suit which could create a potential hazard to the occupant. To minimize this potential hazard, an analysis of the internal suit atmosphere should be made prior to initial occupant entry following a decontamination cycle. The problem of skin contact with ETO which may have permeated through the suit material does not appear to warrant any further precautionary procedures, since atmospheric analysis should be sensitive enough to detect this.

Continuous monitoring of the internal BISS helmet environment for toxic or noxious contamination does not appear necessary from a safety standpoint. However, it does appear desirable to provide a capability to monitor the oxygen and carbon dioxide levels in the BISS helmet on a continuous basis to assure maintenance of a safe air mixture. An automatic alarm should be incorporated to alert control and support personnel if a proper gas mixture is not maintained.

5.5.3 Accidental Occupant Injury Potential

Although the BISS design concept provides for good visibility and maximum mobility within the constraints imposed by the tunnel design, some limitation is inherent in this system. This tends to increase the potential of injury of the occupant, particularly while working on elevated platforms. An injury sustained while in the BISS would hamper the ability to egress, and first aid would be difficult to administer. For these reasons, the helmet has been designed with hard hat and face shield safety features; and hard boot toes, and non-skid boot soles are incorporated.

5.5.4 Emergency Rescue and Egress Considerations

In considering what type of design and operational features should be incorporated in the BISS concept to facilitate potential emergency rescue and egress, the following possible accident situations were examined:

a. The BISS occupant becomes ill or injured, but is still capable of unassisted egress.

b. BISS malfunctions significantly reduce breathing air flow to the occupant; however, the condition is noted prior to onset of physiological distress, and bio-integrity is not compromised.

c. The BISS occupant suffers an incapacitating injury or illness, and cannot exit unaided (bio-integrity not compromised).

d. The BISS air supply fails (bio-integrity not compromised).

e. A catastrophic accident occurs which causes immediate and serious hazard to BISS occupant and bio-integrity has been, or must be compromised.

Under conditions a and b, the BISS occupant should be able to return to the antechamber and close the door within a 5 minute maximum time period. Once in the sealed antechamber, either the occupant can effect a normal egress, or if required, the antechamber can be purged with air and an emergency escape from the BISS can be effected by having the suit cut open by standby personnel.

Under condition c, the affected BISS occupant must be aided by being carried into the antechamber by other BISS personnel. The personnel aiding the injured occupant into the antechamber must leave the antechamber prior to closing the door. The injured occupant can then be assisted by stand-by personnel entering the antechamber. These personnel can either fill the antechamber with air or use back-packs.

Condition d will require the use of an emergency breathing air system provision. If the air supply lines are operable, the external emergency back-up air supply will be actuated, allowing the BISS occupant to effect a normal egress from the BISS. If the external back-up air supply is not operable, the emergency air supply in the Assembly/Sterilizer main chamber would be used.

Under condition e, any attempt to maintain bio-integrity must be disregarded. In this case, emergency back-up personnel would put on breathing air back-packs in order to quickly enter the Assembly/Sterilizer chamber to effect the necessary rescue operation.

5.5.5 Warning Lights

The experience gained during mock-up testing showed that it would be desirable to have a facility system of flashing red, steady amber, and steady green lights to indicate safety status. The flashing red light would signify that the BISS operator must be removed immediately. The steady amber light would signify that the BISS operator could complete

a short task of up to 5 minute duration. A steady green light would indicate all systems were normal. These lights should either be visible by all console operators or to be placed on each console. These lights should be integrated into a warning system compatible with the requirements of Paragraphs 3.4.4 and 3.4.6 of the system criteria, Appendix A hereto.

5.5.6 Rescue Team

Rescue teams should be provided to assist in emergency egress of a suit occupant in the event of disability or system malfunction. Team members should be trained in all emergency procedures for the facility including administration of first aid. All medical ministrations would be performed under the direction of the appropriate medical monitor or a physician or nurse on short notice emergency call.

In the interest of efficiency of personnel utilization, it is recommended that the rescue team be composed of **BISS** suit workers who are "off duty".* This should enhance the confidence of the suit occupants and provide considerable motivation for close attention to duty by the rescue team personnel.

5.5.7 Redundancy

Wherever possible redundant primary power sources, life support equipment, and lighting should be provided. The life support of the individual **BISS** occupants must be decoupled from each other and from other facility equipment *as* much as possible. The system detail design and interface with the Assembly/Sterilizer must be such that any credible system malfunction or accident can be accomodated without jeopardizing the life and health of suit occupants; and, in particular, must be designed **so** that such malfunctions or accidents do not cause multiple concurrent emergencies. After the work flows and manning requirements have been fully defined for the **BISS** system in the Assembly/Sterilizer, they must be carefully scrutinized to assure that the personnel subsystem possess the degree of redundancy required for system safety. This can be facilitated by cross-training personnel **so** that persons performing routine non-critical jobs can act in an emergency service capacity as required.

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* See work shift discussion in Section 5.2.2.

6.0 INTEGRATED TEST PLAN

6.1 BACKGROUND

The Integrated Test Plan was prepared during the first quarter of the contract period and submitted to Langley Research Center for review in November 1966. It was issued as GE Document Number 67SD418 on January 3, 1967 and is included as part of this final report as Appendix F. The plan, as originally written, covered both the Materials Testing and the Mock-up Test Program to be conducted during the course of the contract period. It was found necessary during the test program to make modifications to the plan to incorporate experience gained in day to day mock-up work and materials testing. In addition, some tests were combined in the interest of greater efficiency of time and effort, while not reducing evaluation validity. The changes are reflected in Sections 7.0 and 8.0.

6.2 BISS TEST AND DEMONSTRATION PLAN

A Test and Demonstration Plas was prepared for the BISS System and is detailed in this report as Appendix G. The plan describes the manner in which a prime suit and its subsystems shall be interfaced, tested, and demonstrated to satisfy the overall requirements for the various environmental conditions under which BISS will be expected to perform. This plan, although it is not detailed to the extent of the Integrated Test Plan, incorporates the experience gained from the materials testing and mock-up portions of the subject contract, and should provide the basis for testing of engineering models on a subsequent test program.

0 ANALYSIS OF CANDIDATE MATERIALS

7.1 GENERAL

The objective of this task was to define optimum materials for use in the BISS outer and inner suit based on their ability to withstand the thermal, chemical, and mechanical stresses planned for the assembly sterilizer facility.

To provide more accurate results, it was found necessary to make some slight alterations to the previously submitted Integrated Test Plan, herein referred to as Appendix F. The tests that were modified were:

- Fungus Growth Test
- Mycelial Penetrability Test
- Transfer of Microorganisms, Liquids, and Gases Across Suit Materials Test

A more detailed explanation of the reasons which necessitated the changes, and the results of the chemical and biological tests, appears in Section 7.3 under the appropriate headings.

A literature search was initiated to eliminate those materials which obviously could not meet the qualifications. Based upon the results of the literature search, a list of the materials which looked most promising was compiled and a series of tests were subsequently designed to assess the physical, chemical, microbial, and thermal properties of these materials.

Although it was desirable that the materials provide a barrier to microbial and fungal penetration, this requirement was deemed a necessity only on the outer suit, as the inner suit could be treated periodicallv to destroy any adhering organisms.

The materials investigated for each portion of the system were as follows:

1) Suit and Tunnel

- Neoprene Rubber Film, XA-3785-2
- Silicone Rubber Film, SE-555

- Armalon/Glass Fabric, 414-141
- Armalon/Glass Fabric, 408-128
- Armalon/Teflon Fabric, 97-001
- Gold Coated Polyimide Film
- Kapton Polyimide Film
- Butyl Rubber Film, T-5595
- Fluorinated Silicone/Fabric, 44-002
- Viton A/Teflon Fabric, 86-007

2) Helmet

- Allyl diglycol carbonate, CR-39
- Lexan Polycarbonate
- Epoxy-glass Laminate, PD-177
- Epoxy-glass Laminate, Textolite 11546

3) Face-Plate

- Allyl diglycol carbonate, CR-39
- Lexan Polycarbonate
- Optical glass

4) Bonds

- Neoprene/neoprene, Roberts Consolidated 'Industries #835B, 3M EC-847, 3M EC-226
- Silicone/Silicone, RTV 560 silicone rubber adhesive
- Armalon/Armalon, RTV 560 silicone rubber adhesive
  Rigid epoxy adhesive, Epon 934
  Flexible epoxy adhesive, EC-2216

Based upon the quantities of materials utilized in the Phase II mock-up, calculated projections were made concerning the total weights of some of the various candidate materials listed above if they are selected for the final construction of the BISS. These calculations were based on the test thicknesses of the candidate materials on hand, and also include the estimated material thicknesses required for final suit, tunnel, and helmet fabrication. This data is shown in Table X.

7.2 PHYSICAL TESTING

As a result of the investigations conducted on the combined effects of heat aging, flexing, and abrasion tests, some deficiencies in several of the candidate materials were revealed, requiring either some modification of material approach, imposition of use limitations, or the elimination of the candidate material from further consideration for the BISS system. Some photographs of the equipment used during the physical testing program appear in Appendix H. Each one of the candidate materials is discussed in greater detail below. The test data from which evaluations were made is contained in Appendix I.

7.2.1 Neoprene Rubber, XA-3785-2

The neoprene rubber, originally considered as a condidate for suit and tunnel, and boot and glove applications, embrittles after repeated heat age cycles to 150°C (300°F), as evidenced by an increased abrasion wear index as a function of repeated cycling, a high weight loss (2.57%), and reduced resistance to the flexibility-permeability preparation method. Of more serious concern, however, was the failure of the material during fungus evaluations where rapid growth was observed.

As a consequence, neoprene rubber was eliminated as a candidate for exterior use in the suit and tunnel, or boot and glove areas, and its recommended use confined to inner suit applications only.

Based upon the requirements for inner suit use, the evaluation parameters for the remaining tests were reestablished as follows:

- Deletion of the puncture evaluation
- No further permeability evaluations, and the associated flexibility preparation
- No further heat aging, ETO/Freon, or disinfectant evaluations
- Continue tear, detergent, abrasion for 100 cycles, and tensile tests on the unaged material only

TABLE X ESTIMATED FINAL WEIGHTS OF FABRICATED BUSS CANDIDATE MATERIALS

Suit & Tunnel Material	Test Thickness (MIL)	Suit Thickness (MIL)	Max. Weight (LB) Suit*, (2.5 yd^2)	Max. Weight (LB) Tunnel** (23 yd^2)
Butyl Rubber	62.	60	8.8	81
Silicone Rubber	62.	60	7.9	73
Neoprene Rubber	25.	60	10.	93
Gold/Polyimide	1. ***			
Kapton Polyimide	6.5 ***			
Fluorinated Silicone/Fabric	15.	60	11.	99
Armalon 97-001	12.	30	6.5	58
Armalon 414-141	14. ***			
Viton A/Fabric	20.	60	13.	122
Armalon 408-128	8. ***			

Lexan	0.5
CR-39	0.6
Epoxy-glass, PD-177 and Textolite	0.8
Optical Glass	1.1

* Less helmet, boots, gloves, L/S system
** Less supports and other systems (20 foot tunnel)
*** Materials too rigid for soft suit application

The tensile and tear properties of neoprene were unaffected by the detergent treatment as shown in Appendix I, and abrasion resistance increased as a result of the detergent treatment. Therefore, neoprene rubber is the recommended material for inner suit use.

7.2.2 Silicone Rubber SE-555

Tests on this material were conducted under *worst case exposure conditions, and the silicone rubber successfully passed the fungus, heat aging, microbial permeability, abrasion and flexibility evaluations. However, notch sensitivity of the non-fabric - reinforced films, and the relatively low associated tear strengths, indicate that the use of this material should be confined to high temperature fabric-reinforced types which will tend to minimize puncture and tear sensitivity. This latter class of polymeric material is recommended as the prime back-up choice for exterior suit and tunnel, and boot and glove use.

7.2.3 Armalon 414-141 (Glass Fabric)

The Armalon 414-141 (14 mil thickness glass fabric material) successfully passed the microbial permeability evaluations; however, the material was found to support fungus growth, and on the latter basis was eliminated from further consideration. Of secondary importance was the lack of flexibility and "hand" of the coated glass fabric for suit fabrication at practical thicknesses.

7.2.4 Armalon 408-128 (Glass Fabric)

The Armalon 408-128 (8 mil thickness glass fabric material) was found to be resistant to fungus attack and subsequent growth. This material, however, was found to be permeable to microbes, and was eliminated from further consideration on this basis. Although 6 mils thinner than the 414-141 materials, the insufficient flexibility and "hand" was also deemed unsuitable for successful fabrication.

* This represents the greatest number of heat (20), abrasion (1000), and flexure (200) cycles.

An additional observation may also be made regarding the two Armalon coated glass fabrics. The 8 mil gauge material was permeable, whereas the 14 mil gauge material was not permeable, Vendor contacts (DuPont) indicated that this class of material in excess of 12 mils will pass their in-house permeability tests, while those thinner do not pass, substantiating the results of the current investigation. A minimum gauge thickness of 15 mils is therefore indicated to provide a slight margin of safety, if judged only on the basis of permeability.

7.2.5 Armalon 97-001 (Teflon Fabric)

Based upon the fungus, microbial permeability, and heat age evaluations previously conducted on the glass fabric Armalon class, and the need for increased flexibility and "hand" for ease in fabrication, the Teflon/ Teflon fabric class of Armalon was then considered to be a prime suit and tunnel material candidate. This class of fabric, however, is not a standard stock item, as are the glass fabric types. The vendor (DuPont) stated that the current lead time for delivery of the material is approximately *4* to *6* months from receipt of order, and that no supply was currently on hand for delivery.

Efforts were, therefore, expended to find a converter with an excess of material. With the excellent cooperation of the DuPont Fabric Sales personnel, contact was made with Mr. Brumbaugh of Fab-Ohio, Inc. Fab-Ohio had received an order of the Armalon 97-001, processed fabrications for their customer, and had an excess of 5 to 7 lineal yards of nominal 21 inch wide material available. An order for this material was processed, and an expedited delivery received FW 10 for a full scale evaluation.

A complete evaluation of the Armalon 97-001 material was conducted under "worst case" environmental conditions, and the material successfully passed fungus and microbial permeability tests, abrasion, flexure, heat aging, tear, tensile, and other physical property evaluations. This material is recommended as the prime suit and tunnel material for the **BISS** system.

7.2.6 Gold Coated Polyimide Film, Kapton Polyimide Film

Polyimide high temperature resistant film materials, as received and gold vacuum coated, were submitted for fungus and microbial permeability evaluations. Both materials were rated acceptable for use as judged by these tests; however, the films were not sufficientlv flexible for suit fabrication, either alone or fabric supported, and were susceptible to tear propagation. As a result, these materials were eliminated from further consideration as suit and tunnel candidates.

7.2.7 Butyl Rubber, T-5595

Based upon the results discussed previously for neoprene rubber, an additional rubber candidate for suit and tunnel, and boot and glove applications was deemed necessary. "Fairprene"* butyl rubber film was, therefore, obtained, and was evaluated on a "worst case" environment basis.

The butyl rubber successfully passed the fungus, heat aging, flexure, abrasion, gas and microbial permeability tests, and disinfectant and detergent compatibility evaluations. This material, together with the silicone rubber, is also considered to be a prime back-up candidate for suit and tunnel use. However, greater heat stability was demonstrated by the silicone rubber.

7.2.8 Allyl Diglycol Carbonate, CR-39

CR-39, allyl diglycol carbonate was eliminated from further consideration as a candidate material. Specimens of the allyl diglycol carbonate clear plastic face-plate candidate material were exposed to an environment of detergent followed by heat aging. The specimens exhibited serious stress cracking, and discoloration ranging from colorless to a medium amber color,

Additional laboratory evaluations were conducted to further define the failure. It was found that the stress cracking could be eliminated by heat tempering the material, followed by a slow cool-down. However, considerable discoloration occurred as a result of the dry heat sterilization time-temperature treatment, and this material was eliminated from further consideration.

7.2.9 Lexan Polycarbonate

The Lexan polycarbonate plastic was exposed to the fungus, and ETO/Freon tests, and has been successfully qualified in these environments. Abrasion, optical transmission, and detergent and disinfectant tests were then conducted on the virgin material, with no problem areas being identified. Other physical tests, and additional optical transmission measurements were also successfully conducted.

Repetitive heat cycle aging of physical test specimens to 145°C revealed a potential problem area. Flat specimens required for optical transmission, abrasion, tensile, impact, and compression tests exhibited

* DuPont trade name

various degrees of warpage varying from minor aberrations to bowing of approximately 1/8 inch on 4" x 4" specimens 1/4 inch in thickness. This distortion generally occurred after three to five heat cycle treatments; however sufficient numbers of specimens distorted in the first treatment to cause concern.

Laboratory evaluations were conducted to determine the temperature level at which distortion first occurs. Specimens were placed both horizontally and vertically in a recirculating air oven, and the temperature was slowly increased to a maximum of 149°C (300°F). Distortions consistently occurred in the 135-138°C (275-280°F) temperature range. Imposition of a 3°C (5°F) safety factor would thus limit the maximum peak temperature to 132°C (270°F), with a corresponding increase in the required sterilization time.

Efforts were made to stress relieve the polycarbonate, for subsequent heat age cycles, by both a rapid and a slow cool-down to ambient temperatures between the platens. Specimens treated in this fashion, however, continued to distort in the 135 to 138°C (275-280°F) range, and contact with the polished platens at high temperature resulted in surface marring, and also in the formation of "pock-marks" in the surface, all deleterious to optical transmission. These effects are shown in the Figures 51A and B.

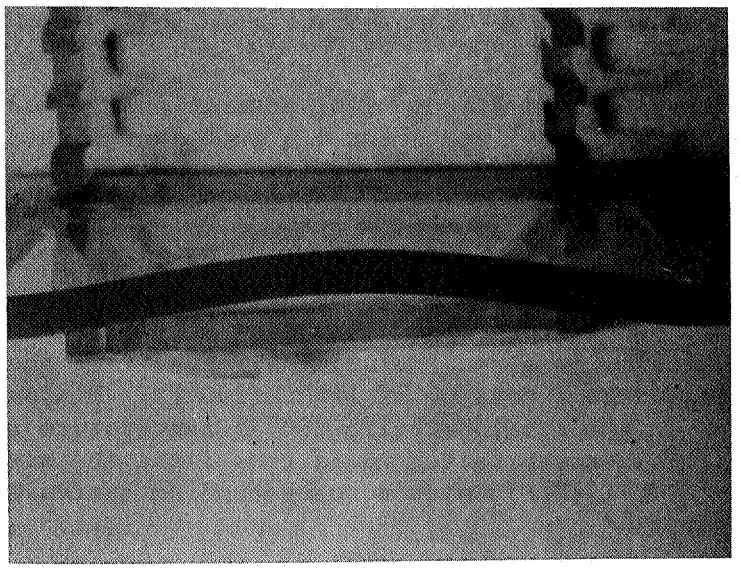
It must be concluded, therefore, that although Lexan polycarbonate plastic offers many potential advantages, such as stability to the chemical environment, relative ease in blow or vacuum forming, impact resistance, etc., the 135°C (275°F) heat distortion point at a loading of 264 psi (ASTM D648) must also be considered as a limiting factor for the no-load condition as well.

The recommendation, therefore, is to limit the maximum use temperature of Lexan to 132°C (270°F), as noted above, or consider the use of an optical glass face-plate in a rigid, reinforced plastic helmet.

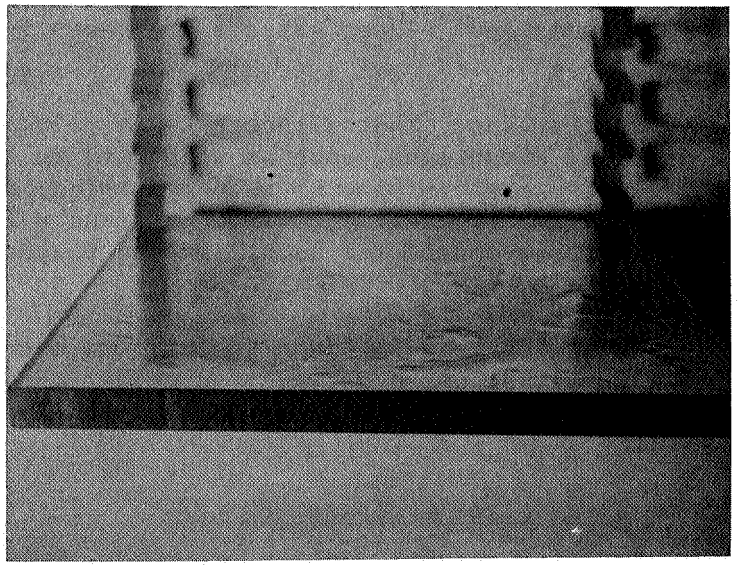
7.2.10 Epoxy Glass Laminate, PD-177

Epoxy glass laminates (nominal 3/32 inch thickness) were prepared in the laboratory using glass cloth, Epon 828, and TETA (Triethylenetetramine) catalyst. With the exception of the catalyst, the materials had previously been found to be non-nutrient per MIL-E-5272, and MIL-F-8261. The TETA catalyst is also non-nutrient per MIL-E-5272.

Fungus tests were conducted on the laminate material per MIL-F-8261, and fungus growth was observed on the as-laminated specimens. Additional specimens were then prepared representing additional post-cure conditions



(B) BODY DISTORTION



(A) POCK MARK - SURFACE

Figure 51 Lexan Distortions

(5, 10, and 20 heat age cycles) and exposed to the fungal environment. It was postulated that the additional post-cure, in addition to further cross-linking the resinous matrix, would also drive off low molecular weight resin and catalyst fractions which might contribute to the positive fungus growth, In general, a lesser amount of growth was noted as the post-cure time at 150°C (300°F) was increased.; however, all test specimens were positive, As a result, this laminate formulation was eliminated from further consideration.

7.2.11 Epoxy Glass Laminate, Textolite 11546

A commercial epoxy glass laminate, General Electric Textolite Grade 11546, (conforming to NEMA Grade G-10, and MIL-P-18177 Grade GEE) had previously been qualified as non-nutrient per MIL-E-5272 and MIL-F-8261 This material was therefore considered for use as the BISS helmet, and a sample of the material, 3/32 inches thick, was obtained for evaluation.

The laminate has successfully passed the fungus and mycelial Penetration tests, ETO/Freon, detergent and disinfectant evaluations, heat aging, and abrations, and physical property testing. It is recommended as the prime candidate for the BISS helmet.

7.2.12 Optical Glass

Due to the distortion problems outlined above for Lexan, greater emphasis was placed upon the consideration of glass to provide a stable viewing area.

Two approaches may be considered. The first is a face-plate incorporated into a reinforced plastic helmet, and the second is the use of a full helmet glass bubble. Several disadvantages are inherent in the first approach:

- Reduced operator peripheral vision due to a more limited viewing area
- Reduced test conductor visibility of the operator's head and face
- Increased difficulty in assuring a leak-free system, with the incorporation of the additional bonding/gasketing/attachment area, and
- Thermal expansion mismatches during the sterilization cycle

The second approach must also be carefully analyzed in view of the increased possibility of helmet damage, potential operator hazard due to scratch and impact propagated failures, and the anticipated greatly increased cost of an all glass helmet,

Of the various glasses which might be considered, plate, general purpose borosilicate, and fused silica (quartz), quartz has the highest optical transmission in the ultra-violet and visible ranges. Ouartz is also somewhat more impact and abrasion resistant than the plate or borosilicates, and also has the lowest coefficient of thermal expansion of potential glass materials. Properties of several glasses in comparison to quartz are shown in Table I-VI11 of Appendix I and the gas permeability of quartz at elevated temperature is shown in Table I-XI.

7.2.13 Bonds

After the selection of candidate materials was completed, a test program was initiated to evaluate various types of adhesives and their suitability for use on the BISS. Shear strengths and peel strengths were measured initially, and following successful completion of these tests, the bonded test samples were tested for microbial permeability flexure, heat aging, etc.

With few exceptions, as noted below, it was possible to produce bonds having shear strengths of up to 250 psi. However, it was found that all the adhesives were permeable to microorganisms. The results of the microbial permeability test are to be found in Table II of Section 7.3.

7.2.13.1 Neoprene/Neoprene

Several adhesives were evaluated for bonding neoprene to neoprene. These were:

1. Roberts Consolidated Industries #835B.
2. 3M EC-847
3. 3M EC-226

The bonded samples, after a one week cure at room temperature, had shear strengths of 150-175 psi and peel strengths of 10/12 lb/in. All of the above adhesives are suitable for use in the **BISS** and due to the fact that this material is recommended for inner suit use, microbial permeability testing was not considered necessary.

7.2.13.2 Silicone/Silicone

Initial bonding efforts with the use of RTV-560 were not successful, with cured bonds shearing at 2 to 30 psi. It was determined, however, that processing aids incorporated in the silicone rubber gum during compounding to aid in extrusion inhibited the cure of the RTV rubber. After consultation with silicone compounders, and numerous laboratory trials, the following bonding procedure proved successful:

- Bake silicone rubber for 1 hour minimum at 350°F
- Glean bond faying surfaces with acetone and toluole
- Wipe faying surfaces with the RTV catalyst and allow to stand for 10 minutes minimum
- Wipe excess catalyst from surface, and bond with catalyzed RTV-560

After a room temperature cure of one week at ambient, or 24 hours at ambient plus 4 hours at 350°F, shear bond strength of 200 to 250 psi were realized.

7.2.13.3 Armalon/Armalon

The Armalon fabric was solvent cleaned, and etched with a metallic sodium etchant solution prior to bond fabrication in all cases.

7.2.13.3.1 RTV-560

The RTV-560 silicone rubber did not provide satisfactory bond strengths, and failures occurred at 2 to 30 psi with peel strengths in the order of 2 to 5 lb/in. Further consideration of the RTV bond was eliminated.

7.2.13.3.2 Rigid Epoxy, Epon 934

Epon *934,* a hard rigid epoxy was evaluated in a limited manner to determine if epoxies would be more satisfactory. Bonding was excellent, however, the epoxy and adhesive was too brittle for the intended application.

7.2.13.3.3 Flexibilized Epoxy, 3M EC-2216

Bonds produced with EC-2216 have been consistently excellent, and have successfully been evaluated in the flexibility equipment with no

failures in the as made, heat aged, and heat aged plus ETO/Freon conditions. Bonds produced exhibited lap shear strengths of 200–250 psi and this adhesive was submitted for microbial penetration studies.

7.2.13.3.4 Heat Seals

Heat sealing of the Armalon fabric has not been experimentally evaluated in the program due to heat seal equipment limitations. However, consultations with several fabricators of Teflon items highly recommend this method, generally with a double seal to provide the greatest reliability in a leak–free system.

7.3 CHEMICAL AND BIOLOGICAL TESTING OF MATERIALS

7.3.1 Fungus Growth Test

The fungus Growth Test was conducted to determine if the materials under consideration for use on the BISS would support growth of fungus type organisms. The organism's selected, a choice of which is described in MIL–STD–810A (USAF) 23 June 1964, were as follows:

- Aspergillus niger ATCC 9642
- Asperigillus flavus ATCC 10836
- Myrothecium cerrucaria ATCC 9095
- Penicillium Citrinum ATCC 9849

The test method utilized was as described in Procedure II of the above STD. Performance testing of the candidate materials was done in accordance with Specification MIL–F–8261A. The culture media chosen for the propagation of each of the above selected organisms was as follows:

- Aspergillus niger - Enriched Mineral Salts or Potato Dextrose
- Aspergillus flavus - Sabouraud Maltose or Potato Dextrose
- Myrothecium serrucaria - Mineral Salts Cotton
- Penicillium citrinium - Sabouraud Maltose

The above specifications establish methods for testing materials for compliance with the requirements of USAF specifications, and other governmental specifications, and were prepared to eliminate unnecessary and undesirable variations in testing procedures.

Prior to conducting the tests however, two slight procedural changes were made. The changes consisted of placing both the test material and the control in separate petri dishes, and pre-washing the spore suspension prior to inoculation. These changes were deemed necessary to prevent the possible leeching of a carbon source from the degradation products of the positive control, and also to prevent a earry-over of nutrient after separation of the spores from the growth medium. After prewashing, the separated spore preparations were used within 8 hours. The results of fungus growth testing, incorporating these changes, are recorded in Table XI.

TABLE XI FUNGUS GROWTH TESTS

Suit and Tunnel Materials	Fungus Growth	Control
Armalon 414-141	Neg.	Pos.
Armalon 408-128	Neg.	Pos.
Gold-Coated Polyimide	Neg.	Pos.
Kapton Polyimide	Neg.	Pos.
Silicone Rubber SE-555	Neg.	Pos.
Neoprene Rubber XA-3785-2	Pos.	Pos.
Armalon 97-001	Neg.	Pos.
Texolite (Epoxy Glass)	Neg.	Pos.
Butyl Rubber	Neg.	Pos.
Viton A	Neg.	Pos.
Fluorinated Silicone (Dacron 44-002)	Neg.	Pos.
Helmet and Faceplate Materials		
Allyl Diglycol Carbonate CR-39	See Note 1	
"Lexan Poly Carbonate	Neg.	Pos.

Epoxy Glass (Virgin) PD–177	Pos.	Pos.
Epoxy Glass (5 Heat cycled) PD–177	Pos.	Pos.
Epoxy Glass (10 heat cycled) PD–177	Pos.	Pos.
Epoxy Glass (20 heat cycled) PD–177	Pos.	Pos.
Texolite (Epoxy Glass)	Neg.	Pos.
NOTE 1 - Shattered after sterilization		
Bonded Material		
Silicone Rubber RTV 560	Neg.	Pos.
Armalon 97–001 RTV 560	Neg.	Pos.
Armalon 97–001 EC 2216	Neg.	Pos.

The fungus growth test, after the above noted modifications, was straight–forward, and provided no difficulty in interpretation. Materials which supported growth were identifiable, in the vast majority of cases, within 5 or 6 days of incubation.

The test also proved very selective in one case. Epoxy Glass (PD–177) was positive, while Texolite, another epoxy glass material, was negative. This indicated that the test was also extremely sensitive to variations in the formulations of these plastic type materials.

7.3.2 Mycelial Penetration Test

This test was conducted to determine if the candidate materials under consideration were penetrable by the mycelium of filamentous fungi. The organisms selected, a choice of which is described in MIL–STD–810A (USAF) 23 June 1964, Procedure II, were as follows:

- Aspergillus niger ATCC 9642
- Aspergillus flavus ATCC 10836
- Myrothecium verrucaria ATCC 9095
- Penicillium citrium ATCC 9849

The test method utilized was also a modification of the above Standard specification. Performance testing of the uandidate materials was done in accordance with Specification MIL-F-8261A, while the culture media chosen to propagate each of the above selected organisms was the same as that used in the fungus growth tests (Section 7.3.1).

The modifications to the standard test methods were necessitated by the incidence of spore migration from the medium in the base of the testing plates, to the medium in the cylinders superimposed on the test specimens. In addition, the original volume of inoculum as prescribed was too high. The inoculum migrated to the periphery of the test specimens and caused an abundant amount of growth in that area. This produced an excess of spores in the plates, which, upon migration in the condensate formed on the lids during incubation, resulted in many false positive tests in the indicating cylinders. The test sample and control were both located in one 150 mm diameter petri dish, as prescribed in the test plan (Appendix F). In those cases where a large amount of growth was observed, the test material was also covered.

To remedy these unforeseen circumstances the following modifications were made:

1. The amount of medium used as a base was raised from 40 ml to 120 ml. This effectively raised the test cylinders to the lid of the 150 mm diameter petri dish when they were superimposed on the test specimen. Subsequent tests demonstrated that this did not entirely solve the problem. When the control samples sporulated sufficiently, spores still migrated by making use of the condensate which formed on the lids of the petri dishes during incubation.

   A final solution was achieved by placing the test material on a single 100 mm diameter petri dish, and the control samples on another. The base medium was then reduced in volume to 20 ml.

2. Using a sterilized cork borer, holes were cut in the media in the area where the test specimens were to be placed. This served to contain the inoculum and prevented its migration to the periphery of the test material.

3. The spore suspension used as the inoculum was reduced in volume to 0.1 ml which also acted as a deterent in preventing the migration of inoculum to the periphery of the test material.

The media used in the performance of this test was the Enriched Mineral Salts specified in MIL-F-8261A. The enrichment consisted of 20 grams of glucose/liter.

Positive controls were tested simultaneously using the same batches of media. The results of the modified mycelial penetration tests appear in Table XII.

TABLE XII - RESULTS OF MYCELIAL PENETRATION TESTS

Suit and Tunnel Materials	Results	Control
Armalon 414-141	Pos.	Pos.
Armalon 408-128	Neg.	Pos.
Gold-Coated Polyimide	Neg.	Pos.
Kapton Polimide	Neg.	Pos.
Silicone Rubber SE-555	Neg.	Pos.
Neoprene Rubber XA-3785-2	Profuse Growth	Pos.
Viton A	Neg.	Pos.
Fluorinated Silicone	Neg.	Pos.
Butyl Rubber	Neg.	Pos.
Armalon 97-001	Neg.	Pos.
Helmet Materials		
Allyl Diglycol Carbonate CR-39		
"Lexan" Polycarbonate	Neg.	Pos.
Epoxy Glass (Virgin) PD-177	Profuse Growth	Pos.
Epoxy Glass (5 heat cycles) PD-177	" "	Pos.
Epoxy Glass (10 heat cycles) PD-177	" "	Pos.
Epoxy Glass (20 heat cycles) PD-177	" "	Pos.
Texolite (Epoxy Glass)	Neg.	Pos.

Face Plate Materials	Results	Control
Allyl Diglycol Carbonate CR-39	Shattered after sterilization	
"Lexan" Polycarbonate	Neg.	Pos.
Bonded Materials		
Silicone RTV 560	Neg.	Pos.
Armalon 97-001 RTV 560	Neg.	Pos.

The test procedures prescribed in MIL-STD-810A (USAF) and MIL-F-8261A, and modified as previously noted, may easily give rise to misleading results, and for this reason, care must be exercised during interpretation of the test data. For example, Epoxy Glass (PD-177) exhibited such profuse growth, that no definite conclusion could be made as to whether or not mycelial penetration had in fact occurred without further study. Microscopic examination showed that the cycelium had penetrated into the body of the material, but not through it. The material was therefore considered positive for Mycelial Penetration.

In contrast to the Epoxy Glass (PD-177) discussed above, the positive indication for Armalon 414 could not be misinterpreted since Armalon 414 does not support fungus growth. (See Table XI) A subsequent test, Microbial Permeability, confirmed the fact that Armalon 414, while not contributing to the support of microorganisms, is permeable to the organisms themselves.

7.3.3 Transfer of Microorganisms, Liquids, and Gases Across Suit Materials

The objective of these tests was to determine whether or not materials which had been exposed to physical and chemical stresses were thereby damaged sufficiently enough by wear to enable microorganisms, liquids, and gases to pass through them. Testing was conducted on both treated and untreated materials.

In most instances, values for the permeability of the candidate materials exposed to liquids and gases, such as water vapor and carbon dioxide, were obtained from the available literature and appear in Appendix I-XI. For others, the values were obtained experimentally. Two laboratory tests were developed to measure the permeability of the candidate

materials to microorganisms. These were, the radioisotope test and the viable culture Spinner Flask confirming test. Both tests are explained in greater detail below.

The other physical tests performed were a gas permeability test using helium as the test agent and the retention and release of detergents and disinfectants tests. The latter tests utilized two liquids and one gaseous disinfectant, each of which required a different method of detection.

7.3.3.1 Transfer of Microorganisms Across Suit & Bonded Materials

7.3.3.1.1 Radioisotope Procedure - The candidate materials were attached to test chambers, as illustrated in Figures 52 and 53 which were then filled with a suspension of C^{14} labeled Micrococcus candidus of specific activity (0.12 cpm/bacterium). A background count of the material was made just prior to the inoculation of the test organisms, and another background count was made immediately after inoculation. The chambers were then pressurized to 4" water and held for twenty-four hours. Following the test period, the chambers were placed in the gas flow proportional counter (Baird-Atomic Model 146) to measure the radioactivity. A sufficient number of counts were obtained in all cases to give a probable error of 5%. Any increase in the sample count rate greater than 5 counts per minute was assumed to indicate the permeability of the material to microorganisms. In a few cases, false indications of permeability occurred due to leaks in the test chambers. As a result, a study method of testing was initiated using punctured materials containing holes of known dimensions. To accomplish this, samples of gold-coated polyimide film and Armalon 408-128 were treated with a focused laser beam to produce holes averaging 70 microns in diameter. The hole sizes were measured with an ocular micrometer. The holes produced in the Armalon were slightly irregular, but also averaged 70 microns in diameter. Two holes were produced in each sample and the samples were then fixed to test chambers. A background count was made of the test samples which were then filled with a suspension of C14 labeled M. candidus of specific activity (0.12 cpm/bacterium). Background counts were made again with the test chambers at ambient pressure. The chambers were pressurized to 4" H_2O, allowed to stand for one hour, and then counted again. The results are presented in Table XIII.

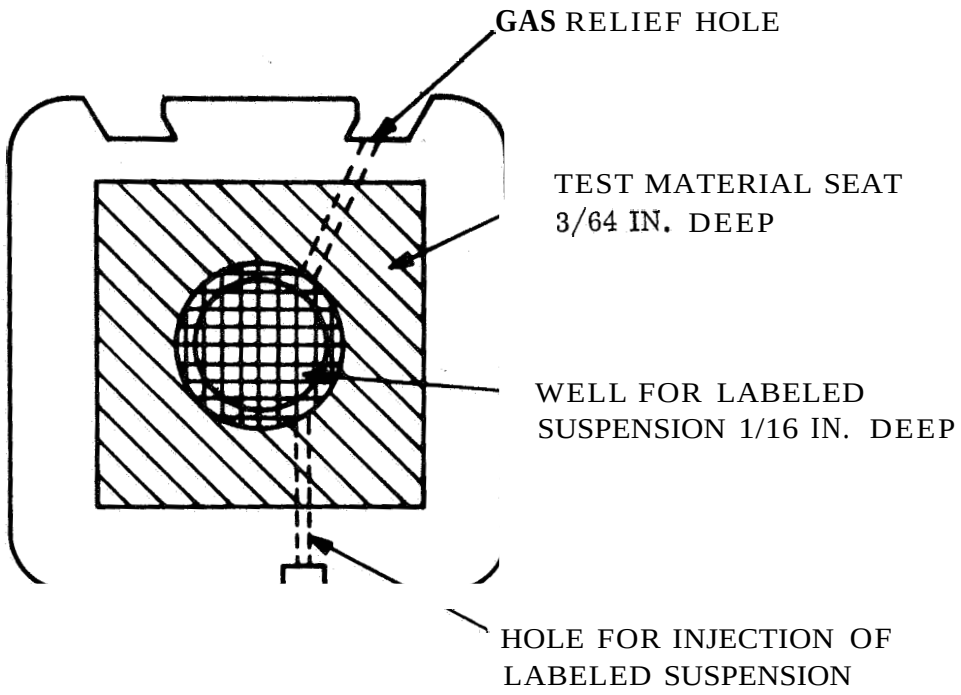


Figure 52 Test Chamber for Permeability of Materials To Microorganisms and Gases.

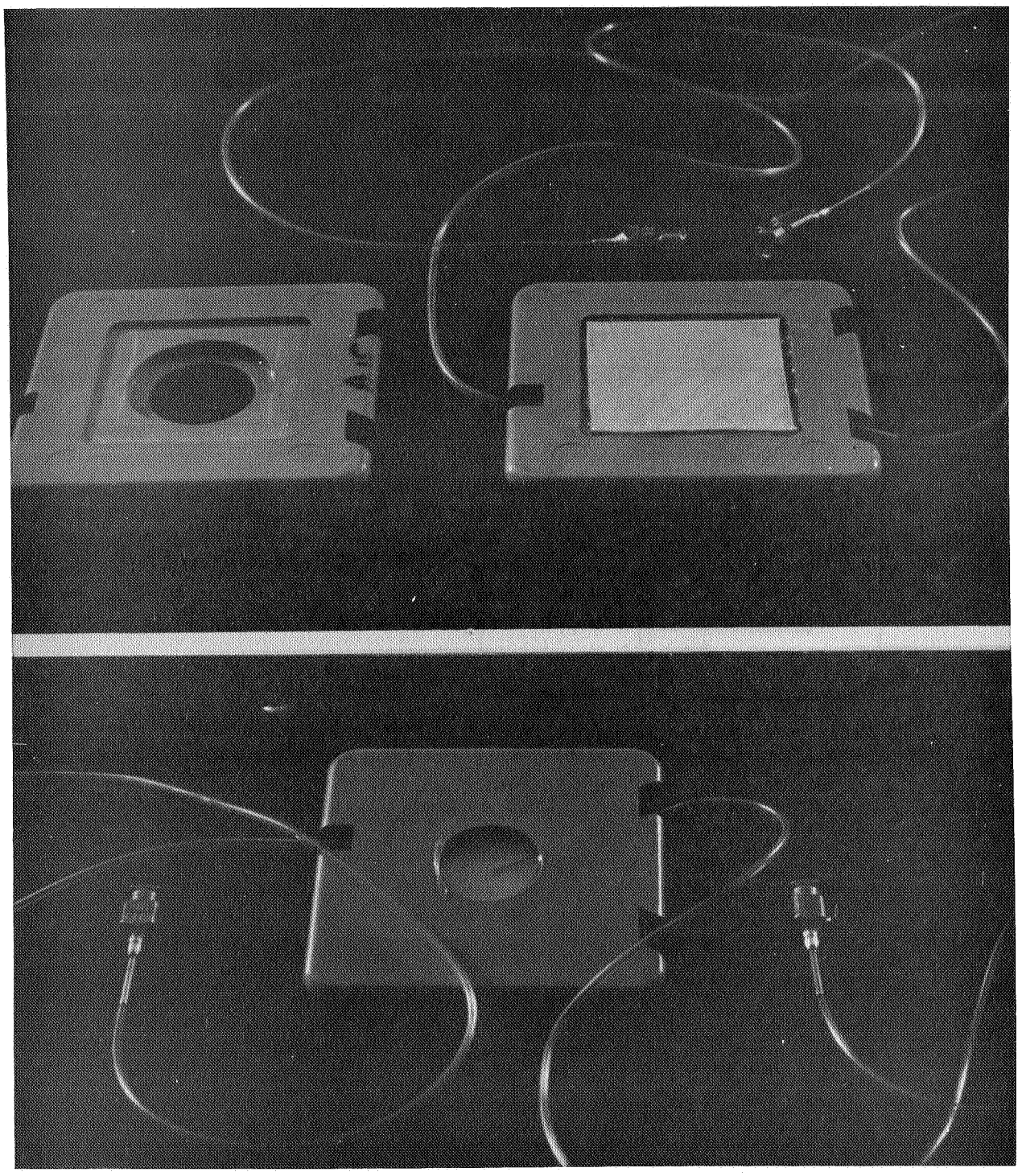


Figure 53 Planchet Test Chamber Construction

TABLE XIII TRANSPORT OF **MICROORGANISMS** THROUGH KNOWN HOLES

I	Gold-Coated polyimide film with two 70 micron holes.		
	Background with Cell Suspension	After 1 Hour at 4" H_2O	△
	1493 cpm	6158 cpm	4665 cpm
II	Armalon 414-141 with two 70 micron holes.		
	Background with Cell Suspension	After 1 Hour at 4" H_2O	
	32 cpm	1145 cpm	1113 cpm

7.3.3.1.2 Alternate Viable Culture Procedure Confirming Test -

Materials

Spinner Flask 100 ml
Bellco Glass Co., Vineland, N.J. CAT 113008

Four Position, Non-Heating Magnetic Stirrer
Bellco Glass Co., Vineland, **N.J.** CAT. #6005

Gelysate Medium
Gellysate (Bacteriological Peptone) BBL 2.5 g/1
Dextrose 1.25 g/1

Air Pressure gage - 0-10" H_2O

Compressed air supply sufficient to deliver 4" water pressure.

Methods

The test apparatus is shown in Figure 54. A circular piece of the test material, one inch in diameter, is used as a separator between both halves of the spinner Flask. Approximately 130 ml of gelysate medium is placed in each side of the flask and one side is then inoculated with the test organism (M. candidus). The flask is then pressurized to 4 inches of water, placed on the magnetic stirrer, and incubated at room temperature. If growth occurs in the uninoculated side of the flask within 48 hours it is examined microscopically to provide assurance that it is the same species as the bacterial growth in the inoculated side.

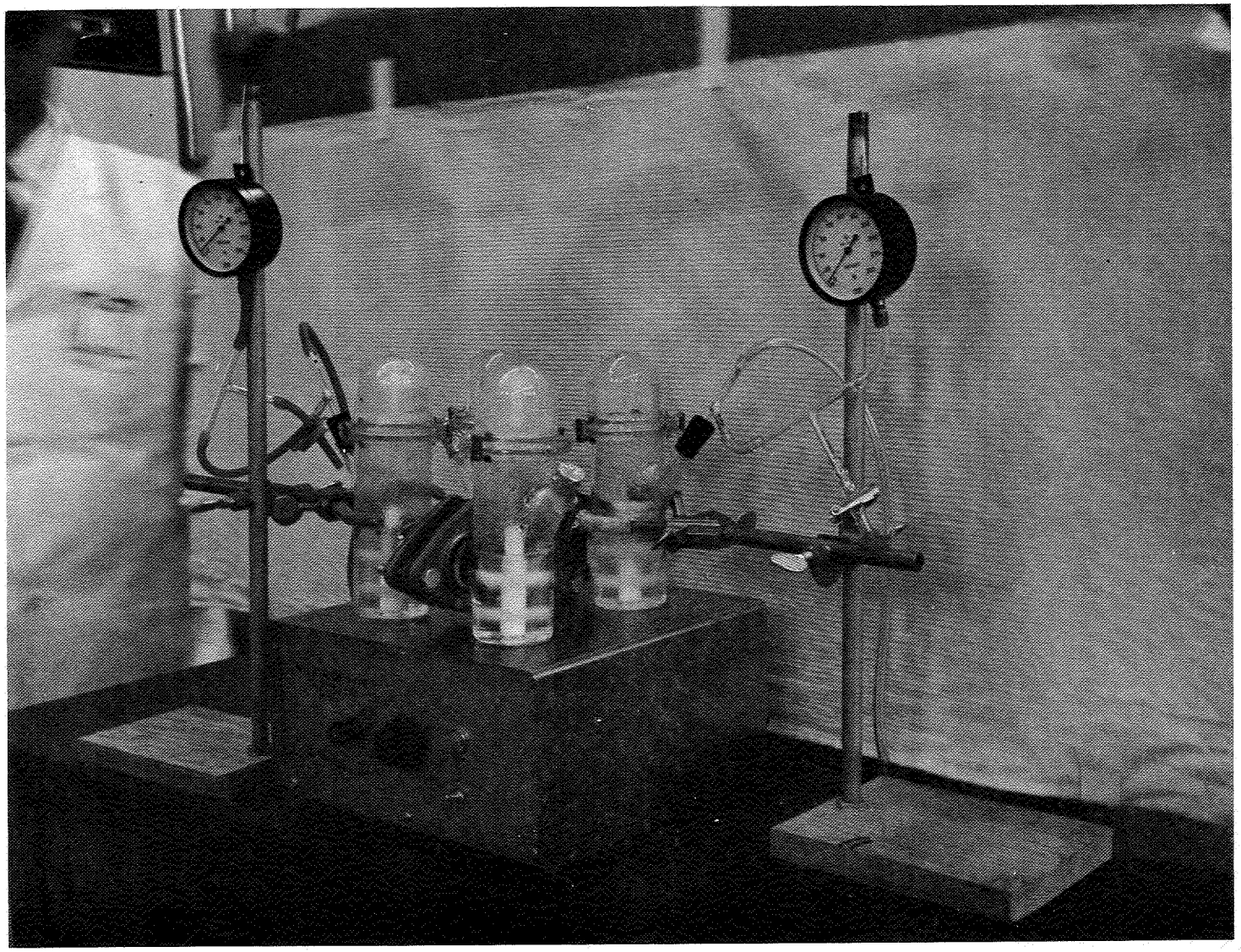


Figure 54 Viable Culture Test Apparatus

7.3.3.1.3.1 Silicone Rubber - The results of testing silicone rubber are recorded in Table XIV.

TABLE XIV TRANSFER OF MICROORGANISMS ACROSS SILICONE RUBBER SE-555

Chamber	Change in Count Rate After Holding at 4" H_2O for 24 Hours (cpm)
Virgin Material	
1	13
2	76
3	1
Heat Cycled - 10 Times	
4	2
5	0
6	1
Heat Cycled - 20 Times Abraded 1000 Cycles	
7	0
8	0
9	0
Heat Cycled - 20 Times - Flexed 200 Cycles	
10	1
11	0
12	0
Heat Cycled - 20 Times - Abraded 1000 Cycles - Soaked in detergent for 48 hrs	
13	3
14	0
15	1

Confirming Test - Virgin Material and Treated Material

One-inch square samples were tested by the spinner flask method. The test materials were exposed to a culture of Micrococcus candidus for a test period of 48 hours. No turbidity appeared within the test period indicating that both the virgin material and the heated-abraded material were impermeable to the transfer of the test organisms.

Discussion

The apparent leaks in the untreated silicone test samples were most probably due to faulty construction of the test chambers. The confirming (spinner flask) test was developed to determine this. The fact that the spinner flask was negative for the untreated material helps to support this statement. The level of confidence in this material was increased by testing a larger number of samples, all of which were negative.

7.3.3.1.3.2 Armalon *408-128* - The results of testing Armalon *408-128* are presented in Table *XV.*

TABLE XV TRANSFER OF MICROORGANISMS ACROSS ARMALON *408-128* VIRGIN MATERIAL

Chamber	Change in Count Rate After Holding at *4"* H_2O for *24* Hours (cpm)
1	*71*
2	*37*
3	*33*

Confirminp Test - Virgin Material

The test material was exposed to a culture of Micrococcus candidus for a test period of *48* hours. Turbidity appeared within *24* hours indicating that the untreated candidate material was permeable to the test organism.

Discussion

As a result of the positive results in the transfer test and confirmation of these in the spinner flask test, Armalon *408-128* was no longer considered as a candidate suit material.

7.3.3.1.3.3 Armalon *414-141* - The results of Testing Armalon *414-141* are presented in Table XVI.

TABLE XVI TRANSFER OF MICROORGANISMS ACROSS ARMALON 414-141 VIRGIN MATERIAL

Chamber	Change in Count Rate After Holding at 4" H_2O for 24 Hours (cpm)
1	1
2	1
3	1

Discussion

The material was found to be impermeable to microorganisms in the permeability test. The confirming spinner flask test was made on one sample and also gave negative results; that is, no penetration by the microorganisms during the 48 hour test period. However, since the test material failed to pass the mycelial penetration test, as noted in Table XII, it was used only as an aid to further techniaue development.

7.3.3.1.3.4 Gold-Coated Polyimide - The results of testing gold-coated polyimide are presented in Table XVII.

TABLE XVII TRANSFER OF MICROORGANISMS ACROSS VIRGIN GOLD-COATED POLYIMIDE

Chamber	Change in Count Rate After Holding at 4" H_2O for 24 Hours (cpm)
1	173
2	255
3	83

Two one-inch squares were tested by the spinner flask method. The test material was exposed to a culture of Micrococcus candidus for a test period of 48 hours. No turbidity appeared within the test period, thereby confirming the previous results.

Discussion

Although this material proved impermeable to microorganisms under the conditions of the test, it was discarded as a candidate suit material due to its low resistance to puncture or tear, and stiffness at practical suit fabrication thicknesses. The increase in count rate was due to diffusion

of cell constituents through the membrane. This was confirmed by the spinner flask test as noted above.

7.3.3.1.3.5 Armalon 97-001 - The results of testing Armalon 97-001 are recorded in Table **XVIII.**

TABLE XVIII TRANSFER OF MICROORGANISMS ACROSS **ARMALON** 97-001

Virgin Material Chamber	Change in Count Rate After Holding at 4" H_2O for 24 Hours (cpm)
1	1
2	2
3	0
Heat Cycled - 20 Times - Flexed 200 Cycles	
4	1
5	1
6	2
Soaked in Detergent for 48 hours - Heat Cycled - 20 Times - Abraded 1000 Cycles	
7	2
8	2
9	0

Confirming Test - Virgin Material

Two one-inch squares were tested by the spinner flask method. The test material was exposed to a culture of Micrococcus candidus for a test period of 48 hours. No turbidity appeared within the test period, thereby confirming the previous results.

7.3.3.1.3.6 Neoprene Rubber - The results of testing neoprene rubber are recorded in Table XIX.

TABLE XIX TRANSFER OF MICROORGANISMS ACROSS NEOPRENE RUBBER XA-37852

Virgin Material Chamber	Change in Count Rate After Holding at 4" H_2O for 24 Hours (cpm)
1	0
2	1
3	0
Heat Cycled - 20 Times - Abraded 1000 Cycles	
4	0
5	0
6	1

Although the material was found to be impermeable to microorganisms by the radioisotope method, no confirming tests were carried out since the material was found to support fungal growth, as noted in Table XI.

7.3.3.1.3.7 Butyl Rubber - The results of testing butyl rubber are recorded in Table XX.

TABLE XX TRANSFER OF MICROORGANISMS ACROSS BUTYL RUBBER

Virgin Material Chamber	Change in Count Rate After Holding at 4" H_2O for 24 Hours (cpm)
1	3
2	2
3	0
Soaked in detergent for 48 Hours--Heat Cycled--20 Times--Abraded 1000 Cyc.	
4	4
5	2
6	0
Heat Cycled - 20 Times - Flexed 200 Cycles	
7	1
8	1
9	

Confirming Test - Virgin Material

Two one-inch squares were tested by the spinner flask method. The test material was exposed to a culture of Micrococcus candidus for a test period of 48 hours. No turbidity appeared within the test period, thereby confirming the previous results.

7.3.3.2 Transfer of Microorganisms Across Bonding Materials

Two of the prime candidate materials, Silicone Rubber SE-555 and Armalon 97-001, were tested for microbial integrity. The silicone rubber sections were bonded using RTV 560; the armalon sections were bonded using EC-2216. Tests were run on the materials in the untreated condition, and also following exposure to heat, flexing, and disinfectant treatments. The test results appear in Tables XXI and XXII.

TABLE XXI TRANSFER OF MICROORGANISMS ACROSS BONDED SILICONE RUBBER SE-555

Virgin Material Chamber	Change in Count Rate After Holding at 4" H_2O for 24 Hours (cpm)
1	7
2	24
3	10
4	Visible leak
5	Visible leak
Exposed to Disinfectant for 48 hours - flexed 200 cycles	
6	56
7	90
8	72
Exposed to Ethylene Oxide Cycles - Heated 10 Cycles - Flexed 200 Cycles	
9	22
10	7
11	29

A confirming test, spinner flask method, was not performed on this material.

TABLE XXII TRANSFER OF MICROORGANISMS ACROSS BONDED ARMALON 97-001

Chamber	Change in Count Rate After Holding at 4" H_2O for 24 Hours (cpm)
Virgin Material	
	1
	0
*3	25
Exposed to Ethylene Oxide Cycles - Heated 10 cycles - Flexed 200 cycles	
4	656
5	593
6	Visible leak

* Flexed for 200 Cycles

Confirming Test

Two one-inch squares of virgin material were tested using the spinner flask method. One side of the bonded material was exposed to a culture of Micrococcus candidus for 48 hours. No turbidity appeared within the test period.

Discussion

Silicone rubber, bonded to itself using RTV 560, was found to be permeable to microorganisms. It is the opinion of the testing facility that, based upon the experimental results, further testing of this material would be desirable using other bonding agents in various configurations.

Armalon 97-001 material, indicated no breech of integrity when maintained in the virgin condition. However, after physical testing, the material became permeable to microorganisms. It is therefore recommended that further study of the bonding characteristics of this material be initiated.

7.3.3.3 Transfer of Gases Across Suit Materials

In order to determine the rate of permeability of helium through the candidate materials, the test apparatus shown in Figure 55 was erected. A circular piece of the test material, one inch in diameter was used as a separator between both halves of the test chamber. One side was flushed with dry helium and maintained at a pressure of 1" H_2O relative to the other. The second side, containing air only, was closed off at atmospheric

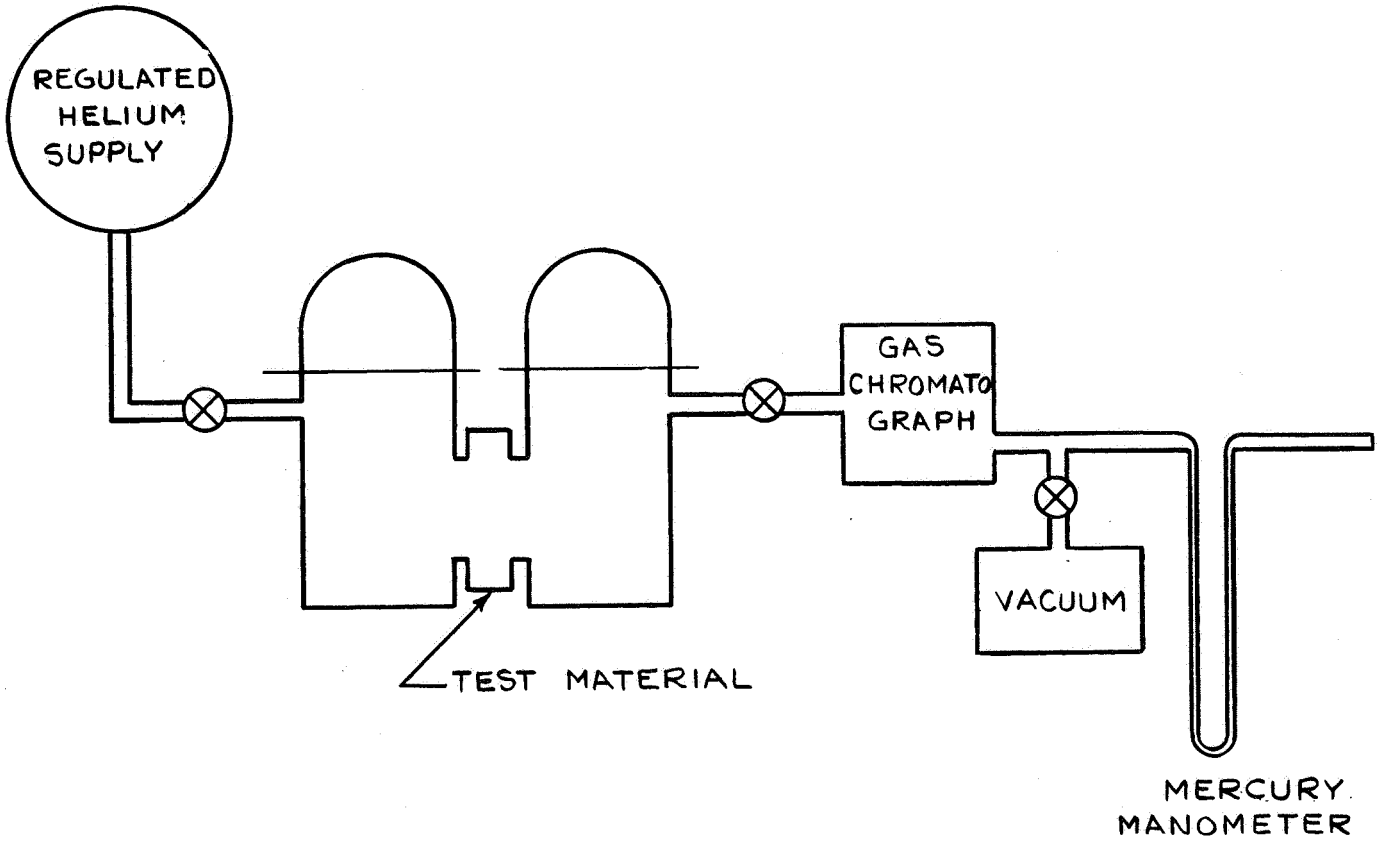


Figure 55 Test Apparatus For the Measurement of Helium Permeability

pressure for the duration of the test period. At the end of a given exposure period the gases in the air side were allowed to expand into its components by a silica gel column, and the concentrations of those components were then measured by their thermal conductivities. The sensitivity for helium in this test was 2.1 x 10^{-5} moles.

After completion of the microbial permeability test, the Armalon 414-141 material, containing known diameter holes, was then placed in the above test apparatus. Non-punctured material was also tested, and an evaluation was made of the leak rates of helium between the two types of materials. The results appear in Table **XXIII** below.

TABLE **XXIII** LEAK RATES OF HELIUM THROUGH PUNCTURED AND NON-PUNCTURED MATERIAL

Material	Thickness	Leak Rate cc/cm^2/Sec. @.19 cm Hg.
Armalon 414-141	14 mils	2.07 x 10^{-3}
Armalon 414-141 with two 70 micron holes	14 mils	1.18 x 10^{-2}

The difference between the values, as indicated in the above table, represents the leak rate due to the two 70 micron holes.

The leak rate of helium was then determined on other candidate materials for which no values could be found in the existing literature. The resultant data is shown in Table XXIV.

TABLE XXIV LEAK RATES OF HELIUM THROUGH EXPERIMENTATION

Sample	Material Thickness	Leak Rate cc/cm^2/Sec. for the specified thickness at 0.19 cm Hg.
1. Armalon 97-001	*12 mils	3.66 x 10^{-5}
2. Silicone Rubber	62 mils	1.46 x 10^{-5}
3. Butyl Rubber	62 mils	3.44 x 10^{-7}
4. Lexan	62 mils	5.90 x 10^{-7}

* This material is composed of a fabric backed teflon film. The film has a thickness of 7 mils. This value should be taken as the actual material thickness for the purposes of rate determinations.

7.3.4 Retention and Release of Disinfectants by Materials

The objective of the following tests was to determine the degree of absorption and retention by the candidate materials when exposed to ethylene oxide/Freon mixtures, isopropanol, and peracetic acid liquid disinfectants. Each disinfectant required a different method of approach, and each method as described in the Integrated Test Plan (Appendix I) is summarized below.

7.3.4.1 Ethylene Oxide/Freon Tests

Weighed samples of the candidate materials, silicone rubber, armalon 97-001, lexan, and texolite, were exposed to 28 hour ethylene oxide cycle at a temperature of 50°C. The chamber atmosphere was composed of 12% ethylene oxide and 88% freon with a variation no greater than 10%. After testing, the samples were weighed again at ambient temperature, (25°C), and normal atmospheric pressure. Periodically, the samples were weighed to observe the retention of ethylene oxide. The results are given in Figure 56. Similar samples, tested at the same time, were checked for Freon-12 retention by means of gas chromatography. There was no freon-12 detected within 10 minutes after removal from the test chamber.

7.3.4.2 Isopropanol Disinfectant Test

Samples of the candidate materials (0.5" x 2") were weighed and placed in a 70% solution of Isopropanol for twenty-eight (28) hours. The samples were then removed, blotted, and placed individually into test tubes.

Testing was performed using "BOGENS MODIFICATION" of the Nicloux Reaction with isopropanol standards. This is the method by which Ethyl Alcohol in blood is determined. A standard curve was drawn using isopropanol as the standard instead of Ethyl alcohol. Samples were assayed periodically, or until no alcohol was detectable. The results of this test appear in Table XXV.

Conclusions

This type of testing was not meant to give any hard and fast data on the retention and release of alcohol on materials. The testing procedure used was only to develop some preliminary data on the physical property parameters.

If true determinations were to be made, many variables would have to be controlled such as blotting time and type, temperature, humiditv, air flow across samples, areas exposed to air, etc.

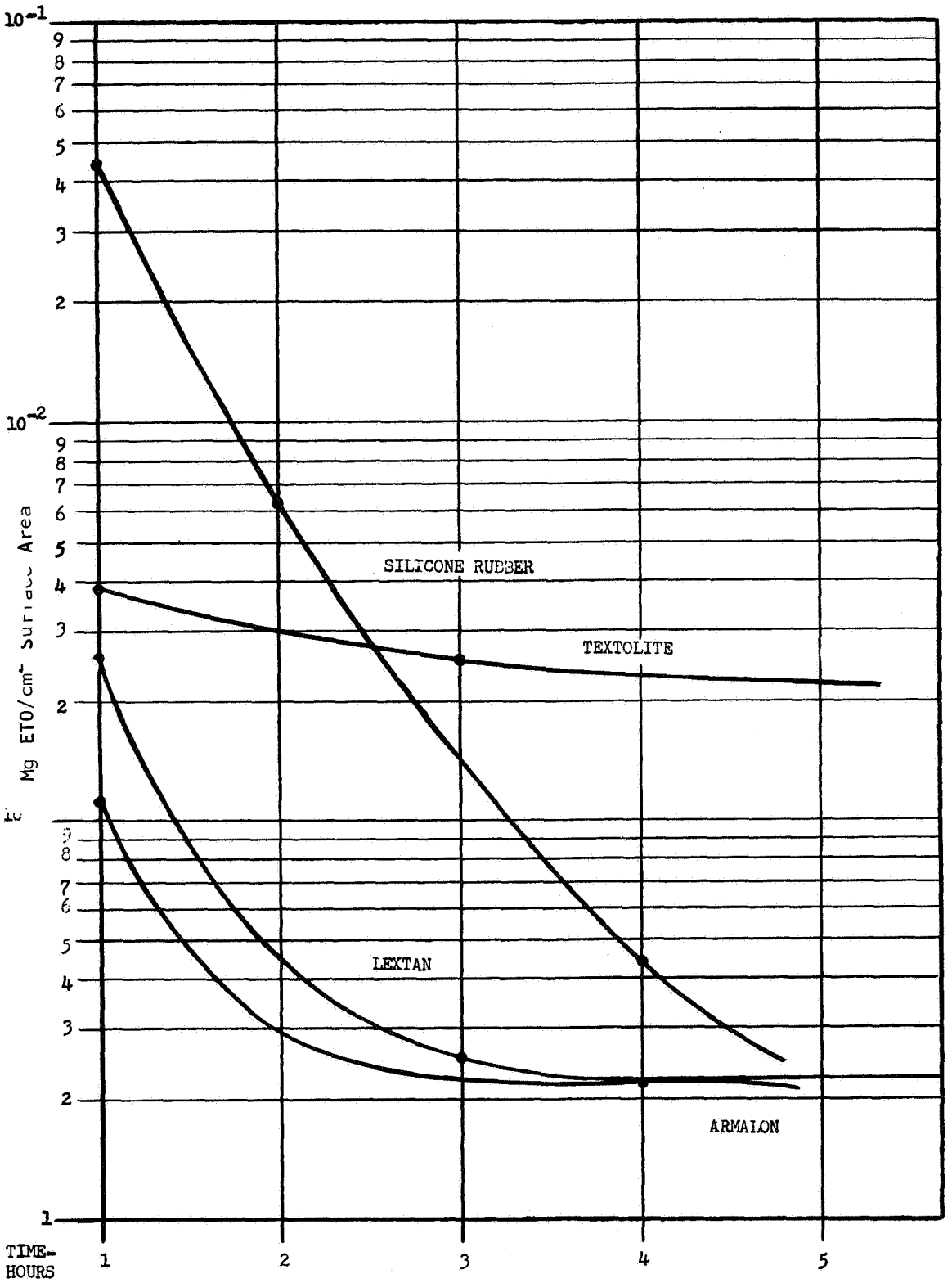


Figure 56 Release of Ethylene Oxide From Candidate Materials

TABLE XXV - RESULTS OF ISOPROPANOL DISINFECTANT TEST

	(Time in Minutes vs ppm/gm) 1	15	30	60	90	120
Lexan (1)	0	--	--	--	--	---
Textolite (2)	157	0	--	--	--	---
Silicone Rubber (3)	73500	--	990	450	252	0
Armalon 97-001 (4)	0	--	--	--	--	---
Butyl Rubber (5)	620	275	0	--	--	---

1. After blotting, no alcohol was detectable upon completion of the distillation period in a 2.5 gm sample.

2. No trace within 15 minutes.

3. All samples tested were in excess of 3500 ppm initially. The smallest sample tested was 0.2 gm.

4. None found within 1 minute in 1.2 gm sample.

5. Sample weight was 2.8 *gm.*

7.3.4.3 Peracetic Acid Disinfectant Test

Test samples (4" x 4") were immersed in a 2% solution of peracetic acid for twenty-four (24) hours. The samples were then removed, blotted, and placed individually into bottles containing distilled water. The samples were allowed to stand for another twenty-four (24) hours to permit any residual peracetic acid retained by the material to leech out into the agueous solution. Testing was performed using the Ferroin Method to determine Peracetic Acid content. No peracetic acid was detected.

The results obtained using the Ferroin method demonstrated that the peracetic acid had degraded to a point where the results were inconsequential. The amount of acetic acid was therefore determined by a Potentiometric Titration procedure, and then used as an index of peracetic acid content of materials. The results appear in Table XXVI.

TABLE **XXVI** - PERACETIC ACID DETERMINATION USING POTENTIOMETRIC TITRATION

	Results in gms/Acetic Acid/per gm ct/material		
Sample	Immediately after test	3 hrs after test	6 hrs after test
Textolite	7.4×10^{-5} gm/gm	4.08×10^{-5} gm/gm	3.6×10^{-5} gm/gm
Lexan	1.4×10^{-5} gm/gm	1.4×10^{-5} gm/gm	1.4×10^{-5} gm/gm
Silicone	3.4×10^{-4} gm/gm	3.3×10^{-4} gm/gm	3.0×10^{-5} gm/gm
Armalon	3.2×10^{-4} gm/gm	3.3×10^{-4} gm/gm	3.3×10^{-5} gm/gm

7.3.5 Helmet Cleaning and Disinfection

The objective of this test was to determine if the helmet materials could be effectively disinfected for purposes of prophylaxis. The test procedure was in accordance with the Integrated Test Plan which appears herein as Appendix F.

The two organisms which are representative of the most hazardous type of contamination likely to be encountered were tested. They were:

- Staphylococcus aureus
- Mycobacterium phlei

These organisms were used according to the test plan with the evaluations conducted in triplicate.

There was no growth observed throughout the test period. This indicates that the method prescribed constitutes an adequate disinfecting procedure for the purposes of prophylaxis.

8.0 MOCK-UP TEST PROGRAM

8.1 INTRODUCTION

The BISS mock-up study program was intended to serve two major purposes:

- Provide an empirical testing to examine the feasibility of operating in the environment peculiar to the BISS concept.
- Provide a means for experimental examination of developing system concepts to support concept development trade-offs.

The earliest decision in the mock-up study was that of approach, that is: should the study program provide for subsystem tests, each developed in its own context, and meeting downstream in the procurement of mock-up equipment; or should the study program be conducted in two phases, with all subsystems integrating in both phases? The decisions was to use the second approach because it was felt that while there was considerable information available about life support and communications systems and protective suits as separate entities, the major unknown in the BISS program was the integration of these subsystems into an operating system for use in the Assembly/Sterilizer. Hence, the earliest goal was to gain experience in the use of these subsystems in a BISS environment, and for this purpose it would be best to have a rudimentary system available as an entity. This rudimentary system could then be examined in detail under the special BISS conditions and a second phase would then serve the purpose of incorporating all of the data and experience gained in the first phase into a more refined system. This second system would then better simulate a prime BISS system and the data from tests on this refined system would more closely reflect ultimate BISS operations. Moreover, this mode of study allowed other program developments (fabrics study, bacteriology, physiology, etc) to develop data which could be used in the second phase and provide additional refinements not possible for the first phase.

The mock-up tests did not simulate BISS sterilization conditions. Instead, the mock-up program aimed at the simulation of all BISS conditions outside of strict sterile requirements. For this purpose a chamber had to be procured or modified, and tested for pressurization. A 12 x 12 x 20-foot Tenney Altitude was used for the BISS tests, and was modified to serve as a pressure chamber by clamping the main chamber door and installing a heavy wooden framework, which supported the hatch assembly in place of a small door located in the center of the main door. Also, stairways and an emergency access door were installed to make the

facility compatible with testing requirements. The Chamber was tested in excess of 4 inches of water, outward gage pressure. Figure 57 illustrates the front of the chamber with the hard tube installed.

Simultaneously with these operations, an integrated test plan (appendix F) was written to systematically detail the goals and methods of testing. It was recognized that because of the objective of the testing and the rudimentary nature of the equipment, that objective data alone would not reflect all the important variables to be evaluated. For this reason it was decided to include subjective data and a Subject's Assessment Scale (SAS) was constructed for the purpose. The SAS is explained in detail in Appendix F.

8.2 PHASE I TESTING

The Phase I mock-up test program contained four constituent parts:

8.2.1 Mock-up Equipment Construction

This aspect contained trade-offs and decisions affecting life support equipment, communications equipment; selection, procurement and adaptation of an outer suit/tunnel and helmet; selection, procurement and adaptation of an undersuit; donning rack design and construction hatchway design and construction; integration of all these subsystems into an operating system in the chamber environment; and the selection and orientation of a suitable test subject. Figures 58 through 62 show various mock-up system elements evolved.

8.2.2 Quantitative Tests

This part of the mock-up program contained tests such as obtaining temperatures in the undersuits, humidity measurements, rates of flow of air and water, air and water temperatures, and time measurements of operator/subject operations in suited conditions.

8.2.3 Qualitative Tests

This area represented use of the SAS to reflect the operator/subject sensations in various phases of operations or conditions of equipment function. In addition, test personnel made observations which were presented to the subject to obtain his evaluative comments. Finally, debriefing sessions were held with all cognizant personnel to evaluate both the qualitative data and their subjective observations, on a daily basis.

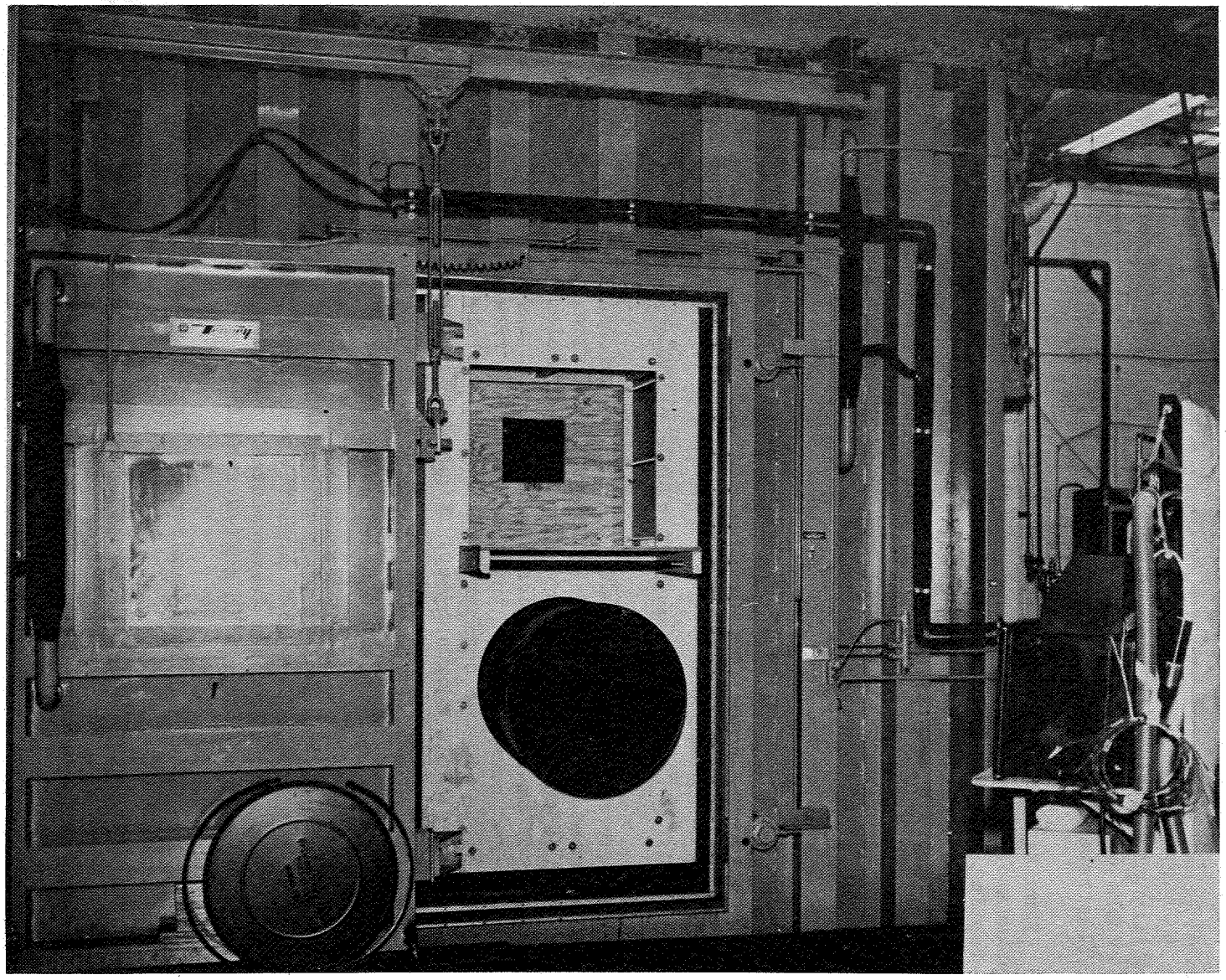


Figure 57. Front View of Tenney Chamber with Hard Top and Safety Access Door

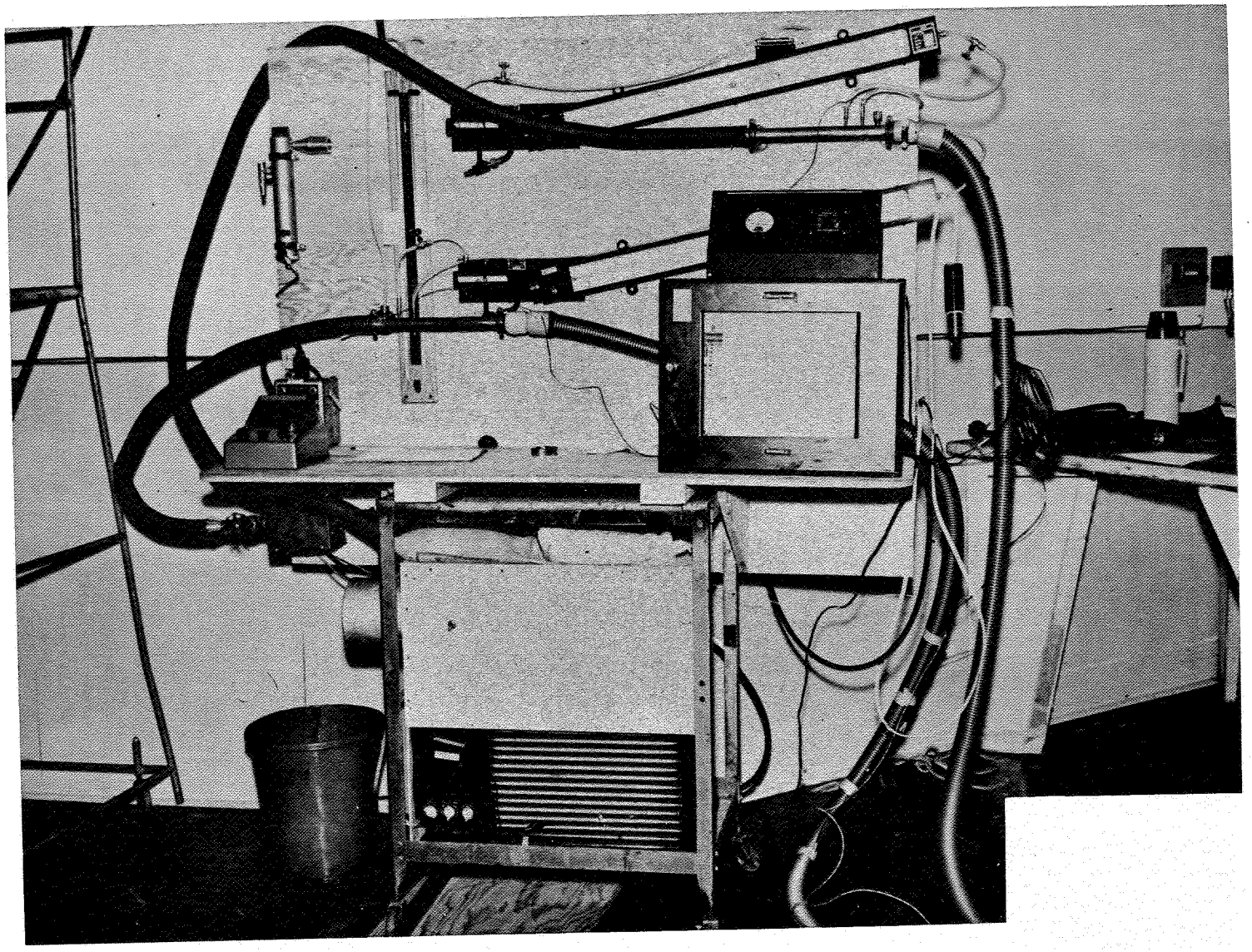


Figure 58. Phase I Life Support Console

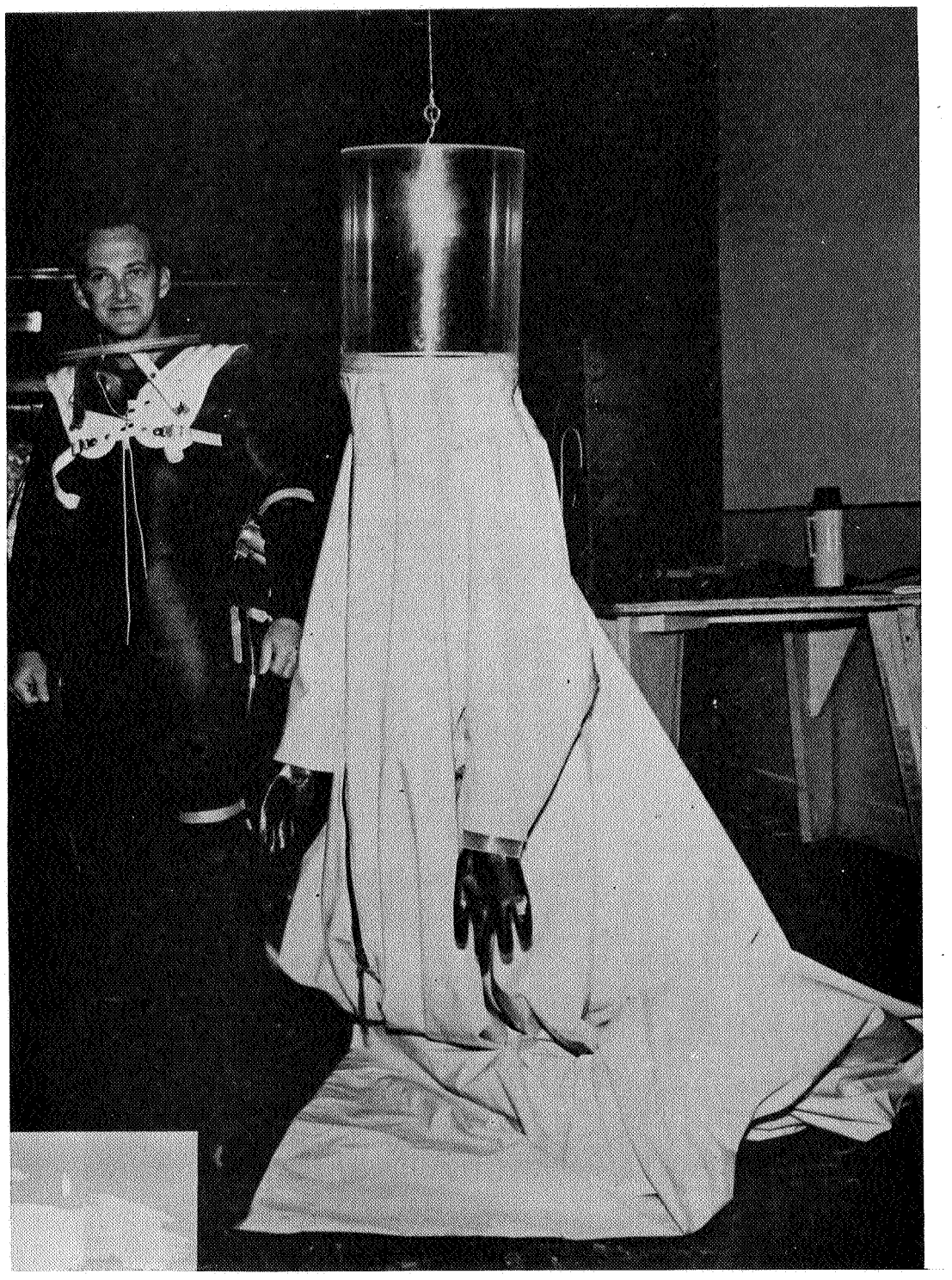


Figure 59, - Phase I. Air Cooled Undersuit and Unmodified Outersuit

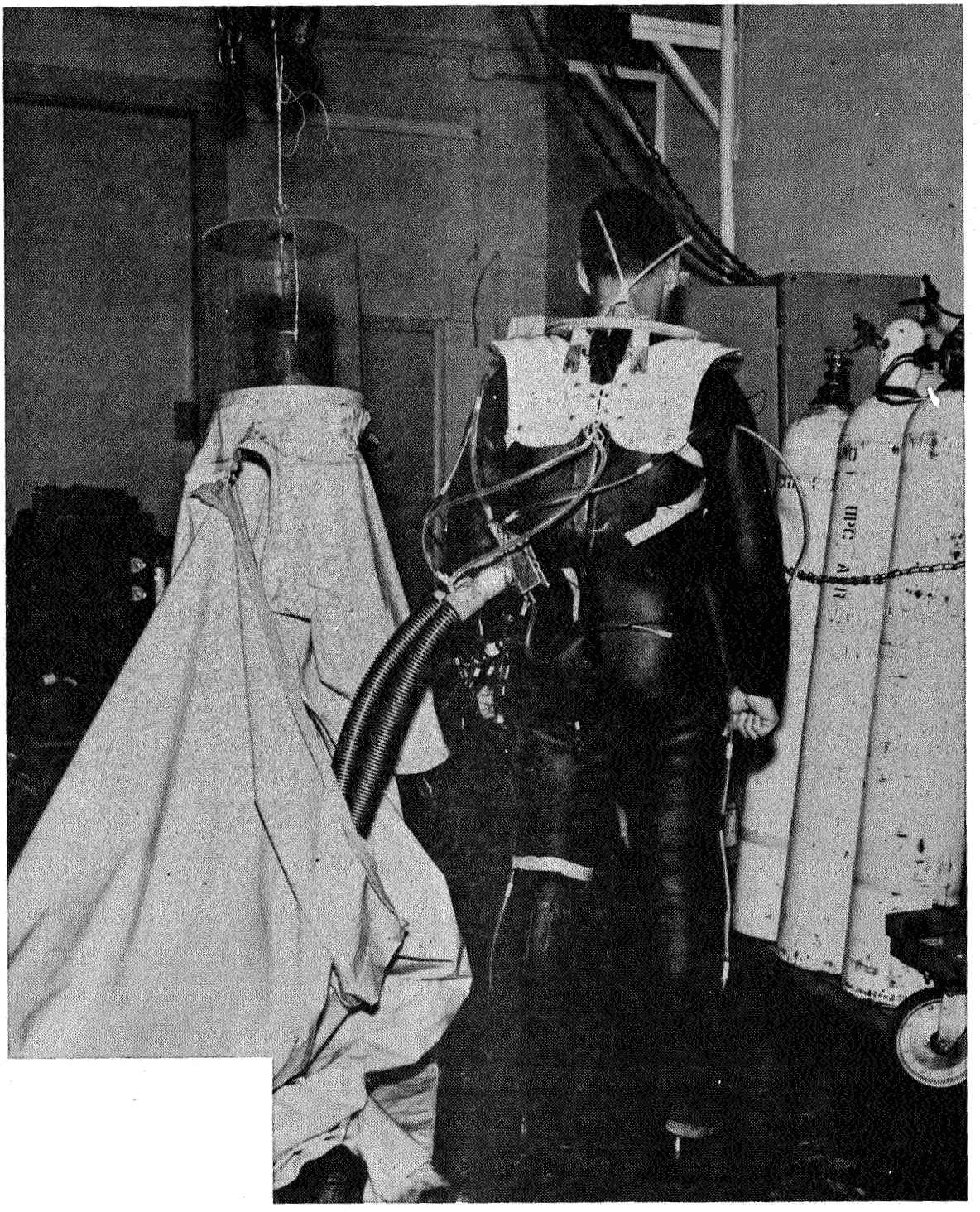


Figure 60 - Rear View of Air-Cooled Undersuit Showing Life Support Gear and Thermocouple Connectors

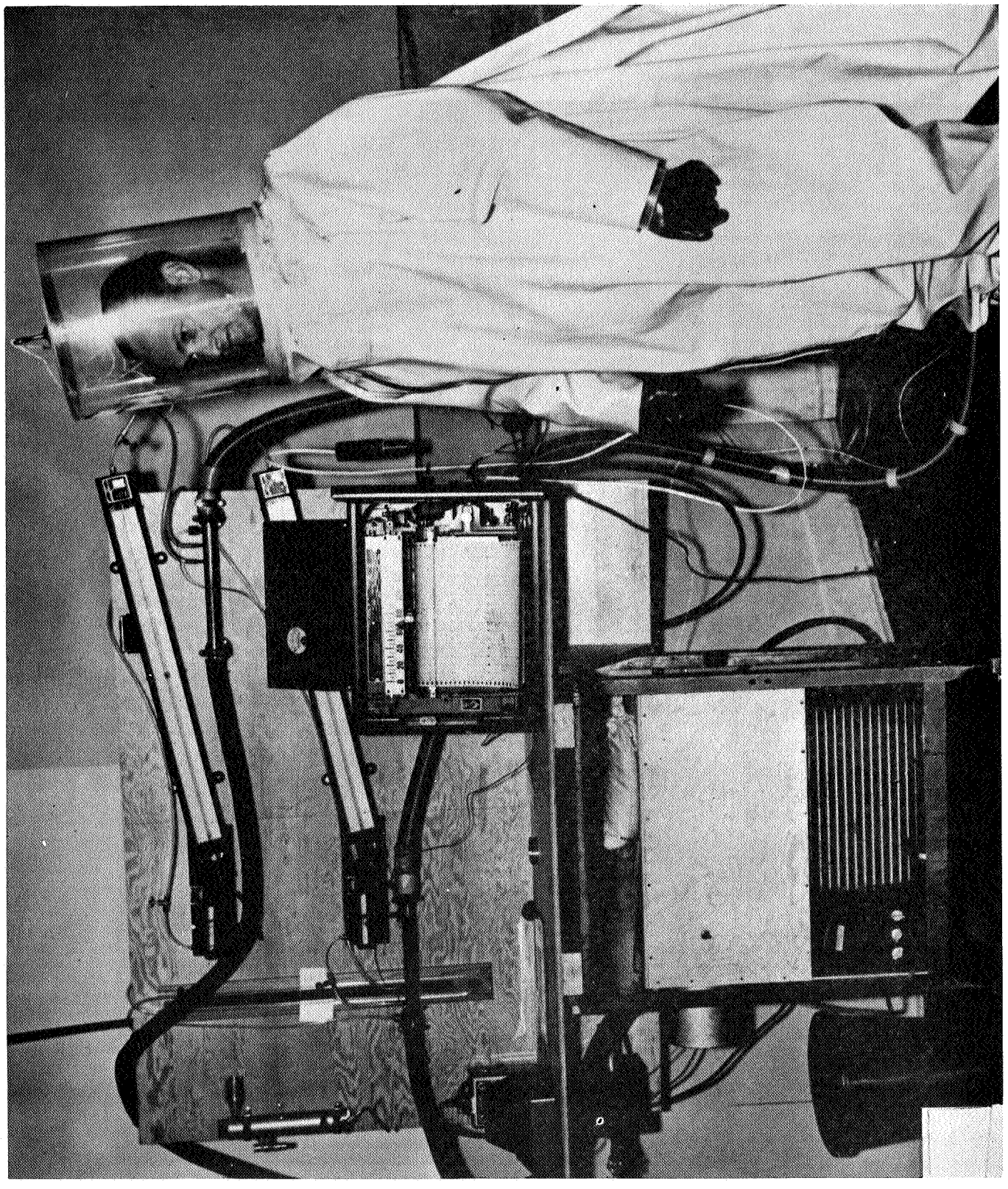


Figure 61. - Subject in Phase I. Outer Suit (Before Modifications)

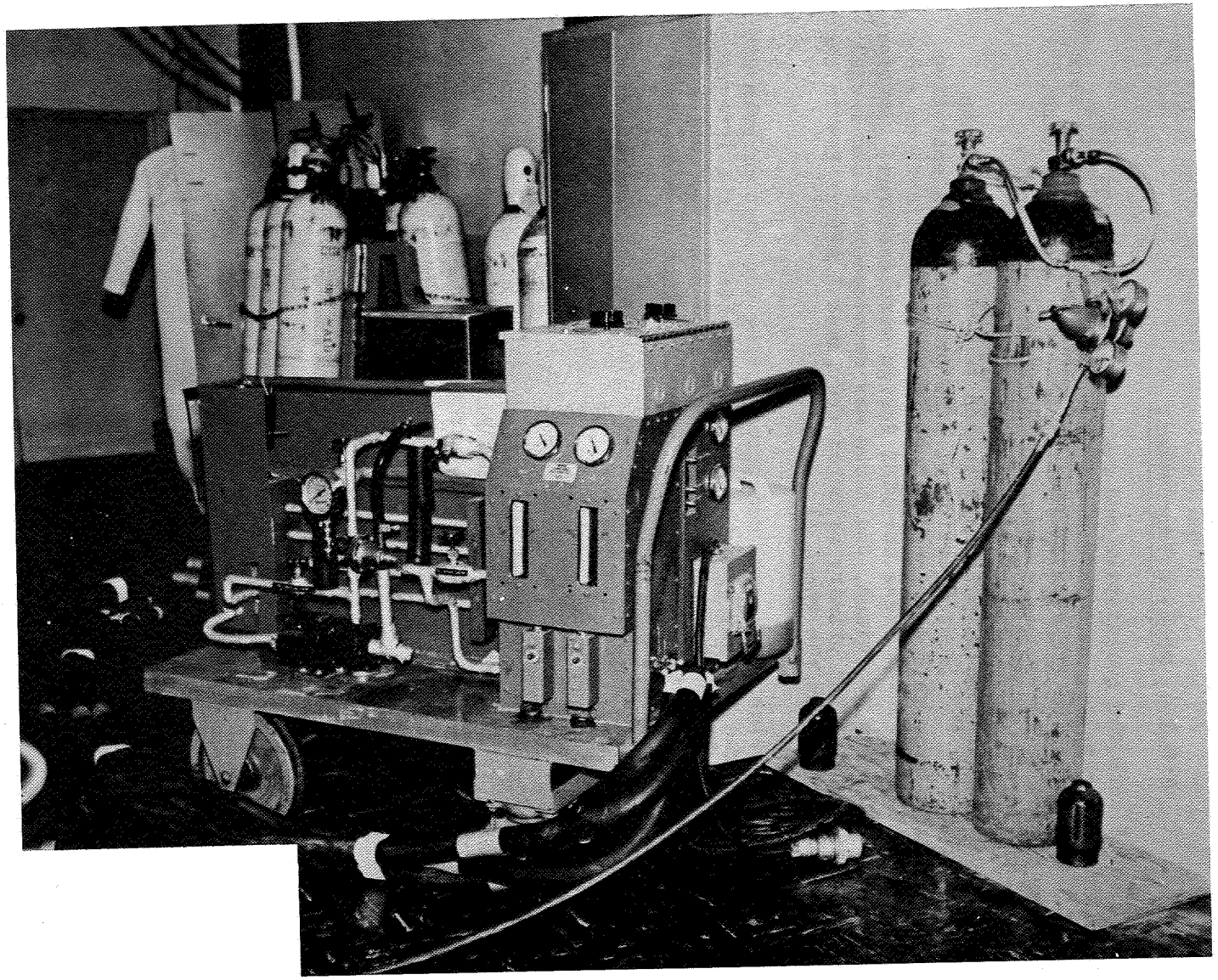


Figure 62. - Water Cooled Supply Apparatus
(Thermal Control Unit)

8.2.4 Mock-up Improvement

By use of both the qualitative and quantitative data, and the daily debriefing results, immediate mock-up equipment improvements were affected. When required, re-runs of Phase I quantitative tests were made after equipment improvements were incorporated.

In essence, the Phase I tests were geared to exploration of the BISS environment and the identification of BISS problem areas operative in, and resulting from, this environment. Further, the implications and dimensions of these problem areas for BISS design vere explored. Insofar as hardware itself was concerned, the focus was developmental and largely qualitative. Overall, the primary value of the Phase I effort lay in the guidance value it had for the Phase II effort.

The manner in which tests were conducted during the test program did not in all cases agree totally with the manner specified in the Integrated Test Plan. Entry-exit tests were added and performed prior to suit-system tests. Reefing tests were conducted only manually since no'mechanized reefing device was available for testing.

8.2.5 Tests Performed

The tests which were performed are listed below, and are presented in the same order as in the Integrated Test Plan, with the addition of entry-exit tests, which were carried out just before the suit-system tests.

1) Component Tests

   (a) Gas flow/temperature tests - Vortex tube cooling system

   (b) Gas flow/temperature tests - air conditioner cooling system

2) Subsystem Tests

   (a) Chamber Pressurization

   (b) Water cooled undersuit

   (c) Air cooled undersuit

   (d) Suit - tunnel leak test

   (e) Helmet air supply

(f) Visual field test

(g) Outer suit fit

(h) Safety rescue

(i) Communications

(j) Entry-exit

3) Suit-system Tests

(a) Comfort

(b) Mobility

(c) Entry-exit

(d) Communications

(e) Subject comments

(f) Reefing

8.3 TEST RESULTS

Results of tests are presented in the following sections: Alpha numeric designators following the title correspond to the designators in the preceding section.

Gas flow/temperature tests - Vortex tube cooling system 1(a)

This tests called for the measurement of flow rates and temperatures in various parts of the cooling system. For ease of reference, the data collected has been imposed upon the system schematic, Figure 63.

Gas flow/temperature tests - Air conditioner cooling system 1(b)

For the air conditioner cooling system the following, information was obtained:

- Plenum air temperature - 64°F
- Blower exhaust temperature - 64°F

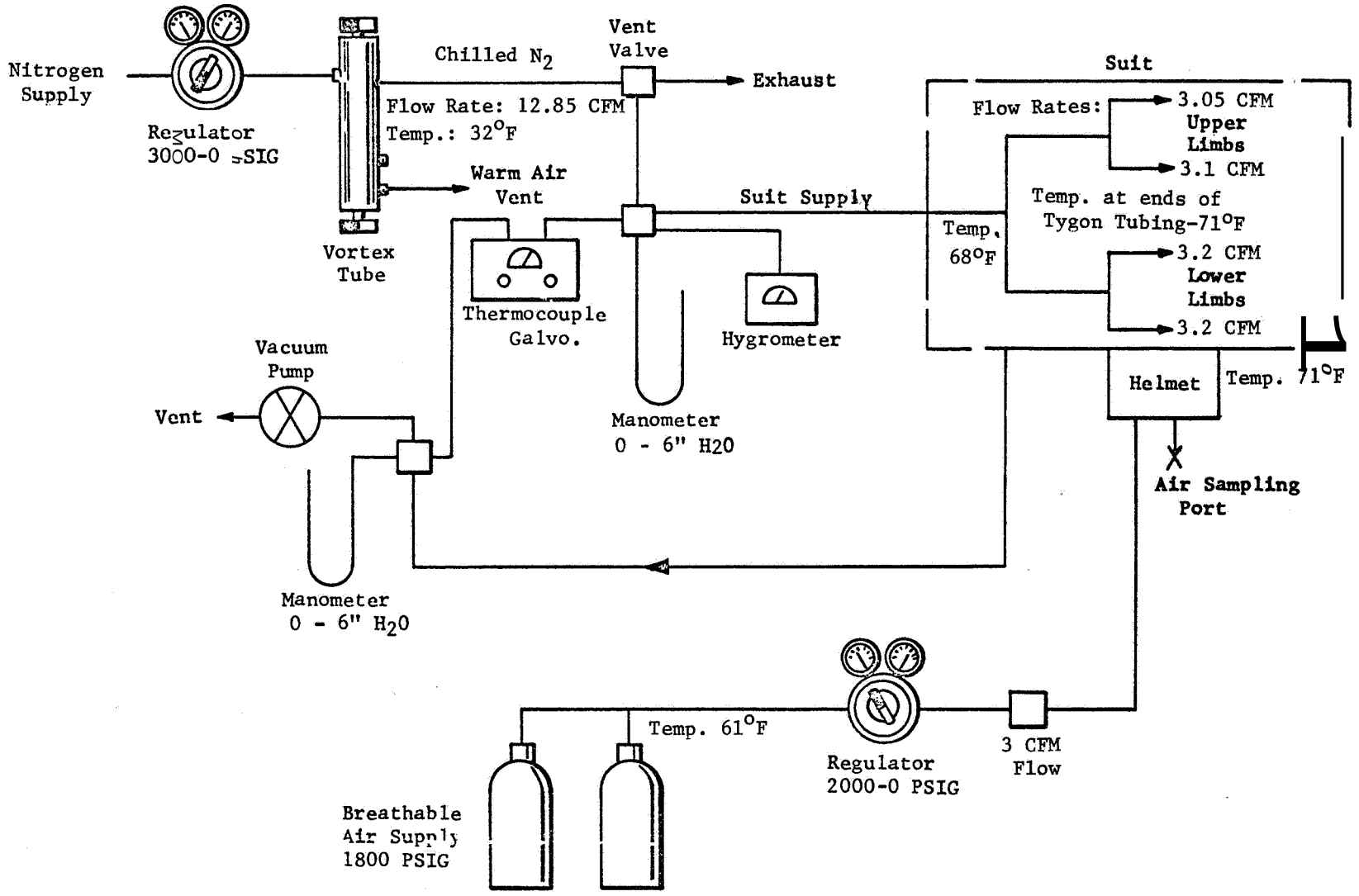


Figure 63. Vortex Tube Life Support System

Temperatures in the system leveled off at room temperature since the ducting was not insulated.

Air Conditioner - Vortex Tube Comparison

A maximum air flow of 20 cfm was available from the air conditioner cooling system. This exceeded the 16 cfm requirement indicated in the test plan while the vortex tube (12.85 cfm maximum) fell short of this criterion. Other factors favoring the air conditioner were that temperature could be adjusted independently of flow which was not possible with the vortex tube and that on independent helmet breathing air supply was not required as it was for the vortex tube.

These factors combined to indicate the superiority of the air conditioner system for supporting the BISS air cooled undersuit. It was also recognized that subsequent editions of the system (if the air cooled system was chosen over the water cooled system in the system tests), would have to employ an air conditioner of greater capacity and insulated hosing from the console to the operator. As a result of these tests, and the trade-offs listed in Table IX of Section 4.7, the Encon vortex tube was eliminated from further consideration in this study.

Subsystems Tests (2)

Chamber pressurization Test 2(a)

The chamber pressurization test established that the chamber could be pressurized and held at a four inch (H_2O gage) pressure. For this test the hard tube was capped and shop air applied from a 90 psi source. The chamber achieved the 4" pressure at a sate of approximately 1" per minute. After achieving the 4" pressure it was readily maintained at this level by an input pressure of 30-40 psi for a period of one hour.

Undersuit Tests (2(b) and 2(c)

Tests of both the air cooled and water cooled undersuits were conducted underunpressurized chamber conditions with the subject clad in long underwear and the outer suit. The objective of the tests was to determine the capability of the undersuits to provide environmental control for the subject while resting and after exercising. Since the requirement that the undersuits cool a subject while exercising was more stringent than while resting the tests for the resting conditions were not conducted in as rigorous a manner.

Resting Subject - Air Cooled Suit

Phase I hardware did not provide adequate cooling ability to test a significant range of inlet temperatures. However, the effect of different rates of air supply was determined.

By varying the input flow rate systematically it was found that the subject, in the air cooled undersuit and outersuit, with the tunnel sealed off, was very comfortable when a flow rate of **8-12** cfm was provided. It was not possible to ovescool the subject in this input range and the only negative comment was that the humidity of the air conditioner supply was too low (the humidifier became operational later in the tests).

Resting Subject: Water Cooled Suit

Inlet water temperature was varied over the range **65-90°F** in 5° increments. The subject was exposed to each temperature for a period of 3 min. Overall comfort was rated as excellent for the inlet temperature values of 75° and 80°. The **70, 85** and **90** degree values were quite acceptable, although the subject did report that he felt a little uncomfortable at **850.** At 90° he did not feel much different from 85°, but when taken down to a 65° inlet temperature, the subject reported that the temperature was unsatisfactorily cold and the comfort poor. Humidity posed a minor problem with the water cooled suit in the helmet area since the subject experienced lip-drying due to his breathing of U.S.P. bottled air with virtually no moisture content.

A water inlet temperature of 75° was considered to be ideal. Cooling distribution was reported as being satisfactory throughout the test except for the subject's legs at 85° and 90° inlet temperatures. At these temperatures, the subject sensed the water distribution in his legs as being poor. Overall, it was concluded that cooling distribution in the water cooled undersuit was quite acceptable and that the system was not taxed in any way, keeping the subject comfortable when resting. It was also recognized that moisture would have to be introduced into the breathing air supply if it was decided to further explore the water cooled suit in the Phase II tests.

In conclusion, both the air and water cooled undersuits and supply hardware served to provide good overall comfort to a resting subject.

Exercised Subject - Air cooled & Water Cooled Undersuit

For the exercised condition, the testing was more rigorous. The subject was given a series of 3 minute timed runs on an exercycle (speed constant for all runs) inside the chamber, with a 0" differential pressure. For each trial input parameters were varied (flow rate for the air cooled suit and inlet water temperature for the water cooled suit), and SAS comfort ratings were taken. (See attachment A of Appendix F)

Temperature data was recorded by a thermocouple recorder for the following points:

- Supply temperature
- Exhaust temperature
- Ambient
- Left arm - cubital region (Inside of the forearm)
- right arm - axilla region (Armpit)
- left leg - poplitcal region (Back part of leg behind knee joint)
- small of back
- groin
- chest

For the air cooled undersuit there were six 3 minute runs with the air flow being raised from 2 to 12 cfm in 2 cfm increments. For the water cooled suit the inlet coolant temperature was raised from 70° to 85° in 5° increments then lowered to 65° and, finally lowered from 65° to 55° in 5° increments. The SAS (comfort) was administered to the subject and an overall SAS average was obtained by averaging the SAS ratings for overall comfort, temperature, humidity, and the average of the six cooling distribution ratings. These ratings are shown in Table XXVII.

The air-cooled suit received its best overall rating of 5.3 at an airflow of 12 cfm., exceeding the nearest competing rating by 1.4 points. The water cdoled suit received its best overall rating for an inlet temperature of 60° as contrasted with 75° when the subject was resting.

TABLE XXVII. - SAS COMFORT RATINGS FOR EXERCYCLE RUNS

RUN	FLOW RATE (CFM)	INLET T(°F)	COMFORT						COOLING DISTRIBUTION															
			ALL		TEMP		HUM		HEAD & FACE		ARMS		HANDS		LEGS		FEET		TORSO		AV COOLING DISTR		OVERALL AV	
	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C	A/C	W/C
1	2	70	3	4	1+	3+	1+	3+	2	3	2	2	2	3/2	2	3	2	3	2	3	2.0	2.8	1.8	3.2
2	4	75	3	4	1+	3+	1+	3+	2	3	3/2	2	2	2	2	4	4	4	2	4	2.4	3.2	1.9	3.3
3	6	80	3	3	2+	3+	2+	3+	3	1	3	3	3	3	3	4	3	4	3	4	3.0	3.1	2.5	3.0
4	8	85	4	1	3+	1+	3+	1+	4	1	3	2	4	2	3	3	4	3	4	3	3.7	2.3	3.4	1.3
5	10	65	4	4	4	4	3+	3+	5	3	4	3	5	3	4	4	5	4	4	4	4.5	3.5	3.9	3.6
6	12	60	5	4	5	4	5	4	6	4	6	3	7	3	6	4	7	4	6	4	6.3	3.7	5.3	3.9
7		55		4		3-		4		4		4		3/4		4		3		4		3.8		3.7
																	AVERAGE RATINGS				3.7	3.2	3.1	3.1

LEGENDS
* unweighted cooling distribution used

\+ = too high
\- = too low

NOTE:
SAS rating

1 = unsatisfactory
4 = satisfactory
7 = excellent

Table XXVIII compares the temperature values recorded for the best rated air cooled run with the best rated water cooled run and also makes the same comparison between the worst rated runs. Table XXIX on the other hand, compares the best rated air cooled run with the worst rated air cooled run and the best rated water cooled run with its worst rated counterpart. Examination of the data in both tables suggests that there is no set of "ideal" temperatures for a subject which is independent of the undersuit system used.

For both undersuits, the conditions rated least comfortable were considered as being too hot by the subject. It is to be noted in Table XXIX that temperature is not the influential variable. Inlet air flow rate is the influential variable since the worst case was for the lowest flow rate (2 cfm) and the best case was for the greatest flow rate (12 cfm) used.

For the water cooled suit, on the other hand, inlet temperature clearly seems to be the controlling factor in determining subject comfort. The worst case was considered too hot by the subject and all temperatures were greater than for the most comfortable case.

Flow rate was the principal determinant of subject comfort in the Phase I BISS air cooled undersuit and coolant temperature the principal determinant for the water cooled undersuit. Examination of Table XXVII shows that both undersuits received the same overall average comfort rating (3.1,) but that the high for the air cooled undersuit was 1.4 points higher than both the nearest air cooled and water cooled undersuit ratings.

Subject comments throughout both runs correlated quite well with the ratings. Worthy of note is the fact that with the air cooled suit, the subject sweated heavily in the 2-6 cfm runs, but noted improvement after that. By the end of the test, the subject reported that the joints of his arms and legs which were repeatedly flexed by the exercycle were the only spots that were perspiring. There was still some accumulated perspiration from the early part of the test, but the joints were the only places that were worthy of note. As can be seen from Table XXVII, the subject indicated a marked improvement in comfort as the test progressed.

Comments regarding the water cooled suit also correlated well with the ratings. It was noted that the subject felt that a larger volume of air was needed for the helmet than was provided to meet breathing requirements. The subject reported that at 65°F inlet temperature his body was cool, but his face was still sweaty and uncomfortable.

TABLE XXVIII TEMPERATURE (°F) COMPARISONS-BASED ON SAS RESPONSES

MEASUREMENT	MOST COMFORTABLE				LEAST COMFORTABLE			
	A/C	W/C	△T(°F) A/C WITH RESPECT TO W/C		A/C	W/C	△T(°F) A/C WITH RESPECT TO W/C	
SUPPLY TEMPERATURE	73.5	60	+13.5°		76.0	85.0	-9.0	
EXHAUST/RETURN TEMP	82.0	82.0	0		77.0	85.0	-8.0	
AMBIENT TEMP	78.0	83.0	- 5.0		77.5	86.0	-8.5	
LT. ARM, CUB.	86.5	79.0	+ 7.5		72.0	81.0	-9.0	
RT. ARM, AXILLA	83.5	91.5	- 8.0		90.0	94.5	-4.5	
LT. LEG, POP.	89.5	89.5	0		92.5	90.0	+2.5	
SMALL OF BACK	89.5	80.0	+ 9.5		90.0	91.0	-1.0	
GROIN	88.0	74.5	+13.5		86.5	89.5	-3.0	
CHEST	89.5	89.0	+ 0.5		90.0	93.0	-3.0	

TABLE XXIX TEMPERATURE (°F) COMPARISONS-BASED ON SAS RESPONSES

MEASUREMENT	AIR COOLED			WATER COOLED		
	BEST	WORST	△T(°F)*	BEST	WORST	△T(°F)*
SUPPLY	73.5	76.0	+ 2.5	60.0	85.0	+25.0
EXHAUST/RETURN	82.0	77.0	- 5.0	82.0	85.0	+ 3.0
AMBIENT	78.0	77.5	- 0.5	83.0	86.0	+ 3.0
LT ARM, CUB.	86.5	72.0	-14.5	79.0	81.0	+ 2.0
RT ARM AXILLA	83.5	90.0	+ 6.5	91.5	94.5	+ 3.0
LT LEG-POP.	89.5	92.5	+ 3.0	89.5	90.0	+ 0.5
SMALL OF BACK	89.5	90.0	+ 0.5	80.0	91.0	+11.0
GROIN	88.0	86.5	- 1.5	74.5	89.5	+15.0
CHEST	89.5	90.0	+ 0.5	89.0	93.0	+ 4.0

* Worst with Respect to Best

In summary, it was concluded that the performance of the air cooled undersuit was superior to that of the water cooled undersuit in providing operator environmental control. Also, it was concluded that the performance of the water cooled undersuit was good enough to warrant a continuation of the undersuit comparisons in the system tests.

Suit Tunnel Leak Test - 2(d)

The outer suit leak test was run to determine whether the suit tunnel combination leaked, and if so to determine the leakage rate. To run this unmanned test, the suit and tunnel were first installed in the chamber. The hard tube was then capped, the only opening in it being for a manometer. The first time the system was pressurized, the rate of pressurization was poor (nearly 7 min. to reach 4"ΔP) and it was obvious that there were leaks.

A study indicated that a better gasket was needed for the chamber door and that a better seal was needed at the suit-tunnel interface. These matters were corrected along with miscellaneous small leaks discovered when the suit was pressurized as a part of the repair process. After all the repairs were completed, the 4"ΔP was achieved in 3 minutes using an 95 psi source. It was then possible to maintain this pressure with an input pressure of 30-40 psi. A 2.8 cfm leakage rate was measured using the manometer and a pitot tube. This value was considered acceptable for subsequent pressurized chamber tests.

Helmet Air Supply 2(e)

Difficulties in scheduling precluded running this test until other Phase I testing had been completed. Since this was the case, and ample experience had been gained with the helmet air supply throughout all the tests of Phase I, it was felt that the detailed tests indicated in the integrated test plan were no longer required. It was decided that the most significant aspect of the specified test at that point in the program was the gas analysis.

Since the Phase I tests had been concluded and a new exhaust system and helmet device had been designed for the Phase II suit, it was decided that testing these devices would be more significant than running the tests on the already outdated design. The exhaust system change involved the addition of supraclavicular. exhaust ports to the Phase I undersuit. The new distribution device was a collar type manifold. Samples of room air, helmet supply and helmet exhaust were all taken.

Results were as follows:

Gas	Room Air %	Helmet Supply %	Helmet Exhaust %
O_2 + A	25	25	24.7
N_2	74	74	74
CO_2	.08	.05	.55
H_2S	--	--	Not detectable
O_3	--	--	.05 PPM–Not detectable

The above analysis was accomplished by means of a gas chromatograph. The high percentage of CO_2 in the exhaust air was attributed to the subject exhaling directly in the exhaust tube which was coincident with one of the supraclavicular exhaust ports. This was interpreted to mean that the exhaust system was functioning well and CO2 was being discharged from the helmet envelope without any significant portion being mixed with other helmet air.

Tests for carbon or other particulate matter coming from the exhaust blowers were also negative. Therefore, the results of the helmet air supply test were deemed satisfactory.

In conjunction with the helmet air supply test, medical monitoring of the subject was performed. The monitoring of the respiration rate and heart rate by a tonoscope (Luminiscope) having a volume range from 5 decibels to a maximum of 30 decibels at the stethoscope ear tips and covering a frequency response of 10–10,000 cycles was attempted. With the transducer taped to the subject's chest in both the anterior and posterior areas at the level of 4–5th rib (interspace) heart rate and respirations were easily heard while the suited subject was at rest. During periods when the subject talked, the voice sounde made the detection of heart abd respiratory sounds impossible to be distinguished from the sounds of phonation.

During periods of exercise, the tonoscope sounds were over-ridden by the noise made by motion of the transducer on the subject's chest and also by the noises caused by motion of the subject's garments and equipment.

The transducer was placed on the subject's neck in the area of the carotid sinus. Tests in this area were similar to those run when the transducer was applied to the chest area.

For the above reasons, the use of an electronic stethoscope for the **BISS** System was discarded in favor of a system composed of a radio-cardiograph (RKG) to obtain heart rate, and a voice communications system has the ability to transmit respiratory sounds. During the **BISS** Phase **I** exercise periods, the stress was insufficient to produce labored respiration sounds. To test the voice communications system, the subject was instructed to hyperventilate. These sounds weseeasily heard over the communications system.

On four separate days, a system composed of an RKG-100 (Telemedics) Radiocardiograph transmitted (1" x 3½" x 4½", weight 10 *oz.*, range 250 ft.) was used. Thin flexible wires carry the EKG signal from disposable adhesive type electrodes (1½" square with metallic screen, paste-reservoir and snap-on fasteners) to the transmitter. These electrodes comply with the curvature of the skin and retain necessary conductivity for extended time periods. The Telemedic receiver (14" x 12" x 8", weight 17 pounds) has a collapsible antenna which extends to a height of 3 ft. This receiver contains skin resistance meter, standardization, and a selector switch for channeling to conventional electrocardiographic recording apparatus, oscilloscope, magnetic tape recorder, or all three simultaneously.

The recharging unit for the transmitter is part of the receiver units For the tests on Phase **I BISS** Suit, the Telemedics RKG-100 was attached to a Sanborn Viso-Cordiette electrocardiographic recording apparatus.

The electrodes were attached to the subject's right and left clavicular area, so as to produce EKG approximating the standard lead position known as L_1. Electrocardiographic tracings of excellent quality were received from the actively exercising suited subject from within the pressurized chamber. No interference was caused by the metal construction of the chamber, the building or the activities of such ancillary equipment as operating pumps, motors, compressors and air conditioners. The heart rate of the suited subject at rest was 88 beats/min. During the **BISS** exercises, this heart rate went up to 98 beats/min. This is well within normal range. The graphic results were read and reported as being normal graphs with no signs of stress.

Visual Field Test 2(f)

The visual field test established that the subject could see 79° above his line of sight (L.O.S.) and 70° below his L.O.S. The criterion of 140° total vertical field was exceeded by the total measured field of 149°. The helmet did, however, miss the 800 below the L.O.S. criterion by 10°. This fact was noted for consideration in the Phase II helmet redesign. The criterion of 220° in a horizontal plane was far exceeded by a measured value of 266°, 130° to the left and 136° to the right.

It was concluded that the dimensions of the helmet were adequate for head rotation, but that the Phase II helmet would have to be reconfigured to permit greater ventral flexion.

Outer Suit Fit 2(g)

Outer suit fit could not properly be called a test, but was rather a critical evaluation of the way the outer suit fitted the Phase I subject. This evaluation was carried out by the subject and two observers. Its purpose was to identify gross deficiencies in the initial version of the Phase I outer suit which would be amenable to quick repairs. Adjustments or changes that could not be made without redesign were noted for incorporation in the Phase II specifications.

The main observations made under an ambient pressure environment were:

- Front of outer suit torso was too long; excess material should be removed from the crotch area.
- Improved glove fit was needed.
- Greater arm mobility needed because the subject could not bring his arms closer together than the width of his body when his hands were extended forward, parallel to the floor.
- Yoke assembly required reconfiguration to permit subject to raise arms upward without having the helmet rise,

As a result of these observations, a six inch tuck was taken in the front of the suit to reduce the problem of material bunching in the crotch area. Gloves were not altered for the Phase I study, but it was decided that the use of a better fitting glove, molded in a curved finger mold would be better for Phase II usage than the large, straight-fingered gloves of Phase I.

It was not possible to alter the underarm to promote better freedom of movement of the subject's arms, but this data was noted for application in the Phase II suit specifications. Likewise, yoke modification was not feasible at the time of the suit fit observations, but yoke redesign was scheduled for Phase II as a result of this effort.

Safety-Rescue Test 2(h)

In order to assure the safety of the Phase I BISS subject in the event of an emergency during the test program, it was necessary to assure that the subject rescue criterion (4 minutes) could be met in the modified Tenney Altitude Chamber test facility. The four minute criterion was for the interval from detection of the difficulty to removal of the subject from the chamber. A secondary criterion of *30* sec. for the medical monitor to reach the victim in the chamber was also imposed. Since the only way in which a subject could be removed from the outer suit was to cut him out, it was necessary to simulate cutting operations to avoid ruining the outer suit.

The fully suited subject was told to call for help at his discretion and to feign collapse. Upon hearing the distress call, the test conductor dispatched two rescuers who were standing in the room outside the chamber. It was necessary for these men to ascend the chamber ladder, open the rescue hatch, and descend the inner ladder to reach the subject. This operation took **28** seconds under ambient pressure and **26** seconds under a pressure of **4".** Both values met the *30* second access criterion. The time required to simulate cutting and freeing the subject was *49* seconds under ambient pressure and *42* seconds under the *4"* pressure. It was obvious that the **4"** pressure posed no problem since both the pressure times were less than under ambient. The 68 seconds required under 4" pressure for reaching and freeing the subject leaves a balance of nearly **3** minutes for removal of the subject from the chamber. This is more than enough time to cut the tunnel away from the end of the hard tube and slide the victim out through the hard tube where he could be placed on a litter by other chamber personnel.

Throughout the chamber Eests, a knife was located in the chamber and sufficient personnel were available to effect rescue if it had been required. In addition to satisfying the design criterion, plant safety personnel agreed that emergency rescue provisions were satisfactory for the test situation.

Communications Test 2(i)

The communication tests for Phase I were not rigorous evaluation tests, but were geared to establish operating levels and transducer locations for the Phase I mock-up system. The detailed position location tests specified in the test plan were found to be unnecessary when early tests indicated that completely satisfactory results were being obtained with the speaker and microphone mounted on the helmet ring directly in front of the operator's face.

This placement posed no obstruction to operator vision and did not impede operator head movement. It was found that with the noisy, Phase I life support blowers running at high speed, the intelligibility of signals suffered. When the blowers were running at a lower speed, this noise no longer posed a problem. It was found that the high voulme setting on the amplifier was required to provide excellent received signal intelligibility (SAS rating of 7) in the helmet. This high volume setting was more a reflection of the limited gain of the intercom type amplifier than an index of the loudness of the signal in the helmet. The subjects reported that the overall effect was quite satisfactory.

In the Phase I communications system the link to the subject and to the chamber speaker from the test conductor was provided by an intercom master unit. In the initial version of the system, the link to the test conductor from the subject was simply a speaker, connected as a slave to the intercom master. In addition to the switching from receive to transmit required of the test conductor, it was found that the volume control had to be adjusted each time the test conductor changed modes, i.e., when the volume setting was comfortable for the suited operator, it was too low for the test cpnductor. For this reason, a separate amplifier and crystal microphone were procured for the link from the suit to the test conductor. This permitted independent control of the volume of the link into and out of the suit. When this modification was made, the BISS operator reported very satisfactory results. The chamber speaker could be operated in parallel with, or independent of, the suit speaker. Using the intercom amplifier to drive the chamber speaker, it was not possible to achieve a volume level which permitted the operator to adequately hear the chamber speaker throughout the chamber, It was possible for the subject to hear the chamber speaker by getting near it so that in the event of suit speaker failure, it was possible to instruct the subject via the chamber speaker, The obvious requirements for a paging horn type speaker and a much more powerful amplifier were noted for inclusion in the Phase II system.

The real intent of the Phase I communications test was to ascertain that the system was adequate for maintaining two-way communication with the subjects throughout the test, and this was done. The other matters of concern were those of transducer placement in the suit-helmet envelope and the determination of whether there were any reverberation or echo effects in the helmet. As has been previously mentioned, the placement of the! transducer posed no problem.

Entry-Exit Tests 2(j)

Although these tests were not specified for Phase I in the Integrated Test Plan, it was recognized that more experience was required with the suit under pressure prior to the system tests than would have been gained by following the test plan. Therefore, the entry-exit tests were conceived as informal developmental tests and were run with the expectation of providing a basis for further modification to the suit system before running the system tests. One of the principal elements in this test was to determine the influence of different pressure levels on the performance of the system.

The first run of this test was made at a chamber pressure of 1"; there were also runs of 4", 3", 2", in that order. At a differential pressure of 1", entry required 225 sec and 80 sec. The subject was aided by one man in the chamber during this process. Generally, the assistance given during these tests was kept to a minimum, but since the donning rack was not refined, periodic assistance had to be offered the subject.

When the pressure was run up to 4" the subject could not even get his feet into the garment. Also, subsequent runs at 3" and 2" did not permit subject entry with the prevailing suit and donning rack design. Throughout these efforts and the successful 1" entry and exit the subject was asked to identify the difficulties he encountered so that modifications could be made prior to the system tests. Based on these comments, the following suit related conclusions were reached.

- Add stiffening rings at suit terminus of tunnel
- Add knee and arm rings to provide a target for the man entering the suit.
- Reduce friction between undersuit and rubber boots.
- Replace slippers with heavy socks. The bulk of the slippers impeded operator entry into the suit.
- Attach helmet support yoke to outer suit so that subject enters the suit with no yoke on and comes up underneath the yoke, already affixed to the outer suit, as part of the suit donning process.

These alterations were made, incorporated in the suit, and another run scheduled. The second series was run at pressures of ½", 1", 2", 2½", and 3" (3" for exit only).

At ½" the entry time was 120 seconds and the exit time 50 seconds. Entry is defined to include the time required for the subject to traverse the hard tube, don the outer suit and step away from the donning rack. Exit is the converse of this process.

It was noted during this run that the Velcro used for holding the gloves was ineffective and it was replaced by hooks and eyes for the subsequent 1" run. At a 1" differential pressure 56 seconds were required for entry and 78 seconds for exit. During this trial, the subject observed that the positioning of the glove hooking mechanism was poor.

At 2", the subject required 104 seconds to enter and 120 seconds to exit the chamber. At 2½", entry required 105 seconds, but the subject reported that it was difficult to pull away from the hard tube. The pressure was then raised to 3" and the subject attempted to exit. At this pressure the subject had great difficulty. Ultimately both glove rings came loose and it was necessary to depressurize the chamber to permit exit of the subject.

This test provided experience and confidence to the subject in pressurized operations and also indicated to test personnel that it was clearly not possible to run the system tests under more than a 2" pressure.

Suit-System Tests 3

The Integrated Test Plan described a 6 run test comprised of 1 ambient run and 2 pressurized runs in each of the undersuits. The original intent in having the ambient trials in the test was to provide subject familiarization with system operations, particularly with the mechanics of entry and exit. Since the entry-exit tests had been added to the Phase I test program to establish operational pressure limits, and to provide operator experience, and since these tests preceded the system tests, the ambient pressure runs were eliminated.

The air cooled tests were set up initially at input flow rates of 10 to 12 cfm with approximately equal exhaust flows. These values had been given high comfort ratings in the undersuit tests and the intent of the system tests was to establish the best possible life support conditions for the subject and then vary them only--if requested by the subject.

Both air cooled trials were run at a differential pressure of 2" H_2O. The first of the water cooled runs was at a pressure of 1" H_2O and the second run was at 2" H20 pressure with a short increase to 4" during the course of the trial. The 1" run and the check at 4" served to augment the data of the entry-exit tests and the 2" run provided data for comparison with the air cooled runs.

The water cooled trials were run at an inlet cooling fluid temperature of 68°F. This was between the optimal value indicated for the resting and exercising conditions during the undersuit tests. The flow rate of the available cooling unit was approximately one pound per minute.

The test routine for the system tests was as follows:

1) Subject donned undersuit, entered chamber, and finally donned outer suit.

2) Subject was administered SAS item IV (a) (ENTRY), followed by SAS Section I (COMFORT) via the communications system.

3) Subject was then directed to walk the length of the chamber twice, bend at the waist ten times, climb and descend a ladder three times and perform ten deep knee bends.

4) Subject was then administered SAS Section II (MOBILITY), followed by Sections I (COMFORT) and V (c) (COMMUNICATIONS)

A single subject was used for all tests. The subject was a male, in good health, height 69" and approximately 165 lbs. in weight.

Overall, the system tests showed that both undersuits performed satisfactorily. The only unsatisfactory ratings (SAS rating = 1) given during the tests regarded the donning rack, background noise level (with water cooled suit), chamber speaker performance, and in one instance, cooling of the head and face.

Comfort 3(a)

Figures 64 and 65 shows the results of comfort ratings taken during the system tests. For ease of reference the points representing the ratings for each run have been joined by coded lines. Figure 64 shows the results of the eight sets of comfort ratings taken during the tests.

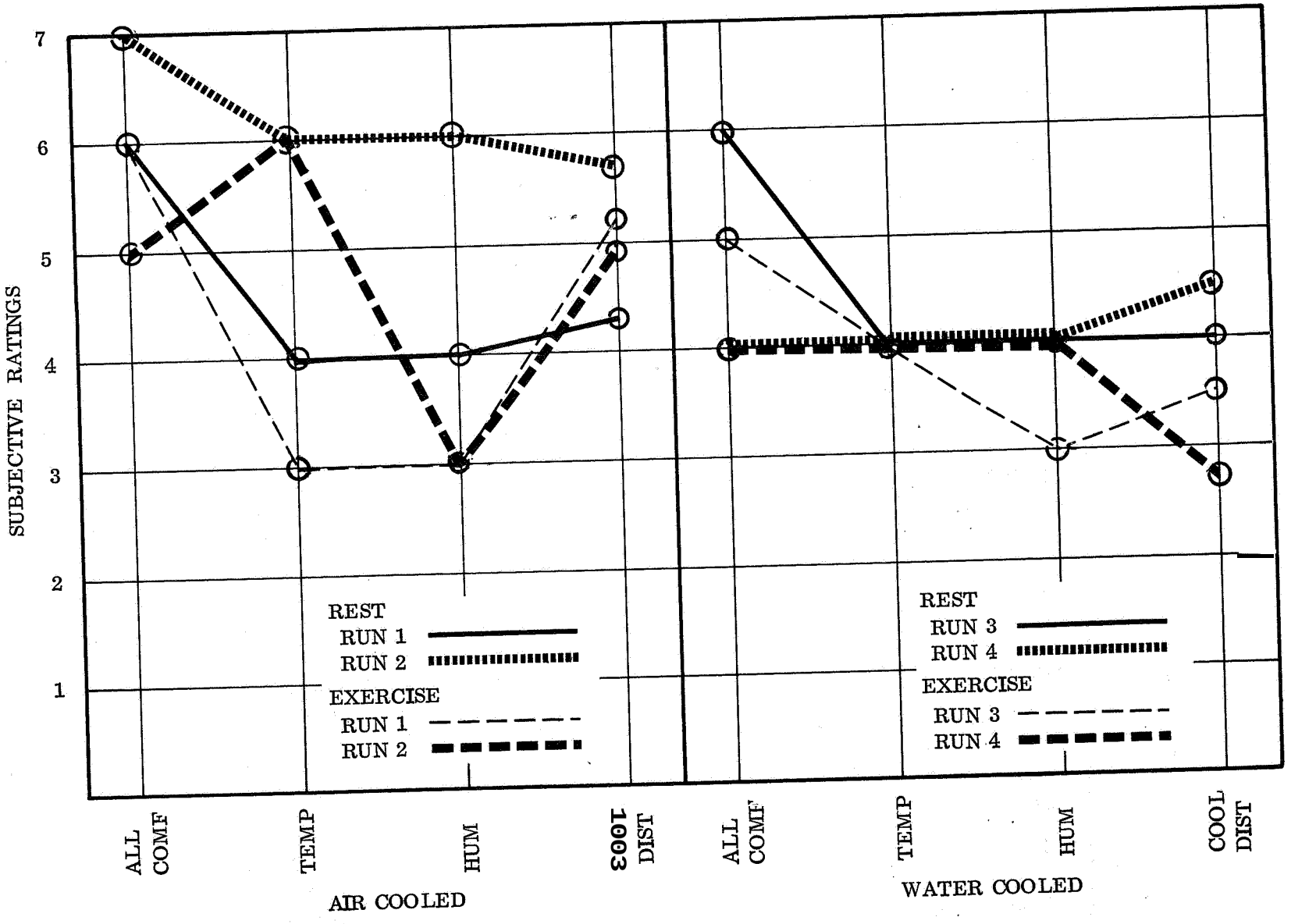


Figure 64. - SAS Comfort Ratings - Individual Runs

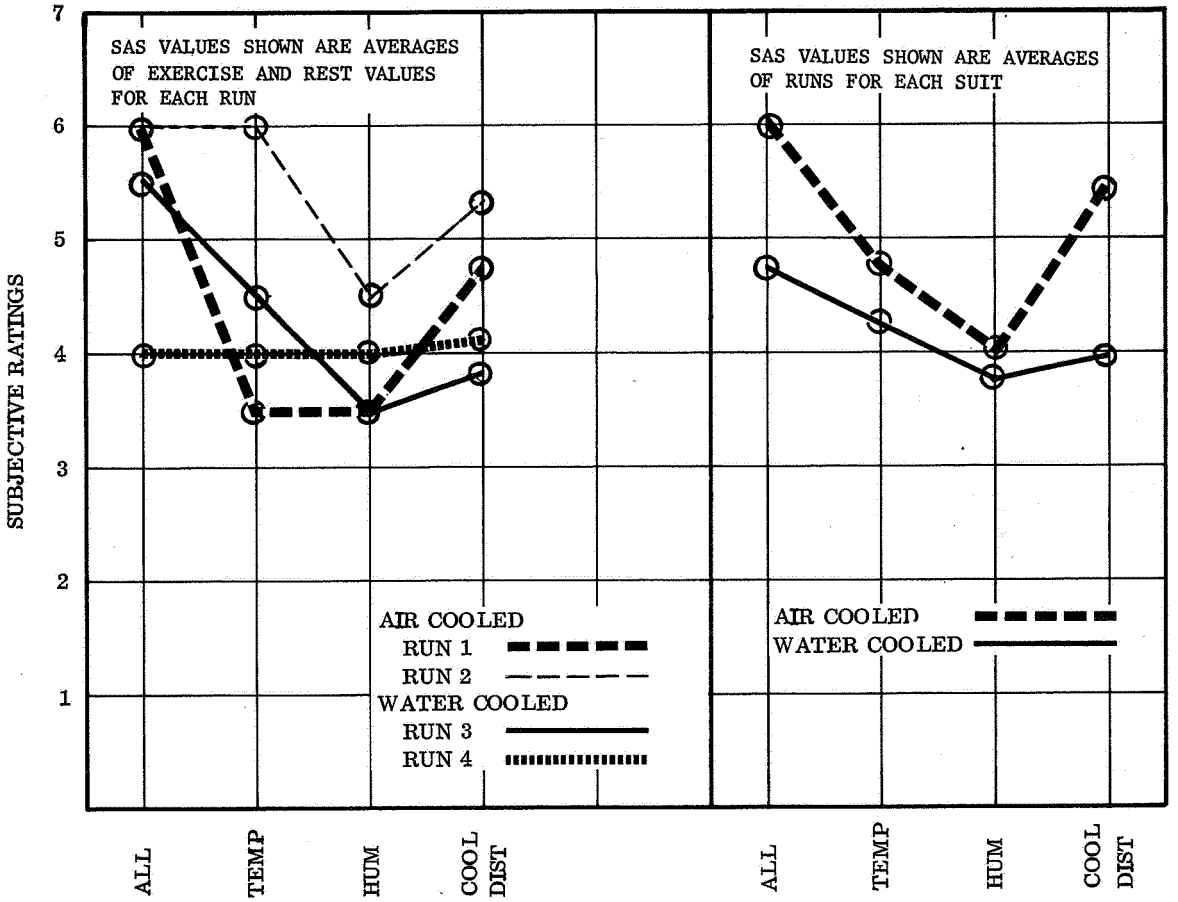


Figure 65. - SAS Average Comfort Ratings

It should be noted that the cooling distribution rating represents an average of the six cooling distribution questions asked. The left side of the graph shows the air cooled runs, with both resting and exercised conditions represented. The right side of the graph shows the analogous information for the water cooled undersuft. It is evident from these graphs, as might be expected exercise values have lower ratings than the correspnnding resting values. The left hand graph in Figure 65 shows the averaged comfort values for all four tests, and the right hand graph combines the air cooled and water cooled data for both runs. Examination of these graphs clearly shows the perceived comfort superiority of the air cooled undersuit; It should he noted that this occurred even though the water cooled data included run #3, at a differential pressure of only 1". If anything, this should have biased the data towards the water cooled suit, It should also be noted that for both air cooled undersuit runs the subject requested additional air flow during the course of the test. During run #1 the input flow was raised from 10 to 16 to 20 cfm and during run #2 from 12 to 16 cfm.

Mobility 3 (b)

Subject mobility in the water cooled suit was superior to mobility in the air cooled suit as can be seen from Table XXX. Both were satisfactory, but the water cooled suit was rated higher by the operator.

Entry-Exit 3(c)

Entry ratings as shown in Table XXX indicated that both undersuits were good in this respect and essentially equal in ratings. Exit ratings showed that the water cooled suit had a one point edge on the SAS over the air cooled suit. This was probably attributable to the fact that the water cooled suit was less bulky than the air cooled suit and that the water cooled suit had a slick exterior as opposed to the air undersuit's neoprene outer layer.

Entry-Exit times for the four runs were as follows:

Run#	P	Type Undersuit	Entry Time (Sec)	Exit Time (Sec)
1	2"	A/C	63	165
2	2"	A/C	90	75
3	1"	W/C	75	53
4	2"	W/C	58	115

TABLE XXX SYSTEM TEST RATINGS

		WALK	BEND	CLIMB	SQUAT	N=4 M		N=6 M
MOBILITY	A/C	2.5/5	5	5	5	4.7		
	W/C-4*	4/7	7	6	7	6.4		
	W/C-3**	5/6	6	4	6	5.4		
		ENTER	POSITION	DONNING	OFF RACK			
ENTRY	A/C	6	6	6.3	7	6.3		
	W/C-4	7	7	6	6	6.5		
	W/C-3	6	7	7	6	6.5		
		ON RACK	DOFFING	ENTER TUNNEL	EXIT			
EXIT	A/C	1	4	5	6	4		
	W/C-4	1	6	6	7	5		
	W/C-3	1	7	7	7	5.5		
		INTEL.	VOL.	BK. NOISE	XDUCER LOCATION	XDUCER SIZE	CHAMBER SPKR	
COMMO	A/C	7	7	6	7	7	1	5.8
	W/C-4	5	5	3	7	7	1	4.7
	W/C-3	3	3	1	4	4	1	2.7

LEGEND

* $\Delta P = 2''$ For Run 4
** $\Delta P = 1''$ For Run 3

These times suggest the superiority of a water cooled under suit over an air cooled undersuit insofar as entry and exit are concerned. In addition to the factors already mentioned, the fact that one of the water cooled runs was at a pressure of 1", and that some learning probably occurred, which tended to bias the data in favor of the water cooled suit.

Communications 3(d)

Communications ratings favored the air cooled undersuit. The reason for this was that the subject requested large rates of helmet air when in the water cooled suit. The difference in flow rates was sufficient to degrade reception in the helmet due to high air noise.

The subject requested far more air for the helmet than was needed for breathing when in the water cooled suit, No doubt, to some extent, this air aided in facial cooling. In general, the subject expressed a desire to feel air blowing over his face, above and beyond meeting breathing air requirements.

Subject Comments 3 (e)

By and large, subject comments were compatible with the ratings given. During all runs, as can be seen from Table XXX, the subject gave two values for each walking rating. The top rating shown in the chart was for initial conditions before the tunnel was pulled away from the hard tube by the reefers. The second, and higher, value reflected a walking rating after the tunnel had been pulled away from the hard tube. This is because once the tunnel has been pulled away from the hard tube, the tunnel closed on itself and the subject no longer experienced the axial force (relative to the hard tube) which had previously impeded him.

It was noted that during run #3 the subject had some difficulty in ladder climbing. Both the excess suit material, and the supply hoses tended to impede such movement.

The subject made the observation that there was not much difference between experiencing the one and two inch pressures environments. Overall, he felt that a one inch pressure would provide an ideal working environment, but that a 2" pressure was acceptable.

The short excursion to a 4" pressure in the water cooled undersuit permitted the subject to comment that pressure effects in the air cooled and water cooled undersuits were essentially equivalent. The 4" pressurized experience in the air cooled suit was obtained in an earlier informal test, in which the chamber was raised to a 4" pressure after the subject had entered at a lower pressure.

Reefing 3(f)

There were no separate formal reefing tests as specified in the Integrated Test Plan because it was first necessary to observe the effect of overpressure on the tunnel. Upon making these observations, an attempt was made to reef the tunnel manually through the hatch hard tube. This was found to be impossible and indicated that reefing had to be accomplished within the chamber. Trials were made consisting of manually reefing the tunnel on the in-chamber portion of the hard tube'. The times required for two reefers to reef in the fully extended 20' tunnel under pressure were recorded as follows:

$\Delta P = 2''$: 380 sec; 210 sec M = 295 sec or 4.9 min.

$\Delta P = 1''$: 160 sec or 2.7 min.

It was apparerent that the difficulty of handling the tunnel material and reefing went up as the pressure increased. However, the fact that the material could be successfully reefed manually at 2.0" pressure supports the idea that a mechanical means of doing this can be devised.

8.4 IMPLICATIONS FOR PHASE II BISS

The implications for Phase II BISS were twofold: one, several discrete design problem areas were identified which required special attention in the Phase II design effort, and secondly, the basis was provided for making a final undersuit selection.

The specific problem areas which were highlighted for Phase II were:

- Inadequacy of the donning rack, particularly with regard to ease of attachment of outer suit to it.
- Inadequacy of the chamber speaker system.
- Reefing and development of a reefing mechanism.

The other facet of the system test conclusions was the air cooled - water cooled undersuit decision. To summarize, the air cooled undersuit was superior with respect to subject comfort ratings and communications ratings. The water cooled suit looked better regarding entry-exit and mobility ratings. Both suits performed satisfactorily and both had strong and weak points. Therefore, the decision to select the air cooled undersuit was made largely on the basis of support equipment considerations, i.e., a less complex device was required to cool air than water and

secondly, an independent breathing air supply was not required. It was also believed that design improvements could be made in Phase II to the air cooled undersuit to enhance subject mobility.

8.5 PHASE I TEST CONCLUSIONS

As a result of the Phase I testing the following equipment-oriented conclusions were developed.

8.5.1 Outer Suit

The outer suit must have relatively straight fit up and down the front so that the overpressure will not compress excess fabric causing forces which inhibit the operator's limb movements. The implication of this is that the BISS outer suit cannot be too deviant from a relatively form-fitting garment and that an adjustment strap is required for the small amount of deviance that may exist between operators. This adjustment strap should be in the waist-to-crotch area.. The further inplication is that the operators selected for the ultimate BISS system will have to be rather homogeneous in physical dimensions.

The chamber overpressure compresses the outer suit as it hangs in the donning rack. -This makes entry very difficult, especially the initial search for the legs by the operator. The thigh portion of the outer suit has to be stiffened (as was accomplished by rings in Phase I) in order to facilitate suit entry. In addition, stiffening rings are helpful in the arms of the outer suit, (also added in Phase I). Finally, the interface of the outer suit and tunnel requires two relatively close stiffening rings to permit a good tunnel/outer suit-hard tube interface for entry and exit. This was also added in Phase I.

The original concept had the operator entering the outer suit while carrying a helmet mating ring attached to his shoulder harness (yoke). He had to mate the ring with a matching helmet ring for positive support of the helmet. It was found that this mode of operation inhibited easy passage of the operator through the hard tube and that the ring mating was a difficult task because of the tolerance required, the compression of outer suit material in the ring interface area, and the generally limited visibility afforded in the task, For these reasons the helmet, helmet neck ring, and shoulder harness should be part of the outer suit. This requires that the operator enter the shoulder harness and helmet as a unit and thenattach adjustment straps for snug fit. Modification of the Phase I mock-up confirmed this improvement.

The shape of the BISS helmet and its material will be important to operational efficiency. If the helmet is too close to the ears of the operator, it will provide for too much sound reverberation and if the helmet possesses too much flexibility it will add to the noise level because the material tends tovibrate with sound. An evaluation of the Apollo helmet made of relatively thin Lexan, as compared to the plexiglass tube-shaped helmet, has revealed these facts. Moreover, the shape of the helmet is important in determining how the air supply is channeled about the interior of the helmet and baffling is required to direct the air flow toward the operator's face (discussed later in this section).

The use of a properly-designed donning rack is vital for satisfactory entry to and exit from the BISS outer suit. Moreover, the manner in which the suit is held and oriented for the operator is critical to the donning operation effectivity. Positive, but quick disconnects are required for the helmet and the four extremities. At the same time, the tunnel-suit interface must fit properly with the hard tube through which the operator exits and enters.

The difficulties of entry and exit operation are very pronounced as overpressure is raised in the chamber. Every chamber-suit operation is practicable at two inches of water pressure, or less overpressure, but difficulty of entry, exit and reefing operations goes up sharply as the pressure is raised from 2 inches to 4 inches of water pressure.

The use of a boom for support of the tunnel is necessary. This takes the load of thetunnel and life support hoses off the suited operator and allows the tunnel to collapse under overpressure in a relatively uniform manner.

8.5.2 Undersuit

The exterior surface of the undersuit must have a low co-efficient of friction to permit easy entry to the outer suit in the outer suit/tunnel/donning rack interface. This requirement poses some difficulty in that the air-cooled undersuit must have elasticity, which usually means use of a rubber material. Since rubber generally has a relatively high coefficient of friction, the use of a talcum powder or silicone spray may be required.

The open-cell foam in a life support garment has been shown to be extremely satisfactory. This fact is emphasized because it represents the effectiveness of one of the developmental items for **BISS,** not common to other suit programs. A satisfactory undergarment that is both comfortable and efficient in life support is especially important to optimization of **BISS** work cycles and operator work effectiveness.

The fit and hygiene aspects of the undersuit imply that the garment must be a personal garment, fitted to the wearer and worn by no other individual. For the air-cooled undersuit the operator should also wear "long john" underwear to act as the first absorber of skin slough and sweat, and to act as a skin-comfort layer. The use of this underwear will permit ease of laundering and reduce such requirements on the undersuit. To accommodate the donning of the undersuit over the underwear, the innermost layer of the undersuit must also have a low coefficient of friction.

The air-cooled undersuit must act as the interface with the life support gear and the communications equipment. In consonance with the desire to keep all heat-sensitive gear from being attached into the outer suit, the undersuit should be used to transport the required equipment into and out of the outer suit. This objective is supported by the finding that the life support plenum and the speaker/microphone are best located on the undersuit for efficiency in use. The nature of the undersuit requires direct interface with the life support plenum for maximum efficiency. Mounting the speaker/microphone in the neck/chin area of the undersuit provides good efficiency, easily accommodates body movements, and does not obstruct vision.

The air-cooled undersuit used for the Phase I mock-up was made of 1/16 inch neoprene rubber, to which a very thin layer of dense foam was bonded, with 1/4 inch thick open-cell foam (10 pores per linear inch) on the inner-most surface. The suit was fashioned on the general lines of a SCUBA suit with a long torso zipper and a short zipper at each extremity, to facilitate donning and doffing the suit. The mock-up study demonstrated that the relatively close fit of the suit was too restirctive and that while the Phase II suit must also be form-fitting, it should be lighter and not as snug fitting. The 1/16 inch neoprene is too heavy and can be replaced by neoprene as thin as 1/64 inch to retain elasticity while reducing weight.

8.5.3 Tunnel and Hatch

Simple, manual reefing through the hard tube is impossible. Moreover, no very simple method of reefing appears practicable. While manual reefing of the tunnel onto the hard tube in the chamber has been repeatedly accomplished under a variety of overpressures by two men, the manner by which this can be accomplished mechanically is not simple.

A means is required to prevent the tunnel from being pushed by the overpressure into the hard tube. This was accomplished by putting a "piston" into the hard tube after the operator entered the outer suit. This close-fitting object is placed at the chamber end of the hard tube so that the tunnel is not pushed into the tube as the operator walks out into the chamber and the tunnel collapses behind him. The smooth, rounded surface of the piston also provides some spreading effect as the tunnel is reefed back onto the hard tube.

The hard tube is necessary to facilitate entry to and egress from the outer suit and acts as an interface with the outer suit as it is held in the donning rack. While the mock-up study uses a circular hard tube, the ultimate tube should have parallel sides with semi-circular ends, much like a standard watertight door in ships. At the outside of the chamber the hard tube can be flush with the chamber, but on the inside of the chamber, the hard tube must be of a length sufficient to permit reefing of the tunnel. After the tunnel collapses behind the suited operator, mobility of the operator in the chamber is good, regardless of overpressure.

8.5.4 Life Support

The suited operator must have the sensation of a cooling effect in the helmet. It is not sufficient that the operator is simply fed cooling and breathing air in the helmet, he must be able to feel this air blow across his face. This sensation of air flow appears necessary for psychological comfort and a sense of "real" cooling. Having the knowledge of cooling/breathing air being available is apparently not enough.

Within limits, the undersuit exhaust system appears to be paramount in importance. for comfort, more so than the temperature of the cooling air. That is, changing the cooling air temperature from 70°F to 65°F does not appear to effect a cooling sensation for the operator as much as changing the exhaust flow from 5 cfm to 10 cfm. This became apparent soon after the fact that the subject began to ask for increased exhaust flow rather than cooler air as work load went up.

Humidity "control" in the form of a definite humidity range requirement is necessary to prevent lip drying. This was evident in the use of both the water-cooled and air-conditioner life support systems, (Phase I solved the air conditioner system problem by putting humidity into the air supply).

8.5.5 Monitoring

Respiration measurement by means of a cardiac microphone placed on the operator's chest is unacceptable. The respiration communication is drowned out by speech and body movements of any sort. The signal is audible only when the operator is standing very still and quiet. Therefore, this method is extremely limited and useless for BISS goals.

The suited operator's verbal remarks are more useful for life support purposes than is any feedback in the form of displays. The verbal remarks reflect real time information while the displays require time to reflect changes in the system. For this reason verbal communication becomes primary as a source of work information, life support information and requests, and safety information.

8.5.6 Communications

The original concept of the use of a sfngle channel to and from the in-chamber operator is unacceptable. This is important because it has been shown that the sound levels required in the helmet and at the test conductor's console are different, and because a dual channel cuts down on the need to repeat messages while aiding in rapidity of information processing and understanding. Duplex communication is not especially necessary for other channels (e.g. test conductor to life support console operator).

The in-chamber speaker is a satisfactory back-up for regular operator-test conductor communications. Experience with this form of back-up has indicated that the suited operator can use information from such a speaker in the event his primary communication system fails. However, such a back-up is only a temporary measure and requires that the regular communications channel be repaired as soon as possible.

The shape of the helmet is important to good communications. Helmet shape can affect reverberation and produce poor understanding of information. Moreover, the material from which the helmet is made is important, in that a material that has too much flexibility tends to act as a vibrating membrance and increases reverberation.

8.6 PREPARATION FOR PHASE II MOCK-UP TESTING

8.6.1 Suit Procurement

Using the qualitative data cited in the first oral presentation report, selected quantitative data, and relying heavily on detailed observations and critiques from mock-up study personnel, the procurement specifications for the inner suit and the outer suit/tunnel were written. The helmet requirements were not written as a formal specification, but rather as a dimensional and shape requirement. The helmet procurement was handled in this manner because continuous contact had been maintained with Airlock, Inc., Milford, Conn., and from this contact and samples of their helmet products, it was possible to procure their services and be assured of the quality of the end product. The following illustrations show two aspects of the helmet procured. The side view of the helmet has been shown in Figure 23. The innermost layer of the helmet is actually a Lexan "bubble". The rear portion of the bubble is covered with fiberglass which extends down to form the shoulder yoke. The mating clamp contains two bolted connectors, allowing the outer suit to be clamped down after being bonded to the fixed portion of the clamp. The 1/2 inch thick foam which was bonded to the shoulder yoke and also to the inner rear of the helmet has been shown in Figure 24. The purpose of the latter foam is to act as a protective pad as well as to attenuate reverberation in the helmet.

The contract for the inner suit and the outer suit/tunnel was let to B. Welson, Inc., Hartford, Conn.

Experience gained from Phase I indicated that it was not convenient to suspend the air supply/exhaust plenum on the inner suit. For this reason a beited plenum was procured from Airlock, Inc., the same firm which has vended the helmet. Figure 66 shows the waist plenum. The ports on either side are for air supply and exhaust, while the front belt contains Velcro and is pressed together around the waist of the wearer to form a snug fit. The air supply portion of the plenum will connect to the five hoses which supply air to the four extremities for cooling and the neck manifold for breathing. The exhaust side of the plenum will interface with a cone in the waist of the undersuit to insure adequate return flow from the suit.

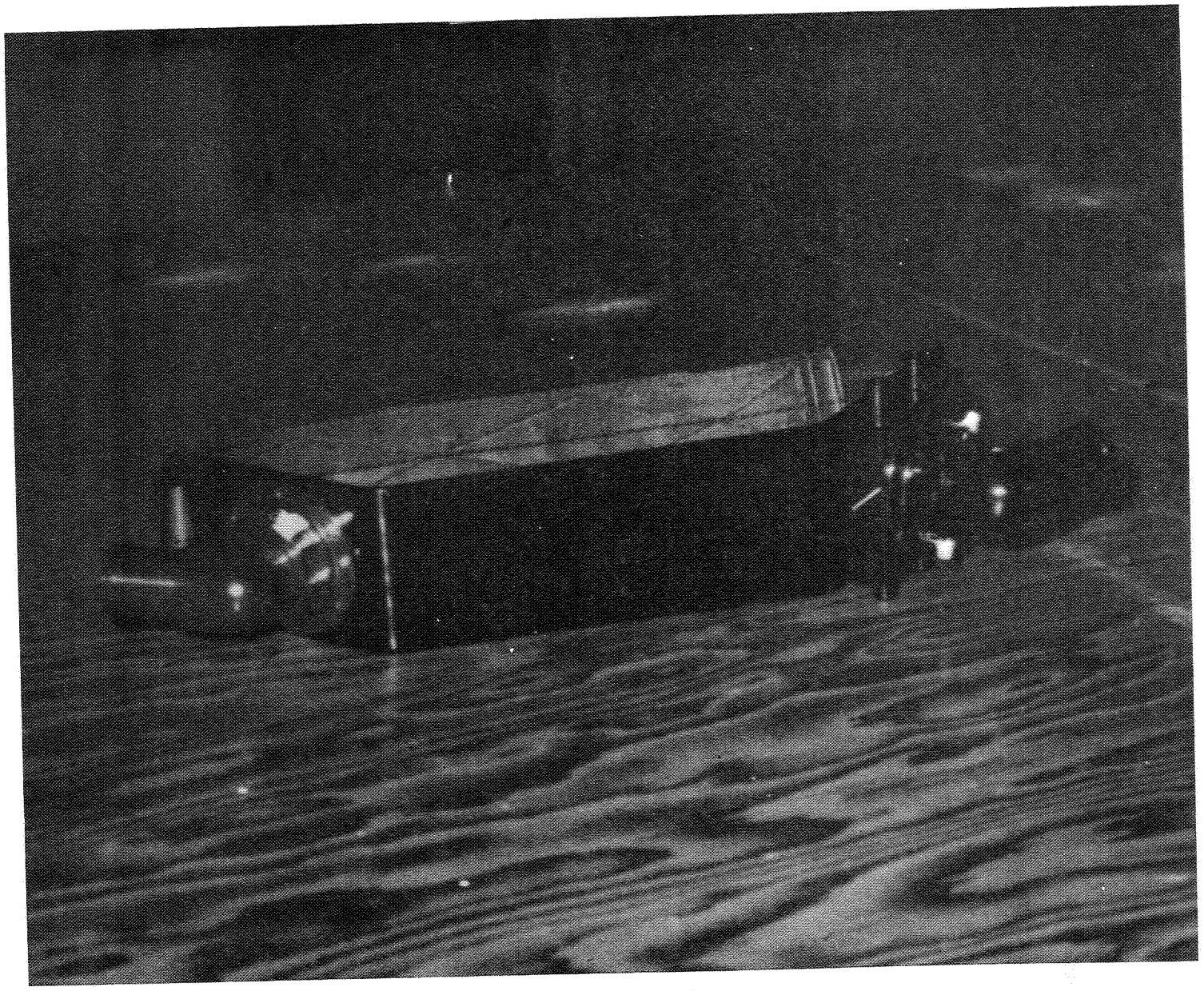


Figure 66. - Belted Waist Plenum

8.6.2 Support Equipment

The chamber used for BISS mock-up testing had to be refurbished and revised for two reasons:

- The chamber had to be vacated between Phase I and II to allow other programs to run engineering tests, and
- The results of Phase I indicated the need for more sophisticated support equipment for the formal runs of Phase II.

Figure 67 illustrates the new supporting equipment necessary for running Phase II tests. The donning rack was improved as a result of Phase I experience and the support structure was improved for safety and efficiency.

Special attention was given to the redesign of the donning rack because of its importance to efficient entry and exit to and from the BISS suit. Accordingly, the specifications for procurement of the Phase II suit had provisions in them for efficient interface with the donning rack requirements.

Other minor revisions were also accomplished. The hard tube was shortened on the exterior portion of the hatch to be flush with the hatch. The outside surface of the in-chamber part of the hard tube has been made more slick by use of epoxy enamel paint. This process will facilitate reefing.

Figure 68 illustrates the Assembly Test Object which was designed and fabricated to enable testing of hand tool work by the suited/unsuited operator. The object includes several kinds of electrical connectors of different sizes, bolts, and screws of varied sizes and kinds. The operator performed representative tasks which enabled a comparison of assembly/disassembly efficiency in both the suited and unsuited conditions.

8.6.3 Life Support Equipment

The life support subsystem was re-designed, procured, assembled and checked-out. This subsystem incorporated all of the improvements derived from Phase I; subsystem checkout indicated a more than satisfactory capability on the part of the equipment to satisfy the operator's needs.

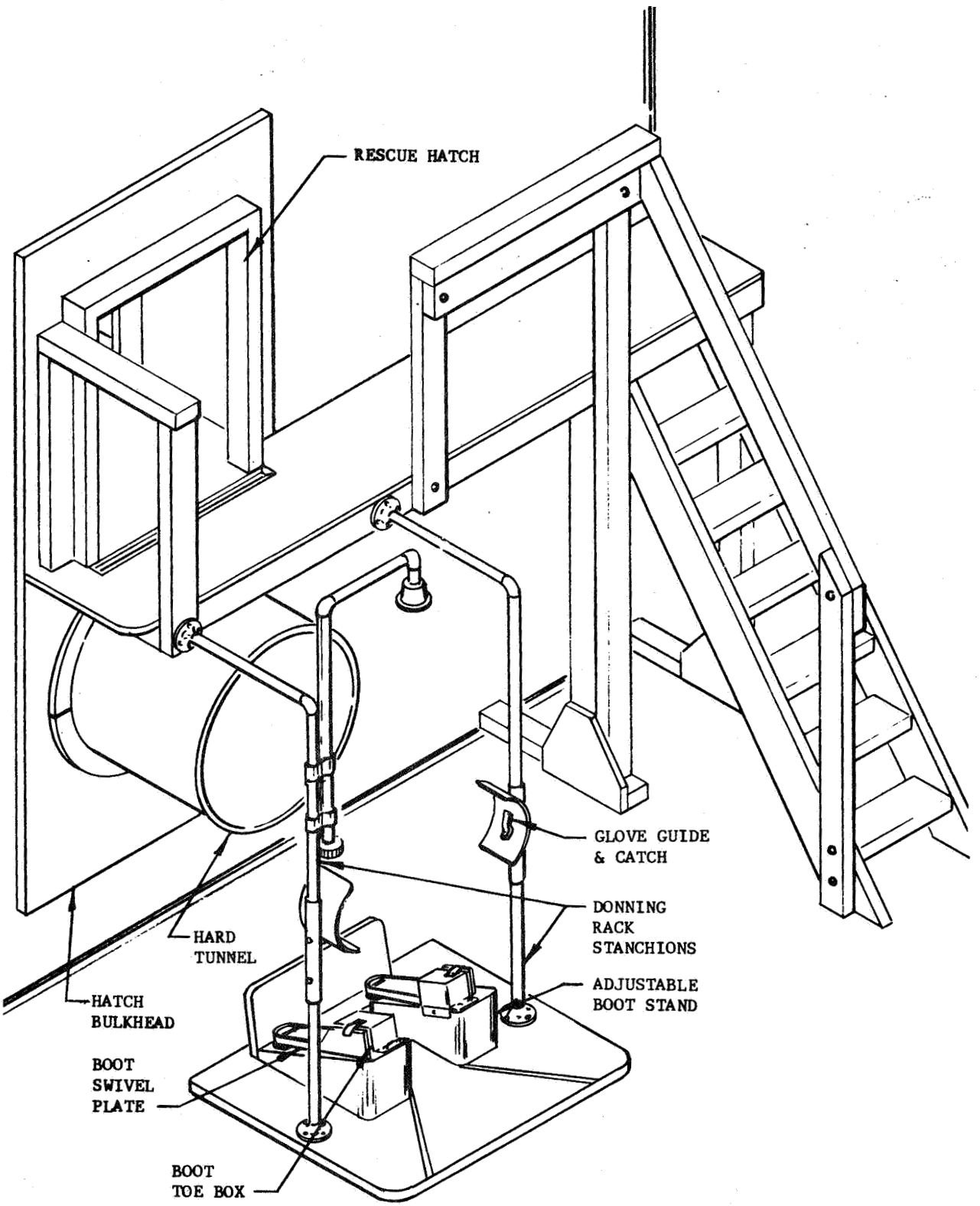


FIGURE 6.7 BISS DONNING RACK & CHAMBER SUPPORT EQUIPMENT

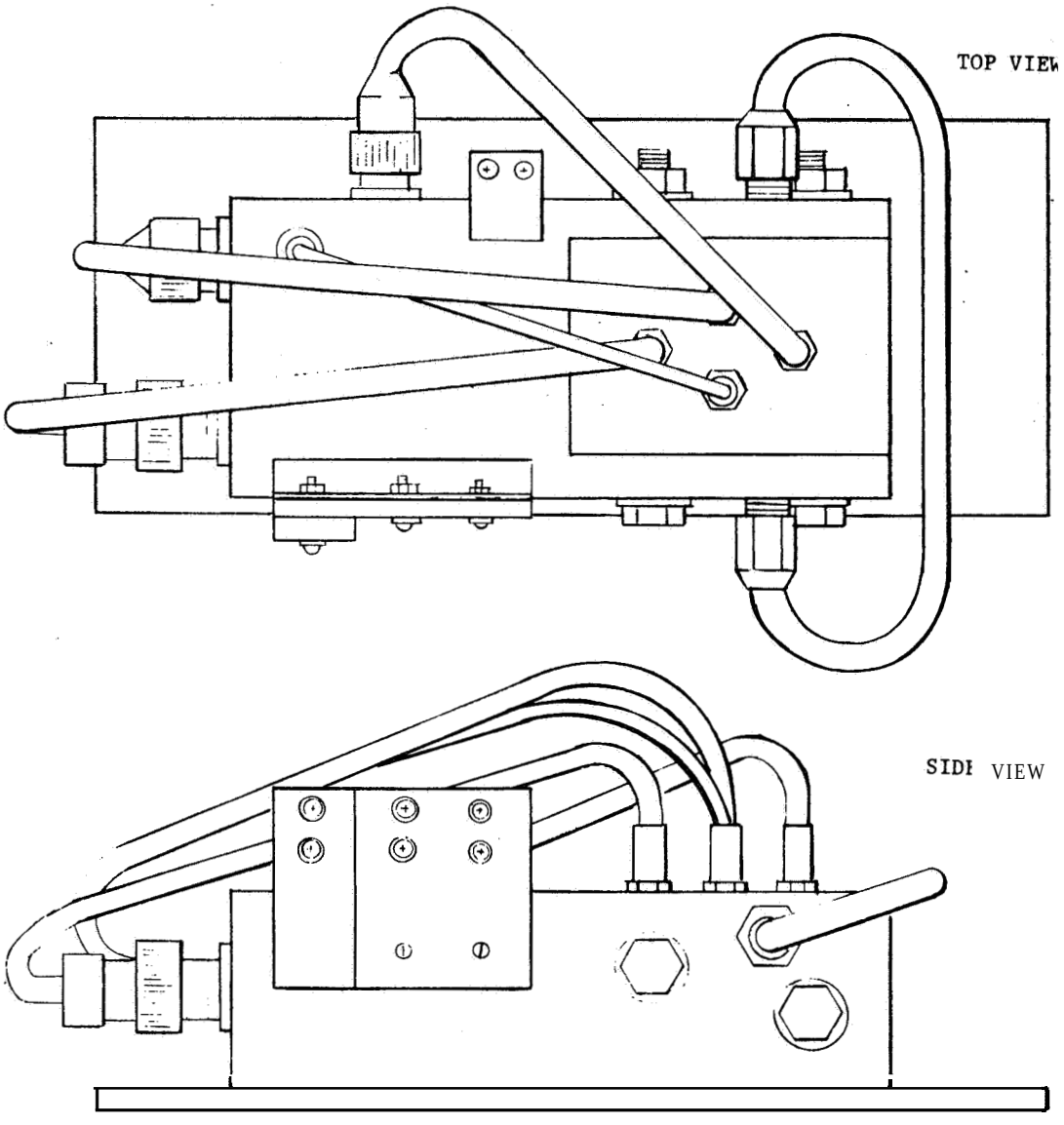


Figure 68 Assembly Test Object

8.6.4 Communications

In like manner, the communications subsystem was re-designed and procured. The equipment incorporated all of the experience gained in Phase I. Moreover, the suit specifications required precise interface hard points which accommodate the operator's equipment in the suit.

8.7 PHASE II TESTING

8.7.1 Purpose

The purpose of the Phase II mock-up testing program was to evaluate the performance of the second generation BISS. The first phase of the testing program was almost entirely exploratory and developmental in nature, as opposed to the goal of system evaluation put forth for Phase II. Another fundamental difference between the two testing efforts was in the number of subjects. Almost all Phase I tests were conducted on one subject, whereas four subjects were used in the Phase II program. Though four subjects is not a sufficient sample on which to make fine discriminations, some generality can be ascribed to the results obtained, unlike the case of Phase I where in most tests only one subject was used.

The Integrated Test Plan identified six explicit areas in the Phase II Program. These were: the taking of certain anthropometric measurements, and the performance of entry-exit, mobility, dexterity, communications and subject endurance tests. Implicit in all of these tests was the question of subject Comfort. In the early phases of the program when the Integrated Test Plan was written, it was proposed that each of the six areas would be assessed by the use of independent tests. However, reassessment of the Phase II Test Plan suggested that more realistic test results would be realized by performing the in-chamber tests in review, with the added advantage of obtaining a more valid reflection of subject endurance.

The principal evaluative questions to be answered by the Phase II test effort were:

- Can a man do useful work in a pressurized environment, outfitted in the BISS?
- Can a man perform in this environment for a four hour period?

The answers to these fundamental questions and the discussion of the supportive evidence developed as a result of each of the six areas of investigation presented in this section. Additionally, facets of the design which still require further development will be identified.

8.7.2 Revision of Integrated Test Plan

It was decided to consolidate the entry-exit, mobility, dexterity, and communications tests with the endurance run but anthropometric measurements still had to be conducted as a separate effort. It was also necessary to introduce a pressure tryout test for subject familiarization with the Phase II BISS. This tryout provided an

opportunity to completely familiarize the subjects with BISS pressurized operation and to provide data for making a final decision on the pressure level at which to conduct the endurance tests. Since two of the subjects were new and two had been under pressure during Phase I, the tryouts were scheduled so that one experienced man was with each of the inexperienced men during these first trials to advise them on such matters as entry techniques. All subjects made at least two pressurized entries and one pressurized exit during the course of the tryouts. In addition to the above, the tryout tests provided necessary information on last minute system modifications and adjustments (e.g., the positioning of the donning rack).

8.7.3 Endurance Test Sequence

The sequencing of events during the modified endurance test were as follows:

Approx Time (min)	Activity
000	Entry
005	SAS IV a (Entry)
010	SAS I (Comfort) & Vc (Communications)
020	Mobility Test
030	SAS II (Mobility)
035	Communications (Test Conductor to Subject)
065	SAS I (Comfort)
070	Assembly Test Object disassembly
100	SAS III a, b, c2 (Dexterity)
110	Rest
120	Mobility Test
130	SAS II (Mobility) & SAS I (Comfort)
140	Communications (Subject to Test Conductor)
170	SAS I (Comfort)

Approx. Time (min)	Activity
175	Rest
185	Assembly Test Object assembly
215	SAS III a, b, c1 (Dexterity)
220	Communications (Test Conductor to Subject via chamber speaker).
235	SAS I (Comfort) & SAS Vc (Communication)
240	Reef Tunnel
-	Exit
-	SAS IV b (Exit)

As can be seen, the subject was asked to make five comfort ratings during the course of the test. The mobility test was repeated twice and all three communication links were exercised by the test. Dexterity was assessed by haveing the subject assemble and disassemble the test object. Each subject also assembled and disassembled the Assembly Test Object in an ambient pressure environment, wearing normal work clothes. Entry and exit under pressure were also a part of the test and the appropriate SAS items were administered to the subjects immediately after execution of these maneuvers.

It should be noted that throughout the endurance test, the component tests were initiated at the scheduled times. If the activity was concluded before the scheduled time, the accompanying SAS appraisal was usually administered immediately afterward.

The Phase II test program, as modified, was conducted over a two week period in March of 1967. Each subject participated in three discrete suited test situations; the anthropometric measurements (ambient pressure), the pressure tryouts, and the endurance tests. Two of the four subjects, as will be discussed later, had to repeat portions of the endurance test.

8.7.4 Test Configuration

Figure 69 portrays the organization of personnel and equipment used for all Phase II pressurized tests. Four test personnel were involved in the communications link. The test conductor (Figure 70) was positioned

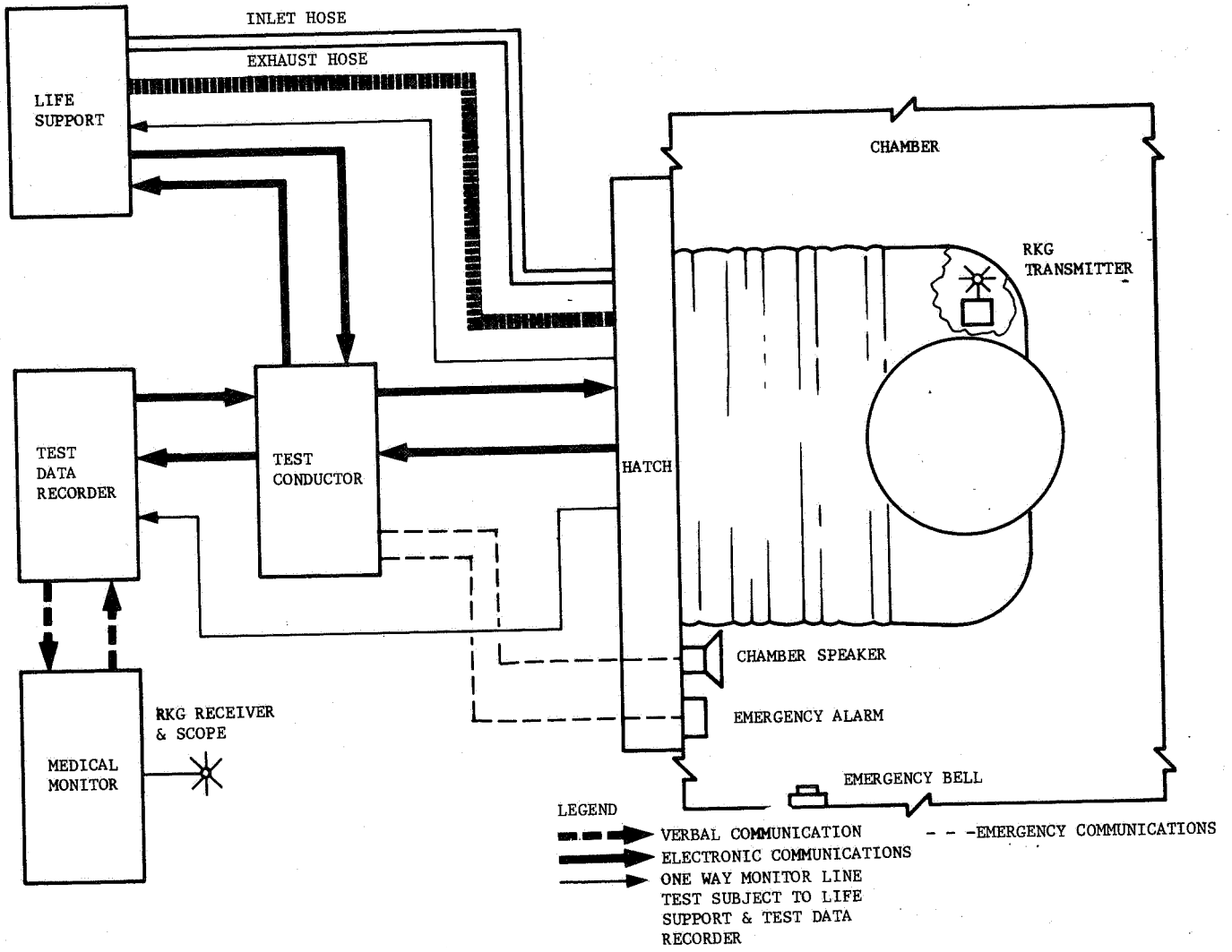


Figure 69 Organization of Personnel and Equipment for Phase II Testing

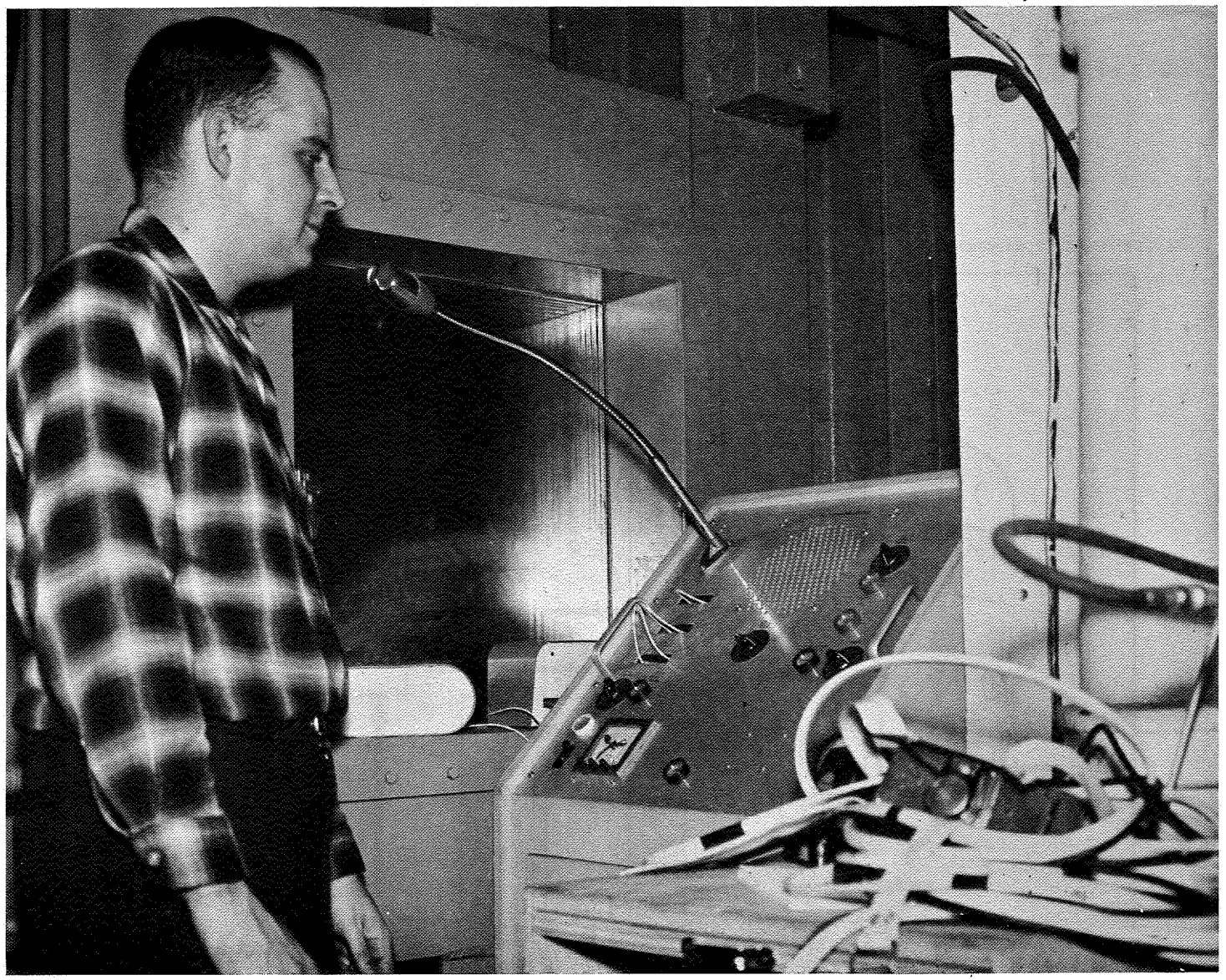


Figure 70. - Test Conductor's Console

at a window of the modified Tenney Altitude Chamber and maintained both visual and audio contact with the subject. The test conductor also had two-way contact with the life support operator and the test data recorder who was physically co-located with the medical monitor, and who relayed information to and from the test conductor. A minimum of two additional men were available in the chamber area for rescue and reefing operations.

A team of 6 men in association with the modified Tenney Altitude Chamber, the life support console, and the medical monitoring station, comprised the experimental framework by and in which the BISS was evaluated. Figure 71 shows the medical monitor/test data recorder station. The life support console exercised control over the subjects input air temperature, input and exhaust flow rates, and input humidity. It also provided a means of measuring the temperature and humidity of the exhaust air. The medical monitor ovserved the cardiograms of the subjects throughout the test. Sensors were placed on the subject and the signal transmitted by the small FM transmitter shown hanging from the subject's waist, The signal was received by the unit with the whip antenna and the pattern was displayed on the oscilloscope. Periodically, or when the subject showed signs of stress, the medical monitor made a permanent record of the cardiogram using a standard paper strip recorder. The other equipment shown on the table in Figure 71 was for the communications link.

In operation, the test conductor instructed the subject on a step-by-step basis throughout the tests. The medica1 monitor and life support monitor gave periodic status reports to the test conductor and also advised him immediately of any irregular or potentially dangerous occurrences. If the subject requested a change in life support parameters, the test conductor evaluated the request and passed his decision on to the life support operator.

The test conductor recorded event times and SAS ratings; the life support operator recorded life support console readings; and the data recorder comments from the subject. The visual observations were recorded by the test conductor since he was the only member of the team haveing visual contact with the subject.

The modified Tenney Attitude Chamber used during the Phase I tests was also used during Phase II. As noted in Section 8.6.2. The chamber was refurnished and the donning rack improved to provide more sophisticated equipment for the performance of the Phase II tests.

The Phase II outersuit and undersuit and the donning rack used during this testing period are shown in Figures 72 and 73. The BISS outfit occupied by a subject is shown under no pressure in Figure 74 and under 2" H_2O differential pressure in Figure 75.

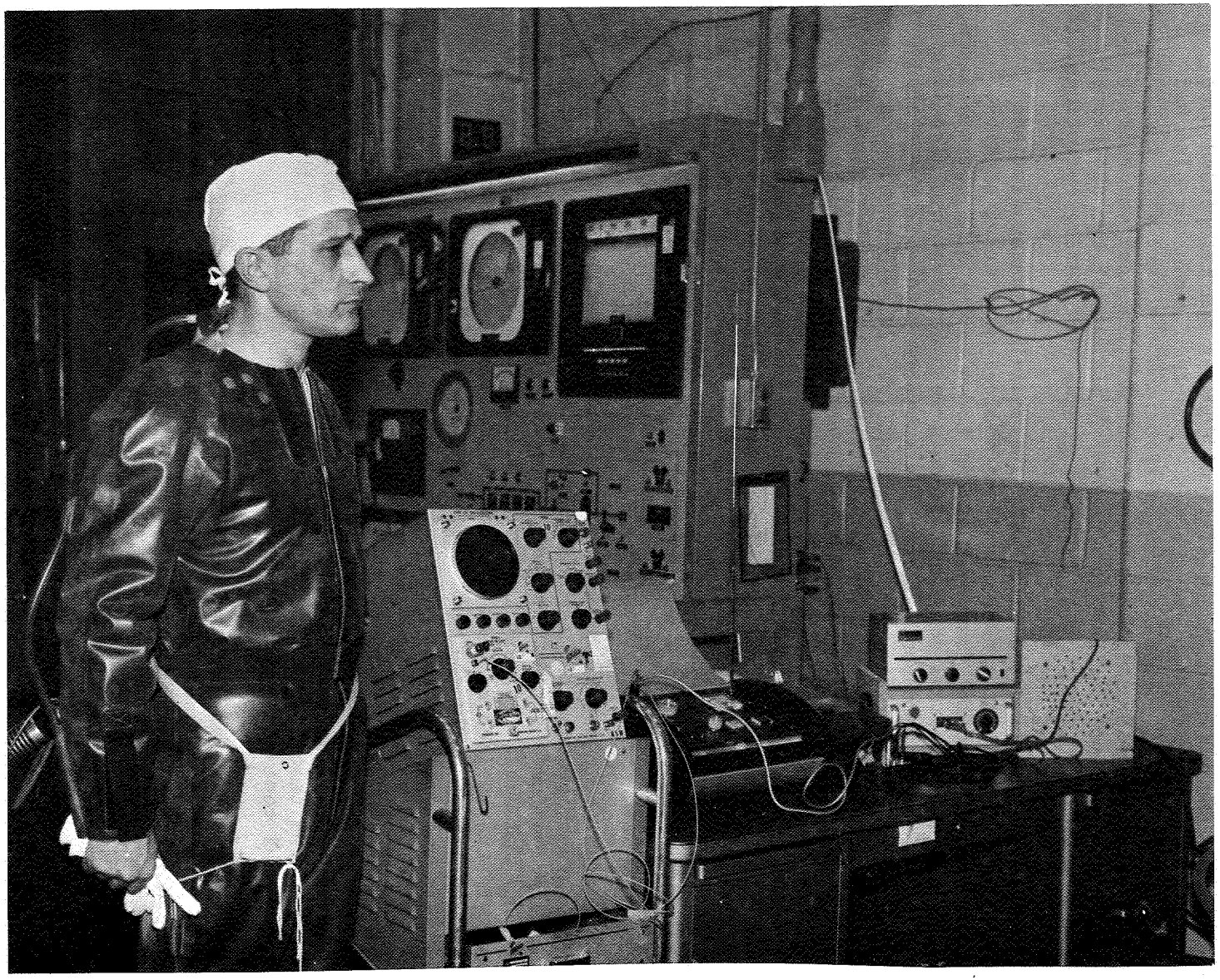


Figure 71. - Medical Monitoring Equipment at the Medical Monitor's Test Data Recorder's Station

Figure 72. - PHASE II Outer Suit Rear View Inner Suit

Figure 73. - Phase II Outer Suit Front View of Inner Suit

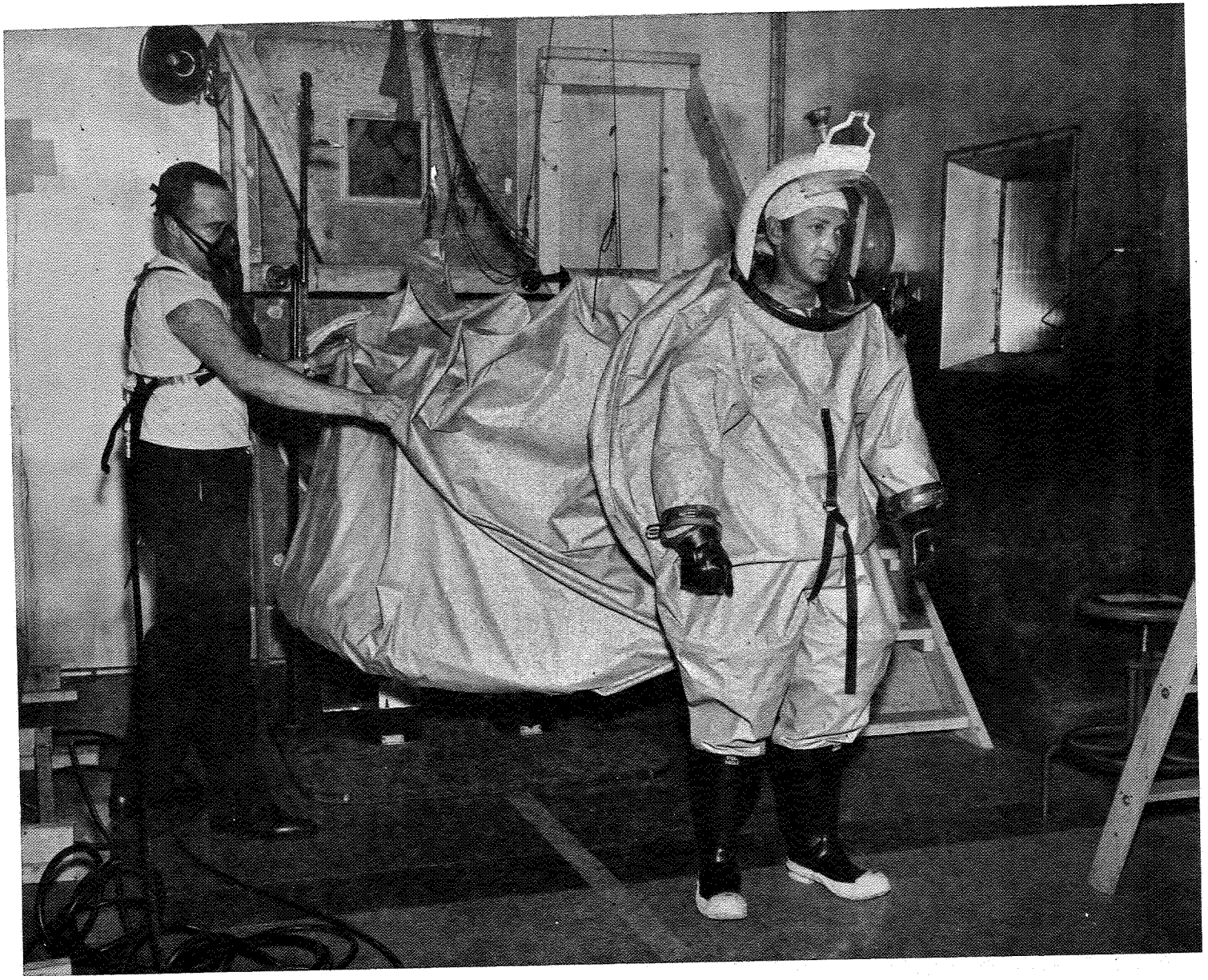


Figure 74. - BISS Differential Pressure - 0" Water

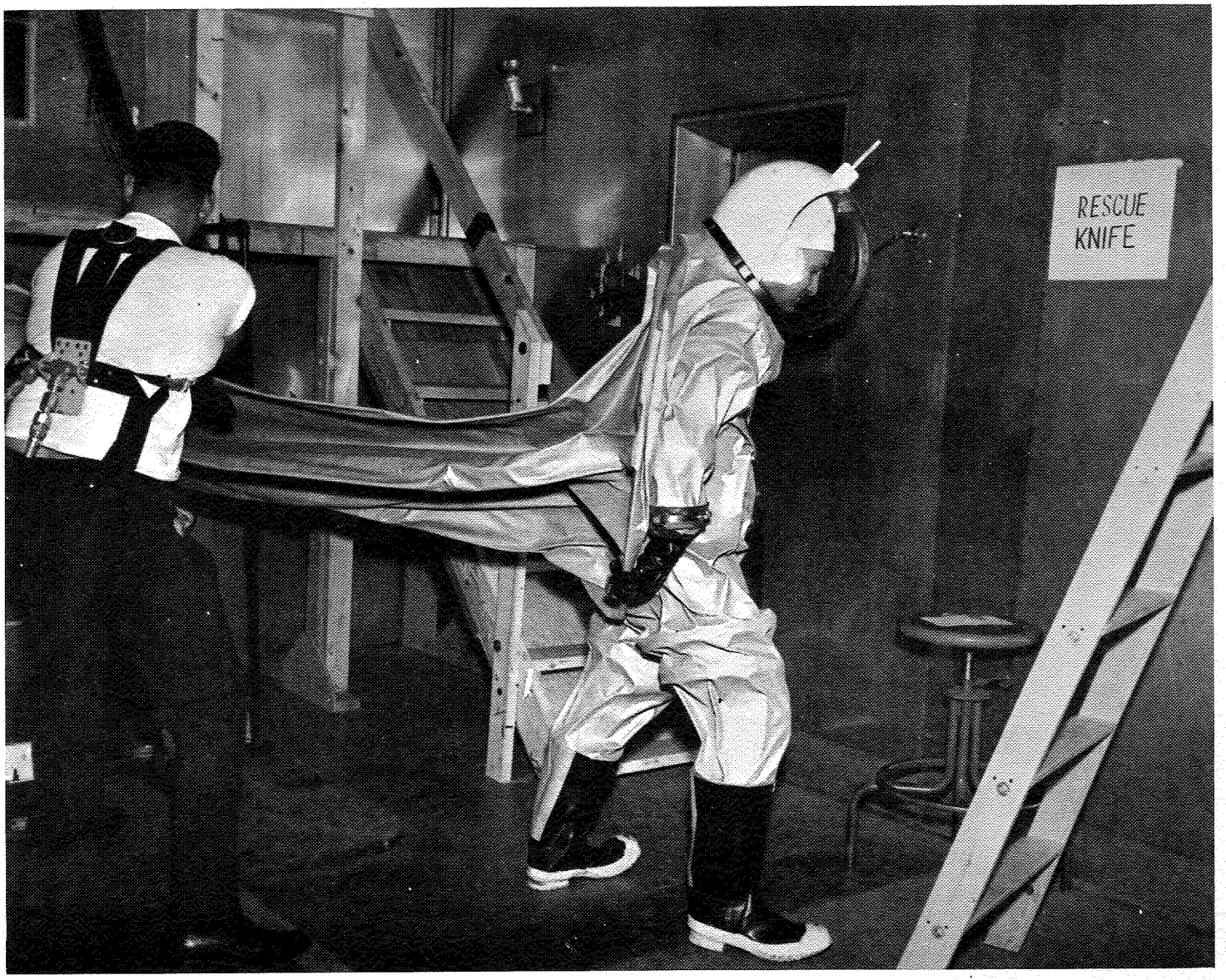


Figure 75. - BISS Differential Pressure, 2" Water

8.7.5 Anthropometric Measurements

The objective of the BISS anthropometric measurements was to assess the decrement in mobility of the arm, hand, wrist and neck of a subject outfitted in a BISS, as contrasted with the same individual garbed in normal street clothes. Guidelines for taking these measures were derived from WADC TN 57-311 "A Statistical Evaluation of Joint Range Data" and the "Human Engineering Guide to Equipment Design", by Morgan, et al. These measurements all required the experimenter to measure the angle between a link line or other reference line passing through the bbdy member and a reference plane, usually the vertical or horizontal. (See Figure A1 Appendix A, Section **3.5.5;** note wrist abduction and adduction values are reversed). Since the link lines are contained within the envelope of the body member, measurement error is possible, even when the movable member is in full view of the measurer. When the subject is clad in a fairly bulky garment such as the BISS, definition of link line locations becomes very difficult. In addition to this measurement problem, the degree of exertion which the subject puts forth in achieving maximum joint or member rotation or movement is not amenable to control by the experimenter.

For these reasons, some negative values will be observed in the percentage difference tabulations (Table XXXI). These negative values imply that the subject had greater freedom of movement in the BISS than in common work clothes. Total means for subjects and means across subjects exclude these negative values.

The data can be summarized as follows:

Wrist Measurements

a. Flexion **A M** = 4.8% **N*** = 3

b. Extension A M = 10.0% N = 3

c. Abduction A M = 44.6% N = 4

d. Adduction **Δ M = 0% N = 2**

These measures are within the design goal of a 10%difference with the exception of wrist abduction. The abduction measure is taken with the hand held steady on a vertical surface, the subject standing and the wrist being bent away from the body around and imaginary axis perpendicular to the flattened hand. This movement places a maximum requirement on garment sleeve length. Since subjects did not report sleeve length

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* **N** = Number of data points.

TABLE XXXI ANTHROPOMETRIC DATA

SUBJECT	A			B			C			D			
MEASUREMENT	WORK CLOTHES	BISS	W/C-B / W/C	WORK CLOTHES	BISS	W/C-B / W/C	WORK CLOTHES	BISS	W/C-B / W/C	WORK CLOTHES	BISS	W/C-B / W/C	Δ M (+VALUE)
WRIST FLEXION	82	83	-.012	90	90	.000	80	80	.000	105	90	.143	.048/3
WRIST EXTENSION	93	93	.000	94	94	.000	95	100	-.053	98	95	.031	.010/3
WRIST ABDUCTION	25	23	.080	22	16	.273	35	23	.343	28	10	.643	.446/4
WRIST ADDUCTION	24	24	.000	15	15	.000	15	18	-.200	16	20	-.250	000/2
FOREARM SUPIN.	102	95	.069	115	102	.113	120	120	.000	108	111	-.028	.061/3
FOREARM PRONAT.	105	110	-.048	101	98	.030	77	77	.000	98	105	-.071	.015/2
ELBOW FLEXION	153	105	.314	155	131	.155	155	120	.226	135	135	.000	.232/4
SHOULDER FLEXION	175	--	--	171	--	--	185	--	--	175	--	--	
SHOULDER EXTN.	55	--	--	74	--	--	60	--	--	60	--	--	
SHOULDER ADDUCTION	40	--	--	47	--	--	52	--	--	37	--	--	
SHOULDER ABDUCTION	115	--	--	138	--	--	131	--	--	127	--	--	
SHOULDER ROTATION-M	104	109	-.048	101	105	-.040	105	107	-.019	91	100	-.099	-.069/4
SHOULDER ROTATION-L	30	32	-.067	34	19	.441	34	25	.265	26	35	-.346	.235/2
(HEAD/NECK)	--	--	--	--	--	--	--	--	--	--	--	--	--
VENTRAL FLEXION	69	53	.232	82	37	.549	80	70	.125	80	75	.062	.323/4
DORSAL FLEXION	35	34	.028	35	40	-.143	60	11	.817	35	35	.000	28.2/3
RT. OR LFT. FLEXION	40	40	.000	32	35	-.094	22	20	.091	45	45	.000	.030/3
RT. OR LFT. ROTATION	85	85	.000	86	86	.000	80	80	.000	85	85	.000	000/4
			-.080 N=9			-.156 N=10			-.187 N=10			-.110 N=8	

as being inadequate at any time during the test it is probable that most of the wrist abduction can be ascribed to the unnaturalness of the position assumed and difficulty in locating the forearm link in the suited condition. The fact that two of the adduction measures were negative in the suited condition trends to confirm this hypothesis. It is also clear that if there were any serious impairment to wrist movement, it would have been reflected in the dixterity test results, which were good. Figure 76, on the next page illustrates a phase of the measurement process.

Forearm Measurements

a. Supination $\Delta M = 6.1\%$ $N = 3$

b. Pronation $AM = 1.5\%$ $N = 2$

These mean difference for forearm supination and pronation are well within the design goal. The negative cases, all low percentages, can probably be ascribed to differences in effort on the part of the subjects under the different conditions.

Elbow Measurements

a. Elbow flexion $AM = 23.2\%$ $N = 4$

Elbow flexion was measured with the subject sitting and the arm supported parallel to the surface of a table. The forearm was then maximally flexed and the angle measured between the projection of the arm link line and the forearm link line. It is understandable that flexing the arm in this way would be impeding by bunching of the heavy suit material as the arm closed. Even with this impediment the mean value is under the design requirement of 25%.

Shoulder Measurements

a. Medial rotation $\Delta M = 6.9\%$ $N = 4$

b. Lateral rotation $AM = 23.5\%$ $N = 2$

The medial and lateral rotation measures were taken for the seated subject with the arm supported as was done for elbow flexion. This data suggests that the measurer could not accurately locate the forearm link line for these measurements when the subject was suited. From a practical standpoint, the shoulder mobility of subjects was very satisfactory in performing the assembly and disassembly tasks.

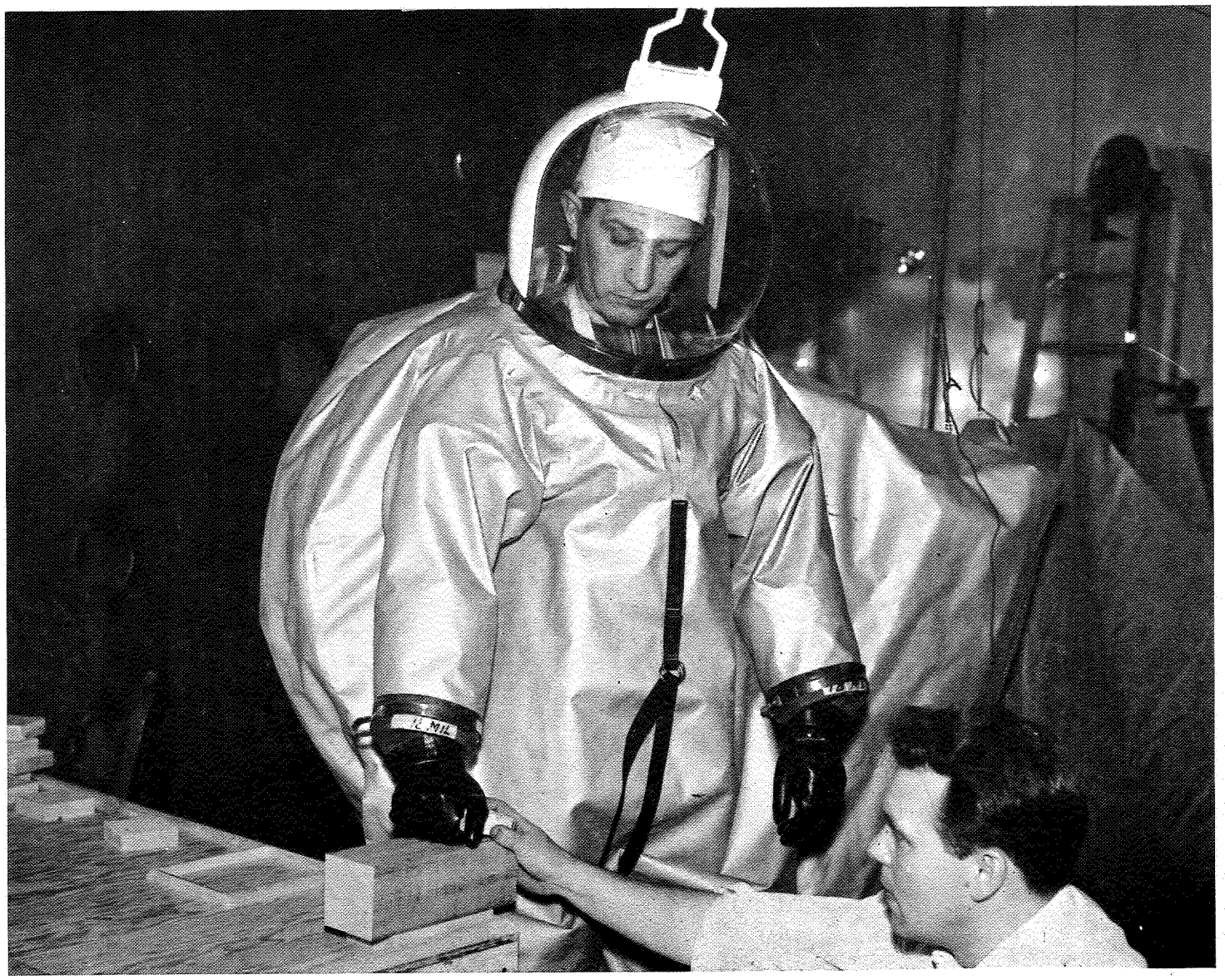

Figure 76. - Preparation for Taking Wrist Flexion Measurement

Head and Neck Measurements

a. Ventral flexion $\Delta M = 32.2\%$ $N = 4$

b. Dorsal flexion $\Delta M = 28.2\%$ $N = 3$

c. Right or left flexion $\Delta M = 3.0\%$ $N = 3$

d. Right or left rotation $\Delta M = 0\%$ $N = 4$

The head and neck measurements clearly support other data obtained in the study, i.e., that the helmet provides an abundance of room for head rotation, but requires additional depth and repositioning. This repositioning will be achieved by redesign of the yoke assembly. The depth and height of the helmet have also been increased in the final BISS specifications.

8.7.5.1 Conclusions

The mean difference (all + ratings for the four subjects were 8.0%, 15.6%, 18.7%, and 11.0%, with an unweighted composite mean of 13.3%. This value exceeds the design goal of 10%, but is well within the design requirement of 25% specified in the criteria document (Attachment A of Appendix F.). It can be concluded that with the exception of the helmet/yoke redesign and possible alteration of the outer suit sleeve to better accommodate elbow flexion, the design implications of the anthropometric data are limited.

It has been concluded that in view of the difficulty in locating reference links in the suited condition, that other means of assessing joint mobility, e.g., expanded assembly test object tasks, be used in future BISS studies. It should also be noted that BISS comparison data were not taken for shoulder flexion, extension, abduction and adduction. This data could not be taken because it must be taken with the subject lying flat on his back on a table which was not possible with stiffening rings located at the suit terminus of the tunnel, (see Figure 77)

The reader will find that other data, developed throughout this report, indicate the suit to be essentially unrestrictive. Additional data suggested that beyond the helmet/yoke modification already mentioned, that the only significant impediment to operator comfort and mobility was posed by the large rings in the end of the tunnel. These rings were replaced by webbing in the preparation of the final BISS specifications.

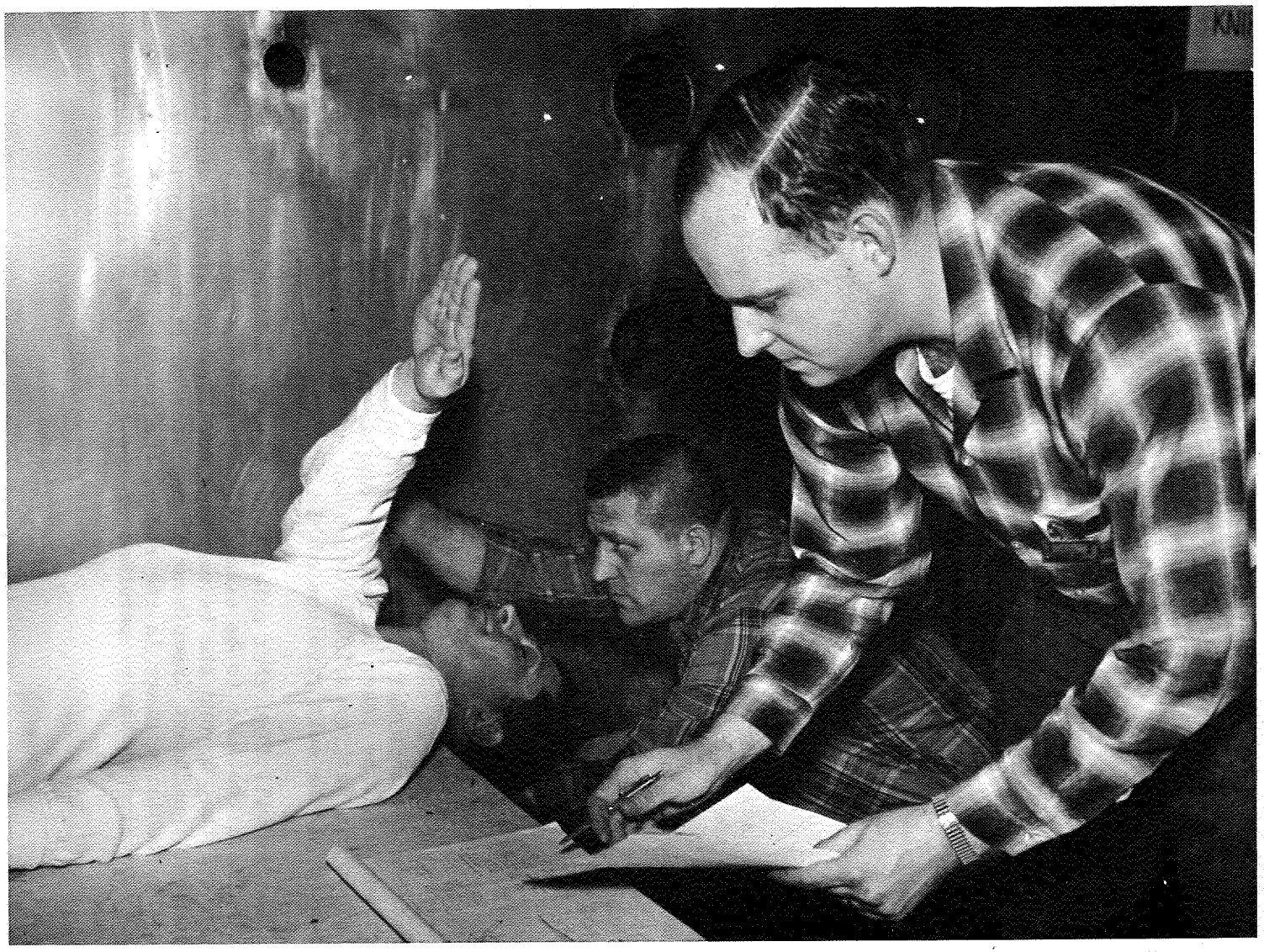

Figure 77. - Taking Shoulder Adduction Measurement

8.7.6 Pressure Tryout Tests

8.7.6.1 Purpose

The goals of the pressure tryout tests were:

- subject familiarization with the pressure environment
- identification of system problem areas amenable to quick modifications
- determination of a suitable pressure level for the endurance tests.

Various subjects were run at each pressure level from one to four inches H_2O. All subjects made a minimum of two pressurized entries and one pressurized exit. Both of the new subjects made two pressurized exits.

8.7.6.2 Results

8.7.6.2.1 Hardware

Problem areas identified during the tryout runs were:

- Donning rack - glove hooks needed repositioning (accomplished)
- Yoke - needed padding or straps to elevate yoke slightly (accomplished)
- Air distribution tubing - under pressure, the tubing tended to partially collapse from the action of the suit-tunnel interface rings on it (tubing replaced).
- Large suit-tunnel interface rings tended to impede subject movement and cause some discomfort (no action possible).
- Glove Air - insufficient glove air (later in test program repositioning of hand air distribution tube helped this problem).
- Compressor - needed modification to prevent icing in high R.H. ambients (accomplished).
- Communications transducer package too bulky (modified after 1st of 4 endurance runs)

This hardware shakedown greatly benefitted the subsequent endurance tests. The only hardware-type difficulties encountered during the endurance testing related to facility power. One power failure occurred as a result of a condition in the building over which test personnel had no control and the other resulted from inadvertently overloading a local circuit breaker. Both of these events were handled routinely by established rescue procedures.

8.7.6.2.2 Pressure Level Decision - The consensus amoung the subjects was that a 2" differential pressure was the highest pressure at which they believed they could operate for a four hour period. Even at a two inch pressure the subjects could not pull the reefed up tunnel away from the hard tube without great exertion, but once this was done for them the compressive effects of the pressure did not cause significant discomfort. One specific difference noted between the 2" and 3" levels was that the first communications transducer package which was suspended from the subject's neck caused discomfort from the pressure at 3" as opposed to 2". The function of the device was also impaired since the subject had to pull the suit material away from the transducer package to hear and talk to the test conductor. Though the large transducer package was eliminated, thereby aleviating this problem, it was decided to run the endurance tests at a 2" pressure based on the consensus of the subjects.

8.7.7 Endurance Tests

8.7.7.1 Introduction

The original intention was to study Phase II system performance without any significant modification or adjustment. However, during pressure try-outs, it was found that a pressure differential of 3 or 4 inches of water posed several problems for this system. At these values it became difficult or impossible for the subject to step out of the donning rack and pull away from the hard tube. Also, the suit became restrictive; inhibiting the normal movement required of the subject and cutting off air circulation to the extremities. Suit-tunnel interface rings and communications trandscuers were pressed into the subject's body causing discomfort, and it became necessary for the subject to pull the suit material away from the communications transducer to hear the Test Conductor. To avoid the complications which were encountered during the pressure try-outs at 3" and 4" P, the endurance tests were conducted at a 2" differential pressure.

Subjects A and D completed the entire endurance test. After being stopped 3 times in the early testing stages, once because of a power failure and twice by the Medical Monitor, Subject B completed approximately three hours before being stopped again by the Medical Monitor. After a brief rest, Subject B reentered to complete the endurance test.

Subject C was stopped twice at about 1½ hours into testing; once because of a power failure and once by the Medical Monitor. Subject C's endurance test was not continued, due to fatigue, morale, and time constraints.

In the cases where the subject performed corresponding tasks more than once due to restarts, the data taken was handled in one of two ways. Corresponding SAS data was averaged and for corresponding objective test measurements, the first test values were used. The rationale behind this approach was that learning effects would be found in the objective tests while conditions which affected the SAS ratings varied.

Measurements were made for five catagories of tasks. These catagories were: Comfort, Communications' Dexterity, Mobility, and Entry/Exit. For each category the subject assesment scale (SAS See Attachment A of Appendix F) was completed by the subject and was administered to the suited subject by the Test Conductor via the normal communications link.

8.7.7.2 Comfort

Comfort SAS ratings (SAS item I) were obtained at five different points in time during the endurance tests as shown in the endurance test sequence, section 8.7.3. These ratings were received from the subject via the normal communications link and were received and recorded by the test conductor. The ratings were obtained shortly after entry and at approximately one hour intervals thereafter. This provided for ratings after both resting and exercised conditions. Average ratings per each subject, for each four hour endurance run, were calculated as were averages across subjects for each point during testing at which comfort ratings were taken. Tables XXXII and XXXIII include these averages across time and across subjects. Both these tables include the corresponding life suppoty data. The time interval referred to in the table represents the time at which the SAS Comfort ratings were taken. Informal data analysis indicates a decline in the SAS comfort ratings, other than humidity, at approximately two hours (time interval 3) into testing. The ratings then rise again at approximately three hours (time interval 4) into testing. It is seen from the data that relative humidity into the suit as well as the differential between temperature in and temperature out remained fairly constant.

The differences in SAS comfort ratings over time may be ascribed to the activities imediately preceding administration of the SAS. All ratings with the exception of the one at hour two (time interval 3) were taken following communications tasks or following resting. The ratings at hour two were taken following a mobility test which involved

TABLE XXXII SAS RATINGS AND CORRESPONDING LIFE SUPPORT VALUES FOR SUBJECTS ACROSS TIME

		OVER ALL	TEMPERATURE	HTY	MEAN COOLING STRIBUTION	MEAN COMFORT	TEMP (°F)		AIR FLOW (% MAX.) (MAX.=23 5 CFM)		R.H. (%)	
							INPUT	EXHAUST	INPUT	EXHAUST	INPUT	EXHAUST
SUBJECT	A	4.2	3.6	3.2	4.5	3.9	71.8	86.8	42.4	47.0	46.4	--
	B	4.4	5.5	5.0	4.9	4.9	69.2	88.8	44.5	46.3	36.6	33.7
	C*	5.0	5.5	4.2	5.0	4.7	72.6	85.8	43.8	50.0	48.5	43.5
	D	5.2	4.4	3.7	4.6	4.5	72.8	90.1	39.2	53.0	39.5	44.4

* First two SAS comfort ratings only.

TABLE XXXIII SAS RATINGS AM) CORRESPONDING LIFE SUPPORT VALUES OVER TIME

ACROSS SUBJECTS

		SAS COMFORT					LIFE SUPPORT VALUE					
		OVERALL	TEMPERATURE	HUMIDITY	MEAN COOLING DISTRIBUTION	MEAN COMFORT	TEMP (°F)		AIR FLOW (% MAX.) (MAX.=23.5 CFM)		R.H%	
							INPUT	EXHAUST	INPUT	EXHAUST	INPUT	EXHAUST
TIME INTERVAL	$\bar{1}$	4.9	4.6	4.1		4.6	72.5	88.8	41.8	54.2	41.3	43.3
	$\bar{2}$	4.9	4.8	4.0	4.8	4.6	71.2	87.2	41.8	47.6	41.8	36.3
	$\bar{3}$	4.3	4.0	4.0	4.3	4.2	70.8	88.5	41.7	46.7	42.7	43.5
	$\bar{4}$	4.7	5.0	4.0	5.0	4.7	70.9	88.3	43.3	46.7	43.2	37.5
	$\bar{5}$	4.3	4.0	3.8	4.6	4.2	71.5	89.0	43.0	48.7	40.0	38.0
	AVE	4.6	4.5	4.0	4.7	4.5	71.4	88.4	42.3	48.8	41.8	39.7

a certain amount of exertion. Also, following a mobility test which involved a certain amount of exertion.. Also, the pattern followed by air flow input rates is similar to that of the SAS cooling distribution. Generally, the higher SAS ratings, other than humidity SAS, were accompanied by the largest differences between humidity input and exhaust.

The mean comfort and life support data between subjects shows a pessible bias due to subject experience. Subjects A and D took part in Phase I testing and were far more experienced in the BISS environment. This might be demonstrated by fact that in all cases except overall comfort, the subjective ratings of the two newest subjects were higher than those of the more experienced subjects. It is impossible to say unequivocally however, that this was a bias effect since the life support parameters did vary. Generally, the higher input air flow rates received higher subjective ratings and the highest subjective ratings for input temperature and input humidity corresponded to the lowest life support value for these parameters.

To further evaluate trends, certain statistical operations were performed. Data was normalized so that all values could be expressed in similar terms. The average value for each SAS scale and each life support parameter was used as the baseline for its own scale or parameter. Each value within a parameter or scale was divided by the corresponding value and multiplied by 100. The resultant normalized data was therefore expressed as a percent of the average value for the values in its own scale or parameter.

Once the data had been normalized it was grouped according to the mean SAS value (Table XXXIV). The mean SAS value was the average of all the comfort SAS rating scales including temperature, humidity, overall comfort and the mean of the cooling distribution scales. Each different mean SAS value was grouped with other equal mean SAS values. When more than one value was contained within a group, corresponding SAS scales and life support parameters were averaged to obtain one value for each scale and parameter. Table XXXIV presents the data after grouping. Nine groups of data were found. Ranks were then assigned to the grouped values from 1 (highest value) to 9 lowest value).

The final statistical operation was the calaulation of correlations between all scales and parameters. This was done to assess possible relationships between values. Spearman Rank Correlation Coefficients techniques were used for this purpose. The formula for this coefficient is:

TABLE XXXIV GROUPED, NORMALIZED * COMFORT DATA

SAS RATING SCALES					LIFE SUPPORT PARAMETERS					
					TEMPERATURE		AIR FLOW		HUMIDITY	
	OVERALL COMFORT	TEMPERATURE	HUMIDITY	MEAN COOLING DISTRIBUTION	SUPPLY	EXHAUST	SUPPLY	EXHAUST	SUPPLY	EXHAUST
.0	130.4	133.3	100.0	121.3	100.6	101.8	94.6	102.5	108.8	105.8
r.8	130.4	133.3	125.0	110.6	94.5	100.1	106.4	92.2	86.1	75.6
l.1	130.0	115.6	112.5	108.5	100.3	99.9	100.1	110.7	110.2	105.9
5.7	104.4	111.1	120.0	100.0	97.7	100.8	127.2	96.8	82.5	89.4
7.8	119.6	88.9	95.0	97.9	101.0	98.6	99.3	105.0	112.6	104.6
1.1	87.0	88.9	100.0	91.5	102.9	102.9	94.6	112.7	112.4	125.9
4.4	87.0	88.9	75.0	87.7	100.4	97.6	100.5	87.1	112.4	---
0.0	87.0	66.7	75.0	89.4	102.6	99.9	94.6	97.6	81.1	121.0
3.3	65.2	66.7	75.0	91.5	102.0	98.4	106.4	102.5	107.7	---

*ALL VALUES EXPRESSED AS PERCENT OF AVERAGE

$$r_s = 1 - \frac{6 \sum_{i=1}^{N} d_i^2}{N^3 - N}$$

where r_s equals the correlation coefficient, N equals the number of groups, and $\sum_{i=1}^{N} d_i^2$ equals the sum of the squared differences between ranks of the two parameters or scales correlated.

Although no test of significance were attempted, trends and relationships between variables may still be suggested by the correlation values. Generally, for an N of 9 (applicable to all parameters other than humidity) a Spearman Rank Correlation of .600 or greater is considered significant. All coefficients found to be ,500 or greater are reported here, however, since no attempt at determining significance has been made. It should be noted that the N for correlations involving exhaust humidity have an N of 7 since data were not available for that parameter in 2 groups. When correlating parameters or scales with exhaust humidity only the highest 7 values of that scale or parameter were considered.

Tables XXXV, XXXVI, XXXVII, present values of .500 or greater for SAS scale intercorrelations, life support parameters intereorrelations and correlations of SAS scales with life support parameters, respectively. A brief discussion of a relationships, which the data suggest, follows each table. Differential values included in Table XXXVI refer to exhaust parameters minus supply parameters.

8.7.7.2.1 Discussion - As might be expected, certain differential parameters show varying degrees of relationship with the supply and exhaust parameters on which they are based. Strong relationships do, however, also occurs between other parameters. Generally, differential temperature magnitude shows strong direct relationship with differential air flow shows strong inverse relationsheps, i.e. as one parameter increases the other decreases, with humidity differential magnitude and direction. Strong inverse relationsheps are also indicated for exhaust air flow with exhaust humidity and for supply temperature with supply air flow and differential humidity magnitude and direction.

TABLE XXXV **SAS** RATING **SCALE** INTERCORRELATIONS

SAS SCALE	MEAN	OVERALL COMFORT	TEMPERATURE	COOLING DISTRIBUTION	HUMIDITY
MEAN	---	.929	.975	.922	.812
OVER ALL COMFORT		---	.870	.850	.688
TEMPERATURE			---	.875	.833
COOLING DISTRIBUTION				---	.788
HUMIDITY					---

DISCUSSION:

Strong direct relationships are shown by all SAS rating scale inter-correlations indicating a probable strong positive interdependence between scales i.e. as one increases the others increase also. The least-related to the other parameters is the SAS humidity scale.

TABLE XXXVI LIFE SUPPORT PARAMETER INTERCORRELATION

LIFE SUPPORT PARAMETERS	AIR FLOW DIFFERENTIAL WITH RESPECT TO MAGNITUDE	AIR FLOW DIFFERENTIAL WITH RESPECT TO MAGNITUDE AND DIRECTION	SUPPLY AIR FLOW	EXHAUST AIR FLOW	HUMIDITY DIFFERENTIAL WITH RESPECT TO MAGNITUDE	HUMIDITY DIFFERENTIAL WITH RESPECT TO MAGNITUDE AND DIRECTION	SUPPLY HUMIDITY	EXHAUST HUMIDITY
TEMPERATURE DIFFERENTIAL WITH RESPECT TO MAGNITUDE		.933	.629	.811				
TEMPERATURE DIFFERENTIAL WITH RESPECT TO MAGNITUDE AND DIRECTION	-.567							
SUPPLY TEMPERATURE			-.804			.929		
AIR FLOW DIFFERENTIAL WITH RESPECT TO MAGNITUDE AND DIRECTION	.579		.804	-.871	-.562	-.723		
EXHAUST AIR FLOW						.536		-.714*
HUMIDITY MFFERENTIAL WITH RESPECT TO MAGNITUDE								-.683*
HUMIDITY DIFFERENTIAL WITH RESPECT TO MAGNITUDE AND DIRECTION							-.705*	.562*

*N=7

TABLE XXXVII SAS RATING SCALE/LIFE SUPPORT PARAMETER CROSS ORRELATION

LIFE SUPPORT PARAMETERS / SAS COMFORT RATINGS	TEMPERATURE DIFFERENTIAL WITH RESPECT TO MAGNITUDE AND DIRECTION	EXHAUST TEMPERATURE	AIR FLOW DIFFERENTIAL WITH RESPECT TO MAGNITUDE AND DIRECTION	HUMIDITY DIFFERENTIAL WITH RESPECT TO MAGNITUDE	EXHAUST HUMIDITY
MEAN	-.712			-.786*	-.768*
OVERALL	-.529	.562		-.759*	-.818*
TEMPERATURE	-.692		.525		
COOLING DISTRIBUTION	-.796	-.542		-.759*	-.580*
HUMIDITY	-.904			-.545*	-.616*

*N=7

DISCUSSION:

Strong inverse relationships are shown between differential temperature, magnitude and direction, and all SAS rating scales, with the exception of the overall comfort scale. Strong inverse relationships are also shown of mean and overall comfort SAS scales with exhaust humidity and differential humidity magnitude. Differential humidity magnitude also shows this same relationship with the SAS cooling distribution scale.

8.7.7.2.2 Comfort Comments - Comments made by the subjects to the test conductor were recorded. These comments fall generally into two main classes or categories. These classes are life support related comments and suit/tunnel design comments. These classes overlap to a great extent, so many of the comments are grouped with those to which they seemed best related. Only those comments which had implications for further design modifications to Phase II BISS are presented.

8.7.7.3.3.1 - Life Support Related Comments:

- Cooling was reduced when subject sat.
- As supply and exhaust air flow differential increases, the pressure was felt more by the subjects.
- Greater cooling capability was needed
- At times general discomfort was felt but it was impossible to localize it
- No hot spots were experienced
- Independent controls for air flow rates in suit and helmet were recommended
- Subjects tended to warm up rapidly from only slight exertion

8.7.7.2.2.2 Suit/Tunnel Design Comments:

- Force6 exerted by the suit-tunnel ihterface rings became annoying and were detrimental to subject comfort in all cases with the exception of standing in place.
- Helmet-uoke assembly shifted forward, pushing the subjects head forward and causing general neck and back discomfort.
- Inability to move head back (dorsal flexion) was hard on the neck
- Air distribution tubes across the back should be harder.
- Glove clamps should be facing out to avoid snagging the suit
- Weight of tunnel was hard on the small of the back
- Weight of Helmet-Yoke assembly was tiring

8.7.7.2.3 Conclusions - It is apparent that **SAS** comfort scales are not independent. Part of this dependence probably stems from the fact that certain of the life support data show strong relationships and that **SAS** comfort ratings often show a high degree of correlation with several different life-support parameters. In general, **SAS** comfort ratings show the strongest relationships with differential temperature magnitude and direction and with the exhaust humidity and differential humidity magnitude. It would seem that these relationships show a definite activity effect for work versus rest since all three parameters can be expected to increase with subject exertion and they show inverse relationships with **SAS** comfort ratings. Exhaust temperature and air flow differential magnitude and direction show limited direct relationships with certain comfort ratings.

Although differences between subjects, across time, show some ratings which are less than satisfactory, averages across subjects, over time and averages across subjects and time prove to be satisfactory.

Hardware implications of the above conclusions are that wider ranges of temperature control and humidity control should be incorporated into future life support systems and that the areas of suit-tunnel design called into question by subject comments should be investigated in the light of both the comfort data and other relevant endurance test data.

8.7.7.3 Communications

Two types of Communications data were obtained during the endurance test. The Comunications **SAS**, item Vc, was administered twice, once shortly after entry and once shortly before exit. Also, a modified from of the Harvard P.B. (phonetically balanced) Word Test was administered to obtain a more objective measure of communication system effectiveness. The P.B. word lists were used to test reception by both subject and test conductor via the normal communications link and by the subject via the chamber speaker.

From the original P.B. lists of 100 words a prescribed number of words was chosen randomly to be transmitted. The original list was then used by the person receiving communications. The randomly selected words, 50 for normal communications link tests, and 25 for chamber speaker communications tests were numbered sequentially. The randomly selected word list was read by the "Speaker" pausing between words to allow the "Listener" to search his list for each word and to enter the corresponding number beside his choice. The "Listener's" word list contained twice as many words (100 words for the normal communications link tests and 50 for rhamber speaker tests) as were transmitted for each test. Tables XXXVIII and XXXIX present sample Speaker's and Listener's word lists repectively.

The first test involved the subjects as Listeners and the test conductor as the Speaker. The second test reversed these roles. Both the first and second tests were normal communications link tests.

TABLE XXXVIII SPEAKER'S WORD LIST

TEST CONDUCTOR TO SUBJECT B			
cloak	1	deck	26
ache	2	move	27
neat	3	dig	28
shout	4	dill	29
neck	5	sit	30
drop	6	heed	31
bee	7	shin	32
oils	8	tick	33
pinch	9	bead	34
bath	10	nest	35
sour	11	strap	36
lush	12	take	37
sob	13	gnaw	38
hurl	14	peck	39
crave	15	hiss	40
rut	16	raw	41
thrash	17	fin	42
leave	18	new	43
kite	19	vow	44
dupe	20	race	45
budge	21	rack	46
hatch	22	path	47
baxb	23	starve	48
shed	24	wharf	49
beast	25	hot	50

TABLE XXXIX LISTENER'S WORD LIST

TEST CONDUCTOR TO SUBJECT B			
dig	cast	raw	budge
turf	bald	sketch	race
who	lush	pod	dodge
barb	fame	bus	fin
stag	ache	rut	slap
fax	sit	eel	pert
cape	wharf	how	scab
air	tail	bush	hiss
oak	thrash	frown	court
check	muck	earn	merge
sob	crave	heed	kite
law	class	course	or
rouse	path	sage	strap
fig	rate	pinch	dupe
crime	nest	bath	bee
leave	vow	peck	cloak
deck	sped	hatch	rack
shout	dill	sour	new
pulse	gnaw	float	touch
hurl	flush	tick	shed
bead	trip	hot	rave
why	size	starve	blonde
jam	drop	move	neat
neck	take	oils	test
please	wedge	shin	beast

The third and final test involved the subjects as Listeners and the test conductor as the Speaker to test communications via the chamber speaker. Incorrect answers were those for which the word and number did not correspond to the ones read as well as those omitted by the listener.

8.7.7.3.1 Results -

8.7.7.3.1.1 S.A.S. Ratings

Table XL contains all **SAS** ratings for communications. All parameters rated by all subjects, with the exception of Subject D (Transducer size) were considered as satisfactory or better. The transducer was repackaged before Subjects A, B and C were run and this accounts for the difference between Subject D and the others for this **SAS** rating. Generally, overall average values show a drop in **SAS** ratings between the first and second trials. By not including Subject C's values (these values are very high for trial 1 and since trial 2 was never run, no corresponding values exist for it) the effect is reduced but is still present for all rating catagories except transducer size. The reasons for this effect are unknown and since the rating catagories are interdependent it would be extremely difficult to determine these reasons.

8.7.7.3.1.2 Communications comments

The subjects reported slight reverberation in the helmet when their face was turned to either side. The test conductor also periodically noted slight reverberation effects in the received signal.

Though the influence of the overpressure environment acting on the communications transducers was improved greatly by repackaging, a slight annoyance was reported by one subject with suit/communication transducer interaction.

Since the volume levels from the test conductor to all personnel were not independent, the best volume level for the subject was uncomfortably loud for the monitoring personnel. Independent received volume controls are needed at the individual stations.

8.7.7.3.1.3 Modified Harvard P.B. (Phonetically Balanced) **WORD** TEST

Table XLI presents data for the three types of word list tests. The most noticable effect is the very large difference found between subject and test conductor reception. Possible causes include feedback problems which required that the bass level be kept at a value somewhat higher than optimum while the volume level from the subject was kept at a value somewhat lower than optimum; high background noise level near the Test Conductor's Console and the use of speakers rather than headsets at the test conductor's console.

TABLE XL COMMUNICATIONS SAS RATINGS FOR
EACH SUBJECT AM) TRIAL

SUBJECT	TRIAL	COMMUNICATIONS SAS						
		RECEIVED SIGNAL INTELLIGIBILITY	VOLUME LEVEL	BACKGROUND NOISE LEVEL	TRANSDUCER LOCATION	TRANSDUCER SIZE	AVE	CHAMBER SPEAKER PERFORMANCE
A	1	6	6	7	7	6	6.4	7
	2	5	5	4	7	7	5.6	4
	AVE	5.5	5.5	5.5	7.0	6.5	6.0	5.5
B	1	6	6	4	4	4	4.8	4
	2	6	6	4	5	5	5.2	4
	AVE	6.0	6.0	4.0	4.5	4.5	5.0	4.0
C	1 AVE	7	7	6	7	7	6.8	5.5
	2	-	-	-	-	-	-	-
	AVE	-	-	-	-	-	-	-
D	1	6	7	6	3	4	5.2	7
	2	6	6	4	1	4	4.2	4
	AVE	6.0	6.5	5.0	2.0	4.0	4.7	5.5
ALL	- 1	6.2	6.5	5.8	5.2	5.2	5.8	5.9
	- 2	5.7	5.7	4.0	4.3	5.3	5.0	4.0
	AVE	6.0	6.1	4.9	4.8	5.2	5.4	5.0

TABLE XLI MODIFIED HARVARD WORD TEST RESULTS

	TO SUBJECT	FROM SUBJECT	TO SUBJECT VIA CHAMBER SPEAKER
SUBJECT	% CORRECT		
A	96	68	68
B	100	68	84
C	88	-	-
D	96	60	60
AVE	95.0	65.3	70.7

8.7.7.4 Dexterity

A test was devised to assess the ability to perform tasks requiring common hand tools-and to work with electrical and hydraulic connectors, thereby providing a simulation of assembly and checkout operations. An "Assembly Test Object" (ATO), Figure 68, was constructed for this purpose. Each subject disassembled and assembled the ATO twice, once in the BISS environment, Figure 78, and once in a shirtsleeve environment. Two different sets of gloves were used for disassembly/assembly by the suited subjects. The difference between the two glove sets was'the thickness of the material. The "heavy" gloves, 30 mil., and "light" g.loves, 18 mil., were both tested since they represent the extremes of the expected range for glove material-requirements. These two variables were balanced between subjects and in relation to experience with Phase I and II suits. Table XLII shows the final balanced presentations.

8.7.7.4.1 Results - Table XLIII presents the SAS data obtained for the dexterity tests. Generally, the parameters were rated as being more satisfactory for disassembly than for assembly, the only exception being, for the hydralic connectors. All parameters other than,"handling small objects", were rated as satisfactory or better. Subjects comments indicate that small objects such as washers were difficult to handle.

Informal analysis indicated that dexterity was rated as more satisfactory for the heavy than for the light gloves it is difficult to compare heavy with light glove performance. The SAS values for the one subject wearing heavy gloves are generally higher than the average values of the two subjects wearing light gloves. Slight practice effects (suit versus shirtsleeve first) are exhibited for the SAS connector ratings. The use of tools and small objects tended to be rated lower by "practiced" subjects.

These differences are seen'for the disassembly task but it is impossible to determine if it holds true for assembly due to the lack of data. No suit experience bias is indicated by the data.

The times for disassembly/assembly are presented in Table XLIV. Generally, more time was required to assemble than to disassemble the ATO. In all cases more time was required for either operation in the suited condition than in the shirtsleeve condition. No differences between heavy and light gloves are observed in the data. Slight practice effects are seen in suited disassembly times for subjects who performed this operation

Figure 78 - Assembly Test Object Disassembly by White Subject

TABLE XLII , BALANCED VARIABLES FOR DEXTERITY TESTS

		GLOVE THICKNESS		RELATIVE EXPERIENCE	
		HEAVY	LIGHT	EXPER	UNEXPER.
FIRST TRIAL	SUIT SHIRTSLEEVES	C D	A B	A D	C B
RELATIVE EXPERIENCE	EXPERIENCED UNEXPERIENCED	D C	A B		

TABLE XLIII SAS DEXTERITY RATINGS

SUBJECT	OPERATION*	EASE		CONNECTORS				MEAN DEXTERITY
		HAND TOOLS	SMALL OBJECTS	BENDIX	BNC	HYDRAULIC	CONNECTORS AVERAGE	
A	D	5	4	5	6	3	4.7	4.6
	A	4	2	5	5	5	5.0	3.7
B	D	3	3	4	4	4	4.0	3.3
	A	4	3	5	6	5	5.3	4.1
C	D	7	5	3.3	7	7	5.4	5.9
	A	-	-	-	-	-	-	-
D	D	4	3.5	6	7	7	6.7	4.7
	A	6	2.5	4	6	6	5.3	4.6
ALL	$\bar{D}$	4.8	3.9	4.6	6.0	5.2	5.3	4.6
	$\bar{A}$	4.7	2.5	4.7	5.7	5.3	5.2	4.1
	AVE	4.8	3.2	4.6	5.8	5.2	5.2	4.4

D - DISASSEMBLY
A - ASSEMBLY

first in the shirtsleeve conditon. On the average, subjects with relatively inexperienced subjects.

No such observations may be made concerning assembly however, due to the lack of assembly data for subject C.

8.7.7.4.1.1 Dexterity Comments

- Gloves restricted use-of screw driver.
- Washers are the most difficult parts to handle.
- Access problems become greater in the suit.
- Smooth gloves made it difficult to hold smooth handled wrenches Rough handled tools would make necessary operations easier.
- Small parts sometimes became caught in the folds of the light gloves
- Special tools will probably be necessary to pick up the smaller parts

8.7.7.5 Mobility:

Tests were conducted, as a part of the endurance test, to assess mobility as experienced by the suited subject. This test was administered twice during each 4-hour endurance run at 20 minutes into testing and at 2 hours into testing. Table XLV presents the Mobility SAS ratings and the times required to perform the mobility exerciese. Subjects were required to walk forward to the extent allowed by the tunnel and walk backwards to the starting position. This was performed twice. The subjects were also required to assnd and decend the first four steps of a step ladder three times (Figure 79) bend at the waist ten times (Figure 80) and do ten knee bends or squats (Figure 81)

8.7.7.5.1 Results: SAS data for the mobility trials shows only one effect which seems consistent. For all SAS mobility parameters, with the exception of walking, there were slight increases in subjective ratings between trials one and two. This exception is understandable since annoyance caused by the suit-tunnel interface rings, while walking, increased as time progressed. The remaining parameter values for each subject seem to be subject-specific and to depend on suit shape and size. This shall be further explored with regard to the comments made by the subject.

Figure 79. - Suited Subject **Climbing** Ladder

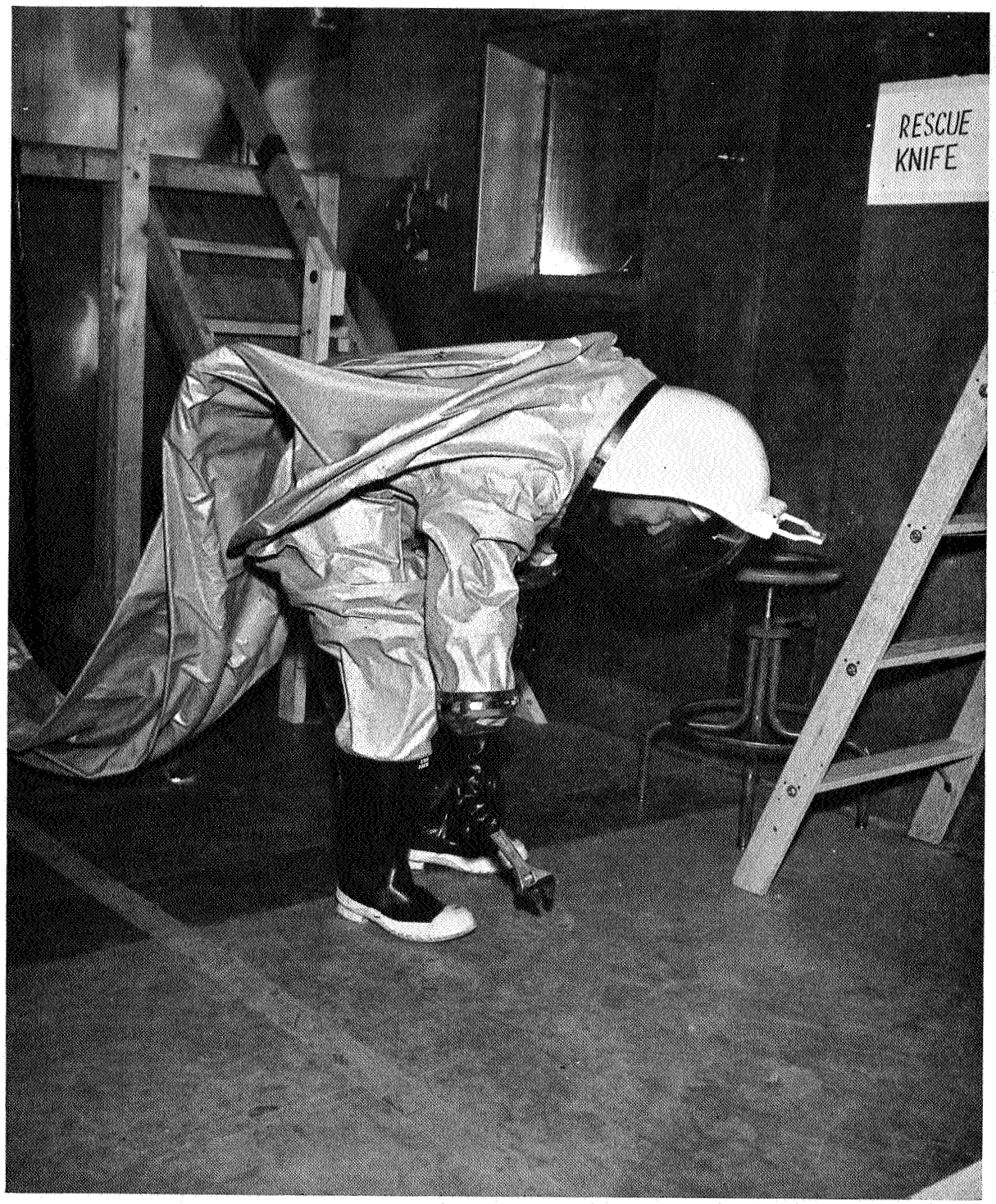

Figure 80. - Suited Subject Bending at Waist

Figure 81. - Suited Subject Doing Knee Bends

TABLE XLIV DISASSEMBLY/ASSEMBLY COMPLETION TIMES

SUBJECT	A		B		C		D		ALL		
OPERATION CONDITION*	D	A	D	A	D	A	D	A	$\bar{D}$	$\bar{A}$	AVE
SHIRTSLEEVES	5.1	4.7	7.2	8.9	6.3	-	5.9	7.9	6.1	7.2	6.6
SUITED	8.1	15.0	9.3	12.7	15.6	-	7.3	14.6	10.1	14.6	12.2

A - ASSEMBLY
D - DISASSEMBLY

TABLE XLV MOBILITY SAS RATINGS AND TIMES

		MOBILITY					
SUBJECT	TRIAL	TIME (MIN)	WALK	BEND	CLIMB	SQUAT	AVE
A	1	2.0	3.0	4.0	3.0	4.0	3.5
	2	1.6	3.0	4.0	3.0	4.0	3.5
	AVE	1.8	3.0	4.0	3.0	4.0	3.5
B	1	2.5	5.0	3.5	4.5	4.0	4.2
	2	2.2	4.0	3.0	3.0	4.0	3.5
	AVE	2.4	4.5	3.2	3.8	4.0	3.9
C	1	3.3	4.5	3.0	4.0	3.0	3.6
	2	-	-	-	-	-	-
	AVE	-	-	-	-	-	-
D	1	2.8	5.0	5.0	3.0	5.0	4.5
	2	-	6.0	6.0	5.0	6.0	5.8
	AVE	-	5.5	5.5	4.0	5.5	5.1
ALL	$\bar{1}$	2.6	4.6	3.9	3.6	4.0	4.0
	2	1.9	4.3	4.3	3.7	4.7	4.2
	AVE	2.2	4.4	4.1	3.6	4.4	4.1

Subject A reported that the helmet hook tended to hit the ladder rungs and that he tended to kick the leg rings when climbing the ladder. This would account for the low SAS ratings this subject gave to climbing. The subject stated that the tunnel hindered walking and this possibly influenced the walking SAS ratings.

For subject B, the only consistently low SAS ratings were those for bending at the waist. This corresponds to the subject's reporo that the suit-tunnel interface rings hit him in the small of the back.

Subject C's low SAS rating for bending was probably also related to his report that the rings hit him in the back. Subject C also reported that when climbing during the first mobility test, the plenum was pressed into his back. This corresponds to his low SAS rating for climbing.

8.7.7.6 Entry-Exit

Table XLVI presents Entry-Exit times and SAS ratings. Average overall SAS ratings, with the exception of EXIT-"getting into tunnel" ratings, are all satisfactory or better. A certain amount of variation between subjects is observed in the data. These intersubject differences appear to be primarity related to intersubject weight and height differences. Table XLVII presents nude body weight and height data for the Phase II subjects.

Comparing average Entry-Exit SAS values for each subject with his weight shows a one to one inverse relationship. This would imply that the heavier the subject, the more difficulty Entry-Exit is. Similar relationships exist for the individual Entry-Exit parameters with weight and/or height.

8.7.8 Helmet Air Analysis

A second helmet air analysis was run during the Phase II mock-up tests to compliment the one run during Phase I. During two of the four endurance tests, samples of suit inlet air and helmet exhaust air was taken on two different subjects.

The inlet air was sampled at the junction of the life support hose and the suit plenum. The "helmet exhaust air" was not sampled at the junction of the suit exhaust air at the level of the plenum'because at this level the helmet air sample would contain a large volume of air that had been in contact with the body and had not been in the helmet. There-

TABLE XLVI ENTRY-EXIT SAS RATINGS AND TIMES

	ENTRY						EXIT					
	ENTRANCE THROUGH TUNNEL**	POSITIONING FOR DONNING	DONNING SUIT	DETACHING SUIT FROM RACK	AVE ENTRY SAS	TIME (MIN)	ATTACHING SUIT TO RACK	DOFFING SUIT	GETTING INTO TUNNEL**	EXIT THROUGH TUNNEL**	AVE EXIT SAS	TIME (MIN)
SUBJECT												
A	2	5					4	5	2	3	3.5	2.5
B[x]	5.5	4.5					5	4	6	6	5.2	1.3
C[x]	5.5	4.0					-	-	-	-	-	3.2*
D	4	4	4	6	4.5	4.1	4	4	3	4	3.a	2.3
AVE	4.2	4.4	4.2	4.9	4.4	3.3	4.3	4.3	3.7	4.3	4.2	2.0

Average Entry Value for 2 Trials

* Average Rescue time for 2 Trials from Time of "Pull" Decision until Subject was out of Hard Tube
Note that Chamber was Depressurized for all Rescue Operations.

** Tunnel inplies the Hard Tube Only

TABLE XLVII SUBJECTS NUDE BODY HEIGHT AND WEIGHT

SUBJECT	HEIGHT (INCHES)	WEIGHT (POUNDS)
A	70.75	171.25
B	70.75	150.50
C	69.50	144.25
D	69.00	165.00

fore a special sample was taken by placing the end of a 20 ft. x ¼" diameter Tygon tube into the helmet near the test subject's right clavicle about 2" from his mouth. Throughout the helmet air tests, the flow rate of air from the life support system to the test subject ranged from 10 - 20 cfm. The subjects reported that they were comfortable and that they were also not aware that their exhaust air was being sampled.

The test was run using gas chromatographic sample tubas attached as explained above on one end and the other end of the sample tube attached to an electrically driven vacuum pump. This apparatus was run for 10 minutes with a guage reading of 1 cfm thru 'the lines. The actual sample was collected for a five minute period.

The gas analysis was made on a Beckman GC-5 gas chromatograph. Carbon dioxide was separated on a 1/8" x 9' 15% HMPA (Hexyl Methyl Phospho Amide) on a Chromosurb P column and detected with a thermal conductivity detector. Oxygen and nitrogen were separated on a 1/8" x 6 molecular sieve column and detected in the same manner as the carbon dioxide. Individual calibration curves were prepared for each component analyzed.

Best & Taylor, "The Physiological Basis of Medical Practice", 8th Edition, 1966, Chapter 50, states that "The mixture of gases in the alveoli consists of inhaled air from which oxygen is being removed and to which carbon dioxide and water vapor are being added. Under resting conditions each inhalation brings into the respiratory system a volume of air representing less than 10 percent of the total lung capacity, and not all of this reaches the alveoli. Hence the composition of the alveolar air shows only minor fluctuations with the respiratory cycle. The composition is not exactly the same in all parts of the ling, since there are variations in the effectiveness of ventilation. The average composition, however, is maintained approximately constant by the mechanisms regulating the respiratory rate and volume.

A sample of expired air taken near the end of a normal expiration (end-tidal sample is fairly representative of the average composition of alveolar air."

Table XLVIII below appears in the book on Page 969.

TABLE XLVIII ATMOSPHERIC AND ALVEOLAR AIR

	O_2	CO_2	N_2 (a)
Atmospheric air Per cent (dry)	20.95	0.04	79.01
Partial pressure, mm. Hg (b) (c)	157	0.3	593
Alveolar air Per cent (dry)	14.0	5.6	80.4
Partial pressure, mm. Hg (c)	100	40	573

(a) Includes other inert gases, 0.93 per cent.

(b) At sea level, barometric pressure 760 mm, Hg.

(c) Assuming absolute humidity of 10 mm. Hg.

8.7.8.1 Results

The results of this test are portrayed in Table XLIX. The only value exceeding the T.L.V. for CO_2 (0.5000% by volume) was 0.658% when the subject was sitting. Since the T.L.V. is computed for an eight hour continuous exposure and since it was only slightly exceeded, it was concluded that the results of the helmet air analysis were satisfactory. The fact that this occurred when the subject was sitting and later improved when the subject was standing is explained by the fact that a portion of the exhaust path (via the foam) was blocked off when the subject was sitting.

TABLE XLIX **BISS HELMET AIR ANALYSIS**

RESULTS					
Sample #	Date	Description	% Volumes		
			O_2	N_2	CO_2
1	3/13/67	Input Air Supply to Helmet	21.70	77.29	0.086
2	3/13/67	Subject D's Helmet Air (20 minutes into test after ladder and waist bends).	21.11	76.85	0.425
3	3/13/67	Subject D's Helmet Air (1 hour in chamber seated for 30 min.)	21.08	76.50	0.658
4	3/13/67	Subject D's Helmet Air (standing and working, 2 hours).	21.06	76.92	0.447
5	3/16/67	Input Air Supply to Helmet (47% humidity).	21.83	77.45	0.09
6	3/16/67	Subject B's Helmet Air (37% humidity).	21.49	76.91	0.320

8.7.9 Helmet Disinfection Treatment

The detergent* treatment and disinfection of the helmet was instituted 15 minutes prior to the scheduled entrance of the operator into the suit, and consisted of the following steps:

1. Disengaging the hook on top of the helmet from its attachment. This will drop the helmet portion down into an inverted position.

2. Swabbing the helmet with a cloth which has been previously dampened with a 5 per cent aqueous solution of Triton X-100 to remove surface film and sputum which may accumulate during usage.

3. Wipping with a dry cloth to remove residual moisture.

4. Swabbing the surface thoroughly with a cloth moistened in a 70 per cent Isopropanol solution. The surface should remain moist for at least five minutes.

5. Wiping with a dry cloth to remove residual alcohol.

Following application of the disinfectant, the helmet was aerated at a rate of 20 cfm and after 5 minutes was examined for odor retention. This examination was conducted by two observers, followed by suit operator who then entered the suit. All concurred that they could not detect any odor of isopropanol.

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* Suitable detergents commercially available for the helmet treatment are:

Triton X-100 - Rohm & Haas

Tergitol NPX Union Carbide

Tergitol 15-S-7 Union Carbide

The physical and chemical properties of these surface active agents are essentially the same. Triton X-100 was selected primarily on the basis of cost.

8.7.10 Medical Monitoring Phase II Test

A system composed of an **RKG-100** (Telemedics) Radiocardiograph transmitter-Receiver connected to an Ocilloscope (Tektronix Inc. Type 531) and a Standard Electrocardiograph (G.E. Cardioscribe) was used for the Phase II mock-up tests. The disposable adhesive-type electrodes (1 1/8" square with metalic screen, paste reservoir, and snap-on fasteners) were attached to the subject's chest bilaterally on the anterior axillary line at the level of the 4th - 5th rib inner space. The RKG transmitter (1" X 3 1/2" X 4 1/2", weight 10 oz., range 250 ft.) was worn in a cloth bag tied by a cord to the subject's waist. Thin flexible wires with snap-on fasteners carried EKG signal from the chest electrodes to the transmitter.

The Telemedic Receiver (14" X 12" X 8", weight 17 lbs.) on the outside of the test chamber contained a skin resistance mover, standardization, and a selector switch for channeling to conventional electrocaridographic recording apparatus, oscilloscope, magnetic tape recorder, or all three simultaneously.

Electrocardiographic tracings of fair quality were received. This reduction in quality was caused by a 60-cycle interference from the operation of the motors in the life support equipment. (The tracings show a 60 cycle interference).

This interference did not present any problem in reading the EKG tracings or the ocilloscope for the determiation of the subject's heart rate. The latter was the parameter of primary concern. Only two tracings, showing anomalies in the QRS portion, are attributed to sixty cycle interference. This anomaly is not seen when the subject's heart rate is beyond the frequency response of the electrocardiograph stylus. The QRS notches are only noted when the subjects heart rate is slow at a time in the test program. When the RKG transmitter has been in use for several hours. At a slow heart rate of 100-110 beats per minute the sixty cycle interference is within the frequency response of the stylus giving a tracing of regular 60 cycle variations in intensity impressed on the waves.

A series of eight trial runs were made using different subjects. These tests had a duration of 15 to 45 minutes. The heart rates during entry & exit via the tunnel ranged between 120 - 180 beats per minute. Best & Taylor (The Physiological Basis of Medical Practice, Eighth Edition 1966) states that the average resting heart rate in adult man is around 70 beats per minute, but there is a rather wide variation between individuals, a rate considerably below or above this average being not uncommon. Muscular training tends to reduce the cardiac rate; athletes not infrequently having a pulse rate between 50 - 60. On the other hand, a rate of between 80 - 90 is sometimes seen in other healthy persons.

A series of 3 tests were made with two different subjects for periods ranging from 1 to 2 hours in the test chamber. Subject C had entry & exit rates 120 to 130. Subject B had a 160 - 170 heart rate on entry & exit .

A series of 3 tests were made with two different subjects for a test period of four hours. Subject A had entry and exit rates of 130-140. His exercise rate was 130 and his resting rates in the chamber under 2" water pressure were 85 to 90. Normal tracings were made before, during and after this 4 hr. test period. Subject D also was tested for 4 hours and had essentially the same results as Subject A, the only difference being that subject D had a short period estimated at between 30-60 seconds where he had trouble attaching life support hoses and his rate was measured at 150 beats per minute. Subject B (approximately 20 yrs. younger than subjects A & D) had higher heart rates throughout the 4 hour test period. His exit and entry rates were 150 - 170. During exercises, he had a rate of 150 and a resting rate of 95 - 120. For subject B, after 3 hours in the chamber, the graph showed directional changes in the QRS segment. When orally quiried at this time he answered that he felt a "little fatigued." He was asked to move about, stretch and also check his electrodes in order to rule out heart positional changes and electrode failure. This did not change the recorded tracings and even though the subject had been in the chamber for 4 hours, only 3 hours were under overpressure conditions, The subject was asked to take a luncheon break and return to the test area in one hour. During the one hour rest period, the transmitter was placed on re-charge. Subject B was re-suited and then spent an additional hour in the chamber under pressure. After one hour of normal tracing, the graph suddenly showed QRS anomalies which have been attributed to the unequal discharge of the batteries in the RKG transmitter. The sudden change in "heart rate" noted at that time is caused by the rapid changes in frequency of the RKG transmitter being beyond the frequency responses of the EKG stylus which produced a recording that could easily be misread as rapid heart rate. No abnormal ST segment changes were noted in any of the graphs.

Dr. James A. Roman of NASA/USAF - EDWARDS AFB was most helpful in the interpretation of these interesting EKG recordings and in dispelling concern about apparent abnormalities noted in the EKG's (See Appendix C). The physiological response to the BISS environment did not appear to present a problem to further development of the system.

8.7.11 Conclusions:

The major conclusions reached as a result of the Phase II mock-up study are presented in two categories. First, findings with implications for hardware design are presented in a summary manner. Secondly, a brief

discussion of the conclusion regarding subject endurance in the **BISS** environment is given. If the finding has been incorporated in the final recommended concept, a notation of incorporated has been indicated beside the recommendation.

8.7.11.1 Hardware Design Related Conclusions

Each design recommendation will be related to the area within the endurance test which yielded the data. The limited findings of the anthropometric measurement exercise were found to be reiterated by the endurance test results.

8.7.11.2 Comfort

- Helemt - yoke redesign is'required to better position the assembly on the subjects shoulders, stabilize it and to permit greater ventra 1 and dorsa 1 flexion; (incorporated)
- Suit-tunnel interface rings require elimination or redesign to remove the discomfort they cause the **BISS** subject.
- A heat exchanger of substantially greater capacity is required for air cooling. (incorporated)
- An adjustment capability for apportioning air to the helmet and limbs is required. (incorporated)
- Greater humidity control must be exercised by the life support console. (incorporated)

8.7.11.3 Communications

- The possibility of employing still smaller communication transducers must be investigated.
- Methods for controlling helmet reverberation and feedback in the communications system must be developed.'
- Independent adjustment of the volume levels of the subjects speaker, to permit private consultation between the test condjctor and monitoring personnel.

8.7.11.4 Dexterity

- Aids are required for handling small hardware (e.g. bolts, nuts, washers)

8.7.11.5 Mobility

- The Suit-tunnel interface support rings must be studied in relationship to mobility impairment as well as comfort since they tended to impede the subjects in bending at the waist and climbing and walking.
- The leg rings must be redesigned to eliminate interference when the subject is climbing.
- The helmet hook must be made smaller and neater to prevent it from interfering with operations when the suit occupant bends forward.

8.7.11.6 Entry-Exit

- Hard tube must be redesigned to permit seated entry and exit.
- The portion of the donning rack which holds the gloves must be redesigned to provide a positive locking action and to permit easier engagement and disengagement by the seated operator.

8.7.11.7 Miscellaneous

- Communications cables should be run inside the air supply and/or exhaust tubes to minimize the possibility of cable entanglement.
- A monometer sensor must be placed in the suit to measure total sensible pressure since a disparity in input and outlet flow rates can raise or lower the total pressure acting on the subject.

8.7.11.8 Subject Endurance

Based on the Phase II BISS mock-up study it is possible to positively state that a suitably selected man can function in the BISS environment (at a 2" P) for four hours. However, since only two of the four subjects successfully completed the run despite the fact that there were long rest periods during the tests, indications are that the four hour period is marginal for the Phase II BISS system. The subjects agreed that a two

hour period would probably be optimal for the present system. However, a final decision as to operator endurance must result from a study which systematically compares subject performance at different pressure levels with varying work-rest cycles.

It should also be noted that for some tests the exhaust air flow rate substantially exceeded the input flow-rate. This implies that the sensible pressure experienced by the subject was in excess of the chamber pressure. For this reason, conclusions reached in this report can be viewed as conservative since in no instance was the exhaust flow rate less than the input air flow rate.

9.0 RECOMMENDATIONS FOR FUTURE WORK

9.1 BACKGROUND

The present program represents the first major step towards the ultimate attainment of a prime BISS system qualified for use in the Assembly/Sterilizer facility. The program was predicated on the knowledge that the detail design, fabrication, and testing of the prime system would be accomplished on a subsequent program. In addition to providing preliminary design information for the suit and tunnel and life support and communications subsystems, the present program has provided a significant amount of detail to be incorporated in the final design, particularly in the areas of the outer suit shell, helmet and undersuit. It has also illuminated two design problems whose magnitude had not previously been fully realized: tunnel reefing and tunnel support.

Based on the experience from the present contract a follow-on program is outlined below for the completion of the required effort for a prime BISS system. This program consists of systems and materials studies, completion of preliminary design, performance of final design, and system fabrication and testing.

In performance of the studies and preliminary design, the BISS Phase II mock-up equipment will be an invaluable aid. The Phase II suit, tunnel and hatch assembly have been delivered to NASA's Langley Research Center. Use of this equipment, in conjunction with appropriate life support and communications equipment will permit extended mock-up studies. During preliminary design, this system can be adapted to incorporate evolving design details for development design verification.

9.2 SYSTEMS STUDIES

9.2.1 Tunnel Reefing and Support

The primary systems study area requiring further investigation is the reefing and support of the BISS tunnel. This involves a systems analysis and synthesis of a complex man/machine system. The problems attendant to the major machine elements of the system have been described in sections 4.3 and *4.4* and the complexity of the integrated system problem is indicated in section 4.5. Performance of this study must run concurrent with the design extension effort on the reefing mechanism and tunnel support boom so that once the system study model or schema has been formulated the preliminary designs for the machine elements of the system can be evaluated and optimized.

9.2.2 Operational Plans

Prior to the employment of a prime BISS system in a spacecraft sterilization facility, careful plans need to be formulated for operation of the BISS in the system. Detailed preliminary plans should be made at an early date to permit proper reflection of these plans in the final design of the system. The plans should be formulated as tentative Standard Operating Procedures. As a minimum, full operation guidelines and decision policies need to be defined. Examples of the impact operations of plans can have on system concepts and equipment designs are given in the discussions on the communications subsystem and bio-integrity and leak detection in Sections *4.8* and 5.1

The recommended plans or guidelines are a natural outgrowth and extension of the work on the present contract and will be based in large measure on the supporting studies of Section 5.0. Some of the required plans are:

- Assembly/Sterilizer organization chart with personnel assignments and responsibilities.
- Typical BISS work team plans
- BISS - Assembly/Sterilizer Comunications Plan
- Bio-Integrity Assurance and Monitoring Plan
- Emergency Rescue Plan
- BISS personnel utilization plan (accounting for the fact that personnel will work less than *8* hours in the suit in one shift)

9.3 MATERIALS STUDIES

Materials investigation is required to select and define physically and biologically acceptable bonds between the several materials of the system. The required bonds are described below:

- Suit fabrication -- Armalon to Armalon
- Suit- Helmet Interface -- Armalon to Texolite
- Helmet Fabrication -- Optical glass to Texolite

- Suit-glove Interface -- Armalon to Silicone rubber *
- Suit-Boot Interface -- Armalon to Silicone rubber*
- Tunnel Fabrication -- Armalon to Armalon
- Tunnel-Suit Interface -- Armalon to Armalon
- Tunnel-Hatch Assembly Interface -- Armalon to Stainless Steel
- Suit or Tunnel Maintenance -- Armalon to Armalon
- Boot or glove Maintenance -- Silicone rubber to Silicone rubber

The bonds described are based on fabrication of a BISS using prime candidate materials identified on the present program. Alternate materials should not be disregarded in the bonding studies since their use may improve overall design by facilitating bonding.

9.4 DESIGN EXTENSION

In varying degrees, each of the elements or subsystems require additional design. The individual system elements and the primary design efforts still required for each are identified below.

- Outer suit shell -- Design fabric joints and interfaces with tunnel, gloves, boots, and helmet, Redesign sleeve/donning rack ihterface to incorporate a positive attachment . Reduce leg stiffening ring diameter. Design external emergency air bottle interface.
- Helmet -- Reconfiguration to incorporate an optical glass face-plate rather than a Lexan bubble, and to incorporate a smaller helmet hook for the donning rack interface.
- Gloves -- Design of a fabric reinforced silicone rubber glove
- Boots -- Design of a fabric reinforced silicone rubber boot with safety toe, corregated soles, and donning rack boot clamp interface.
- Tunnel -- Incorporate graspable attachment points for reefing mechanism interface.

* Or Armalon to Texolite cuff to silicone rubber

- Undersuit -- Design supply and exhaust manifolds and flow balancing valve to adjust relative flow to extremities.

- Reefing Mechanism, Boom and Hatch Assembly -- Concurrent with the tunnel reefing and support study design the elements of an integrated reefing and support system for the BISS suit and tunnel. (If required for reefing the hatch assembly will include a large domed piston).

- Life Support -- Reduce life support breadboard to a preliminary sub-system design.

- Life Support Back-up -- Design two emergency back-up air supplies for the BISS: (1) external automatic supply optrating through life support subsystem hosing; (2) in-chamber supply bottles. The former must be Pntegrated with the life support system and the latter must be designed to interface with the suit shell or helmet.

- Communications -- Design transducers to optimize communications with chest mounted speaker and microphone. After definition of BISS, Assembly/Sterilizer communications plan, design a communications network for BISS to integrate BISS communications into a facility communications system. (As noted in Section 4.83 the further experimental investigation of an integrated headset for the BISS occupant should also be performed). Integrate communications lines from BISS occupant with life support hoses.

- Donning Rack -- Design new helmet and suit sleeve attachments.

- Antechamber -- Design an antechamber for emergency use and maintenance.

9.5 FINAL DETAILING

The final design will result in a prime configuration BISS system. Upon completion of the design extension the final detailing of the BISS system can be performed. With the present status of the system, the design efforts described above will bring the BISS system to the developmental status where the final design effort should consist primarily of detailing the established designs.

9.6 ENGINEERING MODEL FABRICATION AND TESTING

When the BISS system final detailing has been completed, a prime quality system should be fabricated for final verification and type approval testing. The types of testing required are described in the Test and Demonstration Plan in Section 6.0 and Appendix G and in the Quality Assurance Provisions of the specifications in Appendices J through N.

10.0. APPENDICES

APPENDIX A: BIO-ISOLATOR SUIT SYSTEM

APPENDIX A: BIO-ISOLATOR SUIT SYSTEM CRITERIA

1. SCOPE

This document defines the system criteria to be employed in the design and analysis of the Bio-Isolator Suit System (BISS).

2. APPLICABLE DOCUMENTS

The following documents of the issue listed are applicable to the extent specified herein.

- NASA SP3006 Bioastronautics Data Book 1964
  National Aeronautics and Space Administration
- 46th Ed. Handbook of Chemistry and Physics 1965-66
  The Chemical Rubber Co.
- Threshold Limit Values for 1965
  American Conference of Governmental Industrial Hygienists
- Keenan and Keyes, "Thermodynamic Properties of Steam", 1936
  John Wiley and Sons Publishers

3. REQUIREMENTS

3.1 Configuration

The basic configuration requirement is that the BISS system provide capability for a technician to work in a sterile chamber while maintaining absolute biological and topological isolation of the technician from the environment.

3.1.1 Equipment Complement

The general configuration of the BISS shall be consistent with that shown in Figure 4 . The BISS system shall consist of the following (see also section 4.0) :

- BISS Suit and Tunnel
- Life Support Subsystem
- Hatch
- Communication Subsystem
- Ancillary Equipment

3.1.2 Shape and Size

The BISS suit shall be anthropomorphically shaped and shall accomodate American males age 25-34, 50th to 80th percentile by height (69" to 71.4"), and 20th to 80th percentile by weight (146 to 195 lb.).

3.1.3 Mobility

The BISS shall permit good freedom of movement of the technicians body and extremities with minimum forces on the technician. The technician shall be able to move and work throughout a semicircular area with a 60 foot radius centered at the hatch. A 20 foot vertical ascent capability shall be provided except that a line from the hatch center to the center of the tunnel/suit interface need not exceed an angle of 45° from the horizantal. The system shall provide maximum facility for entry to and egress from the suit.

3.2 Bio-Integrity

The BISS suit and tunnel shall maintain a positive barrier between the sterile chamber and their inside surfaces. They shall be impervious to puncture, rupture, tear, or any other failure which would violate the barrier.

The BISS shall have less than 1 chance in 10^5 of permitting microbial penetration to the sterile area.

3.3 Technician Environment

The BISS system shall provide a healthful, comfortable environment for the technician in the suit performing light manual labor. As a minimum the system shall provide control of:

- Composition of gases breathed and in contact with the body (including removal of noxious or toxic gases)
- Humidity of gases breathed and in contact with the body.
- Temperature of gases breathed and in contact with the body.
- Suit pressure.

Control of these parameters shall be achieved primarily by providing facilities and equipment for conditioning and distribution of ambient atmospheric air.

3.3.1 Standard Atmospheric Composition

The standard composition of atmospheric air to be used for the study and design of the BISS system shall be that defined in the Chemical Rubber Company's 46th Edition of the "Handbook of Chemistry and Physics" (pg F116).

The breakdown of this composition (exclusive of water vapor is given in Table A-I.

The water vapor concentration standard (by volume) for the study and design of the BISS system shall be that defined in Table A-II derived from equation 12 of Keenan and Keyes, "Thermodynamic Properties of Steam," John Wiley and Sons, 1936.

TABLE A-I. COMPONENTS OF ATMOSPHERIC AIR
(Exclusive of water vapor)

CONSTITUENT	CONTENT (%)	CONTENT (PPM)
N_2	78.084 ± 0.004	
O_2	20.946 ± 0.002	
C_2	0.033 ± 0.001	
A	0.934 ± 0.001	
Ne		18.18 ± 0.04
He		5.24 ± 0.004
Kr		1.14 ± 0.01
Xe		0.087 ± 0.001
H_2		0.5
CH_4		2.0
NO_2		0.5 ± 0.1

TABLE A-II. WATER VAPOR CONCENTRATION AS A FUNCTION OF RELATIVE HUMIDITY
(For a 760 mmHg Atmosphere)

TEMPERATURE (Degrees F)	PERCENT BY VOLUME FOR RELATIVE HUMIDITIES AS GIVEN									
	10	20	30	40	50	60	70	80	90	100
50	0.12	0.24	0.36	0.48	0.61	0.73	0.85	0.97	1.09	1.21
60	0.17	0.35	0.52	0.70	0.87	1.05	1.22	1.4	1.57	1.74
70	0.25	0.49	0.74	0.99	1.24	1.48	1.73	1.98	2.22	2.47
80	0.34	0.69	1.03	1.38	1.72	2.07	2.41	2.76	3.10	3.45
90	0.48	0.95	1.43	1.9	2.38	2.85	3.22	3.8	4.28	4.75
100	0.65	1.29	1.94	2.58	3.23	3.88	4.52	5.17	5.81	6.46

3.3.2 Breathing Gas Composition Limits

The standards for gas composition limits for the BISS environment shall be in accordance with the "BIOASTRONAUTICS DATA BOOK", NASA SP-3006, and the Threshold Limit Values published by the American Conference of Governmental Industrial Hygienists.

3.3.2.1 Oxygen. Oxygen concentration shall be between 17 and 36 percent by volume (1.2 of Bioastronautics Data Book (BDB)) with a nominal objective of 21%.

3.3.2.2 Carbon Dioxide. Carbon Dioxide concentration shall not exceed 0.5% by volume (1.5 of BDB) .

3.3.2.3 Nitrogen and Inert Gases. No absolute limts are established on concentrations of nitrogen and the inert gases. However, it is the objective that these gases approximate the standard compositions of Table A-I.

3.3.2.4 Noxious and Toxic Gases. The concentrations of all gases shall be maintained below the noxious or toxic limit, whichever is lower. The toxic limits shall be in accordance with the American Conference of Governmental Industrial Hygienists Threshold Limit Values (TLV) where TLV are specified for the gas in question. "The Threshold Limit Values" refer to airborne concentrations of substances and represent the upper limit of conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect."* Specific gases which present a potential hazard to be guarded against in the BISS system are given in Table A-III along with TLV or comments on concentration.

* TLV 1965 p.1

TABLE A-111. GAS CONCENTRATION HAZARD LIMITS

Gas	TLV PPM	Comments
CO_2	5000	
N_2	*	Simple Asphyxiant
H_2S	20	Hydrogen Sulfide
H_2	*	Toxic Hazard slight. Explosive range 4.1% to 74.2% in air
CH_4	*	Methane-similar to H_2
$(CH_2)_2$	50	Ethene
$(CH_2)_2$ O	50	ETO
Cl_2 CF_2	1000	Freon 12

* TLV not defined

Noxious gases and vapors shall be maintained at concentrations sufficiently low that they are not offensive to the technician in the suit. (No noxious gases or vapors were detected during tests with the BISS mock-up on contract NAS **1-6537).**

3.3.3 Body Contact Gas Composition

Any gas mixture supplied for body cooling shall be of the same composition as that used for the supply of breathing gas. Without exception, any gas mixture safe for breathing presents no cutaneous hazard.

3.3.4 Gas Distribution

Gas supply for breathing shall be directed to the face or head area and shall not flaw Over body surface areas enroute to the face. Both breathing and cooling gases may be supplied by a common line to the suit, but must be distributed independently at the suit. Active purging of the suit and helmet shall be employed to prevent buildup of noxious of toxic gases.

3.3.5 Skin Contact Materials

All materials employed in the system in contact with the skin of the technicians shall be materials which have histories of acceptable use in contact with the skin without causing irritation. In no case shall a material be employed which has a history of causing acute or extended irritation in any significant percentage of the population or has caused chronic ailments in otherwise healthy adults. Whenever possible, materials used in contact with the skin shall be materials which have been previously approved by the F.D.A. for medical applications for skin contact or body implantation.

3.3.6 Temperature/Humidity

The BISS System shall provide control of the temperature and humidity of the environment. The nominal environment inside the suit shall be conditioned air at 70°F and 40%RH. The air supply shall be adjustable to give dry bulb supply temperatures from 68°F to 78°F and wet bulb temperatures from 57° to 64°F across this dry bulb temperature range at a flow rate of 20 scfm.

3.3.7 Gas Flow Rate

The air supply shall be adjustable from 0 to 20 scfm.

3.3.8 Biological Environment

See Hygiene, Section 3.6

3.3.9 Pressure

The suit system shall be at a nominal pressure of 760 mmHg with a pressure differential across the outer suit and tunnel of up to 4" of water gage (7.5 mmHg) inward.

3.4 Technician Safety

The highest priority in the design of the system shall be given to the safety of the suit occupant. This shall include, as a minimum, reliability of the life support equipment, protection of the occupant from physical injury, provision for rapid emergency egress from the suit (aided or unaided), and provisions in the facility operating plans to maximize the protection of the suit occupant.

3.4.1 Life Support Reliability

The life support system shall have a probability of not less than .99 of providing a safe operating environment for the operator during any working shift (see also Endurance, Section 3.8). The safe environment shall be that defined in Section 3.3 above.

3.4.2 Life Support Backup

A back-up gas supply shall be provided to maintain a safe breathing environment for the suit occupant in the event of life support system failure. This system shall have sufficient capacity to support the suit occupant for a period of not less than 20 minutes (fifteen minutes planned maximum plus five minutes reserve).

3.4.3 Physical Protectors

As a minimum, the suit shall provide protection of the head,. face, and feet from sources of injury such as falling objects. In addition, the BISS materials, construction, and operating instructions shall be designed and selected to minimize the potential of rips, tears, punctures, or cuts.

3.4.3.1 Helmet. The helmet shall include "hard hat" provisions equivalent to an industrial safety hat and a safety faceplate providing protection from flying objects equivalent to the protection provided by safety glasses.

3.4.3.2 Boots. The boots shall incorporate safety caps to protect the toes and arch from dropped objects. The outer soles of the boots shall be of non-skid construction to minimize the hazards of slipping or falling.

3.4.4 Safety Checking and Monitoring

Checking and monitoring of the environment of the BISS and monitoring of the physiological response of the operator to the environment and working conditions shall be performed to assure operator safety. Automatic alarms shall be provided to bring attention to hazards or abnormal personnel conditions. The measurements of Table A-IV shall be provided and shall. incorporate alarms.

TABLE A-IV. SAFETY MONITORING

PARAMETER	FREQUENCY	ALARM LIMIT
Toxic gas concentration (notes 1 & 2)	Continuously during occupancy	TLV (table 3.2)
Oxygen Concentration	"	17% min., 36% max. by volume
CO_2 "	"	.5% by volume
Pulse rate	"	Further study required (note 3)

NOTES: (1) Gases to be monitored shall be those toxic gases found to be characteristic of system performance (if any). To date no such gases have been observed.

(2) ETO concentration shall be maeasured at least after each ETO cycle.

(3) See Section 4.9 on medical monitoring.

3.4.5 Material Flammability

The suit and tunnel shall be constructed of material which is non-flammable or will not support combustion (materials shall be capable of passing applicable ASTM standard test or equivalent).

3.4.6 Emergency Procedure

Procedures and/or facilities shall be provided to permit rapid egress of a conscious occupant from the suit or rapid removal of an unconscious occupant. Three classes of emergency conditions are defined in Table A-V with appropriate procedural criteria.

TABLE A-V. BISS EMERGENCY CLASSIFICATIONS

Class	Conditions	Procedural Criteria
I	Loss of breathing gas supply Major system leak Toxic gas exceeds TLV	Activate emergency gas supply Operator may complete immediate task Operator shall be clear of the suit within 15 minutes
II	Loss of temperature control	Operator may complete immediate task Operator shall leave the suit if suit temperature goes below 60°F or above 100°F.
III(a)	Operator sustains physical injury	Operator shall be removed from the suit within 4 minutes and shall then receive immediate medical attention (a respirator shall be available)
(b)	Operator faint or unconscious Operator heart failure Operator respiratory failure Operator stroke	Operator shall be removed from the suit within 2 minutes (objective - 4 minutes requirement) and shall then receive immediate medical attention (a respirator shall be available)

3.4.7 Electrical Safety

The **BISS** System design and operating procedures shall be designed to prevent accumulation of static electricity which would cause a discharge between the **BISS** suit or tunnel and any grounded object in the Assembly/Sterilizer.

The **BISS** system shall electrically insulate the occupant from any unprotected electrical contacts in the Assembly/Sterilizer.

3.4.8 Standard Operating Procedures

The operating procedures for the **BISS** in the Assembly/Sterilizer shall be designed to maximize protection of the **BISS** suited operator. Specific procedural criteria are:

- When a man is in the **BISS** suit, there shall always be at least one other man in the chamber to provide any necessary assistance. Work plans and detailed layout shall be designed **so** that physical restrictions of mobility do not limit one man from being able to assist his nearest co-worker in the chamber.

- The environment and **BISS** occupants' response to the environment shall be continuously monitored by personnel trained to interpret the observed data and initiate any immediate corrective action required.

- Personnel shall be available outside the chamber to render any necessary assistance for routine or emergency entry or egress.

- A test director or coordinator shall observe all **BISS** operations in the Assembly/Sterilizer. He shall be responsible for the direction and coordination of all emergency activity and shall determine when and if system bio-integrity must be broken to rescue a **BISS** occupant.

- Trained medical personnel shall be on call at all times when personnel are in the **BISS** suits. These personnel shall be able to reach any **BISS** hatch with necessary emergency equipment within two minutes of being called.

- All personnel shall receive a medical examination prior to the start of the work shift.

3.5 Human Factors

The system shall be designed to high standards of human engineering practice. Where applicable the Bioastronautics Data Book, NASA SP3006, will be used as the primary baseline of human factors data,

3.5.1 Entry and Egress

The design shall provide maximum ease of entry to and egress from the suit through the tunnel. The tunnel shall be longitudinally contracted (or reefed) during entry and egress. Specialized equipment required to aid entry or egress shall be considered as part of the **BTSS** system.

The maximum times alloted to routine entry to, and egress from, the suit shall not exceed 15 minutes with 5 minutes as a design objective. The times for emergency egress are defined in Table A-V.

It is intended that the requirement for routing entry **and** egress be satisfied with the suit occupant unaided by other personnel. Assistance by personnel inside the sterile chamber shall not be employed for routine entry and egress.

Entry and egress times defined herein include the time required to extend or contract the tunnel.

3.5.2 Work Shift Duration

The BISS system shall permit a four hour period without interruption. **It** is an objective that the system permit an eight hour work shift in two four-hour periods with a break for rest and eating between periods. (Further testing is required to determine whether this is feasible).

3.5.3 Occupant Comfort

In addition to the provision of an environment in accordance with Section 3.3, the system design shall provide the maximum possible comfort for the occupant. Suit parameters applicable to this criteria are: types and locations of padding, suit stiffness, freedom of movement, magnitude and location of suit weight bearing points, unbalanced hydrostatic pressures, etc.

3.5.4 Visibility

The design shall not limit the vision of the occupant either by obstruction of visual field or by aberration. The visual field with the head upright and facing forward shall be not less than $+110^{\circ}$ in the horizontal plane and not less than $+600$, -80° in the vertical plane. The helmet and face plate shall be **so** designed that this visual field relative to the head is maintained when the neck is subjected to the ventral and dorsal flexions and right and left rotations of Paragraph 3.5.5. Provision shall be made to prevent fogging of the fade plate. The design shall accommodate the wearing of eyeglasses.

3.5.5 Mobility

The design shall permit maximum mobility of the suit occupant consistant with the other system criteria. The occupant shall be capable of movement throughout a semicircular region with a radius of 60 feet, centered at the hatch. A twenty foot: vertical ascent capability is also required. (Practical limitations of suit and tunnel support may limit ascent with the tunnel fully retracted; however, as a minimum, the system should provide ascent capability equal to the radial distance to the hatch center in a plane parallel to the floor, up to a maximum of 20 feet ascent (i.e, half cylinder of 60 foot radius and 20 foot height with a 45° half cone removed).

The BISS system shall provide as a design goal no more than 10% decrement in the joint motions, and as a requirement no more than 25% decrement. Joint motions for most body joints are defined in Figure A-1. In addition, the following normal neck motions are defined:

. Ventral flexion	60° Mean	12° S.D.
. Dorsal flexion	61	27
. Right or left flexion	41	7
. Right or left rotation	79	14

The system design shall also specifically provide maximum unrestricted capability for:

- 45° forward bend at the waist
- Squatting
- Scaffold or ladder climbing
- Walking

3.5.6 Manual Dexterity

The BISS system shall provide for maximum technician finger and hand dexterity compatible with overriding criteria such as bio-integrity and safety. Manual tasks to be considered in assessing dexterity are:

- Use of common hand tools
- Fastener starting
- , Modular assembly operations
- Connector mating and demating operations.

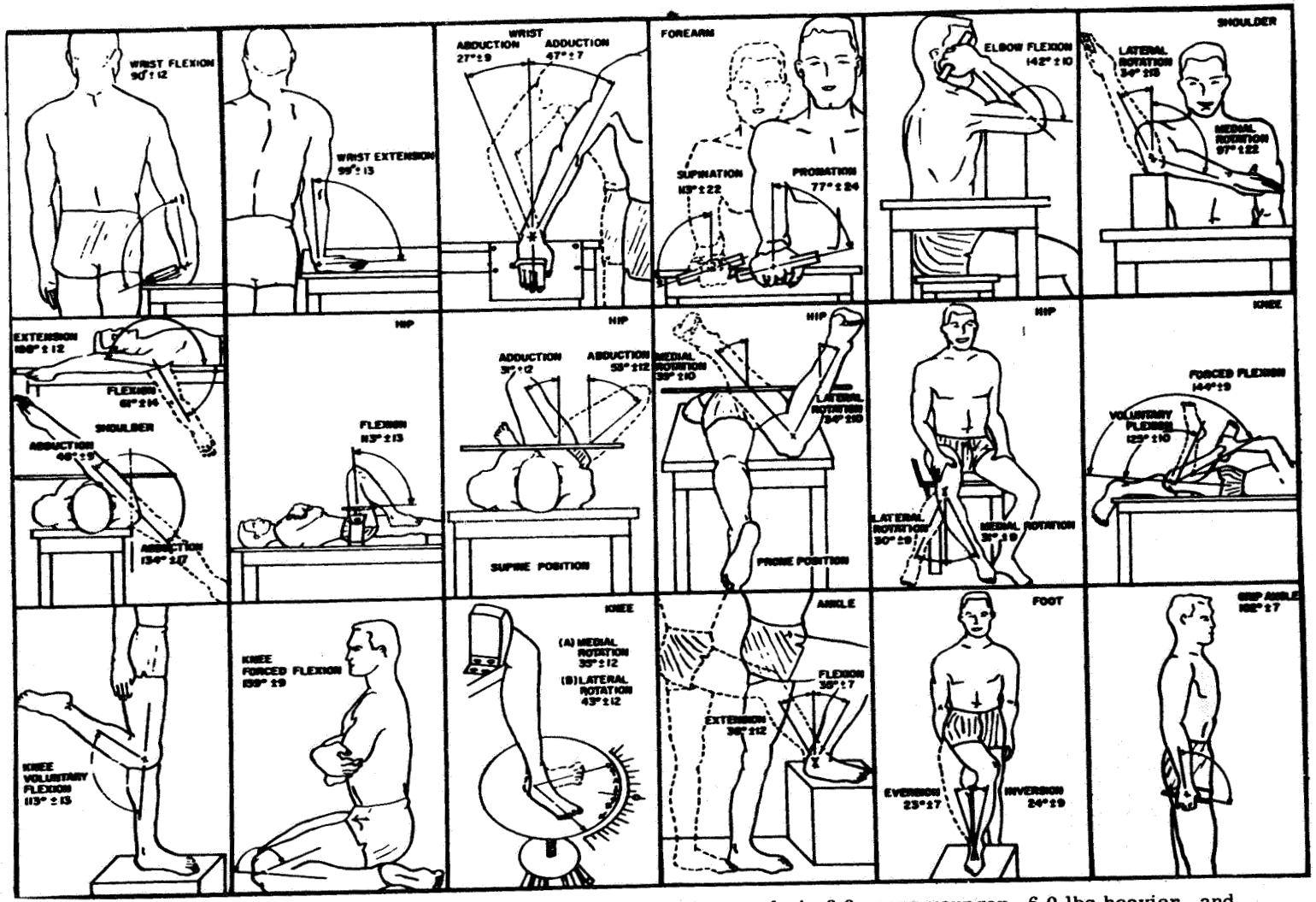

Figure A-1 Joint Motion

Ranges of joint motion in 39 young men, showing the median value in degrees, ± 1 standard deviation. If ± 2 SD are taken, 95% of the sample of 39 is included. Compared with the 1950 Air Force survey of over 4000 flying men, this sample is 6.8 years younger, 6.0 lbs heavier, and 1.4 inches taller.

Source: Adapted from analysis by Barter et al. [2] of data from Dempster [13].

Source for present document: BIOASTRONAUTICS DATA BOOK, NASA SP30006, 1964

3.5.7 Communications

The BISS system shall provide aural communication between suit occupants and between a suit occupant and control or support personnel through the use of an electrical or electronic communications system. A system of hand signals can be employed for back-up in the event of communications system failure. However, as a minimum, this shall be augmented by a signalling system incorporating the following:

- A panic button in or on each suit to draw immediate attention of control personnel to a suit occupant who needs assistance or has lost aural communication.

- A sounder that can be heard by all suited personnel to draw immediate attention of suit occupants to hand or other visual signals from control personnel.

The following additional back-up communications equipment shall also be considered for employment in the Assembly/Sterilizer - BISS:

- A loud speaker system in the Assembly/Sterilizer main chamber with sufficient power capability to create an audible, intelligible voice signal in the BISS helmet.

3.5.8 Suit Fit

The BISS suit shall be designed to provide a comfortable fit for the 50th to 80th percentile by height and the 20th to 80th percentiles by weight of American males in the *25-34* year old age group. If necessary, the suit fit shall be adjustable to accomplish this capability. To the maximum extent possible within these limitations, the suit shall be form fitting with a minimum of protruding bulges or folds of suit materials. Folds necessary to accommodate the smallest acceptable occupant in the suit shall be **so** designed and located as to minimize the hazard of snagging.

3.6 Hygiene

The BISS system design and operating procedures shall incorporate provisions for interchange of suit occupants with a minimum of delay without presenting offensive or unhygienic conditions for the second occupant.

The BISS system will employ an appropriate undergarment, or inner-suit, **so** that an occupant leaving the suit takes with him as large a percentage as possible of the microbial life he produced or liberated during occupancy.

Following egress of a suit occupant, all or portions of the suit interior will be sanitized and disinfected to remove or inactivate any significant residual microbial life from the occupancy. The procedure shall require less than *30* minutes to perform and shall consist of at least the following:

- Sanitize - Clean with detergent solution and rinse
- Disinfection - Spray or wipe with a suitable disinfectant
- Rinse - to remove residual disinfectant if necessary
- Dry

This procedure shall render the suit physically clean and will destroy potentially pathogenic organisms. The organisms of primary concern are:

- Mycobacteri si
- Staphylococcus spp
- Streptococcus spp
- Candida albicans
- Pathogenic fungi
- Respiratory viruses

The disinfectant used shall be non-toxic and non-noxious or the procedures for operation shall provide for removal to the extent that residual concentrations in the suit material and suit atmosphere are below toxic or noxious limits. If they are not inherently non-toxic and non-noxious, maximum acceptable concentrations shall be defined and added to Paragraph *3.3.2.4*.

3.7 Equipment Environment

3.7.1 Outside Assembly/Sterilizer Main Chamber

The environment outside the Assembly/Sterilizer main chamber shall be assumed to be a minimally air-conditioned industrial environment for both operating and non-operating conditions.

3.7.2 Inside Assembly/Sterilizer Main Chamber

In addition to cleaning of the suit and tunnel outer surfaces in the same manner as described in Paragraph 3.6 for inner surfaces, the suit and tunnel will be exposed to the four environmental modes of the Assembly/Sterilizer chambers as described in Table A-VI. The BISS system is operational in Modes A and D and non-operational in Modes B and C.

3.7.3 Inside Suit and Tunnel

When the Assembly/Sterilizer system is in Modes A and D and the operator is in the suit, the environment shall be in accordance with technician environment defined in Section 3.3. When the system is in these modes, the suit and tunnel inner surfaces may be exposed to the cleaning procedure described in Section 3.6.

When the system is in Modes B or C or is unoccupied in the modes of A and D, the environment in the suit and tunnel will be air of atmosphere composition at nominally the same temperature as the main chamber gas. If this gas mixture produces degradation of the materials or equipment inside the suit and tunnel at elevated temperatures of the modes of B and C, the suit can be filled with nitrogen in these modes.

The pressure inside the suit and tunnel will be at nominally atmospheric pressure at all times (i.e., up to 4" H20 below chamber pressure).

3.8 Endurance

The BISS shall be designed to operate in accordance with the criteria herein for a period of not less than 360 (objective 1000 hr) hours of continuous trouble free operation without maintenance beyond replacement of filters, and equipment other than the suit and tunnel shall be designed for a total operating life of not less than 20,000 hours with maintenance.

The suit and tunnel of the BISS and all equipment integral thereto shall be capable of withstanding, without violation of any design criteria, 10 cycles each (20 cycles objective) of cleaning of external surfaces, ETO/FREON decontamination, and dry heat sterilization and 90 cycles (180 cycles objective) of cleaning of internal surfaces.

The total life of the BISS suit and tunnel or parts thereof shall be up to 24 months from production to end of life. This total shall be composed of a storage life of up to 12 months and a service life of up to 12 months. Consideration may be given to extension of storage life without exceeding a total life of 24 months.

TABLE A-VI. ASSEMBLY/STERILIZER SYSTEM
ENVIRONMENTAL MODES

MODE A Characteristics	Maintenance and Transfer - AIR * . Class 100 vertical laminar flow of 90 ± 15 fpm . Atmospheric air . Temperature of 75 ± 5°F . RH less than 90% . Pressure - ambient
MODE B Characteristics	Decontamination - ETO/FREON * . Class 100 vertical laminar flow of 90 ± 15 fpm . ETO/FREON (12%/88% - W/W) . Temperature of 70 to 150°F . RH of *40* to 60% . Pressure up to 4" H_2O gage
MODE C Characteristics	Sterilization - Nitrogen * . Class 100 vertical laminar flow of 90 ± 15 fpm . Nitrogen . Temperature of 70 to 320°F . RH less than 1% above 200°F . Pressure up to 4" H_2O gage
MODE D Characteristics	Operation - Nitrogen * . Class 100 vertical laminar flow of 90 ± 15 fpm . Nitrogen . Temperature of 75 ± 5°F . RH of 20 - 50% . Pressure up to 4" H_2O gage

* Subject to revision based on future consideration of the need for laminar flow in the Assembly/Sterilizer facility.

When either the service life or endurance cycle limits have been reached, the BISS suit and tunnel shall be removed from service.

3.9 Sterile Maintenance

The **BISS** system design shall permit at least one replacement of the tunnel and suit without jeopardizing the sterility of the main chamber.

4.0 Definitions

4.1 BISS - Bio-Isolator Suit System

A system which permits a technician to enter and **work** in a sterile chamber while being biologically and topologically isolated from the system. The BISS system consists of the equipment defined below.

4.1.1 BISS Suit - (or Suit and Tunnel)

The physical envelop which forms the barrier between the technician and the sterile environment of the chamber.

4.1.1.1 Outer Suit. The portion of the BISS Suit which envelops the technician and includes the following:

- Suit shell (or outer shell) - covers the occupants body exclusive of head, feet, and hands.
- Helmet - covers the occupant's head.
- Gloves - covers the occupant's hands.
- Boots - covers the occupant's feet.

4.1.1.2 Tunnel. The portion of the BISS Suit which connects the back of the outer suit to the hatch, and through which the technician enters and leaves the outer suit.

4.1.1.3 Inner Suit. The garment worn by the BISS suit occupant to provide removal of excess body heat. The garment will be air cooled.

4.1.1.4 Personal Under Garments. The garments worn by the BISS suit occupant to separate the surfaces of his body and extremities from the inner surfaces of the outer suit, inner suit, gloves, and boots. These garments will consist of fabric under wear, light weight fabric gloves, and socks or slippers.

4.1.2 Life Support Subsystem. The equipment of the BISS system which provides and maintains a healthful, comfortable, habitable environment for the technician in the BISS suit.

4.1.2.1 Gas Supply Equipment. That equipment which provides the conditioned breathing and cooling gas to the BISS suit occupant. This includes air conditioning equipment, distribution hoses, regulators, manifolds, etc. This includes both normal and back-up gas supply and emergency oxygen enriched breathing supplies.

4.1.2.2 Gas Scavenging Equipment. That equipment which provides a power exhaust of the BISS suit to remove expired gas, cooling gas, and gases released by the body of the occupant. This equipment shall, with the gas supply equipment, provide pressure control of the BISS suit.

4.1.3 Communications Subsystem

The equipment and procedures whereby suit occupants communicate with each other and with personnel outside the chamber.

4.1.4 Ancillary Equipment

Equipment needed to make the BISS a working system but not specifically included in the above categories. Examples are:

- Hatch Assembly
- Tunnel support boom
- Tunnel reefing mechanisms and equipment
- Suit donning rack.

4.2 Assembly/Sterilizer

A facility for: the decontamination and sterilization of a spacecraft with subsequent checkout, assembly, and repair in a sterile environment. The BISS system will be part of the Assembly/Sterilizer.

APPENDIX B: VERTICAL BISS TUNNEL INVESTIGATION

APPENDIX B: VERTICAL BISS TUNNEL INVESTIGATION

1. INTRODUCTION

The present BISS Concept employs a horizontal tunnel connecting the back of the suit to the hatch assembly. A vertical tunnel approach has been conceived which offers relief of some of the problems associated with reefing and support of a horizontal tunnel. The vertical tunnel concept is described herein along with a description of limited testing done on a mock-up of the tunnel.

2. DISCUSSION

The tunnel configuration which has received primary consideration for BISS is the horizontal tunnel described in the body of the report. The reefing and tunnel support problems attendant to this configuration suggested the consideration of an alternate tunnel configuration to ease or obviate these problems. The concept of a vertical tunnel extending from the back of the BISS suit to a hatch in the Assembly/Sterilizer ceiling was developed and subjected to limited investigation. This concept is shown schematically in Figure B-1. An important feature of this concept is that no tunnel support boom is required.

The BISS worker is lowered into the reefed tunnel and dons the suit in an antechamber above the main chamber, then a hatch to the main chamber is opened and the suit occupant is lowered to the main chamber floor. Once on the main chamber floor, the suit occupant is free to move about and perform his assigned work.

Reefing of the vertical tunnel should be less complex than reefing of the horizontal tunnel because the vertical tunnel appears to be compatible with a semi-rigid tunnel design (soft tunnel with circumferential supporting rings or a fine pitch helix). Also, the weight of the vertical tunnel does not tend to cause uneven drag of the tunnel material on the tunnel during reefing.

The advantages and disadvantages of the vertical tunnel compared with the horizontal tunnel are summarized below.

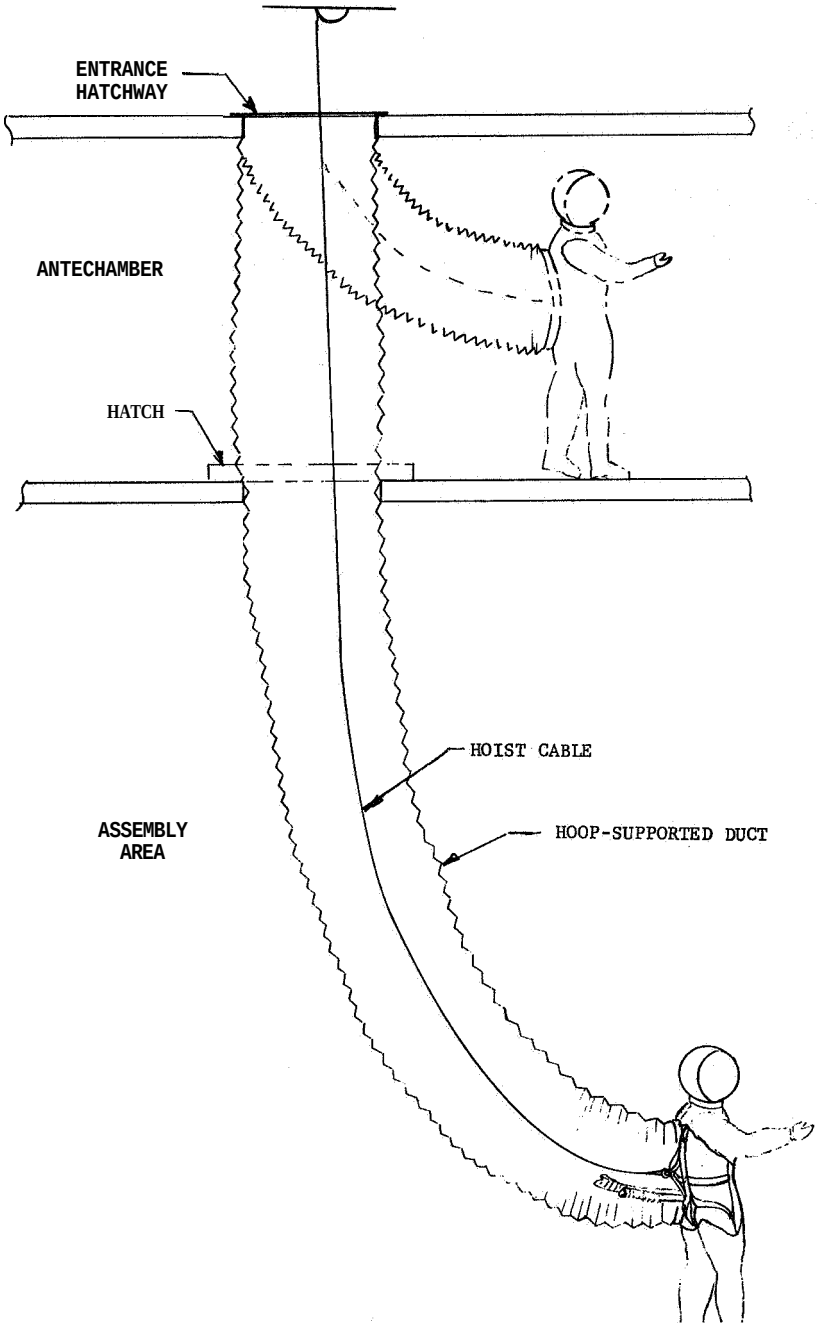

Figure B-1. Vertical Tunnel Concept

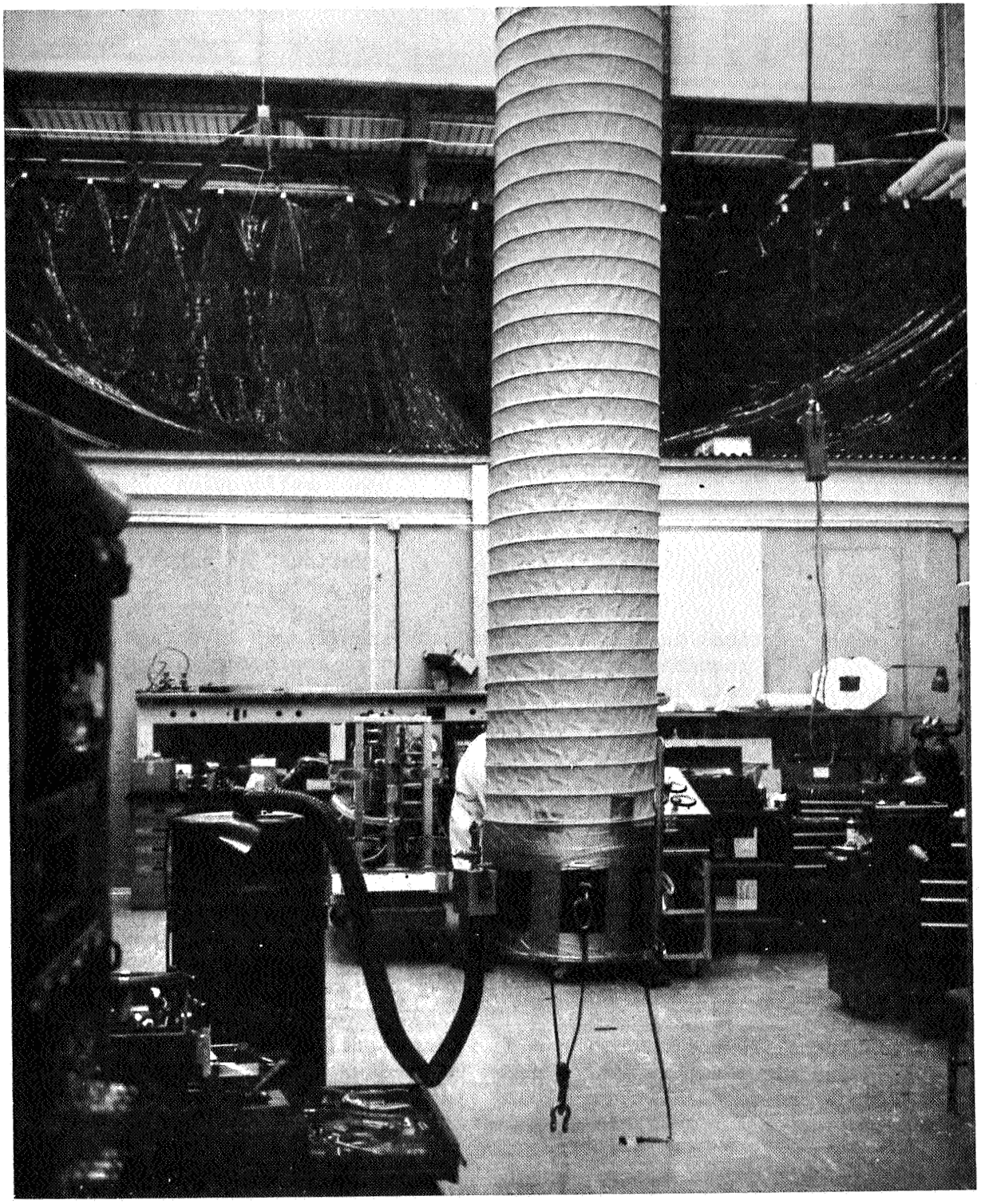

Figure B-2 Vertical Tunnel Test Set-Up

ADVANTAGES	DISADVANTAGES
. Does not require support boom	. More occupants required to cover the same area
. Reduced tunnel length	
. Virtually unlimited vertical mobility of occupant.	. Limited horizontal mobility of occupant.
. Greater ease of several occupants working close together	. Suit donning and doffing are more complicated
. Machine aided emergency egress can be accomplished without assistance from other chamber occupants.	. Emergency egress cannot be aided by other chamber occupants in the event of equipment malfunction
	. Regardless of any other considerations, an antechamber must be employed.

While the vertical tunnel does offer many significant advantages, much more study is required to define a full system employing the concept and perform a detailed trade-off against the horizontal tunnel concept. The advantage of not requiring a boom for tunnel support is of major importance and makes this concept worthy of further study.

One disadvantage of particular importance is the limitation of horizontal mobility of the suit occupant caused by a vertical tunnel. This limitation probably means that more suit occupants would be required to perform the same work functions performed by personnel with horizontal tunnels, and that their work efforts would have to be more closely coordinated. Further study of the vertical tunnel may show that the optimum system should employ vertical tunnels in high personnel density area in the chamber (e.g., around vehicle sections) and horizontal tunnels for work around the periphery (e.g. for pass-through operations).

The vertical tunnel concept can be incorporated in an Assembly/Sterilizer using any air flow pattern than can be used with the horizontal tunnel. Although the vertical tunnel would significantly complicate the upper plenum design for a vertical laminar flow system, it appears that it would actually cause less disruption of the gas flow in the area of the vehicle sections or work pieces.

3.0 TESTING PERFORMED

To obtain some quantitative date for assessment of the degree of difficulty of horizontal movement with a vertical tunnel, a limited test program was performed. The simulation set-up is shown in Figure B-2.

3.1 Procedures

The 25" diameter 10' long neoprene/cotton tunnel reinforced with a helical wire coil was capped at both ends and a vacuum line and manometer were attached to it to provide a means of evacuating the tunnel and monitoring the internal gauge pressure. The tunnel was evacuated and vacuum flow rate and counter-weights were adjusted to provide an internal pressure of -4" H_2O gauge with the tunnel in equilibrium. The distance of the tunnel above the floor was measured and then the tunnel was pulled laterally distances of 2, 4, 6, 8, 10 and 12 feet while the distance to the floor was maintained constant. The lateral force required for each displacement was measured by means of a Hunter Force Gauge (0-150 lbs. cap.) as shown in Figure B-3.

Vacuum flow rate and ballast were then adjusted to provide an internal pressure of -3" H_2O gauge and the test was repeated.

The ballast was removed and the tunnel was evacuated to collapse it completely.

3.2 Results

The following force/distance data were recorded:

-4" H_2O GAUGE BALLAST 41.5 LB.

HORIZONTAL DISTANCE (FT.)		2	4	6	8	10	12
HORIZONTAL FORCE (LB.)	RUN 1	5	10	14	23	*	
	RUN 2	4	9	13	17	23	28

* Inadequate allowance was made for extension, so that at 10 ft. the tunnel was completely extended. The tunnel was retracted approximately 50% and the test repeated (run 2)

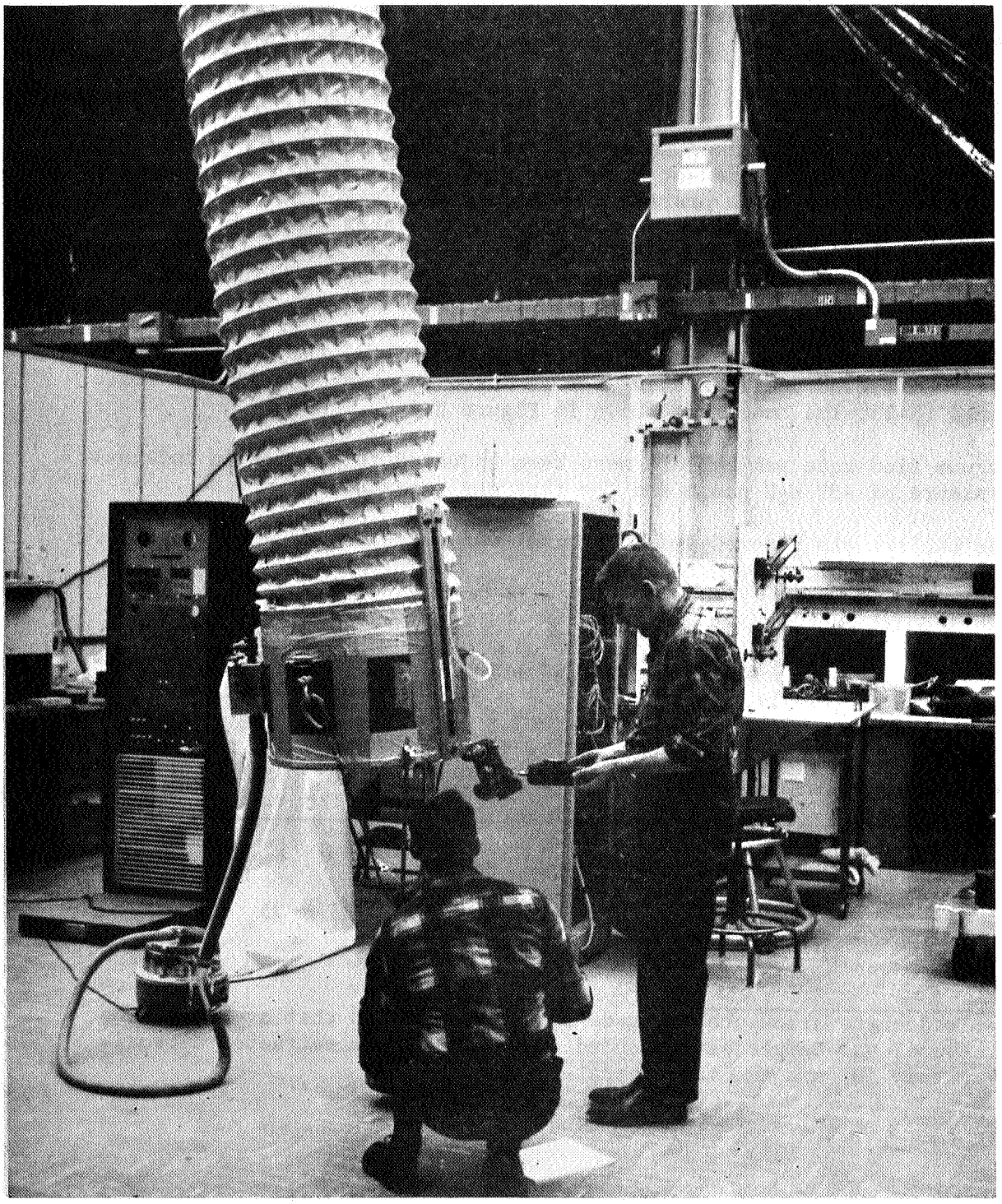

Figure B-3 Measurement of Horizontal Farces

-3" H_2O GAUGE BALLAST 24.0 LB.

HORIZONTAL DISTANCE (FT.)	2	4	6	8	10	12
HORIZONTAL FORCE (LB.)	4	8	11	14	21	22

3.3 Conclusions and Comments

(1) The difference in forces between runs 1 and 2 under 4" H_2O were caused by resistance of the tunnel to extension, probably attributable to the helical spring reinforcement.

(2) Horizontal restoring force is a function of suspended weight, which is a function of tunnel overpressure.

(3) A two hundred pound man has difficulty in maintaining a 28 pound horizontal force on a smooth floor when wearing leather soled shoes. Such a force is very fatiguing when maintained for more than a few minutes at waist level.

(4) Reduction of overpressure is accompanied by reduction in ballast, resulting in lowering of the force required for horizontal motion.

(5) Constant force spring extenders would lower the effective suspended weight if used in place of ballast. This would decrease the force required for horizontal motion.

(6) The tunnel acts as a very effective hoist for raising and lowering when the overpressure is suitably adjusted.

(7) Complete contraction of the tunnel results in a minimum internal volume with the reinforcing hoops being shifted laterally and overlapping to reduce the through-tunnel opening to perhaps 30% of its full area. (This condition can be avoided with a reefing tube).

4. RECOMMENDATION

It is recommended that the vertical tunnel concept be studied further to fully identify its potential for the Assembly/Sterilizer and the cost in terms of system complexity at which this potential can be realized. In particular, the concept of using both horizontal and vertical tunnels should be considered in detail to permit realization of the benefit which may accrue from an integrated system employing both types of tunnels.

APPENDIX C: TRIP REPORT - MEDICAL MONITORING DISCUSSION

1. Purpose
2. Background
3. Discussion
4. Conclusions
5. Recommendations

APPENDIX C: TRIP REPORT - MEDICAL MONITORING DISCUSSION

4 April 1967

VISIT TO: Dr. James A. Roman, Edwards, AFB, Calif.

GE PERSONNEL: J. Crawford, Project Engineer
W.S. Kip, D.O.

1. PURPOSE

The purpose of the trip was to discuss BISS Phase II mock-up EKG's with a NASA/Edwards expert. These electrocardiograms were taken with telemedics RKG. The result of the discussion was to dispel concern about apparent abnormalities in the EKG's. Physiological response to the BISS environment does not appear to present a problem to further development of the system.

2. BACKGROUND

During test planning for the BISS program, contract NAS 1-6537, it was decided that a one lead electrocardiogram would be taken on the suit occupants to provide a quantitative measure of their physiological response to the environment by recording heart rate. The EKG's were taken using the Telemedics RKG transmitter model R-100, feeding a GE electrocardiograph. Two aspects of the resultant EKG's were felt to necessitate further investigation: the recorded heart rates were higher than had been expected, and some of the records displayed anomalies (called artifacts by cardiographers) which on cursory examination could be interpreted as indicative of deviant heart performance.

Arrangements were made through the NASA/LRC technical representative on NAS 1-6537 to discuss the EKG's with Dr. James Roman of NASA Flight Research at Edwards AFB California. Dr. Roman has had extensive experience in monitoring physiological response of personnel to flight environments, and it was felt that this experience would be of considerable value in making a proper interpretation of the EKG's from the BISS studies.

3. DISCUSSION

Dr. Kip and Mr. Crawford visited Dr. Roman at his office on 3/29 to discuss the EKG's. After a brief presentation by Mr. Crawford on the BISS concept and BISS Phase II design, Dr. Kip presented the EKG's for discussion ilong with attendant medical observations about the environment and non-quantitative measurements of BISS occupant response to the environment. The EKG's were then reviewed and discussed in detail with a running discussion of EKG's and personnel response to special environments as measured by EKG.

Three themes recurred throughout the discussion:

1. Medical interpretation of EKG's taken under special environments cannot be properly based solely on experience from measurements made on personnel under standard environmental conditions. (e.g., test pilots in-flight EKG cannot be reasonably interpreted on the basis of experience from a "Master's" test).

2. In making interpretation of EKG's from special environments, particular care must be taken to distinguish between physical and non-physical stress. (Heart rates which would be indicative of incipient collapse from exhaustion if due to physical stress have been found to be relatively common for extended periods for some test pilots).

3. Electrocardiographic recording under special environments is, in general, fraught with equipment difficulties which often manifest themselves in the EKG's as artifacts which can be interpreted as heart malfunctions if caution is not exercised to isolate the cause of the artifacts.

In a point by point review of the EKG's which demonstrated significant artifacts, Dr. Roman said that he felt that each of these was explainable in terms of equipment malfunction and he felt that this was their cause, NASA/USAF have repeatedly experienced artifacts of the nature seen on the EKG's which have been resolved to be equipment performance deficiencies, not heart malfunctions.

In fact, Dr. Roman said that assuming that the observed artifacts are electrical of mechanical in nature, the EKG's are "suspiciously normal."

Further, even if these artifacts were not caused by equipment deficiencies, Dr. Roman saw no great cause for concern about the artifacts. Such artifacts, which are regarded as cause for concern in conventional cardiography, have been frequently encountered during in-flight monitoring of personnel and have been determined not to be cause for concern in this special environment. A reasonable extension to the BISS suggests that such artifacts, even if true heart performance artifacts, should not, in themselves, be cause for concern.

Heart rate interpretations require some further measure of the degree of physical stress imposed on the subject during monitoring. While high heart rates due to physical stress are cause for at least caution, high heart rates due to non-physical stress are, in general, not cause for concern. Dr. Roman gave several relevant observations based flight experience.

1. The "slot man" in the USAF Thunderbirds aerobatic team has a heart rate of 175 bpm for periods of up to 4 hours regularly with no adverse effects. (Such a high heart rate due to physical stress would indicate incipient collapse due to enhaustion).

2. During the 1950's in balloon experiments pulse rates as high as 170 bpm with respiration rates of 70 were experienced on the ground.

3. One of the lead test pilots at Edwards (the most experienced pilot in the world) has a heart rate of 120 bpm sitting on the flight line in the aircraft prior to flight. During flight his heart rate goes as high as 180 bpm. In contrast, a second pilot starts off at 60 and rarely goes above 90.

4. NASA/USAF - Edwards have not been able to correlate heart rate with performance quality. Nor have they seen any correlation between heart rate and "coolness" of pilots.

5. A man's verbal comments are a fairly reliable measure of physical stress. A man under extreme stress is well aware of the fact and will verbally communicate that he is under stress.

6. High heart rates due to non-physical stress should be accompanied by high blood pressure.

Based on the comments of the BISS occupants and the observations of the medical monitor, the high heart rates observed in the Phase II testing cannot be attributed to physical stress. When these heart rates are attributed to non-physical stress, there is no cause for concern.

One further comment made by Dr. Roman is worthy of note. NASA/USAF performed several hundred hours of flight testing without EKG prior to initiation of testing with EKG. The heart rates and artifacts observed on the subsequent in-flight EKG's were such that they would have been cause for considerable concern if it were not known that the pilots involved had performed satisfactorily in the flight environment with no residual indication of medical abnormality.

4. CONCLUSIONS

The EKG's from the BISS Phase II mock-up testing should not be interpreted as indicating any cardiological pathology. The results appear to be as would have been expected had we had sufficient prior experience with personnel in a comparable environment.

5. RECOMMENDATIONS

Proceed with development of BISS and continue to monitor EKG on BISS occupants to develop a history of physiological response to the environment,

Investigate hardwired EKG to remove the RF link as a possible source of artifacts.

Consider use of vector EKG (or multi-lead EKG) to provide more detailed information on heart behavior of BISS occupants.

Consider investigative testing to provide a quantitative measure of physical stress on the BISS occupant.

APPENDIX D: SENSITIVITY ANALYSIS OF CONTINUOUS LEAK DETECTION SYSTEMS

1. INTRODUCTION

The objective of this analysis is to examine concepts for continuous leak detection systems used to infer bio-integrity of the BISS system. The preliminary results of this analysis were presented in Appendix B of report 67SD483 on the present contract.

2. ANALYSIS*

2.1 Basic Relationships

The relationship between detectable hole size and the other parameters of a detection system are analyzed by modeling the simple system shown schematically in Figure D-1. In this simple model the volume V represents an arbitrary partial suit volume, .bounded by suit surface S and monitored by a single detector. A purge flow is employed to transport any leaked gas to the detector orifice. The system parameters other than V are:

Q = rate of leak into volume V through a cylindrical hole

q = rate of permeation into volume V

C_o = Concentration of tracer gas in the region from which the leak and permeation come

F = purge flow into V

C_i = concentration of tracer in purge stream

C(t) = concentration of tracer gas in volume V and exit stream as a function of time.**

These parameters can be stated in any self-consistent set of units.

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* This analysis is based on constant volume systems obeying the perfect gas law and Dalton's law of partial pressures.

** Note that C(0) is not the same as C_o

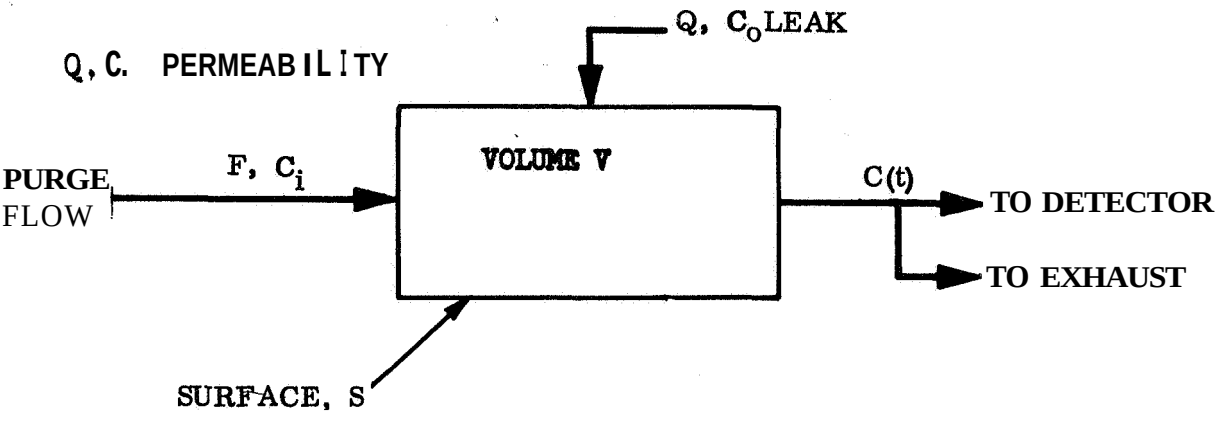


Figure D-1 Conceptual System for Evaluating Leak Detection Sensitivity.

Assuming* perfect mixing of the streams F, Q, and q in V and no sources or sinks of the tracer in V, the differential equation for the concentration C(t) is:

$$\frac{d}{dt} C(t) = \frac{(Q+q)\ C_o + FC_i}{V} - \left(\frac{F+Q+q}{V}\right) C \tag{1}$$

Defining the value of C(t) at time zero as C(0), the complete solution of the equation is:

$$C(t) = \left\{C(0) - \frac{(Q+q)\ C_o + FC_i}{F+Q+q}\right\} \exp\left(-\left(\frac{F+Q+q}{V}\right)t\right) + \frac{(Q+q)\ C_o + FC_i}{F+Q+q} \tag{2}$$

The form of the locus of the concentration is sketched in Figure D-2 as a function of time.

For the system to detect a leak there must be a detectable change in C(t).

Thus the quantity of interest is C(t) - C(0) which is

$$C(t) - C(0) = \left\{\frac{(Q+q)C_o + FC_i}{F+Q+q} - C(0)\right\}\left\{1 - \exp\left(-\left(\frac{F+Q+q}{V}\right)t\right)\right\} \tag{3}$$

The fractional change is

$$\frac{C(t)-C(0)}{C(0)} = \left\{\frac{(Q+q)\ C_o + FC_i}{C(0)\ (F+Q+q)} - 1\right\}\left\{1-\exp\left(-\left(\frac{F+Q+q}{V}\right)t\right)\right\} \tag{4}$$

If the system is assumed to start out leak free (Q = 0), the steady state level approached after several system time constants is:

$$C_{ss} = \frac{q\ C_o + FC_i}{q + F} \tag{5}$$

* A further assumption made is that all gases permeate at a constant rate. The effect of this assumption is discussed later.

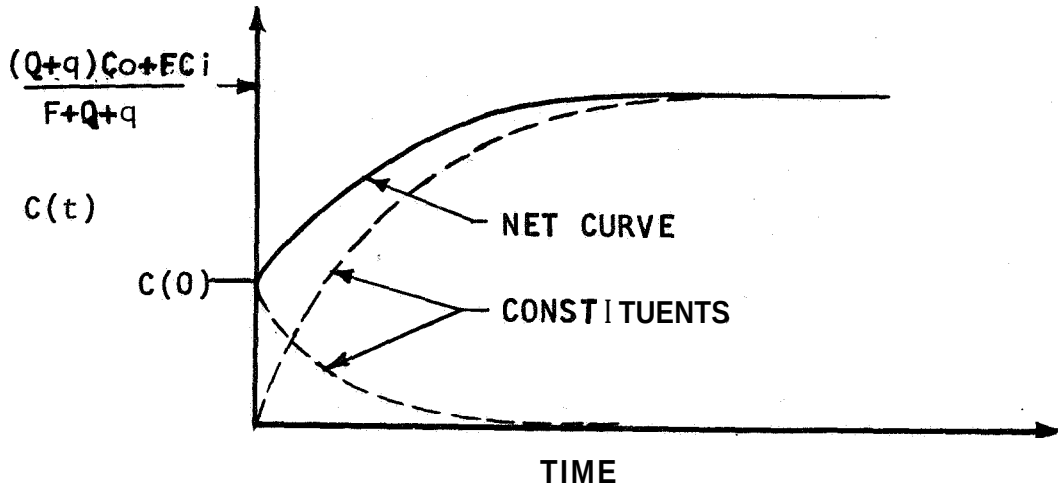


Figure D-2 Concentration As A Function of Time

The **form** of the locus of C_{ss} as a function of the value of F/q is shown in Figure D-3. This figure shows that, as expected, the steady state concentration is essentially C_o for F/q small **and** is essentially C_i for F/q large. This steady state concentration represents a new "initial condition" when considering the effect a subsequent leak, starting at time T, will have on concentration. Equations (2), (3), and *(4)* can be adapted to reflect this by replacing C(0) by C_{ss} and replacing t by t-T. The modified equation **(2)** is:

$$C_T(t) = \left\{ \frac{q\,C_o + FC_i}{q+F} - \frac{(Q+q)C_o + FC_i}{F+Q+q} \right\} \exp\left(-\left(\frac{F+Q+q}{V} \right) (t-T) \right) + \frac{(Q+q)\,C_o + FC_i}{F+Q+q} \qquad (2\text{-A})$$

The amount by which $C_T(t)$ exceeds C_{ss} is indicative of the presence **and** magnitude of a leak. A sketch of equation (2-A) shows a typical time history for a system started at some concentration C(0), reaching a steady state C_{ss}, with a leak starting **some** time later. This is shown in Figure D-4.

At average pressures of approximately one atmosphere, the flow of gases of moderate molecular weight through holes of about one micron is in the transitional region between viscous and molecular flow, tending to be molecular*. For holes greater than 10 microns in diameter, the flow is predominantly viscous.

In the case of molecular flow, the flow rate in cm^3/sec through a cylindrical hole of radius a and length L is given by:

$$Q = 5.26 \times 10^5 \frac{a^3 \Delta P}{M^{\frac{1}{2}} L P} \left(\frac{cm}{sec} \right); \quad \frac{L}{a} > 100 \qquad (6)$$

* Scientific Foundations of Vacuum Technique," S. Dushman, :editor, 2nd edition, pp 80-117, J. Wiley and Sons, Inc. N.Y., M.Y. (1962)

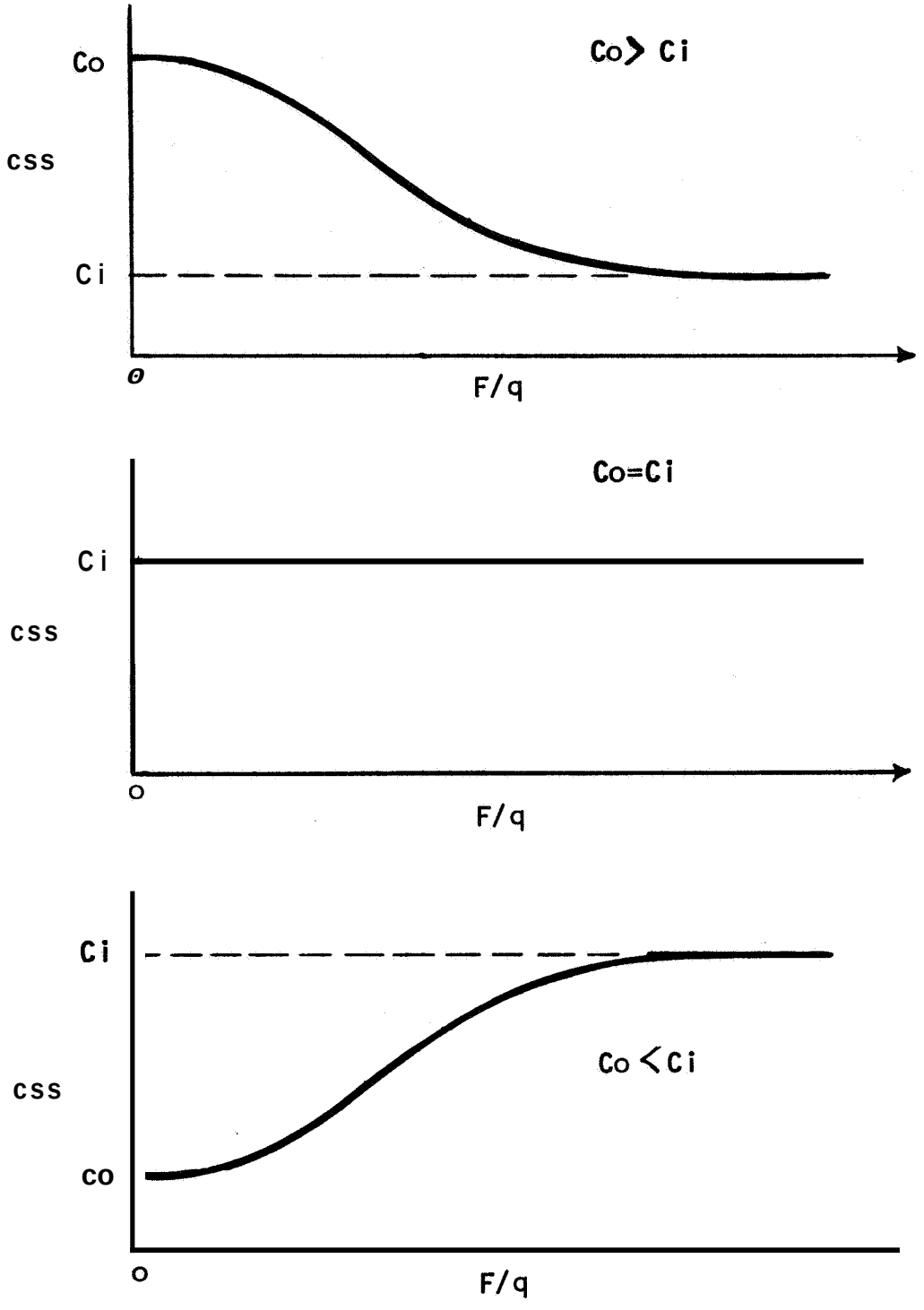


Figure D-3 Steady State Concentration (No Leak).

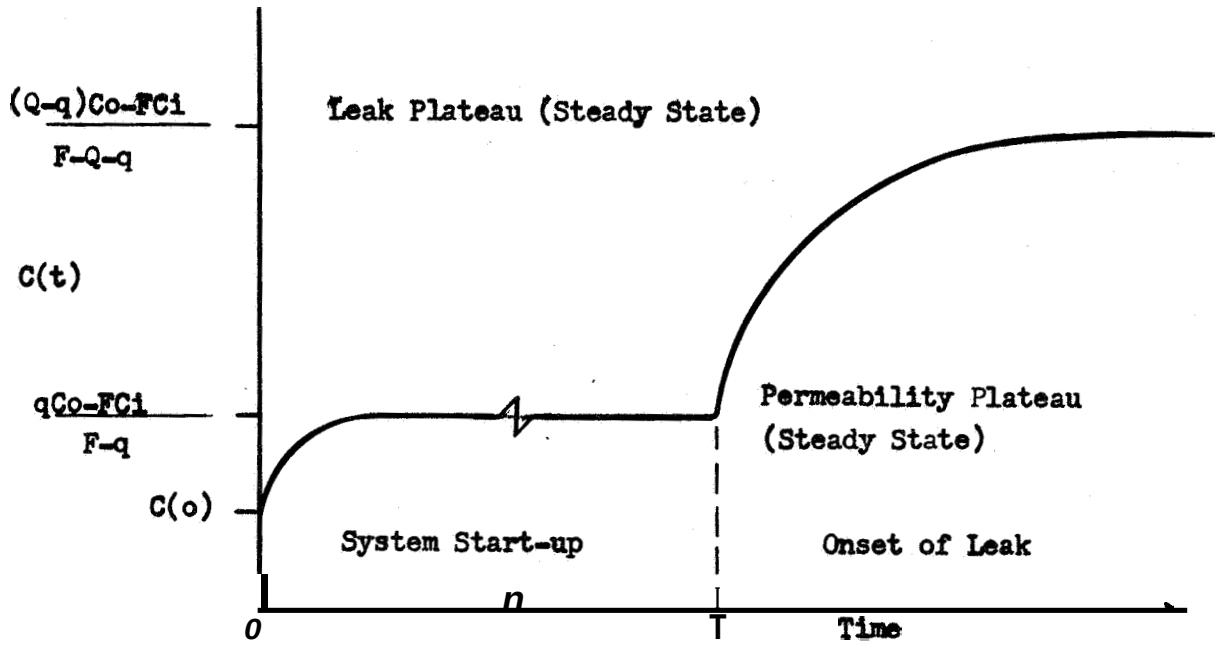


Figure D-4 Typical Time of a system from System from Start-up To Leak Plateau.

Where:

a and L are in cm

M is the molecular weight of the gas

Δ P and P, pressure difference and average pressure in the hole, respectively, in consistent units.

For holes 30 mil long and 0.3 micron diameter the leak magnitude is computed for atmospheric pressure and one inch of water pressure differential.

$a = 0.15\mu = 1.5 \times 10^{-5}$ cm

$L = 30$ mil $= 7.62 \times 10^{-2}$ cm

$P = 1.0$ ATM

$\Delta P = 2'' H_2O = .00492$ ATM

$$Q = \frac{5.26 \times 10^{5} \ (1.5 \times 10^{-5})^{3} \ .00492}{M^{\frac{1}{2}} \times 7.62 \times 10^{-2} \times 1.0} - \frac{11.5 \times 10^{-11}}{M^{\frac{1}{2}}} \quad \text{cc/sec} \qquad (6\text{-A})$$

2.2 Comparison of $C^{14}O_2$ and He Systems

Proper additional approximations to equation (3) are of special value in comparing leak detection sensitivities of different techniques. The first assumption to be made is that permeability is small with respect to leak magnitude of interest.* If this relationship does not hold, permeability can be accounted for using Section 2.3 of this appendix and published permeability data for He and $C^{14}O_2$. The further assumptions are:

$$C(0) = C_i \qquad (7)$$

$$F \gg Q \qquad (8)$$

$$QC_o \gg FC_i \qquad (9)$$

* This approach is conservative in that it shows the system in a better light than would be the case with permeability. If the systems are shown to be unsatisfactory without permeability, they surely are unsatisfactory with permeability.

Using these approximations, equations (2), (3), and (5) become

$$C(t) = \frac{QC_o}{F} \left(1-e^{-\frac{F}{V}t}\right) + C_i\, e^{-\frac{F}{V}t} \tag{10}$$

$$C(t) - C(0) = C(t) - C_i = \left(\frac{QC_o}{F} - C_i\right)\left(1-e^{-\frac{F}{V}t}\right) \tag{11}$$

$$\frac{C(t) - C(0)}{C(0)} = \frac{C(t) - C_i}{C_i} = \frac{QC_o}{FC_i}\left(1-e^{-\frac{F}{V}t}\right) \tag{12}$$

2.2.1 Radioactive Carbon Dioxide

$C^{14}O_2$ is readily detectable at a level of 200 disintegrations per minute (dpm) per liter* and is commercially available at a concentration of 3×10^{12} dpm/liter. For a system using $C^{14}O_2$ the following additional relationship holds:

$$C(0) = C_i \approx 0 \tag{13}$$

Using this relationship equation (11) reduces to equation (10) and equation (10) becomes:

$$C(t) = \frac{QC_o}{F}\left(1-e^{-\frac{F}{V}t}\right) \tag{14}$$

or

$$\frac{C(t)}{C_o} = \frac{Q}{F}\left(1-e^{-\frac{F}{V}t}\right) \tag{14-A}$$

Using the sensitivity and concentration stated above, it is required that

$$\frac{C(t)}{C_o} = \frac{2 \times 10^2}{3 \times 10^{12}} = \frac{2}{3} \times 10^{-10} \tag{15}$$

* V.P. Quinn and C.D. Wagner, 1959, "A Comparison of Ionization Chambers and Liquid Scintillation Methods for Measurement of Beta Emitters," Presented at "Symposium on Ionization Chamber Measurements of Radioactivity and Radiation," San Francisco.

For a 0.3 micron diameter hole in 30 mil material and a differential pressure of 2" H_2O at a nominal ambient pressure, the magnitude of Q is given in equation 6-A. For $C^{14}O_2$ the molecular weight is 46. Thus:

$$Q = \frac{11.5 \times 10^{-11}}{(46)^{\frac{1}{2}}} \text{ cc/sec} = 1.69 \times 10^{-11} \text{ cc/sec} = 1.69 \times 10^{-14} \text{ liter/sec} \quad (16)$$

Taking this value of Q and assigning $Ft/V > 2$ (such that exp $(-FT/V \ll 1)$, equations (14-A) and (15) can be solved for a maximum value of F.

$$F \leq \frac{QC_o}{C(t)} = \frac{1.69 \times}{\frac{2}{3} \times 10^{-10}} = 0.0254 \text{ cc/sec} = 2.43 \times 10^{-5} \text{ liter/sec} \quad (17)$$

Assuming 1000 seconds is required for the concentration of $C^{14}O_2$ to reach the detectable limit (2 time constants), the monitored volume for a single detector is limited to:

$$V \leq \frac{Ft}{2} \leq \frac{0.0254 \times 10^3}{2} = 12.7 \text{ cc} = .0127 \text{ liter} \quad (18)$$

In this model, the detection of leak rates of the order of 10^{-11} cc/sec appears within the state of the art using radioisotopes, but does not appear practical for the BISS system. Utilization of this type of detector for the BISS system would require a multitude of detectors each monitoring a volume of approximately 1/80 of a liter.

2.2.2 Helium

A mass spectrometer can detect a 0.1 ppm (volume) change in helium concentration. Helium is normally present in air at about 5 ppm (table 3-1 of Appendix A). Thus

$$C(0) = C_i = 5 \text{ ppm} = 5 \times 10^{-6} \quad (19)$$

Making the further assumption that $C_o = 1.0$ (i.e., the gas leaking into the detection volume is 100% helium) equation (11) becomes

$$C(t) - C(0) = \left(\frac{Q}{F} - 5 \times 10^{-6}\right)\left(1 - e^{-\frac{F}{V}t}\right) \quad (20)$$

Using the sensitivity and concentration stated above

$$\frac{C(t) - C(0)}{C_o} = C(t) - C(0) = (5.1 - 5) \times 10^{-6} = 10^{-7} \qquad (21)$$

Using the same conditions as used for $C^{14}O_2$ and a molecular weight of 4 for helium:

$$Q = \frac{11.5 \times 10^{-11}}{2} = 5.75 \times 10^{-11} \text{ cc/sec} = 5.75^{-14} \text{ liter/sec} \qquad (22)$$

Comparing equations (21) and (22) with equations (15) and (16) respectively shows that the helium system is more than three orders of magnitude less sensitive than the $C^{14}O_2$ system and produces only 3.4 times as large a leak magnitude to be detected for the same hole size and pressure conditions.

Using the value of Q for helium and $Ft/V > 2$, equations (20) and (21) can be solved for a maximum value of F

$$F \leq \frac{Q}{C(t)} = \frac{5.75 \times 10^{-11}}{5 \times 10^{-6}} = 1.15 \times 10^{-5} \text{ cc/sec} = 1.15 \times 10^{-8} \text{ liter/sec}^* \qquad (23)$$

Thus for a 1000 second detector time

$$V = \frac{Ft}{2} \leq \frac{1.15 \times 10^{-2}}{2} = 0.575 \text{ cc} = 5.75 \times 10^{-4} \text{ liter} \qquad (24)$$

Thus by any standard of comparison the helium system is substantially less sensitive than is the $C^{14}O_2$ system.

* Although examination of this equation and equations (19) and (22) shows that the assumption $Q C_o \gg F C_i$ does not hold for the helium case (in fact $QC_o = FC_i$) the error in the comparison of the helium and $C^{14}O_2$ systems is not significant in terms of the conclusions.

2.3 Gas Permeability Considerations

Permeability of gas through membranes can be approximated by

$$q_i = \frac{K_i A}{L} \left(P_1 C_{1i} - P_2 C_{2i} \right) \quad (cc/sec) \tag{25}$$

where q_i is the permeability gas flow of the **i'** th gas constituent in a mixture

K_i is the permeability constant of the i'th gas constituent for the membrane material

A is membrane area

L is membrane thickness

$P_1 C_{1i}$ is the partial pressure of the i'th gas constituent on one side of the membrane

$P_2 C_{2i}$ is the partial pressure of the i'th constituent on the other side of the membrane.

The physical model for equation 25 is sketched in figure D-5.

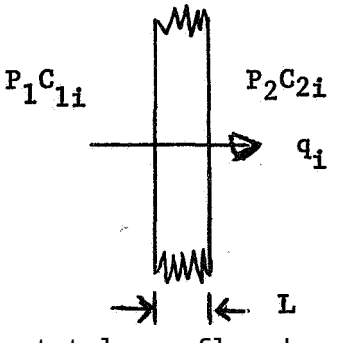


Figure D-5
Permeability Through Membranes

The total gas flow due to permeability is

$$q = \sum_i q_i = \frac{A}{L} \left\{ P_1 \sum_i K_i \, C_{1i} - P_2 \sum_i K_i \, C_{2i} \right\} \tag{26}$$

Using equations (25) and (26) the system differential equation (1) can be rewritten as

$$\frac{d}{dt} C(t) = \frac{QC_o + FC_i}{V} + \frac{q^*}{V} - \left(\frac{F+Q+q}{V} \right) C(t) \tag{27}$$

where q^* is q_i from equation (25) for the tracer gas. In terms of C_o and $C(t)$, q^* is

$$q^* = \frac{KA}{L} \quad (P_o C_o - PC(t)) \tag{28}$$

where P_o is the pressure outside the detection volume and P is the pressure inside the detection volume.

Thus the permeability is a function of $C(t)$. In general, the leak, Q, is also. These effects are minimized and can be neglected if

$$P_o C_o - PC(t) \approx P_o C_o \tag{29}$$

Since in general P_o is not significantly greater than P, for equation *(29)* to hold it is necessary that

$$C_o \gg C(t) \tag{30}$$

If the relationships hold then,

$$q^* \approx \frac{KA}{L} \quad P_o C_o$$

and the equations in the section on basic relationships can be corrected by replacing qC_o by q^*. In a sensitive system with reasonable response times, C_o will be much greater than $C(t)$ for threshold detection of a leak and the permeability and leak can be assumed constant.

3. DISCUSSION AND CONCLUSIONS

Both of the systems examined have been shown to require very small detection volumes. This means that the suit and tunnel would have to have a double layer wall with a compartmented interstice providing a multitude of detection volumes. Consider, for example, a tunnel of 3 meters circumference and 30 meters in length. The total surface area would be 90 square meters or 9×10^5 cm^2. Assuming the interstice in 0.5 cm thick, the total detection volume would be 4.5×10^5 cc. From equation (18) we see that the more sensitive of the two systems examined would require a detection volume of 12.7 cc or less, resulting in not less than 35,433 separate detection volumes and detectors. This, clearly, would impose an unreasonable burden in cost and complexity on the BISS system. An improvement of at least 3 if not 4 orders of magnitude would be required to make the system worthy of further consideration.

In this analysis the two most sensitive candidate detection systems have been examined. In the assumptions made to permit a simple analysis, conservatism has been employed, in that the assumptions have

made the systems appear to be better than they actually would be. In particular, neglecting permeability has made the systems appear more sensitive than would actually be the case. Also the sensitivities used for the analysis can be regarded as maxima within the present state of the art.

Further practical limitations show continuous leak detection systems for the BISS in even worse light. Two of these problems are: (1) Filling an Assembly/Sterilizer main chamber with helium would be quite costly; (2) Filling an Assembly/Sterilizer main chamber with $C^{14}O_2$ would not be permitted due to the very high total radioactive mass; nor would the dumping of this gas into the atmosphere after each cycle be permitted.

In summary, the use of continuous leak detection systems for bio-integrity assurance of the BISS system is not feasible.

APPENDIX E: SANITATION OF THE BISS SUIT

1. Background
2. Methods of Cleansing
3. Methods of Disinfecting
4. Hygienic Practices to be Employed
5. References

APPENDIX E: SANITATION OF THE BISS SUIT

1. BACKGROUND

In use, the BISS System will be exposed to a variety of microbiological flora native to the individuals in the suit. The use'of a chemical means of prophylaxis and disinfection or sanitization of the suit, to protect these individuals from a possible source of infection, is indicated. For the purposes of disinfection, bacteria fall into three categories:

- Vegetative - These are the types of microorganisms which are indigenous to the skin and respiratory system. They are exemplified by the Staphlocci, Streptococci and a variety of respiratory pathogens.

- Tubercle Bacilli - These microorganisms have a waxy capsular material surrounding them. This material provides a barrier which prevents some disinfecting agents from gaining access to the cell and performing its function.

- Spores - Spores are very resistant to both chemical and heat sterilization. The time required for a disinfectant to function against spores is inconsistent with that permitted between suit changes. Fortunately, the few types likely to be encountered in the suit system can be prevented from producing any hazard to suit wearers by prophylactic means. Cleansing must be thorough for satisfactory disinfection to be obtained.

2. METHODS OF CLEANSING

The number of materials available for a cleansing operation is numerous. A non-ionic detergent is preferable in that it will cause no ionic interference with the disinfectant treatment. The purpose of the detergent is to remove oils and films whichcould retain microbes and shield them from the germicide. Among the suitable commercially available detergents in this category are:

- Triton x - 100 - Rohm & Haas

- Tergitol NPX - Union Carbide

- Tergitol 15-s-7 - Union Carbide

These should be used in approximately 5% aqueous solutions. Since the physical and chemical properties of these surface active agents are essentially the same, Triton x-100 was selected, primarily on the basis Of cost.

3. METHODS OF DISINFECTING

For the purposes of BISS application, the disinfectant used must be tuberculocidal. Since this requirement is much mode stringent than that for any vegetative type cells, it follows that if the treatment is tuberculocidal it will be germicidal to any vegetative cells encountered. The number of materials which can fulfill this criteria is not extensive. They are:

- 70 percent isopropanol
- A solution of 8 percent formaldehyde in 70 percent isopropanol
- A solution of Wescodyne (an iodine donor) at 450 ppm.

Other commercially available disinfectants were considered but were not recommended for various reasons. For example:

- Cl_2 Donors - A low PH is needed. Their use would place a constraint on BISS materials due to their inherent corrosive activity.
- Br & I_2 - Acute dermal toxicity
- Chlorophenates - Dermal Toxicity
- Metal Salts - Dermal Toxicity
- Sulfur Compounds - Slow acting - Allergic dermal reactions
- Quaternary Ammonium Compounds - Limited Spectrum of activity

Seventy percent isopropanol was selected as a disinfectant because there is no residual chemical; it has tuberculocidal activity; and according to Spaulding, is effective against the Influenza Virus, Entero Viruses, Coxsackie and Echo Viruses.

Due to the insufficient time between suit changes, this type of treatment was considered inadequate for the treatment of possible spores. For example, the organism causing athletes foot (trichophyton) forms a chlamydospore which is a very resistant spore form. In order to insure its destruction the suit would have to be treated a minimum of 3 hours. The most feasible method of prevention of infection by any organism of this type is by taking prophylactic measures. Any of the commercial preparations such as "Desenex" or "Asterol" should be applied liberally to the socks, feet, and shoes if they are used prior to entrance to the suit. Anyone with a ringworm infection of the hair, skin or nails, which are caused by other members of the dermatophytes, should be barred from the use of the suit.

The use of a liquid disinfecting agent on the BISS suit itself was considered. In view of the problems of maintaining the bio-integrity of the suit, a liquid disinfectant would impose unnecessary hazards. If micron size holes in the suit material developed during the normal work cycle, any liquid at the site of the holes might permit organism migration through capillary action against the opposing pressure differential, thereby violating the bio-integrity of the suit. The use of a surface active agent for a cleansing operation would, by lowering the surface tension, increase the likelihood of a capillary migration of contaminants. This decision to preclude the use of a liquid agent for the suit may be subject to change after further consideration df the full bio-integrity ramifications of the system. As discussed under the bio-integrity in section 5.1 , the mere existence of a hole large enough to permit migration may be interpreted as a violation of bio-integrity if the most conservative approach is used. In such a case, the use of surface active disinfecting agents would be acceptable.

4. HYGIENIC PRACTICES TO BE EMPLOYED

A prophylactic measure which will consist of a shower using a disinfectant detergent such as Phisohex will be mandatory before donning the undergarment. Additionally, personnel should wash their hands with liberal quantities of Phisohex immediately prior to entering the suit. This will provide a residual bacteriostatic deposition on the hands. The use of "undertaker type" white gloves will further protect the worker from possible transfer of infectious microorganisms.

The only area of skin which will be exposed to the surface area of the suit is the head. It will be necessary to disinfect the helmet, which is the most potentially hazardous area of contamination. A liquid disinfectant will be acceptable for this purpose.

5. References

Spaulding, G.H., "Chemical Disinfection of Medical and Surgical Materials", Antiseptics, Disinfectants, Fungicides and Sterilization; 1961, 619-646, Lea and Febiger.

Dubes, R.J., Bacterial and Mycotic Infections of Man; Second Edition; Philadelphia, J.B. Lippincott Co., 1952.

Spaulding, G.H., "Chemical Disinfection"; Becton, Dickson Lectures on Sterilization, Seton Hall College of Medicine and Dentistry, April 1958.

APPENDIX F: INTEGRATED TEST PLAN

INTRODUCTION

A. Objective

B. Project Test Phasing

C. Test Configuration

D. Test Procedures

E. BISS Test and Demonstration Plan

F. Test Plan Schedule

PHASE I. DEVELOPMENTAL TESTS

A. Component Tests

B. Subsystem Tests

C. System Tests

PHASE II. EVALUATION TESTS

A. Anthropometric Measurements

B. Entry - Exit Tests

C. Mobility

D. Dexterity

E. Communications

F. Subject Endurance

G. Hygiene

H. Final Data Analysis

MATERIALS TESTS

Attachment A Mock-up Tests and Subject's Assessment Scale (SAS)

Attachment B Materials Tests

Attachment C BISS Test Plan Schedule

INTRODUCTION

A. OBJECTIVE

It is the objective of this test plan* to set forth the series of tests which will be used to evaluate the BISS concept. The empirical portion of this program has two primary foci, one being the conduct of a mock-up study to demonstrate that a man can perform useful work in the BISS environment and the other being the selection of suit materials optimally suited to withstand the environmental, biological, and mobility constraints placed upon them.

Much of the content in this plan is directed at the conduct of the mock-up study, i.e. the development and evaluation of the suit, tunnel, reefing mechanism, life support, monitoring system and related support equipment. The materials studies are designed to provide guidance to the mock-up study in the selection of materials, but primarily these studies and tests are geared to providing inputs to the final BISS specification. To initiate the mock-up study, the materials effort will provide data on the weight and stiffness of candidate suit material since temperature and microbiological characteristics of the final suit will not be simulated. A parallel material testing effort will evaluate the microbiological and physical characteristics.

B. PROJECT TEST PHASING

The mock-up test program is divided into two major portions, Phase I developmental tests and Phase II evaluation tests. Materials tests will span both phases of the mock-up effort.

The Phase I developmental tests will focus on the selection of competing subsystem elements and on design evaluation and modification of the first generation BISS. The Phase II tests will be designed to evaluate the performance of the system which will result from the Phase I effort.

Components, subsystems and finally the entire mock-up system will be tested during Phase I. It is expected that this will be an iterative process and that a significant portion of the developments will emerge from a cut and try approach in response to test results. At the end of this Phase I development effort, the composite of empirical experience will be reflected in procurement specifications to be written for the second generation BISS system. Results of materials studies completed during Phase I will be integrated with the test results and will be applied to the Phase II BISS procurement specification.

Upon receipt of the Phase II hardware, a series of evaluation tests will be begun. These tests will be more formal than the preceding tests. The emphasis will shift from discovering faults so that they can be corrected, to evaluating just how the Phase II system performs without any significant modification or adjustment. Results of the Phase II effort will be care-

* Published as the "Integrated Test Plan for a Research Study to Definitize a Bio-Isolator Suit System", Document No. 675D418, dated 3 January 1967

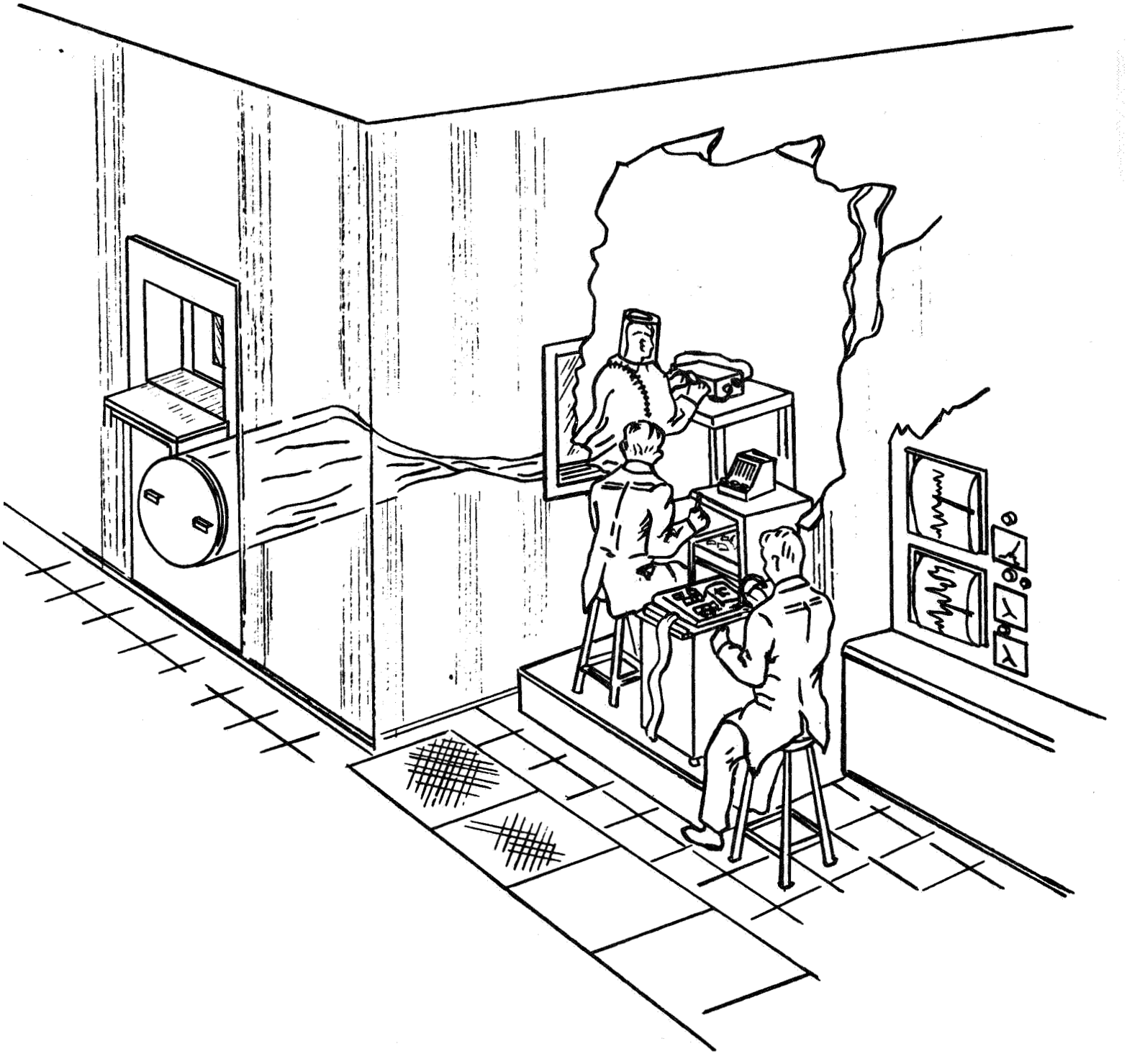


Figure F-1. Hatch Assembly/Monitor's Workstand

fully evaluated and the results fed into both the final BISS system specification and the BISS Test and Demonstration Plan. Results of all materials studies will also be integrated into the program end product documents.

C. TEST CONFIGURATION

The test configuration for the mock-up tests is discussed in some detail below. Test configuration for the individual materials tests are discussed as a part of each test plan.

1. Environment

The test facility will have the capability of providing a nominal overpressure of up to 4 inches of water in which to test the BISS. Chamber temperature will be at normal ambient with the burden for controlling the environment of the subject placed upon the suit life support system, The chamber will be pressurized with shop air which is suitable for breathing for limited periods of time, if the subject's air supply should fail. Unzipping a zipper brings the subject in contact with the chamber environment. Therefore, there is no need to take the safety precautions relating to a back-up air supply which will be necessary in a N_2 environment.

2. Facilities

A Tenney Altitude Chamber, located at the contractor's Chestnut Street facility in Philadelphia, will be modified to serve as a pressure chamber for up to 4 inches of H_2O pressure. Preliminary tests have already indicated the feasibility of this process. The central door in this chamber will be displaced and a hatch assembly substituted for it. (See Figure F-1. This assembly will provide a proper interface for the suit-tunnel. Included in this hatch assembly are a metal tube (reefing tube) through which the subject enters the chamber and a door for emergency entrance and exit. Other special support items which have been fabricated for the tests included a monitor's workstand (See Figure F-L) and a donning rack to assist the subject in getting in and out of the suit.

3. Test Team

The test team will be made up of a subject, a test conductor, a medical monitor, and a chamber technician. The test conductor will be located immediately adjacent to a chamber window and will direct all actions of the subject via the communications system. He will collect data from the subject as different tasks are done and will generally direct the test exercises.

At his side, the medical monitor will be monitoring the RKG (Radio Cardiogram) and respiration and collecting gas samples (gas into and out of the helmet) as well as monitoring all test conductor - subject communications. At any time the medical monitor feels that there is cause to terminate the test or question the subject, he will do so. Additions

ally, the medical monitor will watch the gages on the subject's compressed air breathing supply (for tests in which this is used), and will be responsible for making any adjustments to this system. Both the test conductor and the medical monitor will note any portion of the subjects performance which is suspect and will question him regarding it at an appropriate time.

The chamber technician is primarily responsible for maintaining the desired pressure level in the chamber. Since this task will not load him heavily, he will be able to provide assistance to the test conductor on an as needed basis.

4. Subject Selection

Two subjects have been selected for the Phase I developmental tests. However, it is planned that all Phase I tests will be run on one subject unless illness precludes this. It is believed that the use of the same subject for the developmental tests will permit a consistent evaluation of the BISS in its various states of evolution. The second subject is viewed as a back-up. The Phase II tests will require four subjects and one back-up.

It is recognized that the use of one subject for the Phase I tests will not yield absolute data but rather should provide good relative data. For the purposes of the development tests, the interest of test personnel is in whether the introduction of a given system modification is an improvement over the former condition or not. The absolute value of the change is relatively unimportant. If the BISS can be made to provide comfort, mobility and dexterity for one subject, it is a matter of detailed design as to how to do this for a broader segment of the population. Four subjects will be used in the Phase II tests which will permit a more accurate interpretation of the data obtained from the evaluation tests.

Subjects will be selected for similarity in size, a general familiarity with things mechanical, and a willingness to participate in the project. Additionally, all subjects will be given a comprehensive physical prior to acceptance. This physical will include at least a gross audiometric test to assure that communications system test results are not biased by organic deficiencies of the subjects, Also, an assessment of the diction of the subjects will be made for the same reason.

5. Safety Ground Rules

a. Subject shall have received Company Physician's approval prior to performing chamber studies.

b. Breathing air supply provisions and emergency procedures shall be reviewed and approved by Company Industrial Safety prior to initiating chamber studies.

c. Company Industrial Safety approved breathing air source must be

provided to the subject while performing chamber studies.
NOTE: The pressurized plant air system is not an approved source of breathing air.

d. If a bottled air system is to be utilized for breathing air purposes, it shall comply with the following minimum requirements.

(1) Manifold system, regulator and monitoring device system shall conform to Company Safety Requirements.

(2) A minimum of fifteen minutes of breathing air reserve shall be available at all times during operation, the Medical Monitor shall be responsible for terminating studies when this limit is reached.

(3) Capability for continous monitoring of the quantity of remaining air supply shall be provided in a manner which will allow determination of reserve time available.

e. At least one stand-by person, in addition to the test conductor, shall be present at all times that the subject is performing chamber studies. Emergency access into the chamber shall be available at all times so that the stand-by (medical monitor) can reach the subject to administer assistance within thirty seconds from indication of the need for assistance. Visual observation of the subject shall be provided at all times during operation.

f. Emergency first-aid authority and procedures for stand-by personnel shall be approved by the Company Physician.

g. Emergency access capability in the mock-up suit shall provide for the following:

(1) In event of breathing air supply termination, chamber atmosphere shall be made available to subject's breathing zone within fifteen seconds when the subject is conscious, and forty-five seconds when not conscious.

(2) The subject's face shall be available for applying artificial respiration within thirty seconds of reaching the subject. This shall be accomplished without help from the subject.

(3) Removal of the subject from the chamber and outer suit shall be possible within four minutes, wihtout help from the subject.

D. TEST PROCEDURES

Test data will be collected by a combination of objective measurements (e.g. timing entrance and exit) and subjective ratings. The objective measurements which are to be used are self-explanatory, but the Subject's Assessment Scale (SAS)* requires some explanation.

*See Attachment A

Fundamentally the SAS identifies parameters which are salient to the functioning of the BISS and asks the subject to rate the performance of these parameters on a seven point scale, A rating of seven implies excellent performance while one means unsatisfactory performance, with intermediate numbers representing shadings of good or bad performance. While data collected in this **way** cannot represent absolute values, it is an effective technique for gaging relative performance. Any biases which the subject might have should remain constant over the tests and therefore the impact of the same test conducted under different conditions or the same test before and after some hardware modification should be apparent. Use of multiple subjects'in the Phase **II** tests will permit ascribing more universality to the data collected than to the Phase I data.

It should also be noted that medical and life support monitoring data will be collected for all fully suited tests in both Phase I and Phase 11. Individual mock-up test plans do not indicate that this data (e.g. cooling system inlet and outlet temperatures, suit relative humidity, **gas** flow rate, RKG, respiration and gas composition monitoring (not continous)) is being collected since it is constant for all fully suited tests. When a subject is performing test tasks, record of the prevailing medical and life support parameters will be made. Changes in these values will be noted. Test record sheets will be designed **so** that the medical/life support measurements recorded by the test conductor and medical monitor can readily be correlated with the relevant subject actions, ratings and comments.

E. BISS TEST AND DEMONSTRATION PLAN

The BISS Test and Demonstration Plan will be completed and incorporated in the Integrated Test Plan as an appendix after the conclusion of the Phase II mock-up tests. Experience gained in the materials testing program and both Phases of the mock-up program will be reflected in this plan. The Test and Demonstration Plan will be defined in lesser detail than the mock-up and materials testing plans.

F. TEST PLAN SCHEDULE

A complete Test Plan Schedule is located in Attachment C.

G. Attachments

Attachment A to this document contains the individual test plans for the mock-up tests and a copy of the Subject's Assessment Scale (SAS). Each test plan in Attachment A is referrenced by test phase (I or II) and paragraph number (e.g. I.B.1.a.) to the appropriate text. Attachment B contains the detailed materials tests and Attachment C the Test Plan Schedule.

PHASE I

DEVELOPMENTAL TESTS

A. COMPONENT TESTS

1. Life Support

The purpose of the life support component tests is severalfold. First, the flow rate and temperature ranges for the two competing air cooling systems will be established (see Figures F-2 and F-3) further, the temperature rise and the flow rates at the extremities of the air distribution harness will be measured. It has been determined from literature search that the following flow rates are appropriate for the BISS: 2.4 cfm at the helmet, 3.6 cfm in each hand and 3.2 cfm in each leg.

Data regarding compressed air cylinders is of interest since they will be used to provide breathing air to the subject for not only the vortex tube life support system, but also for the life support system used with the water cooled undersuit. The shop compressed air supply cannot be used as a routine air supply to the subjects since plant safety prohibits such a practice. However, when using the air conditioning system, part of the unit's output can be tapped to provide breathing air, thereby eliminating the need for the compressed air cylinder.

At the conclusion of the two tests set forth in attachment A, a comparative evaluation of the relative merits of the vortex tube and air conditioner systems will be made. The one which best meets the flow criteria (approx. 16 cfm input to the distribution harness/ helmet for the air conditioner system and 13.6 cfm (16 cfm - 2.4 cfm for the helmet) for the vortex system) and at the same time can be adjusted to the lowest temperature will be selected for future use with the air cooled undersuit. The other candidate air-cooling system will be discarded from further consideration in this study.

B. SUBSYSTEM TESTS

The series of subsystem tests discussed in this document are designed to establish the basic functioning of the subsystem elements in the BISS and to provide a first indication of adjustments or modifications which might be required to optimize subsystem performance. Tests 2, 3.b., c., and d., do not require use of the chamber for their accomplishment.

1. Life Support

a. Chamber Pressurization

This test will establish the capability of the chamber's seals

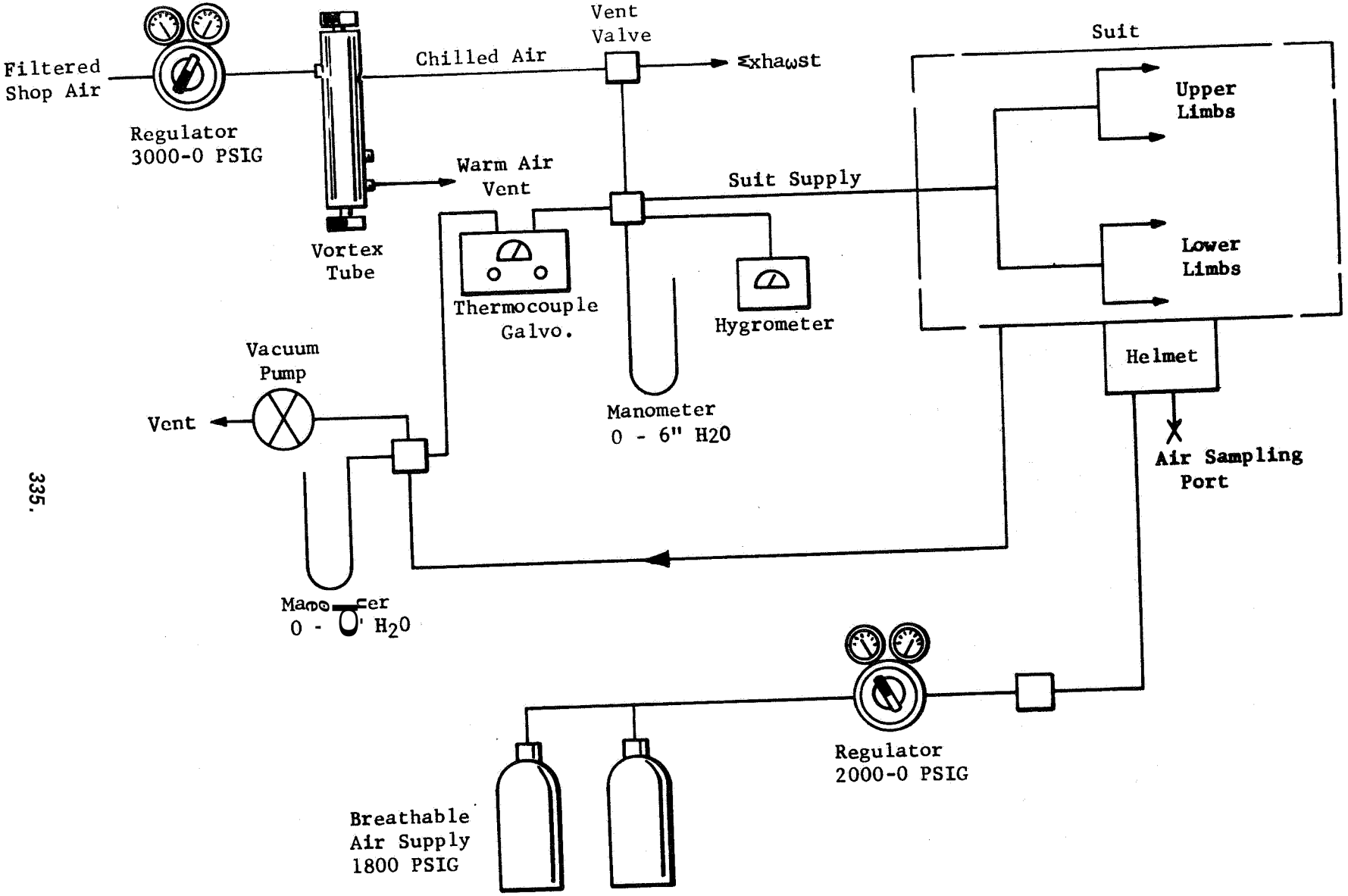


Figure F-2. Vortex Tube Life Support System

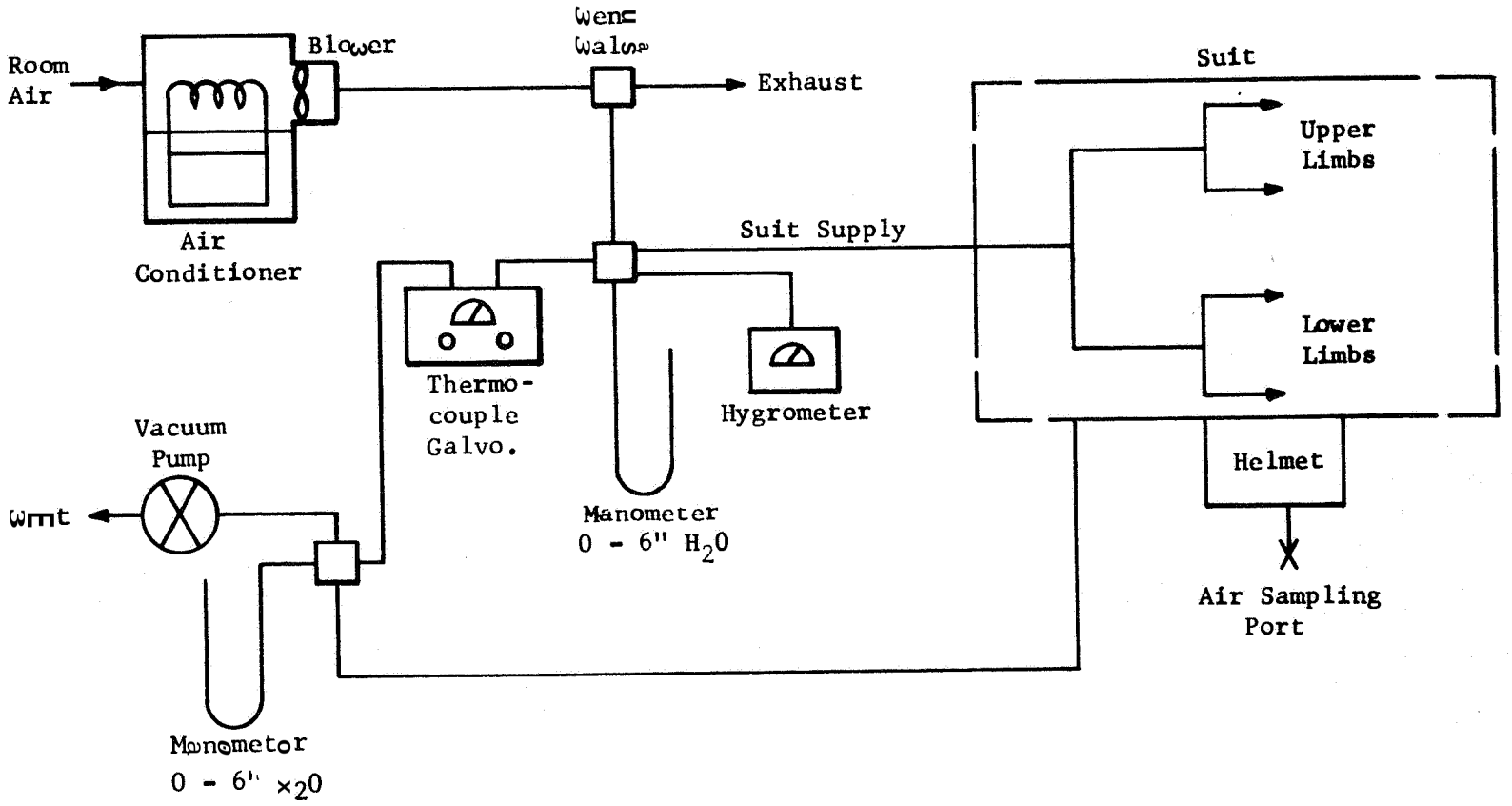


Figure F-3 Air Conditioner Life Support System

to withstand pressurization up to *4* inches of water and to be held at this pressure.

2. Undersuit

The subsystem tests of the competing air cooled and water cooled undersuits are to be conducted under ambient pressure conditions. The life support system which will be selected as indicated in Paragraph **A1**, will be connected to the air cooled undersuit. The life support system for the water cooled undersuit is illustrated in Figure F-4. In both tests, the ability of the undersuit to cool the subject while resting and after exercising will be determined. Temperature and flow rate data will be collected at various points in the subsystem. Section I of the Subject's Assessment Scale (SAS) will be administered to the subject verbally while resting and after exercising to establish the perceived comfort of the subject. Onset of both the high and low temperature discomfort regions will be identified and the subject will be questioned about any deficiencies he observes on the performance of the undersuits.

3. Outer Suit/Tunnel

a. Gross Leak Test

The suit-tunnel leak test will be run with the chamber pressurized at *4* inches of H_2O, the suit-tunnel attached to the reefing tube and a pressure gage or manometer attached to the tube. The objective of this test will be to determine if the suit-tunnel has gross leaks and to minimize any such leakage so that chamber pressure can be maintained for further suited tests in the chamber. This test will be repeated for both the 10 foot tunnel used in the early subsystem tests and the subsequent 20 foot tunnel. (See **IB7**)

b. Helmet Air Supply

The helmet air supply test is designed to assure the basic functioning of the helmet air distribution system under ambient conditions and to identify an optimum air flow rate for initial use in the chamber tests.

c. Visual Field

The visual field possible in the **BISS** helmet will be measured by means of a standard visual field test. The criteria to be met are 140° vertical (80° below the line of sight, 60° above) and 220° in the horizontal plane, If these criteria cannot be met, the helmet will be reworked to meet the criteria.

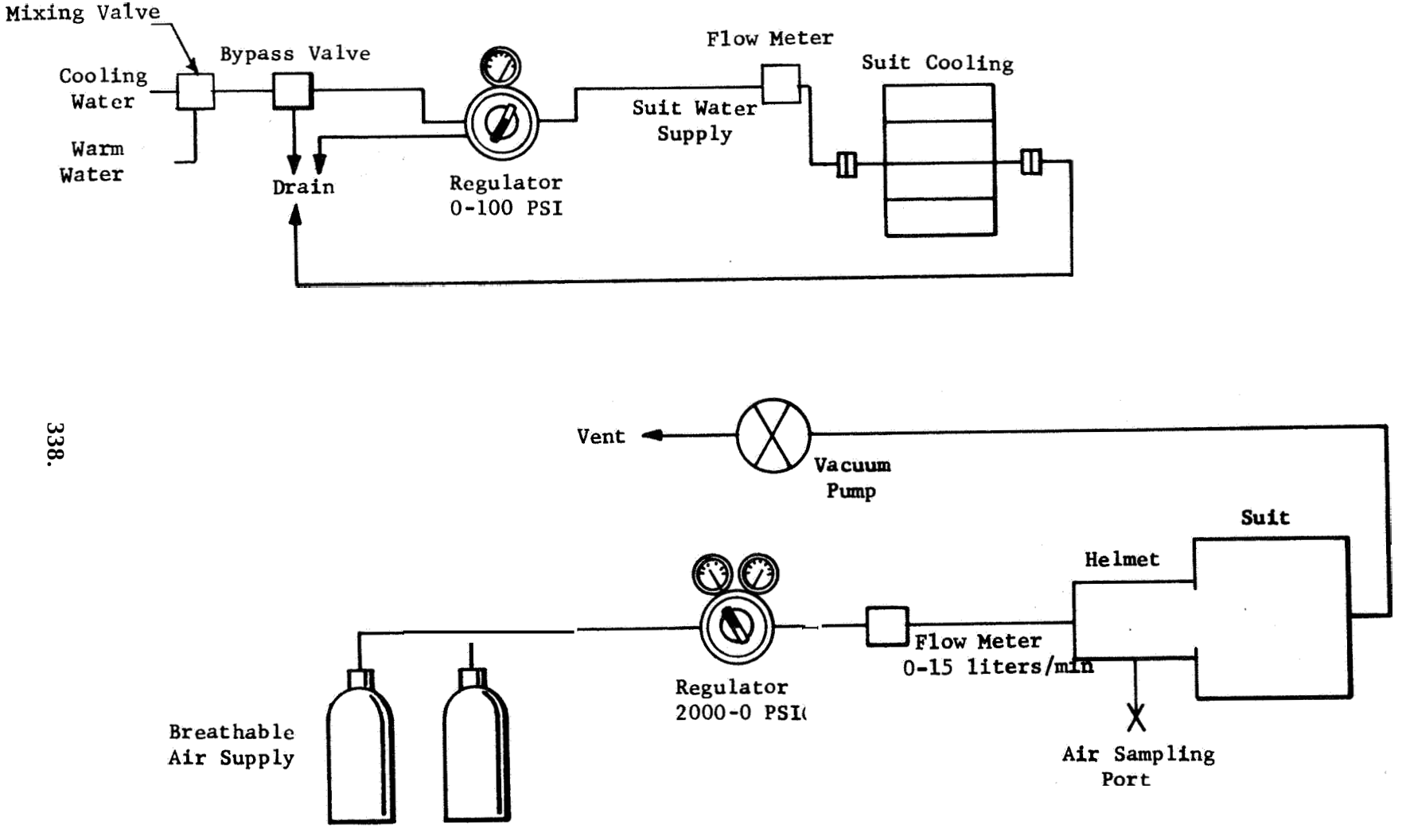


Figure F-4 Water Cooling Life Support System

d. Fit

The outer suit will be tried on by the subject over both undersuits in an ambient pressure environment. Fit will be adjusted as necessary to permit optimum freedom of movement for the subject. Breathing air and cooling will be supplied to the subject during this test.

4. Monitoring Systems Instrumentation

a. Life Support Monitoring

The instrumentation to be used with the life support systems includes pressure test gages, differential manometers, thermocouples, a thermocouple recorder, a hygrometer, and an oxygen regulator.

b. Medical Monitoring

Heart rate will be monitored by use of a radio cardiogram (RKG). If a subject's heart exceeds 120 bpm for two minutes or 130 bpm at any time during the testing, the test will be terminated by the medical monitor. Respiration will be monitored by means of the intercom and gas samples will be collected from the gas supply to the helmet and from the helmet's exhaust. The gas samples will be collected, transported, and held for analysis in standard gas sampling bottles. Oxygen, nitrogen, and carbon dioxide content will be determined by means of a gas chromatograph having a thermal conductivity detector.

5. Safety - Rescue

The safety - rescue tests are intended to assure that if a mishap should occur during the mock-up tests it is possible to effect a timely rescue of the subject. No back-up air supply or rescue air supply will be needed since the chamber will contain breathable air and the subject's isolation from the chamber environment can be readily broken by use of a zipper in the outer suit. This zipper is located across the subject's chest. There is also a zipper which attaches the tunnel to the suit, but this is not accessible to the unaided subject.

Rescue operations will be conducted in the chamber under both ambient and differential pressure conditions. The total time to effect rescue under either condition must be less than four minutes. The chamber's built in "panic button" (klaxon) will be exercised by the subject during this test to assure its proper operation.

6. Communications

The communications subsystems test will be conducted under an ambient pressure environment to assure proper functioning and adjustment of the system and to optimize transducer placement within the helmet.

7. Tunnel Reefing Subsystem

The initial BISS subsystem tests will be conducted with a 10 foot tunnel clamped to the outer surface of chamber side of the reefing tube. Though this approach permits only a crude form of tunnel reefing to be accomplished, it will be adequate for the subsystem level tests. Concurrent with the conduct of the subsystem tests, an independent tunnel reefing subsystem will be in the final stages of development. As the last element in the subsystem tests, this reefing system (using a 20 foot tunnel) will be tested and mated with the outer suit.

C. SYSTEM TESTS

1. Suit System

The suit system tests are designed to exercise the manned suit system, to assess subject comfort and physiological response to the environment (under both the resting and exercised conditions), mobility, chamber/suit entry-exit and communications. These tests will first be carried out under ambient pressure conditions and then under a differential pressure environment. Both undersuits will be run under the differential pressure condition.

The test routine found in attachment A shows the sequence of tasks which the subject will be directea to accomplish and the way in which the Subject's Assessment Scale (SAS) will be used to obtain evaluative data.

The data collected, plus any observations of the subject relative to difficulties not covered by the SAS, will be reviewed after each test and remedial action will be taken, as appropriate. The tests will be performed with the water cooled and air cooled undersuits. For each suit, the tests will be conducted once under no differential pressure and twice under the differential pressure environment.

Mean ratings for the SAS items will be computed for comparison with comparable data to be obtained from the second generation system. Record will also be made of observed deficiencies and corrective actions for guidance in the preparation of the specifications at the end of the Phase I development effort. The undersuit receiving the poorer overall rating (summation of mean scores on the SAS items) will be eliminated from further consideration in this study.

PHASE II

EVALUATION TESTS

GENERAL

The evaluation tests of Phase II will be applied to the second generation BISS procured as a result of the specifications generated at the conclusion of the Phase I t'esting. It is assumed that only a minimum amount of initial adjustment will be required by the second generation system. Therefore the tests discussed in the following text reflect only the formal testing effort and do not enumerate any shakedown tests. If the need for any such tests becomes evident during installation, they will be performed on an "as-needed" basis. All Phase II tests will be performed on four subjects, completely outfitted in the BISS and under a differential pressure environment.

A. ANTHROPOMETRIC MEASUREMENTS

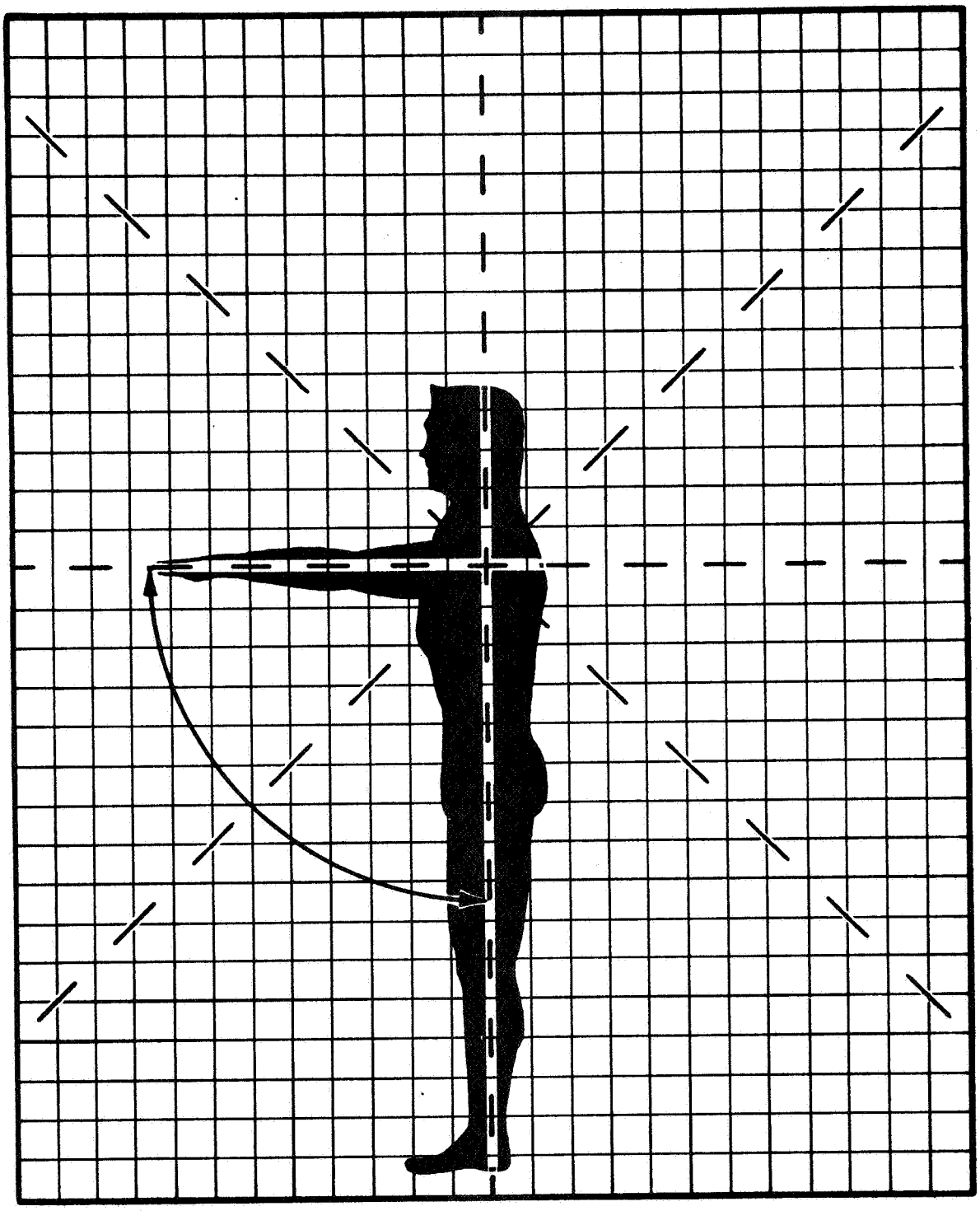
In order to ascertain more precisely than is possible from the SAS the degree of encumbrance imposed by the BISS on the operator, a series of comparative anthropometric measures of the motions of the head and arms of unsuited versus suited subjects will be made. The list of measurements to be taken will be found in the detailed test treatment located in attachment A. Most of the measurements will be taken by the use of a shadow technique illustrated conceptually in Figure F-5. Normal anthropometric instruments will be used to take measurements not amenable to the shadow technique.

B. ENTRY-EXIT TESTS

Each of the four subjects will be run through a series of five timed entry-exit tests. Preceding the five timed trials there will be a familiarization trial for each subject. Entry will be defined as the time elapsing from entry of a fully undersuited subject into the exterior opening of the reefing tube until the fully suited man emerges into the chamber. The time required for exit will be the converse of the foregoing process. Three minutes is the design objective for either of these operations with ten minutes as an upper limit.

C. MOBILITY

The mobility of the subject will be appraised by use of Section II of the SAS as was done in the Phase I Development Tests. The subject will be asked to rate each facet of the suit's mobility via the BISS communication system as he completes the relevant action. Walking, climbing, bending at the waist, and squatting will be tested. A path around the perimeter of the chamber will be chalked in, the ladder position indicated and a circle drawn in which the subject will stand while doing the bending exercises. (See Figure F-6. All subjects will *go* through exactly the same routine to insure comparability of rating data.



FigureF-5. Shadow Measuring Technique

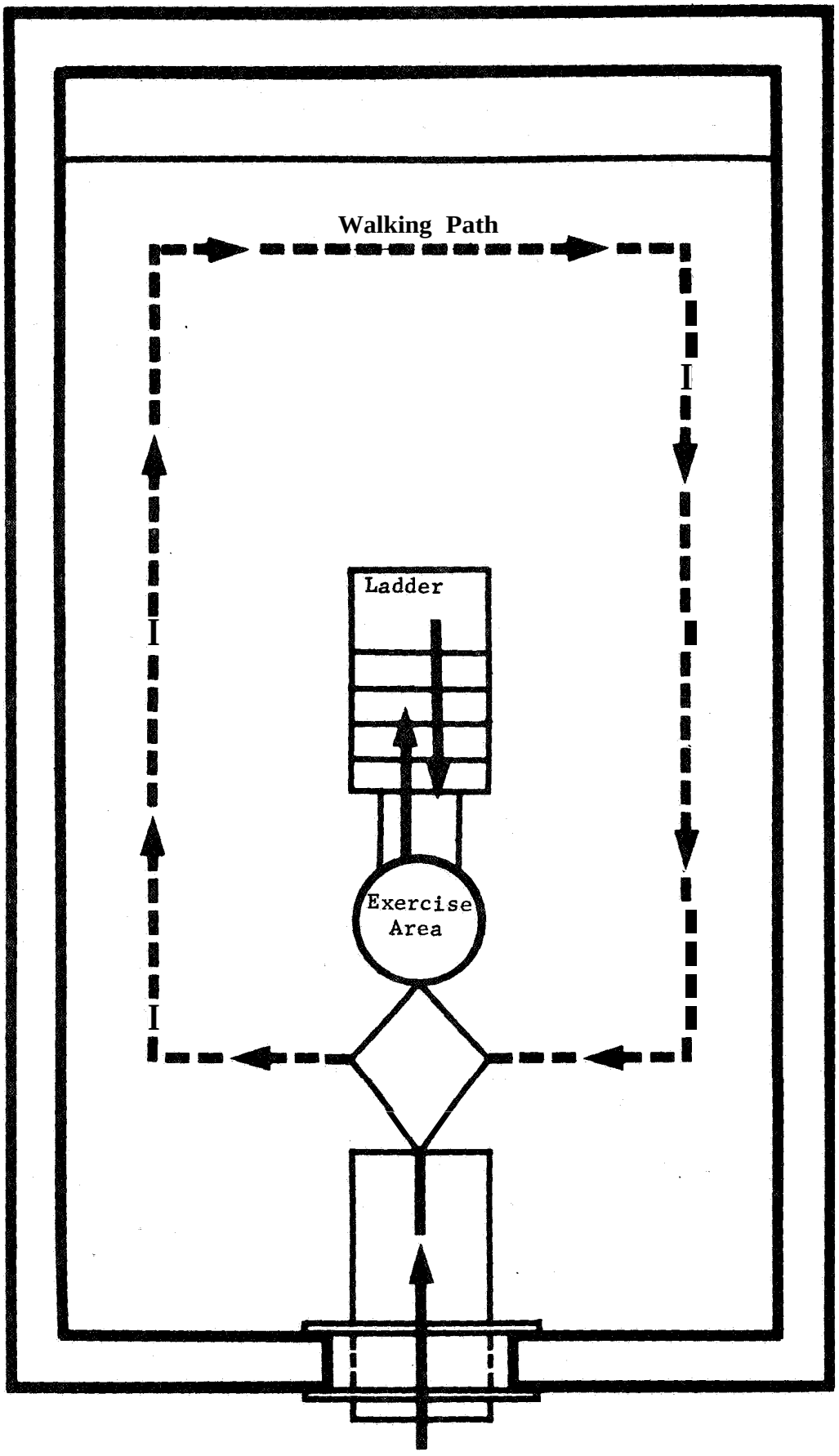


Figure F-6. Mobility Test Chamber Configuration

D. DEXTERITY

It would be possible to use commerically available tests to assess operator dexterity in the suited and unsuited condition, but it is believed that more relevant data can be obtained by the use of an analogue assembly task. The assembly test object is shown in Figure F-7. Its assembly and disassembly will require the use of common hand tools and will also involve the mating and demating of representative electrical and hydraulic connectors.

E. COMMUNICATIONS

Phoenetic nonsense syllables will be used to assess the adequacy of the intercom communications link between the subject and the test conductor. Each subject will be read a list of fifty such syllables. Each syllable will have a sequential number associated with it. The subject will mark the number next to the syllable received on a printed list containing the fifty syllables to be transmitted intermixed with fifty other syllables.

An abbreviated version of another such list (twenty-five syllables to be transmitted, fifty on the list) will be used to assess the chamber speaker's adequacy. The first test (fifty syllables transmitted) will be repeated with the subject transmitting and the test conductor marking the answers.

F. SUBJECT ENDURANCE

The criterion for acceptable endurance of the operator in the BISS environment is four hours. After all other tests have been completed, each of the subjects will be put through a four hour endurance trial. During this period the assembly test object, used for dexterity testing, will be assembled and disassembled several times and movement about the chamber, on an as desired basis by the subject, will be permitted. A stool will be provided on which the subject may rest. Once an hour the entire SAS (less Section IV Entry-Exit and Item V.a and V.b for subsystems communications test) will be administered over the intercom.

If the subject desires to leave the chamber prior to the expiration of the four hour period, this will be permitted. A test will be promptly terminated on the advice of the medical monitor.

If, however, at the end of the four hour period, both the subject and the medical monitor concur, the test will be extended until either the subject or the medical monitor directs its termination. The purpose of such an extension of the endurance test would be to establish a gross feel for the upper limits of subject endurance in the BISS environment.

G. HYGIENE

Tests of the application of helmet internal disinfection will be performed as indicated in test procedure 9 of attachment B.

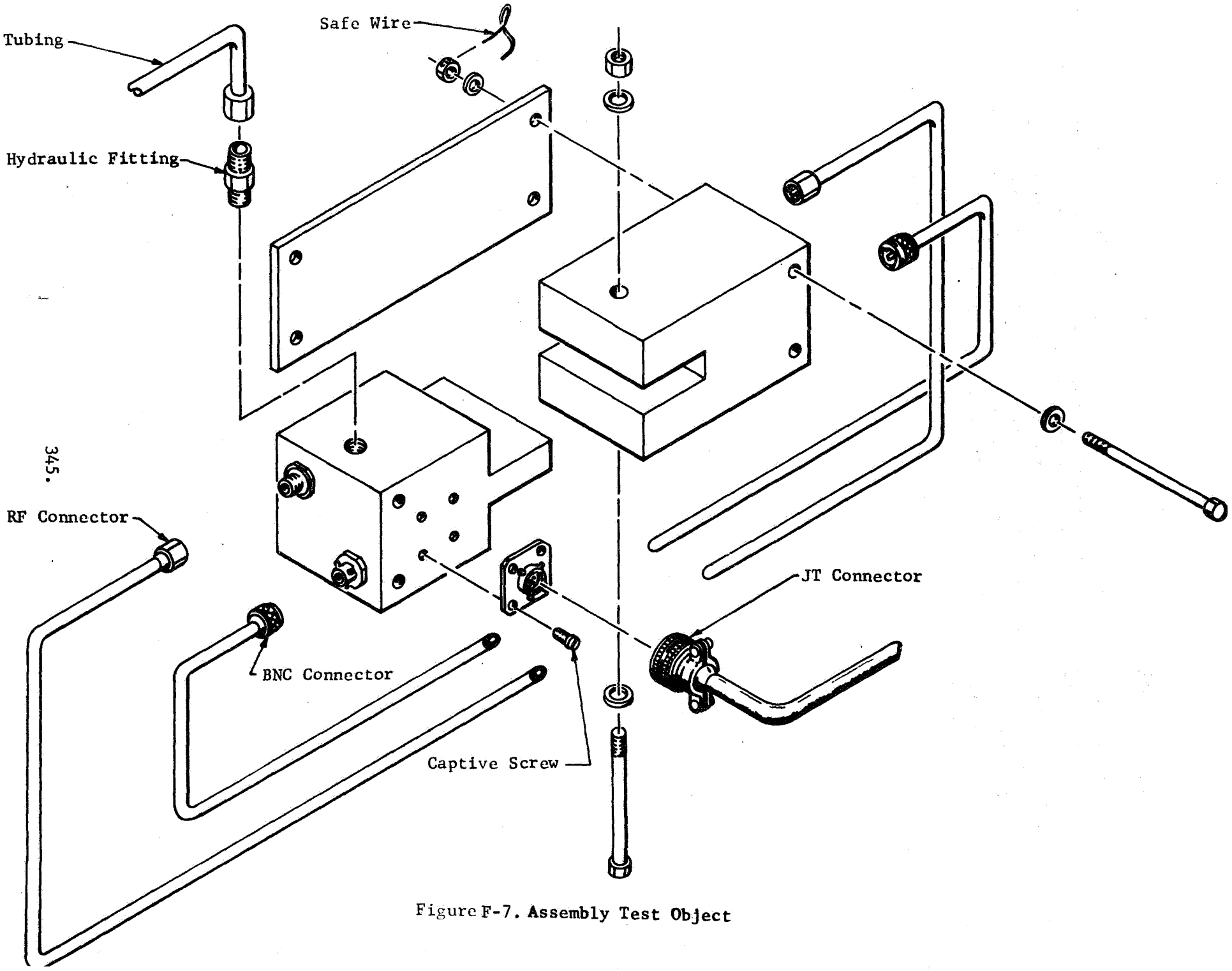


Figure F-7. Assembly Test Object

H. FINAL DATA ANALYSIS

At the conclusion of the Phase II evaluation tests, the data derived from all the tests will be evaluated. Conclusions resulting from the evaluation will be incorporated in the final BISS specification and the BISS Test and Demonstration Plan. When possible, comparison will be made between the Phase I and Phase II data to assess the degree of improvement of the Phase II system over the Phase I system. A summary of the results of the final data analysis will be included in the final BISS program report.

MATERIALS TESTS

The overall objective of the BISS materials testing program is to define optimum materials for use in the BISS outer suit. These materials must withstand the thermal, chemical and mechanical stresses planned for the assembly sterilizer facility and must provide a barrier to microbiological and fungicidal penetration. The materials used for the Phase I mock-up suit have been recommended as a result of early analytical materials study; likewise, the materials of the phase two suit will reflect the requirements of subsequent materials studies and tests. It is required that the materials used for the mock-up suits simulate the weight and stiffness of the final material, but there is no need that this material possess the thermal, chemical and mechanical tolerances or microbiological impenetrability of the final suit.

A series of tests designed to assess the physical properties of candidate materials for the outer suit will be run throughout the term of the program. Materials which have been identified as a result of analytical studies will be subjected to competitive evaluations. The tests included in this evaluation are as follows:

1. Fungus Growth Test.
2. Mycelial Penetrability Test.
3. Permeability/Flexure
4. Abrasion
5. Transfer of Microorganisms and Gases Across Suit Materials
6. Retention and Release of Disinfectants by Materials
7. Compatibility With Detergents & Disinfectants
8. Evaluation of Disinfectants
9. Application of Helmet Internal Disinfection
10. Tensile Test For Rigid, Solid and Laminated Plastics.
11. Tensile Test of Flexible Plastic Sheeting.
12. Puncture Resistance
13. Optical Transmittance
14. Weight Change
15. Impact Test for Plastic Materials

16. Temperature Aging

17. Tear Resistance

18. Compressive Properties

19. Lap Shear

20. Butt Tensile

All of the foregoing tests are detailed in attachment B of this document.

Table F-I. is a matrix showing the materials testing to be performed on the program. For each treatment listed on the left of the table, appropriate tests will be conducted as indicated on the right. The maximum numbers of tests indicated reflect the performance of treatments of varying intensity (number of temperature cycles, number of disinfectants, number of abrasion and flexure cycles) in triplicate. Attempts will be made to reduce the number of tests by making use of preliminary data to make early evaluation of materials. If the data is indicative of unfavorable results, further testing of the candidate materials will be discontinued.

TABLE F-I. MATERIALS TEST MATRIX AND TEST QUANTIES (1)

MATERIALS \ TEST NO.	VIRGIN MATERIAL	TREATMENT 16	TREATMENT 7	TREATMENT 4	TREATMENT 3	TEST 1	TEST 2	TEST 5	TEST 6	TEST 8	TEST 10	TEST 11	TEST 12	TEST 13	TEST 14	TEST 15	TEST 16	TEST 17	TEST 18	TEST 19	TEST 20 (2)
SUIT MATERIALS		x						72				72	72		72			72			
		x		x				216							216						
		x			x			216													
			x(3)									48	48		48			48			
	x					24	24	24	48(3)			24	24					24			
				x				72							72						
					x			72													
			x(3)	x				144							144						
			x(3)		x			144													
		x(5)	x(5)									6	6		6			6			
		x(5)	x(5)	x(5)				6													
H EMET	x					12			36(4)	12	12					12			12		
		x									36				36	36			36		
			x(4)								36				36	36			36		
		x(6)	x(6)	x(6)							6				6	6			6		
FACEPLATE	x					12			36(4)	12	12			12		12			12		
				x										36	36						
		x									36			36	36	36			36		
		x		x										108	108						
			x(4)								36			36	36	36			36		
			x(4)	x										108	108						
		x(6)	x(6)	x(6)							6			6	6	6			6		
BONDING	x					12	12	12												12 →	
					x			36												36 →	
		x																		36 →	
		x			x			108												108 →	
			x(3)																	36 →	
			x(3)		x			72												72 →	
		x(5)	x(5)																	6 →	
		x(5)	x(5)		x(5)			6													

NOTES:

NUMBERS IN ( ) REFER TO NOTES. SEE FOLLOWING PAGE.

N ES FOR TABLE II-II

(1) Numbers in the body of the table indicate the maximum number of tests performed.

(2) Lap shear or butt tensile tests will be performed as applicable

(3) Peracetic acid and ETO only.

(4) Ethylene oxide, peracetic acid, and detergent/isopropanol.

(5) Two selected suit and two selected bonding materials in triplicate will be subjected serially to ETO, temperature aging, and abrasion or flexing as indicated and then tested for physical properties, microbial and gas penetrability.

(6) Two selected faceplate and two selected helmet materials in triplicate will be subjected serially to ethylene oxide treatment, temperature aging, and abrasion as indicated and then tested for physical properties.

(7) Numbers in the heading of the table refer to the number of the test or treatment as listed on pages 20 & 21 of this report.

ATTACHMENT A. MOCK-UP TESTS AND SUBJECT'S ASSESSMENT SCALE (SAS)

GAS FLOW/TEMPERATURE TESTS VORTEX TUBE COOLING SYSTEM

Objective

To obtain flow rate and temperature data on the output of the vortex tube and to assess flow rates and temperature rises in the air distribution harness.

Environmental Conditions

Normal room ambients.

Data to be Collected

Flow rate at cold port of vortex tube, flow rate and outlet temperature at each leg of the distribution system shown in Figure F-8., temperature at the end of a 30' length of 1 1/2" I.D. flexible ducting, outlet temperature of a standard compressed air bottle (1800 PSIG regulated to give 3CFM flow), outlet temperature in the helmet distribution plenum.

Subject Clothed In:

No subject.

Test Routine

Construct breadboard illustrated in Figure F-9, and utilize pitot tube assembly shown in FigureF-10, to obtain flow rate at cold port of vortex tube. When using the pitot tube apply the formula $Q = 1098A\sqrt{\frac{P_v}{d}}$ where:

Q = Gas Flow -CFM, A = Tube area -ft^2, P_v - manometer reading -inches H_2O and d = density of air or N_2 - lb/ft^3.

Using the same technique, obtain the flow rate at each leg of the distribution system shown in Figure F-8.

Also set up Honeywell temperature recorder with iron constantan thermocouples and determine the temperature of the shop air of N_2 at the following places:

1. Cold port of the Encon vortex tube
2. End of the 30' long 1 1/2" I.D. flexible ducting
3. End of the 1/4" I.D. Tygon tubing (see Figure F-8)

4. Outlet of a standard compressed air bottle (1800 PSIG regulated to give 3 CFM flow).

5. Outlet in the helmet distribution plenum of the compressed gas breathing supply.

Data Analysis

Flow rates at the output of the vortex tube and the extremities will be computed and compared. Also the temperature rises in the distribution system will be computed,

Comments

None

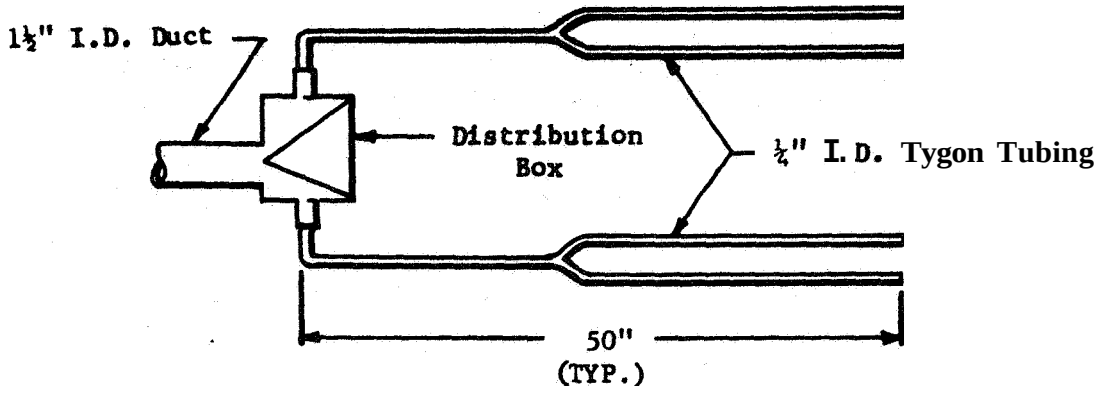


Figure F-8. Air Distribution System

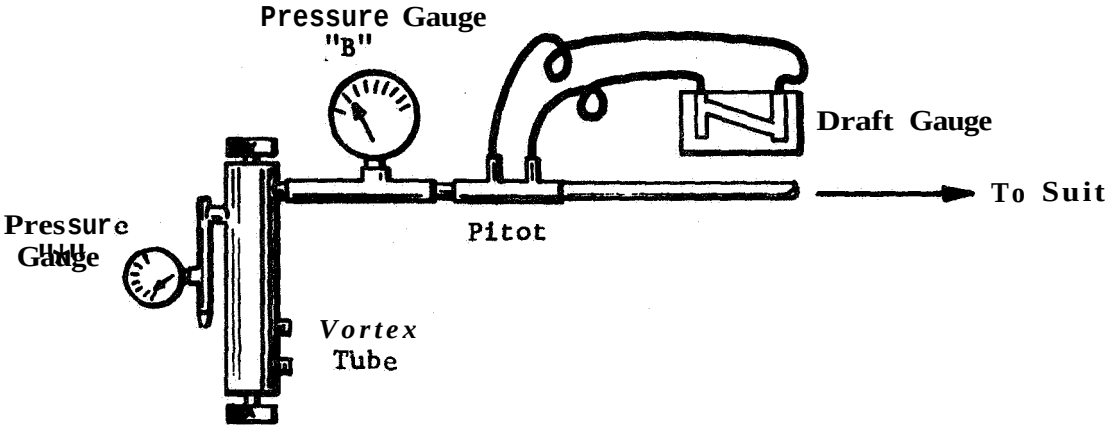


Figure F-9. Vortex Tube Cooling Unit

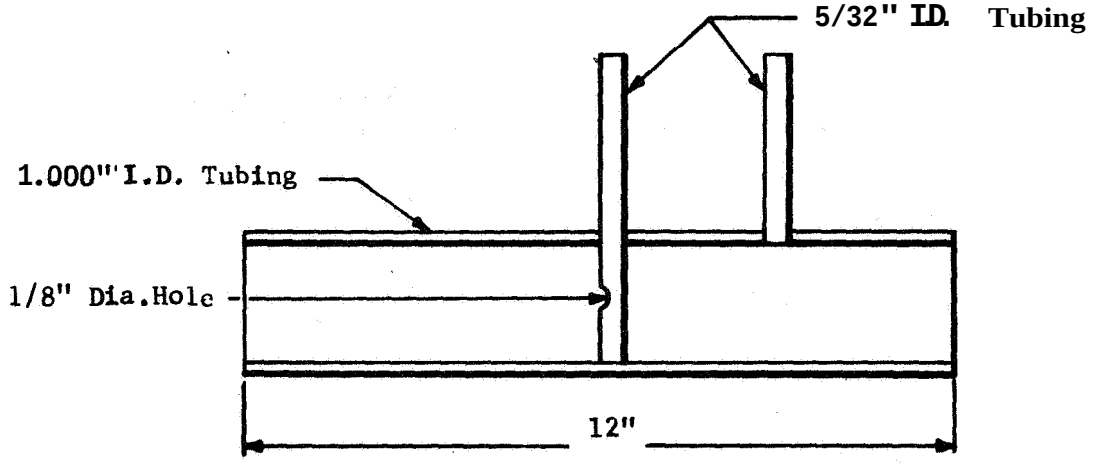


Figure F-10. Pitot Tube

GAS FLOW/TEMPERATURE TESTS AIR CONDITIONER COOLING SYSTEM

Objective

To obtain flow and temperature data on a 9000 BTU air conditioner operating in conjunction with a P-400547-13 blower.

Environmental Conditions

Normal room ambients

Data to be Collected

Plenum air temperature, plenum outlet flow and temperature (no blower), blower exhaust temperature, flow rates and temperatures in the distribution system.

Subject Clothed In

No subject, unmanned test

Test Routine

Install air conditioner in plenum. Initially, the plenum should be open with no blower installed in its exhaust port. The air conditioner should be operated on the "high" setting with the plenum open for ten minutes. Plenum temperature is taken and recorded. The blower is then installed and the air flow and temperature through the plenum's exhaust opening is taken with the blower not operating (air flow is measured using a draft gage and the pitot tube shown in Test I.A.l. (Vortex Tube Cooling System) Finally, with the blower operating air flow and the temperature of the exhaust air is measured.

Data Analysis

Flow rates will be computed using the technique outlined in Test I.A.1. Temperatures at different points in the system will be compared.

Comments

None

CHAMBER PRESSURIZATION TEST

Objective

The objective of the chamber pressurization test is to determine that the chamber can achieve and be held at a pressure of up to *4* inches of water.

Environmental Conditions

Pressure of *4* inches of water inside chamber, ambient chamber temperature.

Subject Clothed In

No subject, chamber unmanned.

Data to be Collected

Chamber pressure (inches of water), input pressure of supply system to chamber and time required to achieve a pressure of *4* inches of water.

Test Routine

The pressure inlet valve will be opened full and the time recorded to achieve a pressure of *4* inches of water in the sealed chamber. For this test the opening for the tunnel will be sealed off. Once this level has been achieved the input pressure required to maintain this pressure for one hour will be recorded. If the leakage rate of the chamber is too high to permit this, adjustments will be made to the seals until the shop air supply can readily maintain the desired pressure at less than maximum inlet pressure for a period of at least one hour.

Data Analysis

No formal data analysis will be required for this test.

Comments

None

(Ref. I,B,2,)

WATER COOLED UNDERSUIT

Objective

To determine the water cooled undersuit's capability to provide environmental control for the wearer under resting and exercised conditions.

Environmental Conditions

Room ambient temperature and pressure.

Subject Clothed In

Long underwear, water cooled undersuit and outer suit.

Data to be Collected

Inlet fluid temperature; fluid flow rate; subject temperatures (both arms, left leg, chest, groin and small of back); helmet temperature; Section I of the SAS (comfort) and subject's impressions of undersuit design deficiencies.

Test Routine

Inlet water temperature will be varied systematically and the subject queried as to his comfort (Section I of the SAS) in the undersuit under both resting conditions and conditions of exertion (i.e. after the subject has completed timed sessions on an exercycle). Also, under resting conditions, the inlet temperature will be varied to determine the onset of the high and low temperature discomfort zones. Each test will be run once. Finally, the subject will be queried as to any deficiencies he has observed in the design of the suit which was not reflected on the assessment scale,

Data Analysis

Subject comfort assessments will be evaluated in relationship to the temperature measurements.

Comments

This test is intended to provide a gross index of the operational efficacy of the water cooled undersuit. Further, the mock-up staff will gain familiarization with the operation and use of this out-of-house developed item.

(Ref, I.B.2.)

AIR COOLED UNDERSUIT

Objective

To determine the air-cooled undersuit's capability to provide environmental control and comfort for the wearer under resting and exercised conditions.

Environmental Condition

Room ambient temperature and pressure.

Subject Clothed In

Long underwear, air cooled undersuit, and outer suit.

Data to be Collected

Subject temperatures (both arms, left leg, chest, groin, and small of back); supply temperature at flow tube; exhaust temperature at flow tube; helmet temperature; inlet and outlet flow rates; Section I of the SAS (comfort) and subject's impressions of undersuit design deficiencies.

Test Routine

Conditioned air source settings (controlling inlet air flow to the undersuit) will be varied systematically and the subject queried (Section I of the SAS) as to comfort under resting and exercised conditions (same exercises as for the water cooled undersuit). The conditioned air source will also be adjusted to establish the onset of the high and low discomfort zones under resting conditions. Each test will be run once. The subject will also be asked to identify any design deficiencies he observes during the test.

Data Analysis

Subject comfort assessments will be evaluated in relationship to the temperature measurements.

Comments

This test will serve to provide a gross appraisal of the efficacy of the air cooled undersuit, and to provide data for any required modification.

LEAK TEST

Objective

To determine if the suit-tunnel leaks and if so to minimize the leakage rate to assure maintenance of up to 4" H_2O pressure in the pressure chamber.

Environmental Conditions

4" H20 pressure, ambient temperature

Subject Clothed In

No subject, unmanned test

Data to be Collected

Leakage rate, chamber pressure

Test Routine

Attach a pressure gage or manometer to the reefing tube after the suit-tunnel has been installed. Seal off the end of the tube and pressurize the chamber to 4" H_2O. Hold at this pressure for 1/2 hour and record pressures to permit calculation of leakage rates from the suit-tunnel.

Data Analysis

No formal data analysis

Comments

If more than nominal leakage is evident, sources of the leakage will be identified and sealed. The test will then be re-run to assure capability of maintaining pressure in the suit-tunnel chamber combination.

(Ref. I,B,3,b,)

HELMET AIR SUPPLY

Objective

The objective of the helmet air distribution test is to empirically determine flow rates of input air required to provide optimum comfort and safety for the subject in the closed suit system.

Environmental Conditions

Ambient temperature and pressure

Subject Clothed In

Long underwear and outer suit (including outfitted helmet) with tunnel sealed.

Data to be Collected

Input pressure, respiration, gas composition, heart rate, and Section I, a-c of the SAS.

Test Routine

Compressed air under the control of a pressure regulator will be used to vary the flow of inlet air to the helmet. Limits within which the flow can be varied without presenting any safety hazard to the subject will be prescribed by project medical personnel before testing is initiated. With these limits, respiration and heart rate will be monitored to assure that hyperventilation does not occur as the flow is varied. For different settings within the prescribed limits, the subject's reports as to comfort and noise will be recorded as well as the physiological indices.

Data Analysis

Formal data analysis will not be required for this test.

Comments

None

VISUAL FIELD

Objective

To measure the visual field of the Phase I subject in the BISS helmet.

Environmental Conditions

Normal room ambients.

Subject Clothed In

Complete BISS outfit including long-johns, undersuit, helmet support and outer suit/helmet. Cooling and breathing air will be supplied the subject for this test.

Data to be Collected

Angular displacements from the subject's line of sight vertically and the angular displacement horizontally at which the subject can see a test marker.

Test Routine

This test will be conducted in accordance with conventional visual field measuring techniques. Essentially, the points in a horizontal plane (both to the left and right) and in a vertical plane (both up and down from the subject's line of sight) at which a test marker can be seen will be determined.

Data Analysis

The values obtained from the test will be compared against the criterion values. (140^{o} vertical, 80^{o} below L.O.S., 60^{o} above and 220^{o} in a horizontal plane).

Comments

If the criterion numbers are not met, the helmet will be adjusted accordingly. If this is necessary, the test will be re-run to confirm that the adjustments achieved the desired result.

OUTER SUIT FIT

Objective

To assure an optimum fit of the outer suit under ambient pressure conditions.

Environmental Conditions

Normal room ambients

Subject Clothed In

Full BISS outfit including long-underwear, either undersuit and outer suit.

Data to be Collected

Subject's appraisal of fit combined with opinions of test personnel viewing the exterior fit of the suit.

Test Routine

The subject will don the suit and will be asked to move about in it. He will be asked to move his various limbs and appraise fit in conjunction with the test personnel who are viewing exterior fit.

Data Analysis

No formal data analysis required.

Comments

Adjustments will be made to the suit by taking tucks or adding panels as required. If such modications are made, the test will be re-run to assure that good outer suit fit has been achieved.

SAFTY RESCUE

Objective

The objective of this test is to demonstrate that the subject can be reached in sufficient time to effect emergency assistance and rescue when operating under the criterion of four minutes from detection of the difficulty to having the subject removed from the chamber. It is also to demonstrate that access into the chamber by the medical monitor can be accomplished within thirty seconds.

Environmental Conditions

Both ambient pressure and temperature, and up to 4 inches water pressure and ambient temperature.

Subject Clothed In

Long underwear, inner suit, outer suit, boots and helmet.

Data to be Collected

Time required to gain access to the suited subject, time for freeing subject from suit and time to remove subject from the chamber.

Test Routine

Experimental test team personnel will be assembled in an operational configuration and the subject will suddenly feign collapse. An observer with a stop watch will note the time required for the medical monitor to gain entry to the chamber through the emergency hatch and reach the subject. Also the time required to free the subject's face and body from the suit and to remove the subject through the reefing tube will be recorded. Assistance to the medical monitor from other chamber personnel in moving the subject through and removing the subject from the reefing tube will be assumed. This test will be repeated once under each pressure environment.

Data Analysis

The times for reaching, freeing, and removing the subject will be totaled for both conditions.

Comments

If the various time criteria are not achieved, the routine will be practiced or modified until this is accomplished.

COMMUNICATIONS

Objective

The objective of the communications tests are to determine helmet loudspeaker position and volume that gives best overall results and volume required for chamber loudspeaker.

Environmental Conditions

Ambient pressure and temperature.

Test Routines

1. Placement of Speaker(s) in Helmet

   a. Using the single-transducer (loudspeaker) in the helmet, a series of locations shall be tried for efficacy of reception and transmission. The following positions shall be employed (referenced to the head in an erect, facing-forward orientation):

      (1) Directly opposite ear

      (2) Directly below ear (within helmet limitations)

      (3) Directly below chin (within helmet limitations)

      (4) Directly below cheek (midway between positions (2) and (3)

      (5) Directly overhead

      (6) Midway between positions (1) and (5)

      (7) Directly in front of forehead (600 up from line of sight)

   b. All life-support and monitoring equipment shall be operating at their normal settings.

   c. The test conductor shall select three volume settings on his Master Unit. These settings shall be used for all position tests. The subject and test conductor shall complete separate copies of SAS item V.a. after each position test.

   d. The Helmet Loudspeaker Positions which have the three best acoustical ratings shall be tested to determine which position offers least physical interference to the operator. The following factors shall be examined:

(1) Obstruction to vision with normal head movements.

(2) Contact with face, head, or ears during normal head movements, including donning and removing helmet.

(3) Conflict of location between loudspeaker and life-support and/or bio-monitoring equipment.

In addition, any physical factors that become apparent in the course of testing shall be noted and evaluated.

e. The helmet loudspeaker position which gives the best overall results shall be used for all subsequent Sub-System and System Tests.

2. Intelligibility of Signals Received in the Helmet

a. The subject shall don the suit and helmet and shall have all life support and monitoring equipment operating at their normal settings. The subject shall determine the intelligibility of signals received in the helmet from the control station at a minimum of three volume levels. These volume levels may be pre-selected, before the operator enters the suit and helmet, if desired.

b. The subject shall complete SAS item V.b after each test condition is run.

3. Intelligibility of Signals Received from the Helmet

a. In an analogous fashion to the above, and at the same volume levels, the test conductor shall determine the intelligibility of signals received from the helmet.

b. The test conductor shall also complete SAS item V.b.

4. Intelligibility of Chamber Loudspeaker as a Back-up or Warning Device

a. The test conductor shall disable the suit loudspeaker and shall communicate with the subject via the chamber loudspeaker, The master unit volume level shall be set at a minimum of three points, as follows:

(1) High Volume - maximum available on control unit.

(2) Low Volume - highest setting used in helmet tests

(3) Medium Volume - midway between above settings.

b. The subjects shall complete item V.b. of the SAS at the conclusion of these tests.

Comments

This test will determine optimum volume and location of the helmet loudspeaker and volume level required for the chamber loudspeaker.

TUNNEL **REEFING** SUBSYSTEM TESTS

Objective

To determine the time required to reef **a** fully extended twenty foot tunnel and to evaluate the design of the reefing system.

Environmental Conditions

Ambient pressure and temperature for test a. and up to 4" H_2O pressure, ambient temperature for tests b. and c.

Subject Clothed In

Tests a. and b. unmanned; for test c. the subject will be clothed in the full BISS including long underwear, undersuit and outer suit.

Data to be Collected

Time required to reef tunnel under each of the three experimental conditions and recommendations of test personnel for design improvements and modifications.

Test Routine

The test will first be run without the suit attached with a weight at the end of the tunnel to simulate the subject under ambient pressure conditions. The same test will then be re-run under a differential pressure environment of 4" H_2O pressure. After these tests have been completed and any modifications which are indicated have been incorporated, the tunnel will be married to the suit and tried out with a subject, under a differential pressure environment.

For all trials, the time required to reef the tunnel and any evaluative comments of project personnel regarding the design will be recorded.

Data Analysis

Reefing times will be compared with the criterion value of two minutes. (not to exceed four minutes).

Comments

If the 20 foot tunnel cannot be reefed within four minutes, the tunnel reefing subsystem will be redesigned **so** that this criterion can be met.

SUIT SYSTEM TESTS

Objective

To assess the overall performance of the suit system with regard to subject comfort, mobility, ease of suit/chamber entry-exit and communications. These tests will also provide tradeoff data for selection of either the air-cooled or water-cooled undersuit for use in the Phase II tests.

Environmental Conditions

Both ambient pressure and up to 4" H_2O pressure, ambient temperature.

Subject Clothed In

Full BISS outfit including long underwear, undersuit and outer suit.

Data to be Collected

SAS items IV.a. and IV.b. (chamber/suit entry and exit), Section I (subject comfort), Section II (mobility), and item V.c. (communications). Record will also be made of any observations on the part of either the subject or the test team which relate to the design of the suit system and which are not covered by the SAS.

Test Routine

The test routine shown below will be run six times. The first two times will be under an ambient pressure environment using either undersuit, and the last four tests will be in a differential pressure environment (up to 4" H20 pressure) with two being run in the water cooled undersuit and two in the air cooled undersuit. The test routine is as follows:

1. Subject dons suit and enters chamber.

2. Subject is administered SAS item IV.a. (Entry) via the intercom followed by Section I (Comfort) of the SAS.

3. Subject is then directed to walk around the perimeter of the chamber twice, bend at the waist ten times, climb and descend a ladder three times and perform ten deep knee bends. (See Figure 6)

4. Subject is then administered Section II (Mobility) of the SAS to obtain his assessment of mobility followed by Section I for comfort under the exercised condition.

5. Subject then exits from chamber through the tunnel.

6. Subject fills out **SAS** item IV.b (Exit) for the exit process and **SAS** Section V.c. relative to communications during the test.

Data Analysis

Comparative analyses of the tests run under the ambient and differential pressure environments will be made. Data from the competitive undersuit tests will be compiled and tradeoffs conducted to eliminate one undersuit from further consideration.

Comments

None

ANTHROPOMETRIC MEASUREMENTS

Objective

To determine the differential between subject's head, neck, arm and wrist range of motions in the suited and unsuited (common work clothes).

Environmental Conditions

Normal room ambients

Subject Clothed In

Normal work clothes and then in full BISS outfit.

Data to be Collected

Each of the measurements listed below will be taken on each subject clothed in both common work clothes (long sleeved shirt, khaki pants and work shoes) and in the full **BISS** outfit. **Also** unclothed weight and height will be measured for each subject.

Reference: Table on page **261,** "Bioastronautics Data Book".

WRIST AND ARM	AV°	SD°
Wrist F1exion	90	**12**
Wrist Extension	99	**13**
Wrist Abduction	**27**	9
Wrist Adduction	**47**	**7**
Forearm Supination	**113**	***22***
Forearm Pronation	**77**	***24***
Elbow Flexion	***142***	10
Shoulder Flexion	***188***	12
Shoulder Extension	61	***14***
Shoulder Adduction	***48***	9
Shoulder Abduction	***134***	**17**

Wrist and Arm - continued	AV°	SD°
Shoulder Rotation, Medial	97	22
Shoulder Rotation, Lateral	34	13
NECK		
Ventral Flexion	60	12
Dorsal Flexion	61	27
Right or Left Flexion	41	7
Right or Left Rotation	79	14

Test Routine

The weight and height of all subjects will be taken in the nude for reference purposes, Then each subject will have each of the listed measurements taken first in the unsuited and then in the suited condition. Most of these measurements will be taken by use of the shadow technique previously illustrated conceptually in Figure F-5 of the main text. Grease pencil markings will be made on the background and labeled in the unsuited condition. Comparable markings will then be made for the subject in the suited conditions. Differences in angular excursion in the two conditions will then be computed for ail measurements. Measurements not amenable to the shadow technique will be taken with conventional anthropometric instruments.

Data Analysis

Differences in the body motions possible in the two conditions will be computed. These differences will then be compared against a design goal of no more than a 10% decrement, and a design requirement of not more than a 20% decrement. Inter-subject differences will also be identified.

Comments

None

ENTRY-EXIT TESTS

Objective

To determine the time required for the subject to enter the chamber (including suit donning) and to exit from the chamber (including suit removal).

Environmental Conditions

Up to 4" H_2O pressure, ambient temperature.

Subject Clothed In

Full BISS outfit including long underwear, undersuit, and outer suit.

Data to be Collected

Time elapsing between entry of a fully undersuited subject into the exterior opening of the reefing tube and emergence of a full suited man into the chamber and the converse exit operation and Section IV (Entry-Exit) of the SAS.

Test Routine

Each of the four subjects will be given a familiarization trial and then put through 5 timed trials. The subjects will be given a three minute rest after getting into the chamber before beginning the exit process. A ten minute rest between trials, will be given outside the chamber. Each subject will be given the familiarization trial and the first two timed trials in one session followed by the remaining three timed trials at a subsequent time. This time must be at least three and not more than thirty-six hours later, This tactic will prevent fatigue from becoming a prominent factor in performance and also will preclude loss of skills acquired in the first session. Section IV (Entry-Exit) of the SAS will be administered after each of the 3 test sessions to each subject.

Data Analysis

Mean times for the entry and exit of each subject will be computed for the five timed trials. Entry and exit means for all subjects pooled, also will be computed. Summary statistics for the Section IV SAS items will be prepared. They will show differences for the same subject in session one and two, and mean ratings for all subjects. Entry and exit mean times will be compared with the design objective of three minutes and the upper limit of ten minutes.

Comments

None

MOBILITY TESTS

Objective

To determine the ability of the subject to walk, climb and bend at the waist and squatting in the suited condition under a differential pressure environment.

Environmental Conditions

Up to 4" H_2O pressure, ambient temperature.

Subject Clothed In

Full BISS outfit, including long underwear, undersuit, and outer suit.

Data to be Collected

Section II (Mobility) of the SAS. Individual ratings will be collected on walking, climbing, bending at the waist and squatting (deep knee bends) as the subject completes the relevant action. Instructions to the subject and ratings will be obtained via the BISS communications system.

Test Routine

Each subject will be directed to walk around the perimeter of the room twice, climb and descend the ladder three times, bend at the waist ten times and perform ten deep knee bends. Each subject will perform this test three times with a ten minute rest between trials. Starting and ending points for the walk and the location for other tests will be constant for all subjects.

Data Analysis

Mean ratings for each subject on each type of test will be computed across trials. A mean rating for each test across subjects will also be made. Mean ratings across subjects for each test will be compared with the criterion mean rating of 4. Intra-subject data, across trials, will be examined for trends. Inter-subject differences will also be examined and compared with findings from Test 11-A, Anthropometric Measurements.

Comments

None

DEXTERITY TEST

Objective

To determine the differential in operator hand and finger dexterity between the suited and unsuited (work clothes as in **11-A**, Anthropometric Measurements) subject.

Environmental Conditions

Up to 4" H_2O pressure, ambient temperature.

Subject Clothed In

Full BISS outfit, including long underwear, undersuit, and outer suit.

Data to be Collected

Assembly and disassembly time and Section III (Dexterity) of the SAS.

Test Routine

The subjects will be given step by step assembly and disassembly instructions for the Assembly Test Object **(Figure F-7** main text) via the intercom. The test will be given to each subject in both the suited and the unsuited condition. Two of the four subjects will be given the test in the unsuited condition first and the other two in the suited condition first. The total assembly and disassembly tests will be timed separately for each subject under both conditions. Section III of the SAS (Dexterity) will be administered to the subject via the intercom after completion of each major test task (i.e. assembly or disassembly).

Data Analysis

Difference scores (suited versus unsuited) will be computed for each individual on both tasks for both the time and SAS rating scores. Mean difference scores across **all** subjects also will be computed.

Comments

None

COMMUNICATIONS TESTS

Objective

To assess the intelligibility of the communications link used between the subject and the test conductor.

Environmental Conditions

Up to 4" H20 pressure and ambient temperature.

Subject Clothed In

Full BISS outfit including long underwear, undersuit and outer suit.

Data to be Collected

Errors in receiving phoenetic nonsense syllables.

Test Routine

Each subject will be given a list with 100 nonsense syllables on it. The test conductor will clearly enunciate 50 of these syllables once and also give a sequential number associated with each syllable. The subject will scan his list and mark the appropriate number next to the syllable he believes he has received. The same routine will be repeated using a different list of 100 syllables with the subject transmitting and the test conductor receiving. This list will be different for each trial so that the test conductor's performance will not be distorted by learning. Finally a third, abbreviated list containing 50 syllables will be used by the test conductor to transmit 25 syllables to the subject over the chamber speaker.

All subjects will have been given audiometric tests and assessed for clarity of diction as a part of the selection process to eliminate possible distortions in the data.

Data Analysis

Error data will be computed for each subject on both tests and on the test conductor receiving from every subject. Error data will also be averaged across subjects for each test and across trials for the test conductor.

Comments

None

(Ref. II,F,)

SUBJECT ENDURANCE

Objective

To determine if the BISS can support the subject in the differential pressure environment for a period of at least four hours and to determine if the subject can function effectively during this period.

Environmental Conditions

Up to 4" H_2O pressure, ambient temperature.

Subject Clothed In

Full BISS outfit including long underwear, undersuit and outer suit.

Data to be Collected

Entire SAS less Section IV (entry/exit) and items V.a. and V.b. (for subsystem communications tests) and total time subject remains in chamber. Comments of the subject relating to reasons for changes in ratings over time.

Test Routine

Each subject will be placed in the chamber for a four hour endurance test. At any time either the subject or the medical monitor may terminate the test. Once an hour the subject will be run through the assembly and disassembly of the test object. During other times the subject may move about the chamber at will or rest on a stool which will be provided.

Also on a once an hour basis, the subject will be administered the entire SAS, less Section IV (entry-exit) and items V.a. and V.b. which related to the subsystems communication test.

Decrements in appraisals will be identified while the subject is in the chamber. The subject will then be interviewed in some detail as to reasons for these changes via the intercom.

Data Analysis

Summary statistics will be prepared contrasting ratings given on the SAS against time in the chamber for each subject. Medical monitoring data records (RKG, respiration and O_2, CO_2, and N_2 concentrations) will also be correlated with SAS ratings over time in the chamber.

An overall profile will be prepared showing mean ratings across subjects against time, Reasons for changes in ratings obtained from the subject during the test will be compiled and evaluated,

Comments

A summary of the subject's comments as to reasons for changes in ratings will be prepared for use in the final data analysis effort,

SUBJECT S ASSESSMENT SCALE (SAS)

I. COMFORT

a. Overall comfort (check one)

- ☐ 7 Comfort Excellent
- ☐ 6
- ☐ 5
- ☐ 4 comfort Satisfactory
- ☐ 3
- ☐ 2
- ☐ 1 Comfort Unsatisfactory

b. Temperature (check one)

- ☐ 7 Temperature Ideal
- ☐ 6
- ☐ 5
- ☐ 4 Temperature Satisfactory
- ☐ 3
- ☐ 2
- ☐ 1 Temperature Unsatisfactory

If temperature was rated less than *4*, was it (check one)

☐ Too High or ☐ Too Low

c. Humidity (check one)

- ☐ 7 Humidity Ideal
- ☐ 6
- ☐ 5
- ☐ 4 Humidity Satisfactory
- ☐ 3
- ☐ 2
- ☐ 1 Humidity Unsatisfactory

If humidity was rated less than *4*, was it (check one)

☐ Too High or ☐ Too Low

d. Cooling Distribution (check one for each column)

HEAD & FACE	ARMS	HANDS	LEGS	FEET	TORSO	RATING	DESCRIPTIVE TERM
						7	Distribution Excellent
						6	
						5	
						4	Distribution Satisfactory
						3	
						2	
						1	Distribution Unsatisfactory

TI MOBILITY

Walking, bending, climbing and squatting (check one for each column)

WALKING	BENDING	CLIMBING	SQUATTING	RATING	DESCRIPTIVE TERM
				7	Mobility Excellent
				6	
				5	
				4	Mobility Satisfactory
				3	
				2	
				1	Mobility Unsatisfactory

III **DEXTERITY**

a. **Use of hand tools (check one)**

- ☐ 7 **Ease of Using Hand Tools Excellent**
- ☐ 6
- ☐ 5
- ☐ 4 **Ease of Using Hand Tools Satisfactory**
- ☐ 3
- ☐ 2
- ☐ 1 **Ease of Using Hand Tools Unsatisfactory**

b. **Handling of small objects (check one)**

- ☐ 7 **Ease of Handling Small Test Objects Excellent**
- ☐ 6
- ☐ 5
- ☐ 4 **Ease of Handling Small Test Objects Satisfactory**
- ☐ 3
- ☐ 2
- ☐ 1 **Ease of Handling Small Test Objects Unsatisfactory**

III

c.

1. Mating of electrical and hydraulic connectors

BENDIX JT	BNC	R.F.	HYDRAULIC	RATING	DESCRIPTIVE TERM
				7	Ease of Plating Excellent
				6	
				5	
				4	Ease of Plating Satisfactory
				3	
				2	
				1	Ease of Mating Unsatisfactory

2. Demating of electrical and hydraulic connectors

BENDIX JT	BNC	R.F.	HYDRAULIC	RATING	DESCRIPTIVE TERN
				7	Ease of Demating Exce1lent
				6	
				5	
				4	Ease of Demating Satisfactory
				3	
				2	
				1	Ease of Demating Unsatisfactory

IV. ENTRY/EXIT

a. Ease of putting on suit / Entry **(check one** in **each column).**

EASE OF ENTRANCE THROUGH TUNNEL	EASE OF POSITIONING SELF FOR PUTTING ON SUIT	EASE OF PUTTING ON SUIT	EASE OF DETACHING SUIT FROM DONNING RACK	RATING	DESCRIPTIVE **TERM**
		7		7	**Exce** 1Lent
				6	
				5	
				4	Satisfactory
				3	
				2	
				1	Unsatisfactory

IV. ENTRY/EXIT - continued

b. Ease of taking off suit / Exit (check one in each column).

EASE OF ATTACHING SUIT TO DONNING RACK	EASE OF TAKING OFF SUIT	EASE OF GETTING INTO TUNNEL	EASE OF EXIT THROUGH TUNNEL	RATING	DESCRIPTIVE TERM
				7	Excellent
				6	
				5	
				4	Satisfactory
				3	
				2	
				1	Unsatisfactory

V. COMMUNICATIONS

a. Loudspeaker Placement in Helmet (check one in each column for applicable test condition)

HELMET LOUDSPEAKER POSITION NO. 1 (SEE TEXT) SYSTEM VOLUME						HELMET LOUDSPEAKER POSITION NO. 2 (SEE TEXT) SYSTEM VOLUME						HELMET... POSITION. SYSTEM..		RATING	DESCRIPTIVE TERM
LOW		MEDIUM		HIGH		LOW		MEDIUM		HIGH		LOW			
INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION	INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION	INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION	INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION	INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION	INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION	INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION		
														7	Excellent
														6	
														5	
														4	Satisfactory
														3	
														2	
														1	Unsatisfactory

V. **COMMUNICATIONS - continued**

b. **Signal Intelligibility (check one in each column for each condition).**

LOW VOLUME		MEDIUM VOLUME		HIGH VOLUME			
INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION	INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION	INTELLIGIBILITY	BACKGROUND NOISE SUPPRESSION	RATING	DESCRIPTIVE TERM
						7	Excellent
						6	
						5	
						4	Satisfactory
						3	
						2	
						1	Unsatisfactory

V. COMMUNICATIONS - continued

c. Communications Effectiveness (check one for each column).

RECEIVED SIGNAL INTELLIGIBILITY	VOLUME LEVEL	BACKGROUND NOISE LEVEL	TRANSDUCER LOCATION	TRANSDUCER SIZE	CHAMBER SPEAKER PERFORMANCE	RATING	DESCRIPTIVE TERM
						7	Excellent
						6	
						5	
						4	Satisfactory
						3	
						2	
						1	Unsatisfactory

ATTACHMENT B. MATERIALS TESTS

1. FUNGUS GROWTH TEST

Objective

The Fungus Test is conducted to determine if the materials to be used will support growth of fungus type organisms.

Test Procedures

The method utilized is as described in MIL STD-810A (USAF) 23 June 1964, Procedure II. This shall be used for materials which can be cut or reduced to a size suitable for testing in a Petri Dish. The test shall be performed in accordance with Specification MIL-F-8261A. A test period of not less than 14 days shall be used.

1. Scope

This specification establishes methods for testing USAF materials for compliance with the requirements of USAF specifications and other governmental specifications, and was prepared to eliminate unnecessary and undesirable variations in testing procedure. This specification does not include special test methods which may be described in the specification applicable to certain materials.

2. Requirements

a. Test Facilities

(1) Incubator - equipment for incubation of all tests shall maintain a temperature 30°C ± 2°C, higher temperatures are detrimental. A relative humidity of 95 ± 5 percent is desirable for testing. Covered dishes containing agar or water are considered to have the desired humidity.

3. Method of Testing

a. Mixed Spore

Specimens of materials shall be prepared as follows:

(1) Three two-inch square specimens of materials shall be cut and handled with clean instruments. Each of the three specimens shall be tested.

(2) Glassware - one covered container such as six-inch Petri Dish, shall be used for each specimen to be inoculated with fungi. Approximately 60 ml of culture medium shall be used in each dish.

(3) Culture Medium - the culture medium shall be composed of the following ingredients and prepared as follows:

NH_4NO_3	3.0g
K_2HPO_4	1.0g
$MgSO_4 \cdot 7H_2O$	0.25g
KCl	0.25g
Agar	15-20.0g
Distilled Water	1000.0ML

Place the above ingredients in a suitable flask, plug with cotton, and melt the medium in an autoclave. Adjust pH, if necessary, to *5.5-6.5* with HCl or NaOH as required. Replace plug and sterilize in an autoclave for 20 minutes at 121°C. Using aseptic technique, pour the volume of agar into the Petri Dishes and allow the medium to harden.

(4) Test Fungi - the following fungi shall be used in this test:

Aspergillus niger ATCC 9642

Aspergillus flavus ATCC 10836

Myrothecium verrucaria ATCC 9095

Penicillium citrinum ATCC 9849

b. Preparation of Spore Suspension

Five ml of sterile distilled water containing *0.005* percent of a non-toxic wetting agent, such as dioctyl sodium sulfosuccinate, shall be added to a test tube of each required fungus. Each test fungus shall be in a ripe, actively growing, fruiting condition and shall be used within three weeks after the beginning of refrigerated storage. After addition of the water, the fungus culture shall be agitated gently to bring spores into suspension. The water in the tube shall contain no small pieces of agar. If no spores are brought into suspension, the agar slant shall be scraped gently with a sterile transfer needle to dislodge the spores. The suspension shall then be poured into about 35 ml of sterile distilled water containing *0.005* percent of a non-toxic wetting agent and the culture tube discarded. The flask shall be gently shaken or rotated to thoroughly disperse the spores. The spore suspension is then ready for use and shall be used within an eight hour period.

c. Viability Control

Several 2-3 inch pieces of heavy untreated cotton cloth shall be cut and placed in a deep covered dish. Tap water and a trace of non-toxic wetting agent, such as dioctyl sodium sulfosuccinate shall be added and the dish shaken vigorously. The pieces shall be separated, replaced in the dish, and sterilized in an autoclave for one hour at 121°C (2509). This material shall be inoculated and exposed one inch from the test specimens and shall show heavy growth and complete coverage by the test fungus or the test shall be repeated.

d. Inoculation

A spore suspension of the test fungus shall be prepared as described in Preparation of Spore Suspension above, The test specimen shall be placed on the center of the hardened agar medium in each dish. About 0.3 ml of the spore suspension shall be used to inoculate each test specimen. A pipette shall be used to measure the required quantity of the spore suspension. The inoculum shall be distributed evenly, lengthwise, and around the edges of the test specimens without flooding the agar medium. In addition the viability control specified in the preceding paragraph shall also be placed on the hardened agar medium one inch from the test specimen and inoculated with 0.3 ml of the spore suspension.

e. Incubation

The period of incubation shall be fourteen days.

f. Evaluation of Results

At the end of the incubation period, the inoculated and exposed specimens shall be observed for fungus growth with the aid of bright, natural or artificial lighting. Questionable evidence shall be investigated with the aid of a microscope. Specimens shall show no scattered, sparse surface growth nar mycelial bridges between specimen and agar. In addition, the viability control shall show heavy growth and complete coverage, or the test shall be repeated,

Maintenance of Test Fungal Cultures

1. Scope

a. This appendix includes the procedures for maintenance of test fungi cultures for use in fungus - resistance tests of BISS materials.

b. In testing materials for fungus resistance a set of the test fungi aids in the identification of the fungi on the test specimens and

on the viability control. In this manner, observations of fungus growth on test specimens may be standardized for qualitative evaluation of fungus resistance.

2. Requirements

a. When frequent or numerous tests are to be conducted to determine the fungus resistance of materials, cultures shall be maintained as specified herein to provide an adequate source of the test fungi.

b. Culture Maintenance Facilities

(1) Sterilization - equipment for steam sterilization such as an autoclave that shall maintain a temperature of at least 121°C (250°F), but no more than 125°C (257°F) at 15 lbs pressure. The period of sterilization shall be at the required temperature.

(2) Incubation - equipment for incubation of fungus cultures shall maintain a temperature of 30°C ± 2°C (86°F ± 3.6°F). Higher temperatures are detrimental. A relative humidity of 95 ± 5 percent is desired for incubation of fungus cultures.

(3) Refrigeration - equipment for refrigerated storage of culture tubes, test fungus cultures, and stock fungus cultures shall be maintained at 2°C to 5°C (35°F to 40°F).

3. Procedures

a. Culture Media for Test Fungi

The following culture media are suggested for maintaining fungus cultures.

Aspergillus flavus - Sabouraud Maltose or Potato Dextrose

Aspergillus niger - Enriched Mineral Salts or Potato Dextrose

Myrothecium serrucaria - Mineral Salts Cotton

Penicillium citrinum - Sabouraud Maltose

4. Mediums

a. Sabouraud Maltose Agar

This agar medium may be obtained from commercial sources such as Difco Laboratories, Inc., Detroit, Michigan. To obtain a satisfactory agar medium for culture tubes, 5 grams of agar shall be added to a liter of the Sabouraud Maltose culture formula.

b. Potato Dextrose Agar

This agar medium may be obtained from commercial sources such as Difco Laboratories, Inc., Detroit, Michigan. To be satisfactory as an agar medium for cultures tubes, 5 grams of agar shall be added to a liter of the Potato Dextrose culture formula.

c. Mineral Salts Agar

This agar medium shall consist of the following ingredients:

NH_4NO_3	3.0 grams
K_2HPO_4	1.0 grams
$MgSO_4 \cdot 7H_2O$	0.25 grams
KCl	0.25 grams
Agar	20.0 grams
Distilled Water	1000.0 ml

d. Stock Salt Solutions

Stock salt solutions of the above ingredients may be prepared when frequent testing of numerous specimens is required. These stock solutions shall be refrigerated. The stock salt solutions are not satisfactory after refrigeration for one month. These stock solutions shall be prepared by adding the indicated proportions to the required amount of distilled water. The proportions shall be as follows:

	250 ML	1000 ML
NH_4NO_3	75 grams	300 grams
K_2HPO_4	25 grams	100 grams
$MgSO_4 \cdot 7H_2O$	6.25 grams	25 grams
KCl	6.25 grams	25 grams

e. Enriched Mineral Salts Agar

This agar medium shall consist of the mineral salts agar as described in Mineral Salts Agar above with the addition of 20 grams of dextrose.

(1) Mineral Salts Agar, Cotton Strip - This agar medium shall consist of the mineral salts agar as d'escribed in Mineral Salts Agar above with the addition of a cotton strip to the

surface of the hardened agar. The cotton strips, 3/8 by 1 1/4 inch shall be cut from untreated, 2 to 4 ounce cotton cloth and placed in a deep covered dish. Tap water and a trace of non-toxic wetting agent such as Dioctyl Sodium Sulfosuccinate shall be added and the dish shaken vigorously. The strips shall be rinsed several times with distilled water and then squeezed to remove the excess. The strips shall be separated and straightened and each strip shall be placed in an individual test tube and plugged. The tubes shall be steam sterilized for one hour. Using aseptic technique, one cotton strip shall be transferred onto the surface of each hardened mineral salts agar culture tube before transferring the fungi to the culture tube preceding sterilization of the agar medium. (See above)

f. Preparation of Culture Media

(1) Stock Salt Solutions - ten ml of each of the stock salt solutions as described in Stock Salt Solutions above shall be added to 960 ml of distilled water to make a liter. A flask shall be used which is a least 50 percent larger than the volume of the medium. The required amount of agar shall be stirred into the above mixture,

(2) The flask shall be plugged with cotton and the medium heated in an autoclave at 121°C (250°F) for fifteen minutes. The medium shall be removed from the autoclave, allowed to cool slightly, dextrose added if needed, the pH shall be adjusted to 5.6. with HCl or NaOH.

(3) Preparation of Culture Tubes - Between 7 and 8 ml of the liquid agar medium is required for each 16 by 150 mm size test tube. The culture tubes shall be plugged and steam sterilized for twenty minutes.

(4) After sterilization the culture tubes shall be slanted at about 15 degrees from the horizontal while cooling resulting in an agar slant. The top level will not extend beyond half the length of the test tube.

(5) The culture tubes shall be refrigerated before use for the transfer of fungi, Culture tubes shall be stored for no more than two or three months. Any tube showing contamination or dessication shall be discarded.

(6) Transfer of Test Fungi - Transfer of any test fungus shall be made from a spore suspension. A sterile graduated pipette shall be used to deliver 0.1cc of spore suspension over the surface of the agar slant in an aseptic manner.

(7) Preparation of Spore Suspension - The spore suspension shall be made as described in Preparation of Spore Suspension above.

g. Incubation of Transferred Fungi

(1) The following test fungi usually require the indicated incubation period:

Two - Four Days

Aspergillus niger

Aspergillus flavus

Myrothecium verrucaria

Penicillium citrinum

h. Storage of Test Fungi

Fungus cultures shall be refrigerated after incubation

(1) Fungus cultures designated for use in the fungus resistance test of materials shall be refrigerated for no longer than three weeks,

2. MYCELIAL PENETRABILITY TEST

Objective

This test is conducted to determine if the materials to be used are penetrable by the mycelium of filamentous fungi.

Test Procedures

The method used is a modification of MIL-STD-803A **(USAF),** 23 June 1964 Procedure II. This shall be used for materials which can be cut or reduced to a size suitable for testing in a Petri Dish. The test shall be performed with the mentioned modification in accordance with specification MIL-F-8261A. A test period of not less than 14 days shall be used.

1. Scope

This specification establishes methods for testing **USAF** materials for compliance with the requirements of **USAF** specifications and other governmental specifications, and was prepared to eliminate unnecessary and undesirable variations in testing procedure. This specification does not include special test methods which may be described in the specification applicable to certain materials.

2. Requirements

a. Test Facilities

(1) Incubator - equipment for incubation of all tests shall maintain a temperature $30^{\circ}C \pm 2^{\circ}C$, higher temperatures are detrimental. A relative humidity of 95 ± 5 percent is desirable for testing. Covered dishes containing agar or water are considered to have the desired humidity.

3. Method of Testing

a, Mixed Spore

Specimens of materials shall be prepared as follows:

(1) Three two-inch square specimens of materials shall be cut and handled with clean instruments. Each of the three specimens shall be tested.

(2) Glassware - one covered container such as a six-inch Petri Dish, shall be used for each specimen to be inoculated with fungi. Approximately ***60*** ml of culture medium shall be used in each dish.

(3) Culture Medium - the culture medium shall be composed of the following ingredients and prepared as follows:

Glucose	20.0g
NH_4NO_3	3.0g
K_2HPO_4	1.0g
$NgSO_4,7H_2O$	0.25g
KCl	0.25g
Agar	15-20.0g
Distilled Water	1000.0ML

Place the above ingredients in a suitable flask, plug with cotton, and melt the medium in an autoclave. Adjust pH, if necessary, to 5.5-6.5 with HCl or NaOH as required. Replace plug and sterilize in an autoclave for 20 minutes at 121°C. Using aseptic technique, pour the volume of agar into the Petri Dishes and allow the medium to harden.

(4) Test Fungi - the following fungi shall be used in this test:

Aspergillus niger ATCC 9642

Aspergillus flavus ATCC 10836

Myrothecium verrucaria ATCC 9095

Penicillium citrinum ATCC 9849

4. Test Methods

a. Preparation of Spore Suspension

Five ml of sterile distilled water containing 0.005 percent of a non-toxic wetting agent, such as dioctyl sodium sulfosuccinate, shall be added to a test tube of each required fungus. Each test fungus shall be in a ripe, actively growing, fruiting condition and shall be used within three weeks after the beginning of refrigerated storage. After addition of the water, the fungus culture shall be agitated gently to bring spores into suspension. The water in the tube shall contain no small pieces of agar. If no spores are brought into suspension, the agar slant shall be scraped gently with a sterile transfer needle to dislodge the spores. The suspension shall then be poured into about 35 ml of sterile distilled water containing 0.005 percent of a non-toxic wetting agent and the culture tube discarded. The flask shall be gently shaken or rotated to thoroughly disperse the spores. The spore suspension is then ready for use and shall be used within an eight hour period.

b. Viability Control

Several 2-3 inch pieces of heavy untreated cotton cloth shall be cut and placed in a deep covered dish. Tap water and a trace of non-toxic wetting agent such as Dioctyl Sodium Sulfosuccinate shall be added and the dish shaken vigorously. The pieces shall be separated, replaced in the dish and sterilized in an autoclave for one hour at 121°C (250°F). This material will serve as a positive control to be used with each material tested and shall show heavy growth and coverage by the test fungus or the test shall be repeated.

c. Inoculation

A spore suspension of the test fungus shall be prepared as described for Preparation of Spore Suspension above. About 0.3 ml of the spore suspension shall be used to inoculate that portion of the agar upon which the test specimen is to be placed. 0.3 ml of the spore suspension shall be used to inoculate the agar on which the viability control cotton piece is to be placed.

The test specimen and viability control pieces will be placed one inch apart.

d. Glass Cylinders with a dimension of one inch outside diameter, and length 0.5 inch shall be washed and autoclaved in a Mason type jar at 121°C (2509) for a period of not less than 20 minutes with the lid unsealed to assure entry of steam. They will subsequently be allowed to cool. These cylinders may be dried by soaking in ethanol or isopropanol and flaming prior to use. They will be placed centrally on the material to be tested and on the viability control. With a sterile graduated pipette 0.75 ml of sterile enriched mineral salts agar which has been previously cooled to 45°C will be placed in the center of the cup, formed by the cylinder and allowed to solidify.

e. Incubation

The period of incubation shall be 14 days.

f. Evaluation of Results

At the end of the incubation period, the agar in the cup, both on the material being tested and the viability control, shall be examined for fungus growth with the aid of bright, natural or artificial light. Questionable evidence shall be investigated with the aid of a microscope. Specimens which show growth in the agar above the material should be regarded as positive for myceliar penetration. The viability control shall show heavy growth or the test shall be repeated.

Maintenance of Test Fungi Cultures

Same as Fungus Growth Test Plan.

3. PERMEABILITY/FLEXURE

Objective

The test method is not designed to yield flexural properties of plastic materials. It will be employed to prepare flexed specimens of thin film and bonded plastics for subsequent evaluation of permeability and tensile properties as shown in Table 1.

Test Routine

Test specimens, nominally 10 inch by 80 inches shall be firmly attached by means of a clamping block to a base plate, passed 180° over a 1/8 inch diameter roller and firmly attached to a spring loaded clamping block which in turn is attached to the base plate. The roller shall be imparted a reciprocating action by means of a variac controlled drive motor to repeatedly flex a 20 inch minimum length of the film material over the roller.

Comments

Report data shall include number of flexure cycles and reciprocating speed.

4. ABRASION

Objective

This test method covers the procedure for determining the abrasion resistance of plastic films, laminates, and optical materials, by means of the Taber Abraser.

Test Routine

1. Rigid Materials

Test specimens shall be 4 inches by 4 inches nominal dimension with a 0.25 inch diameter center hole to allow positioning on the instrument turn-table.

2. Flexible Materials

Test specimens shall be 4 inches by 4 inches nominal dimension with a 0.25 inch diameter center. Specimens shall be mounted on the instrument turn-table by means of pressure-sensitive adhesive cards, or alternatively, by means of a textile and flexible materials clamping ring.

3. Glasses

Glasses shall be abraded by means of CS-17, H-18, or H-38 wheels with 500 or 1000gm load, whichever combination is best suited to the material hardness and abrasion rate desired.

4. Plastic Materials

Rigid plastic materials shall be abraded with the CS-17 or CS-10 wheels under 1000 grams pressure. Five hundred (500) grams pressure shall be utilized where required to extend test duration.

This plastic film materials shall be abraded with H-18, H-22, CS-17, or CS-10 wheels under 500 or 1000 gm pressure, whichever combination is best suited to the material hardness and abrasion rate desired.

Each material will be abraded for 100, 500, and 1000 cycles before and after each environmental test, and weight loss in milligrams recorded as a function of abrasion cycle.

5. Equipment Required

The instrument utilized for this test routine shall be a Taber Abraser, Model 174, with a vacuum dust collection system.

A laboratory analytical balance of 200 gm capacity and sensitivity of 0.1mg shall be used to determine initial and final specimen weight to the nearest 0.1mg.

Comments

Specimen data shall be reported as Wear Index (Taber). The index shall be calculated as follows:

$$\text{Wear Index (Taber) (Weight Loss Method)} = \frac{\text{mg. weight loss x 1000 cycles}}{\text{actual abrasion cycles}}$$

The following data shall also be reported:

1. Wheel identification

2. Abraser head pressure, gm

3. Abrasion cycles

Where applicable, for comparison of specimens of widely differing specific gravity, a volume loss method may be utilized as follows:

$$\text{Wear Index (Taber) (Volume Loss Method)} = \frac{\text{mg. weight loss x 1000 cycles}}{\text{Specific Gravity x Actual abrasion cycles}}$$

Reported data are similar to those for the weight loss method.

5. TRANSFER OF MICROORGANISMS, LIQUIDS AND GASES ACROSS SUIT MATERIALS (PART I)

Objective

The purpose of this test is to develop techniques for testing transfer of microorganisms and gases across suit materials. Samples to be tested shall include controls and those that have been previously exposed to the Abrasion testing procedure and to the Permeability/Flexure preparation procedure.

Test Routine - Microorganisms

Various suit materials will be exposed to radioactively labeled bacteria in a pressurized system. The opposite side of the material from that exposed to the bacteria will be counted in a low level proportional counter in order to determine if the material is permeable to bacteria.

1. Method of Testing

The test materials will be prepared as follows:

a. One inch squares of the material will be fixed to a planchet holder forming a test chamber. This will be leak tested at greater than 12 inches of water of internal pressure.

b. The background will be counted on these test pieces for 100 minutes on a low level proportional scaler with a counting background of 0.5 - 0.6 counts per minute.

c. A suspension of radioactively - labeled bacteria of not less than 0.5 disintegrations per minute/bacterium will be injected into the well of the test chamber. The chamber will again be counted for 100 minutes with an internal pressure greater than 4 inches of water.

d. Microorganisms to be used will be selected from the following group on the basis of greatest dpm/bacterium:

Organism	Isotope
Micrococcus rubens	C^{14} or P^{32}
Micrococcus candidus	C^{14} or P^{32}
Bacillus subtilis var. niger	Ca^{45} or P^{32}
Bacillus cereus	Ca^{45} or P^{32}

Selection of the isotope will be based on relative uptake by the organism and on its energy.

Test Routine - Gases

The suit material samples used in the previous tests will be exposed to a radioactive gas in order to test the transfer of gases through them.

1. Method of Testing

   a. The test material will be prepared as described in paragraph 1.a through 1.b above.

   b. C^{14} carbon dioxide or krypton 85 will be injected into the test chamber at a pressure greater than 4 inches of water.

   c. The test chamber will be contained in an ionization chamber and will be counted for periods of up to 8 hours by a means of a vibrating reed electrometer.

Comments

In any case where the background steadily rises it will be taken to indicate that the test material is permeable to the gas tested. The rise must be rapid in order to separate an increase due to diffusion from one caused by leakage. A list of materials which satisfy the BISS criteria of acting as an absolute microbiological barrier will be prepared. Comparisons will be drawn to determine if gas leaks are a reasonable indicator of membrane holes.

5. TRANSFER OF MICROORGANISMS, LIQUIDS AND GASES ACROSS SUIT MATERIALS (PART 11)

Objective

The prupose of this test is to determine the permeability of the suit materials to water vapor and gas as a supplement to data from the literature.

Test Routine

The prospective suit materials will be tested for permeability to water vapor and gas by exposing one side of the material to a given atmosphere and attempting to detect this atmosphere on the other side. In the case of water vapor, the detection will be by means of the Karl-Fisher titration method. In the case of gases, such as ethylene oxide, detection will be gas chromatography.

Comments

None

6. RETENTION AND RELEASE OF DISINFECTANTS BY MATERIALS

Objective

The purpose of this test is to determine the degree of absorption and retention by the materials when exposed to ethylene oxide/freon mixtures and liquid decontaminants Isopropanol and Peracetic acid.

1. Absorption and Retention of an Ethylene Oxide/Freon Mixture

   The candidate material will be cut to a size of 4 inch square. It will then be exposed to an atmosphere of ETO (12%) and freon (88%). After 28 hours exposure to this atmosphere (see procedure for compatibility testing) it will be removed and placed in a closed 10 cubic centimeter container. After 0.5 hour equilibration, the atmosphere of the container will be measured by a gas chromatograph. After sampling the container air will be displaced and the container again allowed to equilibrate. The atmosphere will be sampled at suitable intervals until neither ETO nor freon can be detected. An approximation of the amount of absorbed ETO can be made by integrating the data from sequential sampling.

2. Absorption and Retention of Liquid Decontaminants

   The candidate material shall be exposed to liquid solutions of the disinfectants to be used as in 1 above, After exposure, absorption of the disinfectant shall be determined by wet chemical methods. Retention of disinfectants will be determined by analyzing test pieces of the material at intervals after exposure.

Comments

Alternative chemical methods to those referenced may be employed in the event that difficulties arise with the analysis.

Chemical Methods

1. Alcohol (isopropanol) will be determined by wet chemistry (ref. Frankel, S. and Reitman, S. "Gradwahl's Clinical Laboratory Methods and Diagnosis." C. V. Mosby Co. 1963 p. 338.)

2. Peracetic acid will be measured by titration with ceric sulfate. (ref. Greenspan, F. P. and MacKellar, D, G. Analytical Chemistry, Col 20, p. 1061 1948.)

7. COMPATIBILITY WITH DETERGENTS AND DISINFECTANTS

Objective

To determine the resistance of materials to disinfectants and detergents.

Routine

Each material shall be submitted to the following compatibility tests:

1. ETO
2. Peracetic Acid
3. Detergent and Isopropanol

ETO Compatibility Test

The ETO Compatibility Test shall proceed in the following manner:

1. Place the load within the decontamination chamber and close the chamber. Verify that the test chamber temperature is in the range of 20 - 25°C prior to insertion of the load.
2. Induce air to flow through the chamber. Heated, humidified air shall be continuously circulated through the chamber.
3. When the chamber reference point reaches a temperature reading of 50°C and the required humidity concentration, stop the circulation of air within the chamber.
4. Apply sufficient vacuum to the chamber to produce a vacuum in the range of 60 ± 5 torr within a period of 17 - 20 minutes.
5. Introduce the decontaminating agent through a heat exchanger which is capable of heating the agent to a maximum temperature of 55°C. The nature of the heat exchanger shall be so that when the decontaminating agent enters the chamber it shall be at a maximum temperature of 50°C. Introduce the decontaminating agent at a rate which will permit reaching an atmospheric concentration 400 mg/liter in 30 minutes. After the stated concentration is reached, close the chamber and hold conditions constant for 28 hours.
6. After the specified exposure period, apply a vacuum per step 1. During the vacuum cycles, all gases shall be vented to the outside atmosphere in a manner that does not constitute a health hazard.

7. Return the chamber to atmospheric pressure within 45 minutes by allowing air at ambient temperature to enter the chamber. Then flush the chamber with ambient air until two air cycles have been accomplished. Flushing will be done at ambient pressure. In some instances, it may be necessary to repeat step 6. and re-flush the chamber to remove the residual decontaminating agent to a safe level.

8. Open the chamber and remove the load for testing.

Relative Humidity

The method of achieving and controlling relative humidity (RH) within the chamber shall be one that assures an even distribution of water vapor and an accurate humidity control over the range from 35 to 55 percent RH. The method used shall guarantee the required RH within the specified tolerance, and shall be compatible with other requirements and devices for controlling temperature and ETO concentration.

ETO Decontamination Compatibility Test for Materials

Each item to be tested shall be subjected to six separate cycles (see ETO Compatibility Test) of ETO decontamination of a maximum temperature of 50°C. Performance tests and other evaluation criteria for determining the effects of the environment on the units shall be accomplished with treated and untreated samples, The decontamination test environment is 88 percent Freon 12 and 12 percent ETO at 50 percent RH and a concentration of 400 mg of ETO/liter of gaseous atmosphere. Each item shall be at an initial temperature of 20 - 25°C prior to placement within the ETO chamber. Contact of the decontaminating atmosphere on all principal surfaces of the item is required.

Peracetic Acid

Each material shall be immersed in a suitable container containing a 2% solution of Peracetic Acid for 48 hours.

Detergent and Isopropanol

Each material shall be immersed in a suitable container in a solution containing 5% Triton X-100 for 48 hours. The sample will be drained dry and immersed in a solution of 70-90% Isopropanol for 48 hours.

Analysis of Test Results

Degradation of material property parameters shall be reviewed to establish decrement values for each test sufficient to be cause for rejection of the materia1.

8. EVALUATION OF DISINFECTANTS

Objective

To determine if the helmet materials can be effectively disinfected for purposes of prophylaxis.

Introduction

Since the present concept as evolved holds that the helmet portion of the BISS suit is the only portion of the suit which is to be chemically disinfected, for sanitary purposes, the helmet materials will be tested.

Two organisms which are representative of the most hazardous type of contamination likely to be encountered are to be checked.

1. Staphylococcus aureus
2. Mycobacterium phlei

Method

A loop of a *24* hour culture of both types will be placed on the materials previously sterilized by dry heat. The inoculum will be spread on the material and then allowed to air dry. These will then be treated in the following manner:

1. Washed with a cotton applicator type swab previously wetted with a 5% solution of non-ionic detergent (Triton X-100).
2. Dried with a cotton applicator type stick.
3. Washed with a cotton swab moistened in 70% Isopropanol and allowed to stand in a moist condition for an appropriate time period.
4. Dried with another swab.
5. The pieces will then be transferred to a nutrient broth and incubated for *48* hours.
6. If any growth results Gram stains will be prepared to compare morphology to ascertain if the original type colonies are present.
7. All tests will be performed in triplicate.

Evaluation of Results

Recovery of either organism in a test would constitute an inadequate disinfecting procedure.

9. APPLICATION OF HELMET INTERNAL DISINFECTION

The suggested method of disinfecting the helmet portion of the suit will consist of:

1. Disengaging the hook on top of the helmet from its attachment. This will drop the helmet portion down into an inverted position.

2. Swab the helmet with a cloth which has been previously dampened with a 5 percent aqueous solution of Triton X-100 to remove surface film and sputum which may accumulate during usage.

3. Wipe with a dry cloth to remove residual moisture.

4. Swab the surface thoroughly with a cloth moistened in a 70 percent Isopropanol solution. The surface should remain moist for at least five minutes.

5. Wipe with a dry cloth to remove residual alcohol.

6. To remove the residual alcohol fumes, a hose should be extended into the helmet and air withdrawn from it for a suitable period of time.

Test Routine

The test will consist of evaluating the mechanical application of the above disinfecting technique in the helmet. Aeration of the helmet will be evaluated by organoleptic methods.

Evaluation of Results

The ease and practicality of the swabbing operation will be determined.

To produce an environment free of objectionable alcohol fumes, the air flow and time required will be determined by a practical application.

10. TENSILE TEST FOR RIGID, SOLID AND LAMINATED PLASTICS

Objective

The tensile property of plastics shall be determined by ASTM test D-638 (Tensile Properties of Plastics).

Test Routine

The apparatus shall consist of a testing machine of the constant rate-of-cross-head movement type with one grip fixed or essentially stationary, and a movable second grip. The load indicator shall be essentially free from inertia-lag at the specified test rate and shall have an accuracy of ± 1%

The test specimens for sheet, plate and molded plastics shall conform to the dimensions as shown in Figure 1 of the ASTM test and may be prepared by machining or prepared as a molded piece. All surfaces shall be free from visible flaws, scratches and imperfections.

Imperfection marks may be removed using a #00 or finer abrasive paper or file.

Standard conditioning procedure for conditioning the test specimens shall be followed (ASTM D-618; procedure A) or the applicable criteria test environment and the test shall be conducted in an area maintained at 23 ± 1°C (73.4 ± 1.8°F) and 50 ± 2% relative humidity.

Speed of testing shall be "Speed B" - or 0.20 to 0.25 inches/min. Modulus values are determined at the above speed, with the exception of molded or laminated thermosetting material. The latter materials shall employ a 0.05 inches/min. crosshead speed.

Final calculations shall be made to determine tensile strength, percentage of elongation, mean rate of straining, elastic modulus for applicable materials, and average values shall be reported.

Comments

The above method shall be followed for rigid, solid and laminated plastics only. For thin plastic sheeting ASTM D-882 shall be applicable.

11. TENSILE TEST OF FLEXIBLE PLASTIC SHEETING

Objective

The tensile test of flexible plastic sheeting shall be determined by **ASTM** D-1530-58T. This test method describes the procedure using thin sheeting less than 0.040 inches and is based on the grip separation as a measure of extension. The test has currently been incorporated into test **ASTM** D-882-64T.

Test Routine

The tensile modulus of elasticity is an index of stiffness of thin plastic sheeting and the absolute values may be greatly affected by specimen dimensions, type of gripping system used, and rate of straining.

The testing machine shall have a constant rate of jaw separation and shall be equipped with a weighing head which shall move a maximum distance of not more than 2% of the specimen extension within the test range. The tensile load recorder and separation of grip measurement shall be made with an accuracy of $\pm$ 2%. The rate of travel of the power-activated grip shall be uniform and adjustable to produce a strain rate of 10 $\pm$ 0.5% for the specimen dimension used. The gripping system shall minimize both slippage and uneven stress.

Thickness measurements of the test specimen shall be made using a pressure on the gage between 23 and 27 psi and measured to a reading of 0.0001 inches or less. The width measuring device must be capable of reading to 0.010 inches or less.

Conditioning specifications for maintaining laboratory atmosphere and conditioning of test specimens shall be in accordance to that specified for the tensile test for rigid, solid and laminated plastics, and shall follow ASTM D-618, or the applicable criteria test environment.

The test specimen shall consist of strips of uniform width and thickness at least 2 inches longer than the test separations used. The width shall be greater than 0.19 inches and less than 1.25 inches. The width to thickness ratio of at least eight shall be used. Nicks, tears, and imperfections are not allowable.

Calculation of the elastic modulus shall be made by drawing a tangent to the initial linear portion of the load-extension curve, selecting any point on the tangent, and deviding the nominal tensile stress by the corresponding strain. In applicable cases, a secant modulus may be calculated by the same method using the secant in place of the tangent. Results shall be reported in pounds per square inch and to three significant figures.

Comments

None

12. PUNCTURE RESISTANCE

Objective

The test method employed to insure puncture resistance capability of the plastic material shall be performed in accordance with a modified ASTM E 154-60T (a Puncture Test of Vapor Barriers) adapted for use with the constraints and requirements of the present program.

Test Routine

The equipment shall consist of a pair of wooden or metallic frames with an outside dimension of 10 inches by 10 inches and an opening of 6 inches by 6 inches. Each frame shall be 1 1/4 inches thick. The two frames shall be equipped and held together by thumb screws or bolts. The contact surface of each frame shall be surfaced with coarse grit sandpaper to insure that no slippage shall occur. A solid plunger, shaped to conform to the head of a medium-sized screw driver shall be provided, with the edges slightly de-honed.

The test shall be performed in the following manner:

1. Cut three 10 inch square specimens of the flexible sheet of plastic, conditioned per the applicable environmental test requirement.

2. Sandwich a single sheet of the flexible plastic sheet between the two frames, insuring that no wrinkles or ripples occur, and tighten uniformly.

3. Place the screw-driver-like plunger in the upper jaw of a constant speed testing machine (parallel to the direction of travel) and place the wooden frame on the bottom platen centered directly under the plunger. Bring the end surface of the screw-driver down to the film surface and zero the load setting. At a constant rate of 0.25 inches per minute, lower the screw-driver plunger into the plastic film until failure occurs. Record the maximum load at failure. Report the average of three tests.

The failure criteria of this test shall be the ability of the plastic to withstand a constant thrust of 50 pounds using the above plunger.

Comments

None

13. OPTICAL TRANSMITTANCE

Objective

Test specimens, 1 inch by 1 inch nominal dimension, shall be measured before and after the applicable criteria environment evaluation, for optical transmittance in the visible range, and reported as percent decrement of transmittance. Optical transmittance for the BISS program is defined as transmittance of incident energy in the visible wavelength range (0.4 - 0.7 microns).

Test Routine

A Gier-Dunkle Absolute Directional Integrating Sphere Reflectometer capable of spectral measurements in the wave-length region 0.30 to 3.0 microns shall be employed. The system consists of a source and transfer optics unit which generates the spectral energy in the solar spectrum. This energy is dispersed spectrally by a monochromator which, in turn, directs monochromatic radiation (2% solar spectrum increments) into the integrating sphere reflectometer and onto a specimen suspended at the center of the sphere. The reflected radiation and subsequent inter-reflections from the sphere wall (magnesium oxide coated) cause a diffuse irradiation upon detectors which view the entire sphere but not the specimen. The detector signal is calibrated when the incident energy is directed past the specimen to the sphere wall by means of a remote controlled rotary mirror in the optical box.

The absolute transmittance of non-opaque materials may also be obtained with the Gier-Dunkle integrating sphere. For these determinations, the sample is located to interrupt the monochromatic energy at the entrance of the integrating sphere. The total hemispherical detection of the transmitted energy is then compared to the detected incident energy, yielding the absolute transmittance at discrete wave-lengths. Transmittance may then be plotted spectrally and determined for finite wave-length intervals. In this case, the visible range, 0.4 - 0.7 microns.

Comments

Optical transmittance shall be reported as percent decrement as a function of the test environment.

14. WEIGHT CHANGE

Objective

This test method is designed to determine the change in weight of plastics exposed to the applicable criteria test environments. (See "Compatibility with Detergents and Disinfectants", and "Temperature Aging".)

Test Routine

Test specimens shall be evaluated before and after the applicable criteria test environment. Test specimens shall be weighed to the nearest 0.1 mg before and after test, and percent weight change calculated. A laboratory balance, of the single or double pan type, with capacity of 200gm., and sensitivity of 0.1 mg. is required for this test routine.

Comments

Report data shall include the following:

1. Initial specimen weight.
2. Final specimen weight.
3. Percent weight increment or decrement.
4. Test environment.

15. IMPACT TEST FOR PLASTIC MATERIALS

Objective

The impact test for plastic materials shall be made using a modified Gardner "Coverall" Mandrel Impact Tester.

Test Routine

Essentially the impact tester is a two piece unit consisting of a rod impacter and a guide tube. The rod impacter is placed in the guide tube, raised to a predetermined height and dropped to impact upon the test specimen (or assembly) which is positioned directly below the guide tube.

Testing shall be performed to produce 125 ft. lbs. impact upon the test specimen or assembly. Thus, modification of the Gardner-unit will require a 12.5 pound weight dropped through 10 feet of guide tube to impact, or any combination of distance times weight to produce the impact force required.

Failure criteria shall be determined visually and shall be classified in the following manner: passed - if no cracks are apparent in the plastic material; failure - if cracks or crazing appear or a hole is produced. In failure cases, supplementary specimens shall be evaluated to determine force level required to produce a discernable failure.

Comments

None

16. TEMPERATURE AGING

Objective

This method, as defined in Fed. Std. 406, Method 1121, is designed to determine the tear-resistance of flexible plastic film and sheeting ranging in thickness from 0.001 to 0.075 inch.

Test Routine

A die shall be used to cut the single or multiple layer specimens to the dimensions shown in Figure F-11. Dimensions shall not vary more than 0.5% from those shown. Thickness of specimens shall be measured with a micrometer graduated to 0.0001 inch having a presser foot 0.25 $\pm$ 0.01 inch in diameter exerting a total force of 3.0 $\pm$ 0.1 ounce.

The specimens shall be gripped in the clamps of an Instron type testing machine (specimen center-line parallel to the direction of load) and load applied at either a rate of 20 inches/minute or 2 pounds/minute per each 0.001 inch of specimen thickness until failure.

Comments

Report data shall include the following:

1. Tear Strength, pounds/inch thickness
2. Number of plies
3. Failure mode.

17. TEAR RESISTANCE

Objective

Test *specimens are to undergo temperature aging during this test. Temperature aging is defined as the cyclic elevated temperature exposure of rigid solid or laminated plastic, or plastic sheeting materials.

Test Routine

Test specimens, of a dimension specified by other applicable test methods, will be exposed to 5, 10 and 20 thermal cycles of 160°C for 3 hours. Subsequent testing will be conducted per the applicable test method for each specimen.

Laboratory ovens of the re-circulating type, of suitable dimension to accommodate all replicate specimens of one test series are required to perform this test routine. Temperature control shall be ± 10°F, and shall be programmed to simulate the dry heat sterilization cycle-in temperature rise and decay.

Comments

None.

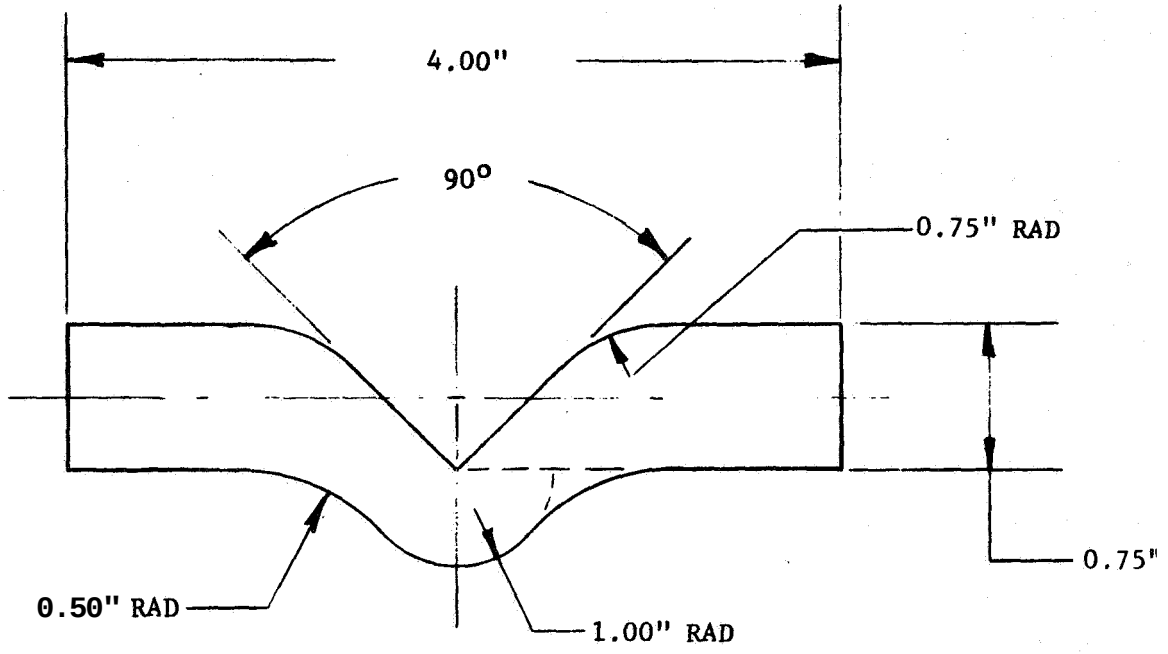


Figure F-11. Tear Test Specimen

18. COMPRESSIVE PROPERTIES

Objective

This method, as defined in Fed. Std. 406, Method 1021, is designed for use in determining the compressive properties of rigid plastics when loaded in compression.

Test Routine

Specimens shall be tested before and after exposure to the applicable criteria test environment. Where applicable, standard specimens in the form of a right cylinder or prism whose ends are parallel within 0.005 inch shall be used. A prism of square cross-section 0.5 inch by 0.5 inch by 1.0 inch or a cylinder 0.5 inch in diameter by 1.0 inch in length is preferred. For rods of less than, or greater than, 0.5 inch, the length/slenderness ratios of Fed. Std. 406, Method 1021, Section 2.5 shall apply. A constant rate of loading, Instron type, compressive testing machine shall be utilized for this test routine.

Comments

Report data shall include the following:

1. Direction, type and rate of loading.
2. Maximum load sustained.
3. Ultimate strength, psi.
4. Failure mode.
5. Slenderness ratio.
6. Compressive deformation at maximum load.

19. LAP SHEAR

Objective

This test method is designed to yield tensile shear strength of adhesive bonded composites.

Test Routine

The test specimen consists of two individual panels, each 1.0 inch by 3.5 inches with suitable holes or grip areas to allow gripping in a tensile machine. The panels are overlapped 1.0 $\pm$ 1/64 inch, and bonded with a controlled thickness of the candidate adhesive. After cure of the adhesive, and after exposure to the applicable criteria test environment, the specimens are tensile stressed to failure. The overlap panels may be of metal such as aluminum, stainless steel, etc. or in the case of rigid plastics bonding, may be constructed of the rigid plastic bonded with the candidate adhesive. A constant rate of loading test machine for the tensile test for rigid solid and laminated plastics (of the Instron type) is required to perform this test routine.

Comments

Report data shall include the following:

1. Yield strength, psi.

2. Tensile load to failure, psi.

3. Failure mode, ie. adhesive, cohesive.

20. **BUTT TENSILE**

Objective

This test method is designed to yield tensile strength of an adhesive bonded composite. The method is applicable to rigid and flexible plastic bonded composites.

Test Routine

The butt tensile specimen consists of two blocks of metal (or rigid plastic) 1.0 inch by 1.0 inch by 2.0 inches bonded together at the 1.0 inch by 1.0 inch dimension by a carefully controlled thickness of the candidate adhesive, The joint area may also consist of a layer of flexible plastic bonded to each face of the tensile blocks. After adhesive cure and exposure to the applicable criteria test environment, the specimens are mounted in a test machine and tensile stressed to failure. A constant rate of loading test machine as defined for the tensile test for rigid, solid and laminated plastics (of the Instron type) is required to perform this test routine.

Comments

Report data shall include the following:

1. Yield strength, psi.

2. Ultimate tensile load, psi.

3. Failure mode, i.e. adhesive, cohesive.

ATTACHMENT C: **BISS** TEST PLAN SCHEDULE

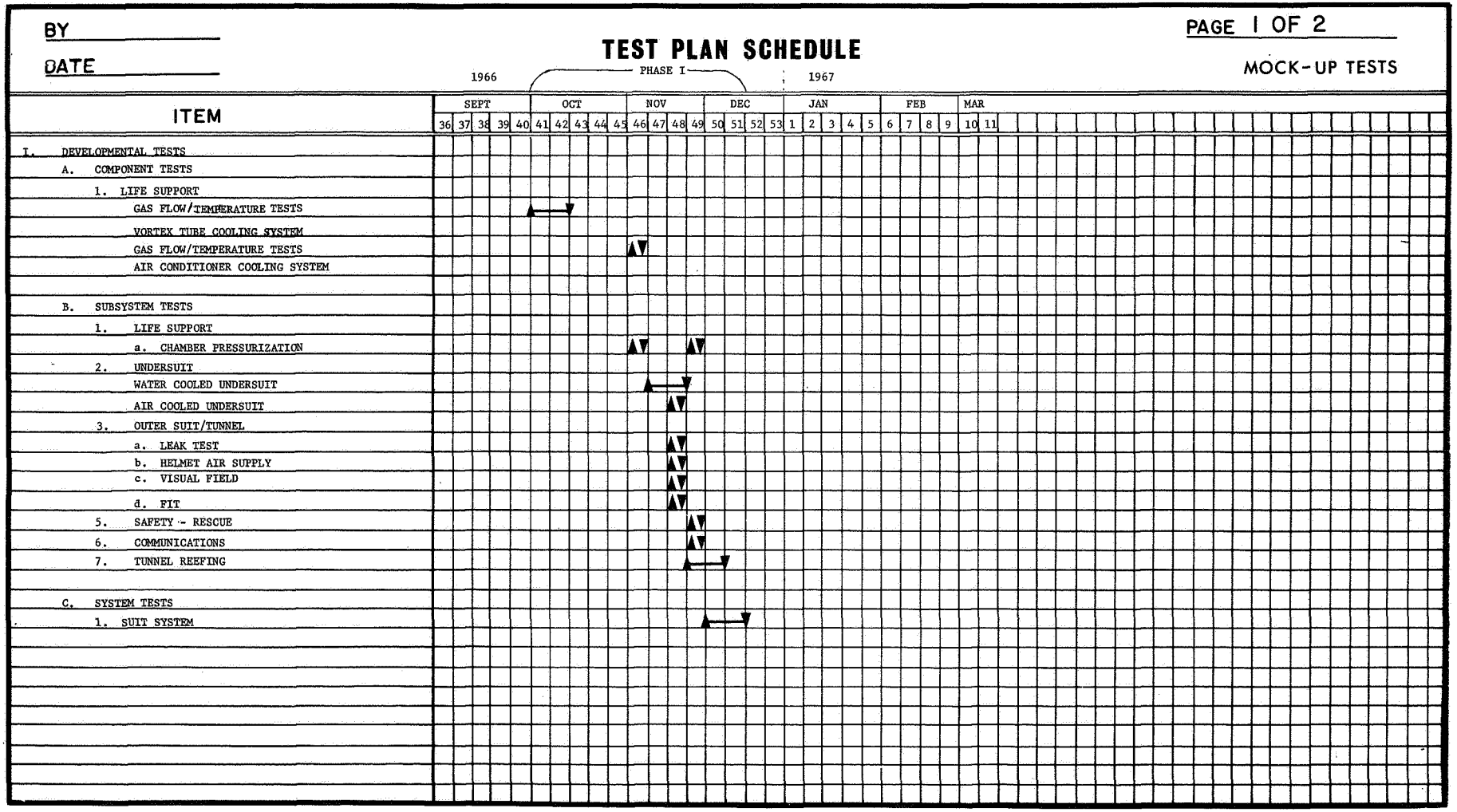
BY

DATE

TEST PLAN SCHEDULE

PAGE 1 OF 2

MOCK-UP TESTS



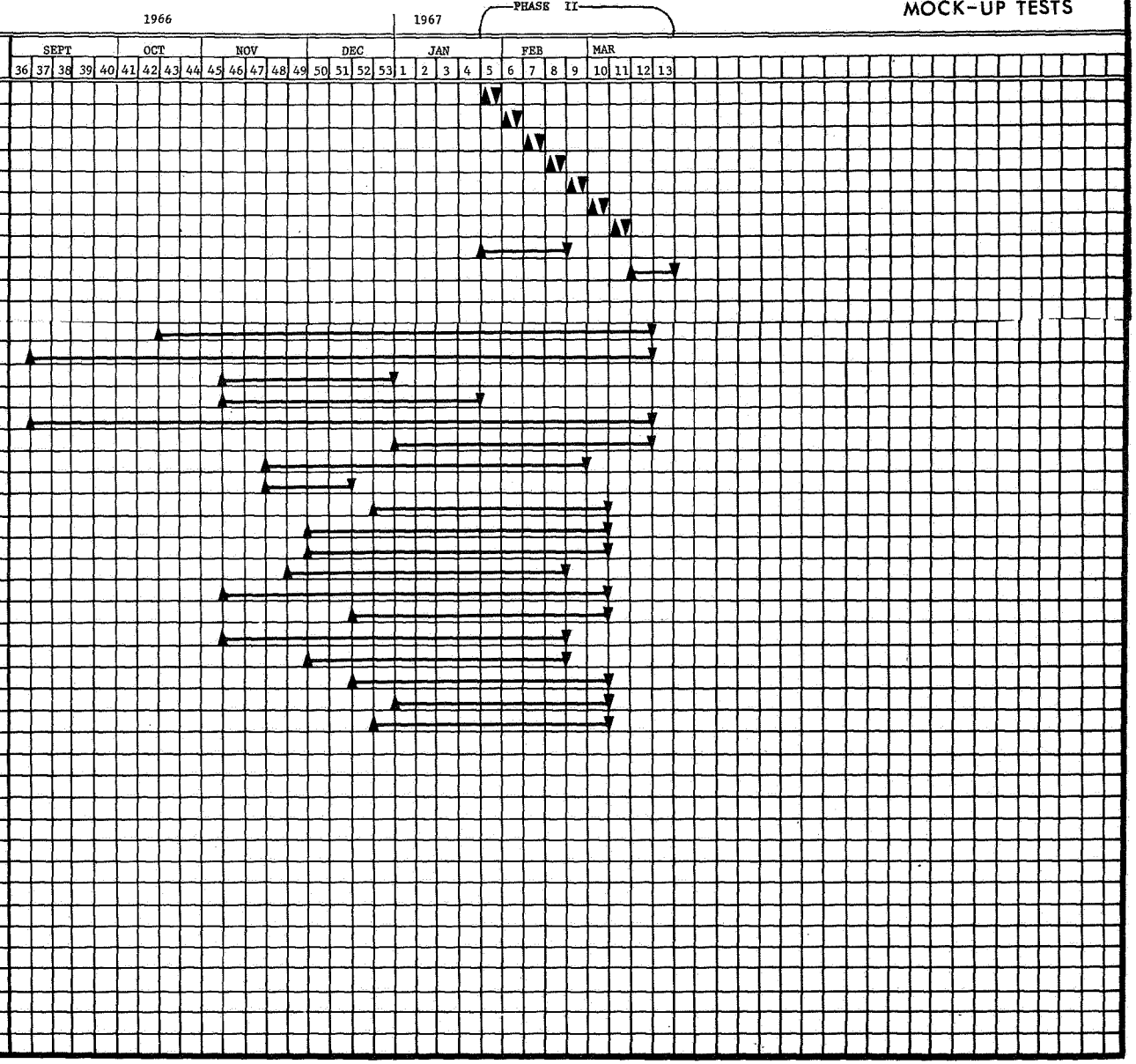
BY

DATE

PAGE 2 OF 2

TEST PLAN SCHEDULE

MOCK-UP TESTS



ITEM
II. EVALUATION TESTS
A. ANTHROPOMETRIC MEASUREMENTS
B. ENTRY - EXIT TESTS
C. MOBILITY
D. DEXTERITY
E. COMMUNICATIONS
F. SUBJECT ENDURANCE
G. APPLICATION OF HELMET INTERNAL DISINFECTION
H. FINAL DATA ANALYSIS
MATERIALS TESTS
FUNGUS GROWTH TEST
MYCELIAL PENETRABILITY TEST
PERMEABILITY/FLEXURE
ABRASION
TRANSFER OF MICROORGANISMS AND GASES ACROSS SUIT MATERIALS
RETENTION AND RELEASE OF DISINFECTANTS BY MATERIALS
COMPATIBILITY WITH DETERGENTS & DISINFECTANTS
EVALUATION OF DISINFECTANTS
TENSILE TEST FOR RIGID, SOLID AND LAMINATED PLASTICS
TENSILE TEST OF FLEXIBLE PLASTIC SHEETING
PUNCTURE RESISTANCE
OPTICAL TRANSMITTANCE
WEIGHT CHANGE
IMPACT TEST FOR PLASTIC MATERIALS
TEMPERATURE AGING
TEAR RESISTANCE
COMPRESSIVE PROPERTIES
LAP SHEAR
BUTT TENSILE

APPENDIX G: TEST AND DEMONSTRATION PLAN FOR THE BIO-ISOLATOR SUIT SYSTEM (BISS)

1. Scope

2. Acceptance Tests

2.1 Subsystems

2.2 BISS System

3. Qualification Tests

3.1 System

4. Operational Demonstration

4.1 Assembly

4.2 Demonstration

1.0 SCOPE - This document defines the test and demonstration plan for the Bio-Isolator Suit System, hereinafter refered to as **BISS.** The BISS subsystems shall be tested, interfaced, (assembled), tested, and demonstrated as set forth in this document. The BISS and its subsystems are defined in the General Electric Company RSD Specification ERS 0100-00-0001 (Bio-Isolator Suit System).

2.0 ACCEPTANCE TESTS

2.1 Subsystems - The individual subsystems of the BISS shall be tested in accordance with the acceptance test requirements of Section *4* of the following specifications:

BISS Undersuit	ERS0230-00-0002
BISS Outer Suit & Tunnel	ERS0230-00-0001
Life Support Subsystem	ERS0210-00-0001
Communications Subsystem	ERS0150-02-0001

2.2 BISS System - The **BISS** system shall be tested in accordance with the acceptance test requirements of Section *4* of Specification ERS0100-00-0001.

3.0 QUALIFICATION TESTS

3.1 System - The **BISS** system shall be subjected to the qualification tests as specified in Section *4* of Specification ERS0100-00-0001.

4.0 OPERATIONAL DEMONSTRATION

4.1 Assembly - The **BISS** subsystems shall be interfaced (assembled) to provide the complete system for operational demonstrations. These subsystems shall be interfaced in accordance with the following procedure:

A. Interface the Facility Supervisor's Console with the following:

1. Net Controller's Console
2. Medical Monitor Console
3. Suit Air Supply Console
4. Assembly/Sterilizer Address Horn
5. Assembly/Sterilizer Warning Horn

B. Attach the EKG sensors to the technician.

C. A technician shall don the undersuit.

D. Interface the suit air supply exhaust and supply hoses with the undersuit plenum.

NOTE: The suit air supply may be adjusted at this point to provide a low'rate of flow of cooling air to the undersuit.

E. Secure the Link transducers to the attachment points on the undersuit, and interface them with the Net Controller's Console.

F. Attach the "Y" back strap to the undersuit waist belt.

4.2 Demonstration

4.2.1 Environmental Conditions - The **BISS** demonstration shall be performed in a chamber capable of maintaining all of the environmental conditions required of the main chamber of the Assembly Sterilizer. (i.e. - Temperature - 70°F to 320°F with RH controlled to less than 1% above 200°F; Pressure - **0** to 4" H_2O gage)

4.2.2 Normal Cycle - With the operator contained within the undersuit in a normal room environment, a functional check shall be made of the following:

a) Life support
b) Communications
c) Medical monitoring

The suited technician shall then enter the outer suit and tunnel via the hard tube and shall position himself in the outer suit which shall have been mounted on the Donning rack and he shall secure the "Y" back strap to the helmet and yoke D-rings.

NOTE: During the technician's entry to the outer suit and tunnel, the suit air supply hoses and the communications cabling shall be carefully fed out down the hard tube.

4.2.2.1 Operational Demonstration - Perform the following functional checks:

A. Check release and engagement of helmet interface loop with donning rack.

B. Check release and engagement of boots with donning rack base,

C. Move the outer suit and tunnel clear of the donning rack.

D. Perform walking, bending, climbing, squatting and head movements.

E. Using planned tools and system/assembly fixtures, perform disassembly, assembly, and check-out functions.

F. Return to donning rack and interface the helmet and boots with the donning rack fixtures.

G. Perform exit procedures from the outer suit and tunnel.

The above functional demonstration shall be repeatedvarying the total time the technician is in the chamber up to a maximum of 4 hours. During these demonstration cycles, the following times shall be recorded.

A. Entrance into the suit

B. Release from the donning rack

C. Re-attachment to the donning rack of the suit for egress from the outer suit and tunnel

The activities of the technician shall be directed by the test conductor via the BISS communication system and the technician's comfort and well being shall be monitored both by oral communication with the test conductor and by observing the real time electrocardiogram recording.

4.2.3 Emergency Cycle #1 - The normal cycle above shall be repeated through Step D at which point the technician shall simulate a semi-comatose condition and a second technician in a second BISS system shall assist him through Steps F & G above. This cycle shall be performed at various Assembly Sterilizer pressure conditions ranging from 0 to 4" H_2O gage and the time from simulation of the comatose condition to the final exit shall be recorded.

4.2.4 Emergency Cycle #2 - The procedures of the emergency cycle #1 shall be repeated, however, the technician shall now simulate a condition of complete inability of physical movement.

APPENDIX H: ILLUSTRATIONS OF EQUIPMENT USED IN PHYSICAL TESTING

1. Taber Abraser Model 174
2. Gardner Impact Tester
3. Temperature Aging Facility
4. "Color-Eye" Spectrophotometer
5. Flexibility Apparatus

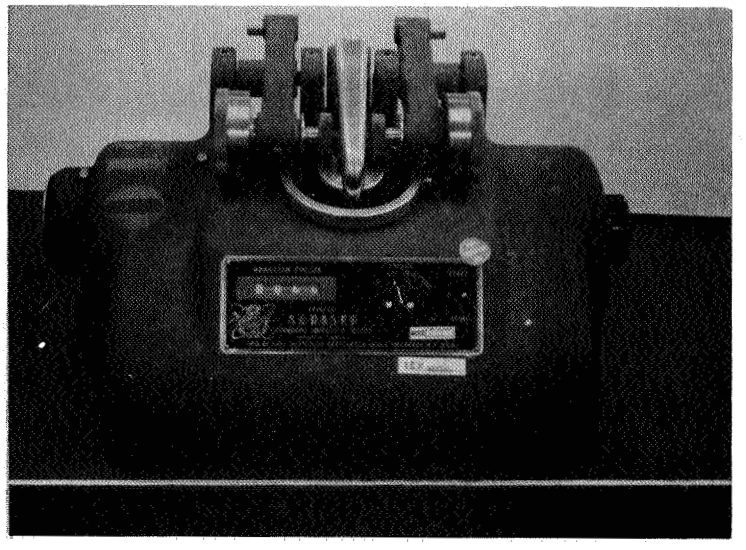


Figure H-1 - Taber Abraser Model 174

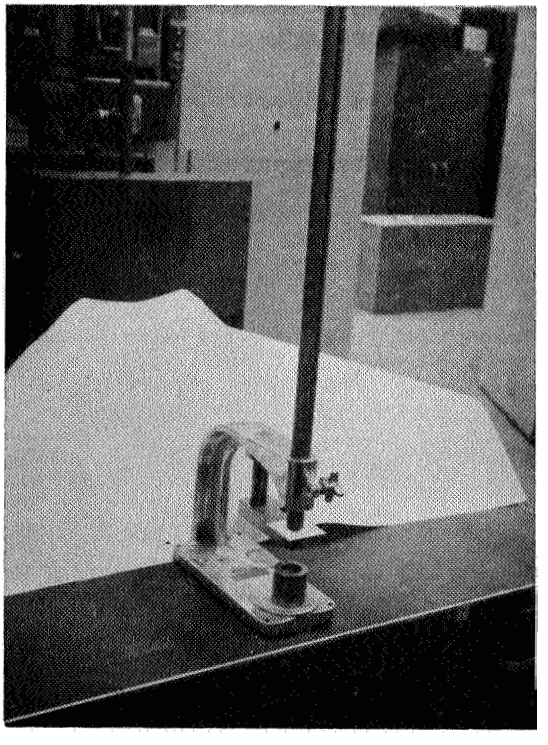


Figure H-2 - Gardner Impact Tester

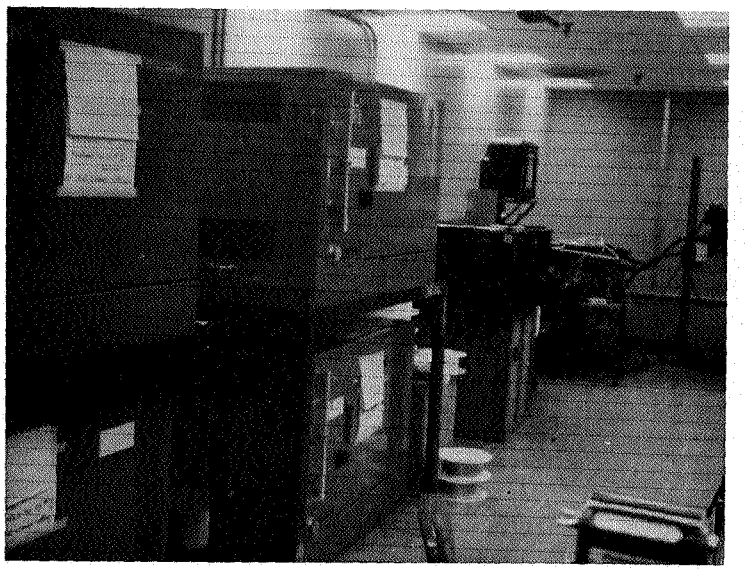


Figure **H-3 -** Temperature **Aging** Facility

Figure H-4 - "Color-Eye Reflectance Instrument

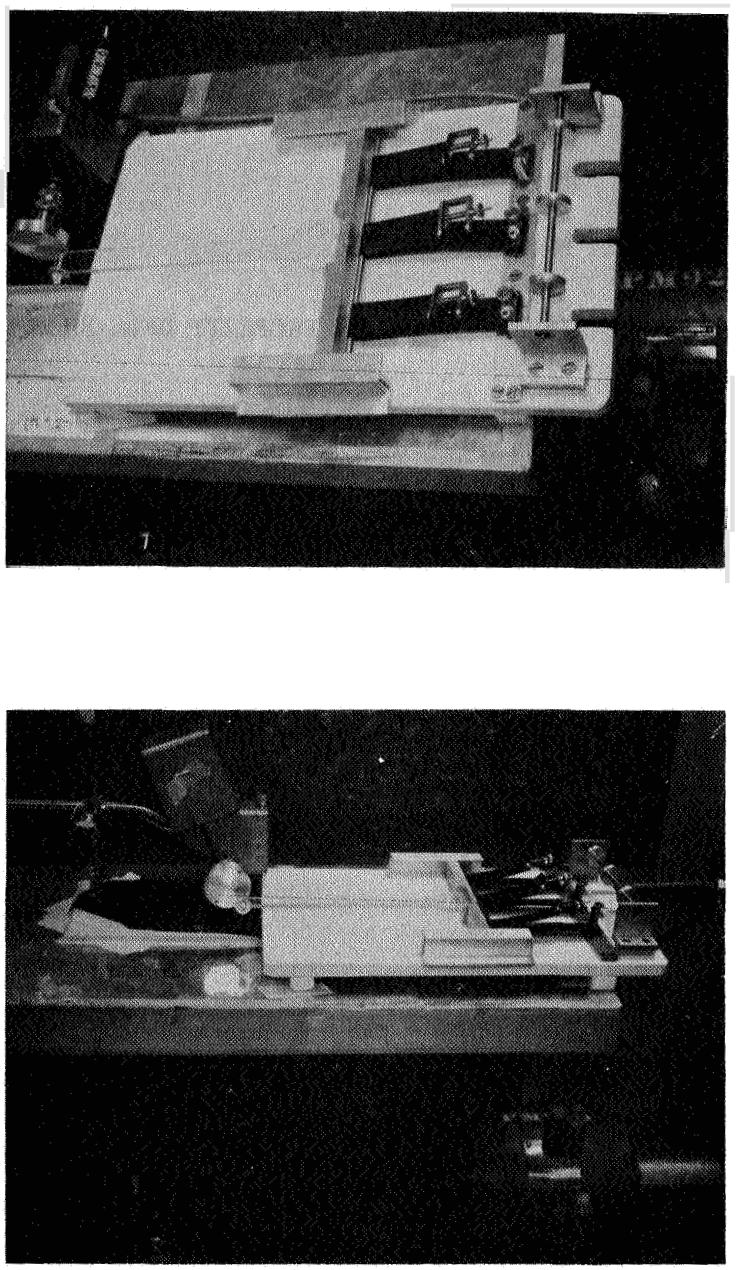


Figure H-5 **- Flexibility Apparatus**

APPENDIX I: MATERIAL PROPERTY DATA SHEETS

1. Introduction
2. optical Transmission
3. Test Results
4. References

APPENDIX I: MATERIAL PROPERTY DATA SHEETS

1. INTRODUCTION

This appendix contains the physical test results, tables, and illustrations from which the final selection of candidate materials was made.

A list of references is included, indicating the sources of information which were used for the literature search during the Phase I candidate materials selection.

2. OPTICAL TRANSMISSION

Optical transmission curves were determined by means of the "Color-Eye" Calorimeter and Abridged Spectrophotometer in the visible wavelength range (.4 - .7 microns), using barium sulfate references in the sample and standard ports. Percent transmission is plotted at 0.02 micron increments over the visible range compared to air.

Lexan specimens, both virgin material, and environmentally aged were measured, as well as a representative quartz (Corning #7940) as shown in Figures I-1 and I-2. No changes were noted in the quartz as a function of the environments, therefore, only a virgin plot is shown for this material.

Quartz exhibits a 93% plus transmission across the entire spectrum, whereas Lexan varies from 57% at the blue region to 85% at the yellow-red end of the spectrum.

Small variations of 1-2% in transmission are noted as a function of heat aging, the ETO/Freon treatment and the detergent treatments, however, for practical considerations these changes may be considered negligible.

The greatest effect, as might be expected, is noted in the cases of abrasion, and abrasion combined with detergent treatment. In these cases, transmission has degraded to a low of 23.5% in the blue and to a low value of 43.5% in the red. It is therefore obvious that handling abrasion, or abrasion-induced by chemical cleaning can be most detrimental to optical clarity.

3. TEST RESULTS

The test results presented herein were derived from both a literature search and experimentation. The results appear in Tables I-I through I-XXV.

Some observations as indicated below, may be noted as a result of the tensile property evaluations:

- Armalon 97-001, Silicone Rubber SE-555, Lexan, and Textolite 11546 are stable in the environment and exhibit negligible property change.

- Neoprene is attacked by the disinfectant and ETO/Freon treatments, and is essentially unaffected by the detergent treatment. Heat aging also causes degradation of the neoprene tensile values.

- Butly rubber tensile strength is reduced 50% by the heat age environment:

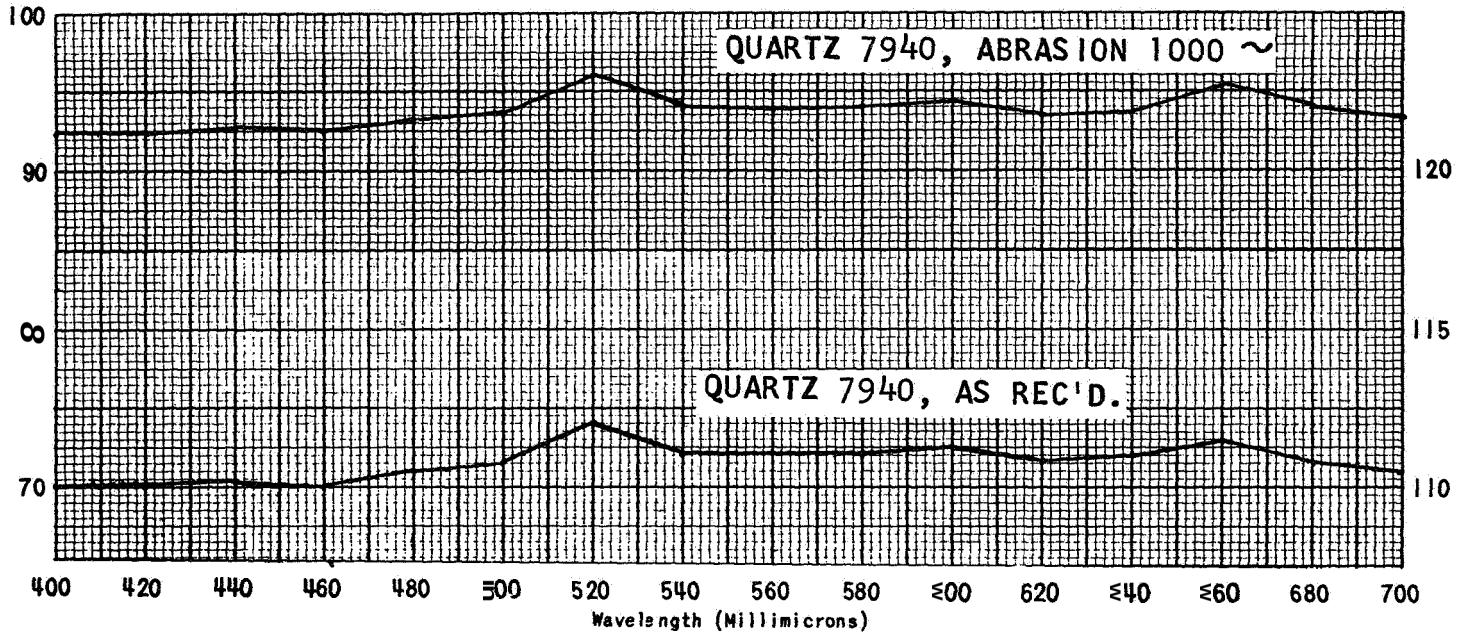
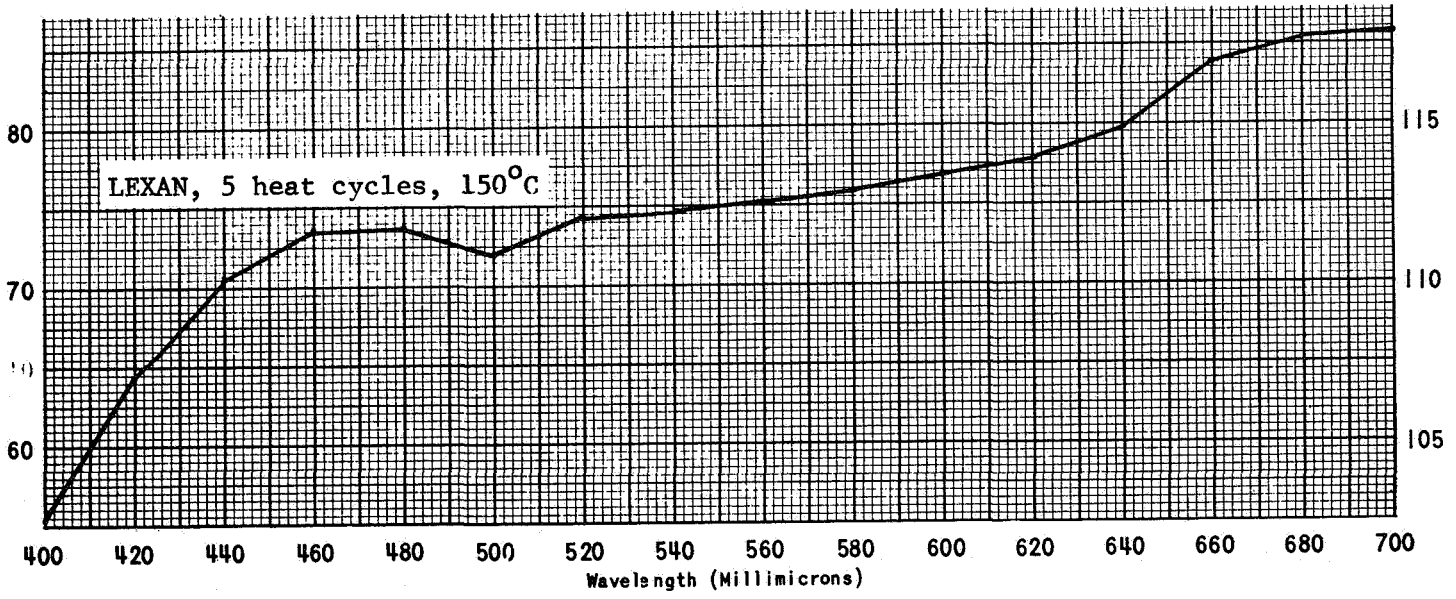


Figure I-1 Quartz Optical Transmission Curves



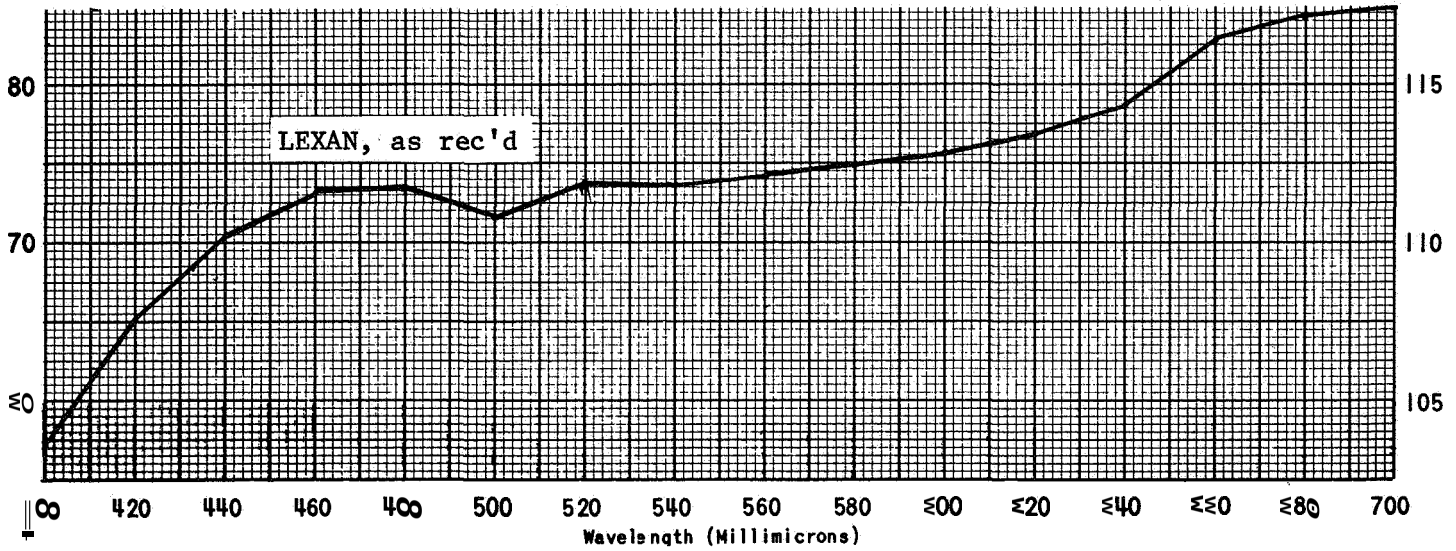


Figure I-2 LEXAN Optical Transmission Curves

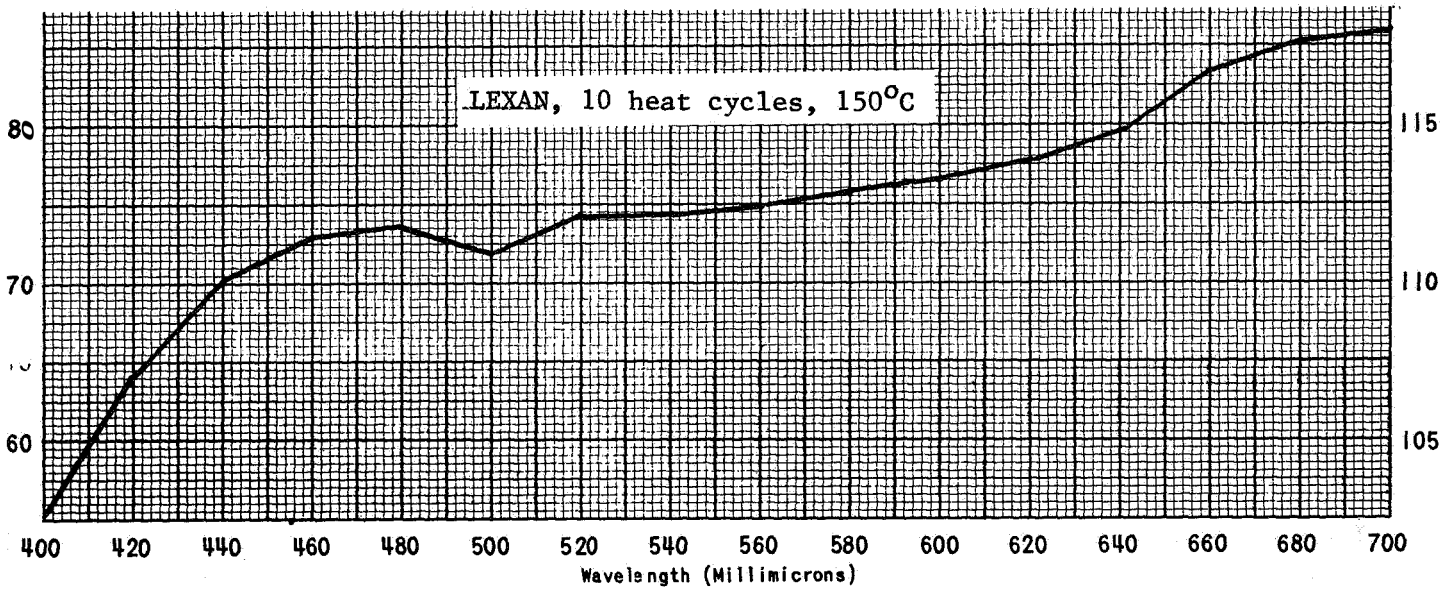


Figure I-2 LEXAN Optical Transmission Curves (Cont'd)

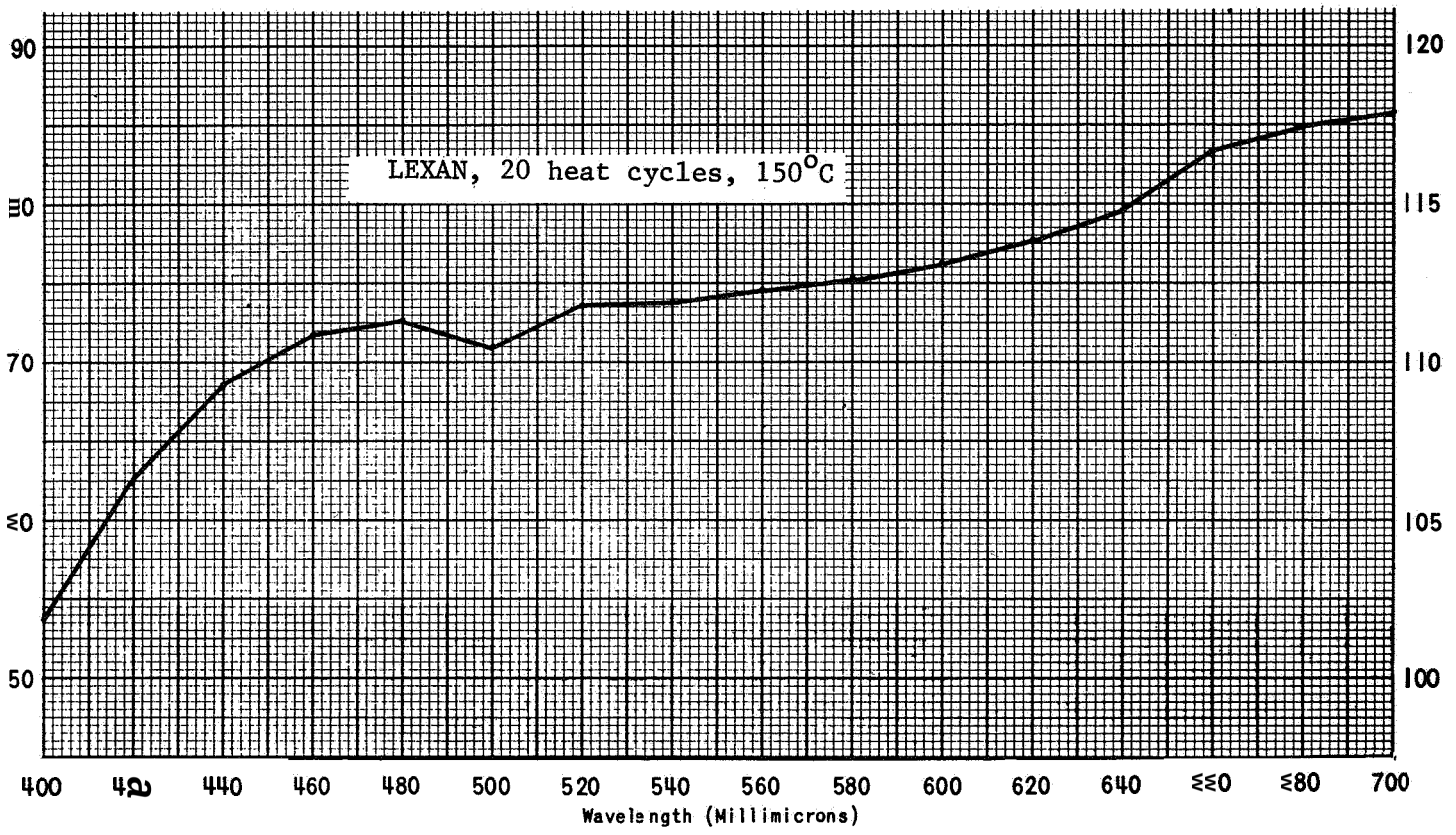


Figure I-2 LEXAN Optical Transmission Curves (Cont'd)

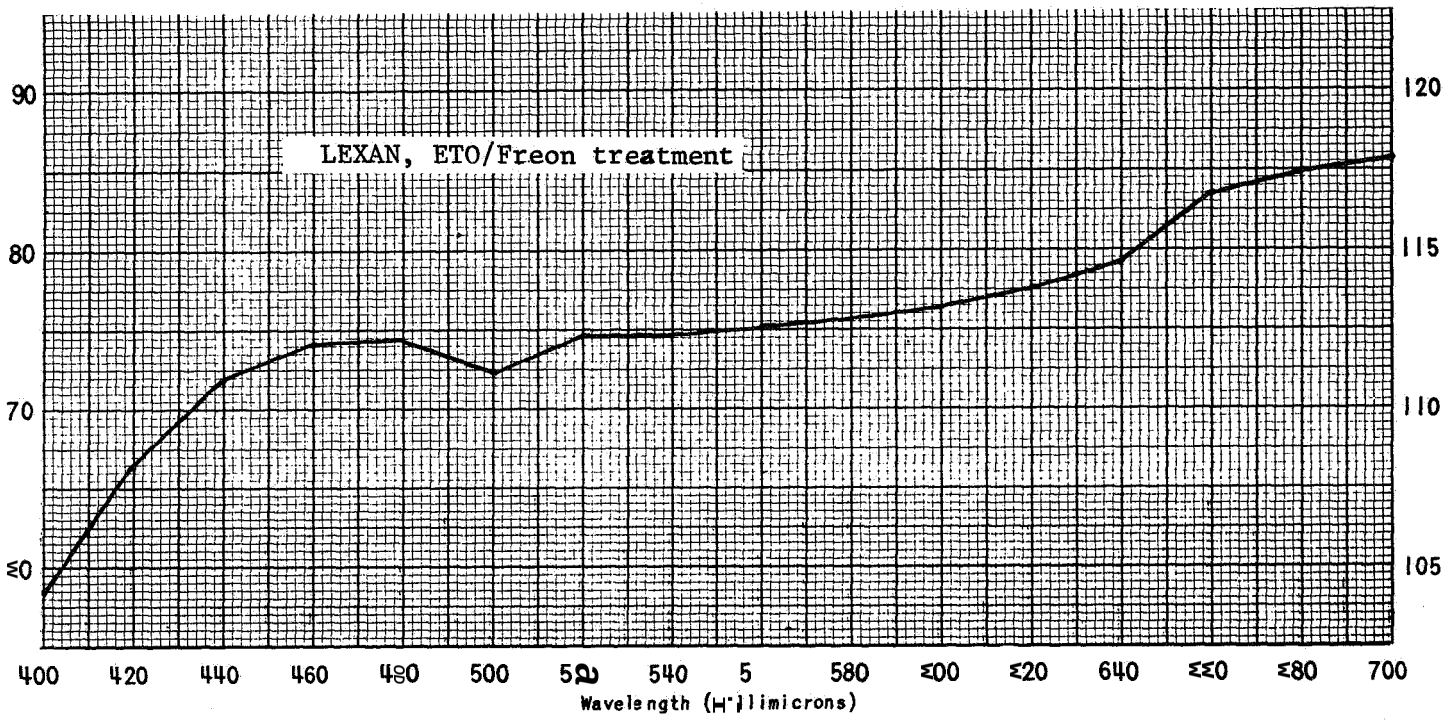


Figure I-2 L EAN Optical Transmission Curves (Cont'd)

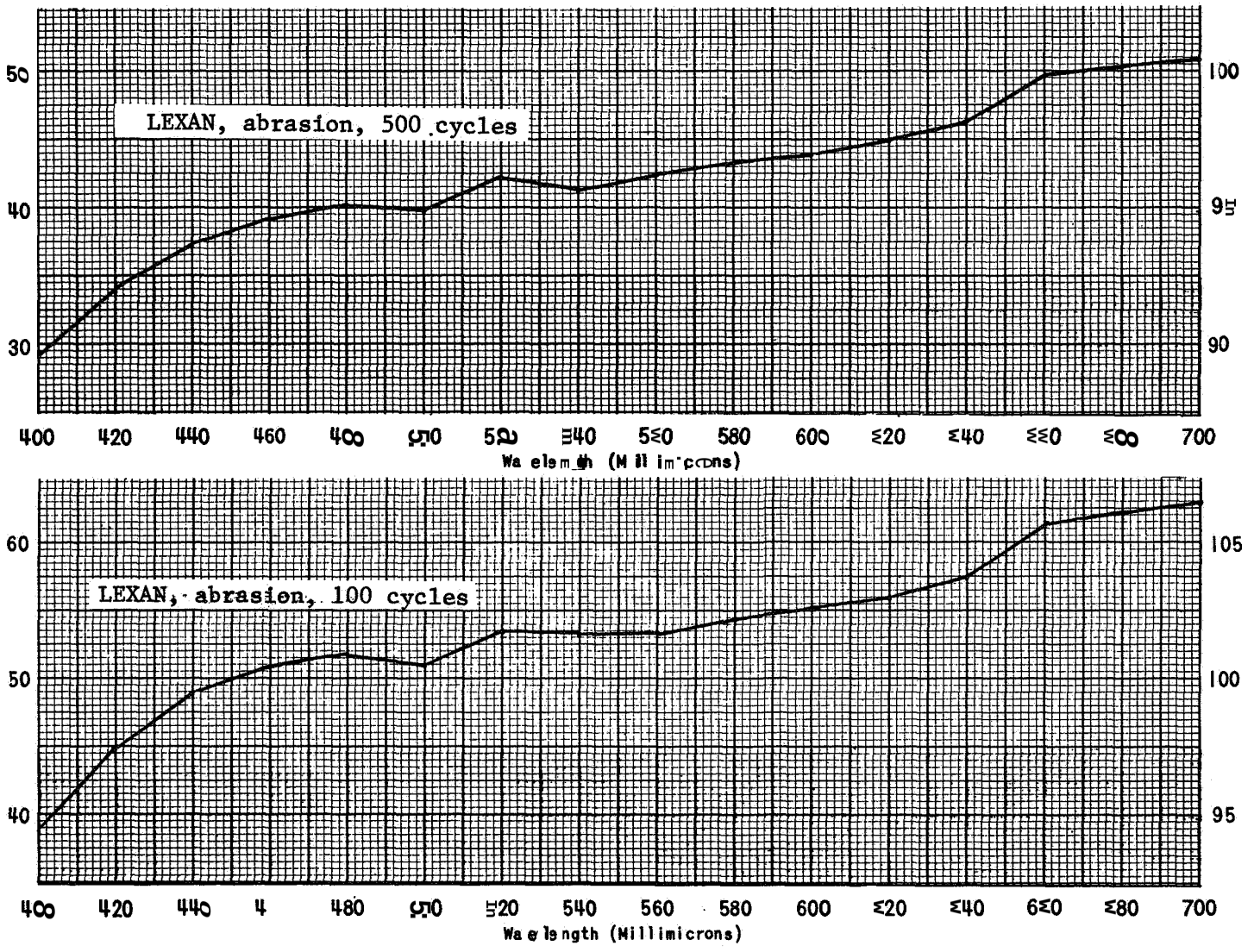
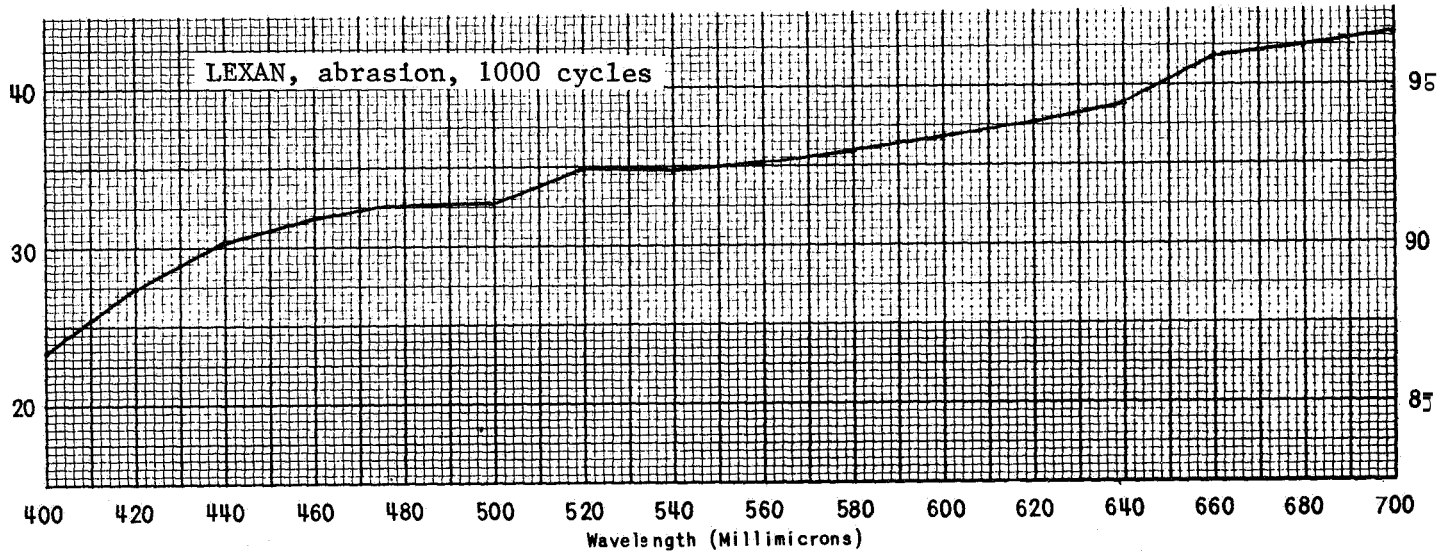


Figure I-2 LEXAN Optical Transmission Curves (Cont'd)



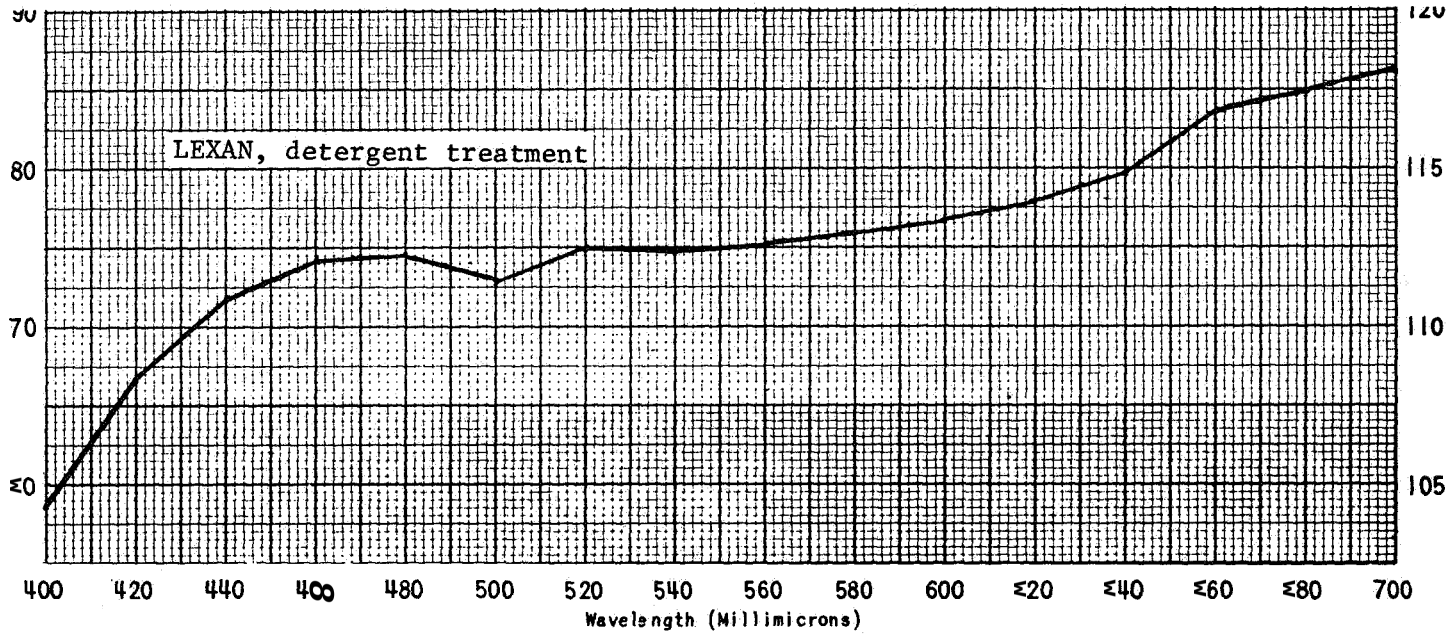


Figure I-2 LEXAN Optical Transmission Curves (Cont'd)

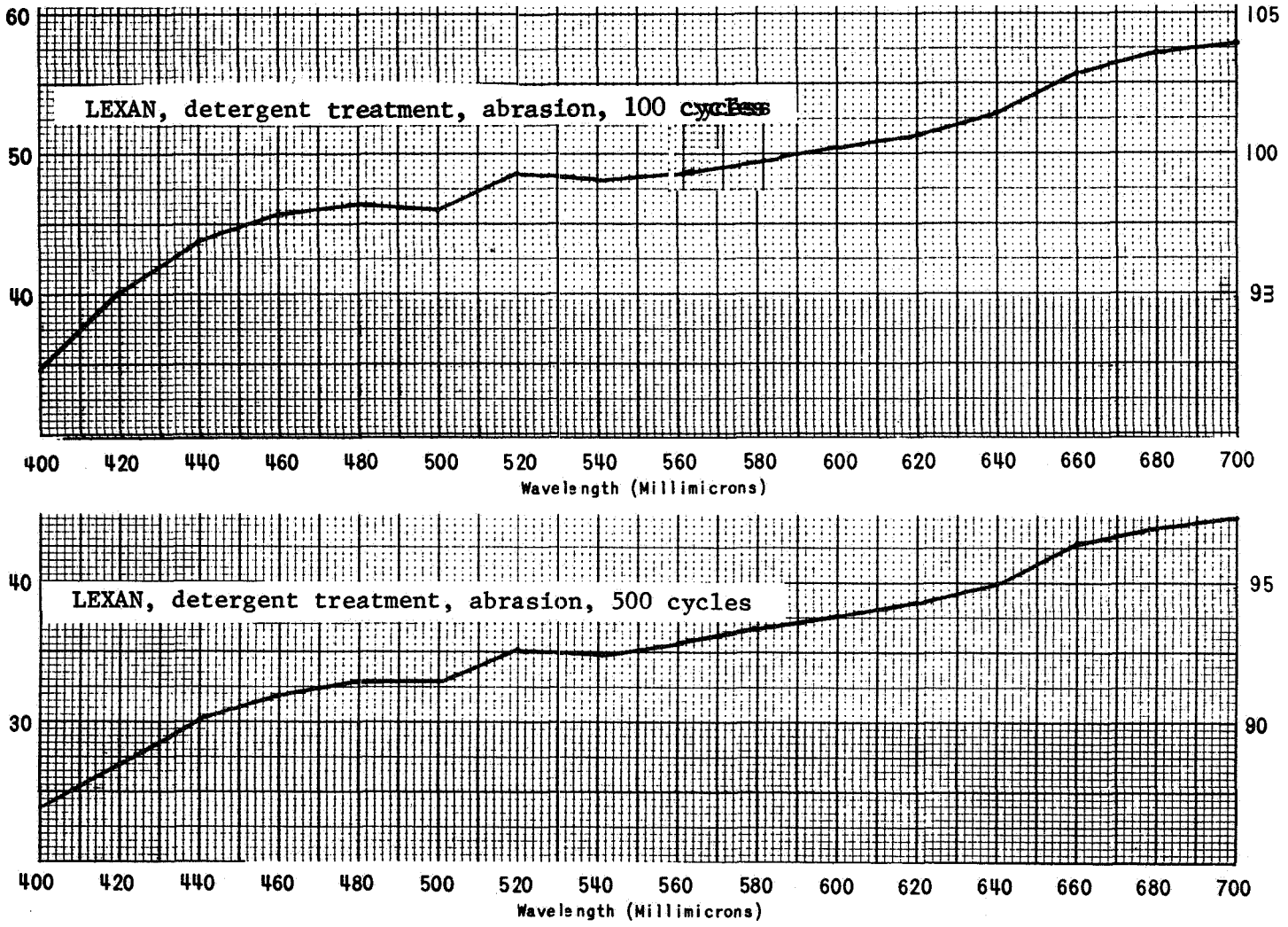


Figure I-2 LEXAN Optical Transmission Curves (Cont'd)

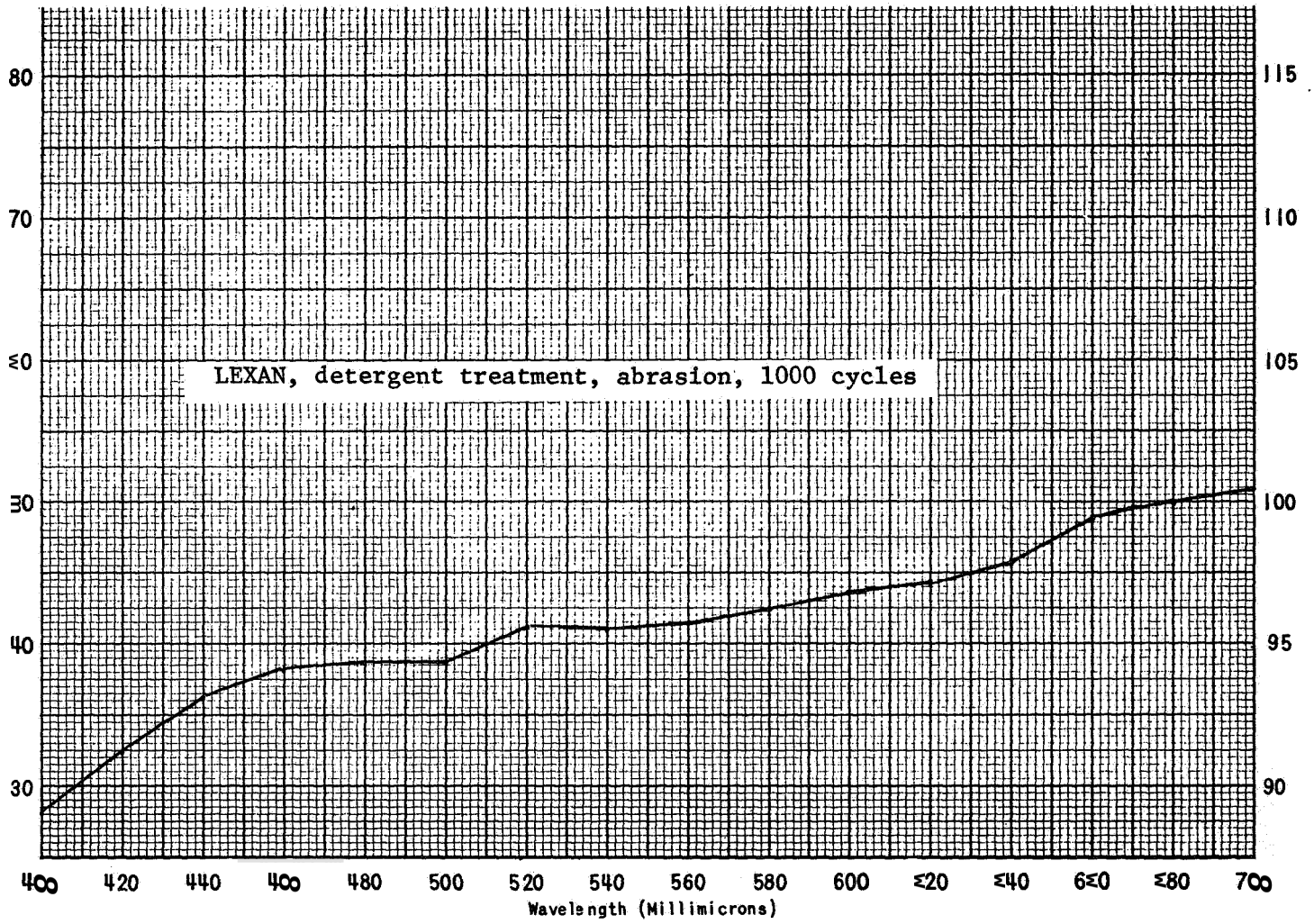


Figure I-2 LEXAN Optical Transmission Curves (Cont'd)

TABLE I-I. PROPERTIES OF CLEAR CR-39 MONOMER*

PROPERTY	VALUE
Specific gravity	1.31
Hardness, Rockwell M	95-100
Abrasion Resistance, X methacrylate	*30-40*
Tensile Strength, RT, psi	5000-6000
Flexural Strength, RT, psi	5000-6000
Mod. Elas. in Flexure, RT, psi x 10^5	1.6-2.0
Compressive Strength, psi	22800
Compressive Modulus, psi x 10^5	2.3
Specific Heat, cal/g/°C	0.55
Thermal Expansion, °C x 10^{-5}	15.3
Thermal Conductivity, BTU/hr/ft^2in/°F	1.45
Water Absorption, %	0.2-0.4

* References 1, 2.

TABLE 1-11. PROPERTIES OF LEXAN POLYCARBONATE*

PROPERTY	VALUE
Specific Gravity	1.20
Hardness, Rockwell M	70
Tensile Strength, psi	9500
Tensile Modulus, psi x 105	3.45
Compressive Strength, psi	12500
Compressive Modulus, psi x 105	3.45
Flexural Strength, psi	13500
Flexural Modulus, psi x 10^5	3.40
Poisson's Ratio	0.37
Modulus of Rigidity, psi x 10^5	1.16
Water Absorption	0.35
Thermal Conductivity, BTU/sec/ft^2/in/°F	0.02
Thermal Expansion, in/in/°F x 10^{-5}	3.75
Specific Heat	0.30

* Reference 3

TABLE I-III. PROPERTIES OF "TEFLON" FEP*

PROPERTY	VALUE
Specific Gravity	2.15
Tensile Strength, psi	3000
Ultimate Elongation, %	300
Tensile Modulus, psi x 10^4	7
Folding Endurance (MIT), cycles	4000
Tear Strength, initial (Graves), gm/mil	270
Kinetic Coefficient of Friction	0.57
Water Absorption, %	0.01
Thermal Expansion, in/in/^{o}F x 10^{-5}	18
Thermal Conductivity, BTU/in/hr/ft^2/^{o}F	1.35
Specific Heat	0.28

* References 4, 5.

TABLE I-IV. TYPICAL PROPERTIES OF MOLDED TEFLON[6,7,8,9]
(TAPE AND SHEET STOCK)

Property	Unit of Measure	TFE
Tensile Strength, 73°F	psi x 10^3	1.5 - 3.0
Elongation, 73%	%	100 - 250
Flexural Strength, 73°F	psi	no break
Flexural Modulus, 73°F	psi x 10^3	50 - 90
212°F	psi x 10^3	
392°F	psi x 10^3	
Impact Strength, Izod, -70°F	ft-lb/in	2.0
73°F	ft-lb/in	3.0
170°F	ft-lb/in	6.0
Compressive Stress, 1% Deformation, 73°F	psi	600
1% Offset, 73°F	psi	1000
Poisson's Ratio, 73°F		0.46
212°F		0.36
Hardness, Shore Durometer		D50 - 65
Coefficient of Linear Thermal Expansion 73°F to 140°F	in/in/°F	5.5 x 10^{-5}
Deformation Under Load		
1000 psi, 24 hr., 73°F	%	2 - 3
1200 psi, 24 hr., 122°F	%	4 - 8
2000 psi, 24 hr., 73°F	%	
2000 psi, 24 hr., 122°F	%	25
Heat Distortion Temperature		
66 psi	°F	250
264 psi	°F	
Thermal Conductivity, 0.18" sample	BTU/hr/ft^2/°F/in	1.7
Specific Heat	BTU/lb/°F	0.25
Dielectric Strength, short time, 0.080"	volt/mil	400 - 600
0.005 to 0.012"	volt/mil	1000 - 2000
0.020"	volt/mil	
Surface Arc Resistance	sec	will not track
Volume Resistivity	ohm/cm	>10^{15}

TABLE I-IV. TYPICAL PROPERTIES OF MOLDED TEFLON [6,7,8,9]
(TAPE AND SHEET STOCK) (Cont'd)

Property	Unit of Measure	TFE
Surface Resistivity, 100%RH	megohm	3.6×10^6
Dielectric Constant 60 cps - 10^9 cps		1.9 - 2.2
Dissipation Factor 60 cps - 10^9 cps		0.0003
Static Coefficient of Friction against Polished Steel		0.04
Dynamic Coefficient of Friction against Polished Steel		0.07 - 0.14
Specific Gravity		2.1 - 2.2
Density	lb/ft^3	131 - 137

TABLE I-V. NEOPRENE RUBBER **FILM** (REF. 10)
(TYPICAL PROPERTIES, **M-5565)**

Tesnile Strength, psi, min.	**1500**	
Percent Elongation, min.	300	
Shore A Hardness	65 $\pm$ 5	
Specific Gravity	1.56	
Oven Aging, 70 hr. @ 212°F		
Percent Weight Change	-6.0	
Percent Tensile Change	-15.0	
Percent Elongation Change	-40.0	
Change in Hardness	+10.0	
Thermal Conductivity (BTU/hr/sq.ft./in/°F	0.08	(29)
Coefficient of Thermal Expansion (in/in/°F)	11-12 x 10^{-5}	(29)
Specific Heat (BTU/lb)	0.4 - 0.5	(29)

TABLE I-VI. BUTYL RUBBER FILM T-5595 (REF. 10)
(TYPICAL PROPERTIES)

Tensile Strength, psi, min.	800
Percent Elongation, min.	500
Shore A Hardness	60 ± 5
Specific Gravity	1.35

TABLE I-VII. SILICONE RUBBER SE-555U (REF. 11)
(TYPICAL PROPERTIES, CURE 16 HR. @ 450°F)

Color	Gray	
Specific Gravity	1.18	
Tensile Strength, psi	1500	
Elongation, %	600	
Hardness, Shore A	60 ± 5	
Tear Strength, psi	200	
Compression Set, %		
22 hrs., 212°F	20	
22 hrs., 350°F	30	
Brittle Point, °F	-150	
Heat Age, 70 hours @ 400°F		
Tensile Strength Change, %	-15	
Elongation Change, %	-30	
Hardness Change, points	+5	
Water Resistance, 70 hours @ 212°F		
Hardness Change, points	-1	
Volume Change, %	1	
Service Life, years, at 300°F	5	(ref. 29)
Thermal Conductivity, BTU/hr/sq.ft./in./°F	1.1-3	"
Linear Thermal Expansion, in/in/°F x 10^{-4}	3.2-7	"

TABLE I-VI11. OPTICAL GLASS PROPERTIES

	Plate	Boro-Silicate	Quartz	
			Vitreosil	GE 101
Specific Gravity	2.52	2.23	2.07-2.15	2.2
Hardness, Moh's Scale			5-7	4.9
Refractive Index Sod. D.	1.525		1.4585	1.4585
Optical Transmission, %	90	90	93 (1)	99 (2)
Thermal Expansion cm/cm/°C x 10^{-6}	8.5	1.8	0.54 (3)	.55 (4)
Impact Strength, psi x 10^3			12.1	
Modulus Rupture, psi x 10^3				
Transverse			9.2	
Torsion			6.75	
Modulus Rigidity, psi x 10^6				4.5
Young's Molulus, psi x 10^6		9.1		10.4
Poisson's Ratio		0.2		0.16
Tensile Strength, psi x 10^3			4.0 (5)	7.0
Compressive Strength, Ult., psi x 10^3			163.5	160.0
Thermal Conductivity, g cal/cm^2/sec/°C/cm				0.0033
Specific Heat, g cal/gm				0.18
Impact/Abrasion Resistance		3.1	3.5-3.6	3.5-3.6
Reference	12	12	13	14

Notes

(1) Rod 1 meter long

(2) 1 cm thickness

(3) 0-1000°C

(4) 20-320°C

(5) Rod, .25-.6" diameter

TABLE I-IX. FLAMMABILITY OF PLASTIC MATERIALS

MATERIAL	RATING	REFERENCE
Teflon - TFE	Non-flammable	15,16
Teflon - FEP	Non-flammable	4,5,16
Lexan Polycarbonate	Self-Extinguishing	3,16
Armalon	Non-flammable	16,17
Poly (vinyl fluoride)	Self-Extinguishing	16,18
Kapton Polyimide	Self-Extinguishing	16,19
Poly (vinyl chloride)	Self Extinguishing	16
Butyl Rubber	Non-flammable	20
Silicone Rubber	Non-flammable	29

TABLE I-X. ELECTRICAL PROPERTIES

Material	Ref.	Insulation Resistance megohm mfds. 60 cps	Dielectric Strength (1 mil), volts	Dielectric Constant 1 KC	Dissipation Factor 1 KC	Volume Resistivity ohm-cm	Surface Resistivity ohm	Corona Start Voltage (1 mil) volts
Polyimide	19	100,000	7,000	3.5	0.003	10^{13}	10^{16}	465
Tedlar	18		4,000	7.0	0.085 (1)	3×10^{13}	10^{16}	
Teflon - FEP	4		6,500	2.0	0.0005 (1)	10^{17}	10^{16}	
Lexan	3		3,910 (4)	3.0	0.01 (3)	2.1×10^{16}		
Neoprene	29		350					
Fluorosilicone	29		350	6-7		10^{13}		

NOTE: (1) 100KC

(2) 100 MC

(3) 1 MC

(4) 1.5 mil

TABLE I-XI GAS AND WATER VAPOR PERMEABILITY OF PLASTIC MATERIALS

MATERIAL	WATER ABSORPTION, %	cc(STP)mm/cm^2-sec-cm Hg x 10^{-8} CO_2	O_2	N_2	H_2	He	H_2O	D_2	Ne
CR-39 ALLYL DIGLYCOL CARBONATE	0.2-0.4 (1,2)								
LEXAN POLYCARBONATE	0.35 (3)	0.8 (3)	0.2 (28)	0.03 (3)			0.00014 (22)		
TEFLON FEP	0.01 (4,5)	1.0 (4)	0.45 (4)	0.12 (4)	1.3 (11)		0.0024 (24)		
TEFLON TFE			0.9 (11)	0.28(21)			6 (28)		
SARAN		0.031 (11)	0.00024 (11)	0.000056 (21)			0.14 (12)		
POLYVINYL CHLORIDE		0.010 (21)	0.012 (21)	0.004 (21)			[illegible] (13)		
TEDLAR (POLYVINYL FLUORIDE)		0.008 (18)	0.002 (18)	0.0025 (18)	0.08 (18)		0.0094 (25)		
KAPTON (POLYIMIDE)		0.027 (19)	0.05 (19)	0.06 (19)	0.15	0.248 (19)	0.0623 (26)		
NEOPRENE		2.5 (20)	0.4 (13)	0.12			0.00048 (17)		
BUTYL		0.52 (13)	0.13 (28)	0.032 (28)			0.0023 (27)		
QUARTZ					0.21 (14)	2.1 (14)		0.17 (14)	0.04 (14)
VITON A		0.78 (28)	0.15 (28)	0.044 (28)			5.2 (28)		
SILICONE		60-300 (28)	10-60				1060. (28)		

TEXTOLITE 11546

VITON A/TFE #86-007

FLUORINATED SILICONE/FABRIC #44-002

NOTE:

NUMBERS IN PARENTHESES INDICATE REFERENCES

TABLE I-XII. FLUOROSILICONE RUBBER (REF. 29)
(TYPICAL PROPERTIES)

Hardness, Durometer	65
Tensile Strength, psi	800-1000
Ultimate Elongation, %	200
Compression Set, 22 hours @ 300°F	20
Tear Strength, lb/in	80
Specific Gravity	1.41
Brittle Temperature, °F	-90

DACRON FABRIC REINFORCED (REF. 30)

Tensile Strength, grab, lb/in	100 x 100
Mullens Burst, psi	150

TABLE **I-XIII.** WEIGHT **LOSS,** HEAT AGING
(300°F, 10 **CYCLES)**

Materia 1	% Weight **Loss**
Lexan	0.11
Textolite 11546	0.01
Viton A/Fabric	0.70
Fluorinated Silicone/Fabric	**3.08** *
Armalon 97-001	**0.03**
Neoprene Rubber	2.57
Silicone Rubber	0.45
Butyl Rubber	2.02

* **High** value caused by Dacron fabric

TABLE I-XIV. IMPACT PROPERTIES

Material	Condition	Result
Textolite 11546	Virgin Material	P
	300°F, 5 cycles	P
	300°F, 10 cycles	P
	300°F, 20 cycles	P
	300°F, 10 cycles, plus detergent	P
	Detergent Treatment	P
	300°F, 10 cycles, plus disinfectant	P
	Disinfectant Treatment	P
	300°F, 10 cycles, plus ETO/Freon	P
Lexan	Virgin Material	P
	Detergent Treatment	P
	Disinfectant Treatment	MF
	ETO/Freon	TF
	300°F, 5 cycles	TF

P = PASS MF = MINOR FAILURE TF = TOTAL FAILURE

TABLE I-XV. TEAR PROPERTIES

Material	Condition		lb/mil
Kapton Polyimide	Virgin Material		*
		Avg.	
Viton/Fabric *86-007*	Virgin Material		0.37
			0.38
		Avg.	0.38
	300°F, 10 cycles		0.39
			0.28
		Avg.	0.34
Fluorinated Silicone/ Fabric *44-002*	Virgin Material		0.43
			0.50
	300°F, 10 cycles		*0.46*
		Avg.	*0.48*
Armalon 97-001	Virgin Material		*1.08*
			1.02
			1.06
		Avg.	1.05
	300°F, 10 cycles		0.94
			0.96
			0.92
		Avg.	0.94
	300°F, 10 cycles, plus ETO/Freon		0.46
			0.48
			0.53
		Avg.	*0.49*
Butyl Rubber	Virgin Material		0.13
			0.12
			0.13
		Avg.	0.13
	300°F, 10 cycles		0.11
			0.11
			0.10
		Avg.	0.11

* Too brittle for measurement - the strain rate was reduced to 2"/min and material still not measurable.

TABLE I-XV. TEAR PROPERTIES (Cont'd)

Material	Condition		lb/mil
Neoprene Rubber	Virgin Material		0.19
			0.19
			0.19
		Avg.	0.19
	300°F, 10 cycles		0.12
			0.14
			0.15
		Avg.	***0.14***
Silicone Rubber	Virgin Material		0.102
			0.127
			0.117
		Avg.	0.115
	300°F, 10 cycles		***0.084***
			0.088
			0.087
		Avg.	***0.086***
	300°F, 10 cycles, plus ETO/Freon		0.092
			0.090
		Avg.	0.091
	200 Flex cycles		0.102
			0.121
		Avg.	0.112

TABLE I-XVI. ABRASION PROPERTIES

Material	Condition	Abrasion Cycles	Wear Index
Silicone Rubber	Virgin Material	100, 500, 1000	2.3
	300°F, 5 cycles	1000	2.3
	300°F, 10 cycles	1000	2.4
	300°F, 20 cycles	1000	2.5
	300°F, 20 cycles, plus detergent	100, 500, 1000	59.1
	300°F, 20 cycles, plus disinfectant	100, 500, 1000	45.8
Neoprene Rubber	Virgin Material	100, 500, 1000	310
	300°F, 5 cycles	100, 500, 1000	465
	300°F, 10 cycles	100, 500, 1000	1100
	300°F, 20 cycles	100, 500, 1000	470*
	Detergent Treatment	100	223
	ETO/Freon	100, 500, 1000	262
Lexan	Virgin Material	100, 500, 1000	5.1
	300°F, 5 cycles	1000	7.7
	Detergent Treatment	100, 500, 1000	8.0
	ETO/Freon	1000	8.5
Butyl Rubber	Virgin Material	1000	80.5
	300°F, 20 cycles	100, 500, 1000	99.6
	Disinfectant	1000	102
	Detergent	1000	100
	ETO/Freon	1000	105
Armalon 97-001	Virgin Material	100, 500, 1000	3.9
	300°F, 5 cycles	100, 500, 1000	6.7
	300°F, 10 cycles	100, 500, 1000	12.3
	300°F, 20 cycles	103, 500, 1000	27.0
	Disinfectant Treatment	100, 500, 1000	7.6
	Detergent Treatment	100, 500, 1000	27.5
	300°F, 5 cycles, plus detergent	100, 500, 1000	14.2
	300°F, 10 cycles, plus detergent	100, 500, ,1000	16.6
	300°F, 20 cycles, plus detergent	100, 500, 1000	16.7
	ETO/Freon	1000	25.3

* Lower value due to embrittlement of the rubber

TABLE I-XVII. PUNCTURE PROPERTIES

Material	Condition	Rating (50# load)
Armalon 97-001	Virgin Material	P
	300°F, 20 cycles	P
	Detergent	P
	ETO/Freon	P
Butyl Rubber (non-reinforced)	Virgin Material	F
Neporene Rubber (non-reinforced)	Virgin Material	P
	300°F, 5 cycles	F
Silicone Rubber (non-reinforced)	Virgin Material	F
	300°F, 10 cycles	F
Viton/Fabric	Virgin Material	P
	300°F, 10 cycles	F
Fluorinated Silicone	Virgin Material	P
	300°F, 10 cycles	P
Kapton	Virgin Material	P

P = PASS F = FAIL

TABLE I-XVIII. TENSILE STRENGTH OF NEOPRENE
XA-3785-2

Condition		Tensile Strength, psi
Virgin Material		> 1750 *
		> 1850 *
		> 1940 *
Disinfectant Treatment		910
		1180
		1280
	Avg.	1123
Detergent Treatment		1440
		> 1860 *
		1890
300°F, 10 cycles, plus ETO/Freon		820
		950
	Avg.	885
300°F, 5 cycles, plus ETO/Freon		1480
		1400
		1450
	Avg.	1480
ETO/Freon		1280
		1430
		1270
	Avg.	1360

* Specimen not broken - elongation exceeded test machine capability.

TABLE I-XIX. TENSILE STRENGTH OF BUTYL RUBBER
T-5595

Condition		Tensile Strength, psi
Virgin Material		> *546* *
		> *600* *
		7800 *
300°F, *20* cycles		*390*
		402
		403
	Avg.	*398*
Disinfectant Treatment		*760*
		760
		770
	Avg.	*760*
Detergent Treatment		> 676 *
		> *825* *
		874

* Specimen not broken - elongation exceed test machine capability

TABLE I-XX. TENSILE STRENGTH OF VITON/FABRIC
86-007

Condition	Tensile Strength, psi
Virgin Material	3460
	3250
	3240
	Avg. 3320

TABLE I-XXI. TENSILE STRENGTH OF FLUORINATED SILICONE/ FABRIC *44-002*

Condition	Tensile Strength, psi
Virgin Material	4340
	4450
	4470
	Avg. 4420

TABLE I-XXII. TENSILE STRENGTH OF ARMALON 97-001

Condition	Tensile Strength, psi	
Virgin Material	6650	5550
	6300	7200
	6700	6150
	6900	5150
	5850	
	Avg. 6270	
300°F, 5 cycles	6210	
	6210	
	6560	
	Avg. 6326	
300°F, 20 cycles	7570	
	6920	
	6300	
	Avg. 6930	
Disinfectant Treatment	6000	
	6350	
	7200	
	Avg. 6516	
300°F, 5 cycles plus Detergent Treatment	6100	
	6820	
	7250	
	Avg. 6720	
Detergent Treatment	7000	
	7140	
	7300	
	Avg. 7150	
300°F, 20 cycles plus Detergent Treatment	7400	
	7200	
	7200	
	Avg. 7270	
300°F, 10 cycles, plus Detergent Treatment	7180	
	6180	
	7070	
	Avg. 6810	
300°F, 10 cycles, plus ETO/Freon	7050	
	5450	
	6700	
	Avg. 6400	

TABLE I-XXIII. TENSILE **STRENGTH** OF SILICONE RUBBER SE-555

Condition	Tensile Strength, psi
Virgin Material	1010
	1040
	1090
	Avg. 1046
300°F, 20 cycles	1000
	960
	1090
	Avg. 1016
300°F, 20 cycles, plus Detergent Treatment	920
	960
	900
	Avg. 926
Disinfectant Treatment	1160
	560
	1000
	Avg. 906
Detergent Treatment	1090
	1030
	1060
	Avg. 1060
300°F, 10 cycles, plus ETO/Freon	> 920 *
	1235
	1255
	Avg. 1245

*specimen not broken - elongation exceeded test machine capability

TABLE I-XXIV. TENSILE PROPERTIES OF LEXAN

Condition		F (psi)	E psi x 10^6	e%
Virgin Material		9150*	.32	*
		8950*	.33	
		9000*	.32	*
	Avg.	9030	.32	
Detergent Treatment		8950*	.31	*
		8950*	.33	*
		8950*	.31	
	Avg.	8950	.32	*
ETO/Freon		9150*	.31	*
		9130*	.32	*
		9050	.30	*
	Avg.	9110	.31	*

* Severe neck down failure - specimen not broken

TABLE I-XXV. TENSILE PROPERTIES OF TEXTOLITE 11546

Condition	F_{tu} (psi)	E psi x 10^6	e (%)
Virgin Material	44.2	3.5	1.4
	40.2	3.4	1.4
	45.8	3.5	1.5
	Avg. 43.4	3.5	1.4 - 1.5
300°F, 5 cycles	45.6	3.5	1.6
	48.0	3.3	1.7
	51.0	3.4	1.8
	Avg. 48.2	3.4	1.7
300°F, 10 cycles	50.0	3.5	1.7
	52.2	3.6	1.8
	52.2	3.5	1.8
	Avg. 51.5	3.5	1.8
300°F, 20 cycles	51.0	3.5	---
	47.8	3.3	1.6
	43.5	3.4	1.5
	Avg. 44.1	3.4	1.55
300°F, 10 cycles plus detergent	46.8	3.4	1.7
	53.4	3.55	1.8
	48.5	3.4	1.7
	Avg. 46.2	3.4	1.7
300°F, 10 cycles, plus disinfectant	51.1	3.5	1.7
	48.4	3.1	1.6
	46.6	3.6	1.5
	49.0	3.6	1.6
	49.5	3.5	1.6
	43.5	3.4	1.5
	Avg. 48.0	3.4	1.6
300°F, 10 cycles, plus ETO/Freon	45.5	3.1	1.7
	47.2	3.3	1.7
	49.0	3.3	1.7
	Avg. 47.2	3.2	1.7

4. REFERENCES

3.. CR-39 Technical Bulletin, Pittsburgh Plate Glass Company

2. Bulletin 5, "Homolite 911 (Cast from CR-39 Monomer)", the Homolite Corporation.

3. Lexan Polycarbonate Sheet, Bulletins E-17, E-18, E-23, to E-26 General Electric.

4. Bulletin T-1C, "Teflon FEP Film", DuPont

5. Bulletin T-2B, "Teflon FEP Film", DuPont

6. Watertown Arsenal WAL TR 397/10, "Thermal Conductivity of Teflon, KEL-F, and Duroid 5600 at Elevated Temperature", A.W. Schultz and and A.K. Wong.

7. "Behavior of Teflon Fluorocarbon Resins at Elevated Temperatures", R.H. Settlage and J.C. Sigle, DuPont

8. "Keeping Cool with Teflon", J.C. Siegle and R.H. Settlage, DuPont.

9. DuPont Design Data for Teflon-10

10. DuPont Product Bulletin A-28854, "Data Guide for DuPont Fairprene Sheet Stocks."

11. General Electric Product Bulletin RBH-4A, "Silicone Rubber Handbook."

12. Materials Selector Issue, "Materials in Design Engineering," October 1966.

13. "Vitreosil Fused Quartz," Product Bulletin, Thermal American Fused Quartz Company.

14. "Fused Quartz," Product Bulletin Q10-8-63, General Electric Company Lamp Glass Department

15. Bulletin A-9819, "Teflon Tetrafluoroethylene Resin," DuPont

16. Plastics World, Film and Sheeting Chart.

17. Industrial Fabrics Bulletin, "Armalon", DuPont

18. Bulletin TD-1B, "Tedlar PVF Film", DuPont.

19. Bulletin H-1, "H-Film, DuPont.

20. "Protective Coated Fabrics", Cooley, Inc.

21. Plastics Design and Processing, September 1965.

22. Lexan Polycarbonate Sheet, Bulletins E-17, E-18, E-23, to E-26, General Electric

23. Plastics Design and Processing, September 1965.

24. Bulletin T-1C, "Teflon FEP Film" DuPont.

25. Bulletin TD-1B, "Tedlar PVF Film", DuPont.

26. Bulletin H-1, "H-Film", DuPont.

27. Enjay Product Bulletin, "Enjay Butyl Latex."

28. "Permeability of Polymers to Gas, Vapors, and Liquids," Alexander Lebovits, Modern Plastics, March 1966.

29. Mil-Handbook - 149A.

30. DuPont Handbook on Flexible Elastomer Diaphragms, Bulletin A-25196.

APPENDIX J: BIO-ISOLATOR SUIT SYSTEM SPECIFICATIONS

GENERAL ELECTRIC COMPANY
Re-entry Systems Department
3198 Chestnut Street
Philadelphia 1, Pennsylvania
Code Ident. No. 15226

SPECIFICATION: ERS0100-00-0001

BIO-ISOLATOR SUIT SYSTEM

(BISS)

1.0 GENERAL

1.1 Scdpe - This specification defines the Bio-Isolator Suit System, herein referred to as BISS, used in the assembly/sterilizer. "he BISS shall be used to provide an absolute biological and topological barrier between a technician and the assembly/sterilizer environment.

1.2 System Description - The BISS is comprised of an undersuit, outer suit and tunnel, life support subsystem, and a communication subsystem.

1.2.1 Undersuit - The undersuit is a form contoured 3-layer garment fabricated from a flexible material. It is sized to fit individual personnel and provides the wearer with a breatheable and cooling air distribution system.

1.2.2 Outer Suit and Tunnel - The outer suit and tunnel is fabricated from a flexible material and forms a complete envelope around a technician, which provides an absolute biological and topological barrier between him and the assembly/sterilizer environment.

1.2.3 Life Support Subsystem - The life support subsystem contains all of the components and systems necessary to perform the following functions:

a. Maintain an adequate supply of filtered breathable/cooling air to the BISS undersuit plenum.

b. Provide a means of maintaining comfortable conditions of temperature, humidity, pressure, and removal of noxious and toxic gases from the BISS outer suit.

1.2.4 Communication Subsystem - The comunication subsystem consists of a Test Conductor's Console, which includes the provisions for selecting the communication patterns, remote stations serving the Life Support and Medical Monitor locations, transducer terminals in the individual suits and at the net controller locations, and listen-only provisions for visitors. The remote station equipment may be either free-standing or an integral part of the remote equipment with which it is associated. Emergency back-up speakers and warning horns are located within the assembly/sterilizer "to provide one-way audio contact with the BISS operators in the event of failure of the components located on the undersuit.

APPLICABLE DOCUMENTS

2.1 Government Documents - The following government documents of the issue specified, form a part of this specification to the extent specified herein.

Military

MIL-P-116D 4 December 1962	Preservations, Methods of
MIL-STD-470 21 March 1966	Maintainability, Program Requirerents for Systems and Equipments
MIL-STD-826A 6 June 1966	Electromagnetic Interference, Test Requirenents and Test Methods for
MIL-P-7936 19 November 1957	Parts and Equipment, Aeronautical, Preparation for Delivery
MS33586 1 October 1952	Metals, Definition of Dissimilar

(Copies of these documents may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C.)

2.2 Non-Government Documents - The following non-government documents of the issue in effect on the date of this specification, form a part of this specification to the extent specified herein.

GENERAL ELECTRIC COMPANY, RSD

Specifications

ERS0230-00-0001	BISS Outer Suit and Tunnel
ERS0230-00-0002	BISS Undersuit
ERS0210-00-0001	BISS Life Support Subsystem
ERS0150-02-0001	BISS Communication Subsystem

Standards

118A1526	Identification Marking
146A9560	Preparation for Delivery

Drawings

SK56-173-316	BISS-Assembly/Sterilizer Interface Concept

(Copies of the General Electric Company documents may be obtained from the General Electric Company, RSD, 3198 Chestnut Street, Philadelphia, Pennsylvania 19101).

REQUIREMENTS

3.1 General - The BISS (Figure 1) shall meet the requirements of this specification and referenced documents to the extent specifird herein. In case of conflict between the requirements and any documents specified herein, this specification shall govern.

3.2 Components - The UISS shall consist of the following components:

a. Outer Suit and Tunnel
b. Undersuit
c. Life Support Subsystem
d. Communication Subsystem
e. Hard Tube
f. Hatch
g. Reefing Mechanism
h. Overhead Telescoping Boom
i. Donning Rack

3.2.1 Design Requirements

3.2.1.1 Outer Suit and Tunnel - The outer suit and tunnel shall consist of the following subassemblies. Design of the outer suit and tunnel shall comply with GE-RSD Specification ERS0230-00-0001.

3.2.1.1.1 Suit Body - The suit body shall be flexible and as light weight as possible.

3.2.1.1.2 Gloves - The gloves shall be flexible and as light weight as possible. They shall be bonaed to the suit body. The bonding shall provide an absolute biological seal.

3.2.1.1.3 Boots - The boots shall be semi-rigid and shall be bonded to the suit body. The bonding shall provide an absolute biological seal.

3.2.1.1.4 Helmet and Yoke - The helmet and yoke shall be of unit construction and shall be bonded to the suit body. The bonding shall form an absolute biological seal.

3.2.1.1.5 Tunnel - The tunnel shall be flexible and as light weight as possible. It shall be bonded to the suit body. The bonding shall form an absolute biological seal.

3.2.1.2 Undersuit - The undersuit shall be a contour fitted flexible garment fabricated to fit individual technicians. The garment shall be a multi-layer fabrication proviaing an integral air distribution system to interface with the life support subsystem. The center layer of the garment shall provide a path for exhausting stale air. Seams in the garment shall be kept to a minimum to provide an essentially air-tight compartment around the wearer. An air-tight type slide fastener shall be located in the chest area and quick-release fasteners shall be used for leg ends, to facilitate entry and egress. Hard points, located at strategic positions, shall be part of the garment structure and shall provide the attachment points for the life support and communication subsystem components. Design of the undersuit shall comply with the requirements set forth in GE-RSD Specification ERS0230-00-0002 (BISS Undersuit).

3.2.1.3 Life Support Subsystem - The life support subsystem shall be a self contained system that shall only require facility electrical power and air for operation, and shall comply with the requirements set forth in GE-HSD Specification ERS0210-00-0001 (bISS Life Support Subsystem). The system shall be contained within a console. The console shall contain the air cooling and humidification components, supply, and exhaust blowers, and a system filter. The console shall provide for monitoring and controlling input and exhaust air flow rates, temperature and humidity.

3.2.1.4 Communication Subsystem - The communication subsystem shall be a self contained system that shall only require facility power for operation, and shall comply with the requirements set forth in GE-RSD Specification ERS0150-02-0001 (BISS Communication Subsystem). The main system shall be containea within a Facility Supervisor's console located outside the assembly/sterilizer. Amplifiers, power supply systems, controls and indicators shall be contained within the console. Additional communication system components shall be contained within net controller's consoles. Other components shall be located within the life support system console, and the medical monitor console. The system shall have the following communication capabilities:

a. Two-way between the test conductor's console and the life support system and medical monitor consoles.

b. One-way only from the test conductor's console to the life support system and medical monitor consoles.

c. Two-way between the Facility Supervisor console and the net controller console.

d. Two-way between the net controller's console and the selected group of BISS operators.

e. One-way between each BISS group and its life support system control and medical monitor station.

f. Two-way between individual BISS occupants.

g. Monitoring (listening) only capability for visitors.

3.2.1.5 Hard Tube - The hard tube shall be metal cylinder with parallel sides and a semicircular top and bottom. The hard tube shall interface at one end with the tunnel and at the other end with the assembly/sterilizer wall (Figure 2). The hard tube shall pass through the wall to the outside of the assembly/ sterilizer. The sealing of the tunnel to the assembly/sterilizer is shown in Figure 1.

3.2.1.6 Hatch - The hatch shall be a metal door with a parallel sides and a semicircular top and bottom (Figure 3). It shall interface with the end of the hard tube on the exterior of the assembly/sterilizer. The hatch shall be supported by hinges, and shall have quick-release locks and a port for either pressurization or gas sampling.

3.2.1.7 Reefing Mechanism - The reefing mechanism shall be an electro-mechanical device that deploys and retracts the tunnel material in a controlled manner. The tunnel material shall be fed from and to the outer surface of the hard tube.

3.2.1.8 Overhead Telescoping Boom - The overhead telescoping boom shall be an electro-mechanical device that supports the tunnel material during operating proceaures. It shall operate in conjunction with the reefing mechanism and provide support via flexible stringers which shall be secured to the tunnel.

3.2.1.9 Donning Rack - The donning rack shall be a metal structure located in the assembly/sterilizer (Figure 4). Supports shall be provided for the outer suit arms and helmet. Two device shall be located at the donning rack base for the outer suit boots (Figure 5). A quick release device shall be located on one side of the donning rack that when operated by the UISS occupant;, shall release the helmet support. The aonning rack shall be located at the end of the hard tube and shall support the outer suit when the tunnel is in the reefed position.

3.2.2 Materials, Parts and Processes - - The materials used in the BISS fabrication shall be of the highest quality and shall be selected on the basis of physical or other essential properties, availability, adaptability to production processes, and suitability to environment conditions.

3.2.3 Undersuit Materials - *The* undersuit materials shall comply with the design requirements set forth in GE-RSD Specification ERS0230-00-0002 (BISS Undersuit)

3.2.3.1 Outer Suit and Tunnel Material - The outer suit and tunnel materials shall comply with the design requirements set forth in GE-HSD Specification ERS0230-00-0001 (BISS Outer Suit and Tunnel):

3.2.3.2 Life Support Subsystem - The materials used shall be of a type, grade, and quality which will ensure the proper operation of the life support subsystem. The materials shall conform to the design requirements set forth in GE-RSD Specification ERS0210-00-0001 (Life Support Subsystem for the Bio-Isolator Suit System Specification).

3.2.3.3 Communication Subsystem - The materials shall be of a type, grade, and quality which will ensure the proper operation of the communication subsystem. The materials shall conform to the design requirements set forth in GE-RSD Specification ERS0150-02-0001 (Communication Subsystem for the Bio-Isolator Suit System).

3.2.4 Standard. Parts - Wherever possible, standard parts shall be used to ensure reliability and expedite procurement. Preferred standard parts in their order of preference are applicable KASA specifications, Military Standards (MS, AN, NAS), General Electric Company Standards, and commercial standards. Non-standard parts may be used when specifically authorized by the procuring agency.

3.2.5 Critical ana Strategic Materials - Materials shall be selected on the basis of suitability and relative availability. Subject to satisfactory operation, the BISS shall incorporate the least critical and strategic materials.

3.2.6 Dissimilar Metals - The use of dissimilar metals, as defined in MS33586, shall not be used in intimate contact unless suitability protected against electrolytic corrosion.

3.2.7 Corrosion Resistance - Materials selected shall be corrosion resistant; or shall be suitably protected by plating, painting, or other surface treatment that is compatible with the BISS environment as set forth in 3.5.

3.2.8 Material Bonding Processes - Material bonding processes for the outer suit and tunnel, and undersuit, shall be of the highest integrity proviaing the required absolute biological barrier (outer suit and tunnel only), The bonding processes shall conform to the requirements set forth in the individual subsystem specifications.

3.2.9 EMI Considerations - Precautions shall be taken to minimize electromagnetic interference both conducted and radiated. The precautions shall include bonding, grounding, shielding, suppression techniques, and proper choice of components to minimize the generation of interference or to suppress it if it should occur. MIL-STD-826 shall be used as a guide.

3.3 Performance - The BISS (Figure 1) shall provide an absolute biological barrier between the technician and the sterile environment of the assembly/sterilizer. It shall allow the technician sufficient mobility, dexterity, and visual field to accomplish spacecraft assembly and check-out operations within the sterile pressurized environment. When unoccuppied by a technician, the BISS shall withstand an overpressure of up to 4-inches H_2O maximum. When occuppied by a technician it shall withstand an overpressure of up to 2-inches H_2O without causing undue discomfort to the technician or reducing his activities. The HISS shall maintain a comfortable and healthful environment within the outer suit and tunnel. Audio contact among BISS technicians within the sterile environment, and with monitoring personnel outside the sterile environment, shall be maintained at all times during BISS operations. Medical and life support shall be monitored at all times by personnel stationed outside the assembly/sterilizer. The life support and medical devices shall be monitored by personnel with specialized training.

3.3.1 Undersuit - The undersuit shall be a form-fitting garment. It shall distribute cooling/breathable air from the life support subsystem to the outer suit's arms, legs, and helmet area. It shall also provide a path for exhausting the stale air from the outer suit back to the life support subsystem. The undersuit shall be flexible and form-fitting without restricting the wearer's movements.

3.3.2 Outer Suit and Tunnel - The outer suit and tunnel shall maintain an absolute biological anu topological barrier between the wearer and the sterile environment within the assembly/sterilizer. The outer suit body and tunnel shall be flexible and shall not restrict movement of the wearer. A reefing mechanism shall extena and retract the tunnel to and from the tunnel/assembly/sterilizer interface to facilitate BISS entry, egress, and operating procedures. An overhead telescoping boom shall support the tunnel. It shall operate in conjunction with the reefing mechanism. The overhead telescoping boom shall decrease the tunnel drag on the BISS wearer and assist in the reefing procedures. A donning rack shall be located within the assembly/sterilizer and shall support the outer suit body in the vertical position for entry and egress procedures by the wearer.

3.3.3 Life Support Subsystem - The life support subsystem shall supply and exhaust cooling ana breathing air to the undersuit distribution system. It shall maintain an adequate supply of filtered breathable cooling air and shall maintain comfortable conditions of temperature, humidity, and pressure within the outer suit and helmet. It shall also remove noxious and toxic gases from the BISS outer suit and tunnel.

3.3.4 Communication Subsystem - The communication subsystem shall maintain audio contact among personnel within individual BISS's and personnel stationed outside. The audio contact shall be maintained under all conditions which nay exist either inside or outside of the assembly/sterilizer. Operation of the communication subsystem by the BISS wearer shall be hands-free, and operation by the personnel outside of the assembly/sterilizer shall require a minimum actuation of controls.

3.3.5 Medical Monitoring Equipment - The medical monitoring equipment shall provide data on the physical status of the BISS occupant by means of an EKG. The equipment shall include provisions for recording the occupants heart data, EKG displays shall be monitored only by personnel strictly trained in the interpretation of such displays.

3.4 Interface Requirements

3.4.1 Mechanical Interfaces - The BISS shall incorporporate the following mechanical interfaces.

3.4.1.1 Outersuit and Tunnel - The outer suit and tunnel shall incorporate the following mechanical interfaces:

a. Air distribution system to life support subsystem
b. Tunnel to assembly/sterilizer
c. Suit body to donning rack
a. Tunnel to reefing mechanism
e. Tunnel to Overhead telescoping boom

3.4.1.2 Undersuit - The undersuit **shall** incorporate the following mechanical interfaces:

a. Air distribution system to life support subsystem
b. Undersuit to outer suit, tunnel and helmet

3.4.1.3 Life Support Subsystem - The life support subsystem shall incorporate a mechanicui interface between **it** and the undersuit.

3.4.2 Electrical Interfaces - The BISS **shall** incorporate the following electrical interfaces.

3.4.2.1 Undersuit - The undersuit shall incorporate an electrical interface between **it and** the communication subsystem.

3.4.2.2 Life Support Subsystem - The life support subsystem shall incorporzte an electrical interface between **it** and the communication subsystem.

3.4.2.3 Communication Subsystem - The communication subsystem shall incorporate the following electrical interfaces:

a. Communication subsystem to undersuit
b. Communication subsystem to life support subsystem console
c. Communication subsystem to medical monitoring
d. Communication subsystem to emergency back-up speakers and warning horns within the assembly/sterilizer.

3.5 Environments

3.5.1 Pion-Operatin6 - The BISS shall meet the requirements of 3.2 and 3.3 after exposure to the following environments.

3.5.1.1 Temperature, Storage - The BISS snall be exposed to a controlled atmosphere free from vapor contaminants at a temperature of 70 ± 20°F.

3.5.1.2 Temperature, Shipping - The BISS shall be exposed to -10 to +120°F.

3.5.1.3 Temperature, Facility (Outside the Assembly/Sterilizer) - The BISS shall be exposed to a minimally air-conditioned industrial atmosphere with an ambient temperature of 80 ± 10°F, dew point of 45 ± 12°F, at ambient pressure.

3.5.1.4 Decontamination - Components located within the assembly/sterilizer **shall** be exposed to 88%Freon 12/12?; ETO (by weight), at 40% RH, at a concentration of 500 mg of ETO/litre of gaseous atmosphere for 28 hours at 104°F (24 hours stabilized at 104°F).

3.5.1.5 Sterilization - Components located within the assembly/sterilizer shall be exposed to nitrogen at a temperature of 70 to 320°F, with RH less than 1% above 200°F, and a pressure of up to 4 inches H_2O gage maximum. Sterilization times shall be selected from the following:

Temp. Deg. F	Sterilization Time, Hours
320	3
311	4
302	6
293	9
284	14
275	22
266	34
257	53
248	84
239	132
230	210
221	336

3.5.1.6 Transportability - The life support and communication subsystems shall be exposed to the following conditions:

a. Temperature: -25°F to +125°F

b. Vibration

Frequency (cps)	Double Amplitude
2–27	± 1.3 g rms
27–52	0.0036 inch
52–500	± 5 g rms

(As modified by shipping container)

c. Acceleration: 3 g's in any direction acting independently

d. Pressure: 4.37 psia to 16.2 psia

e. Humidity: 5% to 95%RH (5% to 100%with Condensation in form of water or frost when suitably protected by shipping container

f. Shock

(1) Packaged

Truck: 8 g's, 5 to 40 milliseconds

3.5.1.6 Transportability - (Continued)

f. Shock

Air	Vert. 5.5 g's, 10 to 30 milliseconds Lat. 1.5 g's, 10 to 30 milliseconds Long. 0.8 g's, 10 to 30 milliseconds (As modified by shipping container)
Handling	Rough handling as defined in Specification MIL-P-7936 for packaged equipment.

3.5.2 Operating - The BISS shall operate in the following environments.

3.5.2.1 Outer Suit and Tunnel - The outer suit and tunnel shall be subjected to the following operating environments.

3.5.2.1.1 Inner Environment - Tne environment within the outer suit and tunnel shall be 70 ± 10°F, dew point 45 ± 12°F, at a pressure between 0.5 in. H_2O and −2.0 in. H_2O gage of ambient.

3.5.2.1.2 Outer Environment - The environment within the assembly/sterilizer shall be nitrogen at a temperature of 75 ± 5°F, RH of 20 to 50 percent, and an overpressure of 2-in. H_2O gage maximum.

3.5.2.2 Undersuit - The undersuit shall operate in the environment specified in 3.5.2.1.1.

3.5.2.3 Life Support Subsystem - The life support subsystem shall operate in the environments specified in 3.5.1.3 and 3.5.2.1.1.

3.5.2.4 Communication Subsystem - The communication subsystem shall operate in the following environments.

3.5.2.4.1 Undersuit Components - Communication subsystem components interfaced with the undersuit snall operate in the environments specified in 3.5.2.1.1.

3.5.2.4.2 Assembly/Sterilizer Components - Communication subsystem components located within the assembly/sterilizer shall operate in the environments specified in 3.5.2.1.2.

3.6 Workmanship - Workmanship and shop practices shall be of the highest commercial quality. Subsystems and components of the BISS shall be constructed and finished in a thoroughly workmanlike manner. Particular attention shall be given to neatness, cleanliness, and thoroughness of soldering, welding, brazing, bonding, wiring, marking of parts, painting, protective coatings, riveting, machine screw assembly, and freedom of parts from burrs and sharp edges.

3.7 Identification and Marking - The identification and marking of all components shall conform with the requirements set forth in GE Document 118A1526 (General Electric Company Standard Identification Marking).

3.8 Finishes and Coatings - Surface finishes and protective coatings shall conform to standard practice for this type of equipment, and shall be compatible with the environmental and service conditions set forth in this specification.

3.9 Maintainability - Design of the BISS shall make use of modular construction to provide ease of maintenance. Accessibility shall be of prime importance. The use of matched parts or selective fits shall be avoided wherever possible. MIL-STD-470 shall be usea as guide.

3.10 Endurance - Overall BISS endurance shall guarantee a minimum period of 360 hours trouble free operation with routine scheduled maintenance, and shall be designed for an operating life of not less than 2000 nours.

3.11 Safety Requirements - The safety requirements for the BISS shall be designed to minimize the possibility of injury to personnel and damage to the equipment. An emergency audio warning system shall 'de comployed to back-up the main power system. All sharp edges and corners shall be rounded-off to prevent damage to the equipment and injury to personnel. All circuits carrying electrical power shall be protectea by aaequate fuses or circuit breakers. All power leads ana terminals snall be clearly marked. Components shall be adequately grounaed. Low impedance components and transformer coupling shall be used to isolate possible malfunctions fron the operators in the BISS. The BISS shall comply with the safety requirements set forth in the individual subsystem specifications.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 **Classification of Tests** - The inspection and testing of the BISS shall be classified as acceptance tests and qualification tests.

4.1.1 **Acceptance Tests** - Acceptance tests shall consist of examination of the product and functional tests (See 4.4).

4.1.2 **Qualification Tests** - Qualification tests shall be conducted to qualify the product design (see 4.5).

4.2 **Rejection and Retest** - Any BISS which does not meet the requirements of the acceptance tests in this specification shall be rejected. Upon correction of any failure, the BISS shall be retested unless this requirement is waived by GE-RSD in writing.

4.3 Test Conditions - All tests shall be performed under the environmental conditions set forth in 3.5.

4.3.1 **Test Equipment** - Laboratory apparatus calibrated at intervals properly spaced to assure accuracy shall be used to test the BISS for specification compliance.

4.4 **Acceptance Tests** - To determine compliance with 3.2 and 3.3, perform the tests specified herein.

4.4.1 Visual Examination - Each BISS shall be visually inspected to determine compliance of manufacture, fabrication, dimensions, and marking with this specification.

4.4.2 Functional Tests - Each BISS shall be subjected to the functional tests specified herein. The outer suit and tunnel and communication subsystem horns shall be installed in the assembly/sterilizer for these tests.

4.4.2.1 Interfaces - The following BISS interfaces shall be checked for compatability.

4.4.2.1.1 **Outer Suit Body to Donning Rack** - The outer suit body shall be positioned in the donning rack. Alignment of the helmet and arms to the donning rack shall be checked. The outer suit body boots shall be positioned in the donning rack and checked for correct alignment and engagement, Operation of the donning rack helmet release and boot release mechanism shall be checked. There shall be no signs of binding and the helmet and boots shall disengage from the donning rack freely. The outer suit body'shall be re-positioned in the donning rack.

4.4.2.1.2 Tunnel to Assembly/Sterilizer - The tunnel shall be aligned with the assembly/sterilizer and checked for correct mating. The tunnel shall be secure.! to the assembly/sterilizer and the interface shall be bonded to provide an absolute biological and topological seal.

4.4.2.1.3 Life Support Subsystem to Undersuit - The life support subsystem air supply and exhaust, hoses shall be interfaced with the undersuit plenum. The quick-disconnect couplings shall be checked for alignment and operation. There shall be no sign of binding during engagement and release, and the hoses shall seat firmly in the appropriate plenum interfaces.

4.4.2.1.4 Comunication Subsystem to Undersuit - The communication subsystem shall be interfaced with the undersuit, The components shall be checked for security of attachment and correct positioning.

4.4.2.1.5 Undersuit to Outer Suit Body - The undersuit shall be donned by a technician and the following checks shall be performed.

4.4.2.1.5.1 Entry and Egress - With the life support and comunication subsystem interfaced with the undersuit, the technician shall perform entry and egress procedures. There shall be no signs of binding between the undersuit and the outer suit body. The technician shall check for freedom of movement within the suit body and check that the communication subsystem components do not bind or interfer with his movements.

4.4.2.1.6 Reefing Mechanism - To be supplied later (TBSL).

4.4.2.1.7 Overhead Telescoping Boom - (TBSL)

4.4.2.2 1st Leak Test - (TBSL)

4.4.2.3 Mobility - The technician shall be garbed in his undersuit and the following mobility tests shall be performed.

4.4.2.3.1 Outer Suit and Tunnel Mobility - The life support and communication subsystems shall be interfaced with the undersuit. The technician shall enter the outer suit and tunnel and he shall free the outer suit from the donning rack, The following mobility tests shall be performed:

a, The technician shall bend at the waist 10 times.

b. The technician shall bend at the knees 10 times,

c. The technician shall ascend and descend a ladder 3 times.

d. The technician shall walk to extend the tunnel to the full length of reach and then walk backwards to the tunnel retracted position.

e. The technician shall interface the outer suit with the donning rack, and he shall exit from the outer suit and tunnel,

4.4.2.3.1 Outer Suit and Tunnel Mobility - (Continued)

f. All the mobility tests shall be evaluated. Any significant difficulty in the execution of the above tests shall be cause for rejection of the outer suit and tunnel..

4.4.2.3.2 Reefing Mechanism Mobility - The reefing mechanism mobility shall be tested with the technician performing the requirements set forth in 4.4.2.3.1. Any significant difficulty in the execution of the requirements set forth in 4.4.2.3.1 due to the reefing mechanism shall be cause for rejection.

4.4.2.3.3 Overhead Telescoping Boom Mobility - The overhead telescoping boom mobility shall be tested with the technician performing the requirements set forth in 4.4.2.3.1. Any significant difficulty in the execution of the requirements set forth in 4.4.2.3.1 and 4.4.2.3.2 due to the overhead telescoping boom shall be cause for rejection,

4.4.2.4 2nd Leak Test - (TBSL)

4.4.2.5 Applied Load Test - With the outer suit and tunnel interfaced with the hard tube, a direct load of 700 lbs. shall be applied to the suit body. All bonded interfaces shall be checked for failure. Failure in the bonded interfaces shall be cause for rejection,

4.4.2.6 Biological Leak Test - (TBSL)

4.5 Qualification Tests

4.5.1 lion-Operating Environmental Tests - The UISS shall meet the requirements specified in 4.4.1 and 4.4.2.1 through 4.4.2.6 after being subjected to the following environmental tests. These tests shall be performed in the assembly/sterilizer with the outer suit and tunnel in the unmanned condition.

4.5.1.1 Temperature - To determine compliance with 3.5 the BISS shall withstand the temperatures specified therein.

4.5.1.2 Decontamination - To determine compliance with 3.9.1.4 the outer suit and tunnel, and specified communication subsystem components shall withstand the conaitions specified therein.

4.5.1.3 Sterilization - To determine compliance with 3.9.1.5 the outer suit and tunnel, and specified communication subsystem components shall withstand the conditions specified therein.

4.5.1.4 Vibration - hefer to GE-RSD Specifications ERS0210-00-0001 (BISS Life Support Subsystem) and ERS0150-02-0001 (BISS Communication Subsystem).

4.5.1.5 Acceleration - Refer to GE-RSD Specifications ERS0210-00-0001 (BISS Life Support Subsystem) and ERS0150-02-0001 (BISS Communication Subsystem).

4.5.1.6 Pressure - Refer to GE-RSD Specifications ERS0210-00-0001 (BISS Life Support Subsystem) and ERS0150-02-0001 (BISS Communication Subsystem).

4.5.1.7 humidity - Refer to GE-RSD Specifications ERS0210-00-0001 (BISS Life Support Subsystem) and ERS0150-02-0001 (BISS Communication Subsystem').

4.5.1.6 Shock - Refer to GE-RSD Specifications ERS0210-00-0001 (BISS Life Support Subsystem) and ERS0150-02-0001 (UISS Communication Subsystem).

4.5.2 Operating Environmental Tests - The BISS shall be subjected to the following tests to determine compliance with 3.3.

4.5.2.1 Mobility - The test procedures specified in 4.4.2.1.5 through 4.4.2.3.1 shall be performed under the environmental conditions specified in 3.5.2.

4.5.2.2 Air Flow - During the tests performed in 4.5.2.1, the life support subsystem air flow shall be checked. The air flows shall meet the requirements specified in GE-HSD Specification ERS0210-00-0001 (UISS Life Support Subsystem).

4.5.2.3 Communication - During the tests performed in 4.5.2.1, the communication subsystem transmission and reception from and to the outer suit and tunnel shall be checked under the environmental conditions specified in 3.5.2. The transmission and reception snall *also* be checked with a maximum supply and exhaust air flow being supplied to the undersuit.

4.5.2.3. 1 Communication Back-up Components - The horns located inside the assembly/ sterilizer shall be actuated under the environmental conditions specified in 3.j.2, with a maximum supply and exhaust air flow being applied to tne undersuit. The horns shall be audible within the outer suit and tunnel helmet,

4.5.2.4 Biological Leak Test - TBSL

5.0 PREPARATION FOR DELIVERY

5.1 The BISS shall be stored and shipped as specified in the following GE/RSD Specifications:

a. ERS0230-00-0001 BISS Outer Suit and Tunnel

b. ERS0230-00-0002 BISS Undersuit

c. ERS0210-00-0001 BISS Life Support Subsystem

d. ERS0510-02-0001 BISS Communication Subsystem

6.0 NOTES

None

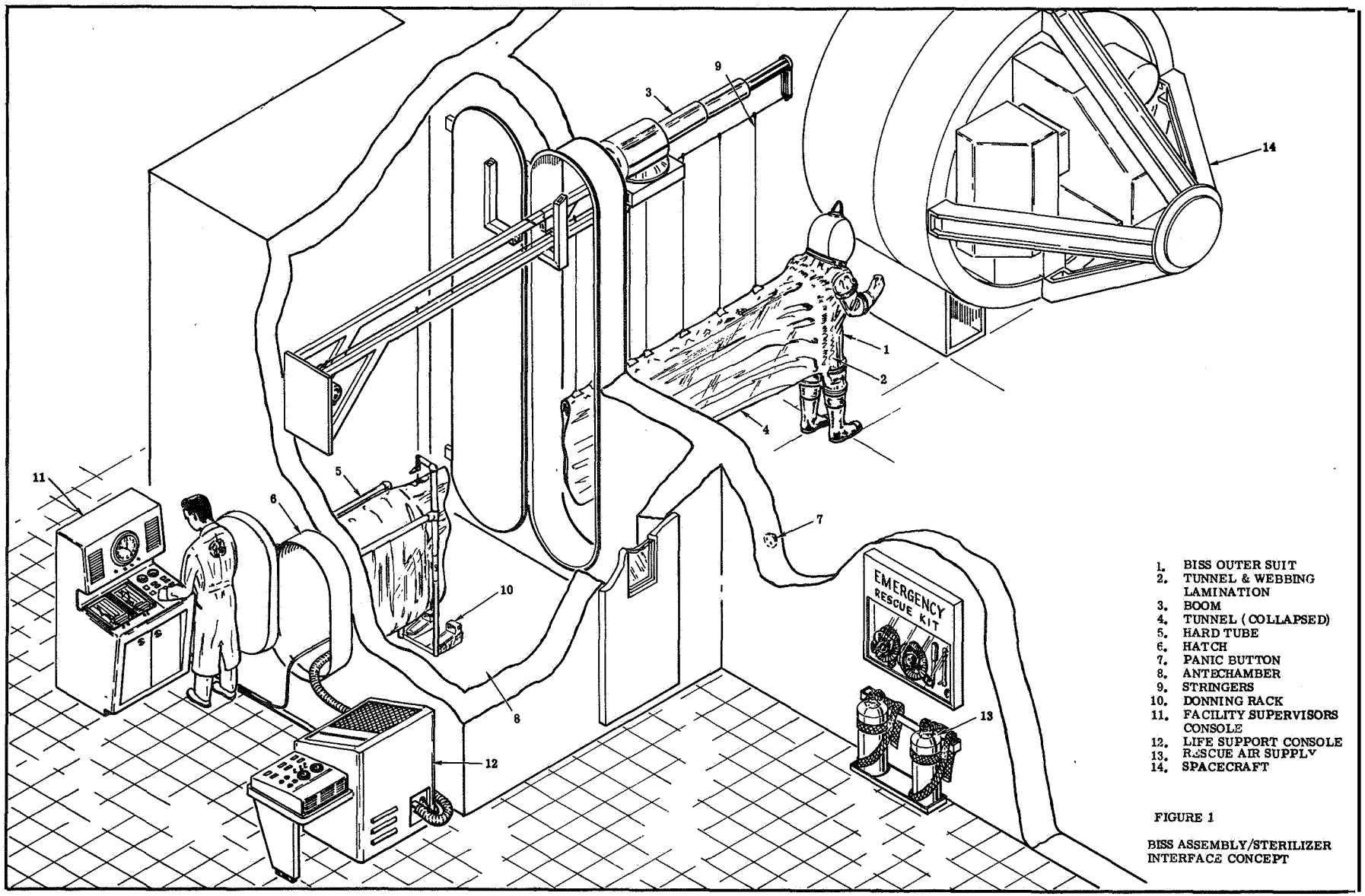


Figure 1 BISS Assembly/Sterilizer
Interface Concept

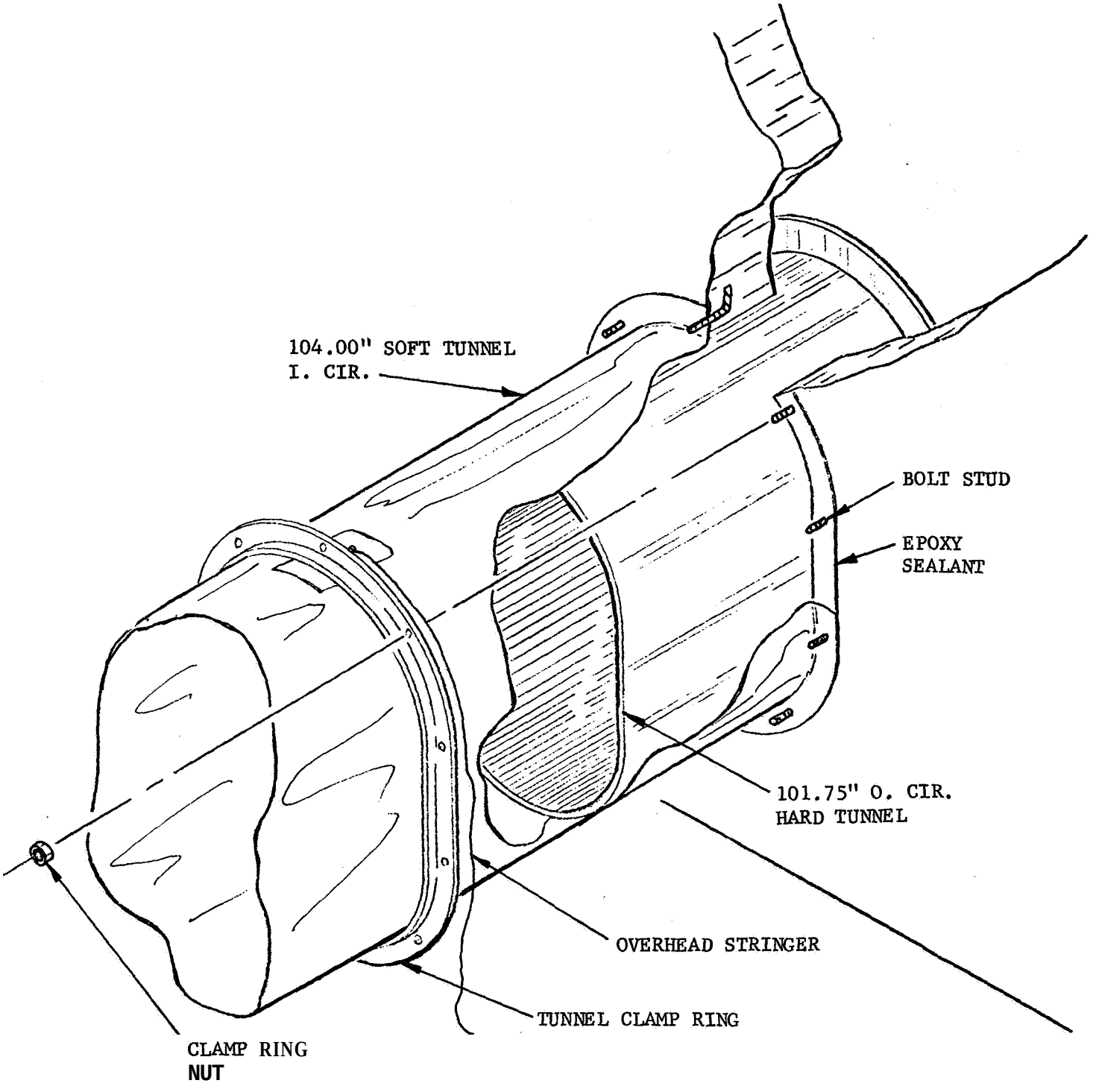
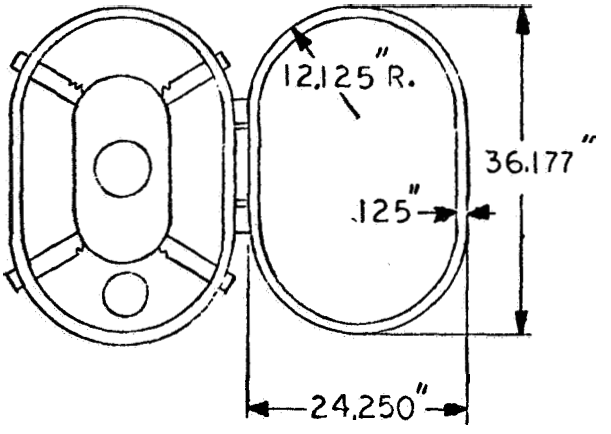
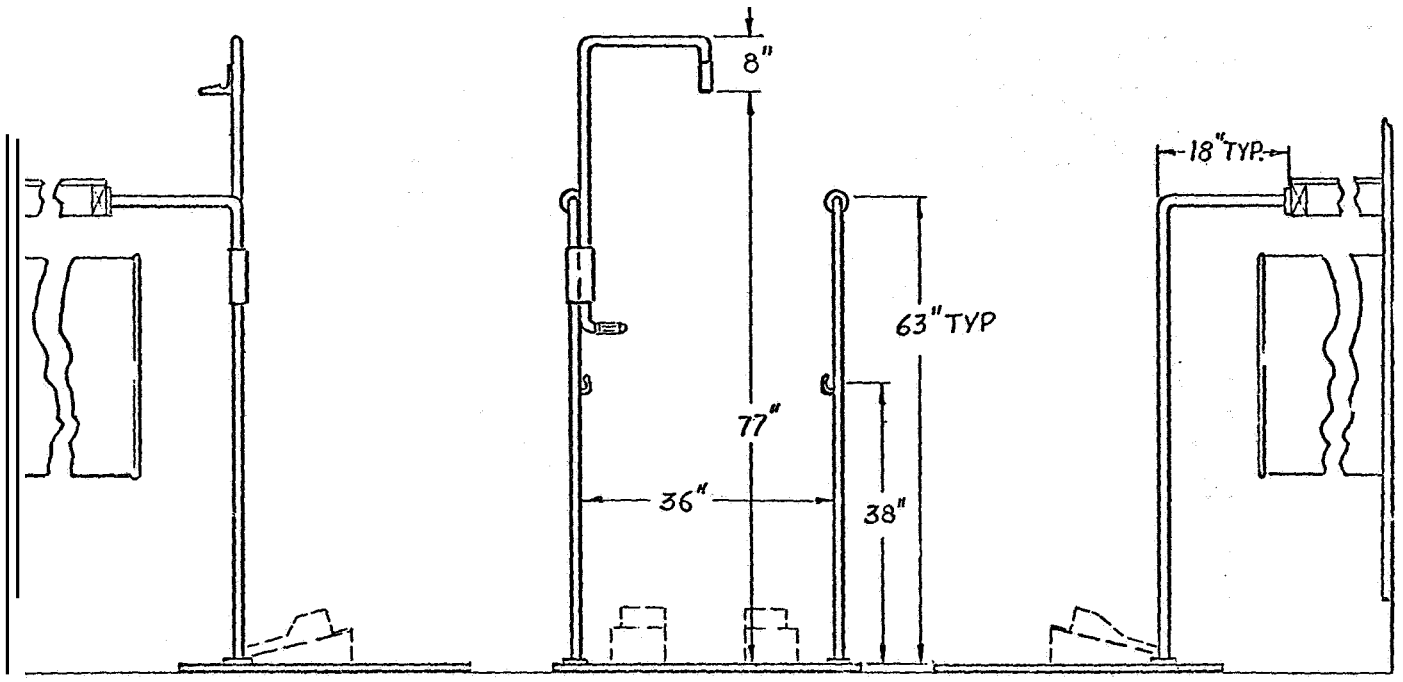


FIGURE 2 TUNNEL HARD TUBE INTERFACE

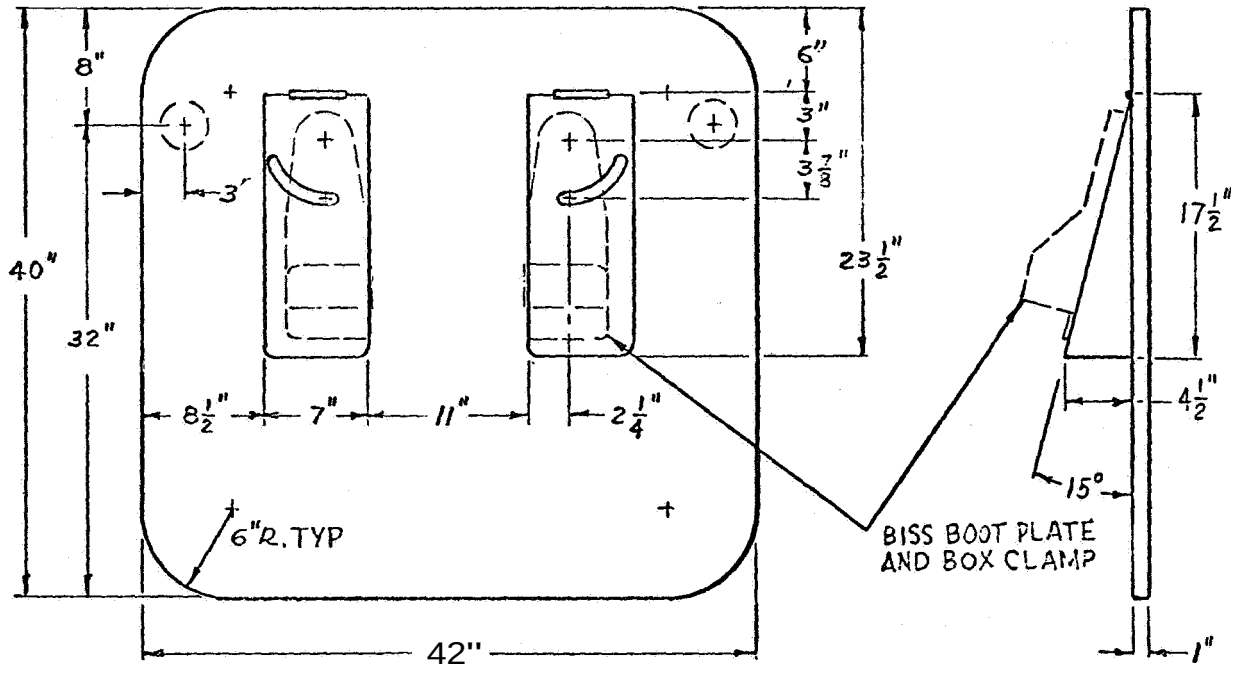


HATCH OPENING
DIMENSIONS

FIGURE 3 HARD TUBE HATCH

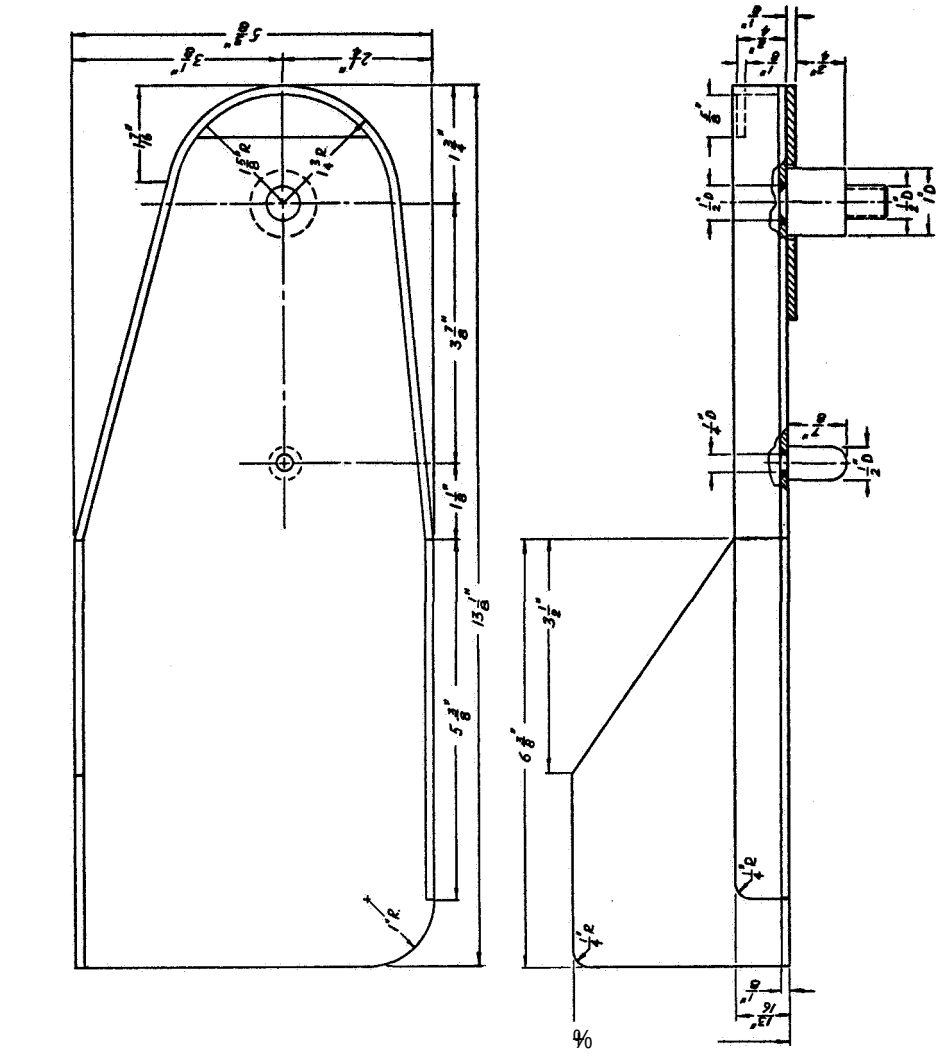


DONNING RACK 1" TUBULAR FRAMING



DONNING RACK BASE - TOP & SIDE VIEWS

FIGURE 4 DONNING RACK BASE - TOP & SIDE VIEWS



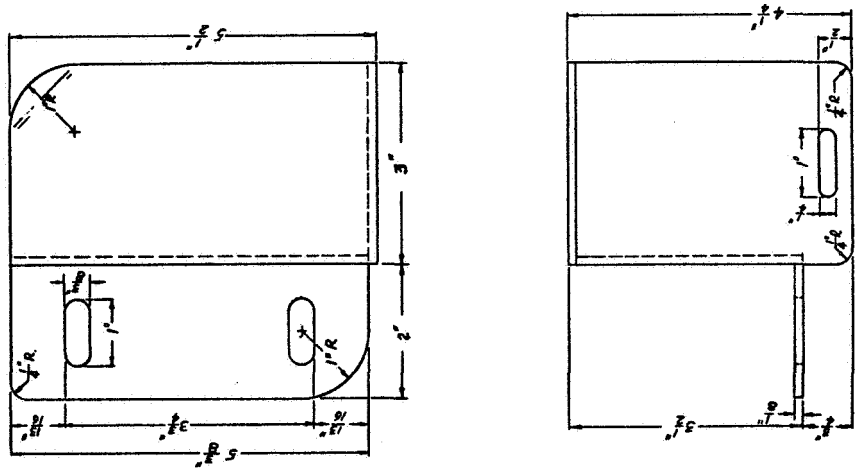


FIGURE 5 DONNING RACK BOOT INTERFACE

APPENDIX K: BISS OUTER SUIT AND TUNNEL SPECIFICATIONS

GENERAL ELECTRIC COMPANY
Re-entry Systems Department
3198 Chestnut Street
Philadelphia, Pennsylvania
Code Ident, No. 15226

SPECIFICATION: ERS0230-00-0001

BISS OUTER SUIT AND TUNNEL

1.0 GENERAL

1.1 Scope - This specification defines the outer suit and tunnel which is one of the major subsystems in the Bio-Isolator Suit System, hereinafter referred to as BISS, (GE-RSD Specification S0100-00-0001). The outer suit and tunnel provide an absolute biological and topological barrier between a technician and the sterile environment within the assembly/sterilizer.

1.2 Description - The outer suit and tunnel shall contain all the components and systems necessary to perform the following functions:

a. Allow the technician mobility in all directions at any point of the tunnel reach.

b. Allow the technician maximum optical vision,

c. Retract the tunnel to the assembly/sterilizer interface for technician entry and egress procedures.

d. Maintain the outer suit body in a semi-rigid vertical position for the technician entry and egress procedures.

e. Support the tunnel when it is extended or retracted to decrease drag on the technician and assist the extending and retracting mechanism.

1.2.1 Components - The outer suit and tunnel shall consist of the following major components:

a. Outer Suit Body

b. Gloves

c. Boots

d. Helmet and Yoke

e. Tunnel

f. Interface Collars

2.0 APPLICABLE DOCUMENTS

2.1 Government Documents - The following government documents of the issue specified, form a part of this specification to the extent specified herein.

Federal

GGG-H-142c 18 December 1961	Helmet, Construction Worker's

Military

MS33586 1 October 1952	Metals, Definition of Dissimilar
MIL-B38325A 23 January 1966	Boot, Rocket Fuel Handlers FWK-6/P22P-1

(Copies of these documents may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C.)

2.2 Non-Government Documents - The following non-government documents of the issue in effect on the date of this specification, form a part of this specification to the extent specified herein.

SPECIFICATIONS

S0100-00-0001	Bio-Isolator Suit System (BISS)
S0230-00-0002	BISS Undersuit

STANDARDS

118A1526	Identification Marking
146A9560	Preparation for Delivery

(Copies of the General Electric Company documents are available from: General Electric Company, RSD, 3198 Chestnut Street, Philadelphia, Pennsylvania 19101)

3.0 REQUIREMENTS

3.1 General - The outer suit and tunnel **shall** meet the requirements of this specification and referenced documents to the extent specified herein. In case of conflict between the requirements and any documents specified herein, this specification shall govern.

3.2 Performance - The outer suit and tunnel shall provide the following performance characteristics.

3.2.1 ~~Leak~~ - It shall provide biological and topological barrier between the wearer and the sterile environment of the assembly/sterilizer such that the probability of microbial penetration through any material or seam is less than 1×10^{-5} and there shall be no air leak greater than 1×10^{-10} cm^3/sec..

3.2.2 Physical Movement and Vision - It **shall** allow the wearer to accomplish spacecraft assembly and checkout operations within the sterile environment such that the following is provided;

a, Head movements - The helmet, neck rings and interfaces between the helmet and suit **shall** allow all normal head movements,

b. Vision and Distortion - The face plate of the helmet shall provide an unobstructed line of vision at all normal head movement limits with no visual distortion.

c. Fit/Mobility - The outer suit and tunnel **shall** not restrict or evidence difficulty in manned entry to or egress from the suit, bending at the waist, knees, elbows, hips and no binding **shall** occur that will obstruct normal air flow to and from the undersuit.

3.2.3 Direct Load - Interfacing of the suit body/tunnel/hard tube shall be capable of withstanding a direct pull of 700 pounds minimum without breaking the absolute biological and topological seal.

3.2.4 Material Characteristics - The materials used in the outer suit and tunnels shall meet the following requirements (Section 6, Notes, **shall** be used as a guide in selecting materials):

a. Stability to dry heat sterilization under conditions specified in para. 3.8.1.4.

b. Minimum ETO/Freon permeability/degradation under conditions specified in para. 3.8.1.3.

c. Imperviousness to micro-organisms as specified in 3.2.1.

3.2.4 Material Characteristics - (Continued)

d. Abrasion resistance

e. Low coefficient of friction

f. Resistance to liquid decontaminants

g. Non flamability

h. Minimum static electricity buildup

3.3 Materials, Parts and Processes

3.3.1 Materials - The materials used in the outer suit and tunnel fabrication shall be of the highest quality and selected on the basis of physical or other essential properties, availability, adaptability to production processes, and suitability to the environment conditions set forth in 3.8.

3.3.2 Standard Parts - Wherever possible, standard parts shall be used to ensure reliability and expedite procurement. Preferred standard parts in their order of preference are applicable NASA Specifications, Military Standards (MS, AN, NAS), General Electric Company Standards, and commercial standards, Non-standard parts may be used when specifically authorized by the procuring agency.

3.3.3 Critical and Strategic Materials - Materials shall be selected on the basis of suitability and relative availability, Subject to satisfactory operation, the outer suit and tunnel shall incorporate the least critical and strategic materials,

3.3.4 Dissimilar Metals - The use of dissimilar metals, as defined in MS33586, shall not be used in intimate contact unless suitably protected against electrolytic corrosion.

3.3.5 Corrosion Resistance - Materials selected shall be corrosion resistant or shall be suitably protected by plating, painting, or other surface treatment that is compatible with the environment to which the outer suit and tunnel is subjected.

3.3.6 Material Bonding Processes - Material bonding processes used in the fabrication of the outer suit and tunnel shall provide bonds of the highest integrity providing the absolute biological barrier required. The bonding shall meet the following requirements:

a, Minimum lap shear of 150 psi.

b. Minimum peel strength of 10 pounds/inch.

c. Probability of microbial penetration as specified in para. 3.2.1.

3.4 Workmanship - Workmanship and shop practices shall be of the highest commercial quality. Subassemblies and components of the outer suit and tunnel shall be constructed and finished in a thoroughly workmanlike manner. Particular attention **shall** be given to neatness, cleanliness, and thoroughness of welding, brazing, bonding, marking of parts, paintings, protective coatings, riveting, machine screw assembly and freedom of parts from burrs and sharp edges.

3.5 Identification and Marking - The identification and marking of all components shall conform with the requirements set forth in GE Document 118A1526 (General Electric Company RSD Standard Identification Markings).

3.6 Finishes and Coatings - Surface finishes and protective coatings shall conform to standard practice for this type of equipment, and shall be compatible with the environmental and service conditions set forth in this specification.

3.7 Interfaces

3.7.1 Outer Suit and Tunnel - The outer suit and tunnel shall incorporate the following interfaces:

a. Outer suit body to tunnel
b. Tunnel to hard tube
c. Outer suit body to helmet
d. Outer suit body to gloves
e. Outer suit body to boots
f. Helmet and yoke to undersuit (General Electric Company RSD Specification S0230-00-0002)
g. Reefing mechanism/Tunnel
h. Telescoping Boom/Tunnel
i. Donning rack/Outer suit body

3.8 Environment

3.8.1 Non-Operating - The outer suit and tunnel shall be subjected to the following non-operating environments:

3.8.1.1 Storage - The storage environment **shall** be controlled atmosphere free from vapor contaminants at a temperature of 70 ± 20°F.

3.8.1.2 Shipping - The shipping environment shall be -10°F to +120°F.

3.8.1.3 Recontamination - Components located within the assembly/sterilizer shall be subjected to 88%Freon 12/12% ETO (by weight), at 40% RH, at a concentration of 500 mg. of ETO/litre of gaseous atmosphere for 28 hours at 104°F (24 hours stablized at 104°F).

3.8.1.4 Sterilization - The environment within the assembly/sterilizer during sterilization procedures shall be nitrogen at a temperature of 70 to 320°F, with RH less than 1% above 200°F, and a pressure of up to 4 inches H_2O gage maximum, Sterilization times shall be selected from the following:

Temp, Deg. F	Sterilization Time, Hours
320	3
311	4
302	6
293	9
284	14
275	22
266	34
257	53
248	a4
239	132
230	210
221	336

3.8.2 Operating– The outer suit and tunnel shall be subjected to the following operating environments.

3.8.2.1 Outer Suit & Tunnel - The environment within the outer suit and tunnel shall be 70°F ± 10°F, dew point 45 ± 12°F at a pressure between 0.5 in. H_2O and -2.0 in, H_2O gage.

3.8.2.2 Assembly/Sterilizer - The environment within the assembly/sterilizer during operation procedures shall be nitrogen at a temperature of 75 ± 5°F, RH of 20 to 50%, and a pressure of 2 inches H_2O gage maximum,

3.9 Maintainability - Design of the outer suit and tunnel shall make use of modular construction to provide ease of maintenance. Accessibility shall be of prime importance. The use of matched parts or selective fits shall be avoided to the maximum possible extent.

3.10 Endurance - Endurance of the outer suit and tunnel shall be such as to permit a minimum period of 360 hours of continuous trouble-free operation without maintenance beyond the replacement of boots or gloves, The outer suit and tunnel shall be designed for an operating life of not less than 2000 hours with maintenance.

3.10.1 Total Life - The outer suit and tunnel, and all equipment integral thereto, shall withstand a minimum of 10 cleaning procedures on the external surfaces, 90 cleaning procedures on the internal surfaces, 10 cycles of ETO/Freon decontamination and 10 cycles of dry heat sterilization (see 3.8 for dry heat sterilization cycles) without violating the basic garment construction or the design criteria. The total life of the outer suit and tunnel and parts thereof shall be up to 24 months from production to end of life. This total shall be composed of a service life of up to 12 months, with the balance of the 24 months being storage time. The design objective for cleaning procedures shall be 20 cleaning procedures on external surfaces and 90 cleaning procedures on internal surfaces.

3.11 Safety Requirements - The outer suit and tunnel shall be designed with incorporation of the following safety requirements:

a. Minimize the possibility of injury to personnel and damage to the equipment.

b. Remove all sharp edges and round-off all Corners.

c. Envelop the wearer and provide an absolute barrier from the nitrogen environment,

d. Minimize the possibility of injury to the wearer from falling objects or accidental falling or slipping of the occupant.

e. The helmet and face plate shall provide the equivalent of hard hat and safety glass protection to the wearer.

f. The boots shall incorporate safety toes and non-skid soles.

g. Adequate grounding shall be provided to minimize static electricity build-up.

h. Interfacing of the suit body/tunnel/hard tube shall be capable of withstanding a direct pull as specified in para. 3.2.3.

3.12 Design Requiremen

3.12.1 Comgonents - The outer suit and tunnel shall consist of the components set forth in 1.2.1.

3.12.1.1 Suit Body - The suit body [Figures 1 and 2) shall be designed with the arms, legs, and torso as integral parts. The suit body shall be capable of interfacing with the tunnel, gloves, boots, and helmet and yoke to form an absolute biological and topological barrier about the wearer. An opening of 104-inches (Figure 3) circumference shall be provided in the back of the suit body for the interface with the tunnel, The opening shall be radially reinforced with layers of webbing material forming a lip that shall be an integral part of the suit body structure. This webbing material shall support the suit body to facilitate entry and egress by the wearer. Wire rings formed from 0.060 piano wire shall be incorporated in the sleeve and leg structures. The rings shall be located above and below the elbow and above the knee areas. They shall be so positioned that they do not hinder the wearer's movements. The rings shall support the material *to* facilitate entry and egress by the wearer. An adjustment strap shall be located at the suit body crotch area. The neck area of the suit will incorporate 22-inches of extra material to permit mating of the helmet and yoke assembly with the suit after fabrication of both items. The excess material will be lapped as shown in Figure 4.

3.12.1.1.1 Material - Refer to Section 6, Note 6.2.1.

3.12.1.1.2 Seams - All seams shall be bonded in accordance with the requirements set forth in 3.3.6. Seams shall be kept to a minimum,

3.12.1.1.3 Tailoring - The suft body shall permit freedom of movement and shall be sized to fit the American male with a height of 70 ± 1 inch, and a weight of 157 ± 14 pounds. Folds and creases shall be kept to a minimum,

3.12.1.2 Sleeve and Leg Interface Collars - The sleeve (Figure 5) and leg (Figure 6) interface collars shall form part of the suit body structure. They shall extend from the sleeve and leg ends sufficiently to provide adequate bonding surfaces for the gloves and boots. The sleeve interface collar shall measure 5.25 inches O.D., 5.00 inches I.D. and shall have an overall length of 3.00 inches. A clamp and eye shall be secured to the sleeve interface collar after bonding to form the interface between the sleeve and donning rack (Figure 7). The leg interface collar shall measure 7.50 inches O.D., 7.25 inches I.D., and shall have an overall length of 3.00 inches. All surfaces shall be smooth and rounded off. Design of the interface collars shall facilitate removal of bonding and glove or boot for replacement procedures without damaging the outer surfaces,

3.12.1.2.1 Material - Refer to Section 6, Note 6.2.2.

3.12.1.3 Gloves - The gloves (Figure 5) shall be of unit construction and shall be highly flexible. There shall be no seams in the glove fabrication. They shall have a minimum thickness of 30 mils. The gloves shall have curved fingers end shall be unlined with a uniformly smooth inner and outer surface. Gloves shall be size 10. *The* glove shall have an overall length of 14 inches when measured flat from finger tip to gauntlet end, The glove gauntlet shall have an inside diameter from 5.25 inches, and shall interface with the suit body sleeve interface collar. The glove shall be bonded to the interface collar to provide a permanent type biological and

3.12.1.3 - Gloves (Continued)

topological seal. It shall be bonded in such a manner to facilitate glove and bonding material removal without damaging the interface collar outer surfaces.

3.12.1.3.1 Material - Refer to Section 6, Note 6.2.3

3.12.1.4 Boots - The boots (Figure 6) shall be semi-rigid. They shall be 15-inches overall length. The calf inside diameter shall be 7.50 inches, The calf and ankle shall have smooth inner and outer surfaces, while the shoe portion shall be lined with a non-absorbing material, The overall shape of the boot shall resemble a short fireman's boot. The boot soles shall have a non-skid construction and the boot shall incorporate a safety toe using the requirements set forth in MIL-B-38325A as a guide. The boot heels shall have a cut-out designed to interface with the donning rack boot fixture. The cut-out shall be designed to retain its' shape at all times. Boot shall be size No. 10. The boot calf shall interface with the suit body leg interface collar. It shall be bonded to the hard tube to form a permanent type absolute biological and topological seal. The bonding shall be in such a manner to facilitate boot and bonding material removal without damaging the interface collar outer surface. Boot seams and joints shall be kept to a minimum,

3.12.1.4.1 Material - Refer to Section 6, Note 6.2.3

3.12.1.5 Helmet and Yoke Assembly - The helmet and yoke assembly shall consist of a helmet, faceplate, yoke, helmet neck ring and clamp, adjustment straps and a donning rack interface loop. (See Figure 8).

3.12.1.5.1 Helmet - The helmet and yoke shall be a unit molded assembly. The helmet shall be of sufficient thickness to provide impact resistance and penetration strength equal to or greater than that specified for the helmet covered by GGG-H-142c. The yoke shall follow the shoulder contours and web belting shall be added to adjust to the shoulder contract points. A 1/4 inch layer of foam plastic shall line the helmet inner rear surface to reduce the acoustic noise level, The helmet shall be trimmed in the neck area to allow maximum head mobility and ease of entry and egress.

3.12.1.5.1.1 Material - Refer to Section 6, Note 6.2.4

3.12.1.5.2 Face Plate - The face plate shall provide the performance characteristics of para. 3.2.2b. It shall be bonded to the helmet, providing a permanent absolute biological and topological seal. The face plate shall be of sufficient dimensions to provide an unobstructed line of vision at all normal head movement limits.

3.12.1.5.2.1 Material - Refer to Section 6, Note 6.2.4

3.12.1.5.3 Helmet Neck Ring and Clamp - The neck ring shall be of unit construction with the inner surface so designed to provide the most practical interface surface between it, the helmet, and the outer suit body. The neck ring outer surface shall be so designed to provide the most practical interface surface between it and the clamp, The clamp shall be fabricated in two semi-circular sections with provisions made for securing the ends together, When tightened, the clamp shall secure the neck ring to the bonded helmet and suit body. The helmet neck ring and clamp shall be located at the helmet base. When the helmet is interfaced with the suit body a permanent-type bonded absolute biological and topological seal shall be completed by the helmet neck ring and clamp.

3.12.1.5.3.1 Material - The helmet neck ring and clamp shall be fabricated from aluminum.

3.12.1.5.4 Adjustment Straps - The adjustment straps shall be secured to the helmet yoke. Each strap shall have a D-ring which shall interface with a personal "Y" back strap (Figure 9). The "Y" back strap shall interface with the undersuit waist belt. Quick-release adjustable fastenings shall be provided on the "Y" back strap. This will enable individual wearers to adjust the "Y" back strap before entering the BISS.

3.12.1.5.4.1 Material - The adjustment straps shall be fabricated from Dacron webbing strips 3/32 x 2 inches.

3.12.1.5.5 Donning Rack Interface Loop - The donning rack interface loop shall be an integral component of the helmet. It shall be located in the top of the helmet in such a position to facilitate alignment with the support hook on the donning rack.

3.12.1.5.5.1 Material - The donning rack interface loop shall be fabricated from aluminum.

3.12.1.6 Tunnel - The tunnel (Figure 10) shall be fabricated from a unit piece of material. It shall be capable of interfacing with the suit body and hard tube. The tunnel shall be 20 ft. long, with a 104 inch inside circumference, The seam in the tunnel shall be lengthwise, and shall be bonded in such a manner to provide a permanent absolute biological and topological seal. The interfaces at the suit body and hard tube shall be capable of withstanding a direct pull of 700 pounds minimum without destroying the absolute biological and topological seals. Flexible stringers shall be attached to the top of the tunnel and shall be spaced 2 feet apart for the entire tunnel length. They shall be secured to the tunnel outer wall by a grommet and swivel eye attachment (Figure 11).

A second short spider stringer fromthe grommet and swivel eye shall be adhered to the tunnel outer wall. This stringer end shall be "sprayed" in such a manner that the strain is divided over a large area. A patch fabricated from the tunnel material shall cover the stringer "sprayed" area to provide additional strain relief and security of stringer attachment. Reefing attachments shall be provided on the tunnel to form the interface between it and the reefing mechanism.

3.12.1.6.1 Material - Refer to Section 6, Note 6.2.1.

QUALITY ASSURANCE PROVISIONS

4.1 Classification of Tests - The inspection and testing of the outer suit and tunnel shall be classified as acceptance tests and qualification tests.

4.1.1 Acceptance Tests - Acceptance tests shall consist of examination of the product and functional tests (see 4.4).

4.1.2 Qualification Tests - Qualification tests shall be conducted to qualify the product design (see 4.5).

4.2 Rejection and Retest - Any outer suit and tunnel which does not meet the requirements of the acceptance tests in this specification shall be rejected, Upon correction of any failure, the outer suit and tunnel shall be retested unless this requirement is waived by GE-RSD in writing.

4.3 Test Conditions - All tests shall be performed under the following conditions:

a.	Temperature	80°F ± 10°F
b.	Dew Point	45°F ± 12°F
c.	Barometric Pressure	Ambient

4.3.1 Test Equipment - Laboratory apparatus calibrated at intervals properly spaced to assure accuracy shall be used to test the outer suit and tunnel for specification compliance.

4.4 Acceptance Tests - To determine compliance with 3.2, performthe tests specified herein.

4.4.1 Visual Examination - Each outer suit and tunnel shall be visually inspected to determine compliance of manufacture, fabrication, dimensions, and marking with this specification and the applicable documents.

4.4.2 Functional Tests - Each outer suit and tunnel shall be subjected to the functional tests specified herein,

4.4.2.1 Boot Safety Toes - The boot safety toes shall be tested for conformance with the impact and compression requirements set forth in MIL-B-38325A.

4.4.2.2 Helmet - The helmet shall be tested for conformance with the impact resistance requirements set forth in GGG-H-142C. The helmet shall be exposed to the environmental conditions set forth in 3.8 and checked for visual distortion. No distortion is permissable.

4.5 Qualification Tests

4.5.1 Non-Operating Environmental Tests - The outer suit and tunnel shall meet the requirements specified in 4.4.1, 4.4.2.1 and 4.4.2.2 after subjection to the following environmental tests.

4.5.1.1 1st Leak Test - To be supplied later (TBSL).

4.5.1.2 Applied Load Test - The tunnel shall be interfaced to a facimile of the assembly/sterilizer hard tube. A direct load of 700 lbs. shall be applied to the suit body, There shall be no sign of failure of any suit body or tunnel bonded surfaces.

4.5.1.3 2nd Leak Test - TBSL

4.5.2 Operating Environmental Tests - The operating environmental tests shall be conducted in conjunction with the system qualification tests specified in GE-RSD Specification ERS0100-00-0001 (Bio-Isolator Suit System).

5.0 PREPARATION FOR **STORAGE** AND TRANSPORTATION

5.1 Storage

5.1.1 Outer Suit and Tunnel - The outer **suit** and tunnel **shall** be stored in a clean, controlled environment free from vapor contaminants at a temperature of 65 to 75°F. The outer suit and tunnel shall be supported by a suitable rack,

5.2 Transportation

5.2.1 **Outer** Suit and Tunnel - **The** outer suit and tunnel **shall** be overpacked in a shipping container which **shall** adequately protect **it** during handling and shipping. The shipping container shall meet the minimum requirements ***of*** the carrier for safe transportation, Additional overpacking **shall** be placed in **fold** areas to prevent sharp bends, The helmet and face plate shall be supported in the most efficient manner and shall be overpacked internally and externally. The packaging used in this area shall be of the highest quality and **shall** not degrade the optical quality of the face plate, Additional overpacking shall be placed within the entire **glove** and finger areas to prevent sharp bends, Wherever possible *the* outer suit and tunnel shall be shipped at room temperature, If transportation temperature is 55°F or **lower,** the shipping container **shall** be opened at the destination **and** the outer suit and tunnel **shall** be allowed sufficient time to reach room temperature before removal.

5.2.2 All other components used in the outer suit and tunnel concept shall be overpacked in shipping containers which **shall** adequately protect them during handling and shipping, The shipping containers **shall** meet the **minimum** requirements of the carrier **for** safe transportation,

5.3 Marking - Shipping and storage containers shall be marked with the name and address of the consignee and consigner, contract or purchase **order** number, and item part number, All markings shall be legible **and** waterproof.

6.0 NOTES

6.1 Reference Documents - The following documents of the latest issue, shall be used for reference purposes only and do not form a part of this specification.

General Electric

165A4434	EPOXY ADHESIVE
128A5469	RUBB, SILICON, MOLDED & EXTRUDED

6.2 Materials - Materials which have demonstrated satisfactory performance to the requirements of this specification are as follows:

6.2.1 Suit Body and Tunnel Material - Armalon, EIDuPont de Nemours.

6.2.2 Sleeve and Leg Interface Collars - Fabricated fron Epoxy EC2216, 3M Co (GE-RSD Standard 165A4434)

6.2.3 Gloves and Boots - Fabric reinforced with Silicone Rubber SE 555 (See GE-RSD Standard 128A5469 for rubber material only)

6.2.4 Helmet & Fore Plate - Lexan, General Electric Co., Chemical Development Operation, Pittsfield, Mass.

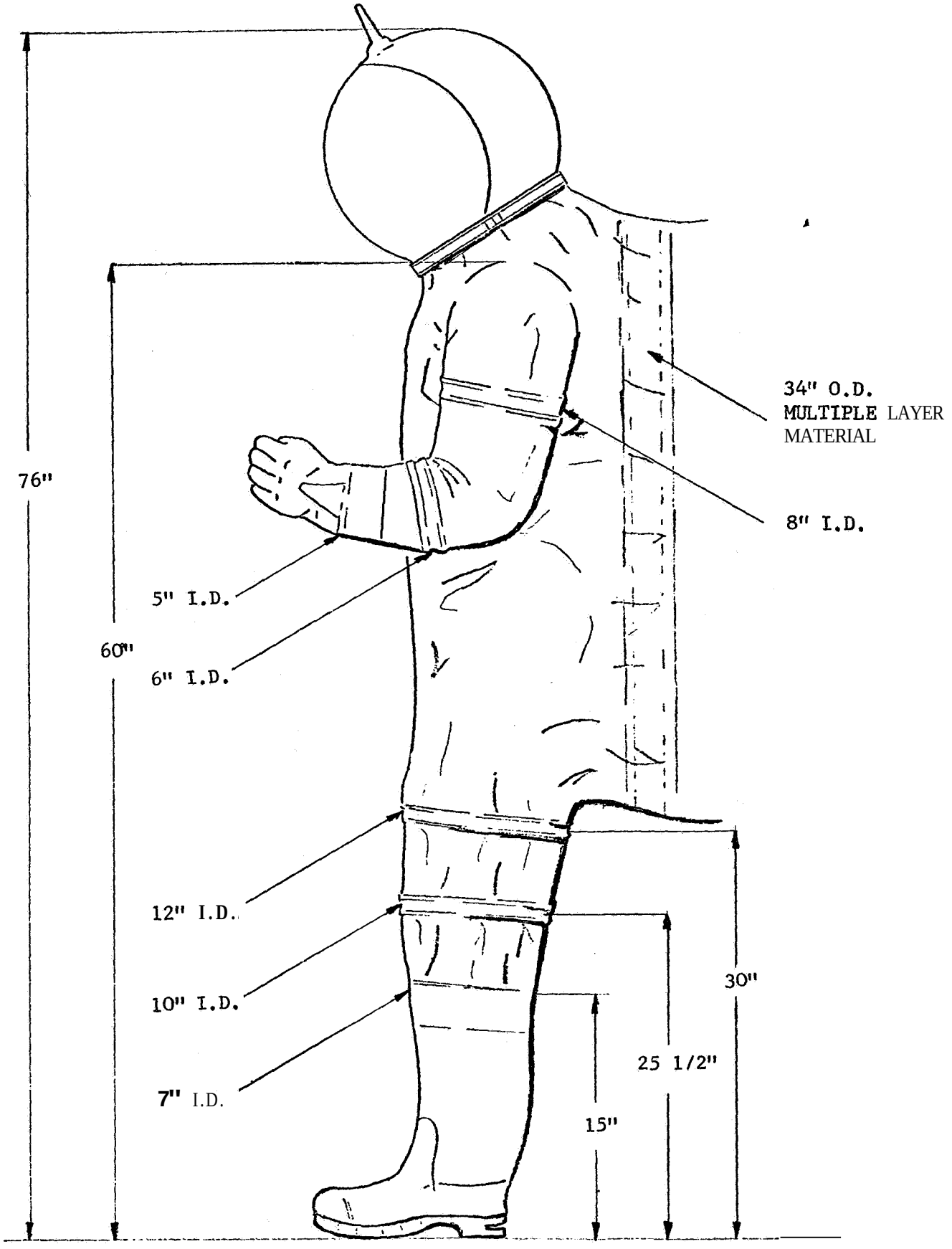


FIGURE 1 SUIT **BODY-SIDE VIEW**

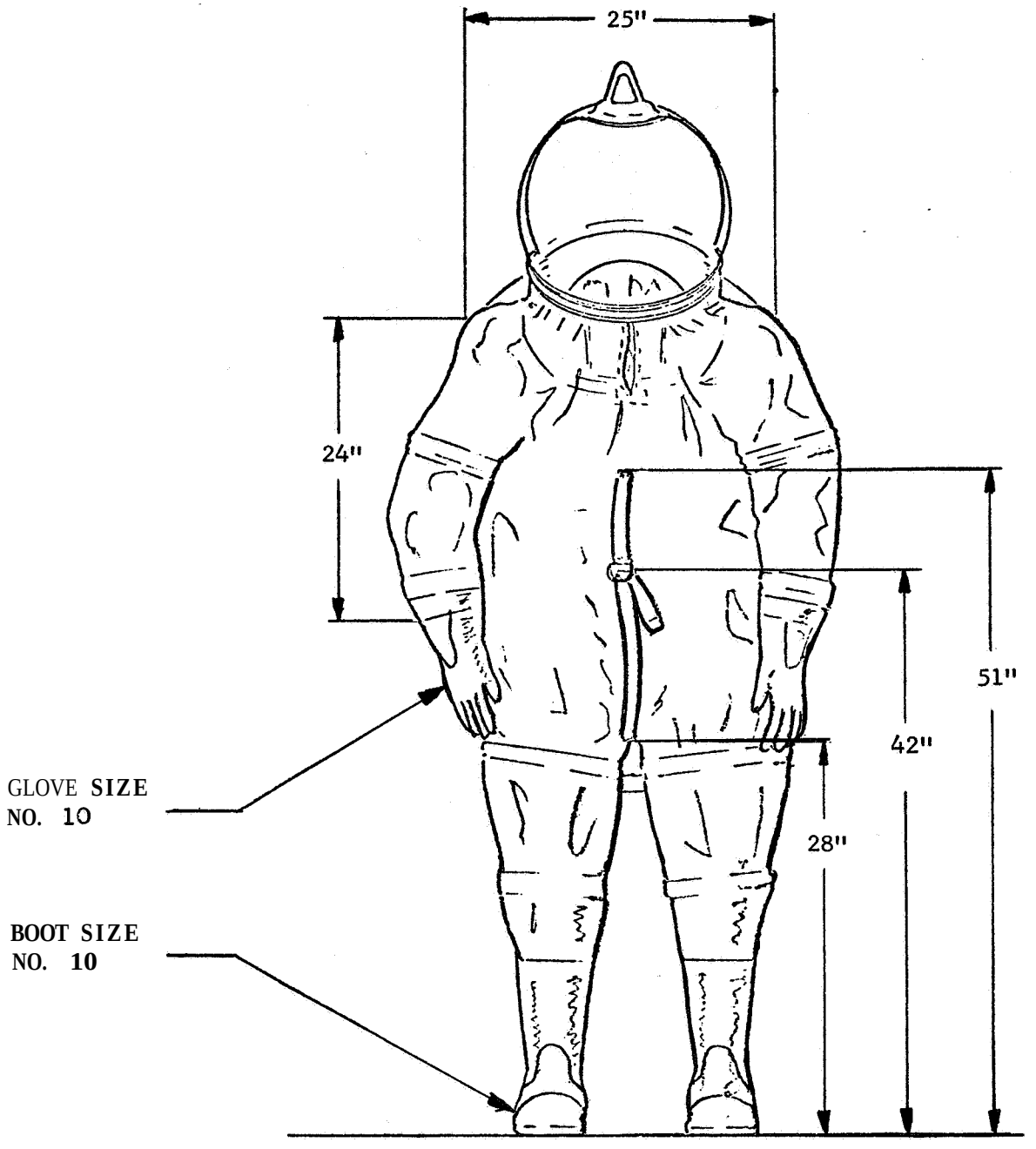


FIGURE 2 SUIT BODY-FRONT VIEW

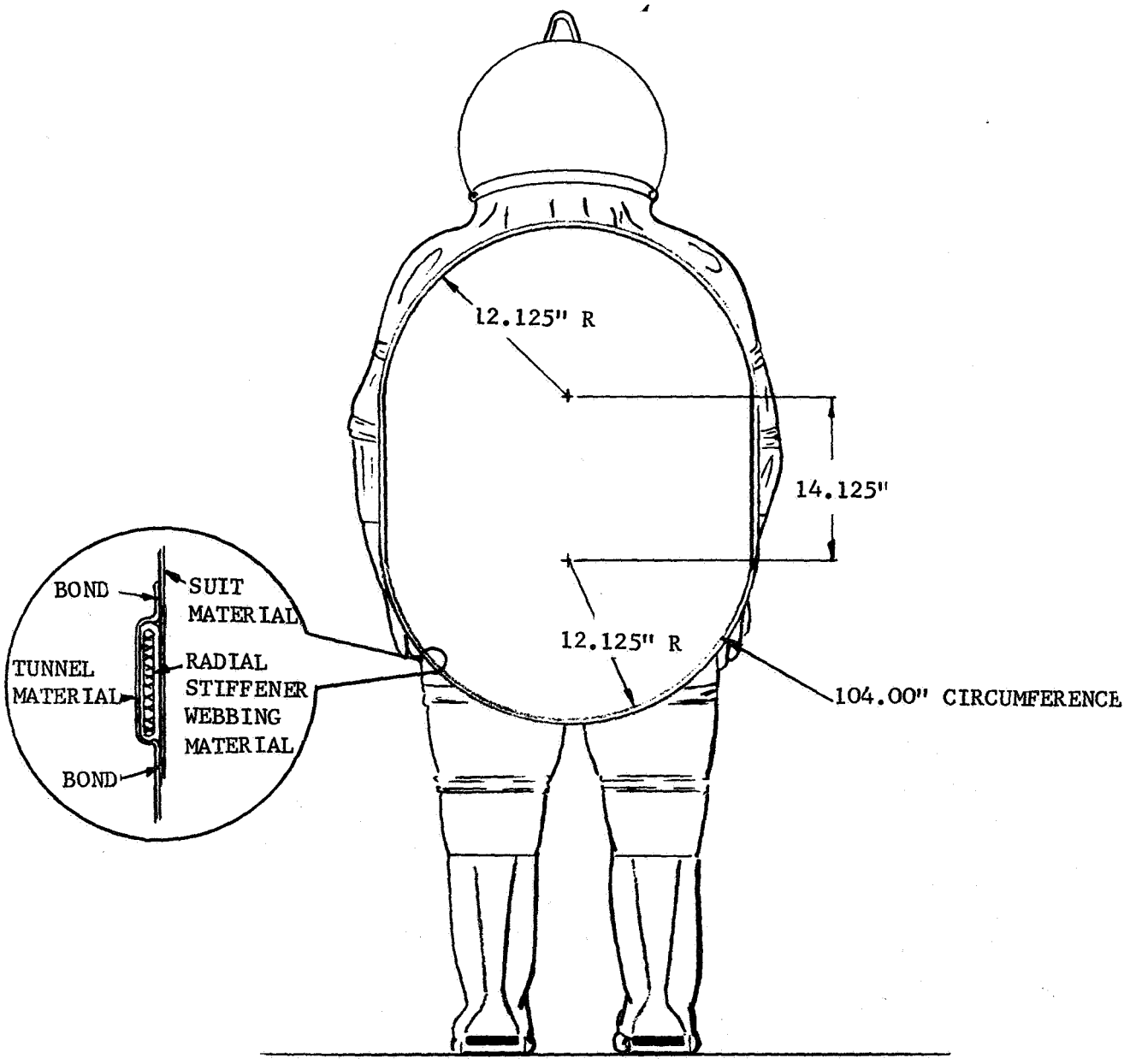


FIGURE 3 SUIT BODY-REAR VIEW

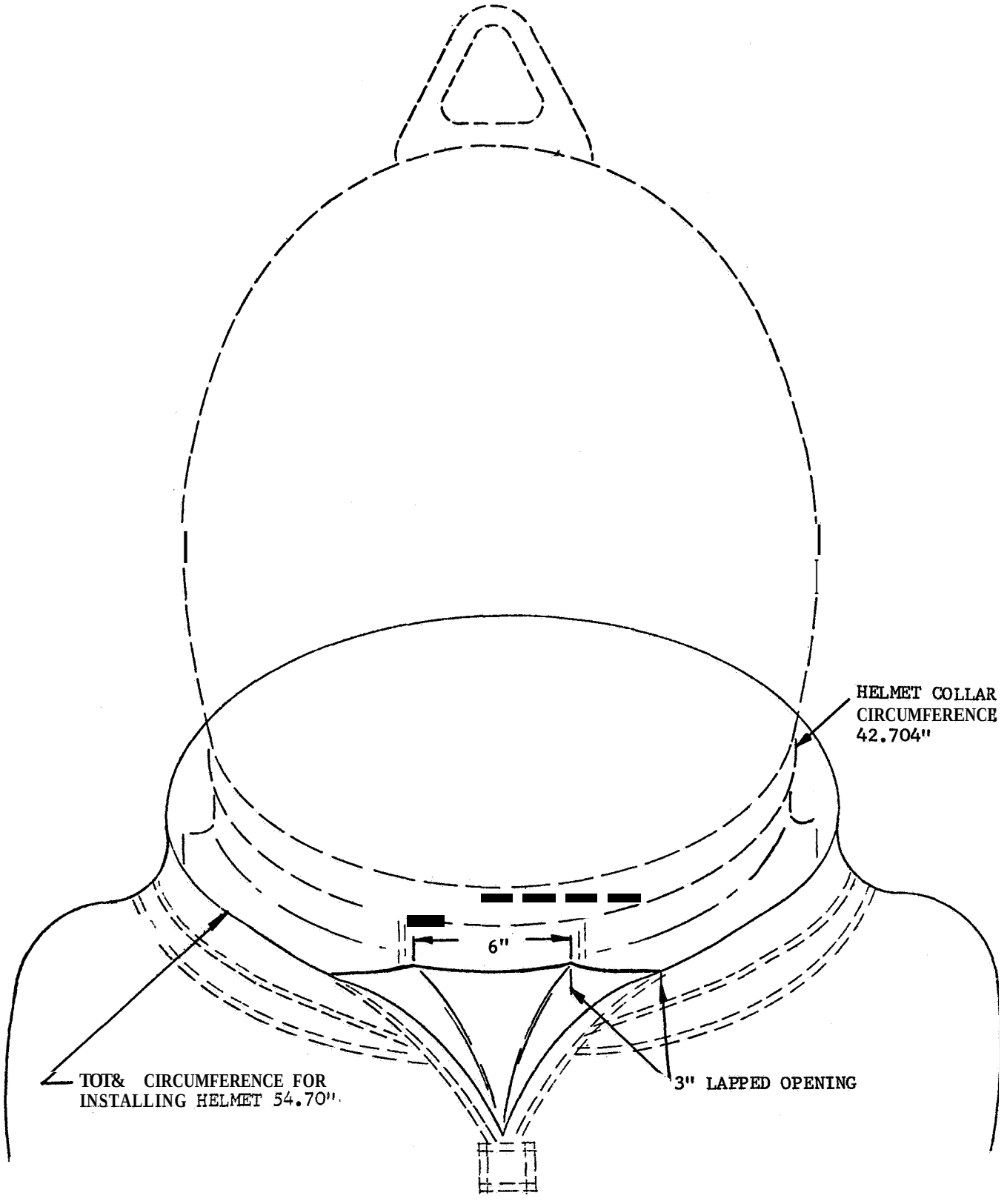


FIGURE 4 HELMET-SUIT INTERFACE

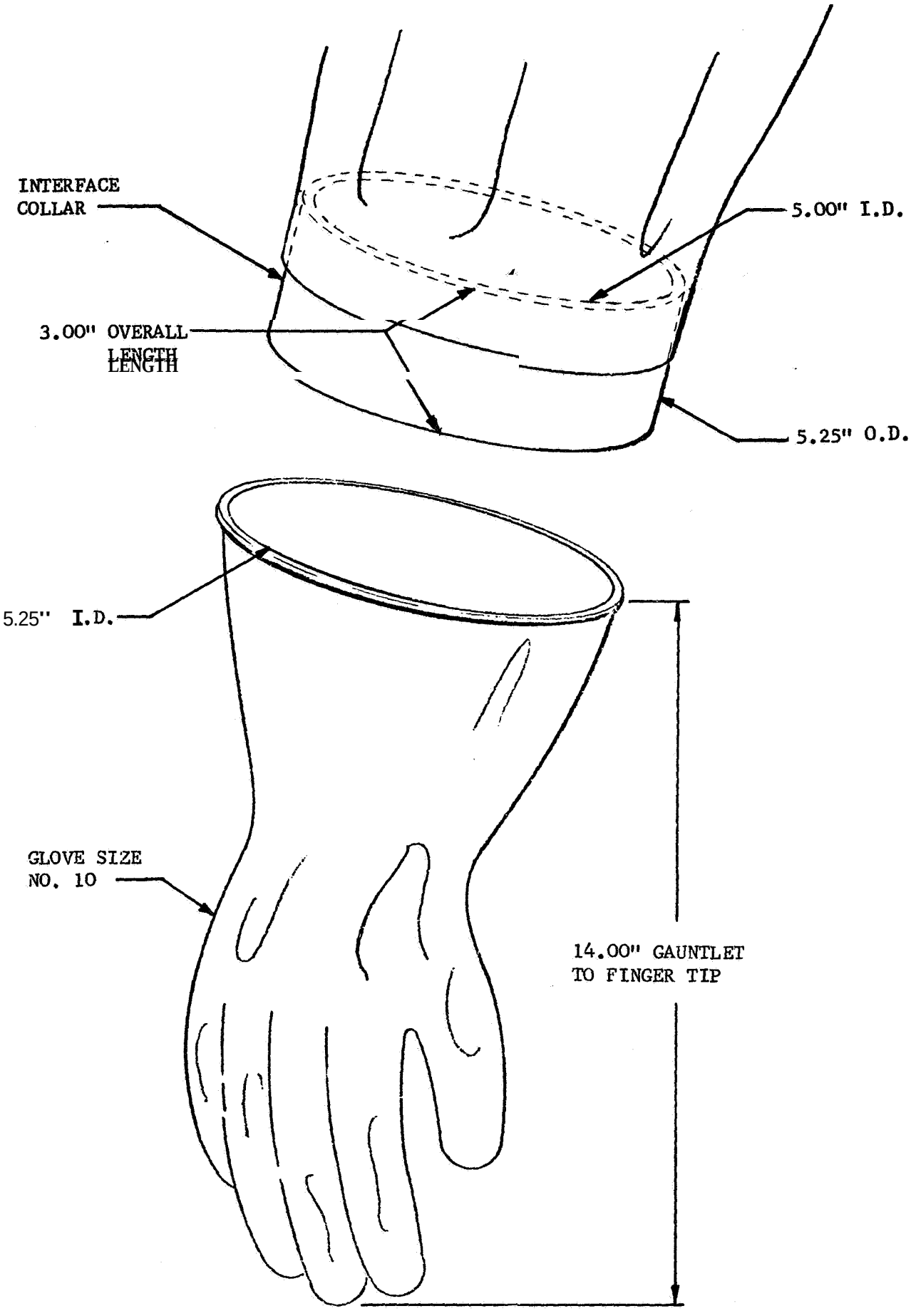


FIGURE 5 GLOVE AND INTERFACE COLLAR

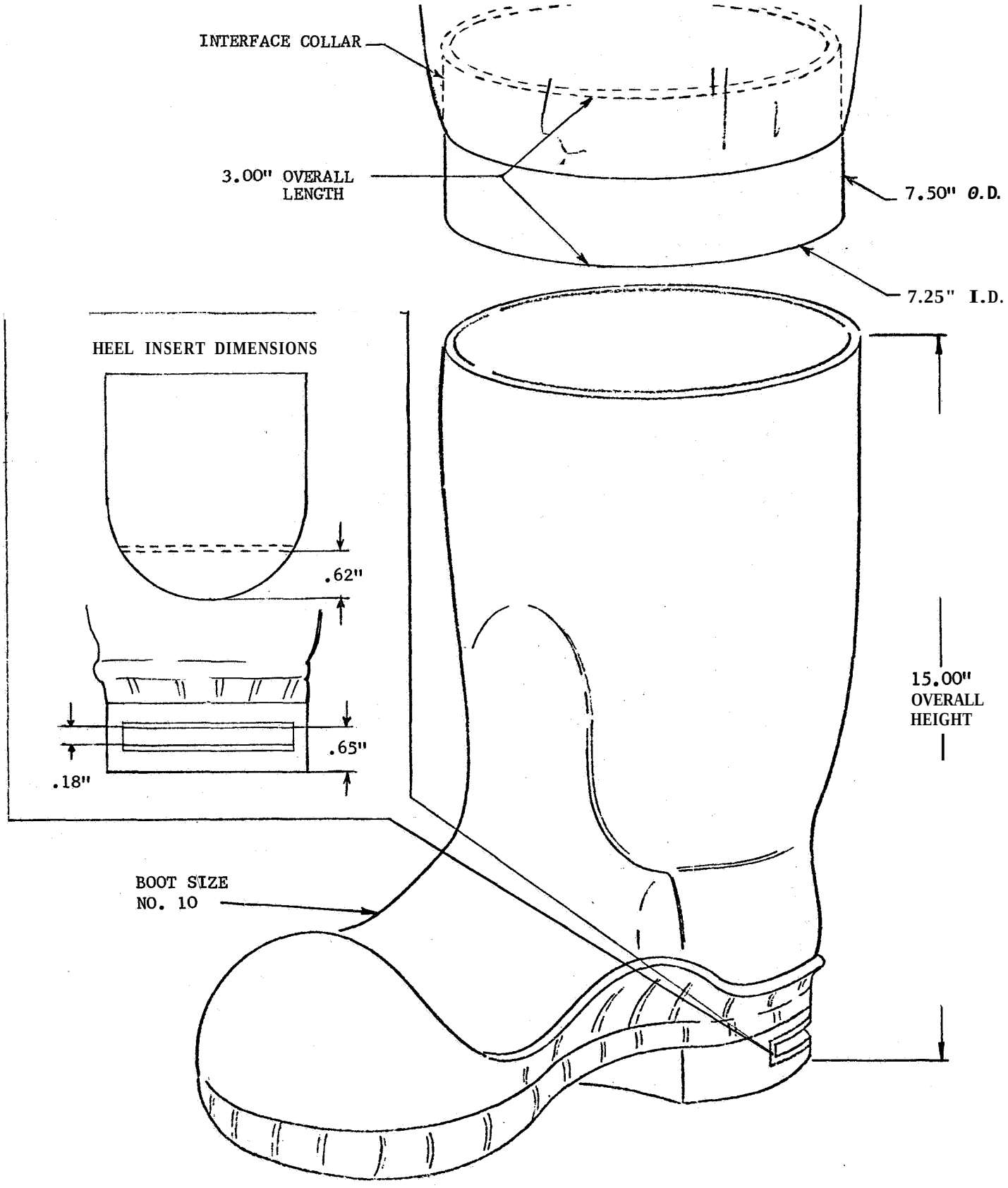


FIGURE 6 BOOT AND INTERFACE COLLAR

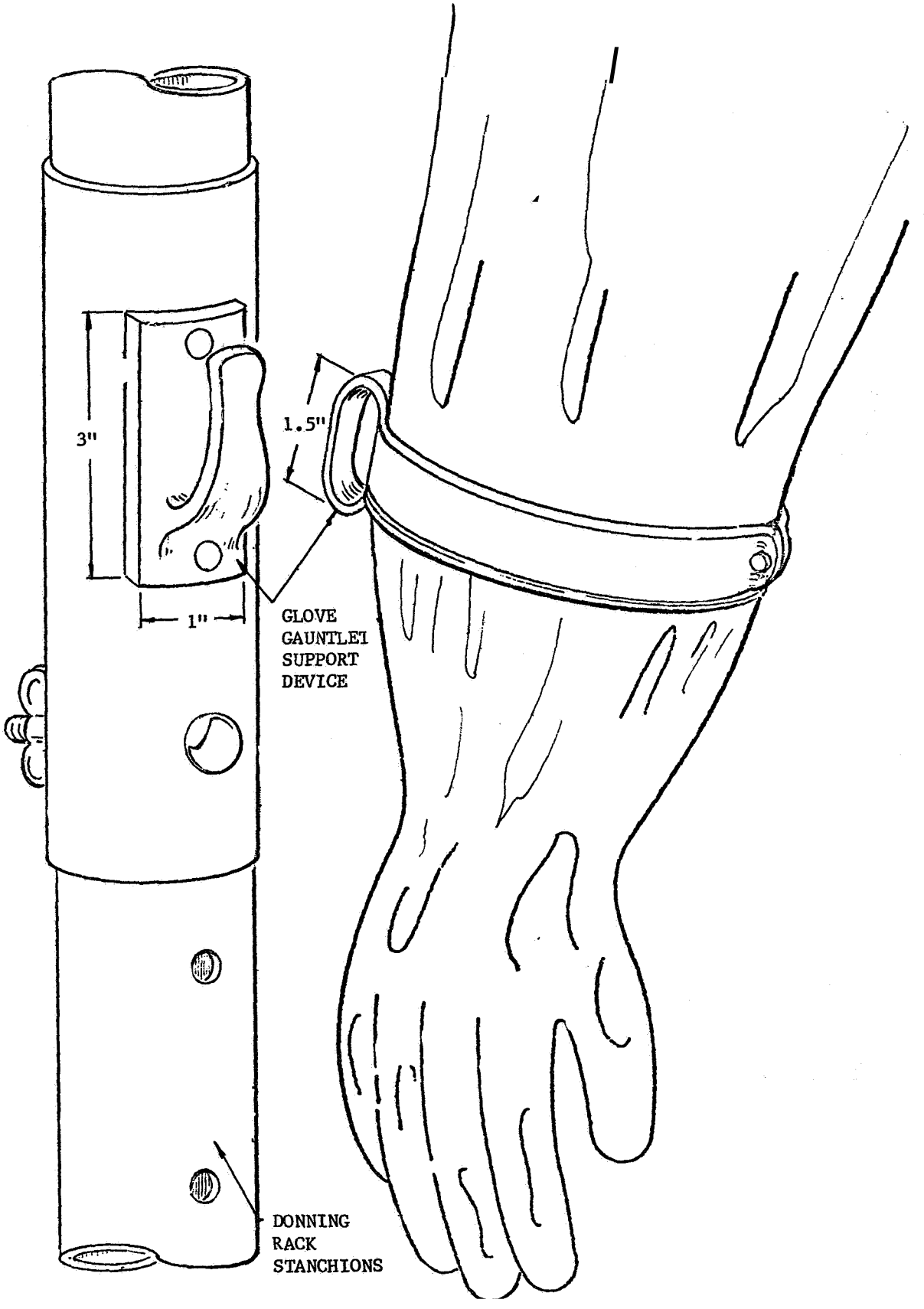


FIGURE 7 GLOVE-DONNING RACK INTERFACE

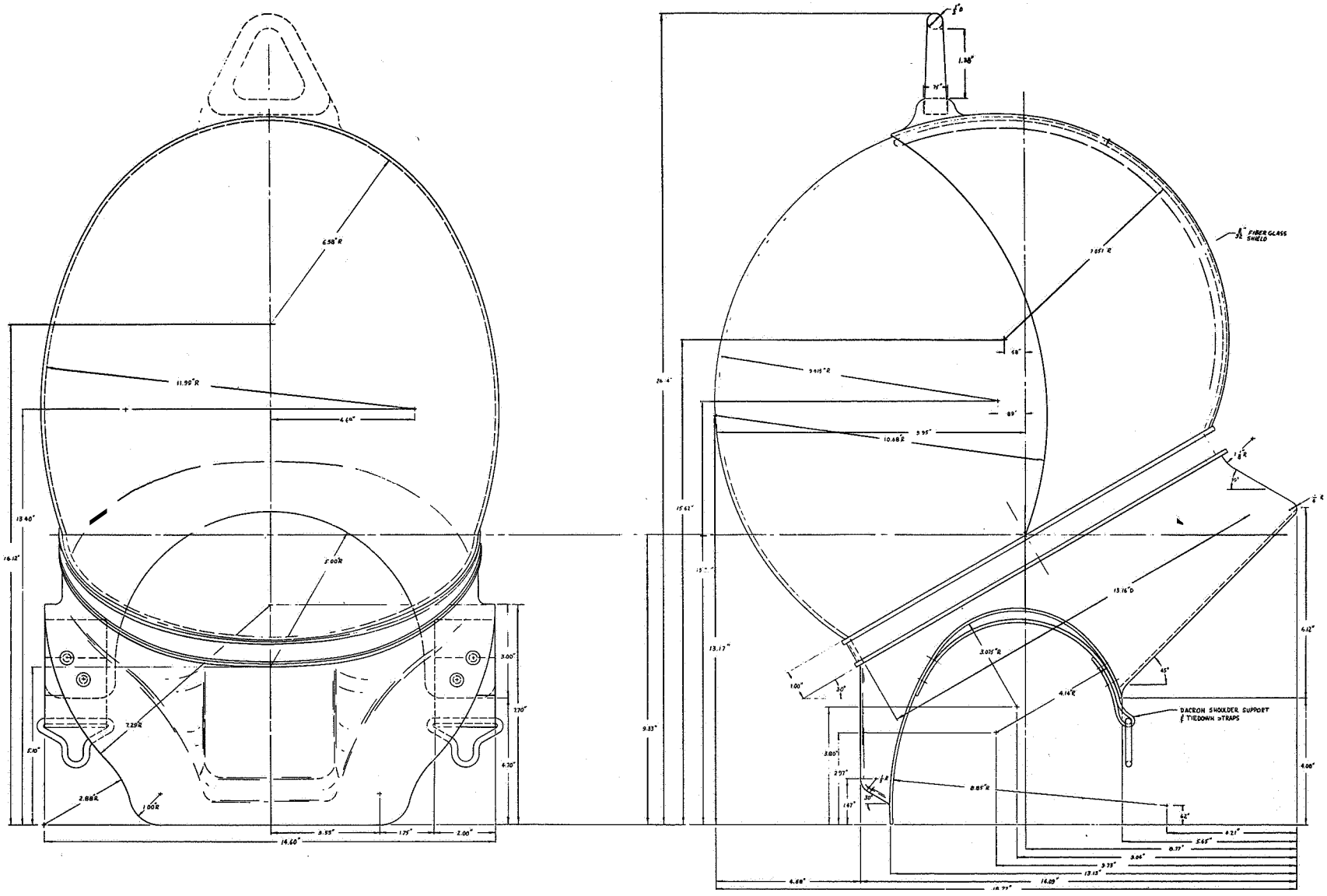


Figure 8 Helmet and Yoke Assembly

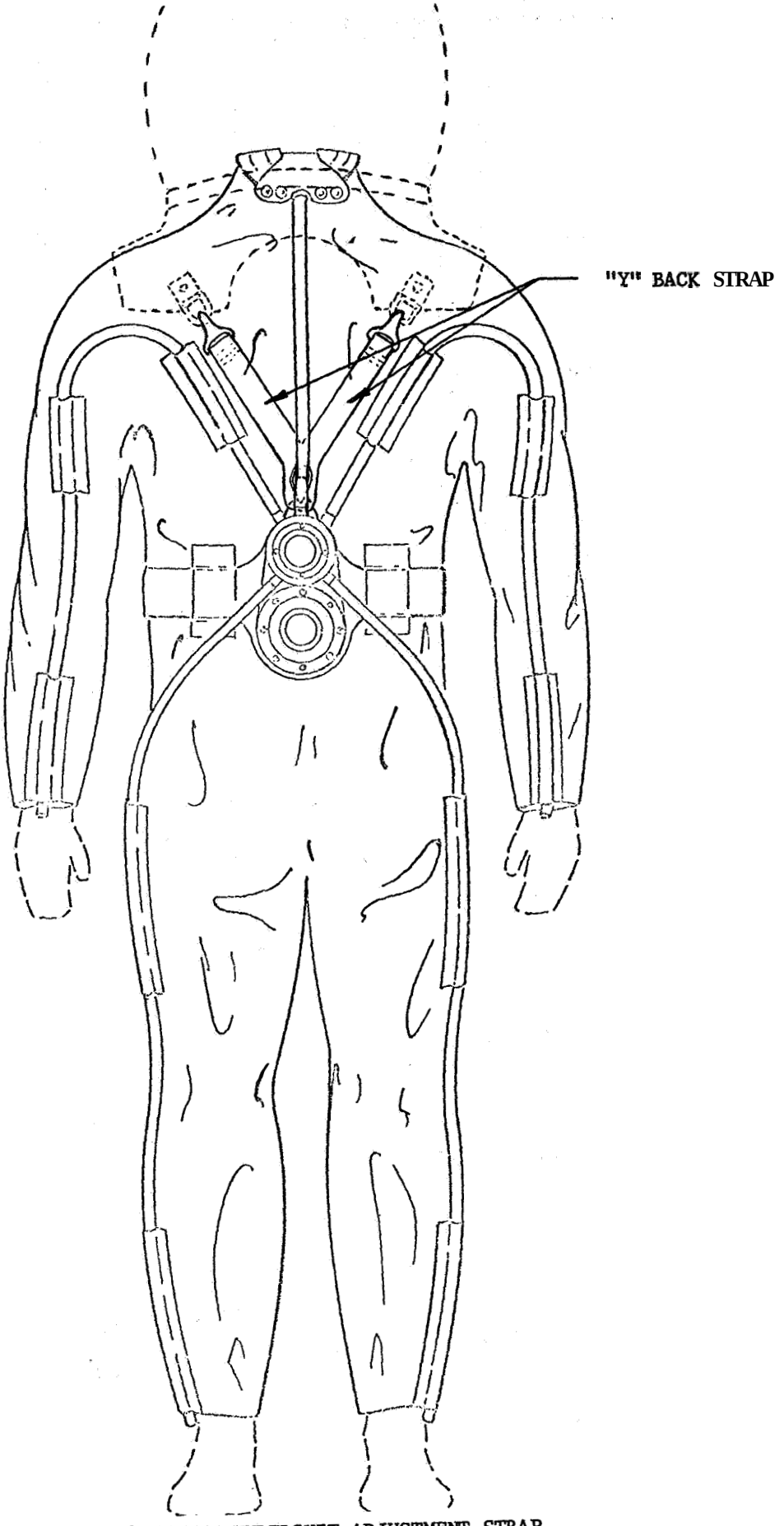
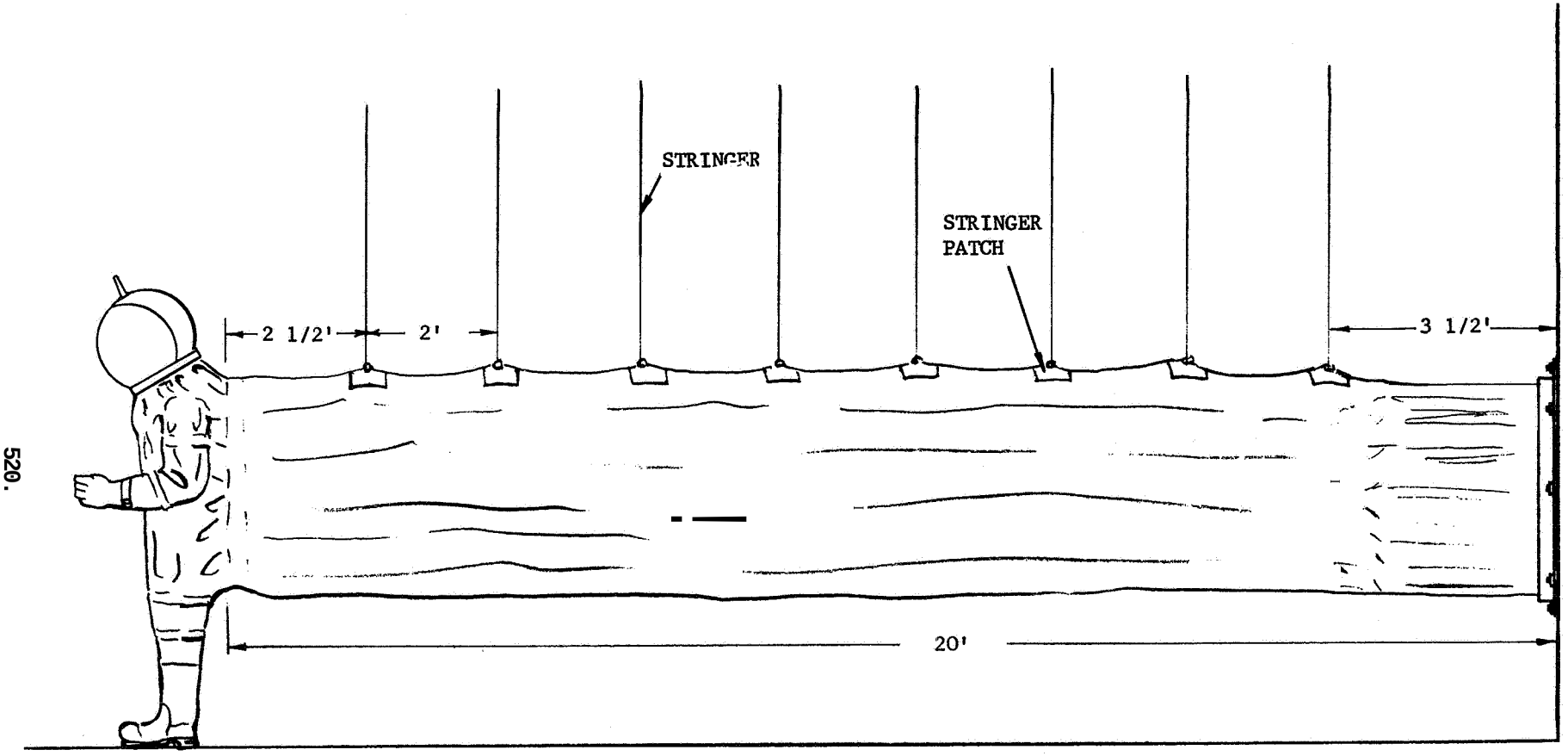


FIGURE 9 HELMET-UNDERSUIT ADJUSTMENT STRAP



NOTES: STRINGERS SUPPORT 8.2 LBS OF TUNNEL MATERIAL.

EACH STRINGER HAS BREAKAWAY STRENGTH OF 100 LBS.

STRINGER PATCH BREAKAWAY STRENGTH OF 150 LBS.

FIGURE 10 TUNNEL-OUTER SUIT

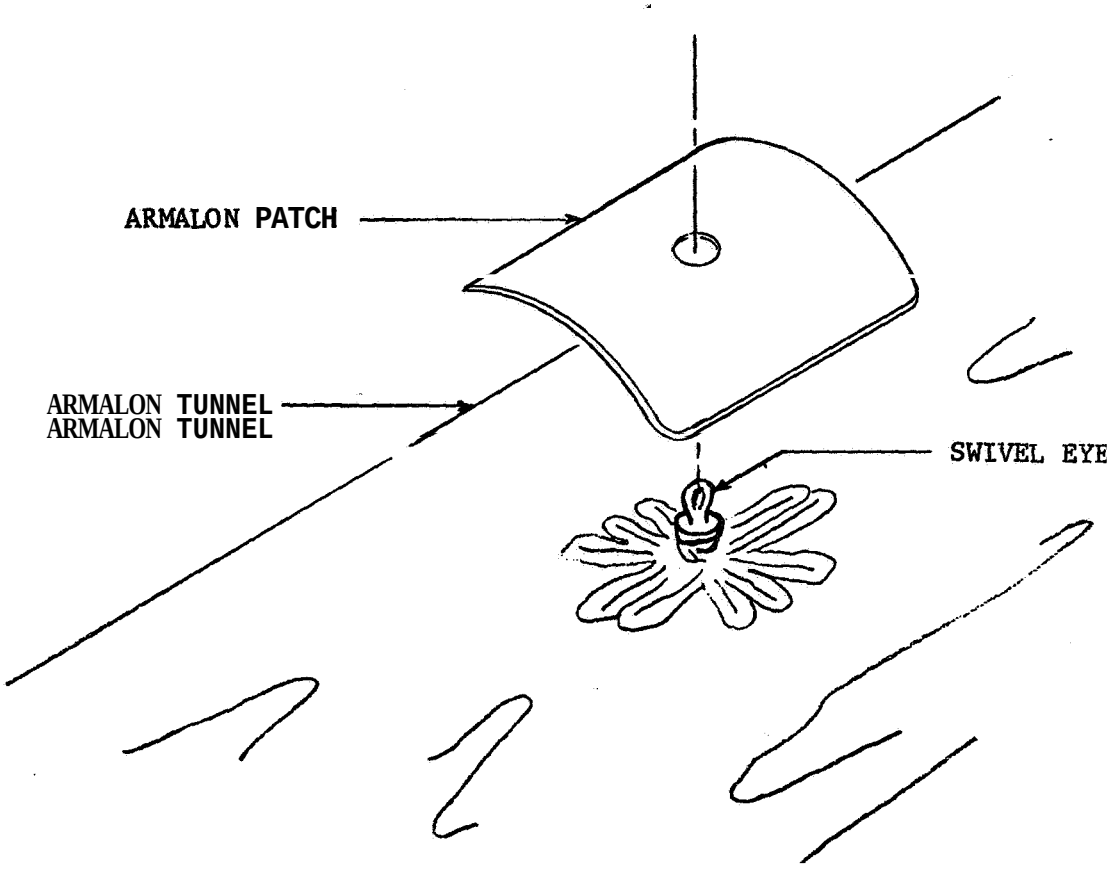


FIGURE 11 TUNNEL SUPPORT SWIVEL

APPENDIX L: BISS UNDERSUIT SPECIFICATION

ENERAL ELECTRIC *COMPANY*
e-entry Systems Department
198 Chestnut Street
hiladelphia 1, Pennsylvania
!ode Ident, No, 15226

SPECIFICATION: ERS0230-00-0002

BISS UNDERSUIT

1.0 GENERAL

1.1 Scope - This specification defines the undersuit which *is* one of the major subsystems in the Bio-Isolator Suit System, hereinafter referred to as BISS, (GE-RSD Specification S0100-00-0001). The undersuit is **worn by** the BISS technician and provides breathing and cooling air distribution.

1.2 Description - The undersuit, hereinafter referred to as the garment, is a contour fitted flexible garment fabricated to fit individual technicians, The garment is a 3-layer fabrication providing an integral air distribution system which interfaces with the life support subsystem, The middle layer of the garment provides a path for exhausting air fromthe BISS, The Garment provides an essentially air-tight compartment around the technician. Quick-release fasteners are located in the chest area and sleeve **and** leg ends, Hard points are located at strategic positions to provide attachment points for the life support and communication subsystem components.

2.0 APPLICABLE DOCUMENTS

2.1 Government Documents - The following government documents of the issue specified, form a part of this specification to the extent specified herein,

Military

MS33586	1 October 1952	Metals, Definition of Dissimilar

(Copies of this document may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C.)

2.2 Non-Government Documents - The following non-government documents of the issue in effect on the date of this specification, form a part of this specification to the extent specified herein,

GENERAL ELECTRIC COMPANY

Specifications

S0100-00-0001	Bio-Isolator Suit System (BISS)
S0210-00-0001	BISS Life Support Subsystem
S0150-02-0001	BISS Communication Subsystem

Standards

118A1526	Identification Marking
118~1600	Finishes and Coatings
147A1850	Adhesive Vulcanized Synthetic Elastic
165A4429	Flexible Polyurethane Foam Set

(Copies of the General Electric Company documents are available from General Electric Company, RSD, 3198 Chestnut Street, Philadelphia, Pennsylvania 19101).

REQUIREMENTS

3.1 General - The undersuit shall meet the requirements of this specification and referenced documents to the extent specified herein. In the event of conflict between the requirements and any document specified herein, this specification shall govern.

3.2 Materials, Parts, and Processes

3.2.1 Materials - The materials used in the undersuit fabrication shall be of the highest quality ana selected on the basis of physical or other essential properties, availability, adaptability to production processes, and suitability to the environmental conditions set forth.

3.2.2 Standard Parts - Wherever possible, standard parts shall be used to ensure reliability and expedite procurement. Preferred standard parts In their order of preference are applicable NASA specifications, Military Standards (MS, AN, NAS), General Electric Standards, and commercial standards. Non-standard parts may be used when specifically authorized by the procuring agency.

3.2.3 Critical and Strategic Materials - Materials shall be selected on the basis of suitability and relative availability. Subject to satisfactory operation, the garment shall incorporate the least critical and strategic materials.

3.2.4 Dissimilar Metals - The use of dissimilar metals, as defined in MS33586, shall not be used in intimate contact unless suitably protected against electrolytic corrosion.

3.2.5 Corrosion Resistance - Materials selected shall be corrosion resistant or shall be suitably protected by plating, painting, or other surface treatment that is compatible with the environment to which the garment is subjected.

3.2.6 Material Bonding Processes - Material bonding processes used in the fabrication of the garment shall provide bonds of the highest integrity required in the design criteria. Bonding shall not restrict the flow of air through the middle and inner layers of material. The bonding shall meet the following requirements:

a. Minimum lap shear shall be 125 psi

b. Minimum peel strength shall be 8 pounds/inch

3.3 Workmanship - Workmanship and shop practices shall be of the highest commercial quality. Subassemblies and components of the garment shall be constructed and finished in a thoroughly workmanlike manner. Particular attention shall be given to neatness, cleanliness, and thoroughness of bonding, marking, of parts, painting, protective coatings, riveting, machine screw assembly, and freedom of parts from burrs and sharp edges.

3.4 Identification ana Marking - The identification and marking of all components shall conform with the requirements, set forth in GE Document; 118A1526 (General Electric Company Standard Identification Marking).

3.5 Finishes and Coatings - Surface finishing and protective coatings shall conform to the General Electric Company RSD Standard 118A1600 (Finishes and Coatings) for this type of equipment, and shall be compatible with the environmental and service conditions set forth in this specification.

3.6 Maintainability - Components for the air distribution system shall be placed and secured in such a manner that they may be accessible for maintenance. The chest, sleeve and leg fastings shall be installed in such a manner that they may be repaired or replaced.

3.7 Endurance - The garment shall withstand a minimum of 1000 hours of operating life, including minor maintenance and repeated cleansing procedures using a mild detergent. Normal operation shall not cause cracking of the garment material **or** deterioration of the air distribution components,

3.8 Interfaces - The garment shall incorporate the following interfaces:

a. Life support subsystem air supply (GE-RSD Specification S0210-00-0001)

b. Life support subsystem air exhaust (GE-RSD Specification S0210-00-0001)

c. Communication subsystem **(GE-RSD** Specification S0150-02-0001)

d, Medical monitoring system (GE-RSD Specification S0230-00-0001)

e, Outer suit helmet and yoke (GE-RSD Specification S0230-00-0001)

3.9 Environment

3.9.1 Garment, Non-Operating - The garment shall be subjected to the following non-operating environments.

3.9.1.1 Storage - The environment within the storage area shall be a controlled atmosphere free from vapor contaminants at a temperature of 70 $\pm$ 20°F.

3.9.1.2 Shipping - The shipping environment shall be -10°F to +120°F.

3.9.2 Garment, Operating - The environment within the outer suit and tunnel shall be 70°F $\pm$ 10°F, dew point 45°F $\pm$ 12°F at a pressure between 0.5 in. H20 and -2.0 in. H_2O gage.

3.10 Safety Requirements - The safety requirements for the garment shall be designed to minimize the possibility of injury to personnel and damage to the equipment. **All** sharp edges and corners shall be rounded off. Life support system interfaces shall be clearly identified. The garment shall provide adequate distribution of the life sustaining air flow. The garment life sustaining air flow distribution system **shall** be positioned to minimize the possibility **of** cutting off the supply and exhaust flows to 'ana from the wearer.

3.11 Performance - The garment shall distribute an adequate supply of breathing air to the outer suit helmet, and cooling air to the outer suit arm and leg extremities as specified herein. The garment shall provide a path for the removal of **noxious,** toxic, ana moisture-laden air from the BISS. **It** shall function in an overpressure environment of **up** to 2 in. H_2O **maximum,** and shall **be** capable of withstanding **an** overpressure of 4 in. H_2O maximum in the unmanned condition.

3.11.1 Air Distribution System - The air distribution system shall be capable of distributing a minimum of 2.5 standard cubic feet per minute (SCFM) of conaitioned breathable air to the technician's helmet in such a fashion that the air flow is down across his face at **all** times. The oxygen content of the helmet breathable air shall not be reduced to less than 17% by volume by dilution with expired air because of turbulance in the helmet or other causes. The air flow to the extremities shall **be** equally distributed within plus or minus 10% among all four extremities. These conditions shall be provided with an air supply of 10 SCFM, +10 SCFM, -0 SCFM applied to the garment 2-chamber plenum.

3.11.1.1 Tubing - The tubing shall withstand an overpressure environment of **up** to 4-inches H_2O maximum, and walking, bending, climbing, and squatting motions performed by the garment wearer, without collapsing.

3.11.1.2 2-Chamber **Plenum** - The 2-chamber plenum shall regulate the percentage of air flowing to the helmet distribution device and the arm and leg extremities. **It** shall regulate the air flow in such a manner that the flow to the helmet distribution device cannot be shut off.

3.11.2 Garment - The garment shall provide the requirements specified herein.

3.11.2.1 Fit - The garment shall fit the wearer in such a manner that **it** form an essentially air-tight envelope around him without causing discomfort or inhibiting his movements.

3.11.2.2 Mobility - The wearer shall be capable of walking, bending, climbing, and squating in the garment, operating in an overpressure of 2-inches H_2O maximum, without any discomfort being caused by the garment.

3.12 Components - The garment (Figures 1 and 2) shall consist of a **body** and a detachable air distribution **system** for the life support subsystem air supply and exhaust interfacing hoses.

3.12.1 Suit Body - The suit body shall be designed with the arms, legs, and torso as integral parts. It shall be a three layer, form contoured garment fabricated from highly flexible materials, The 'suit body shall be essentially air tight and shall have fastenings in the frontal torso area, and sleeve and leg ends to facilitate donning and doffing by the wearer, It shall be fabricated in such a manner that when the three layers are bonded together the middle and inner layer provide an air passage for exhausting stale air. The middle layer shall be capable of withstanding an overpressure of up to 4-inches H_2O maximum without restricting the air flow. Hard attachment points for the communication subsystem and life support subsystem shall be integral parts of the suit body structure, The hard attachment points for the communication subsystem shall be located in the front neck area, and the attachment points for the life support subsystem shall be in the rear waist area. Quick-release fastenings shall be provided in the rear neck area and shall serve as an attachment point for an air distribution device for the outer suit helmet area. Suitable support devices shall be provided at critical locations of the suit body for the air distribution system hoses.

3.12.2 Material - The suit body shall be manufactured from the following materials.

3.12.2.1 Outer Layer - The outer layer shall be fabricated from 1/64-inch Psirprene Neoprene sheet stock (DuPont or equivalent), Refer to GE-RSD Standard 147A1850, No, 4768.

3.12.2.2 Middle Layer - The middle layer shall be fabricated from polyurethane Foam, 1/4-inch thick, 10 pore/linear inch (Scott Paper Company or equivalent). Refer to GE-RSD Standard 165A4429.

3.12.2.3 Inner Layer - The inner layer shall be fabricated from nylon chiffon, 3 1/2 to 4-thousands of an inch thick, .

3.12.3 Seams - All seams shall be bonded to form air tight seals, They shall be of the highest integrity and made in the most practical manner. The seams shall be kept to a minimum and reinforced at critical stress points. Neoprene to neoprene seams shall be bonded using Bostik 1177. All seams shall meet the requirements set forth in 3.2.6.

3.12.4 Tailoring - The garment shall be form-contoured and shall be sized to fit the individual wearer, The dimensions shown in Figures 1 and 2 are suitable for an American male with a height of 70 ± 1-inch and a weight of 157 ± 14-pounds.

3.12.5 Fastener - The slide fastener in the torso ventral area shall be an air tight zipper 28 inches long. Fastenings at the sleeve and leg ends shall be Velcro V-folds with a length of 4-inches and 6-inches respectively, The quick release fastenings for the outer suit helmet distribution device shall be marine type sockets and studs.

3.12.6 Air Distribution System - The air distribution system shall consist of a distribution device for the outer suit helmet area, a two-chamber, belt-support detachable plenum, and flexible distribution tubing,

3.12.6.1 Helmet Distribution Device - The helmet distribution device (Figure 3) shall be a contoured plenum which shall have a curvature that conforms to the nape of the neck, Two air outlets located in the plenum shall point upwards to the helmet area in the outer suit, The helmet distribution device shall interface with the garment distribution system by means of a tubular fitting pointing downwards and flexible tubing, Movable baffles shall be contained within the helmet distribution device to provide a directional adjustment to the air flow.

3.12.6.2 Tubing - The tubing shall be fabricated from non-collapsing tubing with an inside diameter of 3/8-inch. The lengths shall be sufficient to reach the arm and leg extremities and the distribution device for the helmet area. The tubing shall commence at the detachable 2-chamber plenum. Body movement shall not be restrained by insufficient or excessive tubing.

3.12.6.3 2-Chamber Plenum - The 2-chamber plenum (Figure 4) shall be fabricated from aluminum, One chamber shall provide an interface with the garment middle layer for garment exhaust, and the other chamber shall interface with the distribution tubing, The 2-chamber plenum shall be supported by the combination of a waist belt and the garment hard point tie-downs. An air flow adjustment device shall be provided in the supply chamber interface connection. This adjustment device shall regulate the percentage of air flowing to the helmet distribution device cannot be shut off,

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Classification of Tests - The inspection and testing of the garment shall be classified as acceptance tests and qualification tests.

4.1.1 Acceptance Tests - Acceptance tests shall consist of examination of the product and functional tests (see 4.4).

4.1.2 Qualification Tests - Qualification tests shall be conducted to qualify the product design (see 4.5).

4.2 Rejection ana Retest - Any garment which does not meet the requirements of the acceptance tests in this specification shall be rejected. Upon correction of any failure, the garment shall be retested unless this requirement is waived by GE-RSD in writing.

4.3 Test Conditions - All tests shall be performed under the following conditions:

a.	Temperature	80°F ± 10°F
b.	Dew Point	45°F ± 12°F
c.	Barometric Pressure	Ambient

4.3.1 Test Equipment - Laboratory apparatus calibrated at intervals properly spaced to assure accuracy shall be used to test the garment for specification compliance.

4.4 Acceptance Tests - To determine compliance with 3.11, perform the tests specified herein.

4.4.1 Visual Examination - Each garment shall be visually inspected to determine compliance of manufacture, fabrication, and marking with this specification.

4.4.2 Functional Tests - Each garment shall be subjected to the functional tests specified herein.

4.4.2.1 Fit - The following functions shall be performed to ensure the garment complies with the requirements set forth in this specification.

4.4.2.1.1 Donning/Doffing - The technician shall wear long cotton underwear and heavy woolen socks. The garment shall be donned and doffed. There shall be no restriction or impedement.

4.4.2.1.2 Quick-Release Fasteners - All quick-release fasteners shall be checked for operation. There shall be no signs of binding or failure to hold the garment material in position.

4.4.2.1.3 Mobility - The technician shall walk forward and backward, bend at the waist 10 times, perform 10 knee bends, extend arms to the forward, side, and vertical positions 10 times, and climb and descend a ladder 3 times to evaluate the garment mobility. Binding or inhibition of motion to any discernable degree shall be cause for rejection of the garment.

4.4.2.2 Air Distribution - The garment shall be donned by a technician and the 2-chamber plenum exhaust port shall be connected to an exhaust device capable of providing exhaust flows of 5, 10, 15 and 20 SCFM. With the garment being exhausted at these flows it shall be checked for "hot spots" (indication of a restricted or non-existant air flow through the garment middle layer). The exhaust device shall be disconnected from the 2-chamber plenum. A supply device capable of providing a flow of 5 SCFM shall be connected to the 2-chamber plenum supply port. With 5 SCFM applied to the garment, all distribution points shall be checked for the indication of an air flow.

4.5 Qualification Tests

4.5.1 Non-Operating Environmental Tests - The garment shall meet the requirements specified in 4.4.1 and 4.4.2.1 through 4.4.2.2 after subjection to the environmental conditions set forth in 3.9.

4.5.2 Operating Environmental Tests - The operating environmental tests shall be conducted in conjunction with the system qualification tests specified in GE-RSD Specification ERS0100-00-0001 (Bio-Isolator Suit System).

5.0 PREPARATION FOR STORAGE AND TRANSPORTATION

5.1 Storage - The garment shall be stored in a clean, controlled environment free fron vapor contaminants at a temperature of 65 to 75°F. The garment shall be supported by a suitable rack in such a manner that there are no sharp bends.

5.1.1 Life Support System Components - The life support system components shall be stored in accordance with the requirements set forth in MIL-P-166D, Method 1A.

5.2 Transportation - The garment shall be overpacked in a shipping container which shall adequately protect it during handling and shipping. The shipping container shall meet the minimum requirements of the carrier for safe transportaion. Additional overpacking shall be placed in fold areas to prevent sharp bends.

5.2.1 Life Support System Components - The life support system components shall be packaged in accordance with the provisions set forth in GE Document 14649560 (General Electric Company Standard, Preparation for Delivery). The components shall be overpacked in shipping containers which shall adequately protect each package during handling and shipping. The containers shall meet the minimum requirements of the carrier for safe transnortation,

5.3 Marking - Shipping and storage containers shall be marked with the name and address of the consignee and consignor, contract or purchase order number, and item part number. All markings shall be legible and waterproof.

6.0 NOTES

None

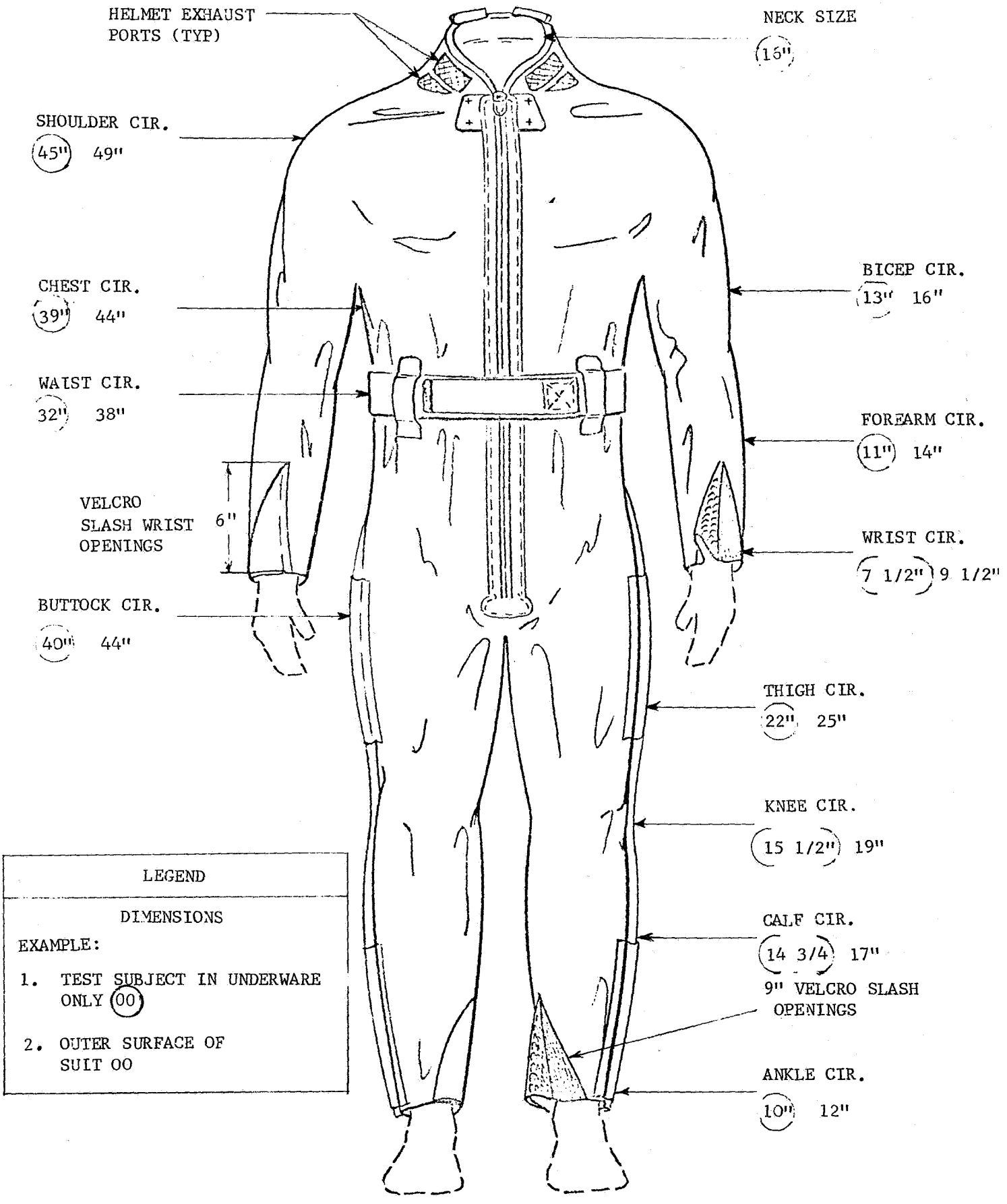


FIGURE 1 UNDERSUIT FRONT VIEW

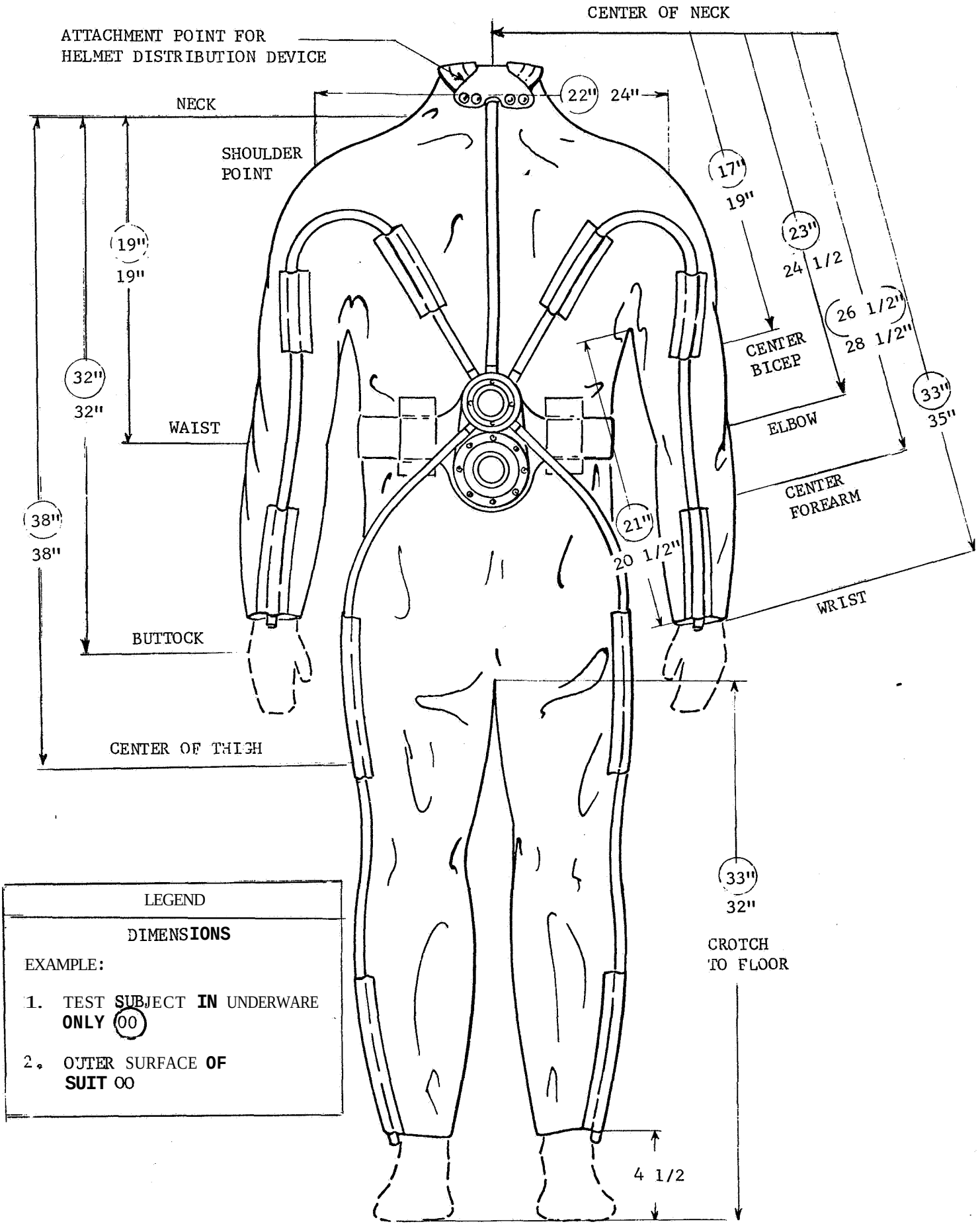


FIGURE 2 UNDERSUIT REAR VIEW

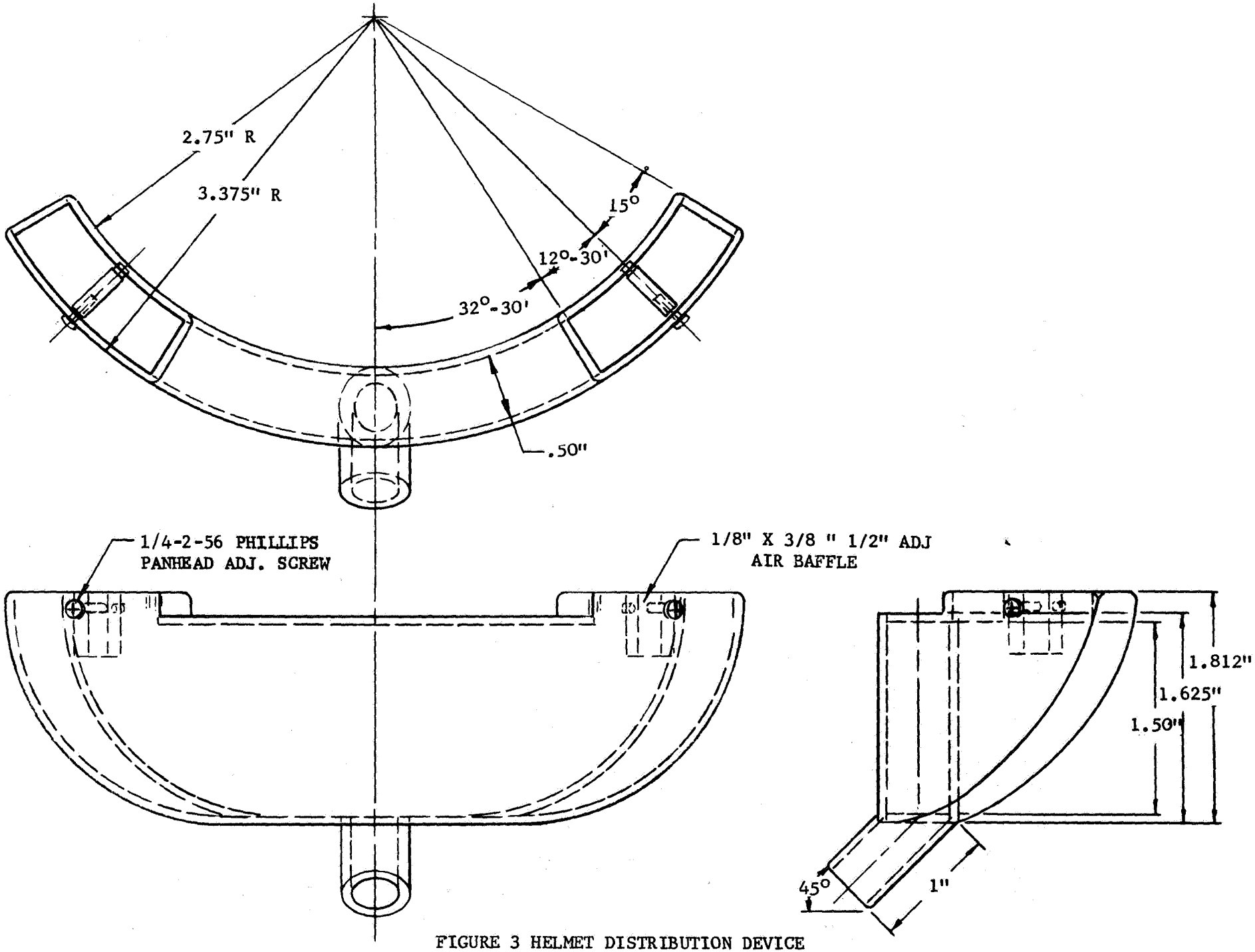
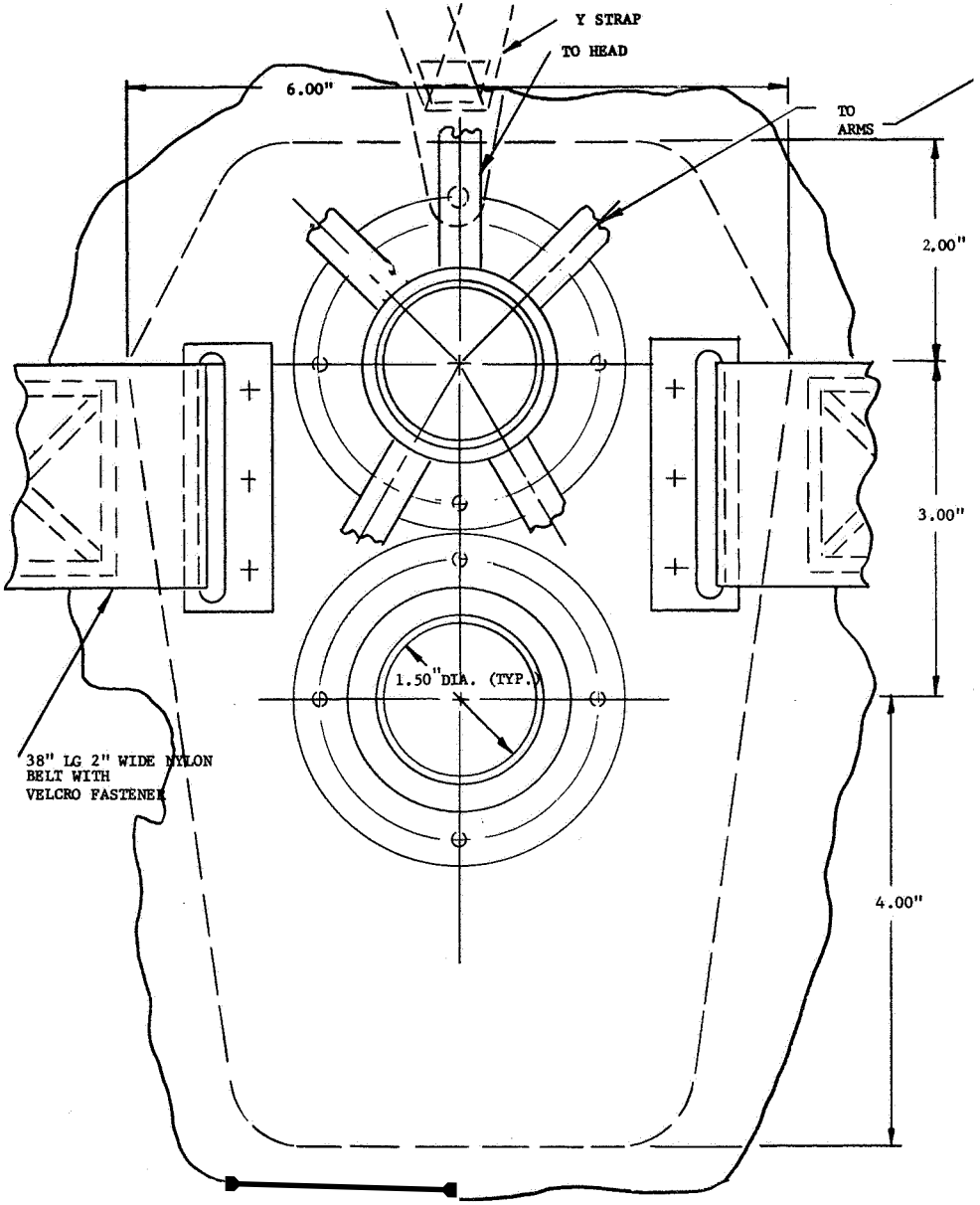


FIGURE 3 HELMET DISTRIBUTION DEVICE



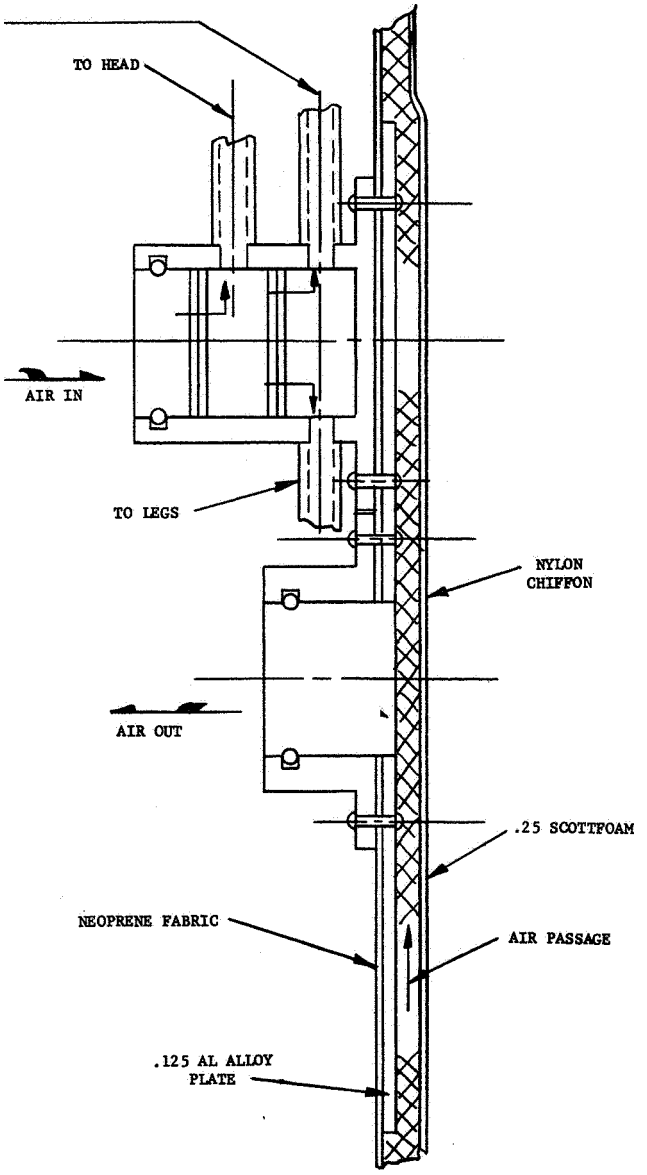


Figure 4 Two Chamber Plenum

APPENDIX M: COMMUNICATION SUBSYSTEM FOR BISS SPECIFICATION

GENERAL ELECTRIC COMPANY
Re-entry Systems Department
3198 Chestnut Street
Philadelphia, Pennsylvania
Code Identification No, 15226

SPECIFICATION: ERS0150-02-0001

COMMUNICATION SUBSYSTEM FOR THE BIO-ISOLATOR SUIT SYSTEM (BISS)

1.0 GENERAL

1.1 Scope - This specification defines the required performance of the Communication Subsystem for the Bio-Isolator Suit System (GE-RSD Specification S0100-00-0001), hereinafter referred to as BISS, used in the assembly/sterilizer. The Communication Subsystem, hereinafter called the Link, shall permit wired intercommunication among all members of the assembly/sterilizer operating team in pre-selectable patterns.

1*2 Description - The Link consists of a Facility Supervisor's Console which includes the provisions for selecting the communication patterns, remote stations serving the Life Support and Medical Monitor location, transducer terminals in the individual suits, stations at the Net Controller locations, and listen-only provisions for visitors, The remote station equipment may be either freestanding or an integral part of the remote equipment with which it is associated. The Net Controllers shall provide the link between the Facility Supervisor and the operators in the BISS's.

2.0 APPLICABLE DOCUMENTS

2.1 Government Documents - The following government documents of the issue specified, form a part of this specification to the extent specified herein,

Military

MIL-STD-470	21 March 1966	Maintainability, Program Requirements for Systems and Equipments
MIL-STD-826A	6 June 1966	Electromagnetic Interference, Test Requirements and Test Methods for
FED-STD-595	1 March 1956	Colors
MS 33586	10ct. 1952	Metals, Definition of Dissimilar
MIL-P-7963A	19 Nov. 1957	Parts and Equipment, Aeronautical, Preparation for Delivery

(Copies of these documents may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C.).

2.2 Non-Government Documents - The following non-government documents of the issue in effect on the date of this specification, form a part of this specification to the extent specified herein.

GENERAL ELECTRIC COMPANY

Specifications

S0100-00-0001	Bio-Isolator Suit Systems (BISS)
S0230-00-0002	BISS Undersuit

Standards

118A1526	Identification Marking
118A1600	Finishes **and** Coatings
149A9560	Preparation for Delivery

(Copies of the General Electric Company documents may be obtained from the General Electric **Company,** RSD, 3198 Chestnut Street, Philadelphia, Pennsylvania 19101).

3.0 REQUIREMENTS

3.1 General - The Link shall meet the requirements of this specification and referenced documents to the extent specified herein. In the event of conflict between the requirements and any document specified herein, this specification shall take precedence. No provision shall be interpreted to mean an abrogation of safety requirements.

3.2 Performance - The prime requirement is for reliable, intelligible communications. The following detail specifications are imposed to insure this prime requirement.

3.2.1 Bandwidth - The response of all audio channels in the Link shall be flat from 100 to 4500 Hz ± 2 DB.

3.2.2 Amplitude - The amplitude available at all loudspeakers and earphones shall be sufficient to provide a minimum of 12 DB signal-to-ambient noise ratio with 5% or less total distortion, when measured at their point of use.

3.2.3 Impedance Levels - Impedance levels shall be kept as low as possible, consistent with power-handling requirements. Where many transducers must be fed from a common amplifier, cnnsideration shall be given to using a "constant-voltage" distribution system. As an alternative, low-impedance transducer (500 or 600 ohms) may be paralleled across a 4-ohm amplifier output in reasonable numbers to provide satisfactory performance.

3.2.4 Back-up Units - As back-up units, the assembly/sterilizer shall be equipped with exponential, public-address type horns, for one way audio communication, and warning horns, buzzers, howlers, or sirens to signal situation which may, in the opinion of the Facility Supervisor or other support personnel, constitute a severe personnel hazard. The 12 DB signal-to-ambient noise ratio requirement for the assembly/sterilizer speaker shall be measured at the operator's ear inside the helmet. The warning horns shall have a nominal level of 98 DB referred to 0.0002 dynes/cm^2 on an axial line 10 feet from the center of each horn front.

3.2.5 Controls - Direct communications between any stations shall be obtainable by means of illuminated switches or other indicating devices on the Facility Supervisor's Panel. This is in addition to the patching and/or switching for normal communication.

3.2.6 Power Requirements - All units of the Link shall operate on 129-volt 60-Hertz, single phase power of commercial quality.

3.2.7 Functional Performance

3.2.7.1 General - The containment of men within BISS suits requires an intercommunication system to permit:

a. Issuing of instructions during various assembly, test and modification phases of the vehicle in the assembly/sterilizer.

b. Reporting of the results and completion of these phases.

c. Permitting limited normal conversation of the kind that would transpire were the men not so confined.

d. Conveying information on the comfort and safety of the men to the Life Support and Medical Monitor attendants.

e. Exchange of information between support personnel.

f. Conveying emergency information.

Each station's microphone or input transducer shall operate an amplifier of no more than 5 watts average power output at a low output impedance (i.e., 4 ohms). This power shall be sufficient to drive whatever maximum number of loudspeakers or 600-ohms headsets are "on the line". (Example: 40 600-ohm headsets have an equivalent impedance of 15 ohms, and at an assumed maximum power of 20 milliwatts per headset shall require less than one watt total for satisfactory operation). Each loudspeaker shall have a booster amplifier of sufficient gain to suit its environment, (Example: Each chamber horn shall have a 20-watt amplifier with a 600-ohm input).

3.2.7.2 Basic Operation - The Link shall be arranged to permit talk-at-will by any party whose microphone has been energized at the Facility Supervisor Console. There shall be no manual or other separate physical effort required for microphone operation in a normal, pre-selected, mode of operation. A "cough" (manual muting) switch shall be provided at all external support personnel microphones to enable temporary silencing of the individual microphones if required. All speakers and headset earphones shall have local volume controls, adjustable by the listener, except those in the undersuit which shall be controlled by the Facility Supervisor or Net Controller. The suited operators shall be grouped into "nets" or operating teams of two or three persons, with a Net Controller for each net. Medical Monitor and Life Support Communication Operators shall also be provided for each net. These latter may be the actual attendants, or they may be separate talkers with minimal additional functions. Figure 1 shows a typical arrangement with two nets of two men each and the directions of communication normally established. The tunnel boom operator (if required), may also function as the Net Controller for communication purposes.

3.2.8 Performance of Individual Units

3.2.8.1 Facility Supervisor Console - The Facility Supervisor Console shall permit the Facility Supervisor to visually oversee all operations within the assembly/sterilizer. The Facility Supervisor Console shall have one high impedance, dynamic, directional microphone on a headset. The outgoing voice channel from the Facility Supervisor shall normally be received by the Net Controllers and all Life Support/Medical Monitor communication operators. A momentary switch shall be provided to mute the lines to the Net Controllers to permit private discussion with Life Support Medical Monitor personnel only. The control panel on the console shall provide master controls for power and signaling and override controls to permit non-scheduled cross-communication. Establishment of the communication interconnections shall be accomplished by a patch board and/or cross-bar switches located within the Facility Supervisor Console.

The Facility Supervisor shall be provided with a master clock and task-timing clocks for monitoring, and eaah received portion of the Link shall be constantly monitored by means of inaudible tones to determine go-no-go status of the Link. The indicators for the tone-monitoring shall be located on the control panel in a light matrix, appropriately colored. Amplifiers for use by the Facility Supervisor shall also be located within the console. Controls shall be provided to temporarily mute any channel as required.

3.2.8.2 Remote Stations - The Life Support and Medical Monitor location shall be served by electrically similar Line terminals and shall be designated as Remote Stations. They shall be equipped with a loudspeaker and an earphone-microphone set. The loudspeaker shall monitor the transmission of the suited operators in the net associated with the Remote Station. The earphones shall monitor the Facility Supervisor's transmission, and the microphone shall connect to speakers at the Facility Supervisor's Console. By removing the earphone plug, the Remote Station speaker shall monitor the Facility Supervisor's transmission.

3.2.8.3 Net Controllers - The Net Controllers shall receive the voice transw mission fromthe Facility Supervisor and shall pass this information to the suited operators in his net. Their transmissions, in turn, shall be relayed to the Facility Supervisor. These locations shall have a small number of audio controls and equipment to provide a degree of communication flexibility. The Net Controllers are in the unique position to interpret directions and results and assist the Facility Supervisor in his efforts.

3.2.8.4 Undersuit - There shall be no physical communication requirements for the suited operators except talk and listen. The undersuit (GE-RSD Specification S0230-00-0002) microphone shall be sensitive enough to transmit the operator's voice regardless of his head position, and the speaker shall have sufficient drive so that the operator *may* adequately hear its output under normal conditions.

3.3 Materials, Parts, and Processes

3.3.1 Materials - The materials used in the Link fabrication shall conform to the highest qualities on the basis of physical or other essential properties, availability, adaptability to production processes, and suitability to the environmental conditions set forth in 3.10. Wherever possible, units shall use solid-state active devices rather than electron tubes.

3.3.2 Standard Parts - Wherever possible, standard parts shall be used to ensure reliability and expedite procurement. Preferred standard parts in their order of preference are applicable NASA Standards, Military Standards (MS, AN, NAS), General Electric Company Standards and Commercial Standards. Eon-Standard parts may be used when specifically authorized by the procuring agency, Re-design of items shall be kept to a minimum.

3.3.3 Critical and Strategic Materials - Materials shall be selected on the basis of suitability and relative availability. Subject to satisfactory operation, the Link shall incorporate the least critical and strategic materials.

3.3.4 Dissimilar Metals - Dissimilar Metals, as defined in MS33586, shall not be used in intimate contact unless suitably protected against electrolytic corrosion.

3.3.5 Corrosion Resistance - Materials selected shall be corrosion resistant or shall be suitably protected by plating, painting, or other surface treatment that is compatible with the environment to which the Link is subjected.

3.3.6 Bonding Processes - Bonding processes required in the fabrication of the Link shall be of the highest integrity required in the design criteria. The bonding processes shall be of the type facilitating ease of part or component repair or replacement,

3.3.7 Interchangeability - Like items (headsets, amplifiers, loudspeakers, etc.) in various consoles and cabinets shall be interchangeable wherever possible. However, due to the custom nature of this equipment, no special interchangeability shall be imposed.

3.3.8 EMI Considerations - Precautions shall be taken to minimize electromagnetic interference, both conducted and radiated. These precautions shall include bonding, grounding, shielding, suppression techniques, and proper choice of components to minimize the generation of interference or to suppress it if it should occur. MIL-STD-826 shall be used as a guide.

3.4 Workmanship - Workmanship and shop practices shall be of the highest commercial quality. Subassemblies and components of the Link shall be constructed and finished in a thoroughly workmanlike manner. Particular attention shall be given to neatness, cleanliness, and thoroughness of soldering, welding, brazing, bonding, wiring, marking of parts, painting, protective coatings, riveting, machine screw assembly, and freedom of parts from burrs and sharp edges.

3.5 Identification and Marking - The identification and marking of all components shall conform with the requirements set forth in GE Document 118A1526 (General Electric Company RSD Standard Identification Marking).

3.6 Finishes and Coatings - Surface finishing and protective coatings shall conform to the General Electric RSD Document 118A1600 (Finishes and Coatings) for this type of equipment, and shall be compatible with the environmental and service conditions set forth in this specification.

3.7 Maintainability - Doors and panels shall be placed in consoles and cabinets so that they may easily be opened or removed for maintenance. Indicators shall be re-lamped from the front of each panel. Fuses shall be replaced from panel fronts. Where possible, parts and components shall be chosen for ease of maintenance and for low failure rates. MIL-STD-470 shall be used as a guide.

3.8 Endurance - Design of the communication subsystem shall guarantee a minimum period of 500 operational hours of continuous trouble free operation exclusive of fuse, lamp or electron tube replacement, and have an operating life of not less than 5 years. The suit microphone, speaker and attached cables shall have a life of 1000 operational hours minimum.

3.9 Safety Requirements - The safety requirements for the Link shall be designed to minimize the possibility of injury to personnel and damage to the equipment. An emergency audio warning system shall be employed to back-up the main power system. All sharp edges and corners shall be rounded-off to prevent damage to the equipment and injury to personnel. All circuits carrying electrical power shall be protected by adequate fuses or circuit breakers. All power leads and terminals shall be clearly marked. Components shall be adequately grounded. Low impedance components and transformer coupling shall be used to isolate possible malfunctions from the operators in the BISS.

3.10 Environment

3.10.1 Non-Operating - The Link shall be capable of satisfactory performance as specified in 3.2 after exposure to the following conditions.

3.10.1.1 Storage - The environmental conditions set forth in MIL-P-116D, Method 2.

3.10.1.2 Shipping - The shipping environment as specified herein:

a. Temperature -25°F to +125°F

b. Vibration

Frequency (cps)	Double Amplitude
2 - 27	± 1.3 g rms
27 - 52	0.036 inch
52 - 500	± 5 g rms

(As modified by shipping container)

3.10.1.2 Shipping - (Continued)

c.	Acceleration	3 g's in any direction acting independently
d.	Pressure	4.37 psia to 16.2 psia
e.	Humidity	5% to 95% RH (5% to 100% with condensation in form of water or frost when suitably protected by shipping container)
f.	Shock	
	(1) Packaged	
	Truck	8 g's, 5 to 40 milliseconds
	Air	Vert. 5.5 g's, 10 to 30 milliseconds Lat. 1.5 g's, 10 to 30 milliseconds Long. 0.8 g's, 10 to 30 milliseconds
	Handling	Rough handling as defined in Specification MIL-P-7936 for packaged equipment.

3.10.1.3 Facility - The environment outside the assembly/sterilizer shall be minimally air-conditioned industrial atmosphere with an ambient temperature of 80°F ± 10°F, dew point of 45 ± 12°F, at ambient pressure.

3.10.1.4 Decontamination - Components located within the assembly/sterilizer shall be subjected to 88% Freon 12/12% ETO (by weight), at 40% RH, at a concentration of 500 mg. of ETO/litre of gaseous atmosphere for 28 hours at 104°F (24 hours stabilized at 104°F).

3.10.1.5 Sterilization - Components located within the assembly/sterilizer shall be subjected to nitrogen at a temperature of 70 to 320°F, with RH less than 1% above 200°F, and a pressure of 4-inches H20 gage maximum.

3.10.2 Operating - The Link shall be capable of operating during the following environments.

3.10.2.1 Facility - Environments set forth in 3.10.1.3.

3.10.2.2 Undersuit - Components attached to the undersuit shall be subjected to 70 ± 10°F, dew point 45 ± 12°F at a pressure between 0.5 in. H_2O and -2.0 in. H_2O gage.

3.10.2.3 Assembly/Sterilizer - Components located within the assembly/sterilizer shall be subjected to nitrogen at a temperature of 75 ± 5°F, RH of 20 to 50% and a pressure of 2-inches H_2O gage maximum.

3.11 Interfaces - The use of the Link and its associated cabling shall not interfere with the operation of any other component or subsystem of the assembly/sterilizer. The Facility Supervisor Console shall be adjacent to a viewing window or port of the assembly/sterilizer. The wiring and panel controls may be integrated with the wiring and physical structure of the Life Support/Medical Monitor equipments to the extent feasible. All cables shall be of suffdcient length to be fastened to existing structures so that they will neither be a personnel hazard nor be subject to wear and abrasion. Tunnel cables shall possess sufficient length and flexibility so as not to impede the operator during any physical activity he may attempt and to permit proper reefing of the cable when the tunnel is reefed.

3.11.1 Connectors - All electrical connectors used in the Link shall be of the quick-disconnect type. Connectors shall be chosen to prevent incorrect mating.

QUALITY ASSURANCE PROVISIONS

4.1 Classification of Tests - The inspection and testing of the Link shall be classified as acceptance tests and qualification tests.

4.1.1 Acceptance Tests - Acceptance tests shall consist of examination of the product and functional tests (see 4.4).

4.1.2 Qualification Tests - Qualification tests shall be conducted to qualify the product design (see 4.5).

4.2 Rejection and Retest - Any Link which does not meet the requirements of the acceptance tests in this specification shall be rejected, Upon correction of any failure, the Link shall be retested unless this requirement is waived by GE-RSD in writing.

4.3 Test Conditions - All tests shall be performed under the following conditions:

a.	Temperature	80°F ± 10°F
b.	Dew Point	45°F ± 12°F
c.	Barometric Pressure	Ambient

4.3.1 Test Equipment - Laboratory apparatus calibrated at intervals properly spaced to assure accuracy shall be used to test the Link for specification compliance,

4.4 Acceptance Tests - To determine compliance with 3.2, perform the tests specified herein,

4.4.1 Visual Examination - Each Link shall be visually inspected to determine compliance of manufacture, fabrication, and marking with this specification.,

4.4.2 Functional Tests - Each Link shall be subjected to the functional tests specified herein.

4.4.2.1 Bandwidth - To determine compliance with 3.2.1, the Link shall be checked at the ranges specified therein.

4.4.2.2 Amplitude - To determine compliance with 3.2.2, the Link shall be checked at the ranges specified therein.

4.4.2.3 Impedance Levels - To determine compliance with 3.2.3, the Link shall be checked at the levels specified therein.

4.4.2.4 Back-up Units - To determine compliance with 3.2.4, the Link back-up units shall be checked at the ranges specified therein.

4.4.2.5 Controls - To determine compliance, with 3.2.5, the Link shall be operated and the controls shall be checked for the operating requirements specified therein.

4.4.2.6 Power - To determine compliance with 3.2.6, apply the voltage specified therein.

4.4.2.7 Functional Performance - To determine compliance with 3.2.7, the Link shall be operated to check the requirements specified therein,

4.4.2.8 Individual Units - To determine compliance with 3.2.8, the Link shall be operated and the individual units shall be checked for the operating requirements specified therein.

4.5 Qualification Tests

4.5.1 Non-Operating Environmental Tests - The Link shall meet the requirements specified in 4.4.1 and 4.4.2.1 through 4.4.2.8 after subjection to the following environmental tests.

4.5.1.1 Temperature - To be supplied later (TBSL)

4.5.1.2 Vibration - (TBSL)

4.5.1.3 Acceleration - (TBSL)

4.5.1.4 Pressure - (TBSL)

4.5.1.5 Humidity - (TBSL)

4.5.1.6 Shock - (TBSL)

4.5.2 Operating Environmental Tests - The operating environmental tests shall be conducted in conjunction with the system qualification tests specified in GE-RSD Specification ERS0100-00-0001 (Bio-Isolator Suit System).

5.0 PREPARATION FOR DELIVERY

5.1 Preservation and Packaging - The Link shall be preserved and packaged in accordance with the provisions set forth in GE-RSD Standard 146A9560 (Preparation for Delivery).

5.2 Packing - The Link shall be overpacked in shipping containers which shall adequately protect each package during ordinary handling and shipping and shall meet the minimum requirements of the carrier for safe transportation at the lowest rate to the point of delivery.

5.3 Marking - Shipping containers shall be marked with the name and address of both consignee and consignor, contract or purchase order numbers, and the item part number. All markings shall be legible and waterproof.

6.0 NOTES

None

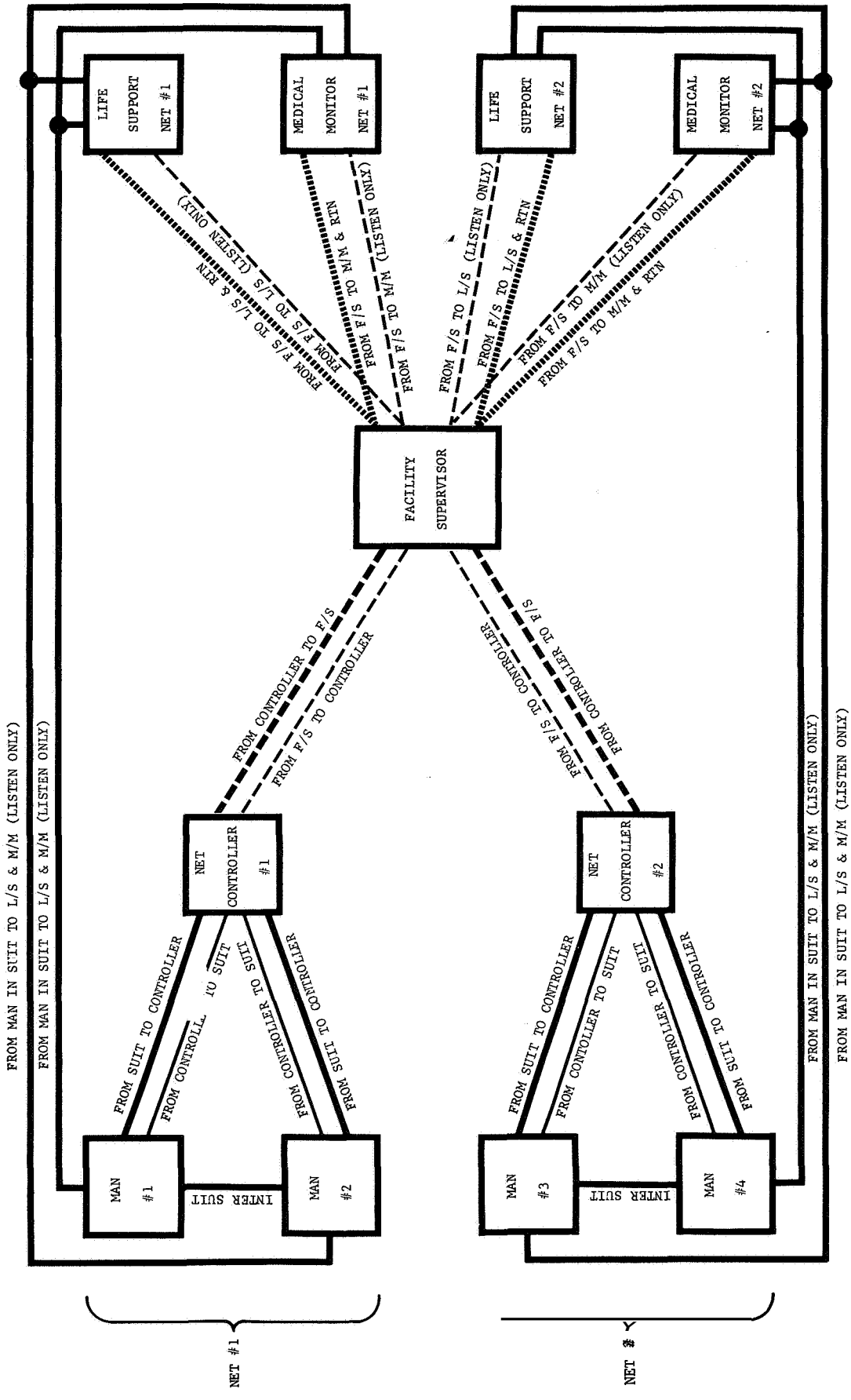


Figure 1 BIOS Communication Subsystem Network

APPENDIX N: LIFE SUPPORT SUBSYSTEM FOR BISS SPECIFICATION

GENERAL ELECTRIC COMPANY
Re-entry Systems Department
3198 Chestnut Street
Philadelphia 1, Pennsylvania
Code Ident, No. 15226

SPECIFICATION: RS0210-00-0001

LIFE SUPPORT SUBSYSTEM

FOQ THE

BIO-ISOLATOR SUIT SYSTEM (BISS)

1.0 GENERAL

1.1 Scope - This specification defines the life support subsystem for the Bio-Isolator Suit System (BISS)(GE-RSD Specification S0100-00-0001), hereinafter referred to as the suit air supply. The suit air supply shall be used to provide a life sustaining temperature and humidity controlled gaseous supply to the occupant within the BISS.

1.2 Descriotion - The suit air supply shall contain all of the components and systems necessary to perform the following functions:

a. Maintain an adequate supply of filtered breathable/cooling air to the BISS undersuit plenum.

b. Provide a means of maintaining comfortable conditions of temperature, humidity, pressure, and removal of noxious and toxic gases from the BISS outer suit.

1.2.1 Components - The suit air supply shall consist of the following ma)or components:

a. Control Console

b. Heat Exchanger

c. Humidifier

d. Blower Fan

e. Exhaust Fan

f. Compressor Unit

g. Heater Unit

0 APPLICABLE DOCUMENTS

2.1 Government Documents - The following government documents of the issue specified, form a part of this specification to the extent specified herein.

Military

MIL-STD-143 14 May 1963	Specifications and Standards Use of
MIL-STD-803A-1 27 January 1964	Human Engineering Design Criteria for Aerospace Systems and Equipment Part 1. Aerospace System Ground Equipment.
MIL-P-116D 4 December 1962	Preservations, Methods of
MIL-P-7963A 19 November 1957	Parts and Equipment, Aeronautical, Preparation for Delivery

Bulletins

ANA Bulletin 400 13 May 1964	Electronic Equipment, Aircraft and Guided Missiles Applicable Documents.

(Copies of these documents may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C.).

2.2 Non-Government Documents - The following non-government documents of the issue in effect on the date of this specification, form a part of this specification to the extent specified herein,

GENERAL ELECTRIC COMPANY

Specifications

ERS0100-00-0001	Bio-Isolator Suit System (BISS)
ERS0150-02-0001	BISS Communication Subsysten
ERS0230-00-0002	BISS Undersuit
ERS0230-00-0001	BISS Outer Suit and Tunnel

Standards

118A1526	Identification Marking
118A1600	Finishes and Coatings
146A9560	Preparation for Delivery

(Copies of the General Electric Company documents may he obtained fron the General Electric Company, RSD, 3198 Chestnut Street, Philadelphia, Pennsylvania 19101).

3.0 REQUIREMENTS

3.1 General - The suit air supply shall be designed for compatibility with the system design requirements set forth in GE document S0100-00-0001 (BISS System Specification), and Figures 1 and 2.

3.2 Design Requirements

3.2.1 Selection of Materials - Materials shall be selected in accordance Kith the appropriate NASA specifications or MIL-STD-143 and ANA Bulletin 400 as applicable,-on the basis-of an optimum compromise of physical or other essential properties, availability and adaptability to production processes.

3.2.2 Standard Parts - Wherever possible, standard parts shall be used to ensure reliability and expedite procurement. Preferred standards in their order of preference, are NASA, Military Standard (MS, AN, NAS), General Electric Company RSD Standards and commercial standards,

3.2.3 Workmanship - Workmanship and shop practices shall be of the highest commercial quality, Elements of the subsystem shall be constructed and finished in athoroughly workmanlike manner, Particular attention shall be Riven to neatness and thoroughness of soldering, wiring, marking of Darts, welding and brazing:, bonding, painting, riveting, machine screw assembly and freedom of parts from burrs and sharp edges.

3.2.4 Identification and Marking - The identification and markinq of all equipment shall conform to all requirements of General Electric Company RSD Standard 118A1526.

3.2.5 Finishes and Coatings - Protective finishes shall be applied as required to meet the environmental design criteria of 3.2.12 below.

3.2.6 Endurance - The suit air supply shall guarantee a minimum period of 360 hours of continuous trouble-free operation without maintenance beyond the replacement of filters and shall be designed for an operating life of not less than 5000 hours with maintenance,

3.2.7 Maintainability - Design of the suit air supply shall make use of modular construction to provide ease of maintenance. Accessibility shall be of prime importance, The use of matched parts or selective fits shall be avoided to the maximum possible extent,

3.2.8 Interchangeability - Each component shall be directly interchangeable with regard to form, fit and function with every other component having the same part number,

3.2.9 Safety - The suit air supply shall be designed to minimize the possibility of injury to personnel due to electric shock or electrical or mechanical failure, All components shall be grounded in a suitable fashion. Circuits carrying electrical power shall be protected by adequate fuses or circuit breakers, Power leads and terminals shall be adequately marked. Sharp edges and corners shall be rounded to prevent injury to personnel. Polarized circuits shall be provided Kith keyed connections to prevent damage to equipment by improper connector orientation.

3.2.10 Controls and Indicators - All manual controls, switches, and indicators required for operating and monitoring the suit air supply shall he positioned on the life support subsystem console. The controls and indicators shall be located so as to minimize human error in operation of the system. They shall be located in accordance with MIL-STD-803A-1.

3.2.11 Dimensions - The maximum dimensions of the life support subsystem console shall be 20-in. wide by 80-in. high by 24-in. deep,

3.2.12 Environment

3.2.12.1 Non-Operating - The suit sir supply shall be designed to withstand the following non-operating environments.

3.2.12.1.1 Storage - The environmental Conditions set forth in MIL-P-116D, Method 1A.

3.2.12.1.2 Shipping - The shipping environments specified herein:

a. Temperature: -25°F to +125°F

b. Vibration

Frequency (cps)	Double Amplitude
2-27	± 1.3 g rms
27-52	0.036 inch
52-500	± 5 g rms

(As modified by shipping container)

c. Acceleration: 3 g's in any direction acting independently

d. Pressure: 4.37 psia to 16.2 psia

e. Humidity: 5%to 95% RH (5%to 100% with condensation in form of water or frost when suitably protected by shipping container)

f. Shock

(1) Packaged

Truck: 6 g's, 5 to 40 milliseconds

Air:
Vert. 5.5 g's, 10 to 30 milliseconds
Lat, 1.5 g's, 10 to 30 milliseconds
Long. 0.8 g's, 10 to 30 milliseconds

(As modified by shipping container)

Handling: Rough handling as defined in Specification MIL-P-7936 for packaged equipment.

3.2.12.1.3 Facility - The environment outside the assembly/sterilizer shall be minimally sir-conditioned inductrial atmosphere with an ambient temperature of 80°F ± 10°F, dew point of 45 ± 12°F, at ambient pressure.

3.2.12.2 Operating - The suit air supply shall be designed to operate during the conditions set forth in 3.2.12.1.3 end the environment within the outer suit and tunnel (GE-RSD Specification ERS0230-00-0001), which shall be 70°F ± 10°F, dew point 45 ± 12°F at a pressure above or below ambient which shall be between 0.5 in. H_2O and -2.0 in. H_2O gage,

3.2.13 Interfaces - The suit air supply shall interface with the BISS communications subsystem (see 3.2.13.1) and the BISS undersuit plenum (see 3.2.13.2).

3.2.13.1 Communication Subsystem Interface - The control console shall have provisions for the support of the communication subsystem components (General Electric Company RSD Specification ERS0150-02-0001, BISS Communication Subsystem Specification). Provision shall he made on the console display for the necessary comunication component controls, jacks, and connectors.

3.2.13.2 Undersuit Plenum Interface - The suit air supply shall be designed to interface with the undersuit plenum by means of quick-disconnect couplings, in accordance with GE-RSD Specificstion S0230-00-0002 (BISS Undersuit).

3.3 Performance

3.3.1 Functional Performance

3.3.1.1 Air Supply and Exhaust - The suit air supply shall provide an adjustable flow of 0 SCFM to 20 SCFM of filtered breathable/cooling air at standard conditions (70°F, 40% RH) to the plenum of the BISS undersuit against a back pressure of 2 inches of water measured at the undersuit plenum. The system shall include a scavenging pump capable of exhausting a minimum of 20 SCFM of air. Air supply and exhaust devices shall have the capability of adjusting the flow through the undersuit between the limits of no flow and 20 SCFM and of adjusting suit internal pressure between the limits of 0.5 inch of water above ambient and 2 inches of water below ambient.

3.3.1.2 Humidification - The humidification device shall be capable of adjusting the internal humidity of the undersuit between the limits of 57°F and 64°F vet bulb and 68°F to 78°F dry bulb, at a flow of 20 SCFM, measured at the undersuit exhaust plenum.

3.3.1.3 Temperature - The suit air supply shall be capable of providing a supply air temperature of 68°F to 78°F dry bulb, at a flow of 3 to 20 SCFM measured at the undersuit inlet plenum.

3.3.1.4 Leakage - There shall be no detectable leakage at ducting or tubinq joints under normal operating conditions, There shall be no leakage of coolant from the condenser unit or heat exchanger or associated tubing.

3.3.1.5 Controls - All manual controls and switches shall operate freely with no signs of binding or interference.

3.3.2 Monitoring -

3.3.2.1 Air Flow Rate - The suit air supply shall be provided with a means of indicating in real time the rate of flow of both supply and exhaust air, independently, Flow rate shall be indicated instantly in standard cubic feet per minute from 0 to 20 SCFM with an accuracy of ± 1% over the entire range,

3.3.2.2 Air Temperature - The suit air supply shall be provided with a means of indicating in real time the temperature of the supply and exhaust air, independently. Temperatures shall be monitored at or near the undersuit plenums and shall be indicated in degrees Fahrenheit. Temperature range of the instruments shall be from 50°F to 150°F with an accuracy of ± 1°F with e time constant of less than one second per degree.

3.3.2.3 Air Moisture Content - The suit air supply shall be provided with a means of indicating in real time the moisture content of both the supply and exhaust air, independently. Moisture content shall be monitored at a point close as possible to the temperature sensors of **3.3.2.2** above. The range of the instruments shall be from 20% to 100% R.H. with an accuracy of ± 1% over the full range with a time constant of less than one second/%,

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Classification of Tests - The inspection and testing of the suit air supply shall be classified as acceptance tests and qualification tests,

4.1.1 Acceptance Tests - Acceptance tests shall consist of examination of the product and functional tests (see 4.4).

4.1.2 Qualification Tests - Qualification tests shall be conducted to qualify the product design (see 4.5).

4.2 Rejection and Retest - Any suit air supply which does not meet the requirements of the acceptance tests in this specification shall be rejected. Upon correction of any failure, the suit air supply shall be retested unless this requirement is waived by GE-RSD in writing.

4.3 Test Conditions - All tests shall be performed under the following conditions:

a. Temperature	+80°F ± 10°F
b. Dew Point	45°F ± 12°F
c. Barometric Pressure	29 in. Hg ± 2 in, Hg

4.3.1 Test Equipment - Laboratory apparatus calibrated at intervals properly spaced to assure accuracy shall be used to test the suit air supply for specification compliance.

4.4 Acceptance Tests - To determine compliance with 3.3, perform the tests specified herein.

4.4.1 Visual Examination - Each suit air supply shall be visually inspected to determine compliance of manufacture, fabrication, and marking with this specification.

4.4.2 Functional Tests - Each suit air supply shall be subjected to the functional tests specified herein.

4.4.2.1 Supply and Exhaust Capacity - The air supply shall be attached to a test plenum that shall provide a back pressure of 24-in. H_2O and the supply blower adjusted until a flow of 20 SCFM is indicated on the supply flowmeter, with the exhaust hose disconnected from the test plenum. The exhaust line shall be connected to the test plenum and the exhaust blower adjusted until the flow of 20 SCFM is indicated on the exhaust flowmeter with the supply line disconnected from the test plenum.

4.4.2.2 Supply Air Temperature - The supply blower shall be adjusted through the range of 3 to 20 SCFM and the air temperature controls adjusted to maintain a temperature of 73°F ± 5°F at the test plenum inlet.

4.4.2.3 Humidification - The supply blower shall be adjusted to deliver 20 SCFM and the air temperature controls adjusted to provide air temperature of 77°F at the test plenum inlet. The humidifier control shall then be adjusted to establish dew points of 57°F and 64°F at the test plenum.

4.4.2.4 Leakage - All air tubing and ducting joints shall be checked for leaks using the soap bubble technique, All refrigeration joints shall be leak tested using Halogen leak detector (sniffer).

4.4.2.5 Controls - All manual controls shall be operated through their entire range to insure compliance with 3.3.1.5.

4.4.2.6 Monitoring Equipment

4.4.2.6.1 Air Flow Rate - The air flow rate indicators shall be calibrated against accurate flowmeters over their full range from 0 to 20 SCFM. Calibration curves shall be supplied to the procuring agency.

4.4.2.6.2 Air Temperature - The air temperature indicators shell be calibrated against accurate thermocouples over their full range from 50°F to 150°F. Calibration curves shall be supplied to the procuring agency.

4.4.2.6.3 Air Moisture Content - The humidity monitors shall be calibrated against accurate electric hygrometers over their full range from 20% to 100% R.H. Calibration curves shall be supplied to the procuring agency.

4.5 Qualification Tests

4.5.1 Non-Operating Environmental Tests - The suit air supply shall meet the requirements specified in 4.4.1 and 4.4.2.1 through 4.4.2.6.3 after subjection to the following environmental tests.

4.5.1.1 Temperature - To be supplied later (TBSL)

4.5.1.2 Vibration - (TBSL)

4.5.1.3 Acceleration - (TBSL)

4.5.1.4 Pressure - (TBSL)

4.5.1.5 Humidity - (TBSL)

4.5.1.6 Shock - (TBSL).

4.5.2 Operating Environmental Tests - The operating environmental tests shall be conducted in conjunction with the system qualification tests specified in GE-RSD Specification ERS0100-00-0001 (Bio-Isolator Suit System).

5.0 PREPARATION FOR DELIVERY

5.1 Preservation and Packaging - The suit air supply unit shall he preserved and packaged in accordance with the provisions of G.E. RSD standard 146A9560.

5.2 Packing - The suit air supply **shall** be overpacked in shipping containers which shall adequately protect each package during ordinary handling and shipping and shall meet the minimum requirements of the carrier for safe transportation at the lowest rate to the point of delivery,

5.3 Marking - Shipping containers shall be marked with the name and address of both consignee and consignor, contract or purchase order number, and item part number. All markings shall be legible and waterproof.

6.0 NOTES

6.1 Components - The following list of components are those used in the BISS Phase II Mock-up Program, and are presented only as a guide to support Figure 1:

1.	Blowers	General Electric	P-400547-13(modified)
2.	Autotransformers	Ohmite	VT8
3.	Flowmeters	Fischer-Porter	10A3565A
4.	Condenser Unit	Tecumseh	CAT34HTK
	Expansion Valve	Alco	TK100FW
	Sight Glass	Sporlan	SA13
	Filter-Drier	Alco	032
	Heat Exchanger	General Electric	XER47E191157
5.	Heater	Chromalox	Type TC 1648
6.	Thermostat	Chromalox	Type AR 2529
7.	Humidifier	General Electric	XER191154
a	Distribution Plenum	General Electric	XER47B115903
9.	Thermometer	Yellow Springs Instruments	14-176TJ
	Probe	Yellow Springs Instruments	15-176-26
10.	R.H. Indicator	El-tronics	Model 106
	Element	El-tronics	2CB47E191154
11.	Undersuit	General Electric	

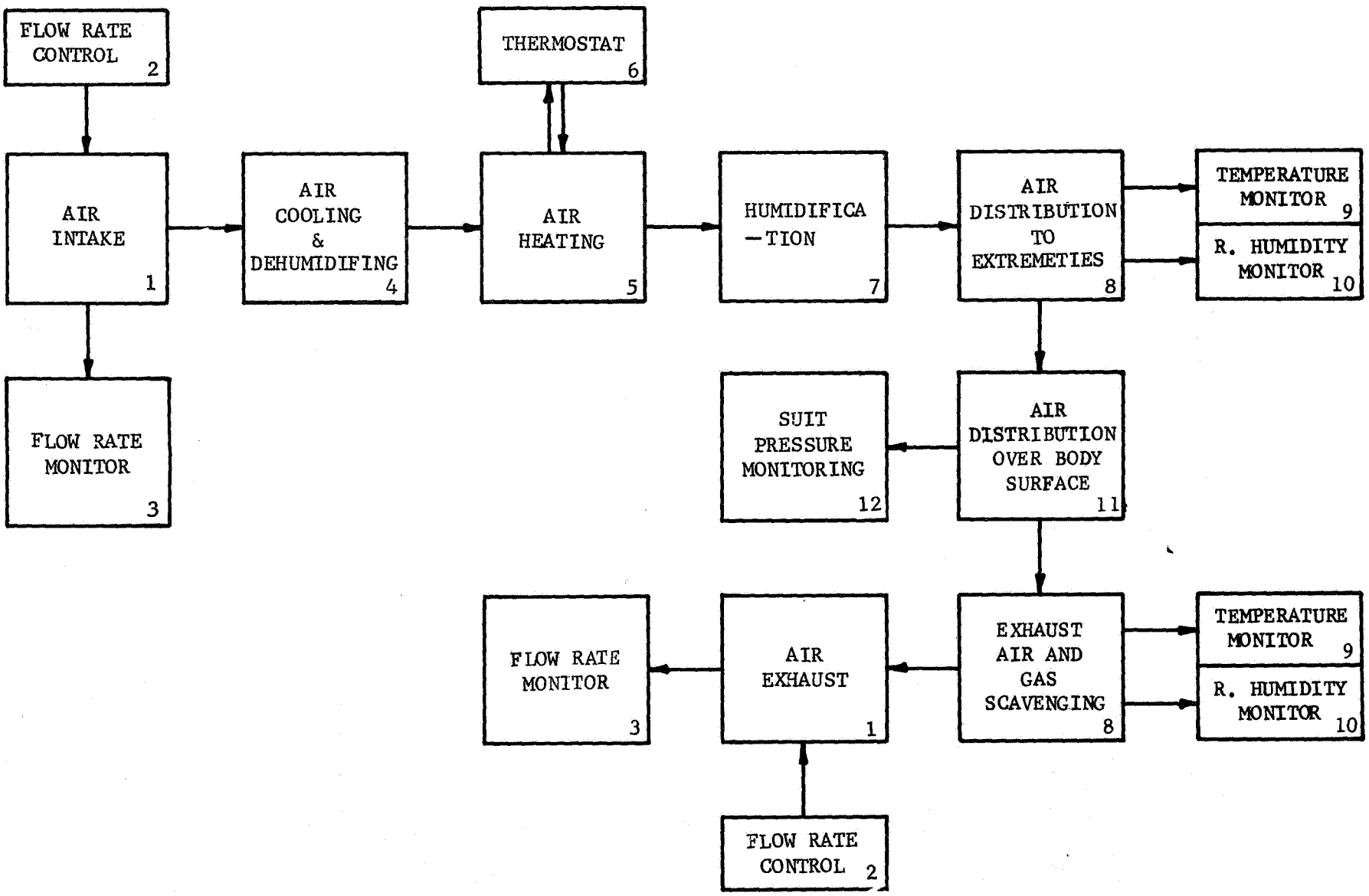


FIGURE 1 FUNCTIONAL BLOCK FLOW DIAGRAM

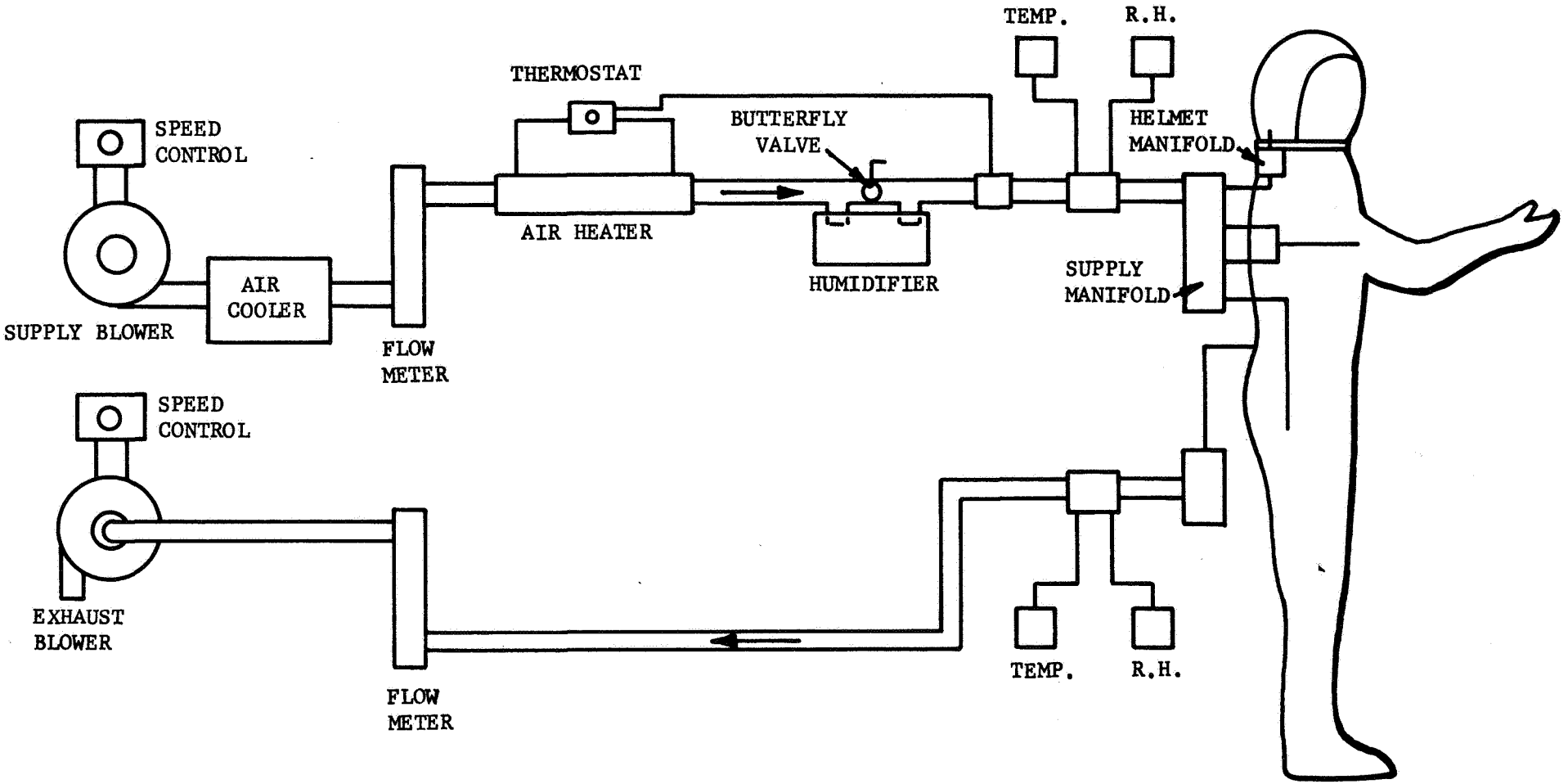


FIGURE 2 LIFE SUPPORT SUBSYSTEM SETUP