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LUNAR SHELTER HABITABILITY EVALUATION

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ABSTRACT

Results are reported of an investigation to determine the capability of pressure suited personnel to deploy lunar shelter/airlock structures, install mockup life support, power and miscellaneous equipment within and outside the shelter, and adequately utilize this equipment after installation. Information was obtained on: (1) dimensional requirements for lunar shelter interiors, hatches, and airlocks, (2) limitations imposed on lunar shelter design by pressure suited crewmen, (3) times associated with various work tasks, and (4) redesign recommendations for a lunar stay time extension module (STEM).

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SUMMARY

The STEM (Stay Time Extension Module) lunar shelter concept can be unpackaged, positioned, pressurized, and externally activated by two suited subjects. The time required appears to be significantly longer than presimulation estimates. Internal activation can best be accomplished with two subjects--one suited subject outside loading the STEM air lock with internal equipment, and one shirt-sleeved or suited and unpressurized subject inside the shelter cycling the air lock and transferring the equipment into the shelter.

The internal activation of the living quarters can be completed partially by the inside subject while the outside subject is loading the air lock. The activation can be completed by the two subjects, shirt-sleeved or suited and unpressurized, after the equipment transfers are completed. Activation of the internal equipment by a single, pressurized, suited subject can be completed; however, this method appears inefficient and should be considered as a contingency operation.

Complete activation of the STEM by a single, suited subject may be possible in a lunar environment; however, it was not possible at 1 G because of two factors: (1) the STEM could not automatically erect when the container was opened as it would in the lunar operation and (2) the STEM in its collapsed mode could not be maneuvered into position by a single subject. After the STEM is pressurized the activation task is feasible for a single, suited subject, but appears marginal in the 1 G simulation mode because of the suit-induced work load.

The suggested procedure for internal equipment activation has been modified to present a more efficient activation sequence; however, the order of activation is not critical. Preplacement of the equipment outside the air lock in preparation for the transfer must be considered because of the difficulty of bending and retrieving equipment (especially small objects and large, flat objects) from the surface.

Sharp objects which may puncture the inner or outer pressure layers of the shelter must be avoided. This involves particular care in handling equipment during the activation sequence.

The deployed thermal mat masks surface irregularities (holes, etc.). A careful survey of the deployment area must be made, and "grading" may be necessary prior to activation to prevent injury to the astronauts.

The STEM is relatively unstable to internal movement, and the chocks provided do not maintain their positions on the thermal mat. A more reliable system of stabilization of the STEM is recommended.

The Environmental Research Associates (ERA) test subjects were able to perform ingress-egress to the shelter in a variety of conditions and under conditions more difficult than are expected to be encountered in the actual lunar operation (i.e., pressurized to 4 psig in a Mark IV suit). A single subject can transfer through the air lock and shelter in both directions; however, redesign of the air lock floor and the shelter to air lock step is necessary because of the geometric interferences and stability considerations.

Two subjects with backpacks can work pressurized in the shelter if necessary; however, suited operation in the air lock is very confined and difficult. To exit the air lock, one subject must stand behind the air lock door while the other exits. The door must then be closed so that the second subject can maneuver around it prior to exiting.

Two shirt-sleeved subjects can work efficiently in the shelter; however, equipment storage is critical. Storage of the backpacks and full pressure suits in the air lock is a definite advantage to efficient and comfortable operations in the shelter.

The STEM concept as it is now designed "walks" during air lock cycling. This movement of the entire STEM module in the order of 2 in. for each air lock cycling could cause serious damage to the life support systems located at the rear of the shelter. The noise level attributable to the internal air for cooling flow appears to be objectionable particularly for long internal stay times.

The STEM configuration yields a portable, erectable shelter concept, particularly for two-man teams. The erection cycle is compatible with initial lunar stay times. The equipment placement internal to the shelter is not optimum from a human factors standpoint, and a redesign of the equipment placement, both as regards concept and geometry, is required.

INTRODUCTION

During the performance of Task 1 of Master Agreement NAS1-8975, "Man-Lunar Shelter Compatibility Studies," under Modification 1, ERA utilized an existing full scale model of the STEM lunar shelter in a series of manned tests for the purpose of gaining a working knowledge of the activation problems and operational characteristics of this particular shelter. The STEM was shipped to ERA for a one-month time period in which a series of tests was performed.

This report identifies the human factors aspects of this shelter, and describes the investigations made during this contract. Tests were performed within the ERA facility and field tests were performed in a rock quarry, for the purpose of evaluating the effect of representative surface conditions during the deployment and activation phase.

There were no reduced gravity simulations performed, with the exception of an evaluation of the air lock door and floor interaction. This simulation was accomplished by counterbalancing a portion of the air lock weight during several cycles of ingress-egress. The reduced gravity of the lunar environment will alter man's capability to apply manual forces. In some cases these forces will be enhanced and in others, degraded. Manual lifting forces applied during the deployment and activation are generally enhanced by a reduction of gravity, and therefore the operations performed by the subjects during the laboratory and field tests are valid in "proving out" the concepts and the approximate sizes and masses with a good margin of safety for the actual mission.

The tentative mission for the lunar surface shelter calls for one- or two-man occupancy for a primary period of 10 days, with possible extension to a 30-day period. The initial design concept calls for a 7 ft diameter by 13 ft length living quarter (cylindrical) with a 7 ft diameter spherical air lock attached at one end.

The integral shelter-air lock structure is fabricated of pliable and expandable material and packaged in one of the packaging containers. The deployed structure is intended to be erected and assembled by a single astronaut on the lunar surface.

BASELINE DESIGN

The STEM is modularized and packaged on the LEM landing stage. The target time for unpackaging, deployment, and assembly is

4 man-hours. The packaging configuration on the landing stage of the LEM is shown in Figure 1, taken from NASA CR-66061 (ref. 1).[1]

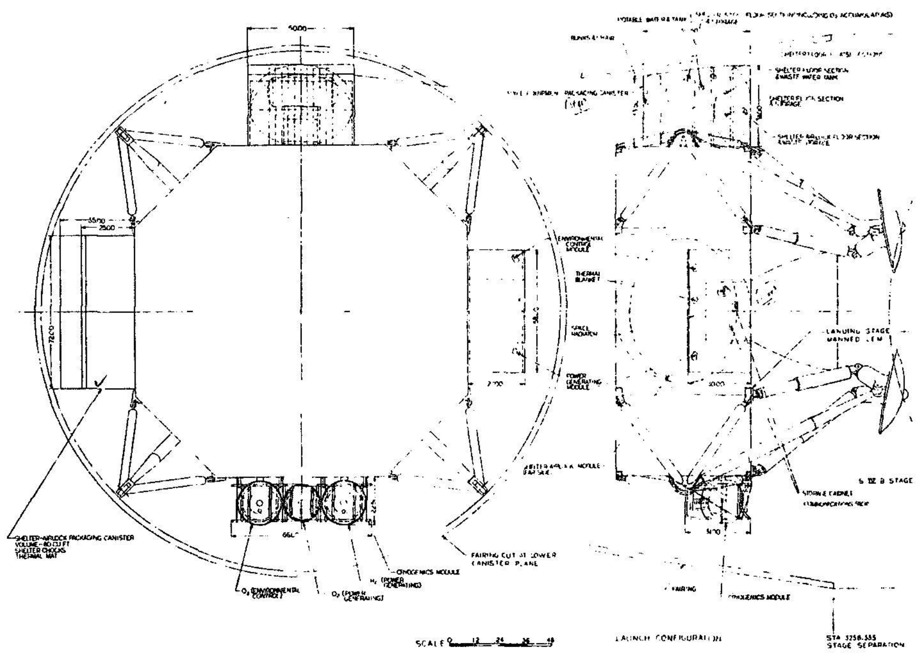

FIGURE 1 - STEM PACKAGED CONFIGURATION ON LEM

Four faces of the landing stage are used for the stowage of the package modules. The shelter-air lock module is the largest element. The shelter-air lock package size is 30×64×72 in., with an estimated weight of 300 lb$_e$ or approximately 50 lb$_\ell$. STEM subsystems are packaged in a 27×30×58 in. package; estimated weight < 300 lb$_e$. A miscellaneous equipment module, 50×50×37 in., and a cryogenic module complete the hardware complement. The modules must be removed from the packaging containers, deployed, and assembled in a predetermined sequence. It was assumed that this function would be performed by a single astronaut, owing to safety constraints. Figure 2 depicts the deployment of the STEM (ref 1).

[1]Lunar Stay Time Extension Module (STEM), NASA CR-66061, 21 Aug. 65

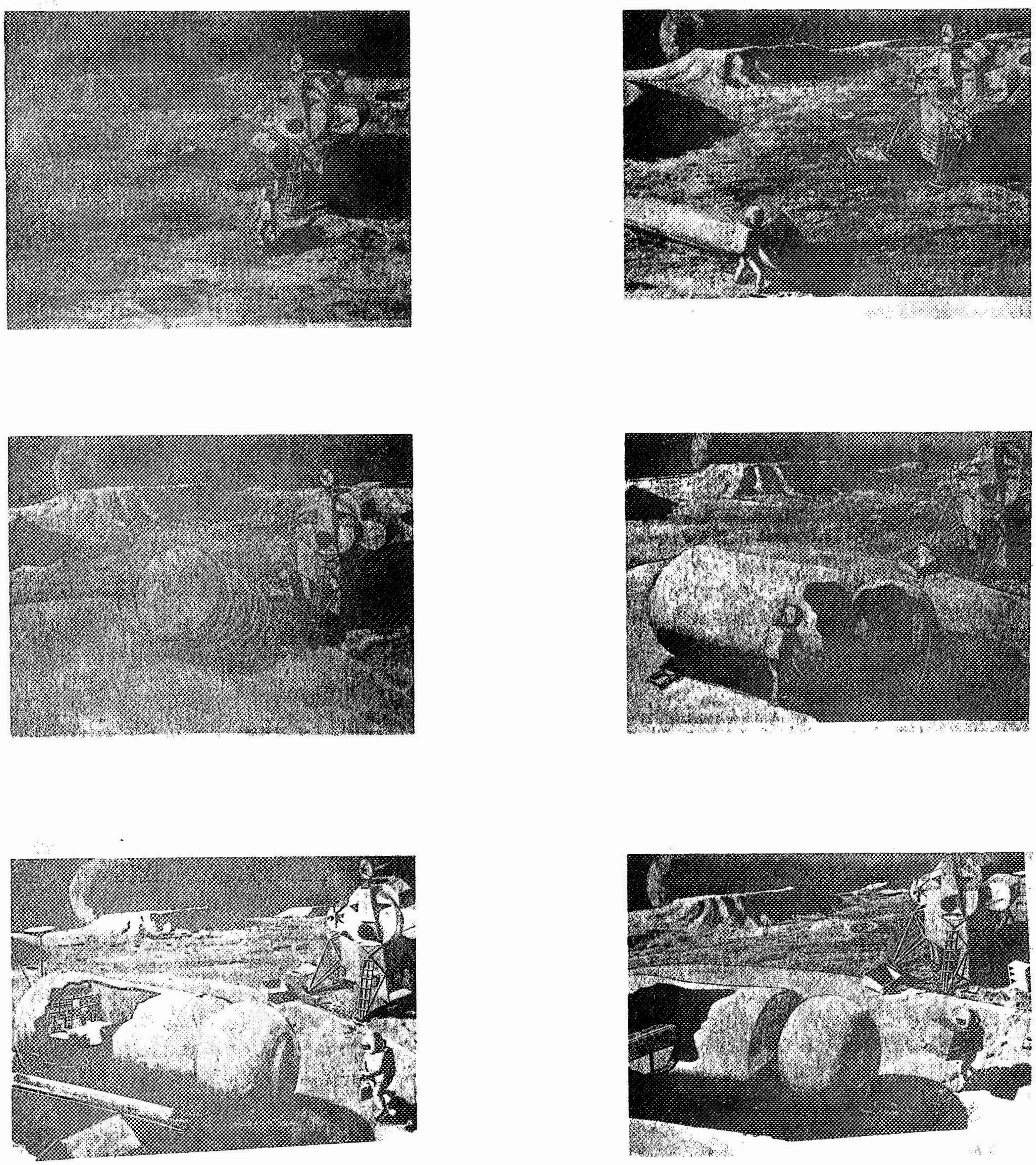

FIGURE 2 - STEM DEPLOYMENT

A full scale demonstration module was fabricated, including a representative prototype of the shelter-air lock, along with mock-ups of the subsystems, furnishings, and equipment. Figures 3 and 4 show the shelter-air lock mock-up and the packaging container respectively. This demonstration module was used by ERA for the human factors evaluation program.

Packaging

Overall dimensions of the shelter-air lock container are 72 in. wide by 64 in. high. The box tapers from 35 in. at the base to 25 in. at the top. Both the front and back faces are removable. Cover attachment hardware is similar to conventional trunk latch fasteners. The package for the fixed equipment is smaller; however, the structure is identical. The fore and aft panels are 50 in. square; the sides taper from 38 in. to 33 in. Fork fittings with wraparound straps are provided.

The subsystem packaging container serves a dual purpose. Two faces of the container serve as space radiators for the coolant system. The top surface of the subsystem package becomes a work area for the STEM console. These panels are provided with quick disconnects (panel type). The side panels employ screw-type fasteners.

The target goal of 50 lb_{ℓ} for the shelter-air lock package was not of itself considered objectionable (ref. 1), but the weight, in conjunction with its shape and size, was considered to constitute a major problem area. The solution--lowering the unit from the vehicle to a convenient position, making the package openly accessible, and taking advantage of the circular package shape for rolling the fabric-enclosed shelter to the site--was assumed to resolve the problem. "Except for the shelter package, distribution of the STEM system to packageable units comply with the established limitations. The major subsystems are unitized to provide complete module assemblies and all packaged items fall within the

FIGURE 3 - SHELTER-AIR LOCK MOCK-UP

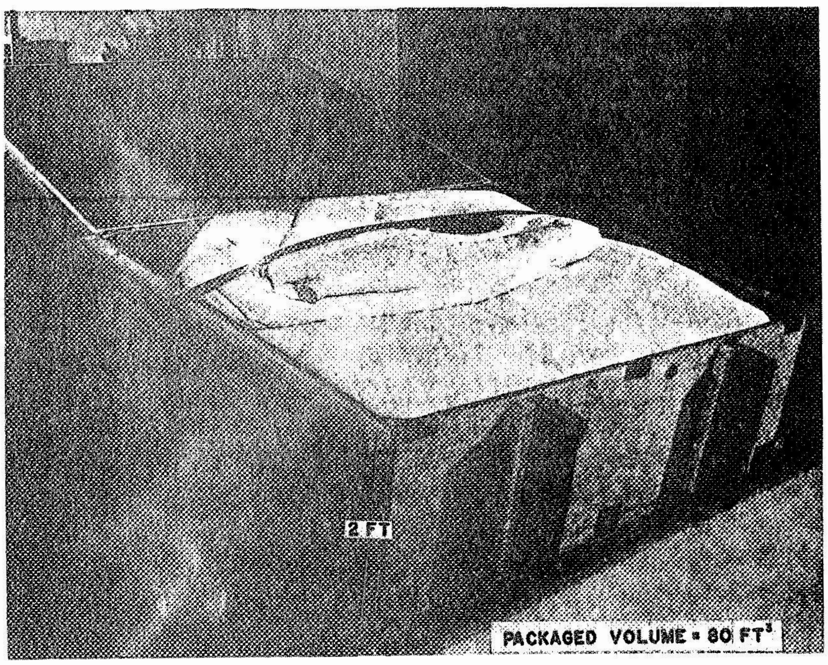

FIGURE 4 - PACKAGING CONTAINER

acceptable weights and sizes for ease of handling in the lunar environment." (ref. 1) The general deployment and erection sequence is summarized in Table I.

TABLE I.--DEPLOYMENT AND ERECTION SEQUENCE

1. Release shelter and associated equipment containers from LEM landing stage vehicle.
2. Unpack and position the 44'ϕ thermal mat on the chosen site plot.
3. Unpack shelter and position in center of the thermal mat.
4. Unpack and connect cryogenics to shelter.
5. Place support equipment inside shelter.
6. Secure air lock door and shelter hatch.
7. Pressurize shelter to 5 psia.
8. Initiate power-generating and life support system.

Table II lists the contents of the packages.

Unloading the System From the LEM

The same unloading procedure is used for all the packages. After the landing, the wraparound straps holding the containers in place are unfastened at the LEM platform upper attachment point. A payout cable, or extension of the strap, is operated from the transport vehicle to lower the unit in a controlled manner. The package supported by a "U" fitting rotates about a pin on the LEM base to terminate at a position permitting direct access to the package enclosure on unhooking the complete package from the vehicle support.

Deployment

The first item to be deployed is the thermal mat. The thermal mat is a 44'ϕ, mylar blanket with specular thermal coating, weighing approximately $(5.0\ oz/yd^2)_e$. The total weight of the thermal blanket is $< 45\ lb_e$. It was estimated (ref. 1) that it

TABLE II.--CONTENTS OF THE STEM PACKAGES

PACKAGE A - SHELTER-AIR LOCK
1. Container (honeycomb sandwich)
2. Thermal mat
3. Shelter-air lock
4. Chocks
PACKAGE B - CRYOGENICS
1. Support (tubular rack)
2. Liquid oxygen and hydrogen tank
PACKAGE C - EQUIPMENT AND MISCELLANEOUS
1. Container (honeycomb sandwich)
2. Flooring and storage
3. Furniture and tools
4. Water and food supply
PACKAGE D - SUBSYSTEMS
1. Space radiator
2. Thermal blanket
3. Container (modular-type container)
4. Power-generating module
5. Environmental control module
6. Communications pack
7. Storage cabinet
8. Communications antennas

would require 5 min for deployment. After the thermal mat is removed, unfolded, and spread out over a suitable surface site, the chocks are removed and the container is placed at the edge of the thermal mat. The restraining laces used to secure the shelter-air lock structure within the packaging container are then released, allowing the structure to deploy upon the thermal mat. The structure is rolled to the center of the thermal mat, positioned for critical alignment of the air lock door, and stabilized by emplacement of the chocks. An estimate of the thermal mat deployment is given in Table III. The proposed deployment sequence detailed in ref. 1 is given in Appendix A.

Installation of Equipment

Subsystem Package

The communications antennas and the space radiator for humidity control are contained in the subsystems package. These items are

TABLE III.--THERMAL MAT DEPLOYMENT SEQUENCE[1]

FUNCTION	ΔT MIN
1. Unstowage of container holding the thermal mat	5-10
2. Deposition on lunar surface	0.5-1
3. Attachment of transportation aid	1-5
4. Transport to site	1-5
Rest	1-2
5. Unstowage of thermal mat	1-5
6. Deployment at site	0.5-1
7. Initial unfolding sequence (1-2 fold/min)[2]	5-10
Rest	1-2
8. Secondary unfolding sequence (RS)[2]	5-10
9. Secondary unfolding sequence (LS)[2]	5-10
Rest	1-2
10. Final mat inspection and smoothout	1-2
Total	(28-65)[3]
Estimated maximum metabolic rate 1500-2000 BTU/hr	(19.5-37)

to be unpackaged and installed as external equipment. The antennas are to be installed on the terminal bulkhead plate at the blind end of the shelter. The space radiator is to be placed on the thermal mat, also at the blind end of the shelter, and properly oriented (relative to the solar incidence angle). After installation, the appropriate connections for both the space radiator and the antennas are made at the terminal bulkhead plate.

[1]On the basis that operation in AL5 and later suits ∿ to Mark IV.
[2]Subject balance plays an important factor in determining the maximum permissible unfolding rate.
[3]Ref. 1 estimated time allotment ∿ 5 min.

Cryogenics Package

After installation of antennas and space radiator, the cryogenics module is to be installed. This module contains the necessary O_2 and H_2 cryogenic for both ECS and power system operation. The unit assembly is first off-loaded from the vehicle, then installed at the blind end of the shelter. After placement, connections are then made to the terminal bulkhead plate on the shelter.

After the external equipment is installed and assembled with the shelter structure, the internal equipment can be unpackaged and installed. The following sequence was identified.

Fixed Equipment Package

The first item to be installed is the air lock floor and waste stowage unit in the shelter immediately adjacent to the shelter hatch. The shelter slat floor assembly is installed next, followed by the 30-inch shelter floor and stowage section, and the two remaining shelter floor and stowage sections at the blind end of the shelter. The remaining items of fixed equipment are to be installed after installation of the subsystems.

Subsystem Package

After the floor sections have been laid down within the shelter, the subsystem modules packs can then be installed. The ECS module should be installed first and positioned at the blind end of the shelter. Next, the power-generating module, the communications pack, the control console, and the storage cabinet are installed. During the installation of subsystem modules, any connections required to external equipment (cryogenic module, communications antennas, space radiator) are made at the terminal bulkhead plate of the shelter.

Remaining Fixed Equipment

The remaining fixed equipment is installed in the shelter after the subsystems have been installed and connected. First, the portable water supply tank is installed atop the control panel console to provide a maximum height, for a positive pressure head, for flow. The work table and bunks are then installed and attached to previously installed fittings on the shelter wall. The work chair is the final piece of equipment installed in the shelter, followed by the placement of the toilet in the air lock. At this point the STEM system should be provisioned with food, followed by start-up of operations.

TEST PERFORMANCE

The STEM human factors evaluation was divided into 5 tasks in 2 categories as identified in the contract document. Tasks 1.A.1. through 1.A.3. were conducted external to the shelter and included the following elements:

1.A.1. Unpacking of STEM from container.

Subjects: 2--shirt sleeve mode.

Description: Open STEM container, remove and deploy thermal mat, remove and deploy shelter, remove and deploy shelter chocks. Deploy cryogenics packages.

1.A.2. Unpacking of STEM container by pressure-suited subjects.

Subjects: 2--FPS mode.

Description: Same as 1.A.1.

1.A.3. Cycle (pressure test) STEM unmanned.

Subjects: None.

Description: Pressurize STEM to various pressures (5.0 psig max.) and evaluate shelter characteristics, pressure drop during cycling of air lock, and record all observations. (This task includes all pressure evaluations made on STEM where no activation procedures were evaluated.)

Tasks 1.A.4. and 1.A.5. were conducted internal to the shelter and included the following elements:

1.A.4. Cycle (pressure test) STEM with shirt-sleeved subjects inside.

Subjects: 2--shirt sleeve mode.

Description: Two shirt-sleeved subjects assemble internal equipment in shelter.

1.A.5. Cycle shelter and air lock with pressure-suited subject.

Subjects: 1--FPS mode.

Description: A single suited and pressurized subject loads and enters the air lock with internal equipment components, cycles into the shelter, and assembles the internal equipment.

Table IV summarizes the task elements performed for each of the 5 tasks. A completed dated reference of the STEM evaluation tests including film and data analysis considerations is presented in Appendix B.

External Operations

The external operations of unpacking and deploying the STEM shelter and its equipment will be affected, to a large degree, by the terrain. Slopes and rock projections are possible hazards and must be considered during site selection. In order to provide a suitable terrain environment, it was decided to perform these tests as a field evaluation utilizing a rock quarry at Delight, Maryland. This quarry had several acres of various surface consistency, and included minor and major slopes. Although several locations were generally suitable, the final site selected appeared to present the best condition of surface consistency, slope, and backdrop. The selection process took about 2 hours. This, and subsequent events during testing, suggests that site selection

TABLE IV.--PERFORMANCE SUMMARY

TASK	DATE 8/4	8/12	8/13	8/25	8/26	8/29	8/30	8/31	9/1
1.A.1. Unpacking of STEM fron container						X	X		
1.A.2. Unpacking of STEM container by pressure-suited subjects								X	
1.A.3. Cycle (pressure test) STEM unmanned	X						X	X	
1.A.4. Cycle (pressure test) STEM with shirt-sleeved subject inside	X								X
1.A.5. Cycle shelter and air lock with pressure-suited subject		X	X	X	X				
SUBTASK									
Thermal mat						X	X	X	
Unpackage STEM						X	X	X	X
Erect shelter							X	X	X
Shelter placement							X	X	
LS equipment placement							X	X	
Shelter cycle	X	X	X	X	X		X	X	X
Air lock waste stowage	X			X	X				
Air lock floor	X			X	X				
Shelter stowage 1	X		X	X	X				X
Shelter floor 1	X		X	X	X				X
Slat floor 1	X		X	X	X				X
Slat floor 2	X		X	X	X				X
Shelter stowage 2	X		X	X	X				X
Shelter floor 2	X		X	X	X				X
Waste water stowage tank frame	X		X	X	X				X
Waste water stowage tank	X		X	X	X				X
Shelter floor 3	X		X	X	X				X
PSM	X								X
Control console	X								X
Communications console	X								X
Stowage cabinet	X								X
Water stowage rack	X								X
Water tank	X	X							X
Work table	X								X
Bunks	X								X
Work chair	X								X
Toilet	X								X
Lighting	X								X
Suit equipment stowage	X								X

on the lunar surface may require considerable time. Figure 5 is an overall view of the field location.

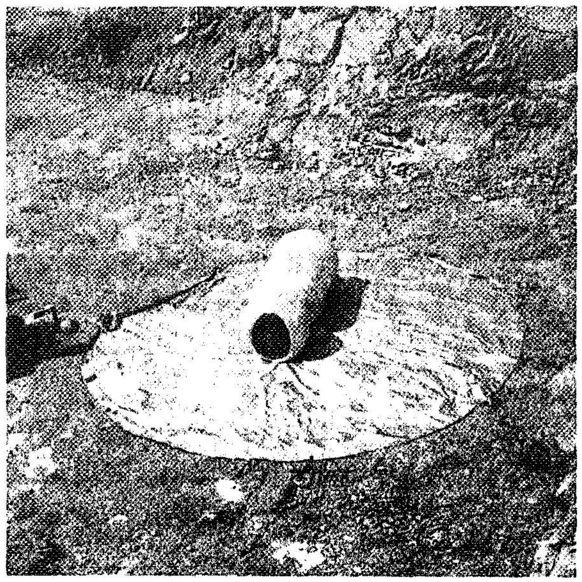

FIGURE 5 - OVERALL VIEW OF FIELD LOCATION

1.A.1.

The objectives of the tests were to evaluate unpackaging and deployment of the STEM, and to assess the value of the test subjects to assist in any unforeseen problems. The elements of Task 1.A.1. were:

1. Remove and deploy the thermal mat.
2. Release the shelter tiedowns.
3. Remove shelter from container.
4. Pressurize shelter.
5. Position shelter in center of thermal mat.
6. Remove shelter chocks from container and chock shelter in position.
7. Deploy cryogenics package.

An initial deployment of the thermal mat was accomplished by a single, shirt-sleeved subject. The shirt-sleeved subject had no difficulties in deploying the mat; however, the deployment time was considerably longer than had been predicted for mat deployment.

The entire 1.A.1. task sequence was then performed by two shirt-sleeved subjects. Again no difficulty was encountered in thermal mat deployment except the longer than expected deployment time. The subjects preferred placing the mat in the center of the deployment area and each walking out with one edge in opposite directions until the mat was completely unfolded. This method did involve carrying the folded mat from the container to the center of the deployment area. It was observed that when carrying the mat it tended to unfold; thus making transport difficult. A method for containing the mat for transport, such as a bag container, appears desirable, and should be evaluated further.

The three containers holding the shelter and its ancillary equipment and the fourth container, the cryogenics module, were placed in their respective positions on the LEM vehicle (relative placement on the ground since no LEM mock-up was used). The subjects began Task 1.A.1. by opening the lid of the shelter container, including the chocks and the thermal mat. At the completion of the mat deployment, the shelter tiedowns were released. Once the restraints are released, the operational STEM would automatically deploy. At 1 G, however, this does not occur. The shirt-sleeved subjects deployed the STEM by assisting (pulling motion) the entire configuration out of the container, attaching a pressurization line, and filling the shelter to an operating pressure of 5.0 psig.

Minor damage occurred to the outside shelter skin on its removal from the container because of sharp objects protruding from the container lid. Had the shelter erected unassisted as it is intended to in the lunar environment, there is a strong possibility that the minor damage experienced during the test could have resulted in damage, with perhaps a total failure of the shelter to hold pressure. It may be advantageous to design the shelter so that it does not erect unassisted, but requires some minimum manual effort which, at the same time, allows a greater control of erecting procedures.

It was found that the shelter and air lock doors did not seal completely until an internal positive pressure was maintained by one subject entering the shelter and manually applying a thrust force. It required approximately 1600 cu ft of air to bring the shelter to 5.0 psig from a completely depressurized and semifolded configuration. The flow required to keep ahead of the door blow-by until the seal closed was approximately 40 cu ft per min. It is postulated that the age and condition of the STEM model and its hatch systems were significant factors affecting this shelter pressurization. It is suggested that this situation be critically evaluated, especially if there are any operational contingency modes wherein the STEM will not assume its deployed shape automatically after releasing its restraints. The total external equipment deployment sequence required 42 min.

The selected deployment area covered by the thermal mat was not quite level and had some rocky portions, but was generally smooth. In order to place the shelter on the thermal mat, the main shelter section was pressurized to 5 lb above ambient, and the air lock section was maintained at ambient. The two suited subjects exhibited little difficulty in moving and positioning the shelter, using a rolling technique. Subsequently, one suited subject succeeded in rolling the shelter up a slight grade with little observed difficulty. An unforeseen problem occurred at this point. The thermal mat had covered the many small depressed areas in the terrain. One of the test subject stepped into one such depressed area while positioning the shelter and could easily have fallen. It was subsequently determined that there were several hidden depressions within the thermal mat area, and it is recommended that the erection site be visually evaluated prior to deployment of the thermal mat. Deploying the shelter chocks presented no problems in the shirt-sleeve or full pressure suit mode. In the FPS mode, the subject simply dropped the chocks to the ground and pushed them into position with his foot. This eliminated the need to bend down in the suit.

1.A.2.

Task 1.A.2. duplicated the 1.A.1. task elements with two full pressure-suited subjects. No major variations to the order of the suggested deployment sequence were deemed necessary; however, two elements were added. First, a subtask calling for the scouting and preparation of the deployment area was inserted prior to mat deployment. Second, periodic rest periods of 1 and 2 min durations were added, as shown in Table V.

TABLE V.--STEM EXTERNAL EQUIPMENT DEPLOYMENT SEQUENCE TIME LINE

ELEMENTS	TIME EST. (MIN)
Open shelter container	2
Remove and deploy thermal mat	13
Rest	2
Release shelter restraints	3
Remove and pressurize shelter	*
Rest	2
Position shelter on thermal mat	8
Rest	2
Remove and deploy chocks	4
Remove and deploy cryogenics package	5
Rest	1
Total deployment time	42

*Simulation did not afford valid estimate of task element time.
Note: Time estimates determined with STEM packages (LEM configuration) approximately at edge of deployed thermal mat.

An Arrowhead FPS pressurized to 1.0 psig was used for Task 1.A.2. Figure 6 shows the suited subject in a PLSS self-contained backpack configuration. The PLSS backpack provided self-contained breathing

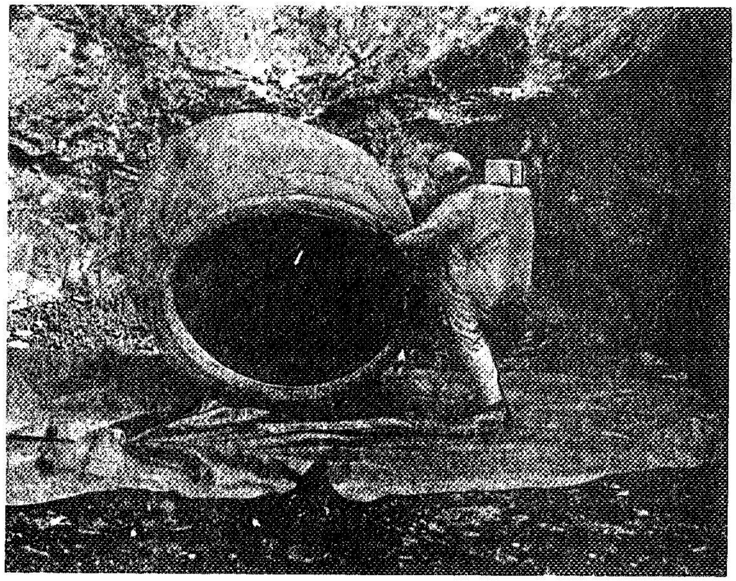

FIGURE 6 - SUIT CONFIGURATION

air. No cooling air was provided since the excess weight of a cooling system could not be carried by the subject in a 1 G simulation. In tasks of extended duration, an umbilical line replaced the self-contained breathing supply to eliminate air bottle changes during the runs.

The work loads for STEM erection sequences were not excessive, although the subjects did note that the rest periods, as shown in Table V, were necessary to successful completion of the task. The STEM external erection sequence was evaluated in the light of one and two astronaut-erection requirements. It was observed that although one astronaut could feasibly complete the erection sequence, the overall task could be accomplished much more efficiently as a two-man operation.

All elements of the 1.A.1. and 1.A.2. STEM external erection tasks were performed at the 1 G level. The majority of the critical human factors elements can be categorized as lifting or pulling operations. It has been demonstrated by Apollo 11 that such work can be performed in a 1/6 G environment. It is postulated that task elements of of this nature, performed in a 1 G mode, should be more difficult than similar tasks in lunar gravity because of the added weight and force requirements involved. Thus, the successful completion of the task elements of STEM external erection at 1 G should indicate that these procedures can be completed successfully, and possibly with more efficiency, on the lunar surface.

One degrading factor in the ground simulation was the lack of suit vent flow (cooling) to the working subject. Field operations added to the problems of task performance because of the increased heat load due to working in direct sunlight. It is felt that the simulated lunar terrain was adequate since it pointed up the problem of hidden surface variations beneath the thermal mat. The overall simulation was successful in pointing out the many general problems of the STEM external equipment deployment concept.

The packaging of the STEM into its containers was not originally considered in the test program. It was noticed, however, that the shelter container was not stowed for maximum efficiency in unloading when first viewed at the ERA facility in light of ref. 1. For this reason, an amended procedure for STEM container packaging was utilized.

1.A.3.

Since the STEM model is several years old and its actual operational condition as regards the prospective tests was unknown, an initial testing procedure was conducted at ERA under close scrutiny of project personnel to determine its ability to hold pressure, etc. Several activation sequences were accomplished with the shelter at low pressure for the purpose of verifying projected time lines prior to full pressurization of the shelter. Communications and closed circuit television capabilities were also added during these initial pressurization evaluations.

A continuous, record pressure sensing device was attached to the STEM shelter end plate, and all pressure variations were recorded on a Rustrak recording system. From the pressure curves, approximate leak rates were calculated for two extended recording periods. For the initial installation period of 47 hrs, the STEM model lost approximately 1.75 psig. The leak rate was 0.037 psig/hr. A second pressure drop experiment was conducted over a separate 66 hr period. The initial pressure was 3.75 psig and the end pressure was 1.50 psig, which is equivalent to an average leak rate of 0.034 psig/hr. Further testing indicated that under normal conditions the leak rate was approximately constant. However, it was noticed that the door seals were deteriorating, and if they were not coated regularly with vacuum grease, the leak rates would increase noticeably. This preventative maintenance function must be considered for inclusion in the STEM lunar operational procedures.

Initial check-out tests were performed to evaluate the operations of the shelter and air lock systems, in particular the air lock hatch seal at minimum pressurization levels. Main chamber pressure variations with air lock activation were also evaluated to establish basic venting requirements. Table VI presents the results of the initial pressurization tests.

During the pressure test, the existing intake and exhaust ports in the STEM end plate proved to be inadequate for cooling and CO_2 ventilation. Calculations of shelter and air lock gas flow and temperature requirements for manned operations were far above the capacities of the existing fixtures. Modifications were made on the end plate and a noise suppressor was added to the intake line inside the shelter.

The general flow requirements for manned operations were calculated using the U.S. Navy Hyperberic Chamber air flow formulas (ref. 2).

TABLE VI.--INITIAL AIR LOCK PRESSURIZATION (LOW PRESSURE) EVALUATIONS

	AIR LOCK		SHELTER		PRESSURIZATION TIME
	INITIAL PRES. PSIG	END PRES. PSIG	INITIAL PRES. PSIG	END PRES. PSIG	SEC
Air lock pressurization	0	2.0	2.7	2.0	40
Air lock venting	2.0	0	2.0	1.9	60
Air lock pressurization	0	1.4	2.5	1.4	75
Air lock venting	1.4	0	1.4	1.4	26

The chamber (shelter and air lock) ventilation requirements are given in Table VII.

TABLE VII.--CHAMBER VENTILATION REQUIREMENTS

	Basic requirements*
VOLUME OF AIR REQUIRED	1. Allow 2 cu ft per min per man. 2. Add 2 cu ft per min for each man not at rest. *Volume as measured at chamber pressure--applies at any depth.
MAXIMUM INTERVAL BETWEEN VENTILATIONS (FOR STANDARD AIR)	Interval (min) = $\frac{\text{Chamber (or lock) vol. (cu ft)}}{\text{Basic vent. req. (cu ft/min)}}$
TIMING OF VENTILATION	1. Use any convenient interval shorter than maximum. 2. Continuous steady-rate ventilation is also satisfactory.

At the completion of the initial pressurization tests, baseline pressurization and life support data was calculated for the subsequent manned internal operations.

The air lock volume is 105 cu ft, the shelter volume is 410 cu ft, yielding a total STEM volume of approximately 515 cu ft. The maximum pressurization and operating pressure is 5.0 psig. Approximate values of temperature, humidity, and air flow were derived from existing Navy standard chamber life support calculations and from the initial pressurization evaluations. The values presented in Table VIII are approximate baseline values.

TABLE VIII.--LIFE SUPPORT BASELINE STANDARDS FOR STEM MANNED OPERATIONS

STEM shelter air flow to maintain temperature and humidity controls	30 cu ft/min
Temperature control	75°F
Humidity control	50%
Minimum flow requirements for CO_2 control at 1/3 atmos. (5.0 psig) for working operations	4 ft^3/min/man

A test was performed on the STEM air lock during Task 1.A.3. to evaluate the effect of gravity on the unpressurized air lock configuration. During initial STEM evaluations, it was obvious that the air lock floor support and waste stowage structure and the floor covering plate could not be installed without preventing the operation of the interior opening air lock hatch. In the unpressurized state, the weight of the STEM results in a sill height of approximately 4 in. above the datum. This results in a sill to air lock floor distance of 1.5 in. This height is below the minimum 8 in. interior sill to soft floor height required for operation of the air lock door with the air lock floor structure and floor plate installed. With the air lock in the pressurized mode, the sill height is 11 in., and the inside dimension is approximately 9.5 in. at a pressure of 3 psig. (Note: The sill height did not increase appreciably at pressures from 3-5.2 psig.) The above observations were made at 1 G. Since the lunar weight of the STEM is less than the earth weight, a set of measurements was made to determine the actual effects of reduced STEM weight on sill height. Counterweights were added to the STEM to reduce the net air lock weight over a sufficient range to include the 1/6 G condition. The maximum weight added (111 lb) lifted the air lock clear of the floor. Figure 7 shows the counterweight rigging.

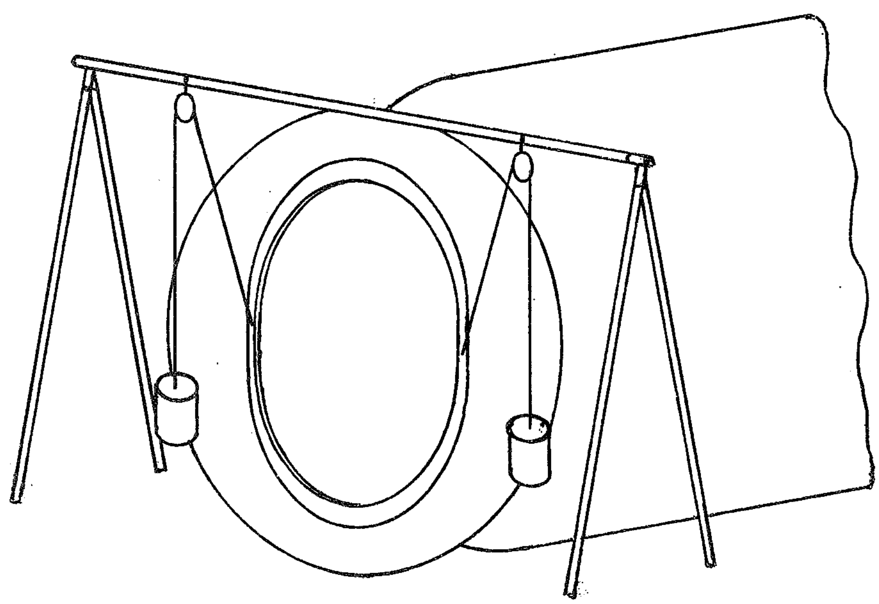

FIGURE 7 - COUNTERWEIGHT ARRANGEMENT

The major and minor axis of the air lock's floor outline caused by the shaping of the flexible air lock floor was also measured. Table IX presents the measurement data. These data are plotted in Figure 8 showing the sill height versus counterweight.

Tests performed under the maximum conditions (111 lb counterweight--lifting air lock clear of the floor) showed that astronaut entry into the air lock reduced the sill clearance and caused an interaction between the air lock floor and the door. The toilet was

TABLE IX.--EFFECT OF COUNTERWEIGHT ON SILL HEIGHT

COUNTER-WEIGHT LB	OUTSIDE SILL HT IN.	FLOOR AXIS TRANSVERSE IN.	LONGITUDINAL IN.
17.1	4-7/8	27	27
25.7	4-7/8	27	27
34.3	4-7/8	27	27
42.9	5	27	27
51.4	5	27	27
60.0	5	27	27
68.6	5	27	27
77.1	5-1/4	27	27
85.7	5-1/4	27	27
94.3	6-3/8	26	24
102.9	7-1/2	24	15
111.4	air lock raised off floor		

installed in place without the air lock floor to ascertain if there would be an interaction between it and the astronaut's required floor space during ingress. There was a definite interaction, particularly when the subject was loading equipment into the air lock and then getting into the air lock himself while encumbered with the pressure suit and backpack. The toilet area was the only place for the subject to stand. The subsequent testing of ingress-egress was performed without the floor or the toilet installed.

The above tests were performed without pressure in the wall bladder. The addition of operational pressure to this bladder may affect the air lock characteristics; however, the physical condition of the air lock structure prevented pressurization of the bladder at this time.

A pressure test was performed on the pressure vessel formed by the outer and inner bladders. This air lock bladder was pressurized

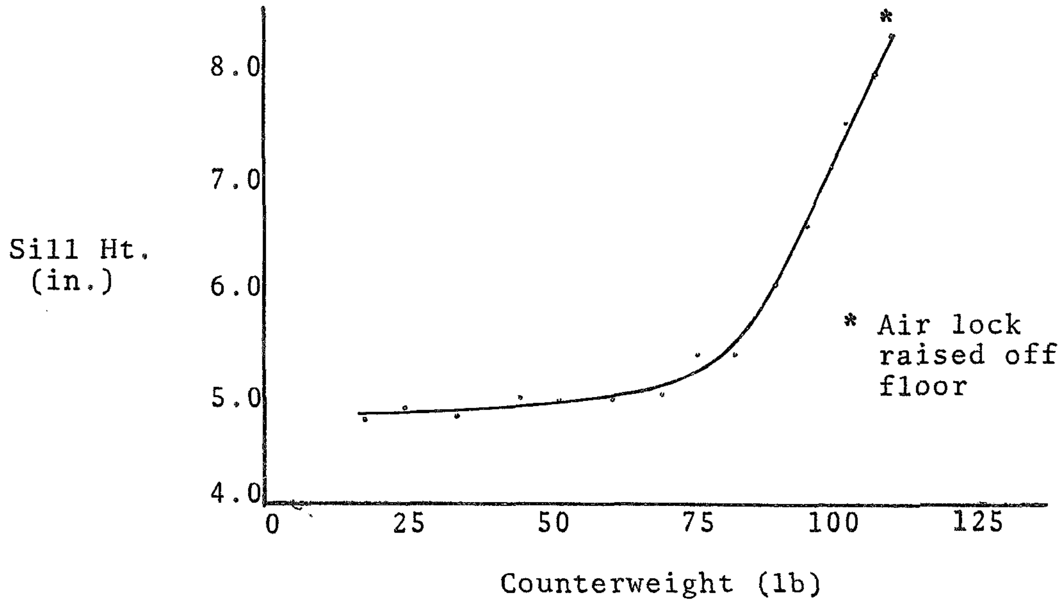

FIGURE 8 - SILL HEIGHT VERSUS COUNTERWEIGHT

to 0.1 psig using the pressure inlet on the underside of the air lock. Pressurization was stopped at this point because the inner lining appeared to be separating from the inner foam (i.e., a bubble, approximately 1.5 in. high and 14 in. in diameter, was forming on the inside air lock floor).

Internal Operations

Tasks 1.A.4. and 1.A.5. completed the human factors evaluation of the STEM. In Task 1.A.4., two shirt-sleeved subjects assembled the internal equipment in the shelter. In Task 1.A.5., a single suited subject loaded and entered the air lock with the internal equipment, and then transferred into the shelter and assembled the internal equipment.

Various STEM activation subtasks were performed initially to evaluate the optimum methods of transferring equipment into the STEM. It was observed that the most efficient method of activating the internal equipment was obtained by the operation of one suited, pressurized subject outside loading the internal equipment into the air lock, and one shirt-sleeved subject inside the shelter cycling the air lock and loading the equipment into the shelter. Where the external equipment had been transferred into the STEM, the subject entered the shelter, doffed his FPS, and together with the second subject assembled the internal equipment.

Prior to the full task evaluation runs of 1.A.4. and 1.A.5., a number of general evaluations were made to familiarize the subjects with the STEM equipment procedures, and also to provide detailed data on particular operations and requirements inherent in the STEM activation. The internal components of the STEM configuration were preassembled exterior to the STEM to familiarize the personnel with the components and their assembly methods.

Familiarization Runs

An ERA subject was suited and pressurized to 3.7 psig. The subject positioned in front of the air lock outer door, and began a transfer into the air lock. The subject's initial transfer was accomplished easily; however, he did require extra time to make his transit through the hatchway. He noted, in the post-run debriefing, that it was difficult to maneuver around the hatch with the air lock unpressurized. He noted that it was necessary to walk up on the curvature of the air lock floor to accomplish the maneuver around the edge of the door prior to closing the hatch. In subsequent runs, the hatch transfer could be accomplished with decreasing difficulty which is attributed to a natural learning process. However, since it was impossible to fit the floor and toilet into the air lock due to geometric interference, this operation is considered marginal at best.

Once in the hatch, the subject found no difficulty in pressurizing the air lock and depressurizing his full pressure suit. Opening the inner hatch, the subject noted that stepping through the hatchway was hampered by two conditions. First, the sill height and the slant of the chamber walls below the sill height to the floor made the wide step over the sill difficult. The air lock floor was not installed for this maneuver; however, the shelter hatch step designed to assist the astronaut in stepping over the sill was installed. Second, the shelter hatch step tended to slide away as the test subject stepped from the air lock to the shelter because of the low friction of the shelter floor material combined with the curvature of the wall. This had also been noted by the shirt-sleeved subject in the previous run, and in both the shirt sleeve and the full pressure suit depressurized transfer, the subject noted that he found it impossible to stand on the inner step without this floor piece sliding out of position. Figure 9 shows the subject entering the air lock. Subsequently it was

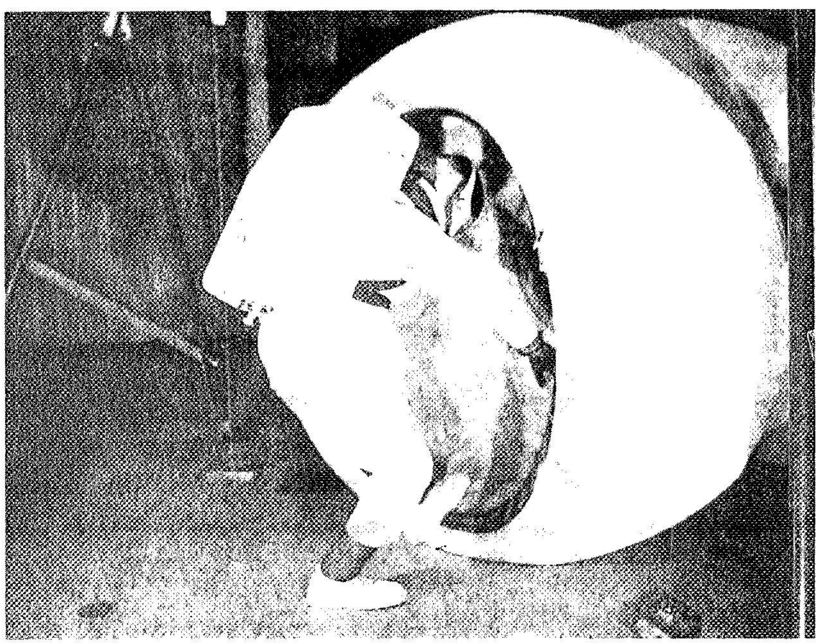

FIGURE 9 - ENTRY INTO THE AIR LOCK

found that even taking into account the reduced lunar loads that it was impossible to stabilize this entry sill. Future design must include positive stabilization techniques.

A second transfer was made by the suited subject. In this transfer the subject attempted to carry the instrumentation console through the STEM configuration. He noted that he had great difficulty passing the instrumentation package around the outside air lock door. Figure 10 shows the package transfer through the outer hatch. The subject also noted that he had difficulty in

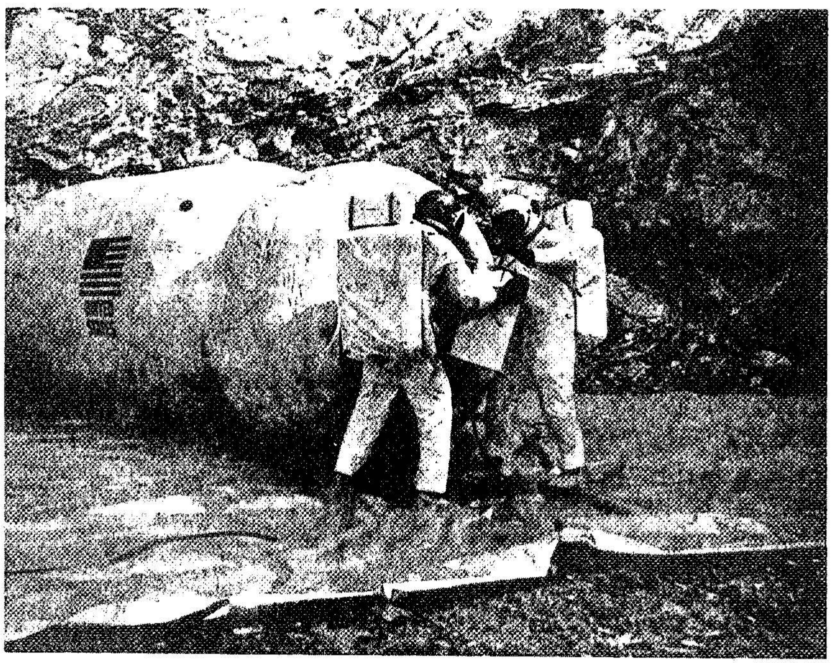

FIGURE 10 - PACKAGE HANDLING INTO THE AIR LOCK

passing the same package through the inner hatch in an unpressurized configuration. The difficulty with equipment and package transfer into the air lock is attributed to the inward opening hatch. The difficulty with equipment transfer into the shelter is attributable to the sill height and step stability. The curved sill to floor bulkhead, Figure 11, required the subject to reach a considerable distance to pass the cargo through the hatch because it was not possible to stand close to the hatch opening.

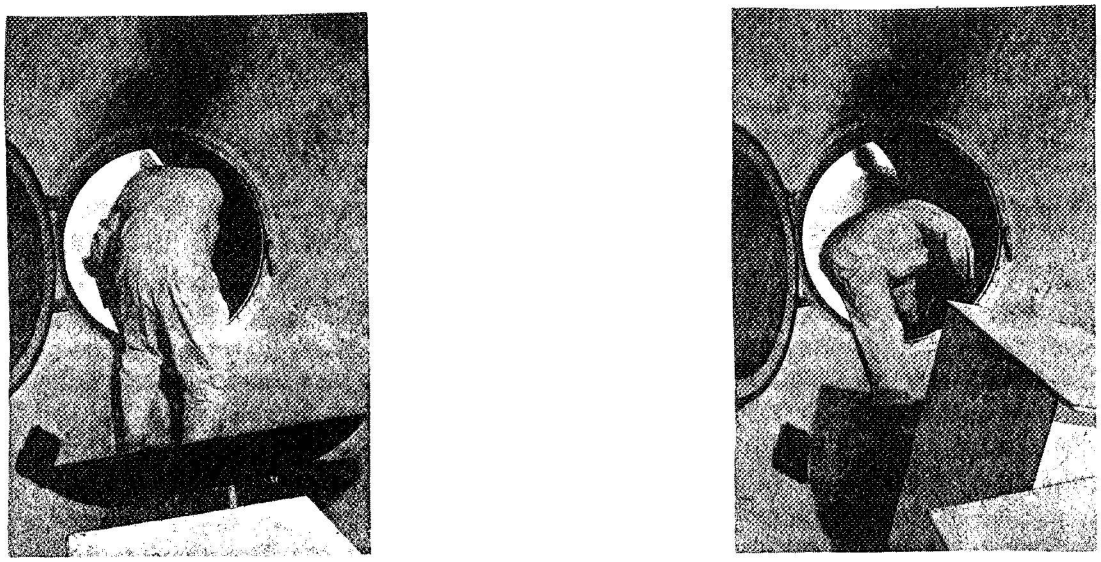

FIGURE 11 - TYPICAL PACKAGE PLACEMENT INTO SHELTER

Following these initial familiarizations, a set of runs was performed to evaluate the effect of suit pressure and configuration. The runs further aided in the preparation of the subject for the STEM activation task time line evaluations. Table X lists the 5 runs performed during this evaluation and the suit configuration. All 5 runs were made by the same subject using the Arrowhead MK4 Mod I FPS.

In the first 2 runs, the subject had no difficulty in ingress or egress of the air lock. Air lock pressurization (cycling) was also accomplished with no difficulty. The subject noted that he was aware of the backpack (PLSS) in Run 2, and the suit provided no hindrance to his movements. In Run 3, however, it was observed that the backpack slightly hindered the subject's hatch transfer.

The 1.0 psig Arrowhead suit pressure maintained during the run has been compared favorably with the present Apollo soft suit at a

TABLE X.--INITIAL EVALUATIONS, SUIT PRESSURE, AND CONFIGURATION COMPARISON RUNS

RUN NO.	MANEUVER	SUIT PRESSURE PSIG	COMMENTS
1	Personnel transfer I-E. Air lock and air lock cycling.	0	No backpack (PLSS)
2	"	0	PLSS
3	"	1	PLSS
4	"	3.7	
5	Cargo transfer and personnel transfer I-E. Air lock and air lock cycling.	3.7	PLSS and carrying portable water tank

lunar operating pressure of 3.7 psig. It is felt that the maneuvers performed in the Arrowhead MK4 Mod I FPS at 1.0 psig are representative of the actual Apollo hardware projected for use on STEM-type missions. Figure 12 presents a comparison of the Arrowhead and Apollo suit configurations. The solid bar presents the 1.0 psig suit motions on the histogram. It can be seen in this comparison that the Arrowhead favorably represents the significant motions in the Apollo suit. Certain of the suit motions are better simulated at other Arrowhead suit pressures. This factor should be considered in subsequent STEM activation evaluations.

Run 4 was performed at a suit pressure of 3.7 psig using the PLSS. The subject noted that he had some difficulty in closing the air lock door during this run. It was observed that he had to lean back in the corner of the air lock wall and the shelter bulkhead wall, and also walk slightly up the incline of the air lock floor. In preparation for exiting the air lock, the subject accidently

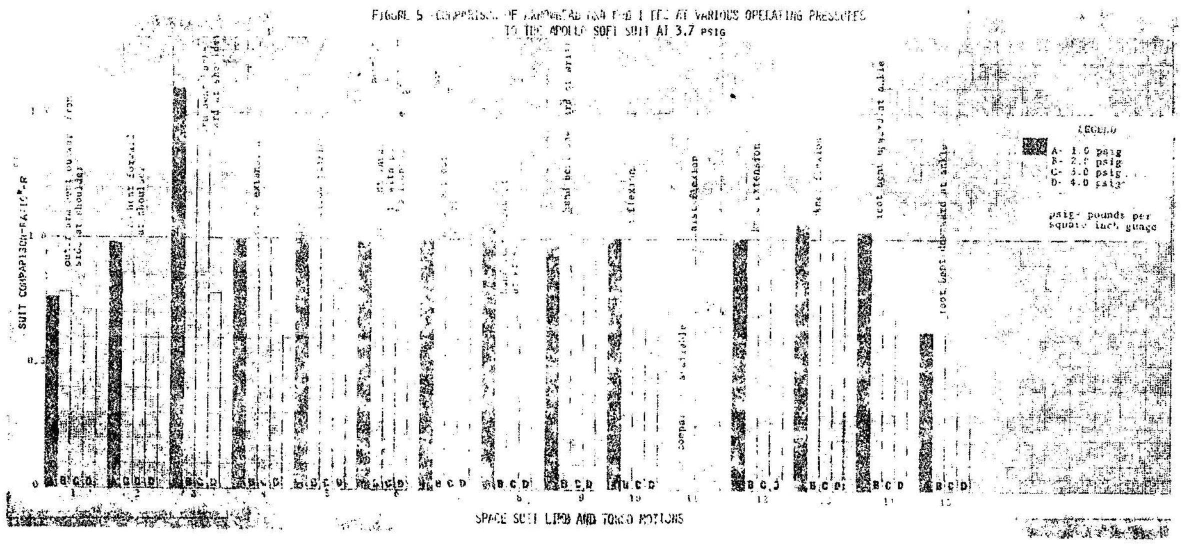

FIGURE 12 - COMPARISON OF ARROWHEAD AND APOLLO SUITS

activated the shelter depressurization valve with his PLSS. In the pressurized configuration he did not notice the partially opened valve until he had depressurized and exited the air lock. This situation could be extremely critical during the lunar missions because, in effect, what the subject was accomplishing was a depressurization of the entire STEM shelter. Modifications on the depressurization valve could alleviate this problem.

Run 5 was performed at 3.7 psig with the PLSS. In this run the subject attempted to carry the portable water tank into the air lock. The subject could not close the door after entering and positioning himself as described in Run 4. The run was terminated at this point to develop adequate methods of equipment transfer.

A closer examination of this maneuver revealed that the subject could accomplish the equipment transfer by first placing the water tank behind the air lock door. This was a difficult maneuver since it required the subject to sacrifice his balanced position when maneuvering the tank around the door from outside the air lock hatch. If the subject entered the air lock with the package, it was almost impossible to maneuver the tank around the door.

Next, the subject attempted a transfer of the water tank into the shelter. He noted that the main problem in transferring the water tank was in stepping over the sill with the tank in hand. He found it relatively easy, however, to pass the tank into the main chamber and then enter.

1.A.4.

Task 1.A.4., internal equipment activation, investigated the capability of the two subjects to assemble and erect the internal shelter operational equipment in the shirt sleeve mode. Figures 13 and 14 show two views of the equipment arrangement within the shelter. It is noted that considerable difficulty was evidenced in the familiarization runs when one subject was required to work in a suited, pressurized or soft-suited mode in the shelter. This was particularly clear when the subject was required to make sorties outside the shelter requiring suit repressurization.

The 1.A.4. task required the subjects to transfer the equipment from the air lock into the main shelter, and then to assemble and activate the equipment. Transfer of the equipment from the air lock proceeded with relatively little difficulty except those factors previously noted caused by sill and step interactions. This operation, with its attendant problems, is shown in Figure 15.

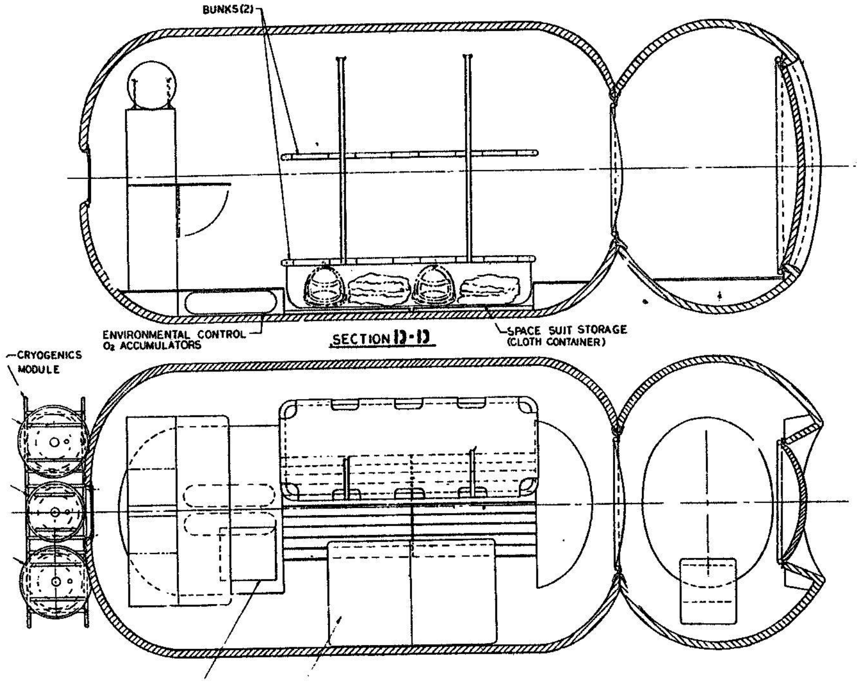

FIGURE 13 - SHELTER ARRANGEMENT-NORMAL VIEW

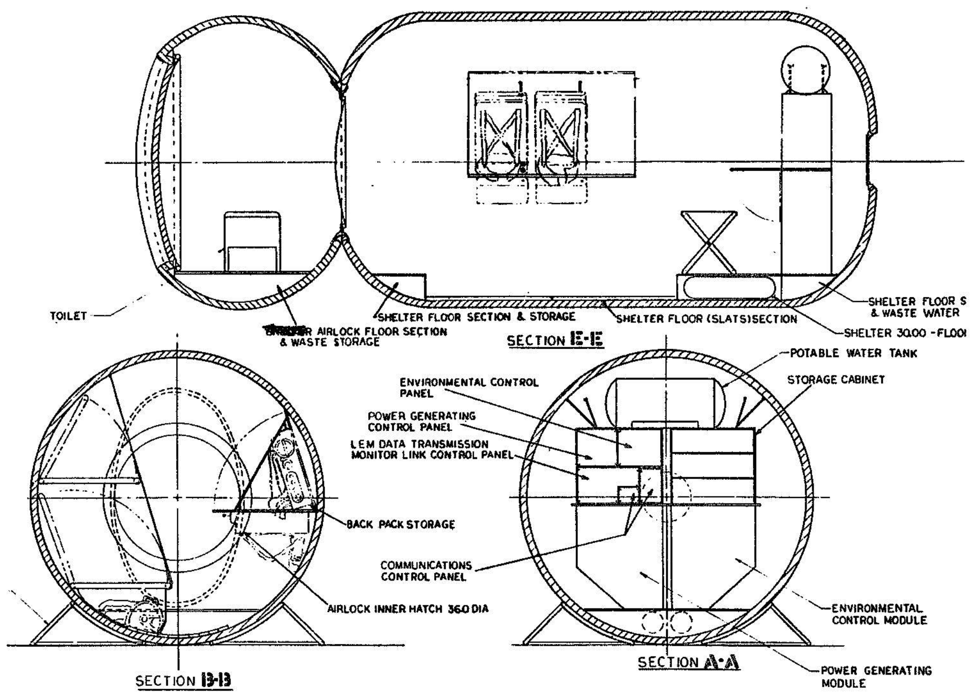

FIGURE 14 - SHELTER ARRANGEMENT-AXIAL VIEW

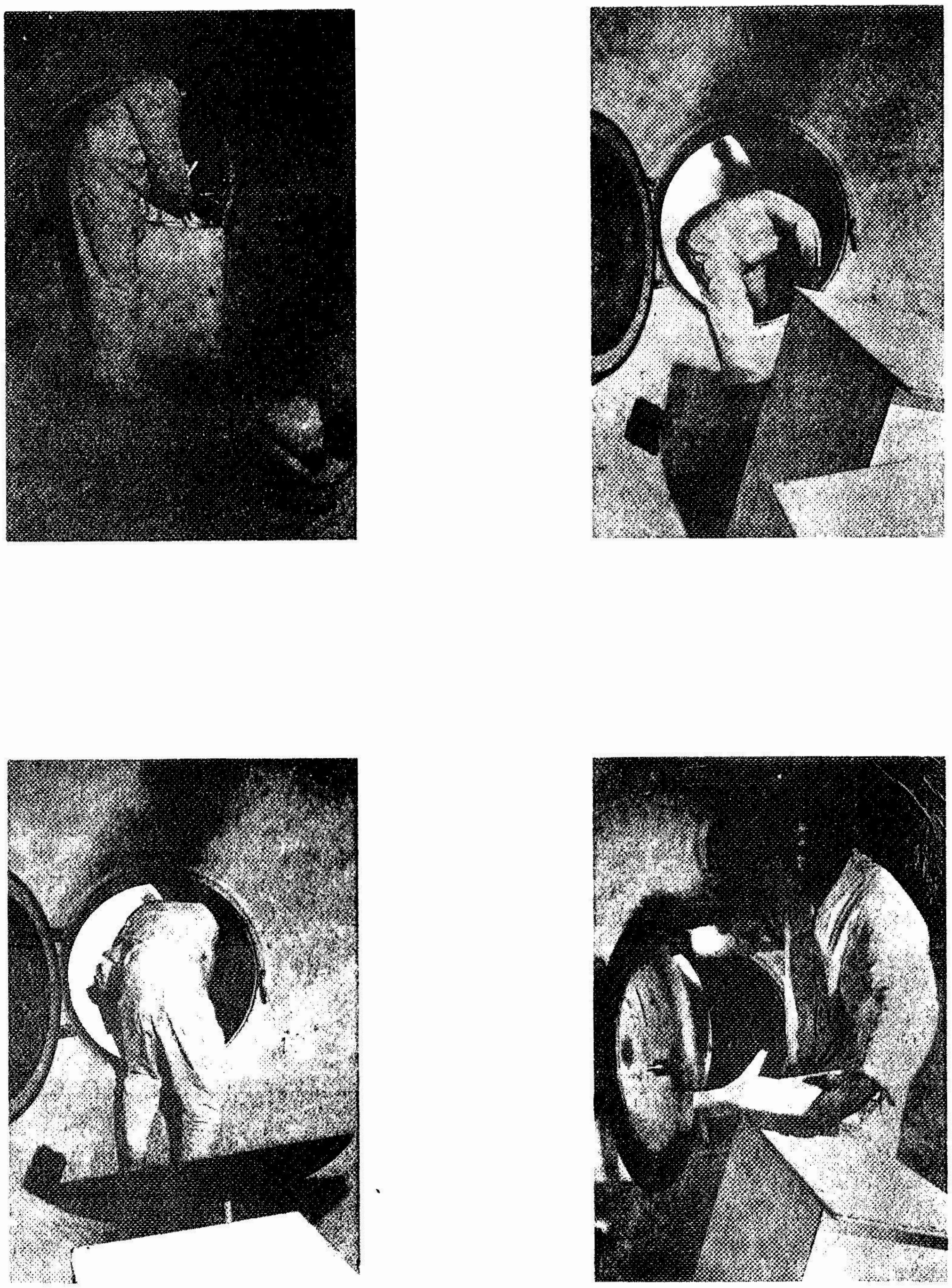

FIGURE 15 - EQUIPMENT TRANSFER INTO SHELTER

Following the transfer, the two subjects began to assemble and position the equipment. Figure 16 is a sequence depicting the assembly of equipment internal to the STEM. The first task was that of storing backpacks and space suit equipment. One subject was in a soft suit mode and the other was dressed in the internal work garment. The first subject doffed his suit and PLSS, and both subjects placed their suits and PLSS at the end of the shelter farthest from the hatch. The subjects moved their suits and PLSS to the air lock after all other equipment had been transferred to the shelter to permit assembly and activation.

The waste stowage section flooring for the back of the shelter was then deployed, followed by the waste water stowage section and its flooring. The slat floors were positioned next, and finally the waste stowage section and step at the shelter-air lock hatch. Complete floor activation took $\sim$ 10 min. Next, the power-generating and ECS consoles were positioned at the back of the shelter, and the storage cabinet, communications pack, and the water tank were installed. These units took $\sim$ 4 min to install. The work table was installed next, and finally the bunks were tied into position. The work table installation took $\sim$ 3 min, and the bunk installation took $\sim$ 5 min. Figure 17 shows a sequence of the deployment of the two bunks. It can be seen in the bunk deployment sequence, with the bunks in the down position and the work table deployed, that the working room for the two subjects is greatly restricted.

The overhead lighting system was installed last during this activation. The lighting installation sequence is shown in Figure 18. This task was performed last because it was noticed earlier that the lighting units hanging from the shelter ceiling were too low to allow the subjects to move around without bumping them. Also, both subjects noted that the movement of the shelter during activation caused the lights to sway back and forth, which was distracting.

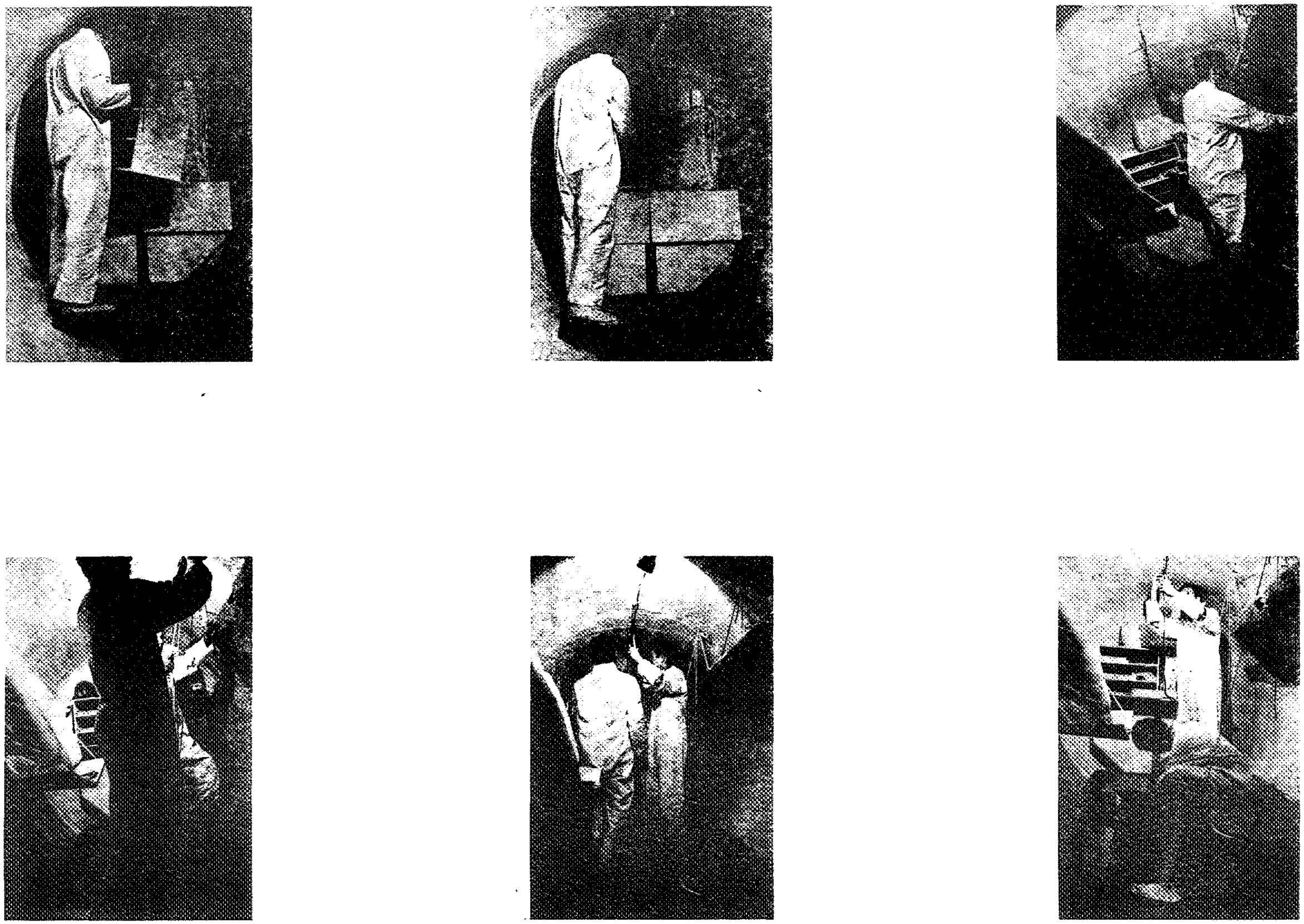

FIGURE 16 - STEM INTERNAL EQUIPMENT ASSEMBLY AND POSITIONING SEQUENCE

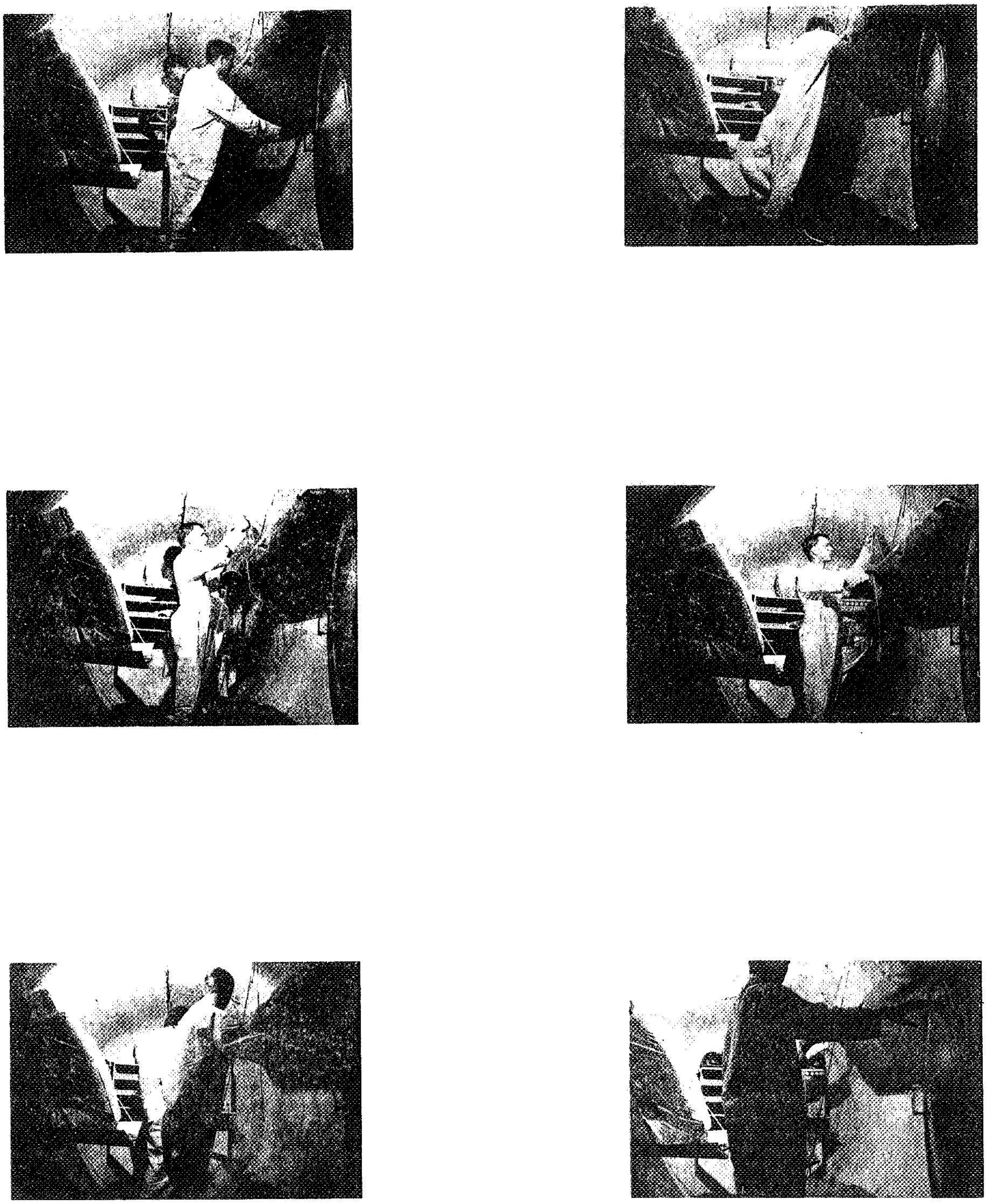

FIGURE 17 - BUNK DEPLOYMENT SEQUENCE

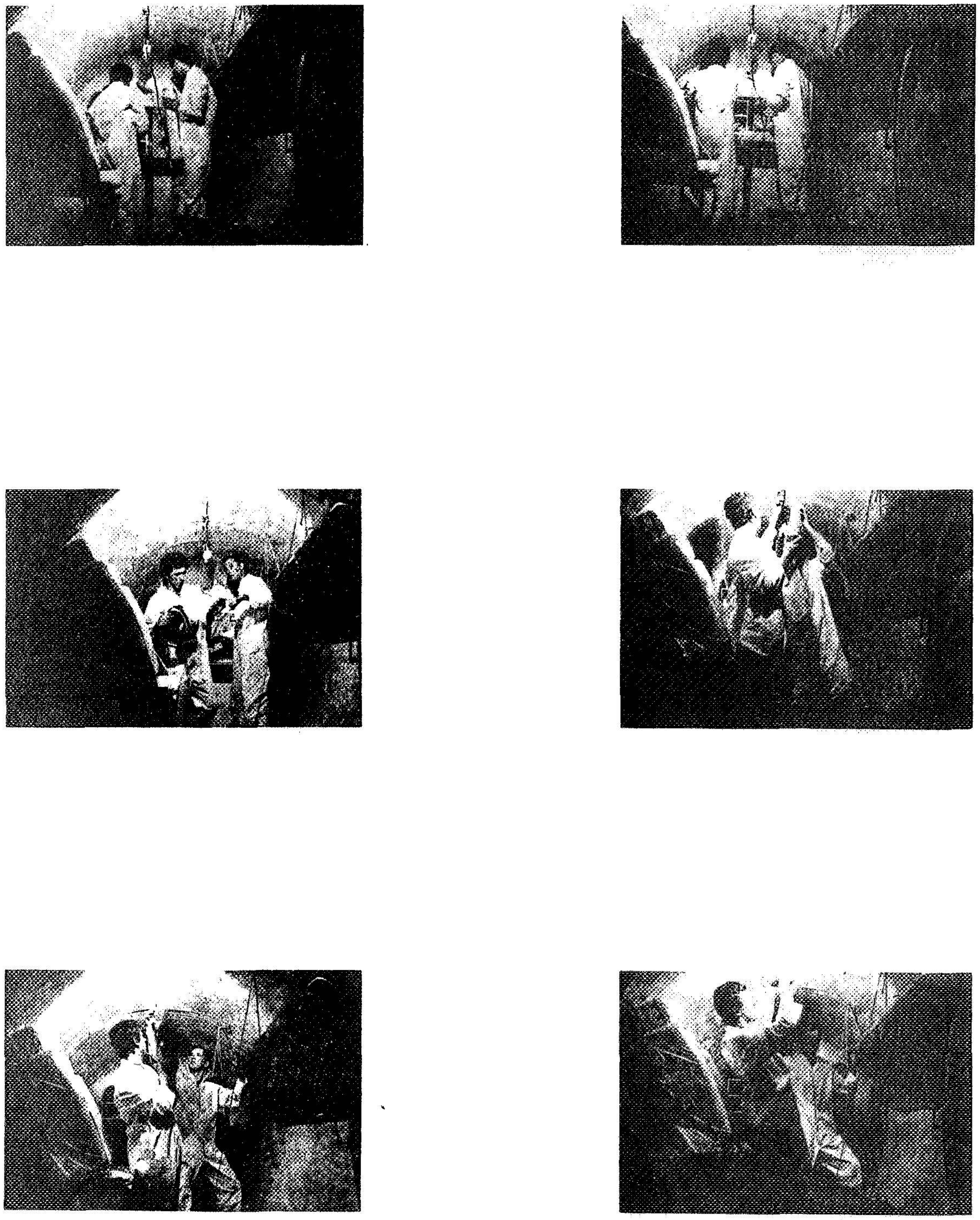

FIGURE 18 - LIGHTING INSTALLATION SEQUENCE

The subjects completed the task by retrieving their backpacks and helmets from the air lock, and positioning them on the work table. The subjects then began general station-keeping operations such as writing, communications, station cleanup, and resting. Figure 19 shows a sequence of the subjects at various positions within the shelter. In this sequence, the spatial restriction of shelter operations can readily be seen, together with the general interactions of the subjects and the internal equipment.

No insurmountable problems were encountered during this internal equipment activation sequence; however, the subjects noted that the configuration of the internal shelter was not designed for ease of operation. For example, with the bunks down, it was difficult to maneuver around the shelter, and with the bunks and work table deployed, the quarters were extremely close. Work at the table opposite the bunks was not practical when the bunks were deployed. Also, with the bunks both on one side of the shelter, the shelter would tend to lean with both subjects in the bunks. The overhead lighting was also poor, since any movements of the shelter caused them to sway and their general position limited overhead clearance where it was most necessary.

In general, it was noted by the subjects that the entire internal configuration should be rearranged for a more comfortable and efficient use of space.

<u>1.A.5.</u>

The complete STEM activation sequence, 1.A.5. (internal equipment transfer and erection) was performed by a single ERA subject wearing an Arrowhead MK4 Mod I full pressure suit pressurized to 1.0 psig. The task called for the subject to load the various internal equipment structures into the air lock, enter the air lock with the equipment, cycle the air lock, and unload the equipment for emplacement inside the shelter. On the first test run it was suggested that the subject enter the shelter and assemble

FIGURE 19 - STATION-KEEPING SEQUENCE

the equipment which he had transferred on each separate cycle. This would allow a resting period in the air lock loading and transfer process which it was felt would be the more difficult of the maneuvers.

The internal equipment structures were first positioned in a semi-circle on the ground outside the air lock. The subject's first task was to pick up the proper unit in the suggested assembly order. Table XI presents the internal equipment installation sequence. The order of assembly presented in Table XI was changed

TABLE XI.--INTERNAL EQUIPMENT INSTALLATION SEQUENCE

1. Air lock waste stowage unit
2. Air lock floor plate
3. Front shelter step stowage section
4. Front shelter step floor plate
5. First (front) shelter slat floor
6. Second shelter slat floor
7. End plate shelter waste stowage section
8. End plate shelter floor plate
9. Waste water stowage unit stowage section
10. Waste water stowage unit
11. 30-inch shelter floor plate
12. ECS module
13. Power system module (power-generating module)
14. Communications pack
15. Storage cabinet
16. Portable water tank
17. Work table
18. Bunks
19. Work chair
20. Air lock toilet

slightly from its original order as presented in CR-66061 (ref. 1). These changes were the result of the familiarization evaluations, and represent a more efficient method of internal equipment activation. The changes involved installation of the shelter flooring prior to installation of the 30-inch shelter floor. The front shelter flooring is installed by assembling the shelter front step in the air lock and placing the step in position prior to entering the shelter. The shelter slat floors are then installed from inside the shelter.

At the beginning of the task, the subject immediately noted that he was having difficulty picking up certain equipment from their prearranged positions around the air lock. The air lock floor plate had been placed flat on the ground, and subject noted that he could not get a hold on its sides. He finally accomplished the pick-up by grasping a slot on the surface of the plate used for attachment of the STEM toilet base.

Two factors were observed at this point. The positioning of the internal equipment in a semicircle in the proper order of installation provides for a more efficient transfer operation. With the large number of equipment sections, it was to the subject's advantage if the units were prepositioned around the air lock after their transfer from the LEM. The order of their installation could be marked on the individual units and thus assure the proper order of transfer through the air lock for internal installation. Transferring the wrong equipment into the shelter hinders efficient assembly and installation because of the limited space in the shelter. When positioning this equipment after off-loading from the LEM storage, care must be taken to lean the flat floor plates in a position that affords handholds for ease of retrieval when preparing for transfer into the STEM. Also, the smaller equipment units, such as the waste stowage units, should be placed upon the larger units, such as the storage cabinet and electronic modules. This would alleviate excess stooping and bending maneuvers which quickly tire the suited subject.

The subject first installed the air lock waste stowage unit and air lock floor plate. He assembled the waste stowage unit, which provides the floor plate base, outside the air lock while on one knee. He then inserted the stowage unit into position in the air lock by reaching through the hatch from outside. Next, he inserted the floor plate in the same manner.

As noted in Task 1.A.3., the air lock hatch would not close with the air lock floor and waste stowage unit installed (i.e., the bottom of the door would not clear the air lock floor plate). To further investigate the problem, the waste stowage section was removed, and an attempt was made to close the door with only the floor plate installed. This method was also unsuccessful. The air lock waste stowage unit and floor plate were removed at this point, and the internal equipment installation task continued.

The subject noted that he found no difficulty during the initial cycle in placing equipment into the air lock. He remained in the air lock and simply pushed the individual equipment units into the shelter. With the last piece of equipment of the first air lock load under his arm, the subject entered the shelter and began assembly of the floor units. He noted upon exiting that the shelter to air lock step did not maintain its position when he put his weight on it. This fact had been noticed in previous runs; however, it proved more of a distraction to the suited subject and could easily be a hazard to operations.

The subject's first air lock cycle had transferred the following equipment into the shelter:

1. Front shelter step stowage section.
2. Front shelter step floor plate.
3. First (front) shelter slat floor.
4. Second shelter slat floor.
5. End plate shelter waste stowage section.
6. End plate shelter floor plate
7. Waste water unit stowage section.

On the second air lock cycle, the subject loaded and transferred the following equipment into the shelter:

1. Waste water unit.
2. 30-inch shelter floor plate
3. ECS module.

The subject assembled these units in the shelter and transferred out of the STEM. The subject commented, at the end of the second transfer through the STEM, that he could not proceed through another run because of the high work level and suit heating. Approximately 1 min 30 sec after exiting from the air lock his pulse was only 80 beats per min, as compared to 110 beats per min during the air lock transfer. The subject noted that the heat in the chamber (84°F) was very uncomfortable, and it was observed that the subject had lost a great deal of body fluid from perspiration during these runs. The subject also noted that his respirations during this final portion of the run exceeded the demand capability of his Arrowhead helmet, and that he felt that he could not get enough air. From past experience this would indicate, since the design of the Arrowhead helmet does permit rapid breathing, that the subject was in actuality overexerted and had exceeded his work limit. At this point, the test director stopped the test because of the subject's physical condition, to preclude a potential safety problem.

The subject's basic biomedical parameters (heart rate, respiration rate, body temperature) had been monitored during this run, and concern over the rapid rise in shelter temperature as early as the middle of the first equipment transfer-assembly cycle had been noted by the test director. The subject's oral temperature had risen to 101° by the middle of the second transfer-assembly cycle. No early signs of over-exertion were detected because of the task work load, and it is assumed that the shelter temperature was the primary cause for the problem. It is not expected that this problem would arise on the actual STEM and Apollo hardware since adequate cooling systems are provided; however, it is presented here as an example of the problems involved should system failures occur.

In the second test run of the 1.A.5. task time line, the life support system was modified to compensate for the high shelter temperatures encountered in Run 1. The internal equipment was loaded into the air lock as in Run 1; however, in this run the subject attempted to load all the internal equipment into the shelter prior to entering the shelter for equipment activation. On the third equipment transfer to the shelter, another problem was encountered. As the subject transferred the power-generating module through the shelter hatch, the subject inadvertently dropped the unit. The impact caused a tear in the major pressure shell of the shelter just inside the door. The puncture was not noticed immediately because of the high noise level from the cooling system and the strip chart recording of the pressurization. At the time, air was being cycled through the shelter at approximately 10 cu ft per min, which was the maximum which we could exhaust through the exhaust port at the 5 psig pressure level. It would have been very difficult to hear the leak because of the sound of the air cycling. There was no problem in stopping the leak while a patch was being prepared. The subject merely placed the palm of his hand over the opening and created an effective seal. Once the patch was made, there was no further trouble maintaining pressure, and the task continued.

The remaining equipment transfers were made in the following groups: Transfer 3, power system module (power-generating module) and communications pack; Transfer 4, storage cabinet and portable water tank; and Transfer 5, work table, bunks, and work chair. The subject had great difficulty in entering the air lock with the larger pieces of equipment. There were no successfully completed tests of equipment transfer by a single, suited subject. Some tests were terminated because of subject overheating and others were terminated because of the subject and equipment interactions while attempting to close the door.

It was determined, after a number of runs, that the best method of internal equipment activation was the utilization of one subject external and one subject internal to the shelter. The external subject would place the equipment inside the air lock and close the outer door; the inside subject would cycle the air lock and remove the equipment for emplacement inside the shelter. Loading the larger equipment units and entering the air lock with these units could be accomplished as emergency procedures; however, the two-subject activation concept appeared more efficient.

Two final unanticipated problems developed during the 1.A.5. task evaluation. First, the STEM was found to "walk" with each cycling of the air lock. When the air lock depressurizes, the lower section of the door falls down and in, and the air lock itself develops a larger "footprint." Since the "footprint" of the major shelter section is minimal because of its high pressurization, the cycling and repressurization of the air lock pushes the main section backward. This motion is in the order of several inches per cycle.

Second, the chocks designed to maintain and steady the STEM's position were inadequate on the slippery surface, such as the thermal mat, and may present a problem on the lunar surface. Movements inside the shelter tended to rock the STEM and move the chocks away from their support positions. After recognizing this problem, the chock configuration was modified by adding a tie line to the chocks that would act as a support cable between the opposite side chocks. In effect, the subject's task would then consist of passing a line under the air lock and shelter innerface and tying this line around the chocks, drawing it taut as need be to maintain the chocks' position. This could also be performed at the terminal end of the shelter with the two chocks that are used in this position. It is possible that some method could be developed to permit the chocks to be preconnected.

CONCLUSIONS AND RECOMMENDATIONS

The purpose of the STEM evaluation program was to determine the operational human factors characteristics in a site closely approximating potential lunar sites. The representative site chosen was an isolated rock quarry whose floor surface exhibited a variety of gentle slopes, indentations, and rock outcroppings consistent with information from the Surveyor and Apollo flights. This site was primarily used to evaluate operations external to the STEM; shelter erection, thermal mat deployment, and equipment transport. Internal operations including shelter activation, station-keeping, and equipment transfer and handling were evaluated at ERA.

During the approximately one-month test period at ERA, an attempt was made to fully exercise the STEM, both in its structural and operational aspects. The rationale was, wherever possible, to subject the STEM and STEM components to forces equivalent to predicted lunar surface forces. For the most part, the loads and forces exhibited were greater than those anticipated during the actual lunar mission because of the 1 G field. For the structural characteristics, a force greater than anticipated served as an additional safety factor, and therefore an evaluation could be made by direct comparison. Operational forces, such as occur in the internal equipment activation, were not found to be marginal; therefore, no problems during actual lunar missions are anticipated because of loads or forces produced by the astronauts. Although the work performed under this contract modification was not intended to specifically apply to the work plan in the original task order, the character and results of these experiments and tests have served to focus subsequent ERA simulation programs under NAS1-8975, Task Order 1.

The two obvious simulation-test artifacts during this program were the increased loads because of 1 G and the substitution of the Arrowhead MK4 suit for the current Apollo model. The effect of both of these was taken into account wherever possible. For those characteristics where increased load was considered a mitigating artifact, static counterbalance force or reduced component weight was utilized. The Arrowhead MK4 suit was pressurized at the 1.0 psig level instead of > 4.0 psig to more closely approximate the actual Apollo suit performance data.

In general, it was concluded that the operational tests at the field site have proven the basic utility of the STEM concept. The test subjects were able to aid in the unpackaging of the STEM from its container. They successfully deployed the thermal mat and the pressurized shelter at a distance from its container. Additional distance did not appear to create any hardship other than additional time for transit. The shelter itself was moved up a gentle slope (approximately 5 percent) by a single test subject with no difficulty. Internal and external equipment was moved to the site and positioned without employing special handling equipment.

The following are the specific conclusions and recommendations developed by ERA as a result of NAS1-8975-1.

STEM Site Selection

There are several considerations for identification of the STEM site. If the STEM is to be left intact for the return of a future flight, it must be far enough from the LEM to insure that it is not damaged during the LEM take-off. For this discussion, let us assume that distance to be a minimum of 120 ft. Since initial considerations do not include special handling or long-range transportation of the shelter and equipment, we will assume the maximum distance from the landing site to be 180 ft.

The annular area offers approximately a 60:1 ratio over the area of the thermal mat (40 ft diameter). This would seem to be adequate; however, there are additional considerations. A portion of this area is restricted because of the take-off path of the LEM vehicle.

The landing area may be similar to that found by Apollo 11, including several small craters and large rocks. It is concluded that a 60:1 ratio of available area over required area for site selection is adequate, and further consideration of equipment transport to the site be given. The discussion of the safety of the shelter during the LEM take-off implies an expectancy to return to the STEM site at some future date. The selected site must, therefore, consider possible future landing sites and their relationship to the present landing site and the present shelter site.

These considerations suggest that additional effort should be placed on an evaluation of package transport modes to the site, and also the possibility of a separate method of thermal control in order to minimize the diameter of the thermal blanket.

Package Transport to Site

The experimental portion of NAS1-8975-1, Task Order 1, when complete will investigate package transport on the lunar surface. Several of the physical aspects of package transport in reduced gravity appear to be obvious, and it is anticipated that the experimental program will verify these assumptions. While man's weight is reduced in the lunar environment, his mass, and consequently his inertia, remain the same. It is expected, as was reported in Apollo 11, that balance is a minor problem since man's ability to sense his weight is concomitantly reduced. Man's capability to apply muscular force appears to remain the same as on earth, but must be modified by his inability to supply weight or friction when necessary. Even though he cannot jump exactly six times as high as he could on earth nor carry exactly six times as much weight of packages, he can jump considerably higher and carry considerably more weight than he could on earth.

It appears that the package loads for the STEM are within the astronaut capabilities; however, package dimensions still leave an area of doubt in that the balance considerations are affected. A suggested technique for long-range carrying of packages is shown in Figure 20. The single subject in the foreground has his

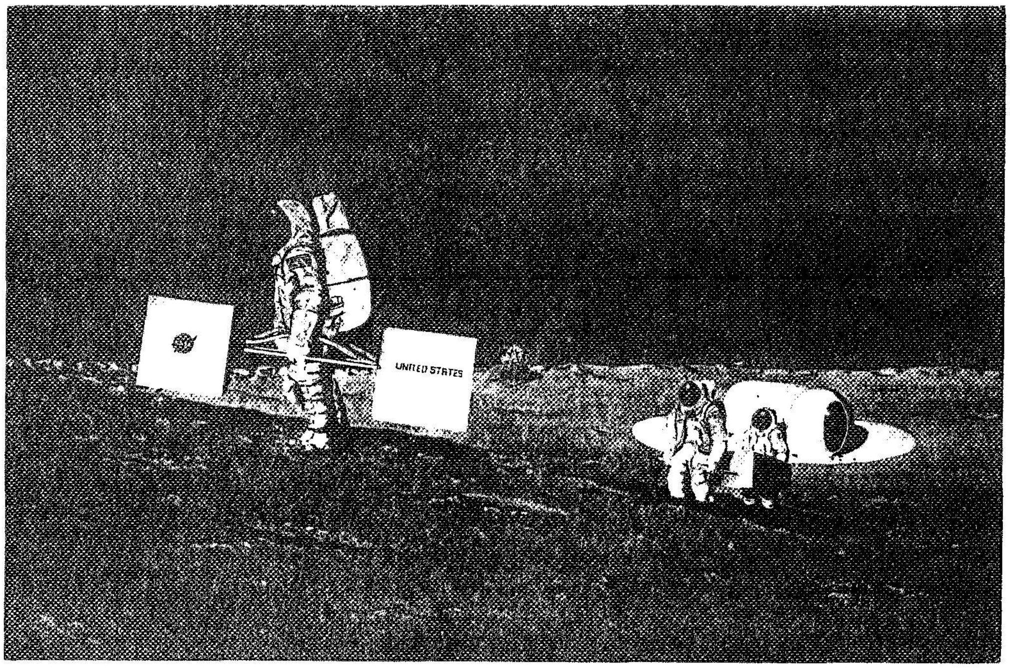

FIGURE 20 - PACKAGE TRANSPORT CONCEPT

package mass equally distributed fore and aft, close to the ground to maintain a low center of mass. The packages are separated by poles placed convenient for hand-carrying. The carrying straps are rigged in such a fashion that the astronaut does not have to keep his hand closed around the pole. He can, however, close his hand around the pole in order to provide a tilt, to avoid an obstacle, or a torque to negotiate a turn. The two astronauts shown in the near background are carrying, in stretcher fashion, a container of sufficient size to house the present STEM. Their handholds are similar to the first astronaut, but they are carrying a greater mass and volume.

Package Transfer Interference

A problem in transferring the equipment modules into the shelter occurred in the air lock. No significant problems occurred in placing any of the equipment modules (large or small) into the air lock or in carrying the modules into the air lock manually. With the larger packages in the air lock, it was difficult to maneuver the package around and behind the hatch, and if the subject was inside the air lock with the package, hatch closure was almost impossible.

The design of the inner hatch and sill was such that passing a package of medium size through the hatch would require marginal balance and reach conditions. This was necessary to avoid loss of balance because of the curved air lock bulkhead. The same problem existed on the shelter side. The transfer and activation sequence previously discussed (i.e., two subjects--one loading the air lock and one shirt-sleeved subject in shelter) will eliminate the interference of the subject in the air lock, and thus expedite package transfer. Recommendations as to the hatch sill configuration are covered under the air lock and shelter discussions.

Puncture of Shell

The shelter floor was punctured during one of the package transfers. The tear in the inner pressure bladder caused no detectable drop in shelter pressure with a 10 cu ft per run inflow. The noise of the inflow air prevented the shirt-sleeved subject inside the shelter from hearing the air leak through the puncture. When he finally noticed the puncture, he simply covered it with his hand until his partner affixed a rubber repair patch.

It appears that the puncture was made by a sharp edge on one of the equipment modules. The subject noted that as he transferred this unit through the hatch, he momentarily lost his balance and possibly leaned on the unit.

The problem underlines the need for a complete evaluation of the transfer methods and the flooring and hatch sill structures since any one or combination of these factors could have caused such a bladder puncture. A requirement for internal equipment would be the feathering of all sharp surfaces and corners. An additional inner abrasion and impact layer on the shelter floor would possibly be a reasonable addition to the STEM design.

STEM Self-Erection

During the deployment of the STEM shelter from its container, minor damage was evidenced on the bottom of the shelter because of abrasion and defects of the shelter container. The flight plan of the STEM calls for self-deployment when the container is opened. If this deployment is rapid, damage similar to that experienced at the field site could possibly be caused by sharp protuberances or rock outcroppings during the lunar mission.

It is recommended that the STEM erection concept allow for a slow controlled deployment. This could be done by adding a restricting strap to the compressed STEM which could be operated by the astronaut to permit slow expansion of the shelter. Another method would be to require controlled addition of gas to the bladder to deploy the unit from the container.

Lunar Surface Variations Masked by Thermal Mat

Both subjects noted that walking on the thermal mat was hazardous after it had been deployed because it had hidden natural depressions and outcroppings in the site surface. Two depressions on either side of the air lock were especially troublesome primarily because of their proximity to the STEM. These depressions were on the order of 1 ft in diameter by 5 in. deep. Even when the defects were visible because of the depressions of the mat, it was extremely difficult to avoid them because of visual degradation of the suit. The situation afforded a constant state of unsteadiness to the subjects while walking on the mat's surface.

It is recommended that the site to be covered with the thermal mat be thoroughly scouted prior to erection, and problem areas be graded or filled in before thermal mat deployment.

STEM Movement During Pressurization Cycle

The entire STEM structure moved (walked) backwards (i.e., toward the external life support system) as a result of each pressure cycle. The distance traveled was small but became significant over six or more air lock pressurization-depressurization cycles. The possibility of damage to the cryogenics stores fixed at the terminal end of the shelter dictates that steps be taken to correct or compensate for the shelter's movements.

It is recommended that a tie down device similar to that described for shelter roll stability be employed at each end of the STEM. This device would also add to the overall stability of the shelter. An effective tie down device is shown in Figure 21. The stakes would be driven into the lunar surface prior to attachment of the tie down ropes.

Activation Sequence

The activation sequence best suited for the STEM concept was evaluated with the following considerations:

1. Safety requirements.
2. Subject's physical requirements.
3. Efficiency
    a. Time requirements.
    b. Order of installation

The subject's physical exertion was a major factor for both safety considerations and task efficiency. Rest periods were evidently necessary from observations of all the activation sequences. The rest periods, of course, lengthened the time line. It was found,

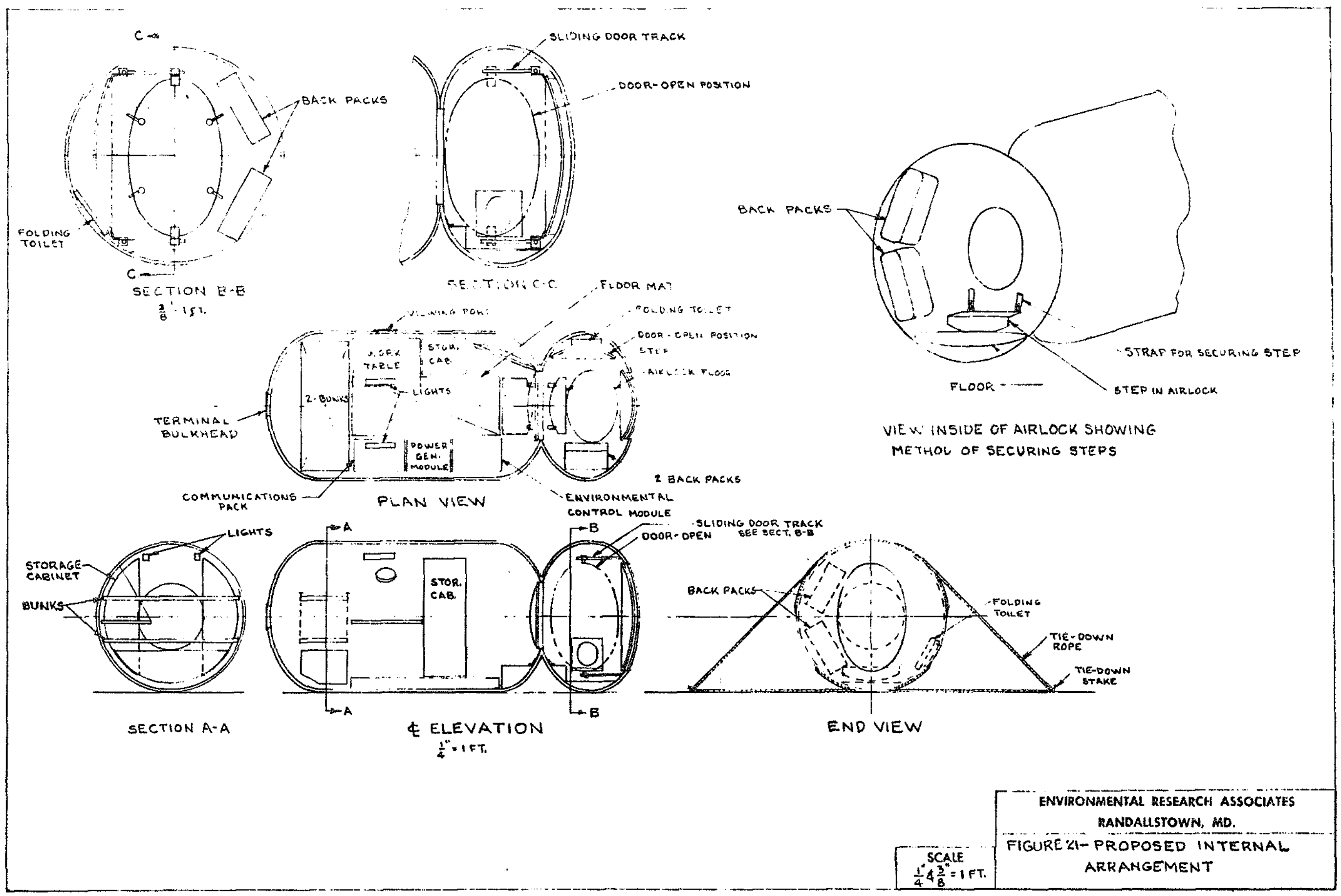

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FIGURE 21 - PROPOSED INTERNAL ARRANGEMENT

however, that by splitting the task load between two subjects, the rest time was minimized.

The activation mode admitting maximum efficiency required two subjects--one subject to remain outside the shelter and load the air lock and the second subject inside the shelter in a shirt sleeve mode. The internal subject controlled the STEM cycling to accomodate the loading and erection of equipment within the shelter.

LEM Packaging - Lunar Surface Interference

It has been noted during the study phase of NAS1-8975-1 that a potential interaction between the STEM package on the LEM and the lunar surface occurs. NASA CR-66061 shows that the height dimension from the upper point of attachment of the STEM stowage container to the lunar surface is 73.25 in. Observation of the photographs from Apollo 11 shows this dimension to be approximately 45 in. This would result in an incomplete deployment of the STEM package, and result in automatic erection over a barrier formed by the raised portion of the container which could give rise to the problems outlined in "STEM Self-Erection."

Air Lock Internal Arrangement

The STEM air lock is required to operate in both the pressurized and unpressurized condition during the lunar mission. Early in the performance of these tests it was noted that the external hatch could not be operated with the air lock flooring in place in the unpressurized state. Subsequent evaluation, using a counterweight to simulate the lunar surface load during subject traversal, supported this conclusion and implies that the design as presently effected is marginal.

Since operations could not be effected with the floor in place, a subsequent evaluation using the toilet without the floor in place was made. With the toilet in place with no floor, the suited subject wearing the backpack could not close the air lock external hatch after entry.

A recommended concept for the STEM air lock configuration is shown in Figure 21. The floor arrangement is comprised of two levels--the lower level containing minimal waste stowage. An intermediate stepway fixed to tabs on the air lock wall is located at the inner hatch threshhold. This stepway can be also detached during entry in the event of interference with package transport. A folding toilet arrangement is also shown which does not interfere with the sliding outer hatchway. The external hatch proposed comprises a sliding concept which eliminates the subject-hatch interactions. The sealing characteristics of the hatch permit pressure-assist and, in conjunction with the symmetrically distributed latches, mitigate the excessive leakage noted on the single point latch concept. It was further noted that because of the interference with the inward opening hatch, the hinges on the door were constantly being deformed. This sliding hatchway eliminates the possibility of this hinge deformation, and thus increases the mission effectivity.

The air lock in this new configuration further permits stowage and servicing of the life support backpacks, which increases the working area and efficiency in the shelter, and also allows servicing of the backpacks in an area which can be isolated from the shelter.

Shelter Arrangement

Two-man operations within the shelter were significantly affected by the stability of the STEM. Entry into the shelter was seriously compromised by movement of the inner sill. With the shelter pressurized, the sill and its support would not remain in position under the most minimum loads. After several incidents involving sill slippage, it was determined by the subjects to eliminate the sill during the erection phase. Sill slippage was less evident after the equipment had been arranged in the shelter. However, it is recommended that the inner sill be handled in a manner similar to that described for the sill in the air lock. This arrangement is shown for the air lock sill in Figure 21.

Location of the equipment, as originally shown in NASA CR-66061, did not lend itself to efficient internal operation. The location of the two bunks on the same side of the shelter amplified the stability problem, and further interfered with the opening of the inner hatch. This would require the bunk to be stowed if one astronaut was to enter the air lock to use the toilet facilities, for example.

Further, the operational station was located at the aft end of the shelter, and appeared to be the logical place to don-doff and service the suit and backpack. This required passage of the suited subject through the shelter in full suit with attendant possibility for interaction with set up experiments and operations of the second subject.

A proposed internal arrangement, taking these factors into account, is shown in Figure 21. The bunks have been located in the aft section, normal to the shelter axis. It is proposed that an annunciator panel indicating the status of the shelter life support be additionally located behind the bunks in the spherical end. This additional location would increase the capability for alert-rest periods.

The basic operating hardware (e.g., power-generating module, life support console, etc.) would be symmetrically located along the walls of the shelter. In this manner the sleep area could be partitioned off for alternate sleep cycle economy. This arrangement further eliminates the inner hatch-bunk interaction previously noted.

It is proposed that the lighting be shifted from the upper center location to fixed positions at the side walls to prevent subject-light interactions, and to increase the ambient light level while minimizing glare.

The viewport shown is an additional element to provide direct visual access for one subject by the other. This port would only be effective when the subject was in view and the port was not obscured by the thermal blanket (not shown). A shutter arrangement could be included to make the port continuously operable. In addition, this location could also serve as a place for equipment which operated through the shell wall (e.g., a small telescope, an experiment vacuum lock, etc.).

This arrangement, in conjunction with the proposed arrangement of the air lock, is considered to significantly increase the efficiency and safety of STEM operations on the lunar surface.

Advanced Concept

The STEM shelter, a soft, inflatable structure, has certain advantages over other shelter concepts. In the early lunar exploration phases, the soft shelter is the only concept capable of being packaged and transported to the lunar surface within current LEM capability. Another feature of this shelter concept is that is can be carried, directed, and positioned at the site by two suited subjects. Our studies and experiments indicate that two suited subjects could carry the packaged shelter to a remote location selected as a site for a minimum lunar base. In order to gain the full value of the soft, inflatable shelter concept, additional materials research must be performed to include:

1. The capability to attach experimental equipment through the shelter walls.
2. The ability to couple shelter sections in order to add to the working volume of the shelter.

Figure 22 shows a modular concept in which the initial shelter section left from a previous flight is about to be joined with

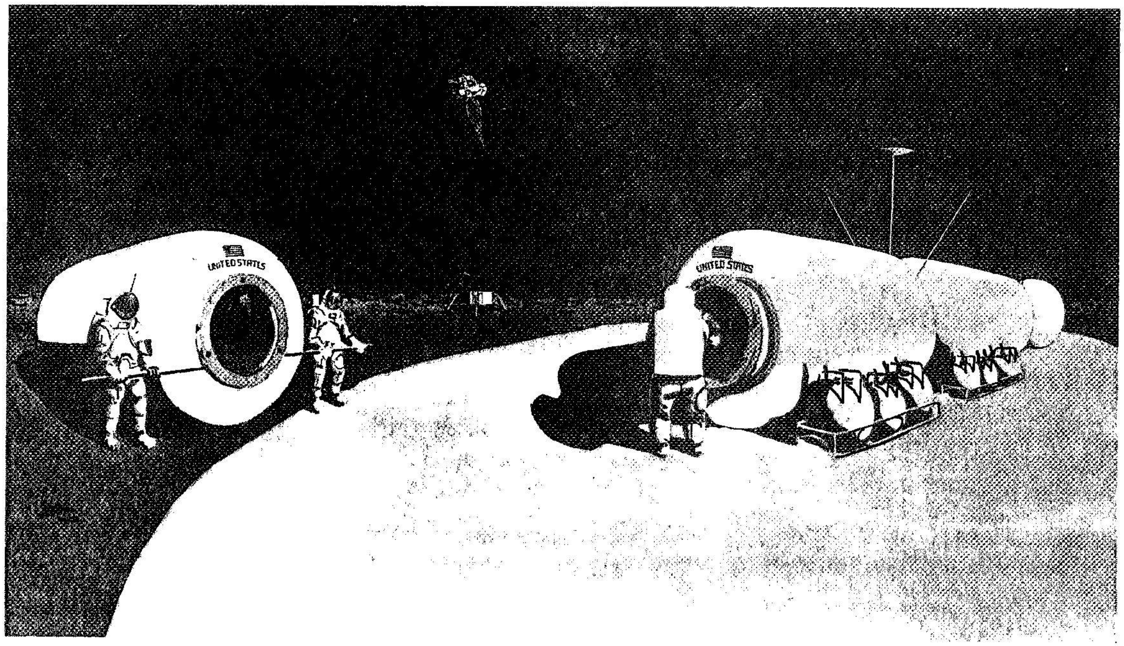

FIGURE 22 - MODULAR STEM CONCEPT

an additional module primarily designed for laboratory work. After several visits, a sizeable shelter and laboratory complex would have been erected for lunar surface explorations and experimentation.

APPENDIX A

DEPLOYMENT SEQUENCE RECOMMENDED

SHELTER CONTAINER

1. Thermal mat is removed, unfolded, and spread on the lunar surface.
2. Restraining laces (securing the shelter to the container) are released.
3. Shelter is removed from container and rolled to the center of the thermal mat.
4. Shelter chafing and retaining fabric cover is removed. (Shelter automatically deploys.)
5. Shelter is repositioned at the center of the thermal mat, and oriented vertically with respect to the air lock entry door.
6. External chocks are placed (4 positions).
7. Package cover is positioned as ramp for air lock door.

CRYOGENIC PACKAGE

1. Cryogenic module is transported to the terminal end plate of the shelter.
2. Cryogenic module is positioned next to domed end.
3. Module leads are connected to appropriate plugs on the terminal.
4. Tankage valves are opened.

EQUIPMENT/MISCELLANEOUS PACKAGE

1. Combination storage-floor sections are installed in the air lock and hatch area.
2. Slat panel floors are unrolled and laid on the pressure bladder in the center section of the shelter.
3. Remaining storage-floor sections are installed.

LIFE SUPPORT PACKAGE

1. Life support package covers which are to serve as space radiators are pinned at their longitudinal apex to form a triangular structure.
2. Life support subsystem lines are connected into the terminal outlet.

APPENDIX A

DEPLOYMENT SEQUENCE RECOMMENDED--CONCLUDED

3. The triangular structure is placed in the shadow of the shelter.
4. Thermal blanket is connected to the thermal blanket control lines.
5. Thermal blanket is furled around the shelter base.
6. Power module is installed on the waste water storage-floor section near the terminal plate.
7. Environmental control module is installed on the waste water storage-floor section near the terminal plate.
8. Communications pack is placed on the power and ECS modules.
9. Supply cabinet is placed on the power and ECS modules.
10. Remaining line connections between the system modules and the terminal outlets are made.
11. Astronaut enters the STEM and initiates the ECS, LS.
12. Remaining secondary equipment is installed in the shirt sleeve environment.

APPENDIX B

LOG SUMMARY OF STEM EVALUATION

20 July to 3 September 1969

7/20 Assisted in demonstration of STEM depressurization, folding, and packaging procedures at NASA Langley.

7/31 Received STEM and STEM hardware at ERA facility.

8/4 Preoperation pressurization tests: Laboratory operations.
Task 3--overall configuration and equipment checkout.
Task 4--initial shirt sleeve equipment assemblies and cycles (transfers).

8/5-8 Design and checkout of life support, communications, and photographic operational equipment for evaluation runs--internal and external operations.

8/11 Photographic measurements and evaluation of overall set-up from a photographic point of view--test director and chief scientist.
Initial calculations for life support systems (air flow and temperature controls, humidity, and CO_2 controls)--project engineer and chief scientist.
Initial discussions on field operation procedures and equipment.

8/12 Lab operations--Task 5. Single subject cycling through STEM configuration. Initial subtask evaluations--various transfer/suit configuration.
Run 1--no backpack, unpressurized, Arrowhead suit (MK4).
Run 2--PLSS backpack, unpressurized, MK4.
Run 3--PLSS, 1 psig, MK4.
Run 4--PLSS, 3.7 psig, MK4, equipment transfer into air lock.
Run 5--PLSS, 3.7 psig, MK4, equipment transfer into shelter.
Debriefing subject Patkus.

8/13 Lab operations--Task 5. Single subject cycling through air lock and shelter, including equipment transfer and erection.
Task 5 time line evaluation.
Debriefing.

8/14 Lab operations--structural performance test. Simulation of 1/6 G air lock and subsequent evaluation of air lock floor.
Analysis and write-up of structural performance test and Task 5, Runs 1-5, and Task 5, Run 1 time lines.

APPENDIX B

LOG SUMMARY OF STEM EVALUATION--CONTINUED

8/15	Preparation of time lines and task descriptions for field operations of Tasks 1-5.
8/18	Modifications to STEM life support and communications as deemed necessary for field operations and as indicated by the initial task run experience.
8/19	Design, construction, and installation of subject's self-contained communications for field operations of Tasks 1-5. Preparation and checkout of dual life support systems (self-contained and umbilical) for 2 subject operations of STEM Task 2.
8/20	Lab operations--subject Morris. Checkout of backpack communications and life support systems. Task 5--low pressure equipment transfer and assembly. Familiarization of subject with proper task procedures (dress rehearsal run).
8/21	Internal air system modification because of excessive heat build-up and noise level.
8/22	Closed circuit TV installation and checkout.
8/25	Lab operations--subject Morris--Task 5. Cycle shelter and air lock with pressure-suited subject; equipment transfers and assembly. Floor puncture sequence. Debriefing--internal/external photographic sequences.
8/26	Lab operations--subject Morris--Task 5. Cycle shelter and air lock with pressure-suited subject. Final laboratory run--internal/external photographic sequences. Magnetic taped task time line. Checkout of all systems for field operations.
8/27-28	Preparation for field operations. Final task/time line write-up for field operations, Tasks 1-5.
8/29	Field operations--quarry. STEM equipment and life support setup. Communications and photographic setup. Task 1--unpackaging of STEM from container, shirt-sleeved subject. Thermal mat deployment. Subject Morris. Photographic coverage--16 mm olor, 35 mm B/W.

APPENDIX B

LOG SUMMARY OF STEM EVALUATION--CONCLUDED

8/30 Field operations--quarry.
Task 1--unpackaging and deployment of STEM by shirt-sleeved subject.
Unpackaging of STEM.
Task 3--pressure test STEM unmanned.

8/31 Field operations--quarry.
Task 2--unpackaging of STEM container by pressure-suited subjects.
Deployment of thermal mat.
Unpackaging of STEM.
Deployment of STEM in center of thermal mat and chocking STEM into position.
Task 3--pressure test STEM unmanned.
Subjects--Morris and Mattingly.
Photographic coverage--16 mm color, 35 mm B/W, 4×5 color Poloroid, stereo 35 mm color, 2-1/4×2-1/4 color and B/W.

9/1 Field operations--ERA.
Internal equipment deployment--internal photographic sequences only.
Task 4--cycle STEM with shirt-sleeved subjects inside.
Subjects--Patkus and Morris.
Photographic coverage--internal only. 16 mm color, 2-1/4×2-1/4 color and B/W.

9/2 Dismantling of life support systems, communications, closed circuit TV, and lighting from internal STEM.
Packaging of STEM and ancillary equipment.

9/3 Return of STEM to NASA Langley.