NASA Contractor Report 3854

Space Station Crew Safety Alternatives Study—Final Report

Volume I—Final Summary Report

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FOREWORD

This report is one of five documents covering the results of the Space Station Crew Safety Alternatives Study conducted under Contract NAS1-17242. The study documentation is designated as follows:

Vol. I	- Final Summary Report (NASA CR-3854)
Vol. II	- Threat Development (NASA CR-3855)
Vol. III	- Safety Impact of Human Factors (NASA CR-3856)
Vol. IV	- Appendices (NASA CR-3857)
Vol. V	- Space Station Safety Plan (NASA CR-3858)

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1. INTRODUCTION

CONTRACT HISTORY AND BACKGROUND

The operation of a space station initiates new issues regarding crew safety. Potential crew activities include construction, maintenance and repair of spacecraft, and scientific and applications experiments. These roles greatly expand man's activity in space but also increases the range, duration, and level of exposure to risk to crewmembers significantly. Efficient, economic space transportation system (STS) use does not permit continuous standby of a STS orbiter at the space station, and therefore, the operational approach differs from Skylab and the Russian Soyuz programs where Earth-return systems are available at the station. As the scope and level of manned activities expands, so does the issue of crew safety. More importance must be given to strategies, alternative strategies, and other solutions as necessary to counteract threatening situations. This study emphasis is to identify strategies or the combination of strategies which are cost effective and meet safety needs for the total spectrum of relevant safety issues. This study will examine the threats (both natural and induced) at the space station and recommend appropriate control strategies. The strategies will include alternative strategies such as escape/rescue.

The primary study contract was let in January, 1983. See Figure 1-1. At the initial Rockwell-NASA meeting, additional scope was requested, that of extra-vehicular activities (EVA). EVA is, therefore, included in the study to assess EVA associated threats. The initial contract conclusion in association with research of analogous activities such as nuclear submarines and arctic station activity (representative space station situations of confinement in a hostile environment) dictated a need to also examine information regarding human behavior. The NASA Life Sciences organization at Ames, as a result of these findings, added funds to the contract for an additional study extension to assess potential hazards to crew safety stemming from human factors/behavioral issues. This study report, therefore, attempts to provide a compendium of the results from both additional effort contract extensions.

Results of the initial study were presented to the space station contractors at a briefing held in Downey, California at the midpoint in the total effort. On November 9, 1983 the results were also presented to NASA at its headquarters (CDG, Concept Development Group). The presentation was repeated at Langley on November 10, 1983 and at Ames on November 21, 1983. Video tapes of the initial study interim briefing at Langley were made available to the other NASA Centers. At an Ames Productivity Symposium during the week of February 27, 1984, a third quarter contract presentation briefing was given which summarized the first phase of the study and the mid-point of the human factors effort. Briefed were NASA and an audience of contractors.

Subsequent study products were presented as noted.

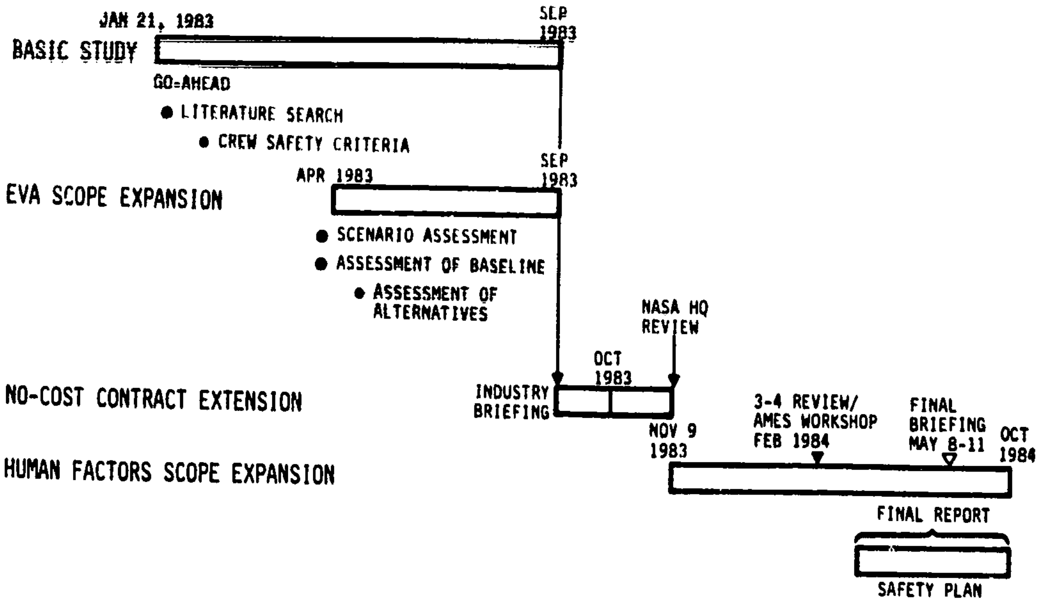


Figure 1-1 Study Contract Key Milestones

DESIGN TO PRECLUDE

THREAT / ELEMENTS THAT PRECLUDE	FIRE	TOXICITY	EXPLOSION	LOSS OF CRITICAL FUNCTION
2-GAS SYSTEM -14.7 PSI	●			
MATERIALS/WIRING CONTROL	●	●	●	
FLUID LINE CONSTRUCTION	●	●	●	
BONDING/GROUNDING	●		●	
IGNITION SOURCE CONTROL	●		●	●
FAIL-SAFE DESIGN & SAFETY FACTORS	●	●	●	●
INTERLOCK/INHIBIT CRITICAL FUNCTIONS				●
PRESSURE VESSELS •FILAMENT WOUND •HIGH SAFETY FACTOR	●		●	●

Figure 1-2 Synergism of Strategies - Design to Preclude

Study Products

A number of documents have been prepared during the course of the contract. These are listed below:

IL294-400-83-040 - Kickoff Briefing Feb. 1983
SSD83-0047 - Space Station Crew Safety Criteria Apr. 1983
SSD83-0064 - Midterm Briefing May. 1983
SSD83-0106 - Interim Briefing Nov. 1983
SSD84-0106 - Third Quarter Status Briefing Feb. 1984
SSD84-0052 - Space Station Crew Safety Alternatives Study - Final Briefing May. 1984
SSD84-0053 - Space Station Crew Safety Alternatives Study - Final Report
  Vol. I - Summary Report (NASA CR-3854)
  Vol. II - Threat Development (NASA CR-3855)
  Vol. III - Safety Impact of Human Factors (NASA CR-3856)
  Vol. IV - Appendices (NASA CR-3857)
SSD84-0055 - Vol. V - Space Station Safety Plan (NASA CR-3858)

The results of the Space Station Crew Safety Alternatives assessment are contained in five volumes, the designated NASA Contractor Report Numbers of which are noted above. References are included in the Appendix A of Volume IV - Appendices. Volume V is a safety planning document which identifies programmatic issues and defines strategic task interrelationships.

PURPOSE

The complete study objective is to define space station crew safety requirements and assess the various strategies developed to meet these requirements. Included in the objective is : (1) to develop a crew safety philosophy and attendant criteria; (2) to assess potential threats to crew safety associated with the existing space station design and operational concepts with its attendant range of potential space activity scenarios in order to identify key crew-safety issues; and (3) to assess the various crew-safety strategies necessary to meet the desired criteria in terms of reasonable cost. To accomplish this, it became necessary to identify those threats which could escape/rescue decisions. Additionally, it was deemed desirable to look at the baseline station and establish how it performs with respect to identified threats. The baseline is the configuration developed by Rockwell for the Space Station circa January 1983 using the shuttle orbiter at regularly scheduled resupply intervals.

SCOPE

The scope of this study considers (operationally) the first 15 years of accumulated space station concepts currently in evaluation by NASA for an initial operational capability (IOC) during the early 1990's. Crew safety threat considerations defined by the original Statement of Work are: individual illness or injury; system failures and operational accidents; and external threats. These threats are on-orbit debris, ground support and STS problems, and briefly considering indirect and direct effects of military actions. It is intended that the depth of analysis be consistent with identifying key issues for crew safety; defining key design, operational, and cost features of various alternative strategies; and determining appropriate crew-safety criteria and concepts for use by evolving future space station studies.

The logic used for the entire study considered three key points as significant: First - philosophy; "How much safety is necessary (i.e., cost effective?"); second, "What are the threats that the program is prepared to deal with?", and third, "What are the strategies and interdependence of these strategies to meet the criteria developed to deal with the threats?" A philosophy of "Cause no damage to space station or injury to crew which would result in a suspension of operations" was selected. Table 1-1 provides a list of the threats identified during the study. In essence the criteria takes the philosophy and restates each threat in terms of the selected philosophy. The strategies were developed to satisfy identified criteria. The strategies, in general, are documented in three categories. These three are: design requirements, operational requirements, and safety device solutions or contingency requirements.

TABLE 1-1 SPACE STATION CREW SAFETY
THREAT LIST

- Fire
- Leakage
- Tumbling/Loss of Control
- Biological or Toxic Contamination
- Injury/Illness
- Grazing/Collision
- Corrosion
- Mechanical Damage
- Explosion
- Loss of Pressurization
- Radiation
- Out-of-Control IVA/EVA Astronaut
- Inadvertent Operations
- Lack of Crew Coordination
- Abandonment of Space Station
- Electrical Shock
- Meteoroid Penetration
- Stores/Consumables Depletion
- Intrusion/Attack
- Structural Erosion
- Orbit Decay
- Loss of Access to a Hatch
- Temperature Extremes
- Debris
- Free Orbit (EVA Astronaut)

Regardless of how well the designs are engineered, the summary is that there will always remain residual threats associated with any baseline. There are several methods one can use to deal with some of these residual threats and perhaps the best is the development of new technology. A second alternative method (which, incidentally is where the study got its name) to new technology development, is to apply developed escape or rescue options. The third method which occurs on all space programs, is to elect to accept the risk associated with particular problems that are above a desired threshold of risk exposure. The magnitude of the threshold is driven principally by the selected Space Station safety philosophy.

STUDY SUMMARY

The Space Station Crew Safety Alternatives Study is complete and several areas are well defined; these are:

Threat and Strategy Development

Identification of Threats to The Space Station - Both natural and induced threats were examined with a total of 25 threats identified and defined. A decision was instituted to place emphasis on those major threats which are configuration "drivers". Nine threats fell into this category: fire, contamination, radiation, injury and illness, debris, micrometeriod penetration, depressurization and explosion. Although the other 16 threats are some which could present equally serious consequences, priority for definition is restricted by resource constraints for the study. Available resources have been used to develop and illustrate strategy concepts for the nine threats considered to be "configuration drivers".

Strategy Development - Some of the strategies were found as synergistic with regard to the other threats. Fire was an example where the strategies taken to preclude its occurrence, compounded the toxic contamination issue and the explosion threat. Figure 1-2 illustrates this synergism, where, in the case of fire/explosion, the strategies or solutions tended to complement one another. For some of the other threats such as debris and radiation, the solutions tend to impede each other. For example, in the case of ionizing radiation, it is apparent that the strategy should be a multiwall vessel with a absorbing filler to screen secondary radiation and barriers to reduce secondary radiation, (viz, the level of REMS that accumulate before the programmed use life is over). Non-ionizing radiation protection is also indicative of multiwall protection. For the debris threat, an optimum solution is a dual wall with no filler, enclosed in an evacuated annulus established by the walls such that impact energy is spread over a larger area. These considerations present a conflict for exterior wall design. Also, for visual sensing, one may use dual transparencies; consequence reduced transmissivity. A dual wall is also desirable for pressure safety considerations. For temperature considerations multiwall with insulation is preferable. (See Figure 1-3.) As one can determine, station exterior wall considerations regarding these particular threats result in significant barrier system design tradeoffs. These strategy areas driving design tradeoffs associated with each of the threats would in themselves require significant study as the selected approach is resolved.

Threat/Strategy Conclusions

It became apparent as the study progressed that creative design solutions and operational work-arounds can provide a defense hierarchy for all the classes of threats except one -- that of injury/illness. This category becomes the singular justification for an escape/rescue vehicle located at or in proximity to the station. Injury and illnesses, when categorized, define the population of each of the categories requiring rescue. The population is shown in Figures 1-4 and 1-5. Note that a ballistic reentry vehicle (occupant experiences between 6-8 g's) could not accommodate any of these cases due to the g load. A lifting body solution is the indicated. When one also explores the percentage of a large crew that could need to escape, an even more disturbing discriminator emerges; lack of capacity. Figure 1-5 shows typical causes which could drive the need for escape for 1 to 3 people.

BARRIER ISSUE	STRATEGY REQUIREMENTS	BARRIER REQUIREMENTS
IONIZING RADIATION	MULTIWALL WITH ABSORBING FILLER	REDUCE INTERNAL RADIATION TO TBD REM
NON-IONIZING RADIATION	MULTIWALL	REDUCE TO 10 mW/cm^2
DEBRIS	DUAL WALL - NO FILLER IN EVACUATED ANNULUS	TBD GRAM PARTICLES AT TBD VELOCITY
VISUAL SENSING	DUAL TRANSPARENCIES	TBD TRANSMISSIVITY
PRESSURE	DUAL WALL	TBD MAX ΔP
TEMPERATURE	MULTIWALL WITH INSULATION	TBD MAX ΔT

- INTERACTING ELEMENTS OF BARRIER SYSTEMS SHOULD BE STUDIED & ASSESSED AS AN INTEGRATED SYSTEM

Figure 1-3 Barrier System Issues for Habitable Modules

SEVERITY	CONSEQUENCES	EXAMPLES OF POSSIBLE INJURY	SPECIAL TREATMENT & PROVISIONS REQUIRED
MAJOR INJURY	BED REST	FRACTURE OF BACK, LEG, OR CRANIUM; CHEST WOUND; POISONING	X-RAY; TRACTION DEVICES, BRACES, CASTS; CLINICAL LABORATORY TESTS; GASTRIC LAVAGE; ANTICONVULSANTS; SURGICAL CLOSURE PROVISIONS
	RETURN TO EARTH	FRACTURE OF NECK WITH PARALYSIS, HEAD INJURY, COMA, FOREIGN BODY IN TRACHEA, THIRD-DEGREE BURNS	X-RAY; TRACTION DEVICES, BRACES; BLADDER CATHETER; ANESTHESIA; BLOOD TRANSFUSION; CLINICAL LABORATORY TESTS; FLUOROSCOPE; INTRAVENOUS FEEDING & FLUID REPLACEMENT
MINOR INJURY	NO LOST TIME	ABRASION, BLISTER, MINOR LACERATION	COMMON FIRST-AID-KIT PROVISIONS
	LIMITED DUTY	SIMPLE FRACTURE OF WRIST OR ARM, JOINT SPRAIN, MINOR MUSCLE STRAIN, MINOR BURN	X-RAY, PRESSURE BANDAGES, COLD PACKS, SPLINTS & CASTS, ANALGESICS, ANTIBIOTICS

Figure 1-4 Possible Crew Injuries and Required Treatment and Provisions

SEVERITY	CONSEQUENCES	EXAMPLES OF POSSIBLE ILLNESS	SPECIAL TREATMENT & PROVISIONS REQUIRED
MAJOR ILLNESS	BED REST & LOST TIME (>1 WEEK)*	APPENDICITIS, BRONCHIAL PNEUMONIA; INFECTIOUS HEPATITIS, MENINGITIS-EPIDEMIC, PROSTATITIS, THROMBOPHLEBITIS	ANTIBIOTICS, INTRAVENOUS FLUIDS, SURGERY, X-RAY, EXPECTORANTS, CLINICAL LABORATORY TESTS, STEROID THERAPY, ANALGESICS, CATHETERIZATION, INTENSIVE CARE, ISOLATION; ANTICOAGULANT
	RETURN TO EARTH	ENCEPHALITIS, MYOCARDIAL INFARCTION, ILEITIS	INTRAVENOUS FLUIDS, TRACHEOTOMY, SEDATIVES, OXYGEN, ANTICOAGULANT, CLINICAL LABORATORY TESTS, ANTISPASMODICS, SPECIAL DIET
*SERIOUSNESS & EXTEND OF THESE ILLNESSES MAY REQUIRE RETURN OF CREWMEN TO EARTH			
MINOR ILLNESS	NO LOST TIME	ATHLETES FOOT, DERMATITIS, CONJUNCTIVITIS, RHINITIS, URETHRITIS, PHARYNGITIS, ABSCESS OF MOUTH & GUM	FUNGICIDES, STEROIDS, ANTIBIOTICS, ANTIHISTAMINES, NOSE DROPS, DECONGESTANTS, ANALGESICS, ANESTHETIC LOZENGES, IMPROVED HYGIENE PRACTICES
	LIMITED DUTY OR MINIMUM LOST TIME (<1-WEEK)	BRONCHITIS, CYSTITIS, DIARRHEA, DYSENTERY, FEVER, COMMON COLD OR INFLUENZA, GASTRITIS	ANTIBIOTICS, DECONGESTANTS, ANTITUSSIVES, ANALGESICS, CATHARTICS, ANTISPASMODICS, ANTIPYRETICS, ISOLATION, ANTIEMITICS, SPECIAL DIET

Figure 1-5 Possible Crew Illnesses and Required Treatment and Provisions

Earlier observations that most of the threats can be mitigated by creative design solutions and operational work-arounds, should not be interpreted as possessing the absence of a risk element. On the contrary, several threats require precise strategies that must be well-defined early in the program. Table 1-2 lists the summary safety issues selected during the study as requiring a high priority of definition early in the program. Included in Table 1-2 are typical recommended strategies. Figure 1-6 depicts representative strategies involved in dealing with the debris threat. Note that there is a finite amount of risk which must be accepted for each of the threats.

Added strategies are shown in Volume III of this report. For example, past American space efforts have focused primarily on the physiological aspects of crew activity and today, added emphasis is considering the psychological. It is suggested by the illustration that an appropriate response to the lack of coordination issue requires a balanced focus similar to our present efforts, augmented by many of the techniques used by the Russians.

TABLE 1-2 STUDY SUMMARY ISSUES

ENVIRONMENT (THREATS)	THREAT	STRATEGIES
NATURAL	• DEBRIS • RADIATION	• INTEGRATED BARRIER SYSTEM DEVELOPMENT
INDUCED	• CONTAMINATION	• MATERIAL REQUIREMENTS DEVELOPMENT, SCREENING CATALOGING, REAL-TIME MONITORING, INVENTORYING, DISPOSAL & CONTROL SYSTEM
	• LACK OF COORDINATION* • HUMAN/SOFTWARE SYSTEM INTERACTION • MAN/MACHINE INTERACTION • ATTITUDE ISSUES	• CREW SELECTION ORIENTATION, INDOCTRINATION & TRACKING PROGRAM • CREW (ORBIT/GROUND) TRAINING PROGRAM
INHERENT	• INJURY/ILLNESS	• LOW "G" RESCUE VEHICLE • REAL-TIME HEALTH MONITORING • CREW FITNESS MAINTENANCE • MINIMUM MEDICAL FACILITY

* NOT INITIALLY RECOGNIZED AS MAJOR THREAT

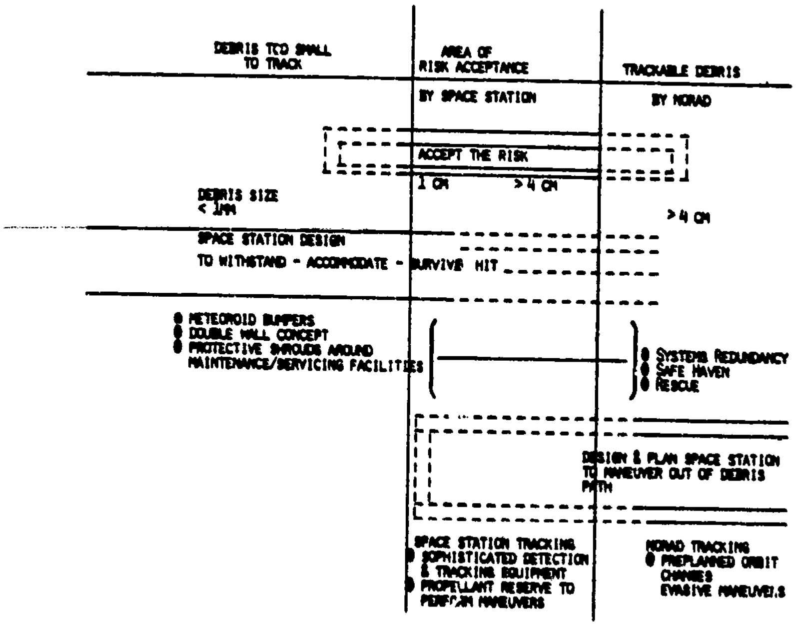


Figure 1-6 Debris Strategy Options

ALTERNATIVE STRATEGIES

This segment of the summary highlights the options for escape and rescue. Several questions were examined, i.e. "How realistic is it to evacuate the space station if the need arises?"; "Do the threats require an immediate response?"; "What are the technology risks?"; "Are the costs prohibitive?"; and "How many of the crew will the escape/rescue mode accommodate and how long does it take to escape (leave the area of threat)?"; "What is the relationship between time to repair vs. time-to-adverse-impact?" (It should be recognized that these scenarios postulate various degrees of calamity); and "Why would less than a full crew desire to escape?" The major postulates why less than a full crew would wish to return to earth are shown in Table 1-3. As previously discussed the medical issue is the only one identified that would cause credible escape or rescue situations and it implies the need for a lifting body rather than a ballistic reentry vehicle. If the station program elects a one man or two man escape or rescue vehicle, it would evolve serious questions: 1) "Can the program tolerate 8 or 4, or even 3 separate escape vehicles at the station?"; it is difficult, and significantly costly, to retrieve a number of escape vehicles simultaneously. 2) "What is the time required to enter the escape vehicle?" Designs (for other than medical evaluations) should contain a dedicated breathing system to enhance the initial overall available time such as associated with entry of an EVA-type escape

Next, Figure 1-7 shows generic options for escape and rescue which may be grouped within 5 categories. Option A has, located at the space station, an escape vehicle which escapes to earth with the actual rescue performed by the Navy or Air Force. Option B is a manned Orbital Transfer Vehicle (OTV) and provides the crew with opportunities to relocate to a second station, to pick up needed repair parts and return to space station, repair the station, and continue operations. Option C is an external safe haven. In this option, the crew egresses to the station and awaits rescue by the orbiter or friendly vehicle which then proceeds to earth by some preselected means. Option D consists of an internal safe haven which provides for rescue by the orbiter or other friendly vehicle at a later time. A ground launched supply vehicle or rescue vehicle, can be sent as the Russians did in late 1983, to repair the space station and thereby allow it to resume operations. Also, if a rescue vehicle were available and repair was not feasible, the crew could reenter and return to earth. The response time for an internal safe haven is highly favorable and requires a short time to enter and because the capability is inherent to the Space Station, it presents low technical risk.

TABLE 1-3 WHAT WOULD CAUSE ESCAPE
OF LESS THAN FULL CREW?

1 MAN?	2 MEN?	3 MEN?
o SOLE SURVIVOR	o TWO SURVIVORS	o THREE SURVIVORS (REMOTE PROBABILITY) ESCAPING IMPENDING DISASTER
o PHYSICAL MEDICAL ISSUE (CUT, SOME BURNS)	o INDIVIDUAL CREWMAN MEDICAL ISSUE REQUIRING CONSTANT AID BY MEDIC	o DECEASED
o PSYCHOLOGICAL ISSUE	o PHYSICAL o PSYCHOLOGICAL	
o DECEASED	o DECEASED	

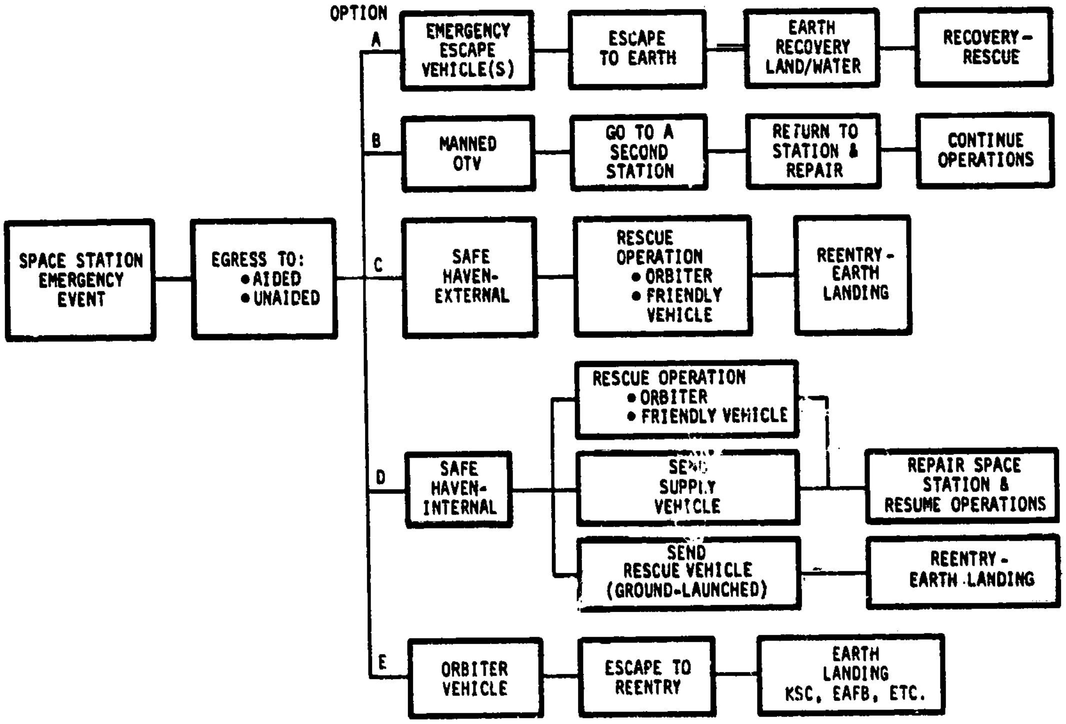


Figure 1-7 Escape and Rescue Options

An STS Orbiter Vehicle on Station, or berthed nearby, offers unique benefits. For example, consider the first time that a specific hazardous operation is being performed at the station, such as transferring hydrazine. It would be prudent to have the orbiter stand by at the station during this operation. In fact, if the orbiter is standing by in the vicinity of the station during any first time risk activity, the overall program risk-level is significantly reduced. Another consideration for this option would be to provide for escape of eminent technical scientists or personnel who in the industrial world possess a one-of-a-kind capability. The program, in this context also may not wish to risk those who are not basically adapted to space to remain in orbit 60 days or more as a function of the next vehicle routinely returning to the station. A proposed solution would be to hold the Orbiter vehicle over a day or two (relative cost consideration being less than one million dollars a day).

EVA SAFETY ISSUES

An evaluation was performed of EVA for the Space Station. Among these were scenarios examining the current philosophy of EVA and evaluating results of the current shuttle missions involving EVA. Several observations were made regarding EVA deficiencies. First, as currently performed, EVA is treated almost as an afterthought instead of an integrated system. One of the key decisions is whether EVA will be a routine activity or a special event. Although the cumulative risks may appear higher for routinely-performed EVA due to increased exposure, the risks per EVA are thought to be greater for the "special event" mode due to the lack of familiarity with the equipment interface which would cause individual excursions to be more risky. It is the Rockwell Safety opinion that EVA should be a baselined operation.

Whether EVA is baselined or not, several policy decisions are advisable:

a) The EVA suit must be designed to preclude prebreathing. This capability does not currently exist on the Shuttle but one can reenter and land within 168 minutes in most contingencies.

b) The EVA suit should be capable of being inspected, maintained and easily de-contaminated on-orbit.

c) EVA airlocks should be designed to sample and recycle internal atmosphere back to a supply rather than vent-to-space during depressurization operations to minimize consumables budget expenditures. For contaminated air, the capability for dumping to space should exist.

d) Capability for a decompression chamber should be available.

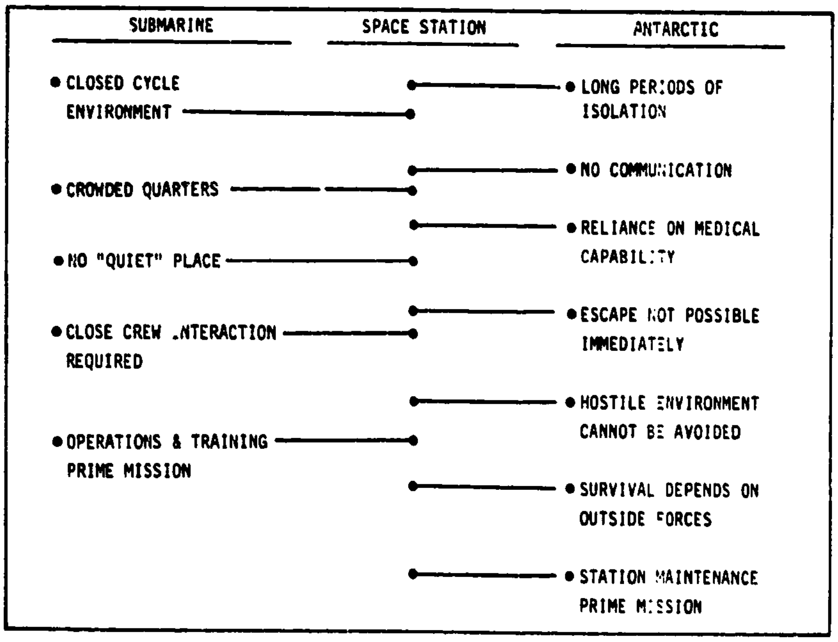
e) Provisions should be made to protect the suited crewman from hazardous incidents such as hypergolic spills or increased solar flare activity.

These and other considerations such as that of maintainability tends to indicate the advantage of utilizing the hard suit technology which is currently approaching maturity.

SAFETY ASPECTS OF HUMAN FACTORS

In viewing space as a hostile environment to unprotected man and in recognition of America's experience as developing, an approach was taken to collect and analyze data from stressful endeavors or environments analogous to those associated with the crew of a space station. Of those examined, two (submarines and antarctic missions) exhibited desirable characteristics, viz, (1) a large population, (2) well defined screening of personnel and (3) competent post mission assessment by psychologists and human factors specialists. Figure 1-8 emphasizes several stressors associated with the confined space of submarines and the isolation of antarctic stations. It is of interest that human factors equations of the space station embody the worst of both submarine and antarctic environments plus that of micro g.

The Russian practice of providing psychological support pre-mission, during the mission, and post-mission, presents one of the most significant strategies. Even with the added Russian emphasis of psychological support, there is some evidence that their record 211-day mission was terminated for psychological causes rather than physical.



NOTE:
MOST SEVERE ISSUES FROM EACH ENVIRONMENT DIRECTLY APPLY TO SPACE STATION

Figure 1-8 Aggregate Stressors for the Space Station

SELECTED OPEN ISSUES

Several issues identified during the course of the study demand further expansion as resources become available. The following issues are emphasized because the technical community appears to lack uniform agreement as to the proper course of action relative to existing space configurations. The issues are summarized in three categories, viz., A) technical, B) programmatic and, C) human factors.

Technical

Safe Haven - Multiple Safe Havens Concept and Attendant Limitations. Proposed configurations which consider every pressurized volume as a "safe haven", lack practicality as each habitable volume would need to incorporate the requirements of safe haven (viz., food, thermal, breathing air, CO_2 removal, etc.). Conversely, if the haven is dependent upon another volume for its habitable elments, then the volume is not a defined safe haven because survival may be lessened due to volume interdependence on evacuation (or "escaped from").

Depressurization - How Many Volume Change-Outs? Volume changeout possesses two major variables, that of the safety philosophy (fail safe vs. fail- operational/fail safe) and the magnitude of volume involved. It is desirable to require a fail-operational/fail-safe capability but the consequence is an "over-kill" if applied to the entire station.

Resource Utility Module Concepts - A conceptual single failure point is defined if the resource module functions are located in a single volume. When module functions are distributed, then a measure of damage tolerance exists compared to the vulnerability of a single location. Further, several concepts consider the resource module(s) as an unpressurized volume(s). Conceptually an unpressurized volume may be acceptable except for evidence that these modules will contain most of the high-maintenance hardware. Accomplishing repair in the volumes requires an EVA (pressure-suit) capability which appears to present a larger expenditure of resources as well as providing attendant higher risk.

Dual Egress Capability - The study concludes that it is highly desirable for all habitable modules to inherently have alternative escape routes or modes of egress. The possible exception to this conclusion is the lab module or work place where hazardous substances can be placed at the opposite end of an egress area and alternate techniques of escape implemented such as allowing people on duty to leave through an adjacent hatch or airlock.

Synergism of Strategies - The positive and negative synergistic contributions of individual strategies were discussed earlier in this narrative and illustrated the range of solutions to fire/explosion and radiation/debris threats. Of particular significance is that there is no single action or actions as a strategy for any of the complex threats but rather a family of solutions. Paramount, therefore, is the selection of and committment to a strategy approach that provide the most cost-effectiveness.

Programmatic

The programmatic issues, those requiring prudent management action are emphasized below:

The Variable Facility Syndrome - On earth there exists two distinct safety disciplines: system safety, which considers the safety of crew, hardware and personnel during all aspects of design, operation and human interface, and industrial safety which governs the workplace environment (OSHA).

The space station will not be compatible with an OSHA-type discipline, but rather it is a sophisticated variation of system safety. The station is a facility that changes with each arrival and departure of an orbiter in that the orbiter either delivers or retrieves consummables, products, materials, fluids and/or experiments to/from the facility. The limitations of the industrial safety approach is that no provision exist for the zero-g uniqueness , the station configuration or its response to the unique environmental constraints. It has been estimated that less than 25% of the industrial safety requirements are useable in a space station setting.

Total System Safety Integration Function Should Be Guided By Strategies- Classical system integration functions are performed at level 2 (B) based on inputs from various level 3 (C) elements. This integration becomes either an interface analysis or a "top-down" assessment or both. The limitations of this approach is that the integration function is limited by the quality of data and is at the schedule mercy of data provided by level 3 (C) elements which more often result in after-the-fact examinations. The appropriate approach is to have an independent up-front strategy for each of the threats and measure the compliance to each strategy of the total vehicle level 2 (B) and 3 (C).

Cost of Strategies - There may be several design and operational solutions to a given threat. Some of these are less expensive while others have fixed costs as opposed to having recurring costs. Also the issue of synergistic effects of various solutions in a strategy need to be well understood.

Human Factors

Some of the more significant open issues in Human Factors are:

Absence of a Proper Repository for Non-Design Criteria/Requirements - Design and operational solutions are driven by requirements which satisfy criteria. Some of the human factor strategies, however, involve programmatic issues such as crew selection, crew training, medical profile for crew selection, etc., which have no requirements home for use on the station. Others, such as acoustics or contamination can be specified in requirements documents.

Absence of a Strong Sponsor for Key Human Factor Issues - The study concludes that the measure of success of removing a given human stress is highly dependent on its overseer such as the government and the particular influence. An example is in the area of acoustics within the habitable module(s). Volume III, Section 5, shows the impact of the lack of a strong accoustics definition for the Apollo and Shuttle Orbiter programs.

<u>Need For Medical Diagnostic/Treatment Center On-Board the Station</u> - Availability of data is currently insufficient to define a medical facility for the space station. It is understood that the medical community is currently reaching an agreement on the minimum medical facility requirement. From a human factors perspective, there is a need for minimum medical capability sufficient to provide the crew with confidence of survival and well-being during all anticipated emergencies.

<u>Need for Expanded Emphasis on Crew Selection/Training</u> - A review of the safety impacts of human factors indicates that more sophisticated crewmembers screening and a greater dedication to training for all tasks would do much to minimize stressor impact on space station personnel.

SUMMARY

The study indicates that a mature well-defined station possesses operational scenarios which include redundancy and appropriate technical and human provisions for dealing with threats. There exists at this time no justification for a dedicated on-orbit rescue vehicle. One study conclusion is that during the build-up phase the program will experience hazardous situations or risks that cannot be avoided. These risks, however, are not excessive.

2. STUDY APPROACH

The Space Station Crew Safety Alternative Strategies Assessment Study is a small but strategic link in the activities now getting underway to establish and define a Space Station as the next major U.S. space program. Manned space flight experience on the Shuttle has shown that safety considerations play a determining role in establishing important configurational and operational features of any program.

To effectively and efficiently identify technical risk situations, methods of dealing with them become essential in the design and operational process. The technique used here was to identify threats (life/survival-threatening situation) and strategies to deal with each situation.

A number of terms recur throughout the study. In Table 2-1 these terms are defined.

TABLE 2-1 - INTERPRETATION OF TERMS

PHILOSOPHY: Summary statement of program safety objectives
THREAT: Situation which endangers either the crew or the space station
POTENTIAL THREATS: Threats which might arise, without regard to probability, frequency, or severity
SPECIFIC THREATS: Threats which have been determined to have a combination of probability, frequency and/or severity for a given scenario that they must be dealt with
CRITERIA: Statement of design or operational means to control individual threats
SCENARIO: Set of mission activities which create situations for specific threats
KEY SAFETY ISSUES: Safety concerns that have significant design or operational impact on the space station
STRATEGY: Approach used to achieve resolution of key safety issues
GUIDELINES AND REQUIREMENTS: Specific design or operational requirements recommended for the next phase of the space station program

The study development logic, identified threats, the strategy development logic, the strategy development processes are defined in the following pages. Those top eight threats which have implied major configuration or operational impact have been dealt with in separate sections of Volume II.

STUDY LOGIC

The study was, by contract definition, divided into six tasks. These were: (1) Literature Search and Data Collection, (2) Crew Safety Criteria, (3) Scenario Assessment, (4) Assessment of "Baseline" Crew Safety Concept, (5) Assessment of Alternate Crew Safety Concepts, and (6) Development of a Space Station Safety Plan. Figure 2-1 shows the logic that was developed for the study and the boundaries for the six tasks. A brief recap of each task follows:

Task 1 - Collect and analyze technical data to provide a data base file and a technical assessment of the data by task categories.

Task 2 - Develop a crew safety philosophy and criteria which allow a proper balance to be obtained between personnel safety, the value of the space station and the exposure which the National Space Program receives in a contingency situation. The criteria will be designed to mitigate threats in a manner compatible with the philosophy.

Task 3 - Identify operations - related safety issues, which in concert with configuration issues must be addressed to minimize risk to an acceptable level. The variable of how the space station configuration may be required to function as a result of specific operations often requires significant modification of proposed subsystems locations and capabilities.

Task 4 - Assessment of the "baseline" crew safety concept provides a determination of how well the autonomy of the space station and shuttle rescue at nominal resupply missions can satisfy the crew safety criteria and hence mitigate the crew safety threats.

Task 5 - Assessment of alternate crew safety concepts allows one to examine the threat exposure reduction by use of means other than the "baseline".

Task 6 - The space station safety plan will allow early emphasis of study results in a format that the NASA may use for advance planning on phases B and C/D.

Figure 2-1 depicts the logic used for accomplishing the above six tasks. It should be noted that once a philosophy for the station has been selected, the challenge becomes two-fold. First, the identification of all credible threats (or risk-generators) and second, the development of a course of action to either preclude the occurrence of each threat or reduce such occurrence to an acceptable consequence. In light of the predetermined philosophy credible threats cannot be completely eliminated. The preferred approach is to use a threat reduction precedence consisting of (1) elimination by redesign or other means, (2) minimize the impact, and (3) safety devices and contingency procedures. (Ref. NHB 5300..1(D-2)).

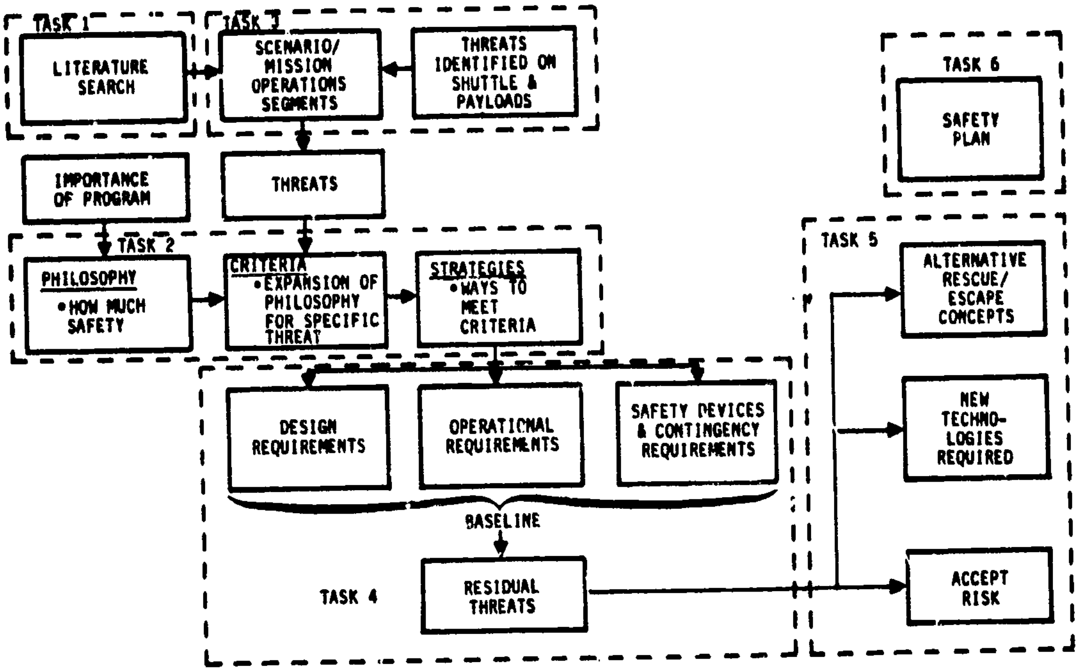


Figure 2-1 Study Approach

The techniques for dealing with individual threats are called strategies. A strategy is a conscious effort to render a given threat harmless, or at least no greater than some predetermined risk threshold. Strategies may be simple (i.e., fix the hole for a leaking volume) or complex (i.e., lower the volume pressure with volume inhabitants using IVA masks or oxygen bottles because of atmospheric contamination). The mechanism for transferring a threat to a solution is a criterion. Criteria are generally top-level statements of policy and are true for all verified threats. The method of implementing a criterion is usually a requirement which may be either a design requirement or an operational requirement. A third type of requirement is one for safety devices and contingency procedures. These are less desirable in that they are usually the last line of defense against a threat. A brief discussion of criteria is provided below.

The final segment of the logic flow deals with alternate strategies, those strategies which address threats which cannot be eliminated by redesign or other means. There are basically three strategy categories: a) Escape/Rescue, b) Development of new technologies, and c) Risk acceptance. A separate section of this report is dedicated to the subject of escape and rescue. New technologies have been studied in some detail and have several promising benefits to the health of the station and its crews. Risk acceptance allows a disciplined examination of the unresolved (or unresolvable) safety issues and the arrival at management decisions regarding their credibility and acceptability.

CREW SAFETY PHILOSOPHY

Rockwell has been intimately involved in assisting NASA to establish safety philosophies and criteria, starting with Apollo (where systematic safety programs were initiated), through Skylab, Apollo-Soyuz, and on the Space Shuttle. It is interesting to trace the evolution of crew safety philosophy through these programs, and to understand the reasons for this evolution. Table 2-2 illustrates key features of these philosophies or goals. The emphasis has gone historically in two directions: (1) a tendency to go from escape and rescue measure (e.g., abort systems) toward obtaining inherent safety (i.e., reduce/eliminate threats); and (2) an increasing interest in saving not only the crew, but also the very valuable space systems. We expect these trends to continue as space operations mature and become more routine, and as space hardware becomes more expensive, with longer mission durations. The safety philosophy which was baselined for the crew safety alternative strategies study was consistent with these trends, and is shown in Table 2-3, selected from a few potential philosophies.

TABLE 2-2 ROCKWELL EXPERIENCE IN THE DEVELOPMENT OF SAFETY PHILOSOPHY IN SPACE PROGRAMS

PROGRAM	SAFETY PHILOSOPHY	RATIONALE
APOLLO	o CREW SAFETY GOAL, ~~.999~~ o ABORT CAPABILITY IN ALL MISION PHASES o BACKUP MODES FOR CRITICAL FUNCTIONS	o MANY UNKNOWNS AT TIME o WORLD-WIDE EXPOSURE OF PROGRAM
APOLLO-SOYUZ	o ABORT CAPABILITY IN ALL MISION PHASES o BACKUP MODES FOR CRITICAL FUNCTIONS	o PROVEN HARDWARE o SINGLE MISSION
SKYLAB	o LAUNCH CREW AFTER SKYLAB SUCCESSFULLY ORBITED o CREW ESCAPE AVAILABLE BY APOLLO CSM	o USE OF EXISTING HARDWARE
SPACE SHUTTLE	o ABORT CAPABILITY USING THE ORBITER o LIMITED CREW ESCAPE SYSTEM DURING ORBITAL FLIGHT TEST o BACKUP MODES FOR CRITICAL FUNCTIONS o ORBITER-TO-ORBITER RESCUE OF CREW	o SPACE PROGRAM MATURITY o EMPHASIS ON ELIMINATING CONTROLLING THREATS RATHER THAN ESCAPING FROM THEM

TABLE 2-3 SPACE STATION PHILOSOPHY PRECEDENCE

CURRENT OPTIONS	COMMENTS
• CAUSE NO DAMAGE WHATSOEVER TO SPACE STATION AND NO INJURY TO CREW	DESIRABLE: COST TRADE
• CAUSE NO DAMAGE TO SPACE STATION BEYOND ROUTINE MAINTENANCE CAPABILITY	COST TRADE
• CAUSE NO DAMAGE TO SPACE STATION OR INJURY TO CREW WHICH WILL RESULT IN A SUSPENSION OF OPERATIONS	BASELINE PHILOSOPHY
• SPACE STATION REPAIRABLE AND OPERATIONAL WITHIN A SPECIFIED PERIOD OF TIME	MAY REQUIRE ESCAPE/RESCUE
• CREW SURVIVAL AT EXPENSE OF THE SPACE STATION	IMPLIES EVACUATION AND RESCUE. AS A MINIMUM

THREATS

A threat is a situation which endangers either the crew or the space station. Threats may be grouped in several categories: simple or complex, personal or community, time-dependent or spontaneous and natural or self-induced by the station. The author has defined a threat as simple or complex based on the physics of its occurrence. For example, a depressurization threat is generally simple. Most have a single cause such as penetration by debris or a failed (open or leaking) barrier or valve to the vacuum outside. A complex threat has multiple causative elements. Fire, for example, generally requires fuel oxidizer and an ignition source. The motivation for making the distinction in classification of threats as simple or complex arises largely from the complexity of the fix, or strategy. Clearly, the simple cause can more easily be accommodated than a threat which has several elements in each cause. Complex threats require complex strategies.

The grouping of threats as personal (involving individual crew personnel such as a crewman or EVA) as opposed to community, in which the entire station has an exposure to risk provides an aid to operational planning.

Whether a threat is time-dependent or spontaneous is a major consideration in Alternate Strategy Development. The time available to ingress an escape vehicle is one of the major discriminators as to whether escape is a viable concept. When a threat is a natural one, such as radiation from solar flares, most of the station hardware and personnel are involved in the strategy. The same may be true for station-induced threats, such as particulate contamination, but the consequences are far less severe for the strategy perspective.

A complete listing of threats, as shown in Table 2-4, was used for this study. This list is a composite of Rockwell experience, augmented by a dozen-odd reviews and presentations to groups composed of the NASA, competitors and safety specialists.

These threats were also considered from the standpoint of their potential impact on configuration solutions. Effort for this study, being limited by resources, was focused on those threats which would have the greatest influence in configuration selection. The eight threats thus selected are indicated in Table 2-4.

Table 2-4 SPACE STATION CREW SAFETY THREAT LIST

---

o Fire
Leakage
Tumbling/Loss of Control
o Biological or Toxic Contamination
o Injury/Illness
Grazing/Collision
Corrosion
Mecahanical Damage
o Explosion
o Loss of Pressurization
o Radiation
Out-of-Control IVA/EVA Astronaut
Inadvertent Operations
Lack of Crew Coordination
Abandonment of Space Station
Electrical Shock
o Meteoroid Penetration
Stores/Consumables Depletion
Intrusion/Attack
Structrual Erosion
Orbit Decay
Loss of Access to a Hatch
Temperature Extremes
o Debris
Free Orbit (EVA Astronaut)

STRATEGIES

A strategy is an approach used to achieve resolution of a threat or a key safety issue. There are rare instances where a single strategy will suffice in the threat mitigation process. For example, a bumper or shield may be used to protect against micrometeroid penetration. The majority of strategies, however, encompass multiple facets.

An example of this is that the steps one would take in making a fire improbable by breaking two legs of the "fire triangle" greatly enhances the reduction of explosion potential by similarly affecting the "explosion penta-ring". One added consideration is that strategies chosen may often have synergistic effects. This synergism may appear either as a positive (beneficial) factor or a negative one.

Strategies may fall into categories of either design solutions, operational solutions or safety devices with contingency procedures. Often the most effective strategy is a combination of two or more of the above. A general rule-of-thumb for strategy application is to first build a "first line-of-defense" for the threat to preclude damage to personnel or the vehicle. Then, assume that the threat was not effectively mitigated and develop a "second line-of-defense" which presumes the existence of the threat and design for the station and personnel to accommodate the threat consequences.

The ideal solution for a given threat may not be realistic from a total station perspective. Thus, each strategy must, of necessity, weigh the following factors, as a minimum. (1) Synergistic reaction with other strategies, (2) Compatibility with station safety philosophy, (3) Flexibility for station growth or expansion, (4) Economic feasibility, (5) Technical risk, and (6) Human factors impact.

CRITERIA DEVELOPMENT

A criterion is a design or operational means to control an individual threat. The primary purpose of the criteria is to provide a source for both design and operational requirements in a manner that is easily incorporated into conceptual tradeoffs and configuration selection studies. Once the safety philosophy has been selected, the criteria are largely determined by this philosophy. Figure 2-2 shows this schematically by highlighting the thread from the philosophy and the threats (derived independently) to criteria, strategies, and requirements.

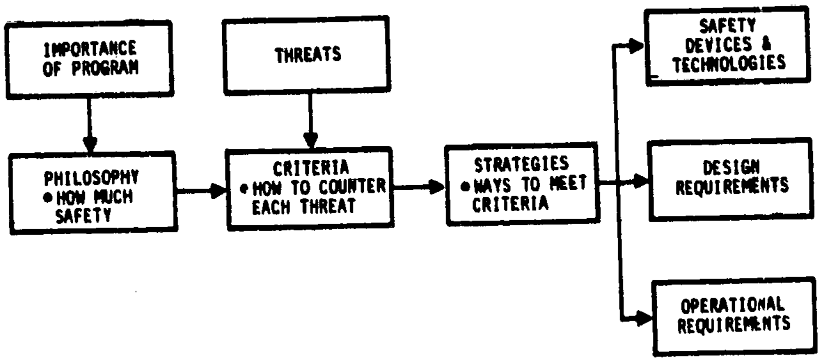


Figure 2-2 Sequence of Study Outputs

RISK ASSESSMENT/ACCEPTANCE

The process of accepting a risk, is a formal technique used for each individual hazard that is not eliminated or otherwise resolved. The priorities for hazard reduction are shown in Figure 2-3. These are: first, design to preclude, then design to control, then operational workaround, and, finally, define the residual hazards. For the residuals (i.e., ones that are left over), one generally tries to solve the threat with one or more strategies: 1) Where adequate strategies do not exist nor does a technology exist to accommodate the hazard, (or if the technology exists, but it is too costly to accommodate the hazard), 2) that an occurrence is a highly improbable (note that it is still a hazard, still a threat, but it's happening is not judged to be that probable). The last consideration is one where the consequence has limited impact. Clearly, categorization each of these is subjective and is a judgement-call and not something where precise guidelines exist. For example, most members of society have accepted the risk of being near 120 volt outlets in their homes or sitting near automobile fuel tanks that have gasoline which, if in vapor phase, is several times more destructive than an equivalent mass of TNT. Aircraft and spacecraft operators accept similar risks on a routine basis. For example, all of the space shuttle flights have been made without benefit of a rescue capability.

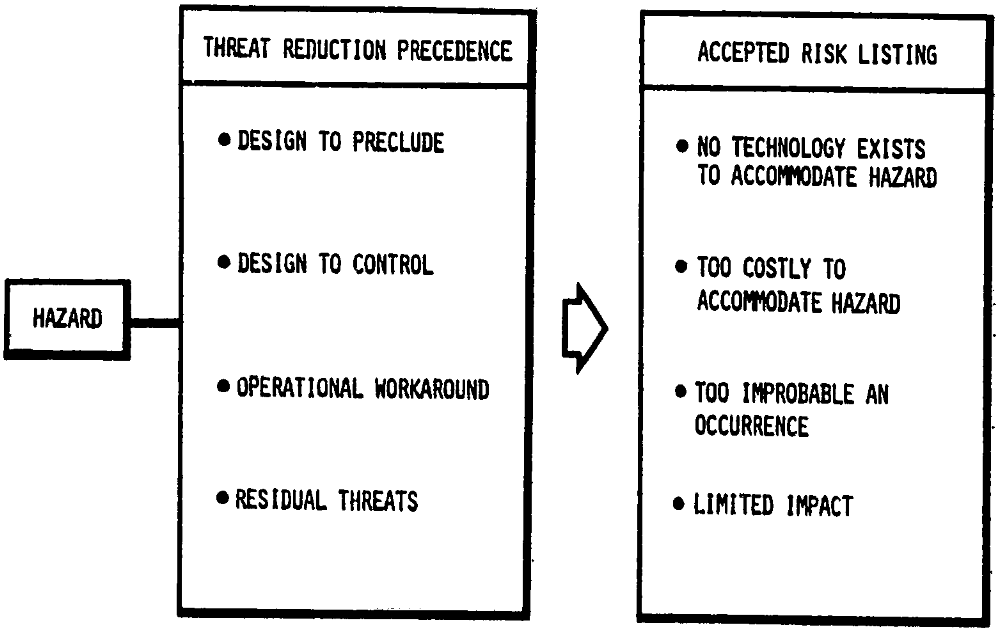


Figure 2-3 Acceptance Risk Discriminators

3. SPACE STATION BASELINE

The baseline space station used in this study was the Rockwell International Configuration in existence at contract initiation in January, 1983. (Reference SSD 83-0032-2, Pg. 69-84). Its Space Station architecture is described in this section. The modular elements that make up each of the station concepts are also described as are the standardized module construction concepts. The station build-up sequence for each station arrangement is also included in the description.

INITIAL SPACE STATION ARCHITECTURE

Architectural development of the initial Space Station considers two categories: external architecture and internal arrangements of the basic configuration and standardization of the construction of the modular elements. Internal arrangements were developed that fulfill the habitable needs of the initial four-man crew, and at the same time, minimize the scars that may result when the initial station progresses to the full-up architecture.

Configuration of the pressurized basic station elements evolved from a standardized module concept that opted for common diameters, bulkheads, environmental protection, floor locations, and docking/berthing interfaces. The pressurized modules are of monocoque aluminum, welded for minimum leakage. Each module is two standardized end cones and a center cylindrical section. A standard segment that contains four standard interfaces is also available. The standard interfaces are also incorporated in the end cones. The cylindrical sections feature standard structural rings 7 inches deep, which allow handling the modules during manufacturing and transportation and are of sufficient depth to allow installation of the environmental shield within a 14-foot outside diameter envelope. A standard floor location was also incoporated into the internal arrangements.

In the habitable volume above deck, an 82-inch high aisle is provided, which will allow the simultaneous passage of two pressure-suited crew members in an emergency condition. In the equipment section below the floor, the aisle is 40-inches wide, which provides for a pressure-suited crewman to perform maintenance operations. Both aisle widths are compatible with the identified equipment envelope sizes.

A false ceiling in each module contains the lighting fixtures and air supply registers. The space behind the false ceiling contains wiring and air recirculation subsystem ducts.

An integrated environmental protection subsystem consisting of meteoroid protection, thermal control radiators and insulation, and radiation protection was provided on each module.

The standard docking/berthing interface accommodates module mating, orbiter-to-station mating, and user module/pallet mating to the station. It features standard mechanical alignment and latching provisions and a standard utilities interface arrangement. A 30-inch by 40-inch clear opening provides for passage of equipment and pressure-suited crewmen. All the utility interfaces are remotely activated after completing and verifying the mechanical mating. In addition, all connections feature manual override provisions permitting servicing or maintenance to be performed by either a shirtsleeve or a pressure-suited crewman.

Other crew safety requirements are fulfilled by dividing the Space Station into two independent pressure volumes, each capable of serving as an emergency safe haven for the entire crew. Safety features and characteristics of both pressure volumes are summarized in Figure 3-1. A pressure bulkhead within the command module separates the two volumes. Volume I contains the energy module, the forward end of the command module and the logistics module. The aft end of the command module is in Volume II.

Initial Station Configuration

The elements that make up the initial Space Station are the utility module, the command module, two airlocks, the logistics module, and the payload service assembly. One airlock is mounted on the energy module and the other on the crew module, thus providing EVA egress from either pressure volume.

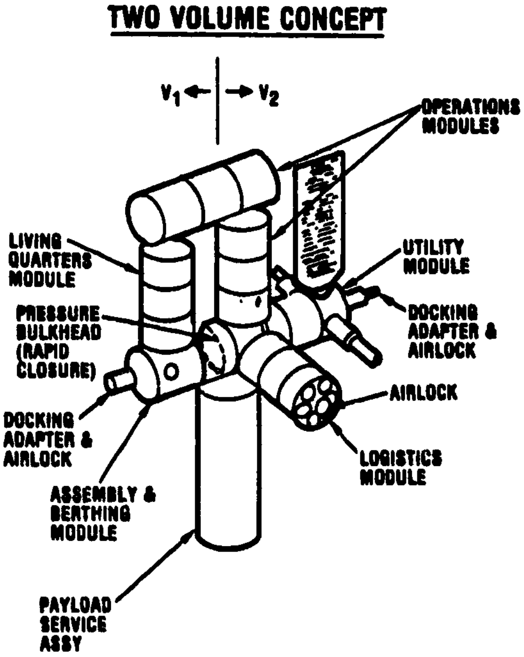


Figure 3-1 Initial Baseline Space Station Arrangement for Crew Safety

Energy Module. The energy module provides the main source of electrical power for the Space Station. It is constructed in accordance with the standardized concept having cone ends and a cylindrical center location that contains four mating ports. Mating ports are also provided at each end of the energy module. The overall length of the module is 20 feet; the maximum inside diameter of the center section is 164 inches (13 feet 8 inches). Peripheral rings between the 90-inch-long center section and each cone end are 178 inches in diameter. The module is of welded aluminum with external meteoroid bumper and insulation.

The internal structure consists of two bulkheads for equipment mounting, one at each end of the center section. Equipment mounted within the module includes fuel cells, electrolysis units and electrical power conversion, and distribution components. The control moment gyros and their associated computer and inertial measurement units are also mounted in the energy module. Docking radar and communication equipment is mounted in one end of the module.

Four reaction control engine modules are mounted on one cone end with provision for shirtsleeve servicing from inside the energy module.

The reaction control subsystem propellant storage and accumulator tanks are mounted outside the energy module around the cone ends. All internally mounted equipment is accessible from a 40-inch-wide aisle for service or removal and replacement. Electrical, fluid, air, and gas lines to other modules, externally mounted equipment, and to a docked orbiter are provided through the interface connections at the mating ports. Air circulation is provided through the interface with the command module, assisted by fans internal to the energy module.

Station access to the orbiter in its normal docked location is through the energy module.

The four berthing ports on the center section are interfaces for two solar arrays, a deployable radiator and an airlock, all detachable and packageable within one orbiter cargo bay. The initial solar arrays, which provide a total of 50 kW of power, are replaced for the growth configuration by arrays that provide 100 kW of power.

Command Module. The command module is of a similar construction as the energy module except its longer center section contains two segments of four berthing ports each and a cylindrical section. Its total length is 40 feet. The volume above deck houses staterooms, hygiene facilities, galleys, dining/ward room, and medical/exercise facility. All of these provisions are removable for the growth phase. A station operations console also located within this volume remains throughout the life of the station. The volume below deck is used primarily for subsystem equipment.

A combined internal arrangement of both the energy and command modules provides two independent pressure volumes. Each volume has an independent environmental control and life support subsystem capable of supporting both volumes. Redundant station control consoles are located in each volume. The main staterooms are in Volume II with back-up sleep stations in Volume I.

Payload Service Assembly (PSA). The PSA is the principal element of the Space Station on which most of the payload servicing activities will take place. The service bay will be utilized in a similar capacity as the orbiter payload bay (i.e., for servicing free flyers, housing research experiments on pallets, storing spares, etc.). The back side of the service bay is the service fixture where a mobile manipulator arm and two sets of payload retention devices on carriage assemblies are featured. The service fixture will be utilized for servicing OTV's. The two retention devices will allow simultaneous servicing of two OTV's. In that event, the service fixture manipulator arm is complemented by the service bay manipulator arm in servicing the OTV's. Both manipulators are operated by crewmen within the control module, which is permanently attached to the service bay structure. The control stations simulate the Shuttle aft deck from where the RMS is controlled and operated. Observation windows similar to those of the Shuttle are also provided. The other end of the PSA features a mating port where incoming OTV's dock for subsequent transfer to the service fixture for servicing. The service fixture manipulator arm is used for OTV transfer to the service fixture.

Logistics Module

The logistics module assumes the same basic exterior configuration as the other pressurized elements. This includes standard end cones, frames, cylindrical body section, and interface ports. A mating port is attached to one end cone while a pressure plate seals the second end cone. On the periphery of the second end cone, a structural skirt is attached to protect external tank installation provisions. The total length of the logistics module is 23 feet.

Inside the logistics module are two structural bulkheads that coincide with the external frames. In the center of each bulkhead is a 40-inch diameter opening. On both sides of each bulkhead, pie-shaped, 20-inch-deep storage compartments with hinged doors are mounted to provide the majority of storage space. Storage compartments are also provided on the end cones. On the near end cone, 10-inch deep by 50-inch wide compartments are mounted around the periphery. On the far end cone, a 48-inch-diameter by 24-inch-deep freezer is provided. Around the freezer, additional storage compartments are mounted. The internal arrangement features 36-inch-wide aisles betweeen storage compartments and between each storage compartment and the end cone. This width is sufficient for opening storage compartment doors and for crewmen, carrying supplies, to easily maneuver. Of the total logistics module internal volume of 2,565 cubic feet, 1,014 cubic feet are available for storage, which satisfies the average requirements for a 90-day resupply period for an eight-member crew.

GROWTH STATION ARCHITECTURE

The growth Space Station, designed to provide a habitable and working environment for a crew of eight, is assembled by building on to the initial Space Station. The core station modules added are: Habitat Module 1, Habitat Module 2, and a life sciences module that interconnects the two habitat modules. These modules are arranged, as shown in Figure 3-2, to provide two exits out of each occupied area and to provide dual independent volumes for emergency safe havens.

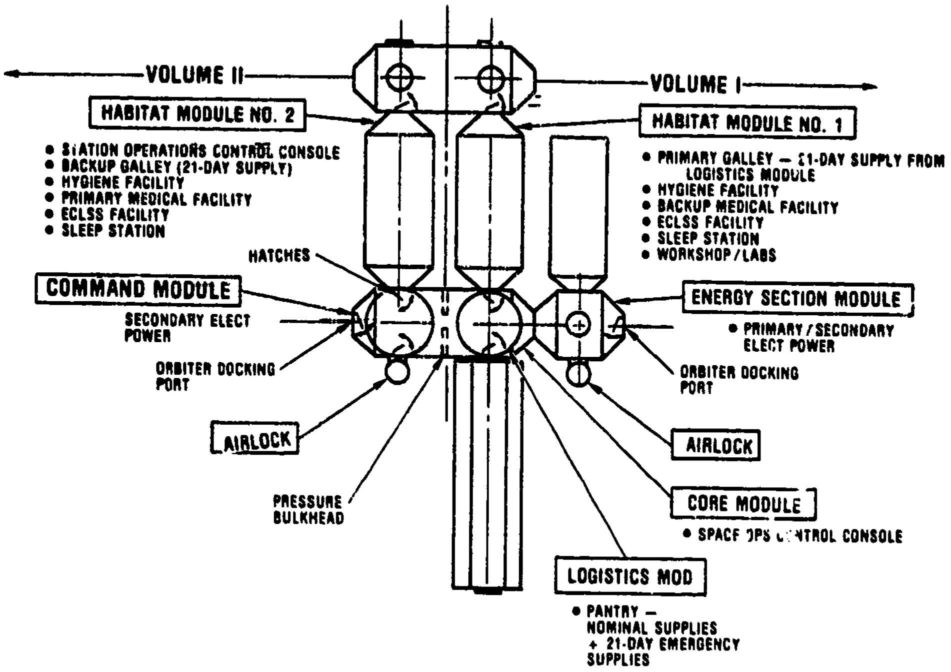


Figure 3-2 Baseline Space Station Concept Arrangement for Crew Safety

Growth Station Configuration

The standard modular construction elements described earlier are used for the 40-foot-long habitat modules. The interior floor location, aisle widths, false ceiling, and integrated environmental protection subsystem are also incorporated. The structural arrangement of the life sciences module is identical to the command module except that the pressure bulkhead separating Volume I and Volume II is not required.

The internal arrangements and features ~~of each module are described in~~ this section. The build-up sequence from the initial station architecture to the growth station arrangement is also described.

Habitat Module 1. Located in the living/working area of this module are four crew staterooms, the galley, a dining/ward room/quiet recreation facility, a hygiene facility without a shower, and a larger volume, 490 cubic feet, identified as a workshop/laboratories facility. The requirements for this facility have not been fully defined. Each stateroom, nominally accommodating one crew member, has the capability to accommodate two during overlap or emergency. The required components of the subsystem are located in the equipment bay below the floor. The end cones provide storage for infrequently needed items and access to the interface connectors.

Habitat Module 2. Located in the living/working volume of this module are four new staterooms of the same configuration and capability as those located in Habitat Module 1, a back-up galley with 21-day food storage capability, a medical/exercise facility, a full hygiene facility including a shower, and a control center containing the station operations console. The subsystem equipment is located in the equipment bay. Similar to Habitat Module 1, the end cones provide storage for infrequently needed items and access to the interface connectors.

Life Science Module. This module is divided into two volumes by partitions above and below the floor. The resulting areas are utilized for life science research (animals) and medical research (humans). A slight pressure differential between the volumes will contain any animal odors. The research facilities are located in the working volume above deck. Only the air circulation equipment has been identified, to date, to support this facility. Consequently, the equipment volume below the floor is available for the installation of special equipment or storage. The end cones provide storage for four emergency escape subsystems and other infrequently required items as well as access to any interface connectors.

Command Module. The command module will have all of the crew habitability provisions, such as crew staterooms, hygiene facilities, galleys, and dining/wardroom removed after the build-up has been completed. Also removed will be the medical/exercise facility and the back-up station operations console. All of these facilities are now contained in Habitat Modules 1 and 2. The scar wiring and plumbing lines will remain. The subsystem components in the equipment bay are retained to maintain the redundancy and safety requirements. The space now available in the living/working volume can be utilized for laboratories and workshops, which have yet to be defined.

4. SCENARIOS

During this study five scenarios were selected as those which typify high risk space station activities. These scenarios are space station activities, and:

1. Space Station Build-up
2. Berthing
3. Material Processing
4. Fluid Transfer
5. Extra Vehicular Activity

The Extra Vehicular Activity is discussed separately in Section 6 of this volume.

APPROACH

Each scenario was addressed using the logic shown in Figure 4-1. The objective was to identify safety critical tasks and related hardware, where applicable, in order to develop safety criteria and guidelines for space station design and operations. In looking at each of these scenarios the related threats were the study drivers. These threats are shown in Table 4-1.

TABLE 4-1 SPACE STATION CREW SAFETY THREAT LIST

- Fire
- Leakage
- Tumbling/Loss of Control
- Biological or Toxic Contamination
- Injury/Illness
- Grazing/Collision
- Corrosion
- Mechanical Damage
- Explosion
- Loss of Pressurization
- Radiation
- Out-of-Control IVA/EVA Astronaut
- Inadvertent Operations
- Lack of Crew Coordination
- Abandonment of Space Station
- Electrical Shock
- Meteoroid Penetration
- Stores/Consumables Depletion
- Intrusion/Attack
- Structural Erosion
- Orbit Decay
- Loss of Access to a Hatch
- Temperature Extremes
- Debris
- Free Orbit (EVA Astronaut)

The scenario study sub-tasks were conducted as follows:

1. Study logic per Figure 4-1.
2. Prepare the scenario task logic diagrams
3. Identify Safety Critical tasks
4. Prepare a task/criteria/guidelines matrix

The product of this sub-study expands the safety criteria and guidelines files.

Scenario assessment for this study was limited to gross task definition. The understanding is that a detailed scenario task plan will be developed eventually for each defined activity. Assuming that Figure 4-2 typifies the approach taken to develop scenario task plans, a risk assessment would be made for each sub-task block. Hopefully, the safety criteria and guidelines developed under this study would be an adequate safety baseline to provide guidance for task development.

SPACE STATION BUILD-UP

The assumed sub-task elements of the space station build-up scenario and their relationships are shown in Figure 4-3. To ensure that the defined build-up tasks are credible, full-scale, high-fidelity dry-runs are required. A fallout of this approacn implied in Figure 4-2 is a detail task plan. The plan is the tool used for detailed risk assessment of the eventually defined build-up scenario.

The safety critical tasks, earth-side, are not too different from those encountered in day-to-day shuttle operations. Basic requirements for the shuttle related ground and flight safety critical tasks are contained in NHB1700.7A and KHB 1700.7. The build-up peculiar segments begin (See Figure 4-3) with "Place in Orbit". The Table 4-2 matrix addresses each of the asterisked sub-tasks, the applicable threats, and related criteria and guidelines listed in Vol. IV.

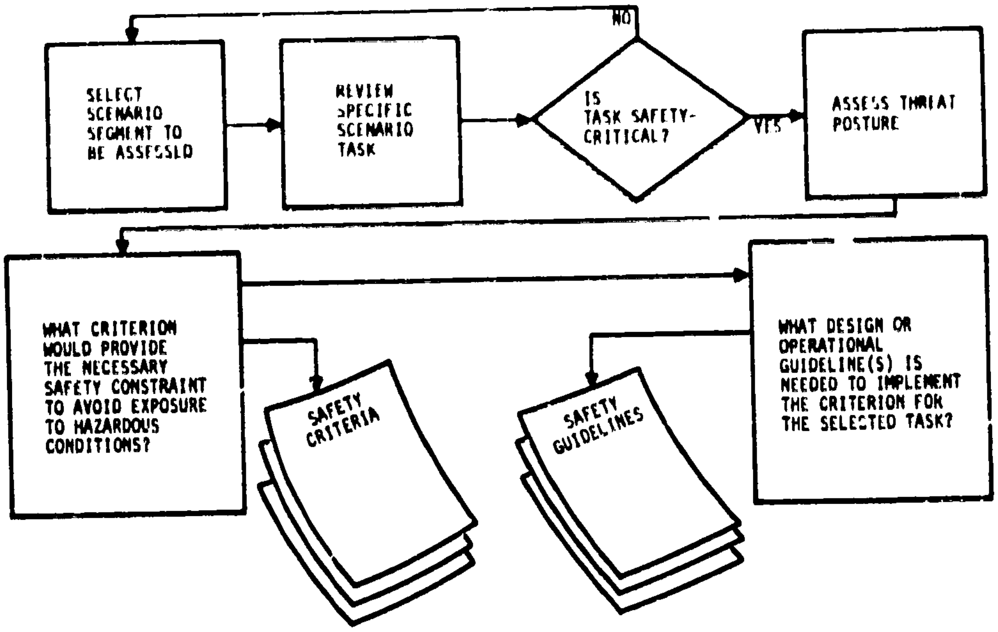
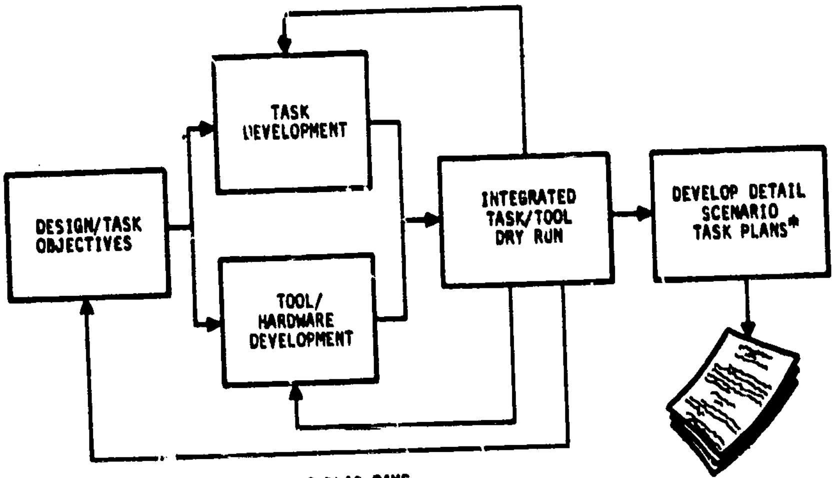


Figure 4-1 Scenario Screening Application Logic



*DETAIL SAFETY ASSESSMENT REQUIRED AT THIS TIME

Figure 4-2 Precursor Plan for Scenario Development

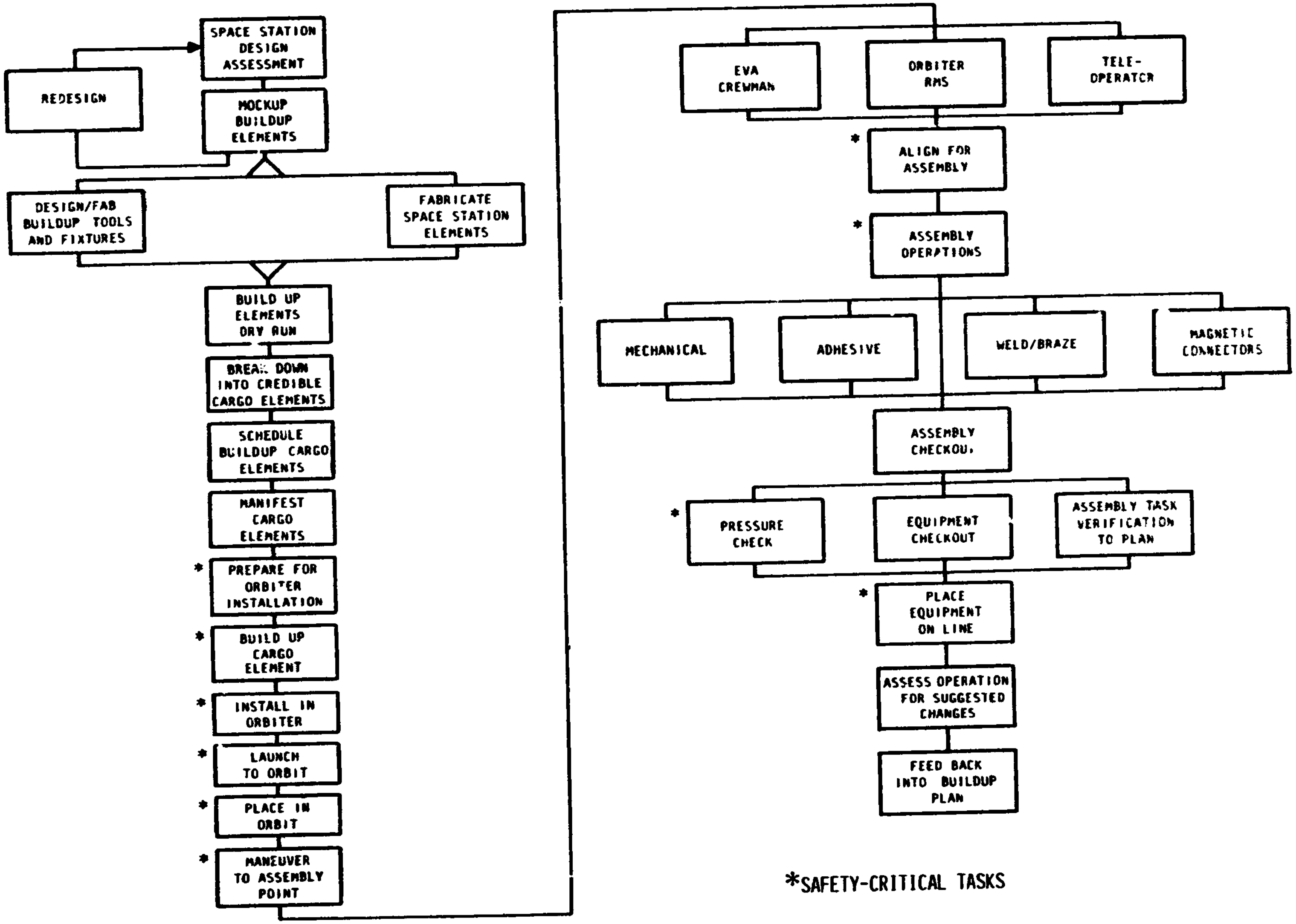


Figure 4-3 Build-Up Scenario

TABLE 4-2 RISK ASSESSMENT MATRIX - BUILD-UP

	TASKS	CRITERIA	GUIDELINES
N/A	Prepare for Orbiter Installation	NHB1700, 7A, C-12	
	Build-Up Cargo Element	NHB1700, 7A, C-12	
	Install in Orbiter	NHB1700, 7A, C-12	
	Launch to Orbiter	NHB1700, 7A, C-12	STR-077
	Place in Orbiter	NHB1700, 7A, B-19, B-25, B-30, C-4, C-8, E-2	INT-011, DUS-011 thru 018, INT-019, IFM-020, DUS-023 & 024, COM-029, RSD-118, OPS-174, C&W-175, COM-184, OPS-188, OPS-190
	Maneuver to Assembly	B-2, B-4, B-8, B-19, B-25, B-30, C-8, D-8, E-2	INT-011, DUS-011 thru 018, INT-019, IFM-020, OPS-202, DUS-023 & 024, COM-029, RSD-118, OPS-174, C&W-175, COM-184, OPS-188, OPS-190, OPS-202
	ALIGN FOR ASSEMBLY	B-2, B-4, B-8, B-19, B-25, B-30, C-8, D-8, E-2	INT-011, DUS-011 thru 018, INT-019, IFM-020, DUS-023 & 024, COM-029, RSD-118, OPS-174, C&W-175, COM-184, OPS-188, OPS-190, OPS-202
	ASSEMBLY OPERATIONS	B-2, B-4, B-8, B-19, B-25, B-30, C-8, D-8, E-2, E-4	INT-011, DUS-011 thru 018, INT-019, IFM-020, DUS-023 & 024, COM-029, FSE-043, INT-068, IFM-075, EPS-084 thru 086, INT-093, RSD-118, STR-170, OPS-174, C&W-175, COM-184, OPS-188, OPS-190, OPS-202

TABLE 4-2 (Cont'd.) RISK ASSESSMENT MATRIX - BUILD-UP

	TASKS	CRITERIA	GUIDELINES
N/A	PRESSURE CHECKOUTS	A-7, B-2, B-4, B-10, B-19, B-25, B-35, C-8, D-8, E-2, E-4	ECS-007, INT-010 thru 018, COM-029, EPD-033 thru 035, FSE-044, INT-159, OPS-174, C&W-175, COM-184
	PLACE EQUIPMENT ON LINE	A-7, B-2, B-4, B-19, B-25, C-8, D-8, E-2	COM-029, EPD-150, AUM-162, OPS-174, COM-184

BERTHING

By definition, a berthing process consists of all operations necessary to join two independent orbiting units into one independent unit. In this study, one of the two independent units is the Space Station. The other unit can be Shuttle Orbiter, OTV/OMV, or other vehicles.

The berthing process becomes essential in supporting the Space Station. Logistics and personnel transfer, whether it is of routine or emergency/rescue nature, can be accomplished through the berthing process.

Also, the berthing process is a very safety-critical operation. Previous berthing operations on both the Gemini and the Apollo programs have been conducted with high degree of success; however, the berthing problems encountered on the Apollo 14 flight and on the Russian Salyut/Soyuz mission highlight how failure to berth can lead to loss of mission. Inability of the Space Shuttle Orbiter to berth to the Space Station could lead not only to loss of the station, but also of the on-board crews (if, for instance, EVA were not possible). Therefore, berthing is a very critical operation and requires a thorough safety analysis.

Out of many berthing concepts proposed, the following concepts appear to be usable:

1) Direct berthing (hard berth)
2) Extendable tunnel berthing (soft berth)
3) Berthing to the Space Station holding frame

The direct berthing concept, Figure 4-4, does not require Remote Manipulation System (RMS) assistance. The active element (for instance, the Shuttle Orbiter) makes the initial contact, berthing port to berthing port, without intermediate assistance; the integrally attached berthing mechanisms make contact for initial capture. The direct berthing concept requires the dissipation of relatively large energy levels because of the coarse velocity control expected for propulsive maneuvers of the large masses involved. The concept was employed during Apollo-Soyuz mission; the berthing operation was performed by aligning the mass centers of the two vehicles.

The extendable tunnel berthing concept, Figure 4-5, uses an extension mechanism. The berthing mechanism, on one of the two berthing vehicles, extends some distance away from the vehicle before effecting initial contact and capture. After the capture, the mechanism is then retracted to draw the two vehicles together for rigidizing. The distinguishing features of the extentable tunnel berthing concept are: 1) it provides a long separation distance of two vehicles at the instance of first contact, 2) it provides stability after capture and during retraction; 3) it affords a long stroke, low stiffness attenuation capabilty. RMS use becomes optional for this concept.

The berthing-to-holding-frame concept uses an open-center holding frame on the Space Station. Retractable booms from the frame draw and lock the Shuttle Orbiter to the holding frame. A good analogy would be a ship (the Orbiter) berthing to a pier (the holding frame). This concept does not require RMS assistance.

In this study, we have chosen the direct berthing concept to demonstrate our scenario screening process. The assumed sub-task elements that comprise the berthing scenario flow are shown in Figure 4-6. The asterisked sub-task elements are considered safety critical as shown in Table 4-3, indicating the applicable threats. An assessment was made of each of these safety critical tasks to ensure the proposed safety criteria and guidelines are present. As an accommodating strategy, the Table 4-4 Risk Assessment Matrix summarizes the task-criteria/guideline relationships.

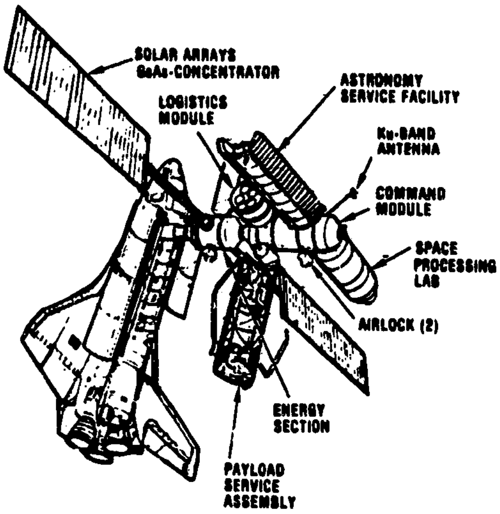
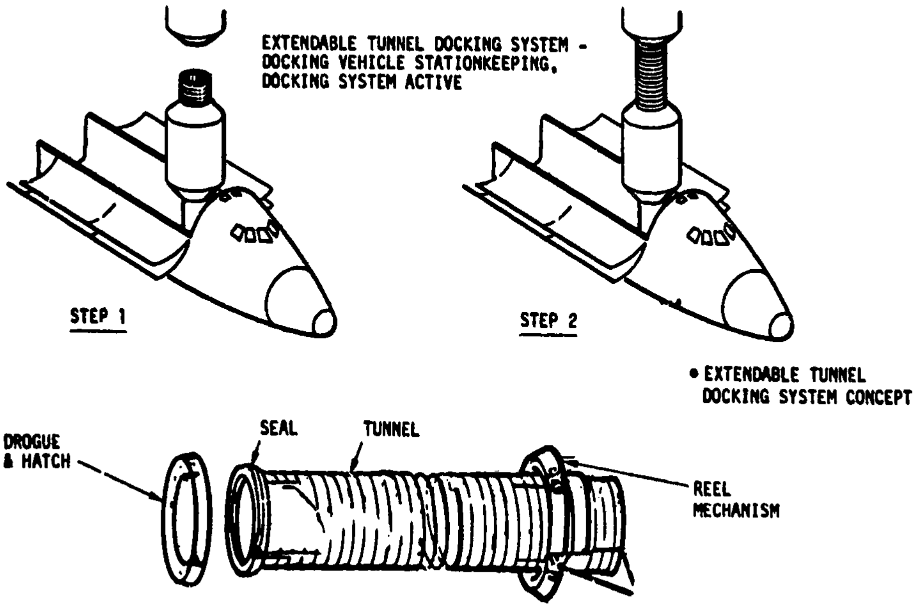


Figure 4-4 Direct Berthing



- ONE EXTENDABLE TUNNEL DOCKING SYSTEM CONCEPT ADAPTED FROM A CONCEPT CONSIDERED FOR THE APOLLO IS SHOWN. IT EMPLOYS A DOCKING PORT ATTACHED TO ONE END OF AN ACCORDIAN-LIKE BELLOWS TUBE, EXTENDABLE TO APPROXIMATELY 3m (10 FT) IN LENGTH. TESTS IN TWO-DIMENSIONAL SIMULATED DOCKING OF THE APOLLO USING THIS SYSTEM SHOWED THAT IT WAS FEASIBLE & HAD NO MAJOR PROBLEMS

Figure 4-5 Extendable Tunnel

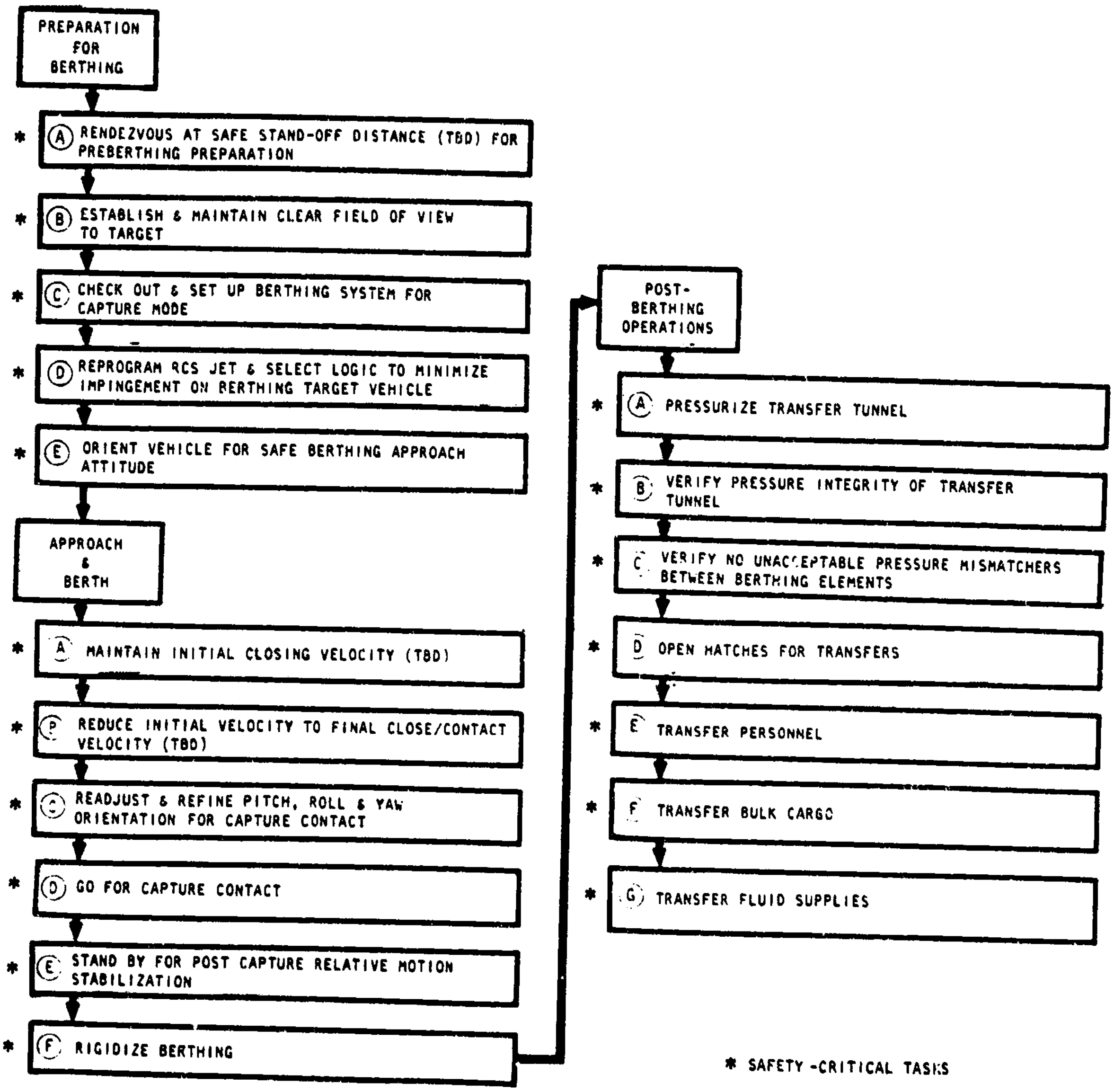


Figure 4-6 Berthing Scenario

TABLE 4-3 - DIRECT BERTHING SCENARIO

TASKS	SAFETY-CRITICAL	THREATS
1. PREPARATION FOR BERTHING		
A. Rendezvous at safe stand-off distance (TBD) for preberthing preparation.	X	Grazing/Collision
B. Establish and maintain clear field of view of target.	X	Grazing/Collision
C. Checkout and set up berthing system for capture mode.	X	Mechanical Damage
D. Reprogram RCS jet and select logic to minimize impingement on berthing target vehicle.	X	Structural Erosion
E. Orient vehicle for safe berthing approach attitude.	X	Grazing/Collision
2. APPROACH AND BERTH		
A. Maintain initial closing velocity (TBD).	X	Grazing/Collision
B. Reduce initial velocity to final close/contact velocity (TBD).	X	Grazing/Collision
C. Readjust and refine pitch, roll, and yaw orientation for capture contact.	X	Mechanical Damage
D. Go for capture contact.	X	Grazing/Collision
E. Standby for post capture relative motion stabilization.	X	Grazing/Collision
F. Rigidize berthing.	X	Mechanical Damage

TABLE 4-3 - DIRECT BERTHING SCENARIO (CONT'D.)

TASKS	SAFETY-CRITICAL	THREATS
3. POST BERTHING OPERATIONS		
A. Pressurize transfer tunnel.	X	Leakage
B. Verify pressure integrity of transfer tunnel.	X	Loss of Pressurization
C. Verify no unacceptable pressure mismatchers between berthing elements.	X	Loss of Access to a Hatch
D. Open hatches for transfers.		
E. Transfer personnel.	X	Loss of Pressurization
F. Transfer bulk cargo.	X	Contamination
G. Transfer fluid supplies.	X	Contamination

TABLE 4-4 RISK ASSESSMENT MATRIX (DIRECT BERTHING)

	TASKS	CRITERIA	GUIDELINES
1A	Rendezvous at safe stand-off distance (TBD) for pre-breathing preparation	8-19	OPS - 105, INT - 210
1B	Establish and maintain clear field of view to target	A-8	INT - 011, DUS - 012 thru 017
1C	Checkout and set up berthing system for capture mode	A-3	OPS - 174
1D	Reprogram RCS jet and select logic to minimize impingement on berthing target vehicle	D-1	OPS - 174, DUS - 019
1E	Orient vehicle for safe berthing approach attitude	D-3	DUS - 019
2A	Maintain inintial closing velocity (TBD)	D-3	DUS - 019
2B	Reduce initial velocity to final close/contact velocity (TBD)	D-3	DUS - 019

TABLE 4-4 (Cont'd.) RISK ASSESSMENT MATRIX (DIRECT BERTHING)

	TASKS	CRITERIA	GUIDELINES
2C	Readjust and refine pitch, roll and yaw orientation for capture contact	D-3	DUS - 019
2D	Go for capture contact	D-3	OPS - 174
2E	Standby for post capture relative motion stabilization	C-11	DUS - 017
2F	Rigidize berthing	D-3	DUS - 018, IFM - 020
3A	Pressurize transfer tunnel	D-5	IFM - 020
3B	Verify pressure integrity of transfer tunnel	D-5	IFM - 020
3C	Verify no unacceptable pressure mismatchers between berthing elements	C-6	IFM - 020, MSE - 022
3D	Transfer personnel	C-4, C-7	OPS - 104, CPH - 206
3E	Transfer fluid supplies	C-4, C-7	OPS - 104

MATERIAL PROCESSING

The possible industrialization of space has been one of the most provocative and stimulating concepts of the United States Space Program. This exciting concept has generated a large number of space industrialization projects that are not easily realizable on earth.

One of the suggested projects is space manufacturing of unique products and materials for earth use or for use in orbit. Space offers the potential for making new or novel products, or for processing materials that can be used on earth to make new, better or lower cost products. The presence of a low gravity environment of space enables us to process materials more efficiently and effectively than on earth. A microgravity environment, with respect to material processing, implies an absense of convection, sedimentation/buoyancy, and body force pressures.

Initial efforts to study material processing in a low gravity environment started in the 1960's. Engineers tried to study what effects low-g would have on propellants in rocket stages that were coasting between burns and on metal that was molten for welding in building large structures. This developed into a basic test program using aircraft and a drop tube to study basic phenomena in a few seconds of low-g. Then three Apollo flights carried equipment for casting immiscible metals and refining certain types of cells. From this there evolved a larger program to be conducted aboard the Skylab during 1972-73. Success led to more low-g experiments aboard the US half of the Apollo-Soyuz missions in 1975. Currently, we are conducting material processing experiments aboard the Shuttle/Spacelab. Such experiments include Monodisperse Latex Reactor (MLR), Continuous Flow Electrophoresis System(CFES), and various experiments as Get Away Special (GAS) payloads. From the information produced by the previous experiments, we are able to select those experiments that have greater economic potential and utility to mankind.

The applications for material processed in space include, to date, a wide variety of electronic, optical, and biological uses. Analysis of previous experiments and current plans for future efforts suggests that initial commercial ventures will probably be associated with the production of electronic material, glasses, and biological products. For example, the products that exhibit greater potential include:

1) Near-perfect Gallium Arsenide (GaAs) integrated circuits
2) Exotic glasses for fiber optics;
3) Interferon (a promising biomedicine)

Space station offers an excellent opportunity for us to advance to full-scale production phase of material processing, culminating in commercial manufacturing. The Space Station provides several location options for material processing: 1) inside the station; 2) outside the station - with processing equipments attached to the station; 3) outside the station - as a co-orbiting free flyer. For example, MLR and CFES belong to the first option; GAS-type experiments to the second option; experiments mounted on Long Duration Exposure Facility (LDEF) to the last option. Regardless of their locations, all material processing experiments possibly need some type of crew involvement. For instance, GAS-type experiments might require EVA while LDEF-type experiments might need EVA using Man Maneuvering Unit (MMU) or an Orbital Transfer Vehicle (OTV).

In this study, we have generated a typical material processing scenario, as shown in Figure 4-7, in order to demonstrate our scenario screening process. This generic scenario is mainly based upon the activities involved in conducting the CFES experiment. Table 4-5 relates the threats to task sub-elements. Table 4-6 contains the risk assessment matrix.

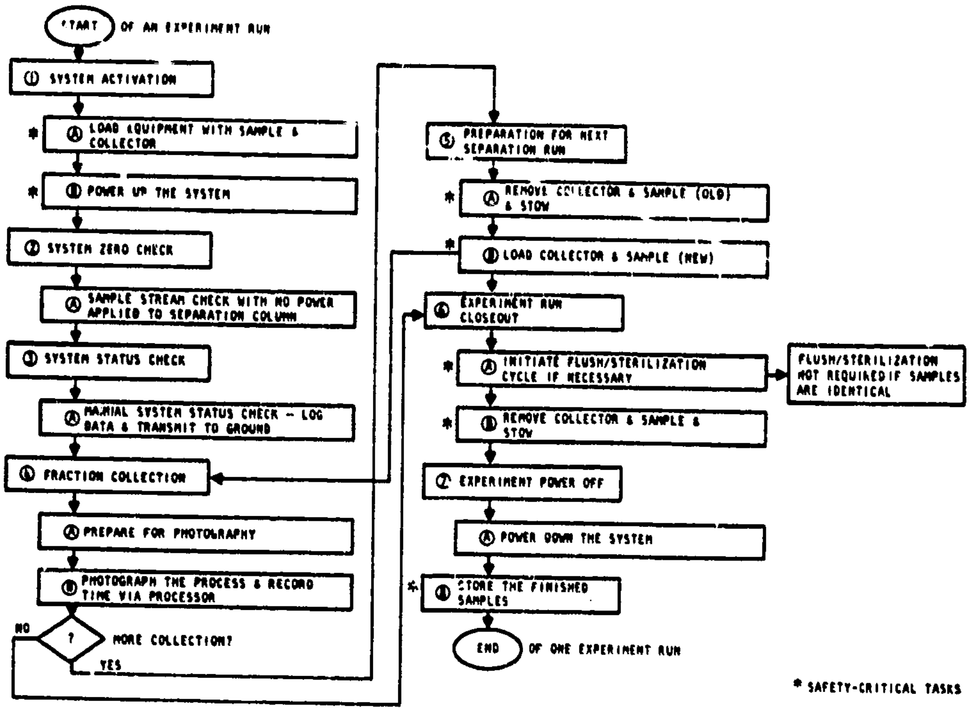


Figure 4-7 Material Processing Scenario

TABLE 4-5 - MATERIAL PROCESSING SCENARIO

TASKS	SAFETY-CRITICAL	THREATS
1. SYSTEM ACTIVATION		
A. Load equipment with sample and collector	X	Biological/Toxic Contamination
B. Power up the system	X	Mechanical Damage
2. SYSTEM ZERO CHECK		
A. Sample stream check with no power applied to separation column		
3. SYSTEM STATUS CHECK		
A. Manual system status check - log data and transmit to ground		
4. FRACTION COLLECTION		
A. Prepare for photography		
B. Photograph the process and record time via processor		
5. PREPARATION FOR NEXT SEPARATION RUN		
A. Remove collector and sample (old) and stow	X	Biological/Toxic Contamination
B. Load collector and sample (new)	X	Biological/Toxic Contamination

TABLE 4-5 - MATERIAL PROCESSING SCENARIO (CONT'D)

TASKS	SAFETY-CRITICAL	THREATS
6. EXPERIMENT RUN CLOSEOUT		
A. Initiate flush/sterilization cycle if necessary.	X	Biological/Toxic Contamination
* Flush/sterilization not required if samples are identical.		
B. Remove collector and sample and stow.	X	Biological/Toxic Contamination
7. EXPERIMENT POWER OFF		
A. Power down the system		
8. STORE THE FINISHED SAMPLES AND COLLECTORS	X	Biological/Toxic Contamination

TABLE 4-6 RISK ASSESSMENT MATRIX (MATERIAL PROCESSING)

	TASKS	CRITERIA	GUIDELINES
1A	Load equipment with sample and collector	B-24, B-10, B-21, D-2	ECS-051, C&W-047, C&W-049
1B	Power up the system	A-2	INT-209, EPD-085
5A	Remove collector and sample (old) and stow	B-10, B-21, B-24, C-4, C-7, D-2	ECS-051, C&W-047, C&W 049, INT-009, INT-154, INT-144, ECS-102, OPS-132, C&W-191
5B	Load collector and sample (new)	B-10, B-21, B-24, D-2	ECS-051, C&W-047, C&W-049
6A	Initiate flush/sterilization if necessary	B-10, B-21, B-24, C-4, D-2	INT-009, FSE-035, C&W-047, C&W-049, ECS-151, CWS-054, INT-167
6B	Remove collector and sample and stow	B-10, B-21, B-24, C-4, C-7, D-2	INT-009, C&W-047, C&W-049, ECS-051, ECS-102, OPS-132, INT-144, C&W-191
8	Store the finished samples and collectors	B-10, B-21, B-24, C-4, D-2	INT-009, C&W-047, C&W-049, ECS-051, OPS-179

FLUID TRANSFER

Orbital fluid transfer operations play a critical role in supporting the Space Station and in carrying out a "fluid-depot" function of the Space Station. The fluids that can be transferred to and from the Space Station range from drinking water to propellants. Table 4-7 contains a list of candidate fluids. As shown in Figure 4-8, there are various vehicles that can interface with the Space Station during fluid transfer operations.

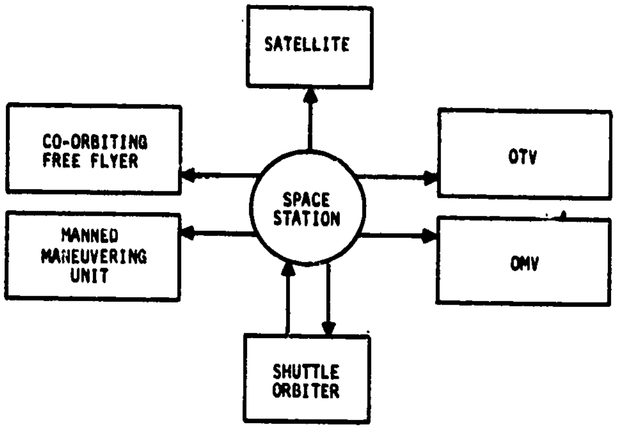
Table 4-7. LIST OF CANDIDATE FLUIDS
FOR ORBITAL FLUID TRANSFER

PROPELLANT	LIQUID HYDROGEN (LH_2) LIQUID OXYGEN (LO_2) MONOMETHYL HYDRAZINE NITROGEN TETROXIDE (N_2O_4) HYDRAZINE (N_2H_4)
PRESSURANT	NITROGEN (GN_2) HELIUM (He)
"ECLSS" TYPE	BREATHING OXYGEN (GO_2) FREON NITROGEN (GN_2) WATER (DEIONIZED) WATER (POTABLE AND WASTE)
MISCELLANEOUS	CLEANING FLUIDS

Three different fluid transfer techniques are considered in this study. The techniques are: 1) transfer-via-conduits technique; 2) fluid module exchange technique; 3) hand-carried-cannister technique.

The transfer-via-conduits technique, illustrated in Figure 4-9, uses conduits (for example, pipes and hose) as fluid transfer lines. This technique requires either Remote Manipulator System (RMS) assistance or Extra Vehicular Activty (EVA) in connecting a fluid transfer line from a supply tank on the supplier vehicle to a matching receiver tank on the receiver vehicle. The technique also requires a fluid transfer line for each fluid to be transferred. It is to be determined whether to transfer one fluid at a time or to transfer several fluids simultaneously. The latter requires some sort of systematic control in connecting several fluid lines so as to eliminate any confusion.

Instead of connecting lines between the two vehicles, we can directly exchange fluid modules. The fluid module exchange technique, shown in Figure 4-10, uses a minimum of two RMS's to replace an empty fluid module (EM) on the receiver vehicle with a refill fluid module (RM) on the supplier vehicle. The technique has the folowing constraints: 1) module exchange activities must



NOTE: ARROWS INDICATE THE DIRECTION OF THE FLUID TRANSFER & DO NOT NECESSARILY MEAN PHYSICAL ATTACHMENT TO THE SPACE STATION

Figure 4-8 Potential Fluid Transfer Vehicles

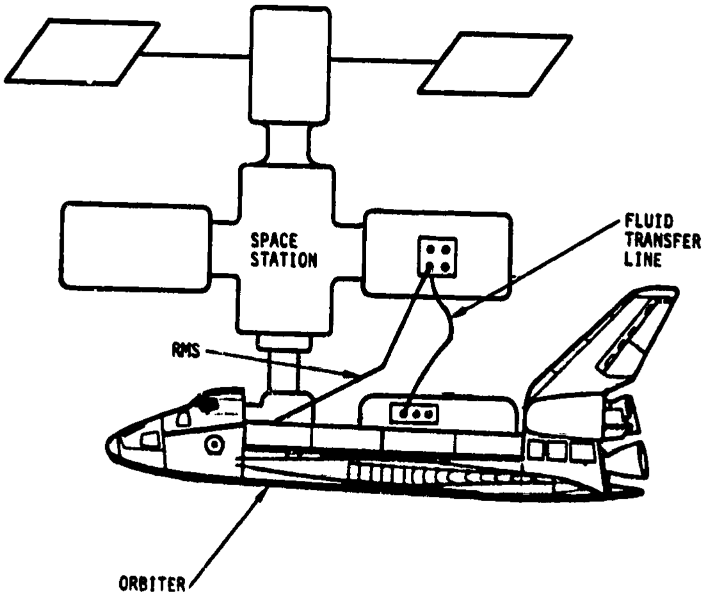


Figure 4-9 Transfer - Via - Conduits Technique

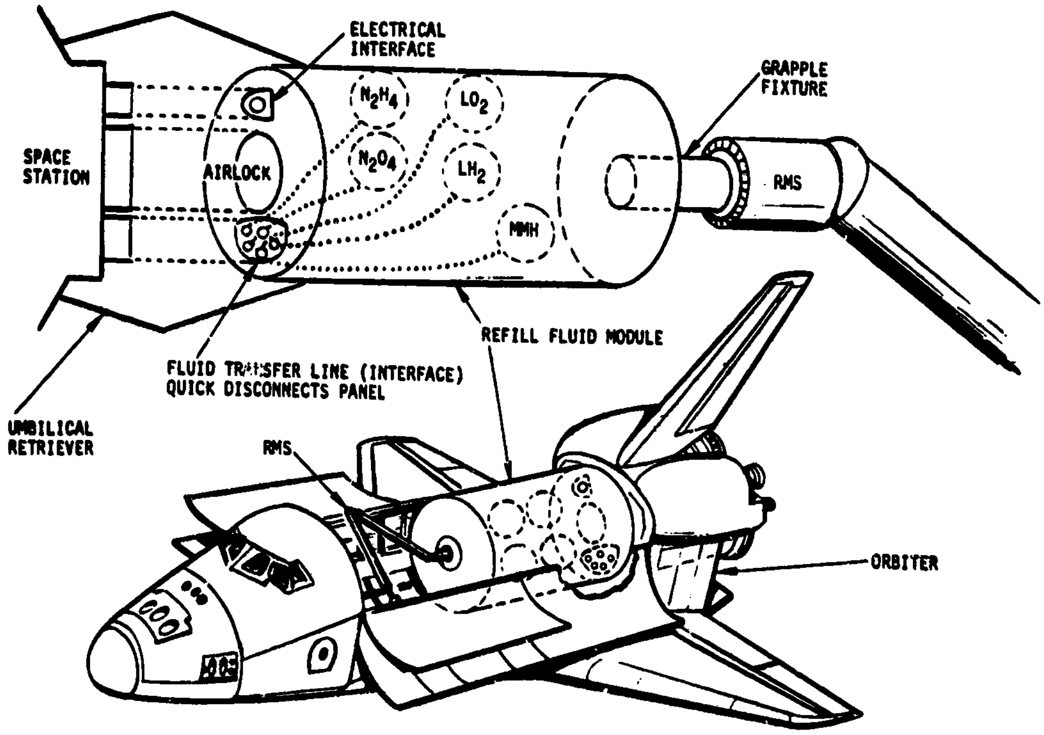


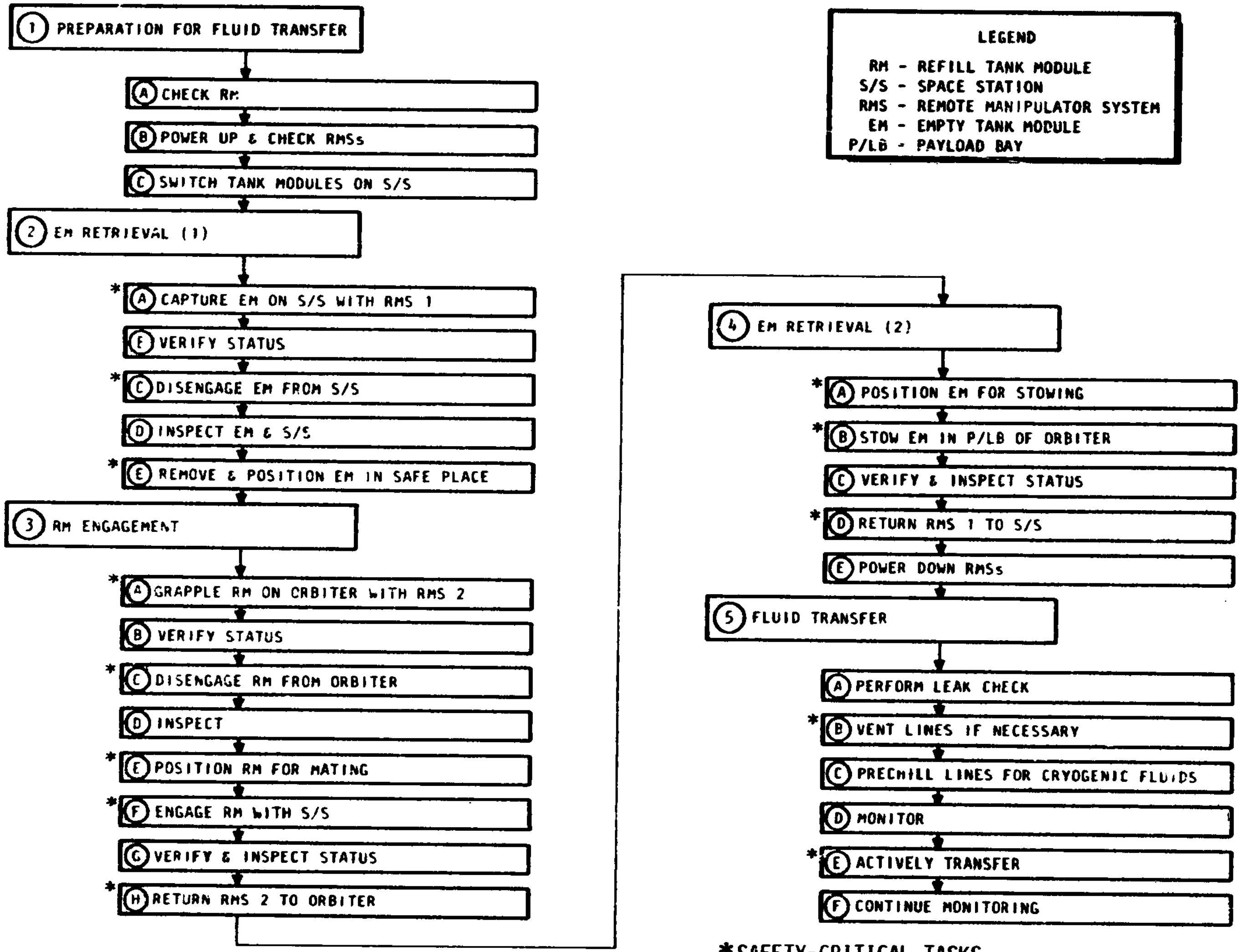
Figure 4-10 Fluid Module Exchange Technique

take place within the reach of the RMSs; 2) a proper design of interface disconnects between the module and the receiver vehicle is necessary; 3) a proper scheduling of fluid consumption should be made to determine the size of each fluid tank so as to minimize the weight penalty involved during the fluid resupply. Also, this technique requires modularization of the fluid storage system of future vehicles including the Space Station.

The simplest of all is the hand-carried-cannister technique. As the name indicates, astronauts handcarry cannisters containing the fluids such as water, freon, etc. Design requirements for these cannisters are subject to the environment in which the transfer is taking place. For example, designers must take into account the pressure differential generated from the vacuum of space if the transfer requires EVA.

In general, fluid transfer operations between the two vehicles may not require berthing. Astronauts can accomplish fluid transfer operations while the two vehicles rendezvous in close proximity; the vehicles must be within the reach of the RMSs.

In this study, we have selected propellant as the transferred fluid and applied the fluid module exchange technique in generating a scenario. We, then, have analyzed the scenario, delineated in Figure 4-11 and Table 4-8, to demonstrate our scenario screening process. The scenario has the Orbiter as the supplier vehicle to the Space Station. Generally, propellant transfer operations are considered one of the more hazardous operations encountered in orbital fluid transfer operations. We can, however, reduce the actual risk to a lower level by using proper safety criteria and guidelines. Table 4-9 shows the risk assessment matrix which contains appropriate safety criteria and guidelines. These safety criteria and guidelines are the outcome of our scenario screening process.



*SAFETY-CRITICAL TASKS

Figure 4-11 Fluid Transfer Scenario

TABLE 4-8 - FLUID TRANSFER

TASKS	SAFETY-CRITICAL	THREATS
1. PREPARATIONS FOR FLUID TRANSFER		
A. Confirm the readiness of the refill tank module (RM) for fluid transfer. (Visual inspecton and using sensor, i.e., pressure and temperature)		
B. Power up RMSs. Check out the function of the RMSs. * The configuration on which this scenario is based requires two RMSs, one on the Orbiter - RMS 2 and the other on the space station (SS) - RMS 1		
C. Switch tank module. There are two redundant tank modules used one at a time on the SS.	X	Leakage
2. EM RETRIEVAL (1)		
A. Capture the empty tank module (EM) on the SS by commanding RMS to grapple a fixture on the EM.	X	Collision
B. Verify secure grappling and stability of the SS.		
C. Disengage the EM from the SS.	X	Leakage
D. Inspect the EM and SS for mechanical damage and leakage.		
E. Remove the E^{M} with RMS 1 and hold it in a fixed position safely away from the SS and Orbiter.	X	Collision
3. RM ENGAGEMENT		
A. Grapple the RM in the Orbiter P/L B with RMS 2.	X	Collision
B. Verify secure grappling and stability of the Orbiter and SS.		

TABLE 4-8 - FLUID TRANSFER (CONT'D.)

	TASKS	SAFETY-CRITICAL	THREATS
C.	Disengage the RM from the Orbiter.	X	Collision
D.	Inspect the RM and Orbiter for mechanical damage and leakage.		
E.	Position the RM for safe mating with the SS. (Visually and using radar.)	X	Collision
F.	Engage the RM with the SS.	X	Collision
G.	a. Verify secure engagement and stability of the SS and Orbiter. b. Inspect for mechanical damage and leakage.		
H.	Command RMS 2 to release the RM and return to the P/L B.	X	Collision
4.	EM RETRIEVAL (2)		
A.	Position the EM for safe stowing into P/L B with RMS 1. (Visually and using radar.)	X	Collision
B.	Stow the EM into P/L B.	X	Collision
C.	a. Verify secure engagement and stability of the Orbiter and SS. b. Inspect for mechanical damage and leakage.		
D.	Command RMS 1 to release the EM and return to the SS.	X	Collision
E.	Power down RMS 1 and RMS 2.		

TABLE 4-8 - FLUID TRANSFER (CONT'D.)

TASKS	SAFETY-CRITICAL	THREATS
5. FLUID TRANSFER		
A. Perform leak check on the RM and its interface with the SS.		
B. Vent the fluid lines if necessary.	X	Biological/Toxic Contamination
C. Only for cryogenic fluids - Prechill the fluid lines by transferring small amount of fluid.		
D. Monitor pressure level, temperature, and flow rate.		
E. Transfer the fluids.	X	Leakage
F. Continue monitoring pressure level, temperature, and flow rate of the fluid transfer system.		

TABLE 4-9 RISK ASSESSMENT MATRIX (FLUID TRANSFER)

	TASKS	CRITERIA	GUIDELINES
1C	Switch tank modules on the Space Station	B-23, D-2, D-4	EPD-033, INT-144, FSE-152, FSE-168, OPS-179, INT-009, INT-010, C&W-049, C&W-083, FSE-035, FSE-043, FSE-070, FSE-071, FSE-074, INT-134, INT-140
2A	Capture EM in the Space Station with RMS 1	A-7, A-8, A-12, C-3, C-5	INT-060, C&W-175, INT-025, INT-046, OPS-179, FSE-035, AOM-178, C&W-201
2C	Disengage EMN from the Space Station	A-7, A-8, A-12, C-3, C-5	INT-060, C&W-175, INT-025, INT-046, OPS-179, FSE-035, AOM-178, C&W-201
2E	Remove and position EM in safe place	A-2, A-7, A-8, A-12, C-3, C-5	INT-060, C&W-175, INT-025, INT-046, OPS-179, FSE-035, AOM-178, C&W-201
3A	Grapple RM on the Orbiter with RMS2	NHB 1700-.7A	
3B	Disengage RM from the Orbiter	NHB 1700.7A	
3E	Position RM for mating	A-7, A-8, A-12, C-3, C-5	INT-060, C&W-175, INT-025, INT-046, OPS-179, FSE-035, AOM-178, C&W-201

TABLE 4-9 (Cont'd.) RISK ASSESSMENT MATRIX (FLUID TRANSFER)

	TASKS	CRITERIA	GUIDELINES
3F	Engage RM with the Space Station	A-7, A-8, A-12, C-3, C-5	INT-060, C&W-175, INT-025, INT-046, OPS-179, FSE-035, AOM-178, C&W-201
3H	Return RMS 2 to the Orbiter	A-7, A-8, A-12, C-3, C-5	INT-060, C&W-175, INT-025, INT-046, OPS-179, FSE-035, AOM-178, C&W-201
4A	Position EM for stowing	A-7, A-8, A-12, C-3, C-5	INT-060, C&W-175, INT-025, INT-046, OPS-179, FSE-035, AOM-178, C&W-201
4B	Stow EM in the payload bay of the Orbiter	NHB 1700.7A	
4D	Return RMS 1 to the Space Station	A-7, A-8, A-12, C-3, C-5	INT-060, C&W-175, INT-025, INT-046, OPS-179, FSE-035, AOM-178, C&W-201
5B	Vent lines if necessary	B-21, B-23, D-2	INT-010, C&W-047, C&W-049, C&W-083, ECS-088, ECS-080, ECS-081, INT-167
5E	Actively transfer	B-23, D-2, D-4	EPD-033, INT-144, FSE-152, FSE-168, OPS-179, INT-099, INT-010, C&W-049, C&W-083, FSE-192, C&W-206, FSE-035, FSE-043, FSE-070, FSE-071, FSE-074, INT-134, INT-140

5. ESCAPE AND RESCUE

Escape and rescue provisions are a design requirement for any manned system. The purpose of this section is to discuss the various escape and rescue alternatives for an Orbiting Space Station.

The Space Station crew safety threats are discussed in various sections in greater detail. They are listed in Figure 5-1 and are grouped according to whether or not it would require immediate response, whether there was some delay allowable or a slow response could be encountered to correct or counteract the threat. The inset graph illustrates the comparative "time until adverse impact" versus "time to repair". If the time to repair is less than the time to adverse impact, then there is a potential of controlling or doing something about the threatened situation. However, if the reverse is true, then the threat situation is one that dictates an immediate need.

The threats which could result in escape or rescue are presented in Figure 5-2. Of those which allow delayed response, escape can be handled by personnel going to a Safe Haven, and can be rescued by the Shuttle. For those threats requiring an immediate response, the problem is to discern if escape or rescue time is available. If escape or rescue time is not available, the risk will have to be accepted for threats of these magnitudes because if they happened, the crew would not be able to escape from them anyway. The ones that fall into this category would be large fires, large tumbling rates, big explosions, rapid decompression of multiple volumes, possible metoroid penetration, debris, etc.

If escape time is available, then what portion of the crew would most likely be involved? All crew members would probably be involved for threats such as a major fire, explosion, mechanical damage, etc. For other threats such as biological contamination or depletion of consumables, possibly only half of the crew may be involved. However, the medical injury/illness issue is probably the only threat that would require only one crewman to escape or be rescued. Table 5-1 shows the probable causes for less than the full crew to escape from the space station.

CONTROLLABLE (N/A)	IMMEDIATE NEED (IM)	DELAY ALLOWED (DEL)	
	X		FIRE
X			LEAKAGE
	X		TUMBLING/LOSS OF CONTROL
	X TO	X	BIOLOGICAL OR TOXIC CONTAMINATION
	X TO	X	INJURY/ILLNESS
		X	GRAZING/COLLISION
X			CORROSION
	X TO	X	MECHANICAL DAMAGE
	X TO	X	EXPLOSION
	X TO	X	LOSS OF PRESSURIZATION
		X	RADIATION
X			OUT-OF-CONTROL IVA/EVA ASTRONAUT
X			INADVERTENT OPERATIONS
X			LACK OF CREW COORDINATION
	X TO	X	ABANDONMENT OF SPACE STATION
	X		METEOROID PENETRATION
X		X	STORES/CONSUMABLES DEPLETION
		X	STRUCTURAL EROSION
		X	ORBIT DECAY
	X TO	X	LOSS OF ACCESS TO A HATCH
X			TEMPERATURE EXTREMES
	X		DEBRIS
X			FREE ORBIT (EVA ASTRONAUT)

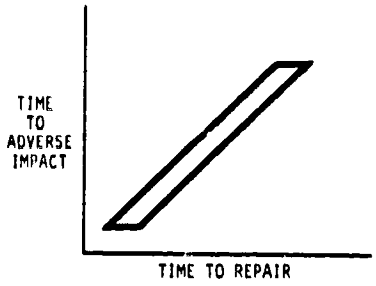


Figure 5-1 Space Station Crew Safety Threat List

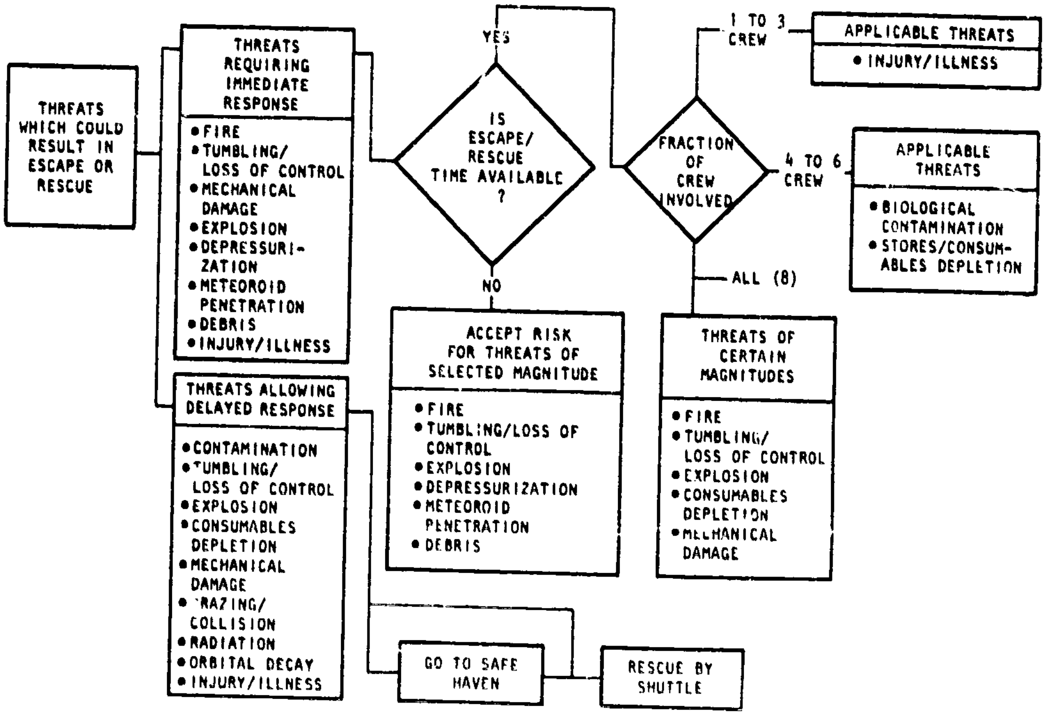


Figure 5-2 Threats Requiring Escape/Rescue

Table 5-1. WHAT WOULD CAUSE ESCAPE OF LESS THAN FULL CREW

1 MAN?	2 MEN?	3 MEN?
o SOLE SURVIVOR	o TWO SURVIVORS	o THREE SURVIVORS (REMOTE PROBABILITY) ESCAPING IMPENDING DISASTER
o PHYSICAL MEDICAL ISSUE (CUT, SOME BURNS)	o INDIVIDUAL CREWMAN MEDICAL ISSUE REQUIRING CONSTANT AID BY MEDIC	o DECEASED
o PSYCHOLOGICAL ISSUE	o PHYSICAL o PSYCHOLOGICAL	
o INABILITY TO RECONNECT WITH SPACE STATION	o DECEASED	
o DECEASED		

ESCAPE AND RESCUE OPTIONS

The options for escape and rescue are divided into 5 categories as shown in Figure 5-3. Option A provides emergency escape vehicle(s) at the space station which enables escape to earth. The actual rescue is performed by the Navy or Air Force. Option B provides an Orbital Transfer Vehicle (OTV) for relocating the crew to a second station. Spare parts or equipment may be obtained for the return and repair of the space station and continued operations. An external Safe Haven is used in Option C for the crew to await rescue by the Orbiter or friendly vehicle, then return to earth. In Option D, an Internal Safe Haven is available. The Orbiter or a friendly vehicle can provide the rescue operations; or a supply vehicle can be sent for Space Station repair & resumption of operations. In Option E, the Orbiter is available for escape to earth.

ESCAPE/RESCUE DISCRIMINATORS

The prime discriminators for the escape/rescue system options are cost, response time, crew size, technology risk (new technologies required) and types of calamities accommodated. The five basic escape/rescue system options are shown on Figure 5-4 along with the discrimintor assessments. For Option A, emergency escape vehicles located at station, costs for safety is charged 100%. Because of the kinds of vehicles involved, a minimum of two are needed to be effective. Response time varies from 10 minutes to 1 1/2 hours. The crew size varies from 1 to 4 per vehicle. Technology risk ranges from medium to very high. Some of these concepts have a minimum of analysis and very little if any development tests. The types of calamities that can be accommodated are shown. If the crewmen go to a second station, Option B, no costs are charged to safety because the capability is already built into the second station. It is simply a matter of using OTV for transfer. Time of response will vary pending the relative positions of the stations. Technology risk is medium, the size of the crew is not known. For the external Safe Haven, Option C; costs would be charged to safety because it is not needed to keep the space station operating. Response time would be approximately 1 hour, crew size could be 8 people, a very high technological risk & it would accommodate the calamities as shown. For the Internal Safe Haven, Option D, total costs are a part of the mission continuation. The response time is very short, risk is low, it can handle all the crew & can accommodate most of the calamities. The orbiter Vehicle, Option E, would have no costs for on-station mission continuation. The response time could be as short as 15 minute for on-station. Otherwise, it depends where the Orbiter vehicle is located at the time of an emergency. The Orbiter could handle a full crew and all calamities including these injury/illness cases. However, there is a potential problem. In the event of a rescue mission that occurred concurrently during a crew-changeover (about 16 people plus the Orbiter crew), a second orbiter may be required to handle this condition.

ESCAPE SYSTEM CONCEPTS

Escape system concepts (Option A above) which are capable of returning to earth, fall into two broad classes, ballistic entry types and lifting - body types. The classifications are a function of the aerodynamic characteristics (body shape, center of mass, center of pressure and aerodynamic coefficients). The pure ballistic types have a lift over drag ratio (L/D) equal to zero. These may be further subdivided within categories of medium and high L/Ds. The high L/Ds having extensive range and crossrange distance to the potential landing area.

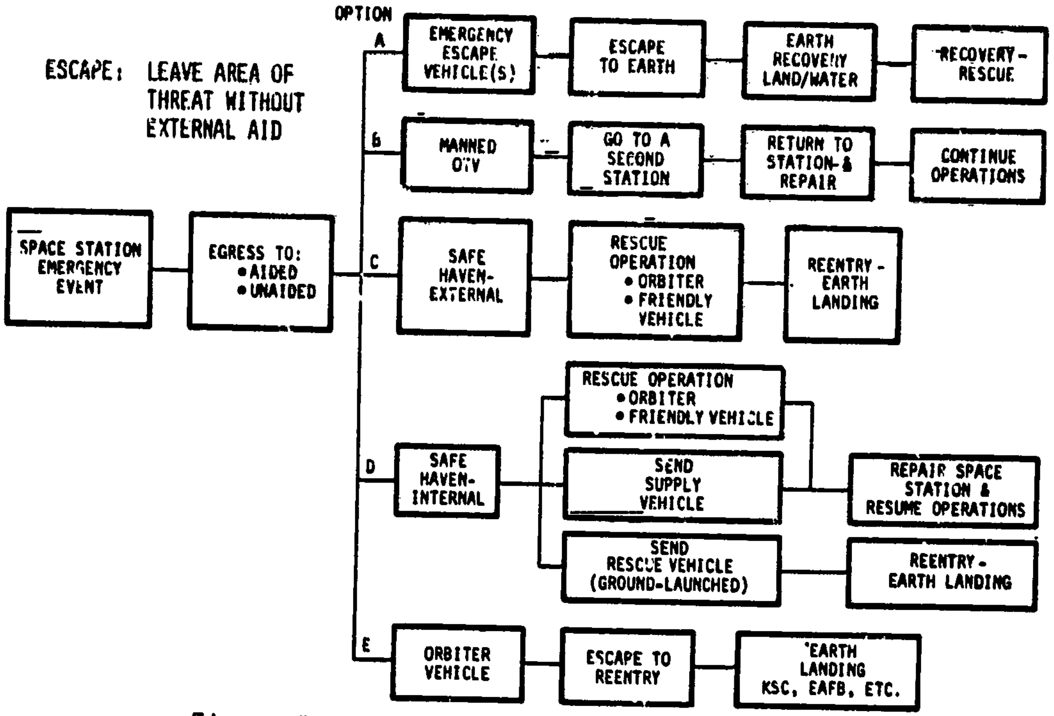


Figure 5-3 Escape and Rescue Options

OPTION	COSTS		RESPONSE TIME	CREW SIZE	TECHNOLOGY RISK	TYPE OF CALAMITIES ACCOMMODATED
	MISSION CONTINUATION	SAFETY				
A EMERGENCY ESCAPE VEHICLES	** NONE	100% (2 VEHICLES MINIMUM) $300 TO $1500M̄	VARIES (10 min TO 1-1/2 hr)	1 TO 4 PER VEHICLE	MEDIUM TO VERY HIGH	• FIRE* • TUMBLING* • MECHANICAL DAMAGE • EXPLOSION* • DEPRESSURIZATION* • METEROID PENETRATION* • DEBRIS *SELECTED
B GO TO A SECOND STATION VIA A MANNED OTV	** NONE	NO COST	VARIES (15 min TO 1-1/2 hr)	TBD	MEDIUM	ALL OF ABOVE
C SAFE HAVEN EXTERNAL	** NONE	TOTAL COST $300 TO $500M̄	<1 hr	8	VERY HIGH	ALL OF ABOVE
D SAFE HAVEN INTERNAL	TOTAL COST	NO COST	<10 min	8	LOW	ALL OF ABOVE
E ORBITER VEHICLE	NONE	< $1.0M̄/DAY	<15 min	10	VERY LOW	ALL OF ABOVE PLUS INJURY/ILLNESS

**POTENTIAL LOSS OF MISSION

Figure 5-4 Discriminators for Escape/Rescue System Options

All escape system concepts are sensitive to crew size, stowage and deployment kinematics, orbital endurance, aerodynamic characteristics, recovery mode, space station interfaces and degree of independency, and extent of earth - based support. Each escape system reviewed provided greater or lesser advantages and disadvantages in the sensitivities listed; none could satisfy all constraints. For example, storage of rigid heat shields is a major problem for single-place escape systems. Foldable, fully expandable and semirigid structures are more readily integrated into space station structures and require less storage space. They are usually the lightest in weight and are stowable in packs or cannisters. However, greater demands and constraints are placed on the crewman to erect and deploy the escape. In certain designs, some or even all of these tasks are accomplished within the distressed space station; in others, a portion or all of the tasks are accomplished in extravehicular activities (EVA). In one case, reaction time requirements place several limitations on the accomplishment of on-board tasks, and other cases, the complex EVA requirements can place very great or impossible demands on man's capabilities to do work unrestrained in the zero-g environment.

Space escape essential functions, overall systems and subsystem support requirements, and capabilities inherent to crew survival are shown in Figure 5-5.

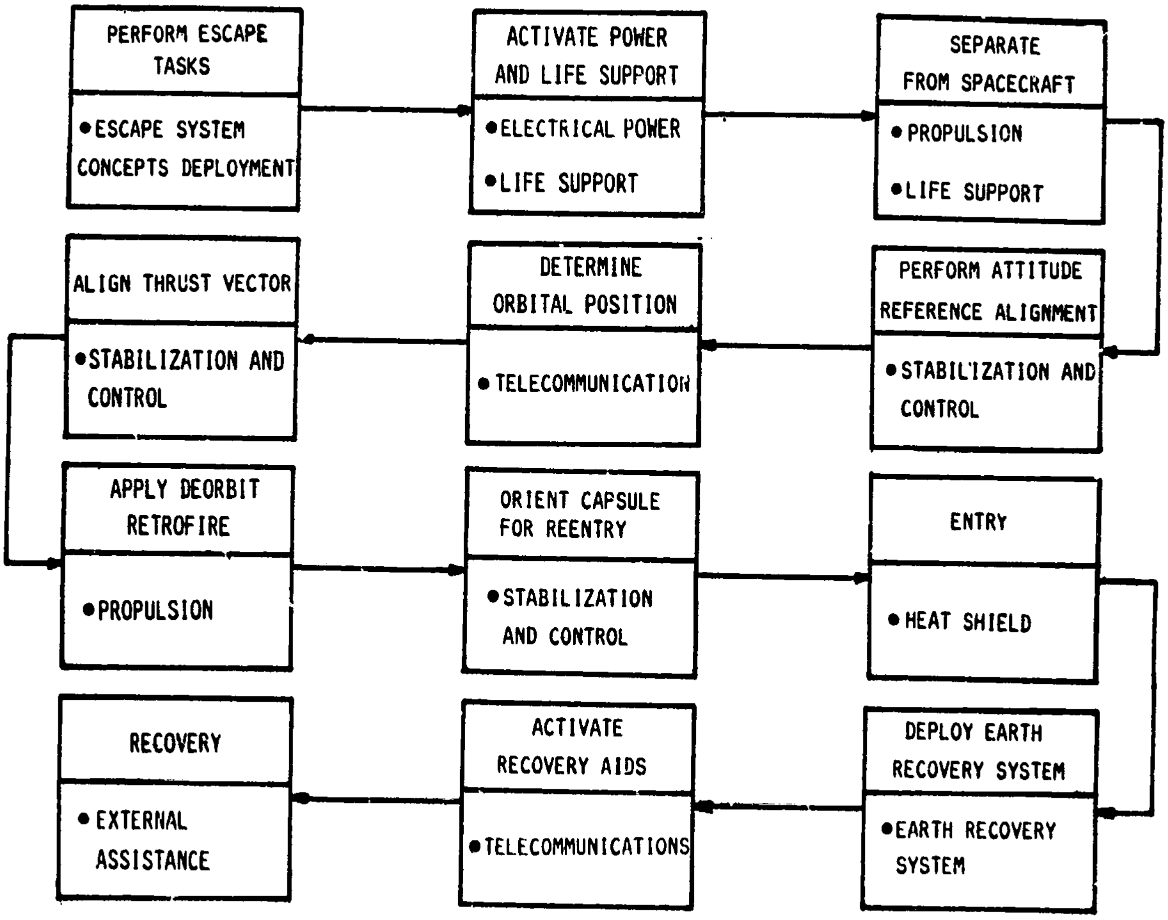


Figure 5-5. Typical Sequential Flow of Events
After Space Escape System Separation

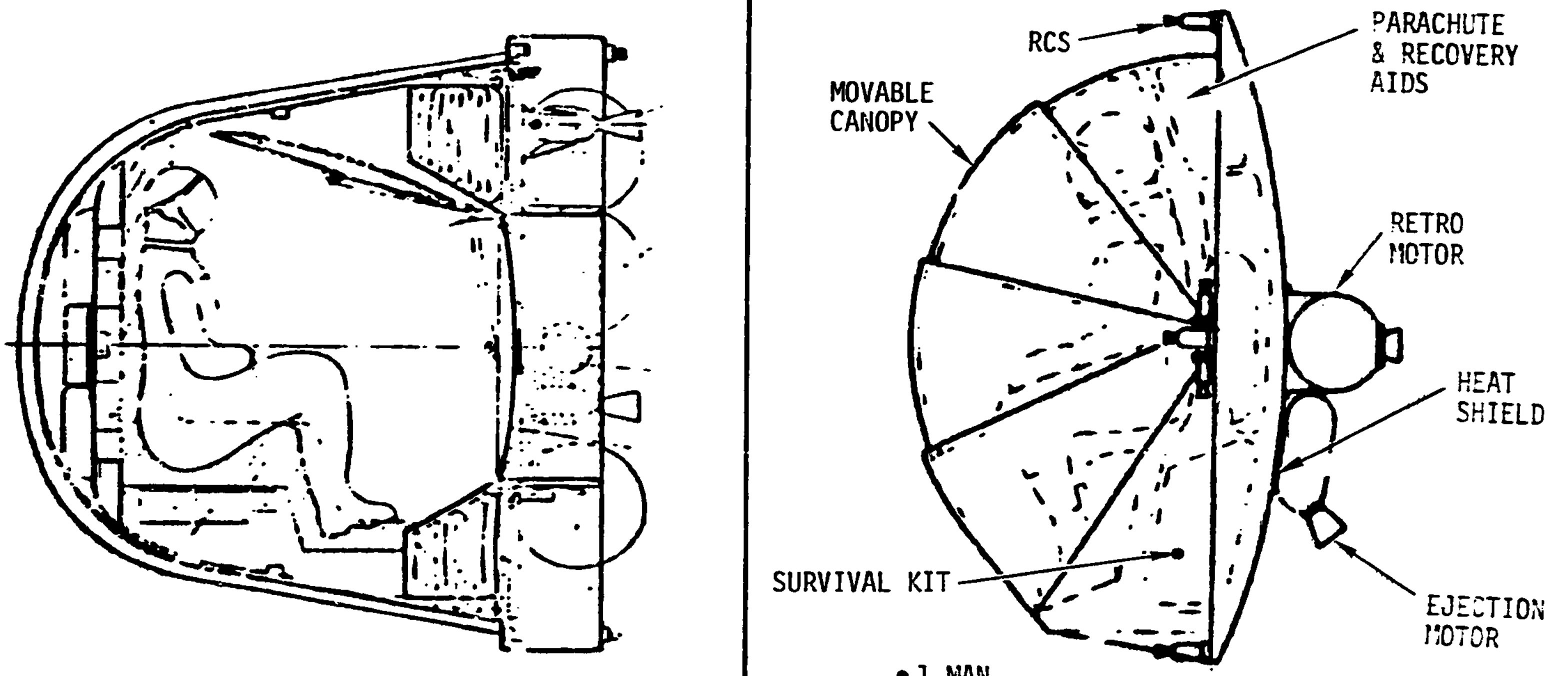
A list of typical escape vehicles which were reviewed is shown on Table 5-2. The escape systems capable of being stowed onboard or attached to the space station are listed as deployable or rigid concepts along with the company responsible for the design concept. These escape systems are illustrated on Figures 5-6 through 5-12. A general description is included giving information regarding the number of crewmen it can accommodate, size/weight, type of recovery and state-of-the-art in technology. The remaining concepts are listed as "Other" and include the NASA rescue ball concept, second station, Shuttle, Hermes and an AF Low G Entry Vehicle.

Table 5-2 LIST OF TYPICAL VEHICLES

DEPLOYABLE	RIGID	OTHER
AIRMATE (GOODYEAR)	MOSES (GE)	RESCUE BALL CONCEPT (NASA)
RIB-STIFFENED (ROCKWELL)	EGRESS (MMC)	SECOND STATION (ROCKWELL)
PARACONE (MDAC)	LIFE RAFT (GE)	SHUTTLE
MOOSE (GE)	EEOED (LOCKHEED)	HERMES
ENCAP (?)	SPHERICAL HEAT SHIELD (ROCKWELL)	AF LOW G ENTRY VEHICLE
SAVER (ROCKWELL)	APOLLO CM (ROCKWELL)	
	LIFTING BODY (NORTHROP)	

MOSES ESCAPE CONCEPT
MANNED ORBITING SHUTTLE ESCAPE SYSTEM
(GE)

EGRESS ESCAPE CONCEPT
(MARTIN MARIETTA)

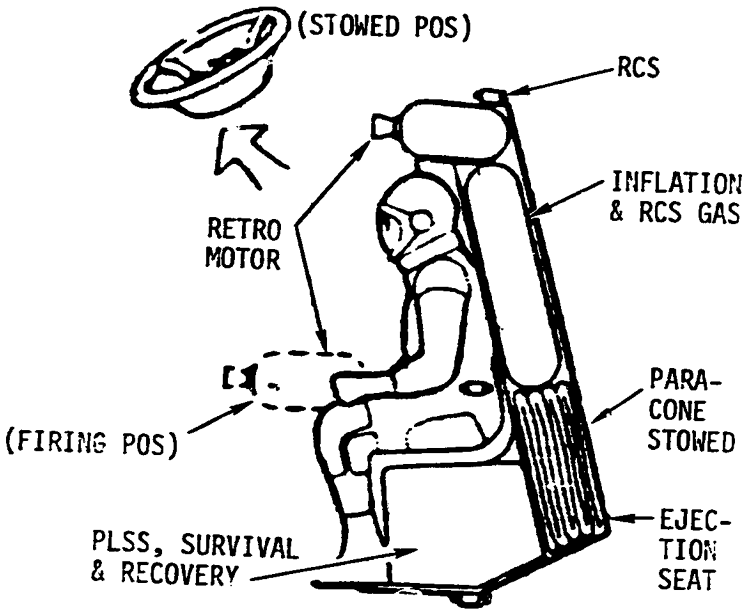


- TECHNOLOGY - CURRENT
- 1-, 2- OR 4-MAN CONCEPTS
- 1610, 2880 & 5110 LB RESPECTIVELY
- ESCAPE SUITS REQUIRED
- BALLISTIC ENTRY
- PARACHUTE RECOVERY
- PROVEN SYSTEM FOR SATELLITE RECOVERY VEHICLES

- 1-MAN
- SHIRTSLEEVE ENVIRONMENT
- EJECTION SEAT
- 370 KG (820 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - MOVABLE CANOPY
    NEW HEAT SHIELD
  - MODIFIED B-58 CAPSULE

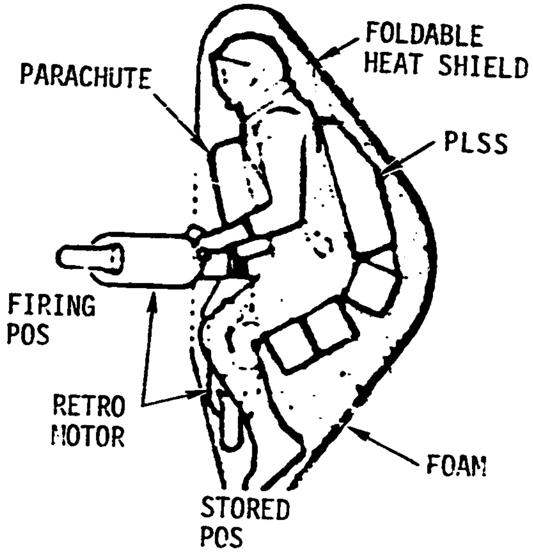
Figure 5-6 Rigid

PARACONE ESCAPE CONCEPT
(MDAC)



- 1 MAN
- SUIT
- INFLATABLE
- 192 KG (425 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - LARGE INFLATABLE & DEPLOYABLE STRUCTURE
  - MATERIAL

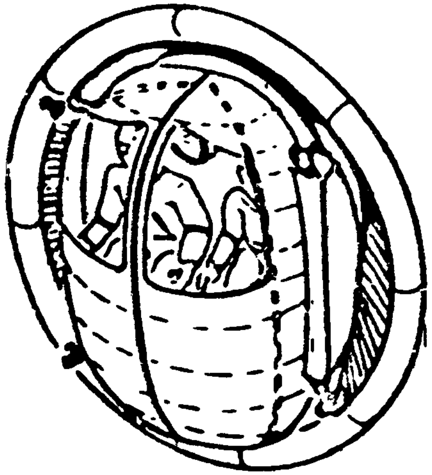
MOOSE ESCAPE CONCEPT
MANNED ORBITAL OPERATIONS
SAFETY EQUIPMENT
(GE)



- 1 MAN
- SUIT
- HAND-HELD RETRO
- ALL EQUIPMENT CARRIED EVA
- FOAM-IN-PLACE
- 215 KG (475 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - FOAM IN SPACE
  - FOLDABLE HEAT SHIELD

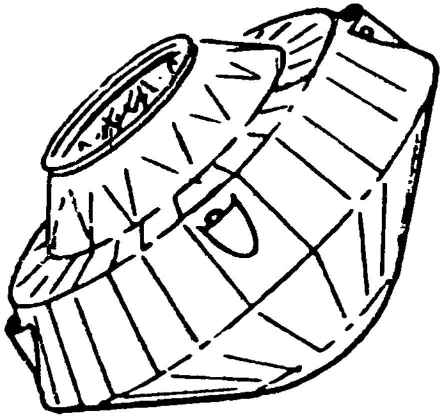
Figure 5-7 Deployable

AIRMAT ESCAPE CONCEPT
(GOODYEAR)



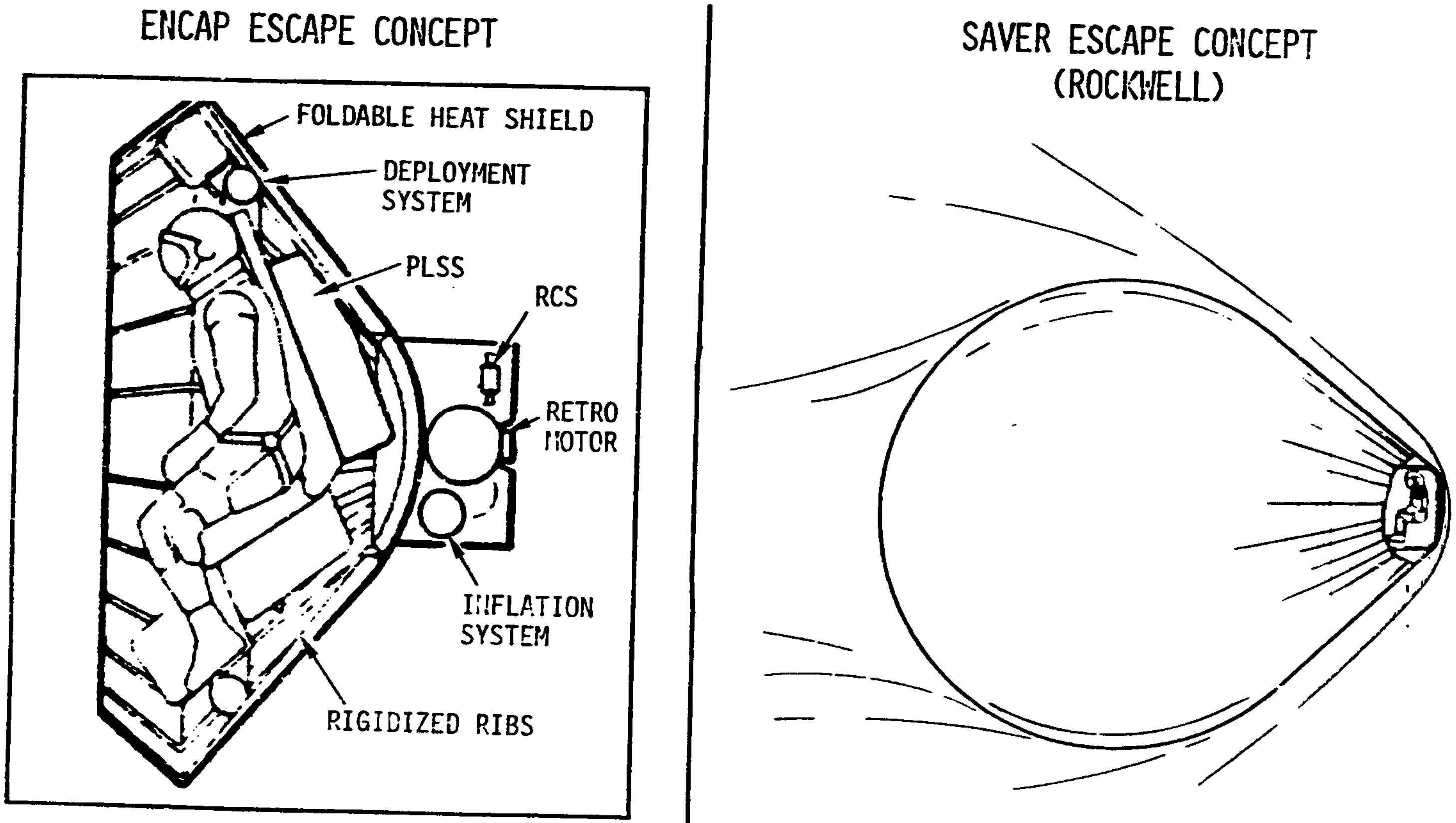
- 2-MAN
- SUITS REQUIRED
- INFLATABLE
- EJECTION SEAT
- 518 KG (1140 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - FLEXIBLE HEAT SHIELD
  - MATERIAL

RIB-STIFFENED EXPANDABLE ESCAPE CONCEPT
(ROCKWELL)



- 3-MAN
- SHIRTSLEEVE ENVIRONMENT
- MECH RIGID
- CANISTER STORED
- 660 KG (1452 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - ARTICULATING RIB-TRUSS STRUCTURE
  - MATERIAL

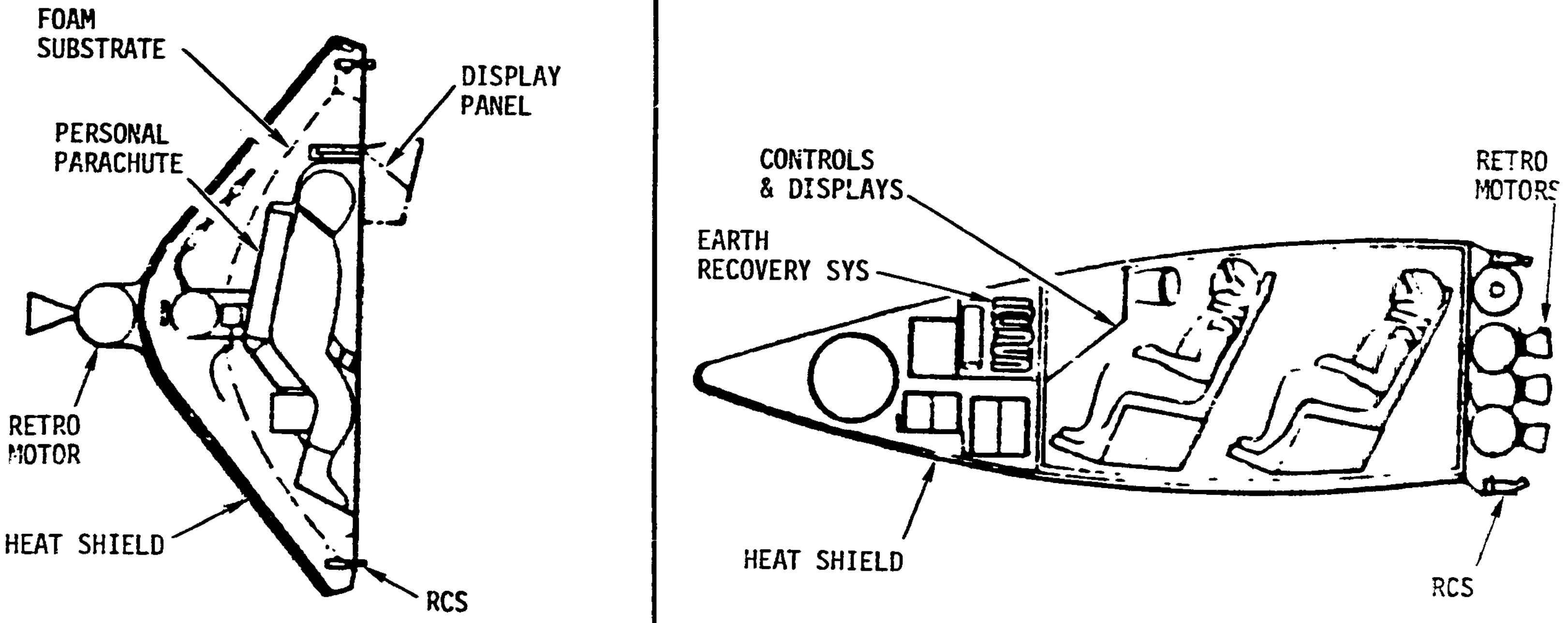
Figure 5-8 Deployable



- 1 MAN
- SUIT
- EVA
- MECH RIGID
- 24 KG (588 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - MECHANICAL DEPLOYMENT MECHANISM
  - FOLDABLE HEAT SHIELD

- 1 MAN
- LARGE INFLATABLE LIGHTWEIGHT BALLOON
- SUITS & LIFE SUPPORT REQUIRED
- MODULATED DRAG & DECELERATION g LOADS
- NEW TECHNOLOGY

Figure 5-9 Deployable



LIFE RAFT ESCAPE CONCEPT
(GE)

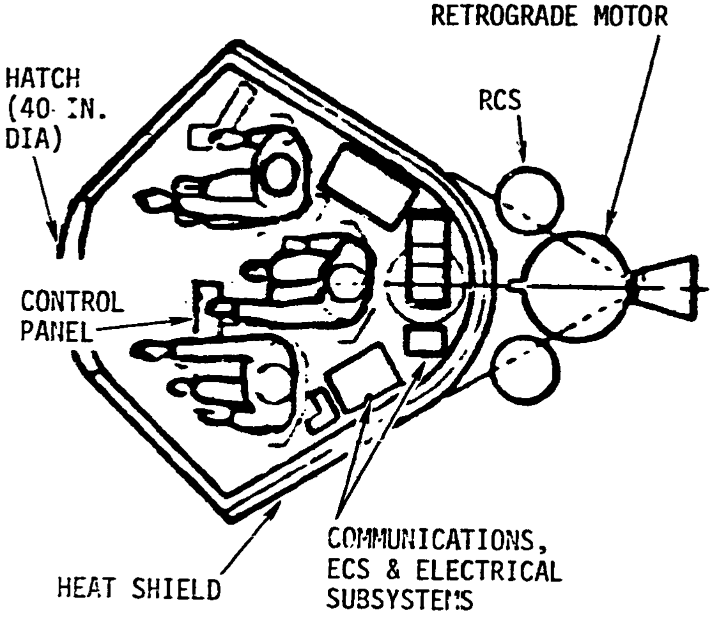
- 3-MAN
- SUITS REQUIRED
- PERSONAL CHUTES REQUIRED
- 420 KG (936 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - NEW HEAT SHIELD
  - FOAM MATERIAL

LIFTING BODY ESCAPE CONCEPT
(NORTHROP)

- 3-MAN
- SHIRTSLEEVE ENVIRONMENT
- 1950 KG (4330 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - NEW HEAT SHIELD
  - REENTRY TECHNIQUE
  - HIGH-SPEED PILOT TECHNIQUES

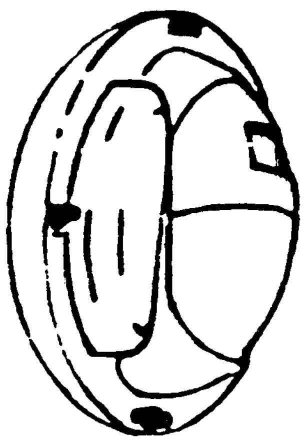
Figure 5-10 Rigid

EEOED ESCAPE CONCEPT
EMERGENCY EARTH ORBITAL ESCAPE DEVICE
(LOCKHEED)



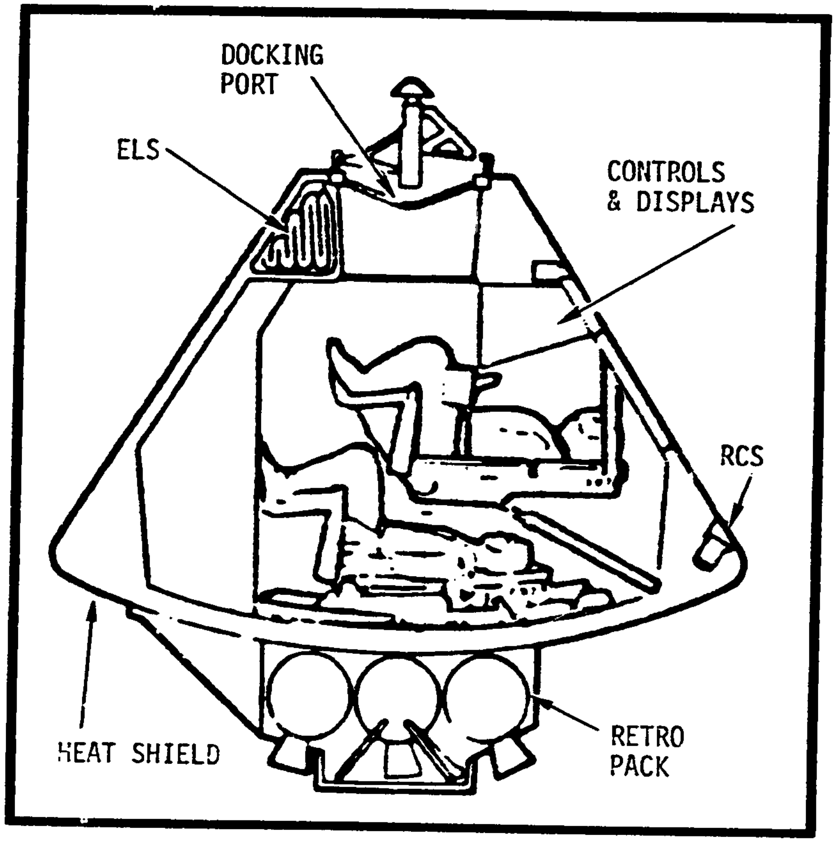
- 3-MAN
- SHIRTSLEEVE ENVIRONMENT
- 1240 KG (2769 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - NEW HEAT SHIELD

SPHERICAL HEAT SHIELD ESCAPE CONCEPT
(ROCKWELL)



- 2-MAN
- SHIRTSLEEVE ENVIRONMENT
- 445 KG (985 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - NEW HEAT SHIELD

Figure 5-11 Rigid



- 2-6 MAN
- SHIRTSLEEVE
- ≈ 4500 KG (10,000 LB)
- NEW TECHNOLOGY REQUIREMENTS
  - NONE

Figure 5-12 Rigid Apollo CM Escape Concept (Rockwell)

France's proposed Hermes manned minishuttle spacecraft is shown in Figure 5-13 (Aviation Week & Space Technology, 8/8/83). The French space agency CNES is evaluating future development of the Hermes for launch on the European Ariane 5 launcher configuration. This version would accommodate four crewmembers in the cockpit and would incorporate a small cargo bay in the center fuselage section.

The Rescue Ball enclosure, Figure 5-14, consists of a pressurized sphere which permits rescue of personnel from a disabled vehicle to be transferred to a rescue vehicle or safe haven. The enclosure accommodates one person in shirtsleeve attire and in the fetus transport position. NASA developed and evaluated three of these units. The original concept used a PLSS (Portable Life Support System, no longer in production) with an oxygen mask. The inflatable sphere is approximately 39 inches in diameter, uses Kevlar and urethane construction with an outside thermal protection cover and has a Lexan window. Rescue activites would require transfer via EVA, MMU, the Orbiter manipulator or other means.

Astronauts performing EVA may become separated from their work station and require rescue. The difficulty in seeing a drifting astronaut suggests the need for a supplementary target. Star (search, tracking and rescue aid) was the result of a Northrop study. It consists of an inflatable target, Figure 5-15, equipped with an RF/radar corner reflector and carried as an item of personal equipment, deployed by a lanyard which also initiates a radio distress call. The target is designed to house the astronaut at his option. The 25 feet inflated sphere would be as visible as a 3D magnitude star at 1,000 nautical miles. The device could be used as a marker for space or surface payloads.

The Space Station escape/rescue discriminators are shown on Table 5-3. The concepts are listed with information which provides a basis of comparison regarding; (1) response time, (2) technology risk, percent of calamities accommodated, (3) crew size, (4) man-rating verification, (5) maturity and (6) specific comments. Table 5-4 provides a parametric evaluation of escape/rescue concepts. The comparative information consists of ; (1) environment, (2) costs, (3) technology, (4) development risk, (5) launch vehicles and (6) recovery. A review of the above shows that the only fast response is provided by escape to a second station. Most of the inflatable/foldable type escape systems have an inherently slow response time. In addition, the crewmen require pressure suits as opposed to having a shirt-sleeve environment. With the exception of Moses escape concept, most of the one to three crewman sized ballistic entry type escape systems have a high technological and development risk. None of these systems have been man-rated. Although the Moses has a proven maturity record for recovering unmanned satellite vehicles, it uses a rotational spin rate to compensate for center of gravity (CG) offsets and encounters an axial deceleration force of between 7 and 8 G's during atmospheric re-entry. Most of these systems would use a water recovery for landing. The Moses has an air/aircraft recovery system.

The only escape/rescue vehicle capable of providing exceptionally low re-entry G loads are the lifting body types such as the USAF/Langley (Northrop) lifting body, the proposed French Hermes concept and the Orbiter Shuttle vehicle. The USAF lifting body has completed a low altitude flight test program. The Shuttle Orbiter vehicle is the only proven low-G entry and airport runway landing vehicle.

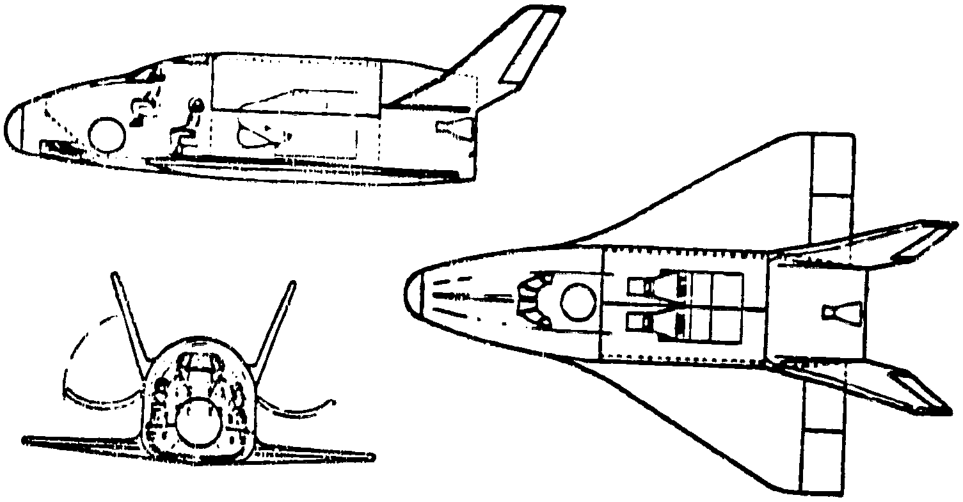


Figure 5-13 Hermes Minishuttle Spacecraft

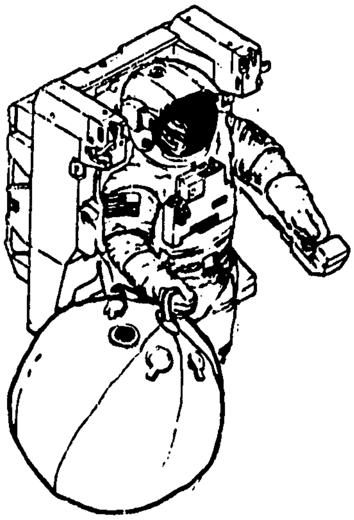


Figure 5-14 Rescue Ball Concept (NASA)

OF POOR QUALITY

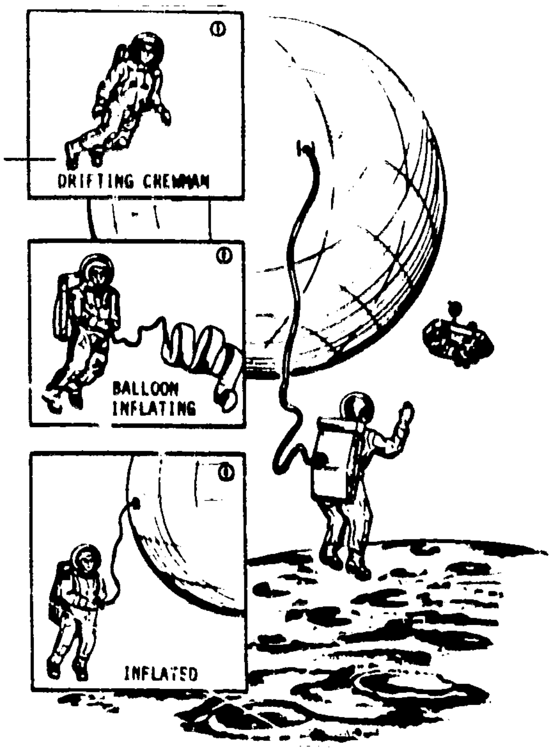


Figure 5-15 STAR (A Search, Tracking and Rescue Aid)

TABLE 5-3 ESCAPE/RESCUE DISCRIMINATORS

CONCEPT	*** RESPONSE TIME	TECH-NOLOGY RISK	% OF CALAMITIES ACCOMMODATED	CREW SIZE	MAN-RATING VERIFICATION	MATURITY	COMMENTS
AIRMAT	MEDIUM	HIGH	80%	2	ANALYSIS & LAB TESTS	NEW	MAN-RATING DIFFICULT
RIB-STIFFENED	SLOW	HIGH	80%	3	ANALYSIS & LAB TESTS	NEW	
PARACONE	MEDIUM	HIGH	80%	1	ANALYSIS & LAB TESTS	NEW	
MOOSE	SLOW	HIGH	80%	1	ANALYSIS & LAB TESTS	NEW	
ENCAP	MEDIUM	HIGH	80%	1	ANALYSIS & LAB TESTS	NEW	CONCEPT ONLY
SAVER	MEDIUM	HIGH	80%	1	ANALYSIS & LAB TESTS	NEW	NOT MAN-RATED
MOSES	MEDIUM	MEDIUM	80%	1-4	ANALYSIS & LAB TESTS	PROVEN	
EGRESS	MEDIUM	HIGH	80%	1	ANALYSIS & LAB TESTS	NEW	
LIFE RAFT	SLOW	HIGH	80%	3	ANALYSIS & LAB TESTS	NEW	
LIFTING BODY*,**	MEDIUM	MEDIUM	90%	3	LOW ALTITUDE FLIGHT ACCOMPLISHED(X-SERIES)	PARTIAL	
HERMES*	MEDIUM	MEDIUM	90%	4	CONCEPT PROVEN	NEW	FRENCH PROPOSAL
EEOED	MEDIUM	HIGH	80%	3	ANALYSIS & LAB TESTS	NEW	
SPHERICAL	MEDIUM	HIGH	80%	2	ANALYSIS & LAB TESTS	NEW	
HEAT SHIELD							
APOLLO CM	MEDIUM	LOW	80%	6	MAN-RATED	PROVEN	OUT OF PRODUCTION
SHUTTLE*	MEDIUM	LOW	90%	10	MAN-RATED	PROVEN	PRODUCTION CONTINUING
RESCUE BALL*	SLOW	LOW	90%	1	PARTIALLY MAN-RATED	PARTIAL	INTERIM TRANSFER VEHICLE
SECOND STATION*	FAST	LOW	90%	8	ANALYSIS & TEST	NEW	

*LOW-"g" ENVIRONMENT

**USAF/LANGLEY,NORTHROP

*** FAST = Less than 15 minutes
MEDIUM = 15 to 30 minutes
SLOW = greater than 30 minutes

TABLE 5-4 PARAMETRIC EVALUATI[illegible] ESCAPE, RES[illegible] SURVIVABILITY CONCEPTS

Concept	Crew Size	Shirt-Sleeve	Cost ($M)	Tech.	Development Risk	Launch Vehicles	Recovery
Escape							
Airmat	2	No	233	New	High	No	Water
Rib stiffened	3	Yes	258	New	High	No	Water
Paracone	1	No	210	New	High	No	Water
Moose	1	No	250	New	High	No	Water
Moses	2-4	No	87	Current	Low	No	Water/air
Encap	1	No	250	New	High	No	Water
Egress	1	Yes	198	New	Medium	No	Water
Life raft	3	No	215	New	High	No	Water
Lifting body	3	Yes	490	New	Medium	No	Water
EEOD	3	Yes	270	New	Medium	No	Water
Spherical heat shield	2	Yes	218	New	Medium	No	Water
Apollo Escape CM	2-6	Yes	88	Old	Very low	No	Water
Saver	1	No	300	New	Very high	No	Water
Rescue							
Shuttle	12	Yes	0-1 launch	None extra	Low	***	Land
Hermes	Unk	Yes	Unk	New	Medium	Yes	Land
Apollo Rescue CSM	2-4	Yes	Very high	Current	Low (S-IB) Med (Titan)	Yes	Water
Rescue Ball	1	Yes	Low	Current	Low	No	
Survivability*							
Cocoon	1	No	Med-High	New	High	Only if needed***	Shuttle
Sortie module	12	Yes	Med-High	Current	Medium		Shuttle
Space Station Module	12	Yes	Med-High	Current	Medium		Shuttle
Apollo Survivability CM	8	Yes	Med-High	Current	Medium		Shuttle
Modular Survivability Vehicle (MSV)	12	Yes	Med-High	Current	Medium		Shuttle

* Assumes shuttle used for rescue (10 nominal, greater than 10 inches emergency.)

** Low = 2000 kg (4500 lb.), high = 4000 kg (9000 lb)

*** Launch vehicles are used only if a rescue or survivability situation arises. Dedicated launch vehicles not required.

A review of the foregoing discussions relative to potential threats and escape/rescue requirements, shows that most threats can be eliminated by design or operational solutions with the exception of injury or illness. Due to the high entry G's encountered, the Orbiter Shuttle vehicle is the only concept currently capable of performing Escape or Rescue operations for seriously "Ill or Injured" personnel.

6. EXTRA-VEHICULAR ACTIVITY

INTRODUCTION

Extra-Vehicular Activity (EVA) is that activity conducted external to the primary shirtsleeve environment afforded by the National Space Transportation System (NSTS), the Space Station, any future planned habitability areas (OTV manned pod or Lunar Base habitability modules). The EVA function in the past, except for Apollo lunar surface and cis-lunar exploration, has usually been a contingency function or an experimental endeavor to determine crew capabilities. For the Space Station, EVA is planned as a normal activity. The contingency element of EVA is not defined at this time. The purpose of this report section is to address the threat impact on EVA crewmen and systems and discuss current EVA systems and their related safety issues.

THREAT/EVA IMPACT

Twenty-five threats to the space station program have been identified during this study. Table 6-1 lists these threats and indicates their impact on the EVA systems. Each related threat is discussed. Threat definitions are included in Appendix B to Volume IV of this report. Many of these threats will be addressed, hopefully in the planned advanced EMU study for FY85.

Fire

Fire issues that relate to EVA are similar to those discussed in Section 2 of Volume II. Design approaches to preclude the onset of fire are classical, that is, 1) proper material selection, 2) isolating the fuel-oxidizer-ignition triangle legs and/or 3) inert affected volume with a non-volatile gas or by evacuating the volume. Electrostatic charge, as an ignition element inside the suit system as well as within the volume where suit storage, maintenance, donning and checkout take place should be addressed specifically as a function of space station/EVA systems interface design.

Leakage

This threat concerns itself with leakage internal to the system volumes: the suit system, the ECLSS system and the mobility system. The strategies for threat accommodation are standard industry approaches" 1) careful material selection for faying surfaces, 2) attention to seal selection for long life material compatibility, 3) maintainable design allowing ready seal removal, replacement and system pressure checkout in orbit.

Tumbling/Loss of Control

EVA suit systems and Environment Control Systems (ECS) asymmetrical venting and Mobility Systems attitude control runaway are threat issues. The concerns can be handled with judicious application of subsystem redundant design.

TABLE 6-1 THREAT/EVA IMPACT

THREAT	EVA IMPACT Suit System	Env. Control System	Mobility System	Tool/ End Effectors
1. Fire*	X	X	X	
2. Leakage	X	X	X	
3. Tumbling/Loss of Control			X	
4. Biological or Toxic Contamination*	X	X		
5. Injury/Illness*	X	X	X	
6. Grazing/Collision	X	X	X	X
7. Corrosion		X	X	
8. Mechanical Damage	X	X	X	
9. Explosion*		X	X	
10. Loss of Pressurization*	X	X	X	
11. Radiation*	X			
12. Out of Control IVA/EVA Astronaut			X	
13 Inadvertent Operations				X
14. Lack of Crew Coordination	X			
15. Abandonment of Space Station				
16. Electrical Shock	X			X
17. Meteoroid Penetration*	X	X	X	
18. Stores/Consumables Depletion		X	X	
19. Intrusion/Attack	X			
20. Structural Erosion	X	X	X	
21. Orbit Decay				
22. Loss of Access to a Hatch				
23. Temperature Extremes	X	X	X	
24. Debris*	X	X	X	
25. Free-Orbit			X	

*Discussed in Volume II

Biological or Toxic Contamination

Suit system contamination, as well as suit ECS contamination are causal factors in the Injury/Illness threat. Growth and sustenance of pathogenic agents in micro-g environments are safety issues to be resolved. This issue, in looking at the EVA system as a microcosm of the large space station community, must be handled in the same manner as the space station. The cleaning/disinfecting is a dominant factor in recommending a hard suit design as opposed to a soft suit design.

Injury/Illness

EVA related injury/illness causal factors include bends, sharp corners, motion sickness, stress generated by suit physical constraints over extended periods of time on EVA in addition to the other threats discussed in this section.

Bends-Present EVA suit systems in use with the STS centers about a soft suit technology with a 4. psi capability. The rule of thumb in use today discourages depressing the human body by more that one half the beginning pressure in mixed gas environments. This has required depressurization of the orbiter cabin from 14.7 psi down to 10.2 psi as a precursor to EVA. In addition, to avoid denitrogenation of the EVA subject, pre-breathing of 100% oxygen for 30 minutes for males, or 90 minutes for females is undertaken before each EVA. An 8 psi, or higher, EVA suit technology - such as that is in existence at NASA Ames Research Center - would alleviate or possibly eliminate the risk of bends. A minimum risk approach would be to use a 14.7 psi EVA suit. The EVA soft and hard suits are discussed later in this section.

Sharp Corners - Inspection of systems for damaging protuberances and abrading contact points is extremely critical if today's soft suit technology extends into the space station operational time period. The ability of a hard suit to protect the EVA astronaut from loss of pressure due to suit pressure shell penetration would minimize the risk from sharp corners and abrading surfaces.

Motion Sickness - the data from current STS flight on this subject is not readily available to the aerospace community, especially for sickness within the EVA suit. If this is a realistic threat causal factor to an EVA astronaut, then design or suit operational hazard strategies should be investigated. A visual reference, a horizon line on the suit helmet, and other similar sensory system orientation aids may be germane.

Stress - For day-to-day EVA operations, as opposed to the one-time exposures being experienced in current STS EVA operations, the space station EVA astronaut may be subjected to the stresses associated with performing in a confined environment. Little, seemingly unimportant, EVA suit features may contribute to a higher productivity when the crewman performs EVA on a repetitive basis. For example, features such as the ability to withdraw ones arms from the EVA suit appendages to touch the face or other parts of the body in lieu of the present suit system "nose scratches" on helmet protruberances may enhance performance significantly.

Injury/Illness, in general, is discussed in Section 4 of Volume II.

Grazing/Collision

This threat affects all EVA systems that can be damaged by grazing/collision contacts. This issue is addressed best if computer simulation modeling of all EVA systems in storage, donning, checkout, operation, doffing and maintenance were available to identify critical contact points for safety assessment. The risks associated with this threat would seem to be minimized if a hard suit system were planned for space station operational time period.

Corrosion

Strategies to accommodate this threat EVA systems are considered good design practice as expected to be employed in other space station design effort. Specifically, EVA systems inspection for corrosion would be a part of the normal maintenance and inspection procedures.

Mechanical Damage

EVA systems design should consider damage tolerance to a definable level as most EVA systems are subject to movement, handling, maintenance and storage inside and outside the space station. Where mechanisms are required, enclosing them to ensure free floating debris/foreign objects would not disable the function is required.

Explosion

EVA systems exposure to the explosion threat - pressure systems and volatile fluid systems - is similar to that described for the space station in Section 5 of Volume II.

Loss of Pressurization

Accepting the EVA suit as a habitable volume, this threat is discussed in general for the space station in Section 6, Volume II. The additional threat concern could be resultant effluent venting causing loss of attitude stability or control while EVA.

Radiation

The radiation threat affects EVA systems in two ways: 1) requires radiation attenuation capability to protect the EVA astronaut to allowable dosage and 2) depending on how well item 1 above is done, the EVA astronaut cumulative dosage may dictate the astronaut time on EVA/time on station and mission scheduling. Additionally, the incidence of solar flares may require EVA scheduling consideration such that the EVA astronaut has time to enter the space station safe haven or an external safe haven if available to the EVA astronaut within his immediate work area. The warning time equals the time from flare optical observation-to-flare/fluence arrival. The radiation issues are discussed further in Section 7, Volume II.

Out-of-Control IVA/EVA Astronaut

The threat here involves both nominal and anominal EVA operations. Nominally, the EVA astronaut should have adequate handholds and restraints to-and-from and at the work stations. Non-tethered operations should involve a minimum of fail-operational/fail-safe attitude control and thruster subsystems. The on-going application of the "buddy system" requires detail definition for productivity purposes.

Inadvertent Operations

EVA operations, inherently, are high risk operations. Assessment of all normal and contingency operations is designed to determine the impact on EVA system design. The industry approach for mechanizing critical functions is to require two (or more) levels of fault tolerance in the design approach for man/machine interfaces.

Lack of Crew Coordination

An EVA operations manual will have to be devised, eventually, to support normal and contingency oerations. These procedures should address all of the operational phases of the EVA activity. Specific tasks should include pre-arranged work arounds if there is a partial systems failure. For instance, hand signals are developed for certain critical activities as a backup to aural interchange.

Abandonment of Station

Impacts EVA operations in the contingency area.

Meteoroid Penetration/Debris

These threats are addressed in detail in Sections 8 and 9 respectively in Volume II. A program level decision is required to determine which size particles and what energy levels are to be attenuated. If the risk of these threats are not accepted for EVA crewmen, then the EVA suit system design will be impacted. Designing to attenuate even minimal particle/energy threats appears to dictate the need for a hard EVA suit system.

Consumables Depletion

EVA or station anticipated activity projection time and motion studies are required to determine safe distances the EVA astronaut may operate from the space station. The need may exist for an on-orbit/at-station refueling station. This concept, that of refueling EVA systems external to the space station, drives the initial design concepts of the advanced EMU to be studied in FY85.

Intrusion/Attack

Not addressed in this study.

Structural Erosion

Whether it be from meteoroid/debris impacts or from erosion by atomic oxygen, the life of the EVA systems will be impacted. The later phenomenon appears to be attitude and material dependent. The erosion impact per EVA is not an issue if the systems are properly inspected prior to use. The EVA system design definition will have to define inspection techniques that will certify the EVA systems for each excursion. The resultant impact is the cost of logistics to replace EVA system elements that have lost their structural integrity.

Orbit Decay

This threat is not expected to impact EVA systems unless EVA excursions are required outside a reentering space station. Then the issues would be Meteoroid/ Debris, Structural Erosion, and Temperature Extremes.

Loss of Access to a Hatch

This threat issue is a design driver for habitats to be used by returning EVA astronauts and, except for suit system/hatch control interfaces, does not directly impact EVA systems.

Temperature Extremes

Time on EVA, astronaut orientation at the work station and consumable supply are factors in this threat. Nominal mission requirements plus reasonable contingency requirements will define the EVA system. The resultant design, when viewed with survivability outside the deorbiting space station, will subsequently define the worst case conditions under which an EVA astronaut can function safely.

Debris

See "Meteoroid Penetration/Debris", in this section.

Free Orbit

This issue results when an EVA astronaut is thrust away from the space station. An orbit EVA-to-EVA rescue capability should be considered. External plug-ins for life support consumables or ways to "handle' the EVA astronaut would be required. Simple design issues - a handhold or sli[illegible]n the EVA suit (helmet?) so the disabled EVA astronaut can be "towed" to safety. Other considerations may include the need for a rescue scooter to be available on-orbit.

EVA THREAT SUMMARY

The threats which impact the EVA system and its operations are a microcosm of the threats of the Space Station itself. The three most serious threats (identical to those on the station) are: injury/illness, debris and radiation. There are some scenarios of injury which may impact the station design, especially the airlock. For example, a hypergolically contaminated crewman would need a safe location in which decontamination is possible without exposing the entire station environment. The next group of threats also appear to be strong discriminators biasing the selection toward a hard suit in the "soft-suit"/"hard-suit" issue. These are: contamination (internal to the EVA suit), mechanical damage, and EVA suit damage from a grazing/collision incident. Cleaning and biological decontamination, as well as the simplicity and speed of on-orbit maintenance, will probably be the most significant discriminator in EVA system selection.

In any case, two conclusions appear dominant. First, the EVA system chosen must be capable of responding to a contingency situation without prebreathing or extensive donning time. Secondly, mobility becomes a more dominant consideration than on the Shuttle where the RMS could function as a backup. This study found that threats were more effectively addressable with the hard suit at a pressure of 8 psi or greater.

EVA SUIT HISTORY

In the early days of space flight, astronauts wore modified U.S. Navy full-pressure suits as a backup to the spacecraft's pressurization system. These garments would enable astronauts to breathe if the capsule lost air pressure, but they could not keep them alive in the severe environment of space. So the first astronauts were confined to cramped quarters, awaiting a suit that would let them step outside.

The development of such a space suit was no simple task. In addition to supplying oxygen to astronauts leaving an orbiting spaceship, it must also protect them from the high-energy radiation of the sun. Moreover, the suit must prevent the astronaut from either frying or freezing in temperatures as high as 250°F on the side exposed to the sun and as low as -65°F on the side in the shadows. And if these were not problems enough for one piece of clothing, a space suit must be able to withstand micrometeorites, tiny particles whipping through space. Such a collision has not yet occurred, but if it did and a micrometeorite punctured an astronaut's suit, oxygen would leak from the suit and the astronaut would need to get inside quickly.

A suit designed as part of the Gemini program solved these problems and allowed astronauts to emerge from the cocoon of their spacecraft to undertake extravehicular activity (EVA). This led to the development of a suit that permitted astronauts to walk on the surface of the moon. By the time of Skylab, astronauts were routinely leaving their orbital workshop to repair equipment, change film, and carry out a variety of EVAs.

The suit designed for space-shuttle missions allows astronauts to do these jobs more readily and to perform other tasks that were never before possible. Technically referred to as the extravehicular mobility unit (EMU), the suit and life-support system provide astronauts with greater flexibility in their shoulders, arms, and hands. When a Skylab astronaut tried to pull film from a telescope mounted outside the spacecraft, the movements were stiff and awkward, as though he were wearing 20 layers of binding clothing. Improved joints with bearings and friction-resistant material allows Shuttle astronauts to remove film from a satellite with greater facility. Shuttle astronauts are handier in space -- able to use a wrench more easily, for instance. The days when a space suit would be used in one mission and then displayed in a museum are gone. Shuttle EMU's are designed to be used again and again over a 15-year period. Rather than producing each suit specially to fit each astronaut, NASA now manufactures components in sizes ranging from extra small to extra large. No longer the beneficiaries of custom tailoring, shuttle astronauts must shop off the shelf choosing a pair of pants, for example, from a selection of six different sizes. When the mission is over, the suit is broken down into its various parts, cleaned, and readied for reuse.

Unlike previous space flights, where space suits were required attire, shuttle flights call for astronauts to wear theirs only for extravehicular activity. Otherwise they will wear simple blue overalls. For an EVA, however, the astronaut first puts on a liquid cooling and ventilation garment that will dispose of the excess heat generated while working in a space suit. NASA quickly learned the importance of this article of clothing - several Gemini space walks had to be ended early because the astronauts became overheated and exhausted. Developed for use in the Apollo program, the liquid cooling and ventilation garment is a one-piece, zippered suit that looks like mesh long johns and contains about 300 feet of plastic tubing. By circulating cool water through this tubing, the garment can dispose of 2,000 Btu's per hour, the amount of heat produced during strenuous exercise. The suit also contains hoses that collect the oxygen used to ventilate the body's surface and return it to the portable life-support system on the astronaut's back.

Once the liquid cooling and ventilation garment is on, the astronaut is ready to don the white outer suit that is familiar from earlier space flights. Improved design has significantly reduced the time astronauts need to spend dressing. It took an hour to put on the Apollo moon suits and life-support systems; it takes a shuttle astronaut 10 to 15 minutes to put on an EMU.

First, the astronaut dons the lower-torso assembly, which looks like a baggy pair of pants with attached boots. The lower-torso assembly is constructed of nine layers of material: the inner two, called the pressure-restraint garment, maintain the atmosphere inside the suit; the outer seven, called the thermal micrometeorite garment, protect the astronaut both from micrometeorites and the extreme temperatures of space. An astronaut puts on the lower-torse assembly much the same way one dons a pair of pants on earth - except in space you can put on your pants two legs at a time.

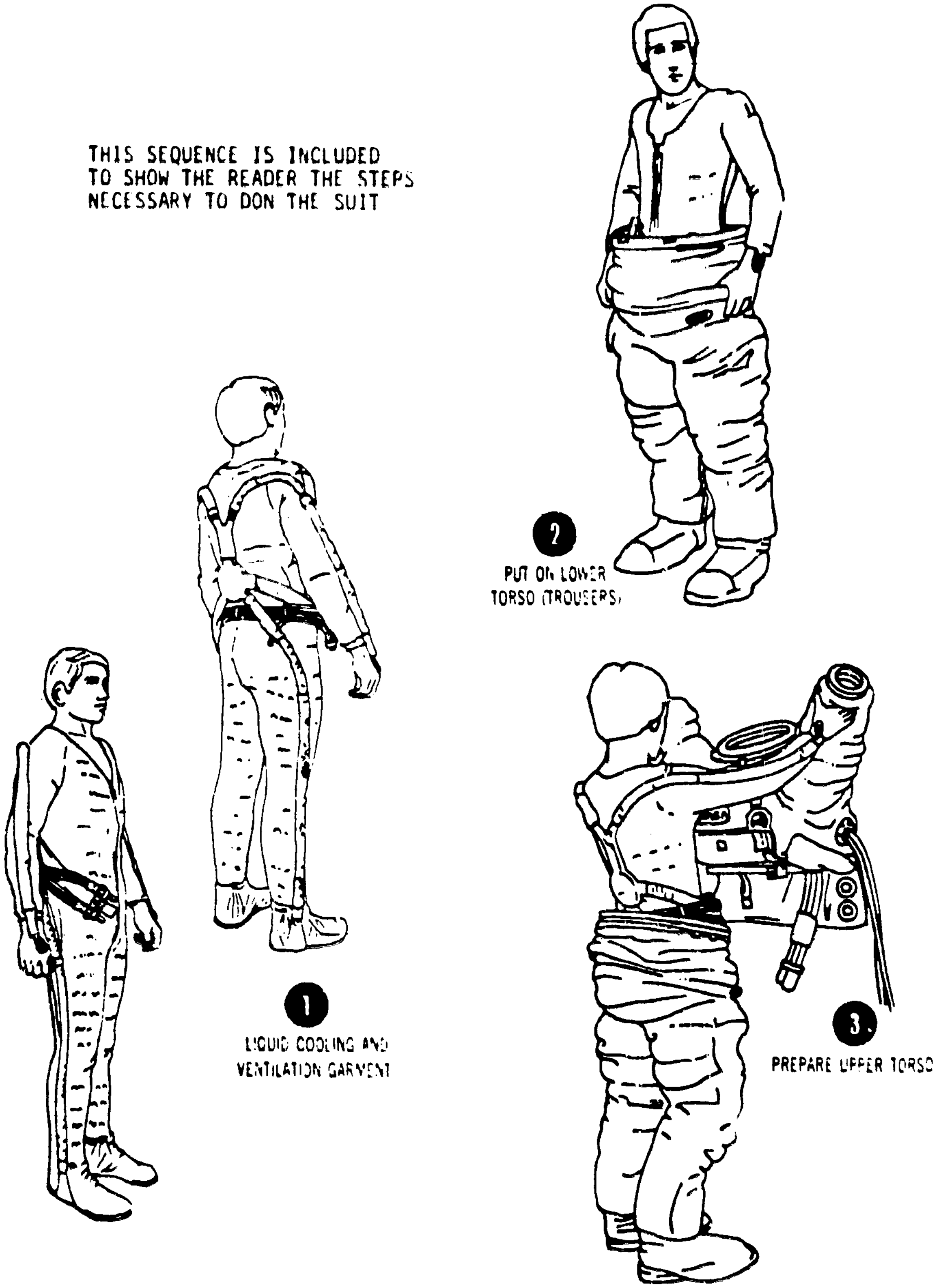
Second, the astronaut gets into the hard upper torso. This is a rigid, fiberglass shell that resembles a vest and has both sleeves and backpack life-support system attached to it. The hard upper torso is mounted to the air-lock wall of the vehicle. To put it on, the astronaut must squat down and then slide up, snaking the arms through the sleeves and putting the head out the neck ring. The astronaut then connects the upper and lower torsos by locking the waist ring.

Third, the astronaut puts on gloves that attach by wrist connectors to the sleeves. Though not custom-fitted, as they were for the Apollo suits, the EMU gloves are more flexible. Spacesuit engineer Ronny Newman says that with the new EMU glove, an astronaut could pick up a dime - with practice. An insulating mitt like a kitchen hot pad can be placed over the glove when the astronaut must handle hot objects.

Finally, the astronaut puts on a helmet. Made of polycarbonate, a transparent impact-resistant plastic, this is one piece of equipment that has remained relatively unchanged since the days of Apollo. The visor assembly, with adjustable eyeshades to block out sunlight, is still placed over the helmet to protect it from damage. If the sunlight becomes excessively strong, the astronaut can pull down a special gold-plated visor that serves as a one-way mirror.

Once inside the EMU, the astronaut checks out the crucial life-support system. The backpack is mounted to the suit so that all the oxygen and water hoses remain inside the hard upper torso. In this way, no external hoses can become tangled or snagged. The system contains lithium hydroxide canisters that remove carbon dioxide so astronauts can rebreathe exhaled air. There is also a backup oxygen that, if the primary system fails, can provide oxygen for 30 minutes, sufficient time for the astronaut to return to the Shuttle orbiter.

This sequence is shown in Figure 6-1. (306)



THIS SEQUENCE IS INCLUDED
TO SHOW THE READER THE STEPS
NECESSARY TO DON THE SUIT

Figure 6-1 Suit Donning Sequence (306)

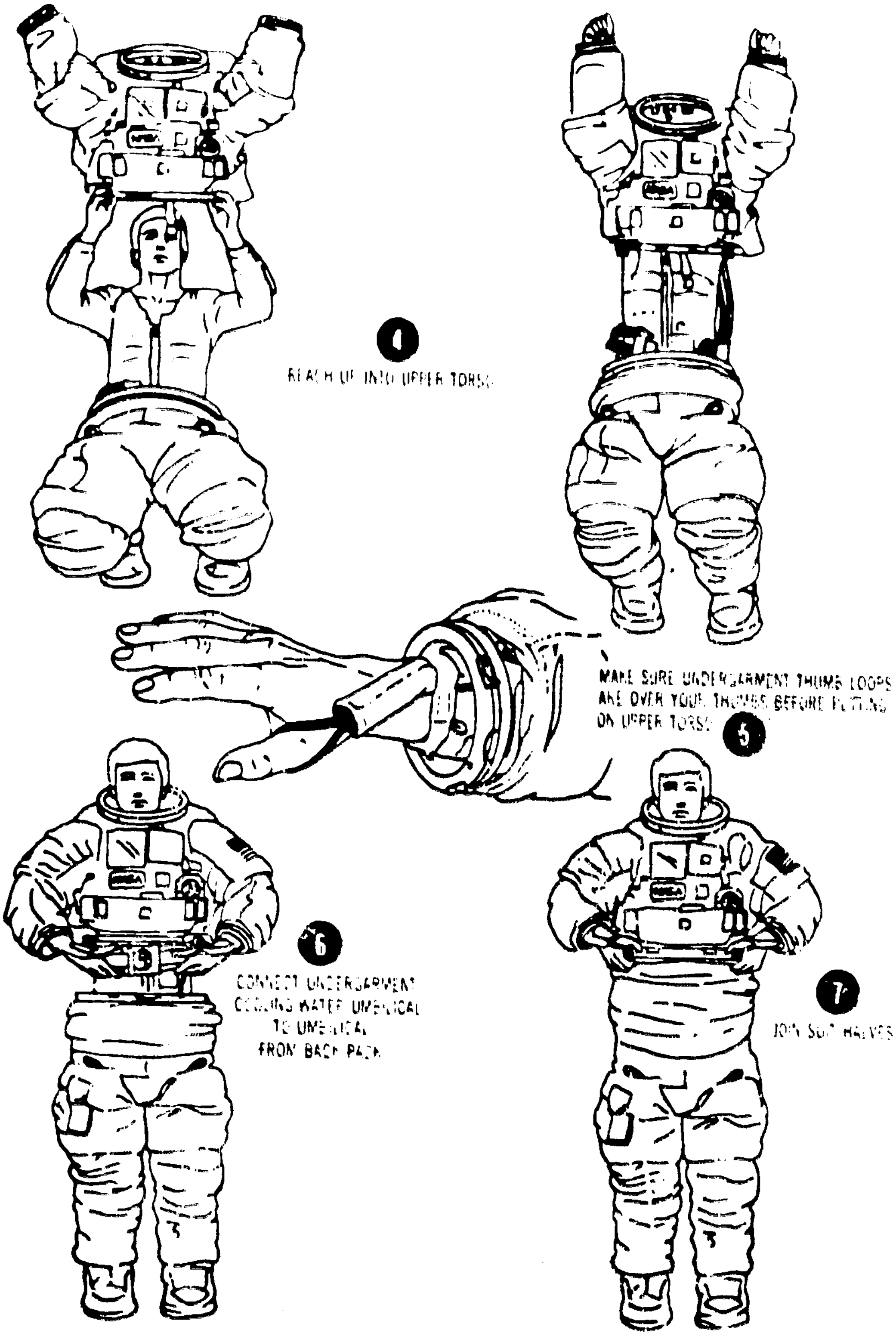


Figure 6-1 (Cont'd) (306)

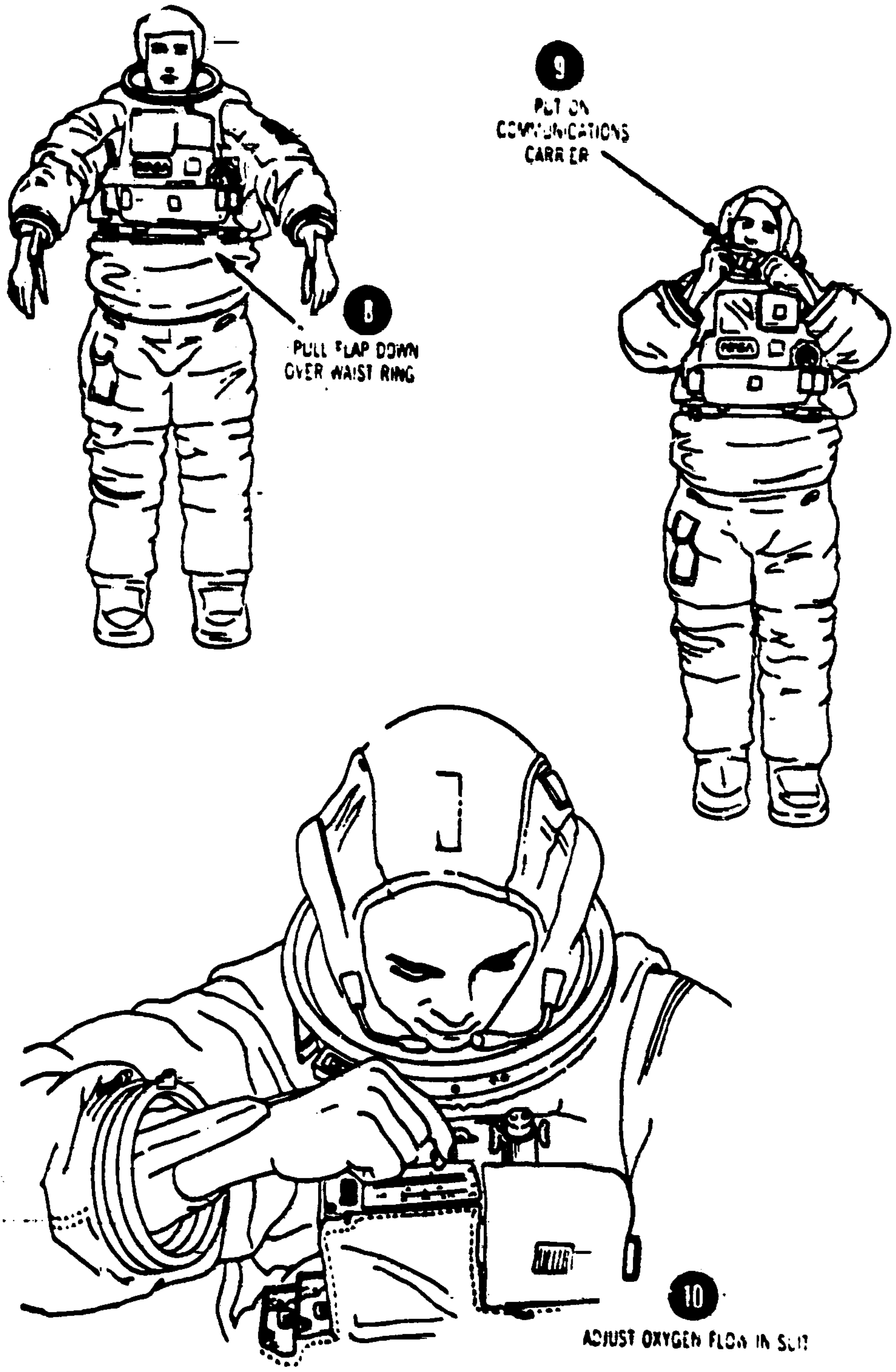
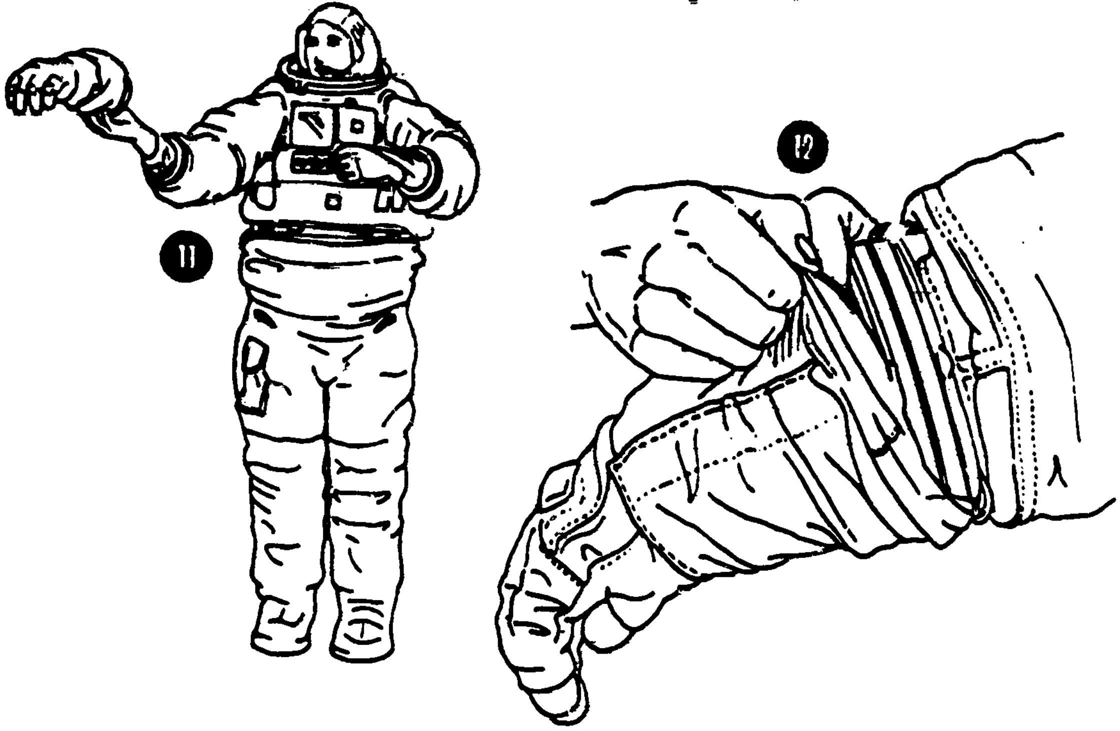


Figure 6-1 (Cont'd) (306)

C-2



PUT ON GLOVES. SNAP AND LOCK CONNECTING RINGS

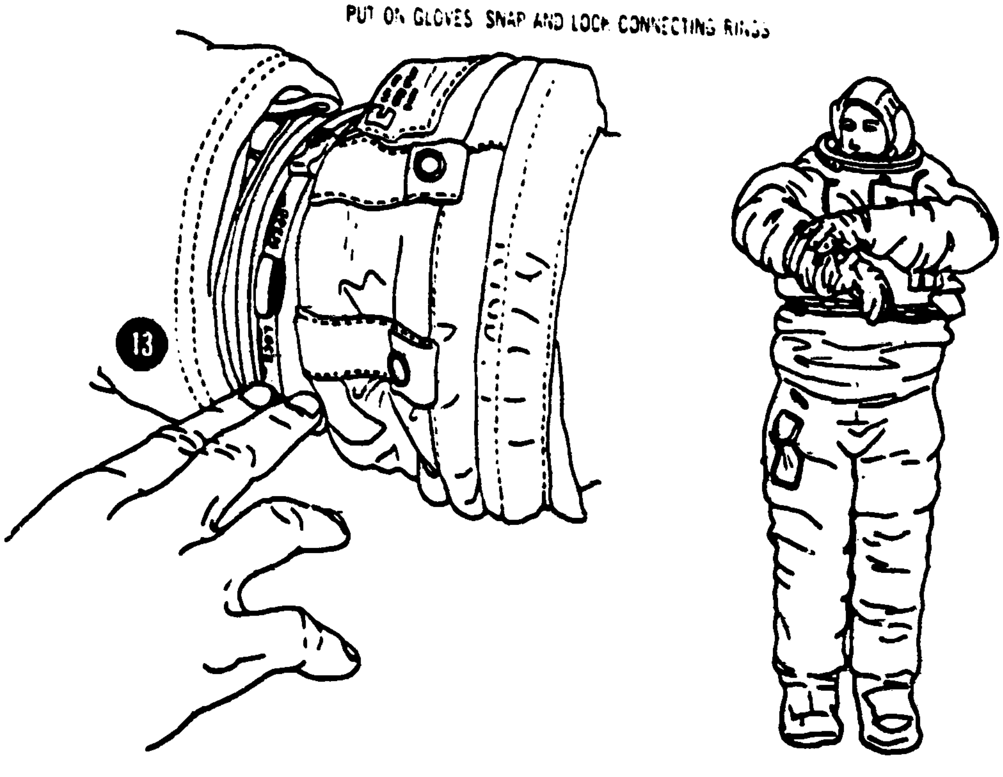
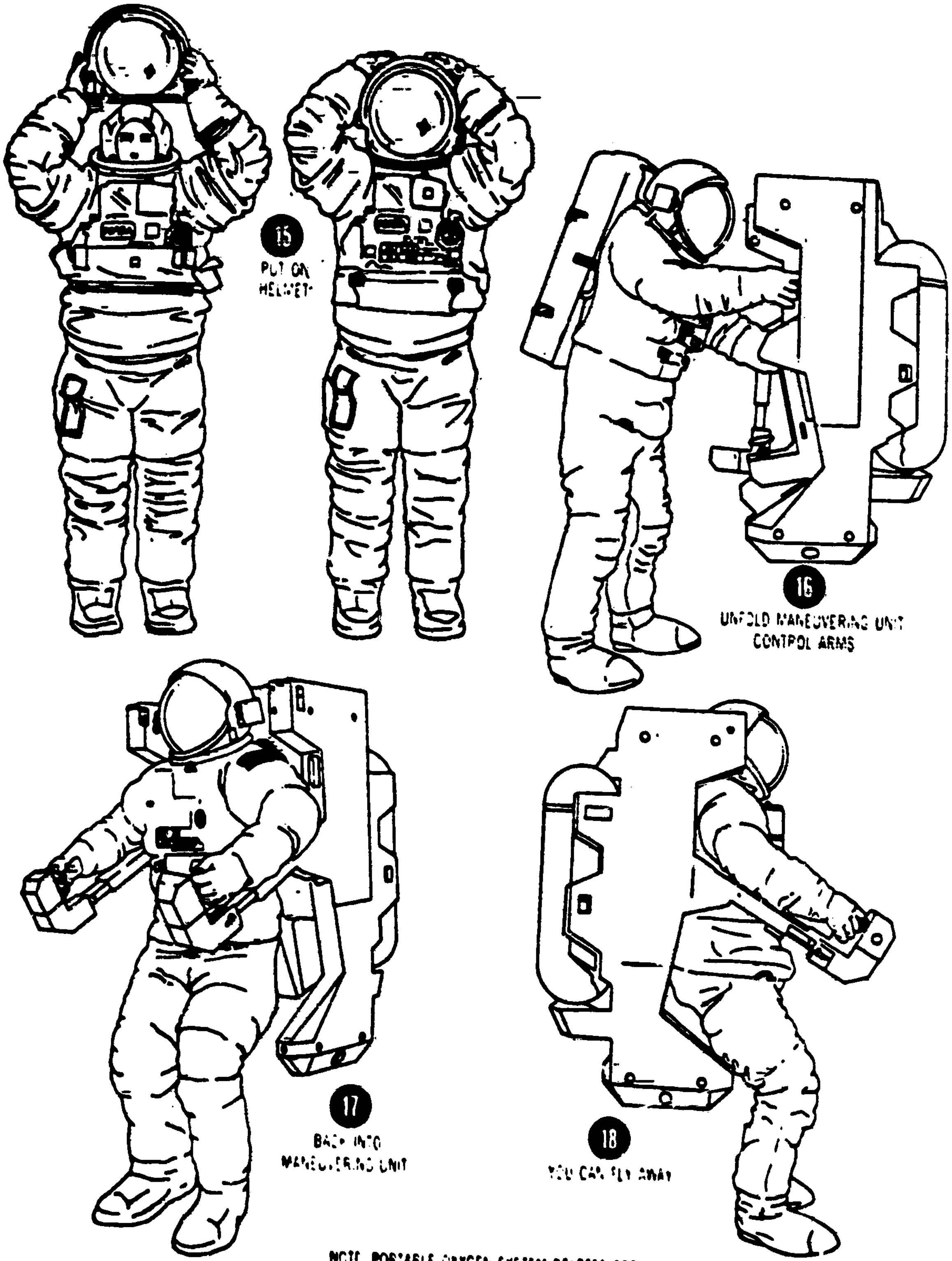


Figure 6-1 (Cont'd) (306)



NOTE: PORTABLE OXYGEN SYSTEM DELETED FOR CLARITY

Figure 6-1 (Cont'd) (306)

The portable life-support system, which also houses the astronaut's radio communication equipment, has a chest-mounted display and control module. The astronaut can monitor and adjust life-support functions through the LED readout atop the module. The life-support system supplies enougn power, water, and oxygen to sustain an astronaut for up to seven hours. After checking pressure and oxygen flow, the astronaut is ready to disengage the EMU from the wall and depart the spaceship.

Because a flight plan might call for an EVA of as many as seven hours - a long time to be restricted to a space suit - NASA has provided the EMUs with some of the conveniences of home. If astronauts get thirsty, they can sip water from a tube in the lower part of the helmet that is conneted to a half-liter drink bag mounted in the upper torso. If astronauts get hungry, they can eat a compressed fruit bar that is also positioned inside the helmet. If a male astronaut must urinate, there is a collection device under the liquid cooling and ventilation garment. (Plans call for women astronauts to wear a diaperlike Disposable Absorption Collection Trunk.)

Malfunctions in both life-support systems caused the cancellation of the EVA scheduled for the fifth shuttle mission of November 1982. Both problems - a faulty magnetic sensor that disabled a blower fan and a small, plastic locking device left out of a regulator - were later diagnosed and corrected.

In the future, astronauts will don their EMUs and, attached to their orbiting craft by only a thin tether, perform important and exhilarating tasks in space.

EVA SOFT SUIT

The current Shuttle spacesuit is a pressure retention structure that, together with a life support system, provides a life sustaining environment which protects the astronaut against the hazards of space. Such hazards include: a vacuum environment, temperature extremes of -180 to +277°F, and the impact of micrometeoroids.

Unlike the spacesuits used in the Apollo or Skylab Programs, where the entire spacesuit was custom manufactured for a specific astronaut, the shuttle spacesuit is comprised of separate components which can be assembled to make spacesuits to fit almost anyone (male and female). Several sizes of each component are manufactured and placed on the shelf for future use. When needed, the components are selected from the shelf (depending on the astronauts size) and assembled into a complete spacesuit. The SSA and the Life Support System (LSS), when combined, become the Extravehicular Mobility Unit, or EMU. The EMU will be used for the Shuttle Program.

The SSA is designed and has been tested for a six-year operational life. The design permits low torque body movements required for performance of tasks in space. The Mini Work Station is used to hold tools needed by the astronauts when working in space.

When pressurized, the "soft" material portion of the suit becomes very rigid and nearly impossible to bend except where specifically designed joints are provided. Such is the case when you inflate the inner tube of an automobile tire. The tube becomes very stiff and is difficult to twist or bend.

Without these joints, it would be virtually impossible for the astronaut to do useful work. These special joints are located at the knees, wrists, shoulders, elbows, ankles, thighs, and waist of the SSA. Normal body movements by the astronaut cause the suit joints to bend. This flexibility permits the astronaut to conserve his energy, reduce fatigue and to work for long periods of time.

A typical cross-section of the SSA is 11 layers deep consisting of; the Liquid Cooling Ventilation Garment (LCVG) (2 layers); pressure retention garment (2 layers); and the Thermal Micrometeoroid Garment (TMG) (7 layers). Simply stated, the LDVG maintains astronaut comfort, the pressure retention garment provides containment of the breathing air, and the TMG protects against the micrometeoroids which hit the suit, and insulates the astronaut from the extreme temperatures of space. See Figure 6-2, Table 6-2.

Table 6-2. EVA SUIT (SHUTTLE)

Following are brief descriptions and illustrations of the units that comprise the Spacesuit Assembly. (369)

1. Communications Carrier Assembly (CCA)
2. Hard Upper Torso Assembly (HUT)
3. Arm Assembly
4. Lower Torso Assembly (LTA)
5. Glove Asembly
6. Helmet Assembly
7. Extravehicular Visor Assembly (EVVA)
8. Liquid Cooling Ventilation Garment (LCVG)
9. Urine Collection Device (UCD)
10. Insuit Drink Bag (IDB)

1. Communications Carrier Assembly (CCA) - Figure 6-3

The Communications Carrier is a skull cap that interfaces with the Electrical Harness Assembly. It contains a microphone and earphones for voice communications. The skull cap is made of teflon and nylon/lycra fabrics.

2. Hard Upper Torso Assembly (HUT) - Figure 6-4

The Hard Upper Torso is a vest-like rigid fiberglass shell which incorporated provisions for Arm, LTA and Helmet attachment. A Water Line and Vent Tube Assembly is fastened to the shell interior and interfaces with the LSVG and the Life Support System (LSS).

The main portion of the LSS, containing water and oxygen storage and circulation provisions, mounts on the back of the HUT, while the LSS controls mount on the front within easy reach of the astronaut.

3. Arm Assembly - Figure 6-5

The Arm interfaces with the HUT by a ring that retains the Arm Scye Bearing in the HUT Gimbal opening. The upper and lower arm joints are separated by an arm bearing which allows lower arm rotation. The lower arm also provides for sizing adjustments and for quick-disconnect/disconnect of the glove via a wrist disconnect.

TYPICAL CROSS-SECTION

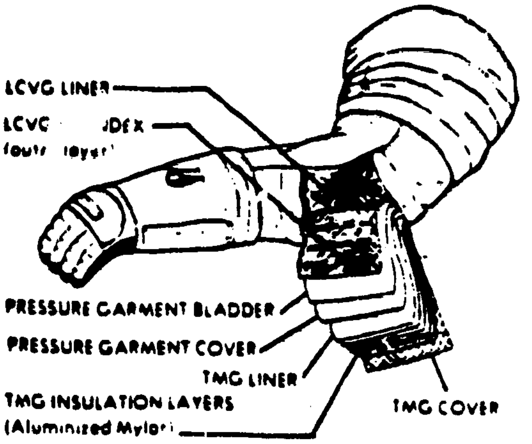
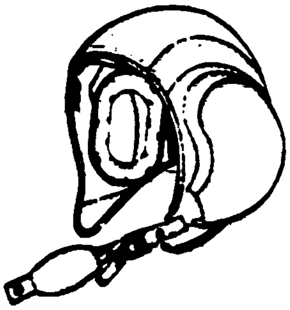
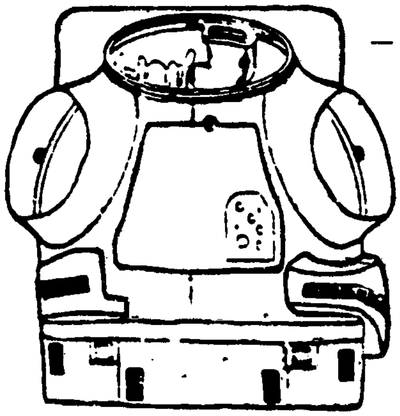


FIGURE 6-2



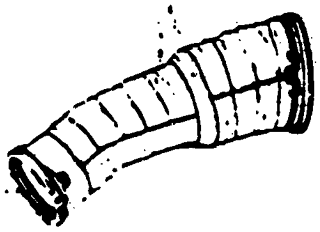
1. COMMUNICATIONS CARRIER ASSEMBLY (CCA)

FIGURE 6-3



2. HARD UPPER TORSO ASSEMBLY (HUT)

FIGURE 6-4



3. ARM ASSEMBLY

FIGURE 6-5

4. Lower Torso Assembly (LTA) - Figure 6-6

The Lower Torso Assembly of the spacesuit consists of an integrated Body Seal Closure, Waist, Waist Bearing, Leg, Thigh, Knee and Ankle Joints plus removal Boots. The LTA encloses the lower body and interfaces with the HUT via the body seal closure. The flexible waist section and waist bearing afford the astronaut a large degree of movement about the waist e.g., bending and hip rotation.

5. Glove Assembly - Figure 6-7

The Glove is made up of a restraint and bladder encased in a TMG. The gloves protect the astronaut's wrists and hands and are attached to the spacesuit arms at the wrist disconnects. The gloves incorporate a rotary bearing to allow wrist rotation, a wrist joint to provide flexion/extension and fabric joints for thumbs and fingers, plus a hot pad for protection of the hand from extreme hot and cold extravehicular conditions.

6. Helmet Assembly - Figure 6-8

The Helmet Assembly consists of a transparent Shell, Neck Ring, Vent Pad, Purge Valve and an adjustable Valsalva device. The Helmet is secured to the HUT and provides an unobstructed field of vision. Optical clarity of the transparent shell is made possible by the use of rugged, impact resistant polycarbonate material. A vent assembly, bonded to the inside rear of the polycarbonate shell, serves to diffuse the incoming gas over the astronauts face.

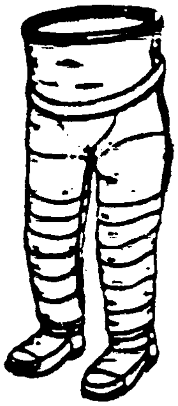
7. Extravehicular Visor Assembly (EVVA) - Figure 6-9

The Extravehicular Visor Assembly is a light-and heat-attenuating shell which fits over the Helmet Assembly. It is designed to provide protection against micrometeoroid activity and accidental impact damage, plus protect the crewman from solar radiation.

A special gold coating gives the sun visor optical characteristics similar to those of a two-way mirror; it reflects solar heat and light, yet permits the astronaut to see. Adjustable eyeshades may be pulled down over the visor to provide further protection against sunlight and glare.

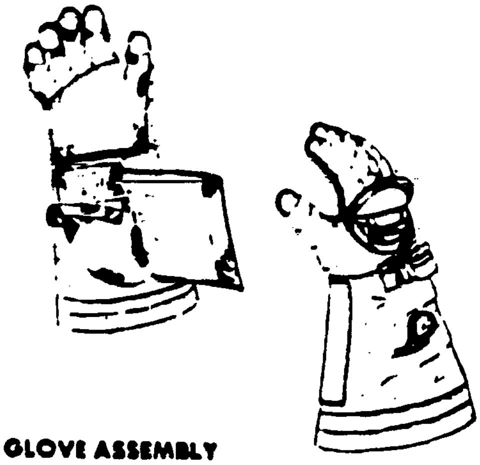
8. Liquid Cooling Ventilation Garment (LCVG) - Figure 6-10

The Liquid Cooling Ventilation Garment is a close-fitting undergarment covering the body torso and limbs. It incorporates a network of fine tubing that is maintained in close contact with the astronauts skin by the outer layer of stretchable open fabric. The spacesuit is so well insulated that normal body heat maintains warmth, even on the cold, dark side of the spacecraft. However, cooling is required, therefore water is circulated through the LCVG tubing to remove excess body heat. Water flows through the various inlets and return tubes and must be uninterrupted in order for the garment to be effective. The LCVG also uses ventilation ducting to return vent flow from the body extremities to the EMU Life Support System (LSS).



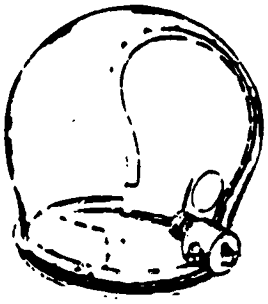
4. LOWER TORSO ASSEMBLY (LTA)

FIGURE 6-6



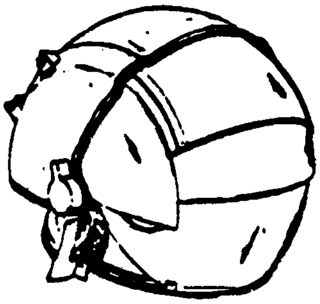
5. GLOVE ASSEMBLY

FIGURE 6-7



6. HELMET ASSEMBLY

FIGURE 6-8



7. EXTRAVEHICULAR VISOR ASSEMBLY (EVVA)

FIGURE 6-9

8. LIQUID COOLING VENTILATION GARMENT (LCVG)

FIGURE 6-10

9. Urine Collection Device (UCD) - Figure 6-11

The Urine Collection Device is worn over the LCVG and provides for the hygienic collection, storage and eventual transfer of astronaut urine discharged during extravehicular activities.

10. Insuit Drink Bag (IDB) - Figure 6-12

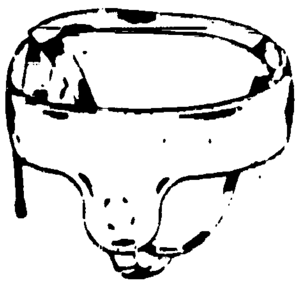
The IDB is a sealed bag with a capacity of 21.0 oz. of potable (drinking) water. The bag is secured by velcro to the inside front of the HUT. Water is readily accessible to the astronaut through a mouthpiece located at the top of the bag.

EVA HARD SUIT (401)

Ames Research Center of NASA has had several studies in-house and others under contract to design and develop EVA suits for future needs. These are shown in Figures 6-13 and 6-14. The AMES AX-1 hard spacesuit in 1966 demonstrated multiple bearing technology and later the AX-2 suit demonstrated rotary closure, increased waist flex range, and metal bellows in the joints. Studies have been done since the 1960's to incorporate high pressure technology and to verify joint designs such as that shown in Figure 6-15. A second generation of suits were demonstrated by Litton in their series of RX suits which used armored rolling convolutes at the extremity joints. The Litton AES suit incorporated the multiple bearing concept in the shoulder and hip areas with amored rolling convolutes at the elbow, waist, knee, and ankle. Toroidal joint technology was used exclusively for the AiResearch AES suit except for a multiple bearing shoulder joint. A multiple bearing suit concept was also proposed by ILC Dover which demonstrated in mock-up configuration an interesting multiple bearing waist joint.

One of the suits to be demonstrated in recent years is the Ames AX-3 (Figure 6-16) which incorporates lessons learned in the previous suits. The torso employs hard structure both above and below the dual plane entry closure and in the briefs section between the waist and hip joint. The torso closure is geometrically similar to the closure used in the RX-4 hard suit. This configuration provides maximum area on the back of the suit for mounting life-support systems (LSS) components and permits ease of donning.

Since mobility, minimum leakage, long operational life, and low cost of fabrication are of primary concern in this development, mobility joints were designed to meet these requirements with minimal development risk. All soft component elements consist of a multiple laminate structure of neoprene-coated nomex and rip stop materials. The AX-3 joints are shown in Figures 6-17 and 6-18. The shoulder joint employs three sealed bearings and an internal linkage, tapered rolling convolute in the first element of the joint. The elbow incorporates a two-segment, dual-opposed, soft rolling convolute arrangement that optimized joint range vs. joint length. The hip joint is similar to the AX-1 and AiResearch AES configuration which consists of a sealed bearing at the hip and thigh locations, a transition element, and a single-axis, soft rolling convolute. A two-segment toroidal joint is utilized at the knee. The ankle joint achieves two-axis motion through the use of an internal, two-axis gimble arrangement and a dual-opposed soft rolling convolute. The "elliptical" cross-section waist joint employs a single-axis, dual-opposed rolling convolute.



9. URINE COLLECTION DEVICE (UCD)

FIGURE 6-11

10. INSUIT DRINK BAG (IDB)

FIGURE 6-12

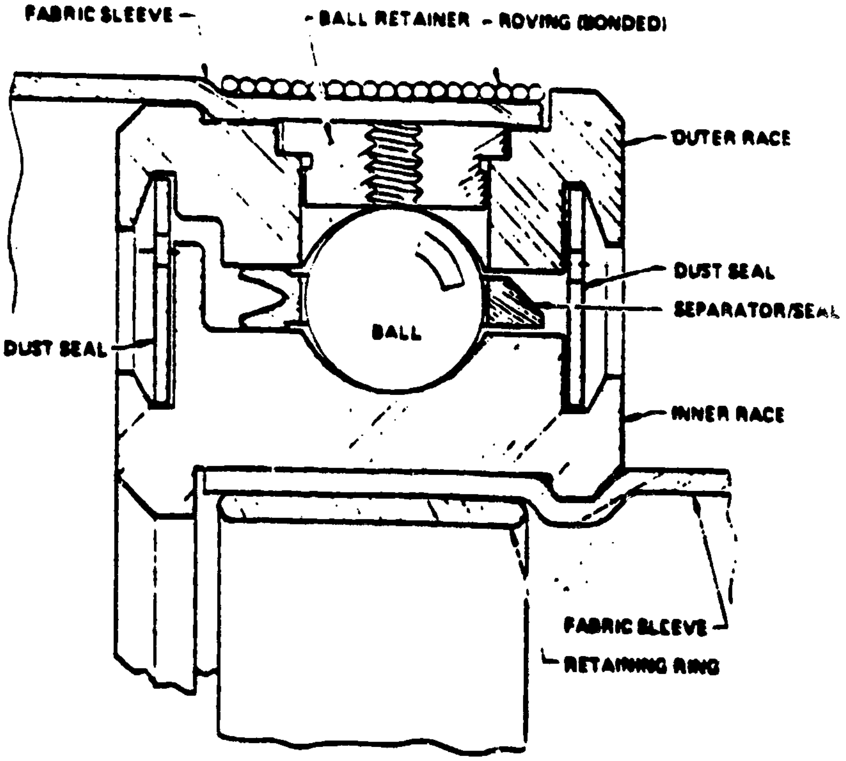
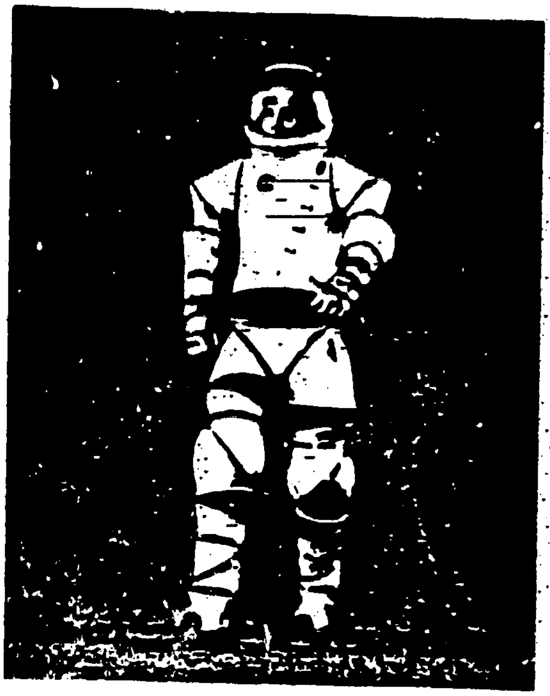
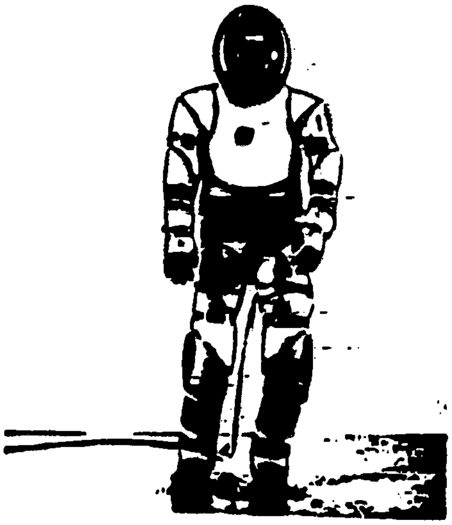


Figure 6-15 Sealed Bearing for Spacesuit Joints

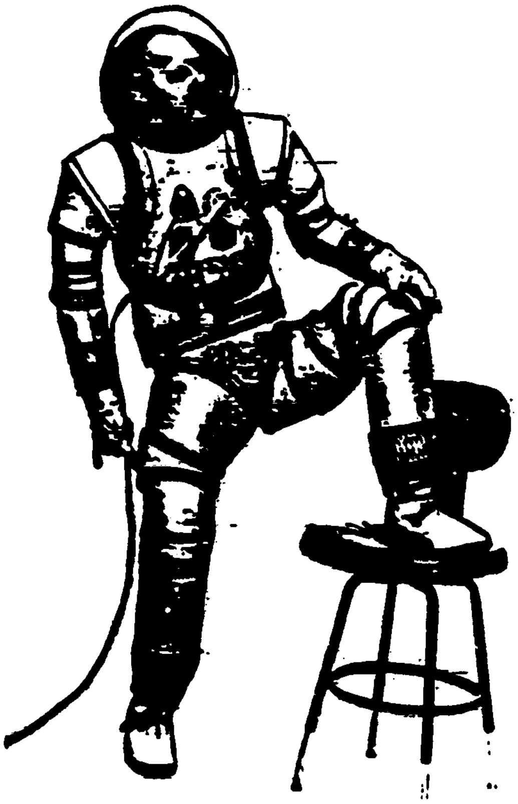


Ames AX-1.



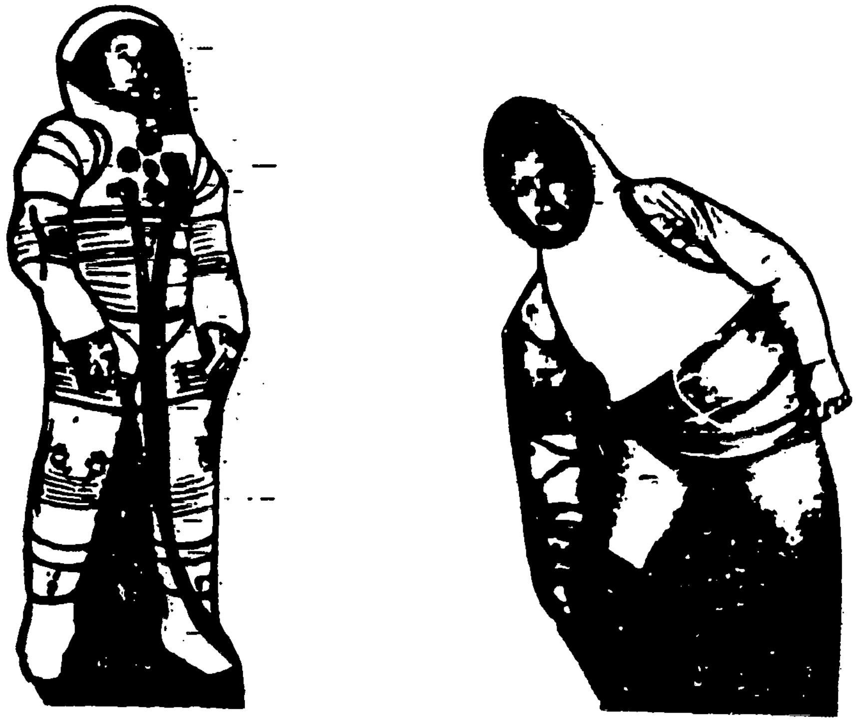
Ames AX-2.

Litton RX-4.



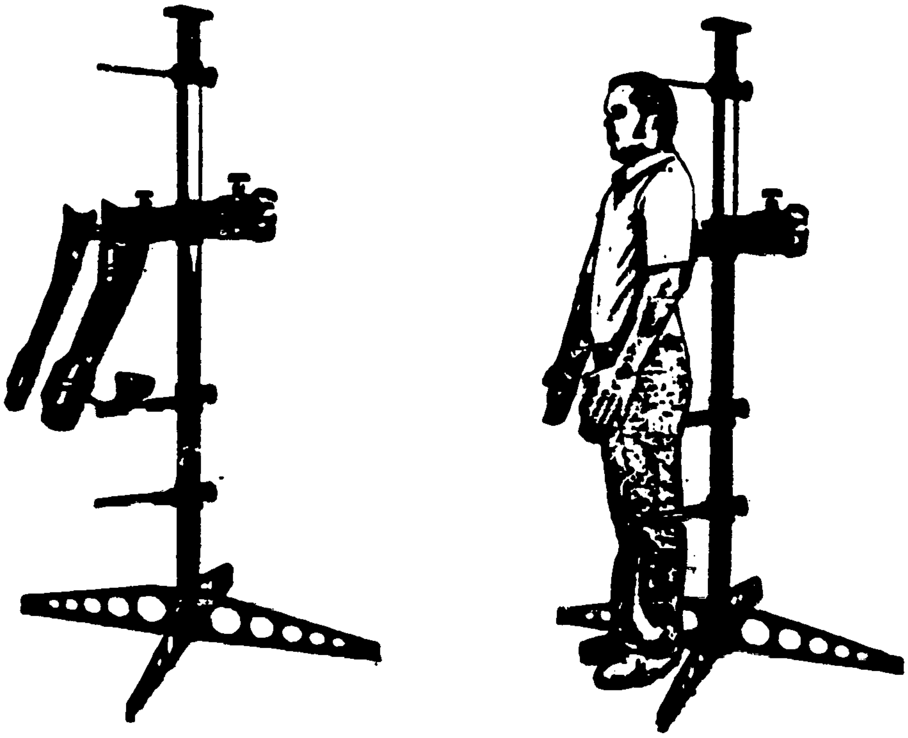
Litton AES.

Figure 6-13 High Pressure Suits



AI Research AES

ILC Dover Mockup



Anthropometric Sizing Fixture

Subject Sizing

Figure 6-14 High Pressure Suits

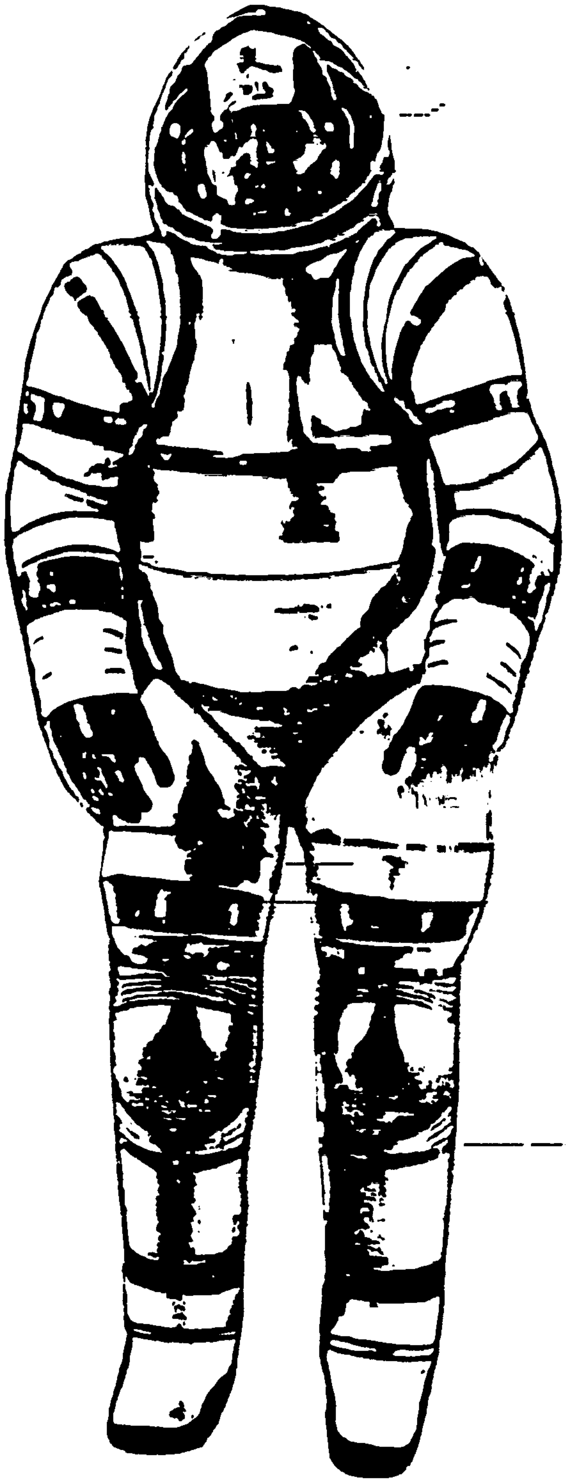
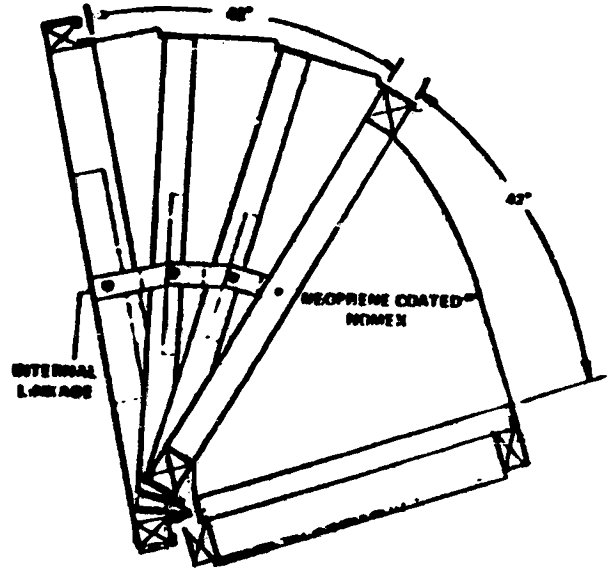
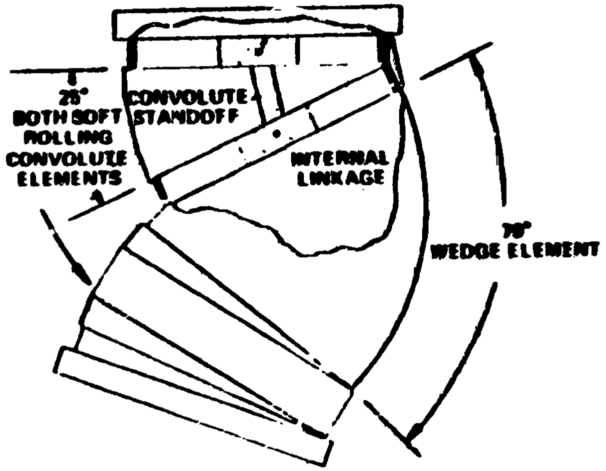


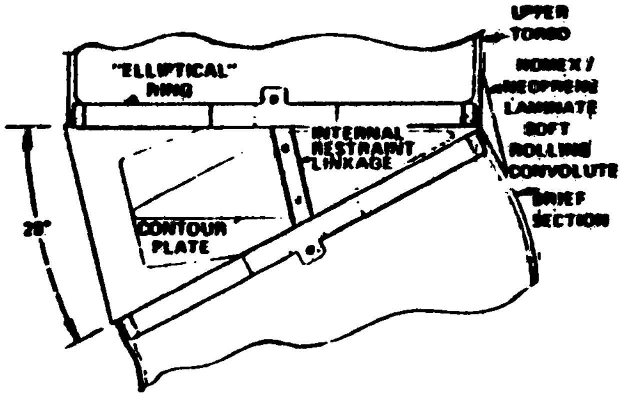
Figure 6-16 Ames AX-3 Suits



AX-3 shoulder joint.



AX-3 elbow joint.



AX-3 waist joint.

Figure 6-17 AX-3 Joint Design

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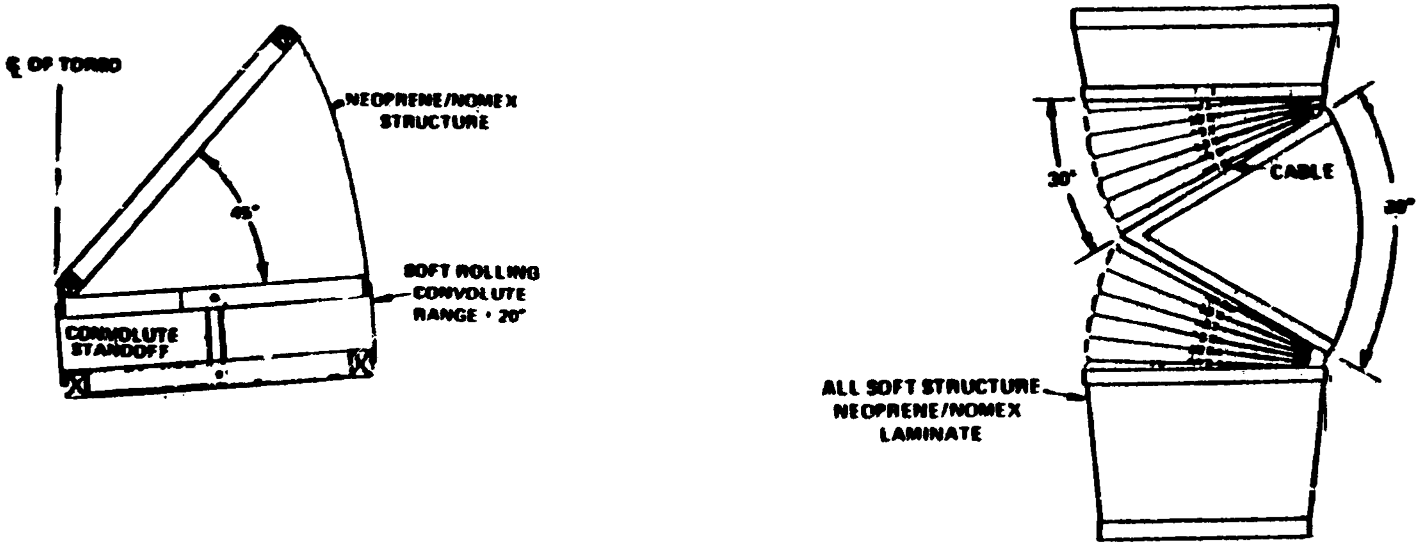
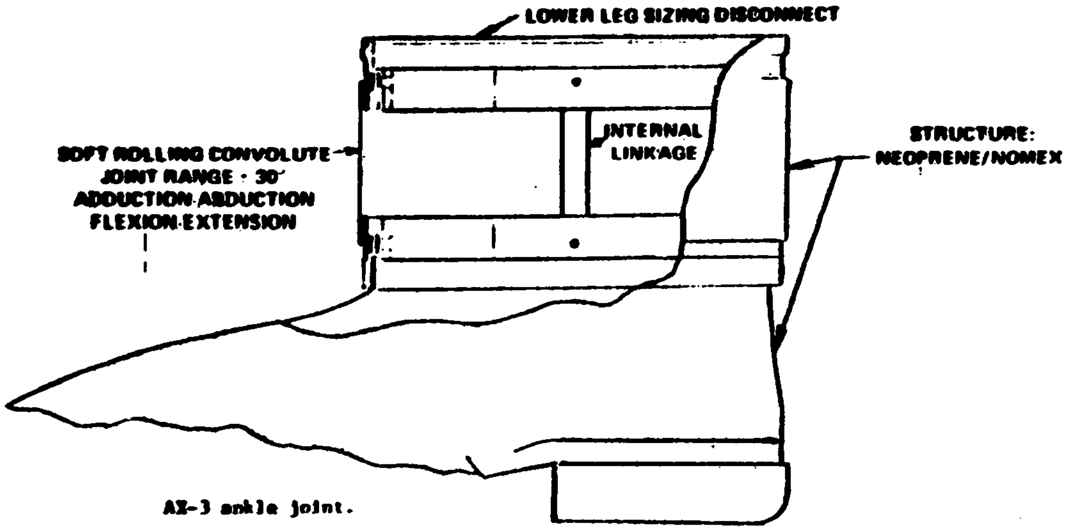


AX-3 hip joint.

AX-3 knee joint.



AX-3 ankle joint.

Figure 6-18 AX-3 Joint Design

To achieve a broad range of suit sizing, interchangeable rings of varying lengths, attached by means of an "Ortman-type" wire coupling, allow for sizing above and below the elbow and knee (a similar scheme was designed for sizing the torso).

An anthropometric measuring device provides a convenient means for selecting the correct sizing ring lengths for suit subjects (shown in Figure 6-14). A universal fit boot, similar to the concept developed for the Ames AX-2 suit, eliminates the need for custom boot liner that typically have been used in the past.

The goals of the AX-3 development were to demonstrate that a high-pressure suit, incorporating state-of-the-art technology, could be developed which would provide excellent mobility, low leakage, low torque, and long cycle life.

The AX-3 suit successfully demonstrated improved mobility (measured joint torques an order of magnitude lower than current shuttle suits), lowered leakage rates (9cc/min. vs. 55 cc/min. for current suits), easier donning and doffing, modular construction (a range of limb inserts to fit the required population distribution) and machine fabricability to reduce manufacturing costs. The suit is also amenable to providing better protection against radiation because of its predominantly metal structure.

GLOVE DESIGN (401)

The mobility of the gloves at pressures up to 8 psia causes one of the greatest design challenges for suit designers. The higher pressure trys to straighten out the fingers and balloon out the palm resulting in reduced mobility feel and dexterity.

Careful attention to detail design of joints have restored a great amount of feel dexterity and mobility. One design uses a rolling convolute on the first metacarpal joints of the fingers and thumb and using mini integrally formed convolutes on the joints of the fingers and thumbs is shown in Figure 6-19. Another design uses a textured rubberized fabric with rubber tips on the finger tips with a restraint in the palm and on the wrist to keep the gloves from expanding or ballooning too much. This is shown in Figure 6-20.

Three companies and NASA/Ames have built four variations of an 8 psia glove for testing and evaluation. The advanced glove would need to be able to have good thumb- 1st finger opposition, good tool grip, and the ability to replace the glove while still on orbit (but not on EVA).

The glove area is also one of the hardest areas to protect from various forms of radiation, because if it's thick enough for radiation protection, it's too thick for mobility and dexterity. For most low inclination LEO missions, this is not a problem, but for GEO missions and some high inclination orbits, increased protection may be necessary.

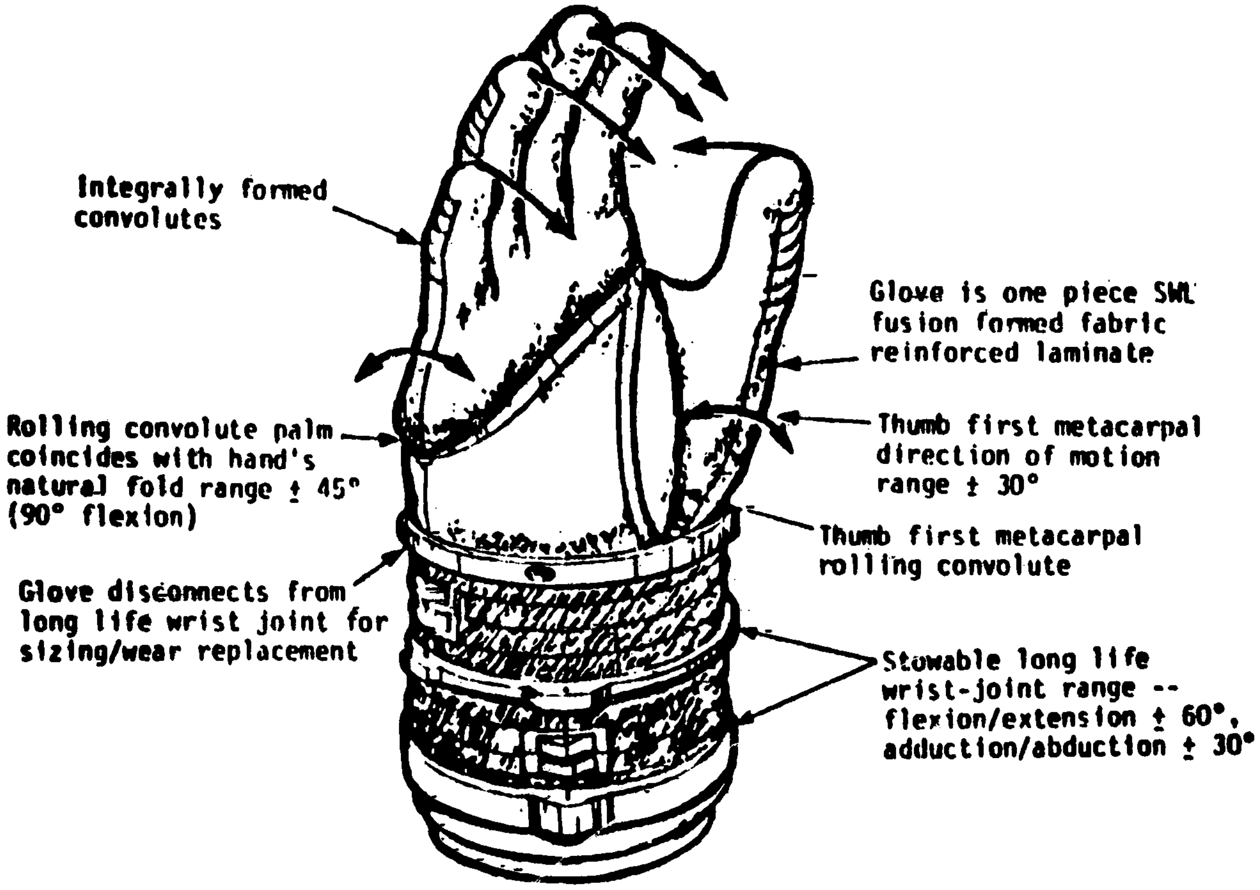


Figure 6-19 8psia Glove Concept

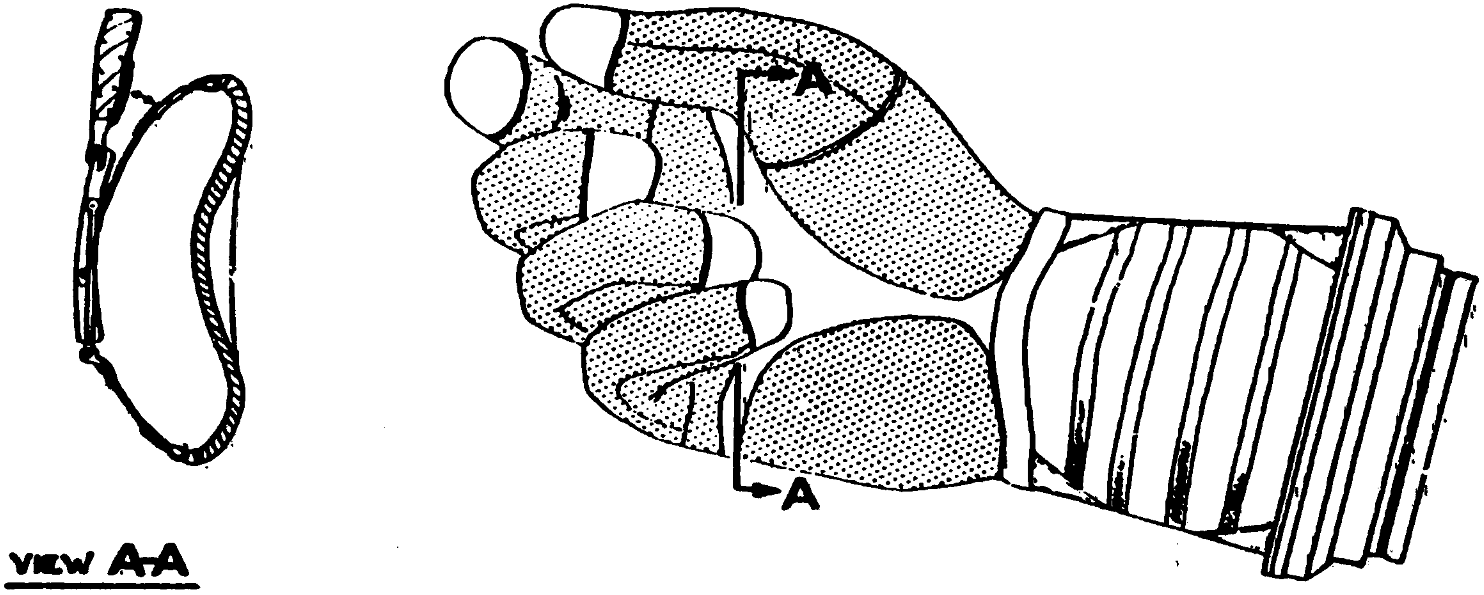


Figure 6-20 8psia Glove Concept

MINI-WORK STATION

The Mini-Work Station (MWS) is used to tether an astronaut wearing his or her Extravehicular Mobility Unit (Spacesuit) at a worksite and to carry tools from the Shuttle tool stowage area to the work area. The MWS is attached by the astronaut to the front of the spacesuit Hard Upper Torso, thereby making the MWS and all attached tools readily available for the astronaut to use when necessary. The MWS tether is a 4-foot long, self-retracting cord with a multipurpose end effector (connector) which allows the astronaut to easily attach the tether to circular sections (handrails, door drive linkages, etc.) or to flat plate. Tethered to a position, and with tools in reach, the astronaut can perform tasks in the Shuttle payload bay and remain relatively stationary. See Figure 6-21.

TOOL CADDY

Before leaving earth, the astronaut knows the specific tasks to be performed in space. Accordingly, the majority of the tools are grouped by the task to be performed. These groups of tools are placed in Tool Caddies which can be attached to the Mini-Work Station. Tools for emergencies, such as jam removal tools, are also placed in caddies. The Tool Caddy shell is an 8-inch by 13-inch stiffened fabric which folds over the tools, closes and seals with velcro. Each caddy is attached to the MWS via a ring and pin while each tool is attached to a 3-foot long tether on the caddy. See Figure 6-22.

EMU TV CAMERA AND LIGHTS

The EMU TV Camera and Lights are worn on the Spacesuit Extravehicular Visor Assembly during EVA. The four lights provide the astronaut with the illumination required for effective accomplishment of extravehicular tasks when in the shade or on a dark side portion of an orbit. The astronaut can select the number of bulbs illuminated on either side of the helmet, i.e, none, one, or two on either side. The upper portion, or housing, of the assembly is used to mount NASA's miniature TV camera. Also mounted in the housing is an on/off switch, a small light (LED) for indication of power on, and a small sliding knob for focusing the TV camera lens. The circular portion on top of the housing is the antenna which transmits the picture to the orbiter cabin, then to earth, thus providing the orbiter cabin crewmembers and ground personnel with a duplicate of the EVA crewmember's view. See Figure 6-23.

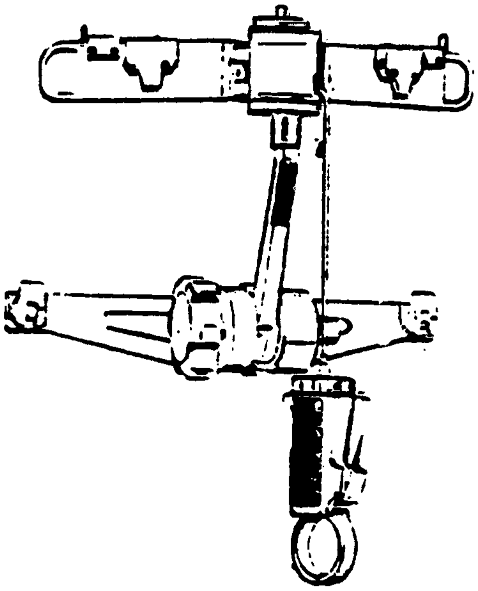


Figure 6-21 Miniwork Station

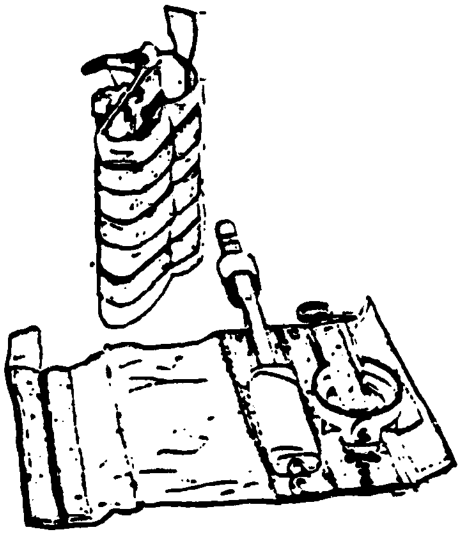


Figure 6-22 Tool Caddy

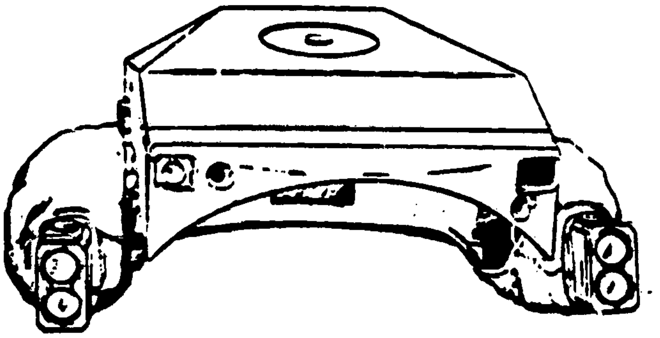


Figure 6-23 EMU TV Camera and Lights

EVA PORTABLE FOOT RESTRAINT

The EVA Portable Foot Restraint is designed to provide restraint at the worksite during certain EVA tasks where the astronaut is required to use torque, which requires, in the weightless atmosphere of space, that the astronaut's feet be locked into place. The restraint's long rod is a telescoping boom which has a clamp which can be located at any point along the boom. The telescoping boom and clamp are normally mounted on the forward and aft payload bay bulkheads (walls). The platform assembly, which is normally stowed in the tool stowage area, is attached to the boom clamp by the astronaut when its use is required. The platform assembly consists of a platform with foot restraint and tether attachment points. The platform may be rotated to allow the astronaut to be in nearly any position required. Figure 6-24.

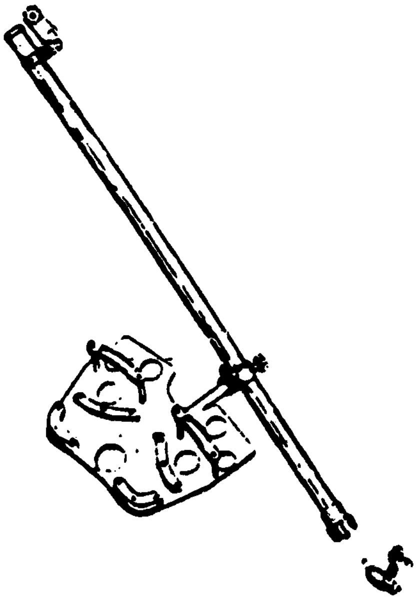


Figure 6-24 EVA Portable Foot Restraint

MANNED MANEUVERING UNIT (MMU)

The current-MMU is a device designed primarily to enable the EVA astronaut to maneuver, without the restriction of mere hand-over-hand translation, in and around the vicinity of the Shuttle orbiter up to a range of 300 ft. With a delta V capability of about 68 feet per second, the device provides transportation from shuttle to worksite, and attitude stabilization required to work at, or rigidize to the worksite. The MMU also provides a limited transport capability for tools and equipment. The ability to fly away from or around a vehicle allows a stable standoff position for photo documentation and general observation, or a closeup inspection of all parts of the vehicle.

MMU safety employs fully redundant fail-safe active subsystems for attitude control including automatic attitude hold, electrical power, and propulsion, and isolation valves providing immediate thrust termination on either or both propulsion systems. One singe point failure inherent in any propulsion system is line or tank rupture and venting, which on an MMU can result in uncontrolled propulsive effects. The requirement for active shuttle rescue reduces risk to an untethered astronaut but restricts both EVA and shuttle for timelines and propellant redlines. Buddy system MMU rescue and propellant transfer improves MMU safety but has limited range. Advanced missions requiring greater flight distances and remote operations will also require greater reliability for control of failures and may involve greater failure separation and controlled (zero thrust) failure-venting. When on-orbit facilities include propellant storage and OMV transportation, MMU rescue will be viable for nearly any mission or activity.

MMU performance for future missions will require additional capability necessary to support on-orbit assembly and servicing activities associated with space station construction and operation. Simple transportation of personnel will expand to transportation of larger more involved materials as a support to more complex EVA activities. Associated with this are requirements for greater propellant and delta V potential. As transportation of larger mass objects becomes a necessity, so will the ability to compensate for shifting center of gravities on MMU dynamics. Complicating this situation will remain the need for a non-contaminating propulsion system for the protection of sensitive equipment, scientific experiments an EVA crewmember himself, arising from the close proximity work an MMU will be required to perform.

EVA ASSESSMENT

Aggregate issues involving EVA must address not only the suit system but also the environment in which the suit system must function. These areas of concern include:

Task-Assessment
Task-Suit System Interface
Suit System Logistics
Man-Suit System Interface

Figure 6-25 shows the relationships of the EVA task elements. Implied are the function, threat, application and importance of logistics element in selecting what the EVA suited crewman is to do, where he is to do it and under what conditions. All of these elements contribute to EVA suit system design definition.

Task Assessment

The EVA/suit system exists to extend man's capabilities to function in inhospitable environments. This could include exploration, surveillance, fabrication, servicing, repair, installation, transportation and rescue. Each of these tasks generates requirements on the man as well as the suit system. Each task must be assessed for threat impact, interface definition, logistics and procedures/requirements development. For instance, in looking at the considerable functions for the EVA suited crewman one sees issues that must be addressed. Table 6-3 relates functions to threats. Each of these threats must be assessed to determine 1) if adequate strategies are available to protect the crewman/equipment, 2) if contingencies can cause inordinate risk exposure within the selected strategies and/or 3) if the candidate functions should be deleted from the EVA agenda.

Task-Suit System Interfaces

Similarly, as above, the interface issues must address each planned EVA function and its accompanying tools and equipment. The basic issue is the EVA suited crewman exiting a habitat. To accommodate the limited capabilities of the existing shuttle EVA suit, the habitat (orbiter) has to lower its internal atmospheric pressure to reduce the suit-cabin delta pressure minimizing the crewman's time for prebreathing. A clear definition of this requirement was not included in the orbiter development specifications in 1972.

Because of this oversight, the orbiter/current EVA suit does not allow for immediate egress of the EVA suited crewman without the risk of exposure to bends. That is, the lower limit of the orbiter cabin pressure is dictated by air mass/volume flow requirement to cool avionic equipment and the fire hazard exposure when the oxygen partial pressure is increased at the lower cabin pressures. At the present, 10.2 psia is the minimum cabin pressure allowed in the orbit crew compartment. There are approaches being assessed to allow the space station to function with an 8 psi cabin so that existing soft-suit (4 psi) technology is directly applicable for the next decade of space exploration. This seems counterproductive. It would appear, on the other hand, that developing a suit whose internal pressure approaches 14.7 psi should be the goal to alleviate these suit/cabin delta pressure generated issues.

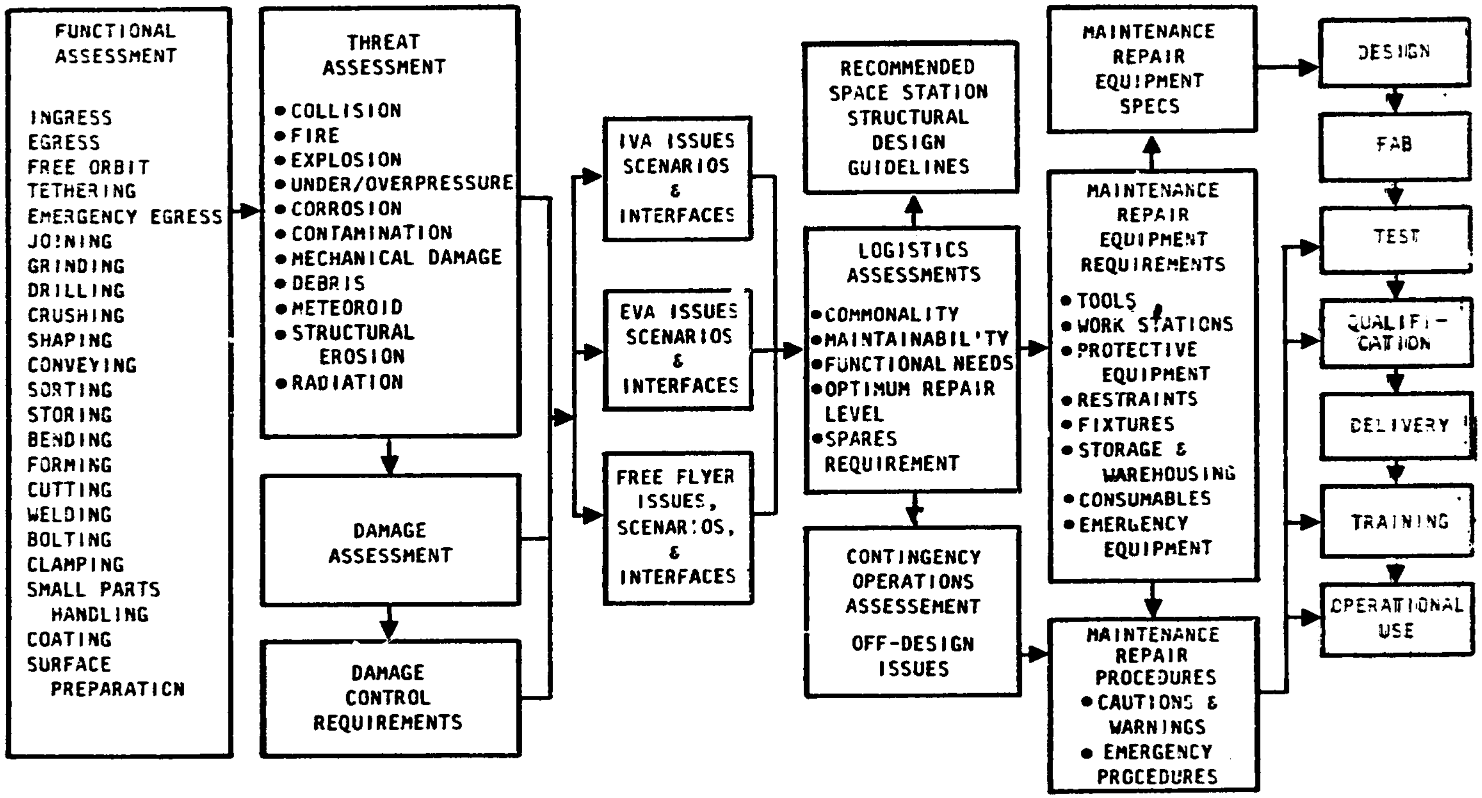


Figure 6-25 EVA Assessment Requirements Definition Taska

TABLE 6-3 EVA FUNCTIONS VS. RELATED THREATS

EVA FUNCTIONS \ THREATS	FIRE	LEAKAGE	TUMBLING/LOSS CONTROL	CONTAMINATION	INJURY/ILLNESS	GRAZING/COLLISION	CORROSION	MECHANICAL DAMAGE	EXPLOSION/IMPLOSION	LOSS OF PRESSURIZATION	RADIATION	OUT-OF-CONTROL IVA/EVA	INADVERTENT OPS	LACK OF CREW COORD	ABANDONMENT	METEOROID PENETRATION	CONSUMABLES DEPLETION	STRUCTURAL EROSION	ORBIT DECAY	ACCESS TO HATCH	TEMPERATURE EXTREMES	DEBRIS	FREE ORBIT
INGRESS			●	●	●	●		●		●		●	●	●			●			●	●		●
EGRESS			●	●	●	●		●		●	●	●	●	●		●	●			●		●	
FREE ORBIT			●		●	●		●		●	●	●	●	●		●	●			●		●	●
TETHERING			●		●			●				●	●										
EMERGENCY EGRESS		●	●		●	●		●		●	●	●	●	●	●	●	●			●		●	
JOINING					●		●						●										
GRINDING	●				●				●				●					●			●		
DRILLING	●	●	●		●			●	●				●					●			●		
CRUSHING					●				●				●										
SHAPING					●								●										
CONVEYING					●								●										
SORTING					●	●							●										
STORING		●			●								●									●	
BENDING					●			●					●					●					
FORMING					●								●								●		
CUTTING	●	●	●		●		●	●	●				●			●		●			●	●	
WELDING	●		●	●	●		●	●	●				●			●		●			●		
BOLTING			●		●			●					●					●				●	
CLAMPING			●		●			●					●					●					
SMALL PARTS HANDLING			●		●			●					●									●	
COATING				●	●	●			●				●					●			●		
SURFACE PREPARATION	●			●	●	●			●				●					●			●		

Additional interface issues are function generated as noted in Table 6-3. It can be seen that high risk tasks, that is tasks that exposes the EVA suited crewman to catastrophic environments, may become candidates for automation or deletion as credible functions. These issues are addressed by cost of robotics vs. risk to EVA suited cremen. Even if external tasks are assigned to robotics, the residual requirement remains to service and maintain the robotic systems.

A key task-suit system interface issue is that of protection of the suited crewman from the environments expected in LEO and eventually GEO orbits. With radiation being the driver, consideration of a suit technology that allows ample attenuation of radiation to the crewman at higher and polar orbits seems mandatory.

Suit System Logistics

This issue may be the eventual driver to go to hard suit (non-cloth) elements. The present shuttle EVA suit requirements for maintenance, repair and refurbishment - unless the suit inventory is dramatically increased - would make its use in the planned space station impractical, if possible. Maintenance, repair and refurbishment of the suit system in addition to on-orbit suit sizing and decontamination appear to be key design drivers for an EVA suit system that must function in an LEO, GEO and eventually a cislunar environment. These logistic requirements appear to grossly define a suit whose elements are readily assembled/disassembled, have resistance to abrasion/erosion, are completely interchangeable and are easily decontaminated as a whole or as separate elements.

Man-Suit System Interface

In suit design, the physical and anthropomretric needs are addressed. In practice, the latter may suffer from logistics (sized spares) problems, not necessarily from lack of design attention. Basic issues at the man-suit interface are those issues that become fatigue generators. The soft suit technology appears to be pressure limited as increases in pressure at or above the 5 psi level appear to immobilize the suited crewman. This is either in motion of arms and legs or gloved digits.

The NASA-ARC AX-2 and AX-3 suit developments address the arm and leg mobility such that reach and dynamic motion appears to be independent of pressure.

End effectors, whether they are gloves or robotic extensions of the suited crewman need further design assessment. Experimental hard/soft gloves and gloves studies continue. End effectors that are essentially manipulator systems operating replaceable specialized tools by an ungloved hand within the suit pressure shell could be considered after the function assessment determines which discrete tasks the EVA crewman is obligated to perform.

Some minor problems have occurred in the existing shuttle EVA suit with mounting of the communication system elements. There may be an advantage to helmet mounting communication gear vs. crewman donned soft cap mounting.

EVA ISSUES

Tool Problems

EVA tasks in the past have been hampered by the difference in what was experienced in training and what was realized in actual on-orbit operations. On STS-11, the crew commented that the equipment they trained on was not the same configuration as the actual article. Additionally, the Solar Max flight, STS-13, presented the problem where the EVA tool-to-Solar Max interfacing tasks were hampered by interference. It has been determined that the interface on the Solar Max was not as reflected on the drawing used in EVA tool design and task planning.

EVA Suit Capability

The present EVA suit requires a reduced cabin pressure and prebreathing; 10.2 psia and 40 minutes. The EVA suit used on the Space Station should support immediate egress from the normal cabin pressure (i.e., 8 psia or greater). Donning and doffing capability of the suit should be investigated.

Exposure to Radiation

A long term issue, not directly addressed, is the impact of EVA crew member exposure to background radiation exclusive of solar flares. The relationship of time on EVA must be related to the total rem dose per flight, per quarter, per year and per lifetime. This assumes solar flare escape to a "storm cellar" within 20-minutes is possible. The "storm cellar" may be station mounted or free-orbit located adjacent to areas of EVA tasks a distance away from the space station.

Fatigue

Some of the EVA's have been fatigue generators, perhaps this is from unexpected contingencies, and lack of upper torso muscle-tone maintenance deficiencies. Also, soft suit tendencies toward immobilization at higher pressures can generate fatigue. Present exercise techniques operate on the cardiovascular system and the lower torso muscular system; a whole body, or at least optimization of upper torso/arms exercise should be considered.

EVA Support

Current EVA's involve two crewmen outside and one or more inside. Space Station EVA support may limit the number and length of EVA segments because of the non-EVA time required for internal activity as well as space station maintenance.

EVA Lighting

There is a shade-side lighting problem without an atmosphere to scatter light. This requires special attention, as it is difficult to determine how much fill-in lighting is needed during tests on the ground. The high contrast light/shade environment in space is not easy to demonstrate on the ground.

Restraint

Limiting restraints to the foot jack may be overlooking the normal fetal position of micro-gravity.

Contingency Operations

EVA operational planning should postulate more contingencies to ensure tool, crewman and expendable capability exists to support off-design operations.

EVA Rescue

Figures 6-26 and 6-27 show an EVA rescue simulation whereas one crewman is returning an incapacitated crewman to the space station. There may be an advantage to considering an external "handle" on the EVA suit - perhaps on the helmet to allow one-hand tow of an incapacitated crewmember.

EVA Suit Maintenance

Present suit and backpack (life support system) maintenance and turnaround does not seem compatible with planned space station operations and staffing.

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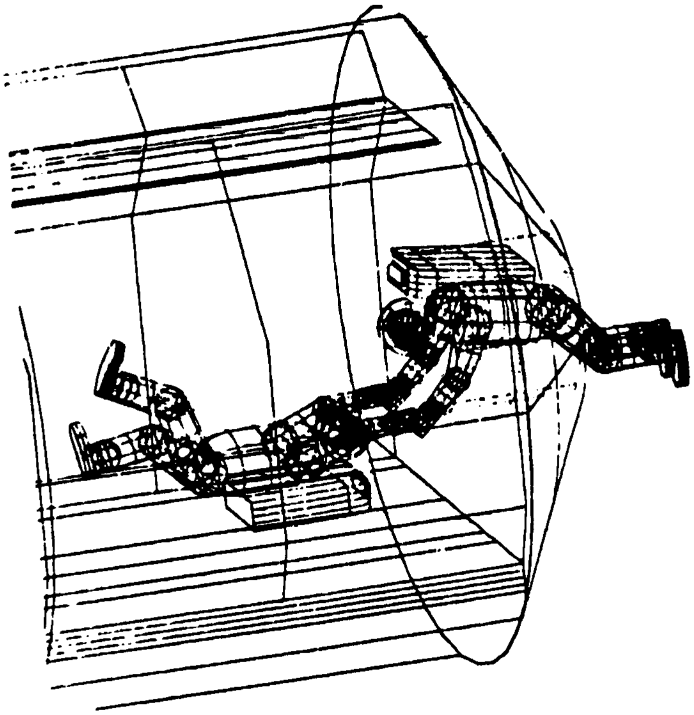

Figure 6-26 Zoom In of Rescue Simulation

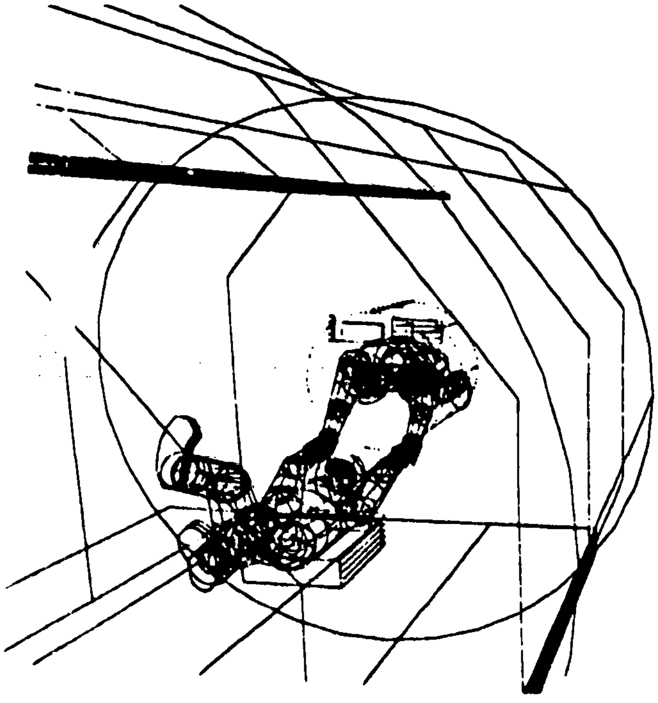

Figure 6-27 View Point Analysis of Rescue Simulation

7. SAFE HAVEN

The concept of a "Safe Haven" in the manned space program predates the earliest data searched out in support of this contract study: circa-1968. A safe haven is a place where a crew can retire when faced with a threat not immediately controllable in the local volume. More than a place, a safe haven is a capability; the capability to keep the crew alive for a specified period of time when the space station has sustained damage. The length of time the safe haven capability must sustain the crew is contingent on the time required to either implement repairs and return to routine operations as possible, or to rescue the crew. For the low Earth orbit space station concept investigated as part of this study, there are in essence four space stations: 1) the build-up station, 2) the 28-day station, 3) the 90-day station and 4) the 15-year station. The build-up station is defined as the initial station through the planned 8-man full operations station. The twenty-eight day station is the station defined as having to sustain life until the crew can be rescued. The ninety-day station is the station that must maintain a crew without physical contact with the Earth for that period of time. The fifteen-year station is the projected life and safe disposal station, that is, removal from orbit station. A safe haven capability must exist in each of these space stations as defined. The twenty-eight day station is the one that specifically defines the requirements of the safe haven capability.

OPERATIONAL NEED FOR A SAFE HAVEN

The safe haven capability may better be defined by looking at its need. Circumstances that precipitate the need for a space station safe haven capability and its use are shown in Figure 7-1. When faced with a threat, the crew will have to make this logical assessment concerning its course of action. This logic flow is no different than those used in everyday life and particularly for operations that may contain inherent dangers.

It is interesting to note that the second level threat addressed is solar flare. This subset of the radiation threat is often overlooked. The radiation intensity of a solar flare, if directed into the space station orbital sector, can increase the ambient background radiation by three orders of magnitude or more This specific threat dictates a specific need for short term crew protection from intense radiation. This protection is called the "storm cellar" for definition's sake. The question to be asked, "Should the storm cellar be integrated into the total space station capability?", begins to drive the configuration.

Continuing with Figure 7-1, once evacuation is deemed necessary, the crew must continue with the bookeeping tasks typical of any emergency alternative. In looking at what the crew must do, Figure 7-1 also indicates what the space station capability must be to support its emergency operations. Each task, and this listing may not be complete, implies the need to be able to accomplish the action specified and also have the necessary hardware to do so.

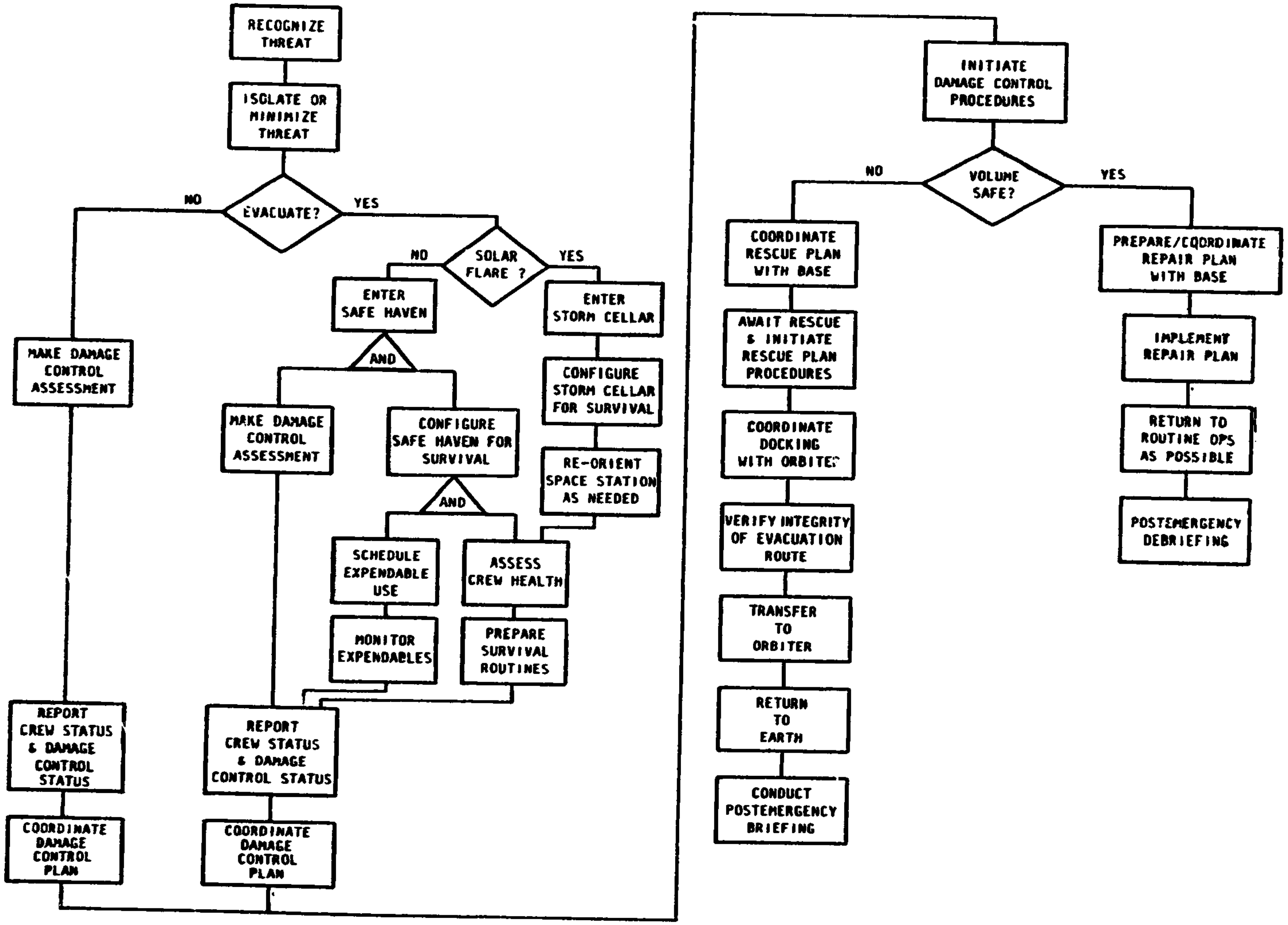

Figure 7-1 Operational Response to Threat

SAFE HAVEN REQUIREMENTS

There are various ways to define the safe haven requirements. One approach is to define the need and another is to define the equipment required to satisfy the need. In that the latter approach is contingent on having a configured space station, the approach used here will be to define the needs so that they may be applied to many configuration approaches. Essentially, the Space Station safe haven capability must include the following:

1. Must remove crew from current threat and/or threat arising from the current threat.

2. Must include facilities to provide and maintain minimum human comforts until rescue is effected or until the crew can return to normal/non-threatened operations.

3. Must include facilities to prevent a deteriorating medical situation during period of use.

4. Must not require the use of EVA to transport personnel to and from safe haven/rescue vehicle.

5. Should not consider any design concept that requires detachment from the basic station (Free Orbit).

6. Must not require any significant reaction time to activate and occupy the safe haven.

7. Must provide continuous communications capability with the ground, the basic station and potential rescue vehicles.

THREAT/SAFE HAVEN RELATIONSHIPS

Of the twenty-three threats defined during this study, sixteen are felt to be drivers for safe haven capability definition. Figure 7-2 relates the safe haven design requirements to the threats expected to be encountered. As can be seen, the safe haven design requirements are a microcosm of space station design requirements. Because of this, it would be prudent to look at the station as a whole when assessing the safe haven capability. Except for consumables, the safe haven capability could be integrated into the overall space station capability.

SAFE HAVEN OPTIONS

In the same way that the threats drive design capabilities, the same design capabilities are related to safe haven options. Figure 7-3 addresses eight options. The Orbiter is addressed as the ninth option primarily to support safe haven capability for the build-up phase of the space station. Once an on-orbit safe haven capability is established, it will be able to support the 28-day station, the 90-day station and the 15-year station. Or at least its design planning should include the specific requirements for each of these station types. Included in Figure 7-3 are relative cost estimates to achieve each of the safe haven capability options.

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DESIGN REQUIREMENTS	THREAT FIRE	LEAKAGE	TUMBLING	CONTAMINATION	INJURY/ILLNESS	CORROSION	EXPLOSION	PRESSURE LOSS	RADIATION	LACK OF COORD	ABANDONMENT	METEOROID PENETR	STORE DEPLETION	ORBIT DECAY	LOSS OF ACCESS	TEMP EXTREMES
LOCAL ARS CONTROL				X				X								X
TBD FREE VOLUME/PERSON					X											
TWO-GAS SYSTEM					X											
DEPRESS 10 MIN/REPRESS 20 MIN (TBD REPRESSES)		X		X				X				X				
TEMPERATURE FROM TBD TO TBD					X											X
REAL-TIME MONITORING OF ATMOSPHERE				X	X			X								
BREATHING MASKS TBD SUPPLY	X	X		X								X				
21-DAY CONSUMABLES FOR TBD PEOPLE													X			
FOOD/WATER IN TWO OR MORE CONTAINERS				X	X											
PERSONAL HYGIENE FACILITIES				X	X											
WASTE DISPOSAL CAPABILITY				X	X											
EGRESS FROM OTHER MODULES <TBD SECONDS	X	X		X			X								X	
REDUNDANT POWER/LIGHTING	X	X	X	X	X	X	X	X	X	X		X	X	X		X
FIRE SUPPRESSION CAPABILITY	X															
RADIATION PROTECTION AGAINST TBD THREAT									X							
EMERGENCY MEDICAL SUPPLIES					X											
PRIMARY/BACKUP COMM MODULES/OUTSIDE										X						
NO TOXIC, FLAMMABLE, RADIOACTIVE OR CORR MATLS		X		X	X					X						
MATERIAL TNT EQUIVALENCY OF <TBD							X									
MATERIAL FLAMMABILITY RATING <TBD% PP O_2	X						X									
SHIRTSLEEVE ACCESS TO RESCUE VEHICLE					X						X					
CONTROL OF ALL MODULE CRITICAL FUNCTIONS	X	X	X	X			X	X		X	X		X	X		X
ABILITY TO DECONTAMINATE SURVIVORS				X												
MAINTAIN STABILITY (ATTITUDE/ORBIT MAINT)			X								X			X		

Figure 7-2 Safe Haven Threat Related Design Requirements

DESIGN REQUIREMENTS	SAFE HAVEN CONFIGURATION OPTIONS STORM CELLAR	OTHER HALF OF STATION	EXTERNALLY MOUNTED INFLAT	ESCAPE CAPSULE	INTERNAL INFLAT BULKHEADS	MULTI-USE AREA	SECOND SPACE STATION	IN-ORBIT TEMP SHELTER
LOCAL ARS CONTROL			○	○				
TBD FREE VOLUME/PERSON				○				
TWO-GAS SYSTEM								
DEPRESS 10 MIN/REPRESS 20 MIN (TBD REPRESSES)			○					
TEMPERATURE FROM TBD TO TBD								
REAL-TIME MONITORING OF ATMOSPHERE								
BREATHING MASKS TBD SUPPLY								
21-DAY CONSUMABLES FOR TBD PEOPLE				○				
FOOD/WATER IN TWO OR MORE CONTAINERS								
PERSONAL HYGIENE FACILITIES				○				
WASTE DISPOSAL CAPABILITY				○				
EGRESS FROM OTHER MODULES <TBD SECONDS							●	●
REDUNDANT POWER/LIGHTING								
FIRE SUPPRESSION CAPABILITY								
RADIATION PROTECTION AGAINST TBD THREAT	○	○	○	○	○	○	○	○
EMERGENCY MEDICAL SUPPLIES				○				
PRIMARY/BACKUP COMM MODULES/OUTSIDE								
NO TOXIC, FLAMMABLE, RADIOACTIVE OR CORR MATLS		○		○		○		
MATERIAL TNT EQUIVALENCY OF <TBD		○		●		○		
MATERIAL FLAMMABILITY RATING <TBD% PP O_2								
SHIRTSLEEVE ACCESS TO RESCUE VEHICLE							●	●
CONTROL OF ALL MODULE CRITICAL FUNCTIONS				○			●	●
ABILITY TO DECONTAMINATE SURVIVORS	○			○				
MAINTAIN STABILITY (ATTITUDE/ORBIT MAINT)				○			●	●

BLANK - READILY ACHIEVABLE
○ - COSTLY TO ACHIEVE
● - NOT EASILY ACHIEVABLE

Figure 7-3 Safe Haven Options as Impacted by Design Requirements

In reviewing the relative cost options shown in Figure 7-3 it becomes apparent that radiation protection against the solar flare is going to be a difficult design issue to resolve. Deleting that requirement, there remain three options of equal relative cost, accepting the fact that a storm cellar is mandatory. Of these three, the externally mounted inflatable is not a normally usable volume. There may be other logistical problems with the externally inflatable safe haven. However, the remaining two are credible approaches to the problem. The multi-use area safe haven implies one volume usable for the purpose of a safe haven but used for other purposes as well, not being a dedicated safe haven. The other half of the station implies a safe haven capability in two separate volumes.

A review of reliability redundancy requirements, Vol. IV-Appendix E, indicates that redundancy issues tend to support the "other half of station" safe haven capability concept.

The unresolved issue, however is how the "storm cellar" is going to be integrated into the space station design. Figure 7-4 proposes a possible approach based on the "other half station" safe haven capability. It should be noted that the storm cellar is a single failure point. What makes it a storm cellar is 1) necessary shielding from the most severe radiation threat, 2) minimum hygiene facilities and minimum life sustenance capability for up to five days. It could be possible to designate the storm cellar volume as the volume which is surrounded by the potable and gray water tanks, or tanks that could have the water pumped to surround the storm cellar area. Another approach is to encase the crew in lead ponchos...or any combination of these approaches. If the storm cellar environment can be created dynamically, it could be an integral part of each or both safe haven half station capabilities.

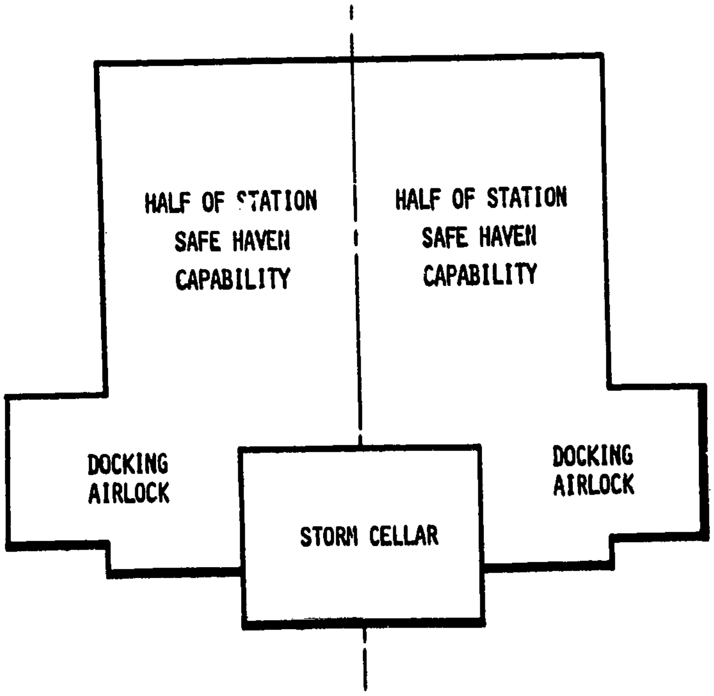

Figure 7-4 Safe-Haven/Storm Cellar Relationships

8. AREAS FOR FURTHER EMPHASIS

Table 8-1 summarizes the areas in this study identified as needing further emphasis. Similarly, Table 8-2 notes those areas to be looked into as a result of the safety impact on human factors assessment.

Some of the items may be underway or have been completed. The listing in no way comments on completness or status of the related items. Rather, the list indicates that within the data reviewed there seemed to be areas of data deficiency.

TABLE 8-1 AREAS FOR FURTHER STUDY

AREA OF RECOMMENDED FUTURE EMPHASIS	THREAT
1. Airlock for lab module vs. dual egress study	Contamination Loss of Access to Hatch
2. Airlock for lab module vs. delta P pressure curtain study	Contamination
3. External stowage of EVA suit (cost impacts) vs. internal contamination	Contamination
4. Free flyer for "dirty" payloads vs. on-board decontamination/clean room costs	Contamination
5. Up-front costs vs. program costs for regenerative ECLSS or a consumable-using ECLSS	Contamination Stores Depletion
6. User safety requirments documents vs. user safety ombudsman	Program
7. Refurb module on orbit vs. return and refurb	Program
8. User guide to automate vs. manual approach to experiments/processes	Program
9. Testing one-of-a-kind payload vs. recommending encapsulation	Program
10. On-board material/inventory control vs. on-ground control with data link (expanded MATCO-RI-System)	Corrosion Contamination Inadvertent Ops Stores Depletion
11. Costs of measuring internal contamination vs. risk of accepting contamination	Program
12. Dedicated (module) vs. centralized ECLSS	Contamination Loss of Pressurization
13. Relaxed contaminant allowables per zone (hazard critical/contamination sensitive) vs. minimum contamination allowables for entire station	Contamination Injury/Illness

TABLE 8-1 (CONT'D) AREAS FOR FURTHER STUDY

AREA OF RECOMMENDED FUTURE EMPHASIS	THREAT
14. Threshold Level Values (TLV's) for 24-hour station vs. TLV's for 8-hour work week regimes	Injury/Illness
15. EVA dedicated module (w/decontamination capability) vs. decontamination in dedicated airlock	Contamination
16. Level of material assessment and control for station vs. user	Program
17. Cost of medical care on-orbit vs. medical screening (appendectomies, radiation max-out, etc.)	Injury/Illness
18. Realtime contamination monitoring vs. "snap shot" monitoring	Contamination
19. Classified Materials Controls vs. "Industrially Sensitive" material control	Lack of Crew Coordination
20. High altitude (Debris/Radiation) vs. lower altitude (oxygen bombardment)	Debris, Radiation, Structural Erosion, Contamination
21. Re-orienting station mass vs. providing shielding from solar flares	Radiation
22. Optimum repair level: Unit vs. Component	Program
23. Walk-around bottles vs. plug-in O_2 system	Loss of Pressurization Contamination
24. Synergistically develop barrier system (module pressure wall) to accommodate debris, meteoroids, radiation, oxygen bombardment, pressure redundancy, shrapnel shielding and structural inspection/repair	Radiation, Debris, Meteoroid Reduction, Loss of Pressure, Mechanical Damage, Grazing/Collision, Leakage
25. Develop body vital signs monitoring system for each crew member with data aggregated for control panel display or down listing	Injury/Illness
26. Define medical facilities for build-up, initial and growth stations	Injury/Illness

TABLE 8-1 (CONT'D) AREAS FOR FURTHER STUDY

AREA OF RECOMMENDED FUTURE EMPHASIS	THREAT
27. Provide orbit changing maneuvering capability of station to avoid debris, including determining cycle-rate and total propulsion requirements	Debris
28. Develop on-going international protocols for traffic control in space. Expand NORADS capability to identify debris down to Xmm diameter	Debris
29. Define fragmentation dispersion of pressure vessels in a vacuum: calculated disperson or actual disperson (291)	Explosion
30. Definition of blastwave characteristics for typical gas storage vessels (291)	Explosion
31. Better definitions of fragment impact effects on a variety of strutures and facilities typical of those occurring in aerospace vehicle explosions (291)	Explosion
32. Centralized/Decentralized work stations (station subsystem maintenance, EVA/EMU maintenance and storage, module repair/refurb, user equipment maintenance and repair)	Lack of Crew Coordination
33. EVA suit vs. chamber/airlock for hyperbaric treatment of the bends	Injury/Illness
34. EVA suit external surface material compatibility or selected overgarments	Contamination
35. Small tool "pass through" compartment to support EVA vs. cost of module or airlock press/depress	Stores Depletion
36. Remote actuating of airlock outer hatch vs. manual actuation by EVA crewman	Injury/Illness
37. Assessment of personal and equipment restraints and tether	Lack of Crew Coordination
38. Minimize types and sizes of fastening devices (weight vs. logistics impact)	Stores Depletion
39. Free flying (permanently co-orbiting station) EVA tool box vs. space station mounted tool box	Injury/Illness

TABLE 8-1 (CONT'D) AREAS FOR FURTHER STUDY

AREA OF RECOMMENDED FUTURE EMPHASIS	THREAT
40. Clear definition of EVA ionizing radiation impact to crewmember and shielding capability of EVA suit materials	Injury/Illness
41. Experiments to investigate and determine properties of combustion and propogation of fire in Micro g.	Fire

TABLE 8-2 AREAS FOR FURTHER STUDY

AREA OF RECOMMENDED FUTURE EMPHASIS	HUMAN FACTORS ISSUE
1. Determine degree of automation needed and/or desired for interactive crisis management	Crisis Management
2. Expand and disseminate anthropometric data on the micro-gravity "neutral body" position	Crisis Management
3. Further develop the software architecture and approaches to allow editing, recombination and understandable annunciation of many data elements to support real time decision making under conditions of stress	Crisis Management
4. Develop testing/screening techniques that can identify or relate subject's ability to function under high stress conditions	Crisis Management
5. As a part of space station systems engineering and integration, develop a "crisis management" overlay of all space station signals and data interchange networks to help coordinate aggregation of annuniations/controlling signals necessary for crisis management (emergency or contingency operations)	Crisis Management
6. Polarized shades vs. opaque shades	Confinement/Isolation
7. Allow personalization of cabins or work areas (photos, cartoons, books, etc.) including decor options	
8. Define crewmember psychological and physiological screening elements to support functioning in a long term confined/isolated enviroment	Confinement/Isolation
9. Include architectural/interior design consultation in habitable module design	Confinement/Isolation
10. Consider possibility of single, large-volume space (inflatable or structurally built-up to provide "open" environment for crew on growth station	Confinement/Isolation
11. Develop standard decision-making techniques to be used for insulation vs. isolation of noise	Acoustics

TABLE 8-2 (CONT'D) AREAS FOR FURTHER STUDY

AREA OF RECOMMENDED FUTURE EMPHASIS	HUMAN FACTORS ISSUE
12. Specify the need for a maximum allowable NC-acoustic requirement per module (work area vs. habitable area) and require acoustic subsystem input apportionment within each module. Include a qualification test to apportioned acoustical requirements	Acoustics
13. Provide for standard hand signals for emergency communication in untenable noise environment	Acoustics
14. Define/provide personal storage space	Territorial Issues
15. Orient crew toward "non-violation" of personal territory	Territorial Issues
16. Include personal consumables (toilet articles, etc.) in a master logistics planning list	Territorial Issues
17. Determine method of measuring reasonable personal "space bubble" - flat vs. the sphere within which an individual feels threatened. Then, screen for crew who can function within this volume	Territorial Issues
18. Screen crewmembers for prejudices and openess to differing cultural norms	Behavorial Protocols
19. Provide education/orientation for crewmembers regarding cross-cultural issues and problems	Behavorial Protocols
20. Train crewmembers to utilized group dynamics to work out potential behavorial protocol conflicts	Behavorial Protocols
21. As a last resort, develop chemical/physical restraint system for out-of-control crewmembers	Behavorial Protocols
22. Dedicated module tasks for crew vs. common task, all-module assignment	Scheduling
23. Generalist vs. specialist for crew training guidelines	Scheduling

TABLE 8-2 (CONT'D) AREAS FOR FURTHER STUDY

AREA OF RECOMMENDED FUTURE EMPHASIS	HUMAN FACTORS ISSUE
24. Less than 90 day recycles vs. on-station expendable costs and crew personal equipment needed to support extended stay	Scheduling
25. Consider adequate capability for storage inventorying, handling and disposition of servicing, maintenance, plain garbage, and consumables for cleaning and repair	Cleaning/Disinfecting
26. Identify family of cleaning/disinfecting chemicals compatible with selected ECLSS approach	Cleaning/Disinfecting
27. Train crewmembers in all phases of station tasks, housekeeping	Cleaning/Disinfecting
28. Define minimum crew cleanliness requirements (this may be an intra-cultural issue)	Cleaning/Disinfecting
29. Define requirements (total volume and flow rates) for potable and non-potable water	Cleaning/Disinfecting
30. Consulting with astronauts, develop a standard for clothing options and hygiene consumables options	Hygiene
31. Consider scheduling hygiene (common) equipment	Hygiene
32. Define a private electronic center for each cabin to include at least an entertainment center (visual/aural), a private television link to Earth, background mood generator (white noise)	Recreation
33. When teaming, screen crewmembers for compatible recreation interests	Recreation
34. Prepare specification for recreation equipment/kit pertaining to safety - with options for person	Recreation
35. Develop realistic allowable radiation dose rate tables for part of body for EVA, flight, quarter, year and whole life	Violation of Safety
36. Develop color coding system for all tubing, piping, emergency passageway, damage control equipment and tasks including "warnings", "cautions", and "notes"	Violation of Safety

TABLE 8-2 (CONT'D) AREAS FOR FURTHER STUDY

AREA OF RECOMMENDED FUTURE EMPHASIS	HUMAN FACTORS ISSUE
37. Clearly identify safety critical segments of tasks to insure mandatory compliance (hardware, procedural software)	Violation of Safety
38. Prepare task flow charts that identify as many contingency operations as possible to determine response need	Violation of Safety
39. Screen <u>all</u> carry-on personal equipment	

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16. Abstract

The scope of this study considered the first 15 years of accumulated space station concepts for Initial Operational Capability (IOC) during the early 1990's. Twenty-five threats to the space station are identified and selected threats addressed as impacting safety criteria, escape and rescue, and human factors safety concerns. Of the 25 threats identified, eight are discussed including strategy options for threat control: fire, biological or toxic contamination, injury/illness, explosion, loss of pressurization, radiation, meteoroid penetration and debris. This report consists of five volumes as noted:

Vol. I - Final Summary Report (NASA CR-3854)
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