AEROSPACE REPORT NO.
ATR-72(7316-01)-1. VOL. III-2

Advanced Missions Safety

Volume III: Appendices

Part 2, Experiment Safety - Supporting Analyses

Prepared by
SYSTEMS PLANNING DIVISION

15 October 1972

Prepared for
OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASw-2301

Systems Engineering Operations
THE AEROSPACE CORPORATION

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PREFACE

This study on Advanced Missions Safety has been performed as Task 2.6 of Contract NASw-2301, entitled, "Advanced Space Program Analysis and Planning." The task consisted of three subtasks.

Subtask 1	–	Space Shuttle Rescue Capability
Subtask 2	–	Experiment Safety
Subtask 3	–	Emergency Crew Transfer

Each subtask is an entity not related to or dependent upon any activity under either of the other two subtasks.

The results of Task 2.6 are presented in three volumes.

Volume I: Executive Summary Report presents a brief, concise review of results and summarizes the principal conclusions and recommendations for all three subtasks.

Volume II: Technical Discussion is in three parts, each providing a comprehensive discussion of a single subtask.

Part 1 provides an assessment of Earth Orbit Shuttle (EOS) capability to perform a rescue mission. It treats several concepts for augmenting this capability and increasing EOS rescue mission utility.

Part 2 presents an analysis of potential hazards introduced when experimental equipment is carried aboard the EOS. It identifies safety guidelines and requirements for eliminating or reducing these hazards.

Part 3 discusses the applicability and utility of various means of emergency crew transfer between a disabled and a rescuing vehicle.

Volume III: Appendices is in two parts, each devoted to an individual subtask. Part 1 contains detailed supporting analysis and backup material for Subtask 1, and Part 2 contains similar material for Subtask 2. Volume III is of interest primarily to the technical specialist.

Since the reader is not necessarily interested in all three subtasks, each part of Volumes II and III is a separate document.

All calculations were made using the customary system of units, and the data are presented on that basis. Values in the International System of Units (SI) are also given. Data taken from reference sources are presented in the system of units employed in the original reference.

The Advanced Missions Safety Task was sponsored by NASA Headquarters and managed by the Advanced Missions Office of the Office of Manned Space Flight. Mr. Herbert Schaefer, the study monitor, provided guidance and counsel that significantly aided the effort. Mr. Charles W. Childs of the Safety Office, NASA Headquarters, and Miss Ruth Weltmann of the Aerospace Safety Research and Data Institute, NASA-Lewis, also provided valuable contributions by reviewing the Experiment Safety Study results and making positive suggestions for improving the visibility of the results.

SUMMARY OVERVIEW

In contrast to safety considerations in experiment ground facilities, which emphasize experimenter safety first, an experiment laboratory in space has to give prime safety considerations to the operational functioning of the Orbiter to enable a safe crew return.

In ground facilities, hazardous experiments are separated from other experiments and personnel. For space operations, experiment equipment of a hazardous nature may be densely packed, because flight costs are high. For this reason special attention has to be given to potential interferences and interactions such as overheating, permeating fields, spurious signals, high-voltage potential, etc. Such interaction between experiments could lead to a malfunction of otherwise safe equipment and might influence the safe operation of the Orbiter.

Many hazardous materials on board the Orbiter, such as cryogenics, storable propellants, etc., will add to the hazards of some of the experiments and the crew. The location of such materials in relation to any experiment or Orbiter equipment, as well as the access and egress routes for the experimenters, requires serious consideration.

In contrast to most ground laboratories, the Orbiter structure outside the crew compartment can withstand a pressure difference of only a few psi. Therefore, experiments with components of a potential high pressure or explosive source have to be constrained, shielded, or safed to prevent inadvertant activation by other experiments.

Toxic and hazardous materials (especially in gaseous or powder form), which present a health hazard to men or which can damage materials or equipment, may have to be double-contained with special environmental conditioning systems, as complete cleanup of contaminants in zero gravity might be impossible to achieve.

Venting of effluents into space, even in small amounts, will create a thrust that has to be counteracted if the Experiment Module or the Orbiter are to remain in a given orbit and prevented from tumbling. Thus, effluent outlets should be designed and located so that any undesired thrust is compensated by a counteracting thrust. If this cannot be achieved in an emergency, sufficient Orbiter thrust should be available to keep the Orbiter on course, even if all effluent has to be vented by emergency relief in one direction. Similar considerations apply also to the case of rotating equipment producing reaction torques.

Many of the experiments being considered for shirtsleeve operation will require venting of one or more fluids because they are conducted in an artificial environment that has to be maintained for crew life support. Different fluid lines require prominent marking, ready accessibility for repair, and arrangement to permit convenient access or egress. All fluid lines require markings and connectors that are unique to any one fluid.

Many of the experiments being considered have high-voltage components with the potential of fire, shock, etc. which could result in injury to the crew and damage to the Orbiter. The clear indication of the operational status of such components is required. In case of emergency, provisions for automatic shut-down and rapid discharge after shutdown are required. Ground circuits should be avoided.

Emergency situations resulting from experiment equipment and/or its operation that could lead to Orbiter damage and/or loss require immediate assessment by the Orbiter crew. This can be accomplished by providing warning signals in the crew compartment which indicate the hazard, its severity, its location, etc. Normal procedures provide the commander with the authority to determine actions necessary to save the Orbiter and crew. This may involve sacrificing an experiment, an Experiment Module, and perhaps even a crew member, if the emergency warrants such drastic means and the Orbiter and most of the crew can be saved by such an action.

Radiation sources, such as radioisotopes, X-rays, lasers, etc., which can cause injury to men and damage to materials, equipment, experiments, and the operation of the Orbiter, should be clearly marked, monitored, shielded, and located so that no interference is possible under normal operating conditions. Emergency procedures and plans should be prepared and executed if an emergency or malfunction is indicated by the monitoring system.

In ground facilities the safety plan for any complex experiment usually identifies start-up, operating, and normal and emergency shutdown procedures. For the case of an Orbiter, where a number of experiments might be operated simultaneously, safety procedures should consider not only single experiments but also the interactions of all experiments to be operated at any one time. A certain shutdown procedure might be safe for one experiment but might create an emergency situation in another experiment, thus endangering the Orbiter and crew. Such procedures might indicate, for example, that if an emergency occurs in experiment A, experiment B has to be shut down prior to taking action on experiment A. In another situation the Orbiter may be required to make a certain maneuver before shutdown action can be taken on either experiment, in order to ensure the safety of the Orbiter.

In the case of hazardous experiment equipment such as lasers and X-rays, there should be a trade-off study made to determine whether the experiment should be conducted within or exterior to the Experiment Module or Orbiter. If located within the Experiment Module, the experimenter can closely supervise the experiment operations and ensure compliance with all safety procedures. If located exterior to the Module or Orbiter, docking or EVA may be required. Such operations also have safety implications, such as collisions and EVA hazards.

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TABLES (Continued)

1. INTRODUCTION

1.1 BACKGROUND

A major NASA objective is to utilize manned space flight capability for the benefit of our nation and mankind. To further this objective, a number of experiment programs have been defined. These experiments are described in the "Reference Earth Orbital Research and Applications Investigations" (Blue Book), Ref. 1. This broad-based experiment program definition encompasses the disciplines of astronomy, physics, earth observations, communications/navigation, materials science and manufacturing, technology, and the life sciences.

Present plans place complete dependence on the Space Shuttle for transporting such scientific and application payloads into space and returning them (where appropriate) from earth orbit. Additionally, the Orbiter element of the Shuttle is required to deploy and retrieve payloads in some instances; in other cases the Orbiter functions as a primary base of operations for an attached experiment payload. In all cases the nature of the experiment payloads and their potential for introducing or precipitating hazards which endanger the safety of experimenters and/or the Orbiter and its crew are of obvious interest. Therefore, this study was undertaken to investigate the safety aspects of in-space experiments performed in connection with the Space Shuttle.

1.2 STUDY OBJECTIVES

The objectives of the study were:

a. Analyze the potential emergency situations created by carrying experiment equipment aboard a Space Shuttle.

b. Identify safety guidelines and requirements for eliminating or reducing hazards to the Space Shuttle and its crew which may be introduced by the experiment equipment and its operations.

1.3 STUDY SCOPE

The safety analysis considered all mission phases from the launch pad through to deployment, free flight (where applicable), experiment operations, retrieval, and final disposition. Also considered were the interactions of the experiment equipment and experiment operations with Experiment Modules (Pallet, MSM, RAM, Sortie Module, etc.) and the Space Shuttle, other payloads within the Orbiter cargo bay, and associated satellites.

2. EXPERIMENT AND HARDWARE DEFINITION

2.1 EXPERIMENT EQUIPMENT AND SUPPORT REQUIREMENTS

A brief review of the literature indicated that a comprehensive identification of basic candidate experiments and experiment equipment being considered as payloads for the Space Shuttle was contained in the Blue Book, Ref. 1. Supplementary experiment and hardware data, more specifically related to Space Shuttle applicability (and extending to automated satellite payload compatibility), was treated extensively in the SOAR study, Ref. 2. These two reference sources, then, were utilized to provide baseline definitions of experiment equipment and support requirements for the present safety analysis.

2.1.1 Blue Book Definitions

The 15 January 1971 edition of "Reference Earth Orbital Research and Applications Investigations" (Blue Book) provides the latest definition of experiment requirements data for continuing NASA Space Station, Space Shuttle, and Research Application Module (RAM) definition activities.

The Blue Book describes experiment requirements for seven scientific disciplines and functional program elements (FPEs) within each discipline, where appropriate. An FPE is a grouping of experiments, experiment classes, or research activities characterized by being mutually supportive of a particular discipline of research or investigation or by imposing similar and related demands on the support systems.

Tables 2-1 through 2-4 (from Ref. 1) summarize the Blue Book experiment requirements. Table 2-1 summarizes the requirements for each FPE except for Fluid Management and EVA, which cannot be summarized at the FPE level due to either the complex and diverse nature of the facility requirements or the uniqueness of each experiment set-up or operation. Summary data for these two FPEs are presented in Table 2-3 (for Fluid Management) and Table 2-4 (for EVA). Table 2-2 lists required crew skills and their code numbers as used in Table 2-1.

Specific experiment equipment, support equipment, and materials used in the conduct of the experiments are delineated in Section 3.

2.1.2 SOAR Study Definitions

Task 1 of the SOAR study (Ref. 2) had three basic elements: to assimilate Shuttle payload data, to assess payload compatibility with Space Shuttle mission capabilities, and to select a representative payload set for detailed requirements and accommodation analyses.

Candidate orbital experiment definition in terms of functional program elements (FPEs) is related to a facility or laboratory approach to orbital research. In order to provide smaller packages affording greater flexibility for short-duration Shuttle application missions, the 25 FPEs in the Blue Book were divided into 56 sub-FPEs, or payload elements. An example of how one of the FPE concepts, the Space Physics Research Laboratory, was expanded into five payload elements is shown in Table 2-5 (from Ref. 2). The resulting 56 payload elements and their relationships to the 25 FPEs in the Blue Book are shown in Table 2-6 (from Ref. 2). These 56 payload elements plus two indivisible FPEs (A-1 and A-6) comprised the payload data base for Shuttle orbital research in the SOAR study.

The second major class of Shuttle applications considered in the SOAR study was the delivery, service, and retrieval of automated spacecraft. This included operations with two types of spacecraft: operations related to free-flying research and applications modules (RAMs) and conventional automated orbital satellites and interplanetary spacecraft. Eight free-flying RAMs were identified from the Blue Book (Table 2-7 from Ref. 2) and, as such, generally include a pressurized or pressurizable compartment within which crewmen service the spacecraft at prescribed intervals, whereas conventional automated spacecraft do not offer this facility.

The NASA Payload Fleet Analysis report (Ref. 3) tabulates the characteristics of 73 automated spacecraft potentially ready for flight in the 1977 to 1990 time period. Of this number, four automated spacecraft (see Figure 2-1 from Ref. 2) were chosen for the SOAR representative payload set to characterize critical mission, design, and interface requirements on the Shuttle system; they were also considered representative of the requirements envelope of the full candidate spacecraft payload set.

Details concerning experiment equipment, support equipment, and materials used in the conduct of the experiments or associated with the accommodation of the automated spacecraft are delineated in Section 3.

2.2 ORBITER ACCOMMODATION MODES

2.2.1 Blue Book

As outlined in the Blue Book, experiment modules containing laboratory facilities will operate either attached to a Space Station, attached to a Shuttle (Shuttle-sortie mode), or will be free-flying, depending on experiment requirements such as pointing, stabilization, g-level, etc. In this regard, the following material is abstracted from the Blue Book (Ref. 1).

> "A possible mode for accommodating experiment programs prior to or in lieu of the operational availability of a space station exists with the concept of using the Earth-to-Orbit Space Shuttle as a short term orbital base for conducting experiments. This concept evolves around the use of the Shuttle and minimum additional support equipment to carry aloft research equipment and, where appropriate, scientists and technicians, to conduct experiments during relatively short stay times in low earth orbit. In cases where man is not directly required for experiment operation, such as most astronomy observations, the concept includes leaving the equipment in orbit to accomplish the program with periodic servicing by subsequent Shuttle flights.
>
> "The primary operating modes envisioned for Shuttle-sortie operations, depicted in Figure 2-2, are as follows:
>
> a. Modes where man is directly involved in the conduct of the experiment program. In these cases the research equipment is carried aloft in the Shuttle along with the necessary support equipment such as crew quarters, life support, and data management provisions. In the attached modes the experiments are conducted during the Shuttle stay time on orbit of perhaps 5 to 30 days. The experiments would be conducted

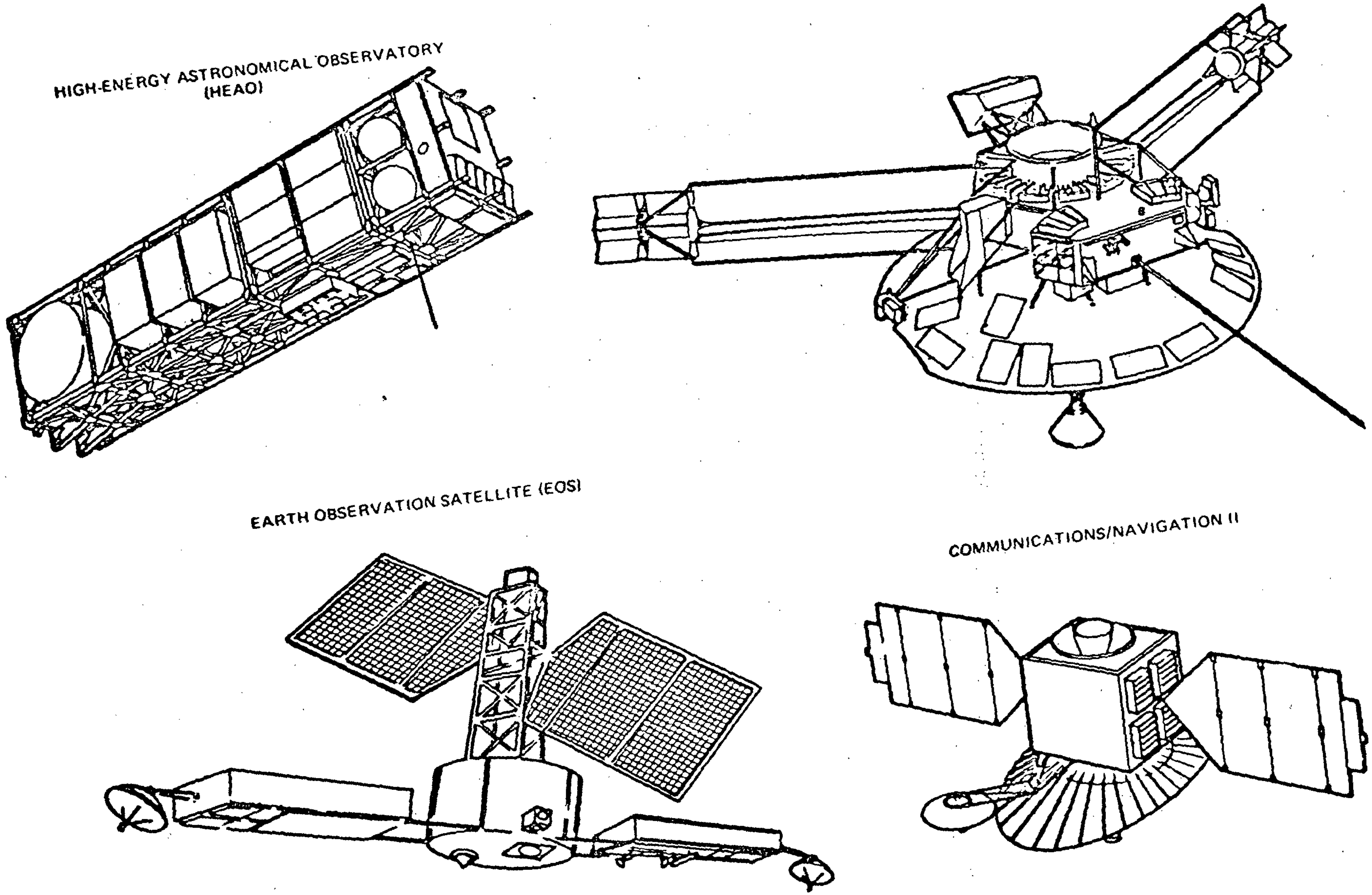


Figure 2-1. Selected Representative Satellite Payloads (Ref. 2)

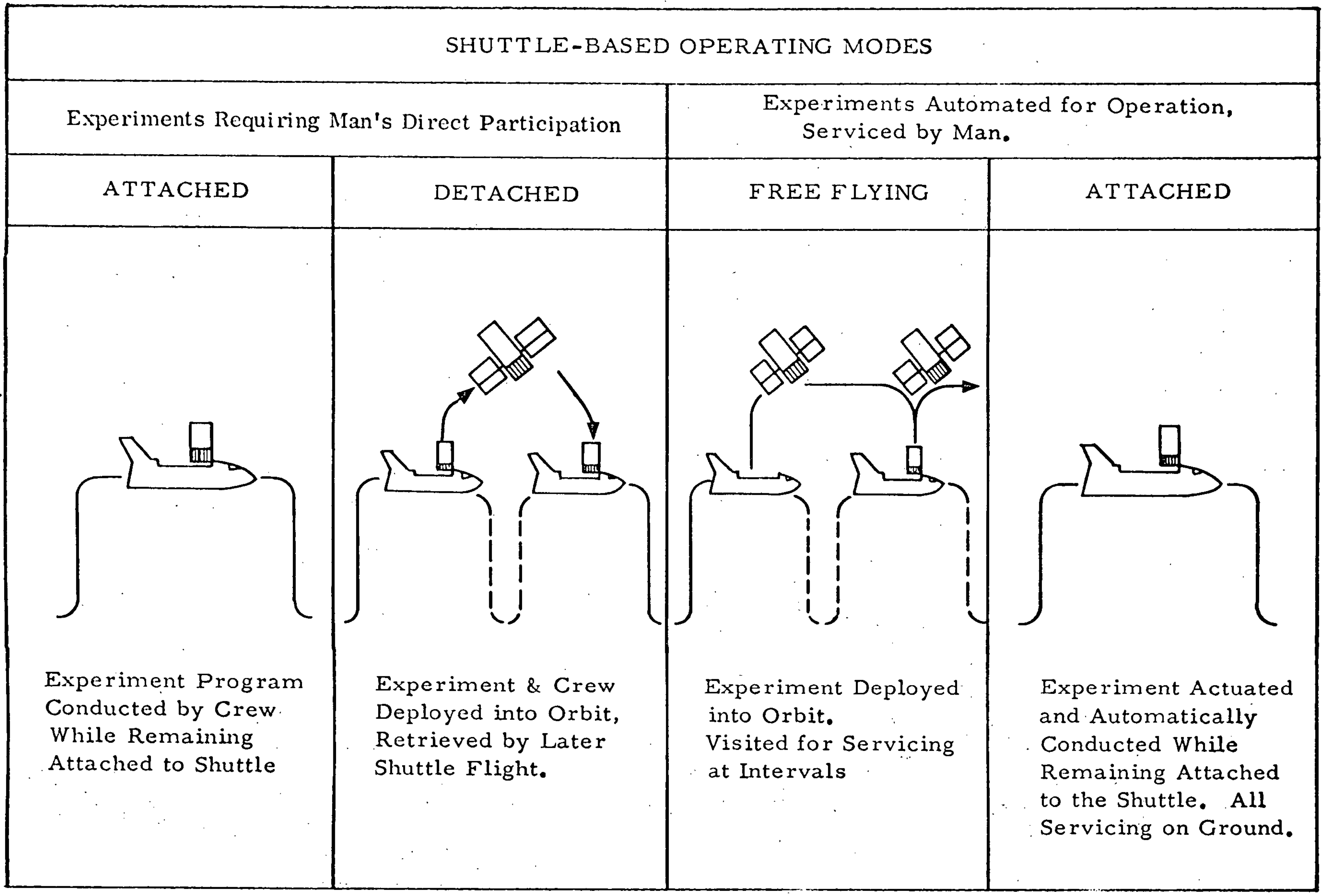


Figure 2-2. Shuttle-Based Experiment Operations (Ref. 1)

either extended from the Shuttle payload bay, as shown, or possibly from within the bay. The assembly is returned to earth after completion of the 5- to 30-day experiment program.

In the detached mode, the experiment equipment and crew are placed in orbit by the Shuttle and retrieved after 30 to 45 days by another Shuttle.

Two potential configurations for accommodating the crew and support equipment are shown in Figure 2-3. In Figure 2-3a, a separate support module is attached to the experiment module. In Figure 2-3b, the crew and support equipment are contained within the experiment module. Studies currently being conducted by NASA are evaluating these methods of implementation.

b. Modes where man is required only for periodic logistics, maintenance, update, or retrieval of the experiment and is not directly involved in conducting the experiment program. In these cases the experiment equipment is carried aloft by the Shuttle, normally without an experiment crew, for unmanned automated experiment operations. Two basic operating modes are considered likely:

1. The experiment equipment is placed in orbit from a Shuttle to commence experiment operations; the Shuttle returns to earth and periodically visits the experiment equipment on subsequent flights for logistics and servicing. This mode is pictured in Figure 2-3c, which shows the servicing operation with an astronomy module.

2. The experiment equipment is self-contained and automated and needs only delivery to the proper orbit to accomplish the experiment program while remaining attached to the Shuttle, after which it is returned to the ground. This concept is depicted in Figure 2-3d. All normal servicing of experiment equipment would be accomplished on the ground to avoid the EVA required in the unpressurizable payload bay.

"It is likely that variations of the above basic modes will be developed to meet the needs of particular experiment programs. The concept includes consideration for operations or orbital altitudes and inclinations other than that of the Space Station orbit, which may be particularly beneficial to the experiment program, or where payload weights dictate use of a lower energy orbit.

"Those experiment operations which can be conducted in the Shuttle-sortie mode will be affected by the characteristics and capabilities of the Space Shuttle system, particularly those of the Shuttle Orbiter. A few examples of these characteristics which must be considered are listed below. In many of these

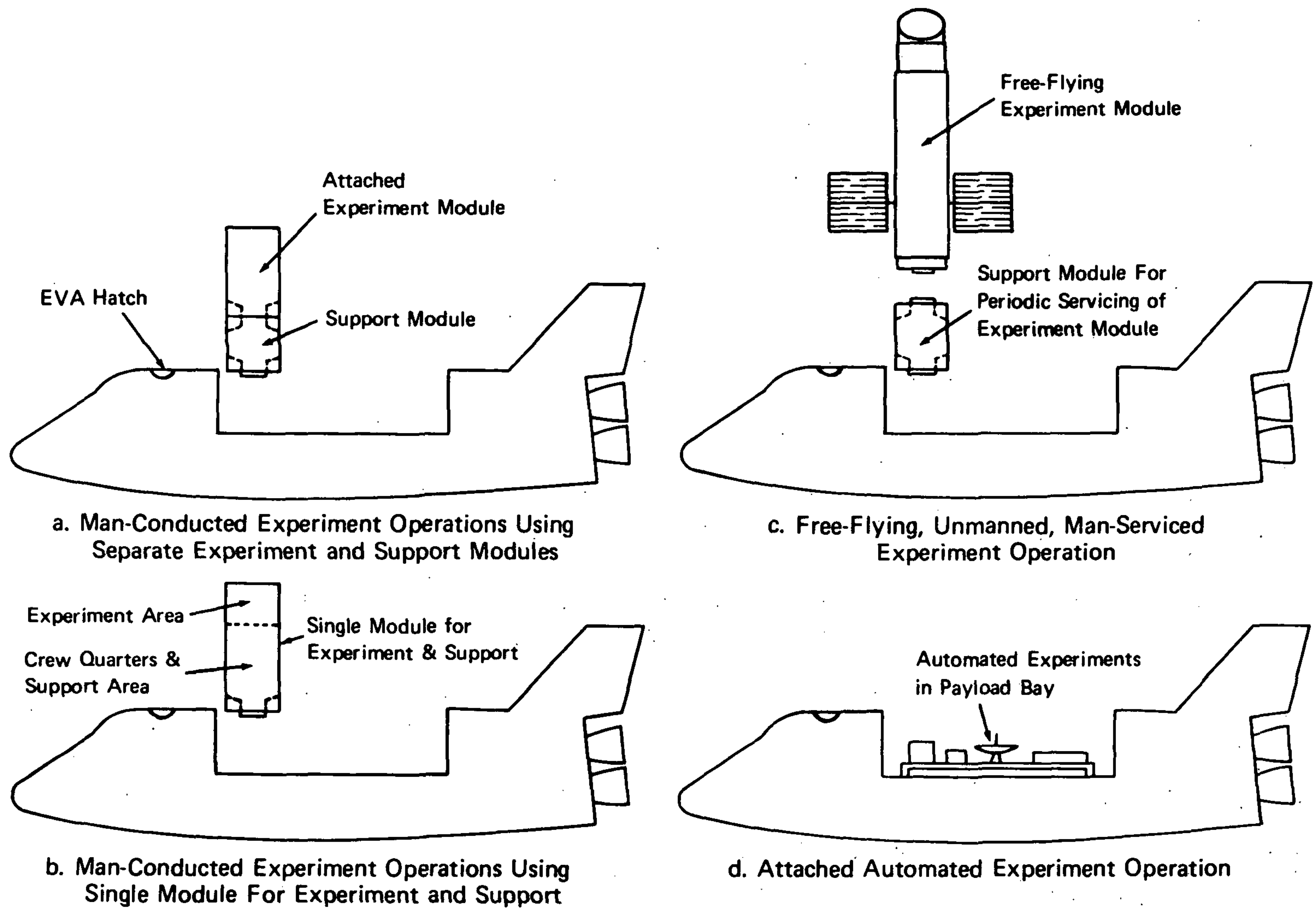


Figure 2-3. Several Operating Modes for Space Shuttle Orbiter - Sortie Operations (Ref. 1)

cases, limitations of the Orbiter capabilities can be overcome or supplemented by support equipment carried as payload, as depicted earlier.

a. Shuttle pilots will have limited, if any, time to conduct or participate in experiment operations. Any significant degree of man participation will necessitate carrying an experiment crew as payload.

b. Shuttle systems will have limited, if any, capability to provide power, data, crew EC/LS or other support to experiment operations, necessitating that these items also be provided by systems carried as part of the payload.

c. Nominal stay time on orbit is 5 days. However, it is likely that it will be possible to extend this to 30 days by carrying as payload all the required expendables and supplies.

d. The Orbiter pointing accuracy and stability will fall short of the requirements of some experiments, and must be provided by the support equipment carried as payload."

2.2.2 SOAR Study

The general emphasis of the SOAR study was on early time frame Space Shuttle missions that were relatively austere compared to initial Shuttle mission concepts. This led to the definition of two general mission classes comprised of three basic system design options (presented in Figure 2-4 from Ref. 2). The first mission class is entitled, "Sortie", and encompasses the conduct of man-supported orbital research with the Space Shuttle Orbiter. The design options consist of either a pallet upon which experiment equipment is mounted, or a mission support module (MSM) within which research is conducted in a pressurized environment by man. In the event that the control of pallet-mounted equipment from within the Orbiter is undesirable or impractical because of operational or physical considerations, an MSM can be used as shown in the figure. Similarly, if the physical or crew limitations of an early capability MSM are excessive for accomplishing certain advanced research, an MSM extension module is feasible and so indicated. This could be a dedicated experiment module, operating attached to the Orbiter/MSM. Alternatively, the MSM extension module might be a nondedicated reconfigurable module in which multiple or large experiment payloads could be operated or additional crewmen could be accommodated.

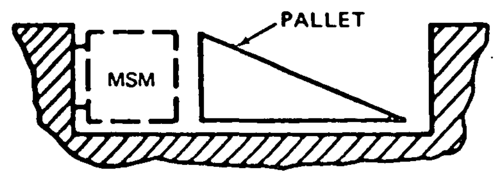
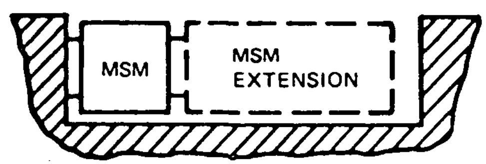
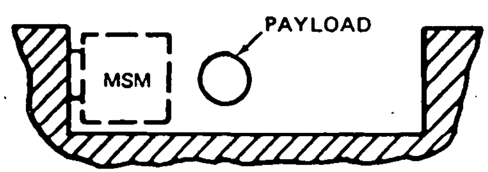
MISSION CLASS	DESIGN OPTIONS	FEATURES
SORTIE		PALLET-MOUNTED EQUIPMENT SHUTTLE-MOUNTED CONTROLS AND DISPLAYS OPTIONAL MSM SUPPORT
		PRESSURIZED MSM INTERNAL EXPERIMENTS MSM EXTENSION MODULE GROWTH VERSION
AUTOMATED SPACECRAFT		AUTOMATED SPACECRAFT FREE-FLYING RAM'S SHUTTLE-MOUNTED CONTROLS AND DISPLAYS OPTIONAL MSM

Figure 2-4. SOAR/Shuttle Mission Classes (Ref. 2)

The second Shuttle mission class relates to the delivery, service, and retrieval of free-flying RAMs and conventional automated spacecraft. The payload may include an attached propulsive stage for orbital transfer after Shuttle delivery to low earth orbit. The design option associated with this mission class allows for including an MSM with the spacecraft payload, if it is required for status displays, deployment, and retrieval controls, or service kits.

2.2.3 Present Study Assumptions

For purposes of the present safety analysis, three basic or generic modes of Experiment Module accommodation by the Orbiter were selected to encompass the various options suggested in the Blue Book and the SOAR study. These three modes and their Blue Book and SOAR counterparts are summarized in Figure 2-5.

The first, or Pallet, mode is restricted to the case where all active experiment equipment is mounted in or on an Experiment Module which remains attached to the Orbiter and has no provisions for pressurization or volume to permit man's participation for operation or on-orbit servicing. Therefore, in this mode the experiment crew as well as associated displays and control equipment must be installed in the Orbiter.

The second, or attached MSM, mode encompasses all cases where a pressurized mission support module, which remains attached to the Orbiter, is included to permit man's direct participation in experiment operations. The actual Experiment Equipment may be partially or totally contained within or attached to the Experiment Module proper. In this mode, then, the Experiment Module is required to furnish life support functions for the experiment crew during the period(s) they are within the Module.

The third, or detached RAM, mode encompasses all cases where the Experiment Module is detached from the Orbiter to accomplish its function. This mode, then, includes both free-flying RAMs per se (manned or unmanned), and automated spacecraft.

Selected For Present Study	SOAR Study	Blue Book
Pallet	o Pallet-Mounted Equipment; Shuttle-Mounted Controls and Displays	o Experiments Automated for Operation, Serviced by Man; Remains Attached to Shuttle; Ground Servicing
Attached MSM	o Pressurized MSM; Internal Experiments o MSM Plus MSM Extension Module o MSM Plus Pallet-Mounted Equipment	o Experiments Requiring Man's Direct Participation; Remains Attached to Shuttle
Detached RAM	o Automated Spacecraft o Free-Flying RAM's (Shuttle Mounted Controls and Displays)	o Experiments Requiring Man's Direct Participation; Detached From Shuttle; Retrieved Later o Experiments Automated for Operation, Serviced by Man; Free-Flying; Visited for Servicing

Figure 2-5. Shuttle-Based Accommodation Modes

2.3 GENERIC EXPERIMENT CATEGORIES

The large number of potentially applicable experiment payload elements (56 sub-FPEs, two indivisible FPEs, eight free-flying RAMs, and 73 automated spacecraft), plus their diverse requirements with regard to design, subsystems, destination, handling, installation, and deployment (see Tables 2-1 through 2-4), were reduced to generic experiment categories of interest from a safety point of view, in order to facilitate the initial analysis efforts.

The SOAR study included a comprehensive assessment, extending to the detailed sub-FPE level, of payload compatibility with Orbiter mission capabilities. Table 2-8 (from Ref. 2) presents a summary of the subgroups recommended in the SOAR study as candidates for accommodation in a limited MSM, an MSM extension module, a Pallet, or a RAM.

With this baseline definition of subgroup accommodation compatibility, the various subgroups were combined into generic Experiment Modules according to scientific discipline (FPE type) and associated applicable generic mode of accommodation (Pallet, attached MSM, or detached RAM, as denoted in section 2.2.3 and Figure 2-5). The resulting group of selected generic experiment categories is shown in Figure 2-6.

By this technique, Experiment Modules of each scientific discipline are identifed as to potentially meaningful configurational modes (i.e., Pallet, MSM, RAM) and as to the spectrum of FPE subgroups which may be incorporated within each configurational or accommodation mode.

It should be noted that the SOAR study did not specifically treat the life science experiments related to vertebrates (LS-2), plants (LS-3), cells and tissues (LS-4), invertebrates (LS-5), life support and protective systems (LS-6), and manned system integration (LS-7) due to the short mission duration considered in the SOAR study. For purposes of completeness, they have been incorporated in the present study, in both the MSM and RAM accommodation categories.

Module Type / Configuration Mode	Pallet	MSM	RAM
Astronomy Module (A)*	3C*; 4A, B, C; 5A, B; 6	3C, D, E; 4A, B, C; 5A, B; 6	1; 2; 3; 4; 5; 6
Physics Module (P)	1A, B, C, E; 2A, B; 3C; 4A	1A, B, C, E; 2A, B, C, D, E; 3C; 4A, B, C	3A, B, C
Earth Survey Module (ES)	1A, B, C, D, E, F, G	1A, B, C, D, E, F, G	—
Comm/Nav Module (CN)	1A, B	1A, B	—
Materials and Manufacturing Module (MS)	1IA	1IA, B, C, D; 1 11A, B, C	—
Contamination Module (T)	1A, B	1A, B	—
Equipment Technology Module (T)	3A, B; 4; 5	3A, B; 4; 5	2
Life Sciences Module (LS)	—	1A; 2; 3; 4; 5; 6; 7	2; 3; 4; 5
Representative Satellite Payloads	—	—	HEAO; EOS; Pioneer-Jupiter; Comm/Nav II

* Refer to FPE (Functional Program Element) and Sub-FPE Nomenclature of SOAR Study (Reference 2). See Tables 2-6 and 2-8 for Description of Experiments shown here by FPE and Sub-FPE Number.

Figure 2-6. Selected Generic Experiment Categories

2.4 ORBITER/EXPERIMENT MODULE INTERFACES

The principal interfaces between the Experiment Module and the Orbiter include not only the physical means for mounting and manipulating the Module but also the provisions for and extent of utilities or other support services provided to the Module by the Orbiter. The following assumptions were made in this study for the purpose of the safety analysis.

2.4.1 Module Mounting

It was assumed that the mounting provisions included in the Orbiter cargo bay would:

a. be adequate to provide secure holding and protection against excessive shock, vibration, and thermal loads from the Orbiter to the Module during all mission phases from ground installation to removal after flight

b. afford a clear egress path from the Orbiter crew compartment to the Module via a hatch and tunnel between the crew compartment and the Orbiter cargo bay

2.4.2 Module Manipulation

It was assumed that manipulator mechanisms would be provided in the Orbiter cargo bay (in conjunction with mounting provisions) to accomplish any necessary erections and retractions of the Module. In the case of MSM or RAM configurations, the access tunnel connection between the Orbiter crew compartment and the Module would remain operative throughout the erection/retraction process.

2.4.3 Module Utilities/Support

2.4.3.1 Electrical Power

It was assumed that an active electrical power interface existed between the Orbiter and Module. On this basis the Orbiter could furnish all or only a small part of the electrical power required by the Module.

2.4.3.2 Life Support/Crew Systems

It was assumed that the Orbiter provided all necessary crew systems and life support for the experiment crew except when the crew was in an MSM or RAM Module. During these periods the Module (MSM or RAM) was assumed to provide any necessary crew systems and life support.

2.4.3.3 Thermal Control

It was assumed that thermal control of the Module and its subsystems would be accomplished with an Orbiter/Module shared fluid-radiator loop.

2.4.3.4 Guidance, Navigation, and Control

It was assumed that Shuttle GN&C system and thrusters would provide at least coarse control for all Modules while attached to the Orbiter. Where the Orbiter pointing accuracy and stability are inadequate for the nature of a given experiment, the Module would contain the necessary sensors and control features to accomplish the fine pointing.

Detached RAM Modules would contain integral GN&C systems appropriate for their mission purposes.

2.4.3.5 Controls and Displays

It was assumed that all controls and displays necessary for the conduct of a given Experiment would be contained within the Module, except in the case of a Pallet configuration where such controls would necessarily be located within the Orbiter crew compartment proper.

In all cases it was assumed that any controls and displays associated with caution and warning systems would be duplicated in the Orbiter crew compartment to the extent necessary to provide for preventive or remedial actions on the part of the Orbiter or its crew.

2.4.3.6 Data Management

It was assumed that all experiment data management systems would be contained within the Module, except in the case of a Pallet configuration where some parts of the system might necessarily be located in the Orbiter for access by the experiment crew. Data would be transmitted to the ground for processing by either the Module or the Orbiter, as required by the nature of the Experiment carried.

2.4.3.7 Checkout System

All checkout systems, whether associated with subsystems aboard the Module or with automated satellites, would be located within the Module. Any fault-detection signals would be appropriately displayed in the Orbiter crew compartment.

2.4.3.8 Voice Communication

It was assumed that voice communication links would be provided:

a. between the Orbiter control station and each manned habitable compartment of the Module

b. between manned habitable compartments of the Module

3. HAZARD ANALYSIS

3.1 GENERAL

A hazard analysis was performed to identify and assess the emergency-causing potential of the various Experiments and their associated equipment; this included hazardous interactions arising from interfaces with the Orbiter as well as interfaces between Experiment Equipment and other payloads likely to be simultaneously carried.

This analysis activity was keyed to:

a. identifying potential sources of basic hazards, in terms of Experiment Equipment characteristics or operations attendant to operation of the equipment or performing the Experiment

b. identifying those causative events/factors/conditions which could arise from or combine with a basic hazard source to produce a hazardous result

c. delineating potentially hazardous results arising from the occurrence of the forcing function (causative event/factor/condition)

d. summarizing the spectrum of potential emergency situations which could arise from implementing experiment programs in concert with the Space Shuttle Orbiter

3.2 EXPERIMENT MODULES

3.2.1 Hazard Source Identification

Each of the generic Experiment Modules selected in section 2.3 (see Figure 2-6) was examined in detail as to the basic types of Experiment Equipment likely to be employed, possible support requirements in terms of both additional equipment and operational needs, expected operating power levels, and nominal GSE and facility utility requirements for installation purposes. The primary source for this level of definition was the sub-FPE descriptive material contained in the SOAR study (Ref. 4).

Figure 3-1 illustrates the type of information provided by this examination effort, in this example, for the Astronomy Module configured in the Attached MSM mode. Similar information for each of the 20 generic experiment category modules selected for examination (from Figure 2-6) are contained in Tables 3-1 through 3-20.

Each generic module class was then examined to determine what particular equipment (experiment or support), related materials, or operations associated with it might be a hazard source because of inherent characteristics. Figure 3-2 illustrates typical results, again for the Astronomy Module configured in the Attached MSM mode. Similar information for all 20 generic Experiment Module categories are contained in Tables 3-21 through 3-31.

Finally, all resulting hazard sources from all generic Experiment Modules were consolidated to facilitate the hazards analysis by means of a single source listing. Figure 3-3 delineates the 26 resulting hazard sources associated with equipment or related contents, and Figure 3-4 delineates the eight hazard source areas associated with operations related to Orbiter/Experiment missions.

3.2.2 Hazard Analysis

With the foregoing definition of hazard source areas (Figures 3-3 and 3-4), each source area, or combination thereof (where pertinent), was analyzed to determine plausible causations leading to potentially hazardous situations.

In some cases the causation was attributed to a "condition" resulting naturally from the inherent characteristics of Experiment Equipment, associated materials, or necessary operating conditions. For example, in this category would be "abnormal combustion" (or combustion instability) as a causative condition leading to fire or explosive propellant mixtures from an experiment combustor.

EXPERIMENT	BASIC EQUIPMENT	SUPPORT (POSSIBLE) EQUIP.	SUPPORT (POSSIBLE) OPER.	POWER LEVEL, WATTS AVE	POWER LEVEL, WATTS PEAK	GSE FACILITY UTILITIES
A-3C, D, E: ADV. SOLAR ASTRONOMY	A-3C: PHOTO HELIOGRAPH	(SPACE VACUUM)	SETUP/DEPLOY OPERATE	130 (SUN)/ 170 (NIGHT)	170	THERMAL FLUIDS: 100-350W; N_2 PURGE
	A-3D: X-RAY PHOTOHELIOGRAPH	(SPACE VACUUM)	NO EVA PLANNED	250/210	350	
	A-3E: XUV SPECTROMETER (PASSIVE AT LAUNCH; SENSITIVE TO ALL CONTAMINANTS)	(SPACE VACUUM) (ELECTRONIC IMAGING, NO FILM)	ASTRONOMER/ ASTROPHYSICIST	30/8	90	
A-4A, B, C: INTER. SIZE UV TELESCOPES	A-4A: NARROW-FIELD UV TELESCOPE (CAMERA & FILM TRANSPORT, SPECTROGRAPHS; ASS'Y MOUNTED ON GIMBAL RINGS)	FILM VAULT FILM PROCESSOR OPTICS LAB. SCIENTIFIC AIRLOCK	SETUP/DEPLOY OPERATE NO EVA PLANNED (WOULD BE FOR A-4C IF NO SCIENTIFIC AIRLOCK)	141/300	300	200-800W
	A-4B: WIDE-FIELD UV TELESCOPE (ON ATM-TYPE PLATFORM WITH INSTRUMENTS AS IN A-4A)	FILM VAULT FILM PROCESSOR OPTICS LAB.	ASTRONOMER/ ASTROPHYSICIST	120/325	325	
	A-4C: SMALL UV SURVEY TELESCOPE (INSTRUMENTS AS ABOVE) (PASSIVE AT LAUNCH: SENSITIVE TO CONTAMINANTS)	" (SPACE VACUUM)	RETRIEVE/REPLACE FILM	20/2	20/56	
A-5A, B: HI-ENERGY ASTRONOMY	X-RAY TELESCOPES (GRAZING INCIDENCE & VENETIAN BLIND), SPECTROMETER/ POLARIMETER ASSY, X-RAY COUNTER ARRAY, DETECTOR ARRAY, GAMMA-RAY SPECTROMETER, SPARK-CHAMBER (ACTIVE CRYOGENICS IN -5B; -5A PASSIVE AT LAUNCH; SLIGHT TO MODERATE SENSITIVITY TO CONTAMINANTS)	(SPACE VACUUM) GAS (-5A) GAS & SOLID CRYOGENICS (-5B)	SETUP/DEPLOY OPERATE ALIGN/CALIBRATE NO EVA PLANNED SHUTDOWN/MAINT. PHYSICIST/ASTROPHYSICIST	116/221	142/391	CRYOGENICS
A-6: INFRA-RED ASTRONOMY	IR TELESCOPE (OPTICAL), INTERFEROMETER, IR DETECTOR ARRAY, AUXILIARY OPTICAL TELESCOPE (IMAGING), ELEVATOR/RETRACTOR MECHANISM, GIMBALS, PRESSURIZED SERVICE HOUSING, CHILLDOWN & COOLING EQUIPMENT: 2 LIQ. NEON TANKS VALVES, VENTS, REGULATORS 2 INSULATED RECEIVING TANKS (FOR GASEOUS NEON COLLECTION; VENTED TO SPACE OR RELIQUIFIED) (ACTIVE CRYOGENICS; SENSITIVE TO CONTAMINANTS, PARTICULARLY WHILE COOLED TO CRYO TEMPS)	(SPACE VACUUM) LN_e LH_e	NO EVA SETUP/DEPLOY OPERATE ASTRONOMER/ ASTROPHYSICIST/ ASTRONAUT	260	300	500W; DRY N_2; LH_e; LN_e

Figure 3-1. Equipment/Support Requirements - Astronomy Modules, Attached MSM Mode

Equipment	Related Operations
Electrically-Powered Equipment	Set up/Deploy/Operate - Touch, Handle
Scientific Airlocks	Deploy Instruments, etc.
Cryogenic Dewars	Gas Boil-off Venting
Cameras and Equipment	Retrieve/Replace/Process Film - Touch, Handle
Telescopes	Set up/Deploy/Operate - Align and Calibrate - Visually Direct Toward Sun
Spark-Chambers	Set up/Deploy/Operate

Figure 3-2. Potential Hazard Sources - Astronomy Module, Attached MSM Mode

A. <u>Equipment-Related</u>

High-Temperature Sources
Overboard Vents
Lasers
Spark-Chambers
Superconducting Magnets
Scientific Airlocks
Sub-Satellites
Rotating Equipment
Telescopes
Booms/Platforms/Antennas
Balloons
Negative Pressure Source
Astronaut Maneuvering Unit (AMU)
Maneuverable Work Platform (MWP)
Teleoperator Spacecraft
Solid Propellant Devices
Radiation Sources
Cameras and Equipment
Batteries
Electrically-Powered Equipment

B. <u>Contents-Related</u>

Biologicals/Animals/Insects/Plants
Cryogenics
Non-Cryogenic Fluids
Non-Cryogenic Gases
Emulsions
Specific Contamination Source

Figure 3-3. Hazard Sources Related to Equipment, Contents

- O Experimentation
  - / Setup Equipment
  - / Deploy Equipment
    - o Internally
    - o Through Scientific Airlocks
  - / Align/Calibrate
  - / Operate/Monitor/Shutdown
  - / Retrieve/Replace/Process (Film)
  - / Dextrous Control Movements
    - o Touching, Handling, Moving
  - / Dispose of Waste, Cleanup
  - / Store Samples
- O EVA
- O Maintenance and Repair
- O Egress
- O Erection/Retraction (of Module)
- O Docking/Undocking
- O Ground Installation
- O Ground Removal

Figure 3-4. Hazard Sources Related to Operations

In other cases the causation was attributed to a "factor," not related to the particular Experiment Equipment characteristics, whose presence or occurrence combined with the equipment characteristics to produce a hazardous condition. For example, in this category would be "mere proximity" of crew or sensitive equipment to permeating-field devices (e.g., RF-fields, magnetic fields).

In still other cases the causation was attributed to an "event" whose occurrence was necessary, in addition to Experiment Equipment characteristics, to produce a hazardous condition. Typical of this category would be eye damage caused by inadvertently "looking" at the sun or at reflected sunlight through an optical telescope, or burns resulting from "touching" or "handling" hot surfaces.

Emphasis was placed on "causation" determination (as outlined above) not only to assess meaningful hazardous results (and their requirements for effective remedial actions), but also to provide the framework for later preventive measure assessments of means for eliminating or reducing the hazards introduced by the Experiment Equipment and its operation (as reported in Section 4).

The results of the hazard analysis performed in this manner are summarized in Tables 3-32 and 3-33. Table 3-32 is a summary of hazard source, causation, and interaction results for the equipment/contents-related hazard sources of Figure 3-3. Table 3-33 is a similar summary for the operations-related hazard sources of Figure 3-4.

In a previous study (Ref. 5) relating to hazards associated with manned spacecraft in general, it was determined that 12 hazard/emergency groups were sufficiently generic to meaningfully encompass all space-related hazards/emergencies. For purposes of comparison, correlation, and insight, the experiment-related hazard sources identified in the present study (Tables 3-32 and 3-33) were tested against this 12-group generic classification for compliance and/or for the identification of new hazards. The resultant groupings are shown in Table 3-34. As can be seen, the 12-group generic hazard/emergency classes were sufficient to encompass all of the specific experiment hazard sources identified in the present study; i.e., the utilization of such Experiment Equipment or operations do not in and of themselves pose hazards or emergencies that are different from those previously determined. The tabulations of Table 3-34 do serve, however, to illustrate and emphasize the extremely broad range of specific hazard sources (equipment and/or their related operations and interfaces) which potentially exist for Space Shuttle missions associated with in-space experiments of the types described in the Blue Book (Ref. 1).

3.3 ORBITER

3.3.1 Hazards and Emergency Situations

Hazards and emergency situations onboard spacecraft of the general configuration of the Orbiter were previously examined in Ref. 5. The results of Ref. 5 pertaining to Orbiter hazards and general emergency situations (resulting from the occurrence of a hazard) were adopted in the present study after a brief confirmatory review. Figures 3-5 and 3-6 summarize the resultant hazards and emergency situations.

3.3.2 Effects of Experiment Modules

The effect of incorporating Experiment Modules as Orbiter payloads is to increase the number of potential sources of hazards because of the wide spectrum of Experiment Equipment they contain, the involvement of man in many experiment operations, and the many interfaces between Experiment Equipment, the Experiment Modules, and the Orbiter. Although the basic potential hazards which might be encountered are not increased, the source listing is very extensive (see Table 3-34).

Another significant effect is that an MSM or RAM Experiment Module represents a separate compartment or spacecraft (with respect to the Orbiter), which poses additional problems and/or requirements with regard to egress

- FIRE
- EXPLOSION/IMPLOSION
- DECOMPRESSION/OVERPRESSURE
- COLLISIONS (INTERNAL/EXTERNAL OBJECTS)
- CONTAMINATION (TOXIC/NON-TOXIC)
- MECHANICAL/STRUCTURAL FAILURES (NON-COLLISION - ORIENTED)
- RADIATION (INTERNAL/EXTERNAL)

Figure 3-5. Orbiter Hazards

- o Ill/Injured Crew (Physical, Chemical, Disease, Mental)
- o Metabolic Deprivation
- o Stranded/Entrapped Crew
  - / During EVA Operations
  - / In Vehicle
- o Inability to Communicate
- o Out-Of-Control Spacecraft
  - / Tumbling in Safe Orbit
  - / Decaying Orbit
  - / Unsafe Trajectory
- o Debris in Vicinity
- o Radiation in Vicinity
- o Non-Habitable Environment in Spacecraft
  - / Lack of Environmental Control (Temp., Humidity Extremes)
  - / Contamination (Experiments, Animals, Bacteria, Insects)
  - / Radiation (Internal)
- o Abandonment (Crew in EVA After Bailout)
- o Inability to Reenter

Figure 3-6. Summary of Orbiter Emergency Situations (escape) and remedial aid (rescue) if emergencies should occur within the Module which require Orbiter-generated assistance. A typical example of the potential interactions between hazard sources, an MSM or RAM module, and the Orbiter is indicated in Figure 3-7 for an Astronomy Module configured in the attached MSM mode. (Similar illustrations for other Experiment Modules and modes are given in Tables 3-21 to 3-31.) As can be noted, the general effects on the Module and/or Orbiter, in terms of condition (emergency situation) or requirement (remedial need) fall into well recognized categories. It is evident from the figure that many Experiments contain inherent hazard sources (and their potential hazardous interactions) which can result in an emergency.

3.4 SUMMARY OF POTENTIAL EMERGENCY SITUATIONS

Tables 3-35 through 3-39 summarize the potential emergency situations which may exist for the Orbiter and Experiment Module (Pallet, attached MSM, detached RAM) during the pre-launch, ascent, on-orbit, return, and post-flight phases of a mission. These tables serve to highlight the nature of potential emergencies associated with the Orbiter or Module and the mission phases during which they could occur.

As can be noted, contamination of an Experiment Module or the Orbiter can occur during any mission phase.

Illness or injury are of concern aboard the Orbiter during all mission phases, and the Orbiter can become non-habitable at any time due to loss of EC/LS supply, temperature or humidity control, etc. The same applies to an MSM or RAM, but only during the on-orbit phase while crewmen are within.

Crew entrapment (in an airlock or module) is of importance during the on-orbit phase where egress activities are planned. It is also of concern during the return and post-flight phases, if a crew member has been entrapped.

EVA stranding, by its very nature, is limited to the on-orbit phase.

POTENTIAL HAZARD SOURCE		POTENTIAL RESULT OF OCCURRENCE	EFFECT ON	
EQUIPMENT	OPERATIONS		MODULE (COND./REQMT)	ORBITER (COND/REQMT)
A. ELECTRICALLY-POWERED EQUIP. (ALL TYPES)	1. SETUP/DEPLOY/OPERATE a. TOUCH, HANDLE	1. ELECTRIC SHOCK, BURNS	1. PROVIDE MEDICAL AID (IMMEDIATE)	1. PROVIDE MEDICAL AID (SUBSEQUENT) 2. REMOVE INCAPACITATED EXPERIMENTER
	b. OTHERS	1. SHORTS, FIRES	1. FIRE SUPPRESSION EQUIP. 2. NON-HABITABLE MODULE	1. FIRE SUPPRESSION EQUIP. 2. JETTISON MODULE
B. SCIENTIFIC AIRLOCK	1. DEPLOY INSTRUMENTS, ETC.	1. OUTER DOOR WON'T OPEN 2. OUTER DOOR WON'T CLOSE 3. INNER DOOR WON'T OPEN 4. INNER DOOR WON'T CLOSE 5. BOTH DOORS OPEN OR LEAKING	1. CAN'T EXPERIMENT 2. NON-HABITABLE MODULE (EGRESS REQUIRED)	1. NONE - UNLESS OPEN OUTER DOOR PREVENTS CLOSURE OF P/L BAY DOORS a. JETTISON MODULE 2. SAME AS 1 ABOVE
C. VENTS	1. VENTING OF CRYOGENIC BOIL-OFF GASES	1. CLOSED VENT; TANK OVER PRESSURE & RUPTURE	1. NON-HABITABLE MODULE (EGRESS REQUIRED) a. CRYOGENIC FLUIDS b. CRYOGENIC GASES 2. INJURY (HUMAN) 3. EQUIPMENT DAMAGE	1. REMOVE INCAPACITATED EXPERIMENTERS 2. JETTISON MODULE
		2. INTERIOR VENTING	4. NON-HABITABLE MODULE - (EGRESS REQUIRED)	3. JETTISON MODULE
D. CAMERAS & EQUIPMENT	1. RETRIEVE/REPLACE/ PROCESS FILM a. TOUCH, HANDLE b. OTHERS	1. CHEMICAL INJURY - FROM PROCESSING CHEMICALS	1. IMMEDIATE MEDICAL AID	1. SUBSEQUENT MEDICAL AID
		2. CHEMICAL SPILLS (LIQUIDS, DRY CHEMICALS)	2. CONTAMINATED MODULE a. CLEAN-UP b. EGRESS (NON-HABITABLE)	2. CLEANUP EQUIPMENT
		3. FIRE (FLAMMABLE FILM)	3. FIRE SUPPRESSION EQUIP.	3. FIRE SUPPRESSION EQUIP. 4. JETTISON MODULE
E. TELESCOPES	1. SETUP/DEPLOY/OPERATE a. ALIGN & CALIBRATE	1. OPERATOR INADVERTENTLY ENTRAPPED BY INSTRUMENT IN LOCKED POSITION	1. PROVIDE RELEASE	1. PROVIDE RELEASE
	b. VISUALLY DIRECTED TOWARDS SUN	2. EYE DAMAGE (TO VIEWER)	2. IMMEDIATE MEDICAL AID	2. SUBSEQUENT MEDICAL AID
F. SPARK-CHAMBER	1. SPARK-CHAMBER OPERATION	1. ARGON/METHANE BLEED FROM SPARK-CHAMBER a. CONTAMINATION b. FIRE	1. NON-HABITABLE MODULE (EGRESS REQUIRED) 2. FIRE SUPPRESSION EQUIP. 3. IMMEDIATE MEDICAL AID	1. REMOVE INCAPACITATED EXPERIMENTERS 2. FIRE SUPPRESSION EQUIP. 3. JETTISON MODULE 4. SUBSEQUENT MEDICAL AID

Figure 3-7. Hazards/Interactions (On-Orbit Phase) - Astronomy Modules, Attached MSM Mode

Inability to reenter the earth's atmosphere is restricted to the Orbiter and the on-orbit phase.

Metabolic deprivation and inability to communicate can occur at any time for crew members in the Orbiter, whereas crew members in the MSM or RAM would be affected only during the on-orbit phase.

Out-of-control (tumbling, unsafe trajectory) would be a condition of concern to the Orbiter during ascent, on-orbit, and return phases, and to the RAM during the on-orbit phase.

Abandonment (by means of EVA) is limited to the Orbiter and RAM during the on-orbit phase.

Debris in the vicinity and radiation in the vicinity are associated primarily with the on-orbit phase of operation.

4. PREVENTIVE MEASURE ASSESSMENT

4.1 HAZARD ELIMINATION/AVOIDANCE

As delineated in Section 3, a very broad spectrum of potential hazard sources is introduced when conducting in-space experiment programs in concert with the Space Shuttle. In order to identify possible means for eliminating hazard sources and avoiding their occurrence, a series of preventive measure assessments were performed. These assessments were based on the inherent hazard source lists (Figure 3-3 and 3-4) and were keyed to the causative events/factors/conditions as described in Tables 3-32 and 3-33.

The approach followed in the assessment was to graphically display and relate a basic hazard source and its attendant causations (events, factors, conditions) to a subjective analysis, and the assessment of meaningful measures which could potentially:

a. prevent a hazardous condition from occurring
b. avoid undertaking a particular potentially hazards event or act
c. separate non-experiment-related factors from association with the experiment process

Three broad basic areas were selected to provide the framework and focus for the investigative analysis:

a. Design features
b. Locational features
c. Operational techniques

Measures in these areas, whose implementation could either eliminate or avoid a hazard, or alleviate the results of its occurrence, were then identified.

The above techniques are illustrated in Figure 4-1 for the case of laser equipment and related operations. In the case illustrated it can be seen

Hazard Assessment			Preventive Measure Assessment		
			Eliminate or Avoid Hazard Source or Causative Event/Factor/Condition by:		
Basic Hazard Source	Causative Event/Factor/Condition	Hazardous Result (Effect)	Design	Location	Operational Technique
A. Laser Equipment	A. Inadvertent Exposure to Laser Beam: / Equipment / Structure / Crew	Fire Injury Equipment Damage Hole in Structure Radiation	1. Interlocks--to prevent inadvertent operation. 2. Stops--to limit directional adjustment. 3. Energy Absorbing means--between beam and vital structure. 4. Limit source strength of beam.	1. Place so beam not aimed at vital equip. (if inside module). 2. Point away from module (if exterior to module).	1. Sensors and warning signal if pointed wrong way.
B. Experimental Operations			5. Guards--to prevent access to beam. 6. Require volitional act to activate beam.	3. Locate away from normal crew passage routes (require deliberate access movement to reach it).	2. Sensors and warning signal if laser is operational.
1. Setup/deploy/operate	See "A" above	See above			
2. Monitor					
C. Basic Operations					
1. Ground Installation	Passive				
2. Egress Activities	See "A" above				
3. Docking	N.A.				
4. Undocking	N.A.				
5. Erection	N.A.				
6. Retraction	N.A.				
7. Removal (Ground)	Should be passive				

Figure 4-1. Precautionary Measure Assessment - Lasers

that six measures were identified in the design features area, three measures in the locational features area, and two measures with regard to operational techniques.

For the total hazard source spectrum so analyzed, a total of 23 general measures pertaining to design features, six measures related to locational features, and 10 measures related to operational techniques were identified. Figure 4-2 summarizes these 39 measures, or potential means which should be considered for eliminating or avoiding experiment-related hazards.

The formulation of methods of implementing or using such preventive measures is presented in Section 5 in terms of statements which express the measure and relate it to the pertinent or example experiment equipments and/or operations to which each preventive measure could apply.

DESIGN FEATURES

- Venting
- Purging
- Safing
- Conditioning
- Shielding
- Source Strength
- Fail-Safe Configurations
- Protective Safety Devices
  - Interlocks
    - Automatic
    - Volitional Actuation
  - Covers
  - Stops
  - Guards
  - Discharge Devices
  - Laser Energy-Absorbing Means
  - Extendable-Aid-Device
  - Emergency EC/LS Provisions
  - Emergency Brake Provisions
- Jettisoning/Dumping
- Remote Deployment/Operation
- Holding
- Packaging/Containment/Marking
- Materials Selection

LOCATIONAL FEATURES

- Exterior Placement
- Interior Considerations
- Circumferential/Longitudinal Placement
- Proximity Considerations
- Accessibility Considerations
- Jettisoning/Dumping Considerations

OPERATIONAL TECHNIQUES

- Setup/Deploy/Operate
  - Protective Garments/Devices
  - Remote Deployment
  - Remote Operation
  - Hooded Work Areas
  - Restricted Operations
  - Special Precautions
- Caution and Warning Systems
- Monitoring and Control
- Deactivating/Securing
- Jettisoning/Dumping

*Not listed in order of equal value as safety measures. General order of preference that should be followed is (1) design to eliminate the hazard; (2) design to control the hazard; (3) use of safety devices; (4) use of warning devices; and (5) operational procedures.

Figure 4-2. Summary of General Preventive Measures

5. PREVENTIVE MEASURE STATEMENTS

The following preventive measure statements are summary expressions which serve to highlight and emphasize areas deserving further consideration in order to enhance in-space experiment safety. More specifically, the statements are directed to future NASA space programs involving the use of the Space Shuttle to transport and facilitate in-space scientific Experiments.

These preventive measure statements are the result of, and were initially identified in, the series of preventive measure assessments described previously in Section 4. For convenience of presentation and utilization, the statements are grouped in the general areas of (1) design features, (2) locational features, and (3) operational procedures, which were the selected areas of investigation in the preventive measure assessment activity. Within each of these general areas, the statements are further categorized according to distinctive sub-levels whose title or heading is suggestive of the key or principal safety-related criteria contained in the statement.

Where appropriate, the statement (or accompanying example of equipment/experiment/condition exemplifying the statement's intent) contains a reference* to the particular Hazard/Emergency Analysis and Safety Criteria Summary Sheet of Table 5-1. This table contains, for each hazard source area of Figures 3-3 and 3-4, a summarization of pertinent causation factors, potentially hazardous results, and the spectrum of preventive measures applicable to the hazard source area.

It is emphasized that the statements in a given area, e.g., in the design features area, in many cases are not singular solutions, but require corollary or complementary considerations in the locational features and operational technique areas. For example, if an item were to be designed for jettisoning

*Reference by "H" number, e.g., "H-1" refers to Table 5-1, H-1.

its location could be important to facilitate jettisoning, and the conditions under which the jettisoning operation should be implemented should be defined. Therefore, for completeness of thought and purpose, in cases where a safety-related issue has reasonable implications in more than just the design area it may also be separately stated as a safety consideration in the locational and operational technique areas, as appropriate.

It is also emphasized that the statements in some cases are addressed to only one of several possible approaches to enhancing safety in a given potentially hazardous situation. In still other cases some statements may be conflicting (with respect to each other or Experiment requirements) under certain conditions. Trade-off analyses would have to be performed to determine the most satisfactory solution in each instance. These trade-off analyses were beyond the scope of the present study.

Further, the preventive measures are not presented in order of absolute value as safety measures. Generally accepted safety practice indicates, however, that the order of preference that should be followed in applying them is:

a. Design features to eliminate the hazard
b. Design features to control the hazard
c. Use of protective safety devices
d. Use of warning devices
e. Implementation of operational procedures

The level of detail in the preventive measure assessment, in many cases, was sufficient to overlap to a certain degree with generalized spacecraft safety criteria, even though the present analysis was restricted to identifying experiment-related safety criteria. Typical overlap areas included:

a. Electrical systems (cable insulation, connectors, grounding, power distribution paths, redundancy, shielding, routing, etc.)
b. Airlocks (mechanical design, materials, sealing provisions, etc.)
c. Vent systems (valves, regulators, location, pressure-relief, etc.)

d. Pressurized containers storing gases or liquids (valves, regulators, pressure-relief, vents, etc.)

e. Batteries (electrolyte containment, venting, etc.)

f. Solid propellants (safing, arming, etc.)

g. Minimum number of egress ports in a manned habitable compartment

h. EVA

Safety practice areas in the above categories are referred to in the general sense only in the following statements, which are supplementary to generally accepted safety criteria for manned space flight equipment and operational procedures.

Specific attention is directed to other recent studies conducted for NASA which resulted in safety criteria which may be directly applicable to experiment and/or accommodating vehicle safety considerations and which should be considered by experiment designers, mission planners, etc. These include:

a. The Prevention of Electrical Breakdown in Spacecraft (Ref. 6)

b. Safety in Earth Orbit Study (Ref. 7, 8, 9, 10)

c. Manned Space Flight Nuclear System Safety (Ref. 11)

d. Space Station Safety Study (Ref. 12)

e. Space Station Study, Experiment Safety (Ref. 13)

Four other documents, even though not specifically safety-oriented, should also be of value:

a. Space Shuttle Baseline Accommodation for Payloads (Ref. 14)

b. Shuttle Orbiter/Payloads Monitor and Control Interface (Ref. 15)

c. Assessment and Control of Spacecraft Electromagnetic Interference (Ref. 16)

d. Shuttle Orbiter Applications and Requirements, Phase II (SOAR) (Ref. 17)

Sections 5.1, 5.2, and 5.3 present the preventive measure statements developed for the areas of design features, locational features, and operational techniques, respectively. These sections relate the complete statement including the purpose or rationale for the statement (where not self-evident), any qualifying conditions, and representative illustrations of equipment/experiments/conditions which serve to illustrate or exemplify the intent of the statement. The formulation of selected measures into summary Safety Guidelines is presented in Tables 4-1 and 4-2 of Volume II, Part 2.

5.1 DESIGN FEATURES

The general area of design features encompasses the Experiment Module, scientific and support equipment (generally referred to as Experiment Equipment), and any ancillary contents or materials required in the conduct of the experiments. The preventive measure statements refer to particular design features or provisions which should be given consideration during the configuration selection and design process.

5.1.1 Venting

5.1.1.1 Provide overboard vent systems, including pressure-regulation and pressure-relief subsystems.

Applicable to components or experiment hardware elements whose contents are susceptible to pressure buildup, fire, explosions, or the accumulation of toxic or noxious substances whose inadvertent release into a compartment would result in contamination of atmosphere or surfaces. Such components/elements would include:

a. Batteries (H-19)*

b. Fuel cells

c. Cryogenic dewars (H-24)

d. Pressurized or volatile liquid containers (including propellants)(H-22)

e. High-pressure gas bottles (H-23)

f. High-temperature sources (gas jets, combustors, furnaces, etc.)(H-1)

g. Holding and rearing cages (for animals, insects, plants)(H-21)

*See Table 5-1, H-19.

h. Special work areas

i. Biological containers (H-21)

5.1.1.2 Configure overboard vent systems to:

a. Avoid common exit sources or immediately adjacent exterior locations to preclude the mixing of potentially combustible or reactive substances, or to avoid cross-contamination.

b. Prevent vent efflux from entering Orbiter cargo bay.

c. Prevent efflux in the vicinity of contamination-sensitive sensors (e.g., telescopes, camera lenses, etc.) aboard either the Orbiter or Experiment Module.

5.1.1.3 Incorporate means for controlled venting which also permits a quick pressure relief of the vent system in case an emergency should arise during a no-venting period.

To permit controlled venting during potentially critical operational periods (e.g., EVA, docking, accurate-pointing hold periods, etc.).

5.1.2 <u>Purging</u>

5.1.2.1 Provide a purge system capability, including associated vent system requirements (see 5.1.1).

Applicable to Experiment Module compartment areas and equipment subject to spills or leaks of fluids, gases, or waste products. Typical examples include:

a. Film-processing areas (H-18)

b. Areas containing cryogenic dewars, non-cryogenic fluids or gases, or transfer lines or outlets from such sources (H-22, H-23, H-24)

c. High-temperature devices (gas jets, combustors, furnaces, etc.)(H-1)

d. Special work areas for handling animals, insects, plants, serums, isotopes, embalming fluids, other chemicals, etc. (H-21)

5.1.2.2 Provide the capability to purge all tanks or containers holding non-inert liquids or gases.

For purging at the completion of experiment activities or prior to return to earth. (H-22, H-23)

5.1.3 Safing

5.1.3.1 Utilize safing mechanisms, devices.

To prevent inadvertent actuation of equipment whose actuation could result in an uncontrolled hazardous situation. Such could include:

a. Solid propellant-containing units (pyrotechnics, solid rocket motors, etc.)(H-16)

b. Biological and radiobiological containers (H-21)

c. Radiation sources (reactor or isotope)(H-17)

d. Balloon-inflating devices (H-11)

5.1.4 Conditioning

5.1.4.1 Consider providing an independent (separate from Experiment Module compartment EC/LS) environmental conditioning system.

Applicable to the holding and rearing cages housing animals, insects, plants. The cage pressure level should in all cases be lower than cabin pressure to prevent cage content efflux into the cabin atmosphere. (H-21)

5.1.5 Shielding

5.1.5.1 Incorporate mechanical shielding around rotating equipment.

To provide for containment of rotating members in the event of breakup due to overspeed. Illustrative equipment includes:

a. Biological centrifuges (H-8)

b. Human centrifuge (H-8)

c. Rotating litter chair (H-8)

5.1.5.2 Utilize radiation shields for the crew and sensitive equipment.

To protect crew and equipment from excessive exposure to radiation fields. Example areas include:

a. X-ray machines (H-17)

b. Radioisotopes (H-17)

c. Radioisotope Thermal Generators (RTGs)(H-17)

d. Nuclear reactor power sources

e. Lasers (H-3)

5.1.5.3 Incorporate shielding in all solid propellant-containing devices and/or areas housing such devices.

To prevent inadvertent activation through exposure to excessive RF or magnetic fields. Example devices include:

a. Pyrotechnics (H-16)

b. Solid rocket motors/stages (H-16)

c. Spin-up rockets (H-16)

5.1.5.4 Provide pressure compartments with an airlock and decontamination equipment for the conduct of experiments with radioactive materials. (H-21)

5.1.6 Source Strength

5.1.6.1 Where possible, select the inherent source strength of equipment with permeating fields, whose loss of control could result in a hazardous situation, to be compatible with crew/equipment.

The source strength maximum value to be tolerable to man and to sensitive equipment in either the Experiment Module or the Orbiter. Illustrative examples include:

a. RF-generators (H-17)

b. Superconducting magnet (H-5)

c. Laser beams (H-3)

d. Negative pressure source for the Lower Body Negative Pressure Chamber (H-12)

e. Radiation sources (X-rays, isotopes, RTGs) (H-17)

5.1.7 Fail-Safe Configurations

5.1.7.1 Design mechanical systems with fail-safe features to prevent the occurrence of hazardous failure modes.

Example areas include:

a. Means to preclude failure of deployment mechanisms to fully retract

1. Scientific airlocks (H-6)
2. Booms/platforms/antennas (H-10)
3. Erection/retraction mechanism (H-30)

b. Means for assuring that if a propulsion system failure occurs it is in the non-thrusting mode
   1. Experiment Module Attitude Control System (ACS)
   2. Astronaut Maneuvering Unit (AMU)(H-13)
   3. Maneuverable Work Platform (MWP)(H-14)

c. Means to prevent failure of docking system mechanisms to release from attached or locked-up mode (H-31)

d. Means to ensure a non-hazardous mode of failure which occurs prior to a potential catastrophic break-up of rotating components due to overspeed (H-8)

5.1.7.2 Configure fluid, gas, and electrical components of experiment equipment to fail-safe. (H-22, H-23, H-24, H-20)

5.1.7.3 Provide fluid line connectors having connect/disconnect features which ensure fast operation, cleanliness of the connection, and positive locking.

5.1.8 Protective Safety Devices

5.1.8.1 Interlocks

5.1.8.1.1 Automatic

Incorporate automatic interlocks of mechanical, electrical, or electromechanical nature.

To provide automatic shutdown and/or to prevent operation under unsafe conditions. Representative areas of application include:

a. Overboard vent systems -- to prevent operation of experimental equipment requiring an operative vent in the event of vent system malfunction (H-2)

b. Field generators -- to provide automatic shutdown in the event field strength intensity exceeds the design range
   1. X-ray equipment (H-17)
   2. Lasers (H-3)
   3. RF-generators (H-17)
   4. Superconducting magnet (H-5)

c. Negative pressure source -- to provide automatic means for a controlled shutdown of the Lower Body Negative Pressure Chamber experiment in the event the vacuum decreases below the permissible level (H-12)

d. Optical telescope covers -- to provide remotely operated lens covers so that they can be covered during non-use periods (H-9)

e. Rotating equipment -- to provide for automatic shutdown in the event rotational speeds exceed design values

   1. Biological centrifuges (H-8)

   2. Human centrifuges (H-8)

   3. Rotating litter chair (H-8)

f. Gas bottle and battery recharging systems -- to prevent maintenance and/or servicing operations until positive engagement is ensured between the recharging system and the component/subsystem to be serviced (H-28)

5.1.8.1.2 <u>Manual Actuation</u>

Incorporate interlocks requiring manual actuation.

To require a knowledgeable volitional act by a crew member to activate, actuate, open, remove, or release inherently hazardous experimental equipment, contents, or devices. Representative areas of application include:

a. To prevent inadvertent activation or actuation of:

   1. Electrically-powered equipment (H-20)

   2. Simultaneous opening of inner and outer scientific airlock hatch doors (H-6)

   3. Laser beams (H-3)

   4. Balloon-inflating devices (H-11)

   5. Negative pressure sources (H-12)

   6. Rotating equipment (H-8)

   7. Solid propellant-containing devices (H-16)

b. To open or remove protective covers or closures for:

   1. Photochemicals (H-18)

   2. Emulsions (H-25)

3. Containerized fluids (H-22)
4. Radioisotopes (H-21, H-17)
5. Cage doors (H-21)
6. The Active Cleaning Device (H-26)

c. To prevent the inadvertent release of externally attached systems:
1. Astronaut Maneuvering Unit (AMU)(H-13)
2. Maneuverable Work Platform (MWP)(H-14)
3. Teleoperator spacecraft (H-15)

5.1.8.2 Covers

Provide protective covers.

To prevent inadvertent contact with potentially hazardous surfaces, contents, and elements. Applicable equipment areas include:

a. Optical telescopes (direct viewing)-- to prevent eye damage from direct or reflected sunlight. (The "cover" may actually be a fast-acting filter.)(H-9)

b. Batteries and fuel cells -- to prevent electrical shock (H-19)

c. Emulsion sheets -- to prevent chemical injury (H-25)

d. High-temperature surfaces, e.g., furnaces -- to prevent burns and inadvertent release of liquid metals, glasses, etc. during melting and casting operations (H-1)

e. The Active Cleaning Device -- to prevent exposure to contaminants inside the device (H-26)

f. Biological containers -- to prevent release of contents (H-21)

g. Scientific centrifuges -- to prevent release of contents (H-8)

h. Rotating portions of ergometer -- to prevent physical injury (H-8)

i. Devices with high-voltage potential -- to prevent electrical shock (H-20)

5.1.8.3 Stops

Provide protective stops or interlocks to confine or limit directional movement or adjustment.

Applies to experiment equipment whose inherent nature requires directional control for safe operation. Applicable equipment includes:

a. Laser beams (H-3)

5.1.8.4 Guards

Provide protective guards.

To prevent access to experiment equipment which could pose physical proximity hazards when in operation. Typical equipment includes:

a. Laser beams (H-3)

b. High-temperature devices (gas jets, combustors, furnaces, etc.)(H-1)

c. Rotating equipment (human centrifuge, rotating litter chair, etc.)(H-8)

5.1.8.5 Discharge Devices

Incorporate discharge devices.

To de-energize high-voltage electrical systems or components when the system is shut down. Applicable areas include:

a. All electrically-powered equipment within the Experiment Module having high-voltage components (H-20)

b. Subsatellites incorporating high-voltage components and which require handling, maintenance, or sensor replacement (H-7)

To establish equipotential between the Orbiter and retrieved satellites/Experiment Modules (H-31)

5.1.8.6 Laser Energy Absorbing Means

Interpose a material suitable for absorbing laser beam energy between the laser beam target and the Experiment Module primary structure.

Such means would prevent Module structural damage in the event of target failure. (H-3)

5.1.8.7 Extendable-Aid Device

Provide extendable-aid devices (e.g., "lassos", telescoping rods with end-hooks, etc.).

To render immediate retrieval assistance to personnel in EVA and preclude EVA stranding. (H-27)

5.1.8.8 Emergency Provisions

Provide special emergency equipment.

Whenever an Orbiter flight carries Experiment Equipment aboard which could cause a hazard for which the normally carried emergency equipment is not suitable, appropriate emergency equipment should be provided (e.g., appropriate fire extinguishers, decontaminants, protective gear, antidotes, etc.).

5.1.8.9 Emergency Brake Provisions

Provide a back-up locking device for rotatable equipment.

Applicable to rotatable equipment which would pose a hazard to the crew members or adjacent equipment upon failure of the primary locking or latching mechanism. Example areas include:

a. Rotatable telescopes (H-9)

b. Rotating litter chair (H-8)

5.1.9 Jettisoning/Dumping

Consider configuring for ease of jettisoning.

Applicable to experiment equipment with inherently hazardous contents or characteristics whose uncontrolled operation or malperformance could jeopardize an Experiment Module and/or the Orbiter or the return to Earth. Applicable equipment which may have to be considered for jettisoning/dumping include:

a. Objects within scientific airlock -- in the event of hang-up or other need to dispose of object (H-6)

b. Spark-chamber -- in the event of malfunction involving argon and methane gas bleed (H-4)

c. Booms/platforms/antennas -- in event of failure to fully retract (H-10)

d. Subsatellites -- in event of certain component or subsystem malfunction (H-7)

e. Cryogenic dewars -- in the event of tankage leak or rupture (H-24)

f. Emulsion plates and containers -- in the event of retracting mechanism failure (H-25)

g. High-pressure gas bottles (H-23)

h. Containerized fluids (H-22)

i. Propellant tanks (H-22)

j. High-temperature devices (e.g., gas jets, combustors, furnaces)(H-1)

k. Radiation sources (radioisotopes, etc.)(H-17)

l. Astronaut Maneuvering Unit (AMU)(H-13)

m. Maneuverable Work Platform (MWP)(H-14)

n. Teleoperator spacecraft (H-15)

o. Automated satellite payloads (including propulsive stages)

p. Any spacecraft or other object docked or partially docked to the Experiment Module (H-31)

q. The entire Experiment Module (Pallet, MSM, or RAM)(H-31)

r. The liquid and gaseous contents of storage tanks, bottles (H-22, H-23)

5.1.10 Remote Deployment/Operation

5.1.10.1 Configure for remote deployment/retrieval and remote operational control.

Applies to experiment equipment with inherently hazardous contents or characteristics. Typical areas and equipment include:

a. Remote deployment of:

1. Subsatellites -- to reduce handling operations and to avoid having to pass through an airlock (H-7)

2. Contamination sample plates, holding racks, and the Active Cleaning Device (H-26)

3. Teleoperator spacecraft (H-15)

b. Remote operational control of:

1. High-pressure gas sources (H-23)

2. High-temperature sources (gas jets, combustors, furnaces, etc.)(H-1)

3. Feeding and cleaning provisions in holding and rearing cages (to avoid opening cage doors) (H-21)

4. Gas bottle and battery recharging systems associated with satellite maintenance (H-28)

5. Docking control system (including guidance and navigation, propulsion, etc.) of any spacecraft attempting to dock with the Experiment Module or Orbiter (H-31)

5.1.10.2 Design and configure experiment equipment for minimum EVA operations.

5.1.11 Holding

5.1.11.1 Provide means for positive holding and securing of transportable containers.

Applies to such containers (chemicals, nutrients, etc.) when not in actual use by crew members. (H-22)

5.1.11.2 Provide protuberances or grips for physical transport.

Applicable to equipment with contents posing chemical injury upon surface contact. Typical items include:

a. Contamination sample plates and holding racks (H-26)

b. Emulsion sheets and holders (H-25)

5.1.11.3 Provide attach and holding means external to habitable compartment.

Applies to equipment whose primary function is accomplished exterior to the Experiment Module. Typical items include:

a. Scientific subsatellites (H-7)

b. Contamination sample plates and racks (H-26)

c. Astronaut Maneuvering Unit (AMU) (H-13)

d. Maneuverable Work Platform (MWP) (H-14)

e. Teleoperator spacecraft (H-15)

5.1.12 Packaging/Containment/Marking

5.1.12.1 Provide holding and rearing cages with means, preferably automatic, for feeding of caged inhabitants and removal and disposal of liquid and solid waste products.

Such provisions should be externally or remotely operable (see 5.1.10.b.3) and be capable of performing on orbit as well as on the launch pad. (H-21)

5.1.12.2 Provide containers or other provisions for preserving and/or storing dead animals, insects, plant specimens, etc.

Candidate techniques include (but are not limited to) embalming, freezing, etc. (H-21)

5.1.12.3 Configure EVA suits and PLSS units, including voice communication, for "plug-in" of an emergency PLSS package. (H-27)

5.1.12.4 Provide an Experiment Module and/or Orbiter with exterior connections (preferably near EVA airlock) for "plug-in" of EC/LS umbilicals and voice communication. (H-27)

5.1.12.5 Configure in modular or self-contained units.

Applicable to hazardous experiment equipment composed of separable components and whose nature indicates the potential desirability of either remote storage/deployment or the need for jettisoning. Typical equipment includes:

a. Gas bottle and battery recharging systems (H-28)

b. Cryogenic dewars (where dewar is an inherent part of the system, as in the supercooled magnet, or where the dewar is used for periodic replacement) (H-24)

c. Systems containing principally quantities of reactive fluids (cryogenic or non-cryogenic); operation in the unmanned detached (free flying) module mode would be preferable for these systems (H-22, H-24)

d. Nuclear and plastic emulsion sheet devices, including remote storage and deployment mechanisms (H-25)

e. Gaseous release devices and their associated ICN and NH_3 canisters (H-22)

f. The leak-detection experiment and its associated GHe container (H-23)

g. The spark-chamber device and its associated argon and methane tankage (H-22, H-4)

h. High-temperature devices such as gas jets, combustors, furnaces, and the fire-sensing and suppression device (H-1)

i. A self-contained cleaning unit (cleaning materials, waste disposal provisions, etc.) for EVA cleaning operations (H-26)

5.1.12.6 Provide end closures, spouts, or caps with no-spill, positive sealing characteristics.

Applicable to equipment intended for use as fluid holders, fluid receivers, or fluid transfer devices. Typical items include:

a. Batteries (H-19)

b. Fuel cells

c. Photochemical storage containers (H-18)

d. Liquid nutrient containers (H-22)

e. Biological storage containers (H-21)

f. Iostope fluid containers (H-21)

g. Miscellaneous liquid chemical containers (H-22)

5.1.12.7 Provide the Active Cleaning Device with covers or end closures.

To prevent exposure of the crew to contaminants within the device. (H-26)

5.1.12.8 Provide an indication of high-voltage equipment operation on the master experiment monitoring panel.

To warn the crew of the high-voltage hazard source. (H-20)

5.1.12.9 Prominently and permanently mark all containers having removable end closures which contain inherently hazardous materials.

To identify the specific nature of the contents together with warning and handling notes including antidotes, where appropriate (e.g., toxic fluids, serums, etc.). (H-22, H-21)

5.1.12.10 Configure and package equipment for retention of integrity and containment of contents.

Applicable to all Experiment Module subsystems (e.g., cages, containers, devices) during the load and temperature environments of all mission phases, including all intact aborts.

5.1.12.11 Provide means to ensure that failure of any subsystem within an Experiment Module will result in containment within the subsystem or Module and not propagate to the Orbiter.

5.1.12.12 Packaging of experiment equipment and materials should reflect consideration of the number and types of discrete hazard sources contained within the limited volume of a Module, and their potential interactions and synergistic effects.

5.1.12.13 Design experiment and support equipment to withstand rapid ΔP changes without causing a hazardous condition (e.g., container deformation under reduced pressure conditions may result in wire-touching and shorts, broken connections, etc.).

5.1.12.14 Design experiment equipment fluid piping and connectors with ready accessibility in an Experiment Module.

5.1.12.15 No equipment whose malfunction could obstruct free passage should be located, internally or externally, near crew access and egress passageways through airlocks, tunnels, or docking ports (e.g., pressure bottles, batteries, etc.).

5.1.13 Materials Selection

5.1.13.1 Avoid the use of magnetic tools when experiments having magnetic field sources (e.g., supercooled magnet) are incorporated in the Experiment Module. (H-5)

5.1.13.2 Utilize non-combustible materials except where the inherent nature of the experiment requires a combustible material; in that case employ special precautionary measures.

5.1.13.3 Avoid the use of mercury in experiment equipment.

If mercury is indispensable, accidentally escaped mercury should be prevented from entering habitable compartments (e.g., by locating it outside such compartments, double containment, etc.), because spilled mercury cannot be removed completely and will permanently poison the compartment atmosphere.

5.2 LOCATIONAL FEATURES

The choice of experiment equipment location involves both relative placement (exterior, interior, circumferential, longitudinal, etc.) and the effect of placement on potential operational needs (ease of jettisoning, proximity, accessibility, etc.). The preventive measure statements refer to preferred particular placement or location features or provisions which should be given consideration during the configuration selection and design process. It should be recognized that special safety features, such as double containment, could in certain cases void one of these particular statements.

5.2.1 Exterior Placement

Consideration should be given to locating inherently hazardous equipment exterior to habitable Module compartments.

Applicable to experiment equipment whose inherent nature, associated contents, or operational modes indicate that a malfunction could precipitate an uncontrollable hazard. Examples of such equipment and conditions include:

a. Spark-chamber -- to prevent argon or methane gas leakage from contaminating Experiment Module atmosphere (H-4)

b. Laser apparatus, with laser beam pointed away from the Experiment Module primary habitable structure, the Orbiter, and any other systems (H-3)

c. Balloons and their inflating devices (H-11)

d. Subsatellites (H-7)

e. Cryogenic dewars and fluid transfer lines (H-24)

f. Emulsion sheet devices (H-25)

g. Containers holding reactive or toxic fluids, gases (H-22, H-23)

h. Gaseous release devices (H-23)

i. Gas jets, combustors, furnaces, etc. (H-1)

j. High-pressure containers (H-23)

k. Devices for EVA operation (Astronaut Maneuvering Unit, Maneuverable Work Platform, teleoperator spacecraft) (H-13, H-14, H-15)

l. Leak-detection experiment module (H-23)

m. Fire-sensing and suppression experiment module (H-1)

n. Radioisotope thermal generators (RTGs) (H-17)

o. Contamination sample plates and racks (H-26)

p. Battery and gas bottle recharging equipment (H-28)

q. Any EVA sensor cleaning units, accessible to EVA airlock (H-26)

5.2.2 Interior Considerations

5.2.2.1 Position rotatable telescopes (when within Experiment Module) to facilitate egress activities.

So that if the telescope latching mechanism fails in any position there will still be sufficient room for a crew member to reach normal Module egress ports. (H-9)

5.2.2.2 Position laser apparatus (if within Experiment Module) so as to prevent laser operation outside a shielded area. (H-3)

5.2.2.3 Position rotatable equipment such that a clear egress path exists when the equipment is in any orientation. (H-8)

5.2.2.4 Locate interior equipment with escapable contents in special work areas with spill containment, waste disposal, purge, contamination control, and vent provisions. Such areas may require separate environmental control.

Examples of equipment types include:

a. Batteries (H-19)

b. Fluid canisters (H-22)

c. Gaseous canisters (H-23)

d. Gas jets, combustors, furnaces (H-1)

e. Radioisotope fluid containers (H-17)

f. Biological containers (H-21)

g. Animal cage and cage rack assemblies (H-21)

h. Contaminated products or devices (H-26)

5.2.3 Circumferential/Longitudinal Placement

5.2.3.1 Orient circumferentially located scientific airlocks in such a position in the Experiment Module that a jammed-open door will not interfere with cargo bay door closure. (H-2)

5.2.3.2 Locate the terminus of overboard vents such that vent efflux will not enter the Orbiter cargo bay. (H-2)

5.2.4 Proximity Considerations

5.2.4.1 Locate devices with permeating fields away from field-sensitive equipment (including solid propellant ignitors) and habitable compartments unless properly shielded.

Example equipment includes:

a. RF-generators (H-17)

b. Superconducting magnet (H-5)

c. Radiation sources (H-17)

5.2.4.2 Locate exterior equipment away from EVA hatches.

To avoid potential EVA hazard sources (e.g., shock, impact, tether entanglement, etc.). Example areas include:

a. Booms/platforms/antennas (H-10)

b. Radiation sources (H-17)

c. High-voltage equipment (H-20)

d. RF-generators (H-17)

5.2.4.3 Located exterior equipment away from docking ports.

To avoid potential docking hazard sources. Examples include:

a. Booms/platforms/antennas (H-10)

5.2.4.4 Keep balloons and balloon-inflating device/apparatus separate from one another until time for inflation. (H-11)

5.2.4.5 Locate batteries away from potentially combustible materials or systems that could be damaged by escaping battery fluids. This applies also to Experiment Module compartments which may have such materials within them at any time during the mission. (H-19)

5.2.4.6 Locate reactive fluid tanks non-adjacently and in different compartment areas. (H-22)

5.2.4.7 Locate the terminus of vents to avoid adjacent locations where potentially reactive vent effluxes could combine. (H-2)

5.2.4.8 Locate equipment with hot surfaces away from other equipment in the same Module. (H-1)

5.2.5 <u>Accessibility Considerations</u>

5.2.5.1 Place high-voltage components of high-voltage equipment in not-normally-accessible zones, requiring knowledgeable volitional acts to reach or touch them. (H-20)

5.2.5.2 Locate film, photochemicals, and film vaults away from potential ignition source areas and remote from open habitable areas. (H-18)

5.2.5.3 Position the laser apparatus (if within the Module) such that it is away from normal crew passage routes, requiring a volitional access movement to reach it. (H-3)

5.2.5.4 Store balloon-inflation device in a remote area to help ensure against activation until balloon use reaches near-deployment stage. (H-11)

5.2.5.5 Locate externally mounted devices for EVA operations (e.g., Astronaut Maneuvering Unit, Maneuverable Work Platform, teleoperator spacecraft) so as to permit unimpeded egress from EVA hatch and to provide convenient access for their use by astronauts in EVA. (H-13, H-14, H-15)

5.2.5.6 Locate external EC/LS umbilicals and communication plug-in unit near EVA hatch. (H-27)

5.2.5.7 Locate EVA tether attach points and fixtures so as to minimize possibility of tether entanglement. (H-27)

5.2.5.8 Locate Experiment Modules (Pallet, MSM, RAM) and experiment equipment so as not to interfere with any egress from or ingress to airlock hatches or the Orbiter tunnel (neither in the installed nor in the extended position).

5.2.5.9 Locate experiment equipment attached externally to Experiment Modules so as not to interfere with any egress from or ingress to airlock hatches or the Orbiter tunnel (neither in the installed nor in the extended position).

5.2.5.10 Locate all docking ports so as to ensure visual observation of the docking operations. (H-31)

5.2.5.11 Locate equipment requiring periodic maintenance (e.g., animal cages) so as to facilitate access on the ground and on orbit. (H-28)

5.2.5.12 Locate equipment within the Experiment Module so as to allow an IVA-suited man to pass by regardless of the position of movable exterior equipment parts. (H-29)

5.2.6 Jettisoning/Dumping Considerations

5.2.6.1 Consideration should be given to locating inherently hazardous equipment for ease of jettisoning/dumping.

Applicable to experiment equipment with inherently hazardous contents or characteristics whose uncontrolled initiation, operation, or malperformance could jeopardize Experiment Module and/or Orbiter integrity. Applicable equipment system areas include:

a. Spark-chamber (H-4)

b. Cryogenic dewars (H-24)

c. Subsatellites (H-7)

d. High-pressure gas bottles (H-23)

e. Containerized fluids (H-22)

f. Propellant tanks and/or contents (H-22)

g. High-temperature devices (e.g., gas jets, combustors, furnaces) (H-1)

h. Radiation sources (radioisotopes require special analysis of the potential radiological consequences) (H-17)

i. EVA use devices (Astronaut Maneuvering Unit, Maneuverable Work Platform, teleoperator spacecraft) (H-13, H-14, H-15)

5.2.6.2 Consider provisions for dumping hazardous fluids (when carried in large quantities) which make jettisoning of their container unattractive.

5.2.6.3 If emergency dumping of fluids is determined to be a requirement, provisions should be made so that dumping can be done during any phase of the mission, including the phase of aerodynamic flight of the Orbiter and on the ground.

5.3 OPERATIONAL TECHNIQUES

The general area of operational techniques encompasses both actual operational steps (setup, deployment, experiment/equipment operation, jettisoning, check-out, purging, deactivating, securing, etc.) and associated caution, warning, and monitoring system elements (sensors, visual and aural alarms, etc.) which may be necessary for safe and timely implementation of the actual operational steps. The preventive measure statements refer to particular operations and operational requirements which should be considered during the configuration selection and design process.

5.3.1 Setup/Deploy/Operate

5.3.1.1 Protective Garments/Devices

5.3.1.1.1 Wear radiation dose-accumulation badges.

To guard against excessive accumulation from both experiment equipment and natural sources. (H-17)

5.3.1.1.2 Wear suitable protective garments, including gloves, face masks, etc.

Applicable when handling or involved with equipment or contents which could cause injury or illness by mere contact or inhalation. Applicable areas include:

a. Film, film packs, film-processing operations (H-18)

b. Toxic or reactive fluid container handling (H-22)

c. Furnace-related operations (melting, casting, etc.) (H-1)

d. Animals, insects, plants (H-21)

e. Exposed contamination sample plates (H-26)

f. Sensor cleaning operations (H-26)

g. Biologicals and biological containers (H-21)

h. Isotopes, serums, etc. (H-21)

i. Embalming of cadavers

5.3.1.2 <u>Remote Deployment</u>

5.3.1.2.1 Deploy emulsion sheets with remote deployment mechanisms. (H-25)

5.3.1.3 <u>Remote Operation</u>

5.3.1.3.1 Control remotely the initiation, activation, or operation of experiment equipment exhibiting characteristics for potential explosion, fire, or contamination due to equipment malfunction and/or contents.

Illustrative experiment areas include:

a. Reactive fluid experiments (H-22)

b. Gas bottle and battery recharging operations (H-28)

c. Leakage-detection experiment (H-23)

d. Spark-chamber experiments (H-4)

e. Gas jet, combustor, and furnace experiments (H-1)

f. Feeding and cage-cleaning operations (H-21)

5.3.1.3.2 Utilize an Experiment Module of the detached, free-flying RAM type, remotely deployed at a safe distance from the Orbiter, for the incorporation and conduct of experiments whose inherent nature implies risks of explosion, fire, or collision.

The safe distance should be established by consideration of pressure wave and shrapnel phenomena associated with the explosion characteristics of the specific experiment type. Applicable experiment types include:

a. Combustion experiments (H-1)

b. Propellant storage and transfer experiments (H-22, H-24)

c. Furnace-related experiments (casting, melting, etc.) (H-1)

d. Maneuverable Work Platform-controlled and teleoperator spacecraft-controlled docking experiments (H-14, H-15)

5.3.1.4 <u>Special Work Areas</u>

Perform experiment operations in special work areas with provisions for spill containment, purge, venting, contamination control, and waste disposal. Such areas (e.g., glove boxes, double containment, etc.) may also require separate environmental control.

Applicable when the nature of experiment equipment or materials involved indicate the possibility of surface or atmospheric contamination through the release of toxic or noxious substances. Examples of operations include:

a. Processing film (H-18)

b. Performing biological experimentation (H-21)

c. Performing uncaged animal, insect, and plant handling operations (H-21)

d. Performing contamination experiments or sensor cleaning (H-26)

e. Handling toxic fluid substances, isotopes, serums, etc. (H-21)

5.3.1.5 Restricted Operations

5.3.1.5.1 Suspend all experiment operations involved with controlled radiation sources, RF-generators, supercooled magnets, and rotating equipment during EVA operations and Experiment Module erection, retraction, docking, and undocking operations. (H-27, H-30, H-31)

5.3.1.5.2 Do not transport experiments with strong RF or magnetic field sources on the same Orbiter flight with payloads having solid propellant propulsive stages unless appropriate precautionary measures are incorporated. (H-5, H-17)

5.3.1.5.3 Control the timing of experiments with magnetic or RF-fields to avoid adversely affecting sensitive Shuttle subsystems.

Some Shuttle subsystems (e.g., guidance and navigation sensors) may be adversely affected by the normal operation of experiment magnetic or RF-fields. Coordinated sequencing of active periods might be used to prevent adverse interactions. (H-5, H-17)

5.3.1.5.4 Perform experiments with chemicals posing toxic gas or vapor contamination hazards in pressure compartments with a separate environmental control system. (H-23)

5.3.1.6 Special Precautions

5.3.1.6.1 EVA Operations

5.3.1.6.1.1 Conduct particularly hazardous EVA experiment operations by at least two EVA men, one of them performing the work and the other being a Safety man who is standing by for instant action in close proximity to the first one.

The sole function of the Safety man is to observe the worker and assist him in case he gets into an emergency situation. Depending on the circumstances, one Safety man might look after two EVA workers. (H-27)

5.3.1.6.1.2 For normal EVA experiment operations provide at least two EVA men who work together as a team (buddy system).

Such men should perform work in relatively close proximity to each other in order to provide aid and assistance to each other. (H-27)

5.3.1.6.1.3 Provide an additional crewman, suited and ready to go into EVA, in the event of an emergency involving any of the men already in EVA.

This man should be in visual contact with the men in EVA (either direct viewing or TV monitoring). (H-27)

5.3.1.6.1.4 Avoid experiment EVA: (H-27)

a. When high-voltage, RF-field, or magnetic fields are present

b. During Experiment Module erection, retraction, docking, or undocking operations

c. Near attitude control nozzle jets

5.3.1.6.2 EVA-Device Operations

5.3.1.6.2.1 Conduct AMU and MWP operations in a tethered mode unless dictated otherwise by the experiment requirements. (H-13, H-14)

5.3.1.6.2.2 Remotely monitor Astronaut Maneuvering Unit (AMU) and Maneuverable Work Platform (MWP) propulsion subsystems and deactivate them if pressures or temperatures exceed normal range values or other evidence of malfunction is indicated. (H-13, H-14)

5.3.1.6.3 Egress Operations

5.3.1.6.3.1 Provide a second or Safety crewman to stand by during airlock operations for purposes of rendering aid and assistance if necessary. (H-29)

5.3.1.6.3.2 Provide pressure suits (including PLSS units) in the Experiment Module for crew members in the event EVA egress from the Module should be required to reenter the Orbiter (via the Orbiter EVA airlock). (H-29)

5.3.1.6.3.3 Wait until the Experiment Module is fully erected and secured, and interface circuits have been checked out, before initiating entry into the Module. (H-29, H-30)

5.3.1.6.3.4 Have all personnel leave the Experiment Module (and enter the Orbiter) prior to initiating retraction of the Module. (H-29, H-30)

5.3.1.6.4 Contingency Plans and Procedures

5.3.1.6.4.1 Prepare contingency plans (including shutdown and backout procedures) for every Orbiter flight.

5.3.1.6.4.2 Appoint a single crew member responsible for implementing safety and contingency plans.

5.3.1.6.4.3 Prepare loading/unloading time schedules for equipment requiring servicing from the ground or Orbiter.

5.3.1.6.4.4 Establish startup and shutdown procedures for all experiment equipment; such sequences should minimize effects on other equipment and should have no adverse effect on Orbiter operating systems.

5.3.1.6.4.5 Establish order-of-connection procedures for all fluid connections. (H-22, H-23)

5.3.1.6.4.6 Experiment equipment containing nuclear materials shall conform with established nuclear safety requirements. (H-17)

5.3.2 Deactivating/Securing

5.3.2.1 Nuetralize (discharge) all high-voltage components after ground checkout and/or operation. (H-20)

5.3.2.2 Purge Orbiter cargo bay in the event of inadvertent hazardous efflux release into the bay by Experiment Module overboard vents. (H-2)

5.3.2.3 Purge, inert, and safe all returnable tanks/containers holding non-inert substances after the experiment is completed or prior to reentry. (H-22, H-23)

5.3.2.4 Secure all containers in their respective storage areas after use. (H-22, H-23)

5.3.2.5 Safe all solid propellant-containing systems prior to ground installation and prior to recovering them into the Orbiter cargo bay in orbit. (H-16)

5.3.2.6 Maintain in a passive or deactivated status experiment equipment capable of causing a hazardous situation upon their mere activation.

Illustrative devices include:

a. Balloons and inflating devices (H-11)

b. Reactive-fluid experimental equipment (H-22)

c. Combustion-related equipment (H-1)

d. Propulsion units (e.g., Astronaut Maneuvering Unit, Maneuverable Work Platform) (H-13, H-14)

e. The negative pressure source for the Lower Body Negative Pressure Chamber (H-12)

5.3.3 Jettisoning/Dumping

5.3.3.1 Consider jettisoning or dumping experiment equipment whose status or condition poses an uncontrollable hazard affecting the safety of crewmen in the Experiment Module and/or the safety and integrity of the Orbiter and crew.

Applicable equipment system areas include:

a. Leaking containers (photochemicals, isotopes, serums, etc.) (H-18, H-21)

b. Containers which exceed normal range values in temperature or pressure (H-22, H-23)

c. Spark-chamber with leaking gases (argon, methane) (H-4)

d. Booms/platforms/antennas (if their presence precludes any necessary docking, retraction, or Orbiter cargo bay door closure operations) (H-10)

e. Scientific airlock outer hatch door (if jammed open and not closeable) (H-6)

f. Cryogenic or reactive fluid tanks (if their pressure or temperature exceeds normal range values) (H-22, H-24)

g. High-temperature devices (gas jets, combustors, furnaces)--if their temperature or pressure limits are exceeded (H-1)

h. EVA-use devices (Astronaut Manevering Unit, Maneuverable Work Platform, teleoperator spacecraft)--if their propulsion systems indicate malfunctions (H-13, H-14, H-15)

i. Automated satellite and propulsive stages (if propulsive malfunctions are indicated)

j. The entire Experiment Module (Pallet, MSM, RAM)--if full and secure retraction cannot be accomplished, or in the event of any uncontrollable hazardous condition in the Module proper.

5.3.4 Caution and Warning Systems

5.3.4.1 Incorporate Caution and Warning signals to alert the crew to hazardous and potentially hazardous conditions.

Such systems (where appropriate) should include the capability to record sensor measurement trends and compare these with predetermined trend predictions in order to provide a timely warning of imminent hazardous conditions. Their display (visual and/or aural) and their location (on Orbiter flight deck or lower deck, or in an Experiment Module) depends on the particular hazard condition and severity. Applicable equipment and operational areas include:

a. RF-field generation (H-17)

b. Magnetic field generation (H-5)

c. Excessive leakage rates through airlock doors (H-6)

d. Status of overboard vent system components (pressure regulators, pressure-relief, etc.) including positive warning of vent malfunctions (H-2)

e. Status of Experiment Module atmosphere with regard to pressure, temperature, humidity, and contaminant levels; positive warning with respect to incidence of fire or contamination (toxic, non-toxic, smoke, chemical vapors, pollen, insects, radioactive elements, biologicals, etc.)

f. Positive warning if laser beam direction is out-of-limits (H-3)

g. Extension or retrieval of booms/platforms/antennas and positive warning if active elements thereon are operational during docking, EVA, or Orbiter cargo bay door closure operations (H-10)

h. Temperature and/or pressure level measurements, with positive warning if design range values are exceeded, for such items as:

   1. Batteries (H-19)

   2. Gas bottles (H-23)

   3. Cryogenic dewars (H-24)

   4. Non-cryogenic fluid containers (H-22)

   5. Gas jets, combustors, furnaces (H-1)

   6. Biological containers (H-21)

   7. Lower Body Negative Pressure Chamber (H-12)

   8. EVA-devices (Astronaut Maneuvering Unit, Maneuverable Work Platform, teleoperator spacecraft), gas bottles, batteries, and propellant tanks (H-13, H-14, H-15)

   9. Gas bottles and battery recharging apparatus (H-28)

i. Radiation levels of X-ray machines, isotopes, radioisotope thermal generators (RTGs), etc., with positive warning if design range values are exceeded (H-17)

j. Speed of rotating equipment, with positive warning if design range values are exceeded (H-8)

k. Status of solid propellant safe-and-arm circuits (H-16)

l. Status of PLSS conditions, with positive warning if conditions deviate from design range values (H-27)

m. Status of airlock EC/LS, pressure levels, and door positions, including positive warning if design range values are exceeded (H-27, H-29)

n. Velocity and alignment of a docking spacecraft relative to the Experiment Module or Orbiter docking port, including positive warning of any deviation from design range values (H-31)

o. Position of erection/retraction system, with status as to fully erected, fully retracted (H-30)

5.3.5 Monitoring and Control

5.3.5.1 Monitor and control, on a continuous or scheduled basis (as appropriate), operations/devices requiring immediate or concurrent measures to prevent or counteract hazardous situations.

Illustrative areas include:

a. Gas bottle and battery recharging operations (H-28)

b. Reactive fluid container pressure and temperature while aboard the Orbiter or in the immediate vicinity (H-22, H-24)

c. The condition and operability of cage feeding and cleaning devices (H-21)

d. Radiation levels of active radiation devices in or attached to the Experiment Module (H-17)

e. Human centrifuge operations (H-8)

f. EVA equipment operations (Astronaut Manevering Unit, Maneuverable Work Platform, teleoperator spacecraft) (H-13, H-14, H-15)

g. EVA operations (H-27)

h. PLSS conditions during EVA operations (H-27)

i. Airlock and crew conditions during airlock egress operations (H-29)

j. Docking sensors and control systems during docking operations (H-31)

k. Erection/retraction control system and status sensors throughout erection/retraction operations (H-30)

l. The total radiation level environment to which the Orbiter and Experiment Module have been subjected due to both natural radiation spectrums and experimental equipment operation. Utilization of dose-accumulation badges by the individual crew members would facilitate the monitoring of their individual exposures. (H-17)

6. REMEDIAL MEASURE ASSESSMENT

6.1 POTENTIALLY UNRESOLVED HAZARDOUS SITUATIONS

Regardless of the care and attention given to spacecraft design and redundancy features, and despite the incorporation of meaningful preventive measures, hazardous situations can and will occur in space operations. This prospect is as applicable to in-space experiment programs as to any other space activity. In order to identify possible means for remedying the situation after the occurrence of a hazard, a series of remedial measure assessments was performed. These assessments were based on the inherent hazard source lists (Figures 3-3 and 3-4) and were keyed to the potentially hazardous results as described in Tables 3-32 and 3-33.

The approach followed in the assessment was to graphically display and relate a basic hazard source and its attendant hazardous results to a subjective analysis and assessment of meaningful measures which could potentially:

a. prevent further propagation of a hazard
b. neutralize the effects of a hazardous occurrence
c. provide needed:
    1. physical aid
    2. medical aid
    3. metabolic sustenance
d. provide for transfer to a haven of safety, if required

The analysis was focused on identifying both remedial equipment and its associated operational or functional requirements in the above areas.

The assessment technique is illustrated in Figure 6-1 for the case of overboard vent malfunctions and related experiment operations. In the case illustrated, four equipment-related measures and three operations-related measures were identified.

For the total hazard source spectrum so analyzed, a total of 11 basic remedial need areas were identified. Table 6-1 summarizes these 11

Hazard Assessment			Remedial Measure Assessment	
			Resolve or Alleviate Hazardous Occurrence by:	
Basic Hazard Source	Causative Event/Factor/Condit.	Hazardous Result (Effect)	Equipment	Operations
A. Overboard Vents 1. Cryogenic Dewars	A. Closed/inoperative Vent	Tank overpressure, rupture; release of cryo fluids, gases	1. Fire-suppression equip. 2. Emergency EC/LS 3. Medical supplies, equip. 4. Decontamination equip.	1. Crew aid and retrieval 2. Physician's duties 3. Decontamination Oper.
2. Gas jets, combustors, furnaces	B. Closed/inoperative vent	Chamber overpressure, rupture; release of flames, toxic gases, liquid metals, glasses, etc.	1., 2., 3., 4. See above	1., 2., 3. See above
3. Holding and Rearing Accommodations (Cages)	C. Closed/inoperative vent	Cage overpressure, rupture; release of animals, insects, plants, pollen, bacteria, waste, etc.	2., 3., 4. See above	1., 2., 3. See above
B. Experimental Opns.				
1. Operating Combustors, furnaces	See "B" above			
2. Conducting life sciences experiments	See "C" above			
3. General	D. Venting into Cargo Bay E. Common vent location	Fire, explosion, contamination, injury	1., 2., 3., 4. See above	1., 2., 3. See above
C. Basic Operations				
1. Ground Install.	See "A", "C", "D" & "E" above			
2. Egress Activities	N. A.			
3. Docking	N. A.			
4. Undocking	N. A.			
5. Erection	N. A.			
6. Retraction	N. A.			
7. Removal (Grnd.)	See "A", "C", "D" & "E" above			

Figure 6-1. Remedial Measure Assessment - Overboard Vent Malfunctions

categories and indicates their applicability with regard to the 12 hazard/emergency groups presented in section 3.2.2.

The formulation of methods of implementing such remedial measures is presented in section 6.2 in terms of statements which delineate potential equipment and operational requirements and relate them to pertinent or example hazardous situations to which each remedial measure may apply.

6.2 REMEDIAL MEASURE STATEMENTS

The following remedial measure statements are summary expressions which emphasize areas deserving further consideration in order to enhance in-space experiment safety. Specifically, they refer to particular features or provisions of remedial measures which should be given consideration during the configuration selection and design process associated with scientific experiments in connection with the Space Shuttle Orbiter.

These remedial measures were initially identified in the series of remedial measure assessments described in section 6.1. For convenience of presentation the remedial measure statements are grouped according to the basic remedial need areas of Table 6-1.

Where appropriate, the remedial measure statement (or accompanying example of equipment/experiment/condition exemplifying the statement intent) contains a reference to the particular Hazard/Emergency Analysis and Safety Criteria Summary Sheet of Table 5-1, which contains the basic hazard/emergency assessment used to form the basis of the remedial need.

It is emphasized that the remedial measures, as stated, in many cases are not singular remedies, but require corollary or complementary activities. For example, if a crew member were injured and required medical aid, there may also be the requirement for emergency access equipment to reach the injured party and the need for crew aid and retrieval personnel and equipment to effect his transfer to another compartment or spacecraft module. The formulation of selected remedial measures into summary Safety Guidelines is presented in Table 4-3 of Volume II, Part 2.

6.2.1 Fire Suppression

In addition to normal fire-suppression provisions, consideration should be given to providing fire-suppression devices (e.g., "fire extinguishers") and/or systems (e.g., controlled chamber decompression techniques, inert gas purge systems, etc.) suitable for those unique combustibles introduced by the nature of the experiment and for which the normal equipment would not be suitable.

Selection of fire suppression device/system type, configuration, and operational characteristics should be compatible with the features and characteristics of the particular spacecraft in which it is installed and reflect consideration of its use by crew members in the spacecraft or its use by remote control and activation from the Orbiter (in the case of Pallet, MSM, or RAM Experiment Modules). The fire-suppression characteristics of selected devices/systems should reflect the range of potential on-board ignition sources and flammable contents sources which include:

a. Electrically-powered equipment (H-20)

b. Closed vent explosions (H-2)

c. Spark-chamber gas leakage (H-4)

d. Film processing chemicals (H-18)

e. Lasers (H-3)

f. Batteries (H-19)

g. Gas bottle explosions (H-23)

h. Cryogenic dewar ruptures (H-24)

i. Non-cryogenic dewar ruptures (H-22)

j. Non-cryogenic gas escape (H-23)

k. Solid propellants (H-16)

l. Gas jets, combustors, furnaces (H-1)

m. Liquid metals, glasses (H-1)

6.2.2 Emergency EC/LS

Provide short term life support within EM's (e.g., face mask breathing devices, portable self-contained "plug-in" EC/LS units, interior and exterior umbilical connections, etc.) which is configured and located to provide ready access and limited term breathing atmosphere.

Selection of emergency EC/LS device/system type, configuration, and operational characteristics should be compatible with the features and characteristics of the particular spacecraft in which it is installed and/or reflect consideration of its use by crew members in the spacecraft or its use in a specific activity (e.g. EVA). The environmental and life support characteristics of selected devices/systems should reflect the range of potential situations and conditions which may require their use. Such conditions include:

a. Experiment Module atmosphere composition, temperature, humidity, and pressure extremes due to:

   1. Basic EC/LS system malfunction

   2. Fire, smoke

   3. Contamination

      a. Toxic gases (H-23)

      b. Film processing chemicals (H-18)

      c. Cryogenic gases (H-24)

      d. Non-cryogenic gases (H-23)

      e. Bacteria (H-21)

      f. Radiation (H-17)

      g. Pollen (H-21)

      h. Waste products (H-21)

      i. Miscellaneous chemicals (H-21)

   4. Decompression/overpressure

      a. Laser beam damage to structure (H-3)

      b. Open/leaking scientific airlock doors (H-6)

      c. Rotating equipment damage to structure (H-8)

      d. Uncontrolled vacuum source for the Lower Body Negative Pressure Chamber (LBNPC) (H-12)

      e. Balloon inflation in Module (H-11)

      f. Overboard vent malfunction (H-2)

      g. Collisions (H-7)

b. Depleted or depleting EC/LS supply due to:

   1. Inability to return from EVA (H-27)

   2. Stranding in RAM

   3. Entrapment in airlock (H-29)

   4. Entrapment in MSM (H-29)

6.2.3 Medical Aid

Provide medical supplies, equipment, and personnel trained in performing physician's duties for potential injury/illness conditions caused by experiments.

Supplies/equipment selection and location should reflect consideration of the nature of the injury to be treated, where the injury can occur, and the rapidity with which the illness/injury should be treated. Examples of potential injuries/illnesses to be considered include:

a. High-voltage shock (H-20)

b. Electrical burns (H-20)

c. RF-field exposure injury (H-17)

d. Magnetic field exposure injury (H-5)

e. Metabolic deprivation

f. Explosion injuries

g. Toxic gas inhalation (H-23)

h. Chemical injury, burns (H-1)

i. Eye damage (from looking at sun) (H-9)

j. Laser injuries (burns, radiation) (H-3)

k. Cryogenic fluid contact (H-24)

l. Emulsion contact or vapor inhalation (H-25)

m. Combustor or furnace burns (H-1)

n. Radiation injuries (field exposure, isotope contact) (H-17)

o. Animal, insect bites (H-21)

p. Biological disease (H-21)

q. Bacterial exposure (H-21)

r. Excessive negative pressure exposure (H-12)

s. Rotating equipment impact injury (H-8)

t. EVA injury (H-27)

   1. Impact
   2. Negative pressure
   3. Metabolic deprivation

u. Excessive physical stress

1. Human centrifuge (H-8)
2. Litter chair (H-8)
3. Ergometer (H-8)

6.2.4 Decontamination

Provide equipment, supplies, and personnel trained in related operational techniques for the purpose of decontaminating spacecraft surfaces and atmosphere.

Such equipment/supplies selection and location should reflect consideration of the nature of the contaminant source, where the contamination can occur, and the rapidity with which the contaminant should be removed. Examples of potential contaminant sources to be considered include:

a. Atmospheric contamination

1. Toxic gases (H-23)
2. Volatile processing chemicals (H-18)
3. Plant pollens (H-21)
4. Airborne bacteria (H-21)
5. Airborne waste products (H-21)
6. Cryogenic gases (H-24)
7. Non-cryogenic gases (H-23)
8. Insects (H-21)
9. Emulsion vapors (H-25)
10. Ionizing radiation (H-17)
11. Powders

b. Surface contamination

1. Liquid and solid waste products (H-21)
2. Processing chemicals
   (a) Liquids
   (b) Solids (powders, granules, etc.)
3. Biological cultures, serums (H-21)
4. Battery electrolyte (H-19)
5. Cryogenic fluids (H-24)

6. Non-cryogenic fluids (H-22)

   (a) Toxic

   (b) Non-toxic

7. Emulsions (H-25)

8. Specific contaminant sources (H-26)

9. Isotope solutions (H-17)

6.2.5 Structure Repair

Provide materials, equipment, and personnel trained in related operational techniques for the purpose of enabling emergency repair of damage to the primary pressure-containing shell of the spacecraft.

Such repair would be limited to patching or reinforcing shell surface areas which had suffered minor or non-catastrophic openings and whose repair was essential to permit continued habitability until affected crew members could exit to a safe haven. Examples of typical sources of such structural damage include:

a. Micrometeoroid penetration

b. Minor explosions

c. Impact holes, cracks

   1. Rotating equipment (H-8)

   2. Exterior collisions (H-7)

d. Laser beam holes (H-3)

e. Uncontrolled negative pressure source (H-12)

6.2.6 Removal Tools

Provide tools, other equipment, and personnel trained in related operational techniques for the purpose of removing spacecraft equipment and/or appendages whose status or condition is such as to pose an immediate hazardous condition or to prevent the ability of the Orbiter to return to earth.

Examples of equipment or appendages which pose this potential requirement include:

a. Protuberances preventing closure of Orbiter cargo bay doors

   1. Scientific airlock outer doors (H-6)

   2. Extending instruments, deployment mechanisms

3 Booms/platforms/antennas (H-10)

4. Unretractable Pallet, MSM, RAM

b. Malfunctions resulting in crew entrapment

1. Telescope latching mechanisms (H-9)

2. Airlock doors

c. Malfunction resulting in inability to undock an attached vehicle

1. Docking mechanisms

2. Astronaut Maneuvering Unit, Maneuvering Work Platform, and teleoperator spacecraft attach mechanisms (H-13, H-14, H-15)

6.2.7 Access Equipment

Provide emergency access equipment (cutting tools, knockout or blow-out panels, etc.) for the purpose of enabling access to and the egress of crew members entrapped within airlocks or spacecraft compartments. (H-29)

6.2.8 Crew Transfer Equipment (Space Rescue)

Provide equipment to enable transfer to the Orbiter of crew members stranded in EVA or in a vehicle unable to close-rendezvous and/or dock with the Orbiter (or attached MSM). (See also Volume II, Part 3, and Ref. 5 for detailed information.)

Such equipment selection should consider the potential need for transporting crewmen who are immobile and who require a pressurized atmosphere for survival. Typical situations which pose the requirement for such transfer equipment include:

a. Astronaut stranded in EVA (H-27)

b. Stranded Maneuvering Work Platform (H-14)

c. Stranded RAM

6.2.9 Crew Aid and Retrieval

Provide personnel trained in the requisite operational techniques for immediate aid and assistance to injured, entrapped, or stranded crew members in the same or adjacent compartments or in EVA operations.

Such personnel should be fully cognizant of all associated equipment and operational characteristics. Training emphasis should concentrate on speed of response to an emergency situation and techniques for retrieval of disabled crew members who cannot participate in a rescue operation.

6.2.10 Ground Facility Aid

Provide aid at the launch and return facilities which is sufficiently broad to encompass the following emergency aid areas:

a. Fire suppression

b. Emergency life support

c. Medical aid

d. Decontamination

e. Access tools, equipment

f. Crew aid and retrieval

g. Purging

h. Cooling (e.g., isotope systems)

Sections 6.2.1, 6.2.2, 6.2.3, 6.2.4, 6.2.7, and 6.2.9 denote typical emergency conditions and sources which may form the basis for the remedial aid required in each area above.

7. EXPERIMENT INTERACTION SAFETY CONSIDERATIONS

Performing experiments in connection with the Space Shuttle Orbiter could result in emergency situations of well-recognized categories. The presence of Experiment Equipment and its operations does not cause hazards that are significantly different from previously known space hazards. It does, however, introduce an extremely broad range of specific hazard sources which are additive to the hazards inherent in space operations.

The number of discrete hazards that can occur due to equipment or operation of any experiment class (FPE) is related to the nature of the Experiment. Materials Science and Manufacturing Experiment Modules, for example, have more equipment of a hazardous nature than Earth Survey Experiment Modules. This class-to-class differentiation loses significance, however, when multiple experiment categories are integrated into any one Experiment Module. The definition of hazards with their resultant potential emergency situations have to be based on the equipment that will actually be used. The synergistic effects and the interactions between Experiment, Module, and Orbiter equipment and instrumentation must be considered in order to reach a complete definition of potential hazards and emergency situations attributable to a specific Experiment.

The discussions in Section 3 regarding parameters affecting experiment safety were necessarily directed to first-order effects because the Experiments and their interfaces are not completely defined at present. Equally important from a safety standpoint are the hazards arising from less well defined potential interactions due to the integration of the diverse Experiment Equipment. This section discusses interactions involving an Experiment and its operational equipment that could have an impact on the safety of the crew and the Orbiter.

7.1 EXPERIMENT-TO-EXPERIMENT INTERACTIONS

Within a given scientific discipline, such as Astronomy, the number and characteristics of hazard sources varies as a function of the accommodation mode (Pallet, MSM, or RAM). The number and types of scientific equipment which can be carried and operated depend on the available volume, weight limitation, and capacity for pressurization, thermal control, contamination control, etc. For multiple-experiment missions, there is also the variation in scientific and supporting equipment required for the different Experiments.

The hazards associated with the Experiments and their equipment, as shown in Tables 3-32 and 3-33, lead to a formidable list of potential emergencies. The less demanding Experiments (in terms of both experiment and support equipment) produce fewer hazards, while more complex or multiple-experiment combinations produce a greater number of potential hazards.

In addition to the hazard sources that exist for any discrete scientific Experiment Equipment, interference with other scientific or operational equipment can endanger safety. For example, field-coupling effects (magnetic, RF, nuclear, etc.), which could produce synergistic interactions, and thus could activate or deactivate sensors, detectors, or control loops of other Experiment Equipment, could result in:

a. Hazardous component/subsystem malperformance
b. Erroneous sequencing of hazardous equipment operation
c. Requirement for manual experiment operator control (to avoid hazardous occurrence) at a time when an operator is not available for such control
d. Overloading of electrical power system
e. Inadvertent start-up and/or shut-down of multiple Experiment Equipment

7.2 EXPERIMENT-TO-MODULE INTERACTIONS

Emergency situations could also be produced by interactions which are related to equipment configuration and placement within the Experiment Module (Pallet, MSM, RAM, etc.) in which the equipment is carried and operated. Therefore, consideration must be given to:

a. The density of packaging of Experiment Equipment within a Module

b. The environment within the Module (i. e., pressurized or unpressurized)

c. Placement relative to Module (i. e., whether "inside" Module or attached "externally")

d. Degree of reliance on sensors, detectors, control loops, etc., which are experiment-specific equipment, or which are central equipment provided by the Module or the Orbiter

e. Effects of special remedial means included in the Module (e. g., special fire detection and suppression equipment)

f. Start-up and shut-down procedures

The conduct of scientific experiments in ground laboratories devoted to a variety of experiments generally allows separation of the different Experiment Equipment, provision for protective enclosures or walls between equipment and operators, and isolation of caution and warning detectors as well as control loops from the primary power source and experiment control systems and stations.

The comparatively small volume available for Experiment Equipment within a Module aboard the Space Shuttle Orbiter suggests centralization of auxiliary equipment, such as central power conditioning and control units, data processing units, caution and warning detectors and alarm systems, etc., in order to maximize the number of experiment packages and equipment for any Module and mission. Such an approach is justifiable because it minimizes costs and maximizes the scope of experiment activity that can be undertaken during any one space mission. It could, however, lead to a safety problem because of interactions. Wall-to-wall experiment and control equipment, with its potential for hazardous interactions and synergistic effects, suggests that a careful and systematic systems integration approach for Modules housing Experiment Equipment should be followed.

7.3 EXPERIMENT-TO-ORBITER INTERACTIONS

The hazard-causing potential of Experiment Equipment can also provide interactions with the Orbiter operational equipment and cause direct hazards due to potential synergistic effects on diverse equipment within a Module or the Orbiter.

All of the subsystems essential for the safety and well-being of the Orbiter and its crew can be detrimentally affected by Experiment Equipment either directly or indirectly, regardless of the location of the equipment. For example, the electrical power system could be overloaded or rendered inoperable; communications with other spacecraft and the ground could be interrupted or cut; the Orbiter guidance and navigation system could be rendered inaccurate or ineffective, etc.

During experiment operations the orientation of the Experiment Module and Experiment Equipment with respect to the Orbiter is of importance. For example, the efflux from overboard vents could contaminate the cargo bay and/or sensitive Orbiter elements (lenses, sensors, etc.).

7.4 INTERACTION SUMMARY

The experiment program foresees a large variety of Experiments aboard the Space Shuttle on any one flight. The multitude of interactions between the Experiment Equipment, and its operations, Accommodation Modules, experimenters, and Shuttle Orbiter operational equipment and crew creates many potential hazards. Malfunctioning Experiment Equipment presents discrete hazard sources; the potential hazards created by them could propagate to other Experiment Equipment and supporting equipment and to operational equipment of the Accommodating Module and the Orbiter.

Implementation of effective preventive or remedial measures to eliminate or reduce to an acceptable level the safety risk of such experiment-related hazards requires an integrated system approach. Such an approach demands the preparation and coordination of failure mode and effect analyses and safety plans which reflect the interfaces between the Experiment Equipment and other systems on board every individual Orbiter flight. Such plans must identify and consider all potential hazards introduced by the mutual interactions of:

a. All Experiment Equipment and its operation

b. All supporting equipment (central controls, displays, detectors, etc.) installed in the Accommodating Module (e.g., Pallet, MSM, RAM, etc.) and its operation

c. Subsystems and Experiment support equipment of the Orbiter (e.g., cargo bay doors, deployment and retrieval mechanisms, electrical power system, venting system, EC/LS, communications system, etc.)

d. Operations required for performing particular Experiments (e.g., set up, deployment, retrieval, disposal, EVA, maintenance and repair, etc.)

The above effort must be carried out at three system levels, all of which must consider the Experiment Equipment operation. The first of these levels is the Experiment Equipment design level which must include considerations of operational safety. The second level is the integration of the Experiment Equipment carried and operated within the Accommodation Module. The third level is the integration of the Accommodation Module with the Space Shuttle Orbiter. The second and third levels must consider the stowed and deployed modes of the Accommodation Module and must consider the full spectrum of potential hazards created by the Experiments carried aboard the Orbiter and operated within it or nearby. These hazards should include considerations of synergistic effects.

Included in all the above system levels, but particularly on the second and third levels, are considerations such as the choice of the central or multiple use of the control, conditioning, and detection systems (e.g., fire, leak, and contamination detection, etc.). This choice must be based on safe operation under the diverse conditions arising during simultaneous operation of several Experiments and operational Orbiter equipment (either planned or accidentally). If there is the possibility that under certain combined operations a spurious signal could result in a false caution or warning alarm, such particular operational modes should be excluded, or flagged for special considerations, such as selected operating time schedules.

Other considerations include damage control, safety trade-offs, jettisoning or dumping of hazardous equipment or materials, contingency plans, etc. The contingency plans, which must be established for every Space Shuttle Orbiter/Experiment Payload configuration, must include the planned emergency shutdown of equipment, consideration of the periods during which several (planned) Experiments will be in progress, emergency backout procedures, etc.

8. SUMMARY

Manned missions being considered for the future include the implementation of a wide variety of scientific and application payloads. Current definitions of a broad-based experiment program are portrayed and summarized in the Blue Book. Specific spacecraft designs which incorporate and implement some types of experiments are currently in progress. It is expected that additional experimental spacecraft designs will evolve in concert with experiment program implementation planning.

A basic element for such experiment missions is the Space Shuttle, used not only for transportation to and recovery from low earth orbit, but also for payload deployment and retrieval and as a primary base of operations for an attached experiment payload. The identification of potential emergency situations created by carrying such Experiment Equipment aboard the Space Shuttle and the indentification of Safety Guidelines for eliminating or reducing hazards introduced by the Experiment Equipment and its operation was the subject of this study.

This section provides a summary overview of some of the significant results presented in detail throughout the report.

8.1 INTERACTION CONSIDERATIONS

The wide spectrum of potential Experiment Equipment, operations, and modes of accommodation inherent in a broad-based Space Shuttle experiment program results in a large number of potentially hazardous interactions between Experiment Equipment, experimenters, Accommodating Modules, and the Orbiter. Experiment Equipment and its attendant operational requirements represent discrete hazard sources which can propagate to other equipment (experimental or supportive) within the Accommodating Module or to the Orbiter proper, depending upon the nature of the hazardous occurrence.

Implementation of effective preventive or remedial measures to eliminate or reduce to an acceptable level the safety risk of such experiment-related hazards requires an integrated system approach for every individual Orbiter flight. Such an integration effort must be carried out at three system levels:

1. The Experiment Equipment design level which must include considerations of integration and operational safety
2. The integration of the Experiment Equipment carried and operated within the Accommodation Module
3. The integration of the Accommodation Module with the Space Shuttle Orbiter

The second and third levels must consider the stowed and deployed modes of the Accommodation Module and must consider the full spectrum of potential hazards created by the Experiments carried aboard the Orbiter and operated within it or nearby, including their synergistic effects.

Other considerations include damage control, safety trade-offs, jettisoning or dumping of hazardous equipment or materials, contingency plans, etc. The contingency plans, which must be established for every Space Shuttle Orbiter/ Experiment Payload configuration, must include the planned emergency shut-down of equipment, consideration of the periods during which several (planned) Experiments will be in progress, emergency backout procedures, etc.

8.2 ACCOMMODATION MODE CONSIDERATIONS

Nine basic or generic Experiment Module categories were examined for Experiment Equipment, contents, and related operational requirements. The specific equipment and operational requirements of these generic Experiment Module categories are influenced by the mode of accommodation of the module by the Orbiter. Accommodation modes examined included:

a. attached MSM mode
b. detached RAM mode
c. attached Pallet mode

In some instances all accommodation modes are applicable to a single generic experiment category; the required Orbiter support functions, however, vary with the accommodation mode. Thus, one accommodation mode approach is not necessarily a competitive alternate to the other modes. Instead, selection would be made on the basis of whether the entire capability represented by the specific accommodation mode is desired and whether two or more experiment categories are to be simultaneously carried by the Orbiter.

During non-operational periods (i.e., Experiment Equipment and support equipment in quiescent state during transport to and from orbit), the mode of accommodation would not appear to be a significant variable with regard to hazardous occurrences in that all Experiment Modules are located within the Orbiter cargo bay.

During on-orbit operational periods (i.e., when actual experimentation is taking place), the attached modes of accommodation (Pallet, MSM) would appear to represent a significantly higher hazard source level than the detached RAM mode (for the same Experiment Equipment contents). This is due solely to their attachment to and dependence on (in some cases) the Orbiter.

8.3 HAZARDS AND EMERGENCY SITUATIONS

The use of the Space Shuttle Orbiter for in-space experiment programs could result in the occurrence of emergency situations requiring remedial aid of well-recognized categories. The presence of Experiment Equipment and its attendant operations do not, in and of themselves, pose basic hazards that are significantly different from previously determined space hazards. They do, however, constitute an extremely broad range of specific hazard sources which are additive to the inherent hazard sources existing in space operations in general.

The number of discrete hazard sources for a single Experiment class (FPE) is related to the nature of the Experiment. Materials Science and Manufacturing Experiment Modules, for example, have more hazardous equipment and contents than Earth Survey Experiment Modules. This class-to-class differentiation loses primary significance, however, when multiple experiment categories are considered for integration in a single Experiment Module. The definition of hazard sources and resultant potential emergency situations for such cases have to be based on the specific Experiment Equipment that will actually be used. Again, the synergistic effects of adjacent operational equipment and the interfaces between equipment, the Accommodating Module, and the Orbiter must be included for a complete definition of hazards and emergency situations attributable to a specific Experiment Module and Orbiter mission.

8.4 PREVENTIVE MEASURES

An extensive listing of preventive measures was identified which, if methodically applied, could result in the elimination of the hazard sources or the avoidance of their occurrence. These measures treated the Experiment Module, scientific and support equipment, and any ancillary contents or materials required on the conduct of the experiments. The measures identified design features, provisions, locational features, and operational techniques which should be given consideration and traded-off during the configuration selection and design process.

The formulation of these measures into summary Safety Guideline statements serving to emphasize these areas deserving of further consideration as preventive measures is presented in detail in Volume II, Part 2.

It is emphasized that these measures are not complete solutions, in and of themselves, for the prevention of hazardous occurrences. Rather, they are both general and specific items which should be fully addressed, treated, and traded-off during the origination and coordination phases of the development of failure analyses and safety plans attendant to the system integration of in-space experiments with the Space Shuttle.

Effective consideration of all viable preventive measures is especially important if the trend develops to configure Experiment Modules with the maximum possible number of experiment and supportive equipments per given Module volume. Not only are the number of discrete hazard sources per Module increased in this case, but the possibility of interactive or synergistic reactions may also be increased.

8.5 REMEDIAL MEASURES

Ten basic remedial measures were identified which could result in remedying an emergency situation after the occurrence of a hazard. These measures were selected on the basis of the potential to:

a. prevent further propagation of a hazard

b. neutralize the effects of a hazardous occurrence

c. provide needed:

   (1) physical aid

   (2) medical aid

   (3) metabolic sustenance

d. provide for transfer to a haven of safety, if required

The identified remedial measures encompassed both remedial equipment and their associated operational or functional requirements in the areas listed in Table 6-1.

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10. SYMBOLS AND ABBREVIATIONS

AMU	Astronaut Maneuvering Unit
E	Experiment
EC/LS	Environmental control and life support system
EE	Experiment Equipment
EM	Experiment Module; a spacecraft element containing or housing principal experimental equipments and experimenters (when involved). Can be a Pallet, an MSM, or a RAM in configuration.
FPE	Functional program element; a grouping of experiment classes, or research activities within a particular discipline of research.
LBNPC	Lower Body Negative Pressure Chamber; a medical research equipment.
MSM	A mission-support-module within which research is conducted in a pressurized environment by man.
MWP	Maneuverable Work Platform
Pallet	A structure upon which experimental equipment is mounted.
RAM	Research Application Module containing experimental equipment.
RTG	Radioisotope thermal generator
SOAR	Shuttle Orbital Applications and Requirements; a study conducted by McDonnell Douglas for NASA.
Sortie	A mission class encompassing the conduct of orbital research with the Shuttle system.
sub-FPE	Payload elements within an FPE grouping

Table 2-1. FPE Requirements Summary (Ref. 1) (1 of 2)

	FPE	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	POWER kW	CREW SKILLS	DATA RATE kbs	LOGISTICS 30-DAY AVG kg/(lb) UP	DOWN	POINTING ACCURACY	STABILITY	ALTITUDE & INCLINATION DESIRED	ACCEPTABLE	UNIQUE ENVIRONMENTAL REQUIREMENTS	REMARKS
ASTRONOMY	X-Ray	4240 (9350)	72 (2540)	0.53	5	10^4	800(1) (1800)	800(1) (1800)	5×10^{-6} rad (1 arcsec)	5×10^{-6} rad (1 arcsec) Obser. Time	740 km (400 n.mi.) 0°	370 km (200 n.mi.) > 0°	Minimum contamination	(1) Exchange sensors once each year (2) Cryogenics 500 kg 6 mo. (3) Film 30 da
	Stellar	5390 (13,200)	75 (2620)	0.86	5,6	10^5	320(1) (705) 220(3) (484)	320(1) (705) 220(3) (484)	Desired: 5×10^{-6} rad (1 arcsec) Acceptable: 5×10^{-5} rad (10 arcsec)	2.4×10^{-8} rad (0.005 arcsec) Obser. Time	460 km (250 n.mi.) 50°	460 km (250 n.mi.) > 0°	Minimum contamination Minimum vibration	
	Solar	3470 (7340)	71.5 (2500)	0.97	5	10^6	450(1) (996) 100(3) (230)	450(1) (996) 100(3) (230)	Desired: 5×10^{-7} rad (0.1 arcsec) Acceptable: 1.2×10^{-5} rad (2.5 arcsec)	5×10^{-8} rad (0.01 arcsec) Obser. Time	370 km (200 n.mi.) Sun-synchronous	370 km (200 n.mi.) 0-55°	Minimum contamination	
	Intermediate Size U.V. Telescope	1680 (3370)	11.5 (395)	0.63	5,6	10^4	345(1) (760)	345(1) (760)	Vehicle: 8.7×10^{-3} rad (30 arcmin) Telescope: 2.4×10^{-5} rad (5 arcsec)	Vehicle: 2.4×10^{-5} rad (5 arcsec) Obser. Time Telescope 2.4×10^{-6} rad (0.5 arcsec) Obser. Time	460 km (250 n.mi.) 55°	370 km (200 n.mi.) > 0°	Minimum contamination	
	High Energy Stellar	3400 (7510)	24 (845)	0.49	5,6,14	10^4	290(1) (643)	290(1) (643)	5×10^{-6} rad (1 arcsec)	5×10^{-6} rad (1 arcsec) Observ. Time	740 km (400 n.mi.) 0°	370 km (200 n.mi.) > 0°	Avoid high flux & energy Van Allen belts	
	I.R.	1500 (3300)	74 (2614)	0.3	5	10^4	1100(1)(2) (2420)	200(1)(2) (440)	5×10^{-6} rad (1 arcsec)	5×10^{-6} rad (1 arcsec) Obser. Time	500 km (270 n.mi.) 60	460 km (250 n.mi.) 25 to 55°	Minimum contamination. Minimum heat load orbit.	
PHYSICS	Space Physics Research Lab	2648 (5800)	3.6 (127)	1.0	5,6,12	6.3×10^3	132 (280)	132 (280)	8 mrad (0.5°)	0.16 mrad sec (0.01° sec)	> 185 km (100 n.mi.) Polar	> 50°	Minimum contamination	(4) Not including sub-satellites (5) Not including TAD 4350 kg (9588 lb) (6) Magnet Dewar once year
	Plasma	550(4) (1210)	1.4(4) (50)	0.3	6,12	3.1×10^3	11 (24)	11 (24)	± 8 mrad (± 0.5°)	0.4 mrad/min (0.025° min)	>185 km (100 n.mi.) Polar	> 50°	Minimum contamination	
	Cosmic Ray	15,700(5) (34,500)	137 (5720)	0.71	7,12	15×10^3	157 (345) 1360(5) (3000)	157 (345) 910(5) (2000)	± 16 mrad ± 1.0°	NA	185 km (100 n.mi.) 28°	520 km (270 n.mi.) 55°	Low background radiation	
	Physics & Chemistry	2700 (6200)	10 (350)	9.6	6,9,12,25	2.4×10^3	85 (200)	85 (200)	±0.05 rad (±3°)	NA	> 185 km (100 n.mi.) Any	NA	Low g level (10^{-3} g max.)	
EARTH OBS	Earth Observations Facility	3490 (7720)	26 (930)	4.5	16,18,21, 22,19,26, 28	5×10^4	550 (1222)	550 (1222)	± 8 mrad (± 0.5°)	0.8 mrad sec (0.05° sec)	>185 km (100 n.mi.) Polar	> 50°	Minimum contamination	
COM NAV	COM/NAV Research Lab	756 (1670)	5.2 (184)	2.64	10,12,14, 17	1.04×10^3	28.6 (63)	28.6 (63)	0.175 mrad (0.01°)	1.75 mrad sec (0.1° sec)	> 185 km (100 n.mi.) > 0.49 rad	NA	NA	
MS/MS	Materials Science Research Lab	Minimum 215 (4750) Desirable 3700 (8300)	Minimum 22.3 (788) Desirable 38.2 (1350)	5.0	1,3,6,8, 10,12,14, 15,23,24, 25	10^3	Minimum 75 (165) Desirable 274 (605)	Minimum 75 (165) Desirable 274 (605)	NA	NA	NA	NA	Minimum 0 ± 10^{-3} g Desirable 0 ± 10^{-5} g	

Table 2-1. FPE Requirements Summary (Ref. 1) (2 of 2)

	FPE	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	POWER kW	CREW SKILLS	DATA RATE kbs	LOGISTICS 30-DAY AVG kg (lb) UP	LOGISTICS 30-DAY AVG kg (lb) DOWN	POINTING ACCURACY	STABILITY	ALTITUDE & INCLINATION DESIRED	ALTITUDE & INCLINATION ACCEPTABLE	UNIQUE ENVIRONMENTAL REQUIREMENTS	REMARKS
TECHNOLOGY	Contamination Measurements	190 (420)	0.68 (24)	0.7	6,12	107 - -10 MHz T.V.	15 (33)	11 (25)	$\pm 6.7 \cdot 10^{-3}$ rad ($\pm 0.5°$)	NA	> 260 km (150 n.mi.)	Any S/C Operational Altitude	Experiment peculiar	
TECHNOLOGY	Fluid Management	(SEE TABLE 4-3)												
TECHNOLOGY	EVA	(SEE TABLE 4-4)												
TECHNOLOGY	Advanced S/C Systems Test	670 (1500)	1.3 (46)	2.8	8,9,10, 11,12	18	70 (160)	70 (160)	48 nrad (0.01 arcsec)	NA	NA	NA	Experiment peculiar	
TECHNOLOGY	Teleoperations	670 (1500)	4.4 (155)	0.3	10,11,12	4.9 -8.4 MHz T.V.	80 (180)	5 (11)	NA	NA	NA	NA	No parent S/C maneuvering during docking and undocking.	
LIFE SCIENCES	Medical Research	3010 (6675)	44 (1560)	3.55	1,2,3,4, 12,13,22	0.93	40 (90)	30 (68) 1st 2 yrs 36 (81) 3rd yr & on	NA	NA	NA	NA	No maneuvering during experiments	
LIFE SCIENCES	Vertebrate Research	1063 (2345)	38 (1340)	4.07	1,2,3,4 12,22	1.095	262 (578)	196 (433) 1st 2 yrs 236 (520) 3rd yr & on	NA	NA	NA	NA	Isolation from noise, vibration, & possibly EMI & ESI. Acceleration $<10^{-3}$ g.	
LIFE SCIENCES	Plant Research	2232 (4920)	16 (565)	3.42	1,3,12,22	0.74	67 (148)	50 (110) 1st 2 yrs 60 (132) 3rd yr & on	NA	NA	NA	NA	Isolation from noise, vibration, & possibly EMI & ESI. Acceleration $<10^{-5}$ g.	
LIFE SCIENCES	Microbiology Research	2081 (4600)	14.3 (515)	3.31	1,2,3,12	0.35	27 (60)	20 (44) 1st 2 yrs 24 (53) 3rd yr & on	NA	NA	NA	NA	Isolation from noise, vibration, & possibly EMI & ESI. Acceleration $<10^{-5}$ g.	
LIFE SCIENCES	Invertebrate Research	2044 (4520)	14 (495)	3.28	1,3,12	0.28	22 (49)	17 (38) 1st 2 yrs 20 (44) 3rd yr & on	NA	NA	Highest Inclination Possible	NA	Isolation from noise, vibration, & possibly EMI & ESI. Acceleration $<10^{-3}$ g.	
LIFE SCIENCES	LSPS	3339 (7360)	25 (883)	3.66	2,11,12, 22	330	101 (223)	76 (168) 1st 2 yrs 91 (201) 3rd yr & on	NA	NA	NA	NA	NA	
LIFE SCIENCES	MSI	2669 (5900)	31.4 (1110)	3.71	11,12,13, 21	7	136 (300)	102 (225) 1st 2 yrs 122 (269) 3rd yr & on	NA	NA	NA	NA	Controlled illumination & noise levels. Seclusion from visual & auditory distractions.	

Table 2-2. Crew Skills (Ref. 1)

1.	Biological Technician	14.	Optical Technician
2.	Microbiological Technician	15.	Optical Scientist
3.	Biochemist	16.	Meteorologist
4.	Physiologist	17.	Microwave Specialist
5.	Astronomer/Astrophysicist	18.	Oceanographer
6.	Physicist	19.	Physical Geologist
7.	Nuclear Physicist	20.	Photo Geologist
8.	Photo Technician/Cartographer	21.	Behavioral Scientist
9.	Thermodynamicist	22.	Chemical Technician
10.	Electronic Engineer	23.	Metallurgist
11.	Mechanical Engineer	24.	Material Scientist
12.	Electromechanical Technician	25.	Physical Chemist
13.	Medical Doctor	26.	Agronomist
		27.	Geographer

Table 2-3. Fluid Management Experiment Requirements Summary (Ref. 1) (1 of 3)

EXPERIMENT	MASS (WEIGHT) kg	(lb)	VOLUME m^3	(ft^3)	ENVELOPE m	(ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS	hours	DATA REQUIREMENTS
2.4.1 Interface Stability Fluid Tanks Structural Instr.	 204 136 68 16 424	 (450) (300) (150) (35) (935)	1.4	(50)	1.5 × 1.5 × 0.6	(5 × 5 × 2)	Nominal 100 Peak 500 for 10 sec	Electromechanical Technician 43 hr Thermodynamicist 10 hr	Controlled g level	Set-up 10^{-3} g 10^{-4} g 10^{-5} g	48.0 hr 9.1 9.1 9.1	Data generation rate = 760 bits/sec. Total data sampled = 7×10^6 bits; film storage = 1200 m (4000 ft), 4.5 kg (10 lb) TV = 5.8 MHz
2.4.2 Boiling Heat Transfer Tankage Structure Propellant Trans Sys Vent Sys Press. Instr	 27 27 77 55 45 18 22 270	 (60) (60) (170) (120) (100) (40) (50) (600)	1.5	(54)	0.9 × 0.9 × 1.8	(3 × 3 × 6)	Nominal 27 Peak 500 for 1 hr	Electromechanical Technician 12 hr Thermodynamicist 100 hr	Pressure 1.3×10^{-4} N/m^2 ($<10^{-6}$ Torr). Controlled g level	Set-up 10^{-3} g 10^{-4} g 10^{-5} g	12.0 hr 10.4 17.8 70.3	Data generation rate = 192 bits/sec. Total data sampled = 2×10^6 bits; film storage = 1900 m (6400 ft), 7.2 kg (16 lb) TV = 5.8 MHz
2.4.3 Capillary Studies Chambers Tanks Fluids Methanol Ethanol Pentane Support Sys	 101 89 254 86 408 13 1011	 (230) (195) (560) (190) (900) (160) (2235)	1.8	(65)	0.9 × 0.9 × 0.9	(3 × 3 × 3)	Nominal 115 Peak 165 for 4 min	Thermodynamicist 18 hours	Temperature Nominally 294 K (70° F). Controlled g level	10^{-3} g 10^{-4} g 10^{-5} g	6.0 hr 6.0 6.0	Data generation rate = 25 bits/sec. Total data sampled = 1.62×10^6; film storage = 0
2.4.4 Condensing Heat Transfer Cond Pkg Suppt Eqpt Fluids Cameras Heat Sink Power Supply Instr Controls Misc	 44 17.7 2 52 27 30 9 16 18 216	 (97) (39) (5) (115) (60) (65) (20) (35) (40) (476)	2.1	(75)	1.8 × 1.5 × 0.75	(6 × 5 × 2.5)	Nominal 1.21 kW Peak 1.65 kW for 12 sec 25 times	Electromechanical Technicion 1 hr Thermodynamicist 3.35 hr	Controlled level	Set-up 10^{-3} g 10^{-4} g	1 hr 126 min 75 min	Data generation rate = 5780 bits/sec. Total data sampled = 17×10^6; film storage = 1800 m (6000 ft). 6.8 kg (15 lb)
2.4.5 Two-Phase Flow Regimes Structure Fluid	 45 164 209	 (100) (360) (460)	0.34	(12)	0.6 × 0.6 × 0.9	(2 × 2 × 3)	Nominal 167 Peak 300 for 15 sec	Electromechanical Technician 16 hr Thermodynamicist 12 hr	Constant thermal environment 294 K ~(70 F). Controlled g level	Set-up 10^{-3} g 10^{-5} g	16.0 hr 6.0 6.0	Data generation rate = 160 bits/sec. Total data sampled = 1×10^5 bits; film storage = 1300 m (4400 ft). 5 kg (11 lb)

Table 2-3. Fluid Management Experiment Requirements Summary (Ref. 1) (2 of 3)

EXPERIMENT	MASS (WEIGHT) kg	(lb)	VOLUME m^3	(ft^3)	ENVELOPE m	(ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS	hours	DATA REQUIREMENTS
2.4.6 Propellant Transfer												
Tanks & Stor	227	(500)	51	(1800)	2.4 x 3.6 x 5.4	(8 x 12 x 18)	Nominal	Electromechanical	Pressure 1.3×10^{-4}	Set-up	50 hrs	Data generation rate =
LH_2	386	(850)					1.3 kW	Technician 8 hr	N/m^2 ($<10^{-6}$ Torr).	10^{-3} g	7.0	160 bits/sec. Total data
GH_e	9	(20)					Peak	Thermodynamicist	Controlled g level	10^{-4} g	1.0	sampled = 8×10^6 bits;
Fill & Vent Sys	114	(250)					4 kW for 6 hr	24 hr		10^{-5} g	7.0	film storage = 0
Instr	23	(50)								Coast	33.0	
Insul	18	(40)										
Test Eq	41	(90)										
TV	41	(90)										
Press	41	(90)										
	896	(1980)										
2.4.7 Long Term Storage of Cryogenics												
Tank	451	(1000)	59	(2095)	3.2 x 3.2 x 5.7	(10.5 x 10.5 x 19)	Nominal	Electromechanical	Pressure 1.3×10^{-4}	Set-up	24.0 hrs	Data generation rate =
Shroud	373	(800)					150	Technician 24 hr	N/m^2 ($<10^{-6}$ Torr).	10^{-3} g	12.0	160 bits/sec. Total data
LH_2	1134	(2500)					Peak	Thermodynamicist	Controlled g level	10^{-4} g	199.0	sampled = 5×10^7 bits;
Fill & Vent Sys	113	(250)					1055 for 7.25 hr	400 hr		10^{-5} g	125.0	film storage = 0
Instr	91	(200)								Coast	4100.0	
Insul	127	(280)										
TV	14	(30)										
Zero-G Vent	19	(42)										
Reliquefier	66	(150)										
	2393	(5250)										
2.4.8 Slush Propellant												
Tanks & Ins	236	(520)	24	(840)	2.1 x 3.6 x 3	(7 x 12 x 10)	Nominal	Electromechanical	Pressure 1.3×10^{-4}	Set-up	8.0 hr	Data generation rate =
Heaters	11	(25)					40	Technician 8 hr	N/m^2 ($<10^{-6}$ Torr).	10^{-3} g	3.6	160 bits/sec. Total data
Structure	54	(120)					Peak	Thermodynamicist	Controlled g level	10^{-4} g	42.0	sampled = 5×10^6 bits;
Press. Sys	41	(90)					1200 for 2 min	60 hr		10^{-5} g	152.0	film storage = 0
Test Eq	54	(120)										
Slush	80	(175)										
Fill & Vent Sys	113	(250)										
Instr	68	(150)										
	657	(1430)										
2.4.9 Two-Phase Dynamics												
Test Sec	9	(20)	0.8	(10)	0.6 x 0.6 x 0.75	(2 x 2 x 2.5)	Nominal	Electromechanical	Controlled g levels	Set-up	2.0 hr	Data generation rate =
Support	66	(145)					400	Technician 2 hr		10^{-3} g	0.7	1.6 bits/sec. Total data
Inst	20	(45)					Peak			10^{-5} g	0.7	sampled = 650 bits;
	95	(210)					1000 for 1.8 sec			Coast	0.7	film storage = 7.5 m (25 ft)
2.4.10 Channel Flow Systems												
Test Sec	23	(50)	0.59	(21)	0.6 x 0.8 x 1.2	(2 x 2.7 x 4)	Nominal	Electromechanical	Controlled g levels	Set-up	8 hr	Data generation rate =
Support	91	(200)					750	Technician 8 hr		10^{-3} g	2	10.0 bits/sec. Total data
Inst	34	(75)					Peak			10^{-5} g	2	sampled = 3000 bits;
	148	(325)					1800 for 1.8 sec			Coast	2	film storage = 12 m (40 ft)

Table 2-3. Fluid Management Experiment Requirements Summary (Ref. 1) (3 of 3)

EXPERIMENT	MASS (WEIGHT) kg	(lb)	VOLUME m^3	(ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS	hours	DATA REQUIREMENTS
2.4.11 Conical Flow Systems											
Test Sec	9	(20)	0.62	(22)	0.6 x 0.9 x 1.1 (2 x 3 x 3.5)	Nominal 200 Peak 750 for 1.5 sec	Electromechanical Technician 2 hr	Controlled g levels	Set-up	2.0 hr	Data generation rate = 0.1 bits/sec. Total data sampled = 100 bits; Total film storage - 6 m (20 ft)
Support	34	(75)							10^{-3} g	0.5	
Systems	20	(45)							10^{-5} g	0.5	
	63	(140)							Coast	0.5	

Table 2-4. EVA Experiment Requirements Summary (Ref. 1)

	WEIGHT kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER	CREW SKILLS	ENVIRONMENT REQUIREMENT	EXPERIMENT TIME LIMITS	DATA REQUIREMENTS	RANGE m (ft)	COMMUNICATION	RADAR	STABILIZATION AND CONTROL	THERMAL CONTROL
4.1 ASTRONAUT MANEUVERING UNIT	2 Units 120 (265)	6(20)	3 x .6 x 1.5 (9 x 2 x 5)	Standby = 193 W Average = 332 W Maximum = 370 W	Elect/ Mech Tech	100% O_2 ± 26 kN/m^2 (3.75 psia) to Pressure Suit	8 Hr Maximum	5000 Bits/sec	60 (200) Any Orbital Direction	Voice	None	N/A	Stored ~ 223 to 340 K (-60 to 160°F) Operational 270 to 322K (20 to 120 F)
4.2 MANEUVERABLE WORK PLATFORM	2 Units 1445 (3200)	6(200)	3 x 3 x 4 (10 x 9 x 14)	2 KW-Hr Per Mission with Redundancy (14 Hour Turn Around)	Elect/ Mech Tech	100% O_2 ± 26kN/m^2 (3.75 psia) to Pressure Suit Metabolic Rate Avg = 370 Watt (1250 BTU/Hr Peak = 630 Watt (2150 BTU/Hr	8 Hrs plus 2 Hr Rescue	8000 Bits/sec	2000(4400) Any Orbital Direction	Range = 3 KM Voice Telemetry Alert Alarm.	Range = 10.5 KM Accuracy = ± 0.3% to 2 KM	N/A	Man and Onboard Subsystems

Table 2-5. FPE-Subgroup Analysis, Space Physics Example (Ref. 2)

Experiment		Weight kg (lb)		Volume m^3 (ft^3)	
P-1	Space Physics Research Laboratory (Space Station)	1,373.0	(3,024)	4.47	(159.7)
P-1A	Atmospheric and Magneto Science	292.4	(644)	1.16	(41.3)
P-1B	Cometary Physics	105.6	(232.5)	0.58	(20.6)
P-1C	Meteoroid Science	40.1	(88.5)	0.81	(28.9)
P-1D	Thick Material Meteoroid Penetration*	865.0	(1,909)	1.47	(48.5)
P-1E	Small Astronomy Telescopes	96.0	(210)	0.51	(18.0)

*Divided because of weight distribution

Table 2-6. FPE-Sub-FPE Relationships (Ref. 2)

Astronomy

- A-1 X-Ray Stellar Astronomy
- A-2 Advanced Stellar Astronomy
  - A-2A Intermediate Stellar Telescope
- A-3 Advanced Solar Astronomy
  - A-3A 1.5m Photoheliograph/0.25m XUV Spectroheliograph/0.5m X-Ray Telescope
  - A-3B Solar Coronagraph
  - A-3C Photoheliograph
  - A-3D X-Ray Spectroheliograph
  - A-3E UV Long Wave Spectrometer
- A-4 Intermediate Size UV Telescopes
  - A-4A 0.5m Narrow Field UV Telescopes
  - A-4B 0.3m Wide Field UV Telescopes
  - A-4C Small UV Survey Telescopes
- A-5 High Energy Astronomy
  - A-5A Lower Energy Experiment
  - A-5B Higher Energy Experiment
- A-6 IR Telescope

Physics

- P-1 Space Physics Research Lab
  - P-1A Atmospheric and Magneto Science
  - P-1B Cometary Physics
  - P-1C Meteoroid Science
  - P-1D Thick Material Meteoroid Penetration
  - P-1E Small Astronomy Telescopes
- P-2 Plasma Physics and Environmental Perturbation Lab
  - P-2A Wake Measurements from Station and Booms
  - P-2B Wake Measurements from Subsatellites
  - P-2C Plasma Resonances
  - P-2D Wave Particle Interactions
  - P-2E Electron and Ion Beam Interaction
- P-3 Cosmic Ray Physics Lab
  - P-3A Lab Without Total Absorption Device
  - P-3B Lab With Total Absorption Device
  - P-3C Plastic/Nuclear Emulsions
- P-4 Physics and Chemistry Lab
  - P-4A Airlock and Boom Experiments
  - P-4B Flame Chemistry and Laser Experiments
  - P-4C Test Chamber Experiments

Earth Survey

- ES-1 Earth Observation Facility
  - ES-1A Meteorological and Atmospheric Science
  - ES-1B Land Use Mapping
  - ES-1C Air and Water Pollution
  - ES-1D Resource Recognition
  - ES-1E Natural Disasters
  - ES-1F Ocean Resources
  - ES-1G Minimum Payload

COM/NAV

- C/N-1 Communications/Navigations Facility
  - C/N-1A COM/NAV Subgroup A
  - C/N-1B COM/NAV Subgroup B

Materials Science and Manufacturing

- MS-1
  - MS-1IA 5-Day Group, Biological
  - MS-1IB 5-Day Group, Levitation
  - MS-1IC 5-Day Group, Furnace
  - MS-1ID 5-Day Group, Small and Low Temp
  - MS-1IIA 30-Day Group
  - MS-1IIB 30-Day Group
  - MS-1IIC 30-Day Group
  - MS-1IIIA Space Station Group
  - MS-1IIIB Space Station Group
  - MS-1IIIC Space Station Group
  - MS-1IIID Space Station Group
  - MS-1IIIE Space Station Group

Technology

- T-1 Contamination Measurements
  - T-1A Contamination Package 1
  - T-1B Contamination Package 2
- T-2 Fluid Management
  - T-2A Long Term Cryogenic Storage
  - T-2B Short Term Cryogenic Storage
  - T-2C Slosh Propellant
  - T-2D Non-Cryogenic Storage 1
  - T-2E Non-Cryogenic Storage 2
- T-3 EVA
  - T-3A Astronaut Maneuver Unit
  - T-3B Manned Work Platform
- T-4 Advanced Spacecraft Systems Test
  - T-4A Long Duration Systems Tests
  - T-4B Medium Duration Tests
  - T-4C Short Duration Tests
- T-5 Teleoperations
  - T-5A Initial Flight
  - T-5B Functional Manipulation
  - T-5C Ground Control

Life Science

- LS-ST/A Minimal Medical Research Facility (Station)
- LS-ST/B Minimal Life Science Facility (Station)
- LS-ST/C Interim Life Science Facility (Station)
- LS-ST/D Dedicated Life Science Facility (Station)
- LS-SH/A 5-Day Life Science Facility (Shuttle)
- LS-SH/B 30-Day Life Science Facility (Shuttle)

Table 2-7. Candidate Blue Book RAM Payloads, Eight Free-Flying Research and Applications Modules (Ref. 2)

Astronomy	A-1	X-Ray Stellar Astronomy
	A-2	Advanced Stellar Astronomy
	A-3	Advanced Solar Astronomy
	A-4	Intermediate Size UV Telescopes
	A-5	High Energy Stellar Astronomy
	A-6	Infrared Astronomy
Physics	P-3	Cosmic Ray Physics Laboratory
Technology	T-2	Fluid Management

Table 2-8. Candidate Payload Subgroups (Ref. 2)

Pallet Operations	Limited MSM			MSM Extension Module	RAM Delivery Service Checkout
	$1.5m^3$ Volume	$4.0m^3$ Volume	$12.0m^3$ Volume		
A-3C	A-3E	All of $1.5m^3$	All of $4.0m^3$	A-3C	A-1
A-4A, B, C	P-1A, B, C, E	Plus:	Plus	A-4A, B, C	A-2
A-5A, B	P-2A, B, C, D, E	A-3C	ES-1A, B, C, D, E, F, G	P-1A, B, C, E	A-3
A-6	P-3C	A-4B, C	LS-1A	P-2A, C	A-4
P-1A, B, C, E	P-4C	P-4A		P-3C	A-5
P-2X	MS-11C, D	C/N-1A, B		P-4A, B, C	A-6
P-3C	T-1A, B,	MS-11A, B		ES-1A, B, C, D, E, F, G	P-3
P-4X	T-3A			C/N-1A, B	T-2
ES-1A, B, C, D, E, F, G	T-3B*			MS-11A, B, C, D	
C/N-1A, B	T-5A*, B*, C*			T-1A, B	
T-1A, B				T3A	
T-3A, B				LS-1A	
T-5A, B, C				A-5A, B;A6	
MS-11A				P-2B, D, E	
				T-3B	
				T-5A, B, C	

*Separate Pallet

Table 3-1. Experiment/Support Requirements – Astronomy Modules, Attached MSM Mode (Sheet 1 of 2)

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
A-3 C, D, E: Adv. Solar Astronomy	A-3 C: Photoheliograph	(Space vacuum)	Setup/deploy/operate	130 (sun)/ 170 (night)	170	Thermal fluids; 100 - 350W; N_2 purge
	A-3D: X-ray photoheliograph	(Space vacuum)	No EVA planned	250/210	350	
	A-3E: XUV spectrometer	(Space vacuum)		30/8	90	
	(Passive at launch; sensitive to all contaminants)	(Electronic imaging; no film)	Astronomer/ astrophysicist			
A-4 A, B, C: Inter. Size UV Telescopes	A-4A: Narrow-field UV telescope (camera and film transport, spectrographs; ass'y mounted on gimbal rings)	Film vault Film processor Optics laboratory Scientific airlock	Setup/deploy/operate No EVA planned (would be for A-4C if no scientific airlock)	141/300	300	200 - 800W
	A-4B: Wide-field UV telescope (on ATM-type platform with instruments as in A-4A)	Film vault Film processor Optics laboratory		120/325	325	
	A-4C: Small UV survey telescope (instruments as above)	Film vault Film processor Optics laboratory	Astronomer/ astrophysicist Retrieve/replace film	20/2	20/56	
	(Passive at launch; sensitive to contaminants)	(Space vacuum)				
A-5 A, B: Hi-energy Astronomy	X-ray telescopes (grazing incidence and venetian blind), spectrometer/polarimeter assy, X-ray counter array, *detector array, gamma ray* spectrometer, spark-chamber (active cryogenics in-5B; -5A passive at launch; slight to moderate sensitivity to contaminants)	(Space vacuum) Gas (-5A) Gas and solid *cryogenics* (-5B)	Setup/deploy/operate Align/calibrate No EVA planned Shutdown/maint. Physicist/ astrophysicist	116/221	142/391	Cryogenics
A-6: Infrared Astronomy *(more)*	IR telescope (optical), interferometer, IR detector array, auxiliary optical telescope (imaging), elevator/retractor mechanism, gimbals, pressurized service	(Space vacuum) LNe LHe	No EVA Setup/deploy/operate	260	300	500W; dry N_2; LHe; LNe;

Table 3-1. Experiment/Support Requirements — Astronomy Modules, Attached MSM Mode (Sheet 2 of 2)

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
A-6: Infrared Astronomy (con't)	Housing, chilldown, and cooling equipment: 2 liq neon tanks valves, vents, regulators 2 insulated receiving tanks (for gaseous neon collection; vented to space or reliquified) (Active cryogenics; sensitive to contaminants, particularly while cooled to cryo temps.)		Astronomer/ astrophysicist/ astronaut			

Table 3-2. Experiment/Support Requirements — Physics Modules, Attached MSM Mode (Sheet 1 of 2)

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
P-1: Space Physics Research Laboratory -1A: Atmos./Magneto. Science -1B: Cometary Physics -1C: Meteoroid Science -1E: Small Astronomy Telescope	Photometric cluster, scanning spectrometers, image isocon TV, mass spectrometers, electric field probes, energetic particle sensors (alum. foil), gaseous release device (ICN, heater, battery pack), meteoroid sensors (panels, dust analyzers) (Passive at launch; minimize contaminants)	Scientific airlocks, extendable platforms, sub-satellites Film (-1A, -1B, -1C) Workbenches Film vault NH_3 cannisters (-1B) ICN cannisters (-1B) (Space environment)	Crew EVA (for external mounts) (P-1A & 1C) Deploy systems, booms, etc. Setup/operate/deploy Electromech.tech./physicist/EVA backup Retrieve/replace film	690 1600 19 458	1137 4000 60 1137	3 - 7 kW;
P-2: Plasma Physics Laboratory -2A: Wake measurements from station -2B: Wake measurements from subsatellite -2C: Plasma resonances -2D: Wave particles -2E: Electron and ion beams (Passive at launch; particle sensors, guns, oxide-cathodes to be hermetically sealed in dry N_2 until use)	Boom-mounted sensors (magnetic and electric fields, ion and electric density), gimbal platforms, oscilloscope, sub-satellite (cold gas propulsion, batteries, particle and field sensors), inflatable ECHO balloons, boom-mounted transmitters and accelerators (up to 10 kW), rechargeable batteries, inverters, pulsers, motor-driven stem, large antennas	Booms; film Scientific airlocks (vacuum & O_2/N_2 at 14.7 PSIA) Sub-satellite maintenance (sensor replace/maint., refueling, charge batteries) Two-beam laser radar to track balloons (with on-board display)	No EVA planned Setup/deploy/operate Operate Maintain subsatellite Deploy antennas, transmitters, accelerators, Physicist/electromech. tech./pilot-navigator	438 111/300 260/616 100/345 200/340	438 300 616 345 540	500W; N_2 for subsatellite
P-3: Cosmic Ray Physics Laboratory -3C: Plastic/Nuclear emulsions (-3C passive)	Plastic and nuclear emulsions	Mechanisms to move emulsions, (O_2/N_2 at 14.7 PSIA; vacuum OK for -3C)	Electromech. tech./physicist Setup/deploy/operate	none		
P-4: Physics and Chemistry Laboratory -4A: Airlock and boom exp. -4B: Flame chemistry, laser experiments -4C: Test chamber exp. Typical Experiments: 1. Molecular beam scattering 2. Gas-surface interactions (more)	"Suitcase payloads" for plug-in; scattering chamber (gas jet, N_2, O_2, He), ionization chamber, mass spectrometer, detectors, oscilloscope, plating source, heaters, combustion chamber, oxidizer and fuel tanks, camera (film), inert gas supply, heat exchangers, transducers, electronics, insulation, thermal shielding, etc.	Working areas and equipment (power, gases, vacuum lines, airlocks, multipurpose test equip., central data collection system, deployment devices and manipulators), feedthroughs (elec., fluid, mech), view ports (visible, IR, UV)	Deploy systems, perform exper. EVA not required Setup/deploy/operate	40 190 450	270 510 1900	270 - 2615W; LHe

Table 3-2. Experiment/Support Requirements – Physics Modules, Attached MSM Mode (Sheet 2 of 2)

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
P4: Physics and Chemistry Laboratory (con't)						
3. Zero-g combustion 4. Critical state experiment	(Passive at launch, except -4C with cooled magnet)	Booms Fire and emerg. syst. Film, mag. tape Waste disposal (Air or N_2 at 14.7 PSIA) LH_2, N_2, Freon	Physicist/ physical chemist/ thermodynamicist/ electromech. tech.			

Table 3-3. Experiment/Support Requirements – Earth Survey Modules, Attached MSM Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
ES-1: Earth Observation Facility	Data acquisition sensors (imagers, radiometers, spectrometers, polarimeters, sferics detectors, optical radar), sensor M&R unit, sensor control and display, data analysis (computer, photo development and analysis), TV	No obstruction in field of view	M & R (preferably IVA); no EVA planned			LN_2 coolant service;
-1A: Meteor. and Atmos. Science				4519	6191	3051 - 5134W
-1B: Land use mapping		Accessible sensors		5085	6300	
-1C: Air and water pollution				4255	5376	
-1D: Resource recognition		Magnetic tape	Setup/deploy/operate	4955	6026	
-1E: Natural disasters		Film		5126	6219	
-1F: Ocean resources		Photo laboratory		4233	5473	
-1G: Min. payload	(Passive at launch)	(N_2/O_2 at 0 - 15 PSIA)	Elec. eng/ Electromech. tech/ Optical tech/ Oceanographer/ Meteorologist Photo. tech. Cartog. Agronomer Geologist Hydrologist	3422	4215	
			On-orbit cleaning of sensors			

Table 3-4. Experiment/Support Requirements – Comm/Nav Modules, Attached MSM Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
C/N-1: Comm/Nav Facility -1A: Exp. 1-7 -1B: Exp. 1-7, 12, 13 Experiments: 1. Opt. freq demo. 2. MM wave comm. system 3. Surv. and search and rescue 4. Sat. nav. techniques 5. On-board laser ranging 6. Auton. nav. systems 7. Transmitter breakdown 8. Terrestrial noise 9. Noise source ident. 10. Sat. radiated energy 11. Tropospheric propagation 12. Plasma propagation 13. Multipath measurements	Receivers, transmitters, processors, parabolic antennas, transponders, inflatable spiral antenna, nav. sensors package (inertial, Doppler, optical, etc.), SHF polarized horn, VHF dipole antenna (Passive at launch)	Several exp. require one terminal in another vehicle (subsatellite) Voice links, T/M links, airlocks, docking ports (N_2/O_2 at 0 - 14.7 PSIA) Avoid waste dumps during optical exp. Magnetic tape, film	Experimentation Data processing Maintenance Troubleshooting EVA Erection of large parabolic expandable truss antenna (PETA) Setup/deploy/operate Electronic eng./ electromech. tech./ optical tech./ microwave specialist	 973 950	 1945 1945	3 kW

Table 3-5. Experiment/Support Requirements – Materials and Manufacturing Modules, Attached MSM Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
MS-1: Materials Science Research Laboratory -IIA: Biological exp. -IIB: Levitation exp. -IIC: Furnace exp. -IID: Small and low temp exp. -IIIA: Mat'ls science and manufacturing -IIIB: Metal matrix composites -IIIC: Crystal growth, free casting, etc. Experiment Areas: 1. Metallurgical processes a. composite mat'ls b. metal forms c. free casting d. liquid dispersions 2. Crystal growth a. from solution b. from melts c. from vapor d. supercooling/ nucleation 3. Glass processes a. preparation b. processing 4. Biological processing a. electrophoretic separation b. lyophilization 5. Physical processes in fluids a. convection	Laboratory unit, power conversion, central control, facilities for melting, casting, and biological processing (Passive at launch)	Atmos. supply and control, power conditioning, clean-up and refurbishment, storage (open mat'ls and fluids) "Accident control system" Sample storage space (N_2/O_2 at 0 - 15 PSIA) Experiment materials	Experimentation (melting, casting, processing) Clean-up Refurbishment No EVA planned Setup/deploy/operate "Store" samples Electromech.tech/ mat'ls scientist/ metallurgist/ bio.tech/ electronic engr./	 700 600/1000 530/830 150/200 200/2500 3000/6000 1500/5000	 1000 1500/2000 700/1030 Not avail. 2000/15,000 7000/55,000 7200/15,000	None specified

Table 3-6. Experiment/Support Requirements — Contamination Modules, Attached MSM Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
T-1: Contamination Measurements -1A: Pkg No. 1 -1B: Pkg No. 2 Purpose: Identify types, quantities, distribution, effects of contaminants in the S/C-induced environment (S/C and instruments)	Photoelectric polarimeter, quartz crystal contaminant gauge, Portable spectroreflectometer and exposure rack, Mass spectrometer, Contaminant measurement camera, Optical properties module (drive shaft, phototube, gauge, table), Active cleaning device (with umbilical), Contamination control panel (electromagnetic and electrostatic protective devices, gas supply line, gas cushion protective device, contaminant gauge, mass spectrometer) (Passive at launch; kept in sealed containers, including samples)	Scientific airlocks, external mounts, extendable platforms, subsatellites (Space environment) N_2, film	EVA Deploying Testing Cleaning Mounting Setup/deploy/operate Physicist/ electromech. tech./ backup EVA/	345/360 100	400 100	GN_2 to fill exp containers; 28 VDC; 120/240 VAC

Table 3-7. Experiment/Support Requirements — Equipment Technology Modules, Attached MSM Mode (Sheet 1 of 2)

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
T-3: EVA -3A: AMU -3B: MWP	Backmounted AMU [life support, cold-gas (O_2) thrusters, auto. stabil. and control (gyros), elect. power (batt.), O_2 storage bottle, hand controllers] Hard-suited MWP (N_2H_4 propulsion system, displays, life-support system, anchoring grappling arms, extendable antenna, tools and spares module, floodlights, ranging radar, elect. and propellant umbilicals) (Passive at launch)	EVA airlocks, batt. recharge, prop. tanks (100 percent O_2 to pressure-suit at 3.75 PSIA O_2 film video tape Hydrazine $LiOH$ H_2O	EVA Cargo-transport, docking, grappling, Build/repair Setup/deploy/operate Electromech. tech.	330 330	370 400	300-330W; 6000 PSIA O_2 For decay check on -3A; He for leak check on -3B;
T-4: Adv. S/C Systems Tests -4A: Long duration tests -4B: Med.duration tests -4C: Short duration tests (Passive at launch)	"Carry-on" experiments: O_2 recovery and biowaste resistojet (O_2, water, power, electrolysis cell, thrusters), maintenance electronics pkg., thermal coating refurbishment (sample plates, instruments), absorption refrigeration syst. (Hx, generator, radiator, power), leak detection and repair, maintainable ACS (tanks, He, propellants, valves, lines, thrusters), ball-bearing lub., adv. guidance syst., exposure of mat'ls, mat'l fatigue (fat. machine, specimens, holders), fire sensing and suppression (module, detector, extinguisher)	Airlocks, stabilized platforms, deployment booms, test cells, instruments fireproof chamber	EVA (for short duration test; -4C) Maintenance Refurbish Repair Setup/deploy/operate Electromech. tech./ elect. eng'r./ mech. eng'r.	Not available Not available 100	 565	None specified

Table 3-7. Experiment/Support Requirements – Equipment Technology Modules, Attached MSM Mode (Sheet 2 of 2)

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operations	Average	Peak	
T-5: Teleoperations -5A: Initial flight -5B: Functional manipulation -5C: Ground control	Small, free-flying T/O S/C (manipulator arms, camera, TV camera, lights, antenna, docking legs, cold GN_2 prop. tank, thrusters, docking interface, batteries, sensors	Control station, 2-way RF link, 2-man airlock (No environment req't; N_2/O_2 at 0-14.7 PSIA accept.)	EVA not planned (inspection, assembly, maintenance, servicing in lieu of EVA by astronaut)	 160/300 160/300 160/300	 300 300 300	300W; He for leak check
	(Passive at launch)	Cold N_2 (gas)	Setup/deploy/operate Electromech. tech/ elect. eng'r./ mech. eng'r			

Table 3-8. Experiment/Support Requirements — Life Sciences Modules, Attached MSM Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
Laboratory Facilities (general) (All passive at launch; animals, insects, plants and support equip. to contrary)	Visual records, and microscopy unit, data management unit, exp. support unit (power, gas, fluid, vacuum distribution), prep. preserv., and retrieval unit, biochemical/biophysical analysis, M&R/fabrication unit, ancillary-storage, bioresearch centrifuge, radiobiology unit, airlock EVA unit	EVA airlock, (O_2/N_2 at 15 PSIA) Equipment spares	EVA Setup/deploy/operate Medical doctor Life science tech.	1146/2165 (core power typical) Depends on experiment selection	1400/4700 given as	Water; N_2O_2; 1.1-2.2 kW; provisions for freezing, biological samples
LS-1 Medical Research Lab	Biomedical measurement unit, lower body negative pressure chamber, ergometer (bicycle), rotating litter chair					
LS-2 Vertebrate Research Facility	Primate holding unit, small mammal holding unit, animals (4 primates, 256 rats and/or mice, marmots, etc.)	Holding and rearing accommodations, food, etc., waste disposal				
LS-3 Plant Research Fac.	Plant holding and growing unit, plants	Plant food, water, etc.				
LS-4 Cells and Tissue Research Lab.	Cells and tissue holding unit (incubators for ECS, inst., operations), wide variety of organisms (single-celled organisms and tissues in culture)	Disposal				
LS-5 Invertebrate Research Lab.	Holding and rearing units, variety of invertebrates	Waste disposal				
LS-6 Life Support and Protective Systems	Test unit, gas analysis, microbiology analysis, biomedical analysis, maintenance, test hardware (e.g., CO_2 collection unit, zero-g shower, etc.).	EVA airlock	EVA			
LS-7 Man-System Integration	Human research centrifuge, nobility unit (portable metabolic analyzer, impact force detector, portable accelerometers), behavioral measurements unit	Men				

Table 3-9. Experiment/Support Requirements – Astronomy Modules, Detached RAM Mode (Sheet 1 of 2)

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
A-1: X-ray Stellar Astronomy	X-ray telescopes, proportional counters, scintillation counters, flat crystal spectrograph, X-ray detectors, (passive at launch except for active cryogenics)	Cryogenics (Space vacuum)	Setup/deploy/operate No EVA planned Top-off cryostat Astronomer/astrophysicist	481	566	1000W; Dry N_2, Cryogenics
A-2: Adv. Stellar Astronomy	Telescope (remotely controlled), alignment and calibration equipment, imaging microscope, electronic imaging tube, film-plate holder, spectrophotometer, spectrometers, polarimeter (passive at launch except for heaters)	Film, Film vault, Film processor, Optics lab. (Space vacuum)	Operate telescope setup/deploy No EVA planned Change/Develop film Astronomer/astrophysicist	1265-1765	1295-1950	2000W; GN_2 for purging, temp. controlled containers
A-3: Adv. Solar Astronomy	Photoheliograph, X-ray telescope, XUV spectroheliograph, X-ray photoheliograph, XUV spectrometer, solar coronographs (Passive at launch; sensitive to contaminants)	(Space vacuum) (Electronic imaging, no film)	Setup/deploy/operate No EVA planned Astronomer/astrophysicist Align/focus optics	780 (operate) 540 (standby)	970	<1200W; N_2 for purge
A-4: Inter. Size UV Telescopes	A-4A: Narrow Field UV telescope (camera and film transport, spectrographs; ass'y mounted on gimbal rings) A-4B: Wide Field UV telescope (on ATM-type platform with instruments as in A-4A) A-4C: Small UV survey telescope (instruments as above) (Passive at launch, sensitive to contaminants)	Film vault Film processor Optics lab. Scientific airlock Film vault Film processor Optics lab. Film vault Film processor Optics lab. (Space vacuum)	Setup/deploy/operate No EVA planned (would be for A-4C if no scientific airlock) Astronomer/astrophysicist	(555-575)	(625)	< 1000W

Table 3-9. Experiment/Support Requirements – Astronomy Modules, Detached RAM Mode (Sheet 2 of 2)

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facilities Utilities
		Equipment	Operation	Average	Peak	
A-5: Hi-Energy Astronomy	X-ray telescopes (grazing incidence and venetian blind), spectrometer/polarimeter assy, X-ray counter array, detector array, gamma ray spectrometer, spark-chamber (active cryogenics in -5B; -5A passive at launch; slight to moderate sensitivity to contaminants)	(Space vacuum) Gas (-5A) Gas and solid cryogenics (-5B)	Setup/deploy/operate Align/calibrate No EVA planned Shutdown/mainten. Physicist/astrophysicist	(300)	(482)	500W; Cryogenics
A-6: Infrared Astronomy	IR telescope (optical), interferometer, IR detector array, auxiliary optical telescope (imaging), elevator/retractor mechanism, gimbals, pressurized service housing, chilldown, and cooling equipment: 2 liq. neon tanks valves, vents, regulators 2 insulated receiving tanks (for gaseous neon collection; vented to space or reliquified) (Active cryogenics; sensitive to contaminants, particularly while cooled to cryo temps.)	(Space vacuum) LNe LHe	No EVA Setup/deploy/operate Astronomer/astrophysicist/astronaut	260	300	< 500W; Dry N_2; LHe; LNe

Table 3-10. Experiment/Support Requirements – Cosmic Ray Physics Modules, Detached RAM Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
P-3: Cosmic Ray Physics Lab	Total Absorption Device (TAD, cesium iodide scintillators), TASC device, superconductive magnet spectrometer (LHe dewar), detector bays (counters, spark-chambers), plastic and nuclear emulsions (Launched with LHe in magnet dewar)	Mechanisms to move emulsions Argon/Methane Particle flux sensor (O_2/N_2 at 14.7 PSIA) (vacuum OK for emulsions) Magnet dewar	Replace LHe dewar intact once each year Electromech. tech./ physicist Possible EVA (4 hrs. once each year) Setup/deploy/operate	850	850	700W; LHe and LN_2 precooling; O_2/Methane

Table 3-11. Experiment/Support Requirements – Fluid Management Modules, Detached RAM Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
T-2: Fluid Management -2A: Long term cryo storage -2B: Short term cryo storage -2C: Slush propellant -2D: Non-cryo's #1 -2E: Non-cryo's #2	Long and short term tanks and cryogenics; transfer lines, GHe and pressurization system, slush tanks, plumbing (fill, drain, vent), mixers, separators, Hx, condensers, batteries, cameras, pumps, blowers, film, temp. and pressure instruments, etc. (Passive at launch)	Film TV recording Display equipment LH_2	Observe/monitor (TV) Setup/deploy/operate Electromech. tech. / thermodynamicist	750-1327	4000	4500W

Table 3-12. Experiment/Support Requirements — Life Sciences Modules, Detached RAM Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Utilities Facility
		Equipment	Operation	Average	Peak	
Laboratory Facilities (General) (All passive at launch; animals, insects, plants, and support equipment to contrary).	Visual records and microscopy unit, data management unit, exp. support unit (power, gas, fluid, vacuum distribution), prep. preserv., and retrieval unit, biochemical/biophysical analysis, M&R and fabrication unit, ancillary storage, bioresearch centrifuge, radiobiology unit, airlock EVA unit	EVA airlock (O_2/N_2 at 15 PSIA) Equipment spares	EVA Setup/deploy/operate Medical doctor/ life science tech.	1146/2165 (Core power given as typical) Depends on experiment selection	1400/4700	Water; N_2, O_2; 1.1-2.2 kW; Provisions for freezing biological samples
LS-1 Medical Research Lab	Biomedical measurement unit, lower body negative pressure chamber, ergometer (bicycle), rotating litter chair					
LS-2 Vertebrate Research Facility	Primate holding unit, small mammal holding unit, animals (4 primates, 256 rats and/or mice, marmots, etc.)	Holding and rearing accommodations, food, etc., waste disposal	Prepare spec.			
LS-3 Plant Research Fac.	Plant holding and growing unit, plants	Plant food, water, etc.	Prepare spec.			
LS-4 Cells and Tissue Research Lab.	Cells and tissue holding unit (incubators for ECS, inst., operations), wide variety of organisms and tissues in culture	Disposal				
LS-5 Invertebrate Research Lab.	Holding and rearing units, variety of invertebrates	Waste disposal				

Table 3-13. Experiment/Support Requirements – Satellite Payloads, Detached RAM Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
1. HEAO (A4) (High Energy Astronomy Observatory)	Solid-state detectors Scintillator crystals Photomultiplier tubes	ACS (N_2H_4, GN_2 pressurization); batteries, pyros; Tug prop. stage (LO_2, LH_2, GN_2, rocket engine)				
2. EOS (SA11) (Earth Observation Satellite)	Spectrometer IR radiometer Microwave radiometer Side-looking radar	ACS (N_2H_4, GN_2 pressurization); batteries, pyros; Delta Stage (UDMH, N_2H_4, GHe, rocket engine)				
3. Pioneer-Jupiter (PL11)	UV photometer IR radiometer Magnetometer Geiger-tube telescope UV spectrometer Television, detectors (RF, plasma wave, trapped radiation, particle, X-ray)	ACS (N_2H_4, GN_2 pressurization); batteries, pyros; RTGs Centaur stage (LO_2, LH_2, GHe, H_2O_2, rocket engine) TE-364-4 motor				
4. Comm/Nav II (NO 5)	LIT surveillance transponder, LIT backlink transponder, Navstar nav. signal generator & transponder	ACS (N_2H_4, GN_2 pressurization); batteries, pyros; Agena stage (UDMH, IRFNA, GN_2, rocket engine)				

Table 3-14. Experiment/Support Requirements — Astronomy Modules, Attached Pallet Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
A-3C: Adv. Solar Astronomy	A-3C: Photoheliograph (Passive at launch; sensitive to all contaminants)	(Space vacuum) (Electronic imaging, no film)	Setup/deploy/operate No EVA planned Astronomer/astrophysicist	130 (sun) 170 (night)	170	Thermal fluids; 100-350W; N_2 purge
A-4 A, B, C: Inter. Size UV Telescopes	A-4A: Narrow-field UV telescope (camera and film transport, spectrographs; ass'y mounted on gimbal rings)	Film vault Film processor Optics lab. Scientific airlock	Setup/deploy/operate No EVA planned (would be for A-4C if no scientific airlock)	141/300	300	200-800W
	A-4B: Wide-field UV telescope (on ATM-type platform with instruments as in A-4A)	Film vault Film processor Optics lab.	Astronomer/astrophysicist	120/325	325	
	A-4C: Small UV survey telescope (instruments as above) (Passive at launch; sensitive to contaminants)	Film vault Film processor Optics lab. (Space vacuum)		20/2	20/56	
A-5 A, B: Hi-Energy Astronomy	X-ray telescopes (grazing incidence and venetian blind), spectrometer/polarimeter ass'y, X-ray counter array, detector array, gamma ray spectrometer, spark-chamber (active cryogenics in -5B; -5A passive at launch; slight to moderate sensitivity to contaminants)	(Space vacuum) Gas (-5A) Gas and solid cryogenics (-5B)	Setup/deploy/operate Align/calibrate No EVA planned Shutdown/maint. Physicist/astrophysicist	116/221	142/391	Cryogenics
A-6: Infrared Astronomy	IR telescope (optical), interferometer, IR detector array, auxiliary optical telescope (imaging), elevator/retractor mechanism, gimbals, pressurized service housing, chilldown, and cooling equipment: 2 liq. Neon tanks valves, vents, regulators 2 insulated receiving tanks (for gaseous Neon collection; vented to space or reliquified) (Active cryogenics; sensitive to contaminants particularly while cooled to cryo temps.)	(Space vacuum) LNe LHe	No EVA Setup/deploy/operate Astronomer/astrophysicist/astronaut	260	300	500W; Dry N_2; LHe; LNe

Table 3-15. Experiment/Support Requirements – Physics Modules, Attached Pallet Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
P-1: Space Physics Research Laboratory -1A: Atmos. and magneto science -1B: Cometary physics -1C: Meteroid science -1E: Small astronomy *telescopes*	Photometric cluster, scanning spectrometers, image isocon TV, mass spectrometers, electric field probes, energetic particle sensors (alum. foil), gaseous release device (ICN, heater, battery pack), meteroid *sensors* (panels, *dust* analyzers) (Passive at launch; minimize contaminants)	Scientific airlocks, extendable platforms, sub-satellites Film (-1A, -1B, -1C) Workbenches Film vault NH_3 cannisters (-1B) *ICN cannisters (-1B)* (Space environment)	Crew EVA (for external mounts) (P-1A & 1C) Deploy systems, booms, etc. Setup/operate/deploy Electromech.tech./ *physicist/EVA* backup	690 1600 19 458	1137 4000 60 1137	3-7 kW
P-2: Plasma Physics Lab. -2A: Wake measurements from station (Passive at launch; particle sensors, guns, oxidecathodes to be hermetically sealed in dry N_2 until use)	Boom-mounted sensors (magnetic and electric fields, ion and electric density), gimbal platforms, oscilloscope, inflatable ECHO balloons, boom-mounted transmitters and accelerators (up to 10 kW), rechargers or batteries, inverters, pulsers, motor-driven stem, large antennas	Booms; film Scientific airlocks (vacuum and O_2/N_2 at 14.7 PSIA) Two-beam laser radar to track balloons (with on-board display)	No EVA planned Setup/deploy/operate Deploy antennas; transmitters, accelerators Physicist/electro-mech.tech./pilot-navigator	438	438	500W
P-3: Cosmic Ray Physics Lab. -3C: Plastic/nuclear emulsions (-3C passive)	Plastic and nuclear emulsions	Mechanisms to move emulsions, (O_2/N_2 at 14.7 PSIA; vacuum OK for -3C)	Electromech.tech./ physicist Setup/deploy/operate		None	
P-4: Physics and Chemistry Laboratory -4A: Airlock and boom exp. Typical experiments: 1. Molecular beam scattering	"Suitcase payloads" for plug-in; scattering chamber (gas jet, N_2, O_2, He), ionization chamber, mass spectrometer, detectors, oscilloscope (Passive at launch)	Working areas and equipment (power, gases, vacuum lines, airlocks, multipurpose test equip, central data collection system, deployment devices and manipulators), view ports (visible, IR, UV) Booms, film, Mag. tape (Air or N_2 at 14.7 PSIA) LH_2, N_2, Freon	Deploy systems Perform exper. EVA not required Setup/deploy/operate Physicist/ Physical chemist/ Thermodynamicist/ Electromech.tech.	40	270	270-2615W

Table 3-16. Experiment/Support Requirements — Earth Survey Modules, Attached Pallet Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
ES-1: Earth Observation Facility	Data acquisition sensors (imagers, radiometers, spectrometers, polarimeters, sferics detectors, optical radar), sensor M&R unit, sensor control and display, data analysis (computer, photo and development and analysis), TV	No obstruction in field of view	M&R (preferably IVA); no EVA planned			LN_2 coolant services;
-1A: Meteor. and atmos. science				4519	6191	
		Accessible sensors				3051-5134W
-1B: Land use mapping				5085	6300	
-1C: Air and water pollution		Magnetic tape	Setup/deploy/operate	4255	5376	
-1D: Resource recognition		Film	Operate	4955	6026	
-1E: Natural disasters				5126	6219	
-1F: Ocean resources		Photo lab.		4233	5473	
-1G: Min. payload	(Passive at launch)			3422	4215	
		(N_2/O_2 at 0-15 PSIA)	Elec. engr. Electromech. tech. Optical tech. Oceanographer Meteorologist Photo. tech. Cartog./Agronomer Geologist Hydrologist			
			On-orbit cleaning of sensors			

Table 3-17. Experiment/Support Requirements – Comm/Nav Modules, Attached Pallet Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
C/N-1: Comm/Nav Facility -1A: Exp. 1-7 -1B: Exp. 1-7, 12, 13 Experiments 1. Opt.freq.demo. 2. MM wave comm. system 3. Surv.and search and rescue 4. Sat.nav.techniques 5. On-board laser ranging 6. Auton.nav.systems 7. Transmitter break-down 8. Terrestrial noise 9. Noise source ident. 10. Sat.radiated energy 11. Tropospheric propagation 12. Plasma propagation 13. Multipath measurements	Receivers, transmitters, processors, parabolic antennas, transponders, inflatable spiral antenna, nav sensors package (inertial, Doppler, optical, etc.), SHF polarized horn, VHF dipole antenna (Passive at launch)	Several exp.require one terminal in another vehicle (subsatellite) Voice links, T/M links, airlocks, docking ports, (N_2/O_2 at 0-14.7 (PSIA) Avoid waste dumps during optical exp Magnetic tape,film	Experimentation, data processing, maintenance troubleshooting EVA Erection of large parabolic expandable truss antenna (PETA) Setup/deploy/operate Electronic eng/ electromech.tech/ optical tech/ microwave specialist	973 950	1945 1945	3 kW

Table 3-18. Experiment/Support Requirements – Biological Module, Attached Pallet Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
MS-1 IA Biological Experiments	Facilities for biological processing (biological enclosure, continuous electrophoretic column assy, buffer recover/ waste disposal system, gas elimination/ cooling system, lyophilization apparatus, UV densitometer, molugraphic interferometer)	Inst. and control center, atmos. supply and control, power conditioning, process control computer		700	1000	

Table 3-19. Experiment/Support Requirements — Contamination Modules, Attached Pallet Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
T-1: Contamination Measurements -1A: Pkg. No. 1 -1B: Pkg. No. 2 Purpose: Identify types, quantities, distribution, effects of the contaminants in the S/C-induced environment (S/C and instruments)	Photoelectric polarimeter, quartz crystal contaminant gauge, portable spectrorefectometer and exposure rack, mass spectrometer, contaminant measurement camera, optical properties module (driveshaft, phototube, gauge, table), active cleaning device (with umbilical), contamination control panel (electromagnetic and electrostatic protective devices, gas supply line, gas cushion protective device, contaminant gauge, mass spectrometer) (Passive at launch; kept in sealed containers, including samples)	Scientific airlocks, external mounts, extendable platforms, subsatellites (Space environment) N_2 Film	EVA Deploying Testing Cleaning Mounting Setup/deploy/operate Physicist/electromech. tech./backup EVA/	 345/360 100	 400 100	GN_2 to fill exp. containers; 28 VDC; 120/240 VAC

Table 3-20. Experiment/Support Requirements — Equipment Technology Modules, Attached Pallet Mode

Experiment	Basic Equipment	Support (possible)		Power Level (Watts)		GSE Facility Utilities
		Equipment	Operation	Average	Peak	
T-3: EVA -3A: AMU -3B: MWP	Backmounted AMU [life support, cold-gas (O_2) thrusters, auto stabilizers and control (gyros), elect power (batt), O_2 storage bottle, hand controllers] Hard-suited MWP (N_2H_4 propulsion system, displays, life-support system, anchoring grappling arms, extendable antenna, tools and spares module, floodlights, ranging radar, elect and propellant umbilicals) (Passive at launch)	EVA airlocks, batt. recharge, prop. tanks (100 percent O_2 to pressure-suit at 3.75 PSIA) O_2 Film Video tape Hydrazine LiOH H_2O	EVA Cargo-transport, docking, grappling, Build/repair Setup/deploy/operate Electromech. tech.	 330 330	 370 400	300-330W; 6000 PSIA O_2 for decay check on -3A; He for leak check on -3B
T-4: Adv. S/C Systems Tests -4A: Long duration tests -4B: Med. duration tests -4C: Short duration tests	"Carry-on" experiments: O_2 recovery and biowaste resistojet (O_2, water, power, electrolysis cell, thrusters), maintenance electronics pkg, thermal coating refurbishment (sample plates, instruments), absorption refrigeration sys (HX, generator, radiator, power), leak detection and repair, maintainable ACS (tanks, He, propellants, valves, lines, thrusters), ball-bearing lub, adv guidance sys, exposure of mat'ls, mat'l fatigue (fat. machine, specimens, holders), fire sensing and suppression (module, detector, extinguisher)	Airlocks, stabilized platforms, deployment booms, test cells, instruments Fireproof chamber	EVA (for short duration tests; -4C) Maintenance Refurbish Repair Setup/deploy/operate Electromech. tech./ elect. eng'r./ mech. eng'r.	100	565	none specified
T-5: Teleoperations -5A: Initial flight -5B: Functional manipulation -5C: Ground control	Small, free-flying T/O S/C (manipulator arms, camera, TV camera, lights, antenna, docking legs, cold GN_2 prop tank, thrusters, docking interface, batteries, sensors (Passive at launch)	Control station, 2-way RF link, 2-man airlock (no environment req't; N_2/O_2 at 0-14.7 PSIA accept.); cold N_2 (gas)	EVA not planned (inspection, assembly, maintenance servicing in lieu of EVA by astronaut) Setup/deploy / operate Electromech. tech./ Elect. eng'r./ mech. eng'r.	 160/300 160/300 160/300	 300 300 300	300W; He for leak check

Table 3-21. Hazards/Interactions (On-Orbit Phase) – Astronomy Modules, Attached MSM Mode (Sheet 1 of 2)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
A. Electrically-Powered Equipment (all types)	1. Setup/deploy/operate a. Touch, handle	1. Electric shock, burns	1. Provide medical aid (immediate)	1. Provide medical aid (subsequent) 2. Remove incapacitated experimenter
	b. Others	1. Shorts, fires	1. Fire suppression equip. 2. Non-habitable module	1. Fire suppression equip. 2. Jettison module
B. Scientific Airlock	1. Deploy instruments, etc.	1. Outer door won't open 2. Outer door won't close 3. Inner door won't open 4. Inner door won't close	1. Can't experiment	1. None--unless open outer door prevents closure of P/L bay doors a. Jettison module
		5. Both doors open or leaking	2. Non-habitable module (egress required)	2. Same as 1 above
C. Vents	1. Venting of cryogenic boil-off gases	1. Closed vent--tank overpressure and rupture	1. Non-habitable module--egress required a. Cryogenic fluids b. Cryogenic gases 2. Injury (human) 3. Equipment damage	1. Remove incapacitated experimenters 2. Jettison module
		2. Interior venting	4. Non-habitable module--egress required	3. Jettison module
D. Cameras and Equipment	1. Retrieve/replace/process film a. Touch, handle	1. Chemical injury--from processing chemicals	1. Immediate medical aid	1. Subsequent medical aid
	b. Others	2. Chemical spills (liquids, dry chemicals)	2. Contaminated module a. Clean-up b. Egress (non-habitable)	2. Clean-up equipment

Table 3-21. Hazards/Interactions (On-Orbit Phase) – Astronomy Modules, Attached MSM Mode (Sheet 2 of 2)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
D. Cameras and Equipment (cont'd)		3. Fire (flammable film)	3. Fire suppression equip.	3. Fire suppression equip. 4. Jettison module
E. Telescopes	1. Setup/deploy/operate a. Align and calibrate b. Visually directed towards sun	1. Operator inadvertently entrapped by instrument in locked position 2. Eye damage (to viewer)	1. Provide release 2. Immediate medical aid	1. Provide release 2. Subsequent medical aid
F. Spark-Chamber	1. Spark-chamber operation	1. Argon/Methane bleed from spark-chamber a. Contamination b. Fire	1. Non-habitable module (egress required) 2. Fire suppression equip. 3. Immediate medical aid	1. Remove incapacitated experimenters 2. Fire suppression equip. 3. Jettison module 4. Subsequent medical aid
G. Cryogenics	1. Venting of cryogenic boil-off gases (LN_e, (LH_e) 2. Spills, leaks, etc. (inadvertent)	1. See Vents, above → 2. Uncontained cryogenic fluids, gases	→ 1. See Vents, above →	→ →
H. Contamination Sources (specific)	1. Cleaning of sensors, e.g., from effluents on surfaces	1. Contaminants on a. Person b. Cleaning equip.	1. Illness - medical aid 2. Decontamination equip. 3. Non-habitable module (egress required) 4. Disposal technique	1. Subsequent medical aid 2. Decontamination equip. 3. Disposal technique 4. Jettison module

Table 3-22. Hazards/Interactions (On-Orbit Phase) – Physics Modules, Attached MSM Mode (Sheet 1 of 5)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
A. Electrically-Powered Equipment (all types)	1. Setup/deploy/operate a. Touch, handle	1. Electrical shock, burns	1. Immediate medical aid	1. Subsequent medical aid 2. Remove incapacitated experimenter
	b. Others	1. Shorts, fires	1. Fire suppression equip. 2. Non-habitable module	1. Fire suppression equip. 2. Jettison module
B. Scientific Airlock	1. Deploy instruments, etc.	1. Outer door won't open 2. Outer door won't close 3. Inner door won't open 4. Inner door won't close 5. Both doors open or leaking	1. Can't experiment 2. Non-habitable module (egress required)	1. None--unless open outer door prevents closure of P/L bay doors a. Jettison module 2. Same as 1 above
C. Vents	1. Venting of cryogenic boil-off gases	1. Closed vent--tank overpressure and rupture 2. Interior venting	1. Non-habitable module--egress required a. Cryogenic fluids b. Cryogenic gases 2. Injury (human) 3. Equipment damage	1. Remove incapacitated experimenters 2. Jettison module
	2. Venting of combustors, flame chambers, etc.	1. Closed vent--chamber overpressure and rupture a. Toxic gases b. Fire 2. Interior venting	1. Non-habitable module--egress required 2. Injury (human) 3. Fire suppression equip. 4. Immediate medical aid	1. Subsequent medical aid 2. Fire suppression equip. 3. Jettison module 4. Remove incapacitated experimenters

Table 3-22. Hazards/Interactions (On-Orbit Phase) – Physics Modules, Attached MSM Mode (Sheet 2 of 5)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
D. Cameras and Equipment	1. Retrieve/replace/process film a. Touch, handle	1. Chemical injury -- from processing chemicals 2. Chemical spills (liquids, dry chemicals) 3. Fire (flammable film)	1. Immediate medical aid 2. Contaminated module a. Clean-up b. Egress (non-habitable) 3. Fire suppression equip.	1. Subsequent medical aid 2. Clean-up equipment 3. Fire suppression equip. 4. Jettison module
E. Lasers a. Laser-radar b. Laser	1. Tracking balloons 2. Laser experiments	1. Inadvertent exposure to beam a. Human (injury) b. Equipment (damage) (1) Fire	1. Immediate medical aid 2. Inoperative equipment a. Non-habitable module (egress required) 3. Fire suppression equip.	1. Subsequent medical aid 2. Fire suppression equip. 3. Jettison module
F. Booms/Platforms/Antennas	1. Extending booms/platforms/antennas	1. Partial extension only 2. Booms/platforms won't retract 3. Hang-up	1. Can't conduct experiment 2. May not allow module to be retracted into P/L bay of orbiter	1. None 2. Jettison module - if can't close P/L bay doors
	2. Crew EVA to mount external equipment	1. Stranded in EVA a. Broken tether b. Tether caught on boom 2. Injured in EVA operation a. Physical b. Electrical shock	1. Retrieve EVA astronaut a. Provide extended EC/LS 2. Immediate medical aid	1. Retrieve EVA astronaut a. Provide extended EC/LS 2. Subsequent medical aid

Table 3-22. Hazards/Interactions (On-Orbit Phase) — Physics Modules, Attached MSM Mode (Sheet 3 of 5)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't.)	Orbiter (Cond./Req't.)
G. Balloons	1. Deploying and inflating "ECHO" balloons	1. Inadvertent inflation a. In module (1) EC/LS ports covered b. In airlock (1) Doors closed (2) Outer door open	1. Entrapment in module 2. Non-habitable environment (egress required) 3. Unusable airlock 4. Non-closable outer door	1. Retrieval of experimenter 2. Jettison module if can't shut P/L bay doors after module retracted
H. Subsatellites	1. Deploying subsatellite (if within module)	1. Airlock hangups	See Scientific Airlock, item B, above	
	2. Maintenance of subsatellite a. Battery recharging	1. Electrical shock, burns 2. Fires, shorts	See "Electrically-Powered Equipment" - "A" above	
		3. Electrolyte spills a. Injury b. Contamination	1. Immediate medical aid 2. Non-habitable module (egress required)	1. Subsequent medical aid 2. Retrieve experimenters
	b. Gas bottle recharging/replacement (hi-pressure N_2)	1. Explosion a. Injury b. Fire	3. Fire suppression equip.	3. Fire suppression equip.
	c. Sensor replacement	1. Electrical shock, etc.	See above	
I. Batteries	1. Normal operation 2. Recharging	See H and A above		

Table 3-22. Hazards/Interactions (On-Orbit Phase) — Physics Modules, Attached MSM Mode (Sheet 4 of 5)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't.)	Orbiter (Cond./Req't.)
J. Cryogenics	1. Supercooled magnet ops. a. LH_e dewar 2. Venting of cryogenic boil-off gases (LH_e) 3. Spills, leaks, etc. (inadvertent)	← See Cryogenics--Table 3-21 → ← See Vents--Tables 3-21, 3-22 →		
K. Non-Cryogenic Fluids	1. Cometary physics exp. a. ICN cannisters b. NH_3 cannisters 2. Zero-g combustion exp. a. Fuel tanks b. Oxidizer tanks	1. Inadvertent interior release of poisonous fumes a. Injury b. Fire c. Explosion 2. Uncontrolled combustion a. Fire b. Explosion 3. Contamination	1. Injury - medical aid (immediate) 2. Decontamination equip. 3. Fire suppression equip. 4. Non-habitable module (egress required)	1. Subsequent medical aid 2. Decontamination equip. 3. Fire suppression equip. 4. Remove incapacitated experimenters 5. Jettison module
L. Non-Cryogenic Gases	1. Subsatellite maintenance a. Gas bottle recharging	← See Subsatellites, item H, above →		
	2. Propellant tank pressurization a. N_2, He	1. Interior release or venting of gases 2. Tank failure a. Explosion b. Injury c. Fire	1. Injury - medical aid (immediate) 2. Fire suppression equip. 3. Non-habitable module (egress required)	1. Subsequent medical aid 2. Fire suppression equip. 3. Remove incapacitated experimenters 4. Jettison module
M. Emulsions	1. Cosmic ray exp. a. Plastic, nuclear emulsions (1) Touching, handling	1. Injury (chemical) 2. Contamination	1. Injury - medical aid 2. Decontamination equip.	1. Subsequent medical aid 2. Decontamination equip.

Table 3-22. Hazards/Interactions (On-Orbit Phase) – Physics Modules, Attached MSM Mode (Sheet 5 of 5)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't.)	Orbiter (Cond./Req't.)
N. Hi-Temperature Apparatus	1. Physics experiments a. Gas jets b. Combustors	1. Injury 2. Fire 3. Explosion	1. Injury - medical aid (immediate) 2. Fire suppression equip. 3. Non-habitable module (egress required)	1. Subsequent medical aid 2. Fire suppression equip. 3. Remove incapacitated experimenters 4. Jettison module
O. Magnetic Field Source	1. Operation of cooled magnet	1. Exposure to magnetic field a. Injury 2. Inoperable auxiliary equipment	1. Injury - medical aid (immediate)	1. Subsequent medical aid 2. Remove incapacitated experimenters
P. Dry Chemicals, Products	1. Disposing of waste products of experiments	1. Injury 2. Contamination	1. Injury - medical aid 2. Decontamination equip. 3. Non-habitable module (egress required)	1. Subsequent medical aid 2. Decontamination equip. 3. Remove incapacitated experimenters 4. Jettison module

Table 3-23. Hazards/Interactions (On-Orbit Phase) — Earth Survey Modules, Attached MSM Mode

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't.)	Orbiter (Cond./Req't.)
A. Electrically-Powered Equipment (all types)	1. Setup/deploy/operate a. Touch, handle	1. Electric shock, burns	1. Injury - immediate medical aid	1. Subsequent medical aid 2. Remove incapacitated experimenter
	b. Others	2. Shorts, fires	2. Fire suppression equip.	3. Fire suppression equip.
	2. Maintenance and repair		3. Non-habitable module (egress required)	4. Jettison module
B. Cameras and Equipment	See Cameras and Equipment--Tables 3-21, 3-22			
C. Contamination Sources (specific)	1. On-orbit cleaning of sensors	See Contamination Sources--Table 3-21		

Table 3-24. Hazards/Interactions (On-Orbit Phase); Comm/Nav Modules, Attached MSM Mode

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
A. Electrically-Powered Equipment (all types)	See Electrically-Powered Equipment, Tables 3-21, 3-22, 3-23			
B. Scientific Airlocks	See Scientific Airlocks, Tables 3-21, 3-22			
C. Cameras and Equipment	See Cameras and Equipment, Tables 3-21, 3-22, 3-23			
D. Booms, Platforms, Antennas	See Booms, Platforms, Antennas, Table 3-22 (Note: erection of PETA -- parabolic expandable truss antenna)			
E. Lasers	1. On-board laser ranging	See Lasers, Table 3-22		
F. Subsatellite	1. Docking with module; several experiments	1. Collision a. Struct. damage 2. Imperfect dock--hang-up a. Won't separate	1. Injury (med. aid, immed) 2. Non-habitable module (egress req'd) 3. Module can't be retracted into P/L Bay	1. Subsequent med. aid 2. Remove incapacitated experimenters 3. Jettison module
G. Contamination Sources (Specific)	See Contamination Sources, Tables 3-21, 3-23			

Table 3-25. Hazards/Interactions (On-Orbit Phase) — Materials and Manufacturing Modules, Attached MSM Mode

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
A. Electrically-Powered Equipment (all types)	← See Electrically-Powered Equipment, Tables 3-21 through 3-24 → (High-voltage for furnaces)			
B. Vents	1. Venting of furnaces, chambers, etc.	← See Vents, Table 3-22 →		
C. Non-Cryogenic Fluids	1. Open storage of fluids used in experiments	← See Non-Cryogenic Fluids, Table 3-22 →		
D. Hi-Temp. Apparatus	1. Mat'ls and mfg experiments a. Furnaces (melting, casting)	← See Hi-Temperature Apparatus, Table 3-22 →		
E. Hi-Temp. Materials	1. Mat'ls and mfg experiments a. Liquid metals b. Liquid glasses c. Vaporized substances d. Flammable, explosive mat'ls	← See Hi-Temperature Apparatus, Table 3-22 →		
F. Biological Materials	1. Biological processing a. Electrophoretic separation b. Lyophilization (strong affinity--colloid to liquid)	← See Electrically-Powered Equipment, Tables 3-21 through 3-24 → ← See Non-Cryogenic Fluids, Table 3-22 →		
G. Dry Chemicals/ Products	1. Store experiment samples 2. Clean-up after experiment a. Touch, handle 3. Refurbishment 4. Waste Disposal	1. Injury 2. Contamination	← See Dry Chemicals, Products, Table 3-22 →	

Table 3-26. Hazards/Interactions (On-Orbit Phase) – Contamination Modules, Attached MSM Mode

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req'd)
A. Electrically-Powered Equipment (all types)	See Electrically-Powered Equip., Tables 3-21 through 3-25			
B. Scientific Airlocks	See Scientific Airlocks, Tables 3-21 through 3-24			
C. Cameras and Equipment	See Cameras and Equipment, Tables 3-21 through 3-24			
D. Booms, Platforms	See Booms/Platforms/Antennas, Tables 3-22 and 3-24			
E. Subsatellites	1. Deploying sub-satellite	See Scientific Airlock, above		
F. Non-Cryogenic Gases	1. Opening experiment containers filled with N_2 gas	No problem unless initially over-pressurized then see Non-Cryogenic Gases, Table 3-22		
G. Contamination Source (Specific)	1. Using active cleaning device 2. Samples and rack (touch, handle) 3. Sensor cleaning	See Contamination Sources, Tables 3-21, 3-23, 3-24		

Table 3-27. Hazards/Interactions (On-Orbit Phase) – Equipment Technology Modules, Attached MSM Mode (Sheet 1 of 3)

Potential Hazard Source: Equipment	Potential Hazard Source: Operations	Potential Result of Occurrence	Effect On: Module (Cond./Req't)	Effect On: Orbiter (Cond./Req't)
A. Electrically-Powered Equipment (all types)	See Electrically-Powered Equipment, Table 3-21			
B. Scientific Airlocks	See Scientific Airlocks, Table 3-21			
C. Cameras and Equipment	See Cameras and Equipment, Table 3-21			
D. Booms, Platforms, or Antennas	See Booms/Platforms/Antennas, Table 3-22			
E. Lasers	1. Ranging radar	See Lasers, Table 3-22		
F. Subsatellites	1. Free-Flying T.O. S/C a. Inspection b. Maintenance c. Servicing 2. AMU 3. MWP	See Subsatellites, Table 3-22		
G. Batteries	See Subsatellites and Electrically-Powered Equipment, Table 3-22			
H. Non-Cryogenic Fluids	1. N_2H_4 in MWP RCS propulsion	See Non-Cryogenic Fluids, Table 3-22		
I. Non-Cryogenic Gases	1. Hi-Press GHe in leak detection exp. 2. Hi-Press O_2 in AMU 3. Hi-Press GN_2 in T.O. S/C	See Non-Cryogenic Gases, Table 3-22		
J. Rotating/Moving Equipment	1. Operation of fatigue machine 2. MWP a. Cargo transport, docking, grappling	1. Injury 2. Structural damage	1. Injury--med. aid 2. Non-habitable module (egress req'd)	1. Subsequent medical aid 2. Remove incapacitated experimenter 3. Jettison module
K. Hi-Temp. Apparatus	1. Operate fire sensing and suppression module	1. Injury 2. Fire	1. Injury--med aid 2. Fire suppression	1. Subsequent medical aid

Table 3-27. Hazards/Interactions (On-Orbit Phase) – Equipment Technology Modules, Attached MSM Mode (Sheet 2 of 3)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
K. Hi-Temp. Apparatus (cont'd)			3. Non-habitable module (egress req'd)	2. Remove incapacitated experimenter 3. Fire suppression equipment 4. Jettison module
L. MWP				
1. Open structure platform	1. Manned operations	1. Astronaut falls off	1. Retrieve astronaut	1. Retrieve astronaut
2. Grappling arms	2. Cargo transport	2. Arms won't retract	2. Can't dock with MWP a. Jettison or leave	2. Can't dock with MWP a. Jettison or leave
3. Antennas	3. Away from module	3. Can't receive signals	3. Recall MWP a. Retrieve astronaut	3. Recall MWP a. Retrieve astronaut
4. Floodlight	4. Manned operations	4. Can't see well	4. Stop operations a. Retrieve astronaut	4. Stop operations a. Retrieve astronaut
5. Propellants, umbilicals, thrusters	5. Anytime	5. Explosion, fire	5. a. Injury (medical aid) b. Stranded astronaut c. Non-habitable module d. Jettison MWP	5. a. Medical aid b. Retrieve astronaut c. Retrieve experimenters d. Jettison module
6. Batteries	6. Anytime	6. Shorts, fire, etc.	6. See 5, above	6. See 5, above
7. EC/LS (Hi-press O_2)	7. Anytime (tank failure)	7. Explosion, fire	7. See 5, above	7. See 5, above
M. AMU				
1. O_2 storage bottle	1. Tank failure	1. Explosion, fire	1. See 5, above	1. See 5, above
2. Batteries	2. Anytime	2. Shorts, fire, etc.	2. See 5, above	2. See 5, above

Table 3-27. Hazards/Interactions (On-Orbit Phase) – Equipment Technology Modules, Attached MSM Mode (Sheet 3 of 3)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
N. T.E. S/C 1. Manipulator arms 2. Docking lens 3. TV Camera 4. Lights 5. Antenna 6. Cold GN_2 propellant 7. Batteries	see corresponding items above			

Table 3-28. Hazards/Interactions (On-Orbit Phase) — Life Sciences Modules, Attached MSM Mode (Sheet 1 of 2)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
A. Electrically-Powered Equipment (all types)	←	See Electrically-Powered Equipment, Table 3-21		→
B. Vents	1. Venting of holding and rearing accommodations a. Controlled--not in common with module atmosphere	1. Closed vent cage overpressure and rupture 2. Interior venting of cage atmosphere	1. Illness/injury-med. aid 2. Contamination of module 3. Non-habitable module (egress req'd)	1. Subsequent med. aid 2. Retrieve incapacitated experimenters 3. Decontamination equipment 4. Jettison module
C. Non-Cryogenic Fluids	1. Specimen preservation a. Embalming fluid 2. Specimen feeding a. Water b. Nutrients 3. Specimen fluid waste	1. Uncontained fluids 2. Contamination	1. Injury/illness--med. aid 2. Decontamination equipment 3. Non-habitable module (egress req'd)	1. Subsequent med. aid 2. Retrieve experimenters 3. Decontamination equipment 4. Jettison module
D. Radiation Sources	1. Operation of X-ray machine 2. Radioisotopes a. Human research b. Animal, plant research	1. Uncontrolled radiation	1. Injury/illness--med. aid 2. Decontamination equipment 3. Non-habitable module (egress req'd)	1. Subsequent med. aid 2. Retrieve experimenters 3. Decontamination equipment 4. Jettison module
E. Rotating/Moving Equipment	1. Operation of: a. Biological centrifuge b. Human centrifuge c. Ergometer d. Rotating litter chair	1. Uncontrolled rotation 2. Physical injury 3. Structural damage	1. Injury--med. aid 2. Non-habitable module (egress req'd)	1. Subsequent med. aid 2. Retrieve experimenters 3. Jettison module

Table 3-28. Hazards/Interactions (On-Orbit Phase) – Life Sciences Modules, Attached MSM Mode (Sheet 2 of 2)

Potential Hazard Source		Potential Result of Occurrence	Effect On	
Equipment	Operations		Module (Cond./Req't)	Orbiter (Cond./Req't)
F. Biological/Animals/Insects/Plants	1. Biological materials a. Cells and tissues b. Organisms and cultures 2. Animals a. Primates b. Rats/mice c. Marmots 3. Insects 4. Plants 5. Cages, etc. 6. Chemical nutrients 7. Waste, excreta 8. Dead animals/insects, etc.	1. Physical Injury a. Bites, etc. 2. Contaminations a. Chemical b. Bacterial	1. Injury - - med. aid 2. Decontamination equipment 3. Non-habitable module (egress req'd)	1. Subsequent med. aid 2. Retrieve experimenters 3. Decontamination equipment 4. Jettison module
G. Negative Pressure Source	1. Operation of: a. Lower body neg. pressure chamber	1. Uncontrolled vacuum source 2. Decompression (extreme case)	1. Injury - - med. aid 2. Non-habitable module (egress req'd)	1. Subsequent med. aid 2. Retrieve experimenters

Table 3-29. Hazards/Interactions Summary (On-Orbit Phase) — Attached MSM Mode (Sheet 1 of 8)

Potential Hazard Source		Potential Result	Potential Effect On			
			Module		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
A. Electrically-Powered Equipment (all types) e.g., Inverters Pulsers Transmitters Television Heaters Sensors, displays, etc. Refrigerators, freezers Furnaces etc.	1. Setup/deploy/operate a. Touch, handle b. Other 2. Maintenance/repair	Electric shock, burns Shorts, fires	Injured crew Fire in module Non-habitable	First aid Fire suppression equipment Egress	Potential fire	Medical aid Fire suppression equipment Retrieve crew Jettison module
B. Scientific Airlocks	1. Deploy instruments, sensors, etc.	Doors won't open/close Doors open or leaking Instrument prevents closure of P/L bay doors when retracted (instrument "hang-up")	Can't experiment Non-habitable	Shutdown equip. Egress	Can't reenter	Retrieve crew Jettison module
C. Overboard Vents 1. Cryogenic boil-off gases 2. Combustors, flame chambers 3. Furnaces, chambers 4. Holding and rearing accommodations	1. Astronomy, physics experiments 2. Physics experiments 3. Mat'ls and mfg exp. 4. Life sciences exp. (animals, insects, plants)	Closed vent; tank overpressure, rupture releasing: / Cryo fluids, gases Chamber overpressure and rupture releasing: / Toxic gases / Fire Cage overpressure and rupture releasing: / Animals / Insects / Plants / Bacteria / Waste / Etc.	Ill/injured crew Contamination / Atmosphere / Bacteria / Insects, etc. Fire in module Non-habitable	First aid Decontamination equip. Fire suppression equip. Egress	Potential fire	Medical aid Decontamination equip. Fire suppression equip. Retrieve crew Jettison module

Table 3-29. Hazards/Interactions Summary (On-Orbit Phase) — Attached MSM Mode (Sheet 2 of 8)

Potential Hazard Source		Potential Result	Potential Effect On			
			Module		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
D. Spark-Chamber	1. Operation of spark-chamber in astronomy experiments	Argon/Methane bleed from spark-chamber / Contaminated atmosphere / Fire	Injured crew Contamination / atmosphere Non-habitable Fire in module	First aid Decontamination Egress Fire suppression equipment	Potential fire	Medical aid Retrieve crew Fire suppression equipment Jettison module
E. Cameras and Equipment 1. Film 2. Film processor 3. Film-processing chemicals 4. Film vault	1. Retrieve/replace/process film / Touch, handle / Other	Chem. injury (from processing chemicals) Chem. spills Fire (flammable film)	Injured crew Contamination / Atmos. / Surface Non-habitable Fire in module	First aid Decontamination equipment Egress Fire-suppression equipment	Potential fire	Medical aid Decontamination equipment Retrieve crew Fire suppression equipment Jettison module
F. Telescopes 1. Optical 2. IR 3. Etc.	1. Conduct of astronomy experiments / Setup/deploy / Align/calibrate / Visual pointing	Latch failure in locked position Optical scope pointed at sun	Entrapped crew Injured crew / Eye damage	Provide release First aid		Retrieve crew Medical aid
G. Booms/Platforms/Antennas 1. Self-erectible 2. Require erection	1. Extension of booms/platforms/antennas 2. Crew EVA to mount external equipment on platforms 3. Erection of PETA (parabolic expandable truss antenna)	Partial extension only / Won't retract / Hang-up Stranded in EVA / Broken tether / Tether caught on boom, etc. EVA injury / Physical / Electrical shock	Can't experiment	Shutdown equip. Retrieve crew provide EC/LS First aid	May not be able to reenter if P/L bay doors cannot close (when module retracted)	Jettison module Retrieve crew provide EC/LS Medical aid

Table 3-29. Hazards/Interactions Summary (On-Orbit Phase) — Attached MSM Mode (Sheet 3 of 8)

Potential Hazard Source		Potential Result	Potential Effect On			
			Module		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
H. Lasers 1. Laser-radar 2. Lasers	1. Tracking (balloons, subsatellites, etc.) 2. Laser experiments	Inadvertent exposure to laser beam / Human injury / Equipment damage / Fire	Injured crew Non-habitable Fire in module	First aid Egress Fire suppression equip.	Potential fire	Medical aid Retrieve crew Fire suppression equip. Jettison module
I. Balloons 1. ECHO Type	1. Deploying and inflating balloons	Inadvertent inflation in module / Trapped crew / EC/LS ports covered Inadvertent inflation in airlock / Outer door open	Entrapped crew Injured crew Non-habitable Unusable Airlock / Outer door open	First aid Egress Shutdown equip.	May not be able to reenter if P/L doors cannot close (when module retracted)	Retrieve crew Medical aid Retrieve crew Jettison module
J. Subsatellites 1. Experiment target 2. Teleoperator S/C	1. Deploying sub-satellite (from within module)	Hang-up in airlock	See Scientific Airlocks			
	2. Docking with module	Collision / Structural damage Imperfect dock / Hang-up / Won't separate	Injured crew Non-habitable	First aid Egress	May not be able to reenter if P/L doors cannot close (when module retracted)	Medical aid Retrieve crew Jettison module
	3. Maintenance / Battery recharging / Gas bottle recharging (Hi-pressure N_2) / Sensor replacement	Electrical shock, burns, fires, shorts Electrolyte spills / Injury / Contamination Explosion / Injury / Fire	Injured crew Contamination Non-habitable Fire in module	First aid Decontamination equip. Egress Fire suppression equip.	Potential fire	Medical aid Decontamination equip. Retrieve crew Fire suppression equip. Jettison module
K. Batteries 1. NiCad 2. Others	1. Normal operation 2. Recharging	Electrical shock, burns, fires, shorts Electrolyte spills / Injury / Contamination				

Table 3-29. Hazards/Interactions Summary (On-Orbit Phase) – Attached MSM Mode (Sheet 4 of 8)

Potential Hazard Source		Potential Result	Potential Effect On			
			Module		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
L. Cryogenics 1. LHe 2. LNe	1. Supercooled magnet operations / LHe dewar 2. Venting of cryogenic boiloff gases	Closed vent--tank overpressure, rupture: / Cryo fluids, gases Spills, leaks / Inadvertent	Injured crew Contamination / Atmosphere Non-habitable	First aid Decontaminate Egress		Medical aid Retrieve crew Jettison module
M. Non-Cryogenic Fluids 1. ICN 2. NH_3 3. N_2H_4 4. Other propellants 5. Embalming fluids 6. Nutrients (animal, plant) 7. Waste products	1. Cometary physics exp. / ICN cannisters / NH_3 cannisters 2. Zero-g combustion experiments / Fuel and oxid. tanks 3. Mat'ls and mfg. experiments / Open storage fluids 4. MWP with N_2H_4 RCS propulsion 5. Specimen preservation / Embalming fluid 6. Specimen feeding / Nutrients / Water / Fluid waste	Inadvertent interior release of fluids, fumes / Injury / Fire / Explosion Contamination Uncontrolled combustion / Fire / Explosion	Injured crew Contamination Non-habitable Fire in module	First aid Decontamination equip. Egress Fire suppression equip.	Potential fire Structural damage (unsafe to reenter)	Medical aid Decontamination equip. Retrieve crew Fire suppression equip. Jettison module Ground rescue
N. Non-Cryogenic Gases 1. O_2 2. N_2 3. He 4. Argon 5. Methane (more)	1. Propellant tank pressurization (N_2, He) 2. Subsatellite maint. / Gas bottle recharging 3. Opening experiment containers (pres. with N_2)	Interior release or venting of gases Tank rupture / Explosion / Injury / Fire	Injured Crew Contamination Non-habitable Fire in module	First aid Decontamination equip. Egress Fire suppression equip.	Potential fire Structural damage (unsafe to reenter)	Medical aid Decontamination equip. Retrieve crew Fire suppression equip. Ground rescue

Table 3-29. Hazards/Interactions Summary (On-Orbit Phase) — Attached MSM Mode (Sheet 5 of 8)

Potential Hazard Source			Potential Effect On			
			Module		Orbiter	
Equipment/Contents	Operations		Container	Requirement	Container	Requirement
N. Non-Cryogenic Gases (cont'd)	4. Leak-detection exp. / Hi-press GHe 5. AMU operation / Hi-press GO_2 6. Teleoperator S/C / Hi-press GN_2 7. Spark-chamber operation					
O. Emulsions 1. Plastic 2. Nuclear	1. Cosmic ray experiment / Touching, handling emulsions	Injury Contamination	Injured crew Contamination	First aid Decontamination equip.		Medical aid Decontamination equip.
P. Hi-Temperature Apparatus 1. Gas jets 2. Combustors 3. Furnaces 4. Fire sensing and suppression module	1. Physics experiments / Jets, combustors 2. Matl's and mfg. exp. / Furnaces 3. Adv. technology exp. / Fire S and S module	Injury Fire Explosion	Injured crew Non-habitable Fire in module	First aid Egress Fire suppression equip.	Potential fire Structural damage (unsafe to reenter)	Medical aid Retrieve crew Fire suppression equip. Jettison module Ground rescue
Q. Hi-Temperature Materials 1. Liquid metals 2. Liquid glasses 3. Vaporized substances	1. Matl's and mfg. exp.					
R. Radiation Sources 1. X-ray machine 2. Radioisotopes	1. Life sciences exp. / Operate X-ray machine / Radioisotopes • Human research • Animal, plant research	Uncontrolled radiation Contamination	Injured crew Contamination Non-habitable	First aid Decontamination equip. Egress		Medical aid Decontamination equip. Retrieve crew Jettison module

Table 3-29. Hazards/Interactions Summary (On-Orbit Phase) — Attached MSM Mode (Sheet 6 of 8)

Potential Hazard Source		Potential Results	Potential Effect On			
			Module		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
S. Magnetic Field Source 1. Supercooled magnet	1. Operation of cooled magnet	Exposure to magnetic field / Human / Equipment	Injured crew Non-habitable	First aid Egress		Medical aid Retrieve crew
T. Biologicals/Animals/Insects/Plants 1. Biological materials / Cells and tissues / Organisms and cultures 2. Animals (primates, rats, mice, marmots, etc.) 3. Insects 4. Plants 5. Cages 6. Food and water 7. Chemical nutrients 8. Waste, excreta 9. Dead animals, insects	1. Life sciences experiments	Physical injury / Bites, etc. Contamination / Chemical / Bacterial	Injured crew Contamination Non-habitable	First aid Decontamination equip. Egress		Medical aid Decontamination equip. Retrieve crew Jettison module
U. Biological Processing 1. Electrophoretic separation 2. Lyophilization	1. Mat'ls and mfg. experiment	← See Electrically-Powered Equipment and Non-Cryogenic Fluids →				
V. Dry Chemicals/Products 1. Assortment of chemicals 2. Waste products 3. Preserved dry samples 4. Nutrients 5. Animal, insect excreta	1. Physics and chem. exp. 2. Mat'ls and mfg. exp. 3. Life sciences exp.	Injury (handling) Contamination	Injured crew Contamination Non-habitable	First aid Decontamination equip. Egress		Medical aid Decontamination equip. Retrieve crew Jettison module

Table 3-29. Hazards/Interactions Summary (On-Orbit Phase) – Attached MSM Mode (Sheet 7 of 8)

Potential Hazard Source		Potential Result	Potential Effect On			
			Module		Orbiter	
Equipment/Contents	Operations		Container	Requirement	Container	Requirement
W. Negative Pressure Source 1. Lower body negative pressure chamber	1. Life sciences exp. / Human research	Uncontrolled vacuum source Decompression (extreme case)	Injured crew Non-habitable	First aid Egress		Medical aid Retrieve crew Jettison module
X. Specific Contamination Sources 1. Active cleaning device 2. Samples and racks 3. Sensor cleaning	1. Contamination exp. 2. Cleaning of sensors in other experiments	Contaminants on / Person / Equipment	Injured crew Contamination Non-habitable	First aid Decontamination equip. Egress		Medical aid Decontamination equip. Retrieve crew
Y. Manned Work Platform 1. Open structure platform 2. Grappling arms 3. Antennas 4. Floodlight 5. Propellants, umbilicals, thrusters 6. Batteries 7. EC/LS (Hi-press O_2; LiOH)	1. Manned operations 2. Cargo transport	Stranded in EVA / Fall off platform / Broken tether / Etc.		Retrieve crew provide EC/LS		Retrieve crew provide EC/LS
		EVA injury / Physical / Electrical shock		First aid		Medical aid
		Grappling arms don't retract	Can't dock with MWP	Retrieve crew		Retrieve crew
		Can't communicate (antenna failure)		Retrieve crew		Retrieve crew
		Light failure (can't see		Cease operations		
		Shorts, fires, explosion	Potential struct. damage Non-habitable	Retrieve crew First aid Jettison MWP	Potential struct. damage (may be unsafe to reenter)	Retrieve crew Medical aid Jettison module Await ground rescue
		Docking collision	Injured crew Non-habitable	First aid Egress		Medical aid Retrieve crew Jettison module

Table 3-29. Hazards/Interactions Summary (On-Orbit Phase) — Attached MSM Mode (Sheet 8 of 8)

Potential Hazard Source: Equipment/Contents	Potential Hazard Source: Operations	Potential Result	Potential Effect On: Module: Condition	Potential Effect On: Module: Requirement	Potential Effect On: Orbiter: Condition	Potential Effect On: Orbiter: Requirement
Z. Astronaut Maneuvering Unit (Backpack AMU) 1. EC/LS 2. O_2 storage bottle 3. O_2 thrusters 4. Batteries	1. EVA	Stranded in EVA / Broken tether / Etc. EVA injury / Physical / Electrical shock / O_2 bottle explosion		Retrieve crew provide EC/LS First aid		Retrieve crew provide EC/LS Medical aid
AA. Teleoperator S/C 1. Manipulator arms 2. Docking legs 3. TV camera 4. Lights 5. Antenna 6. Cold GN_2 propellant 7. Batteries	1. Teleoperations (unmanned)	Explosion Docking collision	Potential struct. damage Injured crew Injured crew Non-habitable	Egress First aid First aid Egress	Potential struct. damage (may be unsafe to reenter)	Retrieve crew Medical aid Jettison module Await ground rescue Medical aid Retrieve crew Jettison module

Table 3-30. Hazards/Interactions Summary (On-Orbit Phase) – Detached RAM Mode (Sheet 1 of 5)

Potential Hazard Source		Potential Result.	Potential Effect On:			
			RAM		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
A. Electrically-Powered Equipment (all types) e.g., Inverters Pulsers Transmitters Television Heaters Sensors, displays, etc. Refrigerators, freezers Furnaces, etc.	1. Setup/deploy/operate a. Touch, handle b. Other 2. Maintenance/repair	Electric shock, burns shorts, fires	Injured crew Fire in module Non-habitable	First aid Fire suppression equipment Egress	– Potential fire –	Medical aid Fire suppression equipment Retrieve crew Jettison module
B. Scientific Airlocks	1. Deploy instruments, sensors, etc.	Doors won't open/close Doors open or leaking Instrument prevents closure of P/L bay doors when retracted (instrument "hang-up")	Can't experiment Non-habitable –	Shutdown equip. Egress –	– – Can't reenter	– Retrieve crew Jettison module
C. Overboard Vents 1. Cryogenic boil-off gases 2. Holding and rearing accommodations	1. Astronomy, physics experiments 2. Life science exp. (animals, insects, plants)	Closed vent -- tank overpressure, rupture releasing: / Cryo fluids, gases Chamber overpressure and rupture releasing: / Toxic gases / Fire Cage overpressure and rupture releasing: / Animals / Insects / Plants / Bacteria / Waste / Etc.	Ill/injured crew Contamination / Atmosphere / Bacteria / Insects, etc. Fire in module Non-habitable	First aid Decontamination equip. Fire suppression equip. Egress	– – Potential fire ..	Medical aid Decontamination equip. Fire suppression equip. Retrieve crew Jettison module

Table 3-30. Hazards/Interactions Summary (On-Orbit Phase) — Detached RAM Mode (Sheet 2 of 5)

Potential Hazard Source		Potential Result	Potential Effect On:			
			RAM		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
D. Spark-Chamber	1. Operation of spark-chamber in astronomy experiments	Argon/Methane bleed from spark-chamber / Contaminated atmos. / Fire	Injured crew Contamination / Atmosphere Non-habitable Fire in module	First aid Decontamination Egress Fire suppression equip.	— — — Potential fire	Medical aid — Retrieve crew Fire suppression equip. Jettison module
E. Cameras and Equipment 1. Film 2. Film processor 3. Film-processing chemicals 4. Film vault	1. Retrieve/replace/ process film / Touch, handle / Other	Chem. injury (from processing chemicals) Chem. spills Fire (flammable film)	Injured crew Contamination / Atmos. / Surface Non-habitable Fire in module	First aid Decontamination equip. Egress Fire suppression equip.	— — — Potential fire	Medical aid Decontamination equip. Retrieve crew Fire suppression equip. Jettison module
F. Telescopes 1. Optical 2. IR 3. Etc.	1. Conduct of astronomy experiments / Setup/deploy / Align/calibrate / Visual pointing	Latch failure in locked position Optical scope pointed at sun	Entrapped crew Injured crew / Eye damage	Provide release First aid	— —	Retrieve crew Medical aid
G. Batteries 1. NiCad 2. Others	1. Normal operation 2. Recharging	Electrical shock, burns fires, shorts Electrolyte spills / Injury / Contamination	Injured crew Contamination Non-habitable Fire in module	First aid Decontamination equip. Egress Fire suppression equip.	— — — Potential fire	Medical aid Decontamination equip. Retrieve crew Fire suppression equip. Jettison module

Table 3-30. Hazards/Interactions Summary (On-Orbit Phase) — Detached RAM Mode (Sheet 3 of 5)

Potential Hazard Source		Potential Result	Potential Effect On:			
			RAM		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
H. Cryogenics 1. LHe 2. LNe	1. Supercooled magnet operations / LHe dewar 2. Venting of cryogenic boiloff gases	Closed vent -- tank overpressure, rupture: / Cryo fluids, gases Spills, leaks / Inadvertent	Injured crew Contamination / Atmosphere Non-habitable	First aid Decontaminate Egress	– – –	Medical aid – Retrieve crew Jettison module
I. Non-Cryogenic Fluids 1. Propellants 2. Embalming fluids 3. Nutrients (animal, plant) 4. Waste products	1. Specimen preservation / Embalming fluid 2. Specimen feeding / Nutrients / Water / Fluid waste	Inadvertent interior release of fluids, fumes / Injury / Fire / Explosion Contamination Uncontrolled combustion / Fire / Explosion	Injured crew Contamination Non-habitable Fire in module	First aid Decontamination equip. Egress Fire suppression equip.	– – – Potential fire Structural damage (unsafe to reenter)	Medical aid Decontamination equip. Retrieve crew Fire suppression equip. Jettison module Ground rescue
J. Non-Cryogenic Gases 1. N_2 2. He 3. Argon 4. Methane	1. Propellant tank pressurization (N_2, He) 2. Opening experiment containers (pressurized with N_2) 3. Spark-chamber operation	Interior release or venting of gases Tank rupture / Explosion / Injury / Fire	Injured crew Contamination Non-habitable Fire in module	First aid Decontamination equip. Egress Fire suppression equip.	– – – Potential fire Structural damage (unsafe to reenter)	Medical aid Decontamination equip. Retrieve crew Fire suppression equip. Ground rescue
K. Emulsions 1. Plastic 2. Nuclear	1. Cosmic ray experiment / Touching, handling emulsions	Injury Contamination	Injured crew Contamination	First aid Decontamination equip.	– –	Medical aid Decontamination equip.

Table 3-30. Hazards/Interactions Summary (On-Orbit Phase) – Detached RAM Mode (Sheet 4 of 5)

Potential Hazard Source		Potential Result	Potential Effect On			
			RAM		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
L. Radiation Sources 1. X-ray machine 2. Radioisotopes 3. RTGs	1. Life sciences exp. / Operate X-ray machine / Radioisotopes • Human research • Animal, plant research	Uncontrolled radiation Contamination	Injured crew Contamination Non-habitable	First aid Decontamination equip. Egress	– – –	Medical aid Decontamination equip. Retrieve crew Jettison module
M. Biologicals/Animals/Insects/Plants 1. Biological materials / Cells and tissues / Organism and cultures 2. Animals (primates, rats, mice, marmots, etc.) 3. Insects 4. Plants 5. Cages 6. Food and water 7. Chemical nutrients 8. Waste, excreta 9. Dead animals, insects	1. Life sciences exp.	Physical injury / Bites, etc. Contamination / Chemical / Bacterial	Injured crew Contamination Non-habitable	First aid Decontamination equip. Egress	– – –	Medical aid Decontamination equip. Retrieve crew Jettison module
N. Dry Chemicals/Products 1. Assortment of chemicals 2. Waste products 3. Preserved dry samples 4. Nutrients 5. Animal, insect excreta	1. Life sciences exp.	Injury (handling) Contamination	Injured crew Contamination Non-habitable	First aid Decontamination equip. Egress	– – –	Medical aid Decontamination equip. Retrieve crew Jettison module

Table 3-30. Hazards/Interactions Summary (On-Orbit Phase) — Detached RAM Mode (Sheet 5 of 5)

Potential Hazard Source		Potential Result	Potential Effect On:			
			RAM		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
O. Solid Propellants 1. Pyro's 2. Solid rocket motors 3. Spin-up rockets		Fire Explosion	Injured crew Non-habitable Fire in module	First aid Egress Fire suppression equip.	– – Potential fire Structural damage (may be unsafe to reenter)	Medical aid Retrieve crew Fire suppression equip. Ground rescue

Table 3-31. Hazards/Interactions Summary (On-Orbit Phase) – Attached Pallet Mode (Sheet 1 of 5)

Potential Hazard Source		Potential Result	Potential Effect On:			
			Pallet		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
A. Electrically-Powered Equipment (all types) e.g., Inverters Pulsers Transmitters Television Heaters Sensors, displays Etc.	1. Deploy/operate a. Other	Shorts, fires	Fire in pallet	Fire suppression equip.	Potential fire	Medical aid Fire suppression equip. Jettison pallet
B. Overboard Vents 1. Cryogenic boil-off gases	1. Astronomy, physics experiments	Closed vent -- tank overpressure, rupture releasing: / Cryo fluids, gases	Fire in pallet	Fire suppression	Potential fire	Medical aid Fire suppression equip. Jettison pallet
C. Spark-Chamber	1. Operation of spark-chamber in astronomy exp.	Argon/Methane bleed from spark-chamber / Fire	Fire in module	Fire suppression equip.	Potential fire	Medical aid Fire suppression equip. Jettison pallet
D. Cameras and Equipment 1. Film 2. Film processor 3. Film-processing chemicals 4. Film vault	1. Replace/process film (automated, remote operation -- no manual contact)	Chem. spills Fire (flammable film)	Contamination / Surface Fire in module	Fire suppression equip.	Contamination (exterior & P/L bay) Potential fire	Medical aid Decontamination equip. Fire suppression equip. Jettison pallet
E. Telescopes 1. Optical 2. IR 3. Etc.	1. Conduct of astronomy experiments	Latch failure in locked position Optical scope pointed at sun	none -- remote operation			

Table 3-31. Hazards/Interactions Summary (On-Orbit Phase) — Attached Pallet Mode (Sheet 2 of 5)

Potential Hazard Source		Potential Result	Potential Effect On:			
			Pallet		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
F. Booms/Platforms/ Antennas 1. Self-erectible 2. Require erection	1. Extension of booms/ platforms/antennas 2. Crew EVA to mount external equipment on platforms 3. Erection of PETA (parabolic expandable truss antenna)	Partial extension only / Won't retract / Hang-up Stranded in EVA / Broken tether / Tether caught on boom, etc. EVA Injury / Physical / Electrical shock	Can't experiment		May not be able to reenter if P/L bay doors cannot close (when pallet retracted)	Jettison pallet Retrieve crew Provide EC/LS Medical aid
G. Lasers 1. Laser-radar	1. Tracking (balloons, subsatellites, etc.)	Inadvertent exposure to laser beam / Equipment damage / Fire	Fire in pallet	Fire suppression equip.	Potential fire	Medical aid Fire suppression equip. Jettison pallet
H. Balloons 1. ECHO type	Deploying and inflating balloons	Inadvertent inflation in P/L bay / Outer door open			May not be able to reenter if P/L doors cannot close	Jettison pallet
I. Subsatellites 1. Experiment target 2. Teleoperator S/C	1. Deploying subsatellite	Hang-up in P/L bay			May not be able to reenter if P/L bay doors cannot close	Jettison pallet
	2. Docking with pallet	Collision / Structural damage Imperfect dock / Hang-up / Won't separate			May not be able to reenter if P/L doors cannot close	Jettison pallet
	3. Maintenance / Battery recharging / Gas bottle recharging (Hi-pressure N_2)	Fires, shorts Electrolyte spills / Contamination Explosion / Fire	Contamination Fire in pallet	Fire suppression equip.	Potential fire	Medical aid Fire suppression equip. Jettison pallet

Table 3-31. Hazards/Interactions Summary (On-Orbit Phase) – Attached Pallet Mode (Sheet 3 of 5)

Potential Hazard Source		Potential Result	Potential Effect On:			
			Pallet		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
J. Batteries 1. NiCad 2. Others	1. Normal operation 2. Recharging	Fires, shorts Electrolyte spills / Contamination	Contamination Fire in pallet	Fire suppression equip.	Potential fire	Medical aid Decontamination equip. Fire suppression equip. Jettison pallet
K. Cryogenics 1. LHe 2. LNe	1. Venting of cryogenic boiloff gases	Closed vent -- tank overpressure, rupture: / Cryo fluids, gases Spills, leaks / Inadvertent	Fire in pallet	Fire suppression equip.	Potential fire	Medical aid Fire suppression equip Jettison pallet
L. Non-Cryogenic fluids 1. ICN 2. NH_3 3. N_2H_4	1. Cometary physics exp. / ICN cannisters / NH_3 cannisters 2. MWP with N_2H_4 RCS propulsion	Inadvertent interior release of fluids, fumes / Fire / Explosion Contamination	Contamination Fire in pallet	Fire suppression equip.	Potential fire Structural damage (unsafe to reenter)	Medical aid Decontamination equip. Fire suppression equip. Ground rescue
M. Non-Cryogenic Gases 1. O_2 2. N_2 3. He 4. Argon 5. Methane	1. Propellant tank pressurization (N_2, He) 2. Subsatellite maint. / Gas bottle recharging 3. Leak-detection exp. / Hi-press. GHe 4. AMU operation / Hi-press. GO_2 5. Teleoperator S/C / Hi-press. GN_2 6. Spark-chamber operation	Interior release or venting of gases Tank rupture / Explosion / Fire	Fire in pallet	Fire suppression equip.	Potential fire Structural damage (unsafe to reenter)	Medical aid Fire suppression equip. Jettison pallet Ground rescue

Table 3.31. Hazards/Interactions Summary (On-Orbit Phase) – Attached Pallet Mode (Sheet 4 of 5)

Potential Hazard Source		Potential Result	Potential Effect On:			
			Pallet		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
N. Emulsions 1. Plastic 2. Nuclear	1. Cosmic ray experiment	Contamination	Contamination		none -- operations are automatic and remote -- may pose ground-handling decontamination req't on return from orbit	
O. Hi-Temperature Apparatus 1. Gas jets 2. Fire sensing and suppression module	1. Physics exp. / Jets 2. Adv. technology exp. / Fire S&S module	Fire Explosion	Fire in pallet	Fire suppression equip.	Potential fire Structural damage (unsafe to reenter)	Medical aid Fire suppression equip. Jettison pallet Ground rescue
P. Biological Processing 1. Electrophoretic separation 2. Lyophilization	1. Mat'ls and mfg. experiment	See Electrically-Powered Equipment and Non-Cryogenic Fluids				
Q. Specific Contamination Sources 1. Active cleaning device 2. Samples and racks 3. Sensor cleaning	1. Contamination exp. 2. Cleaning of sensors in other experiments	Contaminants on: / Person / Equipment	Contamination		Injured crew Contamination	Medical aid Decontamination equip.
R. Manned Work Platform 1. Open structure platform 2. Grappling arms 3. Antennas 4. Floodlight 5. Propellants, umbilicals, thrusters 6. Batteries 7. EC/LS (Hi-press. O_2; LiOH)	1. Manned operations 2. Cargo transport	Stranded in EVA / Fall off platform / Broken tether / Etc. EVA injury / Physical / Electrical shock Grappling arms don't retract Can't communicate (antenna failure) Light failure (can't see)	Can't dock with MWP	Cease operations		Retrieve crew Provide EC/LS Medical aid Retrieve crew Retrieve crew

Table 3-31. Hazards/Interactions Summary (On-Orbit Phase) — Attached Pallet Mode (Sheet 5 of 5)

Potential Hazard Source		Potential Result	Potential Effect On:			
			Pallet		Orbiter	
Equipment/Contents	Operations		Condition	Requirement	Condition	Requirement
R. Manned Work Platform (cont'd)		Shorts, fires, explosion Docking collision	Potential struct. damage	Jettison MWP	Potential struct. damage (may be unsafe to reenter)	Retrieve crew Medical aid Jettison pallet Await ground rescue
S. Astronaut Maneuvering Unit (backpack AMU) 1. EC/LS 2. O_2 storage bottle 3. O_2 thrusters 4. Batteries	1. EVA	Stranded in EVA / Broken tether / Etc. EVA injury / Physical / Electrical shock / O_2 bottle explosion				Retrieve crew Provide EC/LS Medical aid
T. Teleoperator S/C 1. Manipulator arms 2. Docking legs 3. TV camera 4. Lights 5. Antenna 6. Cold GN_2 propellant 7. Batteries	1. Teleoperations (Unmanned)	Explosion Docking collision	Potential struct. damage		Potential struct. damage (may be unsafe to reenter)	Medical aid Jettison pallet Await ground rescue

Table 3-32. Summary of Hazard Source, Causation, and Interaction Results — Equipment/Contents — Related Hazard Sources (Sheet 1 of 8)

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
1. High-temperature sources / Apparatus • Gasjets, combustors • Furnaces • Fire sensing and suppression module	• Closed overboard vents • Abnormal combustion • Combustor burn-through • Touching hot surfaces	• Explosion • Fire • Contamination / Atmosphere (toxic gases) / Surface • Injury / Physical (cuts, burns) / Chemical
/ Materials • Liquid metals, glasses • Vaporized substances	• Faulty handling procedures • Spills, leaks	
2. Overboard vents / Cryogenic dewars / Combustors, furnaces / Holding and rearing accommodations (cages)	• Closed or inoperative vent / Tank overpressure, rupture / Combustor, furnace rupture / Cage rupture • Common vent efflux location / Mixing of reactive efflux • Inadvertent vent of efflux into cargo bay	• Fire • Contamination / Cryo gases, fluids / Toxic gases / Animals, insects, plants, bacteria, pollen, waste, etc. / Liquid metals, glasses, etc. • Injury / Physical (cuts, bites, burns) / Chemical / Bacterial
3. Lasers / Laser experiments / Laser-Radar	• Exposure to laser beam / Equipment / Structure / Crew	• Fire • Basic subsystem malfunction • Decompression (hole in module) • Loss of EC/LS (hole in module) • Injury / Physical (burns, etc.) / Radiation (laser radiation)

Table 3-32. Summary of Hazard Source, Causation, and Interaction Results — Equipment/Contents — Related Hazard Sources (Sheet 2 of 8)

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
4. Spark-chambers	• Leakage or bleed of argon/methane gases / Into module / Into Orbiter cargo bay	• Explosion • Fire • Contamination / Atmosphere (toxic gases) • Injury / Physical (burns, etc.) / Chemical
5. Superconducting magnet	• Field instability • Excessive field strength • Proximity to / Equipment / Crew	• Injury / Physical • Basic subsystem malfunction • Inadvertent actuation of armed devices (e.g., solid propellant igniters)
6. Scientific airlocks / Doors / Deployment mechanisms / Instruments deployed	• Open or leaking doors • Instrument "hang-up" in airlock • Failure to retract	• Module decompression (extreme) • Loss of module EC/LS • Inability to close Orbiter cargo bay doors / Outer airlock door jammed open / Protuberance from airlock
7. Subsatellites / Experiment target • Passive (see also "Balloons") • Active / GN_2 / Batteries (see also "Teleoperator Spacecraft")	• Airlock deployment	• See "Scientific Airlocks" (#6)
	• Docking or maintenance capture	• Collision
	• Maintenance / Battery recharging / Gas bottle recharging	• See "Batteries" (#19) • Explosion • Fire • Contamination • Injury

Table 3-32. Summary of Hazard Source, Causation, and Interaction Results — Equipment/Contents — Related Hazard Sources (Sheet 3 of 8)

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
8. Rotating equipment / Centrifuges • Scientific • Manned / Ergometer / Rotating litter chair	• Loss of rotational control / Overspeed • Mechanical disintegration • Release of contents • Overexertion	• Basic subsystem malfunction / Equipment damage • Decompression (in extreme) / Structural damage • Loss of module EC/LS • Injury / Rotational / Impact / Exertion • Contamination / Biological contents of scientific centrifuge
9. Telescopes / Optical, IR, etc.	• Latch failure in locked position (all) • Visual pointing (optical) (looking at sun or reflected sunlight)	• Trapped crewman • Injury / Eye damage
10. Booms/Platforms/Antennas / Extendable types	• Failure to retract • Hang-up; partial extension	• Inability to close Orbiter cargo bay doors
/ Manual erection • PETA (by EVA · · · see also "EVA", #2)	• Active elements attached to booms, antennas / High-voltage / High RF-fields	• See "Electrically-Powered Equipment" (#20)

Table 3-32. Summary of Hazard Source, Causation, and Interaction Results — Equipment/Contents — Related Hazard Sources (Sheet 4 of 8)

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
11. Balloons	• Inadvertent inflation / In module • EC/LS ports covered • Body encapsulated	• Trapped crewman • Loss of EC/LS
	/ In airlock, outer door jammed open	• Inability to close Orbiter cargo bay doors
12. Negative Pressure Source / For lower body negative pressure chamber	• Uncontrolled vacuum source	• Decompression (extreme case) • Injury (vacuum) to subject
13. Astronaut Maneuvering Unit (AMU) / Backpack type • PLSS • GO_2 bottle • O_2 thrusters • Batteries	• Return to module or Orbiter / Out-of-control • Subsystem malfunction • PLSS Depletion	• Collision • Explosion • Injury / Physical (impact) • Loss of EC/LS • Fire • Contamination / Chemical (electrolyte) See also "Batteries" (#19) and "Non-Cryogenic Gases" (#24)
14. Maneuverable Work Platform (MWP) / Open structure platform / Grappling arms / Antennas / Floodlight / Propellants, umbilicals, thrusters (more)	• Return to module or Orbiter /Out-of-control • Subsystem malfunction • PLSS depletion	• Collision • Explosion • Injury / Physical (impact) • Loss of EC/LS

Table 3-32. Summary of Hazard Source, Causation, and Interaction Results — Equipment/Contents — Related Hazard Sources (Sheet 5 of 8)

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
14. (continued) / Batteries / EC/LS (GO_2); LiOH)		• Fire • Contamination / Chemical (electrolyte, propellants) See also "Batteries" (#19); "Non-Cryogenic Fluids" (#23); "Non-Cryogenic Gases" (#24); "Booms/Platforms/Antennas" (#10); "Elect-Powered Equip. # (#20)
15. Teleoperator Spacecraft / Unmanned, automated / Manipulator arms / Docking legs / TV camera / Lights / Antenna / GN_2 pressurant / Batteries	• Return to module or Orbiter for docking or retrieval / Out-of-control • Off course • Excessive ΔV • Subsystem malfunction	• Collision • Explosion • Fire See also "Batteries" (#19); 'Non-Cryogenic Gases" (#24); "Booms/Platforms/Antennas" (#10); "Electrically-Powered Equipment" (#20)
16. Solid Propellant Devices / Pyrotechnics / Solid rocket motors / Spin-up rockets	• Satellite propulsive stage / Handling / Deployment / Activation by • RF-field • Magnetic field • Squib failure	• Explosion • Fire • Injury
17. Radiation Sources / X-ray machine / Radioisotopes / RTGs / Lasers	• Overexposure • Excessive doses, spills, etc. due to: / Source location / Source strength / Capsule rupture, etc.	• Illness (radiation) • Contamination (radiation) / Surface / Atmosphere • Basic subsystem malfunction / Equipment radiation damage

Table 3-32. Summary of Hazard Source/Causation, and Interaction Results — Equipment/Contents — Related Hazard Sources (Sheet 6 of 8)

Basic Hazard Source	Causative Events/Factor/Condition	Potential Hazardous Results
18. Cameras and Equipment / Film / Film vault / Film processor, chemicals	• Proximity to ignition source • Chemical spills • Film processing	• Fire • Injury • Contamination / Surface / Atmosphere
19. Batteries	• Shorts • Electrolyte spills • Closed or inoperative vent	• Fire • Explosion • Injury (shock, burns, chemical) • Contamination / Surface / Atmosphere
20. Electrically-Powered Experimental Equipment / Inverters / Pulsers / TV / Furnaces / Photomultipliers / Accelerators / Transmitters / Etc.	• Shorts • High-voltage • High RF-field intensity / Presence in field / Proximity to field	• Fire • Injury / Shock / Burns • Basic subsystem malfunction / RF-field damage
21. Biologicals/Animals/Insects/Plants / Cells and tissues, slides / Organisms and cultures / Primates, rats, mice, marmots, etc. / Insects / Plants, pollen / Cages / Food and water (more)	• Cages (release of contents) / Rupture / Inadvertent opening • Handling contact / Animals, insects, plants / Biologicals • Disposal operations	• Contamination / Atmosphere / Surface / Chemicals, isotopes / Wastes (solid and liquids) / Lice, fleas, etc. / Biologicals / Pollen, etc.

Table 3-32. Summary of Hazard Source, Causation, and Interaction Results — Equipment/Contents — Related Hazard Sources (Sheet 7 of 8)

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
21. (continued) / Chemical nutrients / Waste products / Dead animals, insects, etc.	• Feeding operations • Radioisotope experiments	• Injury/illness/disease / Bites / Chemicals / Biologicals / Isotopes / Etc.
22. Cryogenics / LHe / LNe / LH_2 / LO_2	• Tank overpressure, rupture / Vent malfunction, etc. • Spills, leaks / Line breaks, etc.	• Explosion } (reactive fluids) • Fire } • Injury • Contamination / Surface / Atmosphere
23. Non-Cryogenic Fluids / ICN / NH_3 / N_2H_4, other propellants / Embalming fluids / Nutrients (animal, insect) / Waste products / Misc. chemicals	• Handling, ejection, and detonation of gaseous release device / ICN & NH_3 cannisters • Handling other liquids / Spills / Inadvertent release / Cannister rupture • Uncontrolled combustion	• Explosion } (reactive fluids) • Fire } • Injury/illness/disease / Physical / Chemical / Biologicals, waste, etc. • Contamination / Atmosphere (toxic gases) / Surface / Chemical / Bacterial
24. Non-Cryogenic Gases / O_2 / N_2 / He / Argon / Methane	• Tank rupture / Overpressure (inadequate or malfunctioning vent system) • Leaks / Line breaks, etc. • Release to or venting to module interior	• Explosion } (reactive gases) • Fire } • Injury • Contamination / Atmosphere

Table 3-32. *Summary of Hazard Source, Causation, and Interaction Results — Equipment/Contents — Related Hazard Sources (Sheet 8 of 8)*

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
25. Emulsions / Plastic / Nuclear	• Handling • Placing, replacing • Storing	• Injury (chemical) • Contamination / Surface / Atmosphere (from emulsion outgassing)
26. Specific Contamination Source / Active cleaning device / Samples and racks / Sensor cleaning	• Performance of contamination experiment activities / Touching / Handling / Cleaning / Waste disposal	• Injury (chemical) • Contamination / Surface • Person • Equipment

Table 3-33. Summary of Hazard Source, Causation, and Interaction Results — Operations — Related Hazard Sources (Sheet 1 of 3)

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
1. Basic Experimentation Activities / Setup equipment / Deploy equipment ● Internally ● Scientific airlocks / Operate/Monitor/Shutdown / Align/Calibrate / Retrieve/Replace/Process (film) / Dextrous control movements ● Touching ● Handling ● Moving / Waste disposal, cleanup / Store samples	● Personnel error ● Source escape (any) / Gases / Liquids / Powders, etc. / Cage contents ● Hot surfaces, sources ● Cold surfaces, sources ● Processing operations ● Equipment malfunction ● Mere presence in / RF-fields / Magnetic fields / Radiation fields ● Nuclear ● Laser	● Explosion ● Fire ● Injury/Illness/Disease / Physical (cuts, bites, burns, etc.) / Chemical / Biological / Radiological ● Contamination / Surface / Atmosphere / Chemical / Biological / Radiation ● Trapped crewman
2. EVA Activities / Install or remove exterior equipment, samples / Operate AMU / Operate MWP / Erect antennas, booms, etc.	● PLSS depletion ● Broken tether ● Tether entanglement ● Exposure to / High-voltage / High RF-field ● Physical movements ● Presence on MWP ● Collisions	● Loss of EC/LS ● Stranded in EVA ● EVA injury / Physical (impact, RF) / Electrical shock
3. Maintenance and Repair Activities / Recharge batteries / Recharge gas bottles / Replace components / Clean sensors	● Personnel error ● Source escape / Electrolyte / Gases ● Equipment malfunction ● High-voltage ● High RF-field	● Explosion ● Fire ● Injury / Physical / Chemical ● Contamination / Atmosphere / Surface

Table 3-33. Summary of Hazard Source, Causation, and Interaction Results — Operations — Related Hazard Sources (Sheet 2 of 3)

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
4. Egress Activities / Exit Orbiter, enter module / Exit module, enter Orbiter / Exit module for EVA	• Orbiter airlock malfunction • Module airlock malfunction	• Trapped crewman / In Orbiter airlock / In module airlock / In module • Stranded in EVA
5. Erection/Retraction (of Module) Activities	• Mechanism malfunction / Partial extension only / Will not fully retract • Protuberances on module / Will not retract	• Inability to close Orbiter cargo bay doors
6. Docking/Undocking Activities	• Mechanism malfunction / Docking attempt • Does not attach	• Vehicle stranded / RAM / Automated satellite / Etc.
	/ Undocking attempt • Does not release and will not retract into cargo bay	• Inability to close Orbiter cargo bay doors
	• Collision / Excessive velocity / Improper alignment / Out-of-control propulsion	• Explosion • Fire • Injury • Contamination • Vehicle stranded / RAM / Automated satellite • Structural damage / Orbiter / Attached module

Table 3-33. Summary of Hazard Source, Causation, and Interaction Results – Operations – Related Hazard Sources (Sheet 3 of 3)

Basic Hazard Source	Causative Event/Factor/Condition	Potential Hazardous Results
7. Ground Installation of Module	• Dropped module / Collision / Transporter malfunction • Subsystem malfunction • Escape of contents / Inadvertent venting / Rupture of module shell	• Explosion • Fire • Injury • Contamination / Chemical / Bacterial / Radiological
8. Ground Removal of Module	• Dropped module / Collision / Transporter malfunction • Subsystem malfunction • Escape of contents / Inadvertent venting / Rupture of module shell	• Explosion • Fire • Injury • Contamination / Chemical / Bacterial / Radiological

Table 3-34. Summary of Hazard/Emergency Groups and Their Related Experimental Sources (Sheet 1 of 2)

	Hazard/Emergency Groups					
	Fire	Explosion/Implosion	Decompression/ Overpressure	Collisions (Internal/External)	Contamination (Toxic/Non-Toxic)	Injury/Illness
Related Sources	• Gas Jets • Combustors • Furnaces • Fire Sensing and Suppression Module • Liquid Metals, Glasses • Reactive Vent Efflux • Lasers • Spark-Chambers • Batteries • Solid Propellant Devices • Processing Chemicals • Electrically-Powered Equipment • Reactive Fluids, Gases / LH_2, H_2 / LO_2, O_2 / N_2H_4 / Methane / ICN / NH_3 • Recharging Operations / Batteries / Gas Bottles	• Gas Jets • Combustors • Overpressured Cryo Dewars • Batteries (unvented) • Overpressured Gas Bottles • Reactive Fluids, Gases / LH_2, H_2 / LO_2, O_2 / N_2H_4 / Methane / ICN / NH_3 • Solid Propellant Devices • Unvented Volatile Liquid Chemical Containers	• Laser Beam Damage • Scientific Airlocks (Open/Leaking Doors) • Rotating Equipment Damage / Centrifuges / Rotating Litter Chair • Uncontrolled Vacuum Source for LBNPC • Balloon Inflation in Module	• Rotating Equipment / Centrifuges / Rotating Litter Chair / Ergometer • Subsatellites (Targets) • Teleoperator S/C • AMU • MWP • RAMs • Automated Satellites	• Fluids, Gases / LH_2, H_2 / LO_2, O_2 / N_2H_4 / Methane / Argon / He / Ne / ICN / NH_3 • Processing Chemicals • Insects (fleas, lice, etc.) • Pollen • Vaporized Substances (from melting, casting operations) • Radiosotopes • Waste Products / Liquid / Solid • Battery Electrolyte • Biologicals/ Bacteria • Emulsions / Plastic / Nuclear • Specific Contamination Experiments • Radiological	• Eye Damage (sunlight in telescope) • Cuts • Bites (animals, insects) • Burns / Gas Jets, Combustors / Furnaces / Liquid Metals, Glasses / Lasers / Chemicals • Electrical Shock • RF-Field Exposure • Magnetic Field Exposure • Radiation Field Exposure / Lasers / X-Ray Machines / Radioisotopes / RTGs • Bacterial Exposure • Impact / Rotating Equipment / Collisions • Loss of EC/LS • Toxic Atmosphere • Emulsion Contact • Excessive Stress / Centrifuge / Litter Chair / Ergometer • Excessive Vacuum / LBNPC / EVA Suit Failure

Table 3-34. Summary of Hazard/Emergency Groups and Their Related Experimental Sources (Sheet 2 of 2)

	Hazard/Emergency Groups					
	Mechanical/Structural Failures	Radiation (Internal/External)	Personnel Errors	Basic Subsystem Malfunctions	Inability to Return From EVA	Lack of Resupply/Rotation
Related Sources	• Scientific Airlocks / Doors / Deployment Mechanisms • Rotating Equipment / Centrifuges / Rotating Litter Chair • Telescopes / Moving Mechanisms / Benches / Latches • Booms/Platforms/Antennas • MWP / Grappling Arms • Teleoperator S/C / Manipulator Arms / Docking Legs • Airlock Doors / Orbiter / Module • Erection/Retraction Mechanisms / Orbiter Cargo Bay • Docking Mechanisms / Module • Ground Transporter / Installing Removing Mechanisms	• Laser Beam Radiation • X-Ray Machines • Radiosotopes • RTGs • RF-Radiation	• Setup Equipment • Deploy Equipment / Internally / Scientific Airlocks • Operate/Monitor/Shutdown Equipment • Align/Calibrate Equipment • Retrieve/Replace/Process Film • Dextrous Control / Touching / Handling / Moving • Waste Disposal/Cleanup • Sample Storing • Operate AMU • Operate MWP • Erecting Antennas, Booms • Maintenance and Repair / Recharging • Batteries • Gas Bottles / Component Replacement / Sensor Cleaning • Egress Activities • EVA Activities • Docking Control Activities • Ground Installation and Removal Activities • Erection/Retraction Activities	• Electrical Power System / Batteries / Fuel Cells / Orbiter Power Supply to Module • EC/LS / Atmosphere / Thermal • RCS / Attached Module / Detached RAM • GN&C / Detached RAM • Propulsion / Detached RAM • Communications	• EVA Operations / Tethered / AMU / MWP	• Protuberances Preventing Closure of Cargo Bay Doors / Scientific Airlock Doors / Booms/Platforms/Antennas / Unretracted Module / Extending Instruments, Deployment Mechanisms • Entrapment / In Airlock / In Module • Stranding / In EVA / In Detached RAM

Table 3-35. Emergency Situation Applicability, Pre-Launch Phase

Situation/Condition	Location				
	Pallet	MSM[1]	RAM[1]	Orbiter	Vicinity
• Ill/injured crew				X	
• Non-habitable					
/ Loss of EC/LS, temperature or humidity extremes				X	
/ Contamination	X	X	X	X	
• Entrapment of crew					
/ In airlock or module					
• Stranded in EVA					
• Orbiter unable to reenter					
• Metabolic deprivation					
• Inability to communicate				X	
• Out-of-control					
/ Tumbling, unsafe trajectory					
• Abandonment (crew in EVA)					
• Debris in vicinity					
• Radiation in vicinity					

[1] No crew in module during pre-launch phase.

Table 3-36. Emergency Situation Applicability, Ascent Phase

Situation/Condition	Location				
	Pallet	MSM[1]	RAM[1]	Orbiter	Vicinity
• Ill/injured crew				X	
• Non-habitable					
/ Loss of EC/LS, temperature or humidity extremes				X	
/ Contamination	X	X	X	X	
• Entrapment of crew					
/ In airlock or module					
• Stranded in EVA					
• Orbiter unable to reenter				X	
• Metabolic deprivation				X	
• Inability to communicate				X	
• Out-of-control					
/ Tumbling, unsafe trajectory				X	
• Abandonment (crew in EVA)					
• Debris in vicinity					
• Radiation in vicinity					

[1] No crew in module during ascent phase.

Table 3-37. Emergency Situation Applicability, On-Orbit Phase

Situation/Condition	Location				
	Pallet	MSM	RAM	Orbiter	Vicinity
• Ill/injured crew		X	X	X	
• Non-habitable					
/ Loss of EC/LS, temperature or humidity extremes		X	X	X	
/ Contamination	X	X	X	X	
• Entrapment of crew					
/ In airlock or module		X	X	X	
• Stranded in EVA	X	X			X
• Orbiter unable to reenter				X	
• Metabolic deprivation		X	X	X	
• Inability to communicate		X	X	X	
• Out-of-control					
/ Tumbling, unsafe trajectory			X	X	
• Abandonment (crew in EVA)			X	X	X
• Debris in vicinity					X
• Radiation in vicinity					X

Table 3-38. Emergency Situation Applicability, Return Phase

Situation/Condition	Location				
	Pallet	MSM[1]	RAM[1]	Orbiter	Vicinity
• Ill/injured crew				X	
• Non-habitable					
/ Loss of EC/LS, temperature or humidity extremes				X	
/ Contamination	X	X	X	X	
• Entrapment of crew					
/ In airlock or module					
• Stranded in EVA					
• Orbiter unable to reenter					
• Metabolic deprivation				X	
• Inability to communicate				X	
• Out-of-control					
/ Tumbling, unsafe trajectory				X	
• Abandonment (crew in EVA)					
• Debris in vicinity					
• Radiation in vicinity					

[1] No crew in module during return phase.

Table 3-39. Emergency Situation Applicability, Post-Flight Phase

Situation/Condition	Location				
	Pallet	MSM[1]	RAM[1]	Orbiter	Vicinity
• Ill/injured crew				X	
• Non-habitable					
/ Loss of EC/LS, temperature or humidity extremes				X	
/ Contamination	X	X	X	X	
• Entrapment of crew				X	
/ In airlock or module					
• Stranded in EVA					
• Orbiter unable to reenter					
• Metabolic deprivation					
• Inability to communicate					
• Out-of-control					
/ Tumbling, unsafe trajectory					
• Abandonment (crew in EVA)					
• Debris in vicinity					
• Radiation in vicinity					

[1] No crew in module upon return to earth.

Table 5-1, H-1. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-1

HAZARD SOURCE Hi-Temperature Sources		Pallet
A number of high temperature sources are present in the form of gas jets, combustors, furnaces, fire sensing and suppression module and resultant liquid metals and glasses in manufacturing experiments. (See also H-2, H-20, H-22, H-23, and H-24 for related hazard sources.)	X	MSM
	X	RAM
Experiment Groups: P-4; MS-1; T-4		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Combustor or jet burn-through, uncontrolled combustion, and inadvertent release of hot or toxic gases and liquids are principal causative factors.

HAZARDOUS RESULT

Uncontrolled combustion can result in explosions.
Combustor burn-through can result in injury, fire, or contamination.
Spillage of liquid metals, glasses, vaporized substances can also result in fire, injury, and contamination of surfaces and atmosphere.

HAZARD/EMERGENCY GROUPS

Fire, injury, explosion, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide overboard vent systems, including pressure-regulation and pressure relief subsystems.	5.1.1.1
2. Provide capability to purge high-temperature devices.	5.1.2.1
3. Provide protective covers to prevent inadvertent surface contact.	5.1.8.2
4. Provide guards to prevent access to operational high-temperature equipment.	5.1.8.4
5. Configure for ease of jettisoning.	5.1.9
6. Configure for remote deployment and remote operational control.	5.1.10
7. Configure high-temperature equipment in integral or self-contained units.	5.1.12.5
B. Locational Features	
1. Locate high-temperature sources exterior to habitable Module compartments.	5.2.1
2. If interior to the Module, locate high-temperature devices in special areas with spill containment, waste disposal, purge, and vent provisions.	5.2.2.5
3. Orient the spark-chamber, gas jets, combustors, etc. so that an inadvertent bleed or efflux will not be directed toward the Orbiter or cargo bay.	5.2.3.3
4. Locate equipment with hot surfaces away from other equipment in the same Module.	5.2.4.8
5. Locate high-temperature equipment to facilitate jettisoning.	5.2.6.1
C. Operational Techniques	
1. Wear protective garments, gloves, face masks, etc. when performing furnace-related operations.	5.3.1.1.2
2. Perform combustion and furnace related experiments in a free-flying Experiment Module, deployed at a safe distance from the Orbiter.	5.3.1.2.1
3. Remotely control high-temperature experiments.	5.3.1.3
4. Employ caution and warning signals to indicate if high-temperature devices exceed design pressure or temperature limits.	5.3.4.1

Table 5-1, H-2. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-2

HAZARD SOURCE		
Overboard Vents	X	Pallet
The presence of cryogens, gas jets, combustors, furnaces, etc., and various life sciences holding and rearing accommodations necessitate venting various chambers overboard to provide pressure or environmental control during the experiment(s). (See also H-1, H-21, and H-24 for related hazard sources.)	X	MSM
	X	RAM
Experiment Groups: A-1, -5, -6; P-3, -4; T-2; MS-1; LS-2, -3, -4, -5	X	Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Closed or inoperative vents, cargo bay venting, and common vent sink locations are potential causative factors.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
Cryogenic tank overpressure/rupture releases cryo fluids, gases. Jet, furnace or combustor overpressure can release flames, toxic gases, liquid metals, liquid glasses, etc. Cage overpressure and rupture can release animals, insects, plants, pollen, bacteria, waste products, etc. Closed cargo bay venting can result in fire, explosion, or contamination. A common vent sink location can result in fire or explosion if the vent effluxes are reactive.	Fire, explosion, injury, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Configure overboard vent systems to:	5.1.1.2
a. avoid common exit sources or adjacent exterior locations	
b. prevent vent efflux from entering Orbiter cargo bay	
c. prevent efflux in vicinity of Orbiter or Module sensors	
2. Incorporate accumulators to permit controlled venting during critical operational periods.	5.1.1.3
3. Incorporate automatic interlocks which prevent operation of equipment requiring an operative vent, in the event of vent malfunction.	5.1.8.1.1
B. Locational Features	
1. Locate the terminals of overboard vents such that vent efflux will not enter the Orbiter cargo bay.	5.2.3.2
2. Locate the terminus of overboard vents to avoid adjacent locations where reactive vent effluxes could combine.	5.2.4.7
C. Operational Techniques	
1. Purge the Orbiter cargo bay in the event of inadvertent efflux release into the bay by Module overboard vents.	5.3.2.2
2. Employ caution and warning signals to indicate status of vent system components and give positive warning of component malfunctions.	5.3.4.1

Table 5-1, H-3. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No.	H-3
X	Pallet
X	MSM
X	RAM
	Orbiter

HAZARD SOURCE Lasers

Several experiments utilize laser-radar equipment for tracking balloons, subsatellites, etc. Specific laser experiments are included in the Physics FPE.

Experiment Groups: P-2, -4; C/N-1; T-3

CAUSATIVE EVENT/FACTOR/CONDITION

Inadvertent exposure of crew, equipment, or structure to the laser beam is the principal causative event.

HAZARDOUS RESULT

Such beam exposure can potentially result in fire, injury, equipment damage, or a hole in the Module structure.

HAZARD/EMERGENCY GROUPS

Fire, injury, loss of EC/LS, basic subsystem malfunction, decompression

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide radiation shields to protect crew and sensitive equipment from laser radiation.	5.1.5.2
2. Select source strength compatible with crew and nearby equipment.	5.1.6.1
3. Incorporate automatic interlocks to shut down laser if field intensity exceeds design range values.	5.1.8.1.1
4. Incorporate manual interlocks to prevent inadvertent laser activation.	5.1.8.1.2
5. Provide stops to limit the directional movement of the laser beam.	5.1.8.3
6. Provide guards to prevent access to laser equipment when it is in operation.	5.1.8.4
7. Interpose a material means (for absorbing laser beam energy) between the laser beam target and Module primary structure.	5.1.8.6
B. Locational Features	
1. Locate laser equipment exterior to habitable Module compartments.	5.2.1
2. Position laser apparatus (if within the Module) such that:	5.2.2.2
a. beam not aimed at vital equipment	
b. apparatus is away from normal crew passage routes	
c. a deliberate act or access movement is required to reach it	
C. Operational Techniques	
1. Employ caution and warning signals to indicate status of laser beam pointing direction and positive warning if beam direction is out-of-limits.	5.3.4.1

Table 5-1, H-4. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-4

X	Pallet
X	MSM
X	RAM
	Orbiter

HAZARD SOURCE Spark-Chamber

Device for measuring galactic and extragalactic radiation sources in hi-energy astronomy experiments. Utilizes Argon and Methane gases. (See also H-2, H-20, and H-23 for related hazard sources.)

Experiment Groups: A-5

CAUSATIVE EVENT/FACTOR/CONDITION

Leakage or bleed of argon or methane gases with the Module or Orbiter cargo bay are causative factors.

HAZARDOUS RESULT

Leaks and spills can result in toxic gases, fire, or explosion in the Experiment Module or in the Orbiter cargo bay.

HAZARD/EMERGENCY GROUPS

Fire, explosion, injury, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Configure spark-chamber for ease of jettisoning.	5.1.9
2. Configure the spark-chamber and its associated argon and methane tankage in integral or self-contained units to facilitate remote storage and jettisoning.	5.1.12.5
B. Locational Features	
1. *Locate the spark-chamber exterior to habitable Module compartments.*	5.2.1
2. Locate spark-chambers to facilitate jettisoning.	5.2.6.1
C. Operational Techniques	
1. Jettison spark-chambers with leaking gases or other malfunctions.	5.3.3.1

Table 5-1, H-5. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-5

HAZARD SOURCE	Superconducting Magnet		
Cryogenically cooled superconducting magnets (in dewars) are indicated for certain Physics experiments. (See also H-24 for related hazard sources.)			Pallet
		X	MSM
		X	RAM
Experiment Groups: P3, P4			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

The superconducting magnet provides an extremely high magnetic field strength in relation to its physical size and power input. This field strength, its location, and its possible instabilities are conditions which could precipitate hazardous results.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
Excessive magnetic field strength or a location too close to habitable compartments or sensitive subsystems could lead to crew injury or malfunction of equipment permeated by the field.	Basic subsystem malfunction, injury

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Select a field source strength compatible with the crew and nearby sensitive equipment.	5.1.6.1
2. Incorporate automatic interlocks to shut down magnet if field intensity exceeds design range values.	5.1.8.1.1
3. Avoid the use of magnetic tools, etc., when experiments having magnetic fields are incorporated in the Module.	5.1.13.1
B. Locational Features	
1. Locate magnetic field devices away from field-sensitive equipment and habitable compartments.	5.2.4.1
C. Operational Techniques	
1. Do not transport magnetic-field devices on same flight with solid propellant propulsive stages.	5.3.1.5.2
2. Control the timing of experiments with magnetic fields to avoid adversely affecting sensitive Shuttle subsystems.	5.3.1.5.3
3. Employ caution and warning signals to indicate activation of magnetic-field devices.	5.3.4.1

Table 5-1, H-6. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-6

HAZARD SOURCE	Scientific Airlocks		
Several experiment categories require scientific airlocks for the deployment of instruments, sensors, subsatellites, balloons, etc. from within a Module to an exterior position for release, observation, or other experimental procedures.			Pallet
		X	MSM
		X	RAM
Experiment Groups: A-4; P-1; -2, -4; C/N-1; T-1, -4			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Leaking doors or seals, inadvertent opening of inner and outer doors at same time, failure of outer door to close, instrument "hang-up" in airlock, deployment mechanism malfunction.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
Leaking doors or inadvertent simultaneous opening of both doors can lead to loss of EC/LS and decompression in the extreme, with potential injury to affected crew members. Failure of the outer door to close, instrument "hang-up" in the airlock, or deployment mechanism malfunction in the extended position can prevent closure of the P/L bay doors (upon retraction of the Module) and place the Orbiter in the position of being unable to reenter the earth's atmosphere.	Loss of EC/LS, injury, decompression, inability to reenter

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate means to ensure retraction of airlock deployment mechanisms.	5.1.7.1
2. Incorporate manual interlocks to prevent simultaneous opening of inner and outer hatch doors.	5.1.8.1.2
3. Configure airlocks and deployment mechanisms for ease of jettisoning objects which hang-up in airlock.	5.1.9
B. Locational Features	
1. Orient scientific airlocks such that a jammed open outer door will not prevent Orbiter cargo bay door closure.	5.2.3.1
C. Operational Techniques	
1. Jettison outer hatch doors if not closeable.	5.3.3.1
2. Employ caution and warning signals to indicate excessive leakage rates through airlock doors.	5.3.4.1

Table 5-1, H-7. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-7

X	Pallet
X	MSM
X	RAM
	Orbiter

HAZARD SOURCE Subsatellites

A number of experiments require the use of a companion satellite (active or passive) as a target source or for data relay. (See also H-6, H-19, H-20, and H-23 for related hazard sources.)

Experiment Groups: P-1, -2; C/N-1; T-1

CAUSATIVE EVENT/FACTOR/CONDITION

Active or passive subsatellites can "hang-up" in airlocks.
Gas bottle overpressure is a hazardous condition in a subsatellite with active propulsion.
Battery shorts, electrolyte spills, and overpressure are causative conditions in subsatellites with active on-board power.

HAZARDOUS RESULT

Gas bottle overpressure can result in explosion, fire, and injury.
Battery shorts can result in fire, electric shock, burns.
Battery electrolyte spills can result in chemical injury and contamination of surfaces and atmosphere.
Battery overpressure and rupture can cause explosion, fire, injury, and contamination.
Subsatellite hang-up in an airlock may result in inability to close Orbiter P/L bay doors and subsequent inability to reenter earth's atmosphere.

HAZARD/EMERGENCY GROUPS

Fire, injury, explosion, contamination, inability to reenter

PREVENTIVE MEASURES

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate discharge devices to de-energize subsatellites incorporating high-voltage components which require handling, maintenance, or sensor replacement.	5.1.8.5
2. Configure subsatellites for ease of jettisoning from the Module.	5.1.9
3. Configure subsatellites for remote deployment (to avoid deployment through airlocks).	5.1.10
4. Provide means for attaching and holding subsatellites exterior to the Module.	5.1.11.3
B. Locational Features	
1. Locate subsatellites exterior to habitable Module compartments.	5.2.1
2. Locate subsatellites to facilitate jettisoning.	5.2.6.1

Table 5-1, H-8. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-8

HAZARD SOURCE Rotating Equipment			Pallet
A number of rotating equipments are proposed for Life Sciences experiments (scientific centrifuges, manned centrifuges, ergometer, rotating litter chair).		X	MSM
		X	RAM
Experiment Groups: LS-1			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Loss of rotational control (overspeed) and overexertion are the principal causative factors.

HAZARDOUS RESULT

Overspeed of centrifuges can result in impact injury to crew, spread of bioresearch centrifuge contents (contamination), and structural damage to the Module shell (decompression in extreme).
Overexertion in the ergometer could result in fainting or other human injury.

HAZARD/EMERGENCY GROUPS

Injury, contamination, decompression

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate mechanical shielding for containment of failed rotating members.	5.1.5.1
2. Incorporate means to cause principal drive number to fail if excessive speeds or loads are reached.	5.1.7.1
3. Incorporate automatic interlocks to shut down rotating equipment if speeds exceed design range values.	5.1.8.1.1
4. Incorporate manual interlocks to prevent inadvertent actuation of rotating equipment.	5.1.8.1.2
5. Provide protective covers to prevent release of centrifuge contents.	5.1.8.2
6. Provide guards to prevent access to operational rotating equipment.	5.1.8.4
7. Provide emergency means for braking and holding rotatable equipment.	5.1.8.9
B. Locational Features	
1. Position rotating equipments such that a clear egress path exists when the equipment is rotating.	5.2.2.4
C. Operational Techniques	
1. Employ caution and warning signals to indicate if speed of rotating equipment exceeds design range values.	5.3.4.1
2. Continuously monitor and control human centrifuge operations.	5.3.5.1

Table 5-1, H-9. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-9

HAZARD SOURCE: Telescopes		
A wide variety of telescopes -- optical, IR, UV, X-ray -- are utilized in the astronomy experiments. (See also H-6, H-18, H-20, and H-24 for related hazard sources.)		Pallet
	X	MSM
	X	RAM
Experiment Groups: A-1, -2, -3, -4, -5, -6		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Telescopes are normally passive in and of themselves.
Malfunction of holding and rotating mechanisms and visual pointing operations are potential causative factors leading to hazardous results.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
Failure of the latching mechanism in the locked position could result in crew member entrapment. Looking directly at the sun or reflected sunlight during visual pointing operations could result in eye damage.	Injury, entrapment

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate means to ensure that the telescope latching mechanism releases from the locked position.	5.1.7.1
2. Incorporate automatic interlocks to prevent use of direct-viewing telescope if oriented toward sun or reflected sunlight.	5.1.8.1.1
3. Provide protective covers for direct-viewing telescopes to prevent eye damage from direct or reflected sunlight ("cover" may be in fact a fast-acting filter).	5.1.8.2
4. Provide emergency means for braking and holding rotatable telescopes.	5.1.8.9
B. Locational Features	
1. Position rotatable telescopes so that a crew member can reach normal Module egress ports with telescope locked in any position.	5.2.2.1
C. Operational Techniques	
1. Employ caution and warning signals to indicate if optical telescopes are pointed at sun or receiving reflected sunlight.	5.3.4.1

Table 5-1, H-10. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-10

HAZARD SOURCE	Booms/Platforms/Antennas		
Extendable booms/platforms/antennas are contemplated for a number of experiments to deploy sensors, transmitters, accelerators, etc. in positions extended from Module. A manually-erectible parabolic expandable truss antenna (PETA) is also planned. (See also H-20 and H-27 for related hazard sources.)		X	Pallet
		X	MSM
		X	RAM
Experiment Groups: P-1, -2, -4; T-1, -3, -4, -5; C/N-1			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Latch failures or expanding mechanism failures which prevent retraction of the boom/platforms/antennas are causative factors.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
If the boom/platform/antenna extended length is sufficient to preclude closing the Orbiter P/L bay doors (after Module is retracted) the Orbiter will be unable to reenter the earth's atmosphere.	Inability to reenter

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate means to ensure the retraction of booms/platforms/antennas.	5.1.7.1
2. Configure for ease of jettisoning in the event of failure to fully erect or to fully retract.	5.1.9
B. Locational Features	
1. Locate booms/platforms/antennas away from EVA hatches.	5.2.4.2
2. Locate booms/platforms/antennas away from docking ports.	5.2.4.3
C. Operational Techniques	
1. Jettison booms/platforms/antennas if not retractable and their presence prevents cargo bay door closure.	5.3.3.1
2. Employ caution and warning signals to indicate commencement of extension activities and positive warning if elements thereon are active.	5.3.4.1

Table 5-1, H-11. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-11

HAZARD SOURCE	Balloons		
Inflatable ballons (of ECHO type) are called for in wake measurement experiments in Plasma Physics FPE. (See also H-6 for related hazard sources.)			Pallet
		X	MSM
		X	RAM
Experiment Groups: P-2			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

The balloon material and the possibility of inadvertent inflation are principal causative factors leading to potential hazardous results.

HAZARDOUS RESULT

Balloons made from combustible materials are a source of fire.
Inadvertent balloon inflation within a Module can cover EC/LS ports, the crewman's body, or prevent crewman freedom of movement.
Inadvertent inflation in an airlock could result in an outer hatch door being jammed open, preventing Orbiter P/L bay door closure upon retraction of the Module.

HAZARD/EMERGENCY GROUPS

Fire, injury, loss of EC/LS, entrapment, inability to reenter

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Utilize safing mechanisms/devices for inflating means.	5.1.3.1
2. Incorporate manual interlocks to prevent inadvertent balloon inflation.	5.1.8.1.2
B. Locational Features	
1. Locate balloons and their inflating devices exterior to habitable Module compartments.	5.2.1
2. Keep balloons and inflating devices separate from one another until time for inflation.	5.2.4.4

Table 5-1, H-12. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-12

HAZARD SOURCE: Negative Pressure Source		Pallet
A negative pressure source is required for the Lower Body Negative Pressure Chamber (LBNPC) used for human biomedical research experiments.	X	MSM
	X	RAM
Experiment Groups: LS-1		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

An uncontrolled vacuum source is the principal causative factor.

HAZARDOUS RESULT

An uncontrolled vacuum source could result in physical injury to the human research subject.
In the extreme, an uncontrolled vacuum source could lead to cabin decompression.

HAZARD/EMERGENCY GROUPS

Injury, decompression

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Select a low pressure source no lower than required by LBNPC experiment requirements (avoid an uncontrolled vacuum source).	5.1.6.1
2. Incorporate automatic interlocks to provide a controlled shutdown of the LBNPC if the permissible lower range pressure value is exceeded.	5.1.8.1.1
3. Incorporate manual interlocks to prevent inadvertent activation of the LBNPC.	5.1.8.1.2
C. Operational Technique	
1. Employ caution and warning signals to indicate if the LBNPC lower pressure design limit is exceeded.	5.3.4.1

Table 5-1, H-13. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-13

HAZARD SOURCE	Astronaut Maneuvering Unit (AMU) (Backpack)	X	Pallet
A backpack AMU is utilized in Technology experiments. (See also H-19, H-23, H-27 for related hazard sources.)		X	MSM
		X	RAM
Experiment Groups: T-3			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Subsystem malfunction is the principal causative factor (aside from EVA operations attendant to utilizing the AMU).

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
Oxygen bottle overpressure and explosion can result in fire and injury. Battery overpressure and explosion or electrolyte leakage can result in injury, fire, explosion, and contamination.	Injury, fire, explosion, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate means to ensure that any propulsion failure occurs in the non-thrusting mode.	5.1.7.1
2. Incorporate manual interlocks to prevent inadvertent release of the AMU from the Module.	5.1.8.1.2
3. Configure the AMU for ease of jettisoning from the Module.	5.1.9
4. Provide means for attaching and holding the AMU to the exterior of the Module.	5.1.11.3
B. Locational Features	
1. Locate the AMU exterior to habitable Module compartments.	5.2.1
2. Locate AMU so as to permit unimpeded egress from EVA hatch and to provide convenient access for use by astronaut in EVA.	5.2.5.5
3. Locate the AMU to facilitate jettisoning.	5.2.6.1
C. Operational Techniques	
1. Conduct AMU operations in the tethered mode, to the maximum extent possible.	5.3.1.6.2.1
2. Monitor AMU propulsion subsystems and deactivate if malfunction is indicated.	5.3.1.6.2.2
3. Jettison the AMU from the Module if a propulsion system malfunction is indicated.	5.3.3.1

Table 5-1, H-14. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-14

HAZARD SOURCE		
Manned Work Platform (MWP)	X	Pallet
A maneuverable open MWP is utilized in certain Technology experiments. (See also H-10, H-19, H-20, H-22, and H-23 for related hazard sources.)	X	MSM
	X	RAM
Experiment Groups: T-3		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Subsystem malfunctions and incorrect docking conditions (excessive velocity, incorrect heading, etc.) are the principal causative factors (aside from EVA operations attendant to utilizing the MWP).

HAZARDOUS RESULT

Gas bottle overpressure can result in fire, explosion, injury.
Battery overpressure can result in fire, explosion, injury, contamination.
Incorrect docking can result in a collision, with decompression an extreme result.

HAZARD/EMERGENCY GROUPS

Fire, explosion, injury, contamination, collision, decompression

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate means to ensure that any propulsion failure occurs in the non-thrusting mode.	5.1.7.1
2. Incorporate manual interlocks to prevent inadvertent release of the MWP from the Module.	5.1.8.1.2
3. Configure the MWP for ease of jettisoning from the Module.	5.1.9
4. Provide means for attaching and holding the MWP to the exterior of the Module.	5.1.11.3
B. Locational Features	
1. Locate the MWP exterior to habitable Module compartments.	5.2.1
2. Locate MWP so as to permit unimpeded egress from EVA hatch and to provide convenient access for use by astronaut in EVA.	5.2.5.5
3. Locate the MWP to facilitate jettisoning.	5.2.6.1
C. Operational Techniques	
1. Perform MWP-controlled docking experiments with a free-flying Experiment Module, deployed at a safe distance from the Orbiter.	5.3.1.2.1
2. Conduct MWP operations in the tethered mode, to the maximum extent possible.	5.3.1.6.2.1
3. Monitor MWP propulsion subsystems and deactivate if malfunction is indicated.	5.3.1.6.2.2
4. Jettison the MWP from the Module if a propulsion system malfunction is indicated.	5.3.3.1

Table 5-1, H-15. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-15

HAZARD SOURCE Teleoperator S/C (Unmanned)	X	Pallet
An unmanned remotely-controlled spacecraft for cargo manipulation and docking maneuvers is utilized in one Technology experiment. (See also H-10, H-19, H-20, and H-23 for related hazard sources.)	X	MSM
	X	RAM
Experiment Groups: T-5		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Subsystem malfunction and incorrect docking conditions (excessive velocity, incorrect heading, etc.) are the principal causative factors.

HAZARDOUS RESULT

Gas bottle overpressure can result in fire, explosion, injury.
Battery overpressure can result in fire, explosion, injury, contamination.
Incorrect docking can result in a collision, with decompression an extreme result.

HAZARD/EMERGENCY GROUPS

Fire, explosion, injury, contamination, collision, decompression

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate manual interlocks to prevent inadvertent release of the teleoperator S/C from the Module.	5.1.8.1.2
2. Configure the teleoperator S/C for ease of jettisoning from the Module.	5.1.9
3. Configure the teleoperator S/C for remote deployment from the Module.	5.1.10
4. Provide means for attaching and holding the AMU to the exterior of the Module.	5.1.11.3
B. Locational Features	
1. Locate the teleoperator S/C exterior to habitable Module compartments.	5.2.1
2. Locate the teleoperator S/C so as to permit unimpeded egress from EVA hatch and to provide convenient access for EVA checkout.	5.2.5.5
3. Locate the teleoperator S/C to facilitate jettisoning.	5.2.6.1
C. Operational Techniques	
1. Perform teleoperator-controlled docking experiments with a free-flying Experiment Module, deployed at a safe distance from the Orbiter.	5.3.1.2.1
2. Jettison the teleoperator S/C from the Module if a propulsion system malfunction is indicated.	5.3.3.1

Table 5-1, H-16. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-16

HAZARD SOURCE: Solid Propellants		
A variety of solid propellants are required (pyrotechnics, solid rocket motors, spin-up rockets, etc.) for planned automated satellites and related propulsive stages.		Pallet
		MSM
	X	RAM
Experiment Groups: Automated Satellites & Propulsive Stages		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

The principal causative factor is inadvertent ignitor activation, whether by overt act, squib failure, RF-field, or magnetic field inducement.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
Rocket explosion or normal operation while attached to or in the vicinity of the Orbiter can result in fire, injury, or explosion.	Fire, injury, explosion

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Utilize safing mechanism/devices.	5.1.3.1
2. Incorporate shielding to protect against inadvertent activation by exposure to permeating fields.	5.1.5.3
3. Incorporate manual interlocks to prevent inadvertent activation of devices containing solid propellants.	5.1.8.1.2
C. Operational Techniques	
1. Safe all systems containing solid propellants prior to ground installation.	5.3.2.5
2. Employ caution and warning signals to indicate changes in status of safe-and-arm circuits.	5.3.4.1

Table 5-1, H-17. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-17

HAZARD SOURCE Radiation Sources		Pallet
Sources of on-board radiation include X-ray machines, radioisotopes, RTG, lasers, and RF-emitters in various physics, Comm/Nav, and Life Sciences experiments. (See also H-3 and H-20 for related hazard sources.)	X	MSM
	X	RAM
Experiment Groups: P-2, -4; C/N-1; LS-1, -2, -3, -4, -5		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

An uncontrolled radiation source and isotope spillage are the principal causative factors.

HAZARDOUS RESULT

Uncontrolled radiation from X-ray, RTG, laser, or RF sources can cause human injury and result in the malfunction of sensitive equipment within the range of the radiation field.
Contact with isotope spills can result in human injury and surface and atmospheric contamination.

HAZARD/EMERGENCY GROUPS

Injury, contamination, basic subsystem malfunction

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Utilize safing mechanisms/devices for reactor or isotope devices.	5.1.3.1
2. Provide radiation shielding to protect crew and sensitive equipment.	5.1.5.2
3. Select a source strength compatible with the crew and nearby sensitive equipment.	5.1.6.1
4. Incorporate automatic interlocks to shut down generators if field intensity exceeds design range values.	5.1.8.1.1
5. Incorporate manual interlocks to prevent inadvertent activation of radiation sources.	5.1.8.1.2
6. Configure devices for ease of jettisoning from the Modules in the event of uncontrolled radiation.	5.1.9
B. Locational Features	
1. Locate radiation sources exterior to habitable Module compartments.	5.2.1
2. Locate radioisotope fluid containers in special areas with spill containment, waste disposal, purge, and vent provisions.	5.2.2.5
3. Locate permeating field devices away from field-sensitive equipment and habitable compartments.	5.2.4.1
4. Locate externally-mounted field generators away from EVA hatches.	5.2.4.2
5. Locate radiation sources to facilitate jettisoning.	5.2.6.1
C. Operational Techniques	
1. Wear radiation dose-accumulation badges to guard against excessive radiation accumulation.	5.3.1.1.1
2. Do not transport permeative-field experiments on same flight with solid-propellant propulsion stages.	5.3.1.5.2
3. Control the timing of experiments with magnetic or RF fields to avoid adversely affecting sensitive Shuttle subsystems.	5.3.1.5.3
4. Employ caution and warning signals to indicate commencement of radiation source activation, and positive warning if design range values are exceeded.	5.3.4.1
5. Continuously monitor and control the radiation levels of active radiation devices in or attached to the Experiment Module.	5.3.5.1
6. Monitor and control the total radiation level environment to which the Orbiter and Experiment have been subjected (due to both natural radiation spectrums and experimental equipment).	5.3.5.1

Table 5-1, H-18. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-18

HAZARD SOURCE	Cameras and Equipment		
Various experiments rely on photography to record forms of data and require in-space processing of the film to facilitate the experimental evaluation. (See also H-2 and H-22 for related hazard sources.)		X	Pallet
		X	MSM
		X	RAM
Experiment Groups: A-2, -4; P-1, -2, -4; ES-1; T-1, -2; C/N-1			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Combustible materials, chemical spills, and film processing operations are principal causative factors.

HAZARDOUS RESULT

Fire can result from the ignition of film and photochemicals.
Injury can result from the fire or from the handling of toxic chemicals.
Surface and atmospheric contamination can result from chemical spills.

HAZARD/EMERGENCY GROUPS

Fire, injury, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide capability to purge film-processing areas.	5.1.2.1
2. Incorporate manual interlocks to prevent inadvertent removal of covers or closures of photochemical containers.	5.1.8.1.2
3. Provide photochemical containers with end closures, spouts, or caps with no-spill, positive sealing characteristics.	5.1.12.6
B. Locational Features	
1. Locate film, photochemicals, and film vaults away from potential ignition source areas and remote from open habitable areas.	5.2.5.2
C. Operational Techniques	
1. Wear protective garments, gloves, masks, etc. during film handling or processing operations.	5.3.1.1.2
2. Perform film processing operations in special work areas.	5.3.1.4
3. Jettison leaking photochemical containers.	5.3.3.1

Table 5-1, H-19. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-19

HAZARD SOURCE		
Batteries	X	Pallet
Batteries are required in certain experiments to power sensors and equipment. (See also H-2 and H-20.)	X	MSM
	X	RAM
Experiment Groups: P-1, -2; T-3, -5		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Battery shorts, electrolyte spills, and inadequate venting (overpressure) are principal causative factors.

HAZARDOUS RESULT

Shorts near combustible materials cause fire.
Electrolyte spills can result in chemical injury and contamination of spacecraft surfaces and atmosphere.
If overpressured, the battery can explode, resulting in fire, injury, and contamination.

HAZARD/EMERGENCY GROUPS

Fire, injury, explosion, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide overboard vent systems, including pressure-regulation and pressure-relief subsystems.	5.1.1.1
2. Provide protective covers to prevent inadvertent electric shock.	5.1.8.2
3. Provide batteries with closures having no-spill, positive sealing characteristics.	5.1.12.6
B. Locational Features	
1. Within the Module locate batteries in special areas with spill containment, waste disposal, purge, and vent provisions.	5.2.2.5
2. Locate batteries away from potentially combustible materials or systems that could be damaged by escaping battery fluids.	5.2.4.5
C. Operational Techniques	
1. Utilize caution and warning signals to indicate if battery temperature or pressure levels exceed design range values.	5.3.4.1

Table 5-1, H-20. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-20

HAZARD SOURCE	Electrically-Powered Experimental Equipment		
All experiments require some form of electrically-powered apparatus. Examples include: inverters, pulsers, TV, furnaces, phototubes, spark-chambers, photomultipliers, accelerators, heaters, cameras, actuator mechanisms, controls, displays, etc.		X	Pallet
		X	MSM
		X	RAM
Experiment Groups: All			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Many devices employ high voltage; others provide an RF-field. With power off, capacitative devices can discharge inadvertently. With power on, the high voltage and RF sources are active, and shorts can result. Mere presence in the RF-field and touching or handling of equipment can also precipitate hazardous results.

HAZARDOUS RESULT

Shorts and hi-voltage discharge can precipitate fires.
High RF-field intensity can result in physical injury to crewmen or cause a malfunction of nearby sensitive equipment.
Mere touching or handling of active hi-voltage devices can result in electrical shock and burns.

HAZARD/EMERGENCY GROUPS

Fire, injury, basic subsystem malfunction

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Configure electrical interface lines to fail-safe.	5.1.7.2
2. Incorporate manual interlocks to prevent inadvertent activation.	5.1.8.1.2
3. Provide protective covers to prevent electric shock.	5.1.8.2
4. Incorporate discharge devices to de-energize high-voltage equipment.	5.1.8.5
5. Prominently and permanently mark all equipment having high-voltage components to warn crew and users.	5.1.12.8
B. Locational Features	
1. Locate high-voltage equipment away from EVA hatches.	5.2.4.2
2. Place high-voltage components in zones not normally accessible, so that knowledgeable acts are required to reach or touch them.	5.2.5.1
C. Operational Techniques	
1. Neutralize (discharge) all high-voltage components after ground checkout and/or operation.	5.3.2.1

Table 5-1, H-21. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-21

HAZARD SOURCE		
Biologicals/Animals/Insects/Plants		Pallet
A wide spectrum of cells and tissues, organisms and cultures, animals (primates, rats, mice, marmots, etc.), insects, and plants are required to support the Life Sciences experiments. (See also H-2, H-17, and H-22 for related hazard sources)	X	MSM
	X	RAM
Experiment Groups: LS-2, -3, -4, -5		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

The potentially toxic nature of certain biologicals, the animals and insects themselves, plant pollens, and chemical treatments, as well as the products associated with feeding requirements and waste (excreta, vomit, etc.) are the principal causative factors. The diverse handling requirements add another causative event potential. Malfunction of holding and rearing accommodations is yet another causative condition.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
Animal and insect bites can cause injury. The release of insects, pollens, serums, etc. can contaminate the atmosphere. The discharge of waste products into the atmosphere is also a contamination result. Mere contact with toxic biologicals or waste products can result in human injury/illness.	Injury, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide overboard vent systems, including pressure-regulation and pressure-relief subsystems.	5.1.1.1
2. Provide capability to purge any work areas for handling animals, insects, etc.	5.1.2.1
3. Utilize safing mechanisms/devices for biological and radiobiological containers used in life sciences experiments.	5.1.3.1
4. Provide thermal conditioning for biological containers (e.g., incubation control).	5.1.4.1
5. Provide independent environmental conditioning system for holding and rearing cages.	5.1.4.2
6. Provide compartment with airlock and decontamination equipment for conduct of experiments with radioactive materials.	5.1.5.4
7. Incorporate interlocks to prevent inadvertent opening of cage doors or isotope containers.	5.1.8.1.2
8. Provide protective covers for biological containers to prevent release of contents.	5.1.8.2
9. Configure cage feeding and cleaning provisions for remote operational control.	5.1.10
10. Provide the cages with integral provisions for automatic feeding and cleaning.	5.1.12.1
11. Provide containers or other provisions for preserving/storing dead animals, insects, plant specimens, etc.	5.1.12.2
12. Provide biological and isotope storage containers with closures having no-spill, positive-sealing characteristics.	5.1.12.6
13. Prominently and permanently mark all containers to identify nature of contents together with warning and handling notes (including antidotes, where appropriate).	5.1.12.9
B. Locational Features	
1. Locate cage and cage rack assemblies and biological containers in special areas with spill containment, waste disposal, purge, and vent provisions.	5.2.2.5
C. Operational Techniques	
1. Wear protective garments, gloves, masks, etc, when handling animals, biologicals, isotopes, serums, etc.	5.3.1.1.2
2. Control cage feeding and cleaning operations remotely.	5.3.1.3
3. Perform biological experiments and handling of animals, insects, toxic fluids, serums, etc. in special work areas.	5.3.1.4
4. Jettison leaking containers (serums, etc.).	5.3.3.1
5. Employ caution and warning signals to notify if biological containers exceed design range pressure or temperature.	5.3.4.1
6. Monitor and control the condition and operability of cage feeding and cleaning devices.	5.3.5.1

Table 5-1, H-22. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria (1 of 2)

No. H-22

HAZARD SOURCE: Non-Cryogenic Fluids		
A wide variety of toxic and reactive fluids are required in the conduct of certain Physics, Materials and Manufacturing, Technology, and Life Sciences experiments.	X	Pallet
	X	MSM
	X	RAM
Experiment Groups: P-1, -4; MS-1; T-2, -3, -4, -5; LS-2, -3, -4, -5		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Cannister overpressure or rupture, and inadvertent leaks or spills during handling operations are principal causative factors. Uncontrolled combustion and combustor rupture is another factor.

HAZARDOUS RESULT

Cannister rupture, combustor rupture, or the inadvertent release of reactive or toxic fluids or gases can lead to injury, fire, explosion, and contamination of surfaces and atmosphere.

HAZARD/EMERGENCY GROUPS

Fire, injury, explosion, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide overboard vent systems, including pressure-regulation and pressure-relief subsystems.	5.1.1.1
2. Provide capability to purge areas containing fluid tanks, transfer lines, or outlets.	5.1.2.1
3. Provide capability to purge tanks or containers holding non-inert liquids.	5.1.2.2
4. Provide thermal conditioning for fluids affected by temperature extremes.	5.1.4.1
5. Configure fluid interface lines to fail-safe.	5.1.7.2
6. Configure propellant tanks and containerized fluids for ease of jettisoning from the Module, and for ease of jettisoning contents.	5.1.9
7. Provide means for positively holding and securing transportable containers when not in actual use.	5.1.11.1
8. Configure systems containing principally quantities of reactive fluids in integral or self-contained units to facilitate remote storage/deployment and jettisoning.	5.1.12.5
9. Configure gaseous release devices and associated ICN and NH_3 cannisters in integral or self-contained units.	5.1.12.5
10. Configure the spark-chamber and its associated argon and methane tankage is integral or self-contained units.	5.1.12.5
11. Provide liquid containers with caps or closures having no-spill, positive-sealing characteristics.	5.1.12.6
12. Prominently and permanently mark all containers to identify nature of contents, together with warning and handling notes (including antidotes, where appropriate).	5.1.12.9
B. Locational Features	
1. Locate containers holding reactive or toxic fluids exterior to habitable Module compartments.	5.2.1
2. Store cannisters requiring thermal conditioning in an area where their temperature limits will not be exceeded.	5.2.2.3
3. Locate fluid cannisters in special areas with spill containment, waste disposal, purge, and vent provisions.	5.2.2.5
4. Locate reactive fluid tanks non-adjacently and in different compartment areas.	5.2.4.6
5. Locate containerized fluids and propellant tanks to facilitate jettisoning.	5.2.6.1
C. Operational Techniques	
1. Wear protective garments, gloves, masks, etc. when handling toxic or reactive fluid containers.	5.3.1.12
2. Perform propellant storage and transfer experiments in a free-flying Experiment Module, deployed at a safe distance from the Orbiter.	5.3.1.2.1
3. Central reactive fluid experiments remotely.	5.3.1.3

(more)

Table 5-1, H-22. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria (2 of 2)

No. H-22 (cont)

HAZARD SOURCE		
		Pallet
		MSM
		RAM
Experiment Groups:		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

HAZARDOUS RESULT

HAZARD/EMERGENCY GROUPS

PREVENTIVE MEASURES	Reference Paragraph, Section 5
C. Operational Techniques (continued)	
4. Establish order-of-connection procedures for all fluid connections.	5.3.1.6.4.6
5. Purge, inert, and safe all returnable tanks/containers.	5.3.2.3
6. Secure all containers in respective storage areas after use.	5.3.2.4
7. Jettison containers which exceed design range values in temperature or pressure.	5.3.3.1
8. Employ caution and warning signals to indicate if container design pressure or temperature limits are exceeded.	5.3.4.1
9. Monitor and control reactive fluid container pressure and temperature while aboard the Orbiter or in its immediate vicinity.	5.3.5.1

Table 5-1, H-23. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-23

X	Pallet
X	MSM
X	RAM
	Orbiter

HAZARD SOURCE Non-Cryogenic Gases

A variety of non-cryogenic gases stored at high pressure are required for tank pressurization experiment-containment, environment, and propulsive functions in various Astronomy, Physics, and Technology experiments.

Experiment Groups: A-5, -6; P-2, -4; T-1, -2, -3, -4, -5

CAUSATIVE EVENT/FACTOR/CONDITION

Tank overpressure or rupture and inadvertent leaks of inert, toxic, and reactive gases are principal causative factors.

HAZARDOUS RESULT

Tank rupture or the inadvertent release of inert, toxic, and reactive gases can lead to injury, fire, explosion, and contamination of surfaces and atmosphere.

HAZARD/EMERGENCY GROUPS

Injury, fire, explosion, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide overboard vent systems, including pressure-regulation and pressure-relief subsystems.	5.1.1.1
2. Provide capability to purge areas containing non-cryo gas tanks, transfer lines, or outlets.	5.1.2.1
3. Provide capability to purge non-inert gas bottles.	5.1.2.2
4. Configure gas interface lines to fail-safe.	5.1.7.2
5. Configure high-pressure gas bottles for ease of jettisoning from the Module, and for ease of jettisoning contents.	5.1.9
6. Configure high-pressure gas bottles for remote operational control.	5.1.10
B. Locational Features	
1. Locate containers holding reactive or toxic gases, high-pressure containers, gaseous release devices, and the leak detection experiment Module exterior to habitable Module compartments.	5.2.1
2. Locate gaseous cannisters in special areas with purge and vent provisions.	5.2.2.5
3. Locate high-pressure gas bottles to facilitate jettisoning.	5.2.6.1
C. Operational Techniques	
1. Control the leakage detection experiment (GHe) remotely.	5.3.1.3
2. Perform experiments with toxic gas or vapor contamination chemicals in pressure compartments with a separate environmental control system.	5.3.1.5.4
3. Establish order-of-connection procedures for all gas connections.	5.3.1.6.4.6
4. Purge, inert, and safe all returnable tanks/containers.	5.3.2.3
5. Secure all containers in respective storage areas after use.	5.3.2.4
6. Jettison containers which exceed temperature or pressure design values.	5.3.3.1
7. Employ caution and warning signals to indicate if gas bottle design pressure or temperature limits are exceeded.	5.3.4.1

Table 5-1, H-24. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-24

HAZARD SOURCE		
Cryogenics	X	Pallet
Inert cryogenics (LHe, LNe, LN_2) are required in Astronomy and Physics experiments to cool various sensor devices; reactivate cryogenics (LO_2, LH_2) are required in the Fluid Management FPE. (See also H-2, H-5, and H-20 for related hazard sources.)	X	MSM
	X	RAM
Experiment Groups: A-1, -5, -6; P-3, -4; T-2		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Tank overpressure (closed vents, etc.), line breaks, spills, etc. are principal causative factors.

HAZARDOUS RESULT

Inert tank overpressure and resultant rupture, and line breaks or spills can result in physical injury or Module contamination because of the release of cryogenic fluids and gases. Reactive tank overpressure and rupture, and line breaks or spills can result in fire, explosion, injury, and contamination of surfaces and atmosphere.

HAZARD/EMERGENCY GROUPS

Fire, injury, explosion, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide overboard vent systems, including pressure-regulation and pressure-relief subsystems.	5.1.1.1
2. Provide capability to purge areas containing cryo dewars, transfer lines, or outlets.	5.1.2.1
3. Configure cryogenic interface lines to fail-safe.	5.1.7.2
4. Configure cryogenic dewars for ease of jettisoning from the Module.	5.1.9
5. Configure cryogenic dewars and associated equipment (such as super-cooled magnet) in integral or self-contained units to facilitate remote storage/deployment or jettisoning.	5.1.12.5
B. Locational Features	
1. Locate cryogenic dewars and fluid transfer lines exterior to habitable Module compartments.	5.2.1
2. Locate cryogenic dewars to facilitate jettisoning.	5.2.6.1
C. Operational Techniques	
1. Perform propellant storage and transfer experiments in a free-flying Experiment Module, deployed at a safe distance from the Orbiter.	5.3.1.2.1
2. Jettison dewars which exceed design range pressures.	5.3.3.1
3. Employ caution and warning signals to indicate if dewar design pressure levels are exceeded.	5.3.4.1
4. Monitor and control reactive fluid container pressure and temperature while aboard the Orbiter or in its immediate vicinity.	5.3.5.1

Table 5-1, H-25. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-25

HAZARD SOURCE	Emulsions		
Plastic and nuclear emulsion sheets are required in the Cosmic Ray Physics experiment. These sheets are deployed to extend from the Module with an extendable mechanism. (See also H-6 for related hazard sources.)		X	Pallet
		X	MSM
		X	RAM
Experiment Groups: P-3			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

Latch failures or extending mechanism failures which prevent retraction of the extending mechanism are causative factors. Touching and/or handling of emulsion sheets are also possible causative events.

HAZARDOUS RESULT

If the mechanism extended length is sufficient to prevent closing the Orbiter P/L bay doors (after module retraction) the Orbiter may be unable to reenter the earth's atmosphere.

Depending upon the exact emulsion constituents, mere touching could result in human injury or module surface contamination.

HAZARD/EMERGENCY GROUPS

Injury, contamination, inability to reenter

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate manual interlocks to prevent inadvertent removal of emulsion sheet protective covers or closures.	5.1.8.1.2
2. Provide protective covers for emulsion sheet devices.	5.1.8.2
3. Configure emulsion plates and containers for ease of jettisoning in the event of retraction system failure.	5.1.9
4. Provide grips for physical transport of emulsion sheets and holders (to avoid surface contact).	5.1.11.2
5. Configure nuclear and plastic emulsion sheet devices and their deployment mechanisms in integral or self-contained units to facilitate remote deployment and jettisoning.	5.1.12.5
B. Locational Features	
1. Locate emulsion sheet devices exterior to habitable Module compartments.	5.2.1
C. Operational Techniques	
1. Deploy emulsion sheets with remote deployment mechanisms.	5.3.1.2.2

Table 5-1, H-26. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-26

HAZARD SOURCE	Specific Contamination Source		
An active cleaning device (ADC), samples and racks, and sensor cleaning operations are required for the conduct of contamination effects experiments. (See also H-6, H-10, and H-27 for related hazard sources.)		X	Pallet
		X	MSM
		X	RAM
Experiment Groups: T-1			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

The mere presence of contamination products on samples, racks, or cleaning device is a causative condition. Cleaning operations of sensor surfaces is a causative event.

HAZARDOUS RESULT

The deposit of such contaminants on spacecraft surfaces can result in contamination of the surface and atmosphere.

The deposit of such contaminants on human skin can result in chemical injury.

HAZARD/EMERGENCY GROUPS

Injury, contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate manual interlocks to prevent inadvertent removal of the ACD end covers or closures.	5.1.8.1.2
2. Provide protective covers for the ACD to prevent exposure to contaminants within the ACD.	5.1.8.2
3. Configure the sample plates, holding racks, and the ACD for remote deployment.	5.1.10
4. Provide grips for physical transport of sample plates and racks (to avoid surface contact injury).	5.1.11.2
5. Provide means for attaching sample plates and racks externally to Module.	5.1.11.3
6. Configure EVA cleaning units (materials, waste disposal provisions, etc.) in integral or self-contained units to facilitate remote storage and jettisoning.	5.1.12.5
7. Provide the ACD with end closures to retain contaminants within the device.	5.1.12.7
B. Locational Features	
1. Locate sample plates and racks exterior to habitable Module compartments.	5.2.1
2. Locate any EVA sensor cleaning units exterior to habitable Module compartments accessible to the EVA airlocks.	5.2.1
3. Locate contaminated products or devices in special areas with waste disposal, purge, and vent provisions.	5.2.2.5
C. Operational Techniques	
1. Wear protective garments, gloves, masks, etc. during sensor cleaning operations or when handling exposed sample plates.	5.3.1.1.2
2. Perform sensor cleaning, etc. in special work areas.	5.3.1.4

Table 5-1, H-27. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-28

HAZARD SOURCE	Maintenance and Repair Operations		
Battery recharging, gas bottle recharging, component replacement, dewar replacement, and sensor cleaning are specific activities required in experimental operations. (See also H-5, H-6, H-7, H-19, H-20, H-23, H-24, H-26 for corollary or related hazard sources.)			Pallet
		X	MSM
		X	RAM
Experiment Groups: P-2, -3; ES-1; C/N-1; T-1, -3, -4, -5			Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

High-voltage exposure, shorts, electrolyte spills, contaminated sensor surfaces, and tank or dewar overpressure and leaks are principal causative factors.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
Hazardous results include fire, injury (including electrical shock and burns), chemical injury, contamination, explosion, and release of cryogenic fluids and gases.	Fire, injury, explosion contamination

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate automatic interlocks in recharging systems to prevent operation until positive engagement is ensured between recharging system and component/subsystem to be serviced.	5.1.8.1.1
2. Configure gas bottle and battery recharging systems associated with satellite maintenance for remote operational control.	5.1.10
3. Configure gas bottle and battery recharging systems in integral or self-contained units to facilitate remote storage or jettisoning.	5.1.12.5
B. Locational Features	
1. Locate gas bottle and battery recharging equipment exterior to habitable Module compartments.	5.2.1
2. Locate equipment requiring periodic maintenance (e.g., animal cages) so as to facilitate access on the ground and in orbit.	5.2.5.11
C. Operational Techniques	
1. Remotely control gas bottle and battery recharging operations.	5.3.1.3
2. Employ caution and warning signals to indicate if recharging system pressure or temperature design levels are exceeded.	5.3.4.1
3. Continuously monitor and control the gas bottle and battery recharging operations.	5.3.5.1

Table 5-1, H-28. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-27

HAZARD SOURCE: EVA Operations		
EVA operations are required in performing a number of functions: installing/removing external equipment, packages, samples; erecting antennas, booms; operating AMU; operating MWP.	X	Pallet
	X	MSM
	X	RAM
Experiment Groups: P-1, -3; C/N-1; T-1, -3, -4; LS-6		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

PLSS depletion, suit puncture , broken tethers, tether entanglement, collisions, exposure to high-voltage, high-RF, magnetic fields, mere falling off, and propulsion "runaway" are principal causative factors.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
The causative factors can result in loss of EC/LS, stranding in EVA, physical injuries, and electric shock and burn injury.	Injury, loss of EC/LS, stranded in EVA

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide extendable-aid devices to permit EVA retrieval assistance.	5.1.8.7
2. Provide emergency EC/LS umbilicals exterior to Module for use by EVA astronaut.	5.1.8.8
3. Configure EVA suits and/or PLSS units for simple plug-in of an emergency PLSS package and a voice communication unit.	5.1.12.3
4. Provide the Module and/or Orbiter with exterior connections (near EVA airlock) for simple plug-in of EC/LS umbilicals and a voice communications unit.	5.1.12.4
B. Locational Features	
1. Locate external EC/LS umbilicals and communication plug-in unit near the EVA hatch.	5.2.5.6
2. Locate EVA tether attach points and fixtures so as to minimize possibility of tether entanglement.	5.2.5.7
C. Operational Techniques	
1. Suspend permeating field experiments and rotating equipment operations during EVA operations.	5.3.1.5.1
2. Conduct hazardous EVA experiment operations with at least two EVA men (one working, one standing-by as a safety man).	5.3.1.6.1.1
3. Conduct normal EVA experiment operations with at least two EVA men (buddy system).	5.3.1.6.1.2
4. Provide an additional suited crewman ready to go into EVA, in the event of an emergency involving men already in EVA.	5.3.1.6.1.3
5. Avoid experiment EVA:	5.3.1.6.1.4
a. when high-voltage RF-field, or magnetic fields are present	
b. during Experiment Module erection, retraction, docking, or undocking operations	
c. near attitude control nozzle jets	
6. Employ caution and warning signals to indicate if PLSS conditions deviate from design range values.	5.3.4.1
7. Continuously monitor EVA operations and PLSS conditions during EVA operations.	5.3.5.1

Table 5-1, H-29. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-29

HAZARD SOURCE	Egress Operations	
Orbiter and Module entrance and exiting, as well as required EVA operations, present sources of egress operational hazards.		X Pallet X MSM X RAM X Orbiter
Experiment Groups: All		

CAUSATIVE EVENT/FACTOR/CONDITION

Malfunctioning or inoperable airlock doors alone, and in conjunction with EC/LS failures or malfunctions, are the principal causative factors.

HAZARDOUS RESULT	HAZARD/EMERGENCY GROUPS
Multiple door failures (on same hatch) or multiple airlock/hatch failures can result in internal entrapment or EVA stranding. In combination with EC/LS failures, injury and loss of EC/LS can also occur.	Injury, entrapment, loss of EC/LS, stranded in EVA

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Provide emergency EC/LS masks, umbilicals, etc. in each airlock and manned/habitable compartment.	5.1.8.8
B. Locational Features	
1. Locate Experiment Modules and/or other cargo in the cargo bay to avoid blocking or other interference with normal egress from the Orbiter cargo bay airlock/tunnel.	5.2.5.8
2. Locate equipment/devices attached externally to the Experiment Module in such a manner as to avoid interference with normal egress from airlocks or ports.	5.2.5.9
3. Locate equipment within the Experiment Module so as to prevent the wedging-in of a fully-suited astronaut.	5.2.5.12
C. Operational Techniques	
1. Provide a second or safety crewman to stand by during airlock operations.	5.3.1.6.3.1
2. Provide pressure suits (including PLSS units) in Experiment Module to enable EVA egress from Module to Orbiter airlock.	5.3.1.6.3.3
3. Do not attempt entry into the Experiment Module until it is fully erected and secured.	5.3.1.6.3.3
4. Have all personnel leave the Experiment Module and enter the Orbiter prior to initiating retraction of the Module.	5.3.1.6.3.4
5. Employ caution and warning signals to indicate status of airlock EC/LS, pressure levels, and door positions.	5.3.4.1
6. Monitor airlock and crew conditions continuously during airlock egress operations.	5.3.5.1

Table 5-1, H-30. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-30

X	Pallet
X	MSM
X	RAM
	Orbiter

HAZARD SOURCE Erection/Retraction Operations

All Experiment Modules pose the potential requirement for erection (to perform experiments, undock, etc.) and retraction back into the cargo bay for return to earth.

Experiment Groups: All

CAUSATIVE EVENT/FACTOR/CONDITION

The principal causative factors are (1) mechanism malfunction during the erection or retraction process, and (2) protuberances on the Experiment Module.

HAZARDOUS RESULT

If the mechanism malfunction (either at partial or full extension) prevents retraction, the Orbiter P/L bay doors cannot be closed and the Orbiter cannot reenter. Similarly, protuberances may prevent P/L bay door closing.

HAZARD/EMERGENCY GROUPS

Inability to reenter

PREVENTIVE MEASURES

Preventive Measures	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate means to ensure that erection/retraction mechanisms retract from the extended positions.	5.1.7.1
c. Operational Techniques	
1. Suspend permeating field experiments and rotating equipment operations during erection/retraction operations.	5.3.1.5.1
2. Do not erect or retract the Experiment Module until all crew members are in the Orbiter.	5.3.1.6.3.3 5.3.1.6.3.4
3. Employ caution and warning signals to indicate position and status of erection/retraction system.	5.3.4.1
4. Continuously monitor and control the erection/retraction system status and operations.	5.3.5.1

Table 5-1, H-31. In-Space Experiments - Hazard/Emergency Analysis and Safety Criteria

No. H-31

HAZARD SOURCE		
Docking/Undocking Operations	X	Pallet
Free-flying RAMs, automated satellites and manned work platforms (MWPs) pose hazard sources with regard to requirements for docking/undocking with the Orbiter.		MSM
	X	RAM
Experiment Groups: A-1, -2, -3, -4, -5, -6; P-3; T-2, -3; LS; HEAO; EOS; P/S; C/N II		Orbiter

CAUSATIVE EVENT/FACTOR/CONDITION

The principal causative factors are (1) docking mechanism malfunctions, and (2) collisions between docking vehicles.

HAZARDOUS RESULT

Inability of a Module to release from the Orbiter, plus the inability to retract the Module, could result in Orbiter inability to reenter. Inability to effectively dock could lead to a RAM stranded in space or MWP stranded in EVA. Vehicle collisions could precipitate a wide spectrum of hazardous results (fire, explosion, injury, contamination, etc.)

HAZARD/EMERGENCY GROUPS

Fire, injury, explosion, contamination, inability to reenter, stranded (in space or EVA)

PREVENTIVE MEASURES	Reference Paragraph, Section 5
A. Design Features	
1. Incorporate means to ensure that docking mechanisms release from the locked-up mode.	5.1.7.1
2. Incorporate discharge devices to establish equipotential between the Orbiter and retrieved satellites.	5.1.8.5
3. Configure any spacecraft and the Experiment Module for ease of jettisoning from the Module and/or Orbiter.	5.1.9
4. Configure docking control systems of any spacecraft attempting to dock with the Module or Orbiter for remote operational control.	5.1.10
B. Locational Features	
1. Locate the docking ports of Experiment Modules and the Orbiter so as to facilitate visual observations of the docking operations.	5.2.5.10
C. Operational Techniques	
1. Suspend permeating field experiments and rotating equipment operations during docking/undocking operations.	5.3.1.5.1
2. Employ caution and warning signals to indicate if the velocity and/or alignment of a docking spacecraft relative to the Module or Orbiter deviates from design range values.	5.3.4.1
3. Continuously monitor and control docking sensor and control systems during docking operations.	5.3.5.1

Table 6-1. Summary of Hazard/Emergency Groups and Their Associated Potential Remedial Aid Requirements

Remedial Need \ Hazard/Emergency	Fire	Explosion/ Implosion	Decompression/ Overpressure	Collisions (Internal/External)	Contamination (Toxic/Non-Toxic)	Injury/ Illness	Mechanical/ Structural Failures	Radiation (Internal/External)	Personnel Errors	Basic Subsystem Malfunctions	Inability to Return From EVA	Lack of Resupply/ Rotation
Fire Suppression	x	x							(1)	(2)		
Emergency EC/LS	x	x	x	x	x			x			x	
Medical Aid	x	x	x	x	x	x		x				
Decontamination	x	x			x			x				
Structural Repair		x	x	x			x					
Removal Tools				x			x					
Access Tools				x			x					
Crew Transfer Equipment (Space Rescue)				x							x	x
Crew Aid and Retrieval	x	x	x	x	x	x	x	x			x	x
Ground Rescue System												x
Ground Facility Aid	x	x	x	--	x	x	x	x			--	--

(1) Personnel errors are not specifically delineated since they could result in many of the other hazards.
(2) Basic subsystem malfunctions are not specifically delineated since they could be either the cause or the result of many of the other hazards.