MSC-00189

SPACE STATION SAFETY STUDY

SUPPORTING ANALYSES

D2-113070-6

JANUARY 1970

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

THE **BOEING** COMPANY
AEROSPACE SYSTEMS DIVISION, SEATTLE, WASHINGTON

NASA CR 108290

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Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
Houston, Texas

CONTRACT NAS9—9046

January 1970

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PREFACE

This document constitutes one volume of the final report prepared under Contract NAS9-9046, Space Station Safety Study, which was conducted by the Aerospace Systems Division, Aerospace Group, The Boeing Company, under the direction of the Advanced Projects Office, Advanced Missions Program Office, Manned Spacecraft Center, NASA. The objective of the study was to develop a management tool for evaluating conceptual designs of future manned space systems from a safety viewpoint. This objective was achieved through the application of methodical techniques, which are described where necessary in appropriate volumes of this final report, for analyzing space station safety problems. This work resulted in the development of Crew Safety Guidelines which can be used in evaluating future space station concepts.

In Phase I of the study, the work was directed toward a broad class of space stations, using several specific configurations as examples, and considering both crew safety and mission accomplishment as safety goals. In May 1969, the study was redirected by NASA into Phase II to provide more direct support to the NASA Phase B Future Space Station Study, considering only crew safety as the safety goal. To the extent possible, the work done in Phase I was revised and adapted to Phase II and all documents of this final report, except as otherwise noted, include the results from both phases. In both phases the study scope included only on-orbit operations and not launch, boost, de-orbit, and recovery operations, or any operations of the logistics support system, except for close-in rendezvous and docking operations.

The approach taken in the study was to examine the space station from the viewpoint of safety only, with the intent of identifying as complete a list as possible of those measures which should be taken to maximize crew safety. Also, and especially in Phase II, the study dealt primarily with station concepts, rather than specific designs or hardware items. It was not possible, and no attempt was made, to examine the impact of safety measures on other important aspects of space station development, such as cost, design difficulty, or operational suitability. As station development proceeds, trade studies between safety measures and other factors will be required and management decisions must be made as to the extent to which other desirable features will be permitted to override safety measures.

The documents constituting the final study report are:

- D2-113070-4, Condensed Summary Report
- D2-113070-5, Crew Safety Guidelines, Volumes I and II

- D2-113070-6, Supporting Analyses
    - Analysis of Operations
    - Experiment Program
    - Traffic Patterns Analysis
    - Human Requirements
    - Meteoroid Penetration
- D2-113070-9, Logic Diagram
- D2-113070-10, Fault Tree Analysis
- D2-113070-11, Subsystems Analysis

Other documents produced during the study but not part of the final report are:

- D2-113070-1, Detail Study Plan (Phase I only)
- D2-113070-2, Midterm Oral Report
- D2-113070-3, Final Oral Report
- D2-113070-7, Baseline Mission Description (Phase I only)
- D2-113070-8, Baseline System Description (Phase I only)

The references applicable to this document are shown in Section 8.0. However, all the references for those documents which comprise the final study report are compiled in D2-113070-5.

ABSTRACT AND KEY WORDS

This document reports the results of work done in support of or as an extension to the safety analyses, which were the principal output of the study effort. Gross configuration concepts and layouts for the Phase B Future Space Station and Space Base are shown. A brief analysis of Space Station and Space Base operations is presented for the on-orbit phases of the operation, including the relationship of the logistics support vehicles to the station and base. The experiment package was reviewed and hazards inherent to these experiments are identified. Crew distribution at typical times was determined and crew traffic patterns in the event of an emergency are shown. Problems of station contamination, together with possible or probable contaminants, are discussed. Medical requirements of the space station are reviewed briefly. The hazards and probabilities of meteoroid penetrations are discussed.

KEY WORDS

artificial gravity
chemicals
contamination
crew density
crew distribution
docking
escape routes
escape vehicle
experiments
human factors
logistic vehicle
medical
meteoroids
modules
operations
rendezvous
space base
space station
space suit
space tug
toxicology
traffic flow

[redacted]

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1.0 INTRODUCTION

The majority of the effort on the Space Station Safety Study, hereafter called the Safety Study, was devoted to an examination of hazards and the identification of associated safety measures by using techniques such as the fault tree and the logic diagram or by a review of subsystems. This work is described in other documents of this report. In addition, some lesser effort was necessary in support of the major tasks, either to provide background and perspective for them or to explore specialized areas, or both, the results of which are reported by this document. These lesser efforts included: development of configuration concepts, analysis of space station and space base operations, review of safety hazards of the experiment program, analysis of typical crew distribution and activity, review of contaminants and contamination hazards, review of medical problems, and analysis of meteoroid penetration hazards.

1.1 GROSS CONFIGURATION CONCEPTS

A set of gross configuration layouts was prepared, showing one possible space station and one possible space base configuration. They were based on the Saturn V Single Launch Space Station design, modified to meet the criteria presented in the NASA Space Station Program Definition (Phase B) Statement of Work (Reference No. 92), hereafter called the Phase B Study. These layouts were prepared for reference only and were intended solely as a guide for our thinking for the remainder of the study effort. General safety criteria were considered during the preparation of these layouts, but, since they were prepared early in Phase II, they do not necessarily reflect the safety measures identified during the final stages of the study.

1.2 ANALYSIS OF OPERATIONS

The operations involved with prelaunch, launch, and Earth orbit injection (EOI) were identified but not reviewed in the analysis. A key forcing function of the future space station is its long life, up to 10 years versus 14 days for Apollo, with the resulting safety effects of long life. Hence, a study ground rule stipulated that the majority of the effort be expended in analyzing "on orbit" operations, i.e., from EOI through deorbiting of returning logistic vehicles.

In some cases an operation may be accomplished by any of various alternatives. Selection of the optimum method would require trade studies considering aspects of the operation other than safety. Safety measures were identified for hazards common to all space stations and operations that could be predicted on the basis of our reference layouts, but further analysis will be required when the definitive configuration is available.

1.3 EXPERIMENT PROGRAM

The experiment program reviewed in this study was that contained in the Candidate Experiment Program for Manned Space Stations dated May 1, 1969 (Reference No. 14). A review was conducted of the general aspects of the program to identify hazards peculiar to the experiments. These hazards were then compared with the hazards identified with the station itself, to ensure that safety measures appropriate to the hazards had been defined. These analysis results should be re-examined for completeness when the detailed experiment program becomes available.

1.4 TRAFFIC PATTERN ANALYSIS

During Phase I of the study, crew traffic patterns and crew activities were examined by applying the Boeing Crew Activity Sequencing Program (CASP) to the Saturn V Single Launch Space Station (SLSS). It was intended that a mission segment be reviewed which was of sufficient duration, e.g., 30 to 60 days, to ensure identification of all probable hazards. Only the preparations for this review were completed in Phase I. Ideally, Phase II effort would have been of the same scope, but this would have required information on the Future Space Station configuration, mission, and experiment package, at the same level of detail as was available for the SLSS. Since the necessary detailed information would not be available until late in the Phase B study, and too late for our purposes, it was decided to simplify this analysis. By using "hand crank" procedures, CASP was adapted to the space station configurations developed during the study. A "typical day" was identified and four "worst cases" of crew distribution during that day were developed. Safety measures to alleviate the hazards associated with these worst cases were defined.

1.5 HUMAN REQUIREMENTS

Human factors and biotechnology support was directly available to all team members, as required by their work, and is, therefore, implicit in this and the other volumes of this report. An analysis was made of space station contamination problems, with attention to potential contaminants and their effects on crew safety. Medical considerations of the space station were reviewed, with attention to the aspects of both preventive and clinical medicine.

1.6 METEOROID PENETRATION

The meteoroid penetration analysis was initiated early in Phase I, using the SLSS baseline data. Late in Phase II it was up-dated to incorporate the space station configuration concept. An estimate of wall size for meteoroid protection was prepared and the hazards associated with meteoroid penetration, if one occurs, were defined.

2.0 CONFIGURATION CONCEPTS

2.1 INTRODUCTION

Space station safety can be studied to some degree independently of any particular configuration, since many hazards, such as those associated with fire, decompression, and radiation, have aspects that are not configuration-oriented. However, as the work proceeds into more detail, a need develops for at least a gross configuration concept, to direct attention to specific problems and serve as a check against the work already done. In Phase I, three configurations were specified (Reference No. 93): the Saturn V Single Launch Space Station (SLSS), the Earth Orbital Space Station (EOSS), and the rotating, artificial-gravity station concept (JAG-1). These configurations were not specified for Phase II. Gross configuration layouts were prepared for Phase II by adapting the SLSS concept (Reference No. 81) to the Phase B Study Work Statement (Reference No. 92) and included a single concept each for the space station and the space base. The layouts, with reasons for their selection, are presented and described in succeeding parts of this section.

2.2 CONFIGURATION SELECTION

The single concept to be used for the space station was selected to adapt the 6-man SLSS configuration to the 12-man concepts expressed in the Phase B Statement of Work, and does not depart significantly from that statement of work. No attempt was made, however, to define and/or depict the means of obtaining artificial gravity or the means of access to the zero-gravity hub, or center of rotation.

No attempt was made to design the space station so that it could be incorporated directly into the space base. Rather, the space station was assumed to be a prototype of some parts of the space base, this assumption being based primarily on subjective opinion. The reasoning here was, first, that the 12-man space station, as configured for the purposes of this study, including all its features, such as crew quarters, docking ports, experiment areas, and the like, did not appear to match readily and obviously with any portion of the space base. Second, it was assumed that the space station would be operational for a period of years before the space base was activated. The space station would then be approaching the end of its design life. Accordingly, it would appear to be impractical to modify or repair it to equal the design life of other components of the space base. Third, it can be expected that the operation of the space station will reveal shortcomings or deficiencies which it would be desirable to correct in the space base.

Selection of the single space base concept was more difficult than for the space station, primarily because of the multiplicity of concepts which could be considered as potential candidates. Primarily on the basis again of subjective opinion, a "Y" configuration was selected in which crew quarters, maintenance facilities, and some laboratories are located in the tail of the "Y"; nuclear power systems are at the ends of the arms of the "Y"; and docking facilities, zero-gravity laboratories, and storage facilities are in a central, non-rotating hub. The arms of the "Y" are adjustable as to angle and length. It was believed that problems of dynamic balance caused by crew or equipment movement within the station would probably be more easily resolved by a "Y" than by other possibilities, such as straight-line. At the same time, hazards related to the nuclear power supply appear to be more readily resolvable with a "Y" than with other configurations, such as a circle or star.

2.3 TWELVE-MAN SPACE STATION

Figure 2-1 is a layout of the 12-man space station used in this study. As previously stated, the configuration shown was based on the Saturn V Single Launch Space Station, adapted to the criteria of the NASA Phase B Space Station Program Definition Statement of Work (Reference No. 92). Externally mounted experiment hardware is not shown, nor a means of conducting artificial-gravity experiments.

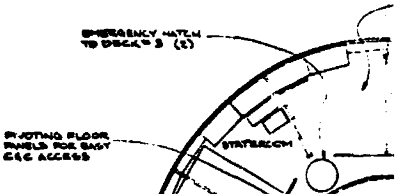
The 12-man crew is housed in a five-deck space station 33 feet in diameter and 53.5 feet long. The station includes an outer pressure vessel, or module, 33 feet in diameter with meteoroid protection provisions, and an inner pressure vessel, or module, 15 feet in diameter. Each deck, including the center section, is a separate pressure deck which can be isolated and environmentally controlled. The inner module serves as a sanctuary during periods of high radiation and/or during an emergency in some segment of the outer module.

2.3.1 DECK 1---LOGISTICS AND SPARES STORAGE DECK

This deck is the logistics and spares storage area. It contains four logistics docking ports, unpressurized storage, and pressurized transfer for crew and cargo. Cargo may be brought directly into the center module via the airlocks and distributed to the remainder of the station, or it may be taken directly into the unpressurized storage area. Two airlocks are provided which permit various routes for cargo transfer. The center module on this deck contains pressure suit and portable life support system (PLSS) storage areas.

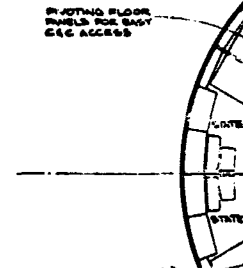
2.3.2 DECK 2---GENERAL LABORATORY DECK

The outer module on this deck contains a physical science laboratory, 14.7-psi bioscience laboratory, bioscience work center, advanced technology laboratory, and photo laboratory. There are four experiment module docking ports which also serve as emergency EVA hatches. The inner module contains an emergency head and waste management system, emergency expendables storage, communications center, and emergency bunks.



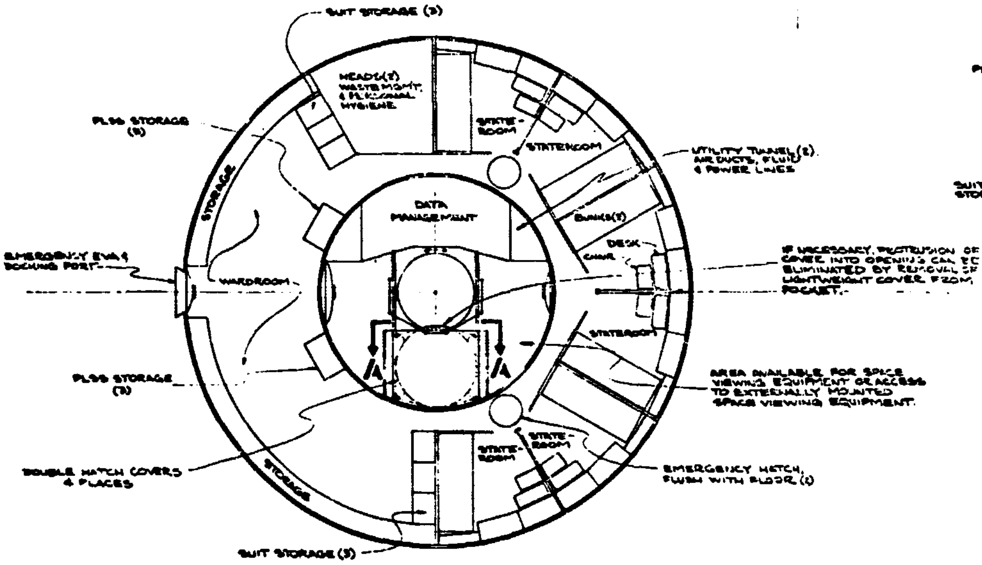
Dec

Crew Quarters, G



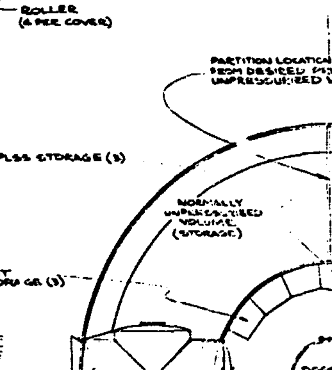
A-A

DOUBLE HATCH COVERS TYPICAL AT ALL INTER-DECK BULKHEADS



Deck 5

Crew Quarters & Wardroom



Dec

Logistics & Spa

FOLDOUT FRAME 1

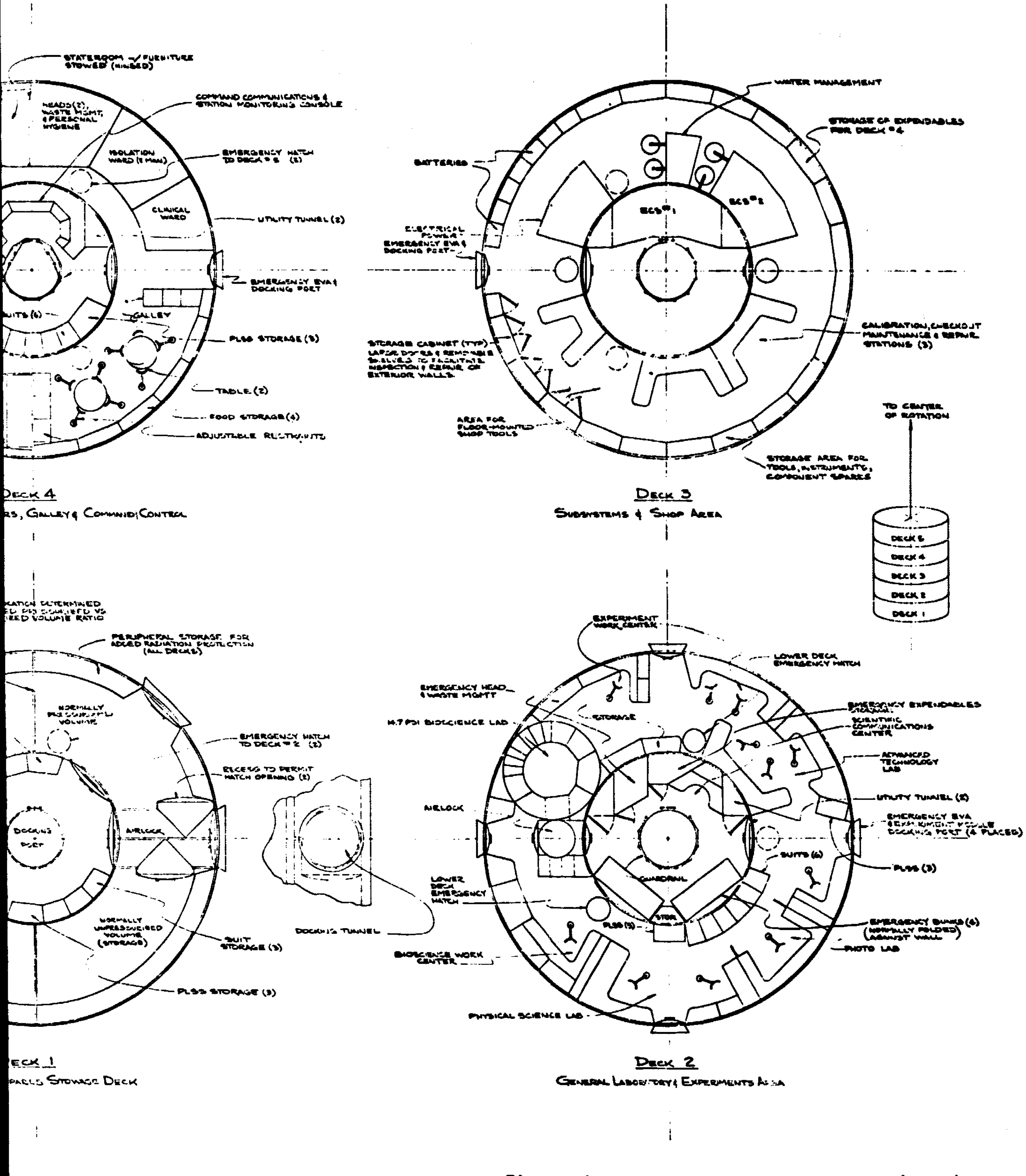


Figure 2-1: 12 MAN SPACE STATION (1975)

2.3.3 DECK 3---SUBSYSTEMS AND SHOP DECK

The outer module contains the electric power subsystem, the environmental control subsystem for all outer modules, and the water management subsystem, as well as calibration, check-out, maintenance, and repair facilities. The deck also contains an emergency EVA and docking port. The inner module contains the environmental control subsystem for all inner modules. This subsystem deck was centrally located in the space station to minimize plumbing and cabling lengths.

2.3.4 DECK 4---CREW QUARTERS, GALLEY, COMMAND AND CONTROL

Six of the twelve staterooms are on this deck. Because of limited space, all staterooms are identical in arrangement and have a minimum, but adequate, floor area consistent with comfortable living. Each stateroom contains a fold-up desk, chair, and two bunks, one bunk being for temporary use in the event that doubling up is required during crew rotation. The galley, dining, and food storage areas for all twelve crew members are located on this deck. A two-man isolation ward with adjacent toilet and personal hygiene facilities, plus a clinical ward (dispensary), are located on this deck. The inner module of this deck contains the command and control and station monitoring console and has storage space for six space suits and PLSS units.

2.3.5 DECK 5---CREW QUARTERS AND WARDROOM

The other six of the twelve staterooms are located in the outer module on this deck and are identical to the Deck 4 staterooms previously described. The twelve staterooms were evenly divided between Decks 4 and 5, and located on opposite sides of the space station, for safety reasons. A large wardroom for exercise and recreation, plus toilet and personal hygiene facilities, are also located on this deck. Six space suits and PLSS units are located in the wardroom area where adequate space for suit donning is available. The inner module contains data management equipment, located directly above the command and control console, and has a large open area for sanctuary purposes.

2.3.6 GENERAL

Two continuous raceways (tunnels) through the inner modules provide space for routing of the numerous fluid lines (gases and liquids) and power and signal cables required between decks. A 5-foot diameter opening through the center of each deck provides the primary path for all inter-deck travel in the station. Secondary (emergency) inter-deck travel is provided through flush, floor hatches located in the outer module area. Travel between the inner and outer modules on all decks is by means of two hatches, one of which is large enough for transfer of cargo to and from the logistics deck.

2.4 SPACE BASE

Figure 2.2 shows the gross layout of a 60-man space base. It would be assembled in orbit, which requires a series of launches. The main elements include: zero-gravity hub, two nuclear power sources, and artificial gravity module. The zero-gravity hub contains laboratory space, docking ports, storage, a hanger for artificial satellites, and various subsystems. The two nuclear power sources are contained in the two extendable arms, as shown in the layout. The arms supporting these power sources may be individually extended, retracted, or their angles changed to maintain dynamic balance. The artificial-gravity module's eight decks contain crew living space, office space, and laboratory space. The internal arrangement of the artificial-gravity module and zero-gravity hub are discussed in subsequent paragraphs.

2.4.1 ZERO-GRAVITY HUB

The zero-gravity hub (non-rotating) contains eight (NR-A, NR-B, and NR-1 through NR-6) decks devoted primarily to multi-disciplinary research and development effort. Each deck contains an inner and outer module, each being able to contain a habitable atmosphere. Two pressure hatches are contained in each inner module for access to the outer module, as well as five-foot diameter hatches between decks.

The zero-gravity hub is divided into two parts, each being separated from the other by the rotating module interface joint. A brief description of each deck follows.

2.4.1.1 DECKS NR-A AND NR-B

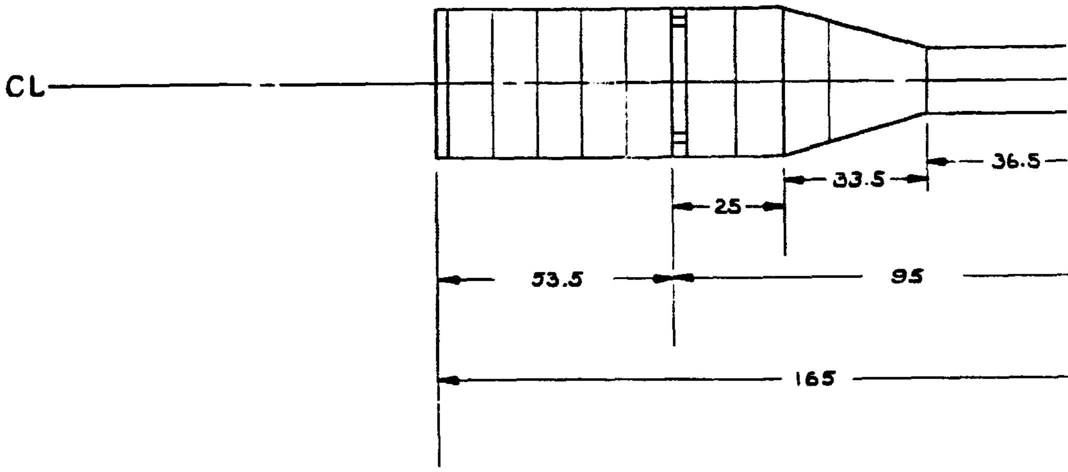
Deck NR-A, which is located above the rotating joint, contains the space astronomy lab work area and the airlocks for access to the space telescopes, detectors, and sensors. These space telescopes, sensors, and detector modules are located in the outer module of Deck NR-B. The remaining volume in this outer module is utilized as unpressurized storage area. The inner module of Deck NR-B contains an emergency logistics docking port.

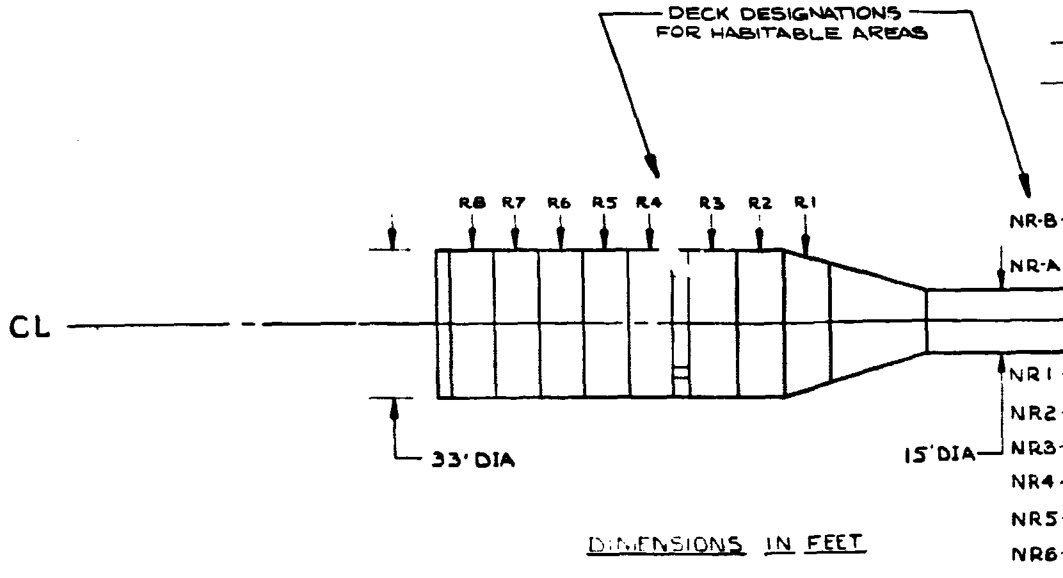
2.4.1.2 DECK NR-1

The outer module contains a high-energy cosmic ray physics laboratory and biomedicine laboratory. The inner module contains electric power conditioning and distribution units and the environmental control unit for all equipment cooling.

2.4.1.3 DECK NR-2

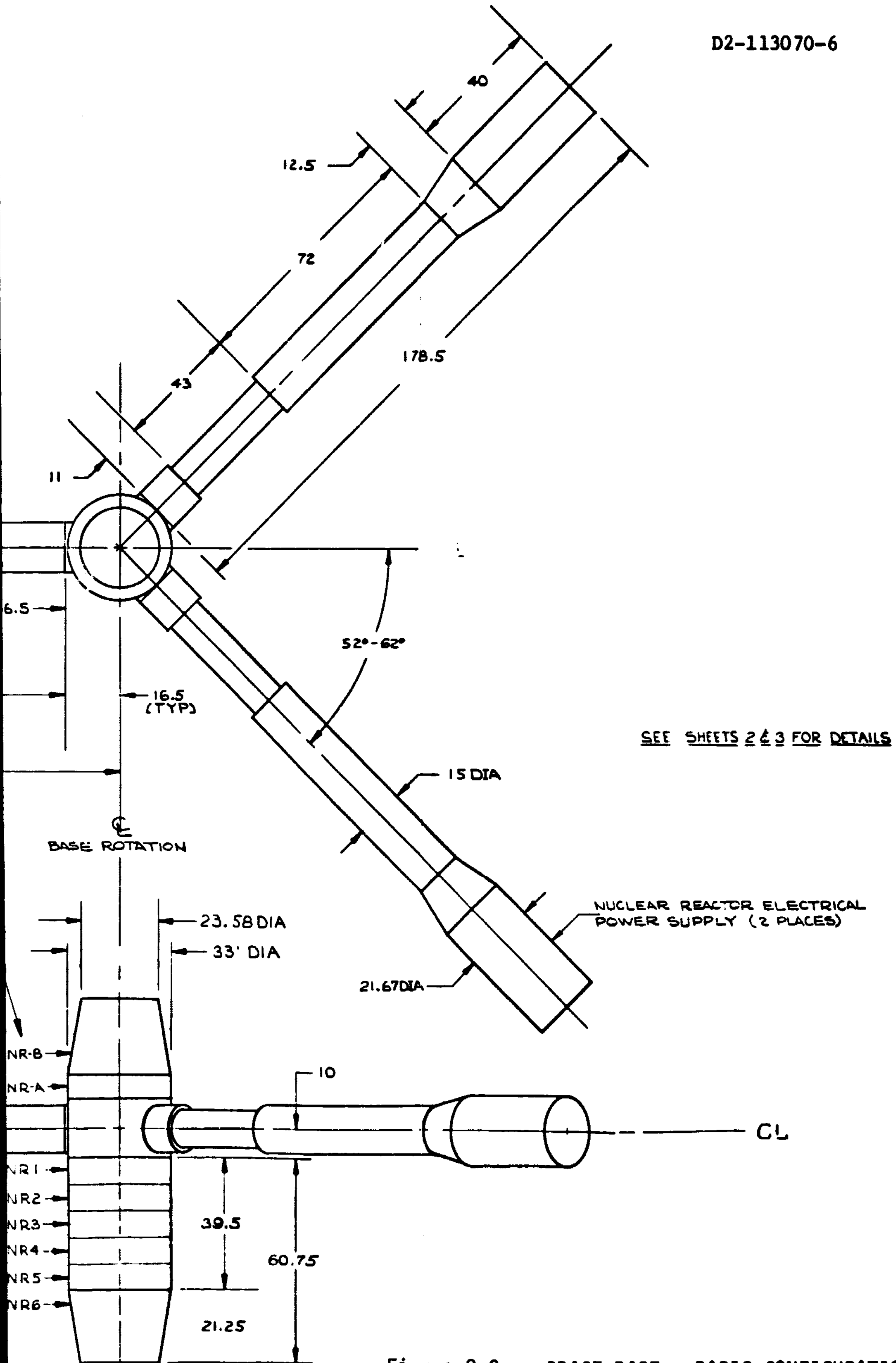
The outer module on this deck contains an optical laboratory and a space materials and processing facilities work area, as well as a pressure chamber which has 0-psia capabilities for space materials and processing





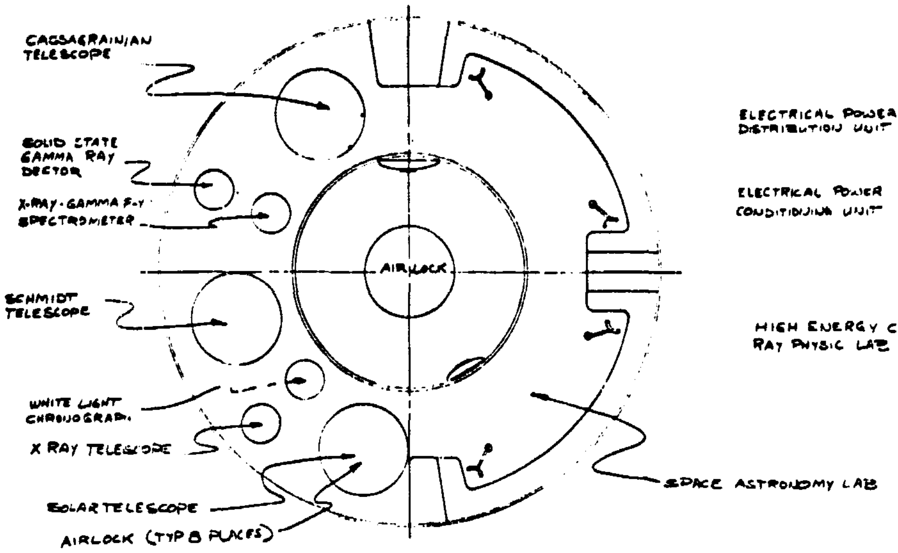
DIMENSIONS IN FEET

FOLDOUT FRAME 1

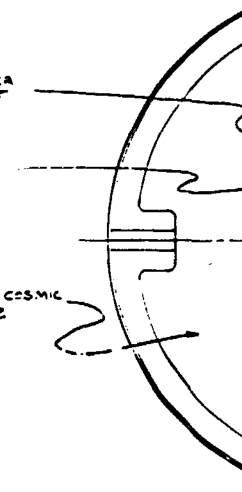


SEE SHEETS 2 & 3 FOR DETAILS

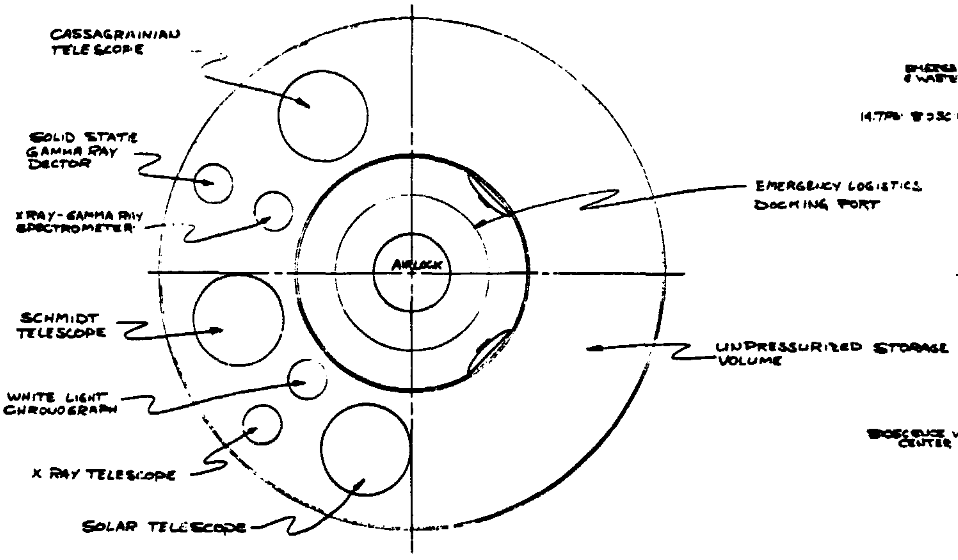
Figure 2-2: SPACE BASE - BASIC CONFIGURATION, 60 MAN (SHEET 1 OF 3)



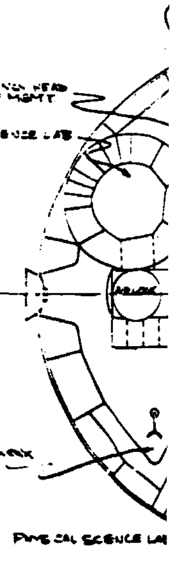
DECK NR-A
ASTRONOMY DECK



PHYS



DECK NR-B
SPACE OBSERVATORY & LOGISTICS DECK



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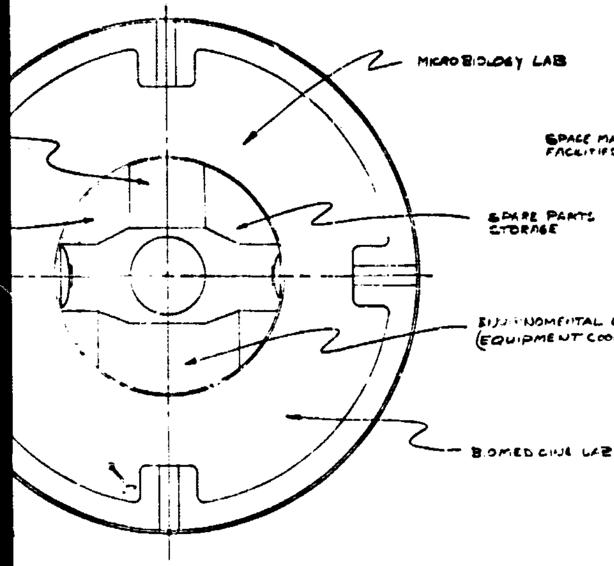
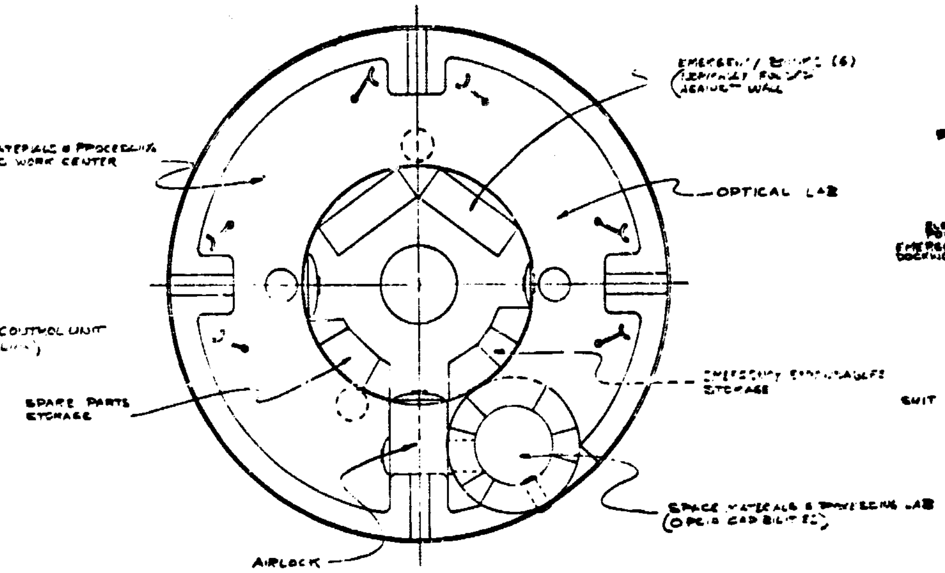
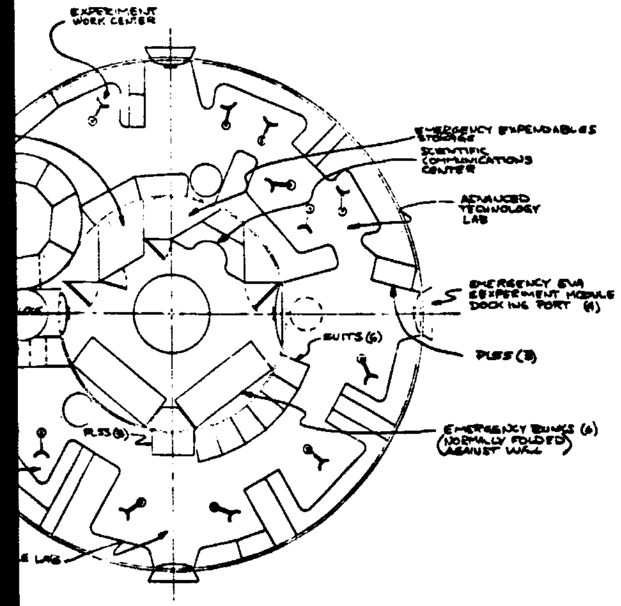


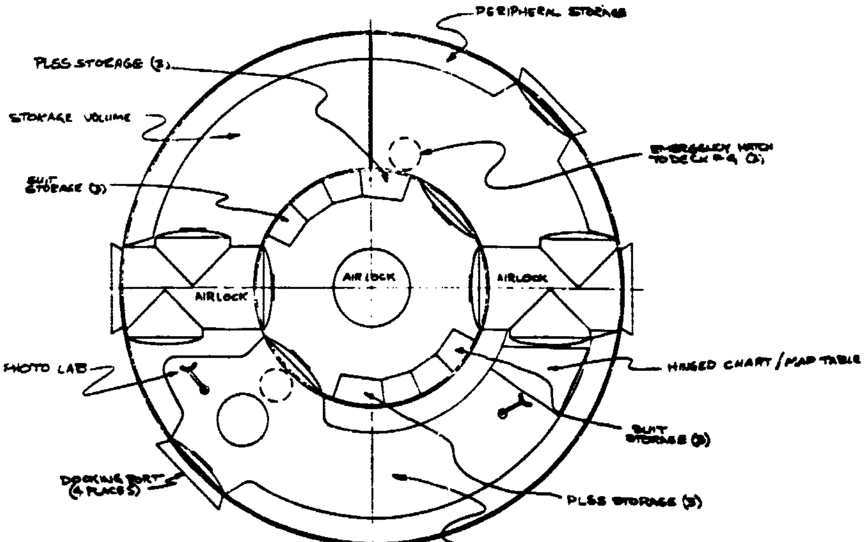
DECK NR-1
PHYSICS & BIOMEDICINE AREA



DECK NR-2
GENERAL LABORATORY & REFUSE AREA

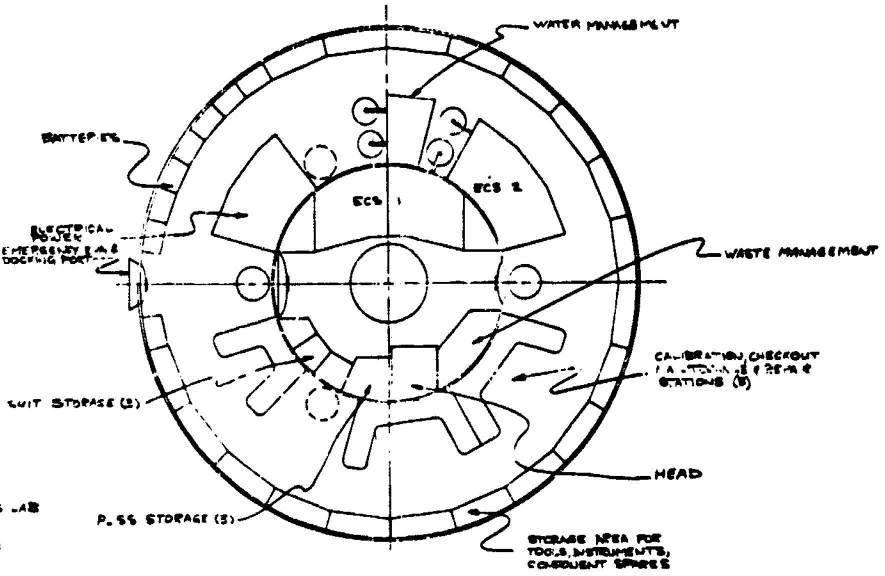


DECK NR-4
GENERAL LABORATORY & EXPERIMENTS AREA

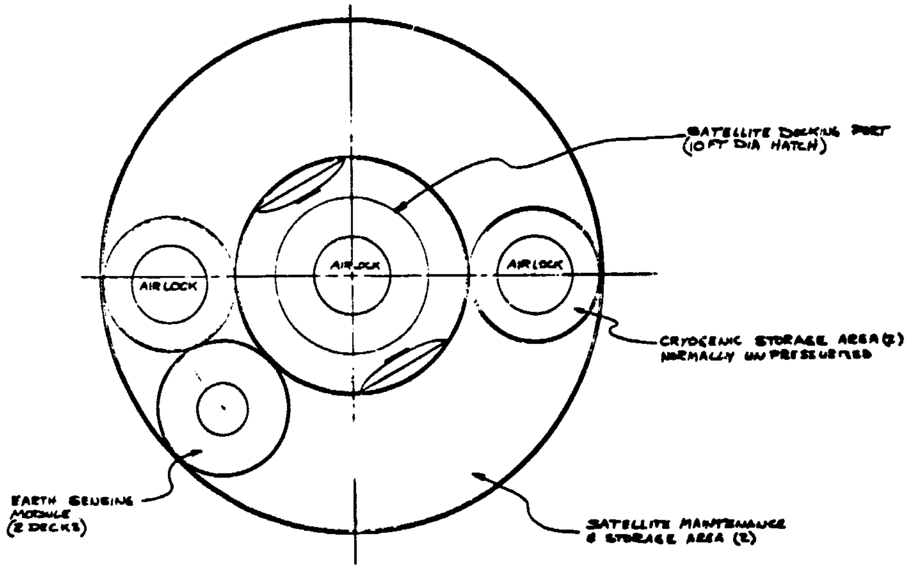


DECK NR-5
LOGISTICS & SPARES STOWAGE DECK

FOLDOUT FRAME 2



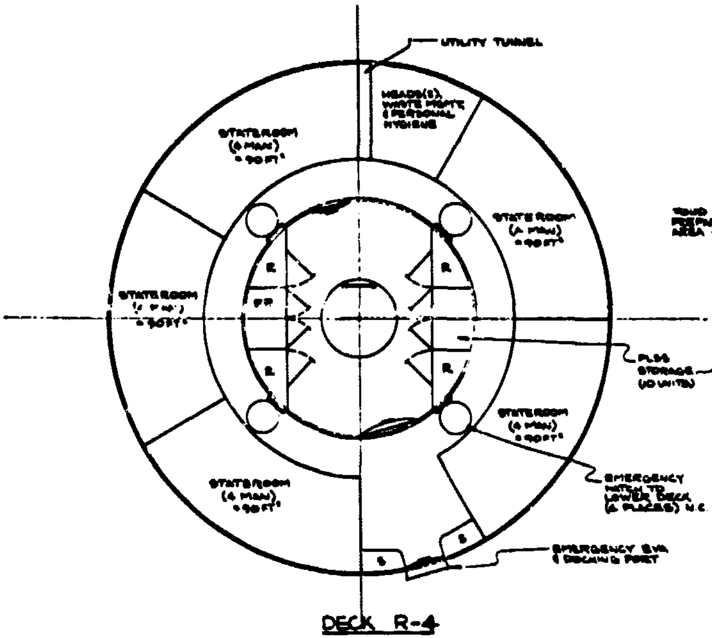
DECK NR-3
SUBSYSTEMS & SHOP AREA



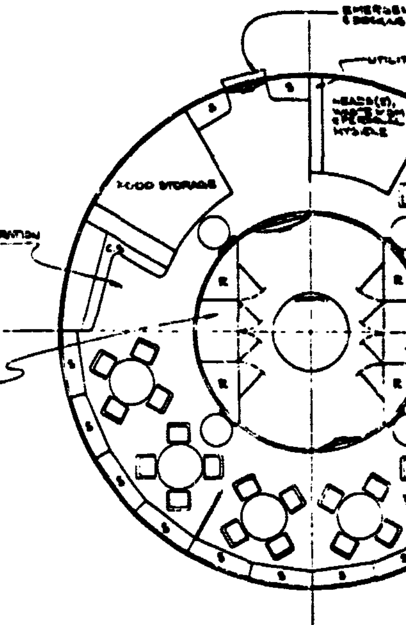
DECK NR-6
SATELLITE HANGER & STOWAGE DECK

Figure 2-2: ZERO "G" HUB --- 60 MAN -
6 DECK SPACE BASE (SHEET 2 OF 3)

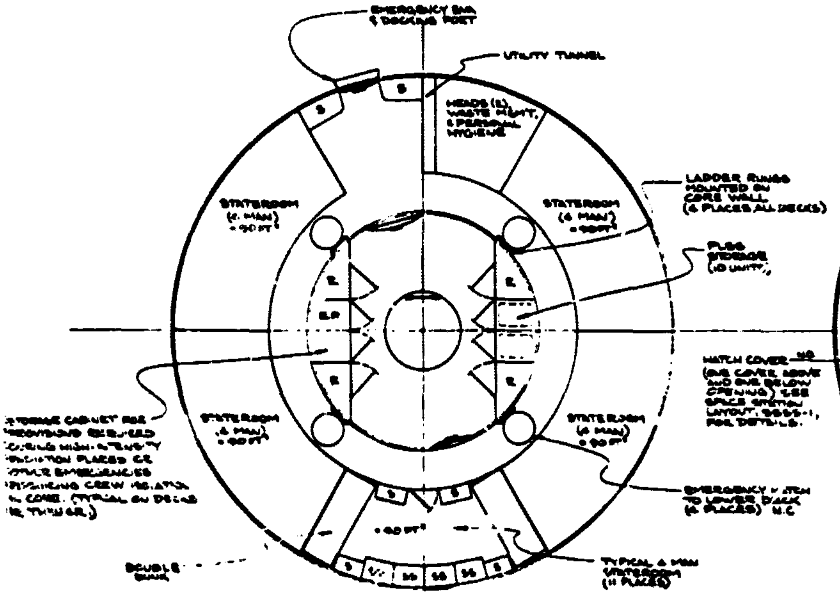
FOLDOUT FRAME 3



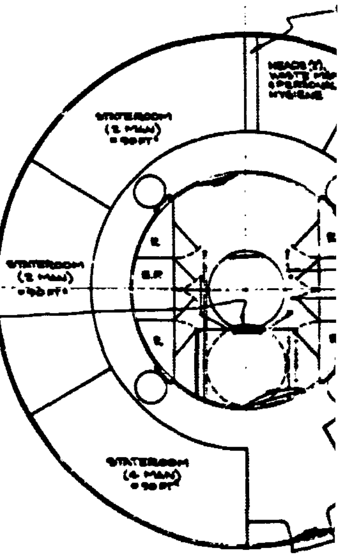
DECK R-4
CREW QUARTERS (20 MEN)



DECK R-5
GALLEY & DINING
FOOD STORAGE
WARDROOM (PARTIAL)

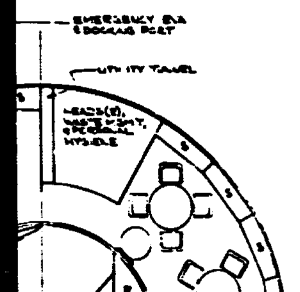


DECK R-3
CREW QUARTERS (20 MEN)



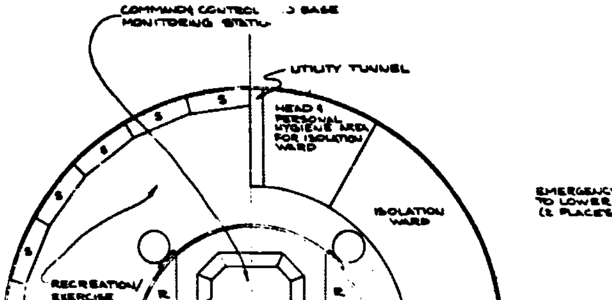
DECK R-2
CREW QUARTERS (

FOLDOUT FRAME 1



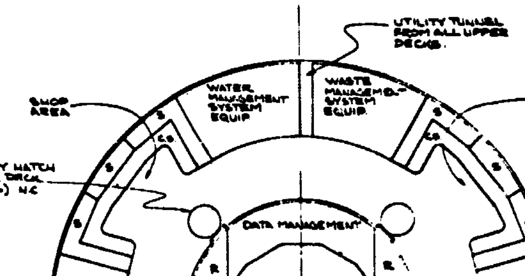
ECK R-5

ALLEY & DINING
OOD STORAGE
ARDROOM (PARTIAL)



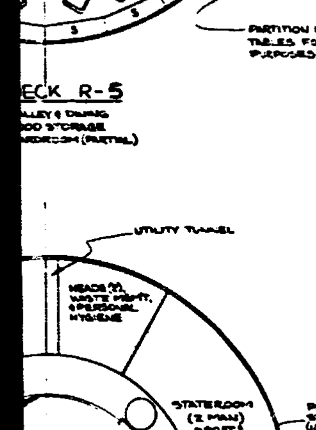
DECK R-6

RECREATION/EXERCISE AREA
COMMAND & CONTROL
BASE MONITORING
ISOLATION WARD
CLINIC



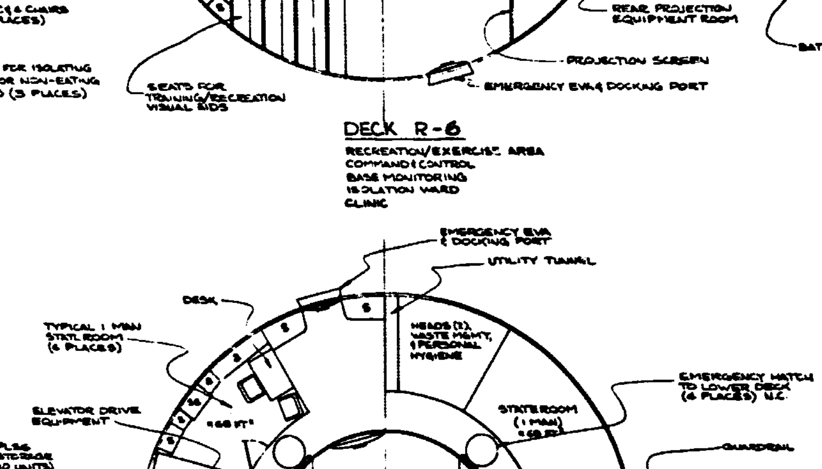
DECK R-7

SHOP AREA
SUBSYSTEMS
DATA MANAGEMENT



ECK R-2

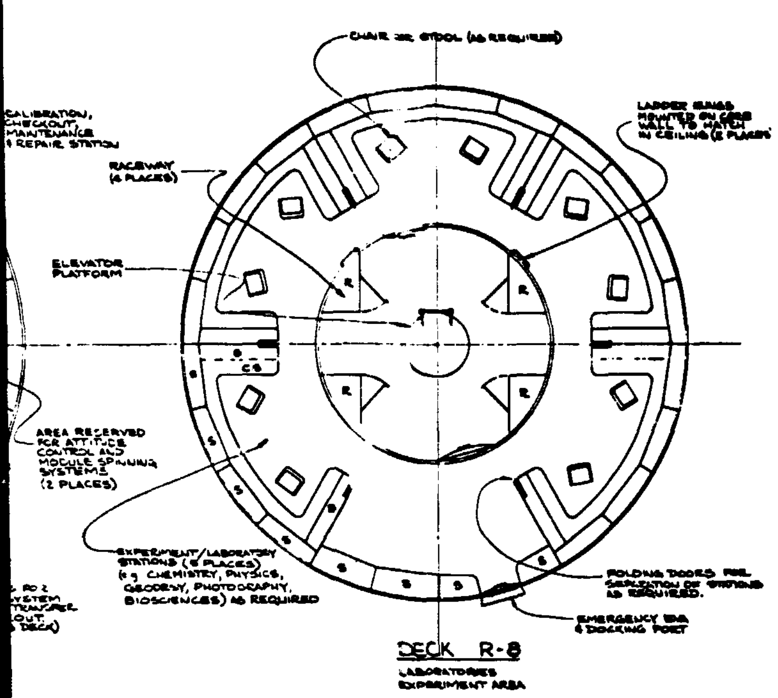
EW QUARTERS (12 MEN)



DECK R-1

CREW QUARTERS (8 MEN)

FOLDOUT FRAME 2



ABBREVIATIONS:

S = STORAGE, GENERAL OR UNASSIGNED
N.O. = NORMALLY OPEN
N.C. = NORMALLY CLOSED
S.S. = SPACESUIT STORAGE
C.S = COUNTER SPACE
R = RACEWAY (ECS FLUID TRANSFER & CABLING)
E.P = EMERGENCY PROVISIONS

NOTES:

1. HATCH COVER, HATCH COVER TRACK, POCKET FOR COVER PROTECTION AND GUARDRAIL AS SHOWN ON DECKS 1R AND 2R ARE TYPICAL FOR ALL DECKS EXCEPT 8R.
2. ONE SPACESUIT PER MAN STORED IN STATEROOMS.
3. ALL HATCHES THRU CORE WALLS TO BE NORMALLY OPEN.
4. UTILITY TUNNELS AND RACEWAYS TO HAVE PRESSURE TIGHT BULKHEADS AT EACH DECK LEVEL.
5. HATCHES IN CORE WALLS TO BE HINGED OVERHEAD.

Figure 2-2: ARTIFICIAL "G" MODULE --- 60 MAN - 8 DECK SPACE BASE (SHEET 3 OF 3) experiments. The inner module contains a six-man emergency crew refuge area and spare parts storage.

2.4.1.4 DECK NR-3

This deck contains the subsystems required to support the zero-gravity hub. The outer module contains battery, electrical power, water management, and environmental control units which condition all outer module decks. A calibration, maintenance, and repair shop is also located in the outer module. The inner module contains an environmental control unit which conditions all zero-gravity inner module decks. Waste management, head, PLSS and suit storage areas are also located in the inner module.

2.4.1.5 DECK NR-4

The outer module contains bioscience, physical science, advanced technology, and general experiment work centers. An isolated 14.7-psia bioscience laboratory is also provided. The inner module provides crew refuge (bunks, emergency expendables, head and waste management), as well as a scientific communication center.

2.4.1.6 DECK NR-5

The outer module is devoted primarily to the space applications work center which supports the Earth sensing module located in Deck NR-6. Four logistic docking ports are located on this deck, with the remaining space alloted to expendables storage. The inner module contains storage for six PLSS and suits.

2.4.1.7 DECK NR-6

The outer module contains the Earth sensing module and two cryogenic storage areas with the remaining volume devoted to satellite maintenance and storage. The inner module is used primarily for satellite docking.

2.4.2 SPACE BASE ARTIFICIAL-GRAVITY MODULE

This eight-deck rotating module is devoted primarily to crew living quarters (eating, sleeping, recreation/exercise, training). The space base command and control and base monitoring center and five experiment/laboratory stations have also been located in this module, since artificial gravity is desirable or required for these functions. A five-foot diameter opening through the center of each deck provides the primary path for all inter-deck travel in this module. This center opening contains both an elevator and a ladder, which extend upward to the space base hub. Secondary (emergency) inter-deck travel is provided through flush, floor hatches located in the outer module area. Travel between the inner and outer modules on any deck is by means of two hatches, one of which is large enough for transfer of cargo handled by the elevator. Four continuous raceways (tunnels) through the inner modules and one through the outer modules provide space for routing the numerous fluid lines (gases and liquids) and power and signal cables required between decks and between the artificial- and zero-gravity modules of the space base. Considerable unassigned storage areas are available on all eight decks. Features of each of the eight decks follow:

2.4.2.1 DECKS R-1 THROUGH R-4

The outer module of these decks contains the staterooms for the sixty crew members, with personal hygiene area and heads located on each deck. Staterooms vary in size and arrangement to accommodate the various ranks and duties of the crew members. A space suit for each member is stored in his assigned stateroom. The inner modules of these decks are used primarily for PLSS storage and the storage of emergency provisions, should crew isolation in the inner modules become necessary.

2.4.2.2 DECK R-5

This deck contains the dining, food storage, and food preparation areas required to accommodate the entire crew. Folding partitions are spaced between dining tables to permit private use for meetings, etc. Heads and a personal hygiene area are also provided. The inner module contains PLSS storage.

2.4.2.3 DECK R-6

The outer module of this deck contains a crew recreation/exercise area, a motion picture projection and viewing area for training and recreation purposes, an isolation ward with adjacent head and personal hygiene facilities, and a clinical laboratory and dispensary. Space base command and control and base monitoring systems are contained in the inner module.

2.4.2.4 DECK R-7

This deck contains the subsystems necessary for space base operation. Areas are allocated for water management, waste management, attitude and stability control, and electrical power systems. All electrical power for use in the artificial-gravity module will be conducted from the nuclear reactor power system to the regulating and conditioning equipment on this deck prior to further distribution. Two environmental control systems are contained on this deck, one for inner module and one for outer module conditioning. A general shop area and a calibration/maintenance/check-out/repair station are also located in the outer module. Data management equipment is located in the inner module, directly below the base command and control station on the above deck (R-6).

2.4.2.5 DECK R-8

The outer module on this deck contains five experiment/laboratory stations which can be outfitted as required to conduct tests that favor an Earth gravity environment (e.g., wet chemistry, physics, geodesy, photography, biosciences). The space in the inner module is unassigned and could be used for storage, such as laboratory supplies and equipment.

3.0 ANALYSIS OF OPERATIONS

3.1 INTRODUCTION

One of the techniques employed during this study was an analysis of operations involved in the type of space mission described in the Phase B Study Statement of Work (Reference No. 92). Its purpose is to complement other analytical techniques, as noted in the Preface, in identifying hazards which a crew may encounter during such a mission. Based on these hazards a number of safety guidelines were developed (Reference D2-113070-5) which are intended to assist in the evaluation of designs of future long-duration manned spacecraft, as well as in the preparation of mission rules, operational handbooks, etc.

Many of the operations are applicable to a broad range of manned space vehicles and, hence, are unrelated to configuration. Others, however, are influenced by specific concepts and mission objectives, as described in the Phase B Study Statement of Work (Reference No. 92), and, in these cases, the analysis was biased accordingly. Likewise, the influence of previous and current space programs is apparent in the analysis, although an effort was made to avoid excessive bias, since it is recognized that continuation of the space program would inevitably antiquate a number of the procedures, techniques, and designs currently being used. An example of this is the docking technique and the frequent references to "soft" and "hard" docking. Future technological advancement may eliminate a two-step operation for the docking of orbiting vehicles by demonstrating the feasibility of a single operation.

Section 2.0 of this document presents a single concept each for the space station and the space base. These concepts did not contemplate incorporating the original space station directly into the space base, for the reasons stated therein. The alternatives considered in the Operations Analysis for the evolution and build-up of the space base, however, do include use of the original station as the basic module for the base, should this be the final choice.

The analysis involved establishing a series of Operational Flow Diagrams depicting the major on-orbit operations involved in various phases of the proposed mission. These are presented in several different figures throughout this report, and referred to in the appropriate operation description.

3.2 SPACE STATION OPERATION

Figure 3-1 is a flow diagram depicting the probable operations involving the space station from before launch, through establishment of the zero-gravity experiment program. In accordance with the study ground rules, however, only the on-orbit operations (shaded blocks) were analyzed during this study.

The space station will be injected into orbit using the S-II second stage. Following propulsion shut-down, the S-II will remain attached for later use as a counterbalance for the space station during the artificial-gravity phase of the mission. Stabilization of the combined space station/S-II stage will be accomplished using the on-board Reaction Jet Control System (RJCS). To ensure operability of the station prior to the first manning launch, as many of the station's on-board subsystems as practical should be remotely activated and checked out by mission control. These may include environmental control, stabilization and control, telemetry, solar panel and antenna deployment, access tunnel extension, and those power supplies required to maintain the space station in a predetermined quiescent mode pending arrival of the first crew members. After mission control has remote verification of satisfactory operation of activated subsystems, a crew manning launch(es) will be made.

3.2.1 SPACE STATION MANNING

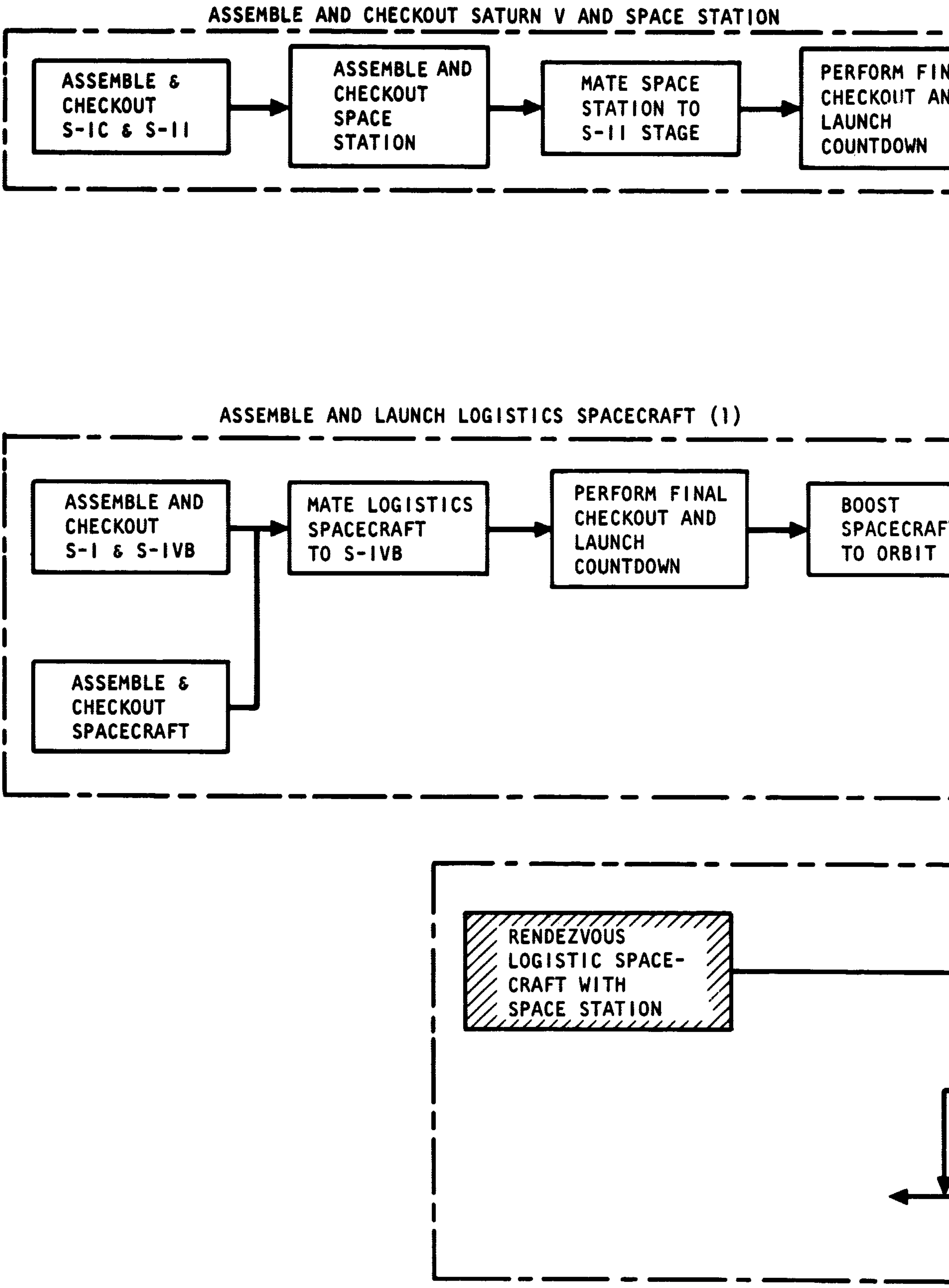
It was assumed that a sophisticated logistic system will be available to support the manning and cargo supply requirements of the station by the time period programmed for the mission. As pointed out in Paragraph 3.4, the initial manning may be accomplished by either an Apollo CSM or Gemini Big "G," either of which could be maintained in a docked mode pending subsequent use as a space tug. Whatever the decision, however, the manning vehicle (logistic spacecraft or adaptable space tug) maneuvers are minimal. Pending the development of an acceptable throttleable propulsion system, minor velocity changes during close-in maneuvering will be accomplished by using the spacecraft's Reaction Jet Control Subsystem (RJCS).

Initially, the crew should establish the vehicle in a station-keeping position, using its RJCS to maintain attitude and a minimum safe distance from the space station, while they inspect the station for proper external configuration; i.e., antenna and solar panel deployment, thermal covers/panels, extension of pressurized access tunnel, etc. When the crew is satisfied that the space station appears safe for manning, and mission control confirms that telemetry data also indicates a safe station, the crew will initiate docking maneuvers.

3.2.2 DOCKING

Routine docking operations will normally be performed by the crew of the docking vehicle, supported by the station crew and/or station control center. For the initial manning launch, of course, this support will not be available and the functions performed by the space station must be accomplished either from the manning vehicle or by remote control from the ground control station.

Following the station-keeping maneuver, the vehicle crew will activate the soft-docking mechanism and confirm proper activation prior to making physical contact. The space station Docking Alignment Target, if required, will be illuminated by the ground control center or the crew of the manning



FOLDOUT FRAME 1

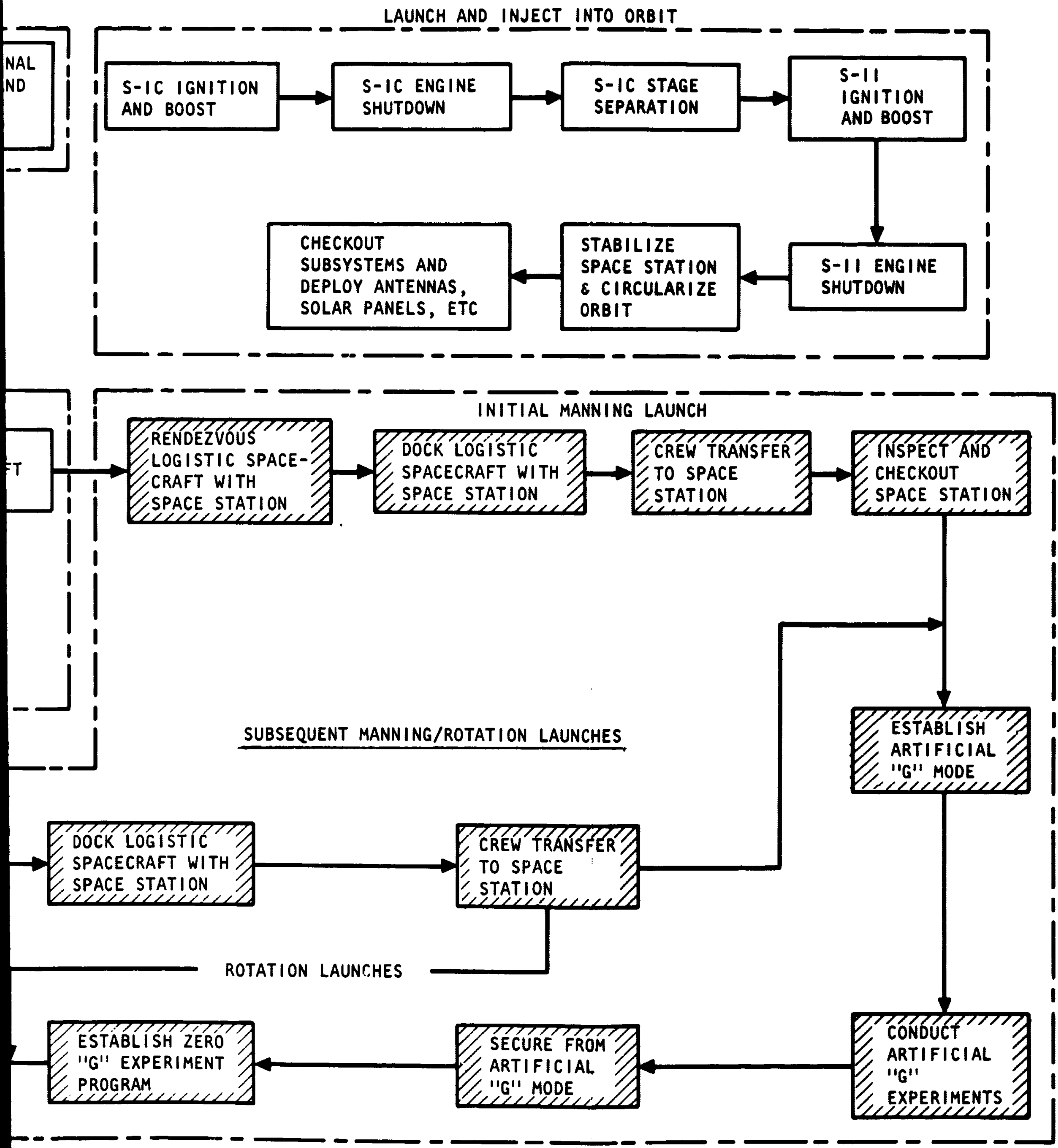


FIGURE 3-1: MISSION OPERATIONS FLOW DIAGRAM

vehicle. The vehicle's RJCS will be used to close on the space station and to make initial contact for soft docking. Prior to contact, however, the crew should make a close-in inspection of the docking port to ensure proper physical configuration; i.e., that the port is free of any physical obstruction, docking mechanisms are in proper order, etc.

Following confirmation of soft docking, the crew will activate the hard-dock mechanism to establish structural and pressure integrity of the manning vehicle/space station interface. Confirmation of a successful hard dock should be made by both the ground control center and the crew of the docking vehicle.

3.2.3 CREW TRANSFER

When docking has been completed, the crew will pressurize the transfer tunnel, using either the station's environmental control system (remotely activated) or repressurization bottles on-board their vehicle. After the crew confirms that the tunnel pressure is holding, the vehicle's access hatch is removed and structural integrity of the interface confirmed by visual observation. Electrical umbilicals between the two spacecraft should be connected so that the crew may monitor the station's environment for habitability prior to opening the station's access hatch.

To further verify space station safety prior to transfer of the entire crew (Reference 3.2.4), a skeleton crew (1 or 2 crewmen) should transfer into the space station and proceed with inspection and check-out. After the advance crew has completed its inspection and check-out, and has verified that the station is ready and safe for operation, the remainder of the crew will make preparations for transferring. The spacecraft will be established in the desired quiescent mode. Those spacecraft subsystems which will be used for backup or emergency use during space station operation should remain powered up. These subsystems may include communications, environmental control, etc. It is expected that power for these subsystems would be obtained from the space station main power source.

3.2.4 INSPECTION AND CHECK-OUT

Although station habitability will have been previously verified remotely, iminent hazards may exist which instrumentation may not have detected. Hence, it would seem prudent that an advance skeleton crew visually inspect the interior of the station for these conditions, thereby precluding needless exposure by the entire crew. In consonance with a procedure which is recommended to ensure operability of the communication subsystem, as well as to maintain cognizance of crew disposition and status, the advance crew should establish two-way communications with both the crewmen remaining in the logistics vehicle and ground control. Using portable check-out equipment as required, they should proceed to check the status/condition of each deck/compartment for toxicity, damage, imminent hazards, etc. Major subsystems should also be given a preliminary inspection for operability.

3.2.5 ADDITIONAL MANNING OR CREW ROTATION MISSIONS

In the event that additional launches are required to staff the space station, the operations involved in such a mission, as well as those of a routing crew rotation mission, would be very similar to those described in 3.2.1 and 3.2.2, with the following exceptions. Station-keeping and visual external inspection would not normally be required unless the incoming crew is requested to do so by the space station commander. The space station crew and control center would be available to monitor and support the docking maneuver. Finally, crew transfer would not normally be a two-step operation unless communications with the space base have been lost. (If this condition exists, it might indicate existence of a serious emergency. The incoming crew should be alerted for a possible rescue mission.)

Generally, space station crew activity and location within the station should be restricted during the docking or arriving vehicles, whether they be logistic spacecraft or space tugs, and during transfer of potentially dangerous cargo (cryogens, pyrotechnics, etc.). Specifically, those compartments and crew stations adjacent to the docking port should be vacated and the compartments sealed. Exceptions might be made in cases where an experiment already in progress requires continuous operator monitoring. This necessity could be minimized with prudent mission/program planning, such that the arrival of logistic vehicles is scheduled to occur during periods of reduced space station activity.

3.2.6 ESTABLISH ARTIFICIAL-GRAVITY MODE

Figure 3-2 depicts the concept offered in the Phase B Study Work Statement, which was briefly analyzed, as a method for establishing an artificial-gravity mode. The spent S-II stage is used as a counterbalance to establish a center of rotation at the in-board end of a boom which telescopes from the station. Access to the zero-gravity environment at the center of rotation is made through a pressurized tunnel integral to the boom. The boom could be extended, pressurized, and checked out remotely by ground control prior to manning, or this could be done by the crew after initial manning.

Establishing the configuration shown, i.e., the S-II tethered in line with the space station, and actual spin-up of the assembly will require extensive trade studies to arrive at an optimum technique. Rearrangement of the components, from launch to orbital configurations, as well as the spin-up operation, might both be done remotely by ground control prior to the first manning launch. The attractive feature of this approach, of course, is that no personnel are exposed to the inherent hazards associated with both operations. On the other hand, aside from the difficulties of remote-controlled rearrangement, spinning-up the station prior to the manning launch(es) presents the problem of having to dock with a non-rotating hub, which under the concept shown would be the center of rotation at the end of the telescoping boom.

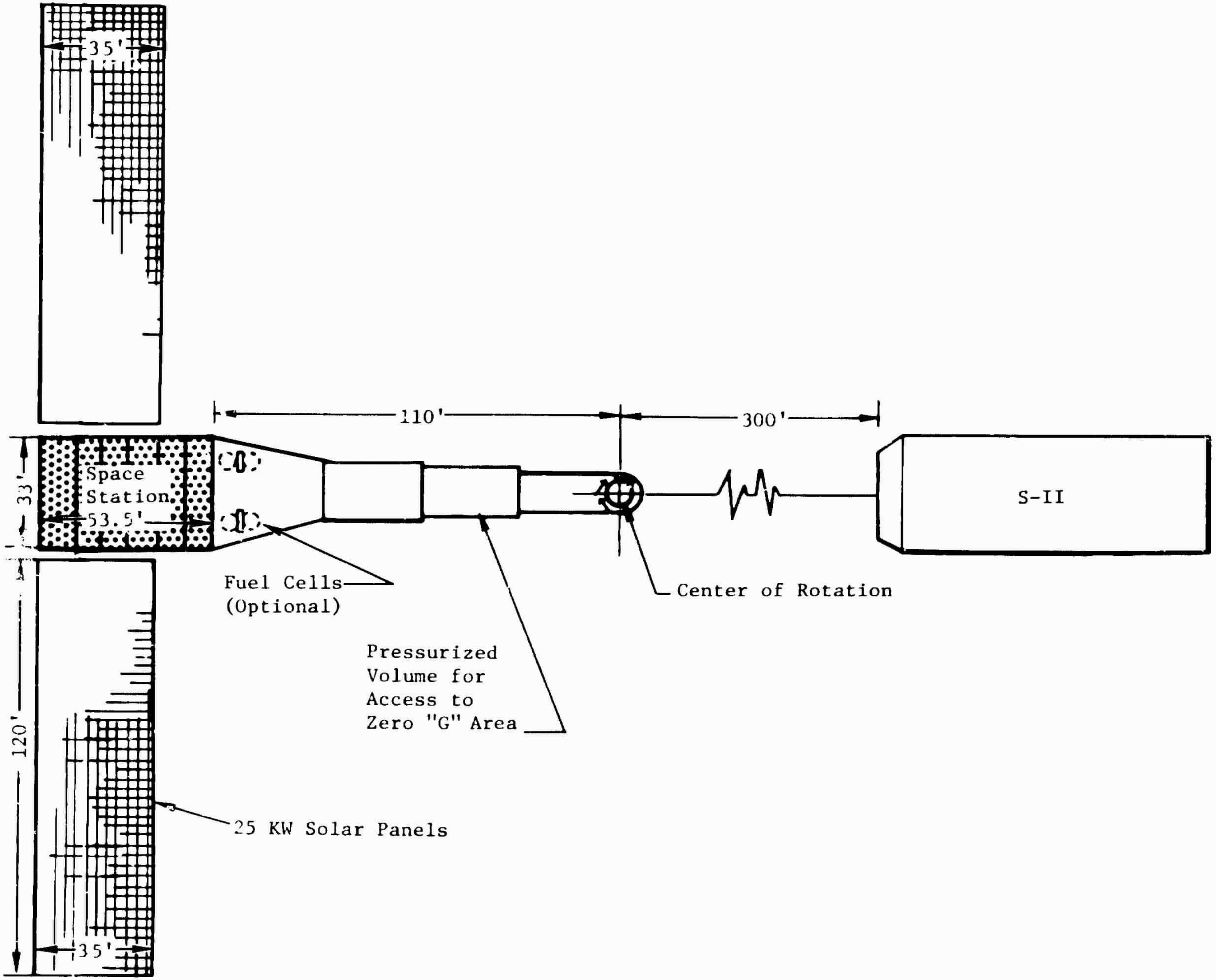


Figure 3-2: SPACE STATION---ARTIFICIAL "G" MODE

The approach taken in the analysis was to do both operations (component rearrangement and spin-up) after the first manning launch. A space tug would be used to ferry and/or position the S-II counterbalance from aft of the station to the desired distance and relative position (12 o'clock) to the station (Reference 3.4). This approach makes the desirability obvious of using the space tug as the initial manning vehicle (Reference 3.2.1). While the remainder of the crew stays aboard the station, a minimum (1 or 2) crew would transfer into the tug, undock, maneuver to, and dock with, the S-II. The latter would then be separated from the station, and, thence, be maneuvered into the desired position. Cable hook-up might require EVA support, but, here again, future studies may reveal how this requirement can be negated. Boom and/or cable adjustment to establish the proper spin axis could be done by the crew remaining aboard the station. Prior to activation of the spin motors, the tug will dock at the hub and its crew will transfer back into the station.

3.2.7 ARTIFICIAL-GRAVITY PROGRAM

As currently planned, the initial phase of the space station mission will be devoted primarily to the investigation of artificial gravity and its effects on systems, operations, procedures, etc. Much of the equipment design, operating techniques, crew procedures, etc., that will be used during the space base mission, will rely heavily on the results obtained during this phase of the space station mission. For example, it will be essential to determine man's capabilities, as well as the effects upon his performance, under frequent changes in gravity, as his activities take him from the space station proper, with its 0.4- to 0.7-g environment, to the center of rotation at the end of the pressurized boom, with its zero-gravity environment.

A summation of objectives, equipment, and crew and station operations of the experiments described in the Candidate Experiment Program for Manned Space Stations (Reference No. 14) is presented in Section 4.0 of this document. A review of the experiment programs suggests that the results of experiment categories Biomedicine (A) and Engineering/Operations (F) may most benefit the planning, design, and development of the follow-on Space Base. Hence, it would seem logical that deliberate emphasis be placed on these two categories during the early part of the space station mission.

3.2.8 COMPLETE ARTIFICIAL-GRAVITY PHASE

After completing the artificial-gravity phase of their mission, the space station crew will secure from this mode, and establish the zero-gravity mode for the next mission phase. Loose or stowable equipment should be lashed or restrained, as required, to operate under a zero-gravity environment.

The de-spin motors will be activated and the station stabilized. The cabling/linkage to the S-II counterbalance will be disconnected and the S-II disposed of. This could be accomplished by activation of the S-II RJCS engines, and firing in retrograde to effect a de-orbit maneuver and subsequent destruction upon reentry.

3.3 SPACE BASE OPERATIONS

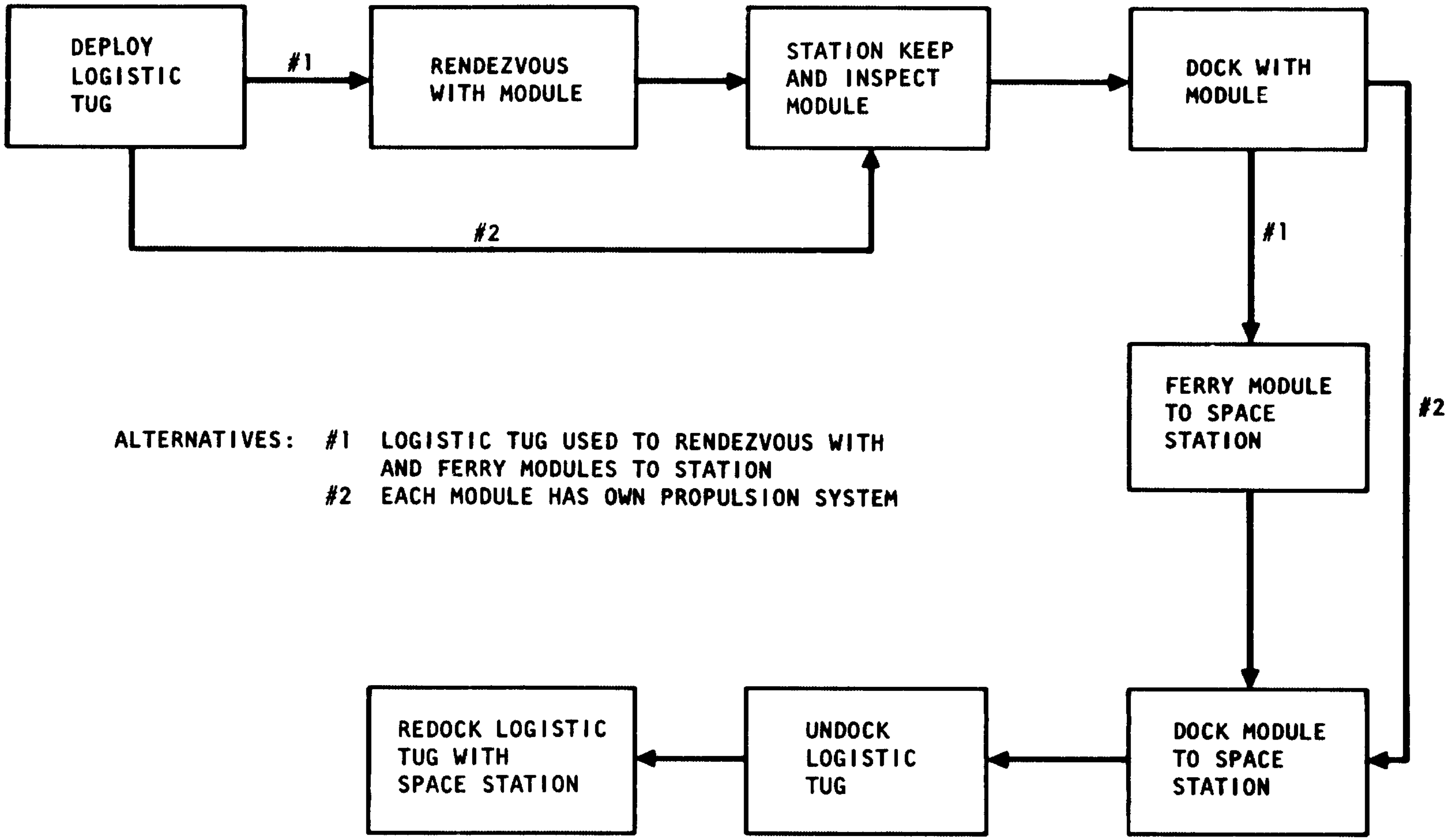
Just as the space station mission will benefit by experience acquired in previous manned space programs, so too will the space base draw heavily on experience from the space station mission. It is presumed that one of the objectives of the space base will be to further develop and refine procedures, techniques, designs, etc., employed during the space station mission. Consequently, an analysis at this time of space base operations is subject to some uncertainty because of the likelihood that the final space base concept may differ drastically from that assumed for the study.

Figures 3-3 and 3-4 are operational flow diagrams showing the space base assembly and its activation and operation, respectively. Base operations theoretically begin with activation of the initial module subsystems. Obviously, if the decision is made to incorporate the original space station into the base, then this would be merely a transition from the original station mission to the start of the mission intended for the space base. In such a case, it is possible that the two missions may overlap to a degree. If, however, the station does not become a part of the space base, then orbit injection, check-out, and initial manning of the initial launches module would presumably be very similar to these same operations for the earlier space station.

Base operations could be incrementally expanded as subsystem capacities and capabilities are increased with the addition of subsequent modules. Certain experiments requiring a zero-gravity environment and limited subsystem support could be performed, thereby maximizing the benefits derived during the lifetime of the base. Power requirements during the base buildup prior to assembly and activation of the Nuclear Power Plant could be obtained from the solar panels of the original space station. Again, if the space station is not used in the space base, then these solar panels might be detached from the station prior to its de-orbiting and destruction. If this were the case, then this would be another assignment for the space tug; i.e., maneuver and assist in connecting the panels to the initial base module. The other alternative would be to delay activation of modules subsequent to the initial one, pending complete assembly of the entire base. At this time, total integrated subsystem activation would occur.

Whichever alternative is selected (as a result of trade studies), the subsystems of each module should be checked, functionally tested, and integrated with the systems of previously assembled modules, before subsequent ones are launched.

SPACE BASE ASSEMBLY



ALTERNATIVES: #1 LOGISTIC TUG USED TO RENDEZVOUS WITH AND FERRY MODULES TO STATION
#2 EACH MODULE HAS OWN PROPULSION SYSTEM

FIGURE 3-3: SPACE BASE OPERATIONS FLOW DIAGRAM

SPACE BASE ACTIVATION AND OPERATION

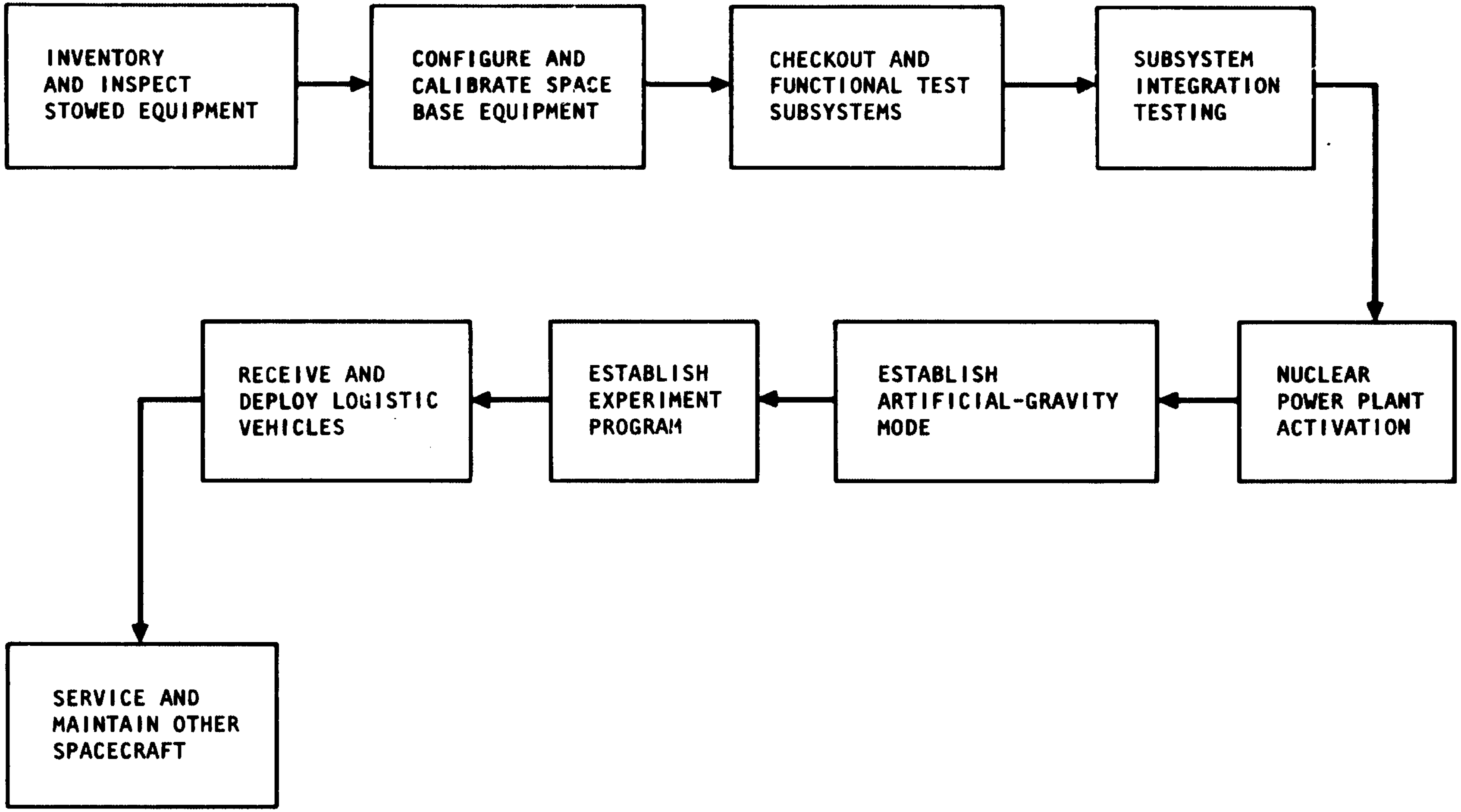


FIGURE 3-4: SPACE BASE ACTIVATION/OPERATION FLOW DIAGRAM

3.3.1 SPACE BASE ASSEMBLY

In considering the space base build-up sequence, no effort was expended to establish an optimum launch sequence for the base modules, since this would require consideration of such factors as mission planning and objectives, experimental program, equipment availability, crew training, priority of benefits to be derived, etc., for which very little information was available. Another influencing factor would be whether the original space station is used as the initial space base module, or whether a derivative of it is launched and used as the initial base module. It seems prudent, however, to plan that launch of the Nuclear Power Plant components would be delayed, pending assembly and verification of operability of all other base modules (Reference 3.3.8).

The assembly of modules in space involves concepts for which no previous experience exists. Different techniques for the modular build-up of a space base were examined, predicated on the limited information available. Although future trade studies may show that extensive use of a space tug is not the optimum technique, this is the method which was selected for investigation during the analysis (Reference 3.4).

The operations involved in securing, assembling, checking out, and testing each module will be essentially the same for each unit; i.e., living quarters, experiment laboratory(s), zero-gravity hub, nuclear power sources, etc. Each module which is to have subsequent modules interfacing with it, will have an integral hard dock mechanism that will enable it to establish pressure and structural integrity between itself and the received unit. Each module should have all subsystems thoroughly checked, including integration testing with formerly assembled modules, before the next unit is launched.

The initial module could be used as the operations center during the assembly phase of the base, and succeeding modules attached to it. This would permit its utilization as living quarters during this phase, prior to activation of the total system of the base.

3.3.2 DEPLOYMENT OF SPACE TUG

Assuming the space tug concept is accepted, it would be maintained in a docked (to initial base module) mode between assignments. While in this mode, its power requirements could be provided by the space base. As each succeeding module of the base is launched, the tug would be deployed, using routine undocking procedures (Reference 3.4.2).

3.3.3 SECURE SPACE BASE MODULES

Two alternatives were analyzed for getting the individual modules into close proximity to the base, preparatory to hook-up: one involves a ferrying operation by the tug, and the other assumes a propulsion system for each module. If the tug is to be used, it will initiate a rendezvous maneuver, using its main propulsion system or its RJCS to effect velocity changes. On-board radar and computer systems will be used, backed up by data from equivalent systems aboard the space base, as well as at ground control. The tug will establish a routine station-keeping position while the crew makes a visual inspection of the module. Telemetry data relayed to the tug from the space base and/or mission control will confirm status of the module.

Normal docking procedures (Reference 3.4.3) will be used to dock to the module and establish structural integrity, verified by talk-back indications. The tug's propulsion system will be used to ferry the module back to the space base.

If the modules have their own propulsion system available for gross maneuvering, this system could be activated by mission control or the operations center of the space base to effect the rendezvous maneuver with the base. Once the module was in close proximity with the base, the tug would complete the assembly, using the station-keeping, inspection and docking operations as previously described.

3.3.4 MODULE ASSEMBLY

The tug will be used to effect final maneuvering and positioning of each module for soft docking preparatory to hard dock operation. The hard dock operation will be initiated by the operations center after all stations have confirmed that soft docking has been completed satisfactorily. The hard-dock mechanism integral to the initial module and each successive module will be activated to effect pressure and structural integrity at the interface of the joining units. Once this has been successfully accomplished the space tug will undock from the module and redock at its own docking station.

3.3.5 SPACE BASE ACTIVATION

Crew activity following hard docking of each successive module will be basically the same. Normally pressurized compartments will be pressurized from either internally-stored repressurization bottles or from the environmental control system of the original module(s). All module interfaces, including structural, as well as cables, umbilicals, etc., should be inspected for integrity. This should be done remotely to the maximum extent possible, or by an advance inspection team when required. When the base crew is assured that the added module is safe, they could proceed to activate the module, integrating its subsystems with previous modules.

The condition and received configuration of all equipment aboard the new module should be checked. Stowed equipment, including its cargo of expendables, should be inventoried. The crew will transfer cargo (as required) into storage lockers of previous modules. Likewise, liquids will be transferred into appropriate storage tanks.

3.3.6 EQUIPMENT CHECK-OUT AND FUNCTIONAL TEST

All equipment of the module (fixed and stowed) will be assembled and set up to support the check-out and functional testing of the module subsystems, as well as future base operations. This should be done, to the maximum extent possible, by using the automatic self-testing capability of the equipment itself, supported by portable test equipment. Malfunctioning equipment could be repaired or replaced as the on-board spares inventory permits or in accordance with the established maintenance policy. Inoperable or irreparable equipment should be reported to mission control so that subsequent logistics support launches may include required spares or replacement items in their cargo.

3.3.7 SUBSYSTEM INTEGRATION AND TESTING

After each of the subsystems has successfully passed functional testing, it may be integrated with those of previously assembled modules, and integration testing performed on the total system. This would permit incremental expansion of crew activity and mission operations as subsystem capacities and capabilities increase. When all available systems are operating satisfactorily, the succeeding module may be launched, provided, however, that unsatisfactory operation would not preclude a module launch if the unsatisfactory condition was in process of being fixed and did not jeopardize the module assembly.

3.3.8 NUCLEAR POWER UNIT

It would seem prudent that launch of the Nuclear Power Plant components would be delayed pending assembly of all other modules of the space base. In any case, activation of the Nuclear Unit should occur only after all modules were assembled. This would eliminate having to maneuver the large modules through a "radiation safe" corridor during the base build-up.

3.3.9 ESTABLISH ARTIFICIAL-GRAVITY MODE

Preparations for space base spin-up should include adjustment of the extension booms to establish dynamic balance and base rotation axis. All loose or portable equipment should be secured to prevent its movement within the base.

As the spin motors are activated, the crew should continuously monitor (remotely) all module interfaces and plumbing connections carrying hazardous materials (explosive, flammable, toxic, etc.) to ensure integrity during the spin-up operation. Particularly, all interfaces at the non-rotating hub joint should be stringently monitored. Consideration should be given to adding additional temporary instrumentation/cameras, as required, to ensure continuous and complete monitoring of these interfaces. Crew location and activity during this phase should be restricted to areas away from these interfaces and liquid/gas plumbing connections.

Potential escape vehicles (logistic or space "tugs") should undock and maintain a safe station-keeping distance from the base, leaving only a skeleton crew aboard the base to man critical operating/monitoring stations. These stations should be isolated from module interfaces and liquid/gas connections.

It was assumed that the artificial-gravity mode would be established early in the life of the base, prior to a full crew complement being aboard. This would permit all but the skeleton crew to leave the base via one or two vehicles.

3.3.10 ESTABLISH EXPERIMENT PROGRAM

Incremental implementation of the experiment program, utilizing the increased capacity of base subsystems and additional equipment as modules are added, would maximize flight data acquisition. Power requirements and other subsystem support limitations would probably delay full implementation until activation of the Nuclear Power Unit and total integration of base subsystems.

Experiment sequencing during the lifetime of the space base requires extensive analysis and trade study of many factors and alternatives (equipment, availability, crew composition and training, priority of benefits to be derived, etc.) and is beyond the scope of this study. As currently envisioned, the program would include experiments integral to the base, externally mounted or tethered modules, and free-flying modules and laboratories operating outside the base's sphere of influence (Reference 4.0).

3.4 LOGISTIC VEHICLE/SPACE TUG OPERATION

Supporting the space station and base throughout their operating life will require extensive and repeated use of logistics vehicles to perform resupply and crew rotation missions. Both the Apollo CSM and Gemini Big "G" spacecraft were reviewed as candidates for fulfilling this requirement. Without extensive modifications at considerable expense, it was considered that neither vehicle has this capability, especially for the large space base, thus mandating development of an advanced logistic system.

As discussed in previous paragraphs, the approach taken for on-orbit maneuvering and docking of large modules was to use a space tug with a minimum crew and maximum maneuverability. Additional applications of the tug could be for ferrying or positioning and maintaining free-flying laboratories, rescue of stranded EVA astronauts, inspection of other satellites, etc. Though it would be desirable to have a common vehicle capable of performing both the logistic and space tug functions, this appears impractical due to widely dissimilar requirements. The large cargo and multi-personnel carrying capability which a logistic vehicle must have, as an example, does not appear to be a current requirement for the space tug. Similarly, the reentry capability of the logistic vehicle would not be a currently envisioned space tug requirement.

It appears feasible, however, that either the Apollo CSM or the Big "G" Gemini vehicle, or some variation of either, could be adapted for space tug usage. Either could be used as an initial manning and/or cargo supply launch, and then maintained in a docked mode until required during the mission. This dual purpose would, at least partially, offset the expense of an additional launch operation. In the light of these and other factors, this is an area which warrants extensive trade studies before a final decision is made.

The use of a vehicle to maneuver and dock other vehicles is a relatively unexplored area. Some experience has been acquired to date in maneuvering two docked vehicles (Gemini-Agena and the Apollo CSM-Lunar Module), but no experience exists in docking two vehicles with the use of a third self-maneuvering vehicle. Hence, for the time being, this must be considered one of the more hazardous operations for the mission being considered.

Heretofore, maneuvering of two docked vehicles has been relatively free of directional restrictions; i.e., area boundaries within which it was required to operate. In the case of the space base, however, the rotating arms, as well as the presence of the Nuclear Power Unit, will necessitate that all incoming vehicles restrict terminal rendezvous and close-in maneuvering to a relatively narrow approach corridor to preclude collision with the rotating arms or exposure to excessive radiation caused by straying outside the radiation shielded area. This restriction will be particularly significant when a space tug is being used to ferry or maneuver a laboratory module or other free-flying vehicles where vehicle control is limited in order to avoid excessive structural loads at the interface. Actual docking to a nonrotating hub of a spinning space base will be essentially the same as with a nonspinning station. If the logistic vehicle or space tug is bringing in a cargo module or an experiment module/laboratory, this would first be "soft-docked" to an appropriate port. "Hard-docking," if required for subsequent entry into the module, would be accomplished by the base operators. The ferrying vehicle would then undock from the module, and redock at its own assigned base docking port.

The transfer of large quantities of cargo from logistic vehicles to the space base will require the employment of new concepts. Hatches, through which equipment can be taken aboard the base, will probably be considerably larger than previous programs have required, in order to accommodate the increased physical dimensions of this cargo---spares, test equipment, experiments, food, etc. Actual movement of this bulky cargo will also require new techniques. One approach to this might be an adaptation of the track-mounted-and-palletized technique widely used in cargo handling and transfer applications under 1-g conditions within the air-freight industry. The large quantities of gaseous and liquid expendables that will need to be transferred to the base also suggests requirements for new or, at a minimum, a broader application of currently used plumbing, valves, seals, pumps, etc.

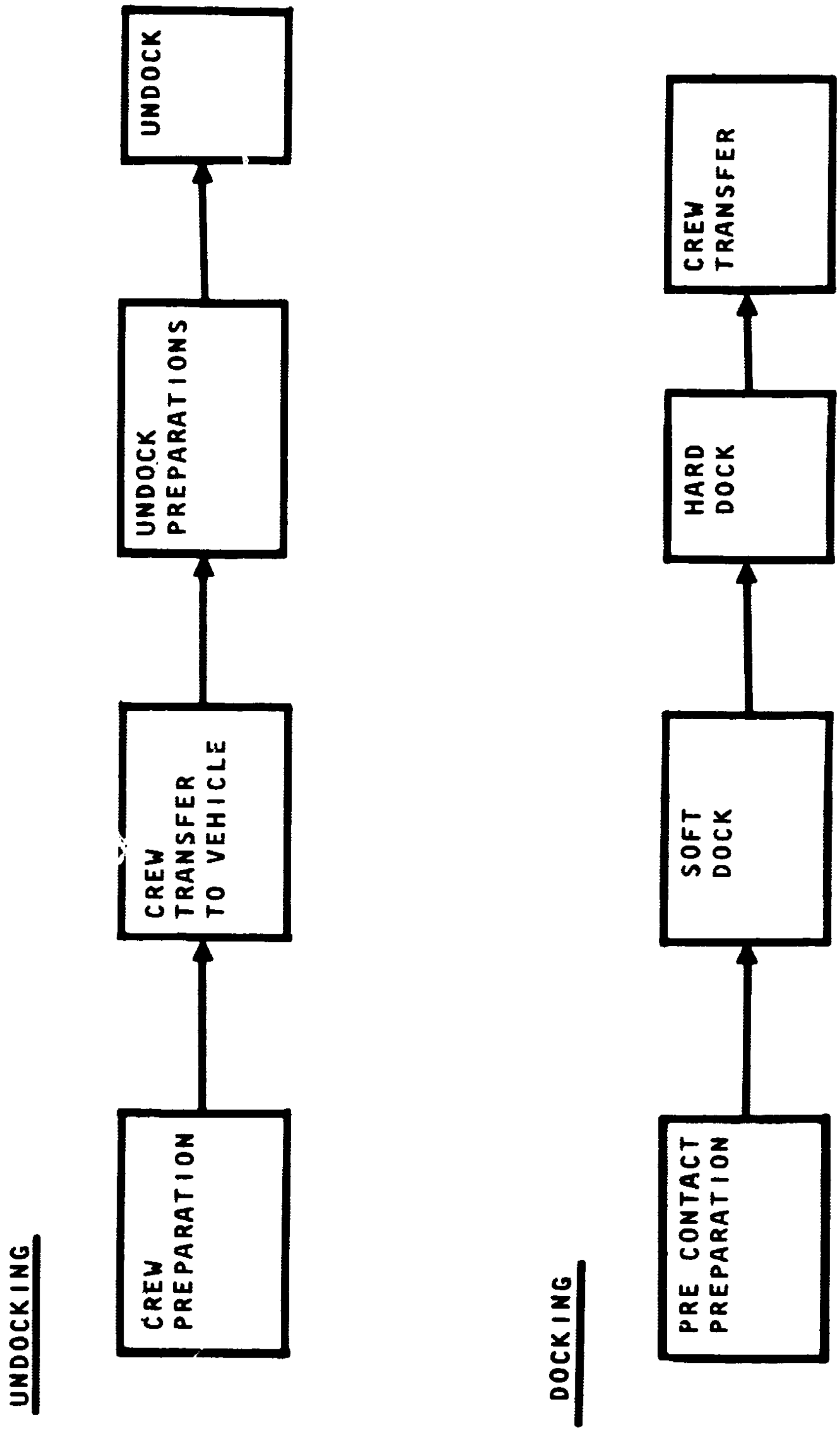


FIGURE 3-5: LOGISTIC VEHICLE DOCK/UNDOCK OPERATIONAL FLOW

Until such time as a high confidence level is achieved in the new hardware, techniques, and procedures that will necessarily be employed on future space missions, it would seem prudent that a capability for total crew escape be provided during the space station mission. This might be accomplished by mandating that some combination of logistic vehicles and space tugs always be in a docked mode in whatever quantity required to accommodate the total on-board crew. As currently envisioned, this same provision would be impractical for a fully complemented space base. On the other hand, by the time period currently predicted for the space base, advanced technology may make mass evacuation quite feasible. Hence, total crew escape from the space base, at least during the early phase prior to fully staffing, should not be ruled out as a possible requirement.

3.4.1 DOCKING/UNDOCKING OPERATIONS

Repetitive docking and undocking maneuvers will be required with both manned and unmanned vehicles (Reference Figure 3-5). Some of the dockings will terminate only after both pressure and structural integrity have been achieved. Others will require only structural integrity, as in the case where merely a ferrying or positioning operation is being performed by the space tug, and no crew or cargo transfer across the interface is planned.

3.4.2 UNDOCKING

Crew preparation prior to deployment for any mission should include a thorough briefing on equipment requirements, assignment of vehicle and its current subsystem status, etc. If a de-orbit operation is to be performed by a logistic vehicle, the crew should be advised of the cargo they will have aboard, as well as the status of Earth recovery forces, weather in landing zone, etc. If the mission requires a space tug to perform maintenance/calibration of co-orbiting or free-flying modules, etc., appropriate spares, tools, and test equipment will be drawn. The crew will then proceed to transfer to the vehicle via the station airlock.

Two-way communications should be established with both the control center and mission control. On-board cargo (Earth return missions) will be inventoried, followed by a cabin configuration check and initiation of subsystem check-out/test sequence.

The forward transfer/pressure hatch will be emplaced, cabin atmosphere stabilized, and umbilicals disconnected. The control center operator will then release the hard-dock mechanism and the vehicle crew will activate their RJCS for backing away and establishing an initial separation distance.

3.4.3 DOCKING

Following the station-keeping maneuver (if required), the crew will activate their soft-docking mechanism and receive confirmation that the mechanism has been properly activated prior to making physical contact. The space station/base docking alignment target will be illuminated by the control center, to give the crew a visual reference during the terminal docking phase. The vehicle's Reaction Jet Control System (RJCS) will be used to close on the space station/base and to make initial contact for soft-docking. Prior to contact, however, the crew should make a close-in insepction of the docking port to ensure proper physical configuration.

Following confirmation of soft-docking, the station/base control center will activate the hard-dock mechanism (if crew or cargo transfer is planned) to establish structural and pressure integrity of the logistic vehicle interface. Confirmation of a successful hard-dock will be made by both the control center and the crew of the docking vehicle. The vehicle crew should establish desired cabin and subsystem configuration while the transfer tunnel is being pressurized from the space station/base environmental control system. The crew will then proceed with removal of forward hatch, umbilical hook-up, and transfer. If no transfer is to be made, as during the course of most space tug missions, only structural integrity need be established.

3.5 SIGNIFICANT PROBLEM AREAS

Considerable experience in crew performance in a zero-gravity environment has been accumulated during past manned flight operations. With the exception of the Apollo program, however, intravehicular crew activity has been restricted to that which could be performed from the crewman's couch position, requiring minimal physical motion or exertion on the part of the crewman. Crew movement and physical exertion increased significantly during the Apollo program, particularly during transfer between the Command Service Module and the Lunar Module. Still, this activity is limited when compared to the relative freedom of movement, and the much broader spectrum of work/experiments to be performed during the space station/base operation analyzed in this study, requiring a greater degree of physical exertion.

A number of mission operations analyzed were considered likely to present significant problems and require further review and analysis. These include: (a) possible adverse crewman reaction to the excessive physical movement, (b) crew traffic flow, particularly under conditions requiring rapid exiting of compartments, (c) maintenance operations---within the space station/base, as well as on free-flying modules, (d) nuclear power plant assembly and operation, (e) handling and transferring cargo between the logistics vehicle and space station/base, (f) adaptation of Apollo CSM or Gemini Big "G" for use as a possible space tug, and (g) development of experiment timelines that would optimize use of all resources as they become available throughout the mission.

3.6 DAMAGE CONTAINMENT AND CONTROL

As was to be expected, the majority of the Crew Safety Guidelines derived from the Space Station Safety Study are oriented toward preventing those conditions or events which endanger the life and health of the crew members. This emphasis is certainly justifiable, since the prevention of emergencies is even more important in the hostile environment of Earth orbit than in the more benign Earth environment. Even if all of these "preventive" guidelines are implemented, we can still expect a certain number of unpredictable failures, some of which will jeopardize the safety of the crew. One previous study of this subject has shown that a space station on-orbit for one year could expect some 140 malfunctions or failures during the mission, with some requiring EVA (Reference No. 34). Crew escape from inflight emergencies has been the subject for many industry and government studies. It should be recognized, however, that unless remedial action time can be extended considerably beyond current estimates and well organized efforts are taken to reduce the possibility of emergencies propagating to catastrophic proportions, crew escape may be rendered impossible. Even though it is likely that equipment reliability and operating techniques will be advanced to improve survivability of future space station crews, it would still seem mandatory that considerable effort be expended to forestall the consequences of a failure, and to contain and control damage resulting from such a failure. Paragraph 4.1 in D2-113070-5 lists those Crew Safety Guidelines (from the Space Station Safety Study) which are judged to be related to Damage Containment and Control. It is believed that utilization of these guidelines in the planning and design of future space stations would significantly contribute to this effort.

In the context of this study, damage has been broadly defined as the breakage or failure of the station or any part of component thereof (Reference No. 86). Containment and control refers to those measures which: first, prevent damage, if it does occur, from escalating in severity or spreading beyond the original site; and, secondly, restore those station functions which have been interrupted or impaired by equipment damage or failure, or, if that is impossible, allow attainment of a safe condition and capability to continue the mission.

In manned space programs to date, high mission success has been achieved primarily through design simplicity, equipment reliability for the short mission durations, and redundant modes of operation. Spacecraft systems were not designed to accommodate inflight repair. Generally, due to the nature of the spacecraft (small size, restricted crew mobility, and limited on-board tools, equipment, etc.) significant maintenance or repair was not practical. Furthermore, failures were more likely to occur during the mission's critical operating phases when the crew was too busy to perform maintenance. However, with the long-duration space flights/missions projected in the future, since equipment failure probabilities will be greatly increased, the system must be designed and the mission planned so that there is a high probability that these failures will be survivable.

Any effort to develop a Spacecraft Damage Containment and Control program must originate from a list of identified hazards which are then analyzed to determine their probability of leading to spacecraft or failure or the impairment of crew safety. Further analysis must then be done to determine: (a) effect on crew and/or vehicle, (b) remedial action time available, and (c) possible remedial actions to alleviate the effects of the damage or failure and reduce its possibility of propagation to fatal situations. Due to the limitations of this study effort, only the last of these three objectives has been explored. It is strongly recommended that all three of these objectives be given serious consideration for future study efforts.

In selecting remedial action for any given emergency, the action must be evaluated to ensure that it does not produce other situations which are equivalent to, or more serious than the original emergency. Use of extinguishing agents to eliminate a fire, as an example, may contaminate the space station to an unacceptable level. On the other hand, rapid decompression of the compartment containing the fire may: (a) impart uncontrolled motion to the space station, (b) temporarily accelerate the fire's progress due to the air velocity gradient resulting from the depressurizing action, or (c) expose crew members and equipment to other hazards unless precautions are taken (donning pressure suits and life support devices, ensuring complete isolation of the compartment being depressurized, etc.). Another example might be the removal of all or a portion of electrical power as a measure to control an emergency. This action might incapacitate the attitude control system, resulting in vehicle instability, or cause loss of vital life support functions. It is obvious then that numerous trade studies are required before optimum remedial actions are selected. It is recognized, however, that real time decisions of crew members may alter or use some appropriate combination of remedial actions for the particular hazard being experienced.

3.6.1 DAMAGE CONTAINMENT

Isolating or confining damage or failure at its origin is paramount to control, if the latter is to be effective in eliminating the hazard, or at least to provide a time span of sufficient duration to allow crew escape. Isolation measures must be taken immediately and must be as effective as possible. Crew training in this regard is imperative. In many cases, particularly for critical hazards, the time differential between the isolation and controlling functions must be so negligible that they will, essentially, occur simultaneously.

Many of the features necessary for isolation are configuration-oriented and, hence, should be specified for the station during the design and development phases. Probably the most recognizable isolation technique is the use of structural barriers which can be used to confine the damage or failure at the original site. Providing tear or crack stoppers in the basic structure, for example, would limit the hole size if the pressure hull is punctures. The use of isolation and shut-off valves in fluid and gas systems is another obvious application of isolation. Flame arresters built into environmental control system (ECS) or other ducting would halt the propagation of fire from one compartment to another.

High safety factors, whether they be in the form of structural features, large quantities of on-board consumables, or generous subsystem capacities, are passive design measures that can be taken to reduce the possibilities of hazards propagating beyond the original site or escalating to catastrophic proportions. In a compartmented space station, itself a segmented structural barrier, structures, seals, isolation valves, etc., must be capable of withstanding rapid decompression if damage to adjacent compartments or equipment is to be avoided. Similarly, the environmental control system must have sufficient repressurization capacity to compensate for a specified number of compartment depressurizations. Extra maneuvering fuel must be provided to accommodate unknowns, such as loss due to plumbing leakage or tank rupture.

Another, and possibly less obvious, method for preventing a hazard from escalating to catastrophic proportions would be the reduction of station activities to conserve the remaining capacity of a subsystem which has been rendered partially inoperative by damage or failure. For example, loss of maneuvering fuel (as mentioned above) for the attitude control system might dictate that station reorientation maneuvers to accommodate certain experimentation be reduced, in order to avoid depletion of the remaining fuel and subsequent total loss of attitude control. Another example might be the elimination of some noncritical station functions following partial failure (or damage) of the electrical power subsystem, to preclude overloading the remaining capacity of the subsystem and possible total power failure.

3.6.2 DAMAGE CONTROL

As used in this study, control means the restoration of station functions which have been interrupted or impaired by equipment damage or failure, or, if that is impossible, the attainment of a safe condition and capability to continue the mission. Heretofore, this has been achieved primarily through the use of redundancy measures, since this was generally sufficient for short-duration missions. The type of redundancy which is probably most recognized is equipment or system redundancy. In theory, this can vary from employing 2 (or more) of everything, to providing 2 of only the most critical item aboard the station. Practically, however, it has been shown, for one space station and mission configuration, that the weight of the redundant systems is about 10 to 15 percent of the total vehicle weight (Reference No. 45). Obviously, here again, extensive studies are required to determine the optimum redundancy for future space stations.

There are several different ways to employ the redundancy technique. One of the most common is parallel redundancy where two (or more) identical pieces of equipment are connected in parallel with the first, and both (or all) operate simultaneously. The advantage of this system is that maintenance initiation is not urgent, since the system function continues to be provided by the remaining component(s), even though one has been damaged or rendered inoperative. Parallel redundancy is particularly useful where no system downtime can be tolerated. It is inefficient, however, in that it requires excessive spares if high system reliability is to be achieved. Since all units in a parallel arrangement accumulate operating time at the same rate, and experience the same operating conditions and environment, their mean time to failure is identical.

A more efficient method is to maintain the redundant item in a nonoperating (stand-by) mode, wherein it can be switched (or plugged) into the system when the first unit fails or is damaged. In this method, mean time to failure of the system is greatly increased, since the spare unit remains in a nonoperating mode until the first unit fails. System downtime is minimal and total spares requirements, although still considerable, are less than for the parallel method.

A third type of redundancy, generally called "use redundancy," employs an interchangeability feature of parts or components; i.e., those items which perform similar functions are designed such that any one of them, or their spares, have several placement options. Consider, for example, the multiple application of pressure regulators, shut-off and check valves, and pressure relief valves in a spacecraft's gaseous or fluid systems. Since their functions are similar, if they were designed to accommodate interchangeability, the high reliability realized with stand-by redundancy could be achieved, but with a significant reduction in spares requirements. It is recognized that this technique may require that optimized equipment be compromised in performance, weight, etc. Hence, extensive trade studies should be performed after the specific mission has been defined and specification requirements identified, to ensure that these parameters are not unacceptably penalized.

Another attractive feature of this method is that it offers the advantage of being able to borrow or "cannibalize" a component from a noncritical or less critical system, in order to maintain operability of a critical system. This method would also have application to whole systems. For example, the normal crew quarters could be designed for use as an emergency shelter. Similarly, docked logistic vehicles could be maintained in some quiescent mode, and used to augment or replace damaged or inoperable space station systems.

As significant as redundancy will be in contributing to mission success, for the long-duration missions planned for the future, in-flight or "orbital" maintenance will still be required to assure continuous availability of operating systems and components. One study conducted by The Boeing Company defines an optimum ratio of redundancy applications and in-flight maintenance operations for manned spacecraft on long-duration missions (Reference No. 43). It would seem prudent that this ratio be used as a guide also for the particular mission and hardware configuration being considered for future space stations/bases.

Preventive maintenance is scheduled primarily on the basis of failure probabilities and function criticalities, and is initiated prior to any failure or warning of impending or potential failure. Hence, this does not become a concern of damage control. Occasionally, unscheduled preventive maintenance is initiated as a result of an indication of imminent or potential failure or damage. A technique which may be useful in this type of maintenance is Incipient Failure Detection Analysis in which unique characteristics (electrical, acoustic) of parts or components are used to warn of an impending failure. This also is not a major damage control technique, although it is related, in that it could be a factor in halting the propagation of a failure to catastrophic proportions.

The type of maintenance which is a major contribution to damage control is corrective maintenance, i.e., returning a component or system to readiness after it fails or is damaged unexpectedly. Under these conditions, proper and rapid identification and evaluation of the hazard criticality becomes the prime consideration in establishing the maintenance level. Remedial action time available after some failures may be so short, that the only alternative to allowing the situation to escalate to fatal proportions, is to have parallel redundancy, thus requiring no crew effort. Other failures, however, may tolerate considerable component repair time. As an example, failure of an electronic equipment cooling system during periods when maximum equipment operation is required might dictate that a remove and replace concept apply; however, during a period when the equipment is in a power-down mode, a lower level of maintenance may be tolerable. Hence, a flexible maintenance level concept might be warranted, depending upon equipment failure or damage probabilities during different mission phases or operations, i.e., critical versus noncritical. Further analysis in this area should be conducted during the design and development phase.

One approach to this problem might be an adaptation of the "field level" versus "depot level" maintenance concept employed in some complex weapon systems. Under this concept, "on-the-spot" maintenance might be restricted to "removal-and-replace," whereas a lower level of maintenance could be performed in a well equipped on-board maintenance shop.

3.6.3 EMERGENCY OPERATING PROCEDURES

Many of the Damage Containment and Control measures mentioned thus far are essentially emergency procedures which are initiated by the crew in response to those situations where system functions or crew health has been impaired, or is in danger of impairment. It is obvious then that these procedures are an integral part of any effective Damage Containment and Control program. Generally speaking, emergency procedures can be divided into three categories: (1) remedial actions which are taken specifically to contain and control an emergency; (2) establishing the mode or state under which the spacecraft and its crew may continue to operate, following containment and control of an emergency, until the original configuration has been re-established and (3) crew escape or mission abort procedures. Each category represents a deviation from the normal, and, though their implementation is unexpected, they must be planned in parallel with the hardware design and mission planning phase.

The first category generally denotes a higher level of criticality, especially from a timing standpoint, since in some cases, if rapid implementation is not made, the other two may not be possible. The crew escape (or mission abort) procedures may be equally as critical, on the other hand, depending upon the degree of success (or lack of) of the first two categories. Consider, for example, a parallel redundant atmospheric CO_2 removal system, whereby one of the units fails. In this case, of course, the system function continues to be provided by the remaining operating unit and no emergency procedures would necessarily have been implemented. On the other hand, if this condition dictated that some station or crew activities be reduced or curtailed entirely, it would represent an emergency operating mode of the category (2) type. Finally, if the remaining unit either failed completely, or operated at less than the required efficiency, it would probably dictate implementation of escape or mission abort procedures.

3.6.4 RECOMMENDATIONS OF AREAS FOR FURTHER STUDY

Establishing an effective Damage Containment and Control program demands consideration of a multitude of factors. The discussion here, although knowingly general, has served to make the interrelationship of some of these factors obvious. It is apparent also, that specific measures and recommendations must await results of trade studies, predicated on specific mission profiles and hardware configurations.

The following areas are those which appear to merit further study:

a. At what phase of the mission are the identified hazards most apt to occur?

b. What are the probable immediate effects of these hazards?

c. What is the available remedial action time following the hazard occurrence?

d. What are the available remedial actions and their probable effectiveness in containing and controlling the hazard?

e. What is the optimum ratio of redundancy usage and maintenance applications?

4.0 EXPERIMENT PROGRAM

4.1 INTRODUCTION

A gross review was made of the Candidate Experiment Program for Manned Space Stations, dated 1 May 1969 (Reference No. 14), for the purpose of identifying the associated hazards, particularly any that are unique or peculiar to the conduct of the various experiments. The Functional Program Element goals, the experiments, their location, equipment involved, required crew support, and number of repetitions are factors generally identified in the experiment program, and are summarized in Table 4-1. Also shown are the identified safety hazards associated with the experiments and remarks, as appropriate.

4.2 DISCUSSION

Table 4-1 is a useful tool in presenting the experiment program in a condensed format, and illustrates any currently recognized absence of information on these factors. A detailed review of the safety problems inherent in the finalized experiment program should be conducted to extend and complete this report.

The experiment program is divided into Functional Program Elements (FPE) within which the individual experiments are grossly grouped according to two dominant features: (a) the individual experiments are mutually supportive of a particular area of research or investigation, and (b) they impose similar and related demands on supporting subsystems. In some of the program elements, however, there is no apparent breakdown of specific experiments and the element itself constitutes the experiment to be performed. A case in point is the Cosmic Ray Physics Laboratory program element, which has two stated objectives: primarily, to determine the detailed properties of the high-energy cosmic-ray particles from 10^{10} to 10^{15} electron volts and, secondarily, to use the very high-energy particles in space to perform controlled laboratory experiments. In this and other cases, these specific laboratory experiments could not be identified.

An item which should be taken into account in assessing safety is the number of repetitions of a hazardous function. Several experiments require the crew to retrieve or replace photographic film. Assuming an on-board film processing facility, this crew function would imply use of, and exposure to, hazardous chemicals. However, the Candidate Experiment Program did not identify the number of repetitions of this function. The servicing of free-flying experiment modules suggests the transfer of cryogens from the space station/base after the two vehicles have docked. Both cryogen transfer and docking are considered particularly hazardous with special precautions required. Information on frequency of the operations is necessary before a final analysis can be made.

Others factors which should be extensively reviewed in order to maximize confidence that all conceivable hazards have been considered include basic skills of participating crewmen, crew training, equipment reliability, predicted maintenance requirements, the mission phase in which the experiment will be performed, etc. These analyses should be implemented as soon as requisite information is available.

While a detailed analysis was impossible, it was obvious that a number of the experiments do involve hazards. These include the handling of chemicals, docking and undocking of free-flying modules, use of high voltages, use of high temperatures, cryogen transfer, and EVA. No experiment-related hazard was identified, however, which had not already been covered by other tasks in the study. For example, use and control of chemicals has been covered in Section 6.0 of this document and by the Subsystems Analysis (D2-113070-11). The applicable guidelines are documented under the "Contamination" Hazard Group in D2-113070-5. Similarly, the use of high voltages and high temperatures is covered by the Fault Tree Analysis technique (D2-113070-10) and documented in D2-113070-5 under the "Electrical" and "Temperature Extremes" Hazard Groups, respectively. Docking and undocking hazards are covered in the Analysis of Operations (Section 3.0 of this document), with the Crew Safety Guidelines in D2-113070-5 cross-referenced under the "Operations" function. Cryogen transfer and EVA are also covered under the "Operations" function.

On the other hand, many of the experiments did not appear to involve any particular hazards. For example, those which comprise the Life Support and Protective System FPE do not in themselves suggest specific hazards. Rather, they appear to be oriented toward the development and effectiveness determination of control and monitoring techniques related to vital space base and life support functions.

4.3 CONCLUSIONS

On the basis of the information available at the time of the study, there are no apparent hazards associated with the experiment program which are peculiar to the experiments. The hazards identified, and the measures required to guard against them, had already been recognized by other tasks in the study. As the experiment program is developed in the future, a further review should be made to insure that unique hazards, if they develop, are recognized and provisions made to safeguard against them.

FUNCTIONAL PROGRAM ELEMENT GOALS	EXPERIMENT	LOCATION	EQUIPMENT
GRAZING-INCIDENCE X-RAY TELESCOPE - Provide high spatial resolution of X-ray sources - Obtain detailed spectral data - Obtain polarization data - Provide technology base for design and operation of larger grazing-incidence telescopes	- X-ray polarimeter - Curved crystal X-ray spectrometer - High resolution studies of X-ray sources	- Remote module	- X-ray polarimeter - Curved crystal spectrometer - X-ray imaging device
STELLAR ASTRONOMY MODULE - Observe stellar objects in the 900 Å - 3300 Å spectral region - Evaluate performance of manned space telescopes and control systems - Develop and evaluate operational techniques and design philosophies	- Manned astronomical space telescope (MAST)	- Remote module	- Cassegrainian telescope
SOLAR ASTRONOMY MODULE - Extend knowledge of solar phenomenon - Evaluate performance of manned space telescopes and control systems - Develop and evaluate operational techniques and design philosophies	- Photoheliograph - UV long wavelength spectrometer - X-ray spectroheliograph - Hydrogen alpha telescope	- Remote or attached	- Camera systems ● Ultraviolet ● Hydrogen-alpha ● White light - UV long wavelength spectrometer - Spectroheliograph assembly ● X-ray imaging device ● Collimated plane crystal spectrometer ● Johann mount crystal spectrometer - H_2-alpha telescope

FOLDOUT FRAME 1

TABLE 4-1 CANDIDATE EXPERIMENT PROGRAM

CREW SUPPORT	SAFETY HAZARD	REPETITION	REMARKS
- Top off cryostat - Monitor operation - Perform maintenance - Monitor and/or assist in docking operation	- Transferring of cryogens - Rendezvous and docking of laboratory module	- Every 90 days or as required - Initial activation plus as required for maintenance	
- Target selection, acquisition, and recognition - Change film and develop - Perform calibration and on-board maintenance - Monitor and/or assist in docking operation - Issue commands for station-keeping maneuvers - Initiate automatic rendezvous and docking	- Rendezvous and docking of module - Transferring of cryogens - Exposure to chemicals	- As required for maintenance, etc.	
- Align and focus optical components - Monitor and maintain equipment - Choose solar region to be observed - Monitor and/or assist in docking operation (remote operation) - Change film - Issue commands for station-keeping maneuvers	- Rendezvous and docking of module (remote operation) - Transferring of cryogens - Exposure to chemicals	- Not available	- Module of same design as for stellar astronomy module

FUNCTIONAL PROGRAM ELEMENT GOALS	EXPERIMENT	LOCATION	EQUIPMENT
SMALL VERTEBRATES (BIO D) - Provide data to facilitate understanding of the fundamental role gravity plays in all aspects of physiology, biochemistry, and behavior of small vertebrates throughout their life cycle - Demonstrate, in a fully operational mode, man's ability to provide scientific responsiveness and flexibility in future orbiting space biology laboratories	<u>Role of Gravity</u> - In cardiovascular function - In embryogenesis, parturition, growth, development, metabolism, and aging in rodents - In immune responses of mammals - In embryogenesis and development in amphibia - In growth and metabolism in reptiles - In hibernation <u>Influence of</u> - Gravity on behavior in mammals - Geophysical factors on biorhythms in vertebrates	- Internal to space station/ base <u>OR</u> permanently docked	- 0-g experiments area - On-board research biocentrifuge - Photographic equipment, TV, etc.
PLANT SPECIMENS (BIO E) - Provide data to facilitate understanding of the fundamental role gravity plays in all aspects of physiology, biochemistry, and behavior of both lower and higher plants throughout their life cycles - Prove the capability of long-term space systems to meet the environmental needs and the spacecraft support requirements for plant research in the operational environment	- Plant responses from 0 to 1 g. - Pea seedling growth in orbit - Plant morphogenesis under weightlessness - Effect of weightlessness on gametogenesis of pteris gametophyles - Role of auxion mediated reactions in developing wheat seedlings during weightlessness - Role of gravitational stress in land plant evolution - Effect of gravitational factors on circadian rhythms in plants	- Internal to space station/ base <u>OR</u> free flight with frequent docking	- On-board centrifuge - Multipurpose photographic capability - TV or near real-time video tape

FOLDOUT FRAME

TABLE 4-1 CANDIDATE EXPERIMENT PROGRAM (cont.)

	CREW SUPPORT	SAFETY HAZARD	REPETITION	REMARKS
ı ip-	- Maintenance and repair - Set up, monitor and terminate experiment - Specimen preparation for logistics return	- Rendezvous and docking (permanently docked module) - Exposure to chemicals	- Not available	
ge o- y	- Maintenance and repair - Set up, monitor and terminate experiment - Specimen preparation for logistic return	- Rendezvous and docking as required - Exposure to chemicals	- Varied after initial	- Experiment envelope not yet defined; experiment selections given are only typical; early experimentation is a separate module flown up and docked to space station with possible free-flying mode and periodic docking

FUNCTIONAL PROGRAM ELEMENT GOALS	EXPERIMENT	LOCATION	EQUIPMENT
METEOROLOGY SUBSATELLITE - Conduct meteorology experiments associated with the space station which, for operational reasons, can only be done remotely	- Ionospheric plasma experiment	- Remote mode	- Own subsystems ● Propulsion ● Stabilization ● Electrical ● etc.
BIOMEDICAL AND BEHAVIORAL RESEARCH - Evaluate changes in human functions and capabilities which may be induced by very long-duration space flights	- Medical/behavioral - R&D support of medical/behavioral experiments	- Internal to space station/ base	- Bicycle ergomet - Rotating litter chair - Body mass measu ment system - Lower body nega tive pressure device - etc.
MAN-SYSTEM INTEGRATION - Provide quantitative and qualitative information on the use of man and his behavior in space flight and on the moon	- Space systems human factors - Extravehicular technology - Maintenance and maintainability - Behavior	- Internal to space station/ base (some EVA)	- Space station/ base equipment/ hardware
LIFE SUPPORT AND PROTECTIVE SYSTEMS - Provide a controlled and physiologically acceptable environment for flight crews during all phases of flight	- Water management - Waste - Thermal control - Personal hygiene and sanitation - Atmosphere supply, control and oxygen regeneration - CO_2 removal - Trace contaminants control - Astronaut protective systems - Subsystems integration - Closed life support systems - Sensors and instrumentation - Food management - Maintenance and repair	- Internal to space station/ base	- Space station/ base equipment/ hardware

FOLDOUT FRAME 1

TABLE 4-1 CANDIDATE EXPERIMENT PROGRAM (cont.)

PMENT	CREW SUPPORT	SAFETY HAZARD	REPETITION	REMARKS
systems ulsion ilization trical	- To be determined	- Deployment/retrieval of vehicle; resupplying vehicle with propellants and other hazardous materials	- Unknown	- Subsatellite is a complete spacecraft
e ergometer ng litter ass measure- ystem body nega- ressure	- Integrated medical and behavioral laboratory measurement system	- None evident		- Five functional elements of IMBLMS ● Physiological ● Behavioral ● Biochemical ● Microbiological ● Data management
tation/ uipment/ e	- Normal crew activities	- EVA activities	- As required	
tation/ uipment/ e	- Normal crew activities	- None evident		

FUNCTIONAL PROGRAM ELEMENT GOALS	EXPERIMENT	LOCATION	EQUIPMENT
MANUFACTURING PROCESS DEVELOPMENT MODULE - Provide a facility in which the development and execution of space manufacturing and materials process projects can be conducted ● Utilization of the buoyancy and thermal convection free environment for processing of unique materials. ● Utilization of the molecular forces of the materials during liquid state for shaping and configuration control of unique products.	- Form solid precision bodies by free, inertia and electrostatic field casting - Form hollow precision bodies as above and develop bubble centering processes - Novel nucleation controlling solidification processes with completely free suspended materials using supercooling.	- Docked mode (permanently OR periodic)	- No information
CONTAMINATION MEASUREMENTS - Develop means of monitoring the environment to determine when contamination is within acceptable limits - Study the composition and distribution of ejecta so that troublesome components and unexpected sources can be eliminated		- Internal to space station/ base - External sensors	- Advanced version of instruments proposed for AAP
EXPOSURE EXPERIMENTS - Determine ● Effects of space environment on the bulk properties of materials ● Effects of space environment on the optical and thermal properties of surfaces ● Rates of micrometeoroid erosion and possible entrapment of meteoric material ● Effective methods of collecting micrometeoroids and other interplanetary material	- Acquire systematic survey data covering very long exposure times - Effects of size, momentum and composition distribution of meteoroids on their penetration into specific materials	- Internal to space station/ base - External sensors	
EXTENDED SPACE STRUCTURE DEVELOPMENT - Develop and test large, lightweight very extended structures external to spacecraft, i.e.: solar cell arrays, antennas, etc.			

TABLE 4-1 CANDIDATE EXPERIMENT PROGRAM (cont.)

CREW SUPPORT	SAFETY HAZARD	REPETITION	REMARKS
- Observe, monitor ● Control experiments from manufacturing development laboratory	- High voltage usage - Possible use of volatile, flammable or explosive materials	- No information	
- No information available	- None evident	- No information	
- No information available	- None evident	- No information	
- No information available	- None evident	- No information	

FUNCTIONAL PROGRAM ELEMENT GOALS	EXPERIMENT	LOCATION	EQUIPMENT
FLUID PHYSICS IN MICROGRAVITY - Investigate ● Free diffusion and thermal conduction in gases ● Internal friction and surface tension in liquids ● Critical point phenomena			
MATERIAL PROCESSING IN SPACE - Investigate the practical uses which eventually complete weightlessness attainable in free-flying spacecraft will have in the development of material processing techniques involving high temperatures and/or transitions between the liquid or gas phase and the solid state	- Melting of floating samples of various materials - Solidification of supercooled liquid drops - Floating zone refining of well understood materials - Crystal growth on seeds suspended in liquid solutions of vapor	- Internal to space station/base	- Provisions for ● High temperature heating and temperature control ● High vacuum and inert atmosphere enclosure ● Heat rejection ● Floating solid and liquid samples
COMPONENT TEST AND SENSOR CALIBRATION - Provide the flexibility needed to accommodate experiments which are only in the conceptual stage at present - Support activities responding to the new technology needs which will only become apparent as actual development of the space station proceeds			
ADVANCED SPACECRAFT SYSTEM TESTS - Conduct qualification tests of advanced spacecraft systems - Provide facility for ● Accommodation of satellites and experiment modules, ● Artificial gravity system, ● An isotope Brayton-cycle power supply, and ● A space shuttle			

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TABLE 4-1 CANDIDATE EXPERIMENT PROGRAM (cont.)

NT	CREW SUPPORT	SAFETY HAZARD	REPETITION	REMARKS
	- No information available	- Possibly high temperatures	- No information	
or rature d tem- ontrol m and sphere tion olid	- Set up and conduct experiment, monitor results, maintain equipment	- High voltages and temperatures - Possible use of volatile, flammable or explosive materials	- No information	
	- No information			
	- No information			

FUNCTIONAL PROGRAM ELEMENT GOALS	EXPERIMENT	LOCATION	EQUIPMENT
ULTRAVIOLET STELLAR ASTRONOMY SURVEY - Conduct an ultraviolet photographic survey of the sky - Obtain spectra in the ultraviolet regions from selected strong ultraviolet sources, and the entire celestial sphere - Provide survey data of selected areas for detail investigation by larger instruments to follow - Develop an ultraviolet technology base and determine man's potential in support of space astronomy	- Ultraviolet photographic survey - Ultraviolet stellar spectrometry - Schmidt image converter spectrograph	- Attached mode (boom mounted stabilized platform)	- (2) 6" ultraviolet cameras - (2) 16-mm cameras - Spectrograph with all-reflective optics
HIGH-ENERGY STELLAR ASTRONOMY - Perform stellar X-ray and gamma-ray astronomy studies from above the Earth's atmosphere	- Large-area X-ray detection - Low-energy gamma-ray detection - Nuclear gamma-ray spectrometer - High-energy gamma-ray astronomy spark chamber detection system	- Permanently docked (launched separately)	- X-ray counters - Gamma-ray detector - Nuclear gamma-ray spectrometer - Spark chamber detection system ● High-energy gamma-ray and charged particle detector ● Electronics ● Display console
SPACE PHYSICS AIRLOCK - Obtain data on space environment in near-Earth orbit - Determine the presence of an induced atmosphere about a space station and measure its temporal changes	- UV airglow horizon photography (S063) - Gegenschein/zodiacal light (S073) - Micrometeorite collection (S149) - Coronograph contamination measurements (T025) - Contamination measurements (T027) - Environmental composition (T030)	- Internal to space station/base (2 airlocks)	- Multiple camera having 8 lens-filter-film transport assemblies - 70-mm camera - Computer for automatic mode - Camera-photometer system - Coronograph - Photoelectric photometer - Photographic photometer, sunshields - Mass spectrometer

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TABLE 4-1 CANDIDATE EXPERIMENT PROGRAM (cont.)

CREW SUPPORT	SAFETY HAZARD	REPETITION	REMARKS
- Set up, operate and maintain - Retrieve/replace film	- Handling of film-processing chemicals - Film retrieval and replacement	- As required	- Similar instruments flown on Aerobees - Subsystem for total FPE ● Boom control mechanism ● Stabilized platform
- Set up, monitor and maintain equipment as required - Change emulsion packs	- Initial rendezvous and docking - Retrieval of emulsion packs (if required)	- 14-day intervals	- Change emulsion packs every 14 days
- Assemble equipment - Initiate and monitor experiment - Retrieve/replace film - Routine maintenance	- Handling of film-processing chemicals - Film retrieval and replacement	- As required	

FUNCTIONAL PROGRAM ELEMENT GOALS	EXPERIMENT	LOCATION	EQUIPMENT	
EARTH RESOURCES - Investigate the various types of sensors and systems from space and evaluate their utility for providing periodic data which will enable the various responsible government agencies to conduct their Earth resources tasks more efficiently		- Sensor and analysis laboratory attached to OR remote maneuvering sub-satellites		- (s n
• Photograph Earth's surface to a resolution and location accuracy capable of allowing maps to be made to a 1:250,000 scale	- Metric photography	- Attached mode (manned)	- Metric cameras	- S t - M t - C
• Determine extent to which multispectral photograph can be applied to Earth sciences	- Multispectral photography		- (6) Hasselblad 500 EL cameras	- S
• Collect simultaneously multiband data (at least five) which will be used to map the spatial distribution of reflective and emissive radiation from the Earth.	- Wide-range imagery	- Remote	- Cassegrainian telescope - Dichroic beam splitter - Detectors	- N
• Determine how accurately the spectral reflectance from terrain features can be recorded in space and to what extent it is modified by atmospheric effects	- Short wavelength spectrometer	- Attached mode (manned)	- (2) accurately bore-sighted telescopes	- S e r
• Construct detailed vertical temperature and water vapor profiles to measure O_3 concentration and to detect and measure minor atmospheric constituents	- Interferometer spectrometer	- Attached mode (automatic)	- Interferometer spectrometer	- R m p
• Determine atmospheric and water vapor vertical profiles and measure cloud top or surface temperatures and pursuant cloud cover	- IR temperature sounder	- Attached mode (automatic)	- Modified Ebert grating spectrometer	- S
• Map brightness, temperature of atmosphere and ground and sea temperature for potential applications in sea, ice, hydrology and geology	- Microwave imager	- Attached mode (automatic)	- Receiver, electronically scanned antenna	-

TABLE 4-1 CANDIDATE EXPERIMENT PROGRAM (cont.)

CREW SUPPORT	SAFETY HAZARD	REPETITION	REMARKS
- Observe, assemble, change film, align equipment, maintain equipment, analyze data, etc.	- Handling of film-processing chemicals - Docking/undocking of space tug (if technique adopted)	- As required	
- Set up and visually acquire target start point - Monitor experiment and assess target conditions - Change film			
- Same as for metric			
- No information			
- Set up, calibrate and monitor experiment; identify site to be recorded			
- Recognize, acquire with instrument, and describe meteorological phenoma of interest			
- Set up, calibrate, and monitor			
- Set up, initiate, and monitor			

FUNCTIONAL PROGRAM ELEMENT GOALS	EXPERIMENT	LOCATION	EQUIPMENT
IONOSPHERE PLASMA INVESTIGATION - Investigate effects on thermospheric plasma of spacecraft traveling through ionosphere - Study cyclotron harmonic wave transmission which is an unexplained resonance at plasma harmonic frequencies	- Plasma wake - Harmonic wave transmission	- Detached mode (subsatellites) - Periodic docking	- Transmitter/receiver with boom mounted dipole antenna - Oscilliscope, tape recorder, magnetometer
COSMIC RAY PHYSICS LABORATORY - Determine detailed properties of the high-energy cosmic-ray particles from 10^{10} to 10^{15} electron volts (ev) - Use very high-energy particles in space to perform controlled laboratory experiments	---	- Internal to space station/base	- Ionization spectrograph

TABLE 4-1 CANDIDATE EXPERIMENT PROGRAM (cont.)

	CREW SUPPORT	SAFETY HAZARD	REPETITION	REMARKS
n ape to-	- Set up, check out, calibrate, monitor, routine maintenance - Maneuver (remotely) - Erect antenna on space station (EVA)	- Subsatellite docking or recovery	- As required	
ro-	- Initial deployment and check-out - Monitor, trouble-shoot and perform maintenance	- EVA activity	- As required	- EVA to remove module wall panel, allowing space vacuum into bay, to window on detector housing

5.0 INTERNAL TRAFFIC PATTERN ANALYSIS

5.1 INTRODUCTION

The purpose of this analysis was to examine the safety problems involved with crew distribution, traffic flow, equipment arrangement, and escape routing. Crew Safety Guidelines to alleviate these problems were developed.

In Phase I of the study, the 6-man Single Launch Space Station (SLSS) and the Early Orbital Space Station (EOSS) were analyzed to identify hazards and potential hazards inherent to traffic flow, crew distribution, equipment arrangement, pressure suit location, and escape routes from a "hazard" area to a "safe" area or emergency return vehicle. The Boeing Crew Activity Sequencing Program (CASP) was used as the basis for the analysis. A "typical day" from a 30-day CASP printout was selected for the initial work. It was intended that later in the study CASP would be modified to accommodate safety criteria generated by the study and that a mission segment of 30 to 60 days would be examined for safety considerations. Before this point was reached, however, the study was redirected into Phase II and realigned to more directly support the Phase B Future Space Station Definition (Reference No. 92).

In Phase II, the 12-man space station was analyzed on much the same basis, with the exception of the factors of pressure suit location and the use of emergency return vehicles. During the redirection it was mutually agreed that pressure suits, at least as presently designed, offer little interest as emergency devices and that for the study purposes it would be assumed that emergency escape vehicles as such would not be considered. Also, the analysis of a 30- to 60-day mission segment was deleted because the detailed information on the 12-man station mission, configuration, and experiment package, necessary for the analysis, would not be available during the Safety Study period.

No specific analysis was made of crew distribution and traffic problems in a rotating station, such as the JAG-1 or future space base. However, it is believed that the Crew Safety Guidelines developed are applicable in general to rotating stations, except for the unknown area of the relative ease of crew movement in zero-gravity versus artificial-gravity environments.

5.2 APPROACH AND ASSUMPTIONS

In general, the approach taken was to identify and examine the "worst case" situation. It was assumed that the "worst case" was that in which an emergency occurred either in an area which was occupied at that time by the maximum number of crew members or which involved the maximum travel distance for escape. Therefore, the situations presented generally represent extremes in crew distribution, and show the traffic patterns which result from crew movement to a safe location. Each case is identified as to gross location of emergency, time of occurrence in a "typical" day, and destination. For each case, the most difficult destination was chosen in order to establish an outside time parameter.

The term "emergency" was not defined in these cases, other than as some condition which makes it necessary to retreat from normal crew distribution to another, and safe, location. It was assumed that the nature and location of the emergency would be made known to all the crew and that all crew members in the area of the emergency would not be incapacitated to the point where they were unable to take whatever action is necessary; e.g., evacuate the area and/or don protective equipment.

In Phase I, for the SLSS and EOSS, it was assumed that the nature of the emergency would be such as to require that the astronauts proceed to the emergency re-entry vehicle (ERV). It was assumed further that pressure suits would be donned either en route to the ERV or after arriving there.

The Apollo Block II suit was used as the baseline suit, in conjunction with its Portable Life Support System (PLSS). At that time in the study, it was recognized that each crew member must use his own suit, with no two suits interchangeable. Consequently, escape routes for a crew member reflect the necessity of reaching his particular suit. Placement of suits is shown in Figures 5-3 through 5-6 and Figures 5-10 through 5-13. Particular suit location is based on astronaut time usage versus location during working hours. For example, crew members 1, 4 and 5 spend a greater portion of their productive hours on the top deck than do crew members 2, 3 and 6. Therefore, suits for 1, 4 and 5 are assumed to be on the top deck. It was further assumed that the cabin atmosphere was adequate for suit storage, that helmets were stored separately, but adjacent to the suits, and that the PLSS units were charged to 900 psig prior to launch and were rechargeable.

Specification times to don and check out suits and PLSS were:

a. Intravehicular suit---3 men together, from fully unsuited to fully suited: 15 minutes (being met at the time of the study).

b. Extravehicular suit---1 man aided, from fully unsuited to fully suited: 15 minutes (not being met at the time of the study).

c. PLSS: 30 minutes normal, with aid; and 15 minutes minimum, with aid.

The physical stature of present astronauts varies considerably, as shown in Table 5-1 (Reference 25). It is assumed that future astronauts, including scientists and technicians temporarily on-board space facilities, such as the space base, will show at least as great, if not greater, variations.

It was assumed that hatches and airlocks between self-sustaining compartments or modules were normally closed or would be closed immediately upon

TABLE 5-1: ASTRONAUT STATURE---DETAILED DATA

Name	Height	Average Shoulder Height	Knee-Floor Height	Crotch Height	Shoulder -Elbow Length	Shoulder Breadth	Hip Breadth	Average Extended Arm Length	Weight
Aldrin	69.4	56.7	18.6	32.0	14.0	19.0	13.4	28.5	167
Anders	67.3	54.6	18.8	31.4	14.4	18.5	13.3	28.0	141
Armstrong	70.4	57.8	20.0	33.5	14.1	19.4	13.4	29.8	173
Bean	68.7	56.2	18.8	31.9	14.7	18.3	13.7		156
Brand	70.1	58.0	19.8	34.5	15.8	20.1	13.9		183
Borman	69.3	57.0	20.0	33.5	13.8	18.4		28.3	168
Bull	69.8	57.5	20.0	32.8	14.3	15.6	12.4		148
Carr	67.7	55.1	18.9	31.9	14.2	18.6	12.2		145
Cernan	71.2	59.2	20.3	33.0	14.2	18.5	14.2		175
Cooper	68.4	58.8	19.8	32.1	14.9	19.4	12.9	29.3	152
Collins	70.9	58.1	20.0	32.5	13.8			29.1	167
Conrad	66.4	53.4	18.5	31.0	13.9	18.9	14.0	28.0	155
Cunningham	69.7	56.0	19.3	32.8	14.8	20.0	13.5		155.5
Duke	71.1	59.3	20.4	34.0	14.6	18.2	13.2		155
Eisele	67.8	54.8	19.0	31.5	14.1	19.1	12.9		152
Evans	70.0	58.0	19.6	33.8	14.9	18.2	14.0		161

TABLE 5-1: (continued)

Name	Height	Average Shoulder Height	Knee-Floor Height	Crotch Height	Shoulder-Elbow Length	Shoulder Breadth	Hip Breadth	Average Extended Arm Length	Weight
Engle	71.8	59.5	19.8	34.4	15.0	18.8	14.0		157
Garrety	69.0	56.7	18.9	33.2	13.8	16.9	13.1		145.5
Gordon	65.6	53.8	17.4	30.6	13.8	19.5	13.9	26.9	154.5
Irwin	66.8	54.0	18.0	31.5	14.5	19.8	13.8	27.6	165
Kerwin	72.0	60.0	20.0	35.5	13.5	18.6	14.1		175
Lind	70.8	58.2	19.9	32.6	14.4	18.5	13.6	28.4	174
Lovell	70.6	58.3	20.0	33.0	13.6	19.0	13.9	28.5	173
Lousma	71.5	58.7	20.2	33.6	14.8	20.8	14.5		199
Mays	70.5	59.0		35.0	15.0	18.5	13.6		167
Mattingly	69.0	56.8	19.5	32.7	14.2	18.2	13.2		140
Michel	70.6	57.7	20.0	33.0	14.5	19.0	13.6		167
Mitchell	69.9	57.6	19.6	32.0	14.2	18.7	13.7		179
McCandless	69.3	56.8	19.3	32.7	14.1		13.0		155
McDivit	70.8	56.7	19.4	32.5	14.0	18.1	13.1	27.5	159
Pogue	68.2	55.6	18.8	31.8	14.1	19.2	13.4		161
Perkowski	67.0	55.2	19.0	30.4	13.5	18.8	13.4		175

TABLE 5-1: (continued)

Name	Height	Average Shoulder Height	Knee-Floor Height	Crotch Height	Shoulder-Elbow Length	Shoulder Breadth	Hip Breadth	Average Extended Arm Length	Weight
Roosa	65.9	55.8	19.7	33.4	14.7	18.6	13.8		161
Stafford	71.5	58.6	19.8	32.8	14.3	18.9	13.5	29.3	172
Scott	71.8	58.0	20.5	33.5	15.1	20.3	14.1		177
Shirra		57.3	20.0	32.0	14.3	19.6	13.9	28.4	197
Sylvester	68.3	55.0	18.6	32.4	13.1	18.8	13.3	27.0	
Swigert	71.7	59.7	19.3	33.2	15.4	20.0	15.3		199
Schmitt	66.8	55.4	18.7	31.7	14.0	19.2	15.3		169
Weitz	69.7	56.9	18.6	32.8	14.5	19.5	14.8		189
Young	69.3	56.0	19.3	31.5	14.0	19.5	13.8	27.6	168
Schweickart	71.8	58.0	20.3	34.6	14.4	18.6	13.3	29.3	165
N	41	42	41	42	42	40	40	17	41
Min	65.6	53.4	17.4	30.4	13.1	15.6	12.2	26.9	140
Max	72.0	60.0	20.5	35.5	15.8	20.8	15.3	29.8	199
Median	69.7	57.2	19.6	32.8	14.2	18.9	13.6	28.5	167

recognition of an emergency. Size of hatches, as dictated by the pressure suit and PLSS, were: with PLSS---39½ inches, and without PLSS---25 inches (maximum shoulder breadth plus one inch).

5.3 SINGLE LAUNCH SPACE STATION (SLSS) EVALUATION

The principal tool used in this evaluation was the Boeing-developed Crew Activities Sequencing Program (CASP). This is a computer program by means of which a space mission may be simulated, taking into account constraints on the mission, such as crew skills, power requirements, target locations, and many others (Reference No. 109). CASP provides a timeline printout showing the activity performed by the station and individual crew members on a minute-by-minute basis for periods of up to 30 days. At the time of the study, however, CASP did not include safety considerations among the parameters evaluated.

At the outset of the work it was decided to select a single "typical day" for an initial review of safety considerations having to do with crew activities and distribution. There being no known basis for selection of one day in preference to another, the first mission day was arbitrarily chosen. Since crew locations and movement were the primary items of concern, the entire CASP printout was not needed, and, for convenience, a very brief extract of the printout was prepared. This brief extract is shown as Table 5-2, and is described in the following paragraphs.

The column, Time/Station Activity, shows first the elapsed mission time in days, hours and minutes. In the extract, only break-point times are shown; that is, times at which there is some change in activity. Second, station activity is shown, with no entry indicating normal operation; TX indicating transmission of data and S/S indicating a subsystem failure which is firmly identified in the complete printout. A failure is shown as occurring at 8:06, which is identified as a component in the electrical power system (Ep 125), by noting that it was repaired by crew member Number 2 from 11:27 through 13:05.

Crew members are identified only by numbers 1 through 6, with the activity and location shown for each member. An alpha-numeric symbol, e.g., ATS 17, under an activity indicates the performance of an experiment, which is further identified in Table 5-3. The hazards associated with experiments were not considered in this task, but were covered under another (see Section 4.0 of this document). Since the Candidate Experiment Program on which Section 4.0 is based was not available for the traffic pattern analysis, the experiment program for the SLSS study was used. It is described in detail in Reference No. 80. Other activities are self-explanatory. CASP did not provide crew locations, so this information was derived by reference to the SLSS configuration (Reference No. 81) and the experiments being done, and is shown in the table by alpha-numeric symbols. Figure 5-1 shows the locations on the SLSS configuration.

Table 5-2: SLSS "TYPICAL DAY" TIMELINE

TIME/ STATION ACTIVITY	CREW MEMBER											
	1		2		3		4		5		6	
	ACTIVITY	LOCATION	ACTIVITY	LOCATION	ACTIVITY	LOCATION	ACTIVITY	LOCATION	ACTIVITY	LOCATION	ACTIVITY	LOCATION
0: 0:01	Sta. + Maint.	F3,4,5	Sleep	Q2	Free	Q2	Free	Q4	Sleep	Q4	Sta. + Maint.	F1-6
0:31	Sta. + Maint.		Sleep		Meal	Q10,7,10	Free		Sleep		Sta. + Maint.	
1:11	Sta. + Maint.		Sleep		Free	Q2	Free		Sleep		Sta. + Maint.	
2:01	Sta. + Maint.		Sleep		Free		Hyg. + Exer.	Q11	Sleep		Sta. + Maint.	
2:11	Sta. + Maint.		Sleep		Sta. + Maint.	Q1-8	Hyg. + Exer.		Sleep		Sta. + Maint.	
2:31	C/E 19	M6	Sleep		Sta. + Maint.		Hyg. + Exer.		Sleep		Sta. + Maint.	
2:48	ATM 17	M2	Sleep		Sta. + Maint.		Hyg. + Exer.		Sleep		Sta. + Maint.	
3:00	ATM 27	M2	Sleep		Sta. + Maint.		Hyg. + Exer.		Sleep		Sta. + Maint.	
3:01	ATM 27		Sleep		Sta. + Maint.		Sleep	Q4	Sleep		Sta. + Maint.	
3:09 TX	ATM 27		Sleep		Sta. + Maint.		Sleep		Sleep		Sta. + Maint.	
3:17	ATM 11	M2,5	Sleep		Sta. + Maint.		Sleep		Sleep		Sta. + Maint.	
3:30 TX	ATM 11		Sleep		Sta. + Maint.		Sleep		Sleep		Sta. + Maint.	
3:34	ATM 14	M2	Sleep		Sta. + Maint.		Sleep		Sleep		Sta. + Maint.	
3:51	ATM 18	M2	Sleep		Sta. + Maint.		Sleep		Sleep		Sta. + Maint.	
4:01	ATM 18		Sleep		Sta. + Maint.		Sleep		Sleep		Meal	Q10,T,10
4:08	C/E 19	M6	Sleep		Sta. + Maint.		Sleep		Sleep		Meal	
4:15 TX	C/E 19		Sleep		Sta. + Maint.		Sleep		Sleep		Meal	
4:25	Unass.	Q2	Sleep		Sta. + Maint.		Sleep		Sleep		Meal	
4:31	Meal	Q10,T,10	Sleep		Sta. + Maint.		Sleep		Sleep		Meal	
4:36 TX	Meal		Sleep		Sta. + Maint.		Sleep		Sleep		Meal	
4:41	Meal		Sleep		Hyg. + Exer.	Q11	Sleep		Sleep		ATM 17	M2
4:53	Meal		Sleep		Hyg. + Exer.		Sleep		Sleep		ATM 27	M2
5:01 TX	Meal		Sleep		Hyg. + Exer.		Sleep		Sleep		ATM 27	
5:10	Meal		Sleep		Hyg. + Exer.		Sleep		Sleep		F13	F3
5:11	ATM 20	09,M2,5	Sleep		Hyg. + Exer.		Sleep		Sleep		F13	
5:17 TX	ATM 20		Sleep		Hyg. + Exer.		Sleep		Sleep		F13	
5:23	C/E 8	M6	Sleep		Hyg. + Exer.		Sleep		Sleep		F13	
5:40	C/E 5	M6	Sleep		Hyg. + Exer.		Sleep		Sleep		F13	
5:41	C/E 5		Sleep		Sleep	Q2	Sleep		Sleep		F13	
5:57	F14; C/E 9	M1,M6	Sleep		Sleep		Sleep		Sleep		F13	
6:14	Unass.		Sleep		Sleep		Sleep		Sleep		F13	
6:17	F14	09,M1,5	Sleep		Sleep		Sleep		Sleep		F13	
6:27	C/E 21	M6	Sleep		Sleep		Sleep		Sleep		F13	
6:38 TX	C/E 21		Sleep		Sleep		Sleep		Sleep		F13	
6:44	C/E 19	M6	Sleep		Sleep		Sleep		Sleep		F13	
7:01	ATM 17	M2	Sleep		Sleep		Sleep		Sleep		F13	
7:13	ATM 27	M2	Sleep		Sleep		Sleep		Sleep		F13	
7:28 TX	ATM 27		Sleep		Sleep		Sleep		Sleep		F13	
7:30	F11	09,M1,5	Sleep	Q2	Sleep		Sleep		Sleep	Q4	F13	
7:31	F11		Hyg. + Exer.	Q11	Sleep		Sleep		Hyg. + Exer.	Q11	F13	
7:41 TX	F11		Hyg. + Exer.		Sleep		Sleep		Hyg. + Exer.		F13	
7:57	F11		Hyg. + Exer.		Sleep		Sleep		Hyg. + Exer.		C/E 11	M6
8:00	Unass.	Q2	Hyg. + Exer.		Sleep		Sleep		Hyg. + Exer.		C/E 11	
8:06 S/S	Unass.		Hyg. + Exer.		Sleep		Sleep		Hyg. + Exer.		C/E 11	

Table 5-2: SLSS "TYPICAL DAY" TIMELINE (Continued)

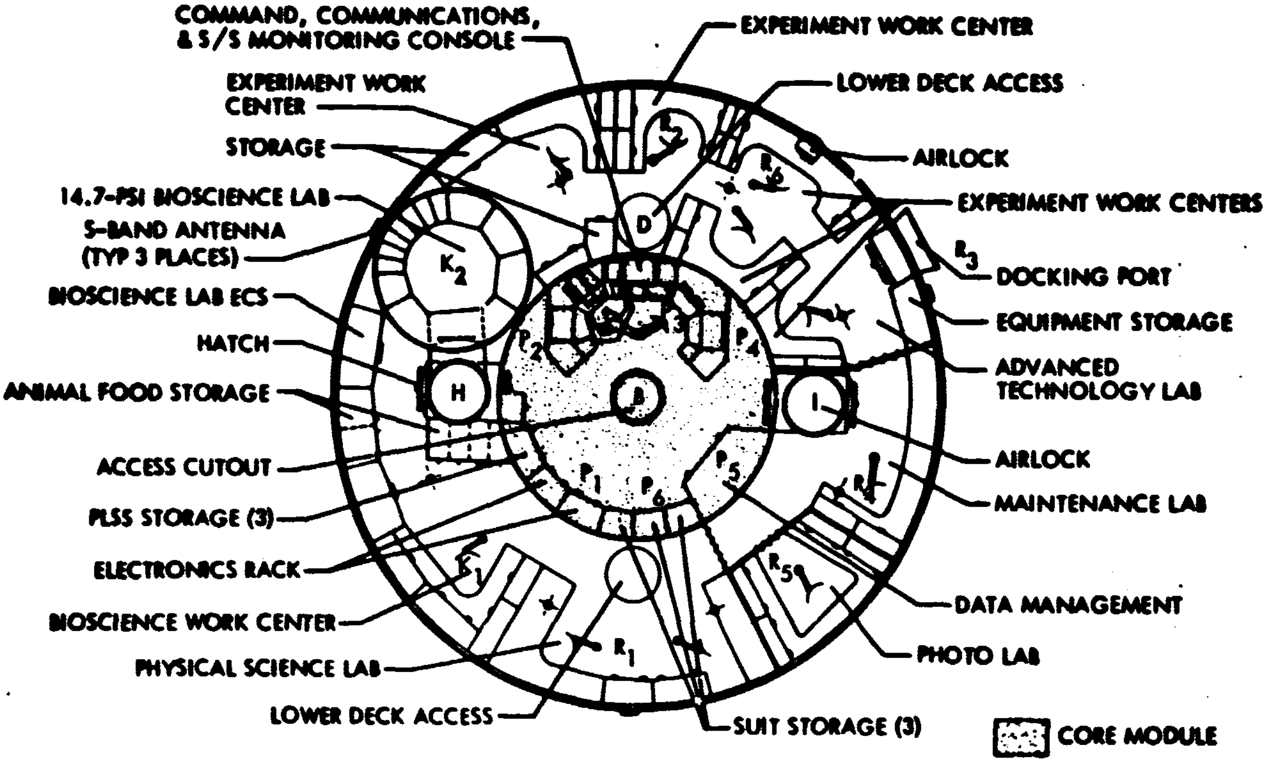
TIME/ STATION ACTIVITY	CREW MEMBER											
	1		2		3		4		5		6	
	ACTIVITY	LOCA-TION	ACTIVITY	LOCA-TION	ACTIVITY	LOCA-TION	ACTIVITY	LOCA-TION	ACTIVITY	LOCA-TION	ACTIVITY	LOCA-TION
8:12 TX	Unass.		Hyg. + Exer.		Sleep		Sleep		Hyg. + Exer.		C/S 11	
8:31	Unass.		Meal	Q10,7,10	Sleep		Sleep		Meal	Q10,7,10	C/S 11	
8:37	Unass.		Meal		Sleep		Sleep		Meal		Unass.	Q4
9:11	Hyg. + Exer.	Q11	Sta. + Maint.	O1-8	Sleep		Sleep		Sta. + Maint.	P1-6	Hyg. + Exer.	Q11
9:47 TX	Hyg. + Exer.		Sta. + Maint.		Sleep		Sleep		Sta. + Maint.		Hyg. + Exer.	
10:11	Sleep	Q2	Sta. + Maint.		Sleep		Sleep		Sta. + Maint.		Sleep	Q4
10:31	Sleep		Sta. + Maint.		Sleep		Hyg. + Exer.	Q11	Sta. + Maint.		Sleep	
11:27	Sleep		Rp125 Repair	Q2	Sleep		Hyg. + Exer.		Sta. + Maint.		Sleep	
11:31	Sleep		Repair		Sleep		Meal	Q10,7,10	Sta. + Maint.		Sleep	
11:41	Sleep		Repair		Sleep		Meal		ER 51	M	Sleep	
11:56	Sleep		Repair		Sleep		Meal		ER 13	Q9,M,R5	Sleep	
12:01	Sleep		Repair		Sleep		Meal		ER 20	M	Sleep	
12:06	Sleep		Repair		Sleep		Meal		ER 33	M	Sleep	
12:11	Sleep		Repair		Sleep		Biomed	Q6	ER 33		Sleep	
12:21	Sleep		Repair		Sleep		Biomed		AA 15	O9,L,R5	Sleep	
12:55	Sleep		Repair		Sleep		Biomed		AS 3	M	Sleep	
12:56	Sleep		Repair		Sleep		Biomed		AS 19	M	Sleep	
12:58 TX	Sleep		Repair		Sleep		Biomed		AS 19		Sleep	
13:05	Sleep		Unass.		Sleep		Biomed		AS 19		Sleep	
13:11	Sleep		Unass.		Hyg. + Exer.	Q11	Biomed		AS 19		Sleep	
13:13	Sleep		AS 3	M	Hyg. + Exer.		Biomed		AS 19		Sleep	
13:15	Sleep		AS 3		Hyg. + Exer.		Biomed		AS 19		Sleep	
13:18	Sleep		ER 25	O9,M,R5	Hyg. + Exer.		Biomed		AS 19		Sleep	
13:25	Sleep		ER 25		Hyg. + Exer.		Biomed		ER 37	O9,M,R5	Sleep	
13:40	Sleep		ER 25		Hyg. + Exer.		Biomed		Unass.		Sleep	
13:41	Sleep		ER 25		Hyg. + Exer.		Free	Q4	Meal	Q10,7,10	Sleep	
13:43	Sleep		Meal	Q10,7,10	Hyg. + Exer.		Free		Meal		Sleep	
14:11	Sleep		Meal		Meal	Q10,7,10	Meal	Q10,7,10	Meal		Sleep	
14:21	Sleep		Meal		Meal		Meal		ER 13	O9,M,R5	Sleep	
14:23	Sleep		ER 20	M	Meal		Meal		ER 13		Sleep	
14:26	Sleep		ER 20		Meal		Meal		ER 33	M	Sleep	
14:28	Sleep		ER 49	O9,M,R5	Meal		Meal		ER 33		Sleep	
14:36 TX	Sleep	Q2	ER 49		Meal		Meal		ER 33		Sleep	Q4
14:41	Sleep		ER 49		Meal		Meal		ER 46	Q9,M	Sleep	
14:43	Sleep		Unass.		Meal		Meal		ER 46		Sleep	
14:46	Sleep		ER 20	M	Meal		Meal		ER 46		Sleep	
14:48	Sleep		ER 51	M	Meal		Meal		ER 46		Sleep	
14:51	Sleep		ER 51		Free	Q2	Sta. + Maint.	O1-8	Unass.		Sleep	
14:54	Sleep		ER 51		Free		Sta. + Maint.		ER 46	R5	Sleep	
14:56	Sleep		ER 51		Free		Sta. + Maint.		AA 8	O9,R	Sleep	
15:03	Sleep		ER 48	M	Free		Sta. + Maint.		AA 8		Sleep	
15:06	Sleep		ER 48		Free		Sta. + Maint.		ER 50	M	Sleep	
15:21	Sleep		ER 48	O9,M	Free		Sta. + Maint.		Unass.		Sleep	
15:23	Sleep		Unass.		Free		Sta. + Maint.		Unass.		Sleep	
15:26	Sleep		Unass.		Free		Sta. + Maint.		AA 8	R,R5	Sleep	

Table 5-2: SLSS "TYPICAL DAY" TIMELINE (Continued)

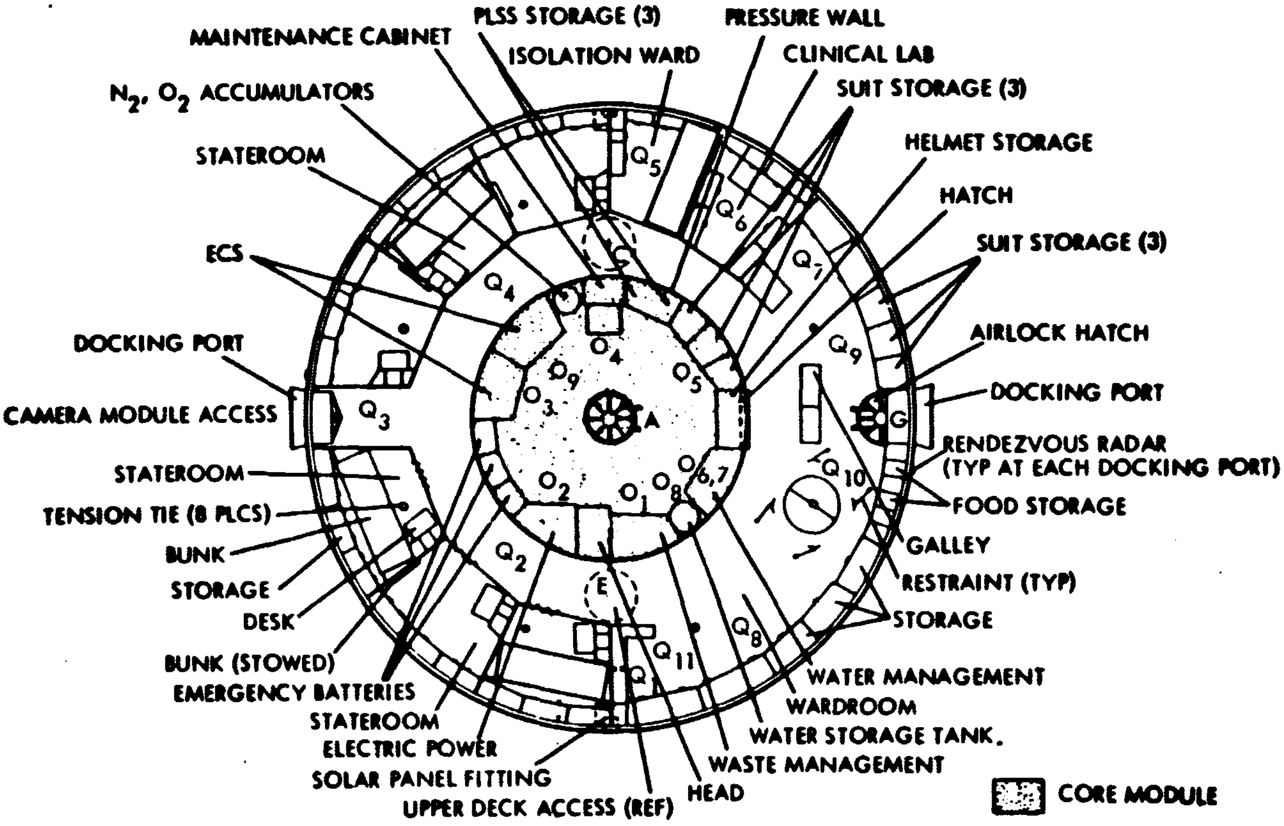
TIME/ STATION ACTIVITY	CREW MEMBER 1		2		3		4		5		6	
	ACTIVITY	LOCATION	ACTIVITY	LOCATION	ACTIVITY	LOCATION	ACTIVITY	LOCATION	ACTIVITY	LOCATION	ACTIVITY	LOCATION
15:28	Sleep		BR 48	B5	Free		Sta. + Maint.		AA 8		Sleep	
15:33	Sleep		AS 20	F3	Free		Sta. + Maint.		AA 8		Sleep	
15:36	Sleep		AS 20		Free		Sta. + Maint.		AS 23	M	Sleep	
15:51	Sleep		AS 20		Unass.	Q2	Sta. + Maint.		AS 23		Sleep	
15:53	Sleep		AS 20		Unass.		Sta. + Maint.		AS 23		Sleep	
15:54	Sleep		AS 20		Unass.		Sta. + Maint.		AS 24	O9,M,B5	Sleep	
16:01	Sleep		AS 20		Biomed	Q6	Sta. + Maint.		AS 24		Sleep	
16:10	Sleep		Unass.	Q2	Biomed		Sta. + Maint.		AS 24		Sleep	
16:19	Sleep		Unass.		Biomed		Sta. + Maint.		Unass.	Q4	Sleep	
17:00 TX	Sleep		Unass.		Biomed		Sta. + Maint.		Unass.		Sleep	
17:21	Sleep		Unass.		Biomed		B4	K1,2	Unass.		Sleep	
17:41	Hyg. + Emer.	Q11	Unass.		Biomed		B4		Unass.		Hyg. + Emer.	Q11
18:21	Hyg. + Emer.		Free	Q2	Biomed		B4		Free	Q4	Hyg. + Emer.	
18:41	Meal	Q10,7,10	Free		Biomed		B4		Free		Meal	Q10,7,10
19:21	Free	Q2	Biomed	Q6	Biomed		B3	K2	Biomed	Q6	Free	Q4
19:35 TX	Free		Biomed		Biomed		B3		Biomed		Free	
19:51	Free		Biomed		Biomed		Unass.		Biomed		Free	
20:01	Free		Biomed		Meal	Q10,7,10	Meal	Q10,7,10	Biomed		Free	
20:25 TX	Free		Biomed		Meal		Meal		Biomed		Free	
20:41	Free		Biomed		Biomed	Q6	B10	K1,2	Biomed		Free	
20:51	Biomed	Q6	Free	Q2	Biomed		B10		Free	Q4	Biomed	Q6
22:01	Biomed		Free		Biomed		B11	K1,2	Free		Biomed	
22:21	Free	Q2	Meal	Q10,7,10	Biomed		B11		Meal	Q10,7,10	Free	Q4
22:42 TX	Free		Meal		Biomed		B11		Meal		Free	
23:01	Free		Hyg. + Emer.	Q11	Biomed		B17	K1,2	Hyg. + Emer.	Q11	Free	
23:21	Meal	Q10,7,10	Hyg. + Emer.	Q11	Biomed	Q6	B17		Hyg. + Emer.	Q11	Meal	Q10,7,10
23:28 TX	Meal		Hyg. + Emer.		Biomed		B17		Hyg. + Emer.		Meal	
23:31	Meal		Hyg. + Emer.		Biomed		B13	K1,2	Hyg. + Emer.		Meal	
23:33 TX	Meal		Hyg. + Emer.		Biomed		B13		Hyg. + Emer.		Meal	
23:51	Meal		Hyg. + Emer.		Biomed		Unass.	Q4	Hyg. + Emer.		Meal	

TABLE 5-3
SLSS "TYPICAL DAY" EXPERIMENTS

EXPERIMENT NUMBER	TITLE
AA 8	Galaxie Characteristics---Part Sky Survey X-Ray Spectrograph
AA 15	Solar High-Resolution Photographic, Spectroheliograph and Spectrograph
AS 3	Weather Type
AS 19	Atmosphere Temperature Profile
AS 20	Atmosphere Density Profile
AS 23	Solar/Terrestrial Radiation
AS 24	Lower Boundary Surface
ATS 11	Heat Transfer
ATS 14	Sensor Behavior
ATS 17	Magnetic Shielding
ATS 18	Solar Pressure and Temperature
ATS 20	Material/Environment
ATS 27	Counter Rotating Radar
B 3	Mutational Rates
B 4	Rat Development
B 10	Rat Healing Ability
B 11	Rat Gravity Readaptation
B 13	Surgery Methods
B 17	Botanical Laboratory
C/N 5	Spacecraft Antenna Pattern
C/N 8	High Frequency Propagation
C/N 9	Long-Range High Frequency
C/N 11	Atmosphere Scintillation and Polarization
C/N 19	Tracking and Navigation
C/N 21	Interferometer
ER 13	Land Use Moisture
ER 20	Gravity Gradient
ER 25	Surface Features
ER 33	Temperature Anomaly
ER 37	Water Mixing Near Glaciers
ER 41	Sea Temperature
ER 46	Fresh/Salt Water Interface
ER 48	Sea Surface Temperature
ER 49	Sea Surface Stress and Roughness
ER 50	Topography Under Oceans
ER 51	Detail Inspection
P 11	Subsatellite Operation #2
P 13	Radio Frequency Sounding
P 14	Daytime Sodium Cloud



UPPER DECK



LOWER DECK

Figure 5-1: SLSS CREW LOCATIONS

As previously stated, it was desired to analyze the "worst cases" of crew distribution. They were identified in Table 5-2 as occurring at 0630 (Case 5-3), 1500 (Case 5-4), 1200 (Case 5-5) and 0458 (Case 5-6). They are also shown in Figure 5-2 in which horizontal bars are used to show crew occupancy of various locations with the height of the bar representing the number of crew members present. The shaded area of the bars indicate crew-oriented activity, i.e., activity devoted to the health and well-being of the crew such as sleeping, eating, recreation and the like. Vertical lines through the figure show the above four cases.

It will be noted that there are some small discrepancies in both Table 5-2 and Figure 5-2 in that in some cases a crew member is shown at more than one location in the same time block. These discrepancies hinge on the fact that, at the time of the study, CASP took into account the total time required to perform an activity but did not consider minor times for crew movement within a general activity. Within the general activity of having a meal, for example, the crew member can be expected to move back and forth between the food preparation and dining areas. In the SLSS, the distances and times involved are considered negligible and it was not thought worthwhile to resolve the discrepancies. However, in future stations, the distances and times may be significant and the existence of this discrepancy should serve to call attention to them. For purposes of the traffic pattern analysis described below, a crew location was arbitrarily selected in those cases of discrepancy.

5.3.1 TRAFFIC PATTERNS IN EMERGENCIES

Having established the crew locations in the 6-man SLSS during Phase I, it was assumed that an emergency occurred. The nature of the emergency was not defined, other than to specify that it required immediate evacuation from the area of the emergency to another, and safe, location; that crew members would then proceed to the ERV's; that pressure suits would be required and would be donned, either en route to the ERV or after arriving at the ERV; and that crew members would all be capable of performing tasks or taking action as necessary.

5.3.1.1 EMERGENCY IN OUTER MODULES---MAXIMUM CREW DISTRIBUTION IN OUTER MODULES

(Timeline 06:30, Traffic Flow to Inner Module, Suits and ERV)

At the time the emergency occurs, crew distribution is as follows (Reference Figure 5-3):

Crew member 1 is in the Advanced Technology Lab---Outer module, upper deck.

Crew members 2, 3, 4 and 5 are sleeping---Outer module, lower deck.

Crew member 6 is at the subsystem command and monitor console---Inner module, upper deck.

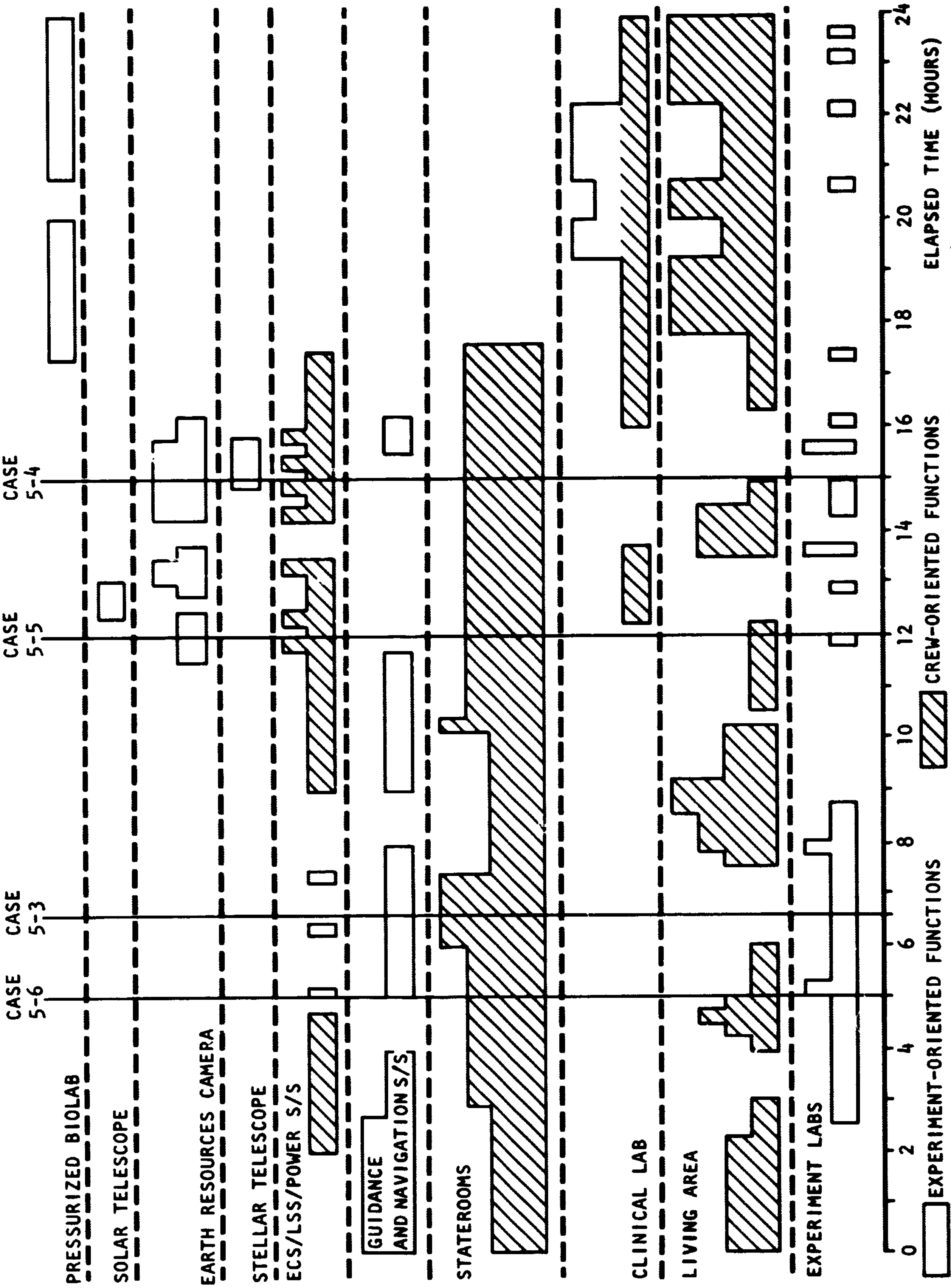


Figure 5-2: SLSS CREW LOCATION DISTRIBUTION WITH TIME (TYPICAL DELAY)

Audible and/or visual warning devices will announce the occurrence of an emergency condition in the outer core. Emergency procedures dictate a swift retreat to the inner module. The most expedient routes are shown in Figure 5-3. Crew members 1, 4 and 5 must travel to the inner module upper deck to reach their suits. Similarly, astronauts 2, 3 and 6 must travel to the inner module lower deck to reach their suits. It should be noted that astronauts 2, 3, 4, and 5 must travel to the opposite side of the outer compartment (although in opposite directions) to enter the inner module in the shortest time. If the emergency in the outer module is on the lower deck in this case, at least two of the crew would be expected to be exposed to this emergency. Traffic flow through the inner/outer module hatch on the lower deck is heavy, since four crew members (2, 3, 4 and 5) must use that hatch, almost simultaneously. An advantage of this flow is that these members can readily account for each other. If the emergency warranted, the suits could be by-passed, and crew members go directly to their respective ERV, where additional suits are stored.

5.3.1.2 EMERGENCY IN INNER MODULE---MAXIMUM CREW DISTRIBUTION IN INNER MODULES

(Timeline 15:00, Traffic Flow to Emergency Re-entry Vehicle)

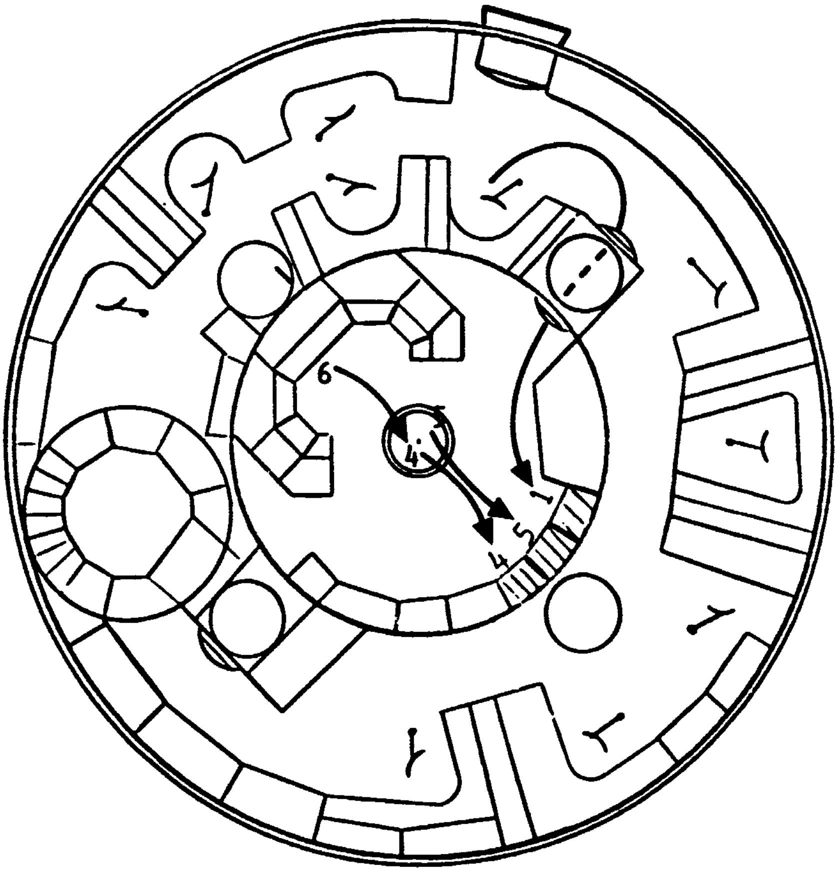
At the time the emergency occurs, the crew distribution is an follows (Reference Figure 5-4):

Crew members 1, 3 and 6 are in their staterooms---Outer module, lower deck.

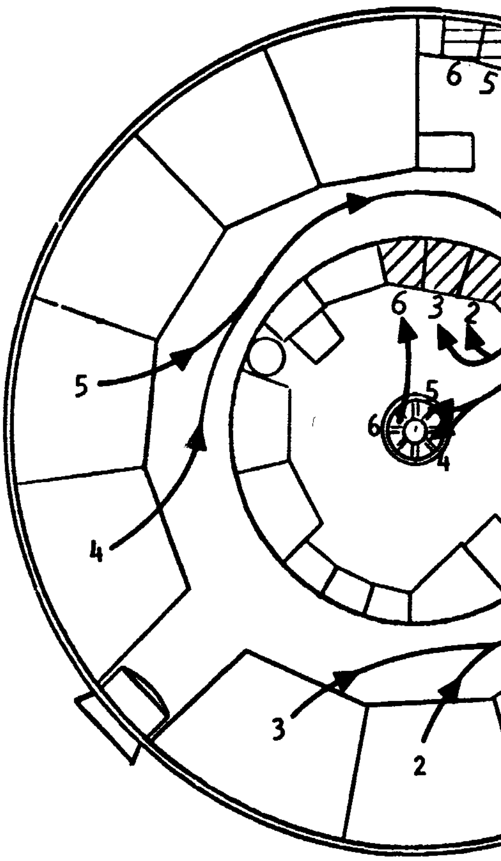
Crew members 2 and 5 are in the camera module.

Crew member 4 is in the environmental subsystem area---Outer module, lower deck.

Audible/visual warning devices would announce the occurrence of an emergency in the inner module. If the emergency warranted, the crew would proceed to their respective ERV, as shown in Figure 5-4, without suits. Crew members 1 and 3 would proceed counterclockwise to the nearest upper deck access, then to their respective ERV. Crew **member** 6 would follow a similar route, but clockwise to his nearest upper deck access. Crew member 4 would immediately leave the inner module through the lower deck hatch and proceed to his ERV, in a clockwise direction, via the upper deck access, or else he would have to travel an additional 180 degrees to gain entry to his ERV, since the biolab blocks the deck. Crewmen 2 and 5 would exit the camera module into the lower deck inner module and travel through the inner/outer module hatch. They would split, with crewman 2 traveling counterclockwise to the upper deck access. Crewman 5 would travel clockwise to the upper deck access. Once they had achieved the upper deck, each would go to his respective ERV. It should be noted that crewmen 2 and 5 have the option to remain in the camera module. This will be based on various information from the emergency detection system, and intercom data from other crew members. A similar situation would occur if a crewman



A-A
UPPER DECK



B-B
LOWER DECK

FOLDOUT FRAME 1

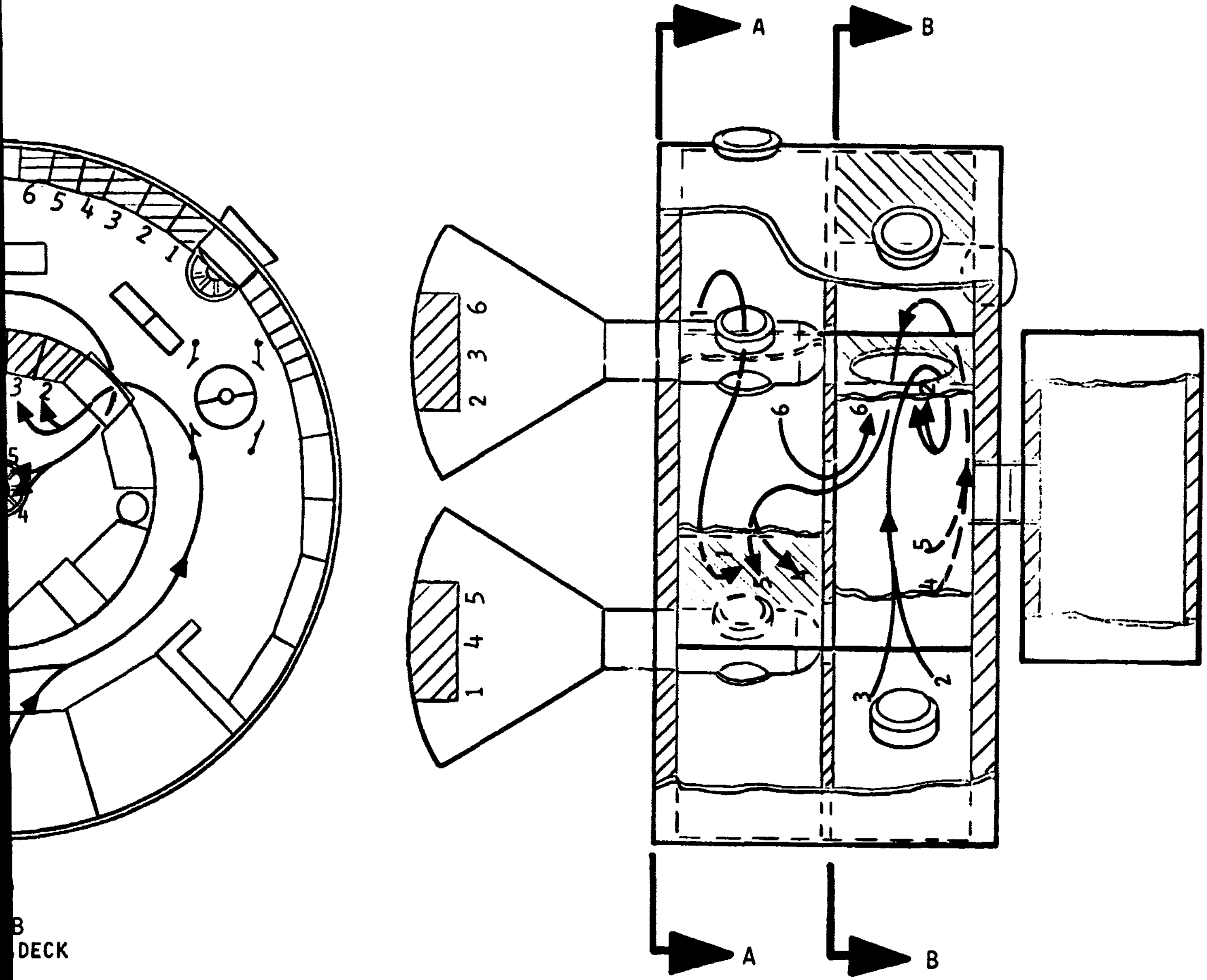
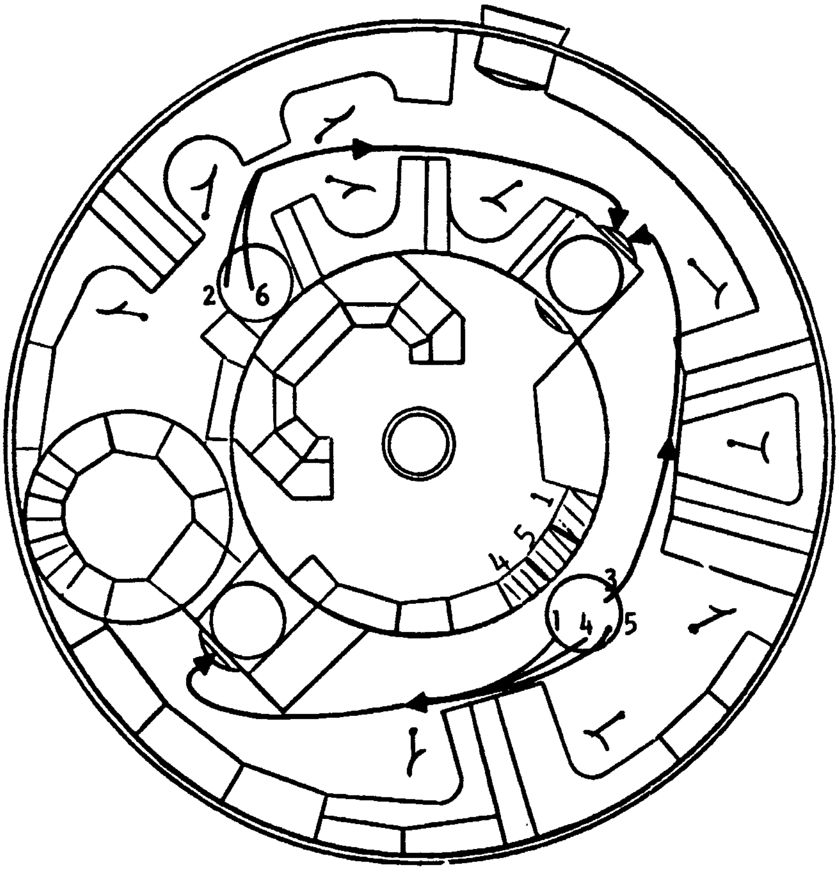
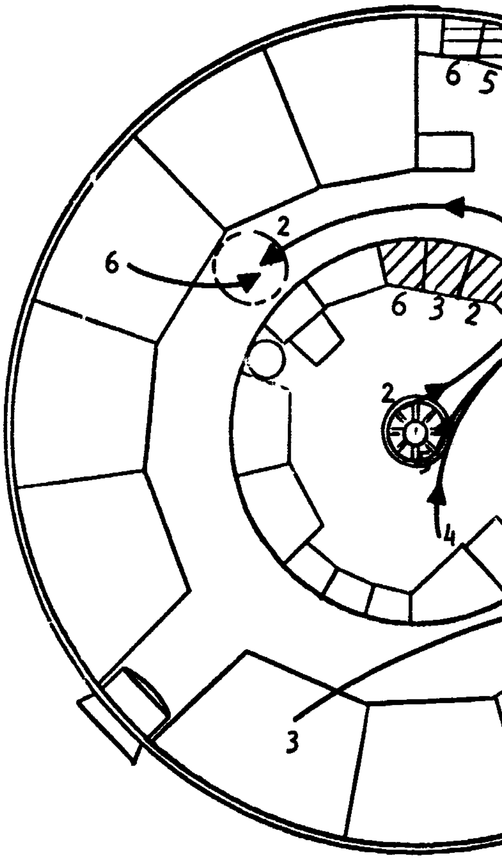


Figure 5-3: EMERGENCY IN OUTER MODULES, MAXIMUM CREW DISTRIBUTION IN OUTER MODULES TIMELINE 06:30 HOURS---TRAFFIC FLOW TO INNER MODULES AND SUITS



A-A
UPPER DECK



B-B
LOWER DECK

FOLDOUT FRAM[illegible] 1

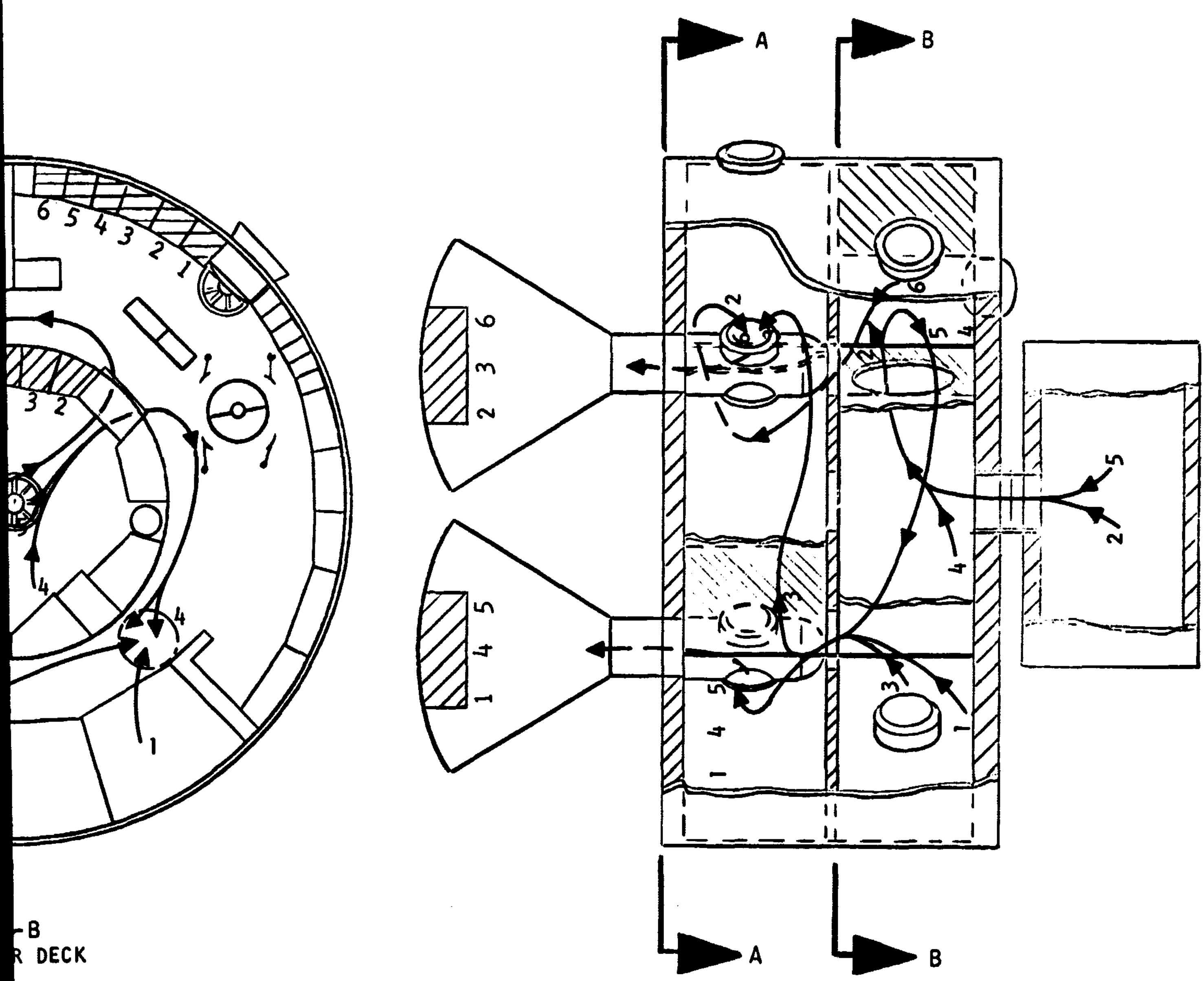


Figure 5-4: EMERGENCY IN INNER MODULE, MAXIMUM CREW DISTRIBUTION IN INNER MODULES TIMELINE 15:00 HOURS---TRAFFIC FLOW TO ERV

were in the solar or stellar telescope modules at the time of outer module emergency, since the access hatches to these modules are in the outer module. For this reason, a separate case for a crewman in the telescope modules was not used.

5.3.1.3 EMERGENCY IN OUTER MODULE---TYPICAL CREW DISTRIBUTION (Timeline 12:00, Traffic Flow to Suits)

The emergency will be announced by audio/visual devices. At that time, crew distribution is as follows (Reference Figure 5-5):

Crew members 1, 3 and 6 are in their staterooms---Outer module, lower deck.

Crew member 2 is performing maintenance functions---Inner module, lower deck.

Crew member 4 is having his meal---Outer module, lower deck.

Crew member 5 is in the camera module.

The most direct route to suits is shown in Figure 5-5. Crewmen 1 and 3 would proceed in a counterclockwise direction to the inner/outer module hatch. Crewman 1 must then travel to the upper deck to get to his suit. Crewman 6 would proceed in a clockwise direction from his stateroom to the inner/outer module hatch. His suit is directly inside. Crewman 2 can step directly to his suit from his initial position. Crewman 4 must travel through the inner/outer module hatch, and then to the upper deck to reach his suit. Crewman 5 must enter the inner module through the camera module hatch, then through the accessway to the upper deck to reach his suit. Should the emergency warrant a direct route to ERV's, the above would change only in that the crewmen 2, 3 and 6 would travel to the upper deck and to their ERV. Whether they would enter the ERV suited or unsuited is dependent on time and the nature of the emergency. Either choice could be accommodated.

5.3.1.4 EMERGENCY IN OUTER MODULE---DURING EVA (Timeline 04:58, Traffic Flow to Inner Module and Suits)

Audio/visual warnings will announce that there is an emergency. At that time, the crew distribution is as follows (Reference Figure 5-6):

Crew member 1 is in the EVA airlock.

Crew members 2, 4 and 5 are in their quarters---Lower deck, outer module.

Crew member 3 is in the exercise/hygiene area---Lower deck, outer module.

Crew member 6 is EVA.

Figure 5-6 shows the most direct route to suits. Astronauts 2 and 3 will travel counterclockwise to the inner module lower deck to reach their suits. Crew members 4 and 5 will travel clockwise to the inner/outer module hatch. Once through it, 4 and 5 must travel to the upper deck to reach their suits. Crew members 1 and 6 have several options to consider, each of which will depend on status information from the emergency detection system and crew via the intercom system. They could:

a. Remain where they are until emergency is over.

b. Remain in airlock until considered safe enough for them to assess damage and/or make repairs.

c. Travel through the airlock and inner/outer module hatch to the inner module.

d. Travel EVA to Emergency Return Vehicles.

NOTE: Timeline 04:58 for this case is taken from the third day of a 30-day computer timeline. It is superimposed into the typical day schedule shown in Table 5-2.

5.3.2 SLSS TRAFFIC DENSITY

A summation of occurrences for area-to-area travel was constructed, using the "Typical Day" timeline as a base (Table 5-2). An arbitrary figure of eight occurrences per day is used as the division between heavy flow and light flow. Heavy flow routes are as follows:

a. Stateroom to/from Personal Hygiene and Exercise (8 occurrences).

b. Meal Preparation to/from Meal Consumption (36 occurrences).

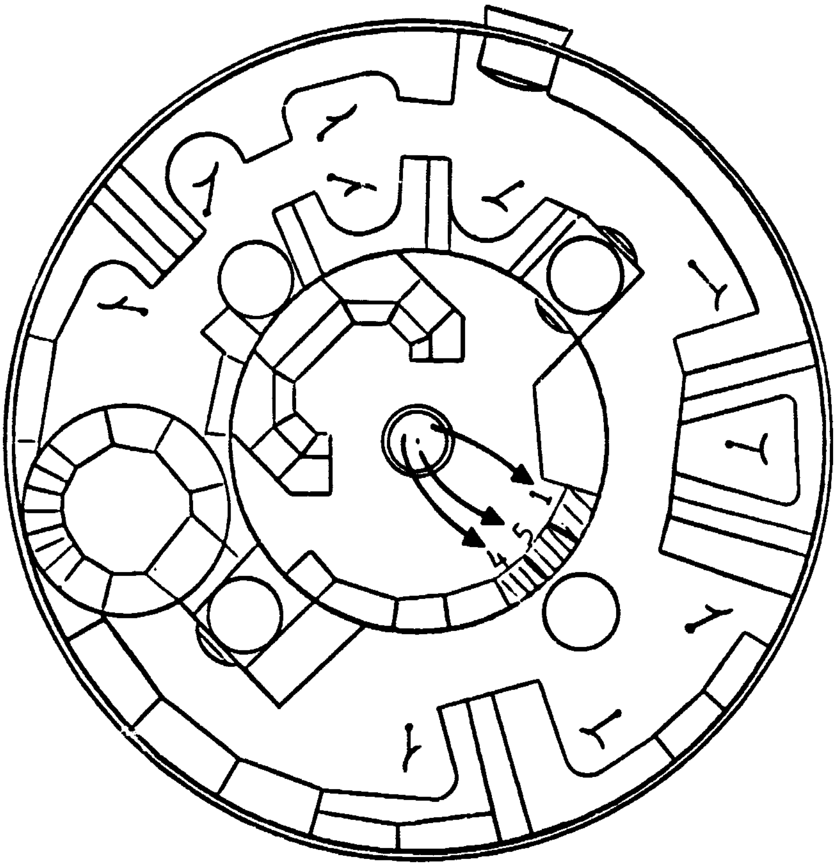
c. Meal Consumption to Personal Hygiene and Exercise (8 occurrences).

d. Photo Lab to/from Camera Module (11 occurrences).

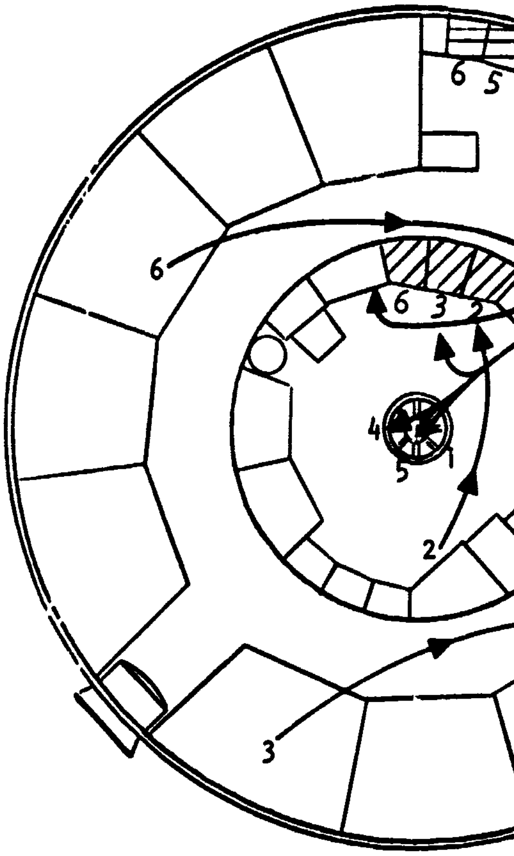
e. Lower Deck, Inner Module to/from Camera Module (12 occurrences).

f. Bio Work Center to/from Bio Lab (8 occurrences).

It is interesting to note that (a) through (c) are crew-oriented functions, and (d) through (f) are experiment-oriented functions. The number of occurrences is greater for crew oriented functions. This is in consonance with the total ratio for crew versus experiment-oriented functions (2:1). The gross statement can be made that the lower deck is busier than the upper deck, and the outer module is busier than the inner module. More specifically the meal preparation/meal consumption/personal hygiene and exercise areas (which are adjacent to each other) show the highest traffic flow.



A-A
UPPER DECK



B-B
LOWER DECK

FOLDOUT FRAME 1

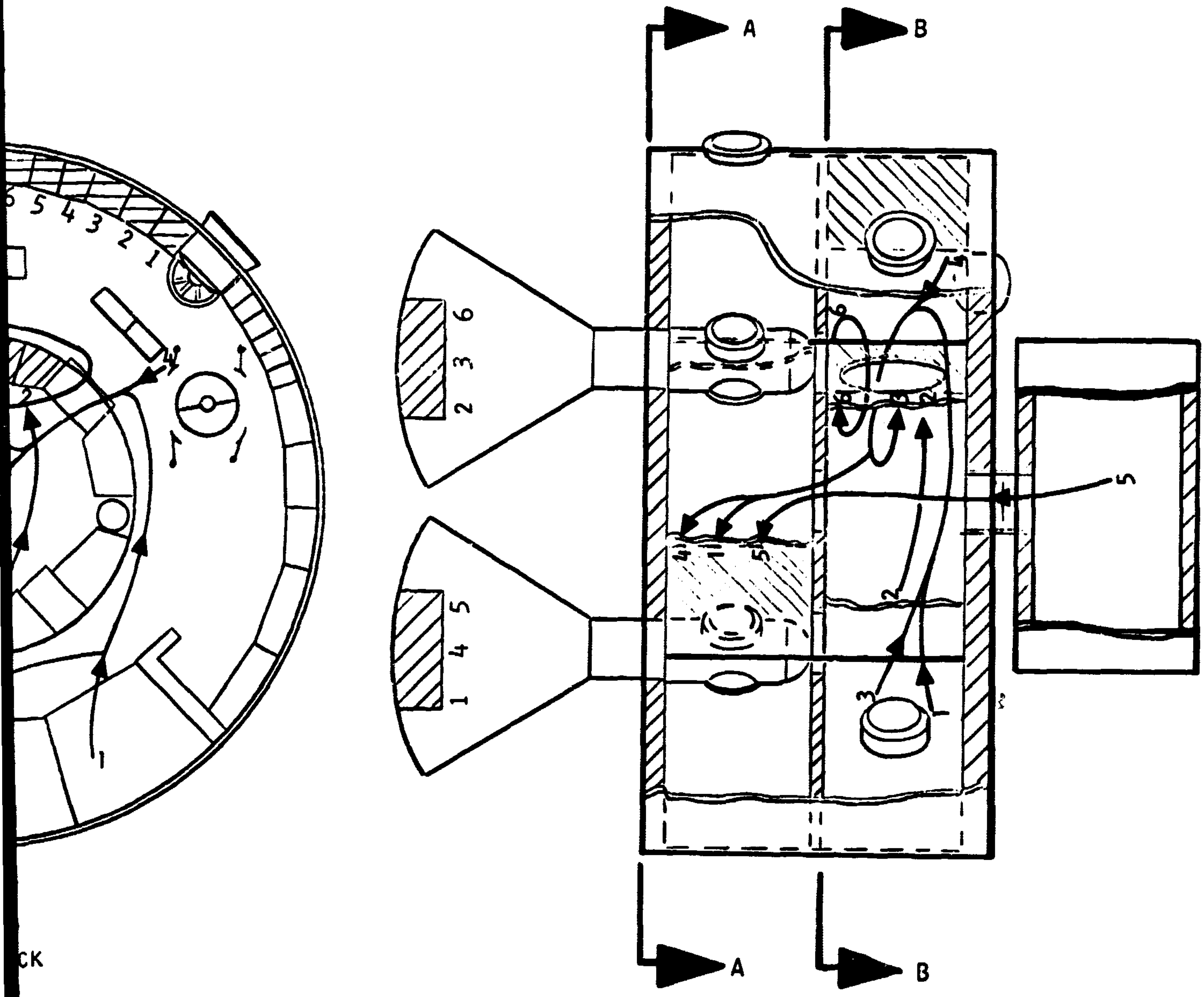
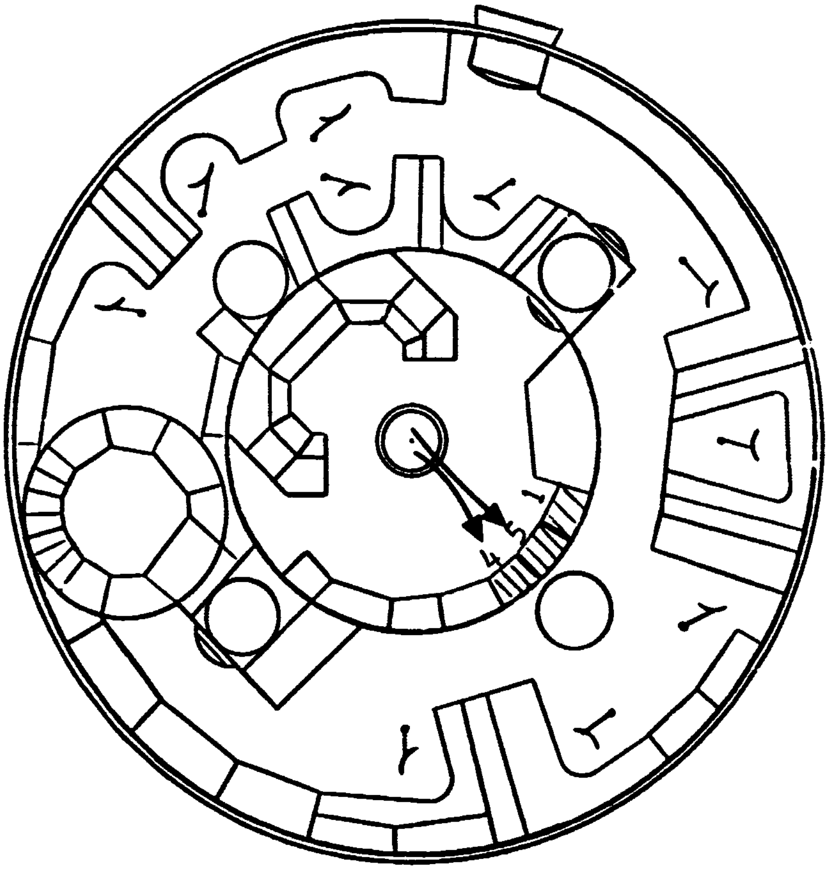
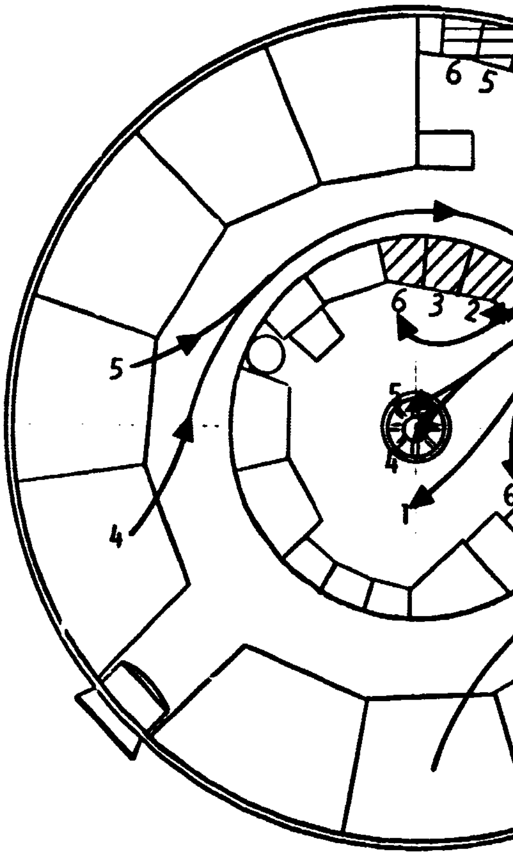


Figure 5-5: EMERGENCY IN OUTER MODULE TYPICAL CREW DISTRIBUTION TIMELINE 12:00 HOURS TRAFFIC FLOW TO SUITS



A-A
UPPER DECK



B-B
LOWER DECK

FOLDOUT FRAME

1

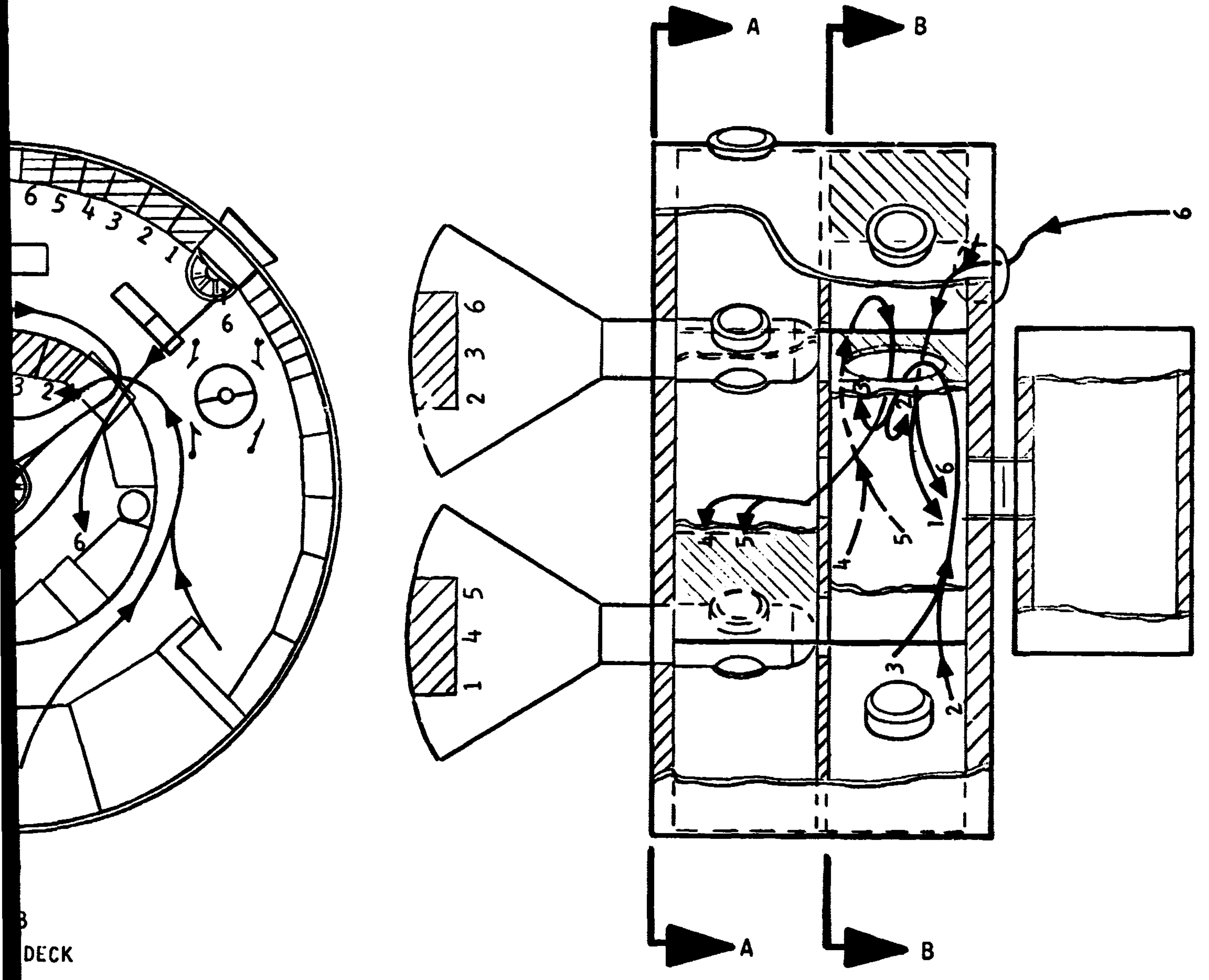


Figure 5-6: EMERGENCY IN OUTER MODULE DURING EVA, TIMELINE 04:58 HOURS, TRAFFIC FLOW TO INNER MODULE AND SUITS

A summation of hatch/airlock/accessway utilization was constructed, using the timeline (Table 5-2). The summation is shown in Figure 5-7. There are three routes which carry heavy flow: the lower deck inner module-to-camera module hatch, the upper/lower inner modules accessway, and the upper deck inner module/experiment deck airlock. Suit wear, pressure-tight seal wear, accessway padding, and obstacles or impediments to traffic are matters of concern.

5.3.3 ACCESS ROUTES TO EMERGENCY RETURN VEHICLES (ERV'S)

Shirtsleeve access to ERV's is unobstructed and uncomplicated in the SLSS, with the exception of the configuration and placement of the Bio Lab. Its location blocks the upper deck, outer module. This in itself is of little consequence, because an accessway and airlock are adjacent to the lab. This precludes a crew member from becoming trapped in the event of an emergency. However, considering that unique space suits make it compulsory for a crewman to reach his particular suit, having to travel an additional distance to reach safety could jeopardize that crew member.

Suited access (with PLSS) is restricted to the inner and outer modules lower deck because the inner/outer modules hatch and the EVA airlock hatch are the only accessways that will accommodate a fully suited crew member. The remaining accessways have a 32-inch diameter, and the minimum diameter to allow access for a suited crew member is $39\frac{1}{2}$ inches. Increasing the minimum hatch size would be necessary to allow a suited crew member complete access to all parts of the station, and to the ERV's.

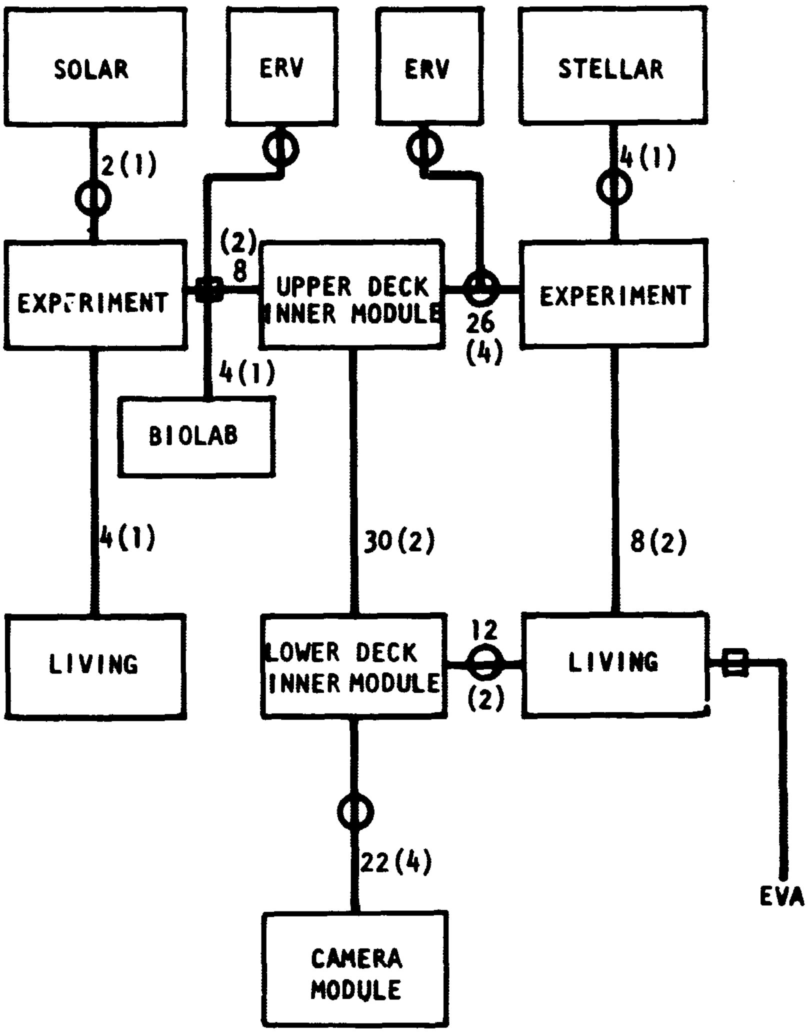
Manning vehicles are not considered in emergency routing, because the integral ERV's are specifically made for this purpose; hence, they are the primary escape vehicle. However, the manning vehicles could be used for emergency escape, if necessary.

5.3.4 SUIT LOCATION

Suit locations are shown in the four emergency escape cases (Figures 5-3 through 5-6). It is desirable to have one suit per man in every isolatable compartment. Otherwise, an emergency in the entrance to the compartment could maroon a crew member. The SLSS presently contains three such compartments: the camera module and two telescope modules.

The timeline (Table 5-2) shows that the solar and stellar telescope modules are frequented by only one crew member---#5. The camera module is frequented by only two crew members---#2 and #5. Storing one suit for crew member 5 in each of the modules, plus one for crew member 2 in the camera module, would eliminate the problem of marooning a crew member.

An astronaut may retreat to his ERV suited or unsuited. His choice is dependent on the nature of the emergency and the amount of time available. If he goes unsuited, there is a suit stored in the ERV for him. If he goes suited he can jettison his extra suit at any convenient time.



Numbers without parentheses indicate total passages in 24 hours.

Numbers within parentheses indicate maximum passages within a 15-minute period.

Circles indicate hatches.

Squares indicate airlocks.

Figure 5-7: SLSS PASSAGEWAY UTILIZATION

5.4 EARLY ORBITAL SPACE STATION (EOSS) EVALUATION

The experiment program of EOSS is identical with that of SLSS, although the configuration is different (Reference No. 22). Because of configuration differences, crew locations on EOSS had to be redetermined. It was assumed that the timeline would also be identical and the same "typical day" could be used for the EOSS as was used for SLSS.

The CASP printout extract used on SLSS was modified to fit the EOSS configuration, to give an EOSS timeline (Table 5-4). This timeline was simplified to show only crew locations in the EOSS and elapsed mission time, using the SLSS times. As before, crew locations are shown by alphanumeric symbols and were determined by references to the EOSS configuration, together with the experiment being performed. Figure 5-8 shows the crew locations on the EOSS configuration.

As in the SLSS, the EOSS timeline was used to identify the cases of crew distribution desired for further analysis. The cases selected are at 0001 (Case 5-10), 1526 (Case 5-11), 1141 (Case 5-12), and 0458 (Case 5-13). Crew distributions are also shown graphically in Figure 5-9, in which numbers of crew members in various locations are given versus elapsed mission time. The four cases selected for further evaluation are shown by vertical lines through the figure. The same discrepancy of a crew member being shown in some cases at more than one location in a time block occurs here for the same reasons as with the SLSS.

5.4.1 TRAFFIC PATTERNS IN EMERGENCIES

As with the SLSS, the assumption was made that an emergency occurred at the time selected for analysis. The emergency was not defined, other than that it required evacuation to another location, the donning of pressure suits, and that the astronauts were capable of taking further necessary action.

5.4.1.1 EMERGENCY IN CENTER MODULE---MAXIMUM DISTRIBUTION IN CENTER MODULE

(Timeline 00:01, Traffic Flow to ERV's)

At the time the emergency occurs, crew distribution is as follows (Reference Figure 5-10):

Crew member 1 is in the Environmental Control/Communication area---Deck 1.

Crew members 2, 3, 4 and 5 are in their quarters---Deck 2.

Crew member 6 is in the Waste Management/Hygiene area---Deck 1.

TABLE 5-4: EOSS "TYPICAL DAY" TIMELINE

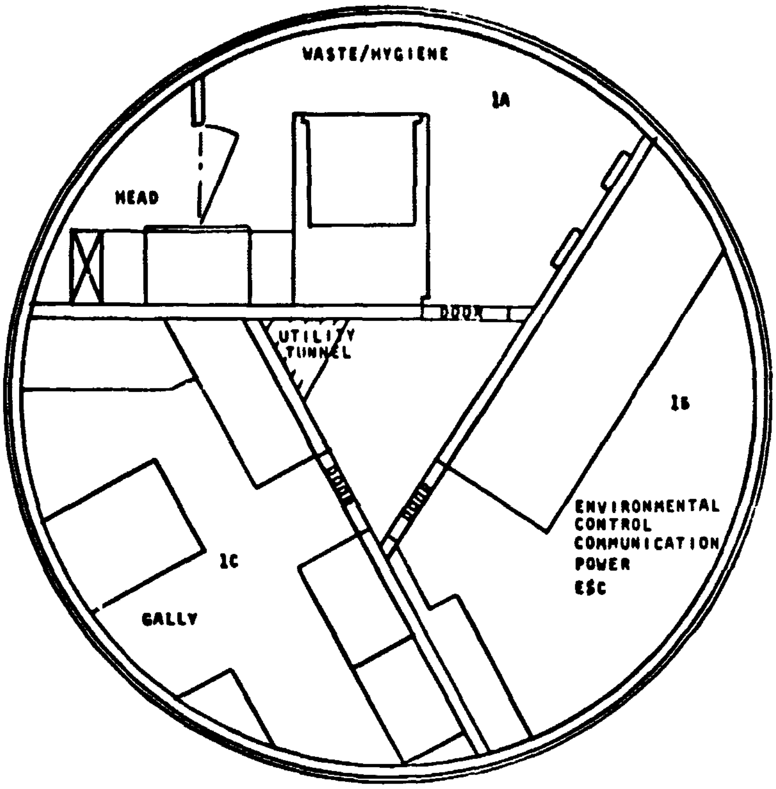
Time		Crew Member and Location					
		1	2	3	4	5	6
0	01	1B	2A	2A	2B	2B	1A, 1B
	31			1C			
1	11			2A			
2	01				1A		
	11			1B			
	31	4C					
	48	4D					
3	00	4D					
	01				2B		
	09						
	17	4D					
	30						
	34	4D					
	51	4D					
4	01						1C
	08	4C					
	15						
	25	1C					
	31						
	36						
	41			1A			4D
	53						4D
5	01						
	10						3A
	11	4B,D,B					
	17						
	23	4C					
	40	4C					
	41			2A			
	57	3A,4C					
6	14						
	17	4B,3A,4B					
	27	4C					
	38						
	44	4C					
7	01	4D					
	13						
	28						
	30	4B,3A,4B					
	31		1A			1A	
	41						
	57						4C
8	00	2A					
	06						
	12						
	31		1C			1C	
	37						2B
9	11	1A	1B			1A,1B	1A
	47						

TABLE 5-4: (continued)

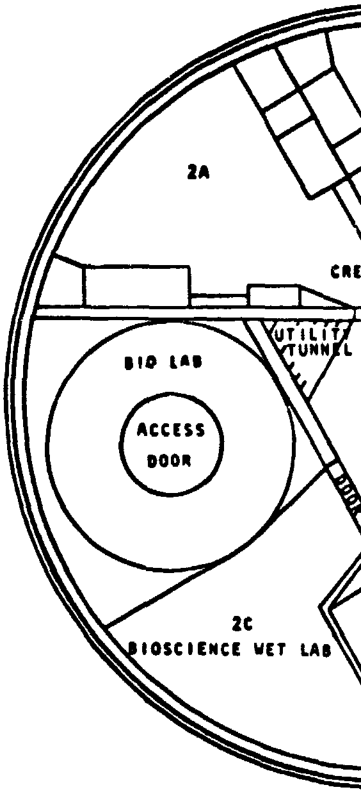
Time		Crew Member and Location					
		1	2	3	4	5	6
10	11	2A					2B
	31				1A		
11	27		MDAM,1B				
	31				1C		
	41					4B,E,4B	
	56					4B,4A,4B	
12	01					4A	
	06					4A	
	11				3B		
	21					4B,A,4B	
	55					4A	
	56					4A	
	58						
13	05						
	11			1A			
	13		4A				
	15						
	18		4B,4A,4B				
	25					4B,4A,4B	
	40						
	41				2B	1C	
	43		1C				
14	11			1C	1C		
	21					4B,4A,4B	
	23		4A				
	26					4A	
	28		4B,4A,4B				
	36						
	41					4A	
	43						
	46		4A				
	48		4B,E,4B				
	51			2A	1B		
	54					4B	
	56					4B,A	
15	03		4A				
	06					4A	
	21						
	23						
	26					A,4B	
	28		4B,4A,4B				
	33		3A				
	36					4A	
	51						
	53						
	54					4B,4A,4B	
16	01			3B			
	10		2A				
	19					2B	

TABLE 5-4: (continued)

Time		Crew Member and Location					
		1	2	3	4	5	6
17	00						
	21				3C,B10		
	41	1A					1A
18	21						
	41	1C					1C
19	21	2A	3B		B10	3B	2B
	35						
	51						
20	01			1C	1C		
	25						
	41			3B	3C,B10		
	51	3B	2A			3B	3B
22	01				B10		
	21	2A	1C			1C	2B
	42						
23	01		1A		B10	1A	
	21	1C					1C
	28						
	31				B10		
	33						
	51				2B		



EOSS - DECK 1



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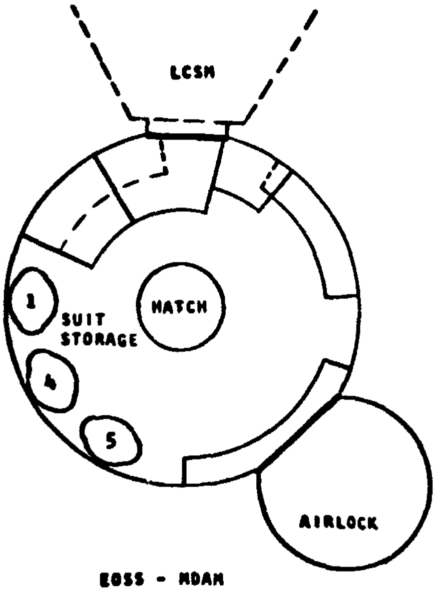
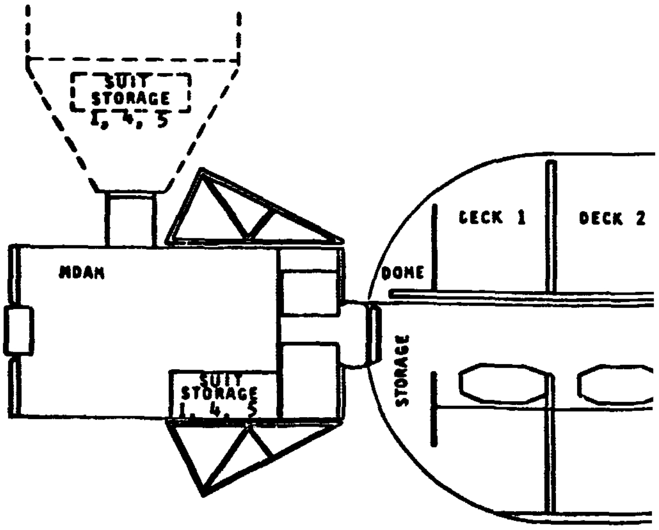


EOSS - MDAM



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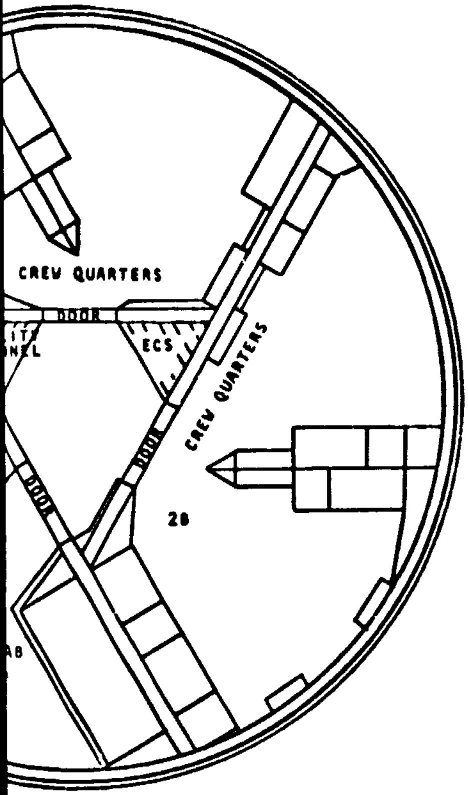
FOLDOUT FRAME /



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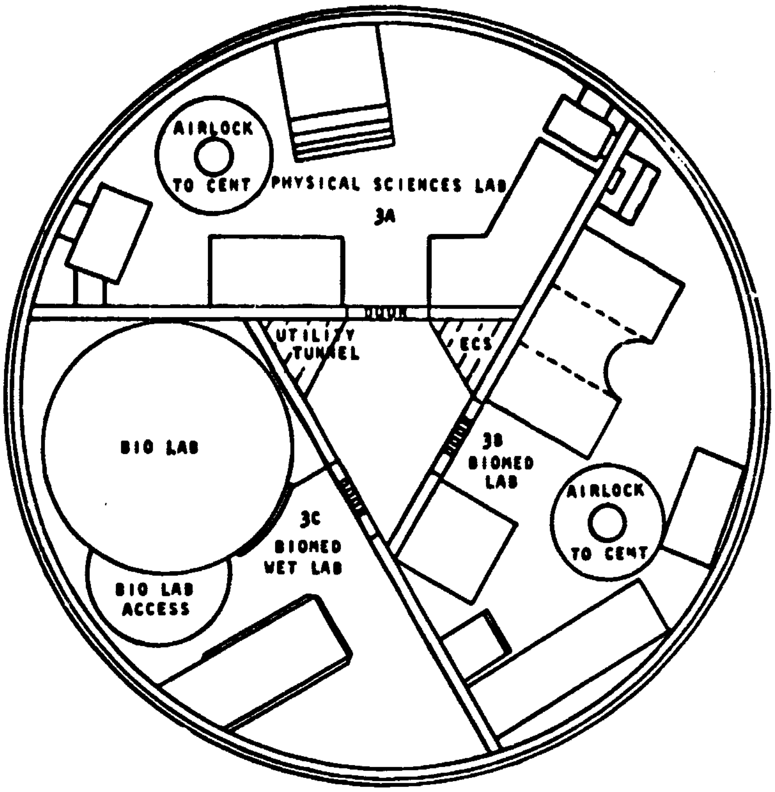

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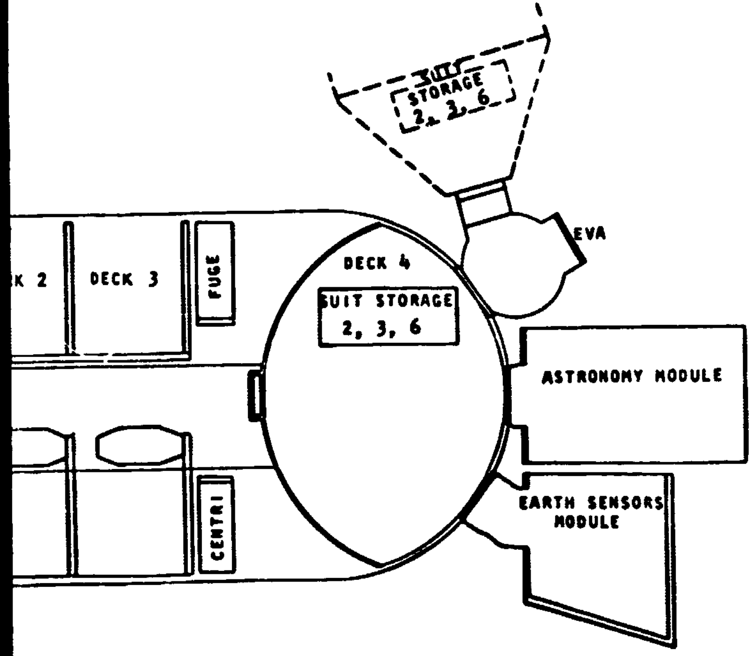
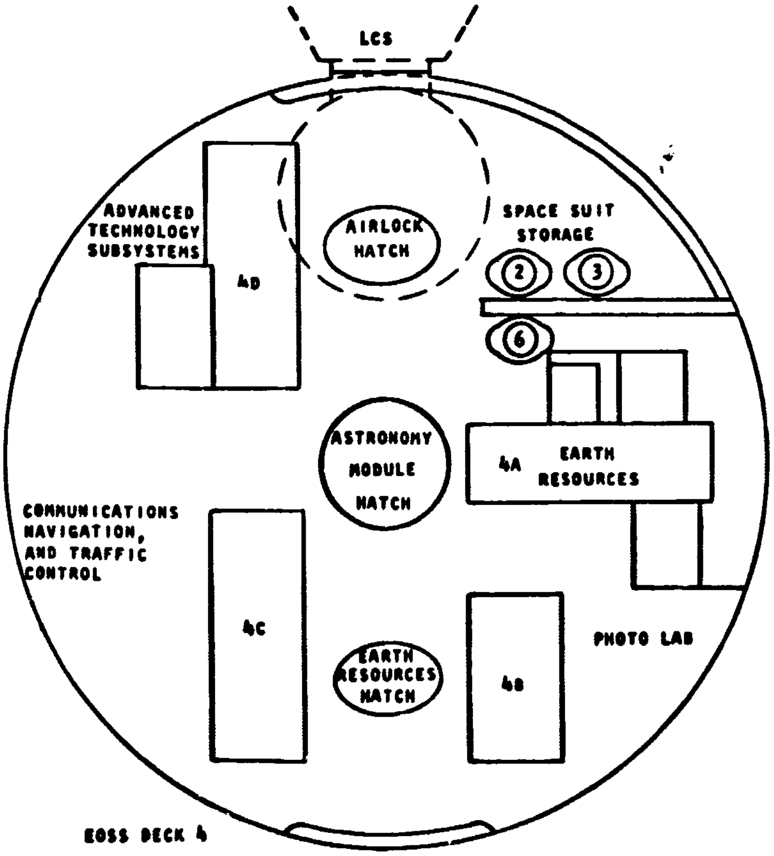


EOSS



EOSS DECK 4

Figure 5-8: EOSS CREW LOCATIONS

FOLDOUT FRAME 2

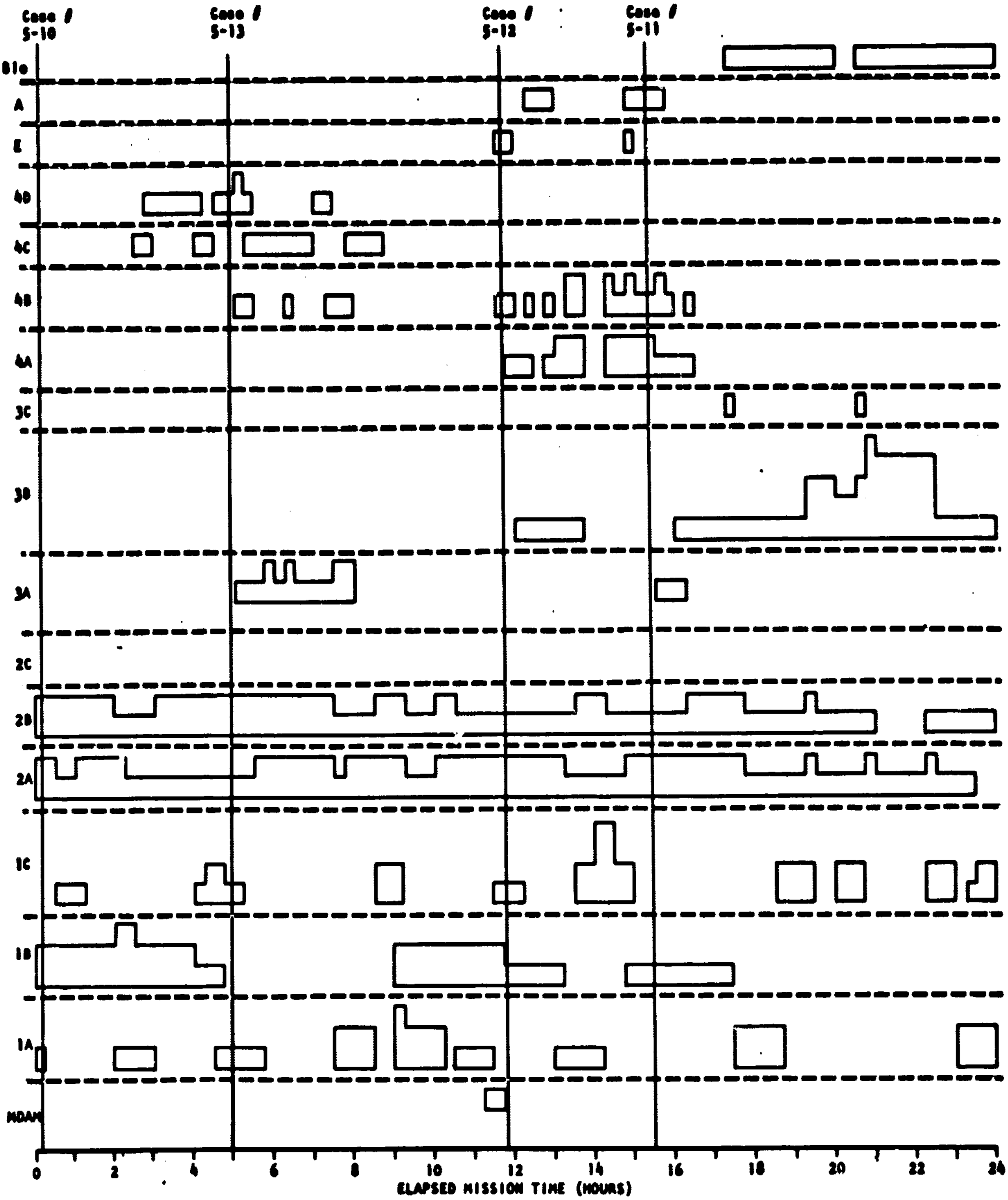


Figure 5-9: EOSS CREW LOCATION DISTRIBUTION WITH TIME TYPICAL DAY

Audible and/or visual warning devices will announce an emergency in the center module. The crew will retreat from the center module to their respective ERV's. Crew members 1, 4, and 5 will exit their respective areas and travel to the Multiple Docking Airlock Module (MDAM) and ERV via the center module access tunnel, center/forward module hatch, and ERV hatch. Crew members 2, 3 and 6 will exit their respective areas and travel to the aft module and ERV via the center module access tunnel, center/aft module hatch, EVA airlock, and ERV hatch.

In the event that the emergency is not severe enough to utilize the ERV's, numerous combinations of crew members suited-up to investigate damage, isolated in ERV's and/or isolated in modules could be used until the emergency is corrected.

5.4.1.2 EMERGENCY IN AFT MODULE---MAXIMUM CREW DISTRIBUTION IN AFT MODULE

(Timeline 15:26, Traffic Flow to ERV's)

At the time the emergency occurs, crew distribution is as follows (Reference Figure 5-11):

Crew members 1, 3 and 6 are in their quarters---Deck 2.

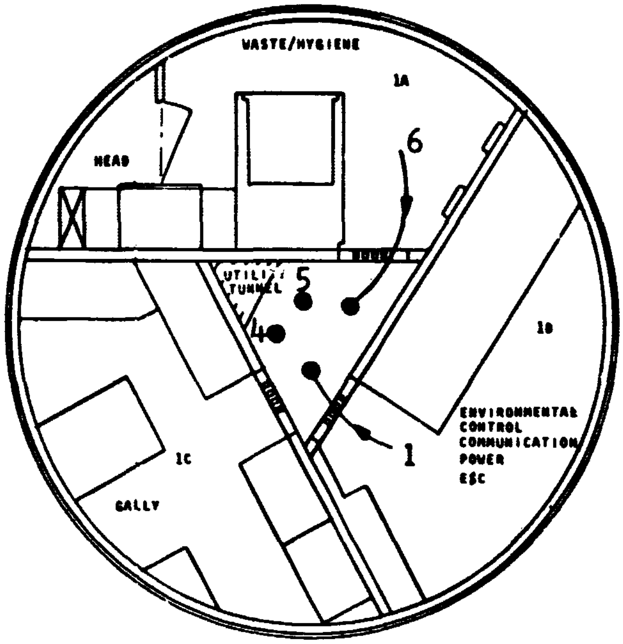
Crew member 2 is in the Earth Resources area---Deck 4.

Crew member 4 is in the Environmental Control/Communications area---Deck 1.

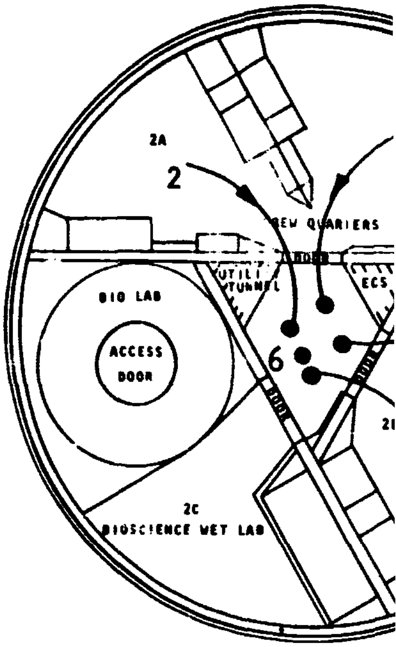
Crew member 5 is in the astronomy module.

An audible and/or visual warning device will announce an emergency in the aft module. Crew members 1 and 4 will exit their respective areas and travel to their ERV via the center module tunnel, forward/center module hatch, and ERV hatch. Crew members 3 and 6 will travel to their ERV via the center module tunnel, center/aft module hatch, EVA airlock, and ERV hatch. Crew member 5 will travel to his ERV via the aft/astronomy module hatch, center/aft module hatch, EVA airlock, and ERV hatch. Crew member 5 will travel to his ERV via the aft/astronomy module hatch, center/aft module hatch, center module tunnel, center/forward module hatch, and ERV hatch. Crew member 2 will step into the EVA airlock and then to his ERV.

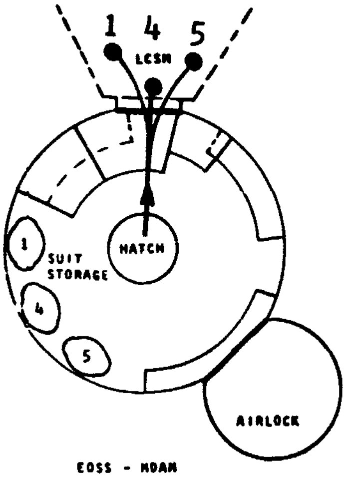
The above routes are the most direct. However, crew members 3, 6, and 5 must expose themselves to conditions in the emergency area to reach their ERV's. Assuming the emergency is such that a suit is required to pass through the area, crew member 5 would be stranded until the emergency is over and the aft module is habitable. Crew members 3 and 6 could be aided as follows:



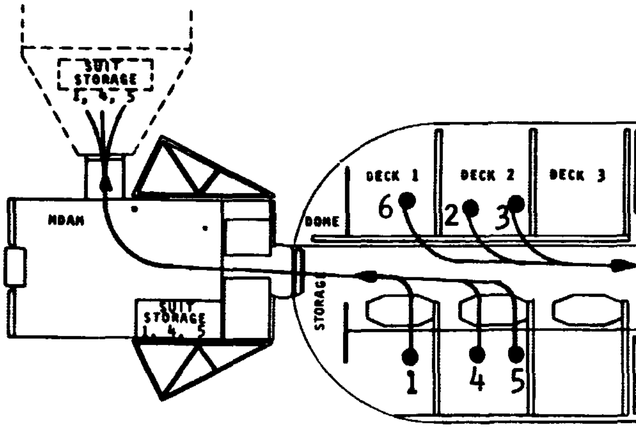
EOSS - DECK 1



EOSS - DECK 2



EOSS - MDAM



EOSS

FOLDOUT FRAME 1

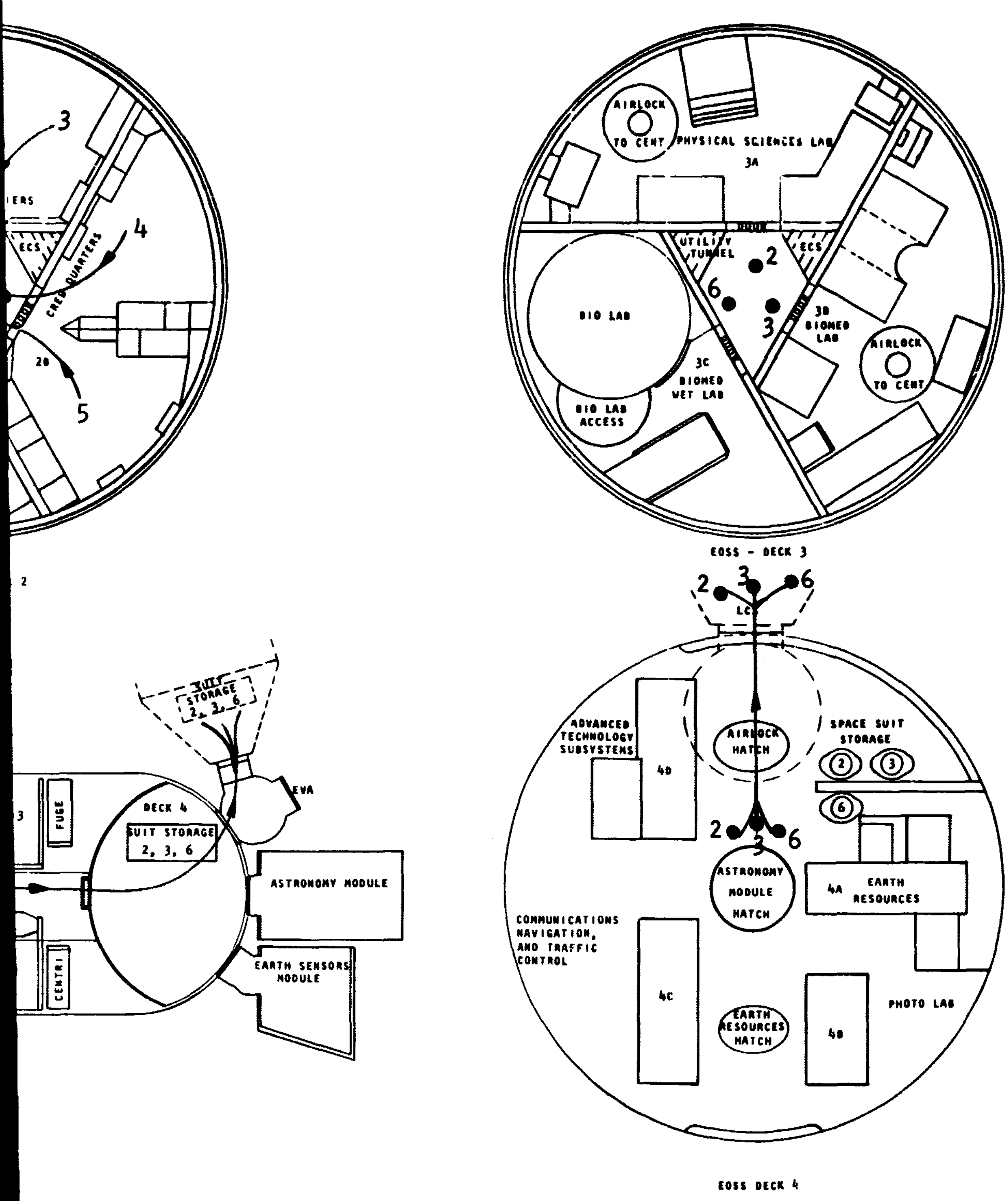
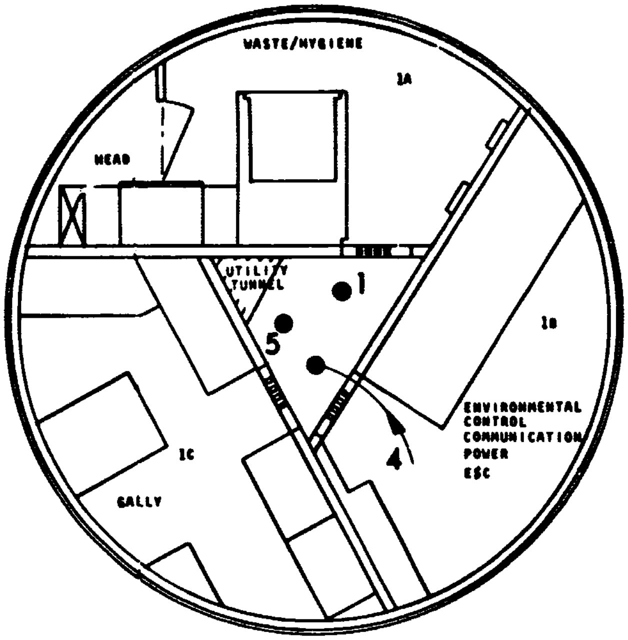


Figure 5-10: EMERGENCY IN CENTER MODULE
MAXIMUM CREW DISTRIBUTION IN CENTER MODULE
TIMELINE 00:01 HOURS TRAFFIC FLOW TO EVR'S



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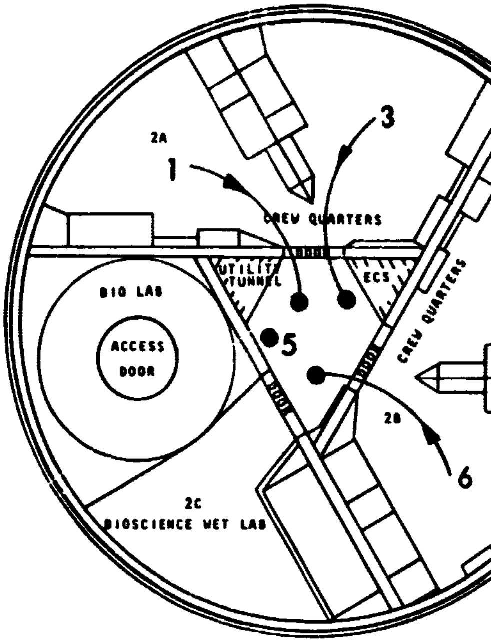
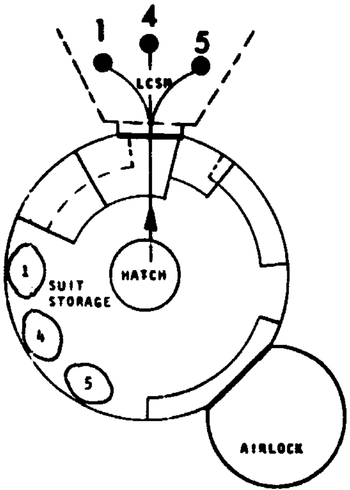
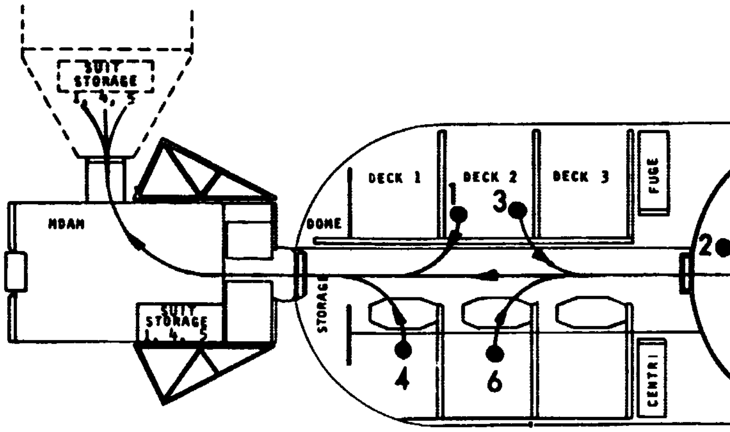


EOSS - DECK 2

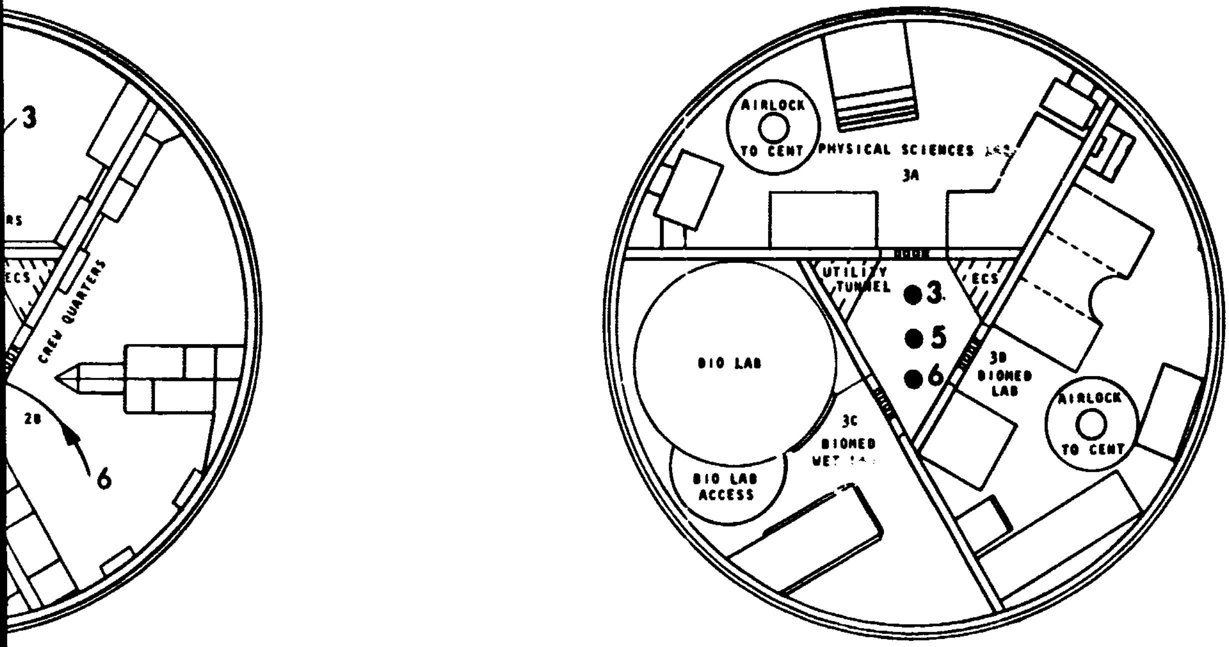


EOSS - MDAM

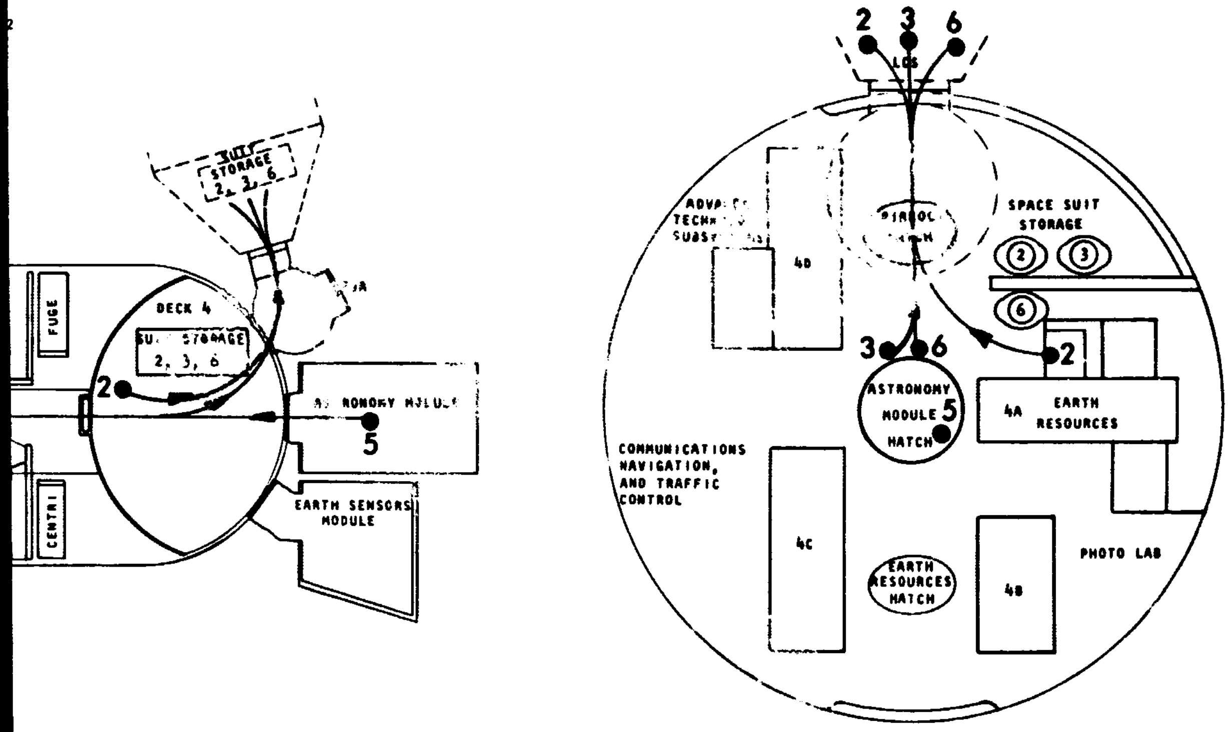


EOSS

FOLDOUT FRAME 1



EOSS - DECK 3



EOSS DECK 4

Figure 5-11: EMERGENCY IN AFT MODULE
MAXIMUM CREW DISTRIBUTION IN AFT MODULE
TIMELINE 15:26 HOURS TRAFFIC FLOW TO EVR'S

a. Crew members 1 and 4 could suit up after 3 and 6 had retreated to the MDAM and let 3 and 6 use the forward ERV, while they go to the aft ERV to share it with crew member 2.

b. Crew members 3 and 6 could retreat to the MDAM while suited crew members 1 and/or 4 and/or 2 bring them suits. Once crew members 3 and 6 are suited, they can follow their normal route to their ERV, or go EVA to their ERV if the situation warrants.

5.4.1.3 EMERGENCY IN FORWARD MODULE---MAXIMUM CREW DISTRIBUTION IN FORWARD MODULE (MDAM)

(Timeline 11:41, Traffic Flow to ERV's)

At the time the emergency occurs, crew distribution is as follows (Reference Figure 5-12):

Crew members 1, 3 and 6 are in their quarters---Deck 2.

Crew member 2 is in the Multiple Docking Airlock Module (MDAM).

Crew member 4 is having his meal---Deck 1.

Crew member 5 is in the Earth Sensors module.

An audible and/or visual warning device will announce an emergency in the forward module. Crew members 1 and 4 will exit their respective areas and go to their ERV's via the center module tunnel, center/forward module hatch, and ERV hatch. Crew members 3 and 6 will exit their respective areas and go to their ERV's via the center module tunnel, center/aft module hatch, EVA airlock, and ERV hatch. Crew member 2 will go to his ERV via the center/forward module hatch, center module tunnel, center/aft module hatch, EVA airlock, and ERV hatch. Crew member 5 will go to his ERV via the Earth sensors/aft module hatch, center/aft module hatch, center module tunnel, center/forward module hatch, and ERV hatch.

Although those routes shown in Figure 5-12 are the most direct, crew members 1, 4 and 5 are subjected to conditions in the emergency compartment to reach their ERV. They may be aided in the following manners:

a. They may retreat to the aft module while crew member 2 and/or 3 and/or 6 brings suits to them, and then proceed to their ERV in an intravehicular or extravehicular mode, depending on the emergency.

b. They could use the aft ERV and let suited crew members 2, 3 and 6 travel to and use the forward ERV, if the situation warrants.

5.4.1.4 EMERGENCY IN THE CENTER MODULE---DURING EVA (Timeline 04:58, Traffic Routes to ERV's)

At the time the emergency occurs, crew distribution is as follows (Reference Figure 5-13):

Crew member 1 is in the aft EVA airlock.

Crew members 2, 4 and 5 are in their quarters---Deck 2.

Crew member 3 is in the waste management/hygiene area---Deck 1.

Crew member 6 is EVA.

An audible and/or visual warning device will announce that there is an emergency in the center module. Crew members 2 and 3 will exit their respective locations and proceed to the aft ERV via the center module tunnel, center/aft module hatch, EVA airlock hatch, and ERV hatch. Crew members 4 and 5 will exit their respective quarters and proceed to the forward ERV via the center module tunnel, center/forward module hatch, and ERV hatch. Crew members 1 and 6 have several alternatives as follows:

a. They could proceed to their respective ERV's, i.e., #6 returns to the EVA airlock and then goes inside his ERV; #1 travels the length of the station via the hatches and tunnel, to the forward ERV.

b. Same as above, except #1 goes EVA to the forward ERV, via the station hull and

    1) the ERV external hatch
    2) the MDAM airlock and the ERV internal hatch
    3) rides the ERV externally away from the station until such time as conditions will allow him to enter

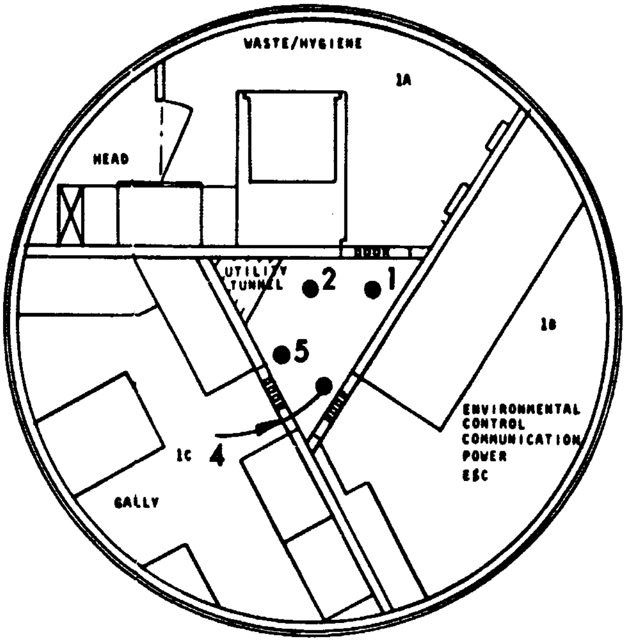
c. #1 and #6 move into the aft module (Deck 4) and perform the functions necessary to control the emergency and/or execute repair/safety functions in the center module.

5.4.2 EOSS TRAFFIC DENSITY

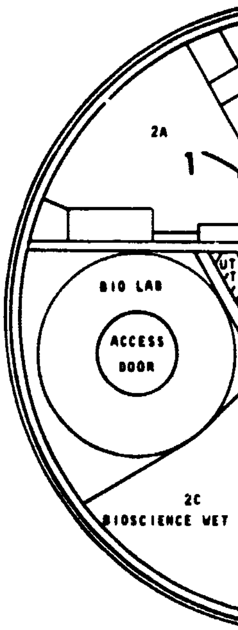
A summation of occurrences for area-to-area travel was constructed, using the "Typical Day" timeline as a base (Table 5-4). An arbitrary figure of five occurrences per day is used as the division between heavy flow versus light flow. Heavy flow routes are as follows:

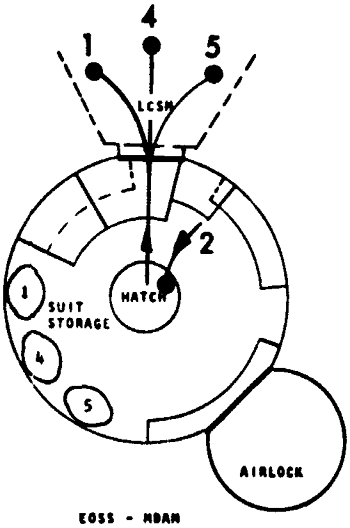
a. Life support system, waste management, and hygiene area to/from crew quarters (15 occurrences).

b. Life support system, waste management, and hygiene area to/from galley and wardroom area (10 occurrences).

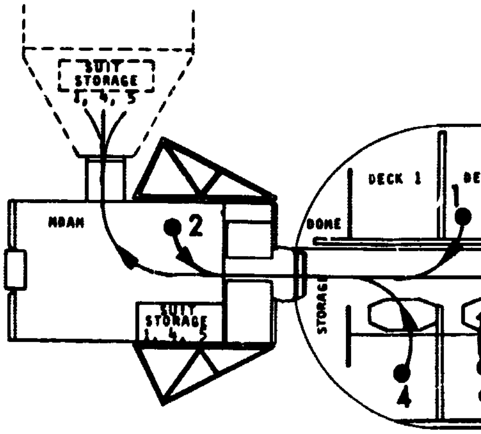


EOSS - DECK 1

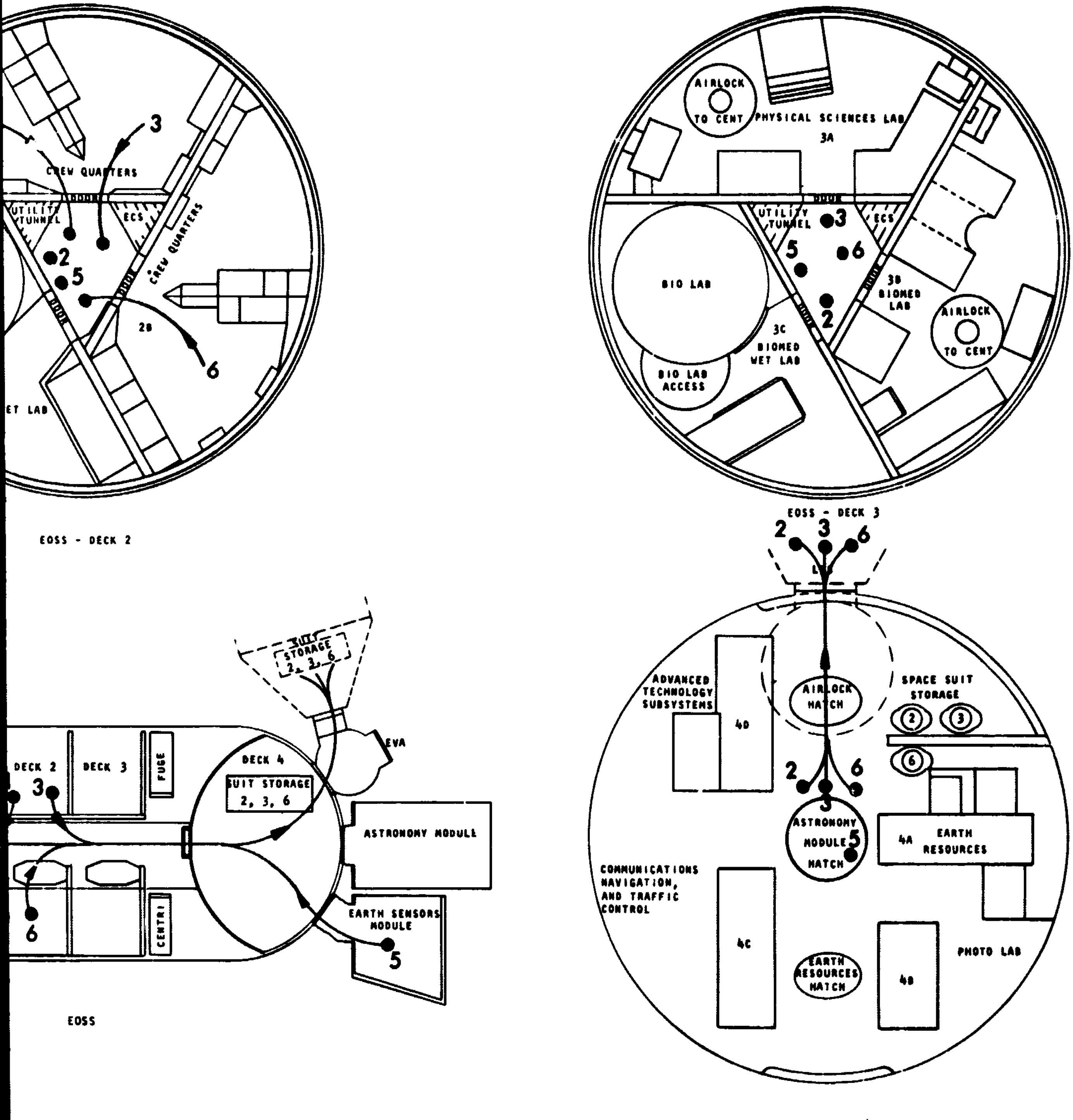




EOSS - MDAM



FOLDOUT FRAME 1



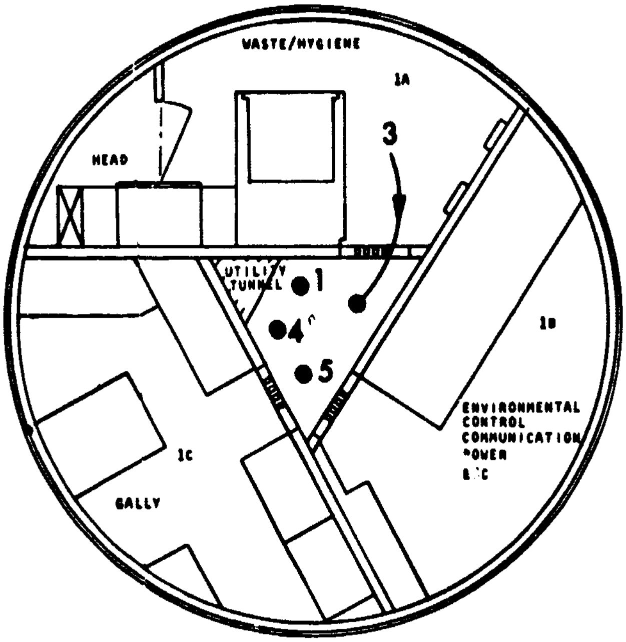
EOSS - DECK 2

EOSS - DECK 3

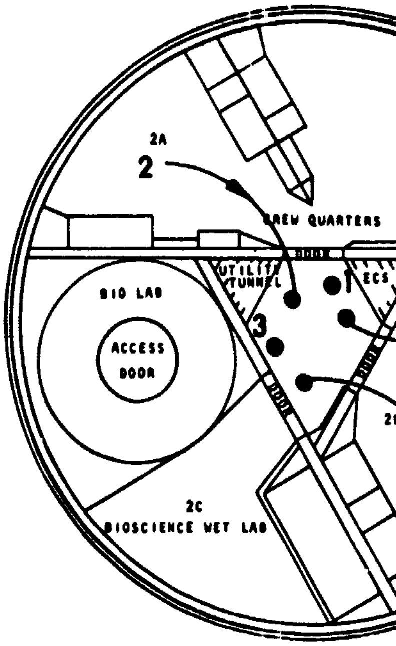
EOSS

EOSS DECK 4

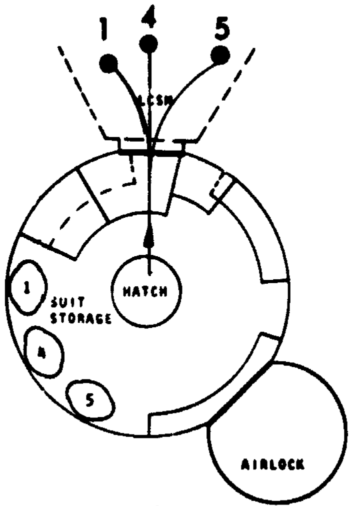
Figure 5-12: EMERGENCY IN FORWARD MODULE
MAXIMUM CREW DISTRIBUTION IN FORWARD MODULE
TIMELINE 11:41 HOURS TRAFFIC FLOW TO EVR'S



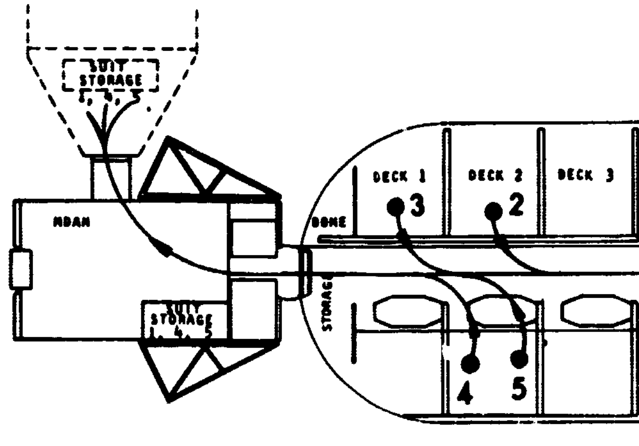
EOSS - DECK 1



EOSS - DECK 2



EOSS - MDAM



EOSS

FOLDOUT FRAME 1

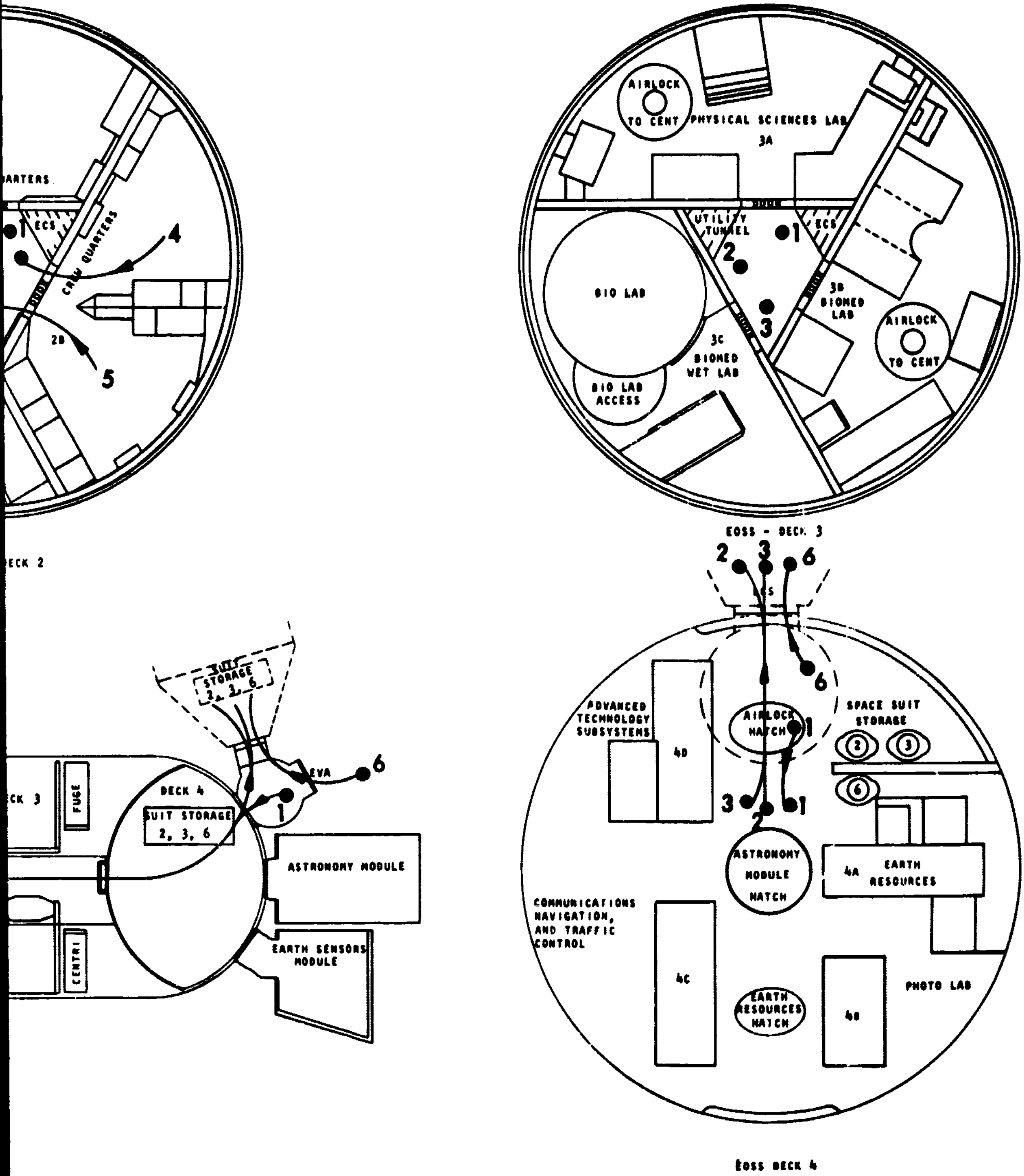


Figure 5-13: EMERGENCY IN CENTER MODULE
DURING EVA
TIMELINE 04:58 HOURS TRAFFIC ROUTES TO ERV'S

c. Galley and wardroom area to/from crew quarters (6 occurrences).

d. Physical sciences lab to/from photo lab (5 occurrences).

e. Earth resources controls to/from photo lab (28 occurrences).

Routes (a) through (c) are crew-oriented functions, and (d) and (e) are experiment-oriented functions. Although the number of occurrences are almost equal (31-33), it is noteworthy that (a) through (c) are predominantly between deck-to-deck areas and (d) and (e) are predominantly between adjacent areas on the same deck.

In general it can be stated that Decks 1 and 2 account for a larger portion of the traffic flow than the rest of the station. Specifically, the crew quarters, hygiene and waste management, and galley and wardroom areas show the greatest concentration.

A summation of hatch/airlock/accessway utilization was constructed, using the timeline (Table 5-4). It is shown in Figure 5-14. There are three routes which show heavy flow. They are:

a. Deck 1 (Galley, waste management, C & C) and
   Deck 2 (Crew quarters)---42 occurrences.

b. Deck 2 (Crew quarters) and
   Deck 3 (Biomedical lab, physical sciences)---32 occurrences.

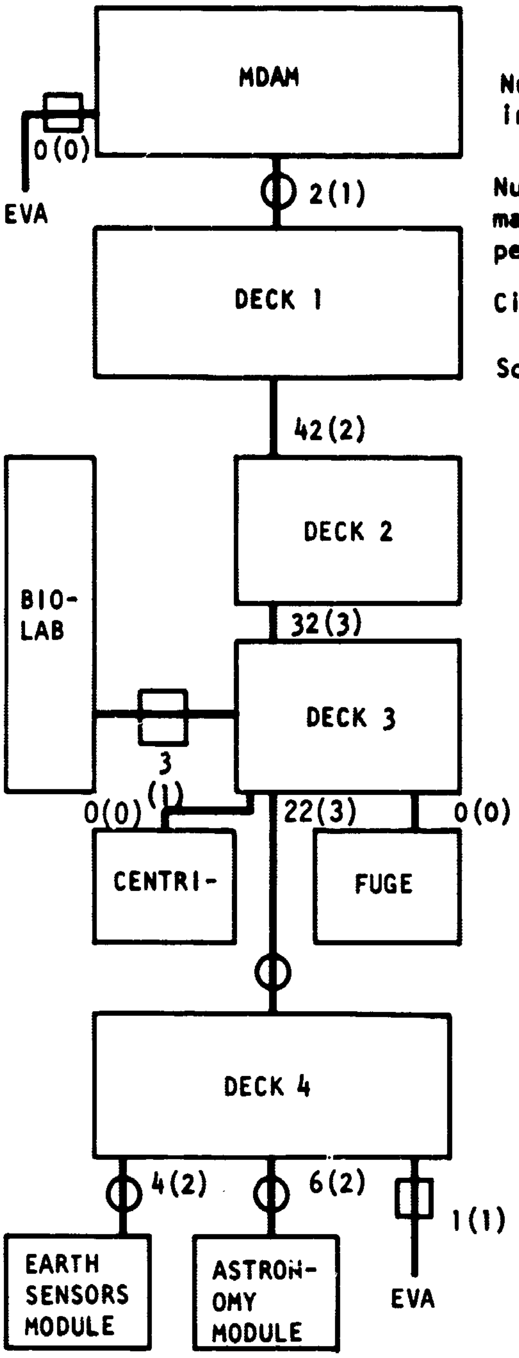
c. Deck 3 (Biomedical lab, physical sciences) and
   Deck 4 (Earth resources, photo)---22 occurrences

The center module tunnel accounts for 96 of the 1[illegible] total occurrences that take place during the "Typical Day."

5.4.3 ACCESS ROUTES TO EMERGENCY RETURN VEHICLES (ERV'S)

Shirtsleeve and suited (with PLSS) access is sufficient to allow a crew member to reach any compartment in the station (43-inch diameter hatches). The routes seem to be straight-forward, though quite congested. Figures 5-10 through 5-13 show that the center module tunnel is the only traffic route between the forward (MDAM) and aft (Deck 4) modules. Consequently, to get to the ERV's, crew members must use this tunnel, often opposing each others progress. Minimum use of the tunnel in the cases represented is by 5 of the 6 crew members (Figures 5-10 and 5-13). The tunnel in some parts is hexagonal in cross section and measures 56 inches flat-to-flat.

A powered dolly is the normal mode of transportation through the center module tunnel. It is guided by two rails, which also serve as hand rails if the dolly is not used. It is assumed that the dolly would not be used in an emergency case, because of its low speed and two-passenger capacity. Therefore, a hand-over-hand method, using the guide rails, would be used



Numbers without parentheses indicate total passages in 24 hours.

Numbers within parentheses indicate maximum passages during a 15 minute period.

Circles indicate hatches.

Squares indicate airlocks.

Figure 5-14: EOSS PASSAGEWAY/HATCH UTILIZATION by the crew. Consider the case shown by Figure 5-12. Crew member 2 must travel from the forward module (MDAM) to the aft ERV. In doing so, he must first maneuver around 1 and 4 who are traveling in the opposite direction to him, and then maneuver past 5, also traveling in the opposite direction, before he can get through the tunnel. Crew member 5 is in the identical situation. The position of the dolly at the time the emergency takes place would also have an effect on the congestion in the tunnel.

5.4.4 SUIT LOCATION

Suit locations are shown in the four emergency cases (Figures 5-10 through 5-13). It is desirable to have one suit per crew member in each isolatable compartment. Otherwise, an emergency could maroon a crew member. The proposed EOSS station configuration would easily allow a crew member(s) to be isolated from his suit by an emergency in the center module. This condition can be alleviated by reversing the suit locations for either the ERV's or the forward and aft modules. This would allow access to one suit per man in the forward and aft modules for the entire crew. However, it would complicate the procedures for suit/ERV routes. Even then, there are four areas where no suits are available. These are: the center module, the astronomy module, the Earth sensors module, and the Bio Lab. The timeline shows that crew member 5 is the only man entering the Bio Lab. Crew members 2 and 5 both use the Earth sensors module. Crew member 2 is the only man to use the MDAM. All crew members use the center module. Since the crew in the center module has access to both the forward and aft modules, isolation is not as severe a problem as it is for the others mentioned. A suit for each crew member using the remaining compartments would be required to remove that hazard.

5.5 NASA PHASE B TWELVE-MAN SPACE STATION EVALUATION

The Space Station Program Definition Study (Phase B) Statement of Work (Reference No. 92) provides gross concepts for the 12-Man Space Station desired. Within those conceptual parameters, a gross configuration was prepared for use as an analysis tool. Further explanation of the configuration is given in Section 2.0 of this document. For the purposes of this analysis, crew locations in this configuration were specified using deck numbers 1 through 5, with a letter arbitrarily assigned to areas on each deck, e.g., 1B, 5D, etc. These locations are shown on Figure 5-15.

The CASP program used for the SLSS and EOSS had assumed a six-man crew, primarily, but with some evaluation of a nine-man crew as well. In work done prior to the Safety Study, it had been determined that it was not possible to complete the experiment program with either six- or nine-man crews, for the reason, among others, that those crew sizes were [illegible] small. A CASP program using a twelve-man crew had been prepared, also prior to the Safety Study which did permit completion of the experiment program, at least from the crew size standpoint.

The available twelve-man CASP printout was used for this portion of the traffic pattern analysis. An extract (Table 5-5) was prepared in the same manner as for the SLSS; namely, only break-point times were shown, with crew locations at those times being determined by comparison of the experiment performed with the configuration layout. Because crew locations and traffic patterns are the only items of concern, equipment failures and the actual experiments performed were not extracted. As with the SLSS and EOSS, there is some uncertainty as to crew locations and the same discrepancies exist of crew members being shown at more than one location during a time block. The times selected for further analysis were taken directly from Table 5-5, with an arbitrary determination of precise crew location where there was uncertainty. There times are: 2001 (Case 5-16), 0111 (Case 5-17), 1141 (Case 5-18) and 0001 (Case 5-19).

5.5.1 TRAFFIC PATTERNS IN EMERGENCIES

For each case shown it was assumed that an emergency of some sort had occurred and that all crew members had been advised of its nature and location. The emergency was not defined, other than to specify that it required evacuation of the compartment or module in which the emergency occurred, that evacuation to an adjacent compartment was sufficient, and that crew members would be capable of taking the necessary action. As previously stated, pressure suits and/or ERV's were not considered as emergency measures.

5.5.1.1 EMERGENCY IN OUTER MODULE, DECK 4---MAXIMUM CREW DISTRIBUTION IN OUTER MODULE

(Timeline 20:01 hours, Traffic Flow to Inner Module, Deck 4)

At the time the emergency occurs, crew distribution is as follows (Reference Figure 5-16):

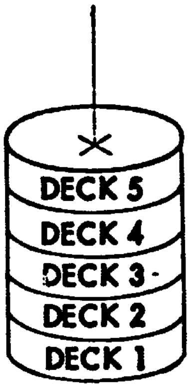
Crew member 1 is resting in his stateroom---Deck 4.

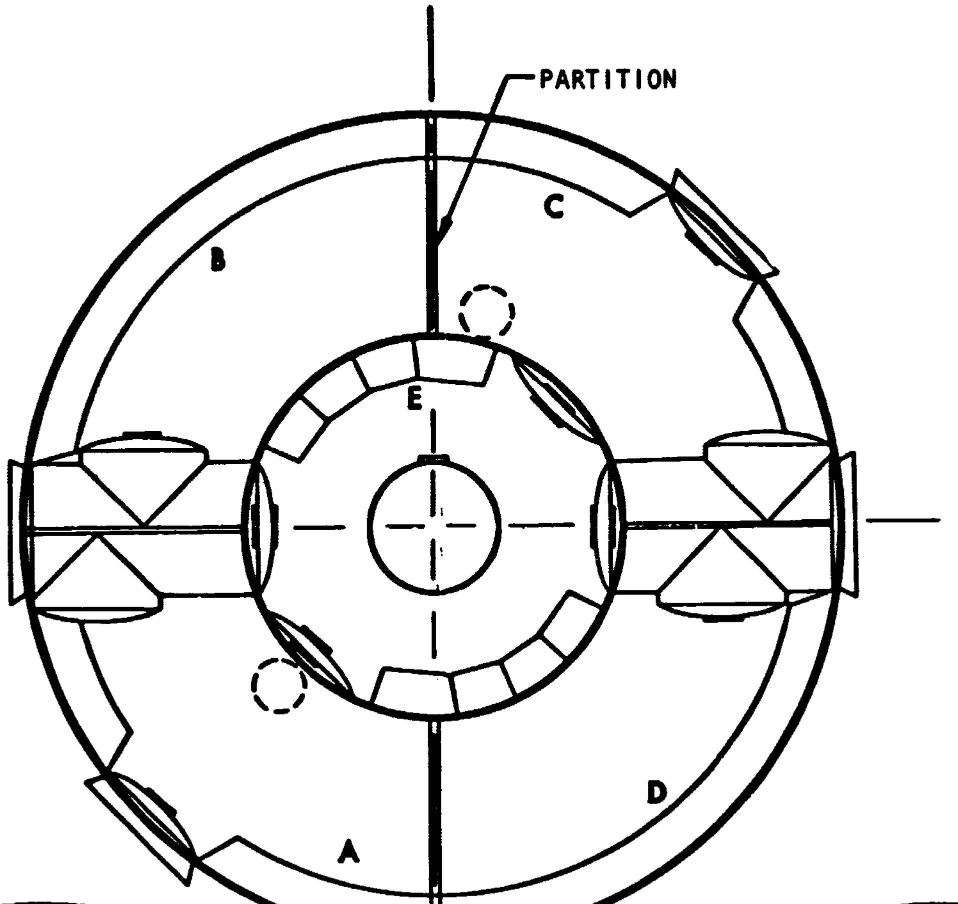
Crew members 2 and 5 are in the Clinical Lab---Deck 4.

Crew members 3, 4, 7, 8, 9, 10, 11 and 12 are in the Galley---Deck 4.

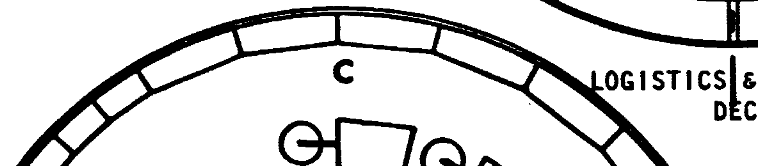
Crew member 6 is in the Waste Management/Personal Hygiene area---Deck 4.

Audible and/or visual warning devices will announce the presence of an emergency in the outer module, Deck 4. The immediate course of action is to evacuate the area. The inner module is the most logical refuge. Crew members 1 and 6 would exit their respective locations and travel to the closest inner/outer module hatch to safety. Crew members 2 and 5 would exit the clinical lab and move through the inner/outer module hatch closest to them. Crew members 3, 4, 7, 8, 9, 10, 11 and 12 would travel from their positions in the galley to the closest inner/outer module hatch and to

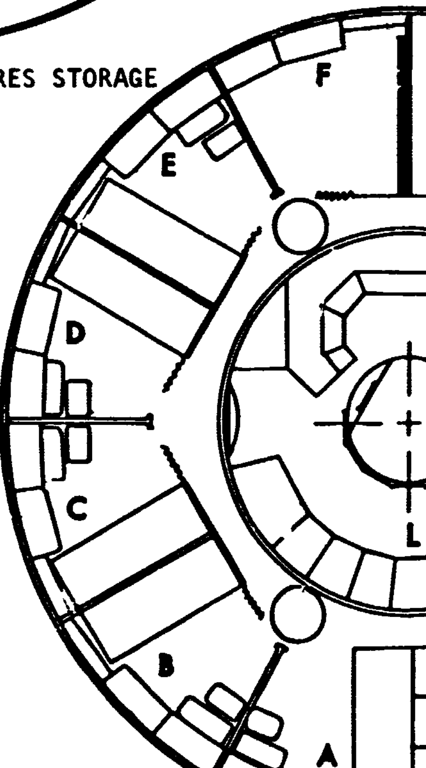




LOGISTICS & SPARES STORAGE
DECK 1

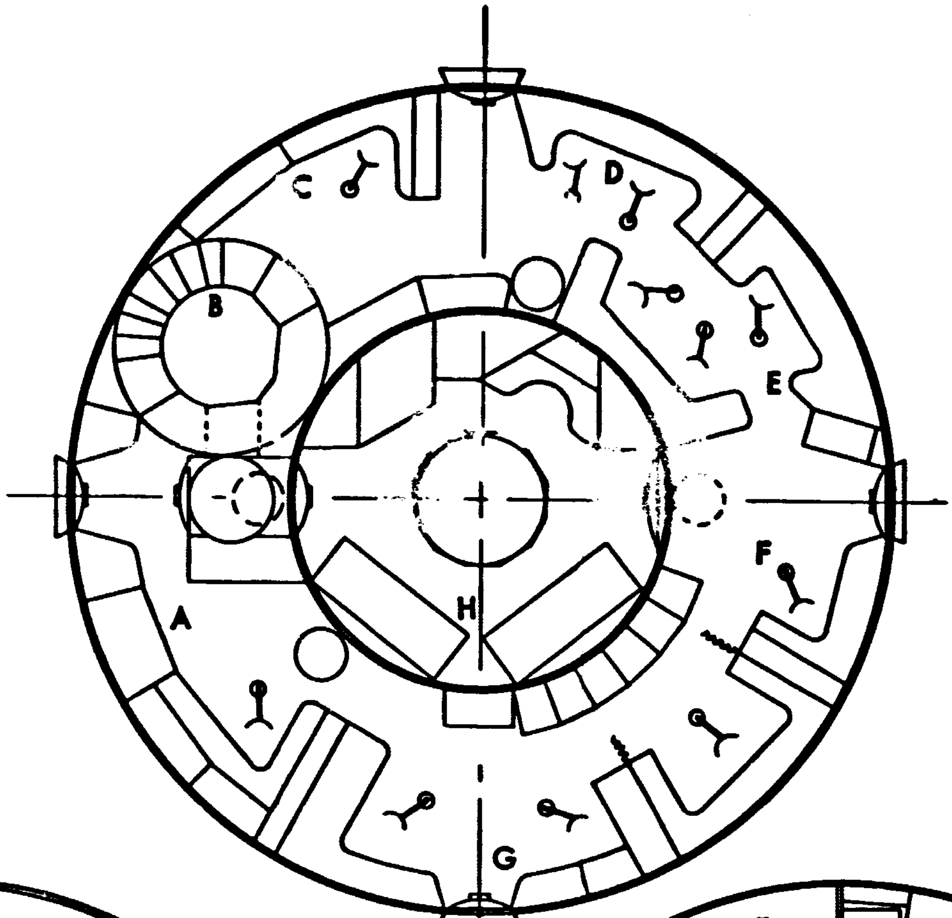


SUBSYSTEM & SHOP AREA
DECK 3

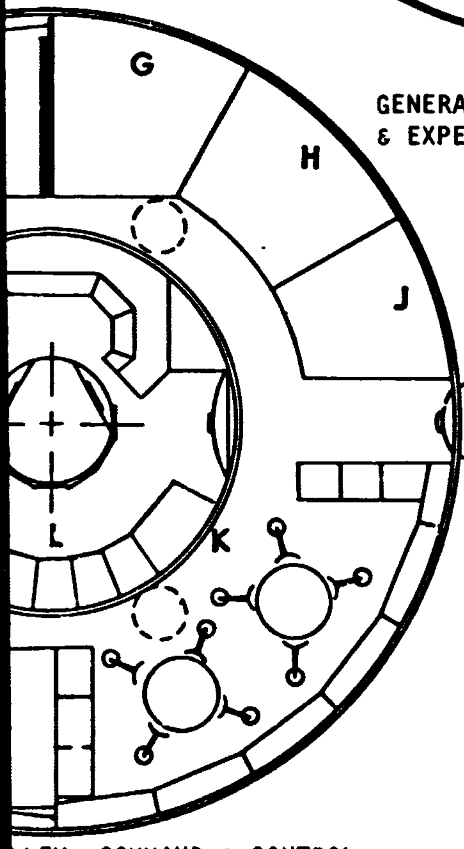


CREW QUARTERS, GALLEY
DECK

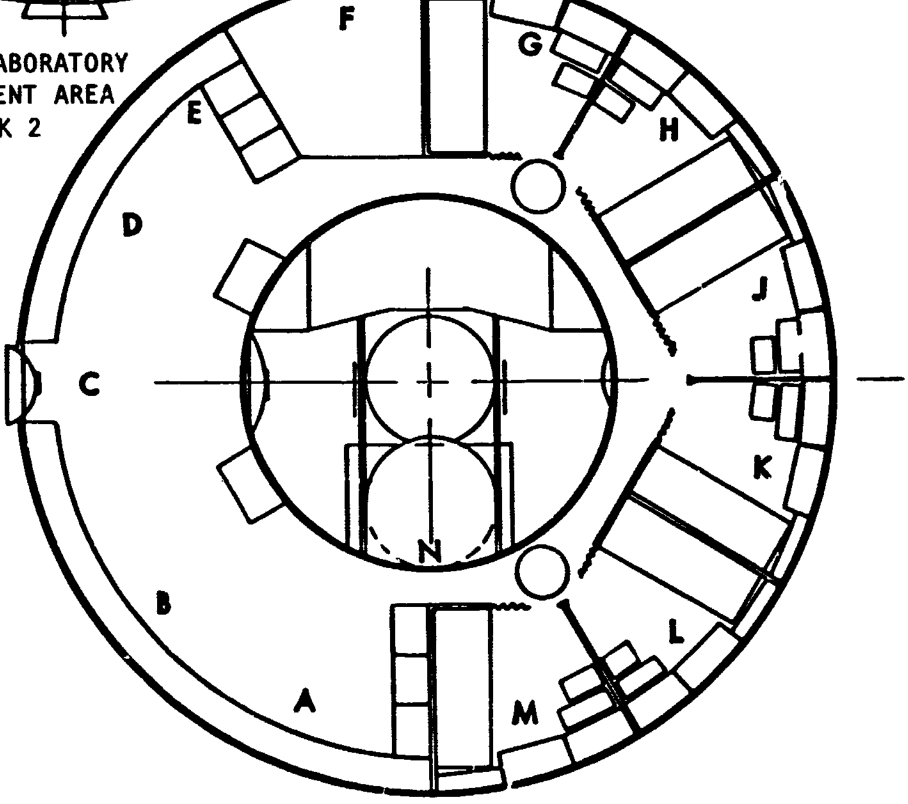
FOLDOUT FRAME 1



GENERAL LABORATORY
& EXPERIMENT AREA
DECK 2



LLEY, COMMAND & CONTROL
DECK 4



CREW QUARTERS & WARD ROOM
DECK 5

Figure 5-15: PHASE B SPACE STATION CREW LOCATIONS

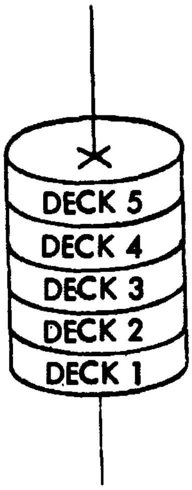
FOLDOUT FRAME 2

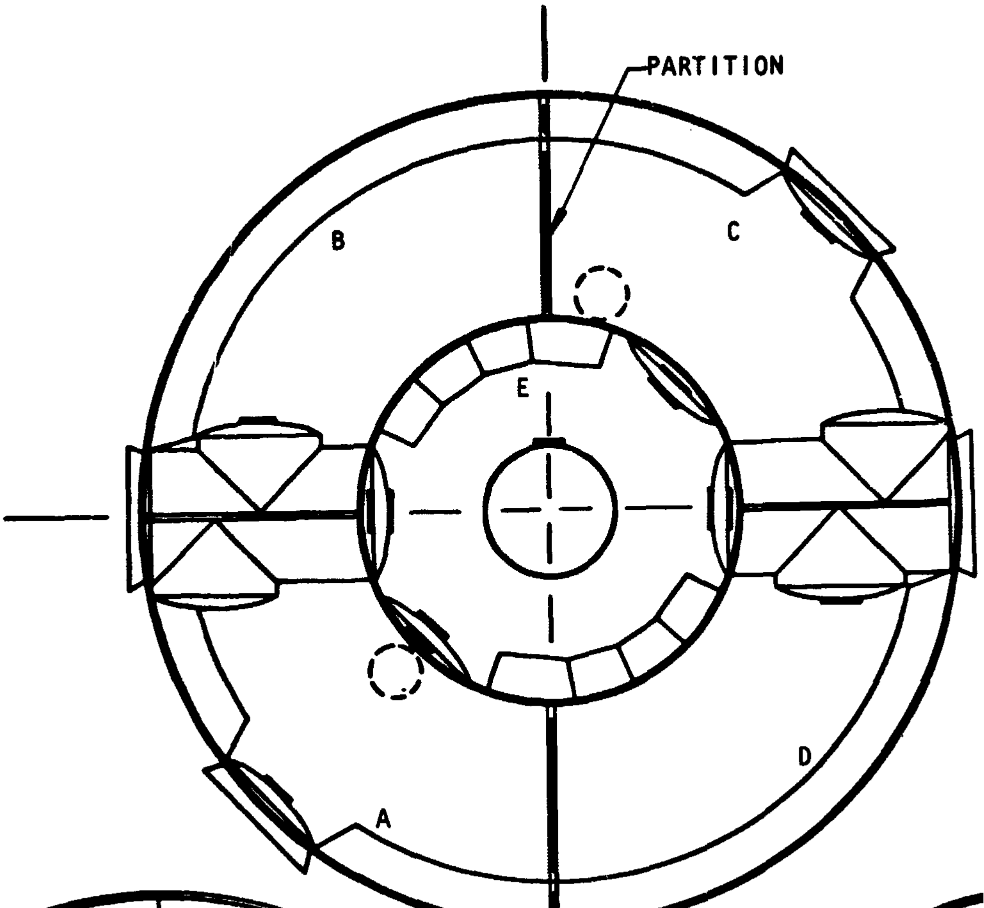
Table 5-5: 12-MAN SPACE STATION TYPICAL DAY TIMELINE

TIME	CREW MEMBER AND LOCATION												TIME
	1	2	3	4	5	6	7	8	9	10	11	12	
00:01	4L,5N	4B	4C,5C	5C,4D	4E	3F,4L	5C,5G	5F,3C,4J	5J,5C	5N,3B,3D	5L,5C	3C,3D,3F	00:01
00:31			4K										00:31
01:11			4C	5C,4D			5C,5G		5J,5C		5L,5C		01:11
02:01	4L,5N		2A,2B,4K	4G			5F	5F,3C,4J	5F	5N,3B,3D	5F	3C,3D,3F	02:01
02:31	2G							1C		2D		1A	02:31
02:36	4A												02:36
02:54										2D			02:54
02:56				4G			5F		5F	5D	5F		02:56
03:01				4D			5G		5J		5L		03:01
03:11												1A	03:11
03:21										5D		5M,5C	03:21
03:31								1C		5D,2C			03:31
03:46								5B					03:46
03:56	4A					3F,4L		2H		5D,2C			03:56
04:01	2G					4K				2C			04:01
04:06	2E							2H					04:06
04:13	2E							2D					04:13
04:18	2G												04:18
04:19	2E												04:19
04:21										2C			04:21
04:26								2D		4K			04:26
04:30	2E							4K				5M,5C	04:30
04:31	4K		2A,2B,4K			4K						4K	04:31
04:41	4K		4G			2G		4K		4K		4K	04:41
05:11	4A		4G					5H,5C		5C,5K		5C,4K	05:11
05:41			4C			2G							05:41
07:28					4E	2H							07:28
07:31					4G	2H							07:31
07:45						2D							07:45
08:02		4B			4G	5C,4F							08:02
08:31	4A	4K			4K	5C,4F		5H,5C		5C,5K		5C,4K	08:31
09:11	4G	4L,5N,3F		4D	2H,3D,5C	4G		5F		5F		5F	09:11
10:11	4A			4G		4E	5G	5H	5J	5K	5L	5M	10:11
10:31				4G			5F		5F		5F		10:31

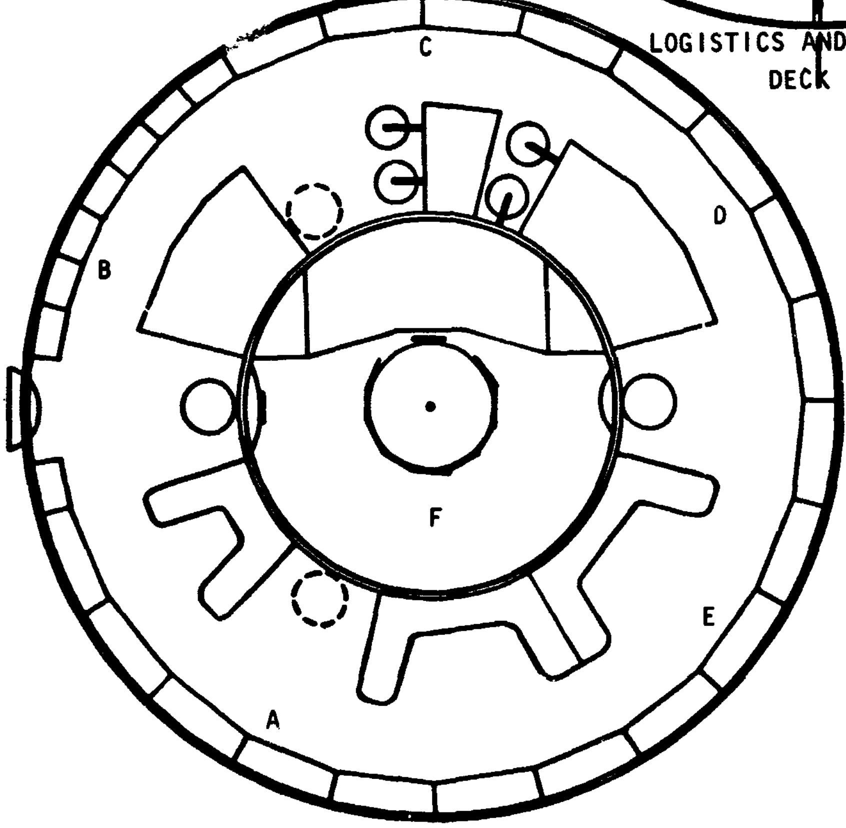
Table 5-5: 12-MAN SPACE STATION TYPICAL DAY TIMELINE (Continued)

TIME	CREW MEMBER AND LOCATION												TIME
	1	2	3	4	5	6	7	8	9	10	11	12	
11:31				4K	2H,3D,5C		4K		4K		4K		11:31
11:41				4K	1C		4K		4K		5F		11:41
12:11				4J	1C		4J		4J		4J		12:11
12:31		4L,5N,3F			5N								12:31
12:55		2C											12:55
13:00			4C										13:00
13:11		2C	4G										13:11
13:13		2D			5N								13:13
13:25		2D			1A								13:25
13:33		4K			1A								13:33
13:40				4J	4K		4J		4J		4J		13:40
13:41			4G	5C			5C		4K,5C,5J		5L,5C		13:41
14:11		4K	4K	4K	4K		4K		4K		4K		14:11
14:21		2D			4E								14:21
14:44		2D											14:44
14:46		2D,5D	4K	4K			4K		4K		4K		14:46
14:51		2D,5D	5C,4C	3F,2A,2B			2A,5F,2B		5A,5F,4G		2H,4K,4G		14:51
15:06		1A											15:06
15:36		5N			4E								15:36
15:46			5C,4C		1A								15:46
16:01		5N	4J										16:01
16:13		4B,5C	4J				2A,5F,2B		5A,5F,4G		2H,4K,4G		16:13
17:21	4A		1A			4E	4J	5H	1A	5K	1C	5M	17:21
17:41	4K		1A			4G		5F		5F		5F	17:41
17:44			2B						1A		1C		17:44
17:49									1A,5D		1C,5D		17:49
18:05									5D		5D		18:05
18:15											1C,5D		18:15
18:26						4G		5F		5F	1C	5F	18:26
18:41						4K		4K	5D	4K	1C	4K	18:41
18:51									5D		5L,5C		18:51
19:01	4K	4B,5C			1A	4K		4K	5C,5J	4K		4K	19:01
19:21	4A,5C	4J		3F,2A,2B	4J	5C,4F		5C,4K	5J,4K	4K,5C		4K,5C	19:21
19:44				2B									19:44
19:59			2B	4D			4J		5J,4K		5L,5C		19:59
20:01			4K	4K			4K		4K		4K		20:01
20:41	4A,5C	4J	4J	5C,4D	4J	5C,4F	5C,5G	5C,4K	5C,5J	4K,5C	4K,5L,5C	4K,5C	20:41
20:51	4J	4B,5C			4E	4J		4J		4J		4J	20:51
22:21	4A	4K			4K	5C,4F		5C,4K		5C		5M,5C	22:21
23:01	4A	4G			4G	5C,4F		5C,4K		5C		5M,5C	23:01
23:21	4K	4G	4J	5C,4D	4G	4K	5C,5G	4K	5C,5J	4K	4K,5L,5C	4K	23:21

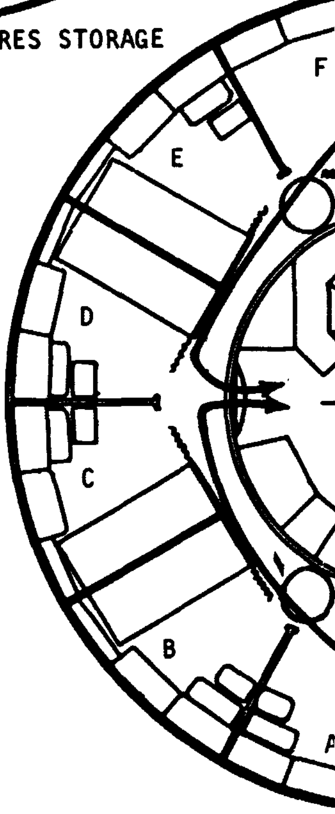




LOGISTICS AND SPARES STORAGE
DECK 1

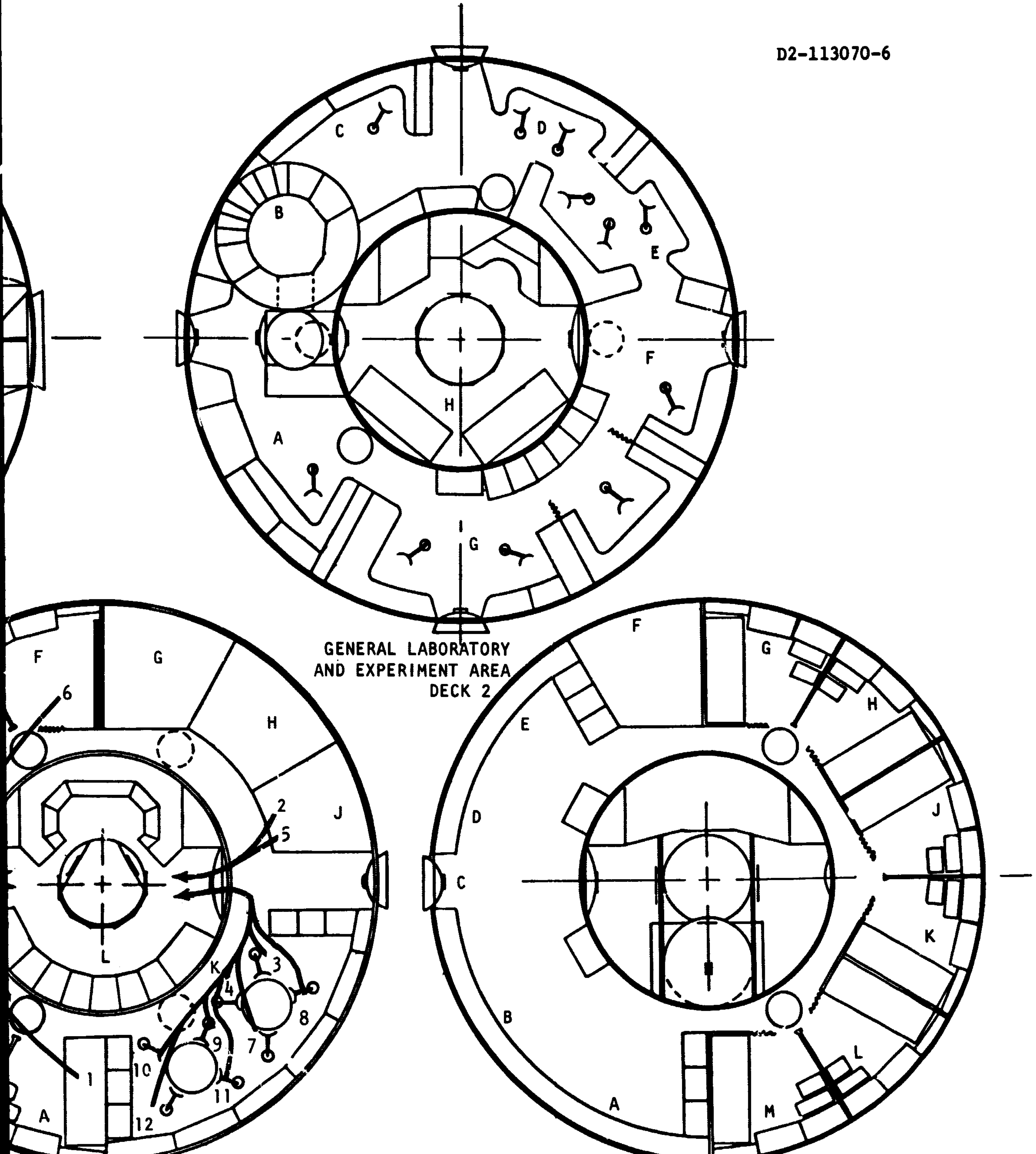


SUBSYSTEM AND SHOP AREA
DECK 3



CREW QUARTERS, GA

FOLDOUT FRAME 1



GENERAL LABORATORY AND EXPERIMENT AREA
DECK 2

, GALLEY, COMMAND AND CONTROL
DECK 4

CREW QUARTERS AND WARD ROOM
DECK 5

Figure 5-16: EMERGENCY IN OUTER MODULE, DECK 4
MAXIMUM CREW DISTRIBUTION IN OUTER MODULE
TIMELINE 2021 HOURS TRAFFIC FLOW TO INNER MODULE, DECK 4

safety. At that time, all crew members have the option of remaining in the inner module, Deck 4, or retreating to other locations, as the condition warrants. It is apparent that the entire crew could conceivably be lost, if the emergency were of a sufficient magnitude. It would seem advisable to schedule crew members such that they could not all be in the same compartment at once.

5.5.1.2 EMERGENCY IN INNER MODULE, DECK 5---MAXIMUM CREW DISTRIBUTION IN INNER MODULE

(Timeline 01:11 Hours, Traffic Flow to Outer Module, Deck 5)

An audible/visual device will announce that an emergency exists in the inner module, Deck 5. At that time, crew distribution is as follows (Reference Figure 5-17):

Crew members 1 and 10 are in Data Management area---Deck 5.

Crew members 2, 3, and 5 are in their quarters---Deck 4.

Crew members 9 and 11 are in their quarters---Deck 5.

Crew members 4 and 7 are in the Wardroom---Deck 5.

Crew member 6 is at the Command and Control Console---Deck 4.

Crew member 8 is in the Water Management area---Deck 3.

Crew member 12 is in the ECS #1 area---Deck 3.

Crew members 1 and 10 will react by immediately retreating from the emergency area, i.e., from the inner module, Deck 5, to the outer module, Deck 5. The other crew members were assumed to be not immediately affected by the emergency, due to the isolation concept of the structure.

5.5.1.3 EMERGENCY IN INNER MODULE, DECK 3---RANDOM CREW DISTRIBUTION

(Timeline 11:41 Hours, Traffic Flow to Outer Module, Deck 3)

The audible/visual device will announce that there is an emergency in the inner module, Deck 3. At that time, crew distribution is as follows (Reference Figure 5-18):

Crew members 1, 3, and 6 are in their staterooms---Deck 4.

Crew members 8, 10, and 12 are in their staterooms---Deck 5.

Crew member 2 is in the ECS #1 area---Deck 3.

Crew members 4, 7, and 9 are in the galley---Deck 4.

Crew member 5 is in the Earth Resources area---Deck 1.

Crew member 11 is in the Personal Hygiene area---Deck 5.

Crew member 2 will exit the inner module, Deck 3, immediately to the outer module, Deck 3. The remaining crew members were assumed not to be immediately affected, due to the isolating nature of the structure.

5.5.1.4 EMERGENCY IN OUTER MODULE, DECK 5---RANDON CREW DISTRIBUTION

(Timeline 00:01 Hours, Traffic Flow to Inner Module, Deck 5)

An audible/visual device will announce that there is an emergency in the outer module, Deck 5. At that time, crew distribution is as follows (Reference Figure 5-19):

Crew members 1 and 6 are at the Command and Control Console---Deck 4.

Crew members 2, 3, and 5 are in their quarters---Deck 4.

Crew member 9 is in his quarters---Deck 5.

Crew members 4, 7 and 11 are in the Wardroom---Deck 5.

Crew member 8 is in the Personal Hygiene area---Deck 5.

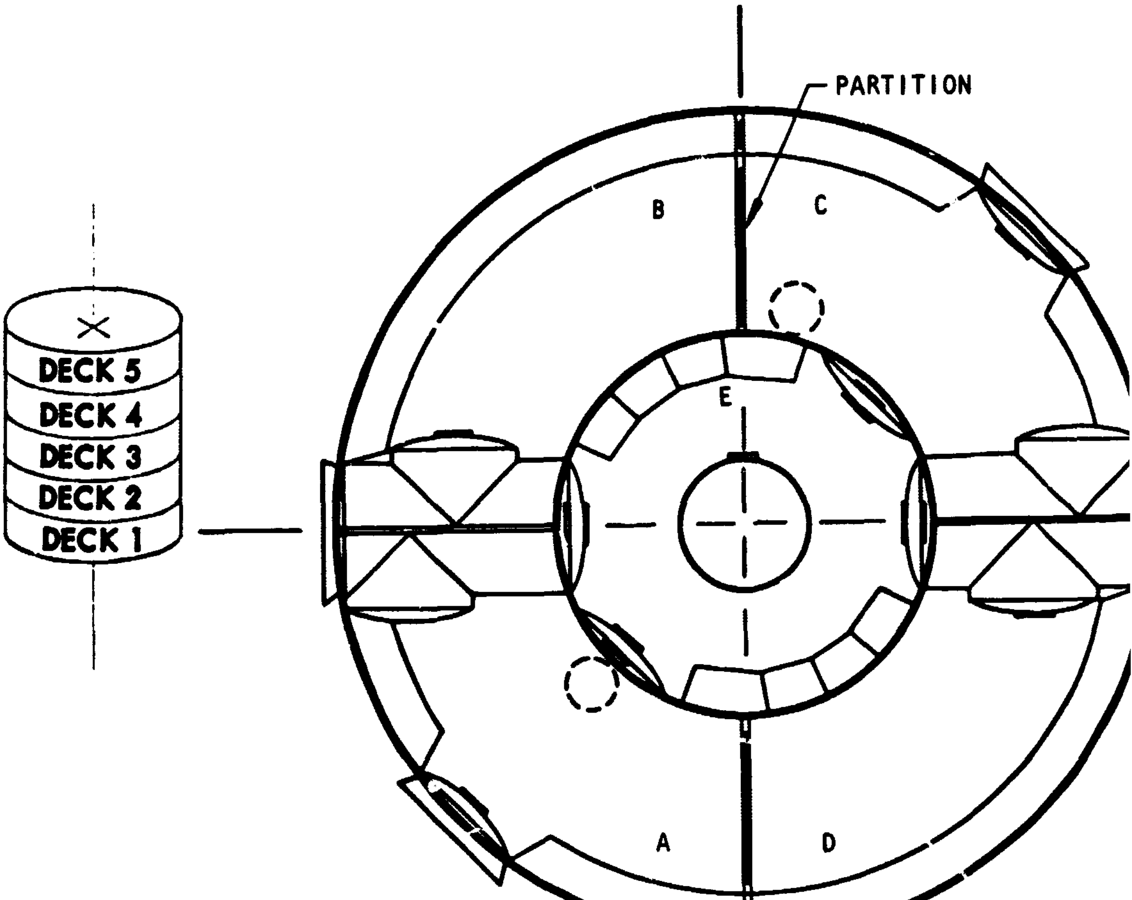
Crew member 10 is in the Data Management area---Deck 5.

Crew member 12 is in the Water Management area---Deck 3.

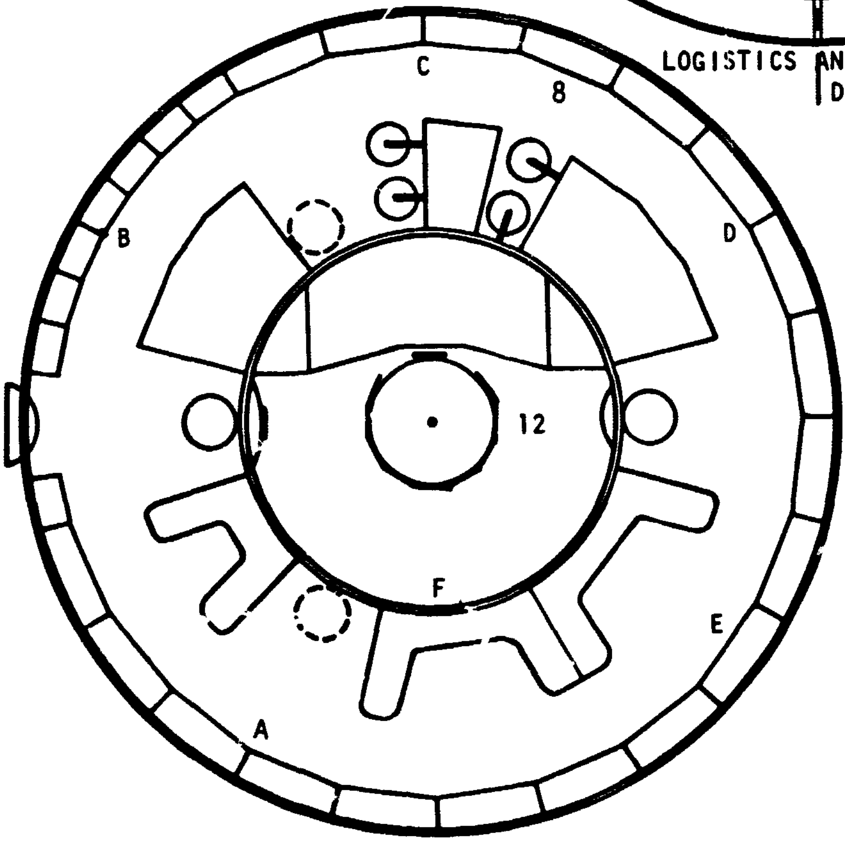
Upon recognition of the emergency, crew members 4, 7 and 11 will exit the wardroom and go directly to the inner module, Deck 5, through the inner/outer module hatch. Crew member 8 will exit the personal hygiene area, travel through the wardroom and enter the inner module through the inner/outer module hatch. Crew member 9 will exit his stateroom and enter the inner module via the inner/outer module hatch closest to him. The other crew members were assumed not to be immediately affected by the emergency, due to the isolation concept of the structure.

5.5.2 PASSAGEWAY UTILIZATION

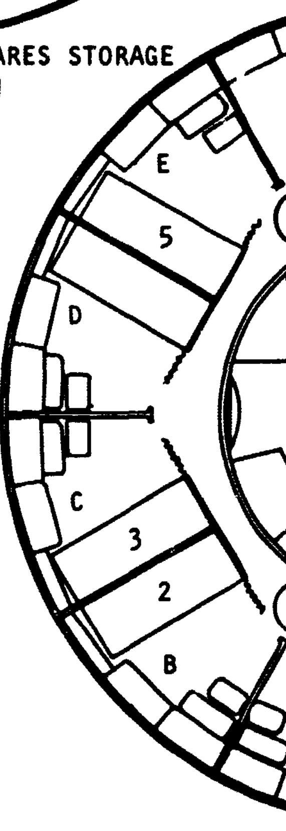
Figure 5-20 is a schematic of the 12-man space station representing the relationship between compartments, hatches, airlocks, and docking ports and their amount of usage during a "typical day." The two heaviest paths of traffic are from Deck 4 to Deck 5 through the inner module, and between the galley (Deck 4) and the wardroom (Deck 5). This trend is generally in consonance with the previous findings discussed in Sections 5.3 and 5.4 of this analysis. The agreement is primarily that crew-oriented traffic outweighs the traffic necessary for experiment execution. Figure 5-21



LOGISTICS AND SPARES STORAGE
DECK 1

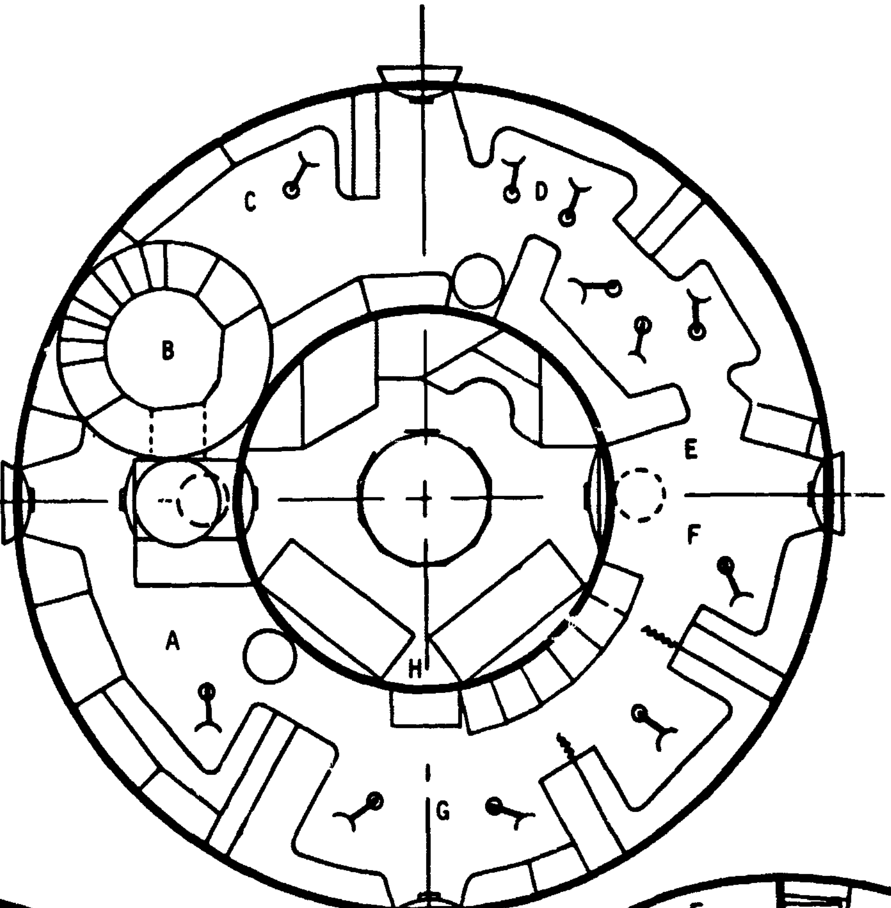


SUBSYSTEM AND SHOP AREA
DECK 3

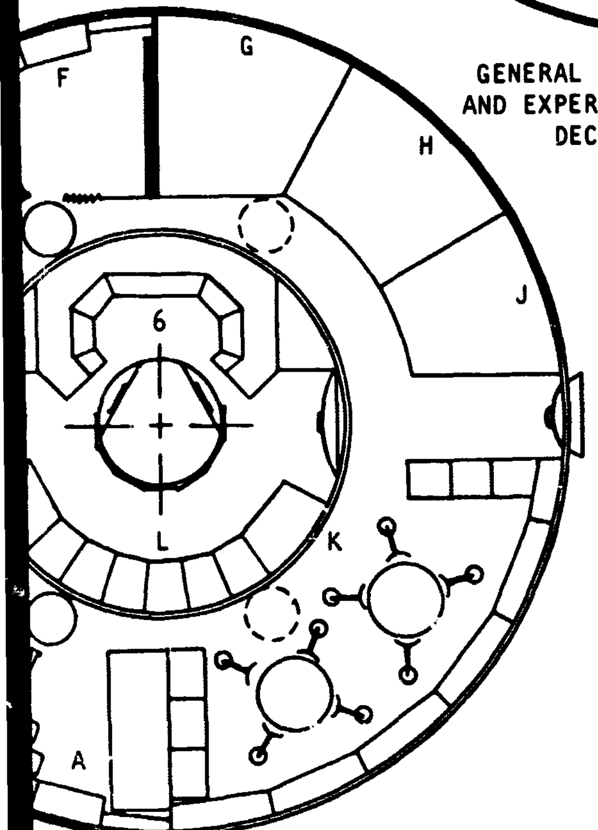


CREW QUARTERS,

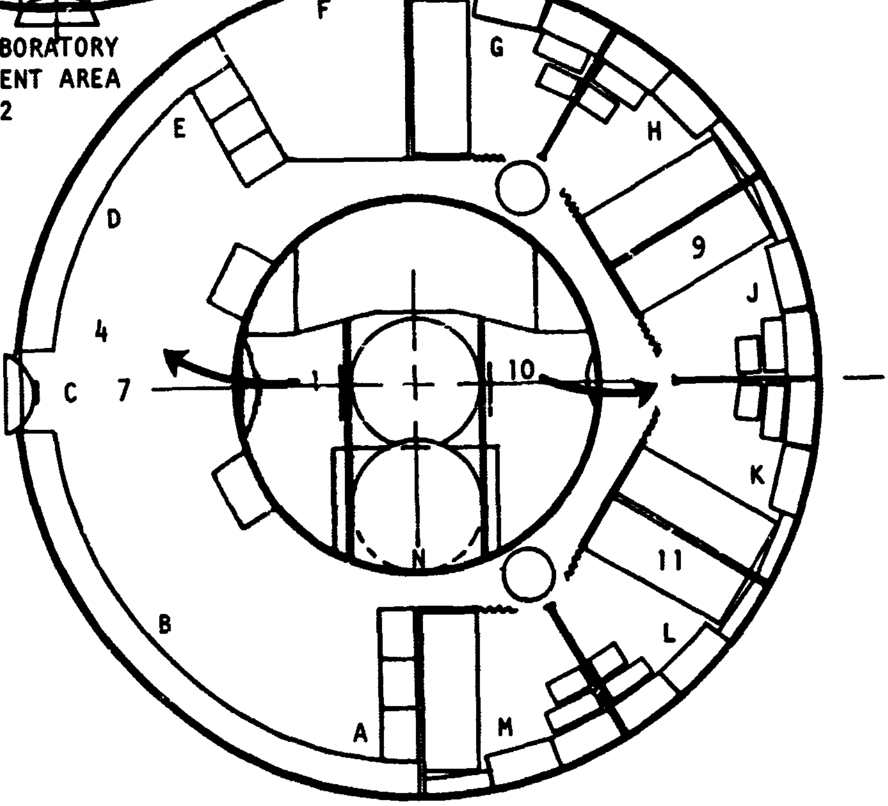
FOLDOUT FRAME 1



GENERAL LABORATORY AND EXPERIMENT AREA
DECK 2

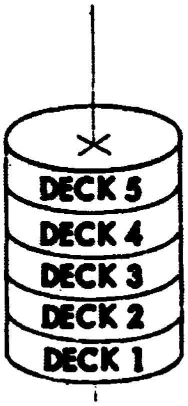


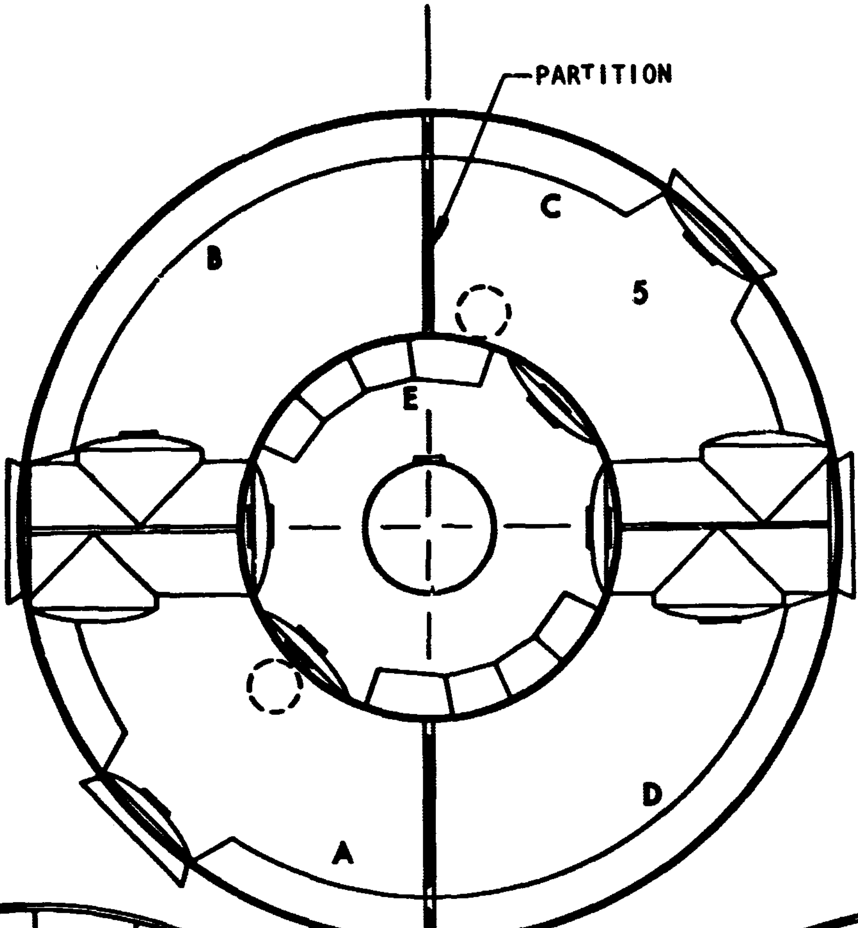
GALLEY, COMMAND AND CONTROL
DECK 4



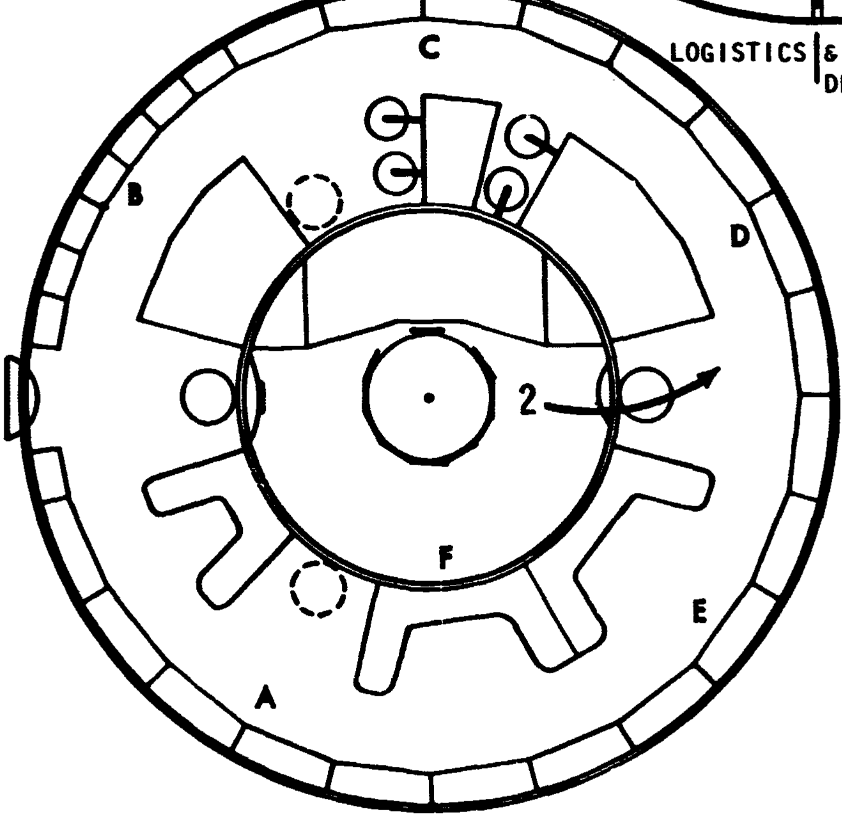
CREW QUARTERS AND WARD ROOM
DECK 5

Figure 5-17: EMERGENCY IN INNER MODULE, DECK 5 MAXIMUM CREW DISTRIBUTION IN INNER MODULE TIMELINE 0100 HOURS TRAFFIC FLOW TO OUTER MODULE, DECK 5

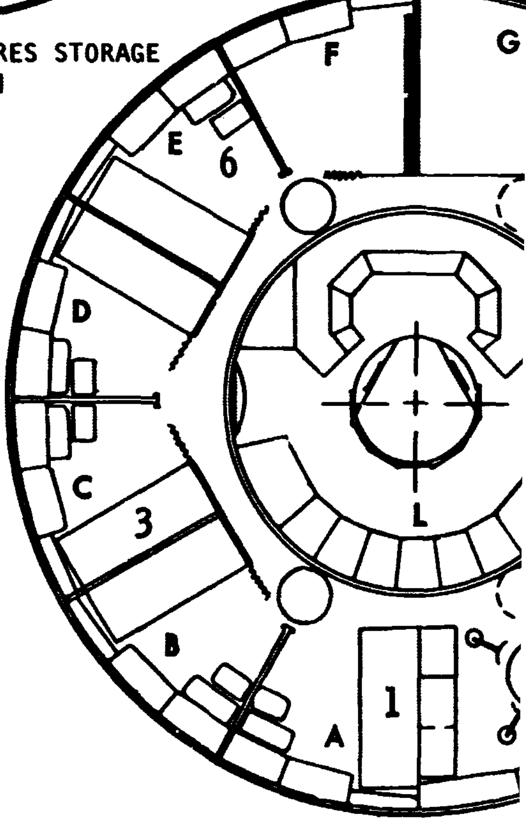




LOGISTICS & SPARES STORAGE
DECK 1

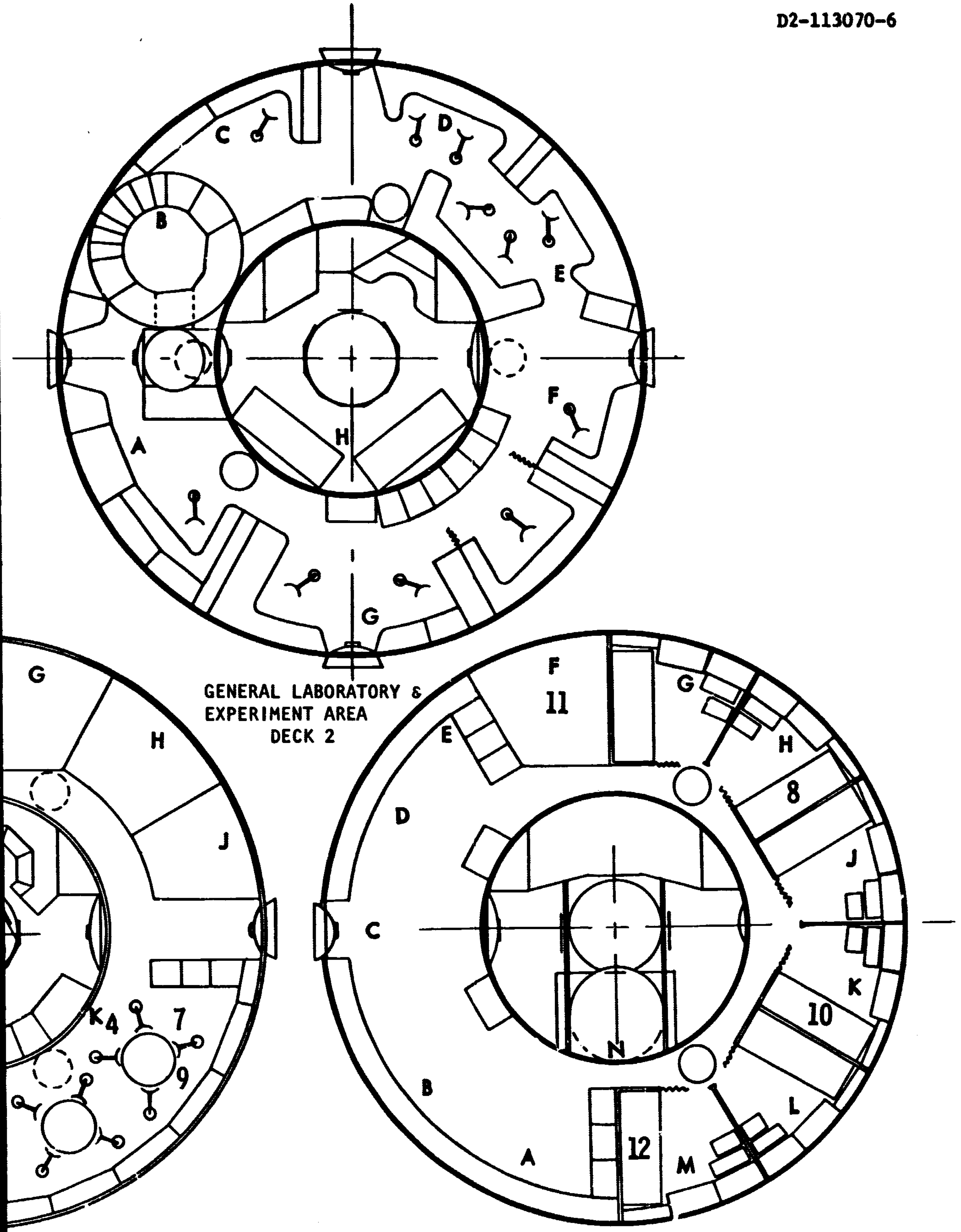


SUBSYSTEM & SHOP AREA
DECK 3



CREW QUARTERS, GALLEY, COMM
DECK 4

FOLDOUT FRAME

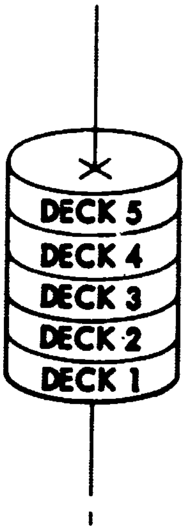


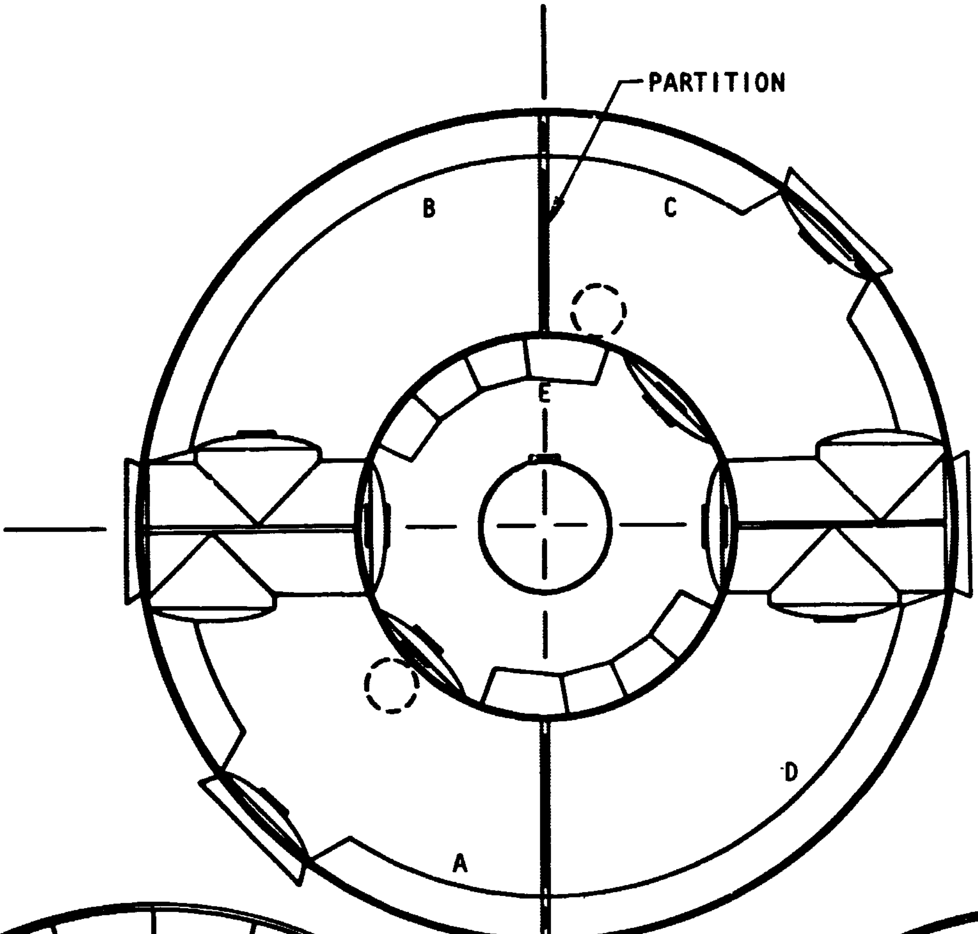
GENERAL LABORATORY & EXPERIMENT AREA
DECK 2

COMMAND & CONTROL
4

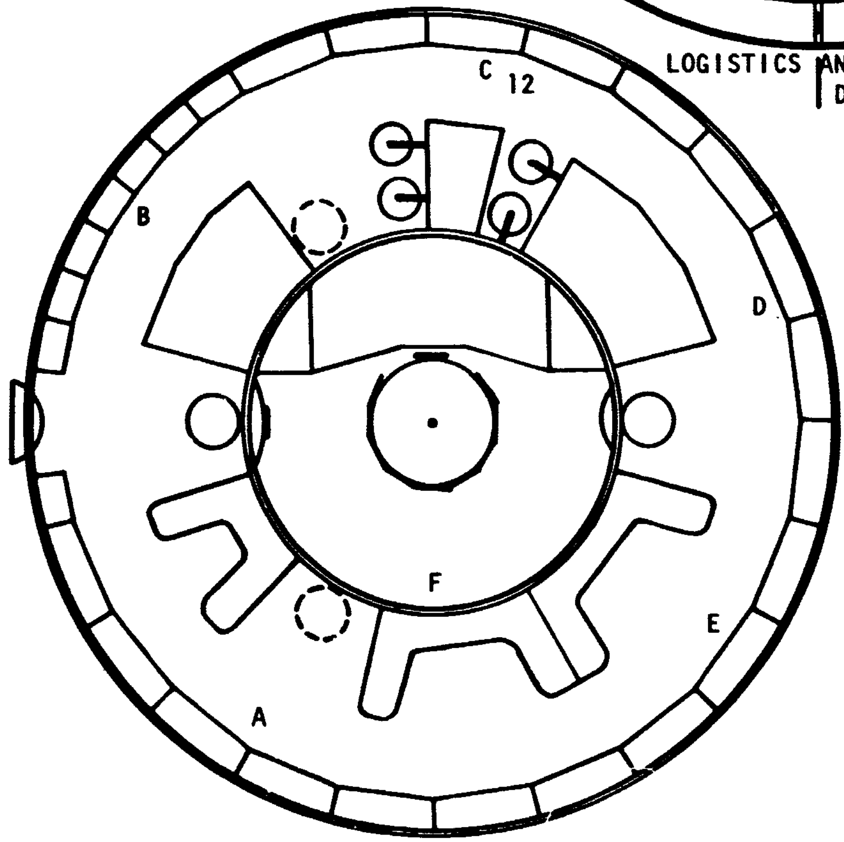
CREW QUARTERS & WARD ROOM
DECK 5

Figure 5-18: EMERGENCY IN INNER MODULE, DECK 3 RANDOM CREW DISTRIBUTION TIME LINE 1,200 HOURS TRAFFIC FLOW TO OUTER MODULE, DECK 3

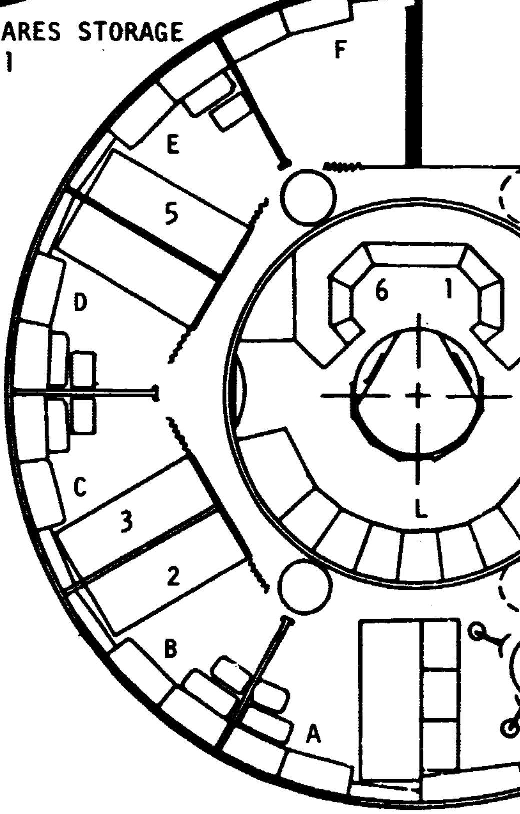




LOGISTICS AND SPARES STORAGE
DECK 1

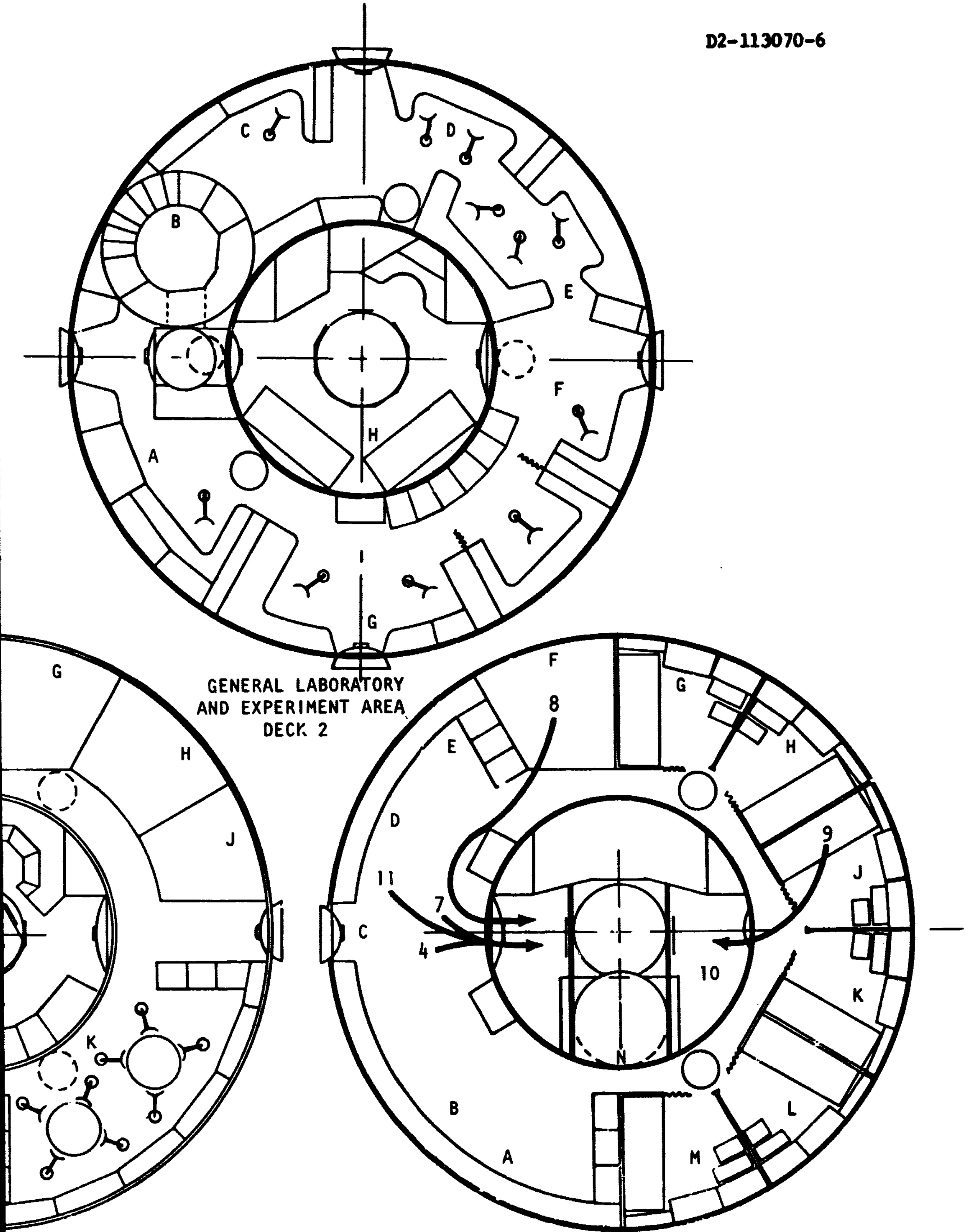


SUBSYSTEM AND SHOP AREA
DECK 3



CREW QUARTERS, GALLEY, COMM
DECK 4

FOLDOUT FRAME 1



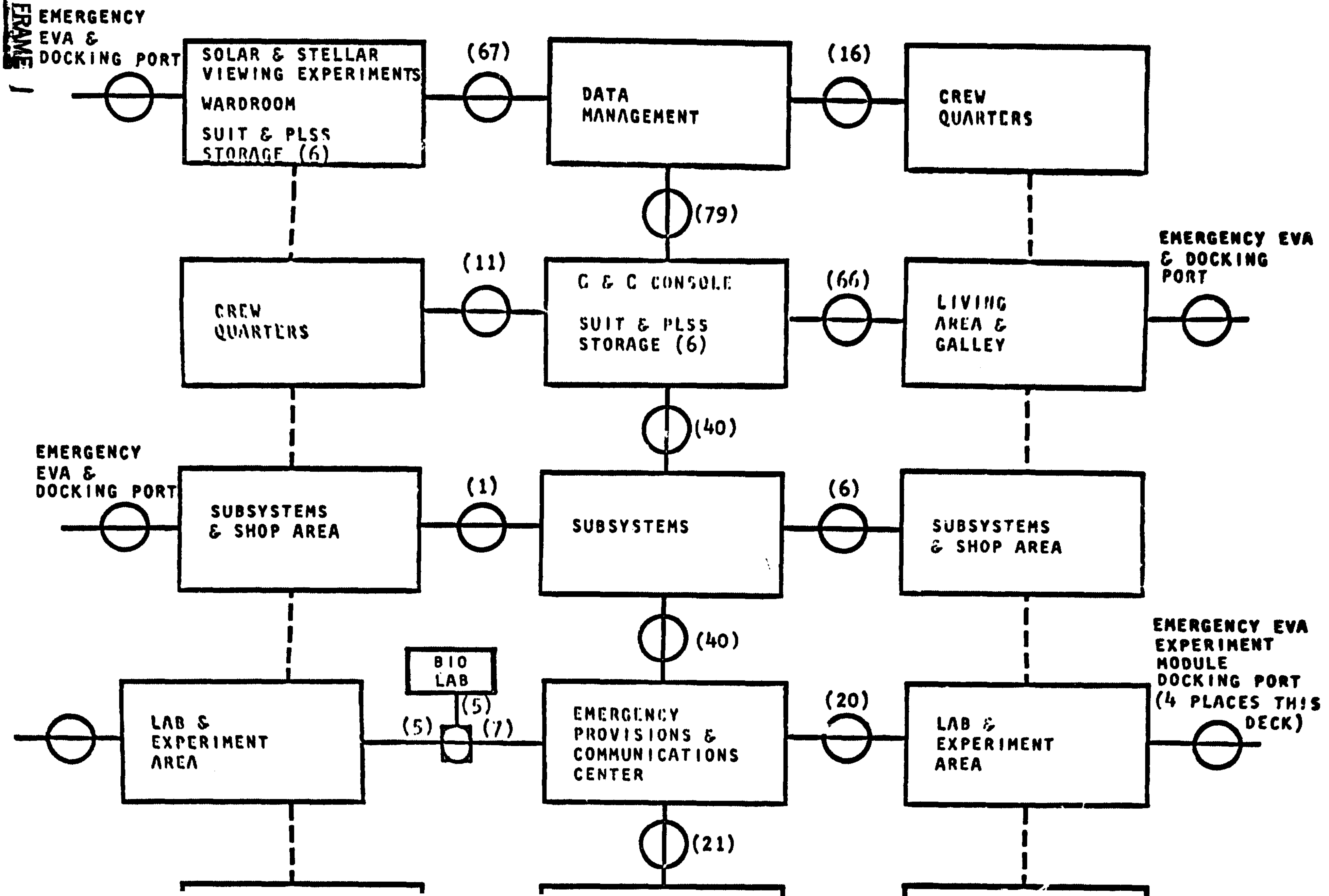
GENERAL LABORATORY
AND EXPERIMENT AREA
DECK 2

COMMAND AND CONTROL
4

CREW QUARTERS AND WARD ROOM
DECK 5

Figure 5-19: EMERGENCY IN OUTER MODULE, DECK 5
RANDOM CREW DISTRIBUTION TIME LINE 0001
HOURS TRAFFIC FLOW TO INNER MODULE, DECK 5

FOLDOUT FRAME 1



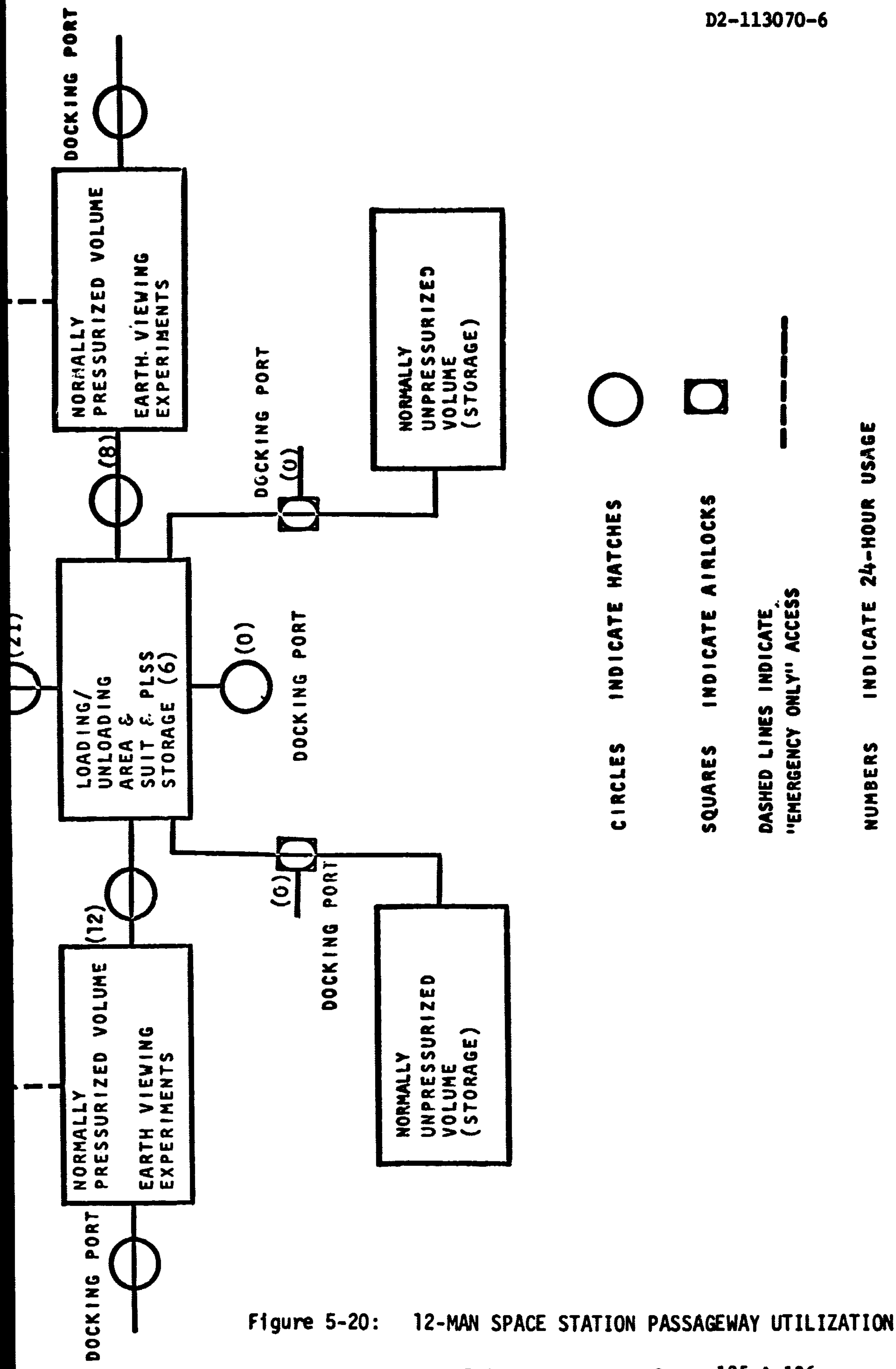


Figure 5-20: 12-MAN SPACE STATION PASSAGEWAY UTILIZATION

reinforces this observation. The decks which contain living facilities (Decks 4 and 5) have a higher concentration of crew time expended than any other decks on the station.

It should be recognized that the crew are considered to spend their spare time in their quarters, the wardroom, or the galley, depending on their particular schedules.

5.5.3 CREW OCCUPANCY

Figure 5-21 depicts the distribution of crew time during the "typical day," with the locations defined by the timeline (Table 5-5). It is evident that the major portion of time is spent in the outer modules on Decks 4 and 5, which are primarily eating, sleeping, and personal care areas. Decks 1 and 5 have more surface area exposed to space than any of the remaining three. The outer modules have such exposed surface area, whereas the inner modules do not, with the exception of those on Decks 1 and 5. Therefore, it would seem that the inner modules of Decks 2, 3 and 4 would be the safest refuge from external hazards. Similarly, it would seem advantageous to configure the station in such a manner that the high density areas would be located within that envelope. This method would be consistent with the "storm cellar" approach, which is concerned with retreat and protection from external hazards, i.e., meteoroid impact, radiation, and docking maneuvers.

5.5.4 AREA-TO-AREA TRAFFIC DEFINITION

Figure 5-22 shows the minimum area-to-area crew movement required to perform those functions schedules by the timeline. Each deck is divided into designated areas. The number of occurrences of movement between adjacent areas is shown for a 24-hour typical day period. The areas of maximum movement are Decks 4 and 5. The paths of maximum movement are between the wardroom and the inner module on Deck 5; between the inner modules of Decks 4 and 5; and between the galley and the inner module on Deck 4. In view of the magnitude of traffic between the galley and the wardroom, it would seem reasonable to either locate them near to each other on the same deck, or make provisions in consideration of the heavy traffic flow, i.e., larger hatches, designate "normally open" hatches, relocation of equipment if necessary, etc.

5.6 ANCILLARY CONSIDERATIONS

The traffic pattern analysis was directed primarily at crew distributions and traffic patterns in an emergency. Some additional considerations were examined briefly, as described in the following subsections.

5.6.1 DEGRADATION OF SAFETY DUE TO TRAFFIC FLOW

Some degradation in safety due to traffic flow may be expected since traffic flow in or around work in progress will either distract attention from the work, reduce the accuracy, or both.

5.6.1.1 SINGLE LAUNCH SPACE STATION

The "Typical Day" timeline (Table 5-2) shows that crew members 2 and 5 work in essentially the same areas from 13:30 to 20:41. Their effort is toward related work, but different experiments are involved for each. Therefore, it is possible that some distraction may occur due to their close proximity.

5.6.1.2 EARLY ORBITAL SPACE STATION

The "Typical Day" timeline (Table 5-3) shows that crew members 2 and 5 work in close proximity on Deck 4 from 13:18 to 15:33. There is also a period from 20:41 to 22:21 when as many as four crew members are in the Physical Science Lab (3B). It is reasonable to expect some distraction under these conditions; however, this study will not attempt to define the magnitude.

5.6.1.3 NASA PHASE B TWELVE-MAN SPACE STATION

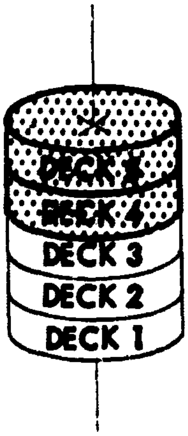
The "Typical Day" timeline (Table 5-4) shows that crew members 3, 5 and 9 have scheduled tasks which overlap from 17:21 to 17:44 in the Earth Resources experiment area (1A). Each is performing a different experiment, and it is possible that some distraction may result.

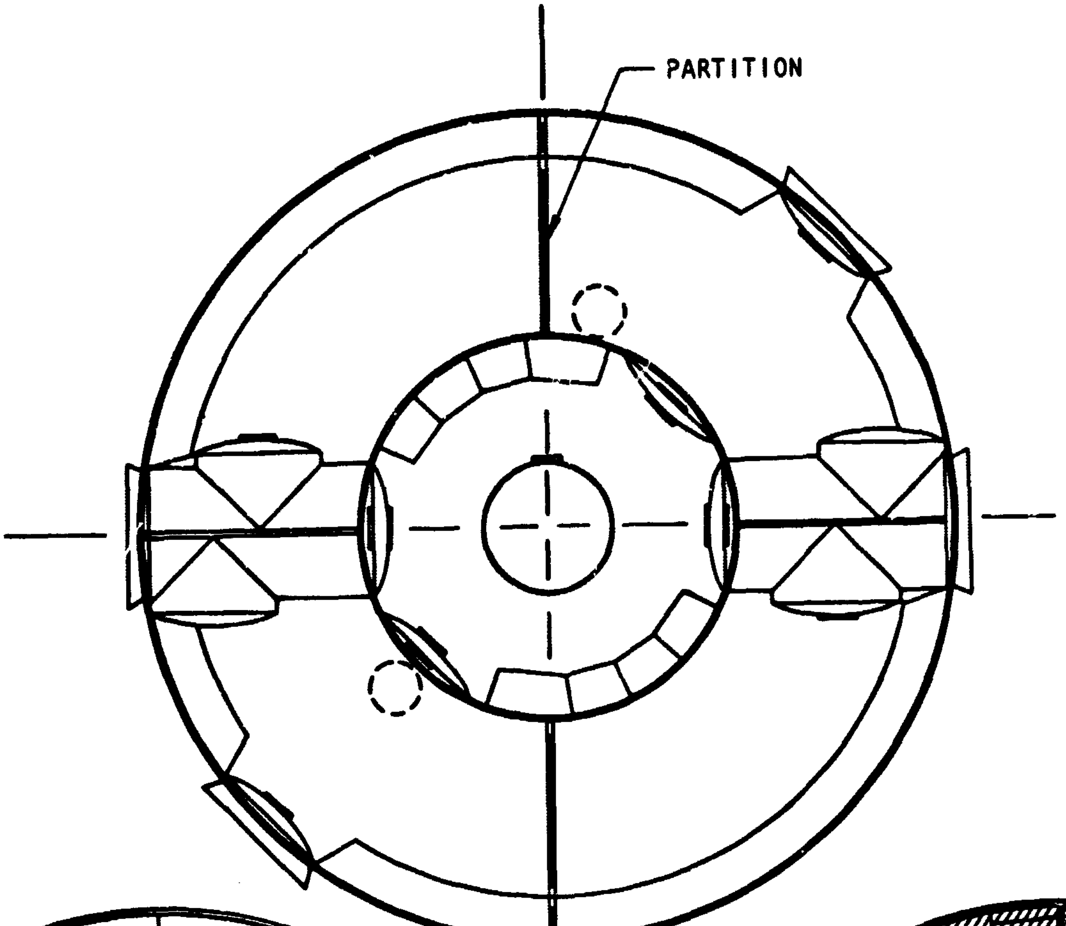
No other potentially disrupting traffic is obvious for the cases above, but this is based on the assumption that all crew members will stay in designated locations and not wander about the station during unscheduled or free time.

5.6.2 DISTANCE TO SAFETY.

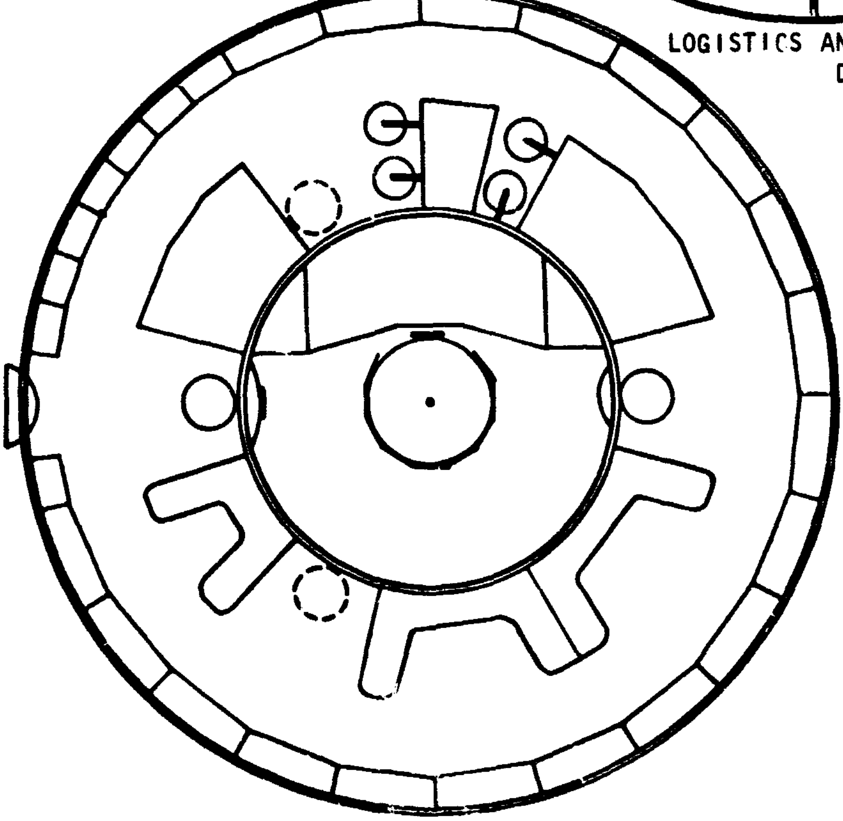
The present data on zero-gravity movement with respect to time is sparse and not directly applicable to the configurations analyzed. Therefore, it is advantageous to use another parameter with which to judge astronaut exposure, based on distance from safe quarters in the event of an emergency. Distance is applicable to the configurations and is easily obtained. Table 5-6 displays the maximum distance traveled by a crewman to reach a safe compartment in each of the cases studied.

The distance to a safe compartment is generally less for the Early Orbital Space Station than for the Single Launch Space Station configuration. There is a fallacy in taking this reasoning verbatim. The Early Orbital Space Station distances to safe compartments and suits will remain the same unless major design changes are made, i.e., new pressure-tight compartmentation, addition of suits and storage facilities, etc. The Single

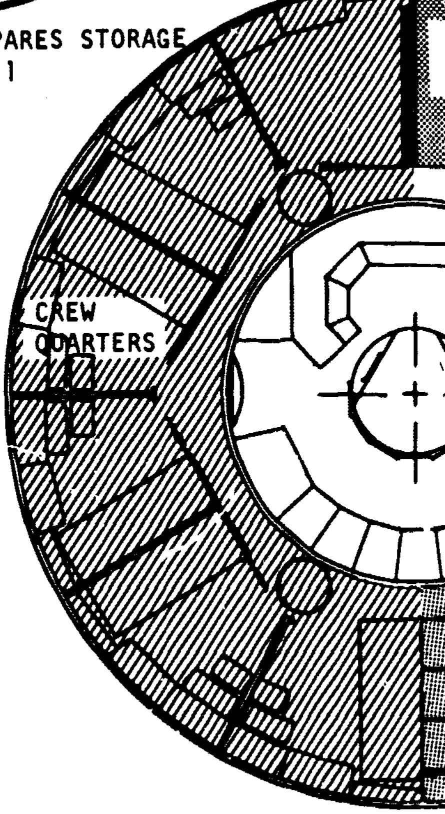




LOGISTICS AND SPARES STORAGE
DECK 1

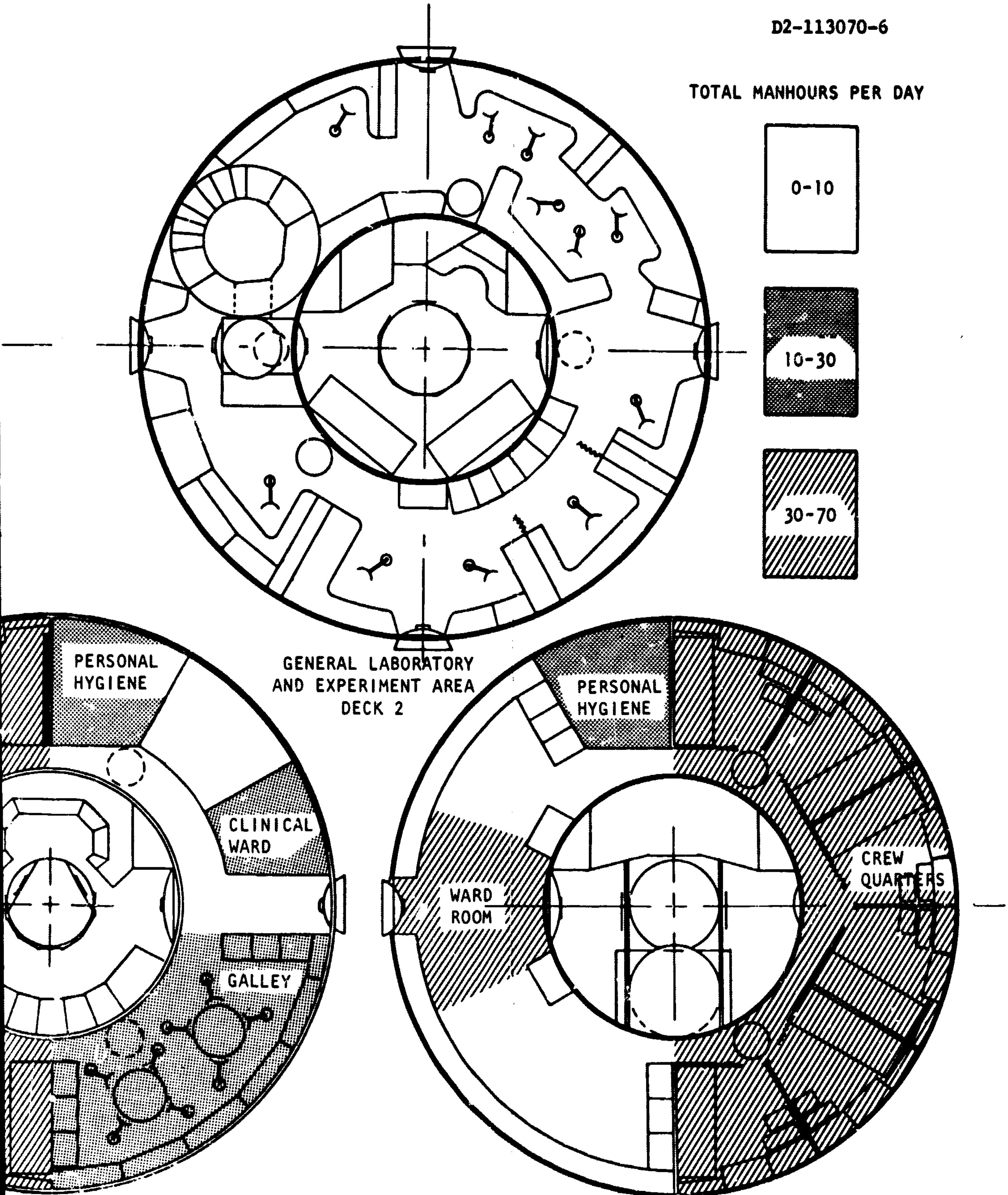


SUBSYSTEM AND SHOP AREA
DECK 3



CREW QUARTERS, GALLEY,
DECK

FOLDOUT FRAME 1

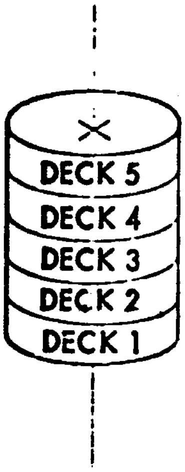


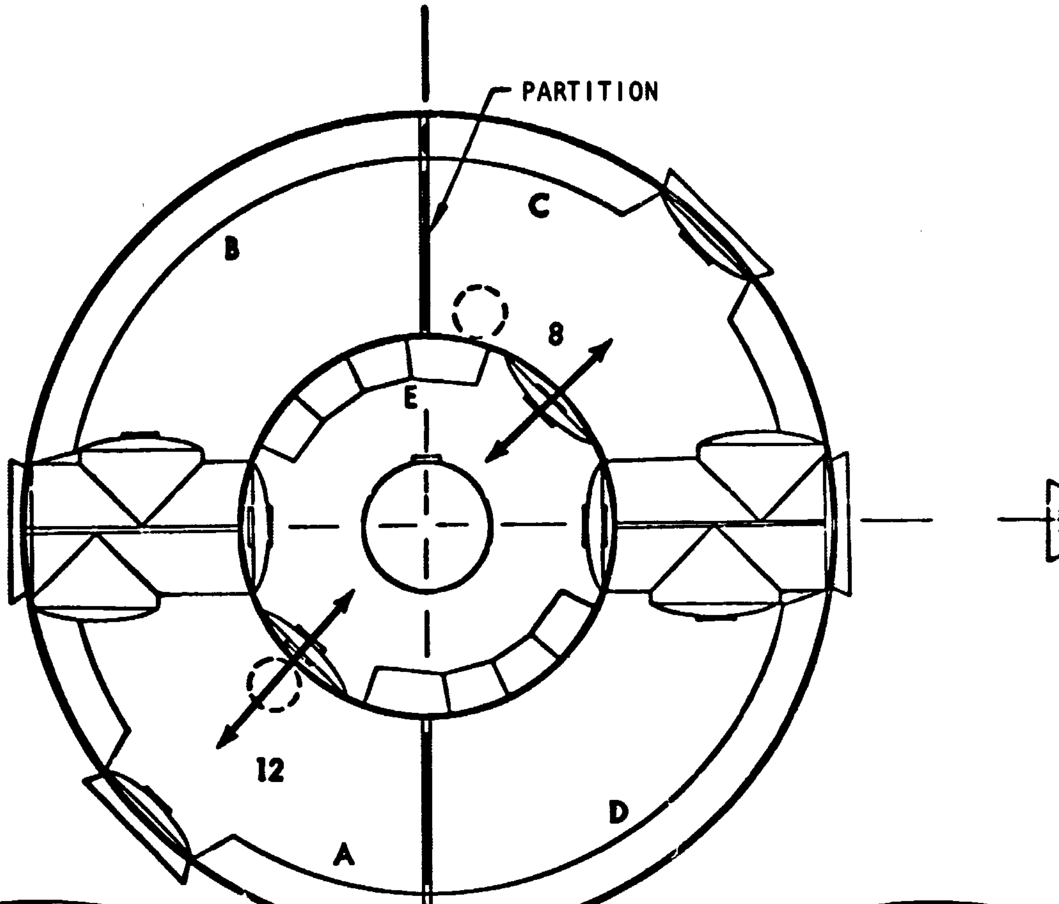
GENERAL LABORATORY AND EXPERIMENT AREA
DECK 2

ALLEY, COMMAND AND CONTROL
DECK 4

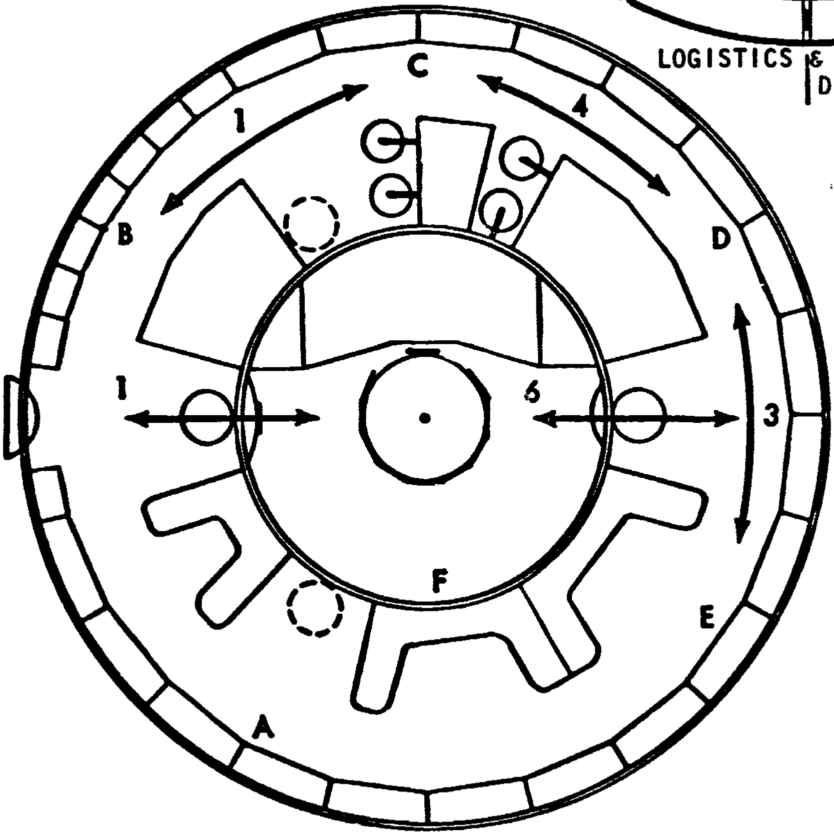
CREW QUARTERS AND WARD ROOM
DECK 5

Figure 5-21: 12-MAN SPACE STATION CREW OCCUPANCY

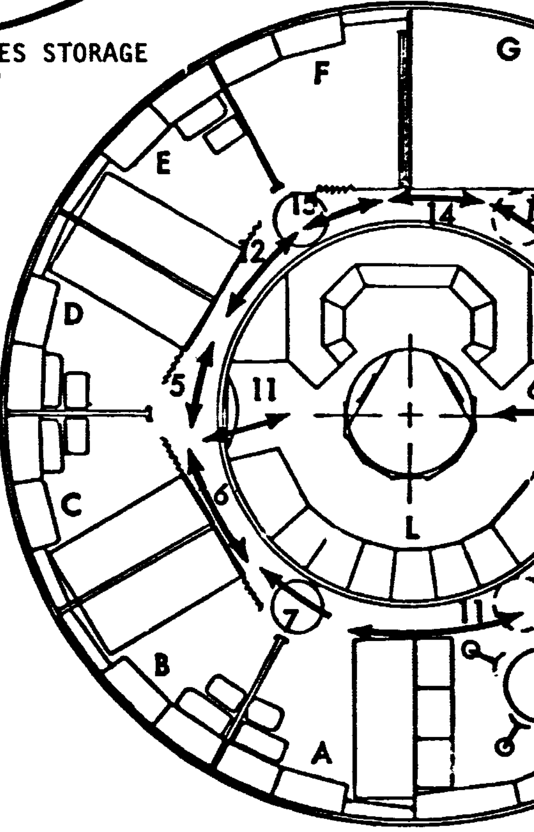




LOGISTICS & SPARES STORAGE
DECK 1

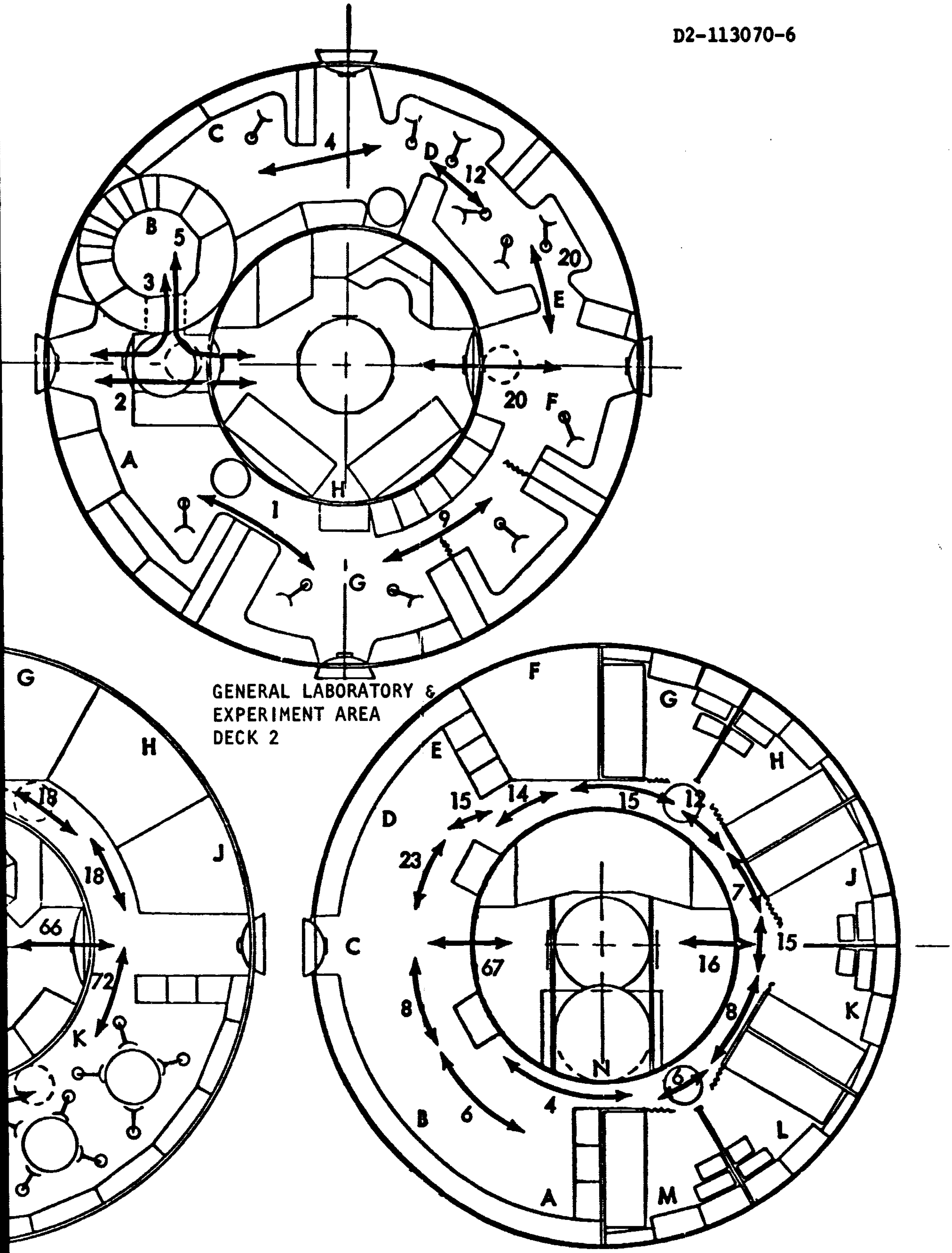


SUBSYSTEM & SHOP AREA DECK 3



CREW QUARTERS, GALLEY, COMMAND &

FOLDOUT FRAME 1



GENERAL LABORATORY & EXPERIMENT AREA DECK 2

D & CONTROL DECK 4

F CREW QUARTERS & WARD ROOM DECK 5

Figure 5-22: AREA-TO-AREA TRAFFIC DEFINITION--24 HOUR TYPICAL DAY PERIOD

TABLE 5-6
MAXIMUM DISTANCE TRAVELED TO SAFETY BY A CREWMAN

CASE FIGURE NUMBER	CREWMAN INVOLVED	DISTANCE TRAVELED TO SAFE COMPARTMENT	DISTANCE TRAVELED TO SUIT	DISTANCE TRAVELED TO ERV
Single Launch Space Station				
5-3	#4	35 feet	54 feet	61 feet
5-4	#4	11	19	71
5-5	#3	35	38	62
5-6	#4	35	54	61
Early Orbital Space Station				
5-10	#6	24	24	51
5-11	#5	23	78	78
5-12	#5	8	18	80
5-13	#3	13	24	54
NASA Phase B				
5-16	#6	16	--	--
5-17	#1	4	--	--
5-18	#2	4	--	--
5-19	#8	16	--	--

NOTE:

a. Distance traveled to safe compartment---A "Safe Compartment" is one that isolates the crew member involved from the emergency, and contains a suit for him or allows safe access to a location containing a suit for him.

b. Distance traveled to suit---Is the distance to the closest suit which is in a compartment not affected by the emergency, and which is made specifically for the crew member involved.

c. Distance traveled to ERV---The ERV considered in each case is that which contains a suit specifically made for the crew member involved.

d. Already suited crewmen are not considered herein (EVA cases).

e. For the EOSS cases shown, suits for crew members stowed in the forward (MDAM) and aft (Deck 4) modules have been reversed in order to improve suit availability, i.e., suits for crew members 1, 4 and 5 are stowed in the aft module (see EOSS Suit Location).

f. Distance to suits and ERV's is not presented for the NASA Phase B Space Station, since they are not used or are not considered as emergency devices in that configuration.

Launch Space Station distances can be drastically reduced by the addition of a second hatch, opposite the existing one, in the bottom deck between the inner and outer modules. For instance, consider crew member 4 in Figure 5-6. If the new hatch were installed, his distance to a safe compartment would drop from 35 feet to 12 feet; similarly, his distance to his suit would drop from 54 feet to 32 feet. Such reductions are also obtainable in other Single Launch Space Station cases.

The NASA Phase B 12-Man Space Station has the lowest distance to safety of the three concepts considered. Figures 5-16 and 5-19 represent the extreme distance from a safe compartment in this station. These distances could be reduced even further by the incorporation of two additional inner/outer module hatches 90° from the existing hatches and opposite each other. It is recognized that a trade study would be necessary to justify this change. It would seem that the optimum configuration from a distance-to-safety standpoint would be the inner/outer module concept, which is isolated between decks and between inner and outer modules.

5.7 CONCLUSIONS

This task assumed that pressure suits (Apollo Block II) would be used as emergency survival devices. Primarily because of the long time required to don the suit, it does not appear acceptable as a survival device. In addition, because the suits are individually fitted and a crewman can use only his personal suit, a considerable number of suits would be required if they are to be readily available in emergencies. It is concluded that a universal, quick-donning survival device should be provided and that each compartment should contain sufficient of these devices to accommodate all crew members who might normally be in that compartment.

With respect to crew distribution, instances were found in which a majority of the crew was in the same compartment at the same time. This situation should be avoided and a minimum number of crew members allowed to occupy a compartment; because, if an emergency occurred in the occupied compartment, a large proportion of the crew could be lost or, at any rate, evacuation of the compartment would be impeded. On the other hand, it was also found that about two-thirds of the crew's activities are directed toward their own health and well-being, e.g., sleeping, eating, recreation, personal hygiene, and medical. It followed that about two-thirds of the crew's time was spent in areas devoted to these activities, with a consequent undesirable concentration of the crew in these areas. While scheduling and crew discipline may alleviate this situation somewhat, attention should be directed to making high crew density areas as safe as possible. An approach to this would be to ensure that all hazards necessarily on-board the space station, such as equipment, materials, experiments, procedures, and the like, be located in other than high crew density areas.

Regarding crew movement and traffic, all traffic routes should be sized such that a crew member wearing protective equipment has access to all parts of the station. Routes should also be sized so as to accommodate necessary traffic, including two-way traffic, under emergency conditions. All compartments should have at least two escape routes and these should not terminate in a common compartment, this to minimize the possibility of crew members becoming trapped in an emergency. Emergency procedures, including designation of traffic routes should be developed, personnel should be instructed in the procedures, and the procedures should be practiced.

To assure that all crew members are aware of an emergency, an automatic emergency detection system should be provided which can locate and identify hazardous conditions. Also, a means should be provided to determine the conditions within isolated or unoccupied areas before crew members enter the area, this to avoid inadvertent spread of a hazardous condition.

6.0 HUMAN REQUIREMENTS

6.1 INTRODUCTION

In the area of human requirements, a primary objective in the design of a spacecraft is to provide an environmental envelope in which the mission can be carried out in comfort, maximum efficiency, and without injury to the occupants. Contamination by potentially toxic or hazardous materials of the closed ecological system of the spacecraft is a basic concern in design, maintenance, and operation. This section presents data that demonstrates the necessity for attention to safety measures, including: materials selection, quality control, instrumentation capable of qualitatively and quantitatively monitoring the environment, and methods for the eradication or control of toxic contaminants. A brief summary of toxicology considerations which apply to occupants of any spacecraft, is given. Known and potential spacecraft contaminants are listed.

A second primary objective in the human requirements area is to provide for those medical facilities and skills which are necessary to assure that the crew maintains an acceptable level of physical and mental health. Two distinct approaches are required, preventive medicine and clinical medicine. A brief discussion of the salient points of these two approaches is given.

6.2 GENERAL CONSIDERATIONS

6.2.1 TOXICOLOGY BACKGROUND

Toxicology is that branch of biological science which deals with the adverse effects of chemical substances on living tissue. Since all substances can have an adverse effect on the body at some quantity or concentration, toxicity is inherent in all substances, depending on the intensity and duration of the exposure (Reference No. 33). The body, through normal processes, is capable of resisting toxic effects up to a point. If that point is exceeded, then adverse effects may occur. In general, the more intricate the organization of the system and the more complex the steps in the biochemical process, the more liable the system is to injury (Reference No. 67).

Exposure to chemical substances may be single, repeated, or continuous. As a rule, a single exposure, if it does not result in death, does not produce persistent deleterious effects in biochemistry, physiology, or structure. Recovery occurs fairly rapidly. However, substances taken into the body repeatedly or continuously, while not producing immediate change, may slowly exert a deleterious effect in one of two ways. Either the substance may collect in the body to such an extent that, eventually, the concentration is great enough to cause change, or repeated small injuries may summate to the point where normal biochemical, physiological, or tissue restorative abilities are exhausted (Reference No. 105).

6.2.1.1 ABSORPTION

Insofar as spacecraft crews are concerned, chemicals will enter the body principally through inhalation and skin absorption, with oral ingestion possible but less likely. With inhalation, absorption is rapid and maximum chemical levels in the blood are quickly reached. The total quantity absorbed by this route is influenced by the rate and volume of respiration, the concentration of the contaminant, and the percentage extracted from the air.

Experience indicates that the following contaminants have fairly easy access to the cell interior once they are absorbed into the body: gases, fat soluble compounds, organic bases, and un-ionized combinations of weak acids.

The following contaminants penetrate the cell membrane poorly: compounds with high water solubility, salts of organic bases, and highly ionized compounds.

6.2.1.2 ELIMINATION

The principal routes of excretion of toxic substances are the expired air, urine, and feces. Less important, but not to be ignored, are the sloughed skin and perspiration. The more rapid the excretion, the less likely are toxic effects to occur.

6.2.1.3 DOSE-RESPONSE

The quantitative relationships of dose to response are exceedingly important in the theoretical and practical evaluations of toxic action. For all substances, the greater the dose, the more severe is the response or the more rapid is its onset. With some substances, time is an equally important factor in determining effect.

6.2.1.4 PHYSICAL STATE

Chemicals which enter the body through the respiratory tract do so in the form of gases, vapors, or particulates. In the context of the space environment, particulate matter is relatively more important than in other forms of environmental exposure. Aerosols of smoke, dust, fogs, or fumes may be present for longer periods than on Earth, because of the absence of the settling effect of normal Earth gravity.

6.2.1.5 INTERACTION OF MULTIPLE COMPONENTS

Rarely are individual chemical toxicants present alone. In the problem of a spacecraft, and particularly considering a space station or base in which chemicals are deliberately brought aboard for experimental purposes, many hundreds of chemicals and compounds may be present. The difficulty in evaluating the milieu of possible contaminants is the interaction which occurs due to the combined effect of these substances.

6.2.1.6 UNUSUAL RESPONSES

In addition to the usual effects which may be predicted in the average individual, based on the observation of physiological, biochemical, and pathological changes which occur when sufficient doses of a toxicant are encountered, there are also unusual responses. These are unusual in that they occur generally at much lower doses than might be expected, require previous contact with the substance, or result in changes which are different from those normally expected.

McNamara (Reference No. 10) describes animal tests for the detection of subtle minimal toxic actions of chemicals. In the compounds he studied, positive effects could usually be noted with a one percent of the LD_{50} dose. With some compounds these effects were still measurable at 1,000th of this quantity. In addition to careful observation for overt toxicological signs, tests included the ability of a rodent to maintain balance on a horizontal rod and to descend a vertical rod, forced activity in dogs, escape avoidance tests, visual discrimination tests, and volitional activity. When the ratio between effective doses in animals and the approximate dose producing impairment of performance in man were compared, with only one compound did the effect occur in man with a smaller dose. Ten of 48 showed approximately comparable doses. The remainder varied from 2 to 100 times larger in terms of an increased response on the part of man.

6.2.1.7 METHODS OF EXPRESSING TOXICITY

The quantity of chemical which produces an undesirable (toxic) effect is defined in standard terms. One procedure describes the quantity in terms of a weight or volume of material per unit weight of the subject, for example, mg/kg. When speaking of the concentrations of a gas or particulate in the air, either a volume/volume relationship, parts per million (ppm), or a weight/volume relationship, mg/M^3, is generally employed. In air exposures the length of contact in minutes or hours is included. In the case of lethal concentrations or doses, the abbreviations LC or LD are used, respectively. Because of individual differences in subjects, a given concentration may be lethal to some, but not all, in which case percent lethality is shown by a subscript; e.g., LD_{50} indicates a dose which is lethal to 50 percent of the subjects tested. When subscripts are not used, the value has probably been based on limited observations and, hence, lacks statistical validity.

6.2.1.8 BASIS OF EVALUATION

Data considered in establishing toxicological standards include the physical and chemical properties of the substance, the uses and type of exposures which are anticipated, toxicity data gained from animal experimentation, extrapolation of animal data to man, and human experience.

6.2.1.9 HUMAN EXPERIENCE

Whenever available, human experience is considered in predicting safe levels, since evidence from this source is directly usable. The effects of accidental exposures resulting in toxic effects, when documented by the measurement of air concentrations producing these, are of the highest value. Measurements made in industrial establishments, where physical examination and clinical laboratory tests of personnel are conducted periodically and where air concentrations are monitored, are also excellent documentation of effect levels. Determination of threshold limits of irritation and unpleasant or irritating atmospheres is made by controlled exposures of human volunteers to noxious atmospheres. These studies generally suffer from the shortness of the exposure and the differences which are seen between members of a test group who are not accustomed to industrial atmospheres. Experimentation on behavior in man is rarely used, but is potentially of great value.

6.2.2 AIR QUALITY STANDARDS

That portion of toxicology which deals with noxious, untoward, and potentially dangerous chemical substances which are constantly in the environment of man is a relatively new science. It has developed chiefly because of public concern regarding air and water pollution and the appearance of various chemical substances in food. The problems of man continuously exposed in a closed system, as exists in the submarine or space capsule, are relatively new.

Air quality standards are used as a measure of the acceptability of air for human use. They describe contaminants in air at levels which will not adversely affect the group which is exposed. They are intended to promote maximum comfort, as well as protect against detrimental effects from continuing intake of any quantity of the contaminant. When considering the application of numerical values to air quality, much can be gained from reference to industrial hygiene standards. These have undergone a period of evolution and have gradually but surely moved in a downward direction. One of the most important features of these standards is that they are dynamic. There is always a place for the inclusion of information on new contaminants or a change in the existing values for old compounds whenever new evidence justifies the need. For our purposes, air quality standards will be defined as the admissible concentration of a discrete chemical substance or an identifiable mixture in the air of the spacecraft.

6.2.2.1 GROUPS COVERED BY AIR QUALITY STANDARDS

By far the greatest effort at environmental control has been spent on that of employed persons. The first air quality standards were unofficial, representing the considered opinion of persons interested in the protection of the health of employed persons. Most of these values were used as guides for the employer and were at a considerably higher level than is now recognized as desirable. Since 1945 scientific associations and professional societies have developed various sets of values. The best known of these are Threshold Limit Values (TLV), which are promulgated by the American Conference of Governmental Industrial Hygienists (ACGIH). The maximum allowable concentrations issued by the American Standards Association's Z-37 Committee are also authoritative opinions.

6.2.2.2 EMPLOYED PERSONS

Threshold Limits for industrial atmospheres are defined according to the philosophy that, though chemical substances are toxic at some concentration, the limit established must be such that the substance will not be injurious, regardless of how often the exposure is repeated. (This is opposed to the philosophy which covers ionizing radiation, for which the current concept is that there is no threshold, that all exposures have an associated risk to health.) Until 1963 the threshold limit value was defined as the time-weighted concentration averaged over an 8-hour work day, or Time-Weighted Average (TWA). This was in opposition to the maximum allowable concentration philosophy defined by the Z-37 Committee of the American Standards Association, which established a limited concentration, or ceiling, below which all concentrations should fluctuate. A solution to this descrepancy was achieved by adopting a "ceiling concept" for certain limits, or suitably lowering the limit and retaining the Time-Weighted Average concept. Certain substances defined by threshold limits were fast-acting and, therefore, no excursion above the limit should be permitted. These were clarified by a "C" notation which indicated that the stated limit should not be exceeded. Time-weighted average concentrations continued to be applied to all other listed values. The assignment of "C" listings was made only when excursions of concentrations for 15-minute periods might result in:

a. Intolerable irritation;

b. Chronic or irreversible tissue change;

c. Narcosis to a sufficient degree to increase accident-proneness, impair self-rescue, or materially reduce work efficiency.

6.2.2.3 GUIDELINES FOR MILITARY PERSONNEL

The U. S. Navy Submarine Service was the first group to acquire control guidelines for contaminants in the atmosphere to which persons might be continually exposed for long periods of time. The description of the development of these data in support of 90-day submergences is given by Siegel (Reference Nos. 101, 64). Forty-one long-term, continuous runs have been completed on 15 different materials important to the Navy. These included paint thinners, nitrogen dioxide, ammonia, cumene, dimethylamine, and Freon 12. Guidelines have been established or are in the process of being extablished for 26 substances. Accepted levels are published in NAVSHIPS 250-649-1 (Reference No. 110).

6.2.2.4 METHODS FOR ESTABLISHING AIR QUALITY STANDARDS

When first established, air quality standard values reflected the arbitrary opinion of single individuals. It is customary at the present time for the agency responsible for the promulgation of air quality standards to convene expert committees to review the data prior to issuing a limit value. For example, the California State Department of Public Health has called experts from around the United States to review data relative to community air quality standards in California, wherein only positive data indicating the nature and scope of physical effects are considered. The ACGIH has expanded its committee to 14 men who represent 10 different states and Canada. All disciplines relative to the committee's objectives are represented, including toxicology, engineering, industrial hygiene, analytical chemistry, and medicine. Solicitation is made by the committee for information from all available sources, including universities, industrial laboratories, and independent consultants.

6.3 SPACECRAFT CONTAMINATION

Contaminants present a formidable challenge in space-borne vehicles. The problem can be resolved if the following approach is used. First, the problem must be defined in terms of each contaminant, theoretically or actually present in the closed system. Second, after the theoretical or actual contaminants have been delineated, defined, and described, instrumentation must be designed for the qualitative and quantitative monitoring of the substances. Finally, feasible methods for eradication or control of these substances must be developed.

Three comprehensive reviews (Reference Nos. 101, 40, 24) of this subject have been made. It is apparent that, in the closed ecologic system of the spacecraft, many contaminants will appear in the immediate environment of the astronaut. Most of these would not be of concern were it not for the peculiarities of the space vehicle's ecologic system. Here, input is continuous, but outflow is limited, so a gradual accumulation of noxious materials could occur over a period of time. This would lead to an uninhabitable situation were not methods of control invoked.

Appendix 6A lists contaminants which have been identified or are suspected as being in various spacecraft, test chambers, and submersible vehicles.

Also shown are the limit values in those cases in which a limit value has been determined.

Contamination in a manned spacecraft can be expected to come from the man, the spacecraft and its equipment, from external sources, or by secondary generation. These sources are further discussed in the following paragraphs.

6.3.1 MAN

The principal sources of man-produced contaminants are expired air, urine, feces, flatus, perspiration, saliva, and sloughed skin. While carbon dioxide is the principal contaminant of expired air, other contaminants are also present. Excretion of water by a normal man averages 2,400 ml daily, the principal loss being in the form of urine, which also contains 55-70 grams of solid material. Over 100 individual electrolytes, nitrogenous substances, lipids, carbohydrates, organic acids, vitamins, and hormones have been identified in urine solids. Nitrogenous substances account for the greatest mass of these, with urea being the principal nitrogen-containing substance. The quantity of feces evacuated in 24 hours is approximately 150 grams. The composition is principally food residue, bacteria, materials secreted through the wall of the intestine, bile, leukocytes, and sloughed epithelial cells. Bacteria usually constitute about [illegible] percent of the total solids. Flatus is a continually occurring effluent and will be introduced at varying, largely unpredictable intervals. The principal intestinal gases are carbon dioxide, methane, organic sulfides, hydrogen, and mercaptans. The volume and composition of these may be varied by changes in the diet. Less work has been done on identification of the constituents of saliva and perspiration. Chromatograms of whole saliva reportedly indicate the presence of ammonia, acetone, methanol, ethanol, methyl ethyl ketone, acetonitrile, and three volatile amines. Sweat has been indicated as containing trace quantities of phenols, urea, ammonia, and electrolytes.

A source of contamination associated with, but not part of, man are the micro-organisms, fungi, and algae, which co-exist with man. The nature of these will be determined by the symbiotic relationships which develop between the variety of micro-organisms which live in the body and on the surface of man. Irvine (Reference No. 101) has estimated that 10 grams of micro-organisms will be present after 60 days and that these, in themselves, may produce noxious gases.

6.3.2 SPACECRAFT AND EQUIPMENT

Although not necessarily directly applicable to spacecraft, a useful approach for examining possible sources of spacecraft contaminants lies in studies of contamination in submarines. The relatively small volume of a spacecraft permits a quick rise in concentration from a small source of contaminating material. It has been estimated that only 0.0005 of the amount of contaminant is needed to reach a similar concentration in the air of a space capsule, such as Gemini, as in that of a submerged submarine.

Anderson and Saunders (Reference No. 101) have reported both ammonia and monoethanolamine originating from devices used in controlling CO_2 levels; hydrogen and stibine from batteries; ozone produced by electronic and electrical equipment; and radon from luminous dials. Other sources of contaminants in submarines have been such common substances as polishes, paints, lighter fluids, shaving soaps, and hair tonics (Reference No. 63).

The materials used in spacecraft interior coatings are a source of contamination. Thomas and Beck (Reference No. 101) have cited the problems of "boil-off" or out-gassing induced through operations inside space capsules at low pressures. Released materials derive from surfacing materials, adhesives, plastics, plasticizers, oils, solvent fluids, and even metals.

A considerable list of materials (Appendix 6B) has been identified as likely to be brought on-board the spacecraft in relatively large quantities. In some cases, these materials have not previously been identified as contaminants (Appendix 6C). Owing to the amounts involved, however, massive contamination of the spacecraft from these materials is possible and could cause serious problems.

Until the precise nature of the structure of the spacecraft and the materials which will go into it are known, it will be impossible to state with certainty all of the possible contaminants. However, in selecting materials to be used aboard a spacecraft, it is valuable to have a toxicological check-list to determine the potential problems anticipated from the outgassing, degradation, or accidental spillage of the material.

Toxic atmospheres result from thermal decomposition of electrical equipment, hydraulic fluid, and oil. On occasion, selenium rectifiers have given problems in aircraft. Pyrolysis of hydraulic fluids, including the silicones, fluorohydrocarbons, and phosphate esters, have given off materials which are irritating to the eyes and respiratory tract. Carbon monoxide and aldehydes are frequent breakdown products on equipment failure. Freon decomposition products form on contact with hot surfaces, and may include hydrogen halides. Analysis of pressure suit atmospheres have identified carbon dioxide, water vapor, and Freon refrigerant used in prelaunch air-conditioning systems. When the malfunctioning of directional stabilizing gyros was induced, low temperature greases volatilized and epoxy-resin wedges and the electrical insulating varnish on windings charred.

Thermal degradation of plastics will yield monomers, many of which are toxic. Though this occurs generally at high temperatures, the percentage conversion in the case of polytetrafluoroethylene, polymethacrylate, and polymethylstyrene is high. The breakdown of plastics from large chain fragments may also include small molecules not particularly related to the structural unit; thus, methyl alcohol, hydrochloric acid, hydrofluoric acid, and hydrogen cyanide may result from the vinyl halide and acrylonitrile polymers.

Mechanisms which produce abrasion of surfaces may physically generate small particles, frequently in the smaller micron range. These particles may have toxic or other deleterious effects or may cause equipment malfunction or failure.

6.3.3 EXTRAVEHICULAR AND SECONDARILY GENERATED

Migration of external contaminants through the skin of the spacecraft is unlikely. The pressure gradient is such that escape is more probable, although there is a possibility of contamination from external sources during airlock operation. A more probable external source is the radiation in space which may create decomposition products from cabin materials. While metals and inorganic materials are generally resistant to radiation, organic substances, especially plastics, show marked changes.

Electromagnetic radiations may enter the capsule from without or be generated by on-board electrical systems. These wave-lengths may catalyze the formation of aerosols similar to the photochemical reaction which occurs in some industrial/metropolitan areas.

Finally, interaction between materials originally on-board the spacecraft with other materials or with the spacecraft equipment may generate toxic contaminants not originally present (Reference No. 85).

6.3.4 PROBLEMS PECULIAR TO THE SPACECRAFT

The spacecraft poses several problems which are not encountered in the ordinary toxic action of chemical substances and which must be considered unique to the problem at hand.

6.3.4.1 WEIGHTLESSNESS

An effect of weightlessness which may be of concern with respect to toxicity is the absence of convection currents for circulation of the cabin air. In the event that the environmental control system leaves "dead spots" in the atmosphere, it is possible that this "deadness" of the air would result in local toxic concentrations.

Aerosols in the spacecraft atmosphere may cause some trouble. There will be a tendency for particles of greater diameter to remain suspended, since the usual settling effect due to gravity will not be present. With nose-breathing, this will probably constitute no problem, since particles of 10 micron and greater would be trapped in the upper air passages. With mouth-breathing, particles of a size greater than those encountered in the non-weightless atmosphere may enter the respiratory tract and impinge on the air passages or gain access to the lower portion of the respiratory tree.

There is an open question concerning the ability of the body, under weightlessness, to resist toxic effects. The employment of water-immersion methods in simulating the weightless state has resulted in diuresis (excessive excretion of urine), but, generally, our knowledge of the effects of weightlessness on body organs and mechanisms which deal with toxic substances is very scanty.

6.3.4.2 ELEVATED OXYGEN TENSIONS

Schafer (Reference No. 12), in discussing the gaseous atmosphere requirements of manned space flight, has set the upper limit of oxygen partial pressure in chronic exposure at a total pressure of 460 mm Hg for the normal 80/20 nitrogen/oxygen atmosphere, or 60 percent of the oxygen available at sea level for other atmospheres. Evidence is cited to indicate that, experimentally, the combined effects of acceleration, breathing, increased oxygen concentration, and chest cage constriction synergize to produce collapse of the basal portion of the lung. Signs of pulmonary oxygen toxicity have been noted in hospitalized patients receiving oxygen therapy. Oxygen toxicity principally involves two body systems: the respiratory, and the central nervous. Decreased vital capacity, symptoms of stress beneath the sternum, and nasal irritation have all been related to increased oxygen tensions. Confusion, motor disturbance, and coma are reported in hyperbaric oxygen treatment.

6.3.4.3 ELEVATED RADIATION LEVELS

The effects of oxygen and ionizing radiation appear to be synergistic. The same free-radical mechanism appears to be the damaging factor in both oxygen toxicity and some types of radiation damage. Since increased radiation levels may occur in space flight, this becomes a problem which requires further investigation. There is little information concerning the effect of radiation on the toxicity of substances acting on specific body systems.

6.3.4.4 ELECTROMAGNETIC ENERGIES

Beischer (Reference No. 37) has reviewed the problems of the extraterrestrial magnetic environment. The possible physiological and psychological influences of magnetic fields, or the absence of these fields, is a matter of interest and concern. Only a few studies have been conducted on the effects of toxic agents and magnetic forces acting at the same time. In one of these studies iron oxide was deposited in the lungs of animals and subjected to alternating magnetic fields, which resulted in corresponding movements of the particles but did not indicate an increased incidence of fibrosis in the animal.

6.3.4.5 INCREASED PARTICULATE LOAD

Particulates, or aerosols, include small particles, either solid or liquid, suspended in the air. Generally, these have a diameter of less than 50 μ. The usual range is from 0.01 μ to 10 μ. Surface air on the Earth contains a considerable aerosol load. The problem, unique in the closed living space, is the tendency of these particles to increase in numbers and mean diameters. Kinsey (Reference No. 101) reported that, in submerged nuclear powered submarines, the concentration reached a steady state at about 0.4 μg/L in approximately 100 hours. This compared unfavorably with the aerosol concentration in Los Angeles on a smoggy day, where the concentration averaged 0.2 µg/L. There was also approximately 8 times the content of organic aerosols in the submarine. The stability of aerosols in the space vehicle may parallel submarine experience. The effects include the increased air load and the problems created by deposition of these materials in the lower respiratory tract.

A second concern relative to these agents, in addition to their systemic effect, is that they act as condensing nuclei for toxic gases. This facilitates the entrance into the lower respiratory tract of such materials which, because of their high water solubility, are generally trapped in the upper respiratory tract. It also provides for local areas of extreme irritation in the body, due to the concentration of the toxic gas in a finite area. Verzer (Reference No. 53) called attention to the reaction of trace quantities of hydrogen sulfide and sulfur dioxide in the air of occupied spaces, indicating that they may be readily transformed into nuclei, probably sulfate, by the photochemical action of sunlight. He recommends, therefore, the exclusion of this source of energy from the spacecraft. Ammonia gas is also reported to form nuclei under the influence of sunlight.

6.3.4.6 REDUCED PRESSURES

While current planning envisions Earth-normal atmosphere, e.g., 14.7 psi, it is possible that lower pressures will be used which could amount to one-half to two-thirds of an atmosphere. No data has been published relative to the toxicity of contaminants at these reduced ambient pressures. The amount of material available presumably would not be influenced by changes in pressure. There is reason to believe, however, that the absorption rate might be more rapid in the absence of the inert nitrogen molecules. At one-half and two-thirds of an atmosphere, the number of blocking molecules would be reduced by 30-50 percent. Conversely, since absorption of gas through the alveolar membrane is a process of simple diffusion and therefore related to external pressure, the quantity taken per unit time would be decreased by a factor of two or three. The overall effect would probably not significantly alter the absorption rate.

6.3.4.7 VIBRATION

Changes in peripheral circulation, heart activity, and respiration have been observed as transient responses to moderate vibrations. Temperature decreases in the lower extremity are apparently due to impairment of the circulation to that part. Tissue damage in the form of hemorrhages in the brain, heart, and lungs occur at higher levels. While there is no reason to believe these forces would accelerate the toxic action of a chemical contaminant, those agents which primarily affect the central nervous system might increase the occurrence of a physiologically unstable state.

6.3.4.8 NOISE

There is no data at present concerning the effects of continuous low-level equipment noises in the spacecraft itself. Crew members will presumably be exposed to noise of this type in their environment without the benefit of recovery periods. As most noises, both moderate and high level, act as a stress factor and add to general fatigue, these factors may contribute to a greater overall physiologic effect from toxic agents that have central nervous system stimulatory activity.

6.3.5 ESTABLISHMENT OF TLV'S FOR SPACECRAFT

Toxicity of substances occurring in a closed ecologic system was the subject of a symposium sponsored by the Lockheed Missile and Space Company and the National Aeronautics and Space Administration in 1963 (Reference No. 101). The most enlightening paper in this symposium relative to the problem at hand was presented by H. E. Stockinger, of the U. S. Public Health Service. Considering the problems of differential pressures, the continuous dosage, temperature changes, restricted motion, increased oxygen concentration, fatigue, and the interactions of all of these factors, he derived a formula by which calculations were made of probable acceptable Threshold Limit Values (TLV) for continual occupancy. These were based on a modification of TLV's now accepted in industry. The ratios between the industrial and space TLV's ranged from 3.3:1 to 50:1 in the 12 compounds for which calculations were shown. The approach, of course, was limited to those compounds for which industrial TLV's had been established. The toxicity of substances of importance in 90-day submergence of personnel in submarines is under investigation at the toxicology laboratory of the Naval Medical Research Institute under the direction of Dr. Siegel. Preliminary data from the latter source has indicated that "no-effect" levels may be expected for most compounds at approximately one-half to one-third of the presently established industrial TLV figures.

6.3.6 THE MULTICONTAMINANT ATMOSPHERE

A study of the combined action of substances exerting a similar type of toxic effect is complicated and rarely undertaken. An evaluation of agents which have different sites of action but operate simultaneously in the same system is even more difficult. To date, no research groups have approached this problem of the multicontaminated atmosphere in depth, with the exception of the studies conducted by Dr. Sandage, of the Mid-West Research Institute. These were sponsored by the Biomedical Laboratory of the U. S. Air Force at Wright-Patterson Air Force Base, Dayton, Ohio. Exposures were made both to the single components alone and jointly in combination, four or five at a time. The compounds examined were hydrogen sulfide, methyl mercaptan, indole, skatole, carbon tetrachloride, and phenol. These are substances with potent and diverse actions. In all cases, the effects of the multiple exposures exceeded those produced by any single agent. With few exceptions, all other continuous exposure toxicological work from which data can be extracted is based on single, rather than multiple, contaminant exposures.

6.4 MEDICAL CONSIDERATIONS

The medical function requires that provision be made to monitor the health of the crew or to acquire other information throughout the mission, to ensure, within acceptable risk levels, that the crew returns to Earth in good health. Medical considerations were incorporated in the various tasks of the study through a supporting effort and are, therefore, discussed only briefly here. Two aspects of the medical function are considered, preventive medicine and clinical medicine.

6.4.1 PREVENTIVE MEDICINE

The intent of preventive medicine is to prevent disease and promote physical and mental health and efficiency. It is especially concerned with all circumstances dealing with the predisposing factors which increase an individual's vulnerability to disease, provoking factors which initiate or precipitate a disease process, and perpetuating factors which tend to cause disease progression. Preventive medicine may be divided into two aspects: that which deals directly with personnel and that which deals with hardware directly affecting the crew.

Personnel aspects include such things as crew selection and training, immunization, and personal and mental hygiene. With the exception of some aspects of personal and mental hygiene, these functions are generally performed prior to the space mission. The Safety Study, being constrained to on-orbit operation only, used the assumption that all crew members arrive in orbit in good health, with no incipient physical or mental defects, and competent, whether by training or otherwise, to perform all assigned tasks. Anything prerequisite to this assumption is not specifically covered by the study, although some factors may be implicit in study results.

Hardware aspects include provision of life support and protection subsystems, maintenance of a habitable environment, provision of sanitary facilities, provision of means for exercise and relaxation, and the like. Support with respect to these aspects was provided to other tasks in the study and the medical considerations with respect to hardware are, therefore, implicit in the results of other tasks.

6.4.2 CLINICAL MEDICINE

Clinical medicine deals with the medical resources and services required to diagnose and treat any illness or injury incurred by crew members. It is assumed that preventive measures will not be completely effective in precluding illness or injury and provision for clinical medicine will be an important feature of the spacecraft.

6.4.2.1 MEDICAL PERSONNEL

A physician is highly desirable as a crew member and will be required to conduct important medical experiments, such as those described in the Biomedical and Behavioral Research Functional Program Element (Reference No. 14). In the absence of a physician, some other crew member should be trained or have medical experience in handling medical emergencies. Short-term or minor illnesses and injuries may be treated by a responsible crew member, providing his medical background is appropriate and adequate facilities are provided. In addition, assistance from ground control facilities is possible, providing appropriate communication links, such as closed-circuit TV, are available.

In any event, a station Health and Safety Officer should be designated, presumably the physician or medical crew member. His responsibilities should include (Reference No. 122): the housekeeping aspects of the spacecraft, development and use of safe operating procedures, proper utilization of personal protective equipment and clothing, identification and preliminary diagnosis of illness and injury, prognosis of illness and injury, decisions as to quarantine requirements, and administration of treatment to ill or injured crew members.

6.4.2.2 MEDICAL SERVICES

Medical services include examination, testing, diagnosis, and treatment; and treatment, in turn, includes medication, surgery, and physical therapy. In this regard, the Biomedical and Behavioral Research Functional Program Element (Reference No. 14) contemplates use of an Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS). The IMBLMS is intended to provide the facilities needed to conduct medical and behavioral experiments involving examination and testing of the crew members themselves. It can be expected that medical and behavioral experiments will be continued in both the space station and space base over several years of operation. Consideration should be given, therefore, to use of IMBLMS, perhaps with special added modules, for routine, as well as experimental, monitoring of crew member's health.

In view of the crew selection, medical monitoring, and (possibly) preflight quarantine processes, the probability of serious illness during the space mission appears quite remote, but the possibility does exist. Minor illnesses and injuries may be expected, with a possibility of serious injury. There is, of course, the still unknown area of the seriousness of the effects of long-duration missions on the crew.

It may be feasible to evacuate seriously ill or injured crew members to Earth for treatment. At the time of the Safety Study, preliminary information on the Advanced Space Shuttle indicated that the forces during reentry would not exceed two and one-half ($2\frac{1}{2}$) "g's", and that high only momentarily. This is comparable to medical evacuation aircraft. It would appear, then, that evacuation to Earth of seriously ill or injured personnel would hinge more on operational considerations than on medical.

The treatment facilities required would be primarily those necessary for treatment of minor illnesses and injuries, with provision for temporary care of major illnesses or injuries. A clinic for examination, testing, and diagnosis will be necessary, which, as previously noted, might well be combined with the medical experimentation laboratory. A sick bay also should be provided for at least temporary care. Although serious communicable diseases are not likely, it may be desirable to include provisions in the sick bay for hospital-type isolation.

There appears to be no need for a hyperbaric chamber. Crew members may be exposed to accidental decompression or may be unexpectedly affected by low pressures during operations such as EVA. Treatment would require only return to normal station pressure, however. Hyperbaric treatment is indicated for certain diseases caused by anaerobic organisms or for certain circulatory defects. The possibility of these occurring on the space station is considered highly remote. If, on the basis of further data, an hyperbaric chamber is indicated, consideration should be given to use of an airlock for the purpose.

On a long-duration space mission there is a possibility of crew fatalities. Provision should be made for preservation of the body, an autopsy if required, and return of the body to Earth. If space burial is authorized, it will be necessary to preserve the necessary tissue samples for a later autopsy.

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APPENDIX 6A

MATERIALS---OCCURRENCES---LIMITS

This appendix lists contaminants or materials which have been identified or suspected in the atmospheres of spacecraft, test chambers, or submarines. The list was compiled from a variety of sources, including: Atmospheric Contaminants in Spacecraft (Reference No. 11), U. S. Navy 1962 Atmosphere Habitability Data Book (Reference No. 10), Contamination Patterns in the Enclosed Atmosphere of Mercury Spacecraft (Reference No. 17), and Nuclear Power Submarine Atmosphere Control (Reference No. 63). For the most part, these materials are trace contaminants.

The listing shows the name of the material and its molecular weight. Under occurrences are shown the vehicle in which the material was identified or its existence suspected. Atmospheric limits are given for those materials for which a limit has been established. The limits shown are in parts-per-million and include: American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV's); 1-hour, 24-hour, and 90-day submarine limits; Boeing Company Limits; and Douglas limits for continuous exposure, which require an "alert" status, and which call for mission abort.

Letters appearing from time to time in the listing are:

b --- Submarine levels which are

Aliphatic hydrocarbons	--- 60 mg/M^3
Aromatic hydrocarbons other than benzene	--- 10 mg/M^3
Benzene	--- 3 mg/M^3

T --- Tentative values based on ACGIH Threshold Limit Values, 1966.

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
Acetaldehyde	44.05	X	X						X	X	X	X	X	X	X	X	X		200				50	5	20	200
Acetic Acid	60.05						X		X	X					X	X	X		10				2	0.4	1.6	10
Acetone	58.08	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		1000		2000	300	500	20	80	1000
Acetylene	26.04	X	X	X					X						X		X			6000	6000	6000	2500			
Acrolein	56.06																X									
Acrylonitrile	53.06							X											20					0.4	1.6	20
Allene	40.07									X																
Allyl Alcohol	58.08	X							X	X	X								2							
Ammonia	17.03			X			X			X		X				X	X		50	400	50	25	25	25	100	100
Amyl Acetate	130.18									X	X								100				20			
Amyl Alcohol	88.15									X																
Arsine	77.93																X									
Benzene	78.11	X		X	X		X		X	X	X			X	X	X	X		25		100	1	5			
Benzyl Ether	198.25								X	X																
1-3 Butadiene	54.09				X		X		X										1000							
n-Butane	58.12	X	X	X	X		X		X	X		X	X		X		X						5000			
Iso-Butane	58.12								X								X									

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
2-3, Butanedione	86.09																X									
2-Butanone	72.11	X	X				X		X	X	X	X		X	X	X	X		200				100	4	16	200
1-Butene	56.10	X		X		X			X						X		X						4000			
2-Butene cistrans	56.10	X	X				X		X								X						4000			
Butyl Acetate	116.16								X	X									150				50			
iso-Butyl Acetate	116.16										X								200							
n-Butyl Alcohol	74.12	X	X						X		X			X	X	X			100				25			
iso-Butyl Alcohol	74.12	X	X	X			X		X	X	X					X			150				25			
sec-Butyl Acrylate	128.17						X																			
n-Butyl Benzene	134.21									X							X									
sec-Butylbenzene	135.21																X									
tert-Butyl Benzene	134.21									X							X									
iso-Butylene	56.10								X			X			X		X									
Butyraldehyde	72.10								X	X	X												100			
Butric Acid	88.10														X								5			
Carbon Dioxide	44.01	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		5000	25000	10000	5000	5000	12500	15000	
Carbon Disulfide	76.14	X	X	X						X		X			X				20				2			

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
Carbon Monoxide	28.01			X	X				X	X	X				X	X	X		50	200	200	25	25	25	100	100
Carbon Tetrachloride	153.82						X		X	X	X				X				10				2	0.5	2	10
Carbonyl Sulfide	60.07											X				X							2			
Chlorine	70.91																X		1		1	0.1	0.5	0.04	0.16	1.0
Chlorobenzene	112.56								X	X	X								75							
1-Chlorobutane	92.57							X																		
Chlorofluoro-Bromomethane	147.47							X																		
Chlorofluoro-ethylene	80.5			X				X																		
Chloroform	119.38			X			X		X	X	X				X	X			50							
Chloromethane	50.49			X				X	X	X		X							100				200	2	8	100
Cyclohexane	84.16	X	X	X	X		X		X	X	X				X			X	300				200			
Cyclohexene	82.14								X	X									300							
Cyclopentane	70.13			X	X					X																
Cyclopentene	68.11									X																
Cyclopropane	42.08								X																	
Decalin (-various -isomers	138.25								X	X	X															
Decane	142.29									X							X									

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
Dichloro-acetylene	94.93											X														
Dichlorobenzene	147.01															X			o 50 p 75							
1-2, Dichloro-ethane	98.88						X		X	X	X			X												
Dichlorodifluoro-methane R-12	120.92																			2000						
1-1, Dichloro-ethylene	96.93	X					X	X	X	X							X						5			
1-2, Dichloro-ethylene	96.95				X														200							
Dichloromethane	84.93	X	X		X	X	X	X	X	X	X			X					500				100			
1-2, Dichloro-propane	112.99							X											75							
1-3, Dichloro-propane	112.99							X																		
Diethylbenzene	134.21									X							X									
1-4, Dimethoxy benzene	138.16								X																	
Dimethylamine	45.08									X									10				5			
2-2, Dimethyl-butane	86.17	X	X	X			X		X	X	X												4000			
2-3, Dimethyl-butane	86.17								X	X	X															
n-Dodecane	170.33																X									
Dimethyl-cychlohexane	112.22	X							X	X	X				X											
Dimethyl-cyclopentane	100.13								X	X																

MATERIALS - OCCURRENCES - LIMITS

MATERIAL	MOL WT	REPORTED OCCURRENCES																	UNITS IN PARTS PER MILLION ATMOSPHERIC LIMITS (PPM)							
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	SUBMARINE 1 HOUR	SUBMARINE 24 HOUR	SUBMARINE 90 DAY	BOEING COMPANY	DOUGLAS CONTINUOUS	DOUGLAS ALERT	DOUGLAS ABORT
1-3, Dimethyl-5 ethylbenzene	134.22																X						25			
Dimethyl Furan	96.13								X	X	X															
Dimethyl Naphthalene	156.22								X	X																
2,4-Dimethly Pentanel	100.21									X						X										
Dimethyl Propane	72.15									X																
Dimethyl Sulfide	62.14									X	X												5	4	16	20
Dimethyl Thiophene	112.19									X																
1,4-Dioxane	88.11	X							X					X					100				10			
Dioxene	86.10	X	X	X	X																		10			
Ethane	30.07		X	X	X	X	X	X	X	X							X									
Ethanethiol	62.13		X		X						X								10				2			
Ethanol	46.07																				500	100				
2-Ethoxyethanol	90.12															X			200							
2-Ethoxyethyl Acetate	132.16															X			100							
Ethyl Acetate	88.10		X	X			X		X	X	X			X	X		X		400				50			
Ethyl Acetylene	54.09			X																						
Ethyl Acrylate	100.12						X												25							

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
Ethyl Alcohol	46.07	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		1000		500	100	200			
Ethylamine	45.08															X			10				1			
Ethyl benzene	106.16								X	X	X				X		X	X	100				20			
Ethyl Chloride	64.52											X							1000							
Ethyl Cyclohexane	112.22	X								X							X									
Ethylene	28.05	X	X				X		X	X	X			X	X		X						500			
Ethylene Oxide	44.05															X			50							
Ethyl Ether	74.12			X	X				X	X	X	X							400				100			
Ethyl Formate	74.08								X	X	X				X				100				20			
M,P-Ethyl toluene	120.19																X									
Formaldehyde	30.03	X	X												X	X	X		5				0.1	0.2	0.8	5
Fluoroethane	48.06							X																		
2-Fluoropropene	60.07							X																		
R-11, Flurotri-chloromethane	137.38	X	X	X			X		X	X	X			X	X	X	X		1000	30000	20000	1000	500			
R-12 Dichlorodi-fluoromethane	120.91	X					X	X		X		X					X		1000	30000	20000	1000	500			
R-22, Chlorodi-fluoromethane	86.48	X	X	X					X	X	X												500			
R-23, Tri.luoro-methane	70.01	X	X																				500			

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
R-113, $FCl_2C-CClF_2$	187.39						X		X	X	X								1000				500			
R-114, $F_2ClC-CClF_2$	170.93	X	X						X	X	X			X			X		1000	30000	20000	1000	500			
R-125, F_2HC-CF_3	121.03	X	X						X		X												500			
Furan	68.07				X				X	X	X												10			
Furfural	96.08									X									5							
Furfural Alcohol	98.10									X									50							
n-Heptane	100.20						X		X	X	X				X	X	X	X	500				200			
Heptene	98.18									X																
Hexafluoro-benzene	186.00									X																
Hexamethyl cyclotrisiloxane	166.00	X													X								50			
n-Hexane	86.17	X	X	X				X	X	X	X				X	X	X	X	500				200			
Hexene-1	84.16	X	X							X													1			
Hydrocarbons	N/A																X									
Hydrogen	1.008		X							X					X		X			10000	10000	10000				
Hydrogen Chloride	36.46																X		5	10	4	1	0.1	0.1	0.4	5
Hydrogen Cyanide	27.03																X									
Hydrogen Fluoride	20.01							X									X		3	8	1	0.1	0.1	0.1	0.4	3

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
Hydrogen Sulfide	34.08			X					X								X		10	50			2	4	16	20
Indene	116.15						X		X	X																
Indole	117.14									X													0.5			
Isoprene	68.11						X		X	X	X				X								200			
Isopropanol	60.09																				200	50				
Mercury	200.61																X				2 mg/m3	0.01 mg/m3				
Mesitylene	120.19																X									
Methane	16.04		X	X	X		X	X	X	X	X				X	X	X	X		13000	13000	13000				
Methyl Acetate	74.08								X	X	X								200				10			
Methyl Alcohol	32.04	X	X	X	X		X		X	X	X	X	X	X	X		X		200		200	10	3	4	16	200
Methylamine	31.06								X										10				1			
2-Methyl-butanone-3	86.13	X									X			X												
Methyl Chloride	50.49																X									
Methyl Chloroform	133.42																X			25	10	2.5				
Methyl Cyclohexane	98.18								X	X	X				X		X	X	500							
Methyl Cyclohexene	96.17									X																
Methyl Cyclopentane	84.13									X					X			X								

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
Methylethyl benzene	120.21									X						X	X						20			
Methyl Ethyl Thiophene	126.22									X																
Methyl Formate	60.05												X						100				10			
Methyl Furan	82.10								X	X	X						X						10			
Methyl iso Butyl Ketone	100.16						X		X	X	X				X	X	X		100				10			
Methanethiol	48.10						X			X	X								10				2	2	4	50
Methyl Methacrylate	100.11										X					X			100				10			
Methyl Naphthalene	142.19								X	X																
Methyl Butyrate	102.13								X	X	X															
2-Methyl Pentane	86.17	X								X	X					X										
3-Methyl Pentane	86.17	X	X							X													1000			
4-Methyl-2-Pentanone	100.16																X									
Methylsiloxane Polymers																X										
Methyl Thiopene	98.17						X			X																
Monochloro Acetylene	60.48											X														
Monoethanolamine	61.08																X		3	50	3	0.5	1			
Napthalene	128.18								X	X	X						X		10							

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
Nitric Oxide	30.01												X				X		25				1	0.4	1.6	10
Nitrogen Dioxide	46.01													X			X		5	10	1	0.5	0.5	0.2	0.8	5
Nitrous Oxide	44.01																X						5000			
n-Nonane	128.25									X							X	X								
Octane	114.23									X	X				X		X	X	500							
Ozone	48.00																X		0.1	1.0	0.1	0.02	0.05	0.004	0.016	0.1
Pentane	72.15	X	X						X	X	X	X			X		X		1000				1000			
3-Pentanone	86.13																X									
iso-Pentane	72.15	X	X						X	X	X	X					X						1000			
1-Pentene	70.13								X																	
Perchloro-ethylene	165.85	X	X						X	X	X	X			X				100							
Phenol	94.11															X	X		5				1.0	0.2	0.8	5.0
Phosgene	98.92											X					X		0.1	1.0	0.1	0.05	0.05	0.04	0.16	1.0
Propane	44.09	X		X	X		X	X	X	X							X		1000				1000			
Propene	42.08					X		X																		
Propionaldehyde	58.08															X	X						50			
Propionic Acid	74.08								X	X					X								5			

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES: MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	ATMOSPHERIC LIMITS (PPM): AGGIH TLV'S	SUBMARINE: 1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	DOUGLAS: CONTINUOUS	ALERT	ABORT
Propyl Acetate	102.18	X							X		X								200							
n-Propyl Alcohol	60.09	X	X						X	X	X			X		X			200				100			
iso-Propyl Alcohol	60.09	X		X	X	X	X		X	X	X				X	X	X		400		200	50	100			
iso-Propyl Benzene	120.19									X							X		50				20			
n-Propyl Benzene	120.19									X							X									
Propyl Chloride	78.54		X								X															
Propylene	42.08	X	X						X	X	X	X			X		X						1000			
iso-Propyl Ether	102.17								X	X	X								500							
Propanethiol	76.16								X	X	X															
iso-Propanethiol	76.16						X																			
Propyne	40.06								X										1000				1000			
Pseudocumene	120.19								X	X							X						20			
Silicone Oil																X										
Skatole	131.17						X																0.5			
Stibine	124.78																X				0.05	0.01				
Styrene	104.14						X	X											100							
Sulfur Dioxide	64.07	X	X														X		5	10	5.0	1.0	0.2	0.2	0.8	5

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
1,2,4,5-Tetrachlorobenzene	215.90															X										
Tetrachloroethane	167.85							X							X											
Tetrafluorobenzene	150.00							X																		
Tetrafluoroethylene	100.2	X	X																							
Tetrahydrofuran	72.10						X	X	X										200				20			
Tetramethylbenzene	134.21						X	X																		
Toluene	92.13	X	X	X	X		X		X	X	X								200		100	50	50			
Triaryl Phosphate	--																X				50 mg/m^3	1 mg/m^3				
1,1,1-Trichloroethane	133.42	X							X	X	X			X			X		350	1000	500	200	50			
Trichloroethylene	131.40	X	X						X	X	X	X		X	X	X			100				20			
Trichloromonofluoromethane R-11	137.88																			50	20	5				
Trifluorobenzene	132.00									X																
Trifluorochloroethane	104.50							X																		
1,3,5-Trimethyl Benzene	120.20								X	X													20			
Trimethyl Hexane	128.24									X																
Trimethyl Pentane	114.23			X					X	X																
Trimethylsilanol	80.00															X										

MATERIALS - OCCURRENCES - LIMITS

UNITS IN PARTS PER MILLION

MATERIAL	MOL WT	REPORTED OCCURRENCES																	ATMOSPHERIC LIMITS (PPM)							
																				SUBMARINE				DOUGLAS		
		MERCURY	GT-3	GT-4	GT-5	GT-7	GT-10	GT-12	SAM I	SAM II	SAM III	MESA I	MESA II	MERC MALFUNC	INTEGRATED LIFT SCI SYSTEMS TESTS	OFFGASSING	SUBMARINES	SEA LAB II	AGGIH TLV'S	1 HOUR	24 HOUR	90 DAY	BOEING COMPANY	CONTINUOUS	ALERT	ABORT
n-Undecane	156.30																X									
Valeric Acid	102.13								X	X																
Vinyl Chloride	62.50	X							X	X	X			X			X		500				100	10	40	500
Vinylidene Chloride	96.95	X					X	X	X	X		X					X			25	10	2	5			
Xylene,m-,p-,o-	106.16	X					X		X	X	X			X		X	X	X	100		100	50	50			

APPENDIX 6B

EXPERIMENTAL/OPERATIONAL MATERIALS

The materials listed in this appendix are those which were identified by the Saturn V Single Launch Space Station Study (SLSS) (Reference Nos. 79, 80, 81) as likely to be brought on-board the space station for operational or experimental uses. As contrasted to the materials listed in Appendix 6A, which are primarily trace contaminants, these materials may be present in relatively large amounts. This leads to the possibility of massive contamination, as well as trace contamination of the station or some areas of it.

The listing shows the name of the material concerned and the toxic levels, if levels have been determined, for 8-hour Threshold Limit Value (TLV) and 90-day continuous exposure. The effects of the material on various body systems are shown with the means by which the material is toxic or hazardous. In addition to toxicity, some materials may be hazardous for other reasons, which are also shown.

MATERIAL	TOXIC LEVELS		TOXIC EFFECTS ON DIFFERENT BODY SYSTEMS													TOXIC OR HAZARDOUS BY			OTHER HAZARDS
	8 HR TLV ppm	90-DAY CONTINUOUS ppm	AUTONOMIC N.S. 1	BLOOD 2	CARDIOVASCULAR 3	CNS DEPRESSANT 4	CNS STIMULANT 5	ENZYME INHIBITOR 6	HEMATOPOIETIC T'SSUE 7	HEPATO AGENT 8	MUCOUS MEMBRANE 9	NEPHRO AGENT 10	PERIPHERAL N.S. 11	RESPIRATORY 12	SIMPLE ASPHYXIANT 13	INHALATION	INGESTION	CONTACT	
Ammonia	50	25					*				*			*		*	*	*	Flammable and explosive.
Ammonia Thiocyanate					*	*					*			*		*	*	*	Very toxic if decomposed by heating or chemical reaction.
Acetone	1000	500				*					*					*	*	*	Highly flammable.
Acetic Acid	10	2									*			*		*	*	*	Highly flammable.
Amines (Ammonia derivatives)	5 to 25	1 to 15	*		*		*			*	*	*		*		*	*	*	Flammable compounds.
Aldehydes						*	*				*	*		*		*	*	*	Flammable.
Aniline Dyes				*	*						*			*		*	*	*	
Carbon Dioxide	5000	5000				*									*	*	*		
Chlorine	1	0.5									*			*		*	*	*	Highly reactive, forms explosive mixtures w/hydrogen
Carbon Disulfide	20 Skin	2				*	*						*			*	*		Very flammable.
Charcoal	--	--														-	-	-	High dust conc. coudl produce coughing & choking.
Cadmium Metal	--	--												*		*	*		Very toxic when vaporized by heating.

MATERIAL	TOXIC LEVELS		TOXIC EFFECTS ON DIFFERENT BODY SYSTEMS													TOXIC OR HAZARDOUS BY			OTHER HAZARDS
	8 HR TLV ppm	90-DAY CONTINUOUS ppm	1 AUTONOMIC N.S.	2 BLOOD	3 CARDIOVASCULAR	4 CNS DEPRESSANT	5 CNS STIMULANT	6 ENZYME INHIBITOR	7 HEMATOPOIETIC TISSUE	8 HEPATO AGENT	9 MUCOUS MEMBRANE	10 NEPHRO AGENT	11 PERIPHERAL N.S.	12 RESPIRATORY	13 SIMPLE ASPHYXIANT	INHALATION	INGESTION	CONTACT	
Carbon Monoxide	50	25		*							*			*		*	*	*	Very flammable.
Disinfectants and Detergents																*	*		
Detergents Soaps Synthetic																	*	*	
2-3 Dimethyl Quinoxaline																			
Ethyl Alcohol	1000	200				*					*					*	*		Flammable.
Estar Polyester with Hydrophilic Celatin																			
Freon 12 Coolant (Dichlorodifluoromethane)	1000	500				*					*			*		*			
Hydrogen Sulfide	10	2						*			*			*		*		*	Flammable--explosive.
Hydrochloric Acid	.5	0.1									*			*		*	*	*	Highly corrosive.
Lithium Hydroxide	--	--					*					*	*				*	*	Acrid, strong alkaline (caustic).
Methane	1000	2500				*									*				Flammable and explosive.
Mercury	--	--					*				*	*	*			*	*	*	Spilled & heated H_g is very hazardous.

MATERIAL	TOXIC LEVELS		TOXIC EFFECTS ON DIFFERENT BODY SYSTEMS													TOXIC OR HAZARDOUS BY			OTHER HAZARDS
	8 HR TLV ppm	90-DAY CONTINUOUS ppm	AUTONOMIC N.S. 1	BLOOD 2	CARDIOVASCULAR 3	CNS DEPRESSANT 4	CNS STIMULANT 5	ENZYME INHIBITOR 6	HEMATOPOIETIC TISSUE 7	HEPATO AGENT 8	MUCOUS MEMBRANE 9	NEPHRO AGENT 10	PERIPHERAL N.S. 11	RESPIRATORY 12	SIMPLE ASPHYXIANT 13	INHALATION	INGESTION	CONTACT	
Methyl Alcohol	200	3				*		*					*			*	*	*	Flammable; explosive.
Monomethyl Hydrazine	0.2	> 0.1		*			*			*		*		*		*	*	*	Hypergolic, explosive.
Nitrogen Oxide (Nitric Oxide)	25	0.5									*			*		*	*	*	
Nitrogen Dioxide	5	0.5			*				*		*	*		*		*	*	*	
Nitrogen--Liquid	--	As a gas 600,000												*				*	Severe "burns" (frostbite).
Nickel Metal	0.4	0.1									*			*					Burns in O_2.
Nitrogen Tetroxide	2.5	>1	*			*								*		*	*	*	Hypergolic, nonflammable in air, but supports combustion.
Oxygen--Liquid	--	As a gas 400,000						*			*			*				*	Nonflammable, but supports combustion.
Phenidone--Hydroquinote--Thiosulfate																			
Potassium Bromide	--	--				*					*						*		
Potassium Alum (Potassium Aluminum Sulfate)	--	--									*			*			*		
Phenidone																			

MATERIAL	TOXIC LEVELS		TOXIC EFFECTS ON DIFFERENT BODY SYSTEMS													TOXIC OR HAZARDOUS BY			OTHER HAZARDS
	8 HR TLV ppm	90-DAY CONTINUOUS ppm	AUTONOMIC N.S. 1	BLOOD 2	CARDIOVASCULAR 3	CNS DEPRESSANT 4	CNS STIMULANT 5	ENZYME INHIBITOR 6	HEMATOPOIETIC TISSUE 7	HEPATO AGENT 8	MUCOUS MEMBRANE 9	NEPHRO AGENT 10	PERIPHERAL N.S. 11	RESPIRATORY 12	SIMPLE ASPHYXIANT 13	INHALATION	INGESTION	CONTACT	
Poly Vinyl Fluoride																			
Potassium Hydroxide--Solid	--	--									*			*		*	*	*	Very caustic to tissue, hygroscopic.
Sulfur Dioxide	5										*			*		*	*	*	
Sulfur Trioxide	> 1										*			*		*	*	*	Combines with water, forming H_2SO_4 with explosive violence.
Sodium Hydroxide--Solid	--	--									*			*		*	*	*	Very caustic to tissue, hygroscopic.
Sodium Thiosulfate	--	--									*					*	*	*	
Sodium Sulfite	--	--									*					*	*	*	Unstable, oxidizing in air to sulfate.
Sodium Carbonate	--	--									*					*	*	*	Hygroscopic--combines with water, evolves heat.
Silica Gel (Silicic Acid)	--	--												*		*	*		Hygroscopic.
Trichloroacetic Acid	--	--									*			*		*	*	*	Very corrosive and hygroscopic.
Thiourea (Thiocarbamide)	--	--									*						*		
Tissue Stains	--	--									*			*		*	*	*	Nature of solvent will affect toxicity characteristic.

APPENDIX 6C

RESIDUAL MATERIALS

The materials listed in Appendix 6A have already been identified as present or likely to be present in spacecraft atmospheres. It is assumed, therefore, that the Environmental Control/Life Support System (EC/LSS) in future spacecraft will provide for their identification and/or removal if there are any hazards involved. It follows that the EC/LSS will also accommodate hazards from the materials listed in Appendix 6B, with the provisos that the materials are common to both lists and that the degree of contamination is within the capacity of the EC/LSS to handle.

There are, however, a number of materials included in the experimental/operational materials listing of Appendix 6B which do not appear to have been identified by Appendix 6A as present or likely to be present in space stations. These "residual" materials are listed in this Appendix 6C. Provisions must be made for their control if they are, in fact, on-board the spacecraft.

Ammonium Thiocyanate
Amines (Ammonia Derivatives)
Aniline Dyes (Aminobenzene, Phenylamine)
Charcoal
Cadmium Metal
Detergents
2-3 Dimethyl Quinozaline
Ester Polyester with Hydrophilic Gelatin
Lithium Hydroxide
Monomethyl Hydrazine
Nickel Metal
Nitrogen Tetroxide
Phenidone---Hydroquinone---Thiosulfate
Potassium Bromide
Potassium Alum (Potassium Aluminum Sulfate)
Phenidone
Poly Vinyl Fluoride
Potassium Hydroxide---Solid
Sulfur Trioxide
Sodium Hydroxide---Solid
Sodium Thiosulfate
Sodium Sulfite
Sodium Carbonate
Silica Gen (Silicic Acid)
Soaps
Trichloroacetic Acid
Thiourea (Thiocarbamide)
Tissue Stains

7.0 METEOROID PENETRATION ANALYSIS

7.1 INTRODUCTION

In this analysis, the meteoroid environment hazards associated with the space station during its orbital stay were examined. Based on the configuration concept presented in Section 2.0 of this document, some basic calculations are given to arrive at total exterior surface exposure over the ten-year mission. Using this value, in conjunction with other information, a determination was made of the meteoroid mass and diameter for which protection must be provided and the shield weight required was calculated. For comparative purposes, and where possible, some parametric data is shown for both the space station and the SLSS system. Data for the latter was derived during the SLSS study conducted under Contract NAS9-6816, and is presented in the report on that study (Reference No. 81). Some preliminary results of an investigation of meteoroid penetration effects are given.

7.2 METEOROID PROTECTION CONSIDERATIONS

7.2.1 METEOROID FLUX

The meteoroid flux given in NASA DS-21, "Meteoroid Environment---Near-Earth and Cis-Lunar," (Reference No. 58) was used in this study. It provides an estimate of the number of strikes by meteoroids of various sizes per unit area per unit time. However, it should be noted that other estimates of meteoroid flux vary considerably from the one used.

7.2.2 STATION EXPOSURE

Table 7-1 summarizes the gross parameters for the space station and the SLSS baseline vehicle, including the exposure during the mission for each.

TABLE 7-1
SPACE STATION PARAMETERS

MISSION	DIAMETER (ft)	LENGTH (ft)	TOTAL AREA (ft^2)	MODIFIED AREA (ft^2)	EXPOSURE ($10^8/ft^2$-hr)
SLSS	33	30.8	5320	3640	.637*
SPACE STATION	33	53.5 (1)	7280 (2)	4960 (3)	4.35** (4)

Notes:
(1) Pressurized compartment only.
(2) Includes end surfaces.
(3) Modified to include Earth shielding at 260-nautical mile altitude.
(4) *Two-year mission **Ten-year mission.

7.2.3 METEOROID DESIGN MASS

The meteoroid size which established the penetration protection requirements can be determined from the flux, exposures, and the Poisson's probability distribution function as discussed in Appendix I to Reference No. 81. In this study, a nomogram, Figure 7-1, taking the foregoing into account, was used to estimate meteoroid size (Reference No. 59).

The probability level stipulated for the space station system as defined in Reference No. 92 is $P_{(0)} \leq 0.9$ (i.e., the probability of zero penetrations in a ten-year mission shall be 0.9). For comparative purposes, a probability of one or less penetration, $P_{(1)}$, at the same level was also examined. For the SLSS, $P_{(1)}$ and $P_{(0)} = 0.999$ for a two-year mission.

The nomogram, Figure 7-1, was used to estimate the particle mass and diameter for varying probability and exposure (Reference No. 59). As it indicates, the meteoroid associated with a penetration probability of $P_{(1)} = 0.9$, a total surface exposure of 4.35×10^8 ft^2-hr., and the flux stipulated in Reference No. 58, has a mass of 0.0054 grams, and a diameter of 0.107 inches. When zero penetrations at the same probability level, i.e.: $P_{(0)} = 0.9$, are considered, the nomogram reflects a meteoroid of 0.02 grams mass and 0.167 inch diameter.

The particle design mass diameters for the stations and probabilities considered are summarized in Table 7-2. Again, it should be pointed out, that the data given for the SLSS station is for a 0.999 probability level, and a two-year mission.

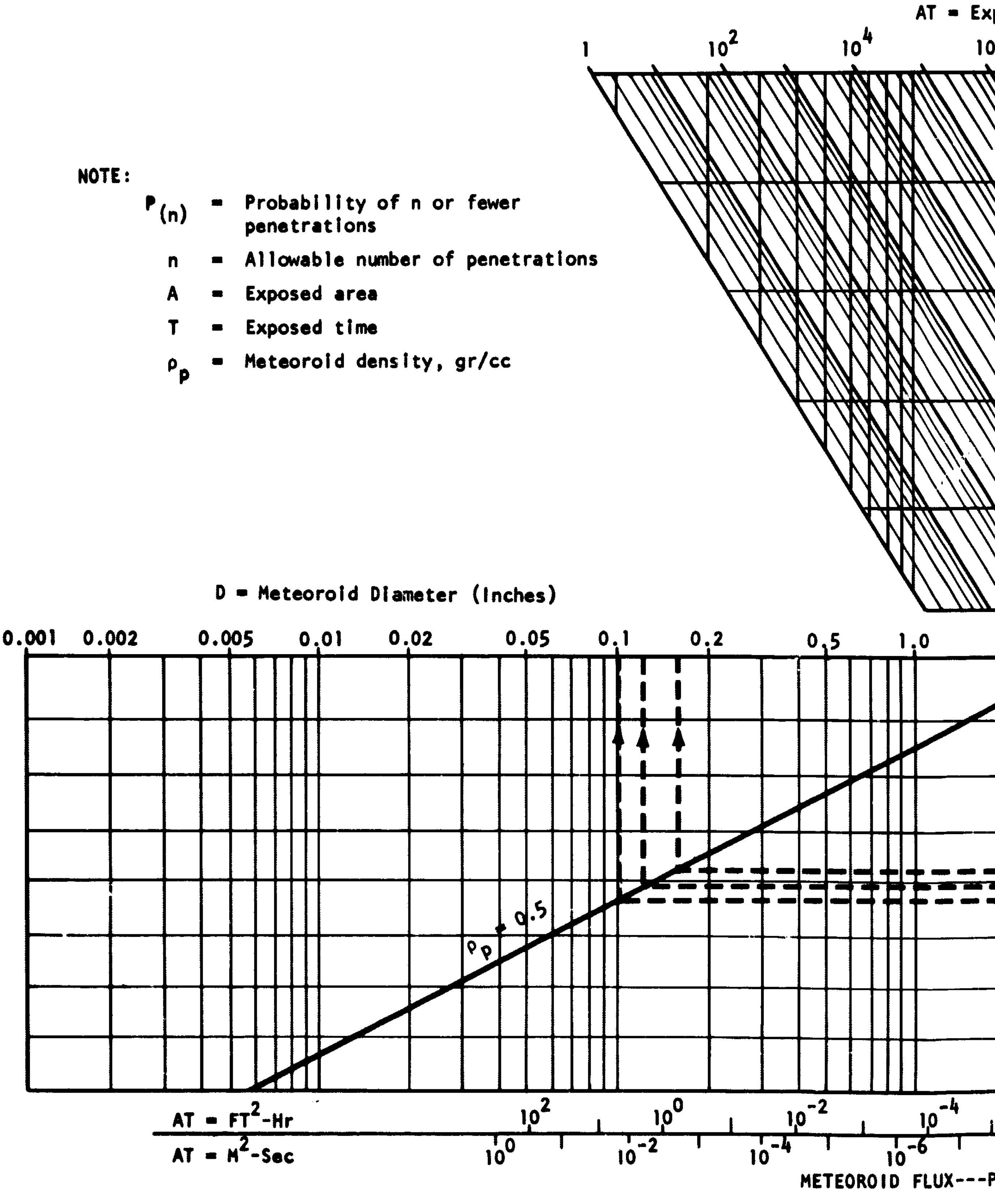
TABLE 7-2
METEOROID MASS AND DIAMETER

MISSION	STATION DIA. (ft)	EXPOSURE (10^8ft^2-hr)	$P_{(1)}$				$P_{(0)}$			
			0.999		0.9		0.999		0.9	
			m (gm)	Dia. (in)	m (gm)	Dia. (in)	m (gm)	Dia. (in)	m (gm)	Dia. (in)
SLSS	33	0.637	0.0102	0.134			0.179	0.346		
SPACE STATION	33	4.35	0.04	0.19	0.0054	0.107	0.05	0.54	0.02	0.167

7.2.4 SHIELD WEIGHT

The total shield weight required for protection against the meteoroids defined above was estimated using the following equation taken from Reference No. 68,

$$W = 41.51\ km^{0.352},$$



NOTE:

$P_{(n)}$ = Probability of n or fewer penetrations

n = Allowable number of penetrations

A = Exposed area

T = Exposed time

ρ_p = Meteoroid density, gr/cc

FOLDOUT FRAME 1

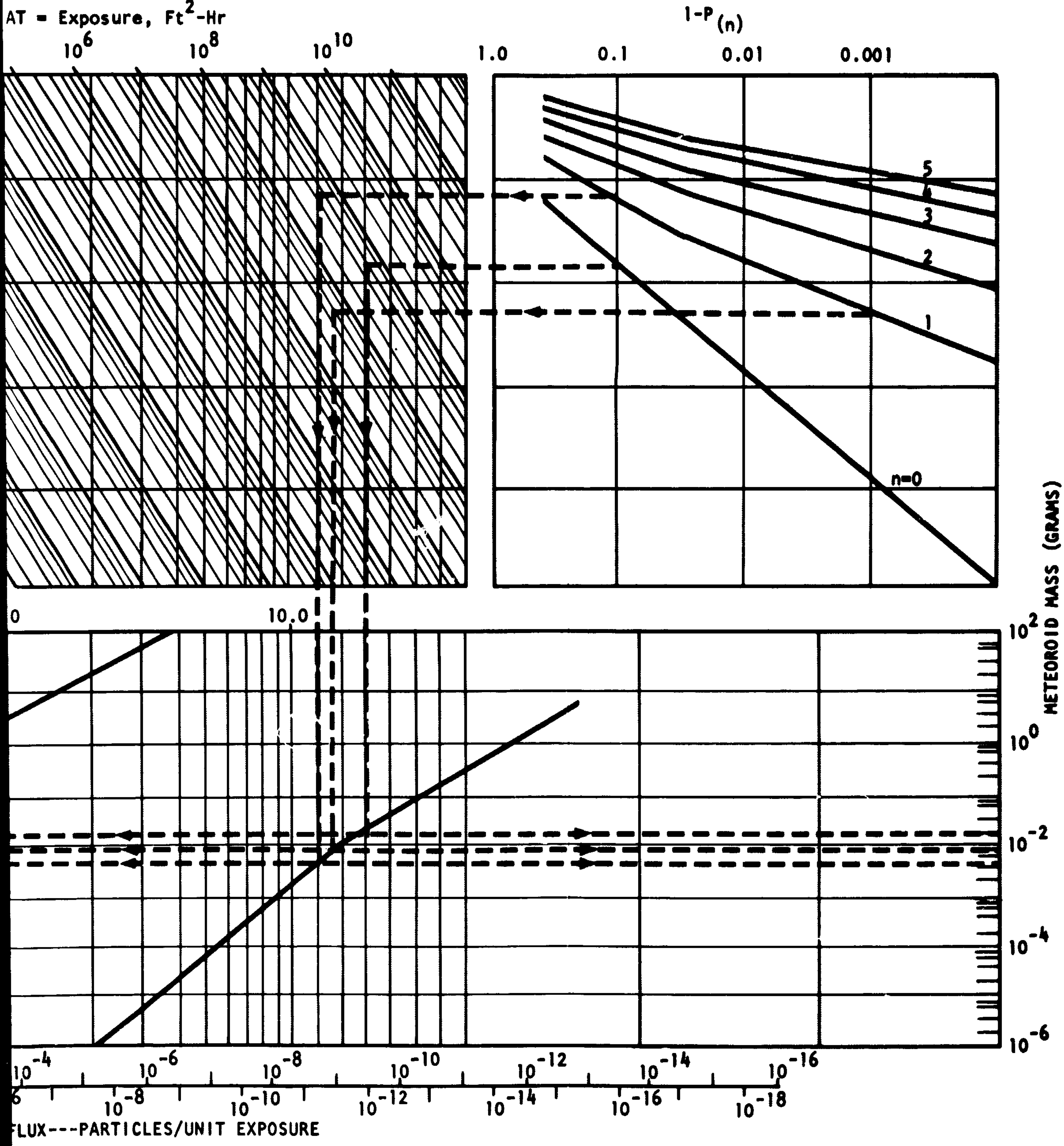


Figure 7-1: METEOROID MASS AND DIAMETER VS EXPOSURE AND PENETRATION PROBABILITY

where

W = total shield weight assuming two sheets of aluminum spaced two inches apart, lb/ft^2,

k = constant associated with the shield configuration, = 1/5, and

m = particle mass, grams.

The results for both the SLSS baseline vehicle and the space station each with a 33-foot diameter are shown in Table 7-3.

TABLE 7-3
TOTAL SHIELD WEIGHT (lb/ft^2)

MISSION	$P_{(1)} \leq 0.999$	$P_{(0)} \leq 0.999$	$P_{(1)} \leq 0.9$	$P_{(0)} \leq 0.9$
SLSS	1.65	4.54		
SPACE STATION	2.68	8.10	1.32	2.105

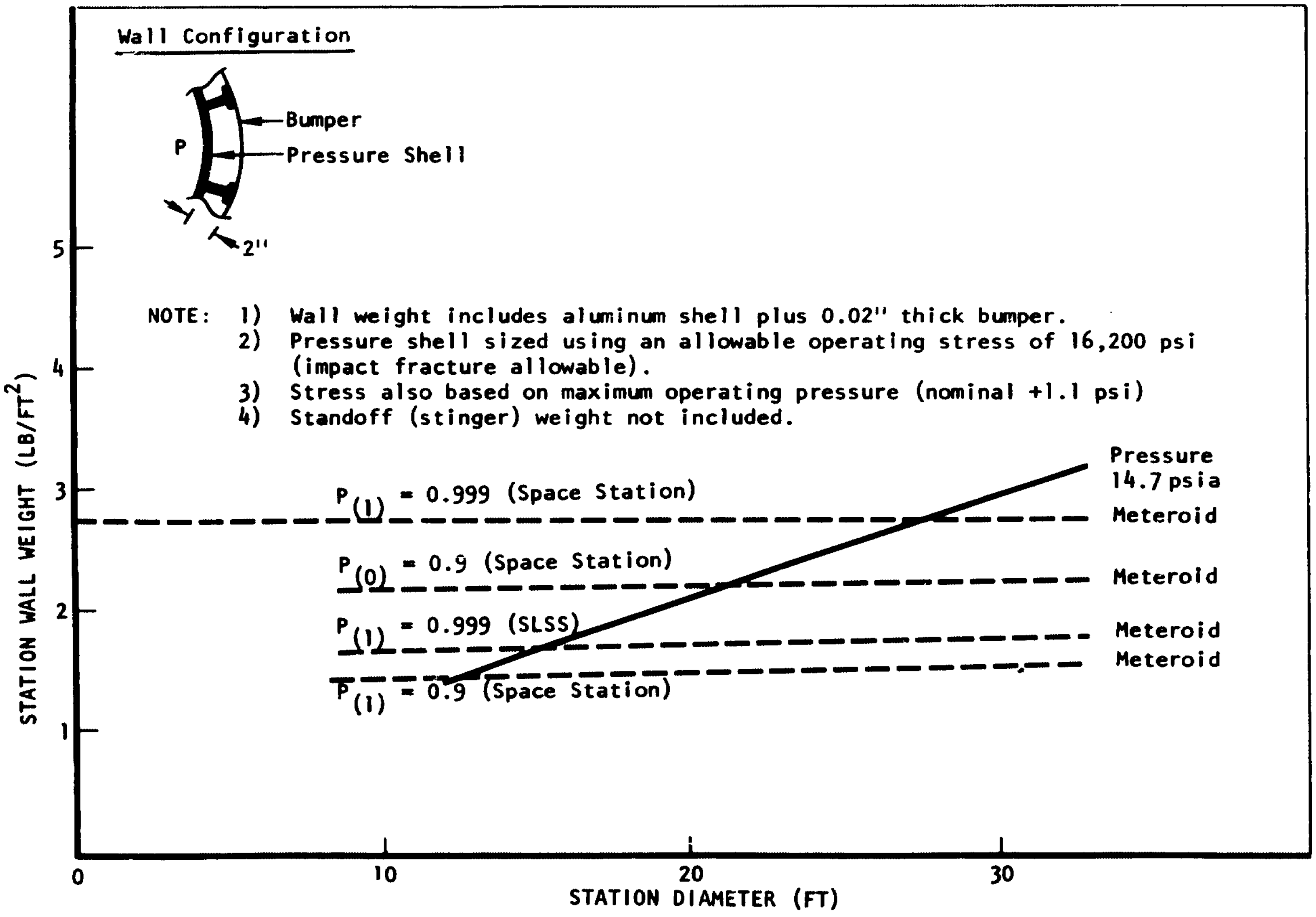
There is a significant increase in the shielding weight requirements when the probability of penetration is decreased from "one" to "zero," i.e.: n = 1 to n = 0. Likewise, in the case of the space station, when the probability level is changed from 0.999 to 0.9, the shielding weight requirement is significantly decreased.

The equation used above does not proportion between the bumper and the pressure wall. The meteoroid bumper construction will be governed by several factors, including radiator concepts, boost loading, etc.

7.2.5 METEOROID PROTECTION VERSUS PRESSURE CONSIDERATIONS

Sizing of the space station walls may be governed by either meteoroid protection or pressure considerations. Figure 7-2 has been adapted from the SLSS study report (Reference No. 81) and summarizes the station wall requirements for both these considerations. The wall configuration used in developing this plot is shown in the figure. It consists of a meteoroid bumper spaced two inches from a thin wall pressure shell. Again, both the space station and the SLSS baseline station are shown.

Wall sizing requirements for both vehicles were compared at an operating pressure of 14.7 psia and a penetration probability of 0.999. In addition, since the space station has been given a 0.9 probability level, wall requirements for this value are also shown.



NOTE:
1) Wall weight includes aluminum shell plus 0.02" thick bumper.
2) Pressure shell sized using an allowable operating stress of 16,200 psi (impact fracture allowable).
3) Stress also based on maximum operating pressure (nominal +1.1 psi)
4) Standoff (stinger) weight not included.

Figure 7-2: WALL SIZING FOR PRESSURE AND METEOROID PROTECTION

Certain preliminary conclusions may be drawn from Figure 7-2.

- At a probability level of $P_{(0)} = 0.9$, the space station wall is designed by internal pressure requirements for all diameters above approximately 21.5 feet and meteoroid protection requirements below that value.
- At a probability level of $P_{(1)} = 0.999$, the space station wall is designed by internal pressure requirements for all diameters above approximately 28.5 feet and meteoroid protection requirements below that value.

7.3 METEOROID PENETRATION EFFECTS

Some effects of meteoroid penetration were considered with respect to decompression, station motion and pressure/temperature decay.

7.3.1 DECOMPRESSION ANALYSIS

The problem of decompression associated with a meteoroid puncture of a pressurized compartment is extremely complicated when all factors are considered. For purposes of this study it was considerably simplified by assuming isothermal and isentropic flow processes and hole-out areas determined from meteoroid penetration tests.

If it is assumed that the environmental control system maintains a constant air temperature in a compartment that has been punctured by a meteoroid, the pressure decay can be expressed as follows:

$$P = P_o e^{-t/\tau}$$

For compressible isothermal flow, the time constant, τ, becomes

$$\tau = \frac{V}{CA}\left(\frac{\sigma+1}{2}\right)^{\frac{\sigma+1}{2(\sigma-1)}} \approx \frac{V}{CA}\ 1.728$$

and

P = pressure after time, t,

t = decompression time, seconds,

P_o = initial pressure, psia,

V = compartment volume (in^3),

C = speed of sound in compartment = $\sqrt{RT_o g} = 1.37 \times 10^4$ in/sec,

A = hole-out area (in^2),

σ = ratio of specific heats = 1.4, R = universal gas constant = 662 in-lb/lb-°R,

T_o = initial gas temperature = 525°R (65°F), and

g = acceleration due to gravity = 386 in/sec^2.

For purposes of analysis, the following compartment volume has been assumed:

Diameter	Volume	
(feet)	(feet^3)	(in^3 x 10^6)
33	7258	12.53

This volume is an approximation of that contained in the outer module of each deck of the conceptual 12-man space station. Actual gas volume would be less due to equipment in the compartment.

The pressure shell hole-out area associated with meteoroids of various diameters penetrating different bumper shell combinations has been estimated by another study (Reference No. 59). One such estimate is reproduced in Figure 7-3 and indicates that, in the worst case, the hole-out area can be approximately 20 times the square of the particle diameter. The meteoroid protection requirements for the space station are based upon $P_{(1)} \leq 0.9$, with the resulting particle diameters being a minimum size for which the shield must be designed. To establish a worst case for purposes of the Safety Study, the particle diameter associated with a $P_{(0)} = 0.999$ is examined. Using the exposure of 4.35×10^8 ft^2-hr. associated with a 33.0-foot diameter space station, the particle diameter is 0.54 inches, the hole-out area is 5.84 square inches and the hole-out diameter 2.72 inches, all figures being approximations. Assuming an initial compartment pressure of 14.7 psia and that man can survive to 5.44 psia, and still be capable of taking evasive or corrective action before losing consciousness, a decompression time of 268 seconds is calculated. However, some modification of this time should be made. First, the particle diameter used is based on $P_{(0)} = 0.999$ for the entire station exposure. The probability level associated with this particle size would be significantly higher for a single compartment. Second, the flow process was assumed isothermal. If isentropic flow is assumed, the pressure decay can be expressed as:

$$P = P_o \left[1 + \alpha t\right] \left[\frac{2\sigma}{1-\sigma}\right]$$

where

$$\alpha = \left(\frac{\sigma - 1}{2}\right)\left(\frac{AC}{V}\right)\left(\frac{2}{\sigma + 1}\right)^{\left(\frac{\sigma + 1}{2(\sigma + 1)}\right)} \approx 0.116 \ \frac{AC}{V}$$

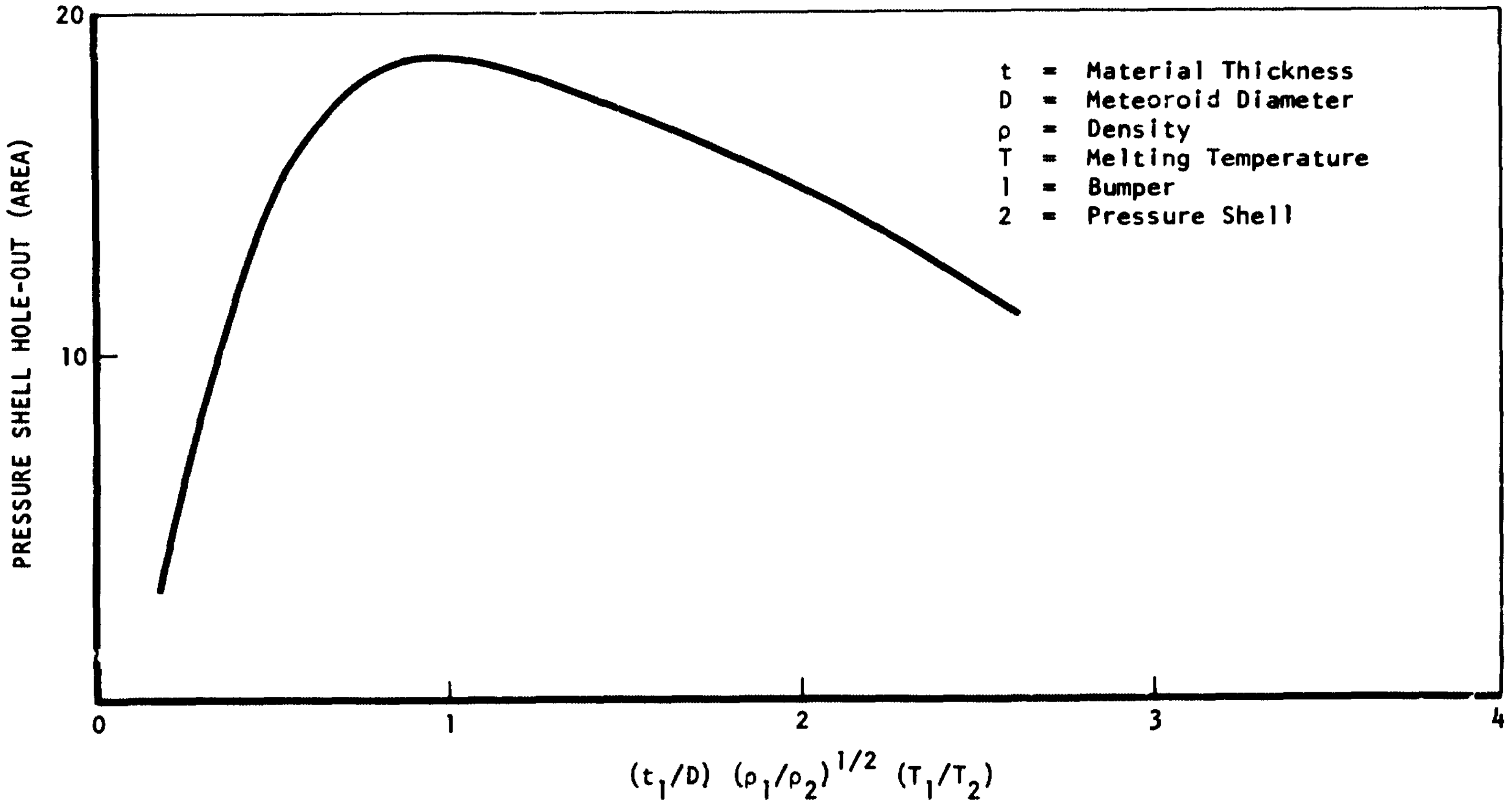


Figure 7-3: SHELL HOLE-OUT (AREA)

The time required for a pressure drop from 14.7 to 5.44 psia, calculated on the same values as before, is 207 seconds. However, the internal temperature at this time is

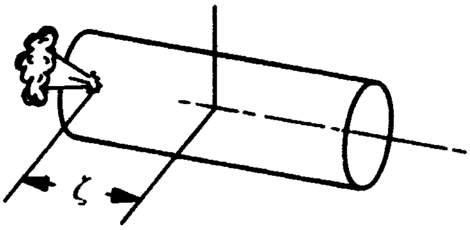
$$T = T_o \left(\frac{P}{P_o}\right)^{\frac{\sigma - 1}{\sigma}} = 393^{o}R \ (-66^{o}F),$$

assuming the initial temperature (T_o) is 525°R. Freezing temperatures are approached in approximately 52 seconds. These results provide reasonable estimates upon which crew reaction times can be based.

7.3.2 STATION MOTION ANALYSIS

To provide a preliminary estimate of the potential problem of station motion resulting from a meteoroid penetration near one end of the station, the following analysis was made:

assume the station geometry shown below:



where

$I = 7.5 \times 10^6$ slug-ft^2, and

$\zeta = 25$ feet

The gas weight contained within a typical compartment is

$$W = \frac{P_o V}{12\ RT}$$

where

W = gas weight, lbs.,

P_o = initial compartment pressure, 14.7 psia,

V = compartment volume = 12.53×10^6 in^3,

T = initial gas temperature = 525°R, and

R = gas constant = 55.2 ft-lb/lb-°R

The gas weight is approximately 530 pounds. Conservatively assuming an isothermal specific impulse, I_{sp}, of 65 seconds (nitrogen), the impulsive torque, F, would be

$$F = WI_{sp}\zeta = (530)(65)(25) = 8.62 \times 10^5 \text{ ft-lb-sec}$$

The resulting spin rate would be

$$\omega = \frac{F}{I} \quad \frac{8.62 \times 10^5}{7.5 \times 10^6}$$

$$= 0.115 \text{ rad/sec}$$

$$= 1.09 \text{ rpm}$$

The centrifugal force field at the extremity of the station would be

$$g = \frac{\zeta\omega^2}{32.2} = \frac{25(0.115)^2}{32.2}$$

$$= 0.0103 \text{ g}$$

Based on this simplified analysis, station motion resulting from a meteoroid puncture does not appear to represent a critical problem. The spin rates and "g" levels are believed sufficiently low to permit repair, even if the stability and control system cannot counteract the motion.

7.4 TEST PROGRAM RESULTS

An in-house research program was conducted by The Boeing Company to define the hazards and study the problems arising from particle penetrations into chambers containing life supporting atmospheres. Detailed results of the test program are given in the test report (Reference No. 123) and in the SLSS study report (Reference No. 81) and are only summarized here.

7.4.1 TEST OBSERVATIONS

Hypervelocity projectiles were fired at velocities above 20,000 fps through typical space vehicle wall constructions into oxygen-nitrogen or oxygen atmospheres. Intense light flashes, heat fluxes, and shock waves formed by the penetration process were measured by various types of instrumentation. Sufficient data were obtained to show the phenomena to be dependent on projectile and wall parameters. Debris from the wall and projectile were found to present a high damage potential a considerable distance from the puncture. This included, for some tests, destruction of the test chamber contents caused by fires started during penetration of organic wall elements. Noxious fumes were generated by each test where organic filler was part of the wall configuration.

7.4.2 TEST FACILITIES AND CONFIGURATIONS

The experimental facility used for the test program was the Boeing 1/4-inch bore light-gas gun range, consisting of a blast tank, a velocity measurement section and a test chamber, and can be evacuated to the micron region. This system was used to fire 1/8- and 1/4-inch projectiles into a pressurized compartment, containing a simulated space station atmosphere consisting of a 60-40 percent by volume mixture of oxygen and nitrogen, respectively, at 7.5 psia.

The simulated space cabin was formed by insulating the test chamber from the velocity measurement section with a metal diaphragm and adding the plumbing and vacuum pumps necessary to establish the cabin atmosphere. The metal diaphragm thus becomes the pressure shell of the simulated vehicle wall. The division of the range in this manner forms a cabin about 2.5 feet in diameter by 4 feet long with an internal volume of 18.2 cubic feet.

Two basic simulated wall constructions and three types of projectiles were used during the tests. The majority of the tests used a simulated wall made of two aluminum sheets. Sheet thickness, determined by boost and pressurization loads for a typical manned space vehicle, were 0.020 inches for the shield (first) sheet and 0.050 inches for the second sheet. The 1-1/2 inch space between sheets was empty for seven tests, filled with open-cell polyurethane foam during three tests and fiberglass wool for one test.

The projectiles fired were 1/4- and 1/8-inch diameter aluminum spheres and 1/4-inch diameter pyrex spheres. The aluminum spheres were used because they are relatively easy to launch in the light-gas gun while the pyrex was chosen as representative of brittle material. Projectile velocities were 21,000 ± 500 fps. While these projectiles are large in mass and size compared to the meteoroids a space vehicle might be expected to encounter, they have approximately the same kinetic energy as design-size space particles.

7.4.3 TEST RESULTS

Some of the more relevant test results and conclusions are summarized below.

a. The penetration of a hypervelocity projectile through a simulated space vehicle wall into a life-supporting atmosphere introduces phenomena within the atmosphere that have sufficient magnitudes to be dangerous to the contents and occupants of the chamber or station. These phenomena can be categorized as wall damage, and light, heat and pressure transient responses generally occurring within 5 milliseconds following pressure wall puncture, and extended responses.

b. The intensities of the phenomena are a function of cabin wall construction, projectile size, and distance traveled through the cabin atmosphere.

c. The puncture of certain wall constructions can lead to a conflagrant destruction of both wall and cabin contents. The damage to the pressure walls from projectile and shielding debris, when 1/4- and 1/8-inch projectiles were fired through walls without an intermediate filler, produced no unexpected response. Circular or slightly irregular holes were formed without evidence of cracks. The addition of an open-cell polyurethane filler, however, transformed the pressure wall puncture by the 1/4-inch projectile into a jagged, petalled hole accompanied by many cracks. During one of these tests, the filler was set afire and completely consumed and during another, the filler was badly burned. Penetration of a wall construction simulating an existing launch vehicle resulted in spectacular destruction of the filler and insulation. The passage of the debris into the polyurethane foam caused the foam to explode, be set on fire and to be thrown throughout the test chamber, adhering and burning wherever it stopped.

d. Most tests resulted in puncture or denting of the 0.020-inch aluminum witness sheets placed at the rear end of the target tank indicating the debris can be dangerous to any occupants. Although the penetration of the wall introduced several long cracks in some tests, no cracks were propagated by the membrane stress in the pressure wall.

e. Intense light flashes accompanied the penetration of the vehicle wall, with luminous material being injected into the test chamber. Radiometer information indicated equivalent intensities greater than 3.2×10^8 lumens/ft^2 from objects at least 3.7 inches from the pressure wall. This is approximately twice as bright as the surface of the sun. Abtronics camera photographs also corroborated this intensity.

f. Filler-less walls and large projectiles produced larger flash intensities, while the incorporation of filler appeared to decrease the flash duration in most cases.

g. Strong shock waves were formed and propagated through the atmosphere as a result of the puncture. The shocks were accompanied by very short but intense heating flux rates. Shock magnitudes exceeding 150 psi and heating flux rates of 1300 BTU/ft^2 sec were measured. Propagation velocities of Mach 9 and shock durations of 0.1 milliseconds were indicated. The shock levels appeared slightly less for several filler walls. The transitory shock consisted of a main shock which propagated down the axis of the chamber at supersonic velocities for the first few feet followed by a secondary wave resulting from the reflection of the primary wave off the sidewalls of the test chamber.

h. A series of oscillating pressure waves were formed following passage of the initial shock waves. Pressures of 10-15 psi and frequencies of 600-800 cps were indicated. It is believed this phenomena is due to ringing of the chamber, although this has not been definitely established.

i. Limited data were obtained to describe the test response for longer time periods. Penetrations into the atmosphere produced an instantaneous rise in ambient cabin pressure. Temperatures greater than 120°F accompanied the overpressure. Overpressures as large as 2 psi were recorded following puncture of the wall that used two aluminum sheets. Inclusion of a filler reduced the peak pressure by 0.5 psi. The overpressure also appeared to be a function of particle size as no significant pressure rise occurred when 1/8-inch projectiles were used.

j. Thermal sensitive paint indicated chamber temperatures in excess of 650°F in 100 percent oxygen and 300 to 350°F for mixed gas atmospheres for those tests which resulted in a fire.

7.5 SUMMARY AND CONCLUSIONS

An estimate was made of wall sizing required to give protection from meteoroids at various probability levels. When compared with wall sizes necessary to contain station pressure, it appears that pressure considerations will size the wall. This, however, is true only for the conditions assumed, namely, meteoroid flux as specified (Reference Nos. 58 and 59) proves to be correct, $P_{(0)} = 0.9$ for ten-year mission, and station 33 feet in diameter by 53.5 feet in length. Since many, if not all of these conditions are subject to change as the space station becomes more firmly defined, meteoroid protection requirements should be re-evaluated in light of the changes. For example, Figure 7-2 indicates that in stations of diameter less than about 21.5 feet, the wall would be sized for meteoroid protection. If the space station as finally designed has a 22-foot diameter, rather than 33 feet, then the wall might well be sized by meteoroid protection requirements, rather than pressure.

The effects of a meteoroid penetration, if one occurs, may be expected to be quite serious. Immediate effects to be anticipated include: intense light flash, intense heat pulse, abrupt increase in ambient temperature and pressure, strong shock waves, and shrapnel. Follow-on effects to be expected include: fire from flammable material within the affected compartments and/or flammable insulating material from the wall, decompression, temperature drop, and undesired station motion.

Many of these effects, and especially the follow-on effects, are not peculiar to meteoroid penetrations, e.g., decompression with its associated drop in temperature and/or undesired station motion, and, to some extent, fire. Measures to alleviate such hazards have been identified by other tasks in the Safety Study. Fire from a meteoroid penetration may occur throughout the affected compartment(s) rather than in localized spots as from other causes and this should be taken into account in developing the means of controlling fires. Also, insulating material in the wall should be non-flammable.

The sum total of the immediate effects, whether peculiar to meteoroid penetration or not, may be expected to include incapacitation of crew members in the affected compartment(s) and extensive equipment damage. The latter, to the extent that it is within the scope of the Safety Study, has been covered by other tasks. Crew members may be incapacitated by temporary (or long-term) blindness from the light flash, flash burns, shock, and shrapnel wounds. Some protection from flash burns may be afforded by a protective garment, e.g., non-flammable coverall. For the remainder, immediate assistance or rescue and medical treatment is indicated. Emergency procedures for assistance, rescue and treatment should be established and practiced. The time elapsed between penetration and the compartment becoming uninhabitable (except possibly for fire effects), while not great, should be sufficient for emergency action, particularly if the survival device identified in Section 2.0, "Traffic Pattern Analysis," of this document, is available.

8.0 REFERENCES

A master list of the principal sources of information used in the Space Station Safety Study is contained in Document D2-113070-5, Crew Safety Guidelines.

The sources which were most appropriate to the supporting analyses reported in this document are shown in the following tabulation. Included are those sources which are specifically cited in the text and sources which provided general background information but are not specifically cited. The reference numbers and format are the same as in the master reference list.

REFERENCES

No.	Title	Report No.	Source	Date	Contract No.	Cl.
	SECTION 2--CONFIGURATION CONCEPTS					
81	Saturn V Single Launch Space Station and Observatory Facility, Earth Orbital Station Design	D2-113539-1	Boeing	11/67	NAS9-6816	U
92	Space Station Program Definition Study (Phase B)--Statement of Work	9-4-7895	NASA/Headquarters	4/14/69	---	U
93	Space Station Safety Study--Statement of Work	---	NASA/MSC	1968	NAS9-9046	U
	SECTION 3--OPERATIONS ANALYSIS					
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No.	Title	Report No.	Source	Date	Contract No.	Cl.
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79	Saturn V Single Launch Space Station and Observatory Facility, Earth Orbital Mission Requirements	D2-113537-1	Boeing	11/67	NAS9-6816	U
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	SECTION 5--TRAFFIC PATTERN					
22	Early Orbital Space Station (EOSS), Technical Report	DAC-56550	McDonnell-Douglas	11/67	---	U
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	<u>SECTION 6--HUMAN REQUIREMENTS</u>					
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121	Medical Aspects of an Orbiting Research Laboratory	SP-86	NASA	1966	---	U
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No.	Title	Report No.	Source	Date	Contract No.	Cl.
	SECTION 7--METEOROID PENETRATION					
19	Design Criteria, Technical Coordination Document	D2-113532-1, Appendix II	Boeing	---	NAS9-6816, NAS9-6796	U
58	Meteoroid Environment--Near-Earth and Cislunar	DS-21, Revision A	NASA/MSC	1/24/67	---	U
59	Meteoroid Protection for Spacecraft Structures	CR-54201	J.R. Lundeberg, et al--NASA	10/65	---	U
68	Preliminary Technical Data for Earth Orbiting Space Station--Standards and Criteria	MSC-EA-R-66-1, Volume II	NASA/MSC	11/7/66	---	U
123	Hypervelocity Particle Penetration into Manned Spacecraft Atmosphere	D2-24149-1	G.T. Burch--Boeing	4/67	---	U