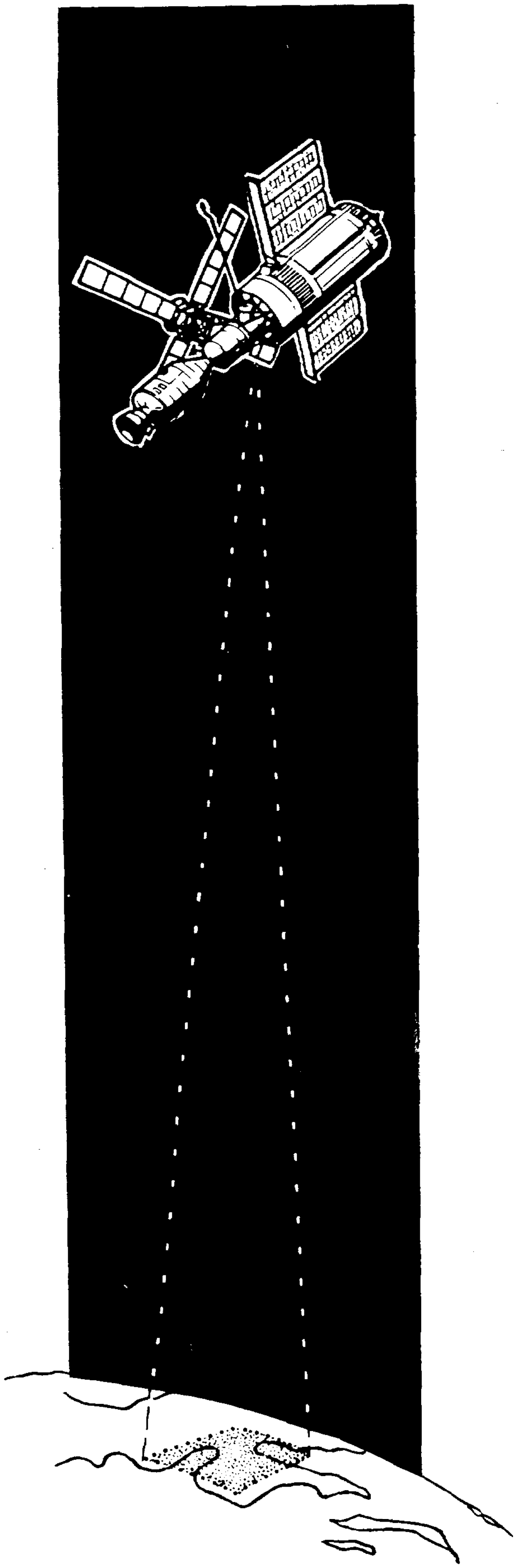
VOLUME II
PROGRAM IMPLEMENTATION AND MATURITY



REPORT
TO
THE ADMINISTRATOR
BY

THE NASA AEROSPACE SAFETY ADVISORY PANEL

ON THE
SKYLAB PROGRAM

JANUARY 1973

SKYLAB PROGRAM

A REPORT TO THE ADMINISTRATOR

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Volume II - Program Implementation and Maturity

January 1973

PREFACE

This volume discusses the maturity of the modules as evidenced during the design and manufacturing reviews, and reviews the scope of the cluster risk assessment efforts and their results. Inherent in this discussion is an assessment of the technical management system and its capability for assessment and resolution of problems.

The detail in volume II supports the conclusions and recommendations in volume I.

In addition, a number of specific ''open items'' are identified during the course of the discussion. While it is anticipated that they will be closed as the program progresses, the Panel is asking for a formal disposition to assure themselves closure was in fact achieved.

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SUMMARY

Volume II provides the detailed material on which the Panel's conclusions and recommendations are based. In addition, the material presented in the SUMMARY represents significant areas taken from the details of this volume. To assure that the Administrator is provided adequate background on the Skylab mission items such as those noted here should be covered in Skylab presentations to him.

1. Reliability, quality, and safety: Open items at the time of the Panel reviews include the following:

(a) Completion of the sneak circuit analysis for the total space vehicle

(b) Completion of the testing associated with corona assessments

(c) Problems associated with the suit drying station and the availability of the suits in case of emergencies

(d) Crew procedures for reaction to the loss of cluster pressure

(e) Further studies on the susceptibility of crew to dangers due to the inhalation of particulate matter during earth orbit conditions

2. Manufacturing, workmanship, and vendor control: At each contractor visited by by the Panel a self-assessment was provided by the contractor in terms of the recommendations made by the Centaur and Thor/Delta Review Boards (reports issued in 1971). Obviously, no self-assessment can give the full assurance that would result from a detailed onsite audit. However, the Panel found that, in fact, these self-assessments when backed by NASA audit teams and astronaut comments did provide confidence in workmanship and vendor control aspects of contractor's activities.

3. Fire prevention, control, and extinguishment: The reviews of individual modules, mission operations, and associated areas indicate that these most important safety areas have been, and continue to be, a mainstream effort throughout the program. The philosophy of fire prevention appears to have been adhered to strictly. Thus, while there are significant quantities of flammables on board the cluster (for example, OWS wall insulation, Coolanol-15 as a refrigerant, various materials contained in experiments), there has been a careful and thorough effort to minimize the quantities of such materials. Where they do exist the effort has been toward their isolation from each other and from both ignition sources and flame propagation paths. However, since this is not completely possible, fire escape plans and fire extinguishment techniques take on added significance. There is every indication that this area is receiving the necessary

emphasis. Nonetheless, continued attention is required to maintain awareness and those necessary communications between personnel and organizations which will preclude anything entering the system that would adversely affect the fire situation. Housekeeping involving thousands of items is of course critical to control of the hazards leading to fires.

4. Results of Skylab medical experiments altitude test (SMEAT): This test subjected three crewmen to the rigors of a 56-day simulated Skylab mission. Data reduction and handling proved adequate. Experiment operating procedures, medical team training, and pre- and postmedical flight data and procedures were evaluated. A medical baseline was established and principal investigator participation was explored. The test, based on available data, was most successful. It did, however, surface numerous operational procedures which were cumbersome as well as a large number of hardware problems. This of course is the reason for running the test in the first place. At the time of the Panel's review of the SMEAT data five items were still in work, not counting the documentation requirements being factored into the operational data. These five items were

(a) Ergometer anomalies

(b) Urine collection insufficiencies

(c) Metabolic analyzer anomalies

(d) Food system problems (minor nature)

(e) Erratic operation of the blood pressure measuring system (minor nature)

Those manned altitude tests conducted after SMEAT will no doubt be used to verify the resolution of most of the SMEAT aired problems.

5. Microbial control: Apparently an exact definition of system requirements for microbial thresholds under Skylab environmental conditions, zero-G and low pressure, cannot be provided. Therefore, the objective of the microbial control program is to minimize the implantation of microorganisms and their growth rate. The establishment of the Skylab intercenter microbial control working group in 1970 has gone a long way toward meeting these objectives. Methodology has centered on pinpointing those areas where relatively large numbers of organisms could accumulate and receive nutrients. This area of endeavor will require operational surveillance during the mission itself as well as strict premission controls.

6. Contamination control: The Skylab organization, with the continuing support of the contamination control working group, has directed a steady effort to identifying contamination sources, assuring adequate material controls, and maintaining hardware cleanliness. To further assure clean conditions the premission and mission operational documentation and mission training efforts are directed toward the same goals. Test programs over the last year have provided valuable data on sources of contamination and possible solutions for the protection of susceptible hardware.

7. Experiments: The number, type, and sophistication of the experiments carried in the Skylab cluster present a very complex technological and administrative task. Problems encountered during the development and testing of the experiments have been as diverse and difficult as any found on the basic Skylab modules themselves. The management systems operating at each Center now appear to be doing the necessary job of providing proper experiment hardware and operating procedures. Those experiments involving two sponsoring Centers, of course, require more detailed coordination and specific documentation. With the experiments being delivered to the KSC it is also necessary that the principal investigators are appropriately involved during the test and checkout periods at KSC. This is a must to ensure that their experiment hardware is properly exercised and that any problems are resolved quickly and with the least perturbation on the overall KSC schedule. The system for defining priorities for the experiments and the assessment of payoff during the mission warrants particularly greater attention. This area has not been defined as far as the Panel reviews are concerned.

8. Command and service modules: Since the Skylab CSM's constitute a modification to the very successful Apollo CSM's and the contractor appears to be maintaining adequate skills and engineering capability, there is a high degree of confidence in the CSM's ability to do its assigned job. Apollo 17 problems will of course need to be evaluated for their impact on Skylab. The following items were noted by the Panel during its reviews:

(a) Adequacy of the tension-tie cutter and explosive charge system

(b) Qualification of the descent battery

(c) The discharge and/or safing of the RCS propellant system during reentry

9. Qualification tests: Those qualification tests still incomplete at the time of the Panel's review (November 1972) included the following number of tests against each of the modules:

Module	Number of tests
Orbital workshop	28
Airlock module	10
Apollo telescope mount	4
Payload shroud	1
Multiple docking adapter	0

ABBREVIATIONS, ACRONYMS, AND DEFINITIONS

The following are abbreviations, acronyms, and definitions used in this volume:

Skylab orbital assembly (OA):

AM	Airlock module
MDA	Multiple docking adapter
OWS	Orbital workshop
CSM	Command and service module
ATM	Apollo telescope mount
IU	Instrument unit

Major module systems:

ECS	Environmental control system
TCS	Thermal control system
EPS	Electrical power system
HSS	Habitability support system
CAS	Crew accommodation system
SAS	Solar array system

Other major hardware:

PS	Payload shroud
L/V	Launch vehicle
SAT-V	Saturn V launch vehicle
SAT-IB	Saturn IB launch vehicle
GSE	Ground support equipment
CFE	Contractor furnished equipment
GFE	Government furnished equipment
MCC-H	Mission Control Center - Houston
LCC	Launch Control Center
EREP	Earth resources experiment package
C&D	Control and display

Skylab reviews, mission terms:

SOCAR	Systems/operations compatibility assessment review
DCR	Design certification review
PDTR	Predelivery and turnover review
COFW	Certificate of flight worthiness
FRR	Flight readiness review
FMEA	Failure mode and effects analysis
SFP	Single failure point
SMEAT	Skylab medical experiments altitude test

EVA	Extravehicular activity
SL-1	First Skylab launch: Saturn V and orbital assembly less CSM
SL-2	Second Skylab launch: Saturn IB with CSM 116
SL-3	Third Skylab launch: Saturn IB with CSM 117
SL-4	Fourth Skylab launch: Saturn IB with CSM 118

NASA and industry organizations:

OMSF	Office of Manned Space Flight, Washington, D.C.
MSFC	Marshall Space Flight Center, Huntsville, Alabama
MSC	Manned Spacecraft Center, Houston, Texas
KSC	Kennedy Space Center, Florida
MDAC-W	McDonnell Douglas Astronautics Company, Huntington Beach, California
MDAC-E	McDonnell Douglas Astronautics Company, St. Louis, Missouri
MMC	Martin Marietta Corporation, Denver Division, Denver, Colorado
NR	North American Rockwell Corporation, Downey, California

Definitions:

Saturn workshop	Inorbit space assembly which includes the orbital workshop (OWS), airlock module (AM), multiple docking adapter (MDA), and the Apollo telescope mount (ATM).
Orbital assembly or cluster	Saturn workshop plus the docked CSM.
Group-related experiments	Experiments that are closely related to each other either through common focus of study or by integration into a single subsystem. These are the medical experiments, solar astronomy (ATM), and Earth resource experiments.
Corollary experiments	Experiments other than group related or passive type that require significant in-flight crew support and are not closely related to each other.
Passive experiments	Experiments whose associated in-flight crew support requirements are almost nonexistent.
Constraint	Restriction that influences the mission profile, or timeline, and for mission planning purposes cannot be violated.
Single failure point (SFP)	Single item of hardware which, if it failed, would lead directly to loss of a part, system, mission, or crew member.
Principal investigator (PI)	Individual NASA has contracted with for the development and delivery of experiment hardware, analyses of returned data, or both.

PANEL ACTIVITIES SCHEDULE

Phase I

September 14-15, 1971	Washington, D.C. (OMSF and Skylab Program)
October 18-19, 1971	McDonnell Douglas, Huntington Beach, California
November 8-9, 1971	McDonnell Douglas, St. Louis, Missouri
December 13-14, 1971	Washington, D.C. (Life Sciences Division)
January 10-11, 1972	Martin-Marietta Corporation, Denver, Colorado
February 14-15, 1972	North American Rockwell Corp., Downey, California
March 13-14, 1972	Chrysler/Boeing/MSFC Launch Vehicle, Michoud, Louisiana

Phase II

April 10-11, 1972	MSFC, Skylab Program Office, Huntsville, Alabama
May 8-9, 1972	MSFC, Skylab Program Office, Houston, Texas
June 12-13, 1972	KSC, Skylab Program Office, Cape Kennedy, Florida
June 19-23, 1972	OWS Pre-DCR, MDAC-West, Huntington Beach, California
July 13, 1972	MSFC Skylab Experiments Pre-DCR, Huntsville, Alabama
July 27, 1972	Saturn I-B Turnover Meeting, Michoud, Louisiana
August 10-11, 1972	Formal DCR for CSM and Selected MSC Experiments, MSC, Houston, Texas
August 31 - Sept. 1, 1972	Pre-DCR Mission Operations, MSC, Houston, Texas
September 5-6, 1972	OWS PDTR at MDAC-West, Huntington Beach, California
September 12-14, 1972	ATM Product Turnover Review, MSC, Houston, Texas
September 15, 1972	DCR for Mission Operations, MSC, Houston, Texas
September 28, 1972	SMEAT Review, MSC, Houston, Texas
September 27-29, 1972	AM/MDA Acceptance Review, MDAC-East, St. Louis, Missouri
October 2-3, 1972	DCR-Module and Experiment Hardware, MSFC, Huntsville, Alabama
November 9-10, 1972	Washington, D.C. (Skylab program update)

RISK ASSESSMENT

RELIABILITY, QUALITY, AND SAFETY

The reliability and safety program defines and integrates the activities of Headquarters, the operating Centers (MSFC, MSC, KSC), and the contractors. It provides guidance, disciplines, and assessment during all phases of design, manufacturing, test, preparation, and mission operations. The experience of NASA and its contractors in both manned and unmanned space missions has been applied at each level of the program. Experience as documented in the MSC 00134 Report "Space Flight Hazards Catalog" and the MSC "Manned Spacecraft Criteria and Standards" along with similar launch vehicle material was used extensively. The results of the Centaur and Thor/Delta Review Boards were factored into the program in late 1971 to assure appropriate workmanship. Contractors developed system safety program plans and instructions on their implementation. Each affected organization throughout the program had dedicated personnel in these areas. Motivational programs have been continued and strengthened during the lifetime of the Skylab program.

The purpose herein is to discuss the procedures and their implementation. In so doing the report assesses the extent that this provides confidence in the hardware and documentation. Related efforts, discussed elsewhere in this report, include sneak circuit analysis; falut current protection; habitation area pressure integrity review (covered in each module); cluster materials; fire detection, control, and extinguishment; and contamination control.

For each design review and "turnover" acceptance meeting, a reliability and safety analysis has been provided by both the contractors and NASA. These appear to be thorough. They follow the basic system originally used during the Apollo program with excellent results. MSC and the crews have instituted very thorough safety efforts on anything relating to "man." Some of these efforts are borne out in MSC's "Manned Safety Assessment for Skylab" reports concerning each item of MSC responsibility as well as the operational aspects of the mission. MSC has produced an "Index of MSC System Safety Studies" (Report No. SN-5-71-43 Rev. B, May 1, 1972) which serves as a baseline for such work. MSFC through its resident offices has exerted continuing pressure to assure that reliability and safety goals were practical and were met to the maximum degree. A part of any reliability and safety program is the support obtained from the configuration management (CM) systems. This assures that reliability and safety groups have the opportunity to assess all changes, know the "as-designed" versus "as-built" hardware, and assure the traceability of hardware and component materials. Thus, CM plays a role in any discussion of reliability, quality, and safety.

Management policies have been initiated at the Headquarters level. Implementing policies and procedures have been developed by NASA centers and contractors. As an example, the following directives are issued and interpreted by the Program Office in Washington:

P.D. #9	Reliability, Quality, and Safety Auditing
P.D. #10A	Nonconformance Reporting and Corrective Action
P.D. #11A	Sequence and Flow of Hardware Development and Key Inspection, Review and Certification Checkpoints
P.D. #13	Failure Mode and Effect Analysis - Single Failure Point Identification and Control
P.D. #16A	Skylab Materials Policy
P.D. #31	Implementation of System Safety Requirements

The Program Office maintains visibility and control by participation in reviews and conduct of audits:

Intercenter panels, CCB participation
Formal reviews, DCR's, etc.
Safety technical interchange meetings
RQ&S quarterly meetings of Centers and Headquarters
Audits of center safety related activities
Participation in NASA-wide panels and advisory groups such as the Spacecraft Fire Hazard Steering Committee, NASA Hazards Identification Committee, NASA Parts Steering Committee, Contamination Working Group

Reliability

The basic approach is to concentrate attention on hardware and operational items critical to crew safety, mission success, and launch operations. These efforts could be classed under the following subheadings: system reliability analysis, design support, and production and test support.

The basic analytical efforts are the failure mode and effect analyses (FMEA). Based on the FMEA, the following work is carried out:

Identification of single failure points
Identification of launch critical components
Caution and warning system analysis

Critical redundant/backup components
In-flight maintenance
Single failure point retention rationale
Criticality analysis
Criticality ranking
Identification of mission/safety critical items

Design support includes those activities associated with in-flight maintenance evaluations, parts and material programs, design review programs, configuration control, and supplier reliability requirements and implementation. The results of systems reliability analyses are used as the basis for determining what hardware items should have in-flight maintenance. This is the foundation on which in-flight spares, tool requirements, and crew contingency procedures are established. The parts and material programs provide for the selection and control of parts and materials used in each module: These include selection and standardization, specifications, qualification tests, parts usage control, and derating requirements. The design review program includes informal reviews within the design technologies, formal design reviews by a single review board, and the basic drawing release system which ensures review and approval by appropriate technologies and agencies during the drawing release. Also included is the review and approval of design specifications. The reliability effort includes the review of all engineering change proposals and attendance at Configuration Control Boards to assure proper attention to the RQ&S areas. Supplier reliability requirements and their implementation are imposed and audited to meet program specifications.

Production and test support provided in the reliability area includes those activities tied to the test documentation, failure reporting system, failure analyses, problem control centers, monitoring of all testing, and the necessary followup to assure resolution of hardware test anomalies.

Based on the material presented to the Panel during its reviews at the contractor plants and at NASA centers, the efforts noted previously appear to be well founded on the experience of prior programs and implemented by experienced and competent personnel. For example, when checked against the findings and recommendations of the Centaur and Thor/Delta Review Boards, the reliability efforts on the Skylab are adequate.

Because of the importance of the FMEA work it is well to further discuss and understand it. The mission level FMEA has several important functions. It doublechecks, evaluates, and validates lower level inputs for adequacy and accuracy (modules, subsystems, components). It examines failure modes across interfaces to discern critical effects. The mission level FMEA, as distinct from the lower level FMEA, is based on composite schematics across the module interfaces. This enables an analysis of the functions required to cause all mission events to occur. These data are then analyzed for the failure modes that can cause loss of those functions. This type of knowledge is considered of prime importance to mission planning and operations. The dispositioning of single failure points is delineated by means of a Pert-type system which typifies the relationship of the module and mission level FMEA events and activities. MSFC Directive MPD 8020.4 shows the necessary activities that take place as a result of contractor, intra-, and intercenter interfaces to dispose not only of single failure points identified but all other action items resulting from these analyses. This then indicates that a closed-loop system does indeed exist. It is an iterative management control process embracing survey, audit, and monitoring activities. These data are then used by the design, quality assurance, test, operations, and safety discipline areas.

Quality Assurance

The prime objective of the quality programs is to provide those functions necessary at the NASA/contractor sites to produce Skylab hardware that meets the requirements of the specifications and is defect-free. The basic NASA documents used in this are NPC 200-2, NHB 5300.5, and NHB 5300.4. Here again the activities and methods used indicate that the Centaur and Thor/Delta problems do not significantly exist on Skylab. The audits conducted by the NASA quality groups and the contractors of their suppliers support this conclusion. The results of tests and the failures noted by the Panel at its reviews are also indicative of quality workmanship equal to that found on the later Apollo hardware. The fact that one can point to many problems with the manufacture of integrated circuits (cracked solder) and other similar types of workmanship problems is more indicative that the system is good enough to catch these problems before they reach the final "ready-to-launch" hardware. The screening of hardware from the initiation of manufacture through the prelaunch checks should provide confidence that only good quality items will appear on the vehicles.

Safety

Safety tasks were evident in the design, development, manufacturing, assembly, checkout and acceptance, and operational mission planning. Tasks associated with the system safety effort include safety analyses and postanalyses actions, safety reports, safety review functions, explosive and ordnance safety, ground handling and transportation, tests, training and certification, and systems installation.

System safety analyses of the modules and supporting GSE are performed to identify and evaluate hazardous conditions that may exist during all mission phases. The hazard criticality of module components, critical functions, and critical operations have been determined and evaluated. Appropriate corrective measures to eliminate or alleviate the hazard to an acceptable level have been effected in most cases. The following hazard identification techniques have been employed:

Review of the FMEA for safety significant items

Review of ECP's for safety impact

Review of all prior safety related history for impact

Special safety studies in support of design, test, and operations

Direct and continuing participation in test plans and operations, reviews, etc.

Safety assessment of failure reports

System safety checklist development and implementation

The results of system safety analyses and reviews noted previously are documented safety assessments and "alert system" reports. Documentation and test plans are reviewed to identify safety significant operations and methods.

Ground handling and transportation, an important phase of Skylab, has encompassed a wide variety of efforts. These include training of personnel, design of equipments for transport of hardware, and maintenance of cleanliness standards.

An integral part of the safety program is the training of personnel at all levels to be proficient in the performance of their jobs. This includes the motivational programs within the factory and at KSC.

An example of the safety office role in support of the Skylab program is that of the MSC Safety Office. Basically this office plans, directs, and coordinates the development and implementation of the MSC Skylab safety program in line with established directives. Of particular note is their support of milestone reviews, safety analyses, participation in test activities, and the monitoring of mission activities.

They have established a flexible but comprehensive approach to hazard identification and control. This includes the following:

1. Contractor provided safety program (fig. 1). Here the contractor provides the total safety plan and performs design hazard analysis, operational hazard analysis, and provides a final safety assessment.

2. Contractor assisted safety program (fig. 2). Here the contractor provides a safety representative and the hazard summary with NASA carrying the main burden.

3. MSC Safety Office provided safety program (fig. 3). Here the MSC organization conducts the design hazard analysis, safety assessment, and crew procedure reviews. MSC makes extensive use of independently prepared safety analyses by safety professionals.

MSFC, with the support of their integrating contractor MMC, developed a series of Skylab system safety checklists. The objective of this program was to summarize the actual status of the Skylab design and operational conditions which could result in systems failure, equipment damage, or personnel injury. These checklists also provide management visibility of the effectiveness of hazard identification and control activities. It also is an aid for effective implementation of followup actions. Typical source data

CONTRACTOR PROVIDED SAFETY PROGRAM

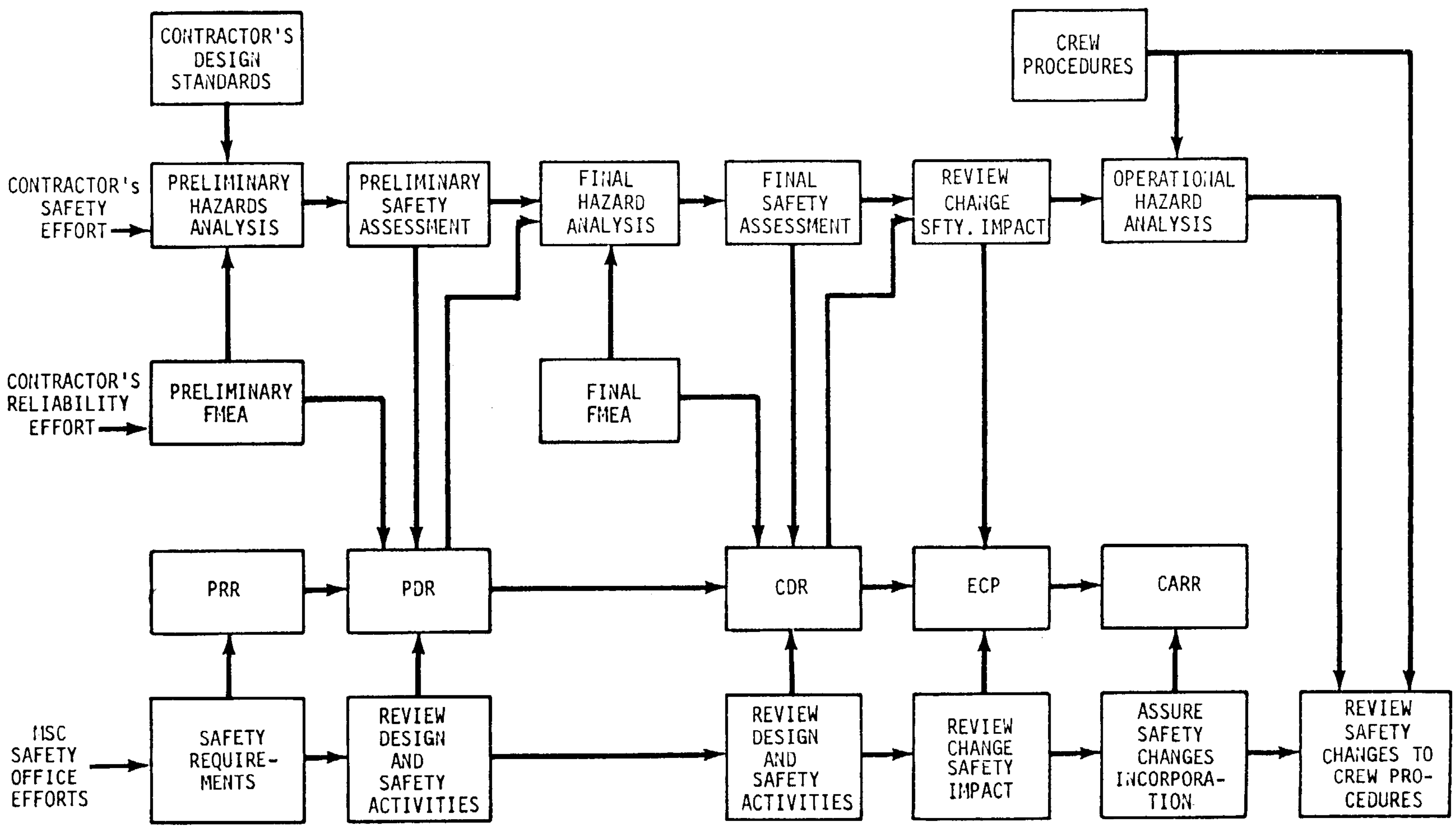


FIGURE 1

CONTRACTOR ASSISTED SAFETY PROGRAM

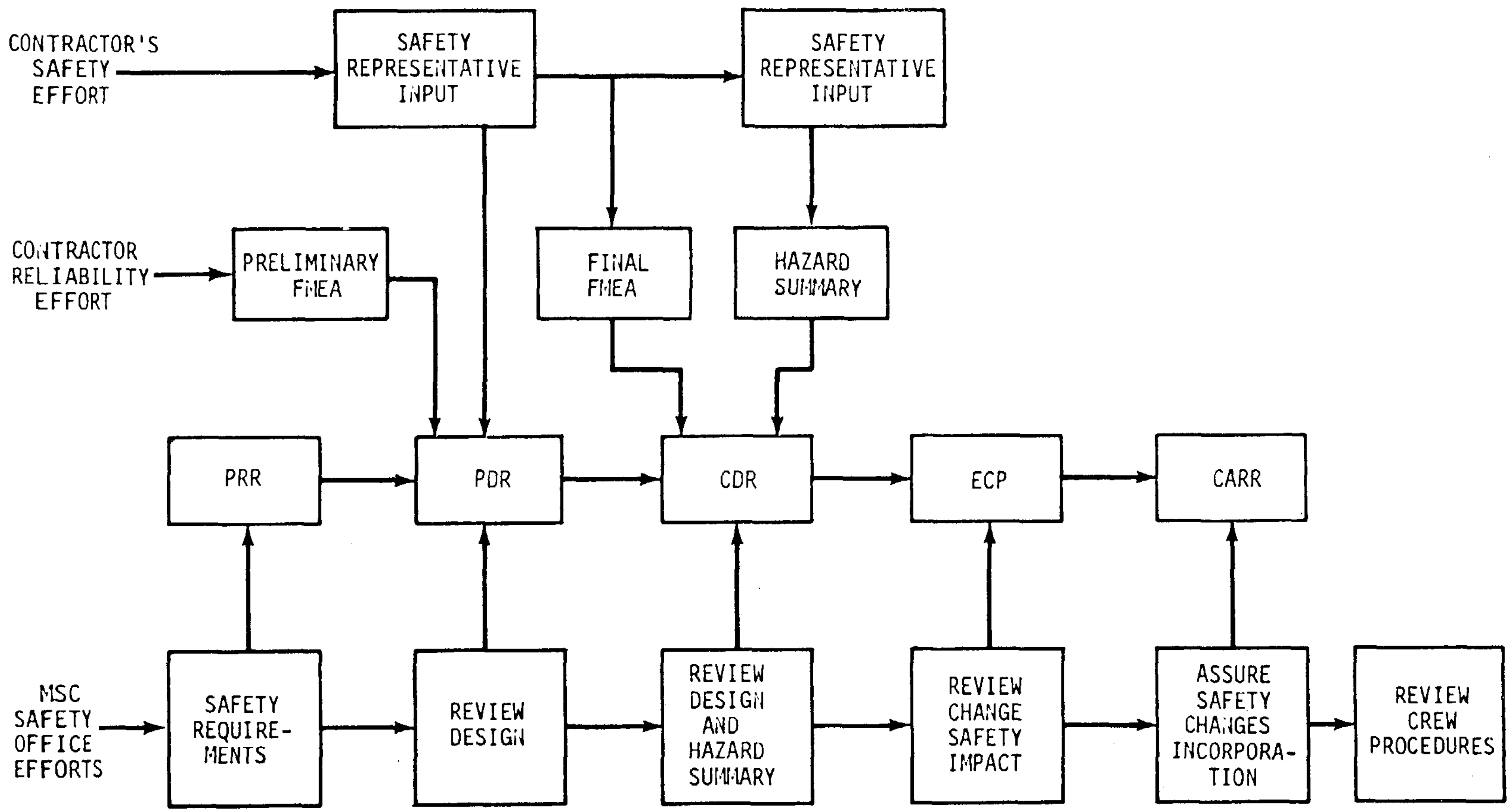


FIGURE 2

SAFETY OFFICE PROVIDED SAFETY PROGRAM

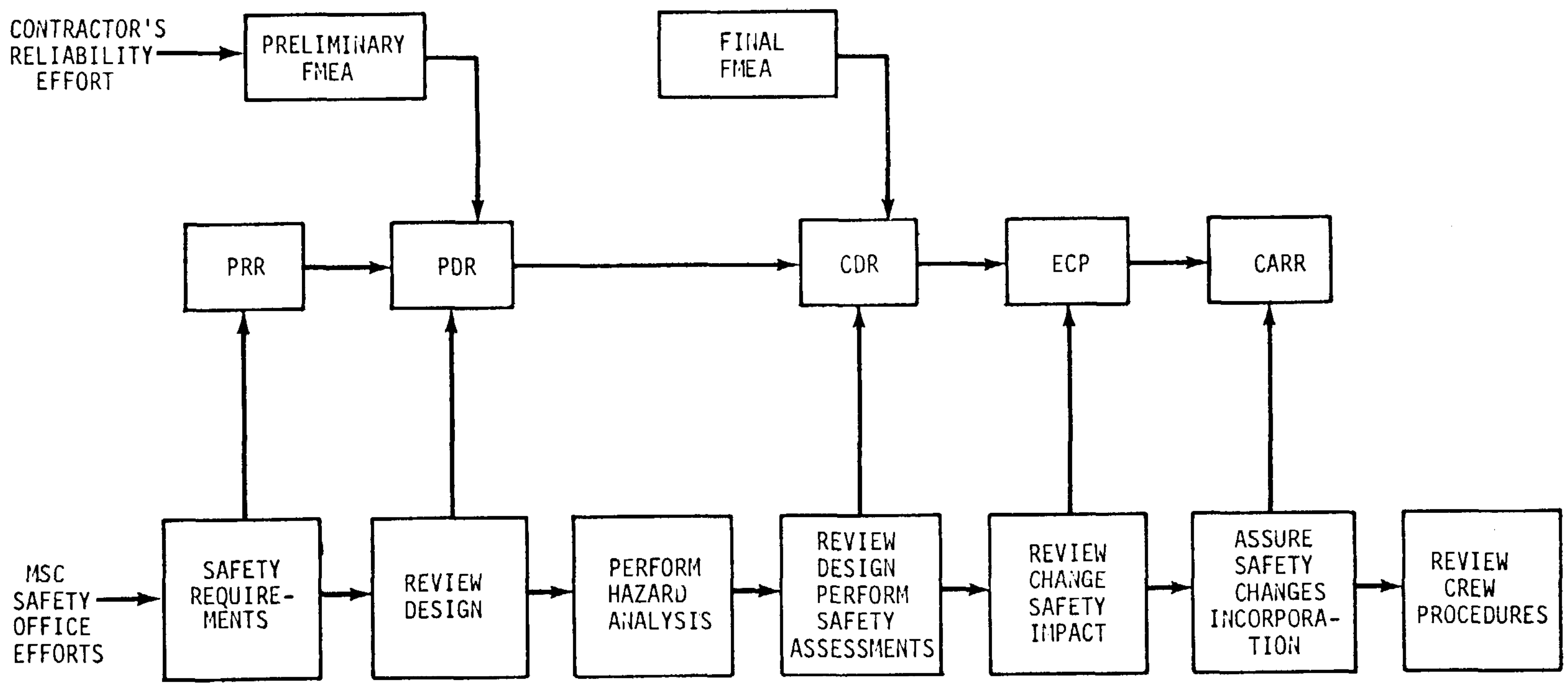


FIGURE 3

for the checklist development were derived from the documents shown in table I.

Safety assessments have been made for individual modules and launch vehicles as well as the Skylab systems across the cluster (total orbiting hardware). This activity, done in support of the design certification reviews, will continue through launch preparation and the mission as required. Manned safety assessments of the operations area are still being conducted as the mission documentation is prepared and hardware moves through KSC test, checkout, and launch preparation. If all available material from hardware assessments is used, this work will identify potentially hazardous operations, provide substantiating data that safety requirements are satisfied, and will indicate where additional contingency procedures development may be required for crew safety. Program management is currently emphasizing this aspect of the safety work to assure completion on time and with adequate coverage. At the time of the review by the Panel, 88 safety tasks had been identified. These tasks covered the mission events from prelaunch through landing, recovery, and rescue. Of these 88 safety tasks, 48 are still to be completed. The incomplete tasks include analysis of lightning strikes, solar heating of service module reaction control system during rendezvous and docking, and some of the cluster on-orbit operations in the fields of activation, habitability, emergency operations, and subsystem operations.

Among the "open items" of interest are the following:

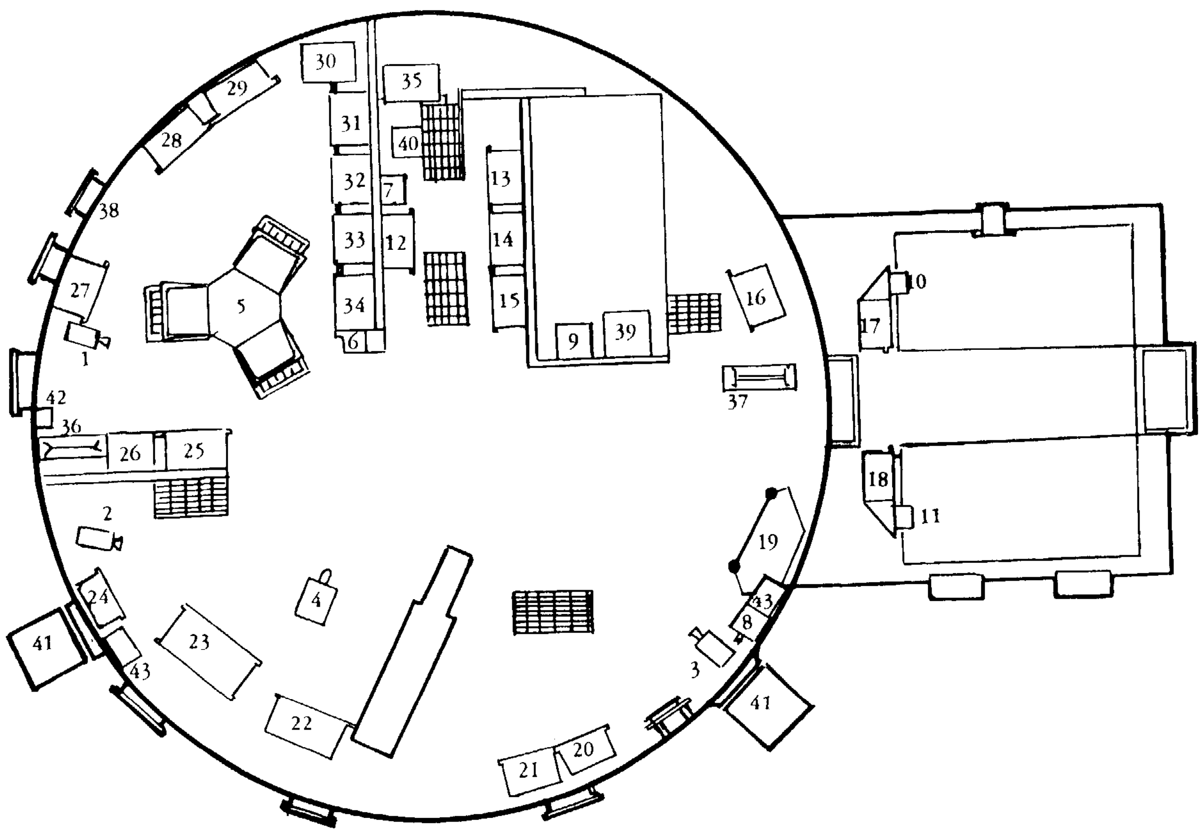
1. Sneak circuit analysis
2. Corona assessment
3. Susceptibility of crew inhalation of particulate matter within the cluster during Earth orbit
4. Suit drying system problems and suit availability for emergencies
5. Safety analysis of partial loss of solar array power and the definition of candidate loads for a power down
6. Detailed crew procedures for reaction to ΔP alerts

Skylab rescue is discussed in the MISSION OPERATIONS section of this report. From the safety standpoint the rescue is not considered to be time critical since it is assumed the cluster is habitable. Identified hazards in the rescue spacecraft include the couch assemblies installed in the lower bay, center couch ballast, and the oxygen umbilicals and "Y" adapters. Tests and analysis indicate minimal risk.

SKYLAB MEDICAL EXPERIMENTS ALTITUDE TEST (SMEAT)

Test Description and Objectives

The Skylab medical experiments altitude test was a 56-day chamber test performed at MSC. It used the Crew Systems Division's 20-foot-diameter altitude chamber. Skylab



1,2, & 3 - TV Camera (overhead installation)
4 - M 171 Ergometer
5 - Food preparation table
6,7,8,9,10, 11 - Intercoms
12,13, & 15 - Stowage (head area)
14 - Sink
16,17, & 18 - Stowage (personnel sleep area)
19 - Off-duty equipment
20 & 21 - Stowage (lounge area)
22 - ESS rack
23 - M 171 MA rack
24 - Experimental trash stowage
25 - Camera and photo stowage
26 - Medical stowage
27 - NASA Hdq stowage
28 - Fecal bag stowage
29 - Vac bag, hygiene, and thermoglove stowage
30 - Refrigerator/freezer
31 - Tools and trash stowage
32 - Galley
33 - Trays and food stowage
35 - Urine chiller
36 & 37 - Ladder
38 - Transfer lock
39 - M 133 sleep monitor
40 - Head
41 - TV display
42 - CO monitor
43 - Speaker entertainment stations

FIGURE 4. CHAMBER ARRANGEMENT

environment and protocol were duplicated as closely as possible.

The test objectives were as follows:

1. The primary objective was to obtain and evaluate baseline medical data for 56 days on those medical experiments which reflect the effects of the Skylab environment. This included microbiological data and additional biomedical data unobtainable in flight.

2. The secondary objectives were to (1) evaluate selected experiments hardware, systems, and ancillary equipment, (2) evaluate data reduction and data handling procedures in a mission duration time frame, (3) evaluate preflight and postflight medical support operations, procedures, and equipment, (4) evaluate medical in-flight experiment operating procedures, and (5) train Skylab medical operations team for participation during real orbiting flight.

The test started on July 26, 1972 and was completed on September 20, 1972. A final report is expected in January 1973.

The layout in the MSC 20-foot chamber was similar to the lower deck of the OWS. It included a waste management area, galley, crew sleeping quarters, and an experiment operation area. These are shown in figure 4. An upper deck area was set up for off-duty crew activities. Chamber modifications affecting the human medical data were made as close to Skylab flight hardware as practical. Other chamber modifications had Skylab hardware appearance but did not function as the flight hardware in order that costs could be held down. Crew activities were conducted according to the mission-like flight data file which was modified to fit the SMEAT test configuration. Communications conducted during the test period followed Skylab protocol except for equipment repair and safety activities.

The medical experiments and other Skylab equipments used and evaluated during the test are defined in table II.

During the Panel's attendance at the various DCR, PDTR, and spacecraft acceptance activities the impact of the SMEAT results during and after the completion of the test were noted. Most of the problems that surfaced during the SMEAT have been, or are in the process of being, factored into the flight hardware at this time.

Experiment Support Medical Requirements

Flight-type qualification preflight and postflight physical examinations were performed prechamber and postchamber. In-chamber exams, administered by physician crewman, were required for in-flight medical support system (IMSS). Vision and audiometry testing and chest X-rays were done prechamber and postchamber.

The SMEAT surfaced both operational and hardware problems. This of course is the reason for such development tests. A partial list of these problems is noted here. The Panel is awaiting the release of the SMEAT report for further data.

M092 - Lower body negative pressure experiment:

1. Differences between BPMS reading and blood pressure obtained by clinical techniques. (Problem may not be real - tests to be done to verify.)
2. BPMS occasionally reads 001 for systolic pressure.
3. Leg bands require calibration and incorporation of foam spacers.
4. Waist seal subject to leakage and damage. May need to carry in-flight spare.
5. Problem with isolation from VCG signals.

M093 - Vectorcardiogram experiments:

1. VCG cable length needs to be increased for use on ergometer.
2. Electrode sponges have caused variation in electrode impedance.
3. Heart rate readout occasionally hangs up at upper limit.

M074 - Small mass measuring device:

1. Elastomer retention sheet tore loose in use.

M133 - Sleep monitoring experiment:

1. Cap sizing critical to comfort. Must provide correct size for designated crewmen.
2. Electrode material caused allergic reaction on some crewmen.

M171 - Metabolic activity experiment:

1. Mode 1 operation is unsatisfactory.
2. Calibration shifts have occurred at 5 and 14 psia.
3. High CO_2 readings indicate high RQ.
4. High water vapor content entering mass spectrometer.
5. Minute volume and initial capacity readings erroneous or inoperative.
6. Moisture accumulates in expiration hose. Need method of cleaning and drying.
7. Ergometer pedals require rework to prevent them from coming off in use.
8. Load module failed in use (may have been nonflight configuration). Evaluation in process.
9. Temperature probe being redesigned for oral use.
10. Mass spectrometer outlet requires standpipe extension.

M487 - Temperature sensor:

1. Temperature sensor failed in use.
2. Stowage container mosites material expanded at 5 psia.

OWS waste management system:

1. 2000-Milliliter capacity of urine collection bags is inadequate.
2. Accuracy of mechanical system for measuring urine volume does not meet specification limits of ±2 percent.

3. Fecal bag seal design is unsatisfactory because of procedural complexity to close bag after use.

4. Fecal bag tare weights are not constant.

5. Minor problems exist with recirculation door latch, recirculation hose connections, and sample bags.

OWS vacuum cleaner:

1. Vacuum cleaner brush modification is required to provide effective operation at 5 psia.

2. Vacuum cleaner airflow is marginal at 5 psia.

The panel was assured that a concerted effort was underway to resolve all of these problems and any others which have arisen since the Panel viewed this area. The Panel fully intends to examine this area further to assure that the system is in fact adequately covering this most important facet of the Skylab development program.

CLUSTER FAULT CURRENT PROTECTION

A review of "Fault Current Protection" for the OWS, AM, MDA, and ATM was initiated in the fall of 1970. Its purpose was to eliminate or reduce possible crew and mission hazards resulting from electrical distribution system failures.

Fault currents in the power feeder lines (cluster solar arrays to the first line of internal circuit protection) can be of the order of hundreds of amperes, yet total protection is neither directly feasible nor practical. Consequently, any power feeder or bus not having overload protection must be physically protected and electrically isolated to the maximum degree possible to obtain lowest probability of fault occurrence. This can be accomplished by appropriate routing of circuits, proper installation and inspection procedures during fabrication, use of protective covers, and potting of buses.

Following this philosophy the practical approach taken by the Skylab program was to size the returns for a maximum fault current that is possible "downstream" of the first line of circuit protection. The maximum fault current based on this approach is 63 amperes.

The following power feeders from the power source to the first line of circuit protection have been identified:

Power feeders from the regulator bus to the AM bus
Power feeders from the regulator bus to the overload transfer bus
Power feeders from power conditioning units to the regulator bus
Power feeders in the regulator bus TIE circuit
Power feeders from the ATM solar array to the ATM battery regulators
Power feeders from the OWS solar array to the AM power conditioning units

ELECTRICAL SYSTEMS APPROACH

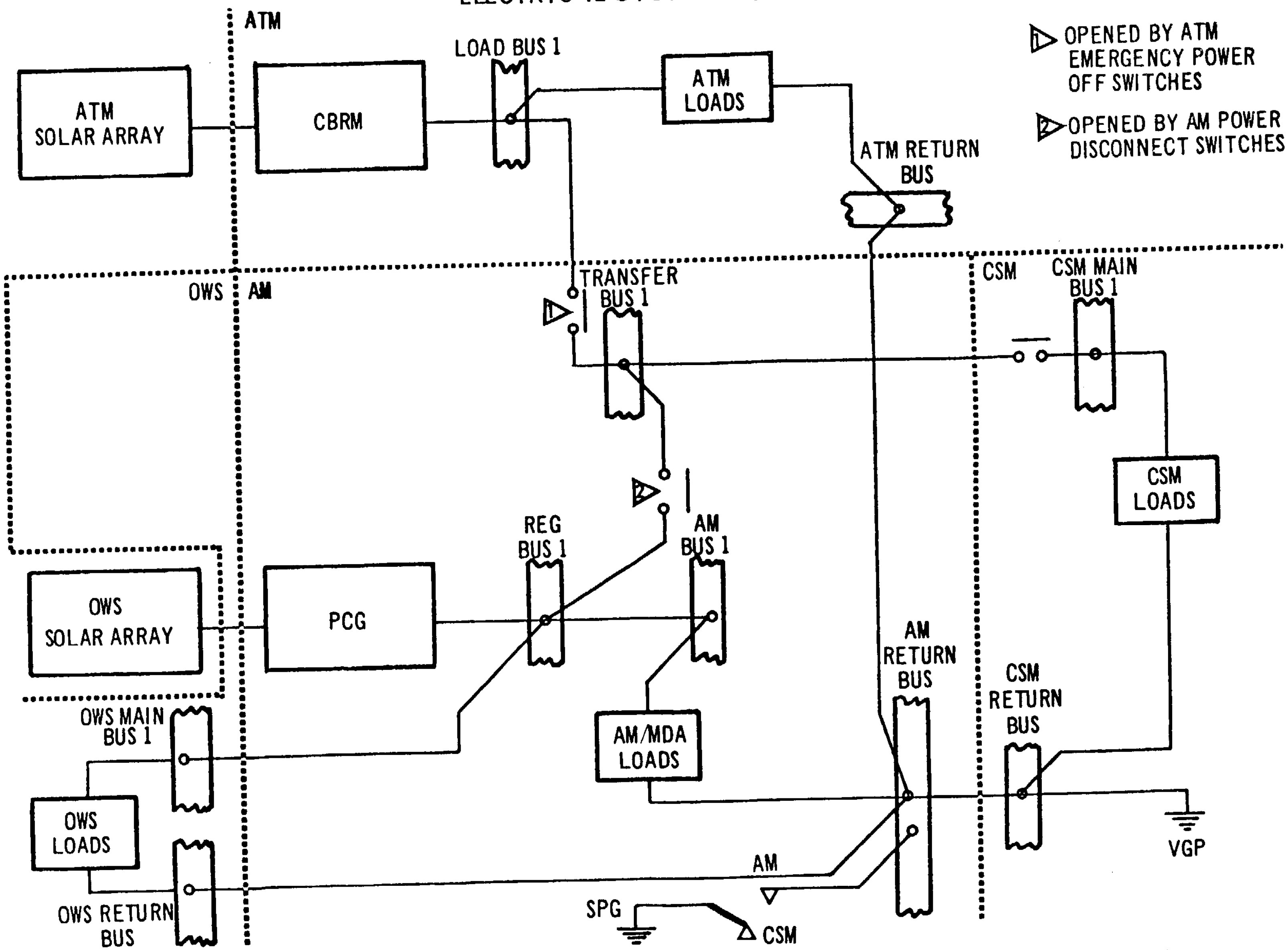


FIGURE 5

The MSFC and MSC Program Offices set up teams and dispatched them to the contractor plants for the major modules. The teams were to review and provide recommendations for electrical system protection. These activities were initiated in 1970 and were completed in the late spring of 1972. During this time several visits to each module contractor's site were made in order to maintain a current picture of this area. Each finding developed by the MSFC/MSC/contractor teams was acted on in what appears to be a responsible manner. Changes to the electrical circuit were made under a management discipline similar to a configuration change board.

The documentation and material presented to the Panel indicates that this area has been adequately covered.

Figure 5 indicates the cluster electrical systems approach.

SNEAK CIRCUIT ANALYSIS

A sneak circuit is an electrical or electromagnetic conducting path which causes an unwanted function (either activation or inhibition) when power is applied to an element of the space vehicle to achieve a desired function. Skylab sneak circuit analyses are conducted by the Boeing Company on a subcontract to the Martin Marietta Corporation. It is accomplished at MSC with the aid of a computerized system developed on the Apollo program. The computer-aided sneak circuit analysis program is shown schematically in figure 6. The purpose is to surface such circuits and alert appropriate programmatic organizations to assure resolution. Skylab Sneak Circuit Bulletins are circulated not only to Skylab organizations but to Apollo and other activities which may also have use for the information.

The sneak circuit program is scheduled for completion just prior to the launch of the SL-1/2 mission in the spring of 1973. Thus, at this time it is estimated that about 35 to 45 percent of the analysis is complete. The SOCAR team and the DCR material reviewed by the Panel indicate that, though the analyses conducted to date have uncovered numerous sneak circuits, none have been identified which would be hazardous to the crew or abort the mission.

Allied areas of corona analysis and electromagnetic interference and compatibility are discussed in the RELIABILITY, QUALITY, and SAFETY section.

COMPUTER-AIDED SNEAK CIRCUIT ANALYSIS

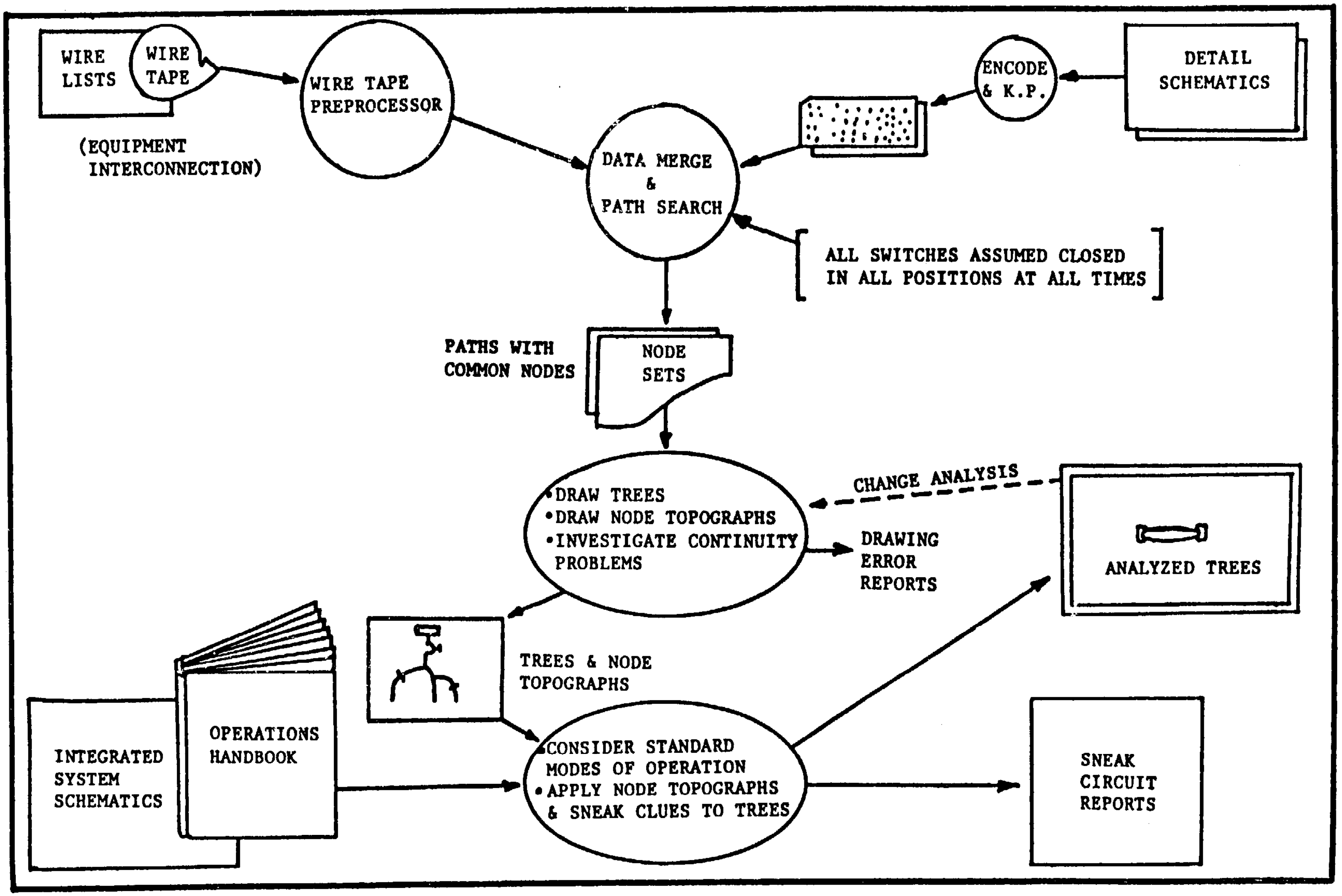


FIGURE 6

MICROBIAL CONTROL

Microbial contamination can occur during both the ground and mission phases. During ground activities, crew and ground personnel can bring organisms into the hardware. During the mission, crewmen will release organisms into an environment that may be supportive of growth. Based on this the program has emphasized source and propagation control.

The Mil Spec concerning fungus certification testing is the only requirement imposed in the cluster and module end-item specifications. Other than that there is apparently the requirement that only general visual cleanliness be achieved during the manufacturing and delivery process. Certain items of hardware such as experiments have very tight cleanliness requirements to prevent degradation of data.

The design of the Skylab had advanced to a rather late stage before the Skylab Program Office authorized the establishment of the Skylab intercenter microbial control working group (SIMCWG). This group consisted primarily of microbiologists and biomedical personnel from MSC, MSFC, and the major contractors. They held an organizational meeting on August 14, 1970. Since that first meeting the SIMCWG has been active and effective in meeting its charter. Essentially, this charter defined microbial control as an overall Skylab cluster program and requires the working group to maintain a continuous monitoring and consulting service for all phases of the Skylab program. From manufacture through the mission they provide assessments of the real and potential microbial problems that may arise, and they make recommendations for microbial control of the problem areas.

The SOCAR microbial control activities provided a most comprehensive review, while other reviews such as the DCR's and PDTR/SAR's carried the SOCAR effort to its logical conclusion by analyzing and following through on the recommendations made by SOCAR.

The primary purpose of the SOCAR team was to analyze all aspects of the Skylab program that could potentially result in significant microbial growth problems and the measures, both design and operational, presently implemented or planned for the control of the microbial growth. The review did not result in the identification of a major microbial control problem. However, several areas were uncovered in which the design or procedures were considered to be inadequate. Obviously, the determination of threshold values at which point microorganisms can be considered a detriment to the crew and/or mission is most difficult if not impossible. Therefore, the objective centered on pinpointing those areas where relatively high numbers of organisms could accumulate and propagate.

Another area covered under the microbial control issue is that of flight crew health stabilization. The purpose here is to establish basic requirements for the preflight, postflight, and in-flight mission phases. Protection of the crew against disease agents is, of course, critical to source control. Owing to the press of time the Panel was limited in its review of this area.

The Panel also reviewed analyses from other sources. The first was "An Etiological Study of Phthalate Self-Contamination or Spacecraft and Contamination From Their Earthly Environs" (NASA Technical Note TN D-6903, August 1972). The second was "Human Factors in Long-Duration Spaceflight" (National Academy of Sciences publication, 1972). They were examined to further understand the possible problems inherent in Skylab and the ability to resolve them.

The following excerpts from these documents are of value in placing the current Skylab posture with respect to microbial control in the proper perspective.

From the NASA technical note:

> All optical experiments are subject to degradation by contamination; however, the vacuum ultraviolet experiments are the most sensitive because nearly all organics absorb in this spectral region. Degradation of star-tracker optics could jeopardize orientation and guidance systems. . . . Contamination of other optical experiment and particle detectors on board can result in false data acquisition or failure of that module.
>
> Those working on the development of a manned orbiting laboratory such as Skylab must consider not only these problems but in addition the problems of long-term environmental stabilization and control for the well-being of personnel. As a result of these developments it can be anticipated, and, in fact, preliminary evidence exists, that phthalate as well as other types of contamination problems will emerge on even a larger scale than previously experienced. This does not seem like the type of problem for which there is any straightforward solution; therefore, people connected with all aspects of the space program must be made fully aware of the contamination pitfalls and work to minimize them so that they will no longer pose a threat to the success of a program.

From the National Academy of Sciences' document:

> Interestingly, observations to date on confined populations indicate that adequate hygienic measures in space crews should minimize buildup and transfer of microorganisms among individuals. . . . There will always be a risk of developing allergies to food and other allergenic agents in spacecraft during long-term missions.

Ground Handling

In general, all contractors have similar procedures for cleanliness and environmental controls during ground handling of their modules and equipments. During this time, for example, relative humidity is maintained at less than 60 percent and temperature is maintained between 40° and 80° F to prevent condensation on component parts. Materials and personnel moving in and out of the hardware work areas practice procedures required for class 100,000 cleanliness. The definition of a clean room class such as "100,000" is shown in figure 7. A 100,000 class room is one in which there are no more than 100,000 airborne particles of 0.5 micron diameter or larger per cubic foot of air with approximately 200 particles per cubic foot larger than 10 microns. On arrival at KSC all modules are to be protected from microbial contamination by procedures outlined in "Cleanliness Requirements for Kennedy Space Center Operations, Skylab I Hardware," SE-014-002-2H, Revision A, April 24, 1972.

STATISTICAL PARTICLE SIZE DISTRIBUTION IN CLEAN ROOMS

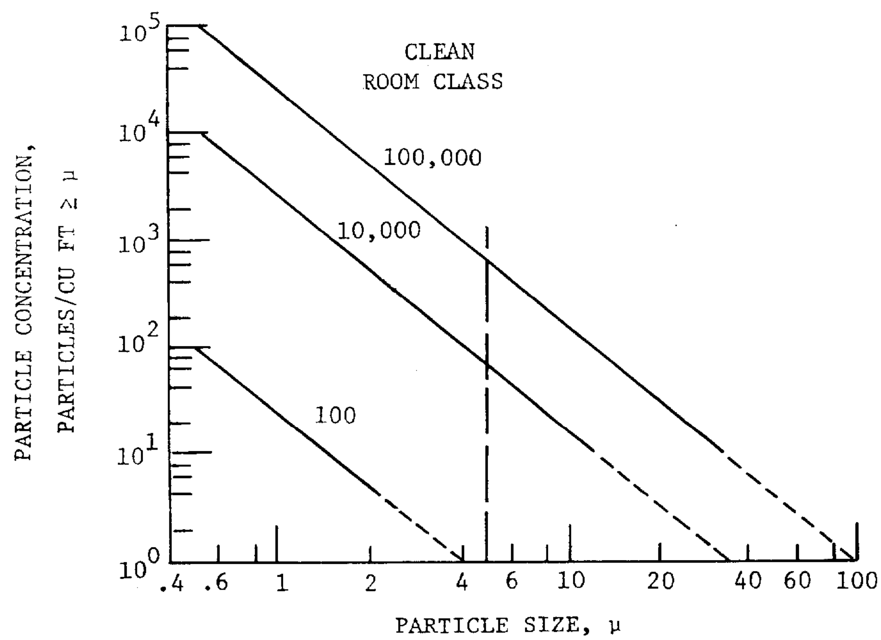


FIGURE 7

In-Flight Systems

Subsystem microbial control analyses have been conducted on the following systems and subsystems: water, food, waste, thermal and ventilation, personal hygiene, trash disposal, and suit drying. Each of these areas, except suit drying, has been discussed elsewhere.

The suit drying station is located on the upper or forward portion of the OWS near the water tank ring. The system is required to recirculate closed-loop cabin atmosphere to dry three suits within 48 to 60 hours. The potential for fungal growth in the interior of the suit arises during the between-use intervals when it is stowed in the CM. Inadequate drying or failure to maintain the appropriate humidity inside the suit may result in unacceptable fungal growths. A suit drying test was conducted at MSC during January and February 1972. The results of the test indicated that the drying procedure was not adequate. The hardware and the procedures were changed and the system retested. Closure of this item will be noted in the next report.

The SIMCWG apparently has developed cleaning and decontamination procedures to maintain a clean crew environment. The SOCAR team reviewed all of these and resolved any problem areas revealed during their examination. The SOCAR did identify two areas of concern. Due to initial management philosophy there are limitations on adequate in-flight monitoring and decontamination procedures. Since these cannot be resolved at this time their impact is under review.

It appears that the continuous attention being paid this area will assure inherent risks remain at an acceptable level.

CLUSTER CONTAMINATION CONTROL

Contamination of spacecraft and associated experiments occurs as a result of a complex interplay between onboard generated components, the environments encountered during construction, testing, launch, mission operations, and the hardware itself. As noted in NASA Technical Note D-6903, ". . . Multimillion dollar spacecraft have often been contaminated by such mundane things as fingerprints, plasticizers from vinyl gloves, plastic tubing or protective covers, and residues from improper cleaning solvents."

The Panel in examining contamination control reviewed effects of (1) materials offgassing, (2) waste dumping, and (3) rocket motor firings on experimental optical surfaces, thermal coatings, and solar arrays.

The contamination control working group, SOCAR team, and supporting in-house activities have directed a continuous effort to

1. Identify contamination sources
2. Assure adequacy of controls on materials and hardware
3. Eliminate vents (overboard) where feasible
4. Verify by test and analysis that remaining vents are acceptable
5. Assure that the Skylab environment (external and internal) is compatible with experiments
6. Assure adequacy of operational documentation

In addition, other agencies have been contacted and their expertise used wherever possible. These agencies include the National Bureau of Standards, the Atomic Energy Commission, and the Air Force Cambridge Research Laboratory.

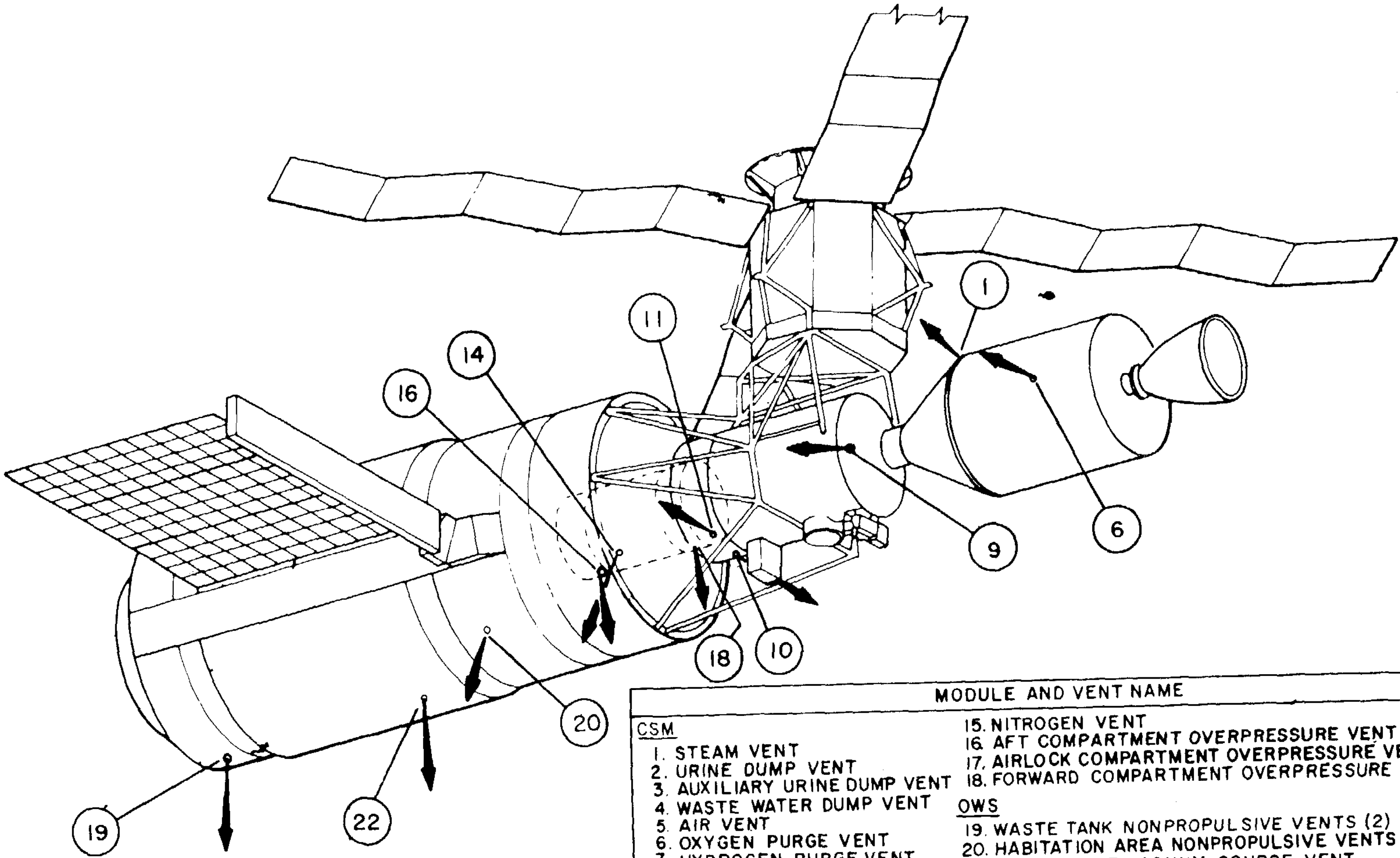
The SOCAR team reported the status of the contamination control activities (including tests) during the review. From their analysis the primary open area is the establishment of acceptable contamination levels for experiment operations. This activity is to be worked by the contamination control working group with the principal investigators. On the whole the cluster modules have been treated in several ways to eliminate possible contamination or reduce it to acceptable levels. The active vents have been designed so that their impingement on critical optical and thermal surfaces is precluded. Major hardware changes have been made to achieve this. This includes the conveyance of condensates into the waste tank rather than overboard, the use of waste tank filters, and the elimination of CSM waste water dump. Figure 8 indicates the location and type of vent. Table III indicates the major vent characteristics. Contamination controls are not relaxed up to the time of launch. The "Contamination Sources Report" ED-2002-879 is a compilation of all contamination sources for the Skylab hardware. This document will receive periodic updates. The contamination baseline will be used as the input and output guide for operational documentation and activities.

The contamination test program has been in progress for some time and is reviewed for necessary updating. Such updates occurred during the May to August 1972 period. Test results will be factored into the operational documentation as required. As an example, reaction control system plume effects and deposition tests are scheduled. Of particular interest here are the effects on the EREP.

Skylab has installed specific contamination sensing devices and experiments to provide real time data and record long term effects. These primary sources of information include the following:

Quartz crystal microbalance
Apollo telescope mount ion gages
Photometers (T027/S073)
Coronagraph (T025)
Proposed mass spectrometer to be mounted on T027 boom

This effort is supported by a ground test program.



MODULE AND VENT NAME

CSM
1. STEAM VENT
2. URINE DUMP VENT
3. AUXILIARY URINE DUMP VENT
4. WASTE WATER DUMP VENT
5. AIR VENT
6. OXYGEN PURGE VENT
7. HYDROGEN PURGE VENT

MDA
8. VACUUM VENT
9. EXPERIMENT VENT

AM
10. MOLECULAR SIEVE VENT
11. MOLECULAR SIEVE VENT
12. CONDENSATE VENT
13. EVA DEPRESSURIZATION VENT
14. AFT COMPARTMENT VENT·
15. NITROGEN VENT
16. AFT COMPARTMENT OVERPRESSURE VENT
17. AIRLOCK COMPARTMENT OVERPRESSURE VENT
18. FORWARD COMPARTMENT OVERPRESSURE VENT

OWS
19. WASTE TANK NONPROPULSIVE VENTS (2)
20. HABITATION AREA NONPROPULSIVE VENTS (2)
21. EXPERIMENT VACUUM SOURCE VENT
22. SCIENTIFIC AIRLOCK VACUUM VENTS (2)

FIGURE 8

The manner in which these data are used is discussed in the MISSION OPERATIONS section. The SOCAR team indicated that there is a deficiency in the contamination data capability because no measurement of the composition of the Skylab environment is available. Knowing the contaminates composition would serve a threefold purpose: Combined with the quartz crystal microbalance output it would help establish "go-no-go" criteria for experiments in real time; it would provide a basis for a correction factor to experiment data affected by environment; and it would enable a more direct determination of the sources of contamination. The proposed mass spectrometer noted in the previous listing is suggested for this purpose. The decision on this suggestion will be noted in the next report.

CLUSTER MATERIALS

Skylab management has given considerable attention to controlling materials and the hazards they present.

Material controls for the Skylab program are based on Skylab Program Directive No. 16A and MSFC Memorandum PM-SL-TQ-17-72. In addition, MSC applied document MSC-DA-D-68-1, "Apollo Applications Program Experiment Hardware General Requirement." Beyond these documents there are numerous NASA and contractor documents specifying the details necessary to meet the overall material requirements. Certain categories of Skylab hardware are necessarily controlled somewhat differently. All methodologies, however, attempt to achieve the same goals.

Material Flammability and Toxicity

Basic to fire prevention and control of toxicity is the control of the materials used and their geometry and location. The Panel's role is not to second guess management judgments but to assure that there is an adequate system in support of it. As viewed by the Panel, the Skylab program has established a system for the identification and management assessment of flammable materials. They have used the data on hazards from past manned programs in their selection and evaluation of materials. All modules and experiments have now essentially been certified by this system. Those items that remain are small in number and they will receive the same thorough treatment as previous items. This does not mean that flammable materials have not been used; however, where they are used it is by conscious management decision. They have taken such actions as they thought possible to minimize the risk through isolating ignition sources, flammables and propagation paths.

The question of materials selection for toxicity of combustion products is actually a paradoxical one. Skylab has selected materials that are primarily either nonburning or self-extinguishing. The paradox lies in the fact that generally the better a material's nonflammability characteristics are, the more toxic its combustion products. Skylab has chosen to use the selection approach, which either will eliminate or limit the size of the fire. The proposed contingency action to counteract toxic combustion products is to isolate the crew from such products. This includes the use of portable masks and oxygen bottles, venting the cluster atmosphere, and a bakeout of the molecular sieves and repressurization with a new atmosphere. At the request of the Panel, MSFC tested a group of widely used, typical spacecraft materials for the effects of their combustion products on ECS components. The tests validated the operational solution and these results were presented to the Panel. Major combustion products of some Skylab materials are shown in table IV. In addition to the normal program activities, material flammability questions have been directed to the NASA Safety Office (Washington, D.C.) and the Spacecraft Fire Hazard Steering Committee.

Of particular interest has been the question of the flammability of crew clothing. Durette is used for the major outer clothing and it is flame retardant with good wear characteristics. The undergarments are made of cotton which has excellent comfort and moisture absorbing characteristics. To date no suitable substitutes have been found for the undergarment material. These materials are equivalent to or better than Apollo clothing. The choice of cotton and Durette has been examined and approved through a waiver. Improved materials are currently under evaluation. If tests work out and the material is available, these new materials could be used as replacements for durette and cotton.

An area of some concern centers on the large quantities of flammable material that must be used and restowed.

There appears to be a concerted, continuous effort to control each and every item that goes into the space vehicle. The requirements are stringent and the implementation if maintained should preclude problems stemming from the use of flammable materials.

Packing Materials

Treated cardboard has been placed in many stowage containers to alleviate the launch environment. These large quantities of cardboard are then discarded. The manner in which this is to be accomplished still appears to be unresolved. A secondary problem attendant to this material is the problem of "shedding" when the material is handled. The Panel understood several groups were working on this and should have resolved this problem as well. Obviously this is not just a hardware concern but also an operations concern since the crew interfaces with this material. The status of this item will be noted in the next report.

The problem posed by the Mosite packing material is different. During tests of the OWS, MDA, and perhaps the AM, the Mosite material had a volume change due to a variation in the pressure surrounding it. Mosite is installed at 14.7 psia and subjected to pressures up to 26 psia during launch. There are pressures of 5 psia during inhabited mission periods and less than 1 psia during quiescent periods of the mission. The material is cut and fitted at 14.7 psia and placed on doors and drawers of the stowage cabinets. When the pressure is reduced to 5 psia and lower, the material expands or swells since it is a cellular material. This makes it difficult and in some cases impossible to open or close cabinets. The Mosite material has been changed to a solid or near solid type. This, of course, has added additional weight to the vehicles. The problem appears to be solved.

Corrosion, stress corrosion, material outgassing, aging, creep, fatigue and coldflow, and hydrogen embrittlement have apparently been given adequate attention.

FIRE DETECTION, CONTROL, AND EXTINGUISHMENT

This section of the Skylab report discusses the "fire" area in terms of the total cluster view and the relevant management systems. The area of extinguishment is covered in some detail. The main purpose is to assess the process by which the current posture on detection, control, and extinguishment has been reached.

The fire detection system has been described in each of the module sections of this report. Briefly the detection system consists of 22 ultraviolet sensors and 12 caution and warning panels. They are located throughout the cluster, except for the CSM. The basic elements of the fire detection system are ultraviolet sensors, memory recall capability, and distinct tones to identify alert by category. These are newly developed items, being used on Skylab for the first time. Because of this and the need to assure detection capability a rigorous test program was carried out. These tests appear to have proven the ability of the system to operate under simulated flight conditions. It had been indicated at one time that the sensor coverage of the OWS forward compartment was marginal due to the viewing distance of the sensors and the ability of the three sensors to adequately cover this large volume. Analysis, test, and crew evaluations indicate that this system for the forward compartment is acceptable. An area that has received considerable study is that of maintenance, since there is little redundant sensor coverage of cluster. Each sensor has the capability of being tested in flight. Spare sensors are carried during the mission for replacement of a failed unit. The test-and-replace capability is an adequate substitute for redundancy if a rigorous test and maintenance schedule is followed during the mission.

Fire control is accomplished by minimizing or eliminating flammable materials, reducing ignition potential, and inhibiting fire propagation paths. This too has been discussed under the sections devoted to each module as well as the CLUSTER MATERIALS section of this report. There is no question in the Panel's mind that this area has been under constant analysis and surveillance by all levels of management and working forces. The learning process that occurred during the design and development period resulted in knowledge that was spread across the entire program to support all NASA and contractor organizations. Materials used in the Skylab modules, experiments, and government furnished equipment have been and will continue to be reviewed for their flammability and toxicity characteristics using a number of proven control methods: (1) material usage agreements requiring NASA approval, (2) material usage maps indicating the location, surface area, and weight of flammable materials, (3) detailed material lists, and (4) computerized programs to assure completeness and consistency throughout the program As a part of the control system the material application evaluation board plays a most important role in maintaining a full-time information desk through which all deviation requests must pass. The board is then convened as required to evaluate these requests. The board in turn notifies the appropriate design organizations and appropriate program managers of the disposition of each request. The data are entered into the control syste Examples of the thoroughness of cluster control by MSFC, MSC, and their contractors are many. The Panel thus feels it is worthwhile to present several cases which provide confidence in the system.

Early in the AM program, testing was conducted to determine the flammability characteristics of silicone/phenolic fiberglass laminates. This testing indicated that nc ignition of these materials would result when tested with the standard ignition source. However, subsequent testing identified these materials to be "configuration sensitive." In addition, it was determined that once ignited, these materials will sometimes propagate to completion rather than self-extinguish. Since major module covers and ducting were fabricated of these materials, it was determined that the applications represented "fire propagation paths" and should be eliminated. As a result, a design change was made which utilized polyimide fiberglass laminates in lieu of the silicone/phenolic fiber glass laminates.

As a result of Apollo experience and the constant pressure to reduce ignition sourc and their ability to reach flammables, a closed trough system was developed to carry a internal wiring. This is seen in the OWS design. The closed trough system consists o rigid troughs, flex troughs, interchange boxes, convoluted tubing, and connector boots. In addition, within these troughs flame barriers have been installed as an integral part of the isolation design to further prevent flame propagation and to cause the flame to self-extinguish. Figures 9 to 11 are indicative of the efforts taken in this design. Tes and analysis indicate that possible ignition source to flammables has been minimized a have been the flame propagation paths.

ORBITAL WORKSHOP
CLOSED TROUGH SYSTEM
(GENERAL CONCEPT)

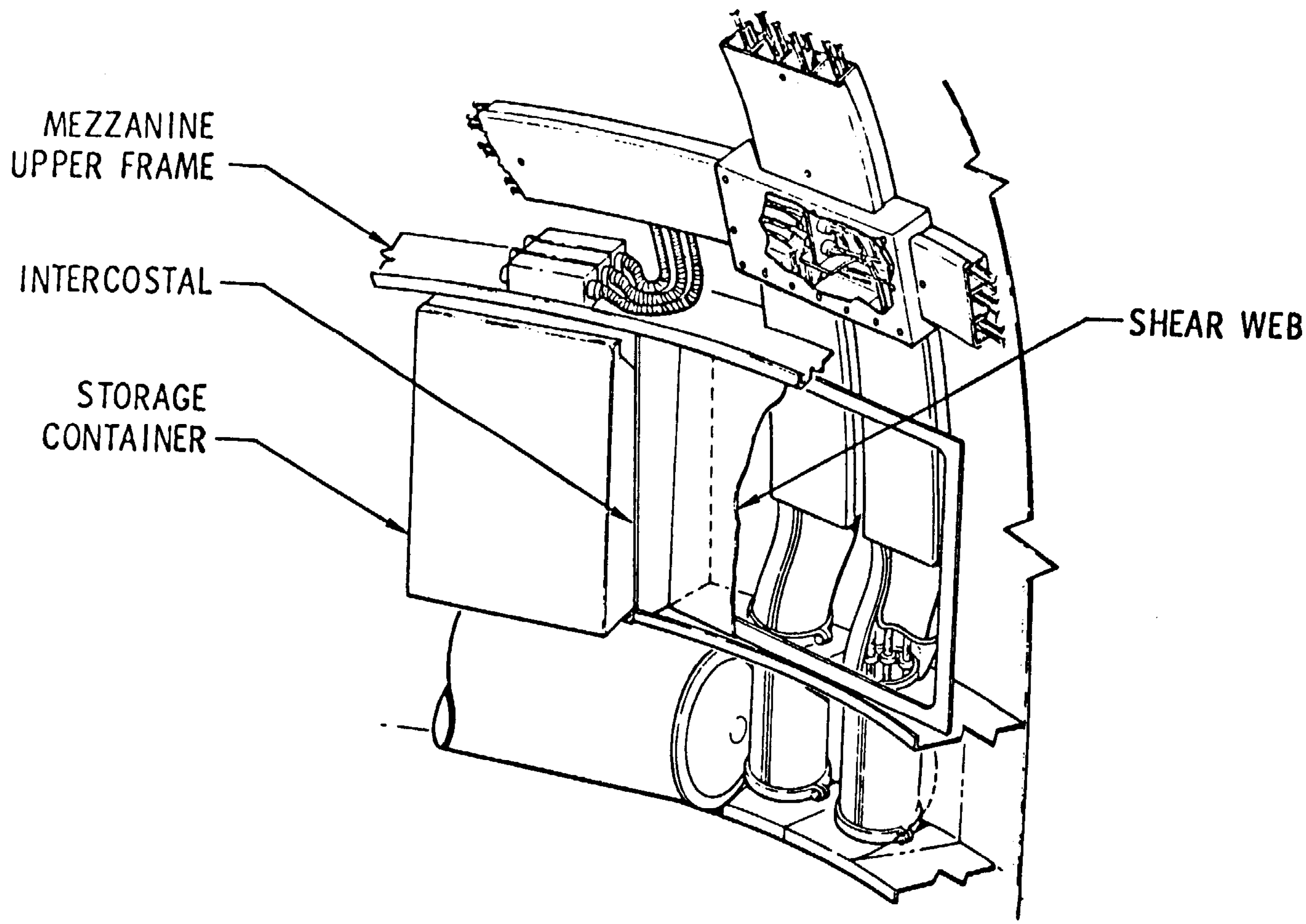


FIGURE 9

ORBITAL WORKSHOP RIGID TROUGH

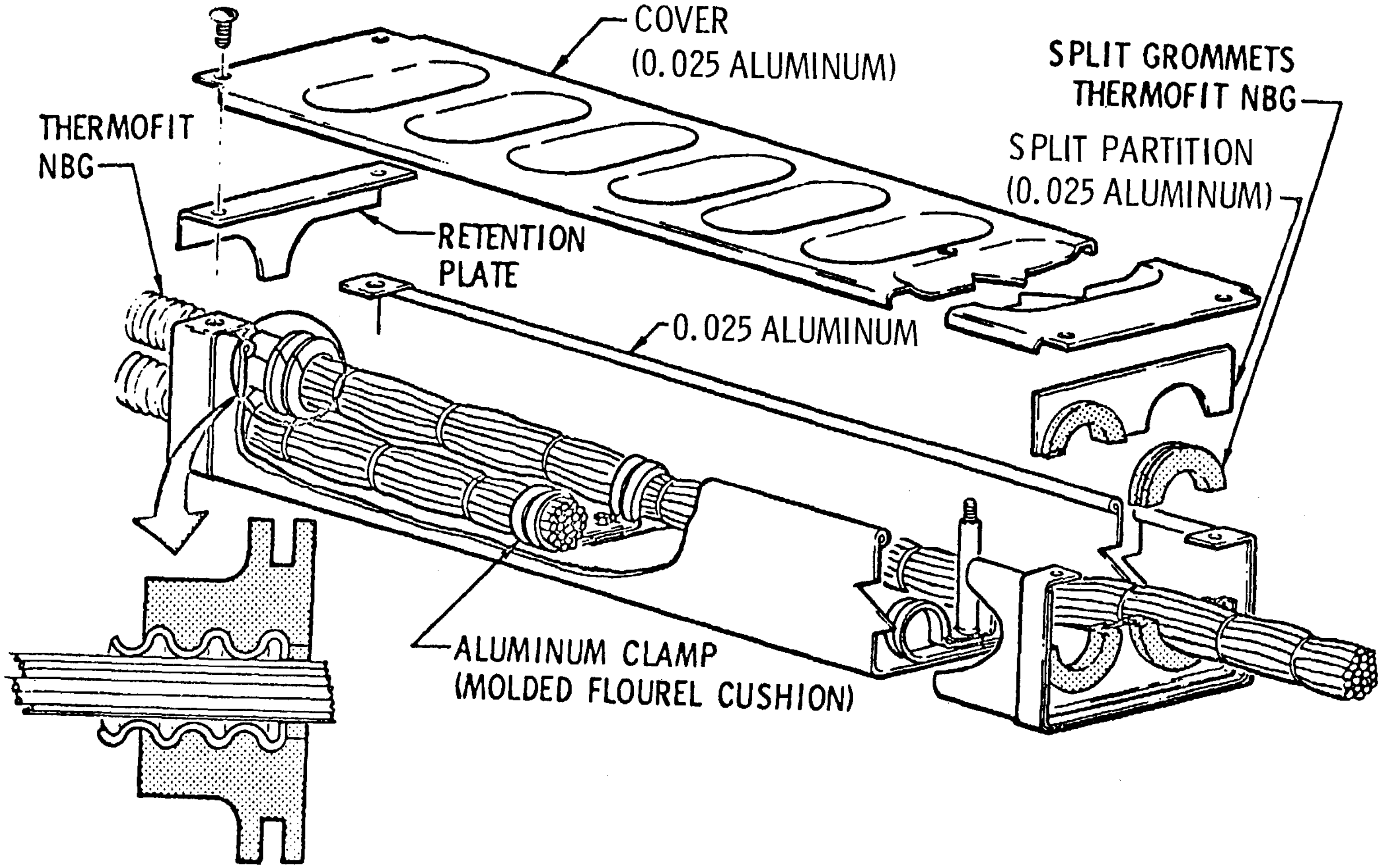


FIGURE 10

ORBITAL WORKSHOP FLEX TROUGH USAGE
(GENERAL CONCEPT)

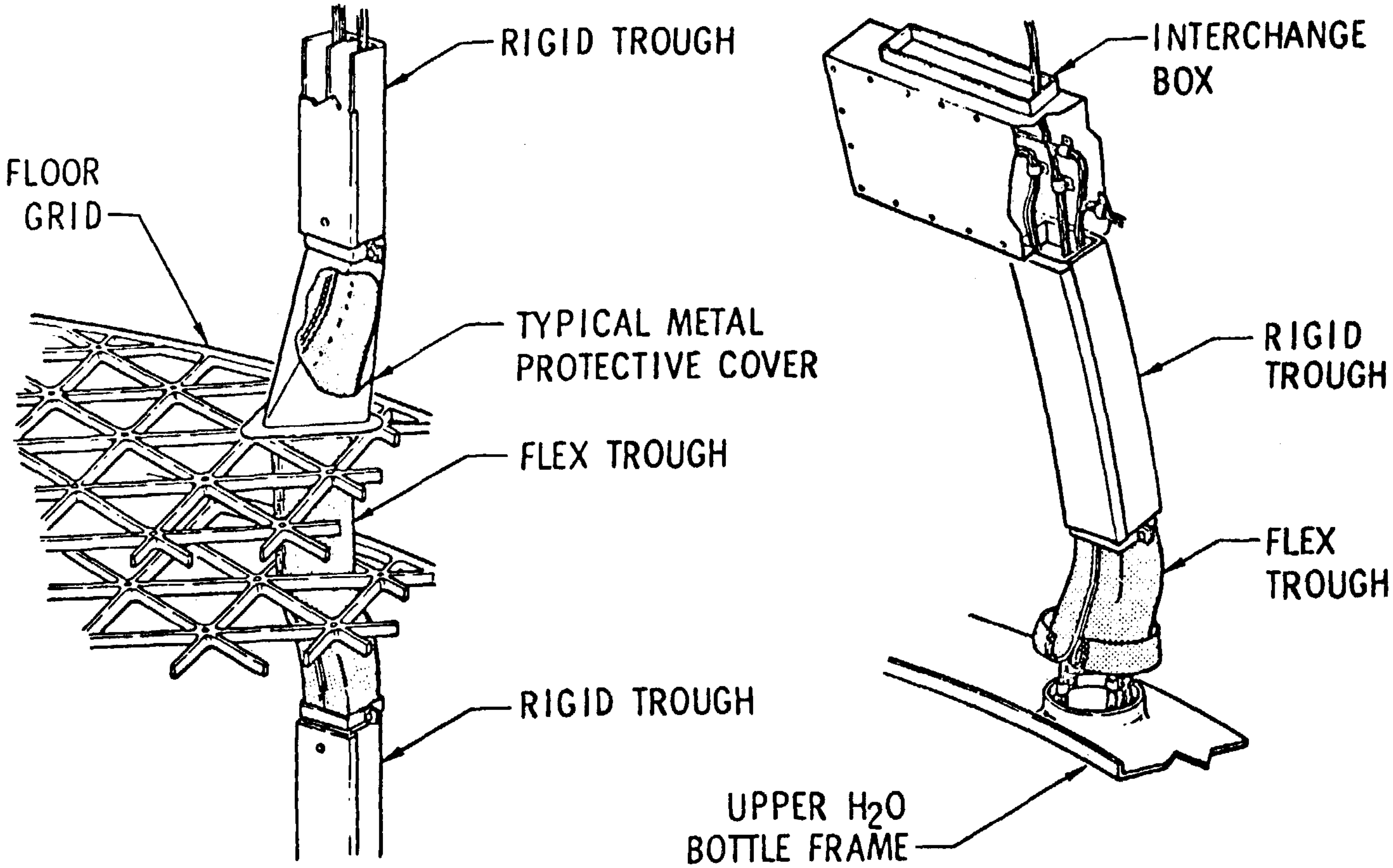


FIGURE 11

Coolanol-15, used as the working fluid in the refrigeration system, could present a critical crew hazard because of the fire potential and presence of toxic vapor. Extensive testing and analysis have been reviewed by management in its decision to accept the risk of using Coolanol-15. Recently, an intercenter Coolanol review team completed an investigation of all potential problems concerning its use. This included a consideration of fabrication, quality control, materials testing, training, safety, and overall system verification of all components and subsystems in the Coolanol loops. It appears to the Panel that the management systems and their implementation have resulted in adequate consideration and understanding of the use of Coolanol-15 and the procedures to alleviate problems if they should arise during testing and the mission itself.

In the event of a fire during the Skylab mission there appear to be four methods of effecting extinguishment: (1) fire extinguishers, (2) use of stored water, (3) shutdown of the atmospheric control system (reduce internal flow or pressure), and (4) shutdown of electrical power system. The Panel's reviews in this area indicate that shutdown of the atmosphere control system and electrical power should effectively allow a fire to self-extinguish. Additionally, fire extinguishers will most likely be used to extinguish the fire as rapidly as possible to minimize propagation and pyrolysis products. No provisions are known for the use of water directly as an extinguishment aid.

The Apollo fire extinguisher was modified for use on the Skylab vehicle. These modifications include the design for one hand use and a flare nozzle attachment to reduce foam velocity. There are five fire extinguishers onboard the cluster, four of these in the OWS and one in the AM/MDA. The CSM carries the same fire extinguisher as used during the Apollo program. MSC, MSFC, and the contractors have conducted comprehensive reviews on the subject of extinguisher locations, required volumes, and degradation with storage time. Further studies have covered the crew training procedures crew translation times in moving from one point in the cluster to another, and the need and location of access holes in panels and equipment covers. With respect to the crew, fire procedures are being developed based on when to fight a fire, what to use, and when to evacuate. The quantity of expelled foam volume of the extinguishers degrades with storage in a one-G condition. Nominal installation of these extinguishers is made 18 days prior to launch. Concern exists that during that time, as well as during zero-G storage in orbit the yield of foam may degrade to an unacceptable level. This appears to be under study at this time, but no resolution is currently known. Fire extinguisher access holes were to be placed in the AM molecular sieves to accept the extinguisher nozzle. The status of both items will be noted in the next report.

A more detailed discussion of the crew procedures associated with fire extinguishment and crew protection is included in the MISSION OPERATIONS section of this repor

In summary then, the Skylab program organizations indicate that they have made a thorough analysis of the fire detection, control, and extinguishment areas, and there is confidence that those items still open will be adequately resolved.

HARDWARE/SOFTWARE ASSESSMENT

MISSION OPERATIONS

Mission operations is a broad category. It includes flight control operations, ground support systems, crew training programs and associated hardware, crew procedures, integration of medical operations, MSFC operations support, flight plans, and contingency analysis and mission rules. Mission operations activities are the summation of hardware performance, flight and ground crew needs and abilities, and the Skylab user requirements.

The Panel centered its attention on the ability of the Skylab program organization and management systems to achieve intercenter cooperation, needed data flow and understanding of hardware capabilities, and realistic planning to translate mission requirements into mission ready documentation and mission ready personnel.

The basic documentation of interest to the Panel includes the Skylab Program Directive No. 43B (March 27, 1972) and the following subordinates: Skylab Operational Data Book, Skylab Operations Handbook, Skylab Systems Handbooks, Flight Plan, and Flight Mission Rules.

The Skylab Operations Directive 43B is a plans and requirements document. It is used as the baseline on which program policies and requirements, mission objectives, and mission planning instructions are issued to the implementing Centers. Several points relevant to an understanding of the mission operations policy need to be clarified. First, if for any reason the Program Director is unable to carry out his duties for delaying a mission (para. 1.4.2 (8)) it is assumed some other individual must be delegated this authority. Second, in the same paragraph it is noted that "if a mandatory item cannot be corrected to permit liftoff within the launch window, . . . has the authority to downgrade an item from mandatory . . . and to proceed with the launch . . ." The possibility of duality in the meaning of "mandatory" may create problems. Last, in Panel discussions at the NASA Centers on the possibilities of setting priorities for the experiments the "Flight Scheduling Precedence Number" discussed in this directive was not mentioned.

The major operations interfaces between MSFC and MSC in developing and implementing operational plans is shown schematically in figures 12 to 15. SOCAR and the many joint design and operational reviews conducted throughout the life of the program provided a valuable opportunity to define relationships and assure mutual indepth knowledge of the flight systems. Those difficulties that have arisen as to roles and responsibilities in the mission operations area appear to be resolved or are in the process of resolution at this time.

MSFC/MSC INTEGRATION RELATIONSHIPS (TYPICAL)

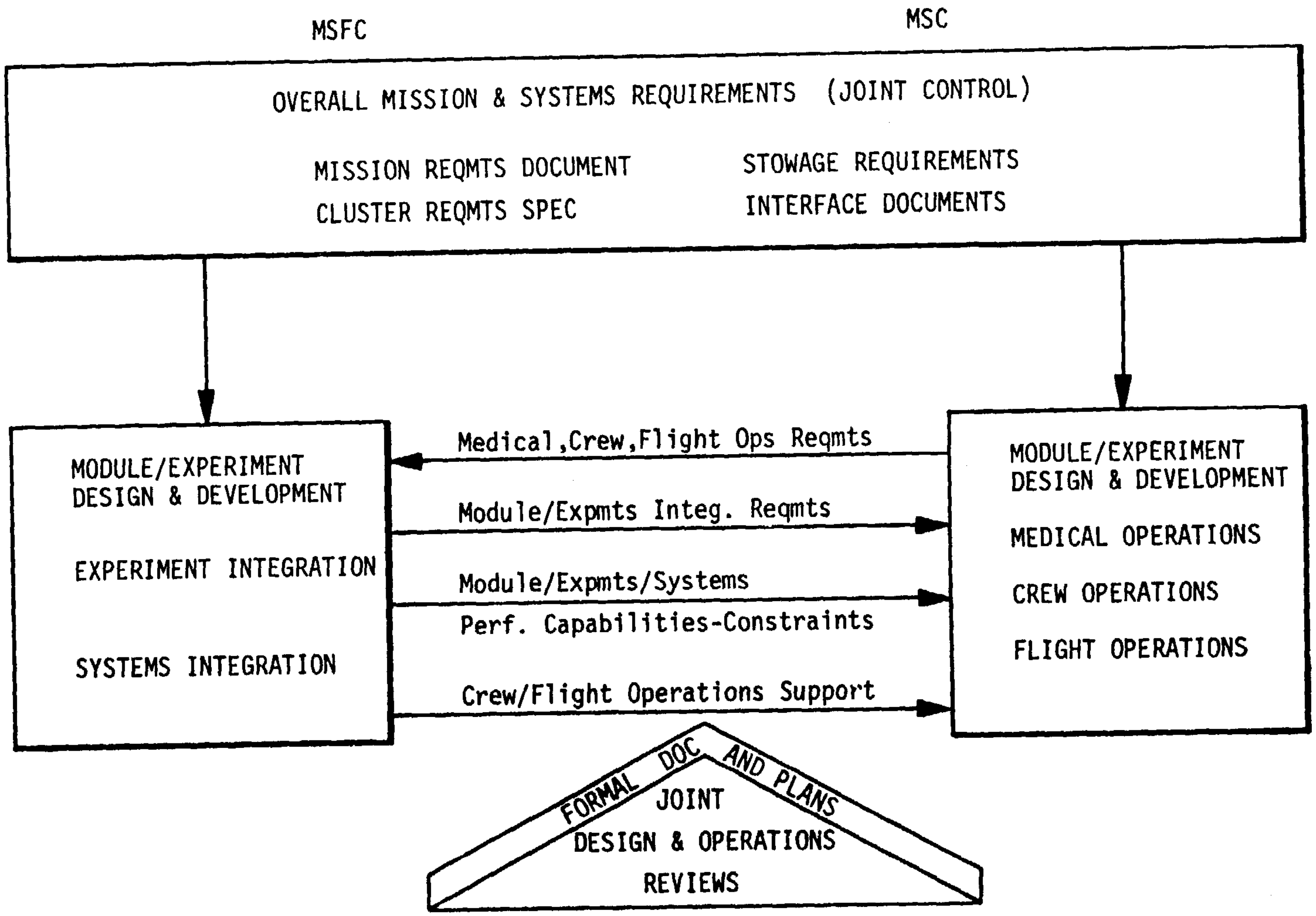


FIGURE 12

CREW OPERATIONS INTERFACES (TYPICAL)

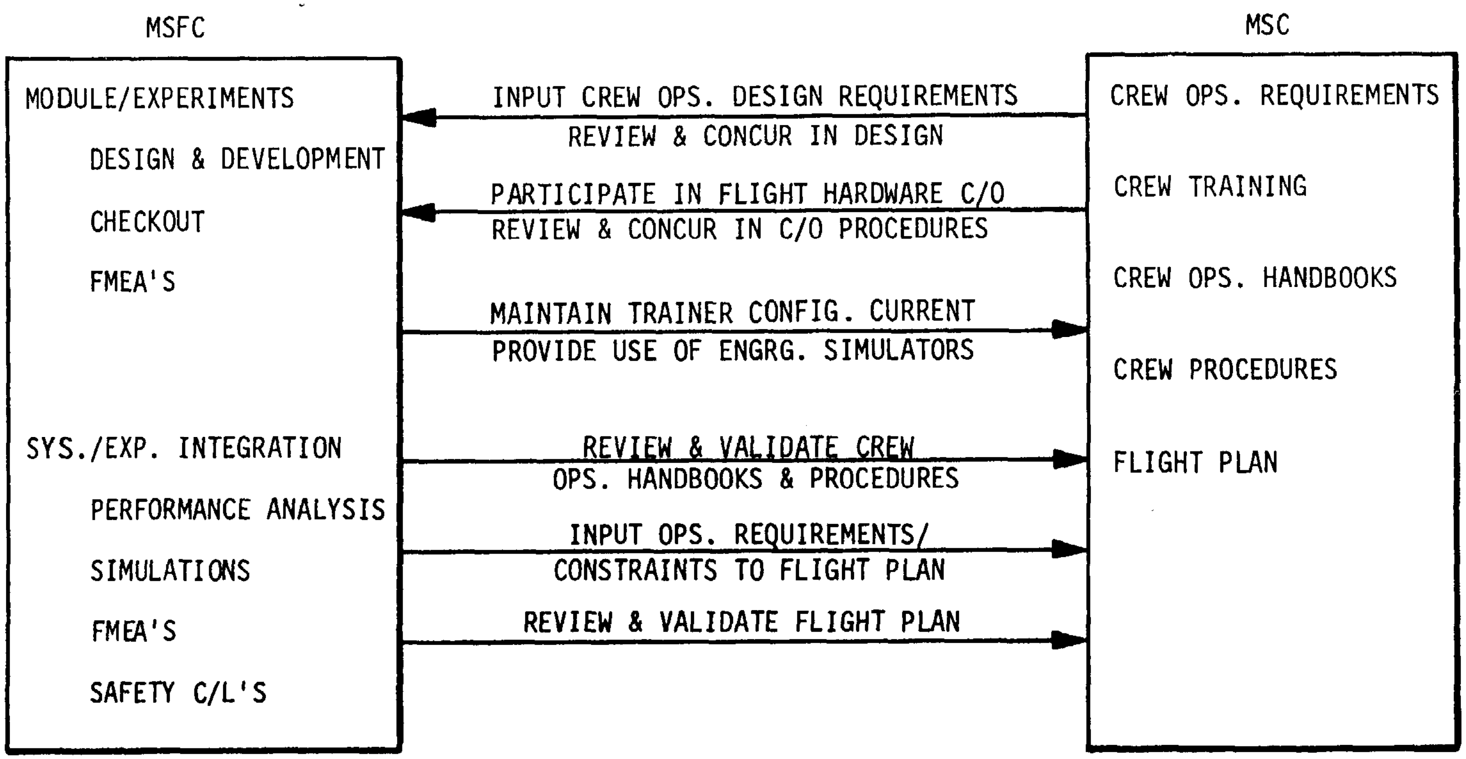


FIGURE 13

FLIGHT OPERATIONS INTERFACES (TYPICAL)

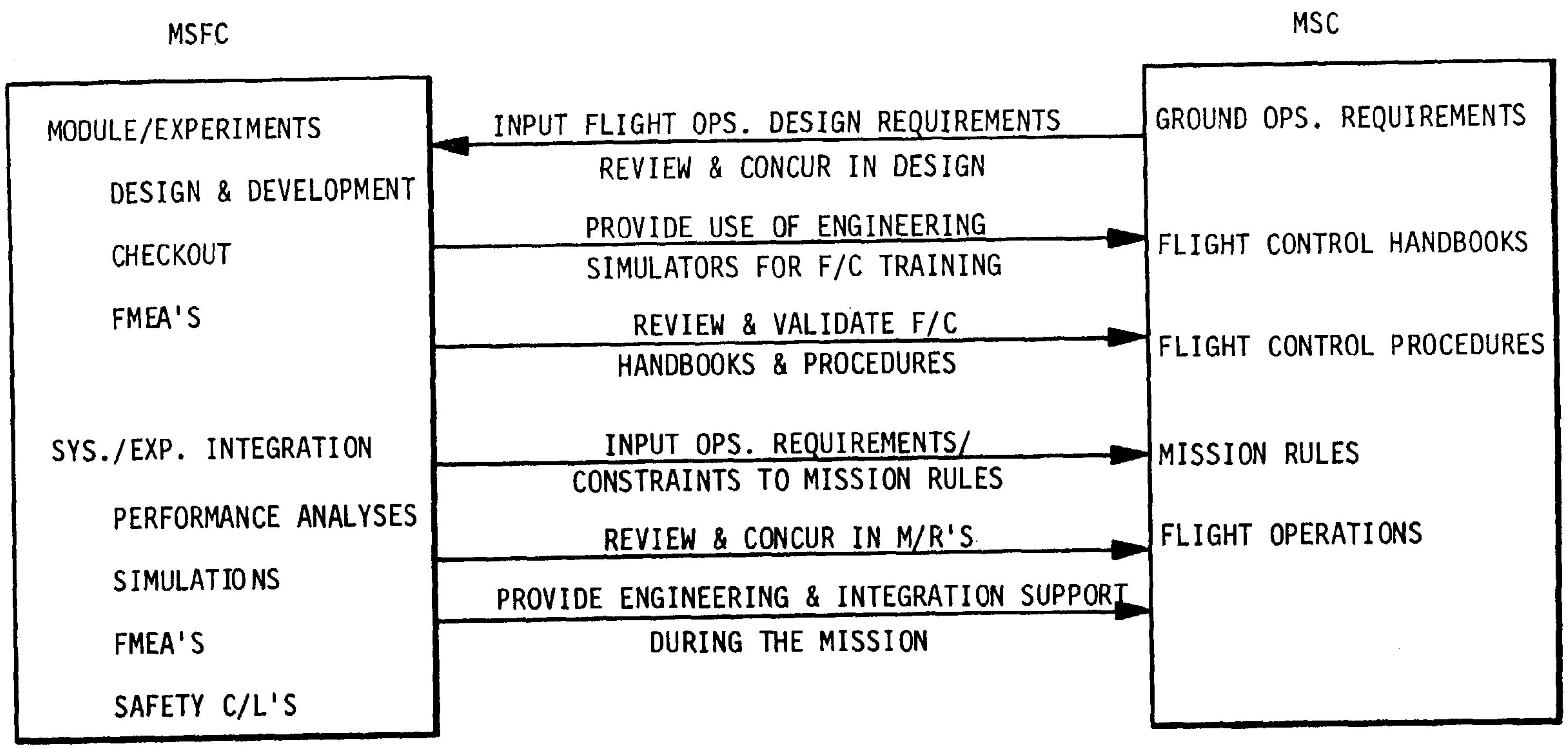


FIGURE 14

MISSION OPERATIONS SUPPORT

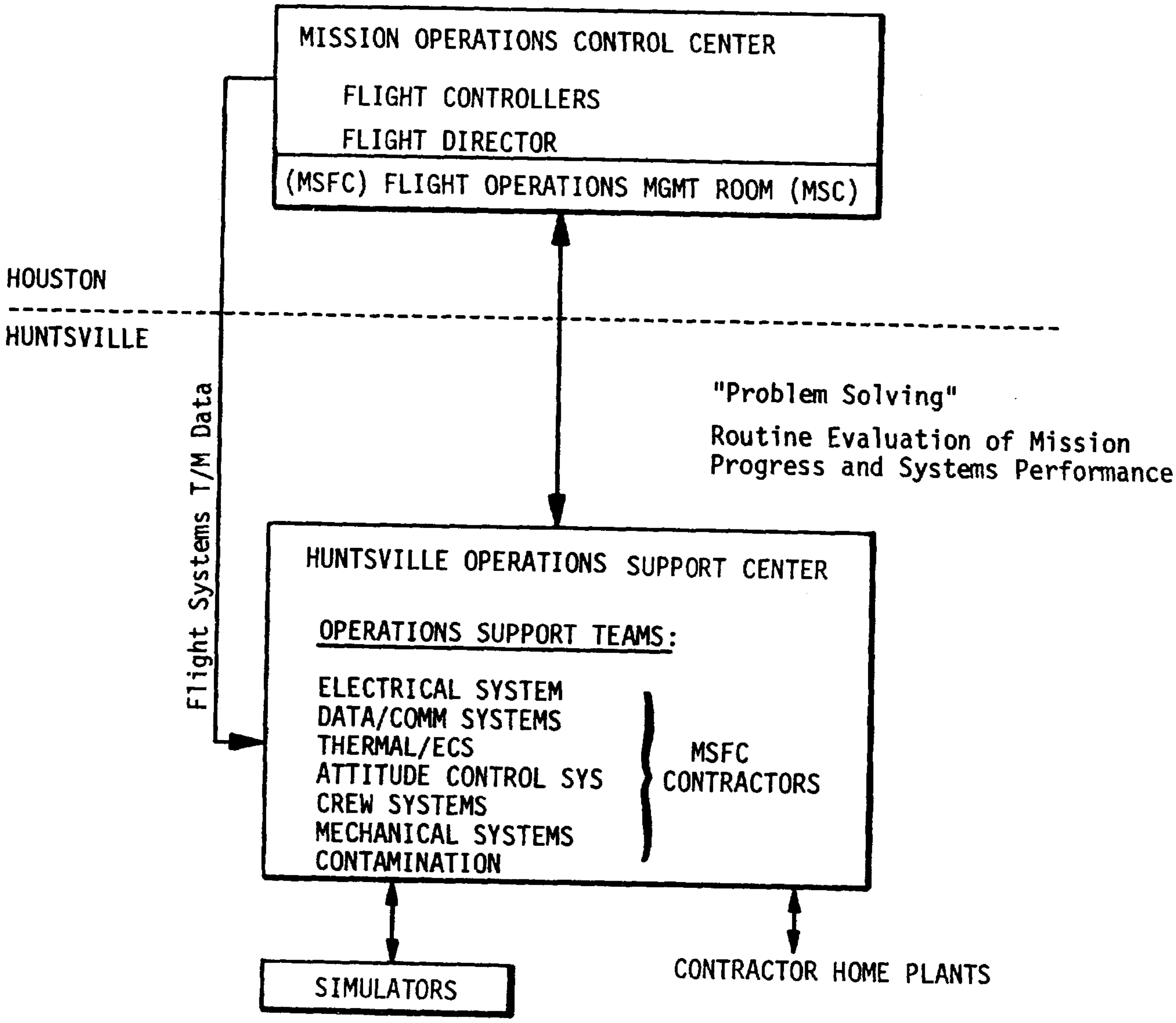


FIGURE 15

The RELIABILITY, QUALITY, AND SAFETY section of this report discusses the manned safety aspects of the Skylab mission operations. Where necessary this area is covered here.

The major portion of the mission operations work is accomplished at MSC through the following organizations: Flight Crew Operations, Flight Operations, Life Sciences, Science and Applications, Safety and R&QA - all of these, of course, under the direction of the Skylab Program Office at MSC. Support contractors tasks pertinent to this area include training hardware maintenance, training instruction, systems/operations handbooks, ground support simulations, mission planning, and so on.

Flight Crew Operations

Crew training. - Crew training is the core of achieving real-time mission operational objectives. The effectiveness of crew training concepts and procedures has been proven on prior manned programs. The Skylab missions are able to take advantage of those lessons learned, but there is one disadvantage of no prior "development flights" for SL-2 and only short periods between SL-2 and SL-3, and SL-3 and SL-4. Furthermore, all of those things which set Skylab apart from previous manned programs bring an extra burden to bear on the training requirements. Using an astronaut mix of seasoned veterans with new personnel, the crew training commenced approximately 2 years ago in the November 1970 period. As trainers became available and mission requirements better known the specific task training and integrated crew and mission team training began in 1972. Support training was also in fact ongoing throughout the Skylab program because of astronaut participation in the design, development, and testing phases. The planned training and hours assigned for each segment are shown in brief in table V. These hours represent the total hours for a crew of three. At this time the percent of training hours accomplished for the crews is about 60 percent of the total. Training at the KSC was somewhat restrained by the Apollo 17 activities.

Fire/evacuation training for Skylab missions encompasses about 76 hours per man, split between "on-orbit emergencies" and "ground emergencies." One might question the sufficiency of such training to meet the stringent time requirements to move from any given station in the cluster to another while determining actions to be taken. On the other hand, the many hours of training applied in other areas is often directly applicable to the fire/evacuation effort. This will be discussed further in another part of the report.

The SMEAT and other simulations conducted recently have added immeasurably to the training of the crews through a better understanding of the workings of the hardware and the problems involved in their use. There is, of course, the inherent limitation in the use of nonflight hardware. It may not show up all the little idiosynchrosies of flight hardware.

PROCEDURES DEVELOPMENT PROCESS

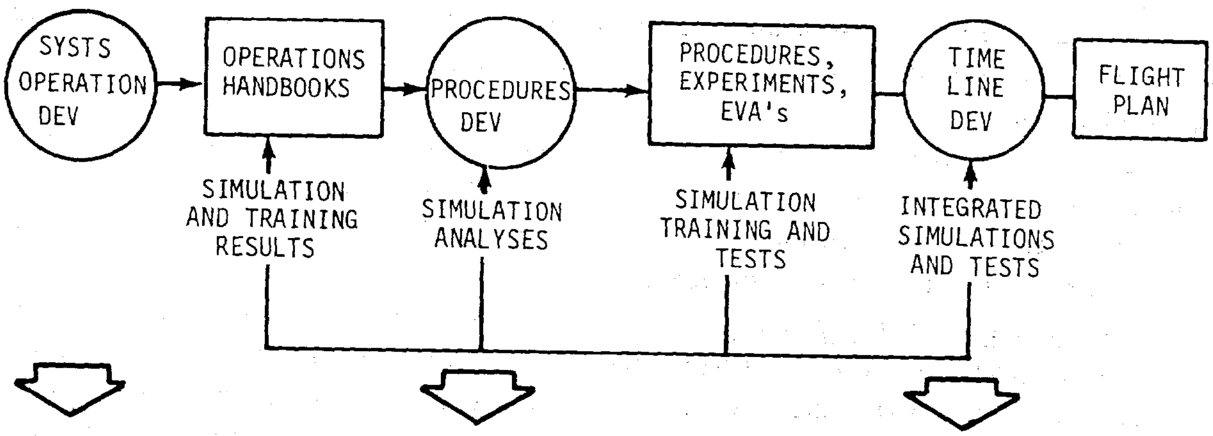
DATA SOURCES

DESIGN DATA
SYSTEMS DATA
EXPERIMENT INFORMATION

TRAJECTORY
MISSION REQUIREMENTS
MISSION RULES
OPERATIONAL DATA BOOK

FLIGHT CREW
TEST DATA
MISSION REVIEWS
CONSUMABLES

DEVELOPMENT PROCESS



FLIGHT DATA FILE

SYSTEMS CHECKLISTS
SYSTEMS DATA
SCHEMATICS
ACTIVATION/DEACTIVATION
SYSTEMS MAINTENANCE
SYSTEMS REPAIR
MALFUNCTION PROCEDURES

LAUNCH, ENTRY RENDEZVOUS BOOKS
EXPERIMENTS OPERATIONS
EVA CHECKLISTS

FLIGHT PLAN
CREW LOGS
STAR CHARTS
MAPS
GRAPHICS

FIGURE 16

An area of particular interest to the Panel is that of Skylab cluster housekeeping. Associated with almost every experiment and most day-to-day operations is the myriad items of loose equipment and discarded materials that must be accounted for and properly restowed. Such efforts as the activities scheduling program, crew flight plan, stowage in-flight management system, and mission operations planning system are used in part or totally in the housekeeping effort. Based on the various programs to control and account for these items, the Panel believes that adequate attention is currently being paid to this area. This does not preclude surprises in flight. Because of its importance to the overall operation of the Skylab mission continued attention must be given to housekeeping.

Maintaining simulation equipment in the in-flight configuration is a continuing problem. This was a problem encountered and managed on Apollo. Different than the Apollo program, though, is the very large number of items and experiments that are still undergoing changes, sometimes subtle in nature. The availability of some of the experiment training hardware appeared to be open at the time of the Panel reviews. The current use of trainer hardware is of the order of 40 hours per week for the OWS and 20 to 30 hours per week for the AM/MDA/ATM. This leaves limited time for further modifications or new requirements.

The crewmen have worked directly into the design, development, test, and operations areas as the program has progressed. Thus, in addition to the many thousands of hours of specific training, the crews also are trained through direct familiarization with the hardware at every phase of its development.

Crew procedures and flight planning. - These activities provide for the organization of crew time, preparation for contingencies, and definition of training and flight data file requirements. Figure 16 indicates the process through which procedures and flight planning are accomplished. The final Flight Data Files are scheduled for completion about 30 days before each launch to assure the most up-to-date file. The process to produce these documents has been planned. But the achievement of this schedule is dependent on the resources and the number of changes introduced into the system over the next few months. This suggests that it behooves the Skylab program organization to restrict changed requirements which affect the crew procedures and flight planning to an absolute minimum consistent with meeting the mission objectives.

Skylab Flight Operations

Flight operations include those activities associated with operational mission planning and the overall direction and management of flight control and recovery. This involves the implementation of manned space flight network instrumentation requirements, configuration and operation of the Mission Control Center, and operational evaluation and testing of landing and postlanding systems. Skylab flight operations have taken into account the very real differences between Apollo and Skylab and the difficulties imposed by constrained resource availability. The flight team and ground support system differ substantially from the Apollo arrangement due to large PI involvement, unmanned mission phases, and the long duration. They have also considered the Skylab peculiar requirement for manned phases, crew time scheduling, and the ability of the ground to monitor the orbiting vehicle on a less than 100 percent time span.

Mission characteristics affecting flight operations. - Ground system design and the flight operational requirements for the Skylab mission are affected by the "unique" character of the Skylab noted previously. In addition, there are such items as (1) the mass of data to be returned and its analysis, (2) the necessity of real-time flight planning, (3) no background of development flights, (4) intercenter hardware responsibility throughout the flight, (5) the housekeeping requirement, and (6) stringent requirements for the removal of "perishables," urine and feces samples, as soon after recovery or splashdown as possible.

Principal investigators. - The PI's form a part of the flight control team. PI mission support has been placed in four separate support categories:

Category I - PI is present in the MCC during experiment execution. His nonavailability (or that of previously designated alternate with same capability) is a constraint on the carrying out or conduct of the experiment. Currently no experiments are in this category.

Category II - PI is present in the MCC during conduct of experiment. He performs analysis of experiment data and makes recommendations for subsequent experiment operations.

Category III - PI is present in the MCC during conduct of experiment and is available for consultation. He maintains mission status visibility and provides assistance to flight controllers as required.

Category IV - The PI is not in MCC but is available via telecon for consultation.

The PI's have specific rooms (ATM science room, aeromed experiment room, EREP room, and science room) assigned for their use. In some cases there appears to be an underlying feeling discerned by the Panel that there is still a good deal of effort yet to be accomplished in setting up these arrangements with all of the necessary PI's. If this is the case, further effort should be extended to make these arrangements as quickly as possible.

MSFC operations support. - The purpose of the MSFC operations support is stated as "Continue to fulfill the MSFC hardware design/development and systems engineering and integration responsibility through active support in the operations phase of the Skylab program." Some concerns in this area are discussed in the PANEL REVIEWS section of volume I.

MSFC will provide qualified senior personnel to the Flight Operations Management Room and Mission Evaluation Room at MSC while maintaining the Huntsville Operations Support Center at MSFC. The concept appears quite sound. With the exercise of good management and cooperation between the two Centers (MSFC and MSC) the MSFC operational support arrangement should provide a valuable and needed function to assure the success of the Skylab mission. Nonetheless, because there are two Centers separated by large geographic distances, it would be unusual if operational problems did not crop up from time to time. These must be minimized or eliminated as quickly as possible.

Flight control training, documentation, and schedules. - The Flight Operations Directorate at MSC published an integrated training plan in October of 1971 defining the types of training, the certification program for each flight controller, and the training for non-Flight Operations Directorate personnel working in support of the basic team. It was interesting to note that videotapes of the classroom sessions were being made to allow additional sessions to be held with new personnel and to refresh the baseline groups as required.

Based on the data presented it appears that much of the training has yet to be accomplished.

Flight control documentation posture was indicated to the Panel as follows:

Document	Preliminary document	Final document
Systems Handbooks	Complete	March 1973
Mission Rules	Complete	February 1973
Flight Control Operations Handbook	October 1972	February 1973
Branch Console Handbooks	October 1972	April 1973
SL-1 Operations Handbook	October 1972	March 1973
Command Procedures Handbook	September 1972	February 1973
Branch Photo Support Albums	--------------	October 1972

Flight control manning plan. - The personnel assigned to the various operations activities, as to type and numbers, is crucial to the success of the MSC operations and efforts and is currently under review. The reason for the difficulty in selecting the number of teams and their mode of operation appears to stem from the smaller number of flight controllers and support personnel available and the cost of ground system hardware. This is not just a function of the current economic posture but is due to the requirement for continuous operations for 8 months versus 2 weeks for the Apollo missions. It has been indicated that the optimum number of mission operations teams would be five. Due to the practical aspects this cannot be achieved. The question now revolves around whether there should be three or four teams. From the material reviewed by the Panel, four teams seems most logical. It allows for a reasonable amount of sick time and leave time for the team members, whereas the three team system does not. It is estimated that 207 people will form a flight control team with specialty personnel used as needed, for example, when retrofiring and recovery. Of these 207 all will be NASA except for 50 to 60 contractor specialists. The number of "new" people, that is, those who have never sat at a console before, will be quite large - as high as 60 percent of the total. This, of course, is a further reason for the detailed and arduous training program envisioned by the MSC organization. Obviously, manning requires further study, and quickly at that, to assure that the personnel with their adequate training are available for the initiation of the Skylab major flight simulations and actual mission.

Ground support systems. - The Skylab ground support equipments includes both hardware and required software. The following differences between the Apollo and Skylab program are indicative of the new requirements that had to be met:

(1) Noncontinuous real-time data retrieval
(2) Continuous data recorded onboard and dumped during periods of real-time communications
(3) Greater variety and extent of data to be communicated up-and-down link
(4) Longer duration of support required
(5) Experiment activity to flight test activity far greater on Skylab
(6) Extent of experiments interaction with space vehicle power, ECS/TCS, vehicle attitudes, and orbit position

As a result of these new requirements the ground support systems have been designed to provide greater system reconfiguration flexibility and to require minimum time for preventative maintenance. In addition, the equipment should also provide data more directly to the users and eliminate remote site tape handling and shipping. It has been indicated that the deliveries of portions of ground equipment have slipped in schedule and that the mission simulations that were to have started in September may slip over into the November-December time period. This, combined with the obvious impact of supporting the Apollo 17 launch in December 1972, will require greater emphasis and effort on the part of both management and working flight controller personnel over the next few months. The reason for the Apollo 17 constraint is that some 50 percent or so of the people will come from there and obviously can work only one program at a time. The communications and telemetry network for Skylab (STDN, NASCOM) appear to be in good shape. Some areas are still under discussion to resolve minor problems. These include the use of ARIA (Apollo range instrumented aircraft) to support the Skylab and scheduling of site usage during the 8-month Skylab mission due to other vehicles on other missions.

To support Skylab requirements the following validation and test and checkout schedule was instituted:

Test description	Estimated completion dates
Mission control center internal validation tests:	
With mission operations computer	November 18, 1972
With real-time computer complex software	December 1, 1972
MCC external validation tests:	
With Merritt Island area	February 1973
With worldwide network	April 1973
Goddard network readiness test	April 1973
MCC simulations readiness test	November 1972
MCC pad readiness date	November 1972
MCC/network simulation	January 1973
Network on mission status	April 1973

Medical operations. - Medical operations support is provided for the preflight, mission, and postflight phases. The Mission Control Center medical team is formulated as shown in figure 17. Planning and documentation in this area appears to be progressing satisfactorily. Yet, as noted in the Panel's preliminary report contained in the Third Annual Report to the Administrator, there still appear to be some problems with staffing for medical support. This, though, is under continual study and it is hoped that the problem will be resolved in the near future.

Fire evacuation procedures. - Fire in any location of the Skylab cluster is a critical crew hazard requiring immediate and correct response from the crew. As a result of fire location, materials, and extinguisher studies, crew procedures have been prepared and to some extent tested through crew/equipment simulations. Procedures associated with the onset of fire warnings or known fires on board the vehicle are based on the philosophy that the crew should always move toward the command module obtaining life support and fire fighting equipment enroute. The fire is to be fought only if it blocks the route to the command module, is visible, and can be assessed as containable. The prime concern is crew protection rather than equipment protection or mission continuation.

MISSION CONTROL CENTER MEDICAL TEAM

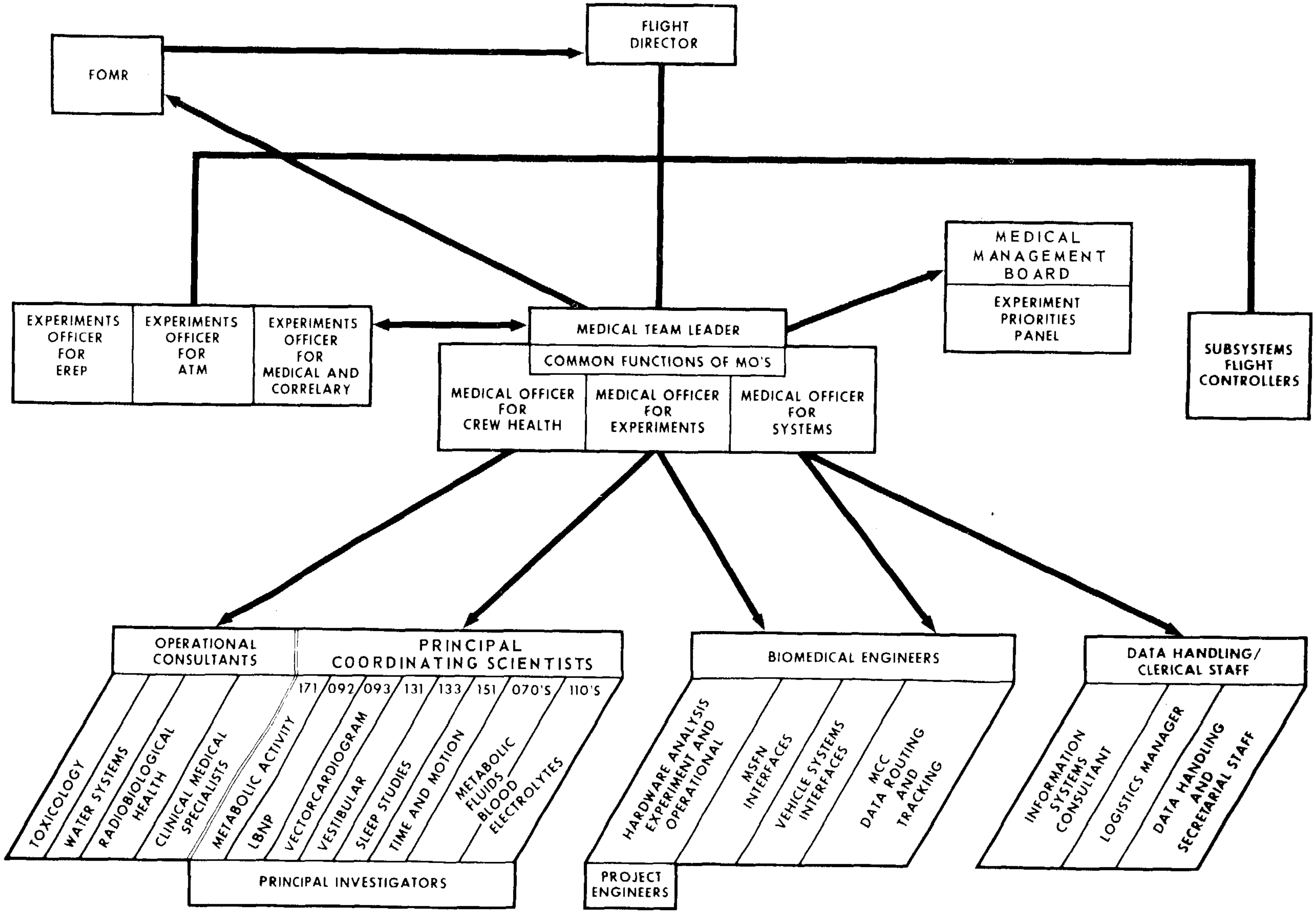


FIGURE 17

As the crew moves toward the CM the procedures indicate they should respond as follows if possible:

Obtain fire extinguisher.

Obtain oxygen mask.

Obtain suit.

Locate and assess fire.

Shut off power to fire area.

Shut off fans.

Shut off coolant loops in fire area.

Enable Manned Spaceflight Network (MSFN) control.

Break fire propagation paths.

Fight fire.

Remove atmospheric contamination if fire is extinguished.

Space suit availability for crew emergencies and crew translation times has received a good deal of study and testing to assure that the maximum protection is afforded the crew in case of emergencies. Based on the material presented to the Panel and that provided through reports it appears that the current procedures for evacuation and fire fighting are acceptable and should provide a good measure of confidence in the system that provides guidance and requirements.

In April 1971 the Safety Office at MSC completed "Skylab Orbital Assembly Fire Study" (MSC-04048, 1971) which covers the following overall aspects of fire protection. Fire prevention requires emphasis on housekeeping aspects of flammable materials control. Those systems using Coolanol-15 are to be monitored to assure their continuing acceptability. Fire detection requires acceptable fire sensor tests and maintenance procedures, coverage, maintenance, and replacement capability. These appear to have been accomplished.

Skylab space rescue. - Although rescue is covered to some extent in the RELIABILITY, QUALITY, AND SAFETY section of this report, it may be well to explore further to gather greater understanding and consequently more confidence.

In the Mercury and Gemini programs, the spacecraft could not be used for rescue because of their restricted size and life support capability. A different and unique spacecraft would have been necessary to retrieve stranded astronauts. In the Apollo program, rescue capability was again not feasible because of the limited life-support capacity of the lunar module coupled with the time required for the CSM to travel from Earth to the Moon. A rescue vehicle standing by in lunar orbit would have been necessary for lunar orbit rescue but still could not pick up astronauts on the lunar surface.

With Skylab, the orbital workshop offers long-duration life support in Earth orbit and a practical rescue capability is feasible. In each of the three Skylab visits, the astronauts fly to the space station in a modified Apollo CSM. It is then powered down after docking, but remains available for life support and crew return in the event of cluster failure. Therefore, the only failures to be considered for rescue requirements are the loss of CSM return capability or the loss of accessibility to the CSM. In this event, a second CSM would be launched carrying only two men with room for the three astronauts to be picked up in orbit, and the rescue CSM would then return with a crew of five. Therefore, after each of the first two manned launches, the next vehicle in normal preparation for launch would be used for rescue if needed. After the third and final launch (SL-4), the Skylab backup vehicle would be made ready for possible use as a rescue craft.

Just how long the Skylab astronauts would have to wait for rescue depends on the point in the mission when the emergency develops. The wait in the well-supplied orbiting cluster could vary from 48 days to 10 days. If, for instance, the need for rescue arose on the first day of the Skylab's occupancy or reoccupancy, present plans indicate that it might take 48 days for the launch crews to ready the rescue vehicle. This would include approximately 22 days to refurbish the launch tower following the previous launch. During this period the rescue kit or modification hardware would be installed in the CSM. The entire vehicle would then be moved to the launch pad for launch requiring about a week.

The later in a mission rescue is needed, the sooner the vehicle would be ready for launch. The response time from the "rescue alarm" to launch is reduced to about 28 days and 10 days at the end of the first and third missions, respectively.

Providing rescue modes for all conceivable emergency situations would obviously require instantaneous response. This is a capability not practical or feasible with the present space vehicle because of the preparations mandatory for a successful launch.

Based on the material presented to the Panel during the reviews the projected rescue techniques for Skylab appear to cover the most likely emergency situations.

ASSESSMENT OF MISSION OPERATIONS

Activities associated with mission operations planning and implementation appear to be proceeding satisfactorily. The schedules are admittedly tight and the resources limited. At this point in mission planning there are naturally a number of items of potential impact:

Clarification of the Skylab Operations Directive No. 43B, paragraph 1.4.2.(8), on delegation of authority for scrubbing missions and the meaning of the term "mandatory" is necessary. These may become more significant as the launch time grows near when all possible areas of misinterpretation should be minimized.

The continuance of open lines of communication is needed between the NASA Centers to assure understanding of their respective roles and responsibilities during the mission.

Flight crew operations:

- Defining realistic Skylab cluster housekeeping
- Limitations of nonflight hardware during training, particularly experiments
- Limited availability of hardware for training
- Control of program changes (hardware/requirements) and their impact on crew procedures and flight planning

Flight operations:

- Ability to integrate the PI's into the mission
- Ability and adequacy of flight control documentation
- Personnel staffing limitations
- Deliveries of needed hardware and software for ground systems support

COMMAND AND SERVICE MODULE

Because of mission differences, duration, and fixed attitude constraints of the Skylab program, several major modifications had to be made in the CSM's allocated for the Skylab program. The CSM's were modified to accept electrical power from the workshop. One of the three power-generating fuel cells on the CSM was deleted. Three batteries were added to the SM to provide power for descent from the workshop since the cryogenic reactants that power the fuel cells will have been depleted during its long Earth orbit stay. Two of the four service propulsion system propellant tanks and one helium tank were not required for the missions and so were deleted. A propellant storage module was incorporated into the SM to increase the quantity of reaction control system propellants, thus enhancing in-orbit attitude maneuvering and providing a backup method of deorbit propulsion.

The caution and warning system was modified. The warning tone was carried to the workshop to allow the entire crew to pursue activities in the OWS and still monitor the CSM.

The CSM audio system was hard-lined to the OWS and will serve as the communications center for the workshop. Stowage provisions in the CM have been vastly increased to allow for the greatest degree of resupply as well as return of experiments, film, biological samples, and other needed material. The thermal control system was significantly modified to meet the requirements of the fixed attitude dictated by the workshop cluster and the need to minimize condensation within the CM while maintaining CSM components and propellants within allowable temperatures.

A tank was added to the SM to allow water generated by the fuel cells after docking to be stored rather than vented overboard. An overboard hydrogen dump system was incorporated into the SM cryogenic system to allow maintenance of the hydrogen tank pressures within safe limits after the fuel cells are shut down. A nonpropulsive vent was used. A similar nonpropulsive vent was installed in the CM hatch to allow venting of surplus oxygen. These vents were necessary and the material ejected through them has been examined for contamination of experiments.

CSM vehicles designation and their assignment to the Skylab missions are CSM 116 for SL-2, CSM 117 for SL-3, CSM 118 for SL-4, and CSM 119 as a backup and rescue vehicle if required. A contingency modification kit for converting a Skylab CSM to a rescue vehicle in the event a crew becomes stranded in the workshop is also being provided. The rescue kit could be installed in any of the Skylab CSM's. Further information on the rescue plan is discussed in the RELIABILITY, QUALITY, AND SAFETY section.

SLA 23, 24, 6, and 25 go with CSM's 116, 117, 118, and 119, respectively. All of these SLA's are in storage at KSC.

The rescue vehicle kit components consists of -

Two aft bulkhead mounted crew couches

Two oxygen umbilicals and hose connector assemblies

Two oxygen masks and hose connector assemblies

Two crew communications umbilicals with cables and connectors

Crew equipment and stowage items to support additional crew

Ballast for required center of gravity

Postlanding vents and associated air ducting assemblies

Experiment return pallet assembly

Probe and drogue modifications

All of these items, along with modification instruction documents, are placed in bonded storage at KSC and are to be made available if required.

The rescue kit has been verified. Fit and function will be checked at KSC.

Since the Skylab CSM's constitute a modification to the very successful Apollo CSM's and the contractor appears to be maintaining adequate skills and engineering capability, there is a high degree of confidence in the CSM's capability to do their job. Apollo anomalies that apply to the Skylab CSM's are being resolved on the same basis as was done for the Apollo program.

The following discussions of the individual major onboard systems is intended to point out the activities which provide confidence in the system and those areas requiring closure.

Thermal Control System

In general, the approach used to verify the capability of the thermal control system involved the construction of a transient computer program. Using the essentials of the

Apollo program, the computer program predicts the temperatures and temperature transients experienced for any given sequence of mission events. It also verifies the predicted responses through exposure of a full-scale vehicle in thermal-vacuum test chamber. In addition, it defines mission constraints, and provides them for incorporation in mission rules and operational handbooks. While the CM shows adequate margin, the SM shows that only a small margin exists in some "worst case" conditions. There appears to be no concern here based on the material presented to the Panel.

Environmental Control System

In conjunction with the thermal control system, the environmental control system (ECS) provides the flight crew and electronic equipment with a conditioned atmosphere. The ECS is operated continuously during undocked mission phases. Except for the primary glycol system, it is shut down during docked operations in orbit. Apollo flight experience has indicated a high degree of reliability under similar flight conditions. For instance, the secondary coolant loop has been operated during boost, deactivated for the entire mission, and reactivated prior to reentry. The major portion of the ECS was subjected to an augmented system Skylab mission test. The test was designed to demonstrate the performance of the ECS during several mission simulations with normal and off-limit conditions. Approximately 1500 hours of testing were accrued. A further test of 120 days under a quiescent mode of operation similar to that occuring while the CSM is docked to the cluster was conducted. Maintenance of wall surfaces above the dewpoint temperature to preclude condensation appears to have been a problem. The Panel understands that condensation has been minimized by system control set-points but is still not clear on whether the condensation that is predicted to occur during docked condition will or will not cause problems which have yet to be resolved. During ground operations prior to launch the GSE must also be capable of precluding the formation of condensates. With respect to SM, thermal control tests were conducted to assure adequacy of current paint system as a result of paint blisters observed during CSM 112 EVA on Apollo. The closure of this potential problem will be noted in the next report.

Structural Systems

Changes to the Apollo configuration caused by the deletion of CM handholds and handrails, repositioning of support structures, and deletion of various portions of onboard systems and their impact on structural adequacy were checked by a combination of structural analysis, similarity with previous vehicles, and extensive testing (particularly for the SM which had far more structural changes). There appeared to have been few problems surfaced by these tests.

Mechanical Systems

The only mechanical system item requiring modification for the Skylab mission was the uprighting system. The uprighting system places the command module in a stable position upon Earth landing. The system consists of three air bags with their associated inflation and retaining hardware. The Skylab system differs from the Apollo in that the two intakes for the air used to pressurize the bags are interconnected in such a way that if one intake is submerged a water trap allows the onboard compressors to continue operating at full output. This system was successfully tested and no further problems were encountered.

Stowage and Crew Equipment

Skylab CSM stowage capability has been revised to support orbital workshop operations with particular attention to increasing the volume available for storage. Crew equipment additions involved are fire extinguisher, optical alinement sight mount, return mission water provisions, and tie-down straps. Crew compartment fit and function (C^2F^2) tests and other tests and analyses indicate no significant problems.

Service Propulsion System

The service propulsion system provides the impulse for X-axis velocity changes throughout a mission. It also provides the service propulsion system abort capability after the launch escape tower is jettisoned. The Skylab mission requires less helium and propellant than the Apollo missions. Therefore, one helium storage bottle and the propellant storage tanks were removed from the Skylab spacecraft. As a result of the extended duration Earth orbit in a fixed attitude (docked), an active thermal control system is required to maintain system temperatures. As presented, the verification program indicated few problems and these appear to have been resolved.

Reaction Control Systems

Skylab, like Apollo, has two separate reaction control systems, one set for the CM and one for the SM. The CM system is essentially unchanged from the Apollo while the SM system was supplemented with an additional 1500 pounds of stored propellant. There appear to be no open items in these systems.

Electrical Power System

The Skylab EPS conditions and distributes power to the CSM during its docked mode. During independent operation the CSM derives its power from fuel cells and batteries depending on the segment of the mission. Through the SOCAR and the DCR system the electrical power systems of the CSM and the cluster have been verified as being compatible. This included that time period during which both the EPS' would be operating in parallel. Parallel operation occurs during the beginning and end of each Skylab mission segment and is estimated to be no more than 4 minutes each time. MSFC, MSC, and contractor studies were conducted to assure this point. The descent battery cases cracked after qualification vibration testing. As a result of this, the cases were strengthened and internal changes made. The results of retest of these improved batteries has not been seen by the Panel. The nonpropulsive vents used to vent the hydrogen and the oxygen were discussed, and it appears that only the hydrogen vent was tested to assure its adequacy. The oxygen vent was assumed to work on the basis of similarity. One could question the validity of such an assumption since the working fluids are different. A clarification of this will appear in the next report.

Displays and Controls/Caution and Warning Systems

The displays and controls provide an integrated arrangement of like functions to control and monitor the various operational systems. The caution and warning system, which is included in the displays and controls, provides a means by which the crew receives a timely alert to actual or potential CSM system failures or out-of-tolerance conditions. The unchanged and modified displays and controls were verified compatible with the Skylab mission by similarity with demonstrated Apollo performance. The new items, not similar to Apollo, were verified by qualification tests and supported by analysis. There appeared to be no major problems in these systems.