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EXPERIMENTERS' REFERENCE BASED UPON SKYLAB EXPERIMENT MANAGEMENT

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16. ABSTRACT

The methods and techniques for experiment development and integration that evolved during the Skylab Program are described to facilitate transferring this experience to experimenters in future manned space programs. Management responsibilities and the sequential process of experiment evolution from initial concept through definition, development, integration, operation and postflight analysis are outlined in the main text and amplified, as appropriate, in appendixes. Emphasis is placed on specific lessons learned on Skylab that are worthy of consideration by future programs.

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PREFACE

Skylab was the most comprehensive manned space program completed to date, involving unprecedented numbers of experiments, government agencies, contractors and supporting personnel. Ninety-four experiments, plus several experimental operational instruments and twenty-six science demonstrations, were developed, integrated with Skylab, and flown. A majority of these were individual experiments, although some (e.g., earth resources and space materials processing experiments) were associated with discipline-oriented facilities provided for scientific users by Skylab. Experiment data gathered aboard Skylab was supplied to over two hundred and fifty scientists from the United States and nineteen other countries.

The many interfaces involved in the development and integration of these experiments imposed new burdens upon the "standard" methods and techniques that had evolved from earlier space programs. As a result, many changes were made, and many lessons learned, throughout the course of the Skylab Program. For example, new types of documentation were established, design review and configuration management techniques were improved and mission support activities took on new dimensions. This Experimenters' Reference records the Skylab experience in experiment management, including lessons learned and recommendations for improved cost-effectiveness, to facilitate the transfer of this knowledge to experimenters in future manned space programs.

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DEFINITIONS

Acceptance - An official act by the Experiment Development Center to accept transfer of accountability, title, and delivery of an end item of hardware or software, whether procured on contract or in-house.

Acceptance Test - The formal assessment or testing accomplished in accordance with Part II of an end item specification to verify the performance, configuration, and manufacture of an end item (1) at the time of its delivery and acceptance by the Government, or (2) for delivery to another NASA Center.

Activation - The activities associated with originally placing an orbital vehicle or ground facility in operational condition.

Baseline - An approved and defined technical description providing a point of departure for control of future changes.

Cluster - The orbital assembly constituting the complete configuration for manned Skylab missions, including all modules of the unmanned laboratory plus a docked Command and Service Module.

Crew Compartment Fit and Function (C^2F^2) - One of the final checkouts performed during hardware integration. Flight crew members inspect the carrier for proper hardware integration, accessibility, and safety considerations.

Delivery - The physical transfer of hardware from one site to another. Includes transfer of responsibility for hardware custodianship (also see Acceptance).

End Item - An article of hardware or software which is deliverable by NASA or a contractor as a complete item as identified, defined and scheduled.

Experiment - A part of the payload devoted to the investigation of scientific or engineering phenomena. Sometimes used as synonymous with instrument; however, instrument generally refers only to the operating flight hardware, whereas experiment refers to the combination of all associated hardware plus the use of the data to satisfy an objective.

Ground Support Equipment - Special equipment required for servicing, testing, handling, maintaining, and/or transporting the experiment hardware during ground operations.

High-Fidelity Mockup - Training hardware that is essentially identical to flight hardware in size, shape, and appearance and provides crew interfaces (switches, etc.) but need not be operational.

Instrument - An item of hardware designed to perform a specific scientific or engineering function in support of an experiment objective (also see Experiment).

Interface - A region common to two or more elements, systems, projects or programs and characterized by mutual physical, functional, environmental, operational, and/or procedural properties.

Integration - Activities that are performed to assure physical and functional compatibility of an experiment with other experiments, the module, and the overall mission. Also the physical mating and testing of a combined system (e.g. module and experiments).

Mission - A single spaceflight from launch to landing, and its objectives.

Module - A major element of the payload or spacecraft, which carries experiments and support systems designed to meet mission objectives.

Near-Real Time - A short period of time, (normally within 24 hours) after actual occurrence of a mission event.

Open Item - A question or problem which is unresolved, and requires action to ensure its resolution.

Orbital Facility - A group of instruments designed to investigate various parameters of a common subject or discipline.

Qualification - Determination that an article or material is capable of meeting all design and performance requirements established for the item. An item can be qualified by test, by analysis, or by similarity to a qualified item.

Single Failure Point - A single item of hardware having an independent failure mode which would result in the functional loss of a system. Examples are nonredundant valves, regulators, pumps, motors, switches, relays, transistors, resistors, diodes, or a single path of passive electrical hardware (e.g., wiring, solder joint, connectors, etc.) that could open or short circuit.

Waiver - A written authorization to accept an end item or other designated item which, during manufacture or after having been submitted for inspection, is found to depart from specified requirements but is considered suitable for use "as is" or after rework by an approved method.

NONSTANDARD ABBREVIATIONS

ADP	Acceptance Data Package
CCB	Configuration Control Board
CCBD	Configuration Control Board Directive
C^2F^2	Crew Compartment Fit and Function
CDR	Critical Design Review
CIL	Critical Items List
CIR	Configuration Inspection Review
COFW	Certificate of Flight Worthiness
CRS	Cluster Requirements Specification
DCR	Design Certification Review
DRF	Data Request Form
ECP	Engineering Change Proposal
ECR	Engineering Change Request
ED	Experiment Developer
EDC	Experiment Development Center
EGS	Experiment General Specification
EHGRD	Experiment Hardware General Requirements Document
EIC	Experiment Integration Center
EIP	Experiment Implementation Plan
EIS	End Item Specification
EITRS	Experiment Integration Test Requirements and Specifications
EOP	Experiment Operations Planning

ERD	Experiment Requirements Document
EVA	Extravehicular Activity
FMEA	Failure Mode and Effects Analysis
FRR	Flight Readiness Review
GSE	Ground Support Equipment
ICD	Interface Control Document
MCC	Mission Control Center
MRB	Material Review Board
MRD	Mission Requirements Document
MSFEB	Manned Space Flight Experiments Board
OMSF	Office of Manned Space Flight, NASA Headquarters
OM&H	Operation, Maintenance and Handling Procedures
PATRS	Post-Acceptance Test Requirements and Specifications
PDR	Preliminary Design Review
PI	Principal Investigator
PRR	Preliminary Requirements Review
RFP	Reference Flight Plan
RID	Review Item Discrepancy
SCN	Specification Change Notice
SOCAR	Systems/Operations Compatibility Assessment Review
SPO	Sponsoring Program Office
TCRSD	Test and Checkout Requirements and Specifications Document

SECTION I. INTRODUCTION

A. Purpose

This document is intended to familiarize prospective participants in future manned space programs with the methods and techniques for experiment development and integration that evolved during the Skylab Program. Future programs may not adopt identical procedures, but insight into the Skylab experience, including the lessons learned, will be of value as a reference for scientific investigators, experiment developers, and integrators who face similar tasks in the future.

B. Scope

The Experimenter's Reference outlines the full spectrum of experiment-related responsibilities, activities and events as they were planned and executed in the Skylab Program. The planning and the execution sometimes varied; exceptions and variations were common as the program developed. This is not a history of such deviations, but rather a compilation of those methods and techniques which experience proved to be most effective for Skylab.

The major activities and events that involve experiments, and their interrelationships, are illustrated in functional flow charts for the overall program and for each of its major phases. An overview is given of the National Aeronautics and Space Administration (NASA) management roles and responsibilities. The alternative approaches of providing single experiments for individual investigators, versus a multi-instrument orbital facility with many "users," are discussed. The evolution of the experiment and its hardware, and their integration with Skylab, are traced from initial concept through delivery, integration testing, mission operations, data analysis and reports. Configuration control and the influence of special disciplines (safety, reliability, maintainability, quality assurance etc.) are separately treated. Public relations aspects are also discussed. Skylab lessons learned are incorporated in the form of specific "Recommendations", interspersed at appropriate points throughout the text. (Additional lessons learned across all program disciplines, as compiled by NASA Headquarters and the various NASA centers, may be found in References 1 through 4.)

The main text is intentionally concise. Additional details, where considered appropriate, are provided in separate appendices. For example, major experiment-related documents referred to throughout the text are described in detail in Appendix A.

C. Program General Flow

The general functional flow of activities and events that involved an experiment followed a fairly standardized pattern (figure 1), whether for an individual experiment or for an instrument forming part of a facility. Distinct program phases, as identified in figure 1, are amplified in sections III through VIII; activities which extended through many phases of the program are discussed separately in sections II and IX through XI and in Appendix B. A second-level flow for each major program phase is included at the beginning of the applicable section to illustrate the relationships of activities discussed within that section. A "waterfall" chart of experiment program elements (figure 2) depicts the overall Skylab experiment program in greater detail.

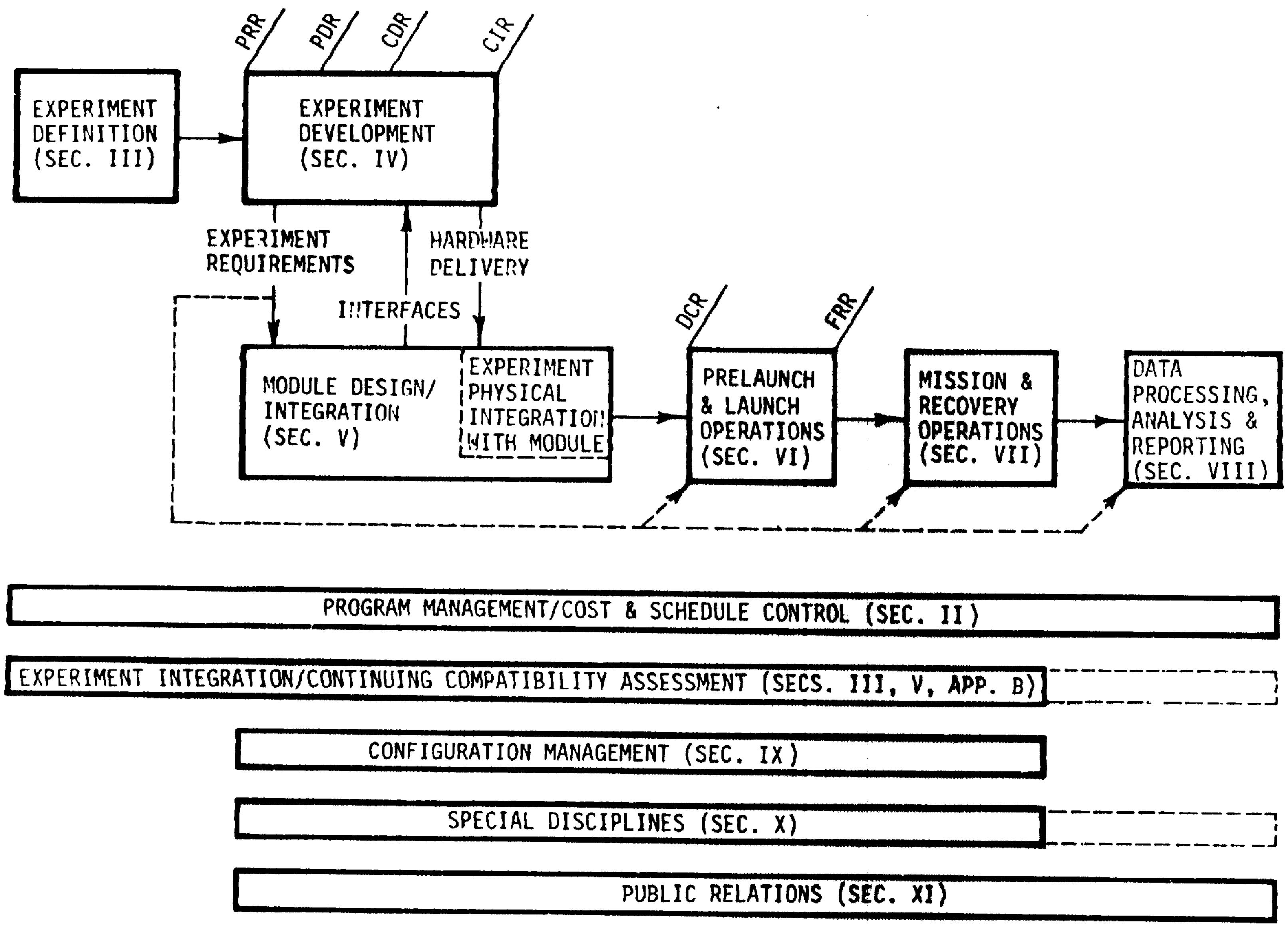

FIGURE 1. PROGRAM GENERAL FLOW

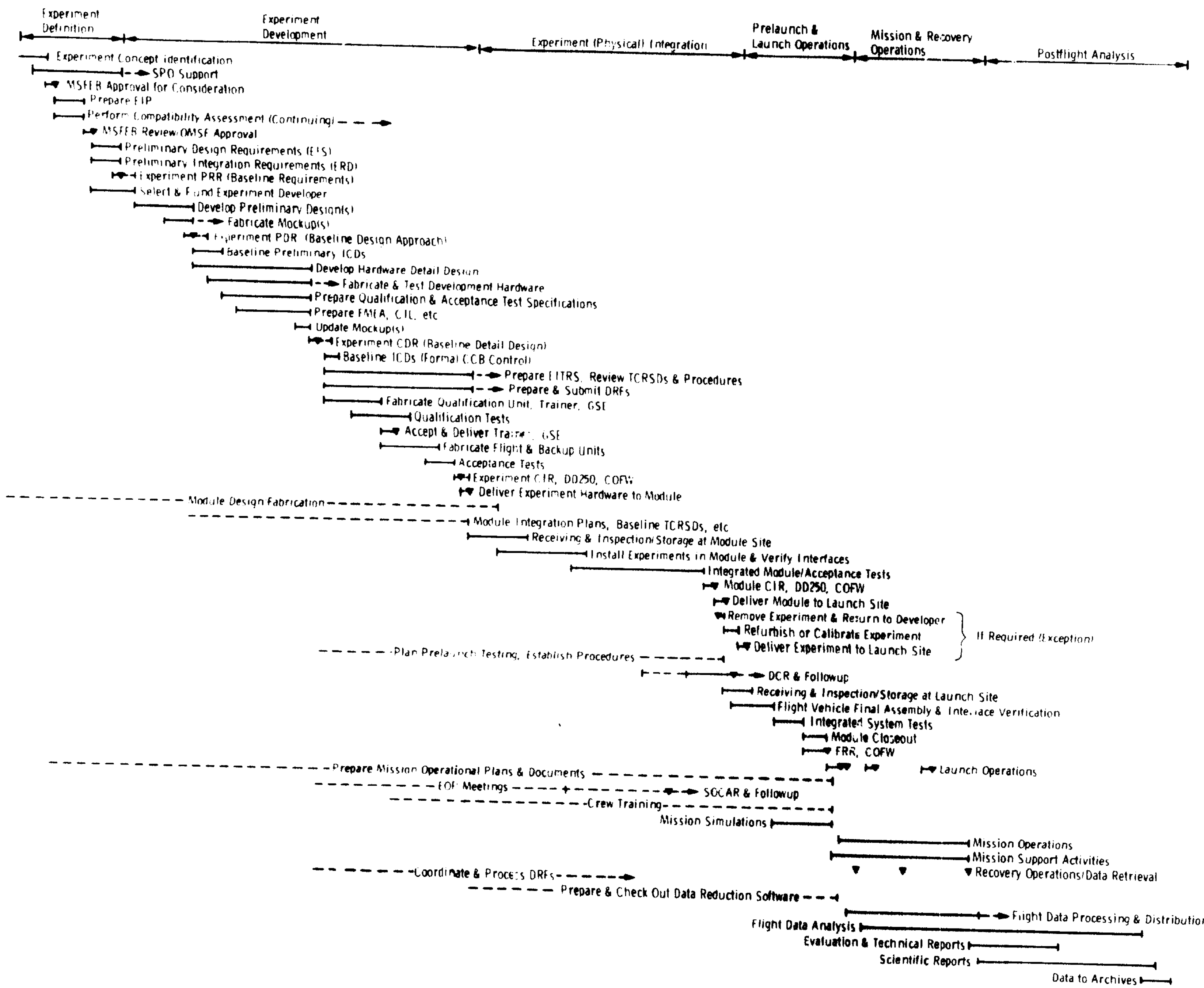

FIGURE 2. EXPERIMENT-RELATED PROGRAM ELEMENTS

SECTION II. PROGRAM MANAGEMENT

In general, management systems and techniques employed by NASA for the Skylab Program were outgrowths from those developed on previous manned space programs. They naturally evolved and changed during Skylab; further variations can be anticipated to accommodate the unique requirements of future programs. In recognition of this fact, an effort has been made to identify the necessary management functions in a general way, regardless of who may be assigned to carry them out.

The areas of general responsibility for a space experiment program are: 1) program direction, 2) hardware development, 3) integration, 4) launch operations, 5) mission operations, and 6) analysis and reporting. For Skylab, NASA Headquarters retained the program direction responsibility, and delegated the other roles to individual NASA centers.

> RECOMMENDATION: At the outset of a program, publish and enforce clearly defined intercenter and intracenter authorities and responsibilities for all program elements.

A. Program Direction

NASA Headquarters provided the initial planning and the top-level direction for all program aspects. A Headquarters Program Office (the Skylab Program Director and a limited staff) exercised this management role by means of guidelines and directives to the NASA Center Program Managers, and overall control of funds and schedules. Major decisions involving program and mission objectives, experiment selections and flight assignments, funding, and milestone schedules were made by Headquarters, with due consideration for inputs from the appropriate centers.

Various offices at Headquarters served as Sponsoring Program Offices (SPO) for individual Skylab experiments (see Section III B). A Manned Space Flight Experiments Board (MSFEB), composed of representatives of various NASA and Department of Defense organizations, performed a continuing advisory function for the Associate Administrator for Manned Space Flight, relative to major experiment decisions. (MSFEB covered not only Skylab, but all current and contemplated manned space flight experiment programs.)

B. Hardware Development Centers

Each major group of associated hardware end items (e.g., an experiment or module) was assigned to an appropriate NASA center for development. Any existing center could be selected, depending on the nature of the end items and center capabilities.

1. Experiment Development Center. The Experiment Development Center (EDC) was responsible for management of the design, development, testing, fabrication, qualification and delivery of the basic instrument, supporting hardware and experiment-peculiar ground support equipment (GSE). Following delivery, the EDC monitored experiment performance and provided technical consultation to the module development and operational centers throughout postacceptance testing and mission operations. In many cases the EDC utilized a development contractor to augment its capabilities. The organization (government or contractor) that actually produced the experiment hardware was referred to as the Experiment Developer (ED). EDCs for Skylab experiments included: George C. Marshall Space Flight Center (MSFC), Lyndon B. Johnson Space Center (JSC), Ames Research Center (ARC), and Langley Research Center (LaRC). Other government agencies, including the Department of Transportation, the United States Air Force, and the Naval Research Laboratory, performed the EDC functions for certain experiments. Specific NASA centers were assigned to work with these organizations, acting as "proxy" EDCs to eliminate any potential difficulties due to management and reporting technique variations utilized by different government agencies.

2. Module Development Center. The Module Development Center had the same responsibilities relative to the module that the EDC had for the experiment. In addition, the module development center managed the installation and integration testing of the experiment hardware prior to module delivery. The actual hardware was developed by contractors under the direction of the center project offices. JSC was the Command and Service Module development center and MSFC was the development center for the other Skylab modules.

C. Integration Center

This center was responsible for overall Skylab systems engineering and integration, which included managing experiment interfaces with the total program. The Integration Center maintained a continuing compatibility assessment to assure that all experiments under its cognizance were designed, fabricated, tested and operated in complete compatibility with all program and experiment requirements; it also participated in the resolution of interface problems that arose. MSFC was the Integration Center for Skylab and utilized the supporting services of a Systems Engineering and Integration Contractor.

In general, experiment integration responsibility was assigned to the center developing the module that would carry the experiment. Thus MSFC was also the Experiment Integration Center (EIC) for all Skylab flight experiments except those in the JSC-developed Command and Service Module, or crew procedural experiments involving no special hardware.

D. Launch Operations Center

This center received the integrated modules and launch vehicle stages and performed final assembly, test and closeout to ensure that the integrated system was ready for launch. The minimum requirements for the final integrated systems test were provided by the Integration Center to the Launch Operations Center. Launch was controlled from this center through countdown and liftoff. Following liftoff, control of the mission shifted to the Mission Operations Center. The John F. Kennedy Space Center (KSC) was the Launch Operations Center for Skylab.

E. Mission Operations Center

This center was responsible for controlling the mission to ensure that mission objectives were satisfied. Prior to launch, this center provided crew training and prepared flight planning and mission operations documentation. After launch it controlled the mission by monitoring all systems and updating preplanned crew activities as required. This center was also responsible for recovery operations and data dissemination (see Sections VII and VIII). The Skylab Mission Operations Center was JSC.

F. Cost and Schedule Control

Cost and schedule considerations were an important factor in selecting the experiments and continuing them in the program. Intense management scrutiny was brought to bear on those experiments that had repeated overruns of estimated costs or delays in meeting established milestones, which in turn added cost.

The NASA Office of Manned Space Flight (OMSF), through the Skylab Program Office at Headquarters, exercised overall control of Skylab budgets, costs and milestone event schedules. A Program Operating Plan (POP), compiled and maintained at Headquarters, reflected experiment resources commitments as originally approved in the Experiment Implementation Plan and subsequently revised by approval of inputs submitted by the cognizant centers. The POP was the authoritative summary of program funding and schedules.

RECOMMENDATION: Prior to approval of an experiment for development, insist upon sufficient definition to provide realistic estimates of cost ceilings. For this purpose, final approval might be withheld until after Preliminary Design Review; or funding could be reviewed and approved in incremental stages.

SECTION III. EXPERIMENT DEFINITION

Experiments proposed for the Skylab Program varied from new investigations to reflight of experiments from other programs. Some, developed during previous programs, had flight hardware already available, while others were only concepts and their hardware designs had not yet begun. The selection process, (see figure 3) was designed to ensure that experiments approved for Skylab had been thoroughly evaluated on the basis of scientific merit and compatibility with the program's objectives, capabilities, schedules and funding. The current (post-Skylab) NASA selection process is described in detail in Reference 5, and reflects the Skylab experience.

A. Conceptual Approaches

Skylab experiment concepts were generated and implemented by either of two approaches. Where an individual scientist conceived an acceptable investigation of a specific scientific objective, a single experiment was generally developed to satisfy that objective, and the originating scientist was identified as the Principal Investigator (PI). Most of the experiments were generated in this way. The other approach (which gained increasing favor during the Skylab Program) was that of implementing an "Orbital Experiment Facility", comprising a group of associated instruments dedicated to general investigations of a particular scientific discipline, such as earth resources or materials processing in space. Facility instruments were generally conceived by a small group or committee of scientists versed in the needs of the discipline involved. When the facility concept or preliminary design had progressed to the point where its capabilities were reasonably well defined, an Announcement of Flight Opportunity (AFO) was issued to potential "users" throughout the world. Interested scientists responded with proposals for using the facility to gather data for their specific investigations. Accepted proposals were contractually implemented with the users by the EDC. A NASA Project Scientist at the EDC performed the PI functions (and represented the users) for each facility instrument. The chief advantages of the facility approach are: much broader usage of the instruments and data, and the fact that all the user scientists need not be directly involved during the full program duration.

B. Sponsoring Program Office

Each experiment required a Sponsoring Program Office to manage the conceptual identification and feasibility phase of the experiment

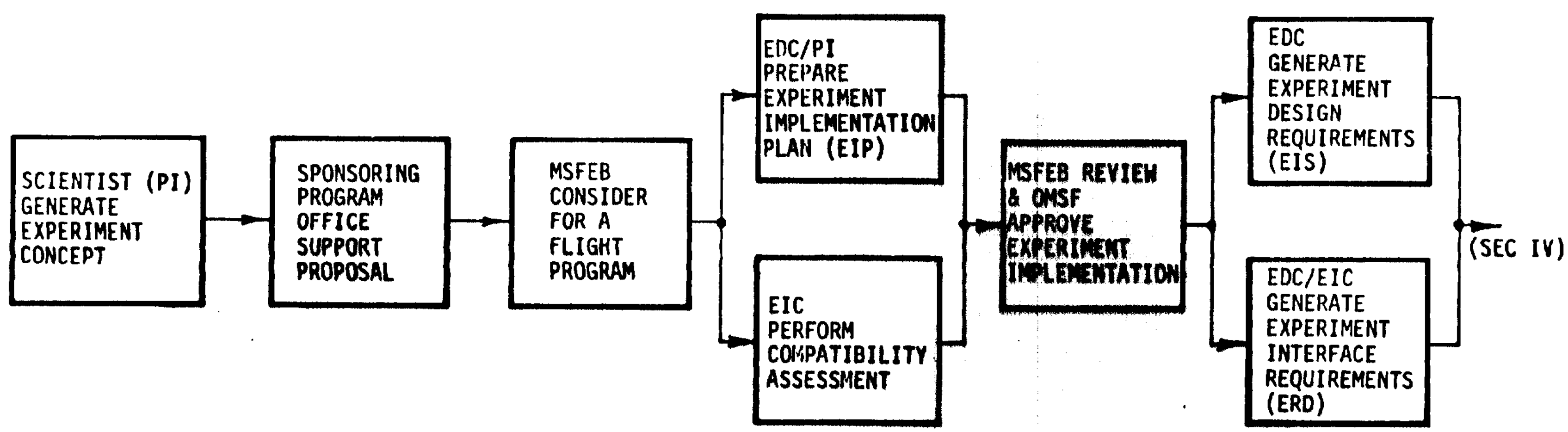

FIGURE 3. EXPERIMENT DEFINITION

definition. For Skylab, the NASA sponsoring offices were the Office of Manned Space Flight (OMSF), the Office of Space Science Applications (OSSA), and the Office of Advanced Research and Technology (OART). The Department of Defense (DOD) also served as sponsoring office for certain experiments. The experiment's scientific discipline generally determined the cognizant SPO.

Having received and concurred with the scientist's conceptual proposal, the SPO formally presented it to the MSFEB for preliminary consideration, and later for final approval. The SPO subsequently monitored the scientific and technical integrity of approved experiments through all program phases to ensure that experiment objectives were satisfied, and that adequate funding was provided.

C. Approval Cycle

Once an experiment was recommended by the MSFEB for consideration, an Experiment Implementation Plan (EIP) was prepared and a compatibility assessment made.

1. Experiment Implementation Plan. The PI and the designated EDC jointly compiled experiment information in an EIP in as much detail as possible. In addition to the experiment objectives, the EIP generally included preliminary information for the design, fabrication, test and delivery of experiment equipment, and the operating procedures necessary to perform the experiment. An experiment development schedule and estimated funding (resources) requirements were also included. Experiment development and delivery schedules as required in the EIP were necessarily keyed to overall program-controlled milestones and module level development and test schedules. Requirements identified in the EIP were concurrently utilized by the Integration Center in performing the compatibility assessment.

2. Compatibility Assessment. This study compared the experiment's interface requirements with the program's existing capabilities and constraints. Where incompatibilities were found, solutions or alternate designs were proposed that would satisfy the experiment objectives without unacceptable impact to the program. At this early stage, the compatibility assessment was necessarily less detailed than that described in Appendix B, but approached it as nearly as the preliminary information would permit. Normally, the Integration Center conducted this analysis, with support from the PI, the EDC, and the operating centers as required.

3. Final Review and Approval. The experiment proposal, supplemented by the EIP and compatibility assessment, was then resubmitted to the MSFEB for its review and recommendation. The NASA

Associate Administrator for Manned Space Flight (who also chaired the MSFEB) made the final decision on approval of the experiment for implementation.

> RECOMMENDATION: Emphasize thoroughness in preparation of the EIP and conduct of the compatibility assessment during the initial experiment approval cycle, for early identification of all program impacts and any major problem areas.

D. Generation of Requirements

Upon final approval, two types of experiment requirements were generated: the design requirements for the scientific instrument development and the integration requirements to support the experiment during all phases of the program. The former were stated in a document called the End Item Specification (EIS) and the latter were identified in an Experiment Requirements Document (ERD). Both of these documents were the responsibility of the EDC; however, the ERD required EIC and operations center support and in some cases was actually prepared by the EIC. [NOTE: Occasionally, in the early stages, the descriptive portions of the ERD were used as a substitute for the preliminary EIS, but this procedure was generally concluded to be less than satisfactory.]

> RECOMMENDATION: Initiate preparation of the EIS and ERD as soon as possible after experiment approval. Since the ERD is an integration document, primarily concerned with program-wide interfaces, it should be prepared and maintained by the EIC, with support and concurrence from the EDC.

SECTION IV. EXPERIMENT DEVELOPMENT

Upon program approval of the experiment, the hardware development proceeded. A series of reviews was held and development and qualification tests performed (see figure 4), to ensure the satisfaction of design and interface requirements. The same sequence of reviews and tests was imposed on all experiments regardless of the hardware development status when approved for Skylab. In general, new tests were waived only when it could be demonstrated that previous tests had met or exceeded the Skylab requirements.

Detailed requirements and procedures for the various development reviews are described in Appendix C. Appendix D presents a listing of specific considerations and constraints pertinent to experiment design. An overview of the total experiment testing program is provided in Appendix E.

A. Requirements Baseline

A formal Preliminary Requirements Review (PRR) was conducted by the EDC at the earliest practical date after experiment approval and ED selection. The purpose of the PRR was to verify all requirements that had to be met to satisfy the experiment objectives, as stated in the preliminary EIS and ERD. The PRR was intended to establish as a requirement baseline: a preliminary EIS which properly specified experiment requirements in terms of performance criteria and limits; an ERD which properly specified experiment interface requirements on the module, crew, launch, flight and recovery operations; the number of required end items (i.e., flight, backup, test and training units, mock-ups) and their schedules; and the development program plan.

> RECOMMENDATION: Involve operations personnel to help identify, assess and resolve the impacts of operational requirements upon experiment design (and vice versa) at the earliest possible stage of development, to permit tradeoffs for the efficient use of crew time and spacecraft capabilities during the mission. Consider the feasibility of unattended or ground-controlled operation for repetitive or time-consuming functions that do not require onboard crew judgment. Minimize experiment impacts on concurrent spacecraft activities.

B. Experiment Design

Implementation of the EIS requirements into hardware design was accomplished in two phases: the design approach, approved at

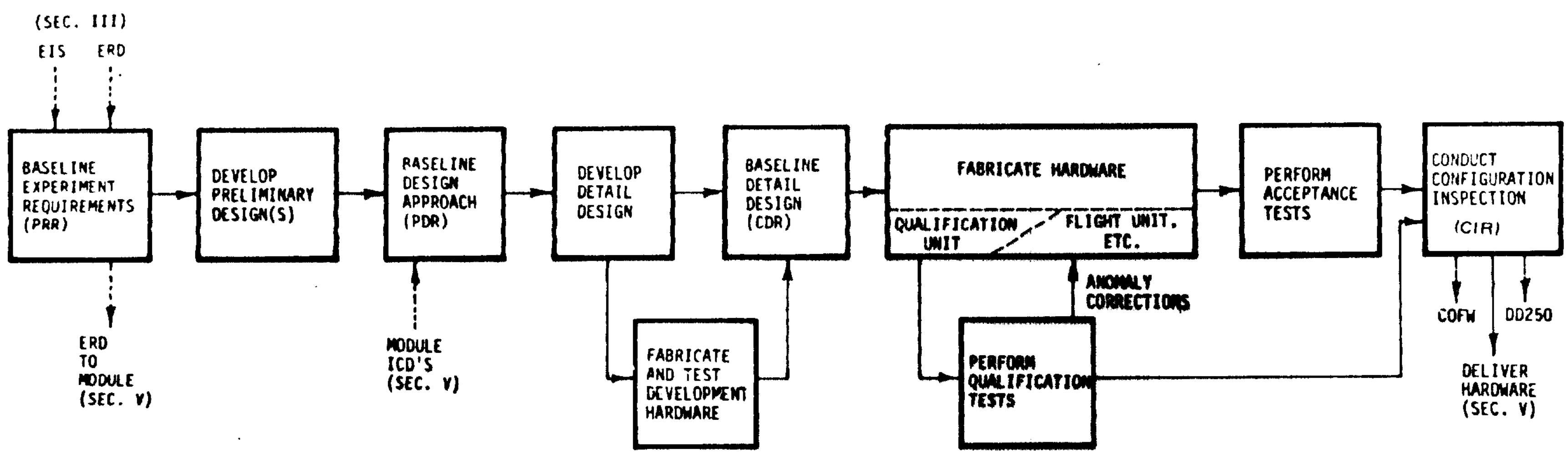

FIGURE 4. EXPERIMENT DEVELOPMENT

the Preliminary Design Review (PDR); and the detail design, approved at the Critical Design Review (CDR).

Development activities leading up to the PDR were to: 1) accomplish hardware preliminary design (subsystem block diagrams, overall dimensions, etc.), based upon the technical requirements of the baselined EIS; 2) perform trade studies to evaluate alternate concepts for subsystems, consistent with the experiment PRR; 3) perform the development activities that verify new subsystems, manufacturing processes, logic design, etc.; 4) define EIS requirements for the GSE; and 5) prepare reliability, quality control, maintainability and safety requirements sections for the experiment EIS.

> **RECOMMENDATION: Conduct necessary trade studies between scientifically desirable and technically achievable requirements (e.g., pointing tolerances) as early as possible in the development process, to avoid downstream incompatibilities.**

The PDR was then conducted by the EDC, wherein a design approach was selected to proceed to final design of flight hardware. The experiment PDR objectives were to: 1) approve the selected design approach for the flight hardware; 2) evaluate the justification for the design approach shown (by trade studies, technical reports, and/or development tests); 3) approve the technical requirements for mock-ups and GSE as stated in EISs for these articles; 4) review the adequacy of preliminary Interface Control Documents (ICDs) provided by the Module Development Center (see Section V); 5) approve the verification plan for the selected design; 6) approve producibility of the hardware; and 7) approve the completed flight hardware EIS with plans for quality, reliability, safety, and maintainability.

Following PDR, the experiment design proceeded to completion. Final detailed schematics and drawings of all parts were based upon the EIS, ICDs, and the approved design approach from the PDR. Appendix D lists a number of specific considerations that were recognized in the detail design of Skylab flight hardware and GSE.

> RECOMMENDATIONS: In addition to the detailed design considerations recommended in Appendix D, the following general design philosophy criteria are particularly emphasized:
>
> o Carefully evaluate the cost-effectiveness of using existing hardware for new programs.

- Build in safety features (e.g., interlocks, limit switches, etc.) to protect the hardware and/or enhance serviceability.

- Standardize crew interface hardware.

- Emphasize simplicity of operation as a primary design objective (e.g., avoid multiple switching operations that would permit selection of invalid modes or require time delays to preclude logic race conditions).

- Design manned spaceflight hardware to facilitate in-flight maintenance (e.g., provide accessibility and suitable workstations with restraint aids for crewmen, documents, small parts and tools).

- Provide telemetry or crew status indicators that give direct readout of specific parameters needed for in-flight assessment of experiment operation or for troubleshooting hardware malfunctions.

- Ensure existence of capability for in-flight visual observation of external experiments.

During this phase, the qualification and acceptance test specifications were prepared, based upon limits in the EIS and preliminary ICDs. A development (prototype) unit was usually fabricated and used for development tests of new design, data system, unusual manufacturing processes, etc., and for crew training.

The design was then reviewed for compatibility with requirements at the experiment CDR. The CDR results were: baselining of the approved detail design of the flight hardware, qualification unit, and GSE for release to manufacturing; approval of qualification and acceptance test specifications; approval of test and manufacturing facilities; and a review of development test results to certify that design and manufacturing would involve minimum risk.

RECOMMENDATION: Baselined experiment design should not be dependent on unproven advanced state-of-the-art features. Resist product improvement type changes after baselining, unless they clearly enhance the probability of mission success and/or improve cost-effectiveness.

C. Fabrication and Test

Using drawings approved at CDR, fabrication activities began. The number of hardware units fabricated was a variable, generally depending upon the experiment's complexity, schedule and budget. In addition to the previously mentioned development prototype and the flight unit, there was normally a flight backup unit, a qualification test unit and various training units, simulators and mock-ups. (In some cases, to minimize cost, it was found acceptable to reuse the same hardware for more than one of these applications.) The qualification unit, flight unit, and backup unit or spare parts were all built and assembled to the same design drawings.

> RECOMMENDATION: Carefully evaluate the need for multiple hardware, trading off the apparent cost against the risk of needing additional hardware too late in the program to produce it without excessive cost or delay.

At the earliest possible date, the qualification unit was fabricated and subjected to qualification tests, to verify that the design was compatible with specified environments. Whenever the qualification unit failed a test, corrective action was taken. If this involved a new design or a modification to the qualification unit, it was necessary that the new design or modification be incorporated into the flight and backup units.

The flight unit was subjected to an acceptance test, usually at levels less severe than the qualification test but adequate to verify conformance to the design requirements of the EIS.

During this phase also, the EDC and ED participated in meetings with the Integration, Module Development, and Launch Operations Centers to establish the test requirements for postacceptance integration testing (see Section V.C).

> RECOMMENDATIONS: Supplementing the details in Appendix E, the following recommendations apply to experiment testing in general:

o Provide experiment hardware and perform testing in the logical order (i.e., have the development unit available early in the program, and complete development and qualification testing prior to flight hardware acceptance).

- Emphasize early identification and timely baselining of test and GSE requirements and responsibilities - preferably as early as PDR. Minimize configuration variations in GSE sets to be used for identical tests at different test sites.

- Utilize a team of test/experiment integration specialists to develop appropriate integration test plans and requirements.

- Place more reliance on experiment development, qualification and acceptance test results to reduce integrated testing.

- Consider the cost-effectiveness of using interface simulators to minimize interface verification tests at the module level, and to preclude premature experiment hardware delivery.

- Support all experiment testing, both preacceptance and postacceptance, with cognizant experiment development and integration personnel for timely problem identification and corrective action.

D. Acceptance and Delivery

Following fabrication and test, a Configuration Inspection Review (CIR) was held to verify that the flight hardware to be accepted by the EDC conformed to the approved design configuration. Qualification and acceptance test results were assessed for validity and conformance to requirements. The CIR also verified that the Acceptance Data Package (ADP) was complete and that problems which occurred after CDR had been properly resolved. The ADP provided a complete set of descriptive data for each deliverable end item, which was maintained current and physically accompanied the hardware when shipped from site to site. Appendix A includes a full description of the ADP contents. A DD250 (a NASA form for formal acceptance of the hardware), indicating any shortages or open work items to be resolved prior to Flight Readiness Review, was approved by the EDC at the completion of the CIR. Prior to shipment from the point of manufacture, a Certificate of Flight Worthiness (COFW) was prepared and endorsed by the EDC representative (see Appendix C).

RECOMMENDATION: Define a standard list of minimum necessary ADP requirements, acceptable to all centers involved, and implement it contractually on all hardware developers.

E. Late Experiment Additions

The value of the Skylab missions was considerably enhanced by approval, late in the program, of many new experiments (e.g., the Multipurpose Electric Furnace, the Student Experiments, and the Comet Kohoutek Observing Program). To develop these experiments without impacting launch dates required an expedited approach to the methodology just described. One aspect of this approach was the use of a specialist team to prepare major experiment development documentation. Integration personnel, already familiar with the interfacing module systems and with Skylab documentation requirements, were assigned to assist the EDs in preparing such documents as the EIS; Failure Mode and Effects Analysis (FMEA); Hazards Analyses; Operation, Maintenance and Handling (OM&H) procedures; Materials List; etc. The results were timely, complete, consistent and correctly formatted documents, prepared at minimal cost.

RECOMMENDATION: Expand upon the Skylab usage of specialist teams for preparation of major experiment development documentation, to preclude each developer having to go through his own learning cycle. Consider using similar teams for experiment-related integration documentation as well.

SECTION V. EXPERIMENT INTEGRATION WITH THE MODULE

Development of the modules that carried the experiments proceeded in parallel with the experiment development, as indicated in figure 1. The modules followed a similar pattern of design reviews, fabrication and testing. In addition, however, experiment installation and integration testing were performed prior to final module acceptance and delivery to the launch site (see figure 5).

A. Module Requirements Baseline

A PRR was conducted by the Module Development Center to baseline the technical requirements for the module. The mission and total orbital assembly (cluster) requirements were reviewed (e.g., mission orbital parameters and durations, module descriptions and interface requirements, experiment assignments to modules, control weight allocations, power profiles, pointing requirements, natural and induced design environments, etc.). [NOTE: As the program progressed, the need was recognized for a separate specification identifying these overall system requirements imposed at the cluster level. An intercenter Cluster Requirements Specification (CRS) was accordingly implemented, and became, in effect, the top-level End Item Specification.] Experiment requirements identified in the ERDs, current compatibility assessments and integration plans and schedules were also reviewed at PRR. These activities, together with completion of any PRR action items, established the program requirements baseline for the module.

> RECOMMENDATION: Early in any new program (preferably prior to module and experiment PRRs) establish and baseline the equivalent of the Skylab Cluster Requirements Specification and impose it upon all program elements, to ensure program-wide compatibility with overall requirements (e.g., operational environments). At module PRR, formalize the module requirements baseline in a preliminary module EIS.

B. Module Design and Integration

The module design and integration proceeded in parallel with the experiment development activities (see Section IV). Module development activities included: 1) the basic analysis and design to meet module requirements; 2) developing preliminary experiment ICDs for use in the experiments' final design, including definition of the module technical inputs (e.g., dynamic and static loads, number and type of

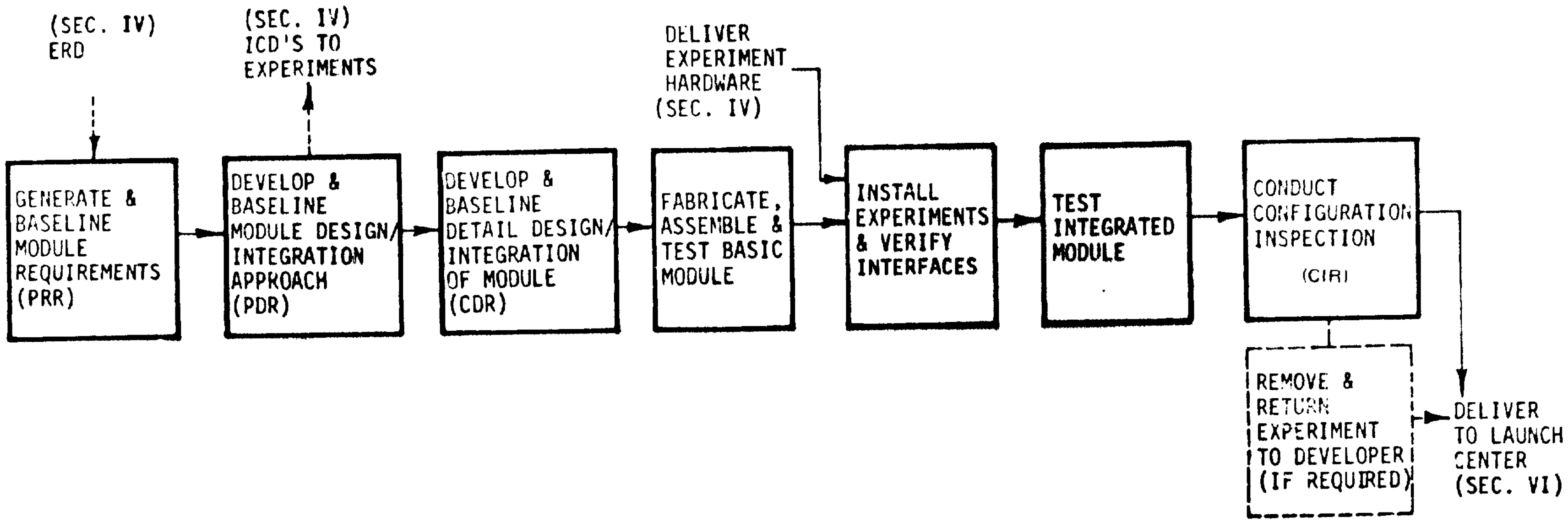

FIGURE 5. EXPERIMENT INTEGRATION WITH THE MODULE

electrical connectors, power level, voltages, etc.); 3) a continuing compatibility assessment to show status of design conformance to requirements and to provide management visibility of problems; 4) providing overall module system block diagrams; 5) defining GSE requirements; and 6) establishing subsystem add-ons (batteries, propellant, etc.) to satisfy mission requirements.

A module PDR was held to baseline the preliminary module design and the integration approach. The preliminary EIS and block diagrams, drawings, matrices, etc., of each subsystem were reviewed to show conformance to technical requirements of the CRS. The technical adequacy of the module design, ICDs, module FMEA, GSE requirements, an updated integration plan, schedules and compatibility assessments were also reviewed.

Final module detail design and integration was then started, utilizing the PDR baseline. This involved: 1) preparing engineering drawings of all parts and assemblies, detail schematics, wiring diagrams, etc.; 2) building of a high-fidelity mock-up of the integrated system for review at the CDR; 3) the detail design of all module-provided GSE; 4) preparation of manufacturing and assembly plans and drawings; 5) preparation of qualification and acceptance test specifications; 6) completion of the module development program (cable layouts, structural vibration, etc.) to support final design; and 7) fabrication of mechanical interface GSE (provided to some experiment developers prior to delivery of flight experiments for verification of interfaces during their acceptance testing).

The module CDR occurred after the majority of the experiment CDRs. Review items included: 1) analyses that supported the design; 2) detail drawings and plans; 3) the module FMEA; 4) module qualification and acceptance test specifications; 5) mock-ups; and 6) ICDs. The CDR baselined the final design configuration of the module.

C. Integration Test Requirements and Procedures

During the final phase of experiment development, the Module Development Center/contractor made preparations for receipt of the experiments and for the assembly and testing of the module subassemblies. In testing the module, experiment electrical simulators (built by experiment developers) were sometimes used in place of actual hardware. This provided confidence in the design and eliminated many problems prior to flight unit delivery. Special Post-Acceptance Test Requirements and Specifications (PATRS) meetings were held with each EDC/ED and the Integration and Launch Operations Centers, to develop experiment requirements and criteria inputs for the module/experiment integration tests and related portions of the integrated systems tests at the launch site. The output of these meetings was a coordinated Experiment Integration Test Requirements and Specifications (EITRS) document, prepared by the

Integration Center and concurred with by all other centers and contractors involved. The Module Development Center then compiled these requirements and limits into a Test and Checkout Requirements and Specifications Document (TCRSD) for the module, from which the detailed experiment integration test procedures* were subsequently prepared by the center responsible for conducting the tests.

> RECOMMENDATION: Baseline EITRS documents for the various experiments and module TCRSDs (or equivalents) as early as possible, and maintain at least the TCRSDs under Level II change control, to ensure clear and complete definition of integration test requirements for all program elements. Maintain uniformity of procedures for performing identical tests at different test sites.

D. Physical Integration, Acceptance and Delivery

The module now entered the final acceptance phase prior to delivery to the launch site. Upon receipt of each experiment at the module site, it was subjected to an unpowered receiving and inspection test for transportation damage and completeness of parts and documentation. The hardware was then installed in the module, using module assembly drawings and the experiment OM&H. A powered functional interface verification (FIV) test of the experiment with the module was performed to verify that all electrical and mechanical interfaces conformed to the specifications in the TCRSD. Following FIV tests for all experiments, a simulated mission test was conducted for the integrated system. Some flight crewmen generally participated in this system test as part of their crew training.

> RECOMMENDATION: Encourage participation in experiment/module integration tests by all flight crewmen who may be required to operate the experiment during the mission(s).

Upon successful completion of all testing, a module CIR was held. The integrated system test results were reviewed to verify that the module had met the established requirements. A module DD250 and COFW were executed by NASA, and the integrated module was then shipped to the launch site. Any experiment or subsystem that was removed for separate shipment needed interface reverification at the launch site when it was reinstalled. Experiments that were returned to the developer for modification or final calibration prior to shipment to the launch site required an additional endorsement on their DD250 and COFW by the EDC.

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* If flight checklists (see Section VII) were available from the Mission Operations Center, these test procedures followed the checklists as closely as possible.

RECOMMENDATION: Discourage removal of experiments after module integration and acceptance. When this is unavoidable, emphasize critical configuration control and maintenance of appropriate records by all parties involved.

E. Continuing Compatibility Assessment

The evolution of the experiment concepts and module designs to hardware was supported throughout by a continuing compatibility assessment, conducted by the Integration Center. This assessment monitored the experiment interfaces with the program for compatibility, proposed and coordinated solutions to experiment incompatibility problems, and provided management visibility of the experiment integration status. Further details of this activity are provided in Appendix B.

RECOMMENDATION: Follow the Skylab practice of utilizing a highly qualified, specialized experiment integration team. Assign responsibility for each experiment (or group of related experiments, depending upon complexity) to an individual engineer, to act as the single-point source for compiling and disseminating experiment requirements and other integration information. Assign responsibility for compatibility of experiments with each carrier system or program discipline to an individual systems engineer, to facilitate experiment liaison with other project groups. Conduct continuous compatibility assessment and frequent reviews throughout the development and integration phases, providing timely management visibility of problem status.

SECTION VI. PRELAUNCH INTEGRATION AND LAUNCH OPERATIONS

Prelaunch and launch activities (see Figure 6) were conducted by the Launch Operations Center, with the cognizance of the Integration Center and the support of the Development and Mission Operations Centers. The peak activity at the launch center obviously occurred after the launch vehicles, modules and experiments were delivered, but there was significant activity prior to this time to establish the test and facility requirements and test procedures. Tasks performed to identify these requirements, as related to experiments, began when the experiment was approved for the program and continued throughout the development and integration phases.

A. Launch Center Test Preparations

Prior to receiving the module hardware, postacceptance test requirements, specifications and constraints for each experiment were reviewed and approved in a series of formal PATRS meetings, attended by representatives from all centers (see Section V.C). Following these meetings, the Module Development Center compiled the applicable module/experiment test requirements, specifications, and criteria necessary for prelaunch checkout and launch operations into the module Test and Checkout Requirements and Specifications Document. Similarly, the Integration Center prepared a TCRSD for the combined integrated systems test. Using the agreed-upon TCRSD, the launch center prepared detailed test plans and procedures for satisfying these requirements, subject to review by the Integration and Development Centers. The launch center also benefited from participation in the Systems/Operations Compatibility Assessment Review (see Section VII. A.2).

B. Receiving and Inspection

Upon arrival at the launch center, all hardware (including GSE) underwent Receiving and Inspection (R&I). The hardware was examined visually for any damage incurred during shipment. The ADP was examined for completeness of all documentation and certifications required for acceptance by the launch center. Any available transportation environmental information, such as temperature profiles, passive accelerometer data, etc., was reviewed to assure that handling and shipment constraints had not been violated.

Experiments that were transported to the launch center integrated within the module passed through Receiving and Inspection with the module. Experiments shipped separately from the module were received independently with their own Acceptance Data Packages.

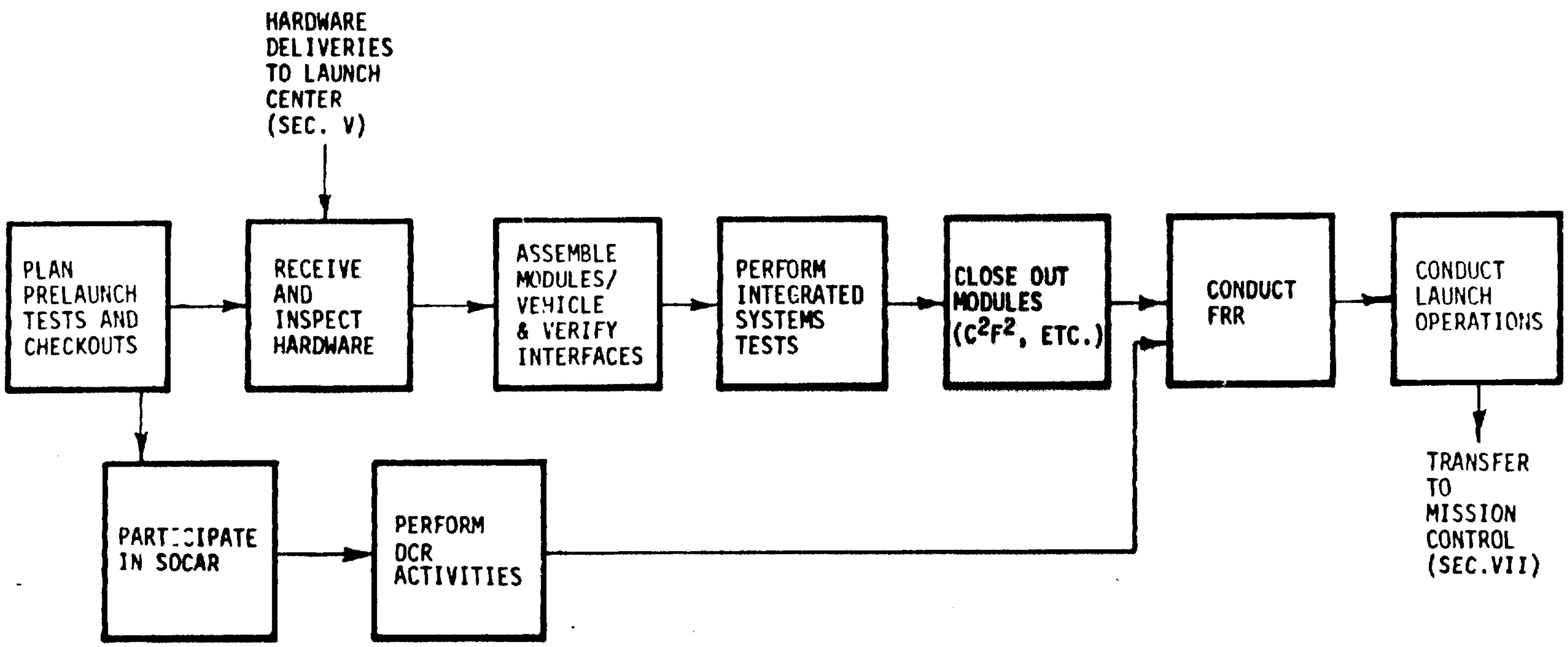

FIGURE 6. PRELAUNCH INTEGRATION AND LAUNCH OPERATIONS

Experiments not installed on-module, or actively involved in tests, were placed in an environmentally controlled bonded storage area until required for use. All GSE underwent a checkout to ensure that it functioned properly before being mated to flight hardware.

C. Prelaunch Integration Tests

Following R&I, testing at the launch center emphasized system-to-system interface verification. Individual experiment testing was minimized and consisted mainly of necessary reverification of interfaces and final calibrations.

The activities at the launch center included: 1) the assembly and integration of modules to the launch vehicle; 2) verification of all instrumentation, communication, environmental, electrical, mechanical, and structural interfaces; 3) integrated systems tests which exercised individual systems as well as combined systems to verify overall space vehicle functional compatibility; 4) final Crew Compartment Fit and Function (C^2F^2) checks to assure flight crew members of proper hardware integration, accessibility, and safety considerations; 5) final calibration of experiment sensors; 6) stowage of perishable items; and 7) securing of all hardware prior to launch.

D. Design Certification Review

As part of a final assessment and certification of the design of the total mission complex, the Design Certification Reviews (DCR) for experiments and modules were held. All involved centers participated and the review was conducted by the NASA Headquarters Program Office. DCR activities began prior to flight hardware shipment to the launch center and ended during launch center operations. The purpose of the DCR was to examine the experiment/module hardware design and the design verification programs in order to certify that the overall design had met the program objectives for flight worthiness and flight safety.

The following topics were covered at the DCR: 1) an analysis of the purpose, design, and interface compatibility of the experiments; 2) a summary of actions taken as a result of previous experiment reviews; 3) a review of safety and reliability considerations included in the hardware design; 4) a review of mission rules and contingency plans; 5) an analysis of all prior hardware test programs; and 6) the status of any remaining open action items.

E. Flight Readiness Review

The Flight Readiness Review (FRR) was held at the launch center prior to launch. This review assured program management that all aspects of the space vehicle, launch vehicle, launch complex, Mission Control Center (MCC), ground instrumentation and networks were ready for flight operations.

The following topics were reviewed at the FRR: 1) the status of action items resulting from the DCR; 2) any hardware configuration changes that had occurred since the DCR; 3) the current status of prelaunch integration testing at the launch center; 4) the status of major anomaly reports; 5) a summary of all significant problems that arose during testing, and their solutions; and 6) a summary of waivers or deviations that had been granted since the DCR.

F. Launch Operations

At the conclusion of the FRR, all testing and stowage was completed and attention focused upon final closeout of the entire flight vehicle. The launch center was responsible for the launch countdown, with the support of the Mission Operations Center. When the flight vehicle cleared the launch complex (i.e., umbilical tower), full responsibility for flight direction reverted to the Mission Operations Center (except that the Air Force Range Safety Officer at the launch site retained the option of intervening if range safety became endangered).

SECTION VII. MISSION AND RECOVERY OPERATIONS

Once the launch vehicle was in flight, the entire mission was under the direct control of the Mission Operations Center. The procedures and techniques used to perform these functions had been under development and rehearsal since the early phases of the program. Figure 7 depicts the premission preparations and real-time functions involved in conducting the mission and recovery operations.

A. Premission Preparations

Concurrently with hardware development and integration, preparations were made for the operational phase of the mission. This activity included the generation of mission and mission support documents, reviews of applicable program documentation, crew training, and the establishment and verification of operational readiness through mission simulations.

1. Documentation Preparation. Using the ERD and module requirements, the Missions Operations Center prepared the basic mission documents.* The primary requirements documents were the Mission Requirements Document (MRD) and the Reference Flight Plan (RFP). The MRD defined the requirements and constraints for both the mission and the individual experiments. The RFP converted the MRD information into a detailed timeline of crew activities during the mission. These documents were utilized during the design and integration phases to show that adequate time and systems support would be available to perform the mission. Shortly before launch, the updated RFP became the actual Flight Plan. The RFP did not contain the detailed steps for performing a function, but was limited to referencing the function (e.g., load film). The Mission Operations Center prepared Checklists for each function (e.g., the detailed steps for loading the film), based upon Volume II of the OM&H. The Checklists and Flight Plan were launched with the crew even though they would be updated during the mission. Other operational documents (e.g., Flight Mission Rules, Operational Data Books, etc.) were prepared to provide further details; these are described in Appendix A.

> RECOMMENDATION: Since Skylab premission estimates of crew time required to perform work tasks in the orbital environment were not always proven accurate in real time, utilize Skylab mission experience correlations (notably Experiment M151, Time and Motion Study) for quantitative crew task planning for future missions.

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* Although Data Request Forms (DRFs) were also prepared to identify data processing requirements during the mission, the discussion of the DRF is in Section VIII, Data Processing, Analysis and Reporting.

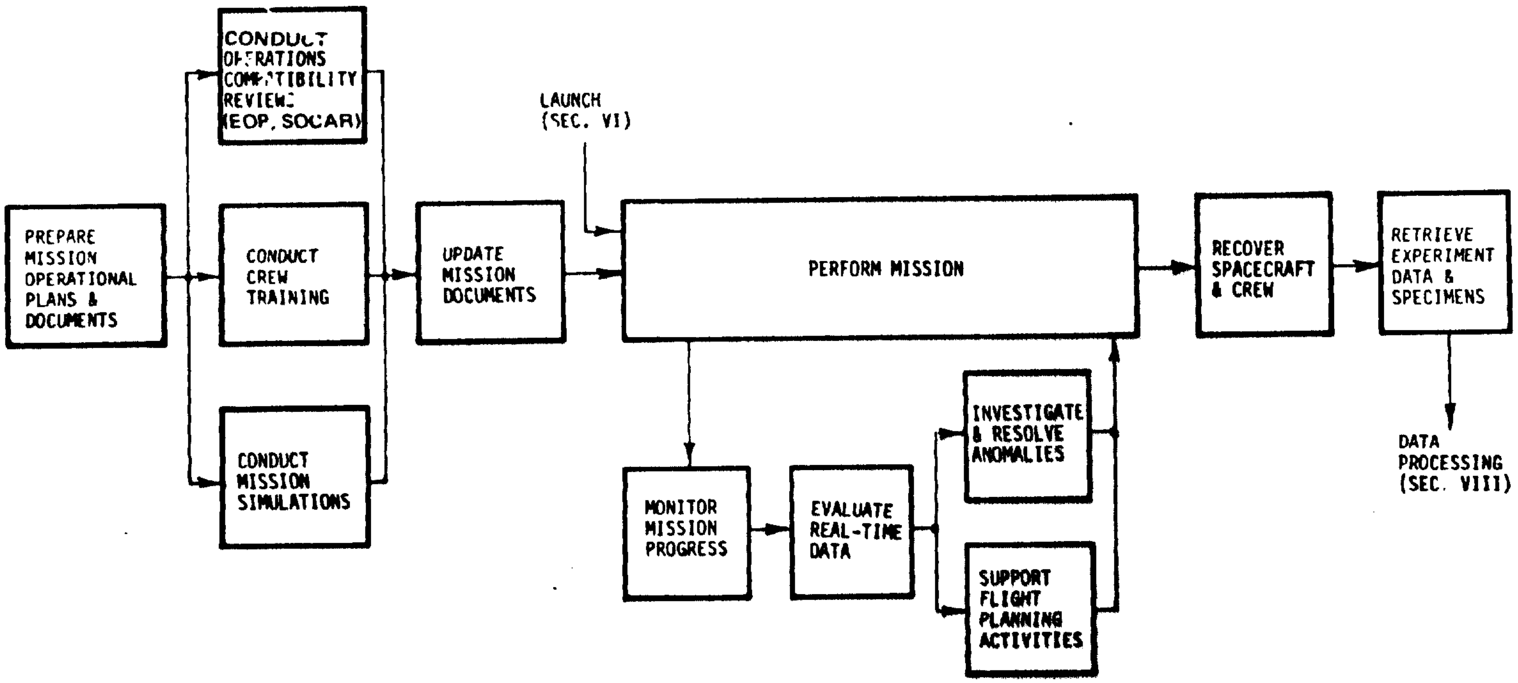

FIGURE 7. MISSION AND RECOVERY OPERATIONS

2. <u>Operations Compatibility Reviews</u>. To assure an integrated approach to mission operations, a series of Experiment Operations Planning (EOP) meetings was convened during the development and integration phases. These meetings brought together representatives of experiment development and integration, mission operations, flight planning, PI/users, and various mission support groups for the purpose of assuring that compatibility existed between experiment objectives and experiment operations. Documentation pertaining to experiment operational requirements and techniques was reviewed and compared for consistency with experiment objectives. Potential operational conflicts between experiments were resolved.

A more formal program-wide review, the Systems/Operations Compatibility Assessment Review (SOCAR) was conducted prior to DCR. It consisted of a series of preliminary meetings, similar to EOPs, but involving design/development and integration personnel for all Skylab systems, interfacing with the operational personnel at both launch and mission operations sites. It culminated in a formal presentation, by system, to senior program management. The SOCAR was generally considered quite effective in enhancing the program's operational readiness.

> RECOMMENDATION: Incorporate the equivalent of the Skylab SOCAR in the formal program milestone reviews, to be conducted at the appropriate time to assure maximum coordination and subsequent readiness of the operational planning.

3. <u>Crew Training</u>. Maximum efficiency during on-orbit operations is attained when the flight crew is thoroughly familiar with the hardware and the general objectives. To this end, the Skylab flight crews underwent extensive training, first with high-fidelity mock-ups of the experiments and modules provided by the hardware developers. Later, during integration tests at the module development centers (Section V) and at the launch center (Section VI), crewmen were used in place of technicians for operating the flight hardware at every opportunity. To simulate mission activities, the procedures for those tests involving crew participation utilized the actual flight checklists wherever possible.

> RECOMMENDATION: Follow up any problems or deficiencies encountered during crew training, to assure proper resolution and incorporation of any resulting hardware and/or operational changes.

4. <u>Mission Simulations</u>. Prior to launch, a series of mission simulations was performed, to exercise the flight and support personnel in a realistic mission environment. For the purpose of these simulations, the mission was divided into distinct phases, e.g., launch, first-day activities, activation, orbital operations, etc. Each

simulation was directed at a particular mission phase and covered a period ranging from one 24-hour mission day, early in the simulation program, to three consecutive 24-hour days as proficiency improved.

All activities directly involved in mission support were exercised, in an atmosphere designed to reproduce the actual mission environment insofar as possible, even to the extent of introducing hypothetical malfunctions and anomalies. Basic coordination, information flow and operational procedures were established during these simulations. Following each simulation, a debriefing was conducted to discuss any operational problems uncovered, and corrective procedures were developed to preclude their recurrence during the actual mission.

> **RECOMMENDATION: Conduct comprehensive prelaunch mission simulations, utilizing all applicable communications, data links and support personnel.**

B. Mission Control

Following launch, all phases of the mission were under the control of the MCC, located at the Mission Operations Center. This included planning for and operation of all module systems and maneuvers, crew activities and experiment operations, from launch through recovery. Activities were planned in near-real time on a daily basis, and all aspects of mission operations were continuously monitored from the ground.

The Flight Operations Director was responsible for the mission operations and provided the management interface between the Flight Director and Program Management. The Flight Director, operating from the MCC, had the direct responsibility for mission control.

The general mission control functions accomplished by flight controllers, with the technical support of other centers and support teams, were to monitor and evaluate, in real and near-real time, the module systems, instrument systems, scientific data, flight plan activity, condition of the flight crew, and trajectory data. Based upon these data, decisions were made concerning the progress of the mission toward satisfying mission objectives and the Detailed Test Objectives from the MRD, and the need for proceeding to alternate flight plans. The flight crew was then advised of updated mission instructions and flight plans, systems anomalies found during ground monitoring, ground evaluations and recommendations to solve or circumvent any anomalies.

C. Crew Operations/Flight Planning

The level of experiment accomplishment is related to the efficiency of the crew operations. A prime consideration during flight plan generation is the effective utilization of crew time. In any twenty-four-hour period, a fixed percentage of time must be devoted to crew personal activities such as sleep, meals, exercise, personal hygiene and rest periods. The remaining time (approximately ten hours each day was available on Skylab) is devoted to experiment operation and, as required, systems housekeeping.

Each day during the mission, a flight plan was generated by the MCC to cover the following day's activities. This plan, identical in format to the premission Flight Plan, was distributed to all mission support groups for review and comment and, after incorporation of approved recommendations, the final version was uplinked to the crew via teleprinter before initiation of that day's activities. Specialized information peculiar to that day's flight plan, such as critical times for target acquisition, precise exposure times or alterations to the on-board procedures checklists, were also uplinked as "preadvisory data" messages (referred to as PADs). The PADs functioned as addenda to the information stowed on-board in the Flight Data File (flight plan and checklists).

D. Mission Operational Support Teams

The functioning of the MCC during the missions was backed up by an extensive support organization, both on-site at the Mission Operations Center and remote at other NASA centers and contractor facilities. The Huntsville Operations Support Center (HOSC) was the focal point of MSFC support activities and fulfilled a major role in the conduct of the mission. Support teams, organized by science/technical discipline or by spacecraft system, were composed of representatives from the development and integration centers, contractors and PIs. They monitored the mission progress in real time, and provided the MCC with immediately available expertise relative to any experiment or system anomaly that arose. Each team initiated and/or reviewed proposed mission changes to ensure satisfaction of the requirements and constraints of their particular area of concern. Their basic task was to assure the optimum success of their experiments in the face of whatever off-nominal conditions might occur during the mission. The primary areas of team concern were: 1) continual planning of future activity necessary to achieve maximum experiment success with relation to all other mission parameters, and 2) rapid and accurate response to any in-flight anomaly, either vehicle or experiment-related, to maximize the experiment data returned under the prevailing conditions. In connection with the flight planning activity, the Skylab experiment support teams made regular inputs to the "Science Planning Meetings," conducted twice weekly by the Program Scientist at the Mission Operations Center, which proved to be an effective means for influencing the MCC flight planning.

RECOMMENDATIONS: The primary recommendations resulting from Skylab experiment mission support experience were:

- Utilize personnel for mission support who have participated in experiment development and/or integration and have experience with hardware-related problems. Ready availability of the PIs or their authorized representatives is highly desirable, particularly for the more complex experiments.

- Provide near-continuous communication between spacecraft and MCC, more direct communication and data links between MCC and the mission support teams, and fewer intermediaries between the teams and the flight crew during anomaly troubleshooting. Also, limited but frequent direct communications between the flight crew and the PIs are both feasible and productive.

- Provide mission support teams with available experiment hardware to permit realistic ground simulation, facilitating real-time troubleshooting.

- Utilize trainer walk-throughs by ground-based astronauts to check out late additions and real-time procedural changes before transmitting them to the crew.

- Emphasize active participation of experiment mission support teams in influencing preparation of daily flight plans by maintaining liaison with the MCC flight planners and supporting semiweekly science planning meetings.

E. Recovery Operations

Operations at the recovery site were planned to ensure that the integrity of physically returned experiment data (primarily photographic film and specimens) was not compromised and that prescribed handling and delivery requirements were satisfied. These requirements, along with any applicable support functions, had been identified early in the program. Preliminary recovery site requirements for each experiment were identified in the original ERDs, and specific handling procedures were later defined by means of DRFs.

These forms were used to detail temperature and humidity limits to be observed, shielding requirements if applicable, special containers required to protect the data, or other handling techniques necessary to isolate the material from the external environment.

Following retrieval of the crew and spacecraft, recovery site operations included deactivating potentially hazardous systems and securing the module subsystems; initiation of ground support functions such as purges, thermal conditioning, ground power, etc.; and the retrieval of experiment and subsystems flight data. The returned data were removed and packaged for transportation to the data distribution center and subsequent processing and/or dissemination to the PIs and data users.

SECTION VIII. DATA PROCESSING, ANALYSIS AND REPORTING

Data requirements of the experiment Principal Investigator or data user were initially stated in ERDs and subsequently amplified in DRFs. Using these requirements, the Mission Operations Center developed the plans and software required to retrieve, process and distribute all flight data. The development centers were responsible for the Mission Evaluation Reports, and the Principal Investigator or data user was responsible for scientific data analyses and reporting of results. Figure 8 shows the functional flow for this phase.

RECOMMENDATION: Clearly define the respective responsibilities of NASA and the participating scientists in the following areas:

- o Funding
- o Data retrieval, processing and delivery
- o Systems performance data required
- o Proprietary rights to data
- o Reporting requirements
- o Data security, accountability and archiving
- o Involvement in Public Affairs Office activities.

This was accomplished late in the Skylab Program by implementation of the Experiment Scientific Data Analysis and Reporting Documents (ESDARDs).

A. Premission Preparations

During the premission phase, arrangements were made for the acquisition of data pertinent to experiment success. The initial requirements were stated in the ERDs. The DRF was later employed as the formal method of requesting data for all users. The data required for the scientific investigations was defined by the PI/user, documented on DRFs, and submitted to a data requirements group at the Mission Operations Center for approval, processing and implementation. The DRFs specified the data recipient, the pertinent data required, the specific times during the mission when the data was to be acquired, desired format, and the date when the data was needed.

Based upon the DRFs, the Mission Operations Center prepared software programs for general processing of the flight data. Further (more detailed) processing, required by certain experiments, was provided by the cognizant EDC. Available programs were exercised during the mission simulations, using recorded data generated during the integration tests.

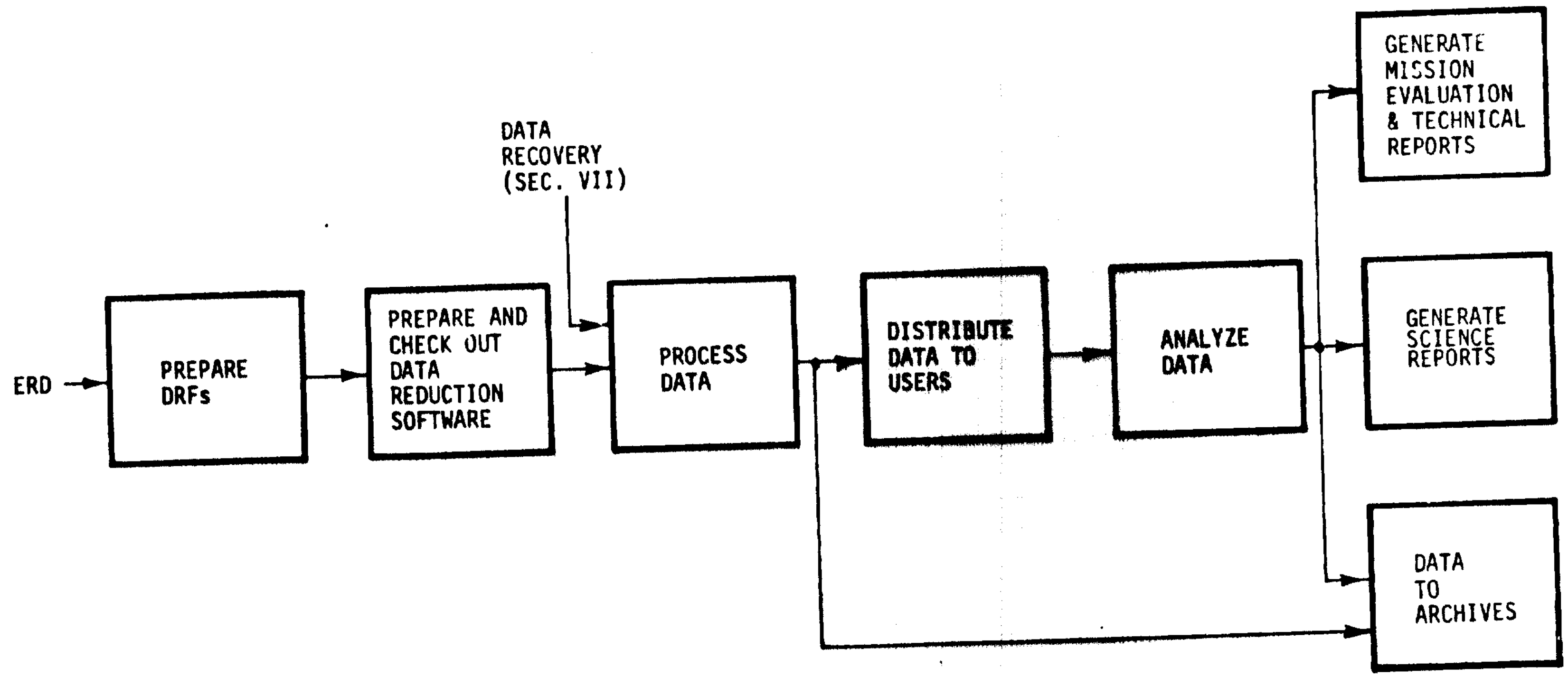

FIGURE 8. DATA PROCESSING, ANALYSIS AND REPORTING

RECOMMENDATION: Skylab data processing and analysis proved to be far more complex and time-consuming (and therefore more costly) than anticipated, indicating the need for more emphasis on premission rehearsals of the entire sequence, in order to optimize the operations, shorten data retrieval time, and determine realistic time and cost requirements for these activities.

B. Flight Data Processing

Flight data was received and catalogued at the Mission Operations Center both during and after the mission. Returned flight samples were released to the PI for examination and analysis. Operational film and much of the scientific film were processed by the Mission Operations Center and duplicates distributed to the data users. In special cases, scientific films were delivered to the PIs for processing and analysis, with the understanding that the original flight film and a reproducible master were to be returned to archives at the completion of the analysis. Recorded and telemetry data were processed through appropriate software programs and reduced to computer-compatible tapes prior to release to the data users. Other requested data formats included: tabular forms, strip charts, microfilm, transcripts, video tapes and digital television displays.

C. Data Accountability

The PI was normally granted proprietary use of the returned scientific data for a one-year period after all requested data was delivered to him. He was responsible for the physical security and integrity of all mission data received by him while it was in his possession. He was required to take proper action to prevent loss, theft or unauthorized use of this material (refer to MSFC Management Instruction 4010.2). At the conclusion of this period, all orbital material was required to be returned to the EDC archives. Thereafter, NASA retained control of the returned material for possible further scientific investigations.

D. Scientific Data Reporting

A PI was normally granted initial publication rights to experiment data for a period of one year. Each PI was responsible for generating periodic reports of his investigative findings at intervals of 30 days, 90 days, 6 months and 1 year after splashdown. Normally, within the 1-year period, the PI was to deliver a final report of his experiment results for publication. [NOTE: The PI's proprietary and publication rights, indicated above, will in no way preclude government access to and use of data for mission analysis, troubleshooting, or other official purposes]

E. Mission Evaluation Reports

The cognizant NASA centers were required to prepare Systems Mission Evaluation Reports within six months following mission completion. These reports (see References 6 and 7) contained performance evaluations of experiment and systems hardware for which the reporting NASA center had development responsibility, and also assessed the degree to which operational constraints and interface requirements had been met during the mission. They did not attempt to evaluate the scientific significance of experiment data.

F. Final Technical Reports

Concurrently with preparation of the Mission Evaluation Reports, the EIC prepared a final technical report (Reference 8), tracing the evolution of Skylab corollary experiment development and integration from the initial experiment concepts through mission operations. Similar final technical reports were produced for the Apollo Telescope Mount experiments (Reference 9) and for each Skylab module.

SECTION IX. CONFIGURATION MANAGEMENT

The configuration management system provided a control cycle for systematic evaluation, coordination and approval or disapproval of all proposed changes to baselined specifications, hardware or systems, to ensure that all involved organizations were working to common configuration baselines. Early identification, timely baselining, and accurate, up-to-date maintenance of the hardware configuration status and related design and operational documentation are essential to effective program management, if for no other reason than to minimize changes. The application of refined configuration management methods and controls contributed to the successful integration of Skylab.

> RECOMMENDATIONS: Configuration management can be made more straightforward (and thus less costly) if the following documentation ground rules are adhered to:
>
> o Establish a clear-cut, nonredundant documentation tree early in the program, and enforce it on all program elements.
>
> o Definitive information should appear in only one document, and each document should be tailored to suit its purpose, omitting nonpertinent or redundant information.
>
> o Impose program-wide standard formats for major document types, such as EIS and ERD.
>
> o Baseline documents prior to initiation of activities that require their guidance.
>
> o Formally delete documents (or sections thereof) from the program as soon as their purpose has been served.

A. Configuration Control Organization

The primary organizations responsible for the Skylab configuration control system were:

1. Configuration Control Boards. The CCB was a primary function of the systems engineering activity and included representatives from

the various project offices and technical systems disciplines as appropriate. Control of the many interrelated documents (see Appendix A) was accomplished on a multilevel basis:

The Level I CCB approved changes to the baselined overall program requirements, including program objectives, experiment assignments, major schedule milestones, and budget allocations. Approval authority rested with the NASA Headquarters Program Director. The Level I CCB also acted to resolve any matters referred to it by the Level II CCB.

The Level II CCB approved changes to baselined requirement or configuration documentation which would impact two or more centers (or two or more project offices within a single center). Approval authority rested with the center-level Program Managers. All affected projects and centers evaluated proposed changes for impacts to their respective areas of responsibility, prior to Level II CCB action. This ensured that the total impact of a proposed change was fully understood, technically assessed, and compatible with established requirements, costs and schedules. If a change affected primary mission objectives, experiment assignments, authorized funding, or major program milestones, the Level II CCB could either disapprove the change or refer it to the Level I CCB for disposition.

The Level III CCB approved changes to baseline requirement or configuration documentation affecting a single project office within the jurisdiction of a single center. Approval authority rested with each Project Manager responsible for development of a major module or group of experiments.

The Level IV boards, often informally at a hardware contractor's facility, controlled discretionary internal changes not affecting parameters controlled at higher levels.

2. Change Integration Working Group (CIWG). The CIWG included representatives of the various technical systems disciplines and systems engineering and integration, and performed a screening function for the CCBs throughout the premission phase of the program. This group proved to be a primary tool for ensuring that the early design was well coordinated.

3. Configuration Change Integration. A configuration management support group was established at each involved center to maintain an up-to-date status of interfacing hardware and documentation and to process requested changes. This group coordinated all proposed changes to ensure that the interests of all interfacing organizations had been considered. This function was referred to as configuration change integration. It included receipt of proposed changes, coordination with

all affected organizations to determine total impact of the change (including cost and schedule), submittal to the appropriate CCB for action, and maintenance of overall configuration status.

B. Configuration Control Operation

Changes to documentation and to hardware prior to baselining were controlled initially by the originator or the hardware developer. Once baselined, full configuration change control was implemented. The proper intercenter experiment change process is illustrated in figure 9.

Necessary changes were identified in various ways: by continuing compatibility assessment of the related documents, by the respective hardware milestone reviews, during hardware development, testing and manufacture, or by the addition or deletion of experiments during the program. The changes were generally initiated either by the hardware developer or by the Integration Center support groups. If initiated by the hardware developer, an Engineering Change Proposal (ECP) was prepared to define the change and its impact to the hardware, systems, specifications, interface documents, cost and schedule. The preliminary ECP was submitted to CIWG by the originator, and was reviewed for impact on program documentation by the compatibility analysis support group, and technically coordinated with the affected PIs and others as necessary. If incompatibilities were identified, an Engineering Change Request (ECR) and supporting change documentation were prepared. The ECR was an adaptation of the ECP for use primarily with program documents and specifications. The ECP, ECR and supporting documents formed a total package which presented all the change impacts for CCB evaluation. The approval, approval with changes, or disapproval by the CCB chairman was implemented by a Configuration Control Board Directive (CCBD).

Changes were also initiated by the Integration Center (through the support groups) when incompatibilities were identified. In this event, the ECR was prepared and submitted to the CIWG for subsequent CCB action. The hardware developer received and analyzed the ECR for impact and, if an impact was identified, prepared an ECP to define it. The ECP and the ECR were then processed by the CCB, as above.

The CCBD resulted in the preparation of Change Orders or Supplemental Agreements for transmittal to the affected contractor(s) or Project Offices, directing the incorporation of the change into the documents and hardware. Document changes were incorporated and distributed by the document custodians.

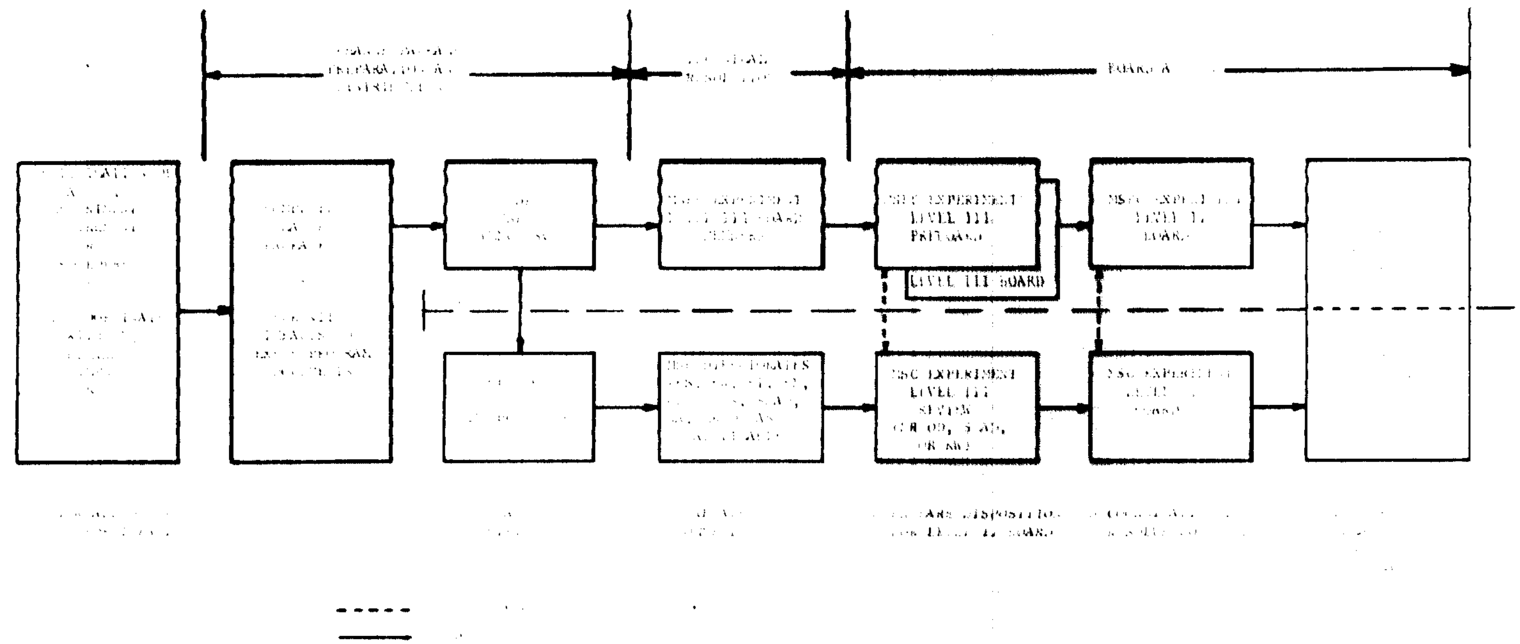

FIGURE 9. INTERCENTER EXPERIMENT CHANGE FLOW

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C. Complete Change Package

It is essential that any change proposal identify all the hardware and documentation (at the same or other levels) which may be affected thereby. Accordingly, when a change was initiated from any source, the Integration Center formally conducted a change impact assessment. This assessment identified impacts to all interfacing hardware and documentation that might be affected. A checklist was used to identify the areas to be investigated. The changes were precoordinated with all affected organizations by the Integration Center before the CCB meeting. Thus the Integration Center was able to prepare a complete and coordinated change package for assessment at the CCB meeting. The Integration Center was uniquely qualified to perform this function and, by so doing, assured completeness and consistency of format and relieved other affected organizations of the need to expend resources to perform this task. Use of this technique greatly expedited CCB control of experiment-related changes at MSFC during the later stages of the Skylab Program.

> RECOMMENDATION: Utilize the "Complete Change Package" concept and precoordinate change packages with all appropriate disciplines prior to presentation to the CCB. NOTE: Configuration control cannot wait for each organization to finalize its document changes before acting on a proposal. The CCB Directive documenting a decision will specify any modifications to the change proposal that are considered necessary by the CCB. Document update pages implementing the CCB direction can then be prepared and distributed by the responsible organizations.

D. Configuration Control Milestones

Configuration control closely followed the hardware development milestones. Following the PRR for each experiment and module, the requirements documents were baselined and thus came under CCB control for changes. After PDR the documents that defined the approved design approach were controlled by the CCB. Likewise, following CDR, the approved detail design and test specifications came under CCB control.

When two or more development activities took place in parallel (such as experiment and module development) there were three key Level II CCB functions that permitted these activities to proceed smoothly. The first occurred following the development PRRs, when the ERDs were placed under Level II control, even though they had been baselined previously at Level III. This allowed assurances to both developers that their design approaches were based on firm requirements, i.e., that changes to interface requirements would be minimized and necessary changes identified to all concerned. The second function occurred during the design period prior to PDR, when the ICDs prepared by the module center had to be coordinated with the EDC to ensure mutual agreement on the interface details. These preliminary ICDs were then baselined at PDR, at which time they came under Level II control. With Level II ICDs, the developers could continue their detail designs with assurance of having firm interface agreements. The third major CCB function at Level II was control of the TCRSDs, which allowed the Module Development and Launch Operations Centers to prepare their detailed test procedures for testing the integrated systems.

SECTION X. SPECIAL DISCIPLINES

Requirements established by specification for safety, reliability, maintainability and quality assurance affected all phases of the program and were necessary to assure mission success. Interrelated with these requirements, specific attention was focused on crew systems (i.e., man/systems integration, or "human engineering"), materials compatibility, contamination control, and various other systems-oriented disciplines. The impacts of these special disciplines upon an individual experiment were influenced to some extent by the criticality of that experiment's potential failures.

Experiments were categorized in the EIS according to the criticality (severity) of potential effects that could be produced by their worst-case failure modes. Criticality category identifications varied between centers, but were generally consistent with the following basic definitions:

Category 1 (or I) - Adversely affects personnel safety (flight or ground).

Category 2 (or II) - Causes loss of a primary mission objective but does not adversely aff ct personnel safety (includes unscheduled termination of launch or mission).

Category 3 (or IIIA) - May cause loss of a secondary mission objective but does not adversely affect personnel safety or preclude the achievement of a primary mission objective.

Category 4 (or IIIB) - None of the above; generally applicable to relatively passive experiments with very simple interfaces.

RECOMMENDATION: Standardize criticality category and sub-category designations to be used by all program elements.

The criticality category influenced the scope of the s ety, reliability, quality assurance and test programs at the experiment, module and overall program levels. Increased safety margins, special design features, increased inspections during fabrication and assembly, and special tests to ensure existence of adquate margins are examples of considerations given to experiments that had high-risk failure modes. The worst-case classification was applied without regard to probability of occurrence.

A. Safety

To ensure that hazards were identified and resolved throughout the program, the development centers required formal or informal implementation of safety program requirements for each end item. This program assured that methods were adequately implemented for identification and either elimination or control of potential hardware hazards that could result in injury to personnel or damage or loss of flight or ground hardware. Hazard Analyses were performed to identify, and offer solutions for, hazards that could result from failures, normal or emergency equipment operations, environments, personnel errors, or design characteristics. A "System Safety Checklist" (Reference 10), containing specific design criteria applicable to flight and ground hardware, has been developed to assist new programs in the application of safety-related experience.

B. Reliability

Integral to the design and development process was the evaluation of hardware reliability through analysis, review and assessment. A Reliability Plan was prepared for each end item, describing how the reliability requirements were to be implemented and controlled. Hardware failure modes were defined in FMEAs. Based on the results of the FMEAs, a Critical Items List (CIL) was prepared, which included a summary of single failure points and critical redundant (backup) components in life- or mission-essential equipment. In addition, design criteria were provided for the reliability of each subsystem. Reliability testing per se was generally not done; however, in certain very critical cases, some lifetime testing was conducted. After the hardware was fabricated, a system of providing information on unsatisfactory conditions or anomalies was utilized to keep abreast of reliability goals.

C. Maintainability

The requirements for maintainability are closely associated with reliability and safety requirements during all program phases, with the major effort concentrated in the design phase. The principal elements of maintainability assurance are: 1) provide design parameters (e.g., mean-time-to-repair, fault detection and isolation, limited lifetime items); 2) analysis of design; 3) design review participation; 4) data on maintainability; and 5) verification and demonstration of the maintainability.

To the extent practicable, experiments were designed for accessibility, replaceability and serviceability during ground operations. Skylab's original design philosophy specifically minimized in-flight maintenance as a design consideration. The rationale for this decision was quite logical in the circumstances. Inadequate data existed at that time on the astronauts' ability to perform complex tasks in space, or on the crew time, workshop space and weight budget that would be available. Thus extensive reliance upon in-flight maintenance, rather than designing for high inherent reliability, would have involved high risk. Actually, as the program matured, some minimal in-flight maintenance provisions were found to be essential, and were added. During the actual missions, however, in coping with unforeseen anomalies, the astronauts demonstrated excellent capabilities in this respect, even with improvised tools and in extravehicular activity (EVA).

RECOMMENDATION: Design future manned space hardware to permit a much greater degree of in-flight maintenance, including EVA. Provide appropriate on-board spares, crew training and supporting documentation for maintenance tasks.

D. Quality Assurance

A Quality Assurance Program was implemented to ensure that all necessary actions were taken to provide confidence that the experiment would perform satisfactorily during flight. The quality program provided methods for detecting, documenting and analyzing deficiencies, system incompatibilities, or trends that could have led to any unsatisfactory quality of the experiment hardware.

At all sites (development, integration, launch, mission operations), a general method was used for reporting all anomalies (failures and unsatisfactory conditions) relating to flight, test, simulator or training hardware. The reports identified the anomaly, where it had occurred, and the corrective action required. All participants (quality, engineering, test, NASA, etc.) concurred in the corrective action by signature. Within this formal method of tracking anomalies and recording their solutions, quality assurance personnel were responsible for verifying that the anomaly occurred as stated and that corrective action requirements were adhered to. A Failure Analysis was performed, where necessary, to determine the cause of the anomaly and identify adequate measures that could be implemented to prevent its recurrence. A status was maintained on all open anomalies until they were satisfactorily resolved.

E. Crew Systems

Strong emphasis in the design, development and integration of Skylab experiments and modules was placed upon man/systems integration and human engineering, to ensure efficient utilization of the ground and flight crews' capabilities in the applicable environments. Man/system design criteria were established for ready accessibility and identification, convenient arrangement, and ease of operation of experiments and cluster systems equipment. General cluster habitability, fixed and portable illumination, controls and displays, mobility aids and restraints, stowage, and provisions for extravehicular activities received particular attention.

High-fidelity mock-ups and/or training hardware were utilized to conduct numerous formal reviews and informal walk-throughs by astronauts, PIs, and integration personnel during the development and integration phases. The C^2F^2 tests were conducted on flight hardware as a part of acceptance tests and prelaunch checkout. Walk-throughs were also extensively used during the missions to check out new or revised operational procedures before transmitting them to the flight crew. Extraordinary activities involving EVA (e.g., deployment of a damaged solar panel) were rehearsed in the MSFC Neutral Buoyancy Simulator.

Postflight evaluation of Skylab crew systems hardware is documented in Reference 11. Additionally, Reference 12 was prepared to provide new and more clearly defined design criteria, based on Skylab experience, for use on future programs. Experiment-related lessons learned are included in the recommendations of Sections IV, V and VII, and in Appendix D.

F. Materials Program

Skylab policy for controlling materials selection, test and evaluation required that each Development Center Program Office prepare an implementation plan and identify an individual materials specialist to serve as focal point for the center's materials program. Intercenter coordination was accomplished by a materials intercenter working group, which exchanged pertinent information, test data and deviations, and reconciled differences between the centers. Hardware developers were required to submit appropriate materials and parts lists, under their respective Reliability Plans.

The Skylab materials program placed particular emphasis on reduction of fire hazards in the oxygen-enriched spacecraft atmosphere, through the use of nonflammable materials wherever feasible, and rigidly controlled usage of any necessary flammable materials. Other important materials characteristics assessed were toxicity, odor, outgassing, offgassing, and flaking or powdering tendencies of paints and coatings. Materials information and test data provided significant inputs to the in-flight contamination control program.

These activities on Skylab resulted in the preparation and release of a new OMSF material evaluation criteria document, NHB 8060.1. Although released too late for formal implementation on Skylab, NHB 8060.1 is understood to be a requirement for current OMSF programs.

G. Contamination Control

Hardware cleanliness monitoring prior to launch is a quality assurance function, amply covered by specifications and conventional quality control methods imposed on Skylab. However, analysis and control of the contamination that can occur in and around an orbiting spacecraft emerged as an important new discipline that warranted status approaching that of a major functional system. In-flight contamination, internal or external to the spacecraft, presented potential problems for nearly all experiments and cluster systems, notably those involving critical optics or other operational surfaces.

A Contamination Control Working Group, including representation from MSFC, JSC, KSC, the PIs and contractors, was established at the Integration Center to conduct, coordinate and manage these efforts. Potential contamination sources were identified and quantitatively defined with the help of extensive materials testing. Experiment and system sensitivities to contamination were determined. Rigorous analyses, supplemented by comprehensive systems ground testing, were conducted to develop mathematical models of the performance of the sources and thereby predict in-flight contamination levels. Recommendations were made for design and operational procedure criteria and changes to minimize contamination effects (e.g., proper timelining of experiment exposure or operation in relation to various sources such as reaction control system firings and overboard venting). Instrumentation was flown, such as quartz-crystal microbalances to monitor mass deposition rates and cloud brightness monitors for the induced atmosphere around the spacecraft. Flight data from these monitors and from certain experiments was used to validate and improve the prediction models' accuracy. The major sources of in-flight contamination, as predicted, were materials outgassing and reaction control system firings. The total Skylab experience clearly demonstrated the necessity for, and the validity of, these measures.

A detailed description and evaluation of the Skylab contamination control program is available in Reference 13. Some experiment-related design considerations are identified in Appendix D.

> RECOMMENDATIONS: Implement rigorous and comprehensive measures for in-flight contamination control early in any new program, particularly where optical experiments are involved. Integrate the degradation effects of all contributory systems into the program design criteria on a level comparable to the major functional systems. Investigate new techniques for in-flight cleaning of accessible and remote optics.

H. Other Special Disciplines

Various other Skylab systems engineering activities influenced experiment development and integration.

1. Electromagnetic Compatibility. An intercenter/contractor Electromagnetic Compatibility (EMC) Working Group monitored compliance with the Skylab requirement that hardware be free of adverse electromagnetic interference (EMI) under operational conditions. EMC compliance was established during the design phase and demonstrated predominantly by component-level testing, where circuit analysis was not considered adequate. A minimum of EMC testing was conducted at the module level to confirm the lower-level results. The EMC Working Group reviewed all pertinent designs, analyses, tests and waivers. No major EMI problems were encountered during the Skylab missions.

2. Corona Suppression. A management-supported, program-wide effort to emphasize corona prevention was the key to success in this area. Corona specialists conducted frequent reviews of designs and test plans with their originators. This effort proved sufficient to minimize the degree of testing required and the rework of test failures that occurred, while maximizing the assurances gained. No serious loss of data or system failure due to corona effects occurred during the Skylab missions.

3. Sneak Circuit Analysis. A sneak circuit analysis was performed on the integrated electrical systems to assure a low probability of undesired current paths. A computer was used to help develop a simplified schematic of Skylab circuits for evaluation. This analysis verified electrical interfaces and provided valuable source material for checking operational documentation and for investigating real-time operational anomalies and workarounds. The program was successful in identifying 44 sneak circuits, plus a number of unnecessary components and documentation errors.

SECTION XI. PUBLIC RELATIONS

Public awareness of program objectives, progress and benefits is an important obligation for NASA, which must be shared by the scientific investigator. Different approaches for public relations were required for the various experiments, depending upon an experiment's public appeal, the public's awareness of the Principal Investigator, and their ability to comprehend the science and potential applications of the experiment.

A. NASA Public Affairs Office

Each NASA center maintains a Public Affairs Office (PAO), with established contacts for releasing space-oriented news to the media. Standard public affairs releases, consisting of NASA photographs with captions and prepared news stories, were released to the national news services. These releases normally contained only general background experiment information.

Press conferences which required the PI's participation were arranged periodically. They were generally scheduled for periods of peak public interest in the experiments (e.g., immediately prior to launch, following experiment performance or return of flight data, or to present results of flight data analysis). These briefings were held where the space-oriented press was gathered; at the launch center for launch, and at the operations center during mission operations. Often a press conference presentation led to a private interview with a newspaper, periodical, or news service reporter.

The press is primarily interested in results which can easily be understood by the public, i.e., the "biggest", the "best", or the "first." It was extremely helpful when the PI played an active role in releasing photographs of returned data with lucid explanations of the observable scientific phenomena. Scientific analysis was not required, or even desirable, in these press releases; simply a statement of what occurred and its potential significance. The objective of press briefings and press releases is to achieve public awareness, rather than public education. An active interplay or established liaison with the PAO assured the PI that accurate experiment information was being released, while the PAO was guaranteed interesting, newsworthy releases.

> RECOMMENDATION: Statements for public release should not be issued without prior program approval.

B. Educational Programs

Various educational programs initiated by NASA may require participation by the PI and/or experiment development or integration personnel. The following educational aids can be produced by NASA with limited participation required from these personnel.

- Film Clips - Ten-minute motion pictures can be filmed of the PI explaining and demonstrating his experiment and the application of its results. These films are useful in providing program personnel with a more thorough understanding of the experiments, or as presentations demonstrating the state-of-the-art of space research to science students.

- Educational Aids - Science educational aids can be prepared to describe groups of experiments, the application of basic principles of science and physics to execute the experiments, and the scientific value of the results.

- Displays - Visitor center or museum-type displays can be distributed to visually stimulate the public's interest in space technology.

- Postmission Historical Texts - Books printed after mission completion, with extensive use of mission and experiment photographs, can provide an informative, nontechnical presentation of mission/experiment operations and results.

Many different types of documents and presentations may be produced for educational purposes. These are the principal ones which will require a degree of cooperation and information from experiment personnel.

APPENDIX A

DOCUMENTATION

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DOCUMENTATION

The principal experiment-related development, integration and mission operations documents required and utilized on the Skylab program are described in this Appendix. A documentation tree illustrating their primary interrelationships is shown in figure A-1. All documents were subordinate to the OMSF Skylab Program Specification, SE 140-001-1, which was the top-level technical specification for major program functional and performance requirements.

A. Experiment Development Documentation

The approved Experiment Implementation Plan (EIP), as described in Section III.C.1, provided the initial experiment definition, from which formal development documentation was derived.

An OMSF "Experiment General Specification for Hardware Development" (EGS) identified requirements to be selectively imposed upon experiment developers, at the discretion of the Experiment Development Center. Considerable flexibility was permitted in EGS implementation (depending upon the experiment's complexity and criticality) to minimize development costs within the constraints of crew safety and mission success. As an EDC, JSC imposed its own "Experiment Hardware General Requirements Document" (EHGRD), which generally paralleled EGS requirements but differed in some significant details. Specific development documentation requirements identified in these two specifications were similar, except as otherwise noted herein.

> RECOMMENDATION: Establish and maintain uniformity of requirements among diverse experiment developers by selective implementation of a single coordinated general requirements specification across all program elements.

Development documents were categorized by the cognizant EDC as: Type I, to be submitted for approval; Type II, to be submitted for review; or Type III, required to be available upon request, but not formally submitted. The Type I category was generally limited to documents that defined and/or controlled major elements of program cost, schedule, or performance.

1. Management Plan. At the outset of the development effort, a Management Plan was prepared by the ED for EDC approval, defining the management organization and procedures to be used during development of the experiment hardware and GSE. It defined the responsibilities

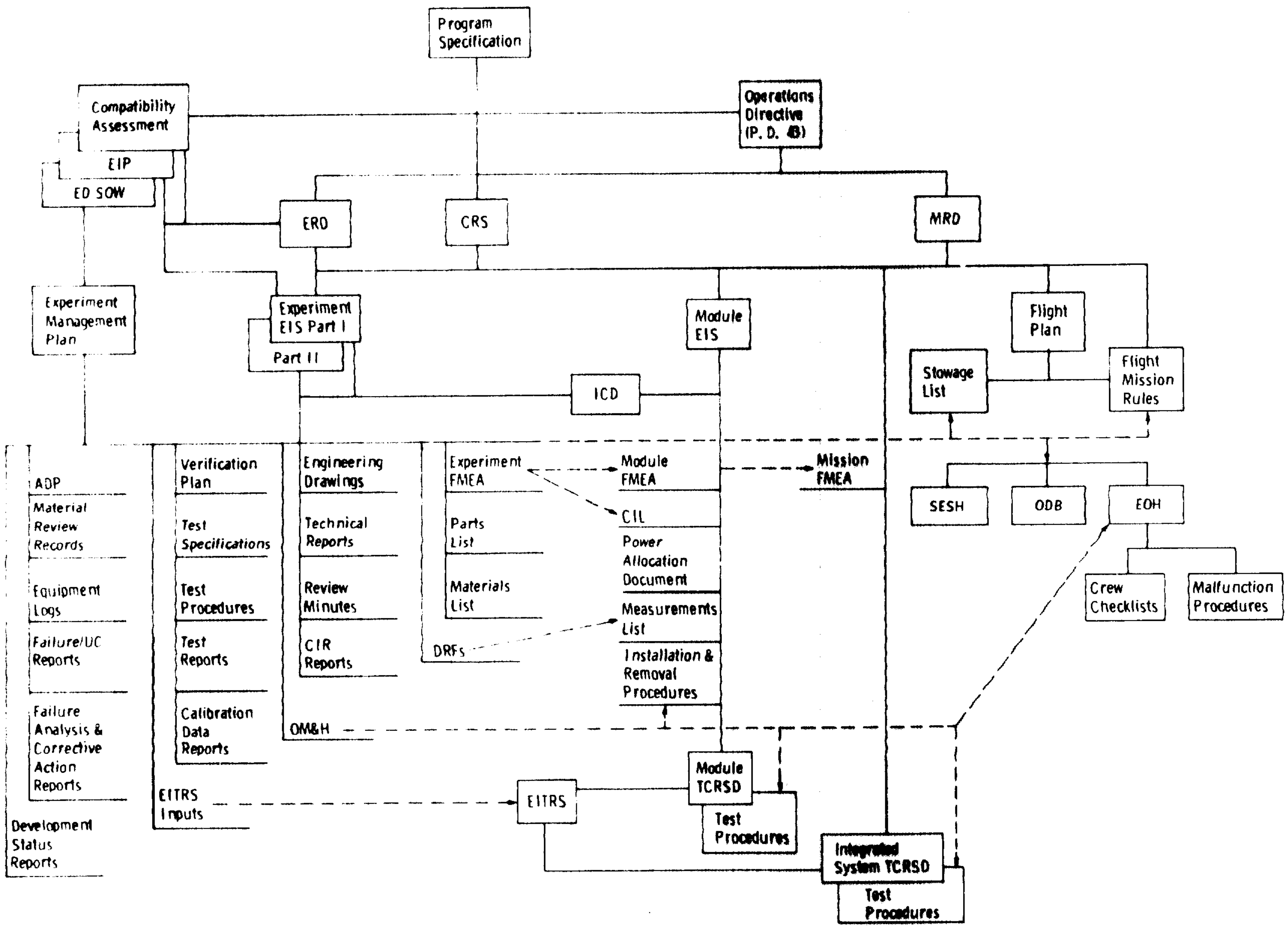


FIGURE A-1 EXPERIMENT-RELATED DOCUMENTATION and controls to be established and maintained throughout an integrated development effort, covering all hardware and GSE for which the developer was responsible. The plan contained the following sections:

- o General Management - defining the management structure, responsibilities and controls for the overall development effort
- o Quality Assurance - defining a Quality Program Plan and a Contamination Control Plan
- o Reliability Plan
- o Configuration Management Plan
- o Test Management Plan
- o Logistics Support Plan
- o Manufacturing Plan
- o Development Schedule - defining detailed schedules for the design, manufacturing and test efforts, including all related configuration management reviews, documentation and hardware deliveries
- o Nonmetallic Materials Plan (EHGRD only)
- o System Safety Plan (EHGRD only)

2. Configuration Management Documents

a. End Item Specification. The ED was required to prepare and maintain a detailed End Item Specification (EIS) for each type of experiment hardware identified in his Statement of Work (i.e., flight, mock-up and training hardware, and GSE). The EIS contained the total requirements for the development program and formed the technical basis for the contract between the ED and EDC. Specifications were prepared on a paragraph-by-paragraph deviation basis to the EGS or EHGRD. The flight hardware EIS was prepared and approved before starting any development effort; minimum inputs for its preparation were the experiment proposal, EIP, and compatibility assessment. The flight hardware EIS covered also the backup, qualification test, and flight-type training hardware, which were required to be identical in configuration with the flight article. The EISs for other hardware were generally prepared on a deviation basis from the flight hardware EIS.

The EIS outline, as prescribed by the EGS, is shown in Table A-I. [NOTE: The JSC EIS, as per the EHGRD, was essentially identical through the area of Performance and Design Requirements, but thereafter included more detail in the areas of Quality Assurance, Reliability, Verification, Configuration Management and Documentation. JSC utilized a separate Configuration Specification as the control document for hardware development, in lieu of the Part II EIS.]

After initial approval, specification changes could be incorporated only through CCB-approved Engineering Change Proposals (ECPs) and Specification Change Notices (SCNs).

TABLE A-I. END ITEM SPECIFICATION OUTLINE (PER EGS)

PART I. PERFORMANCE/DESIGN REQUIREMENTS

1. SCOPE (including Criticality Category)
   - 1.1 Changes
2. APPLICABLE DOCUMENTS
3. PERFORMANCE AND DESIGN REQUIREMENTS
   - 3.1 Performance
     - 3.1.1 Functional (Overall System; Mechanical, Electrical/Electronic and Other Subsystems)
     - 3.1.2 Operability (Reliability, Maintainability, Useful Life, Natural and Induced Environments, Transportability, Human Engineering, Safety)
   - 3.2 Interface Requirements
     - 3.2.1 Flight Hardware (Flight Vehicle, Other Experiments, Ground Communications, Flight Crew, Mission, GSE, Facilities)
     - 3.2.2 Zero Gravity Type Training Hardware
     - 3.2.3 Neutral Buoyancy Type Training Hardware
     - 3.2.4 Simulator Type Training Hardware
     - 3.2.5 ICD List
   - 3.3 Design and Construction
     - 3.3.1 Mechanical
     - 3.3.2 Electrical and Electronic
     - 3.3.3 Fluid (Gas and Liquid)
     - 3.3.4 Debris Protection
     - 3.3.5 Cleanliness
     - 3.3.6 Test Provisions
     - 3.3.7 Single Failure Points
     - 3.3.8 Redundancy
     - 3.3.9 Selection of Specifications and Standards
     - 3.3.10 Materials, Parts and Processes
     - 3.3.11 Standard Parts
     - 3.3.12 Fungus Resistance
     - 3.3.13 Corrosion Prevention
     - 3.3.14 Interchangeability and Replaceability
     - 3.3.15 Workmanship
     - 3.3.16 Electromagnetic Interference
     - 3.3.17 Identification and Marking
     - 3.3.18 Storage
     - 3.3.19 Pyrotechnic Devices
4. TEST/PRODUCT ASSURANCE REQUIREMENTS
   - 4.1 Verification Matrix
   - 4.2 Test Types
     - 4.2.1 Development
     - 4.2.2 Qualification
     - 4.2.3 Reliability
     - 4.2.4 Other Tests (Integrated Systems, Flight Verification, Postflight)
   - 4.3 Rejection

TABLE A-I. END ITEM SPECIFICATION OUTLINE (PER EGS) (Continued)

5. DATA LIST
6. PREPARATION FOR DELIVERY
7. NOTES

PART II. PRODUCT CONFIGURATION REQUIREMENTS

1. SCOPE
   1.1 Product Configuration Baseline Acceptance
   1.2 Changes
2. **APPLICABLE DOCUMENTS**
3. **PRODUCT REQUIREMENTS**
   3.1 Performance
      3.1.1 Functional Characteristics
   3.2 Configuration
      3.2.1 Manufacturing Drawings
4. **TEST/PRODUCT ACCEPTANCE REQUIREMENTS**
   4.1 Acceptance Matrix
   4.2 Test Types
      4.2.1 Acceptance
      4.2.2 Other Tests (Integrated Systems, Prelaunch)
   4.3 Rejection
5. DATA LIST
6. PREPARATION FOR DELIVERY
   6.1 Preservation and Packaging
   6.2 Packing
   6.3 Shipment
7. NOTES

b. Engineering Drawings. The ED prepared engineering drawings to control, by means of pictorial or narrative presentations, the physical and functional engineering requirements for each part of the hardware to be produced. The drawing tree progressed from the top assembly drawing to detail component and part drawings. They provided, directly or by reference, all data needed for use in conjunction with specifications, test procedures and reports, inspection procedures, acceptance and rejection criteria, processes, manuals, operational procedures, safety precautions, surface cleanliness requirements, etc. The engineering drawings included:

- All essential drawing information needed to permit an evaluation or a feasibility study of the proposed design, or to document the results of exploratory research or development effort.

- Sufficient detail to enable evaluation and control of physical and functional design interrelationships of interdependent components, equipments, subsystems, systems, ground support equipment or facilities.

- All drawing information necessary to support installation, operation, maintenance and interchangeability during tests and operational use.

- The necessary design, engineering, manufacturing and quality support information, directly or by reference, to enable the procurement, without additional design effort or recourse to the original design activity, of an item that duplicated the physical and performance characteristics of the original design.

c. Technical Reports. The results of studies and analyses performed during the development effort were documented in technical reports. The reports covered load analyses, stress analyses, trade-off studies, etc., and were not standardized in format.

d. Review Minutes. Minutes were prepared for each PRR, PDR and CDR. The minutes for each review consisted of two parts. Part A provided an immediate record of the review proceedings and included all items requiring post-review actions. Part B was prepared after the final disposition of all Part A action items, and reported the final disposition of each. (See Appendix C.)

e. Configuration Inspection (Acceptance) Review Report. A CIR Report was prepared for each acceptance review (see Appendix C). It provided a record of the review results, including:

- o Action items with their disposition
- o Waivers or deviations authorized
- o Shortages authorized
- o Copy of the completed Form DD250 (Material, Inspection and Receiving Report)

3. Quality Assurance Documents

a. Acceptance Data Package. The ED prepared an Acceptance Data Package (ADP) for each deliverable hardware end item. After delivery, the ADP stayed with the hardware and was updated to reflect subsequent usage. The hardware custodian was responsible for maintaining the ADP current as required. The package included but was not necessarily limited to the following:

- o Equipment logs (see item A.3.c)
- o Engineering drawings down to the replaceable component level (see item A.2.b)
- o Inventory of serialized components, including part number, name, serial number, and the associated experiment hardware subsystem
- o Report of actual weight and center of gravity
- o Operating, Maintenance and Handling (OM&H) procedures (see item A.7)
- o Calibration Data Report (see item A.5.e)
- o Listing of all Material Review Records (see item A.3.b)
- o End Item Specification, Parts I and II or Configuration Specification (see item A.2.a)
- o Certification that the hardware had been cleaned in accordance with the Contamination Control Plan (see item A.1)
- o Failure Reports and Failure Analysis and Corrective Action Reports (see items A.3.d & e)
- o Configuration Inspection (Acceptance) Review Report (see item A.2.e)

b. Material Review Records. A Material Review Board (MRB) at the hardware development site was composed of ED design engineering and quality representatives and the EDC's designated quality representative. The MRB reviewed and determined disposition of articles or materials submitted by ED quality assurance as "nonconforming" with applicable drawings, specifications or other requirements. Accurate Material Review Records of MRB actions, including assurance of effective remedial and preventive actions, were maintained and incorporated in the appropriate hardware ADP.

c. Equipment Logs. An Equipment Log was prepared and maintained for each major hardware component, subsystem, and system to document the continuous history of the item. Entries included, but were not limited to, the following: 1) date of entry, 2) identity of test or inspection, 3) environmental conditions, 4) characteristics investigated, 5) parameter measurements, 6) identity of instrumentation used and calibration dates, 7) record of all storage, operating, and test times, and listing of time/cycle critical items, 8) cumulative number of duty cycles, 9) discrepancies, 10) repair and maintenance records, 11) record of pertinent unusual or questionable occurrences, 12) action taken to formalize quick fixes, 13) identity of individual making entry. The equipment logs, as part of the ADP, were available at all times for inspection and review with the equipment.

d. Failure and Unsatisfactory Condition (UC) Reports. Failure and UC Reports were prepared by the developer for any failure where a system, subsystem, component or part was unable to perform its required function under the specified conditions for the specified duration. Each report contained the part number, name of part, serial number, part manufacturer, date problem was first detected, test being conducted when the problem occurred, conditions at time of problem, problem description, problem cause (if known), and any other information considered pertinent.

e. Failure Analysis and Corrective Action Reports. Failure Analysis and Corrective Action Reports were prepared by the developer for each reported failure. Each report referenced the Failure Report, defined the method of analysis, documented the results, defined the action(s) necessary to prevent recurrence of the failure, and included justification for the selected action. If the proposed corrective action required a change to the baseline configuration, the failure analysis and proposed corrective action were submitted with an ECP. After approval of the change proposal, the approved Failure Analysis and Corrective Action Report was submitted, indicating the need for reverification and containing provisions for signature close-out of the item.

4. Reliability Documents

a. Failure Mode and Effects Analysis Reports. FMEA reports were prepared for each end item to identify critical failure areas and remove susceptibility to such failures. These analyses were performed on each component of the end item and each potential failure was categorized according to its probability of occurrence and consequent effect on mission success (see Criticality Categories, Section X). These reports served as an aid in proportioning the effort required for corrective design action and reliability control. Each report included a Single Failure Point Summary, a Hazards Summary and Reliability Logic Block Diagrams. The single failure point summary summarized all Category 1 and 2 single-point failure modes by identifying the: 1) item name, 2) failure mode, 3) effect of failure upon the system, 4) criticality of the failure, 5) means of detection, 6) required corrective action, and 7) justification or rationale of acceptance if corrective action was not implemented. The Hazards Summary identified and categorized catastrophic or critical hazards in environment, hardware, test, training, operational procedures and interface conditions and discussed steps to relieve these hazards. The Reliability Logic Block Diagrams showed the functional interdependencies among the system components so that the effects of a functional failure could be readily traced through the system. All redundancies or other means for preventing failure effects were shown as functional blocks or notes.

b. Electrical, Electronic and Electromechanical Parts List. An EEE Parts List was prepared to identify all EEE parts in use, and included as a minimum the following: 1) generic part, type, name and number, 2) common designation, 3) manufacturer's name, 4) manufacturer's part number, 5) package type, 6) specification name and number, 7) quantities used per replaceable assembly and identification of replaceable assembly, 8) limited life part restrictions, and 9) qualification methods and status.

c. Materials List. A Materials List was prepared, identifying all nonmetallic materials in use, and also containing a summary of metallic materials used that reflected any recognized flammability, toxicity or odor hazards inherent in the design through úse of metallic materials. The Materials List included as a minimum the following: 1) part number, 2) major assembly part number, 3) generic identification, 4) material manufacturer, 5) material specifications, 6) trade name or commercial name and catalog number, 7) usage category, 8) weight per usage, 9) exposed surface area, and 10) method of verification and status.

5. Test Documents

a. Verification Plan. A separate verification plan for each end item was prepared by the ED and submitted for approval at the PDR. It defined the verification methods (similarity, analysis, inspection, demonstration, validation of records, or test) to be used to verify that the end item met each technical requirement in the EIS. For requirements to be satisfied by assessment, the plan described the specific types of analyses, inspections, etc, to be conducted (i.e., stress analyses, thermal analyses, radiographic inspections, etc), defined the objectives of these methods, and identified the documents that would contain the assessment. When a requirement was to be verified by test, the Verification Plan defined: specific tests to be conducted; equipment components, parts, etc, to be tested; test objectives; locations where tests were to be conducted; facilities and equipment support requirements; and time phasing of the tests. The test program was to provide only the minimum tests necessary, based on the criticality and complexity of the experiment. The entire spectrum of tests was analyzed as an integrated effort to minimize test requirements and prevent duplication. Testing was conducted at the highest feasible level of hardware assembly. For very simple experiments, the test plan, specification and procedure could be combined into the same document.

b. Test Specifications. A Test Specification was prepared by the ED for each type of test defined in the Verification Plan. Each specification included, as applicable: test item nomenclature and identification; test objectives; quantity to be tested; test parameters or performance criteria, with limits or tolerances; acceptance and rejection criteria; environmental conditions; hazardous operations or situations; reference to applicable safety standards, rules and regulations; allowable adjustment or maintenance operations; requirements for data recording, analysis, retest and reporting of test results; and test article disposition.

c. Test Procedures. Test Procedures were prepared by the ED for each type of inspection and test defined in his test specifications. The Test Procedures prescribed steps to be accomplished in detail and sequence, test equipment to be used, calibration requirements, layout and interconnection of equipment, safety practices (for equipment and personnel) to be observed and criteria for passing the test, including tolerances. Development test procedures were not submitted for approval; however, all other (qualification, acceptance, etc) procedures were submitted for EDC approval.

d. Test Reports. Test Reports were prepared for each type of test conducted. Qualification and acceptance test reports were submitted at the CIR for review of their validity and verification of satisfactory tests. The test report contained an evaluation of test data, a comparison of test results with test objectives and design and performance requirements, a listing of any associated failure reports, and conclusions based on the evaluation. The report in many cases also contained an annotated copy of the actual test procedure.

e. Calibration Data Reports. Where applicable, a Calibration Data Report was prepared from acceptance test results and became a part of the ADP. These reports provided the actual calibration data sheets for each measurement produced or displayed by the experiment. For each measurement the report included the following:

- Descriptive title of measurement
- Measurement number
- Indicating device part number and serial number
- Component part number and serial number in which the indicating device was installed

- Original tabulation of actual calibration data points
- Original graph of calibration data

This information was used for data evaluation during integration testing and mission data reduction.

6. Development Status Report. A Development Status Report was prepared by the ED to provide the status of the total development effort at each program milestone. The report was an integrated effort covering the development of all the ED's hardware, including GSE. It included, but was not limited to, the following: 1) schedule status, 2) mass properties status, 3) quality assurance, reliability and system safety status, 4) spares status, 5) delivery status.

7. Operating, Maintenance and Handling Procedures. The Operating, Maintenance and Handling (OM&H) procedures were prepared by the ED and included in the ADP, to define all procedures required during both flight and ground usage. The procedures contained all instructions for operation, servicing, maintenance, calibration, handling, cleaning, storage, packing and shipping. Any limited-life or time-critical items were identified and replacement cycles defined. The procedures included all diagrams, exploded views, sketches, text, etc, necessary to permit efficient procedure accomplishment. They also clearly indicated any step which, if not correctly followed, would result in serious injury to personnel or hardware damage, and gave the reason for such warning. The flight hardware OM&H normally consisted of three volumes. Volume I contained a general description of the hardware and its interfaces; subsystem functional description, operational and design characteristics, limitations and restrictions; and controls and displays. Volume II contained the mission operational procedures for both normal and contingency operations, in a step-by-step checklist format that was used by the Mission Operations Center to prepare detailed checklists for the crew. Volume III contained all necessary procedures to accomplish ground operations, maintenance and handling of the hardware (including recovery operations if applicable); this volume was used by the Module Development and operations centers to prepare their detailed test and handling procedures.

8. Data Request Form. The standard format for the DRF, the formal instrument for identifying experiment data requirements, is reproduced in figure A-2. Contents of the various blocks in the DRF are self-explanatory from their titles.

Page 1 of ____

DATA REQUEST FORM Skylab Program	DRF Control No.	Date
	Exp/Sys No.	Revision

Mission	Period of Interest	Op. Need Date	Rev Date

Request Contact	Data Recipient	Date Req
Name Organization Phone	Name Address Phone	Qty

Reference Documents:

MRD Content

Detailed Requirements:

Comments & Explanation:

Originator	Integrator
Name Organization Phone Signature Date	Name Organization Phone Signature Date
Request Aproval	**Implementing Agency**
Name Organization Phone Signature Date	Name Organization Phone Signature Date

MSFC - Form 65 (October 1970)

FIGURE A-2. DRF FORMAT

B. Integration Documentation

Integration documents were prepared to assure that the experiment interfaces with the program were satisfactorily provided. Beginning with the experiment concept, the requirements for program interfaces were established and systematically compared with program capabilities. Requirement documents were prepared which in turn generated documents that defined the interfaces or identified how the requirements were to be satisfied. In general, these documents were prepared by or under the cognizance of the Integration Center or Module Development Center. Mission operational documentation, which also involves extensive experiment interfaces, is treated separately in Section C.

1. Compatibility Assessment. When the experiment concept was originally considered for approval, compatibility analysis was initiated by the Integration Center. It compared all experiment requirements to program capabilities and reported the compatible areas as well as incompatible areas. Modification of proposed experiment requirements was often necessary to produce a compatible experiment. After experiment approval, the compatibility assessment became a recurring integration document covering total compatibility of all the integrated experiments. The review of major problems identified in the compatibility assessment was supplemented by bimonthly management review meetings held by the Integration Center and attended by representatives of the other centers involved. At these reviews, the status of the problems was presented, a plan agreed to for their solution, and action items assigned (see Appendix B).

2. Experiment Requirements Document. After the experiment was approved, the EDC (or in some cases the Integration Center) prepared an ERD to specify the experiment requirements for module and program interfaces. These interfaces could be of a physical nature (electrical, data, control, crew, thermal, mechanical, stowage, etc) or program interfaces (integration test requirements, number of mission data takes, recovery requirements, etc). The ERD was approved by the EDC and became a Level II baseline document following experiment and module PRRs. As the program proceeded, various ERD requirements became formalized in other Level II documents such as ICDs, TCRSDs, and MRD, and were deleted from the ERD to avoid redundancy. Table A-II presents the standardized ERD outline, as prescribed by an intercenter "ERD Instructions" document.

3. Cluster Requirements Specification. Since Skylab involved several modules, an overall integration specification for the assembled modules (cluster) was found necessary. This document, prepared by the Integration Center, was identified as the Cluster Requirements Specification (CRS), and amplified the general performance and design integration requirements of the Skylab Program Specification to ensure that

TABLE A-II. EXPERIMENT REQUIREMENTS DOCUMENT OUTLINE

1. EXPERIMENT DESCRIPTION
    - 1.1 Objective
    - 1.2 Concept
    - 1.3 Experiment Description and Function
        - 1.3.1 Experiment Equipment List
        - 1.3.2 Additional Supporting Equipment
    - 1.4 Relation to Other Experiments
    - 1.5 Cluster Requirements Imposed on Experiment

2. MISSION ASSIGNMENT AND HARDWARE REQUIREMENTS
    - 2.1 Flight Assignment
    - 2.2 Location Assignment
    - 2.3 Hardware Requirements (Number and types of experiment end items)

3. DATA REQUIREMENTS
    - 3.1 Preflight Data Requirements
    - 3.2 In-flight Data Requirements
        - 3.2.1 Experiment Measurement List
        - 3.2.2 Spacecraft Systems Measurement List (Housekeeping)
        - 3.2.3 Photographic Data Requirements
        - 3.2.4 Other In-flight Data Requirements
    - 3.3 Postflight Data Requirements
    - 3.4 Data Return Requirements
    - 3.5 Special Handling Requirements
    - 3.6 Analysis and Processing Support

4. FLIGHT VEHICLE SYSTEMS REQUIREMENTS
    - 4.1 Structural and Mechanical Requirements
        - 4.1.1 Weight and Volume
        - 4.1.2 Dimensional Sketches
            - 4.1.2.1 Stowed
            - 4.1.2.2 Operational
            - 4.1.2.3 Post-Operational
        - 4.1.3 Mounting, Alignment and Orientation Requirements
        - 4.1.4 System and Equipment Modifications
        - 4.1.5 Plumbing Requirements
        - 4.1.6 Fluid Requirements (Gaseous and Liquid)
        - 4.1.7 Accessibility Requirements
        - 4.1.8 Observation Access Requirements
    - 4.2 Environmental Requirements
        - 4.2.1 Thermal Requirements
        - 4.2.2 Atmosphere Requirements
        - 4.2.3 Radiation Requirements
        - 4.2.4 Lighting Requirements
        - 4.2.5 Other Environmental Constraints

TABLE A-II. EXPERIMENT REQUIREMENTS DOCUMENT OUTLINE (CONTINUED)

4. FLIGHT VEHICLE SYSTEMS REQUIREMENTS (CONTINUED)

- 4.3 Electrical Requirements
  - 4.3.1 Power and Voltage Requirements
  - 4.3.2 Power Profile
  - 4.3.3 Other Power Characteristics
- 4.4 Instrumentation and Communications Requirements
  - 4.4.1 Telemetry System Requirements
  - 4.4.2 Timing System Requirements
  - 4.4.3 Ground Command Requirements
  - 4.4.4 Voice Communication Requirements
  - 4.4.5 Displays and Controls Requirements
- 4.5 Interface Requirements
  - 4.5.1 Interface Schematic
  - 4.5.2 Interface Identification
  - 4.5.3 Existing Hardware Interfaces
- 4.6 Expendable Equipment Disposal

5. EXPERIMENT AND FLIGHT VEHICLE POINTING REQUIREMENTS

- 5.1 Experiment Pointing Requirements
  - 5.1.1 Target Description
  - 5.1.2 Experiment Pointing Accuracy
  - 5.1.3 Allowable Experiment Rates
  - 5.1.4 Number of Performances
  - 5.1.5 Duration of Each Performance
  - 5.1.6 Time of Each Performance
- 5.2 Flight Vehicle Pointing Requirements
  - 5.2.1 Orbit Requirements
  - 5.2.2 Spacecraft Orbital Location During Each Performance
  - 5.2.3 Reference Orientation
  - 5.2.4 Spacecraft Pointing Accuracy
  - 5.2.5 Allowable Spacecraft Rates
  - 5.2.6 Allowable Spacecraft Acceleration
  - 5.2.7 Spacecraft Maneuvers Required

6. FLIGHT CREW OPERATIONS REQUIREMENTS

- 6.1 Experiment Preparation Requirements
- 6.2 Experiment Operation Requirements
- 6.3 Post Operation Tasks
- 6.4 Operation Schedule Constraints
- 6.5 Crew Training Requirements
- 6.6 In-flight Maintenance Requirements

7. FLIGHT OPERATIONS REQUIREMENTS

- 7.1 Flight Support Requirements
  - 7.1.1 Command List
  - 7.1.2 Support Requirements
- 7.2 Recovery Support Requirements

TABLE A-II. EXPERIMENT REQUIREMENTS DOCUMENT OUTLINE (CONTINUED)

8. POSTACCEPTANCE TESTING

- 8.1 Experiment/Module Integration Test and Checkout
  - 8.1.1 Receiving, Inspection and Handling
  - 8.1.2 Ground Personnel Participation
  - 8.1.3 Integrated Test
    - 8.1.3.1 Test Types
    - 8.1.3.2 Test Locations
  - 8.1.4 Facilities
  - 8.1.5 Data Recording
  - 8.1.6 Ground Support Equipment/Test Equipment
  - 8.1.7 Services
  - 8.1.8 Special Test Constraints
- 8.2 Prelaunch Checkout
  - 8.2.1 Receiving, Inspection, and Handling
  - 8.2.2 Ground Personnel Participation
  - 8.2.3 Prelaunch Test and Activities
    - 8.2.3.1 Test and Activity Types
    - 8.2.3.2 Equipment Utilization
  - 8.2.4 Facilities
  - 8.2.5 Data Recording
  - 8.2.6 Ground Support Equipment/Test Equipment
  - 8.2.7 Services
  - 8.2.8 Special Test Constraints
- 8.3 Ground Personnel Training Requirements

9. RESUPPLY AND REACTIVATION REQUIREMENTS

- 9.1 Orbital Storage Requirements
- 9.2 Resupply Equipment and Materials
- 9.3 Reactivation Procedures
- 9.4 Special Requirements

10. REPORTS OF EXPERIMENT RESULTS

all hardware would successfully function as an integrated system to accomplish mission objectives. In addition to the general requirements, the CRS addressed some specific requirements for primary functional areas (i.e., structural, attitude control, electrical, control and display, communications and data, environmental control, crew, and caution and warning flight systems; ground systems; and payload requirements imposed on the launch vehicle). It also provided a comprehensive listing and description of all approved deviations to its technical requirements.

4. <u>Interface Control Documents</u>. Once experiment requirements had been baselined, immediate attention was given to providing the interface details. These details were documented by the Module Development Center in ICDs. Preliminary ICDs were reviewed and baselined at the experiment PDR. Three basic types of ICD were prepared for each experiment:

- o Mechanical/Environmental (weight, center of gravity, attachment provisicns, structural loads, thermal environment, etc - see Table A-III);

- o Electrical (type of power, connectors, pin assignments, wire sizes, etc - see Table A-IV);

- o Instrumentation and Communication (number of data measurements, type, sample rate, etc - see Table A-V).

In addition to the experiment-to-module ICDs, GSE and facility ICDs were also prepared as necessary to define the experiment-to-GSE and GSE-to-facility interface requirements.

5. <u>Module Specifications and Documents</u>. Paralleling the experiment documentation, the Module Development Center prepared a Module End Item Specification, module FMEA, and various other integration documents that incorporated experiment information. Typical of the latter were: the module Power Allocation Document, which integrated the electrical power requirements of the module systems and its installed experiments; module Measurements Lists, which identified and defined the instrumentation and communications services provided by the module; module Critical Items List (CIL), which summarized all Category 1 and 2 critical items within the module, including those identified for experiments; etc.

6. <u>Experiment Integration Test Requirements and Specifications</u>. As described in Section V.C, the Integration Center coordinated preparation of an EITRS document which compiled postacceptance test requirements of all the experiments, and provided source information for the module and integrated system TCRSDs. Figure A-3 shows the format of a typical EITRS page.

PARA NUMBER	TEST	CRITERIA AND SPECIFICATION	CONSIDERATIONS AND CONSTRAINTS	EFFECTIVITY				
					MDAC ED	MMC	NAR	KSC
[illegible]	Verify the operation of the Flammability Timing circuits.	**ELAPSED** light illuminates after 10 **seconds.**	**With: SECONDS** "10"		X	X		
[illegible]	Verify the operation of the **FLAMMABILITY READY** function.	READY light illuminates.	**With: READY/RESET** READY		X	X		X
[illegible]	Verify the operation of the **FLAMMABILITY** Data Start function.	Camera **ON** signal indication at camera interfaces, Flood Light illuminates, and 28^{+2}_{-4} **VDC** at igniter for approximately 3 seconds. After approximately 10 seconds elapsed light flashes and Flood Light flashes.	**With: DATA START** "ON" (Momentary)		X	X		X
[illegible]	Verify that proper water pressure and flow rate is provided by M512 for M479.	Capable of flowing water.	GSE required.					X
[illegible]	Deleted							
[illegible]	Verify the pressure in the MPF.	Work Chamber GN_2 pressure: 4.5 ± 0.5 PSIA High Voltage electronics section pressure. Perfluoral propane @25 ± 1.0 PSIA	This will require backfilling the Work Chamber.		X			X
[illegible]	Verify Crystal Growth Storage Container power to container.	At Crystal Growth Storage Container Test connector 28^{+2}_{-4} **VDC**	**At NAR, Flight Qualifiable Growth Storage Container required.** **At KSC, Flight Unit required for VAB Test** prior to closeout.				X	X
[illegible]	Verify **LO TEMP** notify PI light function	**LO TEMP** illuminates	**LO TEMP/LAMP TEST** switch to **LAMP TEST**				X	X
[illegible]	Verify the operation of the Battery Discharge Indicator Light.	DISCHARGE illuminates. 0.90 + 0.05 **AMP** discharge	**Main Battery Circuit Breaker** ON **Battery Discharge Circuit Breaker** ON		X			X

FIGURE A-3. EITRS FORMAT (SAMPLE)

TABLE A-III. MECHANICAL/ENVIRONMENTAL ICD OUTLINE

1.0 Scope
2.0 Applicable Documents
3.0 Requirements
3.1 Functional Requirements
3.1.1 Environmental
3.1.1.1 Spacecraft/Launch Vehicle Imposed Environments
3.1.1.2 Experiment Required Environments
3.1.1.3 Experiment Imposed Environments
3.1.2 Interface Loads (Maximum Loads at the Attachment Interface)
3.1.3 Mass Properties (Weight, Moment of Inertia, Center of Gravity)
3.2 Procedural Requirements (If Applicable)
3.3 Physical Requirements
3.3.1 Mechanical (Drawing showing Structural Interface)
3.3.2 Envelope
3.3.3 Axes Definition
3.3.4 Alignment

TABLE A-IV. ELECTRICAL ICD OUTLINE

1.0 Scope
2.0 Applicable Documents
3.0 Requirements
3.1 General
3.1.1 Abbreviations
3.1.2 Terminology
3.1.3 Electrical Characteristics
3.2 Interface Wiring
3.2.1 Connector Designations
3.2.2 Cable Pin Functions

TABLE A-V. INSTRUMENTATION AND COMMUNICATIONS ICD OUTLINE

1.0 Scope

2.0 Applicable Documents

3.0 Requirements
- 3.1 Telemetry
  - 3.1.1 Data Signal Characteristics
    - 3.1.1.1 Analog Measurements
    - 3.1.1.2 Digital Measurements
  - 3.1.2 Signal Conditioning
- 3.2 Commands
- 3.3 Timing
- 3.4 Correlation Data - (Measurement originating outside experiment, required during course of experiment operation.)
- 3.5 Electromagnetic Compatibility
  - 3.5.1 Bonding

7. Test and Checkout Requirements and Specifications Documents. The module TCRSDs and the integrated system TCRSD were prepared by the Module Development Center and Integration Center. These TCRSDs defined the module and system acceptance requirements, specification criteria and constraints to be used in preparing the test procedures. The TCRSDs utilized the EITRS as the basis for experiment test requirements. The module TCRSDs were utilized at the module contractor's and launch sites. The integrated system TCRSD was used only at the launch site. The TCRSD format was the same as the EITRS without the effectivity columns.

8. Test Procedures. Module and integrated system testing was performed in accordance with detailed test procedures written by the Module Development Center or the Launch Center to satisfy the requirements and specifications of the TCRSDs. The procedures contained a description of the test, test configuration, special test requirements, data requirements, test evaluation, and step-by-step test performance instructions. For experiment operating details, the OM&H manual delivered with the experiment ADP was used. The EDC supported final preparation of these procedures by reviewing them prior to the test. An addendum to the test procedure contained a listing of all test anomalies, anomaly descriptions, troubleshooting steps and corrective action taken.

9. Installation and Removal Procedures. Based upon the experiment OM&H manual, module integration plans and the ERD, the Module Development Center also prepared documents for handling, installing, and removing the experiments. These procedures contained, for each site, the environmental and handling constraints, drawings necessary for

showing complex processes (loading film, installing experiments, etc.), detailed steps for performing installation, removal and refurbishment, reference to all GSE/Facility ICDs, and a list of all GSE required.

C. Mission Operational Documentation

1. Operations Directive (Program Directive No. 43). A series of formal directives was issued by the Program Director, and controlled at Level I, to amplify the Program Specification requirements in specific areas. Program Directive No. 43 officially identified program objectives, policies and requirements; described the various Skylab missions, their specific objectives and requirements; and identified mission assignments and scheduling instructions for the individual experiments.

2. Mission Requirements Document. The MRD provided the basis for mission planning and design. It was prepared by the Mission Operations Center, based upon the Program Specification, Operations Directive, ERDs, and Experiment OM&H manuals. It defined the integrated functional and performance requirements to achieve program and mission objectives. Many subsidiary mission documents were prepared to implement the MRD requirements. These documents could expand upon, but could not conflict with the MRD contents.

The MRD contained a definition of the mission objectives, a mission profile description, launch date(s), orbital parameters and vehicle attitude capabilities. General ground rules relating to in-flight operations were prescribed for use in flight planning. The MRD also defined, for each experiment, the detailed test objectives (DTOs), requirements, test conditions and types of data required for experiment accomplishment. The test conditions described the environmental limitations, pointing requirements, vehicle attitude stability, electrical tolerances and all other constraints pertinent to experiment operation.

The MRD was updated and expanded in periodic review cycles, under Level II change control.

3. Flight Plan. The Flight Plan, prepared by the Mission Operations Center, was a detailed schedule of all in-flight crew activities. It responded directly to the MRD and endeavored to satisfy all requirements and constraints specified therein. The scheduled activities for each crewman were laid out relative to a time base, using operation times which had been verified during crew training sessions. In addition, the summary timeline format (see figure A-4) provided a simultaneous display of related data such as day and night periods, beta angle, ground station contact times, vent times and tape recorder usage.

The graphical presentation utilized in the Flight Plan facilitated the identification of conflicting requirements and constraint

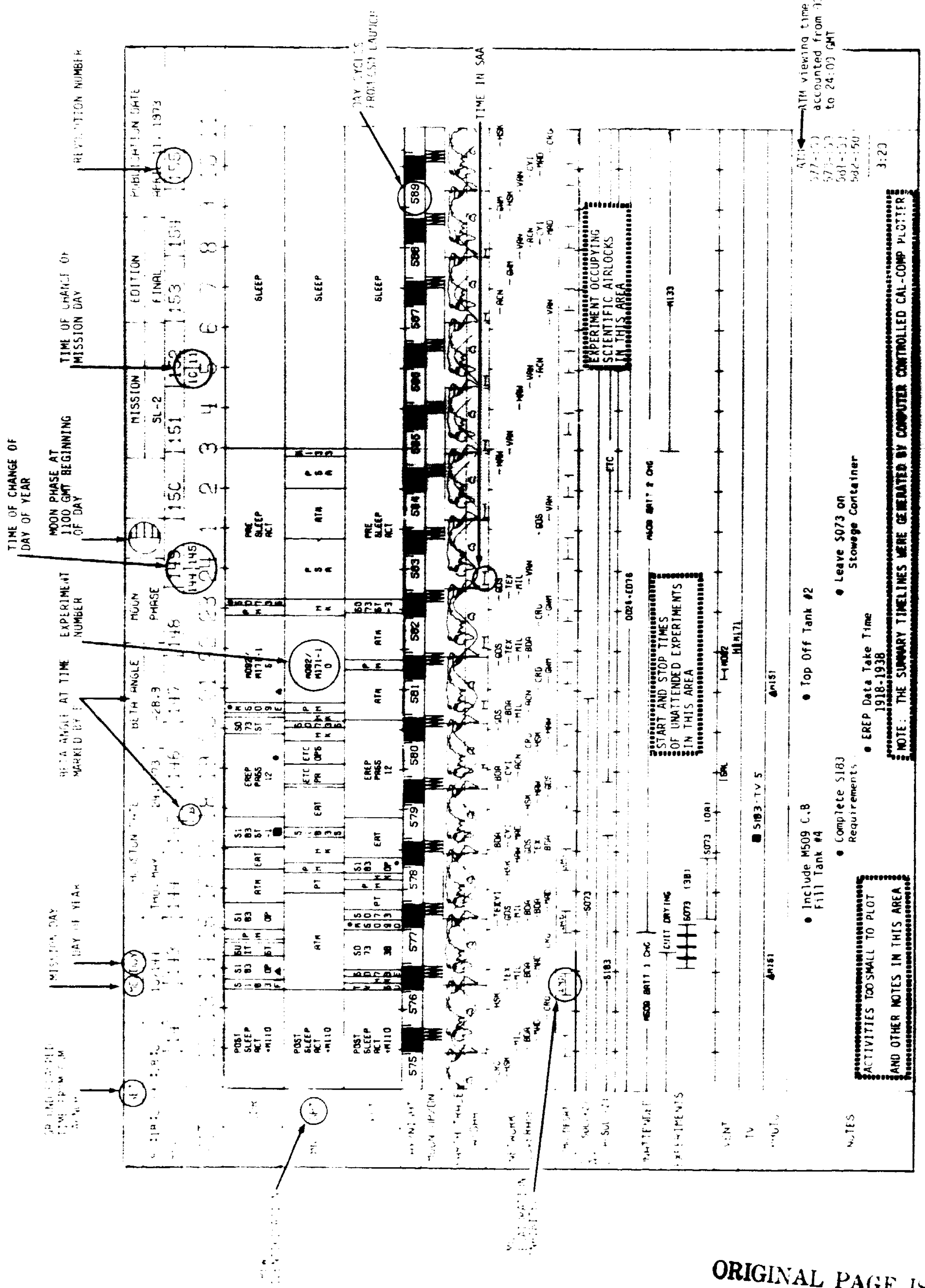


FIGURE A-4. FLIGHT PLAN SUMMARY TIMELINE FORMAT

ORIGINAL PAGE IS OF POOR QUALITY

violations. Although not under formal change control, the Flight Plan was under continual revision, and each publication was widely distributed for review and comment. The information required to produce the Flight Plan was updated as required and stored in a data bank for use during the mission in the computer-controlled, real-time Flight Plan generation.

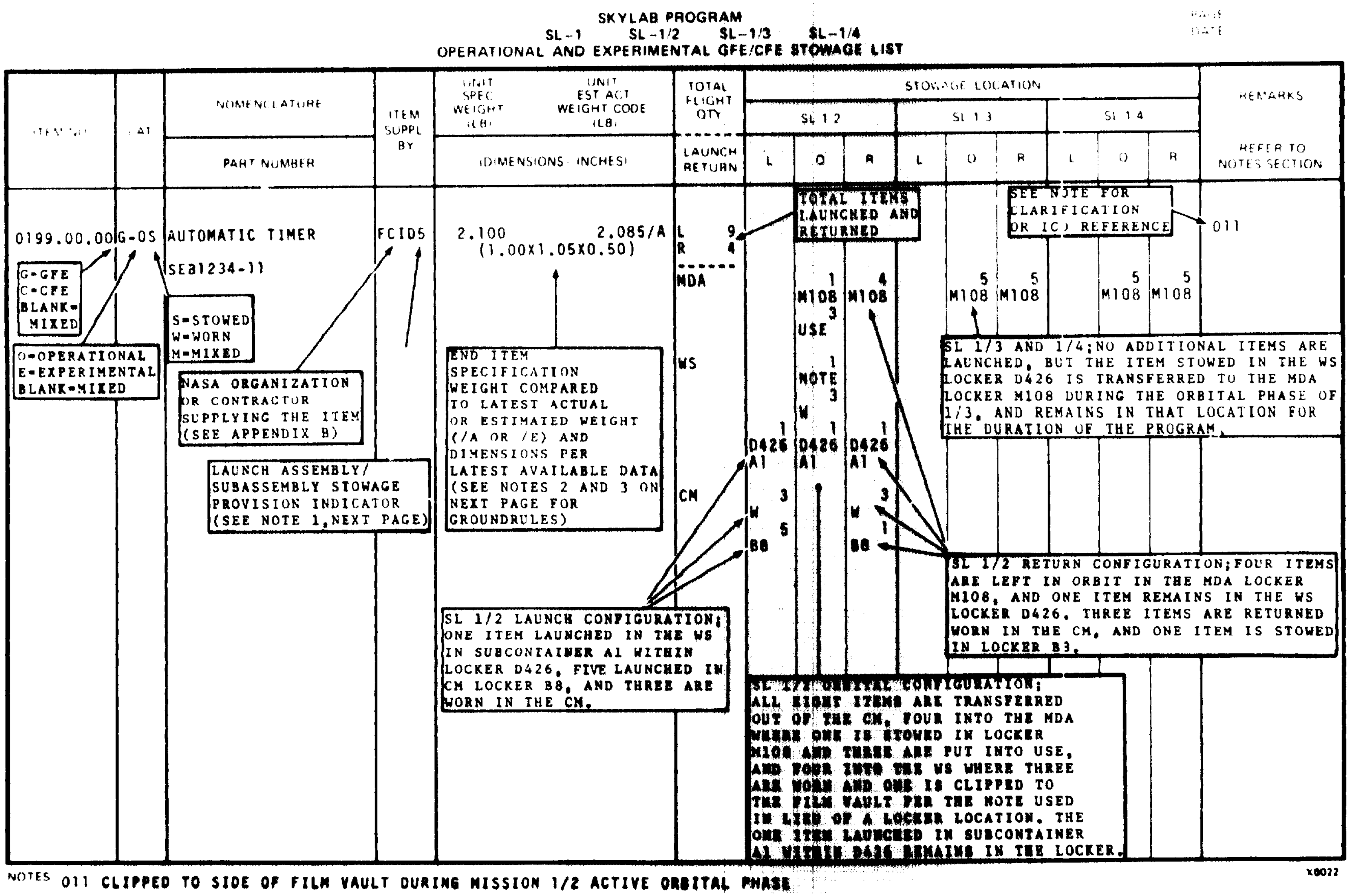
4. Stowage List. Stowage lists were compiled and maintained by the Mission Operations Center to identify and track the proper location of all moveable equipment in the Skylab modules throughout the mission(s). The lists highlighted the article's identification, weight, cumulative quantities launched and returned, and the planned stowage locations for launch, in-flight transfer, and return. A sample Stowage List format is reproduced as figure A-5.

5. Flight Mission Rules. The Flight Mission Rules were a compilation of preplanned responses to possible in-flight contingencies. They were prepared before the missions, and attempted to anticipate anomalies which might occur during flight, together with appropriate corrective actions. These rules were designed to reduce the response time required to cope with anomalous situations during the mission. They were crucially important in those instances where a particular malfunction might compromise crew or vehicle safety, thereby demanding immediate action. In less urgent circumstances, they assumed an advisory role, describing the previously agreed-upon action to be followed after the anomaly's criticality had been determined (see Malfunction Procedures, item 8 below).

6. Experiment Operations Handbook. The EOH was published in two volumes. Volume I was system oriented and provided experiment descriptions. Volume II contained detailed normal, backup, and malfunction operational procedures for these experiments. As such, this document provided the preliminary input for crew training purposes and, with feedback from training, formed the basis for the crew checklists.

7. Crew Checklists. The crew experiment checklists were detailed, step-by-step procedures to be followed for proper experiment operation, included in the onboard Flight Data File. The MRD, experiment OM&H, acceptance and integration test results, EOH, and crew training experience were the principal inputs for these documents. They were updated as required during the mission by the ground support crew at the Mission Operations Center (e.g., to provide specific coordinates of an experiment target).

8. Malfunction Procedures. The nature of space flight experimentation demands that experiment hardware possess a high reliability. During the development stage, every effort was made to ensure that the possibility of an in-flight hardware malfunction was negligible. Despite this, experience has shown that failures will occur. A major advantage of manned space flight is the crewman's ability to repair



NOTES 011 CLIPPED TO SIDE OF FILM VAULT DURING MISSION 1/2 ACTIVE ORBITAL PHASE

FIGURE A-5. STOWAGE LIST FORMAT (SAMPLE) or work around many failures. The Malfunction Procedures, included in the onboard Flight Data File, provided the crew with logical steps to be followed when anomalies occurred. These procedures, expressed in block diagram format, were designed to rapidly isolate the anomaly to the subsystem or component which had failed and, where possible and applicable, described a repair method or alternate procedure which would permit continued operation. In the event that the malfunction procedure did not result in a satisfactory repair, the applicable mission rule was invoked.

9. Operational Data Book. During the mission, there may be occasions when the limit of certain design tolerances may be approached or exceeded, necessitating appropriate action. The ODB was a compilation of the operational performance data and limitations of all vehicle and experiment hardware. From the experimenter it required a description of the mass properties, structure and dynamics of the equipment, the effect of experiment operation on the spacecraft environment, the nature of the load it presented to the electrical power system, data instrumentation requirements, experiment pointing capabilities and all operational limitations and hardware constraints.

10. Skylab Experiment Systems Handbook. The SESH was a compilation of experiment functional flow diagrams and, where applicable, mechanical and electrical schematics, for use by the flight controllers during the missions. It was designed to assist in the rapid resolution of real-time experiment anomalies. Pertinent operational and system constraints were identified, as were the interfaces between experiments, where applicable.

11. Facility Users Handbook. As part of an Announcement of Flight Opportunity, advising the scientific community of the availability of an experiment facility (e.g., EREP), a Facility Users Handbook was prepared by the Experiment Development Center for distribution to potential users. The handbook identified the physical/functional characteristics and operational capabilities of the facility and its individual instruments.

APPENDIX B

COMPATIBILITY ASSESSMENT

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LIST OF ILLUSTRATIONS

LIST OF TABLES

COMPATIBILITY ASSESSMENT

A major feature of Skylab experiment integration activities was the continuing compatibility assessment performed by the Integration Center. This activity assumed various forms as the program developed.

During the program's formative stages, when many different missions and configurations were being considered, an extensive assessment was conducted to categorize over five hundred available or potential experiments into compatible, discipline-oriented payload groupings for performance on particular types of missions. While the early concept of numerous dedicated missions did not survive, these assessments were influential in selecting the initial experiment complement for the configuration and missions that were implemented.

Subsequently, as new experiments were proposed for MSFEB consideration, an initial compatibility assessment was necessary in each case, to evaluate the impacts of the experiment requirements upon all other hardware and operational aspects of the program. Any incompatibilities identified were resolved before the experiment was approved for implementation.

Thereafter, a continuing surveillance was maintained of all pertinent program documentation, information and activities to assure that the experiment requirements and constraints remained compatible with all interfacing cluster and module systems and operational plans. Where incompatibilities were identified, the Integration Center coordinated and participated in their resolution. All involved agencies (PI, ED, EDC, Module Developer/Development Center, operations centers, etc., as applicable) were consulted and mutually acceptable solutions established. Normally, the Integration Center prepared and "precoordinated" any necessary change package for submittal to the cognizant CCB (see Section IX) and maintained corrective action implementation status. When significant hardware changes were involved, the affected hardware developer was responsible for preparation of the ECP.

Many special studies were also conducted to assess the compatibility of associated groups of experiments with their common module interfaces. Some examples were: multi-experiment usage of the Scientific Airlocks, module provisions for storage and environmental protection of assorted experiment photographic film, launch pad access requirements for experiments, etc.

The various compatibility assessment activities continued at a high level throughout the definition, development, and integration phases, and as a monitoring and evaluation function during the mission support phase. Table B-I identifies and defines the general scope of the 17 experiment compatibility disciplines that were initially checked and subsequently monitored for these assessments. Figure B-1 presents a matrix of the pertinent program documentation that was continually reviewed in the various discipline areas.

Management visibility of the experiment compatibility status was provided by oral presentation of bimonthly reviews, and by broad dissemination of a monthly Experiment Compatibility Status Report. Representatives of the module development, launch, and mission operations centers attended the bimonthly reviews and received the status report. A key feature of the monthly report was a compatibility summary of the status of each individual experiment relative to each of the 17 compatibility disciplines (see figure B-2). The summary was supplemented in the report by detailed descriptions of current problem areas and their resolution status, including action items and suspense dates where applicable (see figure B-3). Once entered, problems could be closed and deleted from the status report only by issuance of a CCBD correcting the incompatibility, or by some equivalent positive action acceptable to the Integration Center.

The evolution of these integration techniques provided a very effective means for the timely control of Skylab experiment compatibility.

TABLE B-I EXPERIMENT COMPATIBILITY DISCIPLINES

DISCIPLINE	DEFINITION
Mechanical	Verification that experiment mechanical interface requirements are met for mounting, alignment, orientation, plumbing, venting, sealing, and the use of observation windows.
Weight and Stowage	Verification of current experiment weights relative to experiment and module control weights; of experiment stowage provisions in terms of weight, volume, and location for each launch, orbital storage and return operation in the mission; and that all onboard experiment support equipment is available at the time and in the quantities required.
Consumables	Verification that experiment requirements for oxygen, nitrogen, water, and/or other consumables will be supplied either by the modules or by the experiments themselves.
Electrical	Verification that experiments are compatible with the electrical power provided by the module (voltage tolerances, power profile, and total energy); that all electrical interfaces are compatible (connectors, cables, etc.); and that EMI produced in the electrical system will not cause unacceptable degradation of the system or experiments.
Instrumentation and Communications	Verification that experiment measurements, housekeeping measurements, voice communication, and ground commands required for the experiments will be provided; that experiment equipment, data formats, and data rates will be compatible with module requirements for recording and transmission to ground, and with MMC requirements for processing and display; that all data correlation requirements (e.g., time, ephemeris, etc.) will be provided for; and that experiment-required data will not be lost due to EMI.
Environments	Verification of experiment compatibility with prelaunch, launch, orbital and recovery environments (temperature, humidity, pressure, acoustic, vibration, acceleration, shock, radiation, illumination) as specified in the CRS or defined by NASA-recognized analyses; and of crew and system compatibility with experiment-induced environments.
Materials	Verification that experiment materials are acceptable in accordance with the appropriate specifications as referenced in the CRS, or that waivers to these specifications have been approved.

TABLE B-I EXPERIMENT COMPATIBILITY DISCIPLINES (Cont.)

DISCIPLINE	DEFINITION
Contamination	Evaluation of experiment susceptibility to contamination from internal or external sources; determination of contamination produced by the experiments; and verification of ground contamination control procedures.
Photography	Verification that experiment photographic requirements are met, including photographic support equipment (cameras, lenses, light, cables, etc.) and film; and that adequate environmental protection is provided for film.
Experiment and Spacecraft Pointing	Verification that experiment pointing requirements will be met when integrated into the spacecraft; and that requirements imposed on the spacecraft, including orbit position for performance, orientation, stability, allowable rates and accelerations, and the necessary maneuvers, will be provided for.
Safety	Verification of experiment safety plans and provisions for on-orbit operations.
Systems Test	Verification of compatibility of all experiment handling, test and checkout plans with integration test planning, prelaunch maintenance, logistics, pad access, and launch constraints.
Ground Support Equipment, Facilities and Handling	Verification that GSE and facilities provided will satisfy the experiment postacceptance handling and testing requirements with minimum duplication.
Flight Plans	Verification of flight plan compatibility with experiment requirements, priorities, objectives, constraints, and interfaces.
Crew Interfaces	Verification of experiment-to-crew interfaces, including in-flight access, restraints and aids, controls and displays, in-flight maintenance, and crew training.
Mission Support	Verification of plans for obtaining required evaluation data; for processing, display, analysis, and reporting of this data in support of the mission; and for analysis and reporting after the mission.
Schedules and Hardware Status	Verification and comparison of required dates and delivery dates for experiment mock-ups, trainers, flight hardware (including backup unit), and GSE.

[illegible] Used in Compatibility Assessment
As of December 1, 197[illegible]

Document	Date
Requirements List	01-18-[illegible]
Power Allocation Document AM	[illegible]
Power Allocation Document MDA	[illegible]
Power Allocation Document OWS	[illegible]
Power Profile SL-1/SL-2	[illegible]
Power Profile SL-3	[illegible]
Power Profile SL-4	[illegible]
IP & CL MDA	[illegible]
IP & CL OWS	10-71
IP & CL AM	0[illegible]-30-71
IP & CL ATM	10-30-71
ATM Measurement List, 50M16136	06-0[illegible]-[illegible]
OWS Measurement List, 50M16137	0[illegible]-15-[illegible]
AM Measurement List, 50M16138	12-1-[illegible]
MDA Measurement List, 50M16139	02-26-[illegible]
APCS Definition Document Vol I	03-1[illegible]-[illegible]
APCS Definition Document Vol II	05-01-[illegible]
APCS Definition Document Vol III	05-01-[illegible]
AM ATM ICD [illegible]	[illegible]
AM MDA ICD [illegible]	[illegible]

FIGURE B-1. EXPERIMENT COMPATIBILITY DOCUMENTATION (SAMPLE)

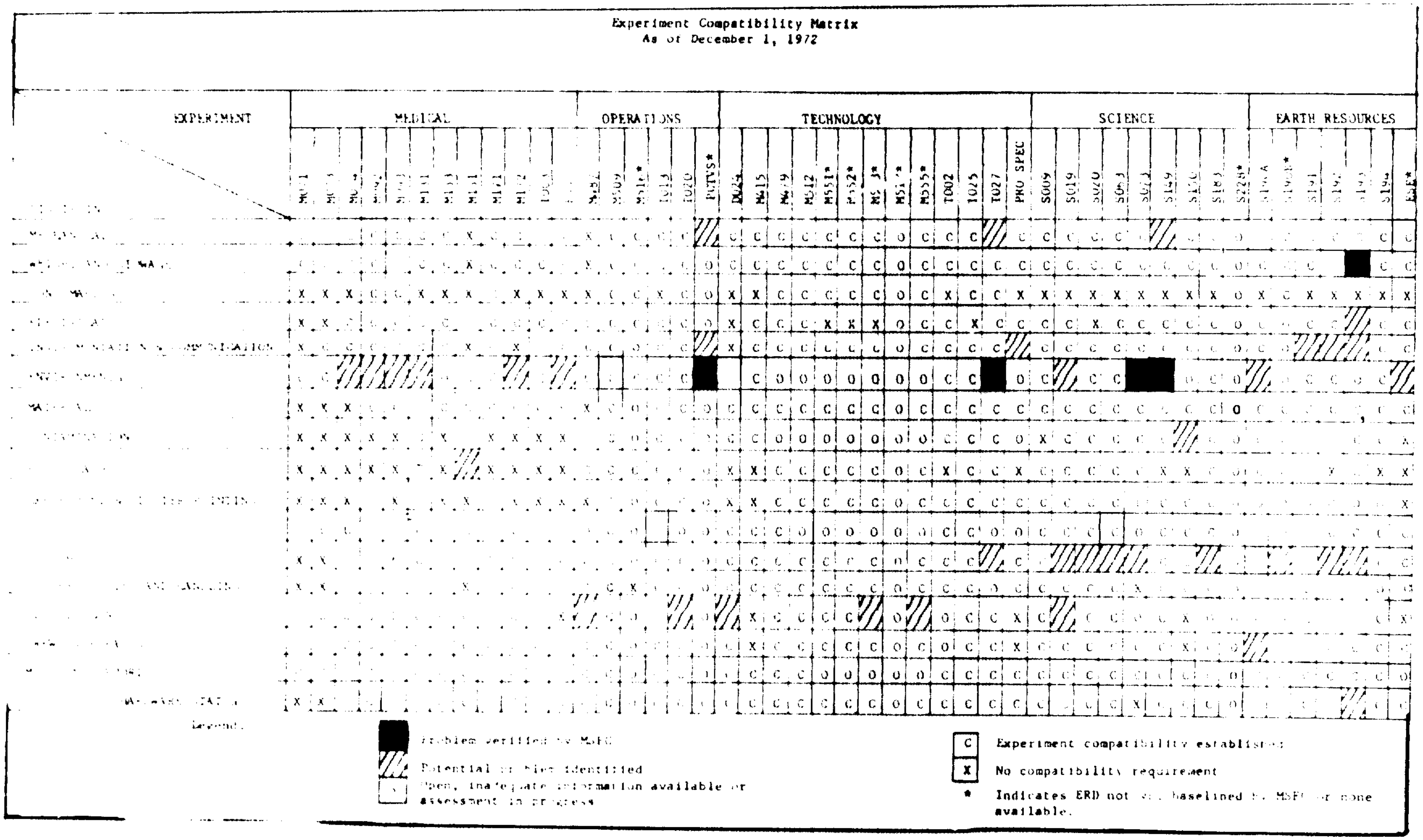

FIGURE B-2. EXPERIMENT COMPATIBILITY SUMMARY (SAMPLE)

Experiment Compatibility Problem Areas (Contd)

PROBLEM NUMBER	EXPERIMENT(S)	INCOMPATIBILITY	ACTION RESPONSIBILITY	ASSIGNMENT DATE	COMPLETION DATE	CURRENT STATUS
24	S019	This experiment uses triacetate base film. ESTAR base film is less flammable, exhibits much better physical characteristics (especially with regard to outgassing), and is available in thinner bases.				The S019 PI has decided to use film type 101-06. This change was approved by CCBDs 800-72-0586, 10-9-72, and 2X0223, 8-11-72. PROBLEM CLOSED.
*25	T027/ S073 S149 PCTVS	The Photometer Tripod has not been qualified to launch vibration levels and has not been cycle tested. In addition, several expando pins and one floor insert were broken during operational tests at MDAC-W.	SL-SW	10-11-72	TBD	Phase I DCR RID T027P-4 recommended Qual Test to launch vibration levels and 100 setup/takedown cycles. The recommended RID action has not been taken. In lieu of the above testing, Memo S&E-ASTN-DIR(72-385), 10-11-72, requests a repair (or spare) kit to provide for continued use of the tripod in the event of damage to expando pins, bolt assemblies or floor inserts. ECRs in preparation by S&E-ASTN-SMD and -SDI to add the spares.

* Problem newly added in this issue of report.

FIGURE B-3. COMPATIBILITY PROBLEM DESCRIPTION AND STATUS (SAMPLE)

APPENDIX C

DEVELOPMENT REVIEWS AND CERTIFICATION

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LIST OF ILLUSTRATIONS

DEVELOPMENT REVIEWS AND CERTIFICATION

This Appendix describes the requirements, responsibilities and methodology for accomplishment of the formal reviews and certifications which were key development checkpoints for Skylab experiments. The seven key management checkpoints established by Skylab Program Directive No. 11 were:

- PRR - Preliminary Requirements Review
- PDR - Preliminary Design Review
- CDR - Critical Design Review
- CIR - Configuration Inspection Review
- COFW - Certification of Flight Worthiness
- DCR - Design Certification Review
- FRR - Flight Readiness Review

The Experiment Development Center was responsible for accomplishment of the first five of these (PRR, PDR, CDR, CIR and COFW) at selected end item levels. The last two reviews (DCR and FRR) were program-oriented, encompassing the total mission complex; they were accomplished through coordinated efforts of the development, integration, launch, and mission operations centers, and were conducted in a different format by the NASA Headquarters Program Director. Experiment involvement in the DCR and FRR is described in Section VI of the main text.

Each development review was a critical examination of documentation and pertinent hardware for compliance with program requirements and for compatibility with related hardware and facilities. The reviews progressed chronologically from requirements (PRR), to design (PDR, CDR), to hardware acceptance (CIR) and formal certification (COFW). Each successive checkpoint provided a more comprehensive assessment of program accomplishment as it matured.

A. Purpose and Scope of Reviews

1. Preliminary Requirements Review. The purpose of a PRR was to verify by formal review the suitability of the conceptual configuration, and to establish a Program Requirements Baseline that would satisfy the experiment objectives and provide the basis for preliminary design. Review material included the experiment proposal, the approved EIP, the Compatibility Assessment, the ED's Statement of Work (SOW), and initial versions of the ERD and EIS. The PRR established:

- A preliminary EIS for the conceptual flight hardware configuration that would be expected to meet mission objectives and the required schedule.

- Operational requirements of the experiment on the module, crew, launch, flight and recovery, as reflected in the preliminary ERD.

- Required end items and schedule.

- Feasibility and/or development tests required to select and substantiate design approaches.

Minutes of the PRR were prepared, as described in Section A.2.d of Appendix A, and included all items requiring post-review action. These action items were to be completed prior to final approval of the Program Requirements Baseline.

2. Preliminary Design Review. The purpose of a PDR was to verify by formal review the basic design approach for the hardware, prior to proceeding with detail design, and thereby to establish a Design Requirements Baseline. The PDR established:

- The integrity of the design approach, by review of design analyses, breadboard models, mock-ups, circuit logic diagrams, packaging techniques, test and study results, reliability analyses, etc.

- The compatibility of the design approach with EIS performance and design requirements, including interface compatibility with other flight hardware, the flight crew, GSE and facilities. This was accomplished by review of preliminary design drawings, layout drawings, envelope drawings, schematics, performance characteristics for functional compatibility, and available test results.

- The producibility of the design approach with respect to cost and schedule impact, through the review of requirements for special tools, equipment, and facilities to manufacture, inspect and test the hardware.

- The adequacy of the planned test program for the end item, by review of preliminary test plans.

- The acceptability of the design requirement baseline configuration, through approval of the design approach.

Minutes of the PDR were prepared and included all items requiring post-review action. These action items were to be completed prior to formal approval of the Design Requirements Baseline configuration.

3. Critical Design Review. The purpose of a CDR was to verify by formal technical review the completed detail design of the hardware, and to establish a production Drawing Baseline before the design was released for manufacture. The CDR established:

- The integrity of the completed design, by review of the drawings (as prepared for release to manufacturing), analyses, mock-ups, qualification status of selected parts and materials, test data, inspectability, etc.

- Compatibility of the completed design with EIS performance and design requirements, as revised since PDR. This included the exact physical and functional interface relationships with other flight hardware, the flight crew, GSE and facilities.

- The production baseline configuration for manufacture of the hardware, through approval of the completed design and associated documentation.

- Adequacy of the planned test program, by baselining the Qualification and Acceptance Test Specifications.

- Adequacy of the design from a safety standpoint, through a review of design details and test results.

- Adequacy of the design for operations, by review of engineering simulations, tests and study results and by examination of mock-ups, operating procedures, and system performance data.

Minutes of the CDR were prepared and included all items requiring post-review action. These action items were to be completed prior to formal approval of the baseline configuration for manufacturing.

4. Configuration Inspection Review. The purpose of a CIR was to verify by formal technical review that the configuration of the end item as being offered for delivery was in conformance with the baseline established at CDR (as modified by approved changes). This was accomplished by establishing the exact relationship of the end item as described by released engineering documentation to the end item as manufactured and assembled. The CIR was most efficiently conducted in two phases:

Phase 1 - Approximately one week prior to start of final experiment hardware acceptance tests, review the qualification status and test data, configuration and overall status of the end item and its GSE.

Phase 2 - Approximately one week prior to delivery, review the final experiment hardware acceptance test data.

The CIR established:

- That the hardware to be accepted conformed to the production baseline configuration, as documented by the released engineering, including all approved changes; and that the configuration of the Qualification Test hardware corresponded to the configuration of the flight hardware to be accepted.

- That the test program of the Verification Plan had been completed and that the verification methods and test results validated the acceptability of the hardware.

- That all failures occurring after CDR had been reported and corrective action completed.

- That Failure Mode and Effects Analyses had been completed and were acceptable.

- That the Acceptance Data Package was complete and acceptable.

- The validity of the hardware acceptance testing, verified by a direct comparison of acceptance test data with EIS performance and design requirements and by verification that the acceptance tests had been conducted in accordance with the approved Acceptance Test Specification and procedures.

- A plan for accomplishing any open work items remaining for fulfillment of the above requirements.

- Identification of all waivers, deviations or shortages authorized.

The results of the CIR were documented in a CIR Report (see Appendix A, section A.2.e).

5. Certification of Flight Worthiness. The purpose of the COFW milestone was to certify that each experiment end item was a complete and qualified item of hardware prior to shipment, and was accompanied by adequate supporting documentation. The COFW was prepared

prior to shipment from the point of manufacture and endorsed by the EDC. The COFW certified that:

- Complete specifications and drawings had been developed in accordance with all program requirements. Additionally, that the exact relationship of the hardware as manufactured and assembled had been established, and that shortages requiring resolution prior to FRR had been indicated on the DD-250 form.

- Acceptance, qualification, and any required reliability demonstration tests had been successfully completed and had met specification requirements.

- Departures from specification and drawing requirements had been approved by Material Review Boards in accordance with EIS requirements.

- Critical hardware failures had been reported, analyzed, and corrected in accordance with EIS requirements.

- The hardware qualification program had been satisfactorily accomplished.

- The hardware was complete and in accordance with the EIS.

- Data for operation and checkout was complete and compatible.

- Interface Control Document requirements had been met and interface compatibility was certified.

- Shipping and transportability requirements as stated in the EIS had been met.

- Delivery status information as required in the EIS was complete.

- The DD-250 form was ready for signature.

When equipment was shipped to an intermediate destination (center test facility or developer's plant) for additional work, further sign-off of the COFW by the cognizant center was required. Eventually, upon completion of the FRR, the COFW was jointly endorsed by the Launch Center and the EDC.

B. Review Format and Activities

The review description and requirements contained in this section were generally applicable to all development reviews; however, flexibility was permitted to meet the requirements of each experiment review. For example, the formal procedure of using Review Item Discrepancy (RID) forms to document problem areas was properly followed for major reviews (e.g., for modules or complex experiments), but was occasionally supplanted by a simple Action Item Log to accomplish the same purpose in reviews of the less complex experiments. This flexibility was implemented by a Review Agenda prepared specifically for each experiment review by the cognizant EDC.

Review personnel consisted of: 1) review teams or working groups, representing each appropriate technical discipline or program interest, to conduct the detailed technical review; 2) a preboard, to perform a screening and advisory function; and 3) the review board, to direct the proceedings and make final disposition of all pertinent review items. The board and preboard normally included representation from the EDC, NASA Headquarters, the Integration Center, the operations centers, the ED and the PI or Project Scientist. The designated captains of the review teams also served on the preboard.

1. Preparations. The cognizant EDC scheduled the review date(s) and site, and appointed the review board chairman, who in turn selected his preboard chairman and team captains. Approximately two months in advance, this group prepared the Review Agenda, notifying invited participants of review objectives and personnel, session timing, applicable documents to be made available, and planned deviations from normal review procedures, if any. At least two weeks prior to PRR, PDR, or CDR, the EDC or ED delivered to each participant a data package, consisting of updated plans, the appropriate technical documentation, and RID forms. Participants were expected to familiarize themselves with the documentation, and identify suspected discrepancies and problems, in advance preparation for the review.

> RECOMMENDATIONS: Apply the following criteria in preparation for experiment development reviews. For maximum effectiveness, each review must:
>
> - Be conducted at the appropriate time--in particular, not prematurely with respect to data definition and availability.
>
> - Involve the most experienced technical personnel available to cover all disciplines that affect the review subject.

- Limit participants to the required discipline and project representatives, authorized to act for their respective organizations (including a single source of crew comments, consistent from one review to the next).

- Have a data package that is complete, but minimal in volume, available to all participants sufficiently early to permit thorough evaluation.

- Emphasize hardware as available.

- Include assessment of test programs and results.

2. Technical Review. Technical reviews began with a general technical briefing by the EDC/ED, to provide all review participants with common background information on development status and technical requirements and final instructions as to review procedures, criteria, and guidelines.

Due to the relative complexity of the review materials, individual team sessions were scheduled for each applicable technical and management discipline. The team sessions opened with detailed presentations to assure maximum understanding of the technical materials subject to review in the team's defined area of responsibility, as interpreted by the team captain. The remainder of the team sessions were devoted to in-depth examination and discussion of the review material, leading to the generation, review and coordination of RIDs, and development of recommendations for their disposition. The MSFC standard RID format is shown in figure C-1. The team members submitted their discrepancies/problems to the team captain to assure proper format, completeness, clarity, coordination, and that the content was within scope of the review guidelines and criteria. After his review the team captain could recommend to the originator that the RID be withdrawn, rewritten or combined with another RID of the same intent. However, any action or changes to a RID during the team meeting and subsequent activities required the concurrence of the originator. RIDs approved for submittal into the review data flow were logged, submitted for the developer's response, and coordinated with other review teams as required. The developer's appointed lead representative for each team provided or made readily available the supporting documentation, analyses or explanations required to clarify or resolve questionable areas encountered during the review. He also coordinated preparation of the developer's response to submitted RIDs, provided liaison for coordinating the team's activities with other teams, and prepared team minutes.

1. TYPE OF REVIEW:	**REVIEW ITEM DISCREPANCY**	4. NUMBER:
2. ITEM:		5. COORDINATION:
3. DATE:		

6. INITIATOR:	7. ORGANIZATION:	8. SYSTEM:	9. TEAM NAME:

10. TITLE:

11. DISCREPANCY/PROBLEM:

12. JUSTIFICATION:

13. RECOMMENDED DISPOSITION:

14. TEAM CAPTAIN'S SIGNATURE:

15. DEVELOPER'S COMMENT:

16. SIGNATURE:

17. PRE-BOARD RECOMMENDATIONS	
17.2 CATEGORY:	17.1 REMARKS:
17.3 ACTION:	
17.4 SUSPENSE:	17.5 PRE-BOARD SIGNATURE:

18. FORMAL REVIEW BOARD ACTION	
18.3 ACTION:	18.1 ☐ DISAPPROVED 18.2 REMARKS:
18.4 SUSPENSE:	18.5 ☐ APPROVED
19 DATE:	20 SIGNATURE OF BOARD CHAIRMAN:

MSFC - Form 3284 (May 1969)

FIGURE C-1. MSFC RID FORMAT

3. Preboard Action. The preboard convened, before the board meeting, to screen and categorize all RIDs submitted by the review teams. Each RID was considered individually by the preboard, combined with others where possible, and assigned to one of the following recommended disposition categories:

A. Recommend acceptance as written
B. Recommend acceptance with (stated) modifications
C. Recommend acceptance for study
D. Recommend rejection
E. Refer to board for resolution

The total RID package, accompanied by pertinent data to support the recommendations, was then submitted to the review board for final disposition.

4. Review Board Action. The board reviewed the RID package and, after considering the preboard's recommendations, either approved or disapproved each presented RID. Suspense dates were established for all items requiring further action. (As noted previously, the formal RID procedure was replaced in some reviews by a simple Action Item Log.) The official review minutes (or CIR Report) provided the formal documentation of the board's actions and directions.

5. Follow-Up Action. The EDC was responsible for assuring satisfactory review follow-up, i.e., that approved RIDs were implemented, directed studies completed, and appropriate action taken to close all remaining open items by the prescribed suspense dates. Upon completion of all required follow-up activity, the final review minutes were prepared and distributed by the EDC, documenting the closeout actions and dates, and certifying to the Program Director that the review objectives had been met.

> RECOMMENDATION: Emphasize the importance of adequate follow-up and formal closeout of all RIDs or review action items, and timely dissemination of this information to all involved program personnel.

APPENDIX D

DESIGN CONSIDERATIONS

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DESIGN CONSIDERATIONS

The following experiment design considerations are categorized into those applicable to flight hardware and those applicable to GSE. These considerations were usually specified as requirements in either the CRS or the experiment EIS. Some considerations were only indirectly applicable to design (i.e., identifying operational methods or procedures that might influence the design). The importance of applying these design criteria was directly related to the criticality category of the experiment, i.e.:

Category 1: Hardware whose failure could adversely affect personnel safety.

Category 2: Hardware whose failure could result in not achieving a primary mission objective, but would not adversely affect personnel safety.

Category 3: Hardware whose failure could result in not achieving a secondary mission objective, but which would not adversely affect personnel safety or preclude the achievement of any primary mission objective.

Category 4: Hardware whose failure would not result in any of the above.

A. Flight Hardware

1. Flight Operation General Constraints

a. Safety of the crew and safe termination of the mission were overriding design criteria.

b. All components that controlled safety-critical functions were required to be designed to operate in a vacuum. This was considered a requirement even for hardware normally located in a pressurized environment.

c. Efforts were made to minimize the number of single failure points (SFPs) in the design; rationale to justify acceptance of those SFPs that did exist was a prime consideration in design and acceptance reviews. Redundant systems, however, were to be provided only if considered necessary to ensure crew safety or primary mission success.

d. Wherever possible, opportunities for human error were minimized by designing connecting parts (e.g., fluid line or electrical connectors that might be reversed in mating) so that they would be physically incapable of being installed improperly.

e. The experiment was designed to satisfy its own objectives, independent of the failure of another experiment.

f. Wherever feasible, flight-proven hardware was utilized in the design.

g. The module generally provided the following subsystems: 1) Data Recording, 2) Power Distribution, 3) Pressurization, 4) Attitude Control, 5) Voice Communications, 6) Atmospheric Circulation, 7) Module Lighting, Food, Water and Waste Management, and 8) Central Caution and Warning System.

2. Flight Operation Mechanical Constraints

a. All experiment hardware having a crew interface was required to remain within touch temperature limits of 55°F to 105°F.

b. The following types of hardware were required to be delivered to the Module Development Center:

(1) Mechanical interfaces tool (a tool that could be used to verify mechanical interfaces prior to installation; e.g., to locate bolt holes).

(2) One full-scale mock-up of the experiment that, as a minimum, satisfied mechanical and crew interfaces.

(3) One flight unit.

(4) One complete set of GSE capable of verifying interfaces and checking out the experiment to acceptance test requirements.

c. Packaging. Experiment equipment which was stowed during the launch phase of the mission, and then transferred to a use location, was required to satisfy the following specifications:

(1) Package limited in size to 20" x 25" x 40" and in moment of inertia to less than 65 lb-in-sec^2, and allowing adequate visibility during transfer. [NOTE: Skylab mission experience indicated no difficulty in handling large masses in zero g; however, the

cross-sectional area of 20" x 25" was considered a realistic limit from the visibility standpoint.]

(2) Hinges designed so that all hinged devices remain as positioned by the crewman.

(3) Rounded edges and corners of packages and containers.

(4) Package fasteners able to withstand prelaunch, launch, and flight loads and:

(a) Designed to prevent inadvertent operation.

(b) Simply operable with either a bare or a pressurized-gloved hand, without requiring extensive astronaut stability aids. Skylab crews indicated a preference for magnetic or lift-handle latches.

(5) Each package marked to indicate:

(a) Proper mounting orientation.

(b) Equipment-peculiar precautions.

(c) Operating instructions, where feasible.

(6) Cameras/film canisters, and other equipment transferred during EVA, designed to meet the following requirements:

(a) Capability for one-hand operation.

(b) Capability for tethering.

(c) Mounting provisions compatible with equipment transfer devices.

(7) Package mounting provisions designed to avoid providing a space for floating articles to pass behind and/or accumulate.

3. Flight Operation Electrical Constraints

a. Module power provided to experiment interfaces had the following characteristics:

(1) Two-Wire System. Power was distributed by a two-wire system. The system did not use module structure for return of current to the power source.

(2) Grounding. Any one set of negative buses was referenced to the structure at only one point. The experiment could not use module structure for return of current to the power source. The module provided the single-point ground.

(3) Bonding. Electrical bonding and grounding of the experiment was in accordance with MIL-B-5087, providing a radio frequency ground reference plane, a fault current return path, and a discharge path for lightning and static charge.

(4) Circuit Protection. All experiment positive polarity lines of the DC distribution wiring were protected with circuit breakers or fuses provided by the module. Use of fuses was minimized.

(5) Crew Mating or Demating of Connectors On-Orbit. The presence of power in the connectors during mating or demating by the crew was circumvented by design or procedure. Connector design or application precluded mismating.

(6) Characteristics of Unregulated 28 V DC Power at Interfaces. The voltages at module interfaces met the following requirements:

(a) Bus Noise. The total AC components of the voltage could not exceed 1.0 volts peak-to-peak for all frequencies from 20 Hz to 20 KHz.

(b) Under and Over Voltage. Under and over voltage with a duration greater than 10 microseconds and less than 100 milliseconds could not exceed the limits $28 \pm {}^{2}_{4}$ by more than 3 volts.

(c) Transients. Transient voltage with a duration of less than 10 microseconds could not exceed $\pm$ 50 volts relative to the limits $28 \pm {}^{2}_{4}$.

b. The module provided interface cabling: 1) between sensor a d control panels, and 2) between experiment hardware components if the cabling required mechanical support from the module.

c. Experiment electrical design considerations were:

(1) The experiment provided a rapid means of switching off power under emergency conditions.

(2) The experiment control panel provided a positive indication of power-on, current level, and power-off status.

(3) Experiment safety-critical and nonsafety-critical circuitry were isolated from each other.

(4) Secondary power sources were provided for experiment safety-critical functions.

(5) Experiment safety-critical electrical components were protected against the effects of liquid leakage, moisture, condensation, vibration, arcing contacts and corona.

(6) Experiment electrical disconnects were located separately from hazardous fluid disconnects, were qualified as explosion-proof and would not have power applied to the connection during or after disconnect.

(7) If batteries were used, they were designed to prevent danger of explosion under any conditions.

(8) Cabling was placed so that it could not be subjected to loads for which it was not designed (e.g., use as a hand- or foot-hold).

(9) Use of high-voltage systems was minimized.

d. The design of an experiment was required to satisfy EMI criteria that met the following minimum requirements: the operation of the experiment in any mode (powered or unpowered) could not degrade the performance of another subsystem relative to that subsystem's performance criteria. The hardware would satisfy the single-point ground requirement and meet EMI MIL-STD-461. Verification of this was required during the qualification/development phase, and evidence of meeting these criteria was included in the ADP.

e. Pyrotechnics

(1) Use of pyrotechnics by experiments was minimized and required approval by NASA.

(2) Pyrotechnic initiators could not be susceptible to ignition in the EMI environment of the module.

(3) The arming of pyrotechnic devices was protected against accidental operation. Arming and safety were clearly indicated.

(4) Pyrotechnic exhaust products were contained or controlled to prevent ignition of combustibles.

(5) The pyrotechnic logic circuits received power from a source other than the pyrotechnic initiation batteries.

(6) Pyrotechnic devices required for safety were designed to allow verification.

(7) Pyrotechnic firing circuits were protected from electrostatic charge buildup.

(8) Sequence logic and pyrotechnic firing circuits were required to be at least "fail-safe/fail-safe".

4. Flight Operation Controls and Displays Constraints

a. Circuit Protection. Circuit breaker devices had manual reset capability and a visual display of position.

b. Panel Lighting. Console floodlighting, electroluminescent panel lighting, and numeric displays were controllable in intensity steps at the panel or console. Lamp testing capability was provided for panel displays. Radiation or luminescent type paint was not allowed.

c. Emergency Lighting. The module provided the manual or automatic emergency lighting of the work areas. This requirement could be satisfied through the use of overhead emergency lighting.

d. Automatic/Manual Override. Controls and displays provided the capability for manual override of critical automatic systems to assure mission success or crew safety.

e. Ground/Crew Operations. Experiment displays for ground and crew controlled systems reflected true system status. [NOTE: Some problems were encountered during the missions with inaccurate or unreliable film and magnetic tape usage indicators.]

f. Pyrotechnics Control. The flight crew was the sole source of control of all pyrotechnic devices required for on-orbit operations.

g. Redundancy Control. Crew controls were provided for selection of redundant system capabilities.

h. All controls and displays were recessed or provided with "bump-proof" switch guards, especially for panels located in high-traffic areas.

i. Operation of experiment controls was limited to one-man operation, i.e., no single experiment operation required two crewmen simultaneously.

j. The crew monitored the progress of each experiment observation and were provided the capability to terminate observation due to lack of data quality.

k. Instruments provided automatic calibration, but provided crew capability to initiate a calibration procedure.

l. Where feasible (and not excessively time-consuming), crew capability to perform a function effectively was utilized instead of automating the function.

m. Experiments were designed to operate in a powered-down mode during launch and reentry phases. If any experiment operation was required during these phases, it was monitored and controlled from the module.

5. Flight Operation Crew Interface Constraints

a. To the maximum extent possible, crew mobility/stability aids for experiments were preinstalled.

b. The crewmen were alerted to any existing or impending crew hazard condition by an appropriate signal to the Caution and Warning System.

c. Attachment provisions for mounting the carry-in equipment, instruments and devices, if any, were preinstalled in the module prior to launch.

d. All launch-stowed experiment equipment was stowed such that it could be obtained without EVA.

e. The module generally provided the following crew aids and restraints:

(1) Provisions for locomotion and restraint were located throughout the module to facilitate crew movement between various work stations.

(2) Both permanent and portable general restraint devices were provided, to allow the crew to adequately perform activities at the various crew stations.

(3) Adequate foot restraints were provided each crewman for use while performing normal or contingency tasks.

f. EVA tasks, including contingencies, could not require more than two crewmen (i.e., at least one crewman remaining inside the spacecraft at all times).

g. A manual backup mode was provided for all mechanical, EVA, and film magazine transfer devices.

h. EVA crew work stations at the experiment were illuminated to 5 ft-lamberts minimum.

i. The module provided the capability to turn off all external lights, either by crew or ground command, while performing light-sensitive experiments.

j. Human Engineering. MSFC-STD-267 or MIL-STD-1472 were applied as guides for standards and practices for Human Engineering design.

6. Other Flight Operation Constraints

a. Fire, Toxicity, Radiation

(1) Nonflammable structural materials were required in the module environment. Interior walls and secondary structure were constructed of self-extinguishing material.

(2) To the extent necessary to ensure crew safety, materials selected for use in habitable areas were nonexplosive, nonflammable, nontoxic, and low-outgassing under normal operational conditions as well as under conditions of depressurization.

(3) Experiment radiation sources required NASA EDC approval for usage.

b. Contamination Control

(1) Shields

(a) Contamination-sensitive elements were located to take maximum advantage of natural shielding by the vehicle structure.

(b) Contamination-sensitive elements were shielded from any direct impingement of the attitude control system or venting contaminants, unless such shielding would be detrimental to the operation of the contamination-sensitive element.

(2) Covers

(a) All optical instruments exposed to the external environment were protected from contamination during non-data-taking periods by movable covers over the instrument aperture.

(b) Instrument covers were designed so that the most probable failure modes were in the open position. A backup activation mechanism to permit emergency cover opening was provided.

(e) Storage containers were provided for contaminant-sensitive experiments which were stowed in the module. Containers were atmosphere-tight and capable of dry nitrogen purge or evacuation after insertion of the experiment for storage.

(3) Material Selection. All materials used in construction of experiment and module hardware were evaluated for outgassing and dusting characteristics. The following specifications were applicable:

(a) Material Outgassing Control. Materials selection conformed to the requirements of the program specifications (e.g., 50M02442, ATM Material Control for Contamination Due to Outgassing).

(b) Material Dusting Control. All materials were selected for minimum dusting, powdering, or flaking characteristics. Where no acceptable material to perform the function was available, covers or coatings were used to contain the dusting products, or other protective means (such as filters) were provided for reduction of dust products entering the cabin or external atmosphere.

(4) Wherever practical, mirrors, lenses, prisms, windows and other instrument optical elements that were expected to be degraded by contamination were designed so that they could be periodically replaced by the crew with a spare element.

(5) Electric heaters on windows, lenses and mirrors were used where practical to maintain the optical element at an elevated temperature in order to prevent contaminant deposition, or to periodically heat the optical element (window) to drive off accumulated internal condensation.

(6) Photographic film was packaged in canisters to reduce possible contamination effects prior to camera loading. Premission film testing revealed that certain film types (in particular, Schulman types, non-overcoated) are susceptible to severe fogging in the presence of non-anodized aluminum or copper; these materials should be avoided in design of film storage containers.

(7) Venting and Dumping

(a) Waste storage tanks were of adequate size to allow a minimum of one orbit's accumulation between dumps. (The design goal to store all liquid wastes for the entire operational period was actually achieved.)

(b) Waste vents were positioned as remotely as possible from sensitive surfaces and were directed so that minimum impingement occurred on any module components.

(c) Nozzle orifice design and discharge pressure were chosen to provide the minimum practical cone angle pattern for the discharge stream. Waste dribble at the beginning and end of a dump was minimized.

(d) Solid waste was packaged and stored wherever possible. If dumping was required, all solid waste was dumped into the waste tank in packaged form. Dumps were timed to occur between operations of critical experiments.

(8) To avoid contamination, dry lubrication was the preferred method for mechanisms exposed to space.

7. Ground Operation Constraints for Flight Hardware.

a. General Constraints

(1) Experiments were installed in the module prior to installation of the module on the launch vehicle.

(2) All subsystems included provisions for deactivation and monitoring required to assure personnel and hardware safety.

(3) The experiments were designed to allow integration, checkout, operation, refurbishment and maintenance activities to be performed in either horizontal or vertical position.

(4) All hardware was capable of satisfying and maintaining Class 100,000 cleanliness as a minimum.

b. Mechanical Constraints

(1) Interface cables and fluid lines were of sufficient length (service loop) to allow interface connections to be made before mechanical mating of the experiment

(2) Interface fluid lines and electrical cables were designed so that individual cables or lines could be removed without disrupting the integrity of adjacent lines.

(3) Transportation and handling equipment was designed to ensure that flight structures were not subjected to transportation loads more severe than flight design conditions.

(4) Design of the experiment minimized problems due to moisture condensation and dripping.

(5) The design and routing of flight and GSE cables and fluid lines was such that these cables and fluid lines would not pose any obstruction to module egress or be subject to damage.

(6) Where possible in the design of the experiment, consideration was given to using captive-type fasteners for internal mounting of experiment components, to preclude loss of attachment hardware.

(7) Experiment thermal control subsystems were designed so that constant or periodic circulation of fluids was not required during periods of power-down or storage, and to provide ease in the servicing of fluids including fill, drain, and dry operations.

c. Electrical Constraints

(1) Instrumentation system capabilities and sensors required to support ground test activities were included in the flight hardware wherever practical, in order to minimize the requirements for separate ground support equipment.

(2) Where feasible, pyrotechnic devices were category B as defined in GP-469, Explosive Safety Handbook (i.e., "Category B electric-explosive devices are those which will not, in themselves or by initiating a chain of events, cause injury to people or damage to property").

B. Ground Support Equipment

1. General

a. Onboard monitoring and control of those operations which might be hazardous to ground test personnel were capable of being monitored and controlled by GSE.

b. GSE required for support of ground testing, monitoring, and servicing activities was minimized by making maximum use of the flight subsystems to support these functions. GSE related to ground servicing included provisions for external excitation voltage and monitoring capability, to preclude the necessity of internal power-up for these activities.

c. Development testing of GSE was required only when it was impractical, impossible, hazardous or not cost-effective to rely solely on an engineering analysis or acceptance verification to establish functional performance.

d. Qualfication testing was accomplished on an exception basis only, for those items of GSE which could not be qualified by analysis or similarity.

e. Experiment-specific GSE was provided by the ED. This GSE was designed to interface with standardized facility support interfaces for power, fluids, etc.

f. The design of the GSE took into consideration the existing facilities' capabilities at the module integration site, launch site, and any other users' facilities, as applicable. Every effort was made to provide identical sets of GSE for use at the various test locations.

g. Means were provided for controlled movement of hardware that was not easily hand-manipulated (e.g., tracks, guides or other restraining devices with spacing and friction controls), to minimize the potential of damage to adjacent equipment and hazards to personnel.

h. The experiments were protected as necessary during all handling operations.

i. Containers for transporting hazardous material had adequate handles and lids and indicated when they were positively closed. Also, easy-to-recognize markings identifying contents, information or special handling notes were provided.

2. Design and Construction. GSE design adhered to known state-of-the-art and to the selection of proven parts, materials, and processes to the degree practical. The design was restricted to the accomplishment of the GSE requirements.

a. Operation Periods. After adjustment, GSE was designed to operate for a period commensurate with the function being performed, without requiring readjustment of controls when set for specific operating conditions.

b. Redundant Electrical Circuits. Redundant electrical circuits in GSE were not routed through the same connector.

c. Operating Power. GSE was designed to be compatible with the power existing at the facilities to be used.

d. Racks and Consoles. The design of subassembly racks and consoles included entry access for cables and cooling systems that were compatible with the facilities in which they were to be used.

e. Fluid (Gas and Liquid). The GSE necessary to support fluid systems transferred, conditioned and/or stored the fluid suitable for the ultimate system usage.

f. Cleanliness. GSE was designed, manufactured, assembled, and handled in a manner such that its presence and/or operation in the applicable clean areas and flight vehicles would not violate the cleanliness levels maintained therein. In cases where GSE was used for the transportation, handling or removal of experiments, the GSE was designed to provide adequate means of contamination control consistent with the cleanliness levels of the module involved.

g. Test Provisions. GSE was designed so that failure within the GSE or interruption of power would not cause failure or damage to the flight hardware being tested. Conversely, failure of the flight hardware being tested could not cause failure or damage to the GSE.

h. Single Point Failures. GSE was designed so that a single point failure would not affect crew or ground personnel safety, cause loss of flight hardware, prevent or compromise accomplishment of a primary mission objective or cause a launch to be rescheduled.

i. Standard Parts. NASA, Air Force-Navy (AN), Military Standard (MS) or joint Air Force-Navy (JAN) standard parts were used in GSE wherever applicable.

j. Corrosion Prevention. Metals used in GSE were of the corrosion-resistant type or suitably treated to resist any corrosive conditions likely to be met in manufacture, assembly, testing, servicing, storage or normal service use.

k. Electromagnetic Interference. Electrical and electronic GSE was designed to perform as specified when operating either independently or in conjunction with other equipment with which an electrical connection was made, or which may have been installed nearby; and would not, in itself, be a source of interference which might adversely affect the operation of other equipment. GSE was designed to meet the requirements and limits of MIL-STD-461. (Reference MIL-STD-462).

l. Single Point Electrical Grounding. All units (racks, consoles, enclosures) using or generating electrical energy were provided with an accessible and clearly marked ground stud for single point grounding purposes. The DC resistance between any metal part of the units (covers, lids, hinged doors, etc.) and the ground stud could not be greater than 100 milliohms.

3. Maintainability. Maintainability criteria for GSE were specified to satisfy the following requirements:

a. Accessibility. GSE was designed to permit ease of access to accomplish maintenance functions, i.e., inspection, servicing, adjustment, calibration, or repair. Inspection, maintenance or test locations were identified and easily accessible.

b. Disassembly Provisions. GSE was designed to permit ready disconnection, removal and replacement of major assemblies or components through use of modular construction design principles.

c. Environmental Requirements. GSE was capable of successfully performing the required functions during or after being subjected to the natural and induced environments encountered during each of the modes of transportation, handling, operation and storage.

d. Transportability. Wherever possible, GSE was designed to withstand handling and transportation environments without the necessity of special containers, or the necessity of monitoring critical environments to verify that design limits had not been exceeded.

APPENDIX E

EXPERIMENT TESTING

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EXPERIMENT TESTING

A. Development Phase

1. Requirements. Experiment hardware acceptance was contingent upon prior verification that the end item would meet each technical (performance, interface or design) requirement of the applicable EIS. Verification could be accomplished either by assessment or by test (or a combination of the two). Commonly used assessment methods were:

- Similarity: Used when it could be shown that the article was identical or substantially similar in design, manufacturing processes, and quality control to another article that had previously been qualified to equivalent or more stringent criteria.

- Analysis: Used in lieu of testing whenever it could be shown by generally accepted analytical techniques that an article would meet the applicable technical requirements.

- Inspection: Used when it could be shown that inspection techniques were adequate to assure that the article would meet the applicable technical requirements. Inspection was used to verify construction features, compliance to drawings, workmanship, and physical condition of the article.

- Demonstration: Used when it could be shown that demonstration was adequate to assure that the article would meet the applicable technical requirements. Demonstration was used to verify such requirements as service and access, handling. convenience and ease of operation.

- Validation of Records: Used when it could be shown that records would substantiate manufacturing processes, materials, traceability, or test history performance.

For cases where assessment methods were not applicable, it was generally necessary to accomplish verification by testing. Test programs were designed to avoid duplication and to require only the minimum tests necessary, subject to considerations of hardware criticality and complexity. The influence of the hardware Criticality Category (see Section X) was to emphasize verification by test for Category 1 hardware, by combinations of test and assessment for Category 2, and by assessment rather than test (where feasible) for Categories 3 and 4.

2. Test Types

a. Development Tests. Development tests, as necessary, were performed to acquire data to support the design and development process; to verify feasibility of the design approach by evaluating hardware performance, design margins and/or failure modes under simulated or actual environmental conditions; and to provide confidence in the ability of the hardware to pass qualification tests by verifying selected performance/design requirements. Hardware used for development testing was representative of, but not necessarily identical to, the flight experiment hardware. A Development Test Specification was prepared by the ED for each development test and submitted for EDC review. Test procedures and a report for each development test were prepared by the ED and made available at appropriate development milestones.

b. Qualification Tests. Qualification tests were performed to verify that the design met the technical requirements of the EIS, assuring operational suitability in the anticipated environments. Qualification test hardware was required to be identical in configuration and production processing to the flight hardware. A Qualification Test Specification and procedures were prepared by the ED and submitted for EDC review. A formal report of qualification test results was submitted for EDC approval at completion of the tests. The qualification test program was to be scheduled such that there was sufficient time to allow for possible failures, rework during testing, and preparation, review and approval of the final test report, prior to acceptance of the flight hardware.

General requirements for qualification testing were:

(1) Qualification tests were to be conducted at the highest practical level of hardware assembly.

(2) If qualification tests were to be conducted on the entire end item, then acceptance tests were conducted on qualification test hardware prior to qualification tests being conducted.

(3) Sequence of the qualification tests followed the same order in which the environments were to be encountered by the flight hardware.

(4) Tests to determine whether the qualification test hardware was performing within specification tolerances were conducted after each environmental exposure, and during the exposure period if the flight hardware was required to operate in that environment.

(5) Qualification tests were performed under strict control of environments and test procedures. Adjustment or tuning of qualification test hardware was not permitted during tests unless it was normal for in-service operation.

(6) Where redundancy in design existed, the qualification tests assured that each redundancy was qualified.

(7) If the design configuration or manufacturing processes were changed after acceptance tests on qualification test hardware were initiated, any differences existing between the qualification test hardware and the flight and backup hardware invalidated verification and required repeating the qualification test.

(8) Qualification tests were to be completed prior to the delivery of flight or backup hardware.

(9) Where considered necessary, components of qualification test hardware were disassembled after testing was completed, and inspected to determine margins of safety and potential failure modes.

(10) Types of Test Environments: Humidity; salt fog; high temperature (160°F on Skylab); low temperature (-40°F on Skylab); shock; fungus; positive pressure (for hermetically sealed equipment); acceleration; vibration (sinusoidal resonance search, sinusoidial cycling, and random vibration); acoustic noise; altitude or space simulation; and atmospheric compatibility (oxygen, nitrogen, or two-gas environment).

c. Acceptance Tests. Acceptance tests were conducted to verify the performance and configuration of each experiment hardware end item at the time of its acceptance by the Government or delivery to another NASA center. The ED prepared (subject to EDC review) an Acceptance Test Specification, defining the limits and methods for each test, and Acceptance Test Procedures based on this specification. Data sheets were prepared showing the results of all acceptance tests performed.

General requirements for acceptance testing were:

(1) Environmental tests were included in acceptance tests in instances where a type of manufacturing flaw could not be detected by inspection or other nondestructive means (e.g., conducting a vibration test on electronic equipment to find faulty solder joints).

(2) The severity, duration, and number of tests were constrained so as not to result in overstressing or degradation of the hardware performance capability.

(3) Where possible, all normal, alternate, redundant and emergency operational modes were tested.

(4) The hardware was calibrated and aligned prior to conducting acceptance tests.

(5) Acceptance tests were performed under strict control of environments and test procedures. Adjustment or tuning of hardware was not permitted during acceptance testing unless it was normal for in-service operation.

(6) Any repairs, modifications or replacements after completion of acceptance tests required retesting to assure the acceptability of the change.

B. Integration Phase

1. Requirements. Integration tests were performed to verify those interface requirements that could not be formally verified at the individual experiment hardware level. General integration test requirements were originally baselined in the ERD, including an experiment hardware flow diagram from the ED through the module integration and launch sites, types of tests at each site and associated special constraints. These requirements and constraints were later amplified and updated in the EITRS documents, which reflected concurrence of all agencies involved (i.e., the ED, EDC, EIC, Module Development Center and Contractor, as applicable). The Module Development Center/Contractor then developed the detailed TCRSD, covering integration testing at both module and launch sites. The TCRSDs contained detailed requirements for each test, criteria for judging the success of the test, and any special constraints. From these detailed requirements, the site responsible for conducting the test prepared detailed test procedures to satisfy each requirement. At module integration sites, satisfaction of the requirements was a constraint on acceptance of the module. At the launch site, satisfaction of the requirements was a constraint on flight readiness.

2. Test Types. Normally, all of the following tests (as applicable) were performed in the initial experiment integration at the module site; ideally, only minimal integrated systems testing was performed on experiments at the launch site. However, if it was necessary to remove an experiment for calibration, maintenance or modification (or if its interfaces were otherwise disturbed) at any time after module integration, all applicable integration tests had to be repeated prior to the launch site integrated systems test.

a. Receiving and Inspection (R&I). Whenever hardware was delivered to a site, the equipment and its accompanying data package were inspected for completeness and any evidence of physical damage. The hardware was not actually operated during R&I unless there was an indication of physical damage during shipment.

b. Pre-Installation Tests (PIT). Following R&I, the hardware was delivered to a clean room (normally class 100,000), where it was set up and tested using experiment GSE. Testing was limited to that needed either to verify that baseline calibration data remained valid or to determine a new data baseline prior to mating the experiment to the flight vehicle. This baseline data (collected either during the PIT or during the earlier acceptance test at the ED site) was needed prior to system testing on board the module for comparison with data collected during the module system test, in order to determine the effect of module environment (electrical, EMI, etc) upon the experiment.

c. Functional-Interface Verification Test (FIV). The objectives of these tests were strictly limited to verification of all interfaces with the module. FIV began with verification of mechanical interfaces by mounting the experiment in the module. If installation of the experiment involved a part of the module primary pressure structure, the seal of the experiment was leak tested following installation. Following mechanical installation in the module, polarity of the module power input at the experiment interface was checked. A megger-ohm test was performed upon the experiment prior to electrical mating, to verify that the experiment hardware was properly isolated from the module and that experiment input impedances met interface requirements. Using a "break-out box" between the module power cable and the experiment power connector, measured power was applied to the experiment and calculations were made to verify the experiment power profile. Following these power checks, the power connector was mated directly and the experiment was operated under flight conditions (as far as practicality would permit) to verify the remaining experiment electrical interfaces. All modes of the experiment operation were not functioned unless an interface was involved that would not be tested otherwise.

d. Integrated Systems Tests. Following successful completion of all interface verifications of individual experiments, integrated system tests were conducted to verify that experiments and module systems could play together without degradation of the performance of either. These tests were characterized primarily as electromagnetic compatibility tests, and were performed utilizing existing flight plans and checklists, with flight crew participation, to the greatest extent possible. The tests were evaluated by comparison of their data with baseline data provided by the experiment acceptance and/or PIT tests.

REFERENCES

1. Lessons Learned on the Skylab Program. Prepared by Headquarters Skylab Program Office, Engineering Directorate; March 11, 1974.

2. Lessons Learned on the Skylab Program. Prepared by George C. Marshall Space Flight Center, Skylab Program Office; February 22, 1974.

3. Lessons Learned on the Skylab Program. Prepared by Kennedy Space Center; April 1, 1974.

4. Lessons Learned on the Skylab Program. Prepared by Lyndon B. Johnson Space Center, Houston, Texas; JSC-09096; July 18, 1974.

5. NHB 8030.6, Guidelines for Acquisition of Investigations. National Aeronautics and Space Administration, Washington, D.C. 20546; July 1974 Edition.

6. MSFC Skylab Corollary Experiment Systems Mission Evaluation. NASA TM X-64820, September 1974.

7. MSFC Skylab Apollo Telescope Mount Experiment Systems Mission Evaluation. NASA TM X-64821, June 1974.

8. MSFC Skylab Corollary Experiments. NASA TM X-64809, July 1974.

9. MSFC Skylab Apollo Telescope Mount. NASA TM X-64811, June 28, 1974.

10. System Safety Checklist, Skylab Program Report. NASA TM X-64830, May 30, 1974.

11. MSFC Skylab Crew Systems Mission Evaluation. NASA TM X-64825, August 1974.

12. Man/System Design Criteria for Manned Orbiting Payloads. MSFC-STD-512.

13. MSFC Skylab Contamination Control Systems Mission Evaluation. NASA TM X-64826, May 1974.

APPROVAL

EXPERIMENTER'S REFERENCE

BY

EXPERIMENT DEVELOPMENT AND PAYLOAD EVALUATION PROJECT

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Henry B. Floyd, Manager
Experiment Development and Payload Evaluation Project

Rein Ise
Manager, Skylab Program Office

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