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MSFC SKYLAB COROLLARY EXPERIMENTS

Skylab Program Office

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George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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16. ABSTRACT

This report documents the evolution of the development and integration of Skylab experiments from initial concepts through mission operations. All experiment systems are covered as well as management controls which were developed and exercised to assure acceptable operational capability and optimize data acquisition for final scientific results.

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NONSTANDARD ABBREVIATIONS

AAP	Apollo Applications Program
ADDT	All Data Digital Tape
ADP	Acceptance Data Package
ADRS	Automated Data Requirements System
AM	Airlock Module
AR	Action Request
ARC	Ames Research Center
ATM	Apollo Telescope Mount
ATP	Acceptance Test Plan
CCB	Change Control Board
CCBD	Change Control Board Directive
CDR	Critical Design Review
CIR	Configuration Inspection Review
CM	Command Module
COFW	Certificate of Flight Worthiness
CMG	Control Moment Gyro
CSM	Command and Service Module
DCR	Design Certification Review
DOD	Department of Defense
DR	Discrepancy Report
DRF	Data Request Form
DSO	Data Support Organization

NONSTANDARD ABBREVIATIONS (Continued)

ECE	Experiment Compatibility Engineer
ECR	Engineering Change Request
ECSR	Experiment Compatibility Status Report
ED	Experiment Developer
EDC	Experiment Development Center
EIC	Experiment Integration Center
EIE	Experiment Integration Engineer
EIP	Experiment Implementation Plan
EIS	End Item Specification
EITRS	Experiment Integration Test Requirements Specification
EM	Experiment Manager
EOH	Experiment Operations Handbook
ERD	Experiment Requirements Document
EREP	Earth Resources Experiment Package
EVA	Extravehicular Activity
FMT	Flight Management Team
FOMR	Flight Operations Management Room
FRR	Flight Readiness Review
GSE	Ground Support Equipment
HOSC	Huntsville Operations Support Center
ICD	Interface Control Document
IE	Integration Engineer
IRN	Interface Revision Notice
IU	Instrumentation Unit

NONSTANDARD ABBREVIATIONS (Continued)

JSC	Lyndon B. Johnson Space Center
KSC	John F. Kennedy Space Center
LaRC	Langley Research Center
LM	Lunar Module
MAR	Mission Action Request
MCC	Mission Control Center
MDA	Multiple Docking Adapter
MRD	Mission Requirements Document
MSFC	George C. Marshall Space Flight Center
MSFEB	Manned Space Flight Experiments Board
MSG	Mission Support Group
MSGL	Mission Support Group Leader
NASA	National Aeronautics and Space Administration
NSTA	National Science Teachers Association
OART	Office of Advances Research and Technology
ODB	Operational Data Book
OMSF	Office of Manned Space Flight
OSSA	Office of Space Science Applications
OWS	Orbital Workshop
PAT	Postacceptance Testing
PATRS	Postacceptance Test Requirements and Specifications
PD	Project Directive
PDR	Preliminary Design Review
PI	Principal Investigator

NONSTANDARD ABBREVIATIONS (Concluded)

PRR	Preliminary Requirements Review
PSRD	Program Support Requirements Document
RID	Review Item Discrepancy
SAL	Scientific Airlock
SAS	Solar Array System
SL-1	Skylab-1
SL-2	Skylab-2
SL-3	Skylab-3
SL-4	Skylab-4
SL-DP	Experiment Development and Payload Evaluation Project Office
SL-EI	Program Engineering and Integration Project Office
SM	Service Module
SOCAR	Skylab Systems/Operations Compatibility Assessment Review
SPO	Sponsoring Program Office
STE	Special Test Equipment
TCN	Test Change Notice
TCP	Test and Checkout Procedure
TCRSD	Test and Checkout Requirements Specification and Criteria Document
TDM	Technical Discipline Manager
TV	Television
UV	Ultraviolet

TECHNICAL MEMORANDUM X-64809

MSFC SKYLAB COROLLARY EXPERIMENTS FINAL TECHNICAL REPORT

SECTION I. SUMMARY

The evolution of the Skylab Program and the corollary experiment payload development and integration are described in this report. The procedures employed by the George C. Marshall Space Flight Center (MSFC) and supporting contractors to bring these experiments from their initial selection through mission operations are discussed. MSFC had development responsibility for 59 experiments and integration responsibility for 88 of 94 total program experiments. This report covers the 60 corollary experiments integrated by MSFC.

The experiment payload selection was guided by the program objectives which were, in order of priority: a) biomedical and behavioral performance, b) man-machine relationships, c) long-duration system operations, d) experiments (solar astronomy, scientific, engineering, technology and other corollary experiments). The final complement of experiments was also influenced by major National Aeronautics and Space Administration (NASA) decisions to employ the cluster concept and the dry workshop, and to incorporate earth resources experiments. Three experiment groups added in the two years before launch were: additional materials processing, student, and space environment experiments. Two investigations were conceived and added during the mission. They were the Comet Kohoutek viewing program and the science demonstrations.

The report discusses in detail each phase of experiment development and integration, and describes the roles and responsibilities of NASA agencies and supporting contractors. It spans the program evolution from the early Apollo extension studies through the Apollo Applications Program, the Cluster concept, the Dry Workshop, the Skylab missions, to the present data analysis and reporting activities.

Finally, conclusions and recommendations are presented from a "lessons-learned" approach. Each conclusion is followed by a recommendation for future programs.

SECTION II. INTRODUCTION

The activities of the Experiment Development and Payload Evaluation Project Office (SL-DP) and supporting MSFC organizations and contractors are described. SL-DP was responsible for development of all MSFC experiments except Apollo Telescope Mount (ATM) (51 experiments, 1 operational instrument and 17 science demonstrations). They were responsible for integration of these plus 29 JSC experiments (9 corollary, 14 medical and 6 earth resources experiments. The total flight experiment complement is listed in table I which indicates development and integration responsibilities and identifies those treated as corollary experiments.

Corollary experiments are defined in Skylab Program Directive 43 as those that require significant in-flight crew support but are not as closely related to each other as the "group-related" experiments (i.e., medical, solar astronomy and earth resources). The student experiments (designated EDXX) are considered in the category of corollary experiments.

The program phases are traced in chronological order, starting with the Principal Investigator's (PI) proposal, the experiment's acceptance, and its assignment to an experiment development center (EDC). Thereafter the report follows the integration of the experiment through hardware development, acceptance by the NASA, postacceptance testing at the module level both at contractor facilities and at John F. Kennedy Space Center (KSC), and culminating in a flight readiness certification. In parallel with these efforts the report discusses the various aspects of mission planning in coordination with the Lyndon B. Johnson Space Center (JSC), especially in establishing operational and flight data requirements and reviewing crew procedures. On-site mission support at MSFC and JSC is described, highlighting the areas of organization, facilities, data handling, problem investigation and resolution.

The management approach, controls, and major events that were employed to successfully develop and integrate the subject experiments are described. MSFC experiment descriptions and mission performance evaluations are presented in TM X-64820, MSFC Skylab Corollary Experiment Systems Mission Evaluation Report [1].

TABLE I. SKYLAB FLIGHT EXPERIMENTS/INSTRUMENT

NUMBER	EXPERIMENT TITLE	DEVELOPMENT RESPONSIBILITY		INTEGRATION RESPONSIBILITY		COROLLARY EXPERIMENT
		MSFC	JSC	MSFC	JSC	
D008	Radiation in Spacecraft		X(DOD)		X	X
D024	Thermal Control Coatings	X(DOD)		X		X
ED11	Absorption of Radiant Heat in the Earths Atmosphere	X		X		X
ED12	Space Observation and Prediction of Volcanic Eruptions	X		X		X
ED21	Photography of Libration Clouds	X		X		X
ED22	Possible Confirmation of Objects within Mercury's Orbit	X		X		X
ED23	Spectrography of Selected Quasars	X		X		X
ED24	X-Ray Content in Association with Stellar Spectral Classes	X		X		X
ED25	X-Ray Emissions from the Planet Jupiter	X		X		X
ED26	A Search for Pulsars in Ultraviolet Wavelengths	X		X		X
ED31	Bacteria and Spores	X		X		X
ED32	In-Vitro Immunology	X		X		X
ED41	Motor Sensory Performance	X		X		X
ED52	Web Formation	X		X		X
ED61	Plant Growth	X		X		X
ED62	Plant Phototropism	X		X		X
ED63	Cytoplasmic Streaming	X		X		X
ED72	Capillary Studies	X		X		X
ED74	Mass Measurement	X		X		X
ED76	Neutron Analysis	X		X		X
ED78	Liquid Motion	X		X		X
Hα-1	ATM Hydrogen Alpha Telescope No. 1	X		X		
Hα-2	ATM Hydrogen Alpha Telescope No. 2	X		X		
M071	Mineral Balance		X	X		
M073	Bioassay of Body Fluids		X	X		
M074	Specimen Mass Measurement		X	X		

TABLE I. SKYLAB FLIGHT EXPERIMENTS/INSTRUMENT (Continued)

NUMBER	EXPERIMENT TITLE	DEVELOPMENT RESPONSIBILITY		INTEGRATION RESPONSIBILITY		COROLLARY EXPERIMENT
		MSFC	JSC	MSFC	JSC	
M092	Inflight Lower Body Negative Pressure		X	X		
M093	Vectorcardiogram		X	X		
M112	Man's Immunity, In-Vitro Aspects		X	X		
M113	Blood Volume and Red Cell Life Span		X	X		
M114	Red Blood Cell Metabolism		X	X		
M115	Special Hematologic Effects		X	X		
M131	Human Vestibular Function		X	X		
M133	Sleep Monitoring		X	X		
M151	Time and Motion Study		X	X		
M171	Metabolic Activity		X	X		
M172	Body Mass Measurement		X	X		
M415	Thermal Control Coatings	X		X		X
M479	Zero Gravity Flammability	X		X		X
M487	Habitability/Crew Quarters	X		X		X
M509	Astronaut Maneuvering Equipment		X	X		X
M512	Materials Processing Facility	X		X		X
M516	Crew Activities and Maintenance Study		X	X		X
M518	Multipurpose Electric Furnace System	X		X		X
M551	Metals Melting	X		X		X
M552	Exothermic Brazing	X		X		X
M553	Sphere Forming	X		X		X
M555	GaAs Crystal Growth	X		X		X
M556	Vapor Growth of IV-VI Compounds	X		X		X
M557	Immiscible Alloy Composition	X		X		X
M558	Radioactive Tracer	X		X		X
M559	Microsegregation in Germanium	X		X		X
M560	Growth of Spherical Crystals	X		X		X
M561	Whisker-Reinforced Composites	X		X		X
M562	Indium Antimonide Crystal Growth	X		X		X
M563	Mixed III-V Crystal Growth	X		X		X

TABLE I. SKYLAB FLIGHT EXPERIMENTS/INSTRUMENT (Continued)

NUMBER	EXPERIMENT TITLE	DEVELOPMENT RESPONSIBILITY		INTEGRATION RESPONSIBILITY		COROLLARY EXPERIMENT
		MSFC	JSC	MSFC	JSC	
M564	Halide Eutectics	X		X		X
M565	Silver Grids Melted in Space	X		X		X
M566	Aluminum-Copper Eutectic					
S009	Nuclear Emulsion	X		X		X
S015	Effect of Zero-gravity on Single Human Cells		X		X	X
S019	UV Stellar Astronomy		X	X		X
S020	UV/X-Ray Solar Photography		X	X		X
S052	White Light Coronagraph	X		X		
S054	X-Ray Spectrographic Telescope	X		X		
S055	UV Scanning Polychromator Spectroheliometer	X		X		
S056	Dual X-Ray Telescope	X		X		
S063	UV Airglow Horizon Photography		X	X		X
S071	Circadian Rhythm, Pocket Mice		X(ARC)		X	
S072	Circadian Rhythm, Vinegar Gnats		X(ARC)		X	
S073	Gegenschein/Zodiacal Light	X		X		X
S082A	Extreme UV Spectroheliograph	X		X		
S082B	Ultraviolet Spectrograph	X		X		
S149	Particle Collection		X	X		X
S150	Galactic X-Ray Mapping	X		X		X
S183	Ultraviolet Panorama	X(FRANCE)		X		X
S190A	Multispectral Cameras		X	X		
S190B	Earth Terrain Camera		X	X		
S191	Infrared Spectrometer		X	X		
S192	Multispectral Scanner		X	X		
S193	Microwave Radiometer/Scatterometer & Altimeter		X	X		
S194	Microwave L-Band Radiometer		X	X		
S201	Far UV Electronographic Camera		X	X		X
S228	Trans-Uranic Cosmic Rays	X		X		X
S230	Magnetospheric Particle Composition	X		X		X
S232	Barium Plasma Observations		X		X	X

TABLE I. SKYLAB FLIGHT EXPERIMENTS/INSTRUMENT (Continued)

NUMBER	EXPERIMENT TITLE	DEVELOPMENT RESPONSIBILITY		INTEGRATION RESPONSIBILITY		COROLLARY EXPERIMENT
		MSFC	JSC	MSFC	JSC	
S233	Kohoutek Photometric Photography		X	X		X
T002	Manual Navigation Sightings	X(ARC)		X		X
T003	Inflight Aerosol Analysis	X(DOT)		X		X
T013	Crew/Vehicle Disturbance	LaRC		X		X
T020	Foot-Controlled Maneuvering Unit	LaRC		X		X
T025	Coronagraph Contamination Measurement		X	X		X
T027	Contamination Measurement	X		X		X
T053	Earth Laser Beacon		X(GSFC)		X	X
	TOTAL EXPERIMENTS - 94	59	35	88	6	64
	OPERATIONAL INSTRUMENT					
	Proton Spectrometer	X		X		

SECTION III. PROGRAM AND PAYLOAD EVOLUTION

A. Program Evolution

The Apollo Extensions Support Study during the early 1960s identified possible new or modified flight projects which could use launch vehicles and spacecraft components being developed for the Apollo Program. One of the possibilities considered at that time was the use of an Apollo Command and Service Module (CSM) to carry an assembly of small solar telescopes into orbit, to deploy and operate them from the Service Module (SM) with the assistance of the astronauts, and to return the exposed films to earth via the Command Module (CM). This assembly was named ATM in 1963. From these early efforts to extend the use of Apollo hardware, a permanent organization evolved. The Apollo Applications Office was established in August 1965 at NASA Headquarters in Washington, DC. The Apollo Applications Program (AAP) included long-duration, earth-orbital missions during which astronauts would carry out scientific, technological, and engineering experiments. Spacecraft and Saturn launch vehicles, originally developed for the Apollo Program, would be modified to provide the capability for crews to remain in orbit for extended time periods.

As these studies progressed, plans developed for more elaborate solar observations with a group of telescopes mounted on Apollo-related spacecraft. A first schedule, established in March 1966, envisioned three experiment modules consisting of Saturn S-IVB spent stages which would be converted to "workshops", and four ATMs. The S-IVB served as the second stage of the Saturn IB launch vehicle and as the third stage of the Saturn V launch vehicle.

According to these plans, the S-IVB stage would ascend into space as part of the Saturn IB launch vehicle, carrying a manned CSM. After the S-IVB stage had depleted its propellant supply, the astronauts in the CSM would dock with an Airlock Module (AM), passivate and enter the stage's hydrogen tank through the AM passageway to convert the S-IVB into an Orbital Workshop (OWS). A number of biomedical experiments would be performed in the CM. No crew quarters were planned in the OWS. Activities would be limited to familiarization with moving about in a controlled and enclosed environment under zero gravity. This concept of using the S-IVB stage was the precursor of the present Skylab.

In July 1966, NASA announced the establishment of new AAP offices at JSC and MSFC. A new schedule, released in December 1966, called for launches of two Saturn IB vehicles about one day apart; the first unmanned, the second manned. The astronauts would make the S-IVB stage hydrogen tank of the first vehicle habitable by installing equipment and introducing a life-supporting atmosphere so they could live and work there without the need for spacesuits. The hydrogen tank would be equipped (before launching) with two floors, some basic equipment, and an inner wall.

An AM would be attached to the S-IVB stage, and a Multiple Docking Adapter (MDA) would provide the CM docking ports. The S-IVB stage, the Instrumentation Unit (IU), the AM, and the MDA constituted this first workshop concept.

This plan introduced the "cluster concept" which envisioned additonal components for attachment to the workshop. A modified Lunar Module (LM) ascent stage of the kind that carried astronauts from the moon's surface in the Apollo Program, and an ATM would be launched together on one vehicle. The LM would be the control center for the ATM in orbit. This first launch would be followed by a manned launch. The LM and ATM would be attached to the workshop at a radial docking port of the MDA. The CSM with the astronauts would dock at the axial docking port of the MDA.

This workshop was called the "Wet Workshop" because the S-IVB stage would be launched "wet", that is, filled with propellant to be consumed before reaching orbit. The empty S-IVB would be passivated and then filled with a life-supporting atmosphere.

It was decided in March 1967 that the OWS would have solar panels to produce electric power. This increase in electric power production was required to enable the astronauts to live in the workshop. Before this change was made, the CSM had been planned to provide the workshop's power, except for the ATM, which was to have its own solar-electric power supply.

Limited funds for AAP led to a reduction of the number of launches and deferment of launch dates. A major redirection of AAP effort was made in July 1969. NASA then announced plans to launch the workshop and an elaborate ATM together on a Saturn V, using only two propulsive stages. The S-IVB (third) stage would not carry propellants, hence it was called the "Dry Workshop". It would be completely equipped on the ground for activation in orbit as a habitable system prior to astronaut entry. This decision was aided by the successful lunar landings which made Saturn V launch vehicles available for other purposes. Plans for two Saturn V launches with two workshops and two ATMs, and for seven Saturn IB launches, were announced in 1969. The first workshop launch was planned for July 1972.

The program was renamed in February 1970, when the AAP became the Skylab Program. The Skylab Cluster was to consist of the S-IVB/OWS, IU, AM, MDA, and ATM. Early in 1971, the planning date for launch of SL-1 (the unmanned cluster) utilizing a Saturn V vehicle, was set for April 30, 1973. Three manned missions (SL-2, SL-3, and SL-4) each utilizing a Saturn IB vehicle, were to follow. NASA announced, in January 1971, a request to United States and foreign experimenters for proposals to identify desired data to be obtained from an earth resources experiment package (EREP). The EREP program would utilize the advantages available by a manned orbital workshop.

NASA approved the Skylab Student Project in November 1971. A national competition among secondary school students was conducted by the National Science Teachers Association (NSTA) to stimulate interest in science and technology by directly involving students in space research. The experiments selected from this competition would encompass the disciplines of stellar astronomy, basic physics, botany, entomology, bacteriology and physiological psychology.

NASA announced the names of the Skylab astronaut prime crews in January 1972. SL-2 astronauts were Charles Conrad, Jr., Joseph Kerwin, and Paul Weitz. SL-3 astronauts were Alan Bean, Owen Garriott, and Jack Lousma. SL-4 astronauts were Gerald Carr, Edward Gibson, and William Pogue. Backup crews were assigned to each flight. SL-2 astronauts were Russell Schweickart, Story Musgrave and Bruce McCandless. Astronauts named for SL-3 and SL-4 were Vance Brand, William Lenoir and Don Lind.

A February 1973 Management Council Meeting decided that the SL-1 and SL-2 launches would not be able to meet the April 30 and May 1 launch dates, due to delays caused by unexpected checkout activities involving the modules at KSC. Tentative launch dates were set for May 14 and 15 respectively.

One of the last milestones prior to launch occurred on April 16, 1973 at 7 a.m. Eastern Standard Time, when the United States' first space station, SL-1 left the Vertical Assembly Building (VAB) and started rollout to Launch Complex 39A. Final checkout continued on the pad until the May 14 launch. Liftoff of SL-1 occurred at 1:30 p.m. Eastern Daylight Time and was nominal. During the SL-1 launch, there was an indication of early OWS meteoroid shield deployment. It was soon discovered that most of the OWS meteoroid shield had been destroyed and one OWS solar array system (SAS) wing torn off. A part of the shield was positioned such that it prevented deployment of the remaining OWS SAS wing. The SL-2 launch was delayed until May 25 to permit development of a thermal protection system and procedures for deploying the SAS wing.

On May 26, the crew successfully deployed the parasol thermal shield through the OWS solar scientific airlock (SAL) to alleviate the OWS thermal problem.

An extravehicular activity (EVA) was performed on June 7 to release the OWS SAS wing from its locked position. The astronauts were successful in doing so and the solar panels were deployed to their operating position. The OWS was now considered to be in a normal operation mode.

Skylab mission SL-2, and the missions that followed (SL-3 and SL-4) were all successfully completed.

B. Payload Evolution

1. Experiment Payload Definition Approach. NASA's first formal announcement of the AAP in 1965 proposed many types of missions, including low earth-orbital, synchronous orbital, lunar surface explorations and even one Mars voyage. In the peak planning period, 38 separate flights were projected. This large number of missions presented the opportunity to dedicate entire flights to specific scientific and technical disciplines.

Over five hundred available and potential experiments were cataloged. The catalog included those that had been considered for Gemini and Apollo as well as the Manned Orbiting Laboratory and other Department of Defense (DOD) programs. The experiments were categorized into the following major disciplines:

Biomedical, behavioral, bioscience
Astronomy
Space environment
Zero-g thermodynamics
Lunar surface
Communications/navigation
Remote sensors
Space station development
Space operations

Some of these experiments utilized existing instruments, but many were only in the conceptual stage, with hardware design no further than the functional block diagram level.

Integration trade studies and compatibility assessments were performed. The requirements of each experiment were carefully logged in an Experiment Analysis Form, later expanded into the Experiment Requirements Document (ERD), and entered into a computerized data bank. Frequent updates were made as firm design information became available.

2. Influence of Mission Evolution on Experiments. The payload complement selection was guided by NASA PDs [2], which established program objective priorities as:

Biomedical and Behavioral Performance - determine and evaluate man's physiological responses and aptitudes in space under zero-gravity conditions and his postmission adaptation to the terrestrial environment, through a series of progressively longer missions, and to determine the increments by which mission duration can be increased.

Man-Machine Relationships - to develop and evaluate efficient techniques utilizing man for sensor operation, discrimination, data selection and evaluation, manual control, maintenance and repair, assembly and set-up, and mobility involved in various operations.

Long Duration Systems Operations - to develop techniques for increasing systems life, for long duration habitability and for long duration mission control. To investigate and develop techniques for in-flight test and qualification of advanced subsystems.

Experiments - to conduct solar astronomy; and other science, technology and applications experiments involving man when his contribution will improve the quality and/or yield of the results.

Skylab experiments were also significantly influenced by major NASA mission decisions for the cluster concept, the dry workshop and EREP assignment.

a. Cluster Concept - NASA made the decision in 1967 to limit the AAP scope to a series of earth orbital flights using excess Saturn IB hardware. Essentially, a workshop or laboratory was to be outfitted in orbit utilizing a spent S-IVB fuel tank. An additional specially-designed docking adapter would allow the mating of a manned CSM. A 28-day visit and a 56-day visit were planned. Following these two missions, a LM-ATM with control moment gyros (CMG) was to be joined to the cluster, and solar astronomy was planned, utilizing a highly stabilized solar-inertial orientation.

A trade study of the experiments, "Impact of Eight Experiment Groups on AAP 1/AAP 2 and AAP 3", was performed to enable NASA to select from eight different discipline-weighted experiment options. The study assessed the integration impact of each option on payload weight and size, astronaut time, electric power, data, pointing, and control and display requirements. Each option included baseline biomedical experiments, but then emphasized either crew mobility performance, earth-looking applications, technology and space manufacturing, or a balanced group including several science experiments.

This study reduced the number of experiments to be consistent with the revised AAP cluster concept, and formed the basis for all subsequent categorizing of additional experiments.

b. Dry Workshop - Significant changes in the experiment complement were made possible when Saturn V launch vehicles became available from the Apollo Program. The workshop was to be outfitted on the ground, rather than in orbit; thus CMG-stabilized solar inertial orientation was made available as the basic operating mode for all three missions: one 28 days long and two 56 days long. This stabilization also provided an opportunity for more stellar-viewing experiments, especially since the increased payload launch capability allowed desireable add-ons such as solar and anti-solar SALs and an ultraviolet (UV) reflecting, articulated mirror system for increased exterior viewing capability. It was at this time that the French-sponsored Experiment S183 was approved, the first of several foreign participations. The French government developed S183, while NASA provided for its integration.

c. EREP Assignment - One of the eight options in the experiment study had been a detailed earth resources survey using an array of instruments. These sensors covered a broad frequency band from microwaves through infrared, into the visible spectrum. The Saturn V capability now allowed addition of EREP to Skylab and utilization of a higher-inclination orbit to survey a larger precentage of the earth's land mass, using man to select, observe and discriminate value and direct applications of space observations in agriculture, geography, forestry, geology, hydrology, oceanography, cartography and other earth sciences.

3. <u>Late Experiment Additions</u>. As part of a continuing assessment of ways to enhance the value of the Skylab missions, experiment add-ons continued to be considered as late in the program as possible. Three experiment groups were added during the two years prior to launch: additional materials processing, student and space environment experiments. Two major investigations were conceived and added during the actual missions: Comet Kohoutek viewing and science demonstrations.

a. Multipurpose Electric Furnance Facility - One option of high priority was the use of the space zero-g environment in biological, metallurgical and manufacturing processes. It became evident that the capability existed to expand the use of the early-planned M512 vacuum work chamber, designed to perform such operations as metals joining, crystal growth and metallurgical tests in space, to accomodate a Multipurpose Electric Furnace Facility, M518. This would allow a variety of small material samples to be processed in self-contained cartridges according to a carefully-controlled time/temperature profile. These samples are of great interest in the fast-growing solid state materials industry. When the opportunity to use this facility was announced, scientists from all over the world responded, resulting in the generation of experiments M556 through M566. The multipurpose electric furnace, along with EREP, developed the "facility" concept, which NASA is proceeding to utilize more and more in its future planning.

b. Student Experiments - In an effort to broaden interest in Skylab, a national competition for new experiments was initiated through the NSTA among all United States secondary school students. Twenty-five winners were selected by the NSTA, encompassing the disciplines of stellar astronomy, basic physics, botany, entomology, bacteriology, and physiological psychology. MSFC was directed by the Skylab Program Director to perform the development and integration efforts, and to be the NASA interface with the students. As a result of design studies and compatibility assessments, 11 student proposals were developed as hardware experiments and 8 were associated with existing Skylab experiments that could provide data to satisfy the requirements of the student's proposal. Six of the winning proposals were found to be incompatible with Skylab.

The Skylab Student Project utilized the concept of small, self-contained and portable experiments. These experiments could be stowed in lockers and easily deployed with a minimum of carrier/systems interfaces. This concept enabled rapid development of hardware at minimal costs and greatly facilitated the integration and mission planning activities. Operational procedures were relatively uncomplicated, requiring little crew time and a minimum of training. They could, in many cases, be allocated to short vacant time periods in the crew timelines, without significant impact on other more sophisticated experiments.

c. Space Environment - Two space environment experiments, S228 and S230, were proposed and approved late in the Skylab Program which required accelerated hardware and software development programs to meet existing launch schedules.

S228, a cosmic ray detector, was approved by the Manned Space Flight Experiment Board (MSFEB) in June 1972 on a contingency basis, i.e., if space and weight allowance were available for both launch and return. Design and fabrication of hardware was started in early November 1972 with delivery of the training unit and mockups the first week of January 1973, and delivery of the flight and backup units to KSC in early February 1973.

S230, a magnetospheric particle detector, was approved by the MSFEB in December 1972 with NASA center assignments made January 10, 1973. Hardware design and fabrication was started in January 1973 and the flight and backup units were delivered to KSC in April 1973.

d. Comet Kohoutek Observing Program - A unique opportunity was presented to astronomers in March 1973 when Dr. Lubos Kohoutek discovered a new comet from a plate taken on 7 March 1973 when it was very far away on its approach towards the sun (4.7 astronomical units). In the summer of 1973, NASA organized "Operation Kohoutek" to obtain physical comet data by every suitable means. A study was quickly made to evaluate which onboard instruments and what quickly-available additional instruments for SL-4 resupply could be used to view the comet in different wave-length bands. Also, a compatibility assessment was conducted to determine the impacts on Skylab systems, particularly the pointing maneuvers required.

After a series of bi-weekly intercenter meetings, it was decided to include two new experiments, S201 and S233. The S201 was a very sensitive, UV-responsive imaging camera, adapted from a prototype employed on the lunar surface during the Apollo Program. S233 provided a series of evolutionary hand-held photographs, which may be used for physical and photometric comet development analyses. In addition, it was agreed that many of the onboard instruments could have their operations supplemented by a Kohoutek Integrated Viewing Program. The Skylab sensors chosen to view the comet were the SAL experiments S019, S063 and S183. One operation of S073 provided three exposures viewing the orbital path for cometary debris. T025 was also chosen, to provide high resolution UV-spectral photography via an EVA during the near-perihelion phase. The ATM experiments were also selected to view the comet in the dynamic near-perihelion phase.

The failure of Comet Kohoutek to achieve its hoped-for brilliance to ground observers served only to greatly enhance the value of this viewing program to the scientific community.

e. Science Demonstrations - In February 1973, the Assistant Administrator for Public Affairs, suggested a program to help sustain public interest in Skylab by demonstrating scientific principles in action in a way suitable for network news programming. An initial list of demonstrations was prepared and reviewed by the Jet Propulsion Laboratory. By mid-March, they submitted a list of twenty suggested demonstrations. These were evaluated (in some cases expanded) by JSC personnel, resulting in twelve demonstrations being prepared for SL-3. The SL-3 Science Pilot, Dr. Owen Garriott, was very influential in getting the hardware and procedures ready for his mission. A science demonstration kit was prepared and launched on

SL-3 with the supplies needed to implement these demonstrations. The emphasis for SL-3 was the demonstration on television (TV) of known scientific principles in the weightless environment.

The SL-3 crew's efficiency was greater than planned, resulting in extra crew time being available. They asked for additional experiments or demonstrations to perform. The MSFC Corollary Experiment Mission Support Group (MSG) in response, requested suggestions from the MSFC laboratories for useful "fill-in" activities that could be performed with equipment already onboard Skylab. Numerous proposals were evaluated and six submitted to the Skylab Mission Scientist. Two of these were selected for SL-3 and were performed by the pilot, Jack Lousma, during the last few days of the mission.

Anticipating that time for "fill-in" activities would also be available during SL-4, 17 SL-4 science demonstrations, including repeats of the two performed by the SL-3 pilot, were prepared by MSFC, with assistance from JSC. An SL-4 science demonstration kit and other launch supplies and crew procedures were prepared and launched on SL-4. Although these extra supplies were needed, most of the equipment to be used was already onboard Skylab. Some of these "fill-in" activities were demonstrations of known scientific principles, but several were investigations of basic scientific principles that should contribute to development of future space experiments.

SECTION IV. ROLES AND RESPONSIBILITIES

The roles and responsibilities of the personnel and organizations associated with the Skylab Program and experiments are described in this section. These roles and responsibilities varied from program control and direction, the Skylab Integration Contractor support role, the "cradle-to-grave" experiment PI involvement, to a single review or test.

Skylab Program control and direction was provided by NASA Headquarters, Office of Manned Space Flight (OMSF), and was the Skylab Program Director's responsibility.

A. Experiment Events Flow

The experiment event flow description from concept through mission support is provided to enable an understanding of the personnel and organization interrelationships. This is shown in figure 1.

The initiation of an experiment varied, but basically the PI submitted a proposal (either on his own or through an EDC) to a Sponsoring Program Office (SPO), or responded to an Announcement of Flight Opportunity (AFO) prepared by NASA. This proposal was presented by the SPO to the MSFEB for evaluation. Selected experiments were assigned an EDC and an Experiment Integration Center (EIC). The PI assisted the EDC in preparation of the Experiment Implementation Plan (EIP) and the EIC with the preparation of the compatibility assessment. The experiment was again reviewed by the MSFEB and, if approved, experiment development began. The experiment progressed from requirements definition through mission operations with the coordinated efforts of EDC and EIC personnel. The MSFC Module Offices, through their module contractors, produced the modules that would support the experiments and installed and checked out the experiments therein. Finally, the Skylab was assembled on a launch vehicle, tested, and launched under the supervision of KSC. Mission operations were directed by JSC.

B. Principal Investigator

The PI was a member of the scientific community who generally developed the initial experiment concept. Typically, the PI's involvement was intense during the initial experiment development phases: initiating and justifying the experiment; planning the objectives and techniques; establishing the performance requirements; and defining

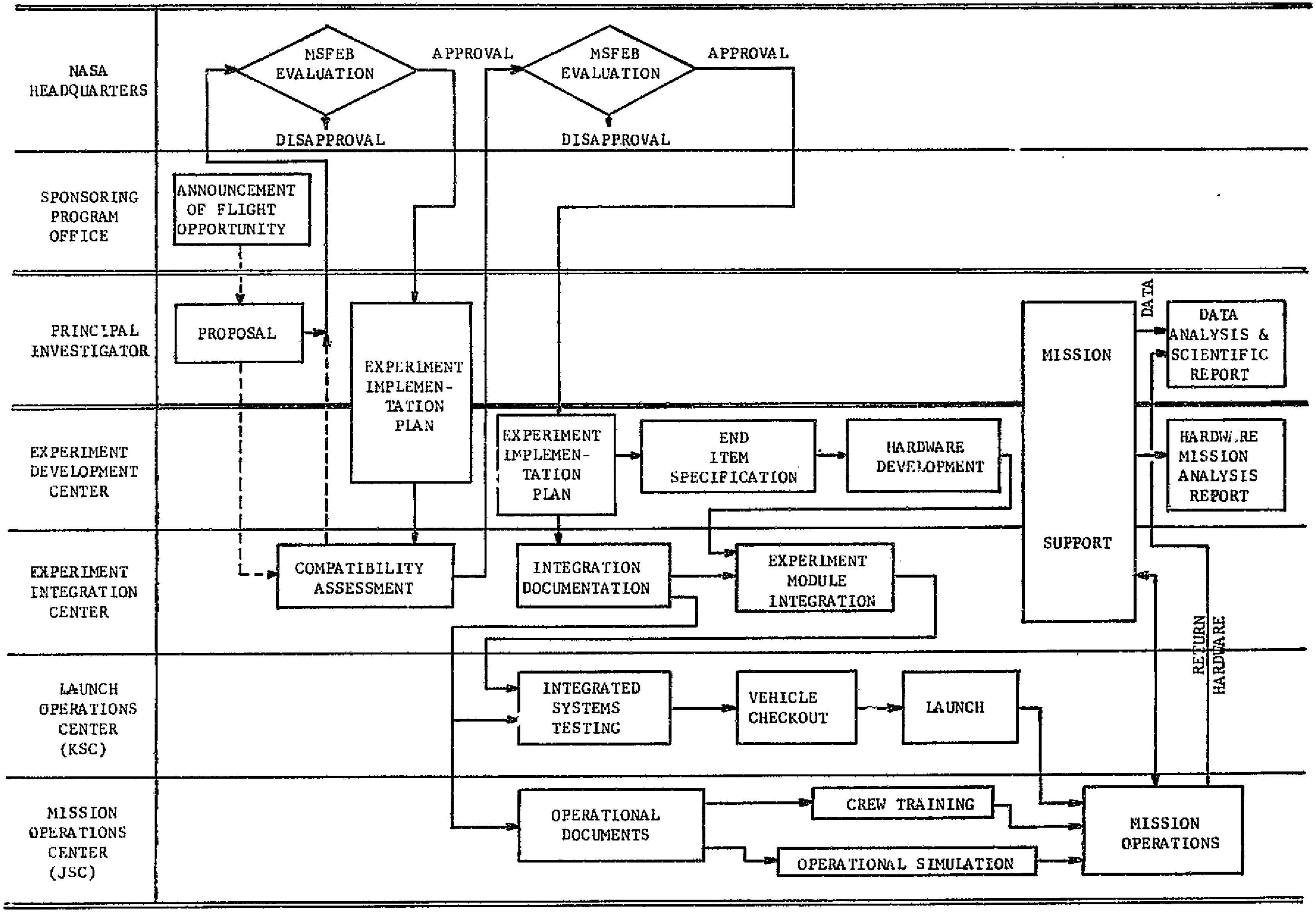

FIGURE 1. SKYLAB TYPICAL EXPERIMENT EVENT FLOW

the form, quality and quantity of data required. His role generally became one of monitoring and consulting during the hardware fabrication and test phases. He participated in the design and hardware reviews, supported mission planning and crew training, and often took an active role in resolving problems during development and test. During the mission, many PIs supported their experiments from the JSC Mission Operations Center participating in the day-to-day mission planning, and resolution of real-time problems. Finally, the PI was responsible for the scientific data analysis and for presenting his findings to the scientific community through reports and papers.

C. Sponsoring Program Office

There were three SPOs within NASA Headquarters: the OMSF, the Office of Space Science Applications (OSSA) and the Office of Advanced Research and Technology (OART). Experiments were allocated among the SPOs according to their scientific disciplines. Experiments primarily associated with man in space (e.g., M487 and the biomedical experiments) were sponsored by OMSF. Experiments concerned with purely scientific investigations (e.g., S019, S073, and S183) were sponsored by OSSA. Experiments that were technologically oriented (e.g., T003, T020, and T027) were sponsored by OART. The DOD developed several experiments for Skylab (e.g., D008 and D024) that had originally been planned for performance during other programs.

These offices received the initial proposals and presented them to the MSFEB. If the experiment was given preliminary approval, they later presented the EIP to the MSFEB. Upon approval for Skylab, they had a continuing responsibility for monitoring the experiments scientific and technical integrity. They maintained a close relationship with Skylab program management, the PIs, and the EDC, while monitoring the fulfillment of objectives.

D. Manned Space Flight Experiments Board

The MSFEB consisted of representatives from the SPOs and other NASA Headquarters organizations, and acted as a recommending committee to the Associate Administrater for Manned Space Flight. They were responsible for the review and recommendation for approval or disapproval of proposed experiments, major changes to existing experiments and of funding.

E. Experiment Development Center

After the initial approval of an experiment, the EDC prepared the EIP, obtaining and coordinating information from the PI and NASA centers. The EDC's primary role, beginning after experiment development approval, was the provision of operable qualified hardware within a specified budget and schedule. During the development phase, the EDC was responsible for: preparation of documentation (such as the ERD, End Item Specification (EIS), Qualification and Acceptance Test Criteria, Experiment Program Plan), the coordination of experiment design requirements with Skylab capabilities, the scheduling of the design and development effort, and the monitoring of funds. During development and testing, the EDC conducted reviews and coordinated the resolution of Review Item Discrepancies (RID), assisted in the planning and implementation of hardware integration tests, and monitored qualification, acceptance, and integration testing. During the mission, the EDC provided technical consultation relative to experiment hardware performance.

F. Experiment Developer

The Experiment Developer (ED), usually a contractor to the EDC, designed, produced and delivered the hardware to satisfy the EIS. In addition, the ED performed development, qualification, and acceptance testing, prepared documentation for reviews and the Acceptance Data Package (ADP), and provided technical support to appropriate NASA centers throughout the program. Hardware produced included flight and backup units, qualification units, engineering models, and training hardware.

G. Experiment Integration Center

Responsibility for experiment integration was assigned to the development center for the carrier module in which the experiment was to operate. On this basis, MSFC was the EIC for all experiments except those that operated in the CSM. The EIC functions for the MSFC Skylab Program Office were performed by SL-DP, with the exception that ATM experiments were integrated by the ATM Project Office (SL-SE-ATM). These functions were concerned primarily with ensuring that the experiments were designed, fabricated, tested and operated in complete compatibility with all their module system and crew interfaces, and with all pertinent Skylab Program and experiment requirements. This task was accomplished by Experiment Managers (EM), from SL-DP; Integration Engineer (IE) from MSFC Science and Engineering Laboratories; and by Experiment Integration Engineers (EIE) and Experiment Compatibility Engineers (ECE), provided by the Integration Contractor. Specific duties of these EIC personnel are outlined in the following four subsections.

H. Experiment Manager

The EM represented SL-DP for a selected group of experiments (usually by discipline) and was in effect ultimately responsible for the successful integration of these experiments. He directed a team of people who followed the experiment hardware from conception to launch to insure its compatibility with the Skylab. All documentation necessary to achieve this goal was also his responsibility. The accomplishment of the integration function through initial compatibility assessment, experiment development, acceptance, testing, mission, and data return is evident in discussions of the roles of the IE, EIE and ECE who operated under his direction.

For those experiments for which MSFC was the EDC, the EM had additional duties associated with the hardware development such as selection and administering funding of the EDs and scheduling and monitoring their performance. Thus, he insured that the hardware designs met both experiment objectives and program requirements.

I. Integration Engineer

The overall responsibility of the IE was to provide assurance that the assigned experiments and carriers were technically compatible. He was responsible for detecting incompatibilities and resolving them through the use of available science and engineering technical expertise. Specifically, he reviewed: experiment to carrier interface control documents (ICD), all waivers, RIDs, flight plans and other systems studies, such as experiment safety analyses, mission rules, compatibility reports, sneak circuit analyses, etc.

In addition, the IE monitored the Skylab systems during the mission to assure that experiment-unique requirements were being met and that experiment constraints were not being violated. He also participated, with other experiment personnel, in resolving malfunctions.

J. Experiment Integration Engineer

The EIE followed individual experiments through the entire development and integration phases and acted as a working point of contact for liaison among the various NASA and contractor agencies involved. His duties in the early phases included assistance in preparation of the EIP and the initial compatibility assessment, preparation of the ERD and review of the ICDs prepared by the module contractors. Throughout the development cycle, the EIE represented SL-DP by: preparing documentation, participating in reviews and providing information to all affected program elements. During module level and KSC testing, he reviewed the experiment test requirements, plans and procedures, monitored the tests, reviewed the data and participated in problem resolution.

Prior to the mission, the EIE helped prepare the operational documentation such as the Mission Requirements Document (MRD), the mission rules, and the crew checklists. He provided on-site support to SL-DP during the mission by following the operation of his experiment(s) through real-time monitoring of the networks, by reviewing daily flight plans and by participating in resolution of anomalies.

Finally, after the mission, the EIE prepared the Mission Evaluation Reports (MER) and other documentation required to complete the program.

K. Experiment Compatibility Engineer

The ECEs were responsible for assuring the compatibility of all experiments and experiment support equipment with the carrier systems, modules and operational aspects of the Skylab program, and for initiating action to resolve incompatibilities.

The ECEs maintained cognizance of all pertinent Skylab program documentation, information, and activities to assure that the experiment requirements were being accommodated in module and system design, in mission planning, and all experiment change activity. They conducted selected compatibility studies as required by various new experiment proposals. They provided visibility to program management by periodic publication of an Experiment Compatibility Status Report (ECSR), which documented the compatibility of each experiment integrated by MSFC with each of seventeen integration disciplines, and identified and gave the resolution status for each significant compatibility problem. During the mission, they maintained cognizance of module/systems status as they affected experiments, and integrated the SL-DP responses to multiexperiment problems, action requests, daily reports, etc.

Whereas the EIE was responsible for integrating an experiment into the cluster, the ECE was responsible for integration of all applicable experiments with a specific cluster system or discipline. Thus, resolution of problems applicable to several experiments were normally coordinated by the ECE.

L. Module Project Offices at MSFC

The module offices were responsible for controlling the design, development, test and operation of the Cluster modules. They provided the management controls necessary for the module contractors to build the individual modules and assure their compatibility with the Cluster. They managed the funding of the module and monitored the progress through program milestones. They conducted module design and acceptance reviews, monitored integration testing and had the final responsibility for the module performance in support of Cluster and experiment systems during the mission.

M. Module Contractors

The module contractors fabricated, tested, and monitored the mission performance of the Cluster modules. The modules provided the support systems required for the experiments during launch, stowage, and operation. They also provided the crew station facilities and habitability requirements for manned space flight operations.

Throughout the design and development phases, the module contractors coordinated with the EDs to insure compatibility of their respective systems and formulated and committed the interface characteristics through ICDs. By defining the carrier capability, the capacity for fulfilling the desired experiment requirements could be evaluated. The integrated experiment/module testing was the responsibility of the module contractor. He developed the test documentation and test procedures based upon the test requirements provided by the Post Acceptance Test Requirements Specifications (PATRS) meetings. The development of experiment requirements for module testing is described in section VIII.

The module contractors monitored the orbital activities for module performance during the mission. When anomalous conditions occurred, they assisted in problem source determination, concentrating on the module performance and the interface conditions.

N. Launch Center

Involvement of KSC with a Skylab experiment typically began early in its development, in some cases, as early as the Preliminary Requirements Review (PRR). The early involvement of KSC personnel provided necessary knowledge which permitted development of plans and procedures necessary for experiment installation, test and checkout at KSC.

KSC hardware flow began with receipt of the carrier modules and the experiment hardware. Experiments were generally delivered installed on the modules, but in some cases, arrived separately. Experiments not installed had receiving inspections and preinstallation checkouts. Selected off-module experiment testing was performed. Backup units were substituted for flight units that experienced problems. The component, subsystems, and combined systems tests were performed, verifying the Cluster readiness for launch. At launch (when the vehicle cleared the launch umbilical tower), the responsibility for flight operations was transferred to JSC.

O. Operations Center

Preparation for the JSC role of controlling flight operations began with inputs to the EIP and compatibility assessment. They prepared mission-related documents such as the MRD, Operational Data Book (ODB), Crew Checklists and Cue Cards, Flight Plans, Malfunction Procedures, Console Handbooks, Mission Rules, and Stowage Lists. They were responsible for all crew training and preparation necessary for performance of orbital operations. JSC's mission role included scheduling and direction of operations, communications with the crew and vehicle, crew safety considerations, and near-real-time flight data acquisition. Following the missions, KSC conducted crew debriefings and disseminated flight data and materials retrieved from orbit.

SECTION V. EXPERIMENT PROPOSAL THROUGH REQUIREMENT DEFINITION

This section encompasses the earliest stages of a manned space experiment development from the PI's proposal through the base-lining of an ERD.

A. Experiment Proposal

The PI presented his scientific space experiment in proposal form to the appropriate SPO. The SPO, together with the PI, presented the experiment to the MSFEB recommending that it be considered for assignment to the Skylab Program. The Skylab Program Director identified the appropriate NASA centers to act as EIC and EDC, and directed them to prepare an EIP and a compatibility assessment. The EDC role was assigned to MSFC, Langley Research Center (LaRC) or JSC, depending on the experiment objectives. MSFC acted as "proxy" EDC for some Skylab experiments proposed by Ames Research Center (ARC) and other government agencies.

B. Experiment Implementation Plan

The EIP was prepared by the EDC, with support from the PI, and coordinated with the EIC, KSC, and JSC. It contained an experiment summary, experiment descriptive information, and sections on the development approach, integration approach, and programmatic information. The experiment descriptive information was generally extracted from the PI's original proposal, but updated to reflect the current status.

The EIP was preliminary in nature, and was used to determine program impact in each discipline. The document was prepared for one-time use only and was not updated after the experiment was approved for flight. The EIP provided initial requirements for use in the experiment compatibility assessment.

C. Compatibility Assessment

The compatibility assessment was conducted to determine if it would be feasible to fly the experiment on Skylab. The assessment examined the experiment parameters (e.g., launch and return weight and volume, power requirements, data system requirements, crew activity and training requirements, testing requirements, environmental considerations, etc) to determine their compatibility with the Skylab capabilities and their subsystems impact. The compatibility assessment also made recommendations for the experiment stowage and operational locations, preliminary interface definition, impacts to timelines, etc. In some cases the compatibility assessment required changes to the EIP. Such changes were coordinated with the PI prior to presentation to the MSFEB. In other instances, minor modifications to the vehicle were recommended to accommodate the experiment.

This document was prepared for the EIC under the direction of the EM. Specialists in the affected disciplines, subsystems and facilities were consulted. The information was coordinated with the PI and the other NASA centers involved. The compatibility assessment together with the EIP were then jointly presented to the MSFEB for their recommendation to the NASA Associate Administrator for Manned Space Flight.

D. Experiment Requirements Document

Once the experiment had been approved for the Skylab Program, the EDC proceeded with the selection of an ED and initiated preparation of a preliminary ERD. In cases for which MSFC was the EDC, the preliminary ERD was prepared by the Integration Contractor's EIE.

The ERD defined the experiment requirements to be met by the Skylab Program. It included sections entitled Experiment Description, Mission Assignment and Hardware Requirements, Data Requirements, Flight Vehicle Systems Requirements, Experiment and Flight Vehicle Pointing Requirements, Flight Crew Operations Requirements, Flight Operations Requirements, Post Acceptance Testing, Resupply and Reactivation Requirements, and Reports of Experiment Results. The preliminary ERD used the EIP and compatibility assessment, as modified by MSFEB, for initial information. The ERD information was generated through coordination with PIs, EDs and specialists in the various subsystems affected. The preliminary (nonbaselined) ERD was reviewed at PRR. The ERD was intended to be used as the official statement of experiment requirements to be met by the Skylab Program. All other Skylab Program documentation had to be consistent with the ERD.

E. Preliminary Requirements Review

The PRR was a formal meeting at which the preliminary ERD and the design concepts of the ED were reviewed by the EDC, EIC, JSC, and KSC. The PRR established, through the review of preliminary drawings and studies, the suitability of the selected design approach to fulfill the experiment objectives and meet the required Skylab program schedule. It established the development tests required to substantiate the design approach and the operational requirements of the experiment. RIDs were written, approved and actions assigned for closure. Approval was given to begin the detailed experiment hardware design and to baseline the ERD, contingent on the closure of the applicable RIDs.

SECTION VI. EXPERIMENT DEVELOPMENT THROUGH ACCEPTANCE

This section encompasses the phases from the experiment PRR through the delivery of flight hardware to NASA. Two major functions occurred during this period. First was the development, fabrication, and testing of the experiment hardware. Second was the integration effort required to assure hardware compatibility with the spacecraft, subsystems, and crew.

A. Experiment Hardware Development

Three significant milestones had to be met during the experiment hardware development. Chronologically, these were: the Preliminary Design Review (PDR), the Critical Design Review (CDR), and the Configuration Inspection Review (CIR) at hardware delivery. These reviews were scheduled to allow sufficient time for the hardware development, fabrication, and test while still being consistent with Skylab Program requirements.

Hardware developed during contract performance varied. The milestone reviews required different hardware but generally consisted of: mockups, prototype hardware, qualification units, flight units, flight backup units and training hardware.

1. Preliminary Design Review. The PDR was the first formal review of the preliminary hardware design approach which ideally, took place at the transition from requirements to detailed design. At this review, the ED presented the preliminary hardware design required to meet the experiment scientific and operational requirements. Although experiment PDR formats varied, in general they were chaired by the cognizant EM with specialist teams assigned to review each specific discipline. Teams were normally assigned to review the following subjects:

Mechanical design and interfaces;

Electrical design and interfaces;

Crew systems and human factors;

Quality, reliability assurance, test, and safety;

Speciality teams, if required to review specific features of an individual experiment (e.g., thermal design, biological/chemical design, etc.).

Review participation was provided by NASA Headquarters and all affected NASA centers and contractors. Each review resulted in either approval of the design concept of the generation of RIDs against the design. The end result of a PDR, after successful completion of all actions, was NASA's approval to the ED to proceed with the hardware detail design.

The following documentation and hardware were required for review at the PDR:

Program Plan - Submitted by the ED to describe the methods that would be implemented to control the hardware development. Included were the: Management Plan; Quality and Reliability Assurance Plan; Manufacturing Plan; Configuration Control Plan; Verification Plan for development, qualification, and acceptance tests; Contamination Control Plan; Logistics Plan and Program Schedules.

End Item Specification (Part I - Performance/Design Requirements) - Submitted by the ED to define the hardware performance and design requirements.

Preliminary Design and Schematic Drawings - Submitted by the ED to present hardware design concepts.

Preliminary Failure Modes and Effects Analysis - Submitted by the ED to identify the impacts of hardware component failures.

Preliminary Components and Material List - Submitted by the ED to identify electrical components and materials used in the hardware design.

Experiment Requirements Document - Submitted by the EDC to identify total experiment impact on the spacecraft and mission.

Preliminary Interface Control Documents - Submitted by the affected module contractors to delineate the interface between the experiment and module. Generally included were separate ICDs for mechanical, electrical, instrumentation and communication, and command module stowage.

Preliminary GSE, STE and Spares List - Submitted by the ED to identify the required ground support equipment (GSE) special test equipment (STE), and spares.

Development Test Results - Submitted by the ED to present the results of development testing accomplished.

Hardware Mockup - Submitted by the ED for review by the involved astronaut crew, and by human factors and safety personnel.

2. Critical Design Review. The CDR was a formal experiment hardware design/configuration review, ultimately approving and base-lining the detail design for hardware fabrication. The CDR was conducted in the same manner as the PDR, with the same technical disciplines reviewing the design. Associated with this effort was the completion of all development testing and preparation of the final detailed design documentation.

The following documentation and hardware were required for review at the CDR:

End Item Specification (Part II - Product Configuration Requirements)

Design and schematic drawings

Failure Modes and Effects Analysis

Components and Materials List

Experiment Requirements Document

Interface Control Documents

GSE, STE and Spares List

Final development test results

Operating, Maintenance and Handling Procedures - submitted by the ED to define ground and flight operating and handling requirements, and maintenance requirements.

Hazards Analyses - submitted by the ED to identify hazards associated with the hardware operation/handling and to propose means to eliminate the hazards.

Qualification Test Specification - submitted by the ED to define the hardware qualification test parameters.

Qualification Test Procedures - submitted by the ED to define the procedures to be used in performing the qualification test.

Acceptance Test Specification - submitted by the ED to define the hardware acceptance test parameters.

Acceptance Test Procedures - submitted by the ED to define the procedures to be used in performing the acceptance test.

High-Fidelity Mockup - submitted by the ED for review by the affected astronaut crew and by human factors and safety personnel.

3. Experiment Hardware Test Program. The ED fabricated a qualification unit which was dedicated for qualification testing and was constructed using the same design, materials, and processes as the flight unit. After final assembly of the qualification hardware, the unit was functionally tested. In many cases the qualification test results necessitated hardware redesign or modification to meet the test requirements. Changes to the hardware design were reviewed and approved by NASA.

Where experiment hardware could not meet the qualification test requirements (e.g., electromagnetic interference, tough temperatures, etc), waivers were submitted by the ED for NASA review. Each waiver was evaluated individually and approval was usually granted where "work-arounds" or corrective actions could not readily be accomplished within cost or schedule limitations, providing safety was not affected.

When the qualification test results had been approved by NASA, a Certification of Qualification (COQ) was issued, certifying the hardware design for Skylab utilization. The flight and flight backup units were usually fabricated in parallel with the qualification unit. The qualification unit, in some cases, was refurbished for use as the flight backup unit or training unit (generally for economic or schedule reasons). These units were acceptance tested after refurbishment, and delivered to NASA.

4. Configuration Inspection Review. The CIR was NASA's formal review of the deliverable flight hardware. This review consisted of an inspection of hardware (for compliance with the approved design) and of the ADP submitted with the hardware. The MSFC ADPs were prepared in accordance with MSFC Program Directive MPD 8040.14A [3], which required the following items:

A complete set of hardware drawings,

Hardware log books,

An operating time and cycle log,

A weight and balance sheet,

Alignment data,

Instrumentation record,

Pressure vessel history,

Thruster logs,

Qualification test report,

Unresolved failure report,

Inventory of serialized parts,

Open testing,

Open work items,

Deferred work items,

Waivers and deviations,

Listing of non-flight hardware delivered,

A copy of the Acceptance Test Procedure and results,

A listing of process specifications used in the assembly,

A copy of the End Item Specification,

Bent pin connector log,

Cleanliness certification,

Fit Check Matrix,

Materials Certification,

Material Review Board Actions.

A successful review resulted in hardware acceptance (via issuance of a DD250 Form or other appropriate form) by NASA and the issuance of a Certificate of Flight Worthiness (COFW).

5. Training Hardware. The ED was responsible for providing training hardware for experiments having significant interfaces with the flight crew. The training unit was used to familizarize the astronauts with the procedures required for correct hardware operation. Normally this hardware was designed as a flight-type training unit. However, in some cases zero-g type (for use in aircraft), neutral buoyancy type (for underwater training), or simulation devices were provided.

B. Experiment Integration

During the entire period of hardware development and fabrication, SL-DP continually monitored the experiment to assure compatibility with all aspects of the Skylab program. The following functions were performed:

Monitored the hardware design and development for changes that might impact compatibility;

Performed special studies, as required, to support the hardware development/integration;

Assisted in the preparation and review of mission documentation, such as the Mission Requirements Document, Flight Plans, Mission Rules, Crew Checklists, and Operational Data Books;

Monitored the hardware test program and assisted in the resolution of test failures;

Maintained the ERD to current status;

Coordinated experiment requirements with module contractors and affected NASA personnel.

During this period the postacceptance test requirements were coordinated with the ED and with each succeeding hardware using site (i.e., the module contractor and KSC). The result was the Experiment Integration Test Requirements and Specification (EITRS), which was used by the sites to develop the detailed postacceptance test specifications and procedures.

SECTION VII. CONFIGURATION CHANGE CONTROL

A. Configuration Definition

The configuration of each Skylab corollary experiment was defined by a multilevel series of documents, in accordance with the requirements of Apollo Applications Configuration Management Requirements Manual NHB8040.1 [4], dated March 1969. A detailed identification of the levels and related documentation is shown in figure 2.

The configuration of each experiment was defined primarily by three types of controlled documentation:

Experiment Requirements Document - Defined systems interface, data, test, and operational requirements of an experiment.

Interface Control Documents - Defined detailed physical functional, environmental, operational and procedural requirements of an item at its interfaces.

Experiment End Item Specification - Defined: (PART I) specific requirements for design, development, test and qualification of the item; (Part II), specific configuration information for production, testing/ quality control, and preparation for delivery.

Additional program documentation was utilized, whereby other experiment characteristics (such as weight, power, requirements, stowage requirements, etc.) could be compiled. (See figure 2.)

B. Configuration Control

Configuration control was progressively applied as the various documents were prepared and baselined. Any changes made to the baseline prior to the CDR were controlled and accounted for by the responsible center or contractor. After incorporation of changes required at CDR, all subsequent changes to controlled documentation were processed and controlled through established Configuration Control Boards (CCB). Configuration Control Board Directives (CCBD) were the action documents used to record approval/disapproval of the Engineering Change Request (ECR). The intercenter experiment change flow is shown in figure 3.

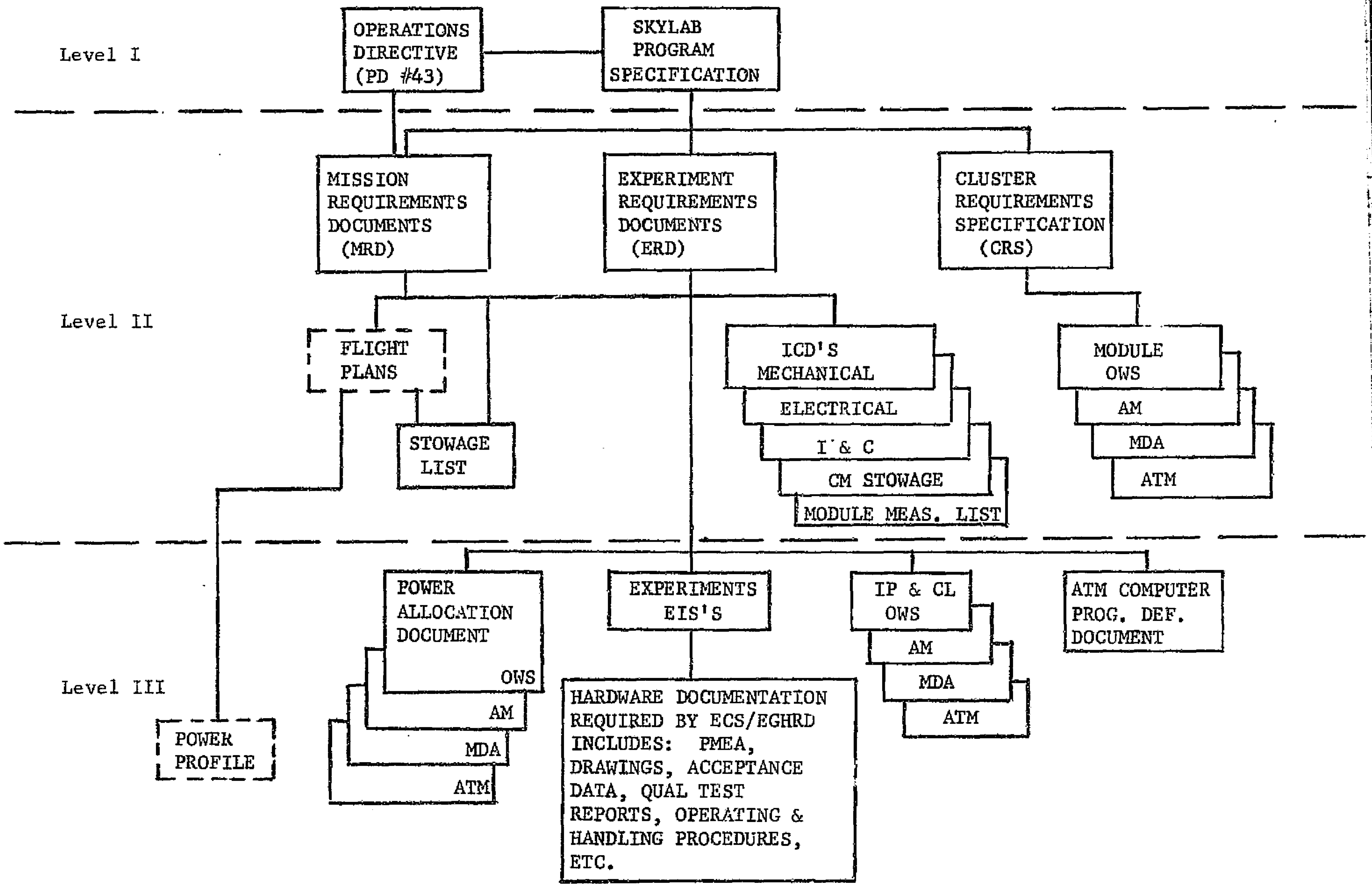

FIGURE 2. SKYLAB EXPERIMENT DOCUMENTATION

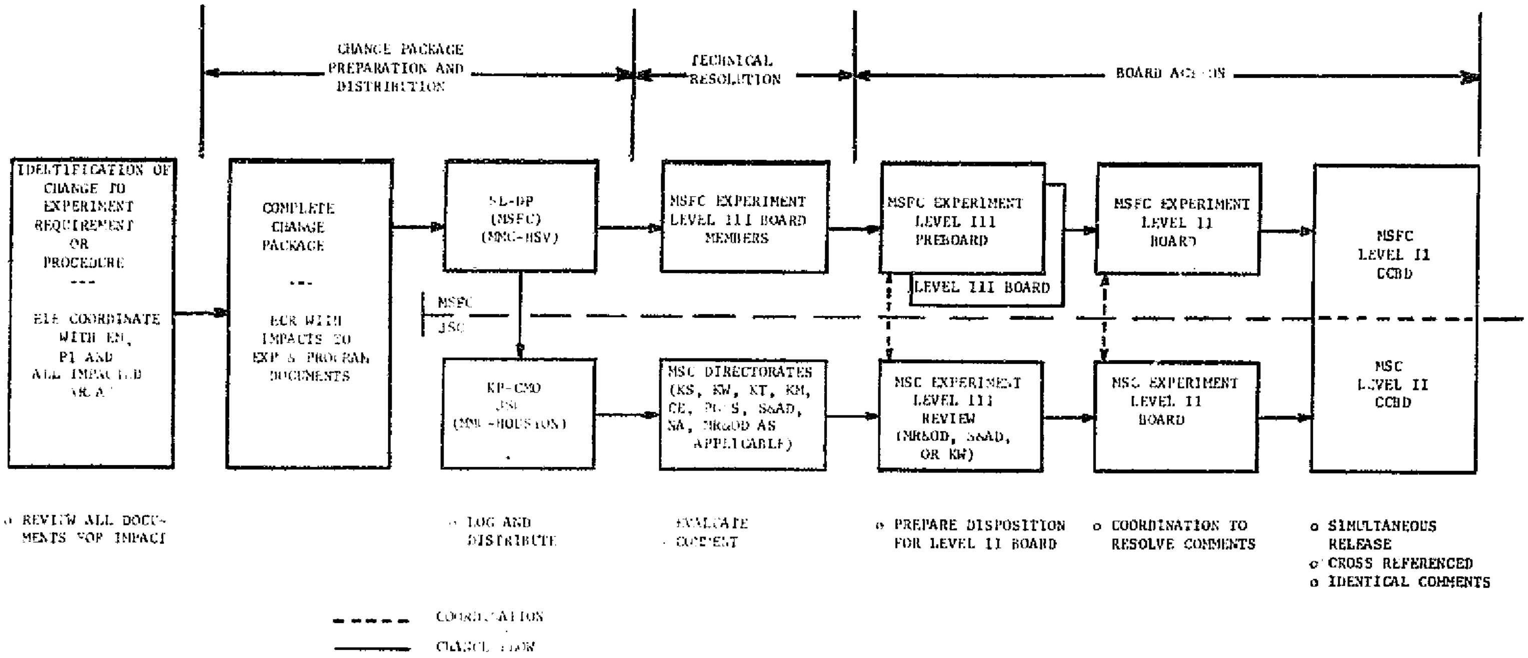

FIGURE 3 INTERCENTER EXPERIMENT CHANGE FLOW

Configuration control by necessity was accomplished on a multi-level basis and in accordance with the requirements of NHB8040.1:

Level I - Program documentation controlled by NASA Headquarters, such as:

Skylab Program Specification, SE-140-001;
Program Directive No. 43;
Any changes that could not be resolved at Level II; etc.
(Responsibility of NASA Headquarters, OMSF)

Level II - Intercenter and some Intracenter documentation (between project offices), such as:

Cluster Requirements Specification, RS003M00003;
Launch Facility Specification;
Experiment Requirements Document,
Interface Control Documentation; etc.
(Responsibility of involved NASA centers, individually or jointly)

Level III - Individual experiment and module documentation (within one project office), such as:

Module End Item Specifications;
Experiment End Item Specifications;
Power Allocation Documents; etc.
(Responsibility of individual NASA centers)

C. Configuration Control Evolution

Beginning in 1968, a continuing review of the latest experiment documentation was established and the discrepancies were identified and published periodically in the Corollary Experiment Integration Status Report (CEISR). It was intended that this technique of discrepancy identification would result in appropriate corrective action; however, this did not always occur. Baselining of the main controlling documents began in late 1969 and early 1970. This same period, however, saw major program changes (e.g., from Wet Workshop to Dry Workshop) and the redefinition of the list of experiments approved for flight. These changes produced further documentation inconsistencies and errors. Therefore, a better means of identification and reporting was sought during the first quarter of 1970.

This effort resulted in development of the ECSR, which identified both hardware and documentation incompatibilities on a monthly basis, and came to be widely circulated and used throughout the program. This, together with preparation of appropriate change documentation by the Integration Contractor, provided a more rapid resolution of the problems identified in the ECSR. However, still other document inconsistencies were revealed. It became apparent that there were requirements in different levels of documentation that were in conflict with each other (e.g., duplication of data such as the detailed measurement lists originally contained in the MRD, the ERD and the Instrumentation and Communication ICDs). Some of the conflicts were the result of higher-level documents containing and controlling a level of detail which more appropriately belonged in lower-level documentation. It also became apparent that the different level CCBs were sometimes unaware of these conflicts and in some cases did not fully recognize the lower-level CCB's responsibility for initiating changes to a higher-level CCB to correct these details. Identification of all these problems to the appropriate NASA centers during late 1970 and early 1971 led to steps which eliminated many duplications and simplified the documents by cross-referencing to the proper controlling document. However, during the same period, it became evident that a revised approach would improve the effectiveness of the configuration control process.

D. Complete Change Package Concept

As a result of these experiences, the Integration Contractor developed a "Complete Change Package" concept and recommended to SL-DP that it be adopted for use. This concept required that any proposed change be evaluated for its impact on documentation of all levels, and that the necessary proposed change documentation for each impacted document be prepared and submitted to the CCB as part of one "complete" change package. Preparation of this package by a single agency (i.e., Integration Contractor) precluded excessive delays in submittal of the change request.

Shortly after the inception of the Complete Change Package concept, a concerted effort was undertaken, using the concept, to clean up all MSFC experiment documentation to the current time frame as soon as possible. This effort was satisfactorily accomplished. However, further contact during CCB action between MSFC and JSC resulted in a JSC request for the Integration Contractor personnel involved with the MSFC documentation clean-up to provide a similar clean-up of the JSC experiment documentation. This additional effort was provided.

1. Change Package Content. The change package utilized existing standard NASA forms provided for this purpose. These included: an ECR (identification, description and justification for change); Preliminary Specification Change Notices (PSCN) (affected document identification and text changes); and Preliminary Interface Revision Notices (PIRN), (ICD identification and changes required). A Change Impact Assessment form was added to assure full compliance with the "Complete Change Package" concept. This form (figure 4) listed the documents to be reviewed for impacts (with space for addition of special documents, where applicable).

ECR NO. ______________
DATED ______________

CHANGE IMPACT ASSESSMENT

DOCUMENT	IMPACT		REMARKS
	YES	NO	
EXP. __________ ERD, __________, DATED __________, PLUS SCN NO. __________ AND PSCN __________.			
APOLLO APPLICATIONS PROGRAM SPECIFICATION, SE140-001-1			
CLUSTER RQMTS. SPEC. RS003M00003,			
MISSION RQMTS., DOCUMENT, I-MRD-001,			
STOWAGE LIST, I-SL-002			
OWS POWER ALLOCATION DOC., 40M35631,			
MDA POWER ALLOCATION DOC., 40M35632,			
AM POWER ALLOCATION DOC., 40M35622, REV A,			
ICD MECHANICAL, NO. __________ REV __________ DATE __________			
ICD ELECTRICAL NO. __________ REV __________ DATE __________			
ICD I & C NO. __________ REV __________ DATE __________			

Figure 4. Change Impact Assessment Form

2. Change Package Operation. Precoordination of the change was accomplished with the PI and the personnel responsible for the ICDs, the Power Allocation Document, etc., prior to formal change package initiation. This action resulted in the change package having a high confidence factor for acceptance and rapid approval was generally accomplished by a "walk-through" (informal submittal to CCB members on an individual basis) instead of a formal CCB meeting.

A jurisdictional problem developed, wherein a lower-level CCB could not approve a change that had a higher-level CCB impact (i.e., a change containing Level II and Level III document impact required Level II CCB approval prior to Level III CCB approval). Copies of the change package were sent simultaneously to each affected CCB level to expedite changes of this type. The change request approval/disapproval cycle was enhanced considerably by this approach.

All experiment change activity was completed or closed at the Flight Readiness Review (FRR). All ICDs were contractually accepted and complete at that time.

During the manned portions of the Skylab Mission, necessary operational document changes were submitted as Mission Action Requests (MAR) for disposition by the Flight Management Team (FMT) or Flight Operations Management Room (FOMR) team at JSC. Crew Procedure Change Requests were reviewed by the flight controllers and approved by the Flight Director prior to transmittal to the flight crews.

SECTION VIII. EXPERIMENT POSTACCEPTANCE TESTING

The experiment Postacceptance Testing (PAT) activities were monitored and supported to assure that all experiment hardware experienced adequate interface testing and would perform as planned in flight. There were two major PAT activity phases: a) module integration testing, and b) KSC integrated system testing and launch support. Figure 5 identifies the experiment PAT documentation.

A. Module Integration Testing

Module integration testing covered the experiment hardware activities from acceptance of the flight and backup units by the module contractors, through the transfer of the integrated module hardware to KSC. The generic postacceptance experiment test requirements were originally defined in the ERD Section 8. These test requirements were coordinated with the ED, the EIC and KSC.

The EITRS document was reviewed in a series of formal Postacceptance Test Requirement and Specifications (PATRS) meetings. These meetings were attended by the PI, EDC, ED, EIC, module contractor, KSC, OMSF, the integration contractor and approval obtained.

The PATRS agreements enabled the module contractors to prepare test and checkout specifications which governed module/experiment test activities as follows:

MDA, Systems Test and Checkout Requirements (STACR), ED-2002-2020 [5].

AM, Acceptance Test Plan (ATP), E914 [6].

OWS, Test and Checkout Requirements, Specifications and Criteria (TCRSC), 1B83429 [7].

IU, Systems Test Specification, Saturn IB Instrumentation Units 206 through 212, 7907967 [8], delineates the experiment test requirements for module integration testing.

Throughout these test activities, SL-DP maintained continuing cognizance and performed special studies to ensure that the EITRS was satisfied. Module integration test reviews resulted in integrated systems test plans and procedures which ensured systems compatibility prior to test performance.

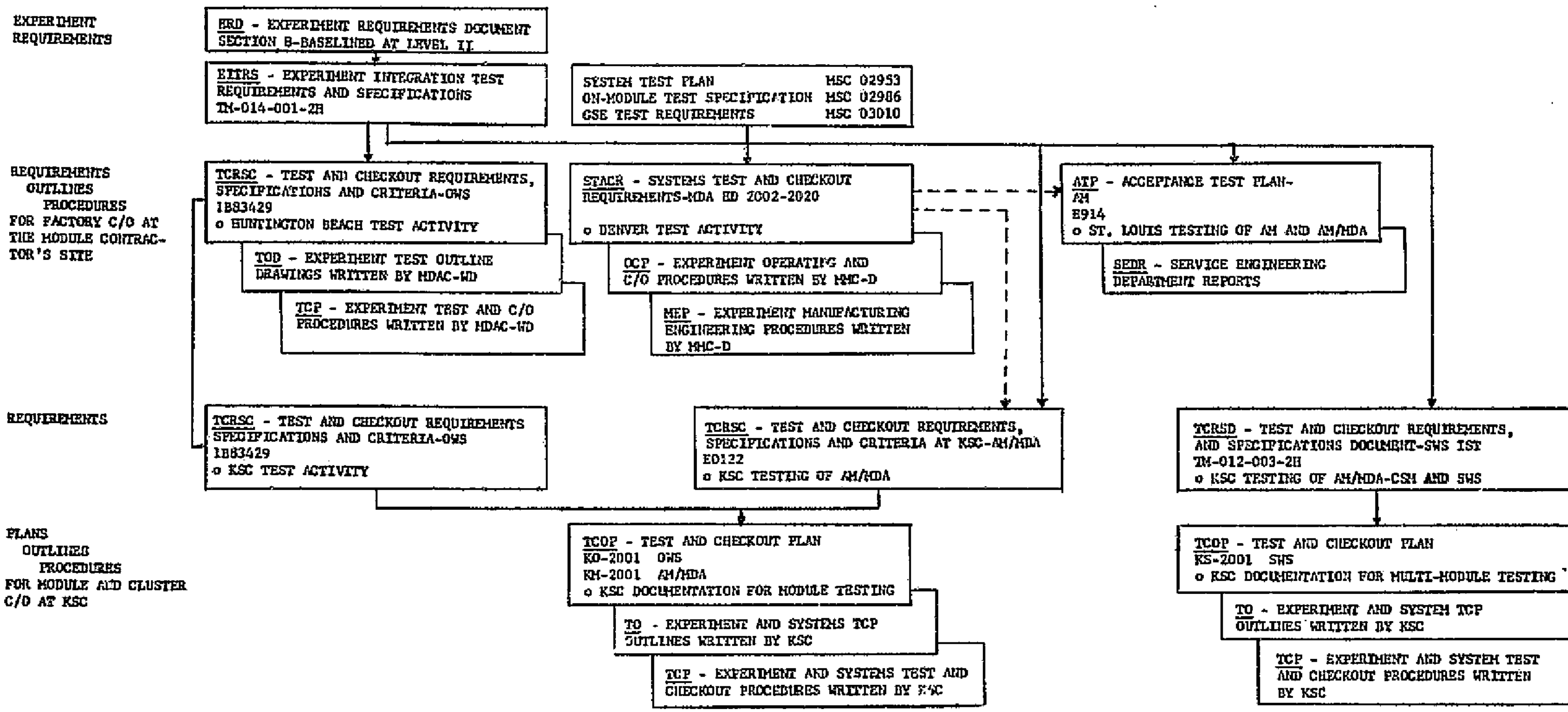

FIGURE 5 SKYLAB TEST DOCUMENTATION

With the advent of experiment test requirements, lists of the GSE necessary to support the PAT activities were amplified during the PATRS meetings. As the test requirements and specifications were finalized, program control of the experiment GSE requirements was established in the preparation of the Skylab Experiment GSE Allocation Plan, 68M00005 [9], utilizing the experience gained from the ERD, PATRS, and EITRS activities. Experiment-peculiar GSE that was required to support the flight unit at the module contractor's plant and/or at KSC was provided by the ED. The peculiar GSE traveled with the flight hardware and was controlled by the MSFC Science and Engineering Systems/Products Verification Office.

Test and Checkout Procedures (TCP) were prepared by the OWS module contractor. Operation and Checkout Procecures (OCP) were prepared by the MDA module contractor. Service Engineering Department Reports (SEDR) were prepared by the AM/MDA contractor. These procedures were reviewed by SL-DP prior to each test.

Experiment tests performed at the module contractor's plant were monitored and supported by SL-DP to evaluate the test data to ensure compliance with the test and checkout specifications. The "as run" TCPs which identified waivers, deviations, anomalies and test data, were maintained and recorded by the module contractor's quality control personnel. Copies of the "as run" TCPs were included in the module ADP.

B. Integrated Systems Testing and Launch Support

The following TCRSDs were the basis for the experiment-related tests at KSC:

Test and Checkout Requirements, Specification and Criteria at KSC for AM/MDA, MDC E0122 [10].

Test and Checkout Requirements Specifications and Criteria OWS, 1B83429.

Skylab Integrated System Test Checkout Requirements and Specification, TM 012-003-2H [11].
Contractor).

IU, Test and Checkout Requirements, Specifications and Criteria, 7921601 [12].

Facility ICDs were prepared when the experiment hardware descriptions, test requirements and specifications and GSE descriptions were established. These ICDs defined the experiment hardware and GSE-to-facility interface requirements.

The Saturn Workshop Test and Checkout Plan (TCOP) was prepared by KSC personnel to identify the test procedures that would implement TCRSD's. This was accomplished by a matrix of requirements versus the KSC TCPs which were used for test activity control. Technical reviews of the experiment-related TCPs were conducted by SL-DP and comments submitted to KSC for incorporation prior to testing.

The flight experiment hardware was shipped to KSC in one of several ways: on module, removed from the module and shipped separately, returned to the ED (for further testing, repair, calibration, upgrading, etc.) and then shipped, or sent to another module contractor for fit checks before being delivered to KSC.

Upon arrival at KSC it underwent receiving and inspection prior to any testing. Experiment equipment not installed in the module or actively involved in testing was maintained in an environmentally controlled bonded storage area.

Experiment-related Test Change Notices (TCN) against the TCRSDs were coordinated with the responsible agencies, and submitted through the MSFC resident office. All TCNs were reviewed for experiment impact and the results submitted to this office for disposition.

The tests were monitored, data was recorded and records were maintained of all experiment-related Discrepancy Records (DR). A technical review of open DRs was held daily. All DR's were closed prior to FRR.

SECTION IX. OPERATIONS PLANNING

MSFC's operational planning responsibility was to support JSC in the preparation of mission operations documents and pla..ing.

A. Documentation

The relationships among the documents directly involved in experiment-related mission operations and support are shown in figure 6. The Skylab Operations Directive (PD43) was the principal document that established and authorized experiment operational requirements. Although not a released document, the Data Base shown below the MRD stored up-to-date information for several of the JSC operational documents. The Data Base was a computerized .ompilation of flight planning information, including scheduling requirements and constraints, crew procedures (activity elements) and time increments required for these procedures. It served as a central collection/storage facility for requirements formally published in several operational documents. For example, the Experiment Operations Handbook (EOH), Volume II was a printout of the preliminary crew procedures, as stored in the Data Base. During training, this portion of the Data Base was continually updated, resulting in the Crew Checklists. The Data Base was also the primary basis for the premission flight plans. The following paragraphs briefly describe the significant experiment operational documents.

1. Operations Directive (PD43). The Operations Directive, issued and maintained by OMSF, was the Program Director's vehicle to issue program policies and requirements, program objectives, and mission planning instructions to the implementing centers. This document provided a broad outline of mission objectives and requirements, set forth guidelines for experiment planning and scheduling, assigned experiments to specific Skylab missions, and established a system of priorities for individual experiment scheduling. It defined the baseline requirements, the minimum scheduling requirements and the performance redline for all experiments and established guidelines for real time contingency planning.

2. Mission Requirements Document. The MRD provided the basis for Skylab mission planning by amplifying the program and mission objectives specified in the Operations Directive. It contained detailed operational requirements compiled from various sources, including ERDs. Detailed Test Objectives were defined in the MRD. It was prepared and maintained by the Skylab Program Office at JSC, with approval by MSFC.

From the Skylab experiment standpoint, the MRD was the keystone of the operations planning. Information contained therein was restricted

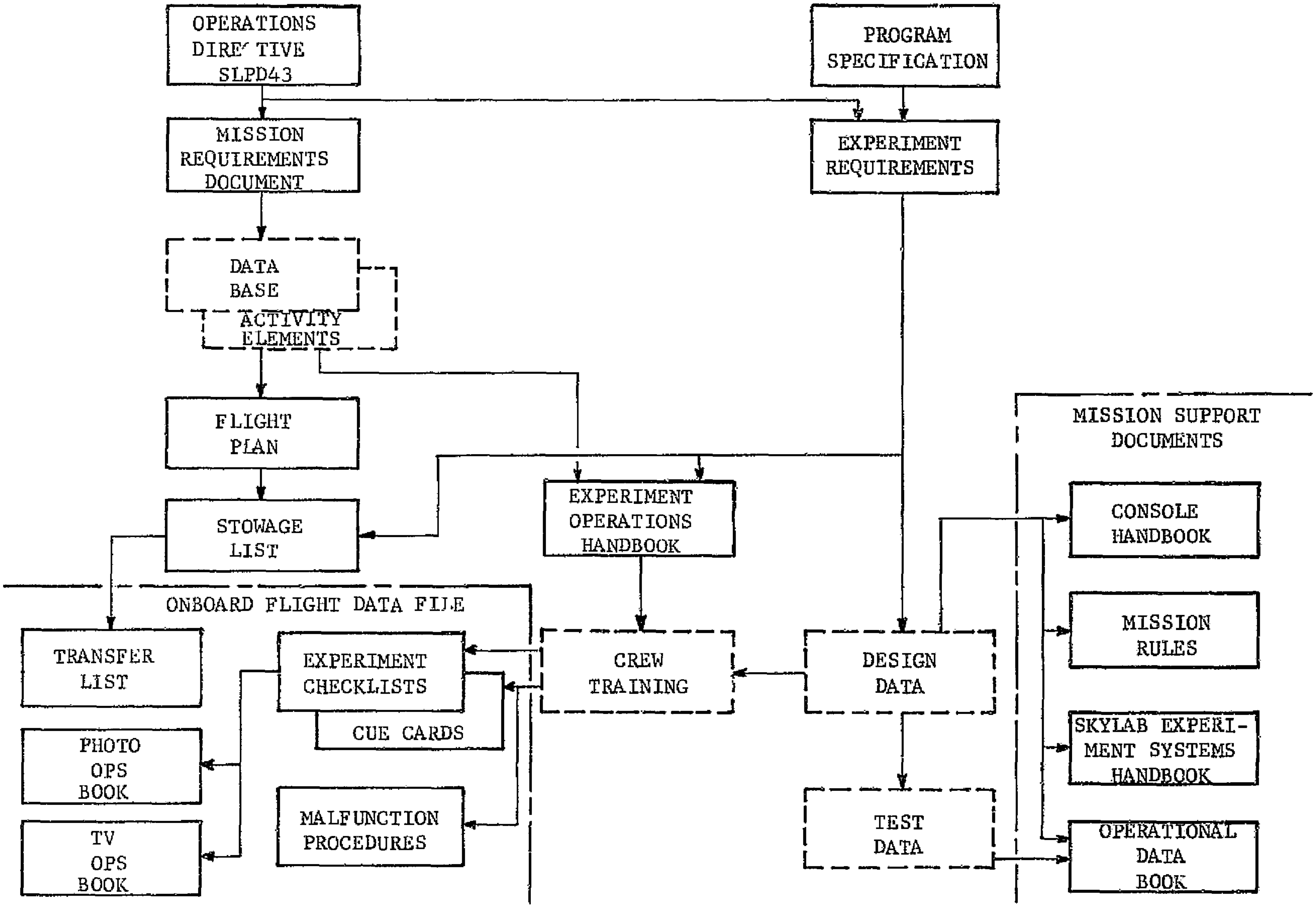

FIGURE 6. SKYLAB EXPERIMENT OPERATIONAL DOCUMENTATION

to a concise presentation of experiment functional objectives, operational requirements, internal and system-related constraints and a summary of the in-flight data (telemetry, film, samples, etc) to be derived from the experiments. Since all the basic operational requirements for all experiments were contained within a single document, erroneous information, mutually exclusive events and conflicting constraints could be readily identified and rectified. Future programs would be well served by a document comparable to the MRD with even greater emphasis on frequent reviews, rapid incorporation of new information and wide distribution.

3. Flight Plans. The Flight Plans accomplished the detailed scheduling of inflight crew activities. From the MRD requirements a daily activity schedule was generated which would maximize experiment accomplishment, optimize crew utilization and preclude experiment constraint violation. Premission flight plans for each mission were published in a sequence of increasing refinement under the titles: Preliminary Reference Flight Plan; Reference Flight Plan and Flight Plan.

4. Experiment Operations Handbook. The EOH was published in two volumes. Volume I was system oriented and provided a description of all Skylab experiments except ATM. Volume II contained the 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.

5. Crew Experiment Checklists. The checklists were developed from the ERD experiment operations procedures and expanded in the EOH, Volume II. These preliminary procedures were refined and updated during the crew training periods and simulations. Crew inputs played a major role in shaping the final onboard checklists in the Flight Data File. Cue cards were prepared, in some cases, to serve as abbreviated reminders located near the experiments.

6. Experiment Malfunction Procedures. The Experiment Malfunction Procedures were a compilation of logical procedures to be followed in the event of an experiment anomaly and were designed to quickly isolate the malfunction to a particular component or subsystem. They were included in the onboard Flight Data File.

7. Photo Ops Book. This document was in the Flight Data File and provided a summary of photographic requirements, which included: experiment requirements for the use of operational film and photographic equipment; log sheets for recording photographs taken; operational instructions for the photographic equipment, including activation, deactivation and malfunction procedures; camera mounting locations; and film vault stowage instructions. The Photo Ops Book was important since all nonspecial film and photographic equipment used by experiments were provided as operational support items.

8. TV Ops Book. This document was in the Flight Data File and provided procedures and scene definitions for use during television recording sessions. TV procedures were provided for several experiment activities. A special SL-4 addendum contained all the checklists for the SL-4 science demonstrations.

9. Stowage List. The Stowage List compiled weight, volume, quantity and stowage location information for all loose equipment planned to be moved by the crew. It was the focal point of tradeoffs between competing experiment and support equipment launch candidates. Transfer lists to guide the crew in unloading the CMs after docking and in loading them for return were derived from the Stowage List and became part of the Flight Data File.

10. Flight Mission Rules. The Mission Rules were developed to ensure crew safety and maximize the probability of mission success by guiding operational decisions during the missions. They were primarily preplanned decisions designed to cope with real-time contingencies.

11. Skylab Console Handbook. The Console Handbook was a ready reference of mission-related information for use by flight controllers in mission control. It was a collection of procedures and information which might be required on short notice. It contained detailed hardware performance data derived from experiment design and test.

12. Skylab Experiment Systems Handbook. The Skylab Experiment Systems Handbook (SESH) was a compilation of experiment functional flow diagrams and, where applicable, mechanical and electrical schematics, used by the flight controllers to complement the Skylab Console Handbooks. 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.

13. Operational Data Book. The ODB supplied a standard set of performance data and limits, primarily oriented to the program operational aspects. Volume I provided experiment performance data including the major subsystem capabilities and limitations. The other volumes provided mass property and performance data on the Skylab systems.

B. Data Requirements

A Data Request Form (DRF) was the standardized method of requesting data for all MSFC/JSC data users. The DRF system was jointly agreed upon by MSFC and JSC for levying data requirements between the two centers. However, program/mission level support requirements (i.e., communications, data lines, TV, etc) were documented in the Program Support Requirements Document (PSRD). The Automated Data Requirements System (ADRS) was developed for statusing and control of all MSFC DRFs and for generating tapes which were used in processing the All Data Digital Tape (ADDT). The organizations that processed and implemented data requirements are described in the MSFC Skylab Final Program Report, Section IV, Mission Operations.

Experiment DRFs were prepared under the direction and cognizance of SL-DP and submitted to the MSFC Data Requirements Group for Processing and implementation. DRFs for KSC test results were processed through MSFC and those to be implemented by KSC were documented in the Program Support Requirements Document. DRFs for processed data were implemented by MSFC.

Scientific data analysis requirements were defined by the PIs and documented on DRFs. These DRFs were signed by the PI, submitted and their progress tracked by SL-DP until implementation was assured. The agreements between the PI and the EDC regarding the data to be supplied by NASA, its protection, his publication rights, and output responsibilities and schedules were documented in the Experiment Scientific Data Analysis and Reporting Document (ESDARD).

SL-DP prepared DRFs requesting the experiment data required to evaluate the hardware performance of MSFC-developed experiments, and the systems housekeeping data required to determine whether interface requirements had been met for each corollary experiment integrated by MSFC. These systems housekeeping data requirements were consolidated into an integrated set for all corollary experiments. Measurements to be incorporated into the Auto Scan program (which scanned the ADDT for specific events or out-of-tolerance conditions to support quick-look statusing and analysis) were defined and DRFs written.

C. Systems/Operations Compatibility Assessment Review

The primary objectives of this review were to assess the Skylab systems design, integration and performance characteristics based on updated engineering analyses, simulations, and actual hardware test experience; and the operational readiness of Skylab through a detailed review of the mission plans, procedures and documentation to be used by the operations team for the conduct of the mission. Additionally, the Systems/Operations Compatibility Assessment Review (SOCAR) [13] contributed materially to the preparation for the Skylab Design Certification Review (DCR).

The review was conducted in a manner to directly interface the responsible Skylab systems design/development personnel and the operations personnel; make maximum utilization of the mainline Skylab program engineering and operations activities; and insure that the products of the review contributed directly to achieving operational readiness and preparation for DCR.

A corollary experiment SOCAR team was set up, consisting of MSFC, JSC, KSC and appropriate contractor personnel. The SOCAR lists of experiments and topics reviewed are identified in tables II and III. Six intercenter meetings were held during the active review phase of SOCAR. Each center (MSFC and JSC) prepared packages of their own pertinent documentation for review, taking care to provide the most up-to-date information available, and to insure its compatibility with other documentation from the same center. These packages were presented at intercenter meetings, which discussed the purpose, contents, format and applicability of the documents and identified cognizant personnel responsible for each document. Subsequently, each center reviewed the other center's packages between SOCAR meetings and reported comments at the following meeting.

TABLE II. COROLLARY EXPERIMENTS CONSIDERED DURING SOCAR

EXPERIMENT NUMBER	TITLE/DESCRIPTION
D008	Radiation in Spacecraft
D024	Thermal Control Coatings
M415	Thermal Control Coatings
M479	Zero-Gravity Flammability
M487	Habitability/Crew Quarters
M509	Astronaut Maneuvering Equipment
M516	Crew Activities and Maintenance Study
M512	Materials Processing Facility
M551	Metals Melting
M552	Exothermic Brazing
M553	Sphere Forming
M554	Composite Casting
M555	GaAs Crystal Growth
S009	Nuclear Emulsion
S019	UV Stellar Astronomy
S020	UV/X-Ray Solar Photography
S063	UV Airglow Horizon Photography
S149	Particle Collection
S150	Galactic X-Ray Mapping
S183	Ultraviolet Panorama
T002	Manual Navigation Sightings
T003	In-Flight Aerosol Analysis
T013	Crew/Vehicle Disturbance
T020	Foot-Controlled Maneuvering Unit
T025	Coronagraph Contamination Measurement
T027/S073	Contamination Measurement/Gegenschein/ Zodiacal Light
T027 SA	Contamination Measure - Sample Array
Operational Instrument	
Proton Spectrometer	

TABLE III. COROLLARY EXPERIMENTS SOCAR TOPICS

1. Systems Design
2. Systems Performance Predictions
3. Systems Operation Constraints and Limitations
4. Systems Interfaces - Functional
5. Waivers and Deviations
6. Test and Test Anomalies
7. Failure Modes and Effects Anal./Single Failure Point
8. Safety Checklists
9. Inflight Maintenance
10. Contingency Analyses
11. Operations and Procedures
    - A. Skylab Experiments Operations Handbook Volume II
    - B. Skylab Experiments Systems Handbook
    - C. Mission Rules
    - D. Operational Data Book

Action items and discrepancies were documented on Incompatibility Item Disposition (IID) forms for tracking and closure. A formal report documenting the SOCAR activities was prepared in late May 1972. This report presented the SOCAR results in terms of open action items, significant comments or problem areas, and summary status of the hardware, the test program, and the pertinent operational documentation.

The SOCAR was culminated with a summary review presentation to senior Skylab management personnel in early June 1972. In addition to meeting the stated objectives of the review, SOCAR served as an introductory mechanism for establishing dialogue and working relationships among the design, development, test, integration and operations personnel, facilitating a smooth transfer of pertinent data such as experiment objectives, hardware descriptions, performance characteristics, operational requirements, constraints and test history.

D. Mission Simulations

Premission simulations were initiated to rehearse flight and support personnel in a mission environment beginning approximately six months prior to SL-1 launch. For the purpose of these simulations, the mission was divided into distinct phases, (e.g., launch, first day activities, activation, orbital operations, etc.). Each orbital operations simulation 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 (see section XII) simulated the actual mission environment including hypothetical malfunctions. The corollary experiment Mission Support Group Leader (MSGL) and his staff in the Huntsville Operations Support Center (HOSC) participated in each orbital operations simulation involving corollary experiments. Support teams for the SAL, materials processing, engineering/operations, and student experiments were implemented in building 4471, along with the systems team for overall coordination. Basic coordination, information flow and sign-off procedures were established during these simulations. Requirements to establish duty rosters, regular courier service between the HOSC and building 4471, systematic flight plan reviews and daily reports were identified and implementation procedures prepared.

The simulations attained two important goals. They provided a rapid and effective means of raising the experience level of the support personnel in the conduct of manned space missions. At the same time, they provided extensive preparation in the areas of anomaly resolution and contingency planning. The procedures developed and the experience level attained during the simulations contributed greatly toward the efficient and orderly approach to the problems encountered during the actual mission.

SECTION X. DESIGN CERTIFICATION REVIEW

The MSFC Corollary Experiment DCR was conducted, as required by Skylab PD No. 11A [14], to examine the MSFC-developed experiment hardware designs and design verification programs to assess and certify that the experiment hardware could accomplish the planned Skylab missions. Specific review objectives were to:

Certify the experiment hardware design for manned flight safety.

Certify the experiment hardware design for flight worthiness.

Experiment M415, Thermal Control Coatings, and Experiment S150, Galactic X-Ray Mapping, were not included in the corollary experiment DCR but were part of the IU DCR.

A. DCR Implementation

The DCR was conducted during the period April 1972 through October 1972. The review was conducted in five phases.

1. Pre-Phase I. This was the DCR planning phase. Meetings were conducted by the SL-DP Project Manager and attended by MSFC and contractor personnel to prepare a DCR procedure, expedite its implementation, and schedule review milestones. The EDs initiated the required written DCR reports. Individual experiment DCR report activity was managed by the responsible EM. Typical contents of an experiment DCR Report are shown in table IV.

2. Phase I. Phase I was to: provide a technical design assessment of suitability for certification; review the initial oral and written reports presenting and substantiating the assessment; identify required activity to review backup documentation, and identify any additional requirements to enable certification.

The EDs submitted DCR written reports to SL-DP. Backup documentation to support the assessment was identified and reviewed. Table V contains a listing of backup documentation which was reviewed to support the written, and later the oral, reports. Phase I culminated in an oral presentation by the ED to the SL-DP Project Manager on July 5, 6 and 7, 1972.

TABLE IV. EXPERIMENT DCR REPORT CONTENTS

1. Experiment Description A. Objectives B. Hardware Description C. Operational Modes D. Interface Summary E. GSE Description 2. Results of Reviews 3. Design and Performance Requirements/Verification A. Flight Hardware B. Qualification/Flight Hardware Differences C. Failure/Corrective Action Summary D. Waivers and Deviations E. Outstanding Changes F. GSE 4. Safety and Reliability A. Safety B. Reliability C. Inflight Maintenance 5. Items to be Addressed by Other DCR Segments 6. Open Items A. Open End Item Deliveries B. Open Design Problems C. Incomplete Qualification D. Open Failures Analyses/Actions E. Summary of Vehicle/Integration Tests Remaining 7. Certification of Design

TABLE V. EXPERIMENT DCR BACKUP DOCUMENTATION

1. Failure histories of critical items and their corrective action results.
2. Prior Review Item Discrepancy actions and their resolution. (Included RIDs from PDR, CDR, Cluster Systems Review, crew station reviews and acceptance reviews.)
3. Outstanding Engineering Change Proposals and planned closeout actions.
4. Limited-life component operating times and cycle data.
5. Test and analysis verification results which supported the verification summaries contained in the DCR Report.
6. Certificates of Flight Worthiness, suitably updated.

Phase I results were summarized on July 13, 1972, by the SL-DP Manager in a presentation to the Skylab DCR Review Board. The summary included a review of the action items assigned (items which did not relate directly to design certification), open items assigned (items which required closure before the design could be certified), qualification test status, waivers and deviations, and outstanding design changes for each MSFC corollary experiment. The board concurred with the recommendations made, except:

A waiver, ECR LGSM 0970, concerning flammable materials scheduled for burning as part of Experiment M479, was discussed in detail. MSFC and JSC had not reached agreement on the use of teflon and polyurethane foam as test materials. The subject waiver was referred to Level I and subsequently approved.

Concern was expressed that the Experiment T027 boom could re-contact the orbital assembly if ejected. An analysis by the integration contractor had shown that the boom would clear the orbital assembly. A separate analysis by Aero-Astrodynamics Laboratory was in process to determine whether a problem of re-contact during subsequent orbits would exist. This analysis was completed in October 1972 and the Board's concern was satisfied.

The S183 review indicated that the flight backup unit had not been pressure tested to the recommended level. Astronautics Laboratory reviewed this condition and recommended waiving the proof test requirement, since fracture mechanics analysis of the windows indicated no problem. No problems in the flight unit were encountered during integrated systems test and the backup unit remained in bonded storage.

3. Phase II. Comments gathered by the EMs on the Phase I oral presentations and written reports were used by the EDs to update their DCR material. The Phase II review and evaluation allowed the SL-DP Manager to perform a technical assessment of all material and methods of presentation being used, thereby providing assurance that the Skylab Program Director and the Skylab DCR Board would have technical visibility upon which to base their certification. A formal certification for the design of each MSFC-developed corollary experiment was signed by the PI and cognizant EDC and EIC personnel.

Due to budget limitations, a complete assessment of the total DCR activity was made during July 1972. The assessment resulted in the cancellation of the formal DCR Phase II oral presentation scheduled for August 21-25, 1972. It was determined that the results of the Phase I DCR activity, coupled with the SOCAR activities, met all requirements for this phase of the DCR.

4. Phase III. Phase III was the formal and official presentation for certification. It was organized and directed by the Skylab Program Director and conducted by the DCR board at KSC on October 3, 1972.

In preparation for these presentations, the Phase I DCR written reports were further updated, addressing significant events which had been completed or problems which had arisen since the Phase I DCR.

The design of the MSFC corollary experiments was certified pending the closure of the following open items:

T027/S073 Photometer System

Furnish certification of materials,
Complete qualification testing and obtain qualification acceptance,
Incorporate new connectors,
Approve electromagnetic interference waivers;

T027 - Sample Array System

Provide qualification acceptance,
Perform leak check on flight unit,
Refurbish and verify pressure integrity of the backup unit;

S183 - Ultraviolet Panorama

Obtain qualification acceptance;

T013 - Crew Vehicle Disturbances

Refurbish force measuring unit load cells and retest prior to KSC delivery;

T002 - Manual Navigation Sightings

Provide qualification acceptance;

M512 - Materials Processing Facility

Provide procedures for vacuum cleaner operation, electron beam gun alignment and sphere retrieval,
Provide protective eye filter for facility viewport,
Furnish M551 (Metals Melting) weld samples,
Provide properly endorsed qualification acceptance,
Determine waste heat profile during operation of experiments to determine impact on the MDA environmental control system;

M415 - Thermal Control Coatings

Provide thermal analysis of modified design,
Qualify coverplate hinge/latch modification and provide qualification acceptance;

Student Experiments, S228 (Trans-Uranic Cosmic Rays), S230 Magnetospheric Paticle Composition, and M518 (Multipurpose Electric Furnace)

Complete DCR for these experiments by submitting written reports to NASA Headquarters.

5. Phase IV. Phase IV was a time period allowed for the closing of the DCR open action items. Items assigned during the DCR were closed by the responsible MSFC, contractor, and ED representatives. Closure actions were reviewed by the MSFC Program Engineering and Integration Project Manager (SL-EI) prior to incorporation into the MSFC Skylab Program Office Manager's periodic status reports to OMSF. This action was completed prior to the FRR.

B. Experiments Approved Late in Program

Experiments approved late in the Skylab program were not covered in the formal MSFC Corollary Experiments DCR. These included: the student project experiments; the Multi-purpose Electric Furnace experiments (M518 series); Experiment S228, Trans-Uranic Cosmic Rays; and Experiment S230, Magnetospheric Particle Composition. The same DCR activities and certifications were accomplished for these experiments, except that formal presentations to NASA management were not made.

SECTION XI. FLIGHT READINESS REVIEWS

The MSFC Corollary Experiment FRR was conducted as part of the overall Skylab program FRR, as required by Skylab PD No. 59 [15], to assess the operational readiness and safety of the MSFC-developed experiment flight hardware and documentation. Separate FRRs were conducted for SL-1/SL-2, SL-3 and SL-4, each in four steps:

Individual experiment reviews were made by the applicable EMs, EIEs and EDs, and the results presented to the SL-DP Manager.

The SL-DP Manager presented the combined review results to the MSFC Skylab Program Manager.

The revised FRR material was then presented to the MSFC Center Director as part of the MSFC pre-FRR.

The final FRR material was presented to the Skylab Program Director and the FRR Board at KSC.

A typical experiment FRR agenda is shown in table VI.

A. SL-1/SL-2 FRR

Preparations for the SL-1/SL-2 FRR began in December 1972. The presentation to the SL-DP Manager took place on February 23, 1973. A summary of the results of the Systems Safety Checklist Program for Corollary Experiments was also included. The MSFC Program Manager's dry run FRR was held on March 16, 1973, and the MSFC pre-FRR on April 10, 1973.

The formal SL-1/SL-2 FRR was held on April 18 and 19, 1973, at KSC. The presentation for MSFC corollary experiments was made by the SL-DP Manager. All DCR open action items for these experiments had been closed prior to the FRR. Forty-seven engineering changes had been authorized since DCR and the affected hardware successfully modified and retested. All MSFC corollary experiments had completed qualification testing and there were no open work items. Ten waivers and deviations had been approved since DCR, none of which adversely affected crew safety or compromised the mission objectives.

Table VI SL-1/SL-2 Experiments FRR Typical Agenda

DCR Action/Open Items Summary
Factory-KSC Acceptance Review and COFW Open Items
KSC Test Status
Significant Problem Status
Qualification/Endurance Test Status
Waivers and Deviations
Configuration Changes
Operating Time and Cycle Status
Hardware Shortages
ICD/IRN Status
Reliability and Safety Readiness Statement
Open Item Summary

There were no unresolved technical issues or open problems. Three problems closed since DCR were identified: malfunction of the M512 Electron Beam Gun during test at KSC; a faulty M512 battery; and a malfunction of the T027 carrousel. Closure of these problems was accepted without discussion, and the MSFC corollary experiments were adjudged ready to fly.

B. SL-3 FRR

The SL-3 FRR was conducted during the period between SL-2 splashdown and July 12, 1973. The SL-3 experiment review concentrated on experiment problems or anomalies that had occurred during the SL-1/SL-2 mission, corrective actions taken, and possible impacts on SL-3 launch or mission operations. The pre-FRR activity also assessed the impact of loss of the meteoroid shield, resultant high workshop temperatures until solar parasol deployment and the subsequent unavailability of the solar SAL for experiments.

The SL-DP Manager's review was held on June 28, 1973. The report to the MSFC Skylab Program Manager was made on July 5, 1973, and the MSFC pre-FRR was conducted on July 9, 1973. The SL-3 FRR for MSFC corollary experiments was presented by the SL-DP Manager to the FRR Board at KSC on July 12, 1973. Specific problems addressed at this review included:

S009 detector package motor failure. It was recommended that the experiment could be operated in a passive mode which would allow all experiment objectives to be met. However, a replacement motor was to be launched on SL-3 for changeout by the crew if time permitted.

The sixth film plate had jammed in the S183 Spectrograph, but was subsequently cleared.

The T027/S073 shaft mechanism would not return from the maximum (354.4^{o}) position after being deployed through the antisolar SAL. During retraction the photometer head lightly tapped the side of the OWS and the malfunction cleared itself.

After reviewing the items to be launched on SL-3 and the hardware delivery status, it was stated that the MSFC corollary experiments were ready to continue the Skylab mission.

C. SL-4 FRR

The SL-4 FRR was conducted during the period between SL-3 splashdown and October 18, 1973. The review concentrated on four categories of experiments scheduled to be performed on SL-4:

Approved experiments
Candidate experiments
Comet Kohoutek experiments
Science demonstrations

Approved experiments were those that had been baselined for performance on SL-4. Candidate experiments included both experiments that had failed or experienced problems for which corrective actions had been established, and those that had been successfully performed but additional data was desired. During July 1973 SL-DP had been assigned responsibility for the Comet Kohoutek Viewing Program and therefore an assessment of this program was included in the FRR. Hardware and operational requirements for the 17 MSFC proposed science demonstrations were included in the FRR.

The review concentrated on the following areas:

Launch stowage requirements,
Return stowage requirements,
Hardware delivery status,
KSC tests remaining,
Problems/anomalies that occurred during previous missions that could affect the SL-4 mission.

The SL-DP Manager took an active role in preparing the SL-4 FRR material, so that no formal presentation to him was required. The MSFC Skylab Program Manager's pre-FRR dry run was presented on October 9, 1973. The pre-FRR to the MSFC Director was held on October 12, 1972. The SL-4 MSFC Corollary Experiment FRR was presented to the FRR board at KSC by the SL-DP Deputy Manager on October 18, 1974.

After reviewing the experiments to be performed, launch stowage requirements, hardware delivery status and problems associated with experiments D024 and S183, it was stated that the MSFC corollary experiments were ready to complete the Skylab mission.

SECTION XII. MISSION SUPPORT

This section describes MSFC's responsibilities and activities for Skylab corollary experiment mission support. It presents the mission support organization, the facilities utilized and the procedures implemented and developed during the mission.

A. Organization

The Corollary Experiments MSG functional organization and its principal interfaces are shown in figure 7. The official contact at JSC for MSFC experiments was the SL-DP Manager in the FOMR. All responses and recommendations related to experiments were routed to this office for initiation of appropriate action in Mission Control. The MSGL directed and coordinated the MSFC experiment team activities and approved all official responses for HOSC endorsement and transmittal to the FOMR. During SL-4, additional support was provided by a separate Kohoutek team at JSC.

B. Mission Support Facilities

A conference work area (CWA 10, also known as the "Wind Room") was provided within the HOSC for the corollary experiments MSGL and his HOSC support team. The majority of corollary experiment support personnel were located in MSFC Building 4471, where facilities included conference areas, flight director and air-to-ground voice loop monitoring capability, limited TV channels, documentation reference files, trend/status boards, and reproduction and Magnafax equipment. High-fidelity mockups of the carrier modules, with experiment hardware installed, were provided in MSFC Building 4619 to support the investigation of anomalies or operational changes and the development and checkout of malfunction procedures.

The SL-DP Manager or his representative occupied a table in the FOMR at the JSC Mission Control Center (MCC). The Kohoutek support team operated, or supported the operation of, a console in the corollary PI support room at the MCC during SL-4. An offsite facility was located near JSC for use by corollary experiment PIs as an optional work area. This PI office was also frequently used on a temporary basis by Huntsville MSG personnel visiting in support of the MSFC FOMR representative.

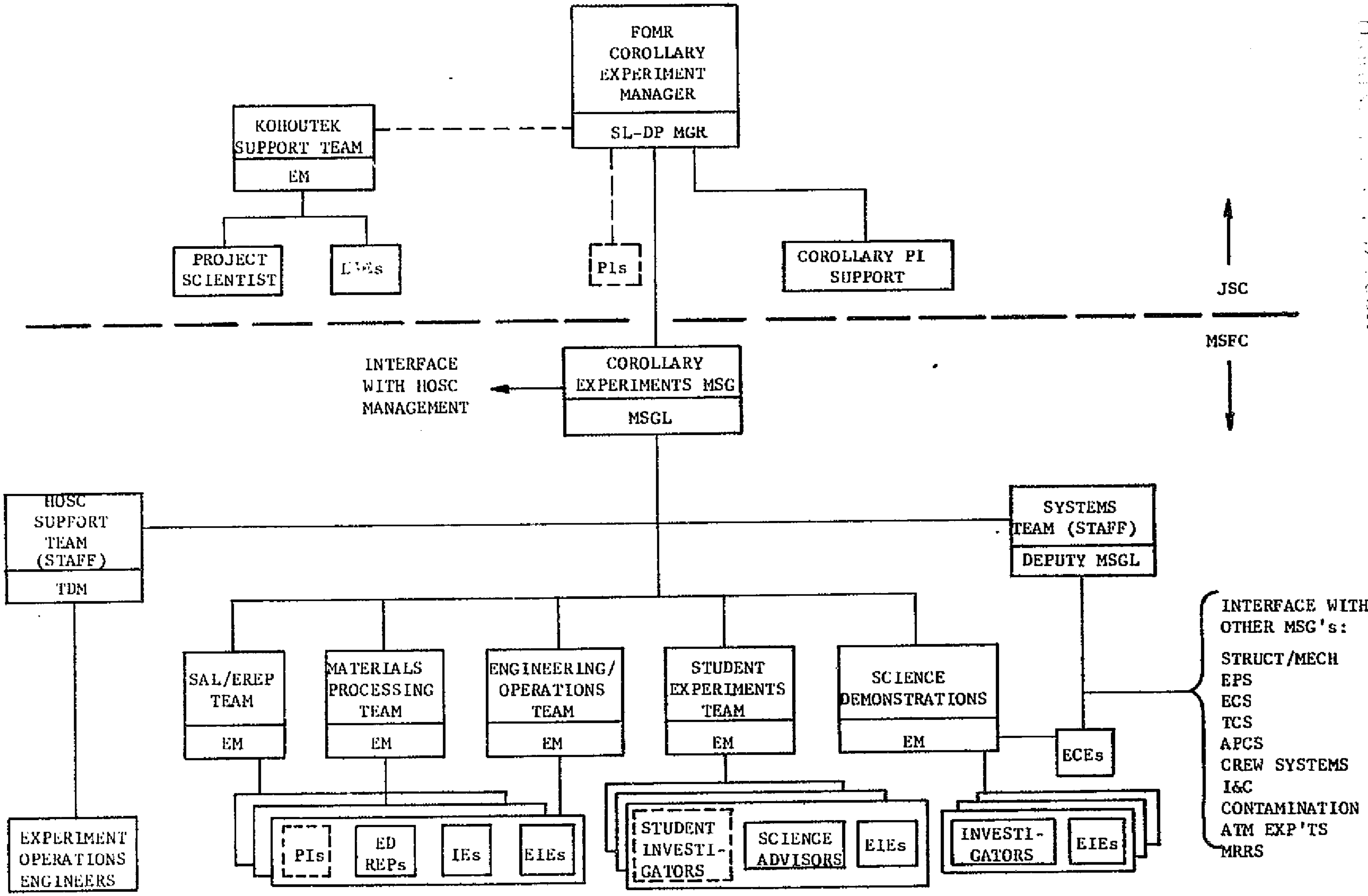

FIGURE 7. COROLLARY EXPERIMENTS MISSION SUPPORT ORGANIZATION

C. Routine Mission Support Activities

MSFC mission support activities were centralized at the HOSC. The HOSC provided a monitoring and evaluation function for all MSFC-managed spacecraft systems and associated anomaly resolutions. HOSC served as the central organization through which all JSC requests for assistance were received and processed.

All experiment activities were performed in support of the SL-DP Manager in the FOMR. All requests for information, or responses to MARs, were processed through the HOSC. This interface was maintained formally through the HOSC, by the Technical Discipline Manager (TDM) supporting the MSGL. He coordinated the preparation of experiment inputs to the HOSC daily and weekly reports and provided around-the-clock real-time HOSC console operation and monitoring, utilizing Experiment Operations Engineers.

The EMs directed the experiment team activities. Team support personnel monitored all operational data and information affecting experiment performances. This activity included: daily review of the flight plan and teleprinter messages to ensure compliance with experiment requirements; monitoring the flight director and air-to-ground voice loops to anticipate anomalous situations; constantly reviewing vehicle systems status for possible experiment impacts; and assessing all real-time change paper for compatibility with experiment objectives. Experiment accomplishment status was maintained throughout the mission. Flight plan recommendations were prepared twice weekly for the SL-DP Manager to present to the Mission Scientist for his generation of a preliminary experiment operating plan for the next week. These planning meetings proved to be extremely valuable in meeting experiment requirements and in balancing time allocations to the competing experiment groups.

Experiment team requirements for real-time telemetry measurement printouts were satisfied by HOSC team personnel who obtained printouts from the Mission Operations and Planning System (MOPS) computer network. Telemetry data was required to assist the experiment teams in assessing hardware performance, interface verifications, and constraint compliance.

The experiment teams generated daily experiment operation inputs to the HOSC report, which was submitted to the FOMR for review and incorporation in the JSC daily report. The teams provided inputs to other MSFC reports and summaries where corollary experiments were involved.

The data coordination ECE received, organized, and filed or disseminated data for the corollary experiment MSG. The data initially included crew transcripts, Auto Scan printouts and data books. During SL-2 and SL-3 the Auto Scan printouts were often several days behind real time and, in many instances, were not available until after the data books. The Auto Scan limit printouts were therefore discontinued about the middle of SL-3, but event printouts were continued.

The data books delivered initially included all systems and subsystems books from which data had been requested (i.e., Experiment Systems Book 12 plus all systems books containing any data from requested measurements). During SL-2 a backlog developed in reproducing and delivering data books that resulted in a distribution policy reassessment. At the end of SL-2, a request to incorporate pertinent system measurements into the experiment book was submitted to the Data Support Organization. This request was implemented during SL-4, thus greatly reducing the volume of data handled by the corollary experiment group.

D. Problem Investigation and Resolution

The experiment teams continually assessed mission operations for potential or real problems. When a problem was identified, the team investigated the circumstances and generated appropriate recommendations for anomaly resolution.

Experiment teams responded to JSC or HOSC queries when assessment of hardware operation, malfunction procedures or operational "work-arounds" were being considered. These queries were documented as MARs when originated at JSC, and as Action Requests (ARs) when originated at MSFC. Investigations and/or special studies were conducted as required, and formal responses to the MARs and Action Requests were processed through the MSGL and the HOSC.

Scientific impact problems were worked by the cognizant EMs and EIEs in consultation with the PI as ˋal point. These problems were typically those involving changes . time allotted to an experiment, or any problem that might affect the quality of the scientific results. Hardware malfunctions were handled by teams built around the ED. The IE was available to coordinate the technical support of the MSFC Science and Engineering Laboratories. Integration problems, such as Stowage List or crew checklist changes, were generally resolved by the EIEs with systems interfaces worked by appropriate ECEs.

Recommended problem resolutions or new experiment hardware malfunction procedures were verified using the high-fidelity mockup hardware whenever practicable. The experiment teams provided anomaly inputs to the MSFC daily operations summary, and to other applicable MSFC and JSC summary documentation.

SECTION XIII. EXPERIMENT INTEGRATION VIA SPECIALIST TEAM CONCEPT

Several Skylab experiments were approved too late in the program to permit a normal approach to development and integration activities. A different approach, utilizing expertise and past experience gained through earlier experiment activities accomplished all the program milestones in a greatly compressed time scale. The utilization of experts in various areas, optimizing overall program expertise, became known as the Specialist Team Concept.

The nucleus of this team was the experienced EIE. His expertise included an extensive background in Skylab, a thorough understanding of general experiment requirements (particularly documentation), established contacts within the involved NASA and contractor organizations, a close association with the EMs and experience in coordinating with PIs.

The Specialist Team Concept was applied to the student experiments, the M518 experiments, S228 and S230 experiments and the SL-4 science demonstrations. Experiment objectives, concepts, design testing, data requirements and operational procedures were thoroughly coordinated from the outset. The time required for experiment development was reduced by assisting the PI and EM in meeting Skylab requirements during the initial design, thus avoiding the review and rewrite cycles prevalent earlier in the program. Having a unique understanding of the various program document requirements and formats, along with understanding the experiment, the EIE was able to directly guide a team effort in preparing the basic experiment documents simultaneously. Specialists obtained information from the EIE, analyzed it from a specific document viewpoint and formatted the material consistent with Skylab documentation requirements. This eliminated the considerable "learning curve" time associated with each ED preparing his own documents. Utilizing the specialist team, the EIE was able to concurrently oversee the preparation of the: ERD, EIS, FMEA, Contamination Control Plan, Non-Metallic Materials List, Operation, Maintenance and Handling Plan, Verification Test Plan, and other documents, as required.

In many instances, documents were simplified by eliminating inapplicable sections. For the student experiments, the ERD was simplified by coding a standard table of contents to indicate inapplicable sections and omitting these sections from the text. This streamlining philosophy was implemented for all student experiment documentation, including the acceptance data package.

This concept was extended to include project organizations in the various NASA laboratories and organizations responsible for each experiment program. These project personnel were familiar with intra-organizational procedures and responsibilities and coordinated the resolution of developmental and integration problems within their particular disciplines. Various studies, tests, and analyses were performed to support the EDs and EIC. Specific examples include:

Thermal analyses for the M518 system to support hardware development.

Structural analyses for the S230 mounting arrangement to eliminate dynamic testing.

Electromagnetic interference testing of the M518 control package.

Conformal coating studies to resolve M518 problems.

The Specialist Team Concept permitted on-time delivery of experiment hardware and documentation that would not have been possible using normal procedures.

SECTION XIV. CONCLUSIONS AND RECOMMENDATIONS

The most significant general conclusions and recommendations that have been drawn from the MSFC Skylab experiment development and integration experience described herein are presented in the following paragraphs. More specific conclusions and recommendations, pertinent to individual experiments, can be drawn from the MSFC Skylab Corollary Experiments Systems Mission Evaluation Report, TM X-64820.

A. Documentation

Conclusion - Skylab documentation evolved gradually during the life of the program, had many redundancies and some inconsistencies, and certain key documents (e.g., the Cluster Requirements Specification) were not accepted by all elements of the program.

Recommendations - Establish a clear-cut, nonredundant documentation tree early in any new program and enforce adherence throughout the program. In addition:

Present definitive information in only one document;

Tailor documents to accomplish a specific purpose, leaving out nonpertinent information;

Baseline documents at appropriate time;

Phase documents out of the program as soon as their purpose has been served.

B. Configuration Management

Conclusion - Skylab experiment integration change control evolved into a very efficient low-cost system. Precoordinating a change with all affected areas and including, in one complete change package, proposed change notices to all impacted documents, nearly eliminated the need for Level III Experiment Configuration Control Board (CCB) meetings.

Recommendations - Establish a single configuration management philosophy throughout all elements of any new program, implement the preceding documentation recommendations, and specifically, as evolved in the Skylab experiment configuration management system:

Precoordinate the change with all affected program elements prior to submittal;

Include with the change request proposed change notices (e.g., preliminary Specification Change Notices, Interface Revision Notices, Stowage List Change Notices, etc., as applicable), to all documents affected by the change, to make a complete change package (use a checklist to ensure that all impacts are identified);

Expedite change processing by having the changes pre-coordinated and prepared by the experiment and system/discipline specialists responsible for integration of the experiment (see subsection D).

NOTE: Configuration Management cannot wait for each organization to finalize a change in their document before acting on the proposal. The change must be evaluated by the CCB on the basis of known precoordinated impacts to all areas of the program if real control is to be maintained. The Configuration Control Board Directive (CCBD) documenting a decision will contain any modifications to the change proposal that are directed by the CCB. Document update pages implementing the CCBD direction can then be prepared and distributed by the organizations responsible for the affected documents.

C. Compatibility Assurance

Conclusion - The integration of experiments into Skylab led to the need for compatibility analyses which compared the experiment requirements with the carrier/program resources. The initial compatibility analysis for an experiment was necessary to provide management visibility for experiment approval or disapproval. Continuous compatibility assessment and reviews during the development, fabrication and testing phases uncovered many significant problems which might not have been discovered until later in the program, and thus avoided greater expense and possible program delay.

Recommendations - In future space experiment programs, continue the Skylab practice of:

Performing experiment to carrier/program compatibility analyses in support of the program assignment decision to determine where major problems exist, propose the best methods of solution, and identify all program impacts;

Conducting continuous compatibility assessment and frequent reviews during the development and integration test phases, to provide timely management visibility of major program problems and resolution progress.

D. Organization and Responsibility

1. Single Point Contact for Each Experiment

Conclusion - During Skylab experiment development and integration, it was found most effective to establish and maintain an individual as the "single point" contact between the experiment and the program at large. He followed the experiment from proposal through delivery and integration and also supported the mission. He was responsible for dissemination of accurate information about the experiment and for ensuring that the experiment remained compatible throughout the Skylab program.

Recommendation - In future space experiment programs, continue the Skylab practice of utilizing systems engineers with pertinent scientific backgrounds who will be responsible and accountable for integration of individual experiments throughout the program. Each of these "experiment specialists" should maintain familiarity with all aspects of his assigned experiment, and specifically be responsible to:

Perform the initial compatibility analysis to support approval or disapproval of the experiment;

Coordinate with the Principal Investigator and developer to define, disseminate and maintain accurate experiment requirements;

Supervise preparation of program-required development and integration documentation by a specialist team;

Act as a single-point contact to the program for accurate information on his experiment;

Support preparation and maintenance of accurate Interface Control Drawings;

Monitor experiment development through continuous coordination and participation in design reviews to ensure program compatibility;

Analyze incompatibilities identified to his experiment and coordinate or support their resolution;

Identify required changes and support Configuration Management by precoordinating each change with all affected program elements;

Review integration test plans and procedures, participate in integration testing and ensure timely resolution of problems encountered;

Support mission operations and anomaly resolution;

Perform post-mission experiment performance evaluation.

2. Support for Each Carrier System or Program Discipline

Conclusion - Integration of the various Skylab experiments involved extensive use of systems engineers with expertise in interfacing carrier systems and specific program discipline areas. These engineers were assigned to facilitate exchange between the experiment group and other Skylab project groups in various specialized areas (e.g., electrical, environments, contamination, etc.). They also coordinated resolution of "group" experiment problems with a system or discipline, and integrated experiment group inputs to program documentation.

Recommendation - In future space experiment programs, continue the Skylab practice of utilizing systems engineers who will be responsible and accountable for all experiment interfaces with a specific system or discipline. These "systems/discipline specialists" should be specifically responsible to:

Support the experiment specialist in performing the initial compatibility analysis for a proposed experiment;

Provide the experiment specialists with a readily-available source of detailed knowledge of the various carrier systems and integration disciplines;

Complie and coordinate accurate information on the total experiment complement for use by other program elements;

Ensure that all program elements involved with his specific system/discipline use accurate information about the experiments;

Coordinate resolution of interface/discipline compatibility problems affecting more than one experiment;

Perform trade studies affecting more than one experiment;

Support Configuration Management by preparing complete change packages, containing preliminary change notices to all affected program documents, for each change identified by the experiment specialists;

Provide management visibility of experiment compatibility problems and their resolution status;

Support mission operations and anomaly resolution;

Perform post-mission evaluation of support provided to experiments by the spacecraft systems.

3. Specialist Teams

Conclusion - The approval of several experiments very late in the program necessitated the use of specialist teams to prepare experiment documentation and expedite development and integration. These teams, working with the Experiment Developer prepared many of the experiment development documents including the End Item Specification, Failure Mode and Effects Analysis, Hazards Analysis, Operating Maintenance and Handling Procedure, and Non-Metallic Materials List. The major advantages gained were that the documents were complete, consistent, correctly formatted, and generated in minimum time at minimum cost.

Recommendation - In future programs, expand the Skylab Specialist Team Concept to the preparation of all experiment-related documentation. Assign specialist teams to prepare all required development and integration documents early in the experiment development program, to preclude each developer and agency going through their own expensive, time-consuming learning curve.

E. Design Philosophy

1. Inflight Maintenance

Conclusion - Skylab has demonstrated the ability of astronauts to perform inflight maintenance. Several major repairs were made during the Skylab missions, although specific ground rules established early in the program prohibited designing hardware for inflight maintenance. Dr. Owen Garriott, SL-3 Science Pilot, stated at the SL-3 debriefing: "I think you can do any job up there that you can do here if you have the right tools, a place to hold everything down and contain all the extra parts." Skylab experiment design studies indicated that inflight maintenance capability could have been provided at little additional cost, if implemented early.

Recommendations - Design manned space flight hardware to facilitate inflight maintenance;

Provide work stations and restraint aids for the performance of maintenance tasks on future manned space vehicles;

Provide telemetry channels or crew status indicators that give direct readout of the specific parameters desired to aid in troubleshooting hardware malfunctions;

Provide viewing capability for inflight observation of external experiments.

2. <u>General</u>

Conclusion - Skylab experiment experience demonstrated the need for hardware design guidelines.

Recommendations - Carefully evaluate the cost-effectiveness of using existing hardware for new programs.

Standardize crew interface hardware.

Establish spacecraft operational environments early to ensure design compatibility (e.g., an overall payload specification like the Skylab Cluster Requirements Specification).

Build in safety features (e.g., interlocks, limit switches) to protect the hardware.

Baseline experiment design only after "advanced state of the art" features are proven.

Resist "product improvement" type changes after baselining.

F. Design Reviews

Conclusion - Experiment requirements, design and acceptance reviews (PRR, PDR, CDR and CIR) were organized and conducted under the auspices and ground rules of the project or directorate office responsible for development of the experiment and, as a result, were not always consistent in the depth and scope of the review or in the acceptance and disposition of Review Item Discrepancies (RIDs). The RID systems became cumbersome in many cases, and it was supplemented by a simple log of Action Items. Most reviews were attended by many more people than were required, which made expeditious completion of the review by authorized program representatives difficult.

Recommendation - Enforce implementation of consistent design review procedures, including coverage of all disciplines that directly affect the subject of the review (e.g., integration aspects, such as environmental qualification test criteria, at CDR). In addition, reviews must:

> Not be conducted prematurely with respect to definition and availability of data.
>
> Have attendance limited to required discipline and project representatives vested with authority to act for their respective organizations (including a single authoritative source of crew comments);

Have complete data packages available to all participants enough in advance of the review to permit thorough evaluation;

Emphasize hardware design and status and carrier support requirements;

Include assessment of test programs and available test results;

Include objective consideration, follow-up and formal disposition of all RIDs or Action Items.

G. Test and Checkout

Conclusions - Many Skylab experiments were delivered prior to completing qualification testing and GSE requirements were not completely defined until late in the test programs, with some resultant incompatibilities. Development of integration test requirements by a specialist team contributed to completeness, accuracy and timeliness of the module contractor and KSC test and checkout requirements definition. Monitoring of all experiment tests by the experiment specialists proved beneficial in early identification of integration problems and enhanced their expertise for mission support.

Recommendations - Provide experiment hardware and perform testing in a logical order i.e., have development unit available early in program and complete development and qualification testing prior to flight hardware delivery;

Baseline qualification and acceptance test and GSE requirements at CDR.

Whenever experiments are supported with GSE supplied by someone other than the ED, control the interface with ICDs.

Utilize a team of test specialists, supported by the experiment specialists, to develop appropriate integration test plans and requirements, as was successfully done for the Skylab experiment integration test program.

As in Skylab, support all experiment testing, both pre- and post-acceptance, with cognizant experiment integration personnel for early program identification and corrective action.

H. Operations Support Planning

Conclusions - Pre-mission estimates of crew time required to perform work tasks in the zero-g environment were not accurate. Some hardware problems encountered during training did not result in appropriate corrective action. Crew walk-throughs and simulations of procedures for a number of late additions and real-time changes facilitated in-orbit operations.

Recommendations - Utilize Skylab experience in quantitative crew task planning for future space flights;

Hardware and operational changes should be made as necessary to incorporate results of crew training;

Utilize walk-throughs by ground-based astronauts for late "add-ons" and real-time procedural changes, as was done for major Skylab changes.

I. Systems/Operations Compatibility Assessment Review (SOCAR)

Conclusion - The Skylab SOCAR served as an introductory mechanism for establishing dialogue and working relationships between the design, development and test personnel and the operations personnel, facilitating a smooth transfer of pertinent data such as experiment objectives, hardware description, performance characteristics, operational requirements, constraints and test history. Reviews and revisions of the mission plans, procedures and documentation advanced the operational readiness of Skylab.

Recommendation - Utilize the experience gained from the Skylab SOCAR meetings by directly interfacing the hardware design/development personnel with the operations personnel to assure maximum coordination and ultimate readiness of the operational planning.

J. Mission Support

Conclusions - For Skylab, an effective specialized mission support team was developed, utilizing experienced operations and experiment personnel. The experiment technical support team, however, had many intermediaries to go through when identifying and resolving problems, which did not always enable them to be solved in a timely manner. Because of the Skylab complexity and extensive experiment program, the twice-weekly science planning meetings conducted by the Mission Scientist proved to be a worthwhile scheduling tool. The use of mock-ups, simulators, and development hardware proved extremely useful in resolving anomalies during the mission.

Recommendations - As in Skylab, utilize personnel for mission support who worked on development and integration of the experiments, and have long experience with hardware-related problems.

During troubleshooting of a problem, establish more direct contact of the technical support team with the crew, reducing the number of intermediaries.

On future manned space experiment programs, continue the Skylab practice of frequent science planning meetings for near-real-time planning of the daily flight activities involving priority definition, allocation of crew time, experiment constraint definition, etc.

Provide facilities and available experiment hardware to facilitate real-time troubleshooting as was done for major Skylab anomalies.

K. Data Analysis and Reporting

Conclusion - Preparation of the Experiment Scientific Data Analysis and Reporting Document (ESDARD) late in the program clarified the mutual responsibilities of NASA and the PIs with regard to data analysis and reporting.

Recommendation - Clearly define the respective responsibilities of the participating scientists and NASA in the following areas of data analysis and reporting:

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

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MSFC SKYLAB COROLLARY EXPERIMENTS

The information in the report has been reviewed for security classification. This report, in its entirety, has been determined to be unclassified.

This document has been reviewed and approved for technical accuracy.

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