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DEVELOPMENT OF SKYLAB ENVIRONMENTAL PROTECTION FOR PHOTOGRAPHIC FILM

W. C. Askew, et al

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

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By W. C. Askew, W. A. Clarke, and C. A. Best
Astronautics Laboratory

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

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16. ABSTRACT

The problems of providing adequate environmental protection for photographic film on three Skylab missions and the technical and management approach to resolving these problems are presented. The radiation, temperature, and humidity environments to which film will be exposed for up to 230 days in space and the effects of these environments on film are discussed. The report concludes with a definition of the design requirements for the Skylab Film Repository.

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ABBREVIATIONS

BRM	Baseline Reference Mission
CCBD	Configuration Control Board Directive
ECR	Engineering Change Request
H&D Curve	Hurter and Driffield Film Characteristic Curve
MDAC	McDonnell Douglas Astronautics Company
MMC	Martin Marietta Corporation
MSC	Manned Spacecraft Center
OWS	Orbital Workshop
RH	Relative humidity
SAA	South Atlantic Anomaly
SCN	Specification Change Notice
SL-1, 2, 3, 4	Skylab Missions 1 through 4
SVWS	Saturn V Workshop (early program notation)

NASA TECHNICAL MEMORANDUM X-64616

DEVELOPMENT OF SKYLAB ENVIRONMENTAL PROTECTION FOR PHOTOGRAPHIC FILM

INTRODUCTION

The Skylab Program includes the corollary experiments shown in Table 1 that depend on photographic film as the primary source for data return. The scientific nature of the individual experiments requires that many different types of film be carried into space and returned without film degradation sufficient to mask the desired experimental data. The orbital characteristics and extended mission duration of the Skylab subject the film to a hostile environment beyond that seen on any previous missions.

During the early analyses of payload integration problems, it was recognized that photographic films could not withstand the Skylab space environment and that additional protection from radiation, temperature, and humidity extremes would be required. The Payload Integration Section (S&E-ASTN-SDI), Astronautics Laboratory, at the George C. Marshall Space Flight Center (MSFC) continued the work of its organizational predecessor (R-P&VE-VAC) in developing a film vault to provide the required environmental protection.

The purpose of this report is to describe the problems encountered, the systematic approach to the problem solution, and the capability that has been developed to solve similar problems that are certain to arise on future missions. It is hoped that this report will serve to develop an awareness of the early planning required to effect a film protection solution for future missions using photographic film for data return.

PROBLEM STATEMENT

The predominant problem was to control the environment for the corollary experiment photographic films within the limitations imposed by the Skylab systems. Proper control would minimize environmental degradation effects on the films to allow defined photographic experimental data to be obtained from the returned Skylab mission films. To attack this problem systematically, it was necessary to identify the environmental factors which

TABLE 1. SKYLAB COROLLARY EXPERIMENTS REQUIRING PHOTOGRAPHY

Experiment No./Title	Principal Investigator (P. I.)/ Organization[a]	Development Center	Proposed Film Type	Photography Objectives
M151, Time and Motion Study	Dr. J. Kubis/Fordham University, N. Y.	MSC	SO168	Movie coverage of repetitive and routine tasks performed by the astronauts on space flights will be used to provide data for time and motion analyses.
M479, Zero Gravity Flammability	J. H. Kimzey, MSC	MSFC	3443	To provide motion pictures of all events during tests and sample identification prior to testing.
M487, Habitability/ Crew Quarters	C. C. Johnson	MSC	SO168	To record the habitability features of the crew quarters and work areas of the OWS.
M509, Astronaut Maneuvering Equipment	Maj. C. F. Whitsett Los Angeles Air Station Calif.	MSC	SO168	Movie coverage of all maneuvering tasks associated with astronaut evaluations of various types of inflight maneuvering devices.
M512, Materials Processing in Space	G. Parks	MSFC	SO168	Movie coverage will be used to record the Materials Melting Facility operation and the experiment task operation for metal melting and spherical casting.
S009, Nuclear Emulsion	Dr. M. Shapiro Naval Research Lab Washington, D. C.	MSFC	Nuclear Emulsion	To record the presence and direction of heavy primary nuclei in galactic cosmic radiation.
S019, UV Stellar Astronomy	Dr. K. Henize	MSC	SC-5	To obtain moderate dispersion stellar spectra of early type stars and low dispersion UV spectra of Milky Way fields of sufficient resolution to permit the study of the UV line spectra and spectral energy distribution.
S020, UV/X-Ray Solar Photography	Dr. R. Tousey Naval Research Lab Washington, D. C.	MSC	SC-5	To photograph the extreme UV and X-ray spectrum of the sun in the 10-to-100 Å range.
S063, UV Airglow Horizon Photography	Dr. D. M. Packer Naval Research Lab Washington, D. C.	MSC	2485	A photographic study of the airglow and the earth horizon in several UV wave lengths by day and by night.
S073, Gegenschein/ Zodiacal Light	Dr. J. Weinberg Dudley Observatory Albany, N. Y.	MSFC	2485	To photographically record the surface brightness and polarization of the night sky light over as large a portion of the celestial sphere as possible, using the T027 photometer system.
S183, Ultraviolet Panorama	Dr. G. Courtes Lab of Spatial Astronomy Marseilles, France	MSFC	103Å SC-5	To photograph specifically selected starfields in the UV spectrum, using the experiment spectrograph.
S190, Multispectral Photography	A. Grandfield (P.I. Representative)[b]	MSC	SO242, 3443 2424, 3401	Photographs will be taken in six discrete spectral bands of the visible and near infrared portions of the electromagnetic spectrum to determine the extent to which multispectral photography of the earth from space may be applied to the Earth Resources disciplines.
S191, Infrared Spectrometer	Dr. T. Barnett	MSC	SO242	To provide photographs of the target area during spectrometer operation.
T013, Crew Vehicle Disturbances	B. A. Conway/ Langley Research Center	Langley Research Center/MSFC	SO168	To record by motion picture photography the total body motions of the astronauts as they apply forces to the vehicle in a zero-gravity environment.

TABLE 1. (Concluded)

Experiment No./Title	Principal Investigator (P.I.)/ Organization[a]	Development Center	Proposed Film Type	Photography Objectives
T020, Foot Controlled Maneuvering Unit	D. Hewes/Langley Research Center	Langley Research Center/ MSFC	SO168	Movie coverage of astronaut evaluation of the maneuvering unit.
T025, Coronagraph Contamination Measurement	G. Bonner	MSC	2403	To obtain data on the scattering of solar light by particles surrounding the orbital assembly and the solar F-corona.
T027, ATM Contamination Measurement	Dr. J. Muscari MMC Denver, Colo.	MSFC	2485	To photographically measure the sky brightness caused by solar illumination of contamination particles using the photometer system.

a. P.I. Organization will be identified only when it is different from the Development Center.
b. Large number of P.I.'s.

contributed to degradation of photographic film, establish the relative importance of each of these factors and obtain quantitative data for the effects of these factors on each proposed film type. Environmental degradation data from each film were compared with the environmental factors existing during the Skylab mission. Where an incompatibility was found between the susceptibility of a film type to environmental factors and the mission environment, one or more of the following actions was taken:

1. Initiated modification of the spacecraft mission or vehicle systems to improve the environment.

2. Provided local environmental protection for the film.

3. Selected a film type less susceptible to the attainable environment.

4. Accepted film degradation at a predicted level.

SKYLAB ENVIRONMENT AND ITS EFFECTS ON FILM

Radiation Effects on Film

In general, the effect of all high-energy radiation (e.g., X-ray, gamma ray, electrons, and protons) exposure on a photographic film is an increase in background density (gross fog), and a reduction in gamma and film speed for optical photographic use. (See Appendix A for a discussion of technical terms and Appendix B for definitions.) These effects as related to the characteristic curve are shown in Figure 1. The increase in background density causes loss of detailed information in the low light level region because of masking by the fog. The total range of contrast available on a film emulsion is reduced by the rise in background density. The reduction in gamma causes a decrease in contrast between areas of varying light level exposure that may, in some cases, cause loss of detail in the recorded information. The reduction in film speed causes the appearance of underexposure of the photograph. Some of these effects can be mitigated to a certain extent by changing the exposure to take maximum advantage of the altered emulsion or by making changes in processing the exposed film. To make use of these corrections, it is necessary to know the effects of the high-energy radiation.

The effects of the high-energy radiations vary in intensity with the level of accumulated radiation and with the type and energy level of the radiation.

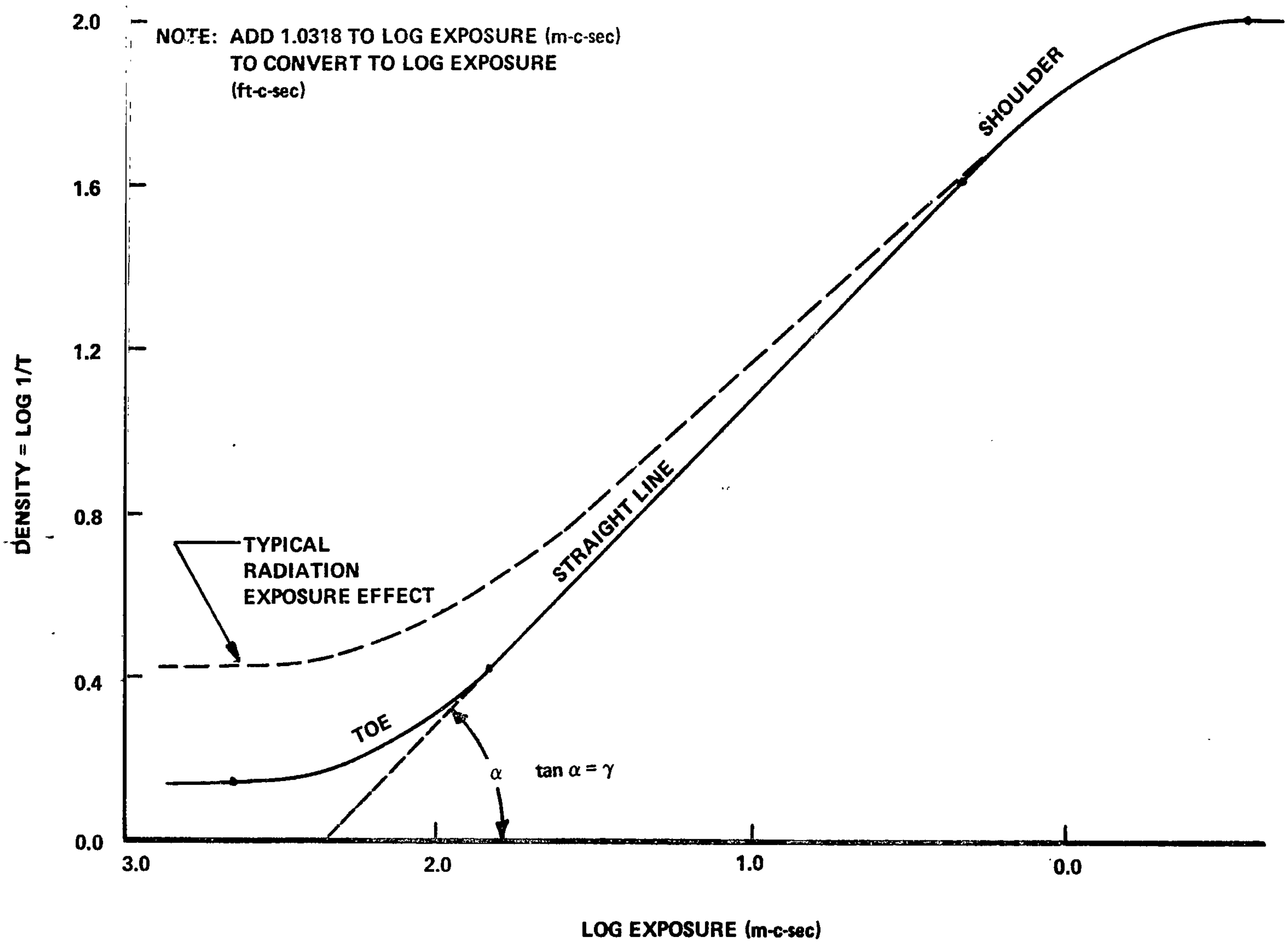

Figure 1. Radiation effects on film characteristic curve.

Current photographic theory cannot be used either to predict the effects of a given radiation on a particular emulsion or to extrapolate the results from one emulsion to a different emulsion. To determine the intensity of the effects of a particular type of radiation at a given energy level, it was necessary to perform empirical tests on the candidate emulsion types for the Skylab missions.

Temperature, Humidity, and Vacuum Effects on Film

Time, temperature, and humidity are factors that can cause photographic deterioration of film. These factors are inseparable and can only be varied in their proportional effects. As time elapses the speed and contrast of an emulsion generally decreases, the fog level increases, and the maximum attainable density decreases. Higher-than-normal temperatures and higher-than-normal humidities will accelerate this process. Lower-than-normal temperatures, within limits, will generally retard this process. Low humidity seems, with a few exceptions, to have little effect on the photographic properties of the film. Low humidity does, however, have a strong effect on the physical properties of the film. The effect is evident primarily when the film is used in a dry condition and takes the form of cracks and tears in the emulsion and static electric markings. High humidities produce physical effects on film. These effects consist of "moisture static" markings, sticking together of layers of rolled film, and can even result in separation of the emulsion from the backing during unwinding from rolls.

Vacuum effects are, for the most part, the same as the effects of low humidity. The static markings that occur under low-humidity conditions lose their discrete character and often show as a diffuse overall fogging of the film under vacuum conditions.

Since no useful test data were available on the temperature or humidity sensitivity of the film, a compatibility analysis could not be performed. The extremes expected during the orbital mission were beyond film manufacturers' normal recommended environment; therefore, a program was established to obtain temperature, humidity, and radiation sensitivity data on candidate films. Design requirements were derived from the sensitivity data for the development of a protection system.

Characteristics of Skylab Predicted Environment

Radiation. The radiation environment encountered during earth-orbital missions was studied extensively; the results indicated that the radiation environment could severely damage unprotected film.

The radiation environment consists of charged particles from three sources: (1) cosmic rays from intergalactic space, (2) protons from solar flare proton events, and (3) electrons and protons trapped in the magnetic field of the earth.

The energy level of the intergalactic cosmic rays is so high that no practical method exists for eliminating cosmic radiation damage. This degrading factor must be accepted and, though significant, it should not be unacceptable for short-term exposure or with relatively insensitive film types. Solar flare proton events that envelope the earth are infrequent and of unpredictable magnitude. To attempt to provide shielding for such events would not prove economical because of the probabilities of a significant occurrence. Therefore, the primary particles of concern are those trapped in the magnetic field of the earth. The regions where these particles are trapped are called the Van Allen belts [1,2].

The Van Allen belts consist primarily of free protons and electrons trapped in the magnetic field of the earth. However, the distribution of these charged particles throughout the field is not uniform. Because of several factors — including charge, mass, velocity of the particles, and strength of the magnetic field of the earth — only a portion of the magnetic field can trap and retain these charged particles. The intensity of the magnetic field at a given point controls the particle density at that point; since the intensity of the magnetic field of the earth is not completely uniform, it follows that the spatial distribution of charged particles in the Van Allen belts is not uniform. The spatial distribution of the particles in the Van Allen belts is further complicated by the fact that (1) the center of the magnetic field of the earth is not located at the geometrical center of the earth, and (2) the axis of the magnetic field is not parallel with the spin axis of the earth. These factors together give rise to an apparent distortion of the Van Allen belts when viewed in geocentric coordinates (Fig. 2). This apparent distortion is called the South Atlantic Anomaly (SAA).

The intensity of the proton radiation in the SAA is shown in Figure 3. The orbits with an inclination of greater than 10 deg (Fig. 3) will at some time pass through a portion of the SAA. Figure 4 shows the radiation dose for each pass as a function of time during the first 120 hr of the mission. The vehicle itself provides adequate shielding against the electrons and protons for the

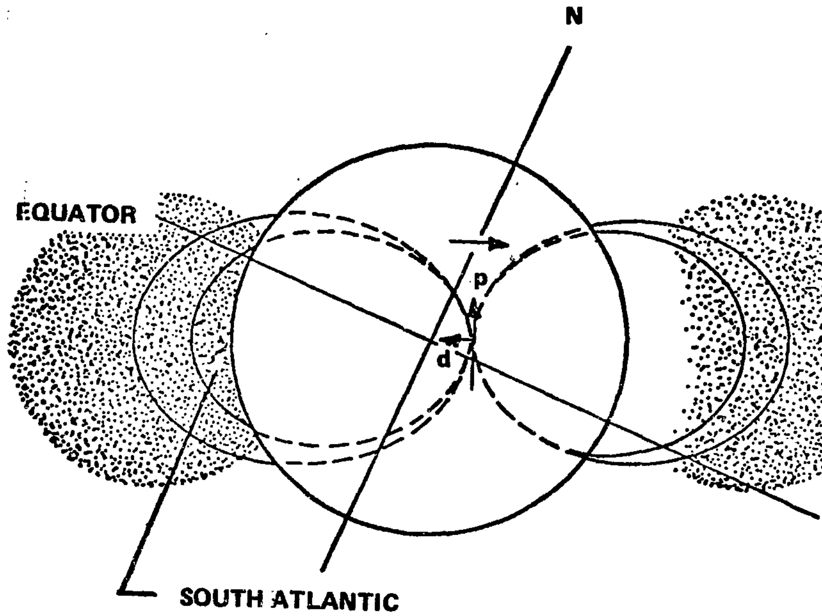

Figure 2. South Atlantic Anomaly diagram.

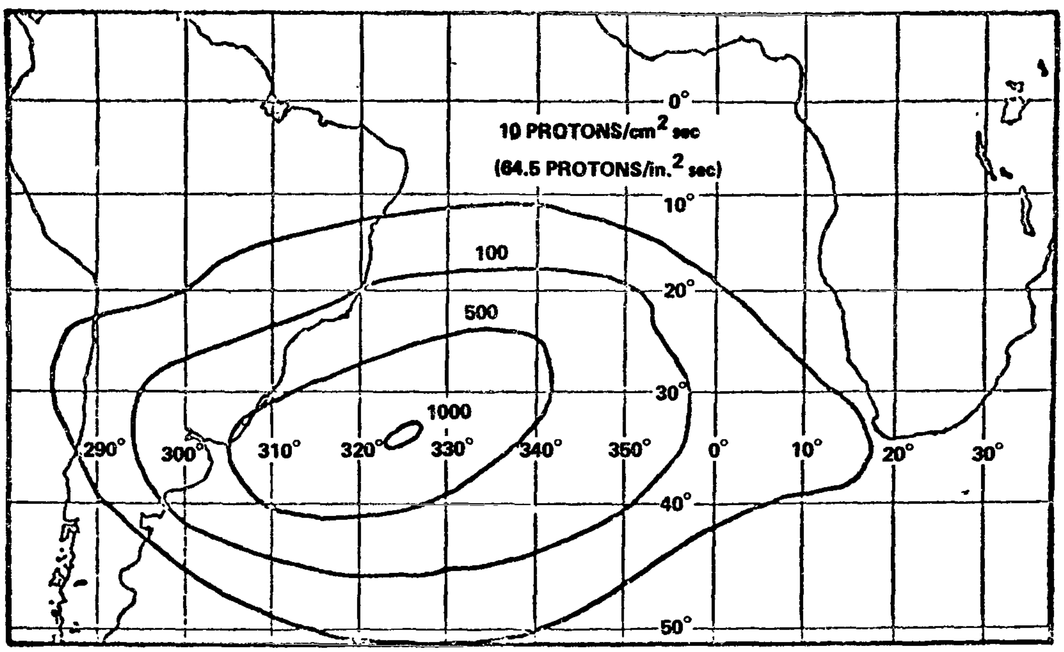

Figure 3. Constant flux contours of the SAA (Vette's proton data API).

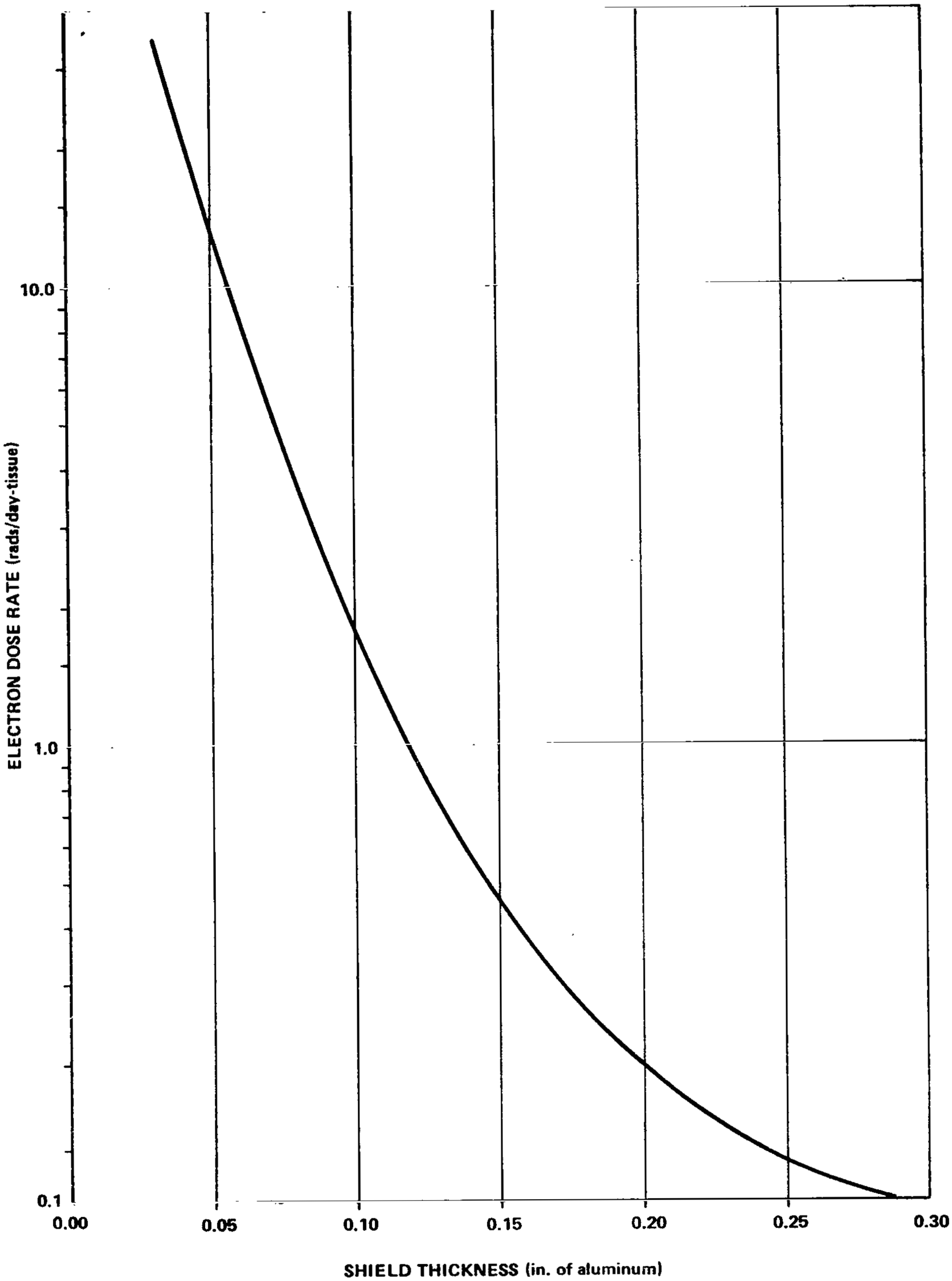

Figure 6. Dose rate versus shield thickness for 1968 electrons in 240-n.-mi., 50-deg orbit.

Predicted Temperature, Humidity, Pressure. Since the Orbital Workshop (OWS) will be the storage location for the corollary experiment film, the predicted temperature, humidity, and pressure variations[1] were obtained for a period of time during which the film is onboard. A ground cooling system will maintain the OWS interior between 40 and 55° F from "button-up" to launch. During orbital hatitation periods, the OWS environmental control system will maintain the temperature between 65 and 80° F, and during the unmanned periods the predicted temperature is between 45 and 80° F with the minimum temperature maintained by radiant heaters.

The relative humidity during prelaunch and after button-up will be near zero because of pressurization with dry nitrogen. This condition will exist until shortly after the beginning of the first habitation period. During habitation, moisture is added by the astronauts' presence, and the environmental control system maintains the relative humidity between 27 and 65 percent with 45 to 55 percent expected during most of the habitation period. During orbital storage periods, relative humidity is expected to be between 27 and 100 percent at the start of the period and to fall to between 4 and 16 percent near the end of the period.

After button-up the OWS will be pressurized to 17.5 psia with dry nitrogen and before launch will be increased to 26 psia. During orbital coast the pressure will be decreased to 1.3 psia and before habitation will be pressurized to 5.0 psia with oxygen. For the orbital stowage period, the pressure is allowed to leak down to approximately 0.5 psia.

Some Skylab experiments will require that film be exposed to space vacuum conditions for relatively short time periods and will require special attention to temperature and drying effects.

PLANNING

As a part of the payload integration activity, each of the Skylab corollary experiments required analysis to establish its compatibility with the carrier and to identify problems that required solution. A "systems engineering approach" was used to define experiment functional requirements. This method utilized

1. H. G. Paul: OWS, AM, and MDA Internal Environment Profiles. NASA MSFC Memorandum S&E-ASTN-PL-70-M-224, Marshall Space Flight Center, October 6, 1970.

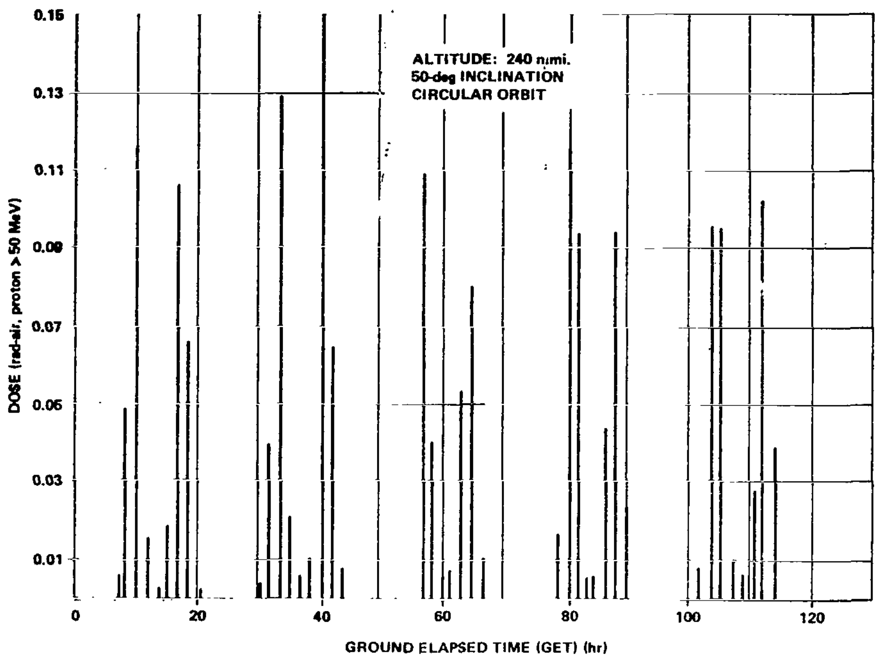

Figure 4. Free space proton dose as a function of time for passes through the SAA.

crew internal to the Skylab [1]. However, because of the transmitted spectrum inside the Skylab, extra shielding is required to protect the film.

The Skylab mission will be in a 240-n.-mi. orbit with a 50-deg inclination. Passes through the SAA will be subjected to the proton radiation spectrum shown in Figure 5. The skin and structure of the Skylab will stop most of the lower energy protons but will allow the remaining higher energy particles to penetrate into the Skylab interior. The spectrum inside the Skylab is expected to have a median energy of 50 MeV, and the spectrum inside the film vault is expected to have a median energy of 130 MeV in the heavier shielded areas.

The skin of the Skylab is sufficient to nearly eliminate all radiation caused by electrons internal to the Skylab. However, an electron radiation problem exists for unprotected films used external to the Skylab. The radiation dose caused by electrons for the 240-n.-mi., 50-deg orbit and varying shield thicknesses is shown in Figure 6. This curve indicates that if the films used external to the Skylab are protected by an aluminum shield of 0.3-in. thickness, the electron dose is reduced by approximately 90 percent. However, a shield would generate bremsstrahlung, which could be virtually eliminated by a thin lead foil inside the aluminum shield.

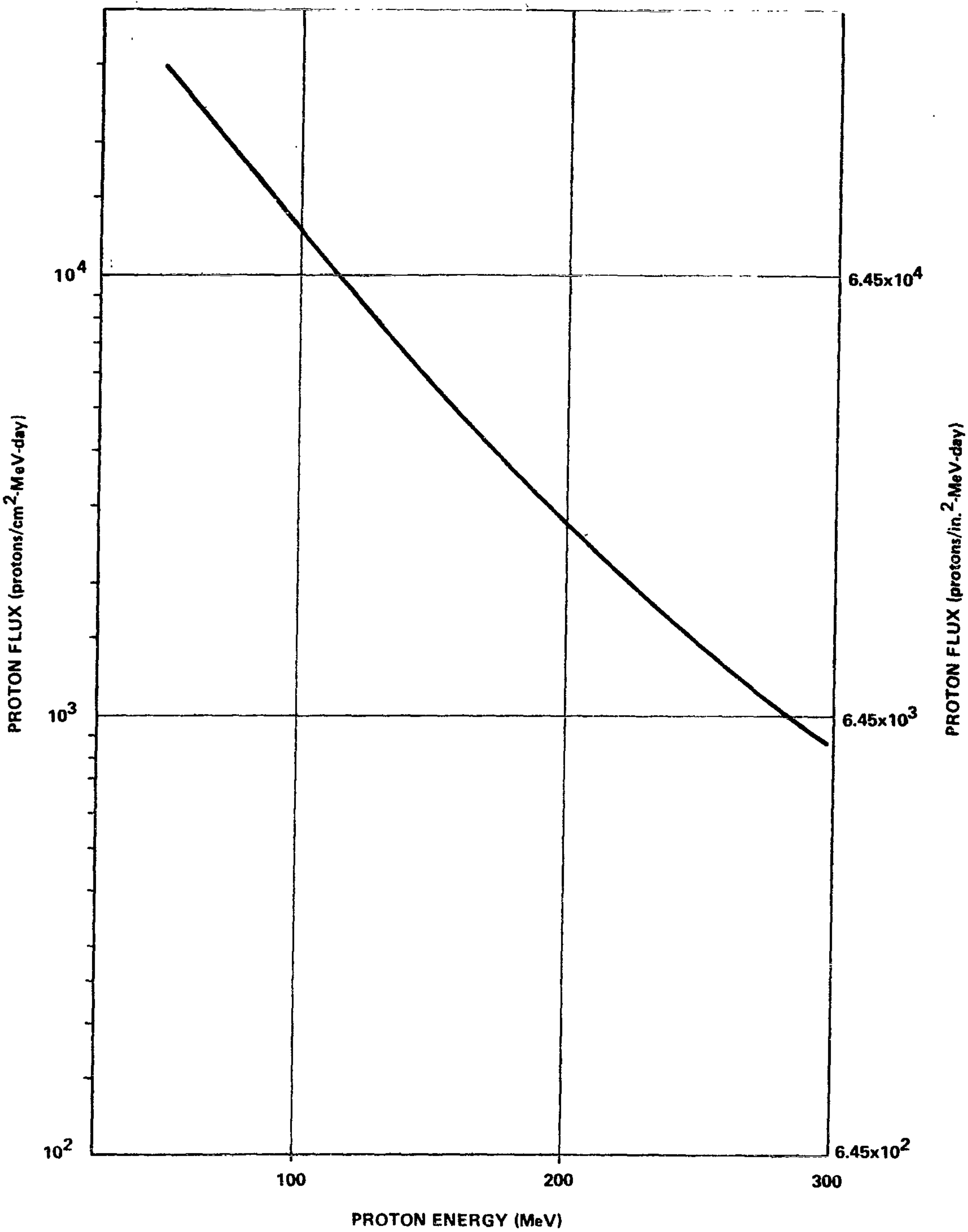

Figure 5. AP7-50 incident proton spectrum.

three levels (top level, system level, and subsystem level) of functional block diagrams. Requirements were identified for each subsystem functional block and were formally documented with Requirements Allocation Sheets.

Because of the large number and complexity of photographic requirements that were identified, a similar systems approach was applied to the Skylab photography system as shown in Figure 7. The system level functional diagram (Fig. 8) shows the major photographic functions. The development of requirements to accomplish functions 1.0, 7.0, and 11.0 revealed a void in planning for photography. It was evident that no effective means of stowing and transferring film had been devised. Contacts with film manufacturers, technical libraries, and photographic scientists revealed that little quantitative data were available on film environmental effects. Thus, the responsible experiment personnel could not establish environmental limits (radiation, temperature, and humidity) for their films. These circumstances, revealed by the early use of systems engineering techniques, dictated that testing programs be undertaken to:

1. Define in quantitative terms the film degradation caused by temperature, humidity, and radiation.

2. Define maximum allowable film degradation for each experiment.

3. Establish design requirements for a film vault for environmental protection and stowage of corollary experiment film.

Figure 9 represents the results of an early analysis to define the tasks required, their interrelations, and the organizations involved. This task flow diagram was used to develop a schedule that would be compatible with the program. A typical revised schedule is shown in Figure 10. In addition, compatibility status analyses were performed at several intervals to define photographic or film problems. A photography data summary was computerized and maintained regularly to identify current film quantities, types, weights, and volumes.

A rather large integration and liaison effort, involving many organizations from MSFC, Manned Spacecraft Center (MSC), and numerous contractors was required to implement the plan as described.

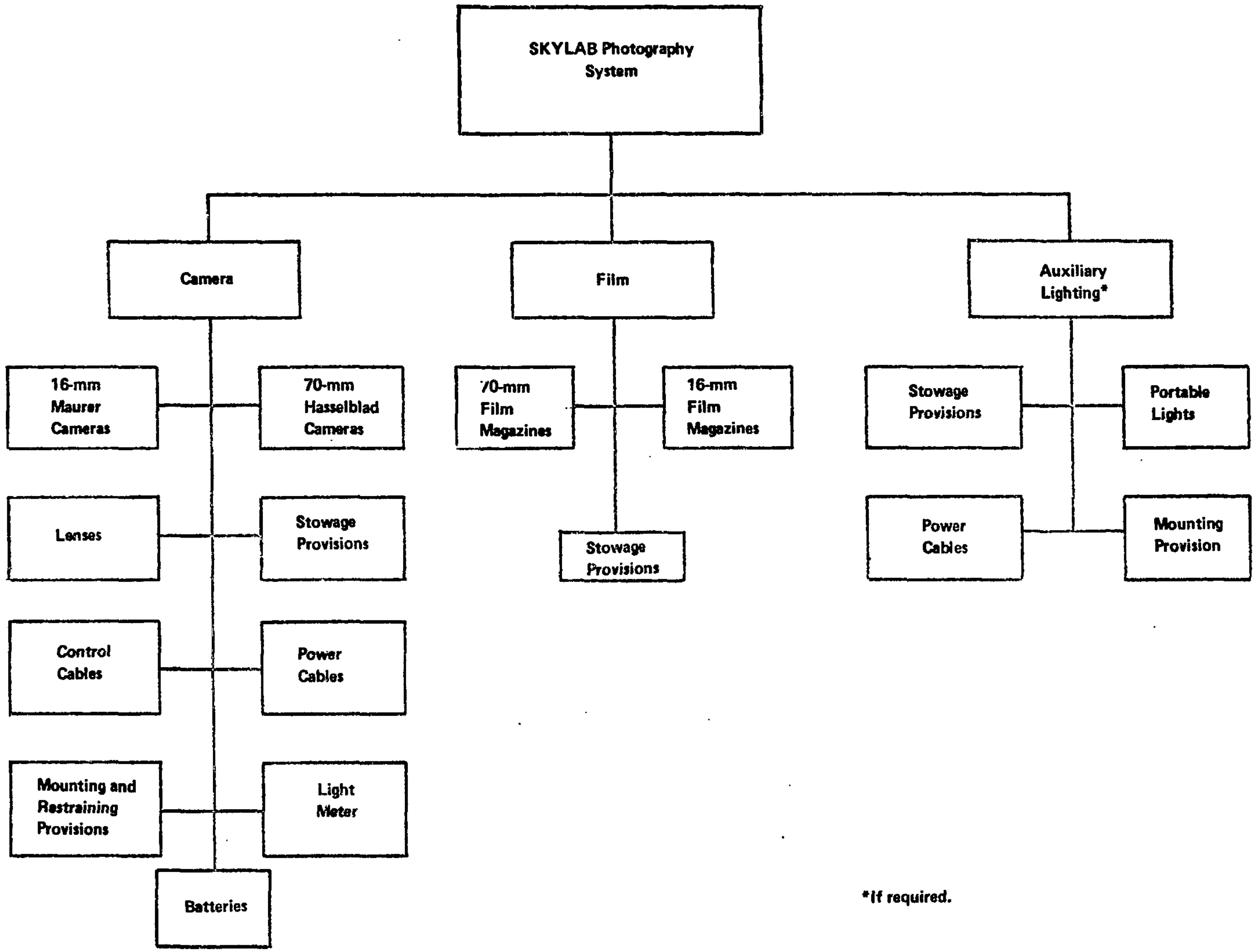

Figure 7. Diagram of Skylab photography system.

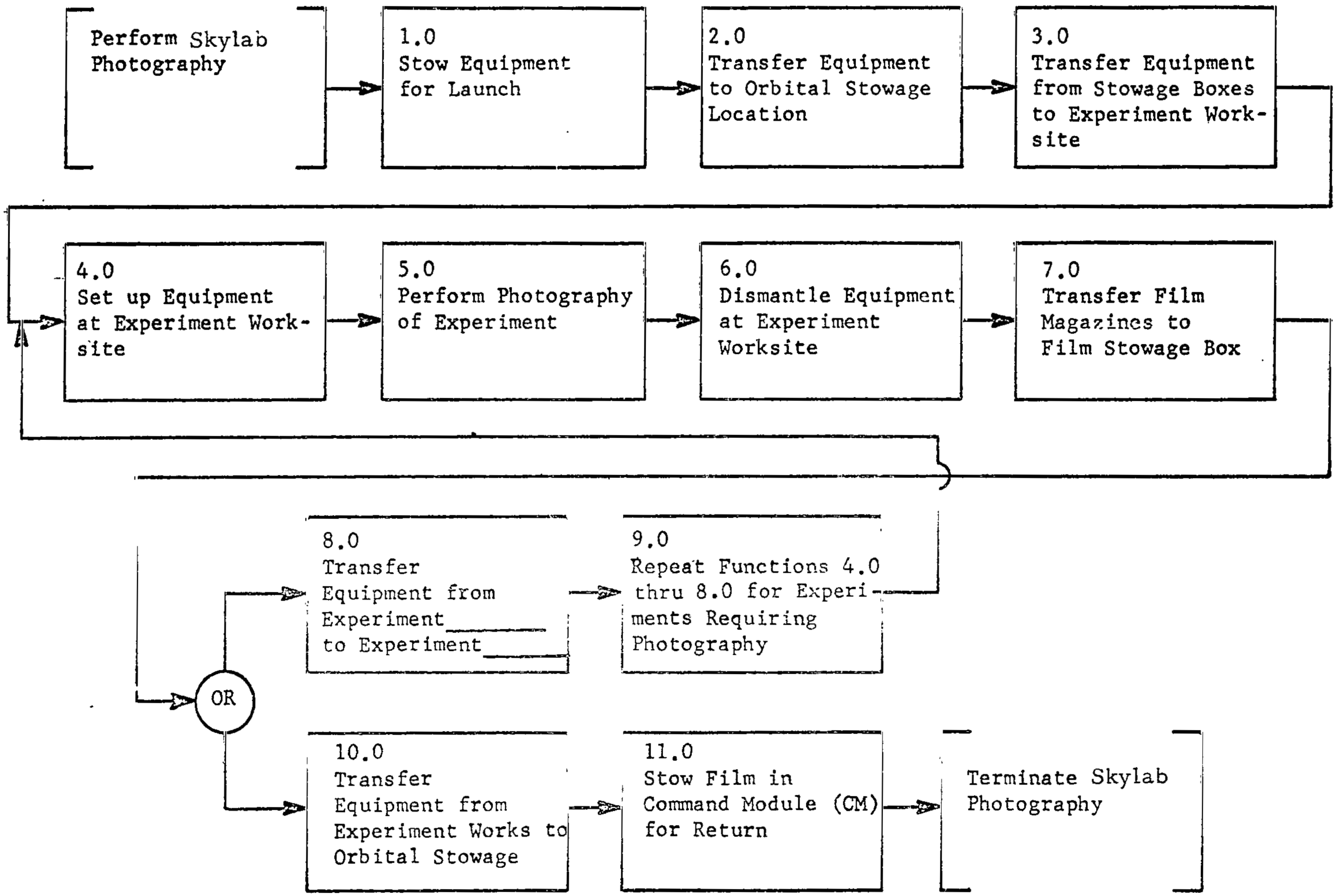

Figure 8. System level functional diagram for Skylab photography.

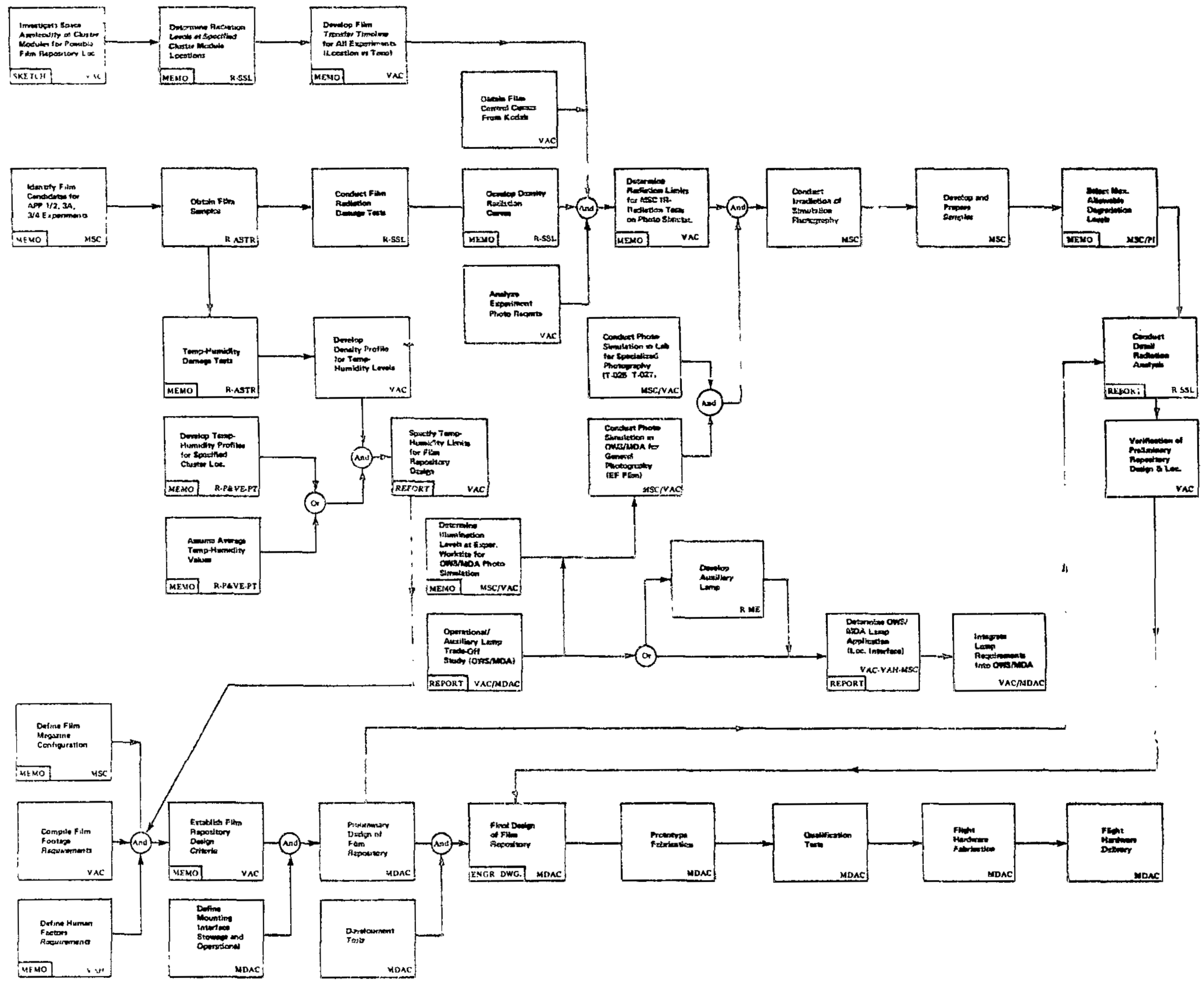

Figure 9. Proposed film evaluation and stowage plan.

	TASK	RESPONSIBLE AGENCY	CY 1969 / CY 1970 / CY 1971 (J F M A M J J A S O N D)
1	DEFINE POSSIBLE FILM REPOSITORY LOCATIONS	S&E-ASTN-SDI	COMPLETED
2	DETERMINE RADIATION LEVELS CLUSTER LOCATIONS	S&E-SSL	COMPLETED
3	IDENTIFY FILM CANDIDATES FOR SVWS	MSC	COMPLETED
4	OBTAIN FILM SAMPLES	S&E-ASTN-SDI	COMPLETED
5	DEVELOP FILM TRANSFER TIMELINE	S&E-ASTN-SDI	PRELIMINARY
6	CONDUCT FILM RADIATION DAMAGE TESTS	S&E-SSL	FINAL
7	DEVELOP DENSITY VERSUS RADIATION CURVES	S&E-SSL	
8	DETERMINE FILM RADIATION LIMITS FOR SIMULATION	S&-ASTN-SDI	
9	CONDUCT PHOTO SIMULATION	SDI/MMC	(EF FILM)
10	IRRADIATE SIMULATION PHOTOGRAPHS	MSC	(EF)
11	DEVELOP AND PREPARE SAMPLES	MMC	(EF)
12	ANALYZE SAMPLES FOR DENSITY AND RESOLUTION CHANGES	MSC/SDI/MMC	
13	SELECT MAXIMUM FILM DEGRADATION LEVELS	KSC/PI	(EF)
14	CONDUCT DETAIL RADIATION ANALYSIS	S&E-SSL	
15	RADIATION REPORT	SDI/MMC	
16	TEMPERATURE/HUMIDITY DAMAGE TEST	SDI/MMC	
17	DEVELOP DENSITY PROFILES FOR TEMP./HUMIDITY LEVELS	SDI/MMC	
18	DEVELOP TEMP./HUMIDITY PROFILES FOR SVWS LOCATIONS	S&E-ASTN-PLA	
19	SPECIFY TEMP./HUMIDITY LIMITS FOR REPOSITORY	S&E-ASTN-SDI	
20	ENVIRONMENTAL EFFECTS REPORT	S&E-ASTN-SDI	
21	OPERATIONAL/AUXILLARY LAMP TRADE-OFF	CSE-MA/MDAC	DELIVERY OF TWO PROTOTYPES
22	AUXILLARY LAMP DESIGN	S&E-ME	DELIVERY OF FLIGHT HARDWARE
23	DETERMINE S-IVB/MDA LAMP APPLICATION	SDO/SMH/MSC	COMPLETE QUALIFICATION TESTS
24	INTEGRATE LAMP REQUIREMENTS INTO S-IVB/MDA	SDI/MDAC	
25	DEFINE FILM MAGAZINE CONFIGURATION	MSC	
26	COMPILE FILM FOOTAGE REQUIREMENTS	SSL/ASTN-SDI	
27	DEFINE OPERATIONAL AND HUMAN FACTORS REQUIREMENTS	MSC/SMH	PRELIMINARY
28	ESTABLISH FILM REPOSITORY DESIGN CRITERIA	S&E-ASTN-SDI	FINAL
29	PRELIMINARY DESIGN OF FILM REPOSITORY	PM-AA/MDAC	* TBD
30	FABRICATE FILM REPOSITORY OPERATIONAL MOCKUP	PM-AA/MDAC	TBD
31	DELIVER OPERATIONAL MOCKUP	PM-AA/MDAC	TBD
32	FINAL DESIGN OF FILM REPOSITORY	PM-AA/MDAC	TBD
33	FABRICATE REPOSITORY DYNAMIC TEST ARTICLE	PM-AA/MDAC	TBD
34	DELIVER DYNAMIC TEST ARTICLE	PM-AA/MDAC	TBD
35	FLIGHT HARDWARE FABRICATION	PM-AA/MDAC	TBD
36	FLIGHT HARDWARE DELIVERY	PM-AA/MDAC	TBD
37			

NOTES:
REVISED SCHEDULE IS PRELIMINARY SUBJECT TO APPROVAL BY ALL RESPONSIBLE AGENCIES

* TBS MILESTONES TO BE SUPPLIED BY MDAC-WD BY DECEMBER 31, 1969.

Figure 10. Task definition and schedule for Saturn V Workshop film evaluation and stowage.

IMPLEMENTATION

The following paragraphs will describe the major efforts during the implementation.

Identification of Film Candidates

Because of the lead time required to perform film tests, to analyze the results, and to design and fabricate hardware, it was necessary to identify corollary experiment film candidates at an early date. At the time this identification was necessary, many of the experiment operations were undefined and the definition of which proposed experiments would actually fly was not available. With the support of Program Management, discussions with experiment Principal Investigators, and data from Experiment Requirements Documents, a list of 14 film types was identified as probable candidates for flight. Table 2 lists the 14 films identified for testing. In a few instances certain films were deleted from testing where data were already available. Two additional film types were identified after testing was begun which allowed only partial test data to be obtained for them.

Availability of Test Film

Many of the film types required for test purposes were not readily available. Some of the film types are available only on special order from Eastman Kodak Company with minimum quantities being prohibitive from a cost standpoint. One special-order film was available only from Kodak Pathe in France. The MSC Photography Laboratory assisted in obtaining and supplying the required films.

Radiation Testing

Early in the problem definition phase it was noted that no radiation sensitivity data were available on the color films planned for use. Some applicable film types were found locally; MSFC Space Sciences Laboratory exposed these films to an existing Cobalt-60 source to assess their gross radiation sensitivity. The test results indicated a lack of repeatability on different samples subjected to the same conditions. The apparent problem was a combination of radiation backscatter in the exposure facility and inadequate control of film processing. The test did provide a warning that future testing would require rather extreme controls in order to obtain useful information.

TABLE 2. DESCRIPTIONS OF FILM TYPES TESTED

SO114[a]	Panatomic X; B & W, very high resolution, 2.5-mil ESTAR base. With dyed gel backing, and without a gelatin overcoat to enhance XUV and attenuate proton sensitivities.
SC-5	Short Wave Radiation Kodak-Pathe (French) manufactured. 5.2-mil triacetate clear base with Anti-Halation backing. In 35-mm × 180-mm strips only. Has about eight times the sensitivity of SWR above 170 Å.
SWR[a]	Short Wave Radiation; for ultraviolet applications in wavelengths shorter than 2200 Å. 5.2-mil triacetate clear base, Anti-Halation backing.
103-0, UV	UV Spectroscopic; for low-intensity or short-duration sources (high speed) in 2500- to 5000-Å band. 5.2-mil clear triacetate base with Anti-Halation backing.
SO392[a]	Solar Flare Patrol; fine grain, high contrast, panchromatic emulsion with extended red sensitivity (maximum at 6563 Å). 4-mil ESTAR base with 0.1 density Anti-Halation dye and fast-dry PX backing.
3400	Panatomic X; B & W, very high resolution. 2.5-mil ESTAR base, dyed backing. ASA 40. Resolution: TOC 1000:1, 170 lines/mm; TOC 1.6:1, 65 lines/mm.
3401	Plus X; B & W, high resolution aerial film. 2-5mil ESTAR base, dyed gel backing. ASA 125. Resolution: TOC 1000:1, 105 lines/mm; TOC 1.6:1, 40 lines/mm.
2403	Tri X Aerographic; panchromatic with extended red sensitivity. 4.0-mil ESTAR base, fast-drying PX backing. AEI 250. Resolution: TOC 1000:1, 71 lines/mm; TOC 1.6:1, 22 lines/mm.
103a-F	Spectroscopic; Selective Sensitizing in 4500- to 6800-Å band; 4-mil ESTAR base.
SO166	High Speed Recording Film, currently designated 2485; Panchromatic with extended red sensitivity, 4-mil ESTAR base dyed to 0.1 density to provide halation protection, fast drying PX back. ASA 6000 normal, 16 000 possible. Resolution: TOC 1000:1, 55 lines/mm; TOC 1.6:1, 20 lines/mm.

TABLE 2. (Concluded)

SO168	Ektachrome EF; Reversal color, daylight, low light level applications. 2.5-mil ESTAR base, clear gel backing. ASA 160 normal, range 500 to 1000. Resolution: TOC 1000:1, 80 lines/mm; TOC 1.6:1, 36 lines/mm.	SO180	Ektachrome Infrared; Reversal color, aerial type. 2.5-mil ESTAR base, clear gel back. Infrared sensitization. Resolution: TOC 1000:1, 71 lines/mm; TOC 1.6:1, 36 lines/mm.
SO368	Ektachrome MS; Reversal color, daylight general application. 2.5-mil ESTAR base, fast-dry PX back. ASA 64, range 16 to 250. Resolution: TOC 1000:1, 80 lines/mm; TOC 1.6:1, 35 lines/mm.	SO246	Infrared Aerographic, currently designated 2424; 4-mil ESTAR base, fast-drying PX back. Sensitized to blue, red, and infrared. AEI 100. Resolution: TOC 1000:1, 80 lines/mm; TOC 1.6:1, 32 lines/mm: Designed for machine processing.
5242	Ektachrome EFB; Reversal color, tungsten-balanced emulsion, high speed. 5.2-mil triacetate base. ASA 160, range 64 to 1000. Resolution: TOC 1000:1, 80 lines/mm; TOC 1.6:1, 36 lines/mm.	I-N	Infrared Spectroscopic; 5.2-mil clear triacetate base with Anti-Halation back.
SO121	Aerial Color; Reversal color, daylight, high resolution. 2.5-mil ESTAR base with Anti-Halation undercoat and clear gel backing. ASA 64, AEI6. Resolution: TOC 1000:1, 160 lines/mm; TOC 1.6:1, 80 lines/mm.		All films are manufactured by Eastman-Kodak, except SC-5. ASA and AEI ratings shown are nominal values given in the Kodak literature. They are not the test values and are supplied only for general information.

a. These film types are not corollary experiment candidates but were included in the testing for the ATM program.

An OWS Photographic Simulation Test was conducted. The largest quantity of film required on the Skylab missions is Kodak EF (SO168) color film. A test was performed in the OWS mockup (old "wet workshop" configuration) to evaluate the use of the Kodak EF film by testing at three light levels, three film speeds, and six radiation levels. Four scenes simulating actual experiment operations were photographed. After the scenes were photographed, the film was irradiated and developed at MSC. The test samples were then evaluated by Experiment M151 personnel and others to establish optimum light levels and film speed and to establish an acceptable radiation limit. Detailed information on this test program is given in a technical letter. [2]

The major effort in the radiation test program was accomplished by Martin Marietta Corporation (MMC) as reported in detail in References 3 and 4. The 14 corollary experiment films tested were irradiated by a Cobalt-60 source to various levels at MSC and shipped to MMC, where test strips were exposed to X-ray, ultraviolet, visible, and near infrared as required to simulate actual experiment requirements. Imagery was placed on the test samples to give pictorial evaluation capability. Hurter and Driffield (H&D) curves; film base plus fog, gamma, and modulation plots were prepared from sensitometric analysis of the test samples. When all testing was completed, Experiment Principal Investigators were invited to attend reviews conducted on the test samples for their experiment. Recommended maximum radiation levels were established from these reviews.

The radiation testing previously mentioned exposed the film only to a Cobalt-60 source. To predict the radiation sensitivity of the film to the predicted environment behind varying shield thicknesses, it was necessary to determine the film sensitivity to proton sources at various energy levels. Some of the films had previously been tested in this manner. [3] The untested films and one tested film (for correlation purposes) were exposed to proton radiation by personnel of the MSFC Space Sciences Laboratory. Cobalt-60 exposures of each film type were made at MSFC, and the proton exposures of 51 and 131 MeV were made at the Harvard University cyclotron. Film processing was performed by the MSFC Photographic Division. Radiation test results of net density versus exposure are shown in Reference 5.

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2. R. L. Ruffin, Jr.: Addendum I to AAP-2 Photography Simulation, Evaluation of Test Results. Technical Letter ASD-ASTNL-639, Teledyne Brown Engineering Co., Huntsville, Ala., Aug. 14, 1969.

3. K. Huff and M. Cleare: Unpublished Film Radiation Test Curves. Eastman Kodak Co., Rochester, N. Y., August 1968.

Temperature and Humidity Testing

Temperature and relative humidity limits, recommended by Eastman Kodak for optimum keeping of the candidate film types for extended time periods, would have placed an inordinate penalty both in weight and power consumption on the design of a film stowage vault. To stow the film efficiently, it was necessary to establish a single environmental condition that would not seriously degrade any of the candidate films and would minimize any penalty caused by maintaining that condition. A search of the literature available — including Kodak information on the relationship between film characteristics and time, temperature, and humidity — was conducted. From sources consulted, very few data were available and the available data provided limited criteria for stowage design.

Martin Marietta Corporation, Denver Division, performed the necessary tests to obtain the required data for the candidate films. Because of time and financial limitations, only the temperature, relative humidity, and time effects on the latent image (i.e., film exposed before storage) were studied in the test program. No environmental effects on physical properties were studied. The program consisted of obtaining measurements of the latent image degradation for specific values of temperature, relative humidity, and time storage periods. Test parameters for 14 corollary experiment film types included three levels of temperature and three values of relative humidity for each temperature level. Each of the nine temperature/humidity combinations was evaluated for environmental storage periods ranging from 1 to 28 days. One temperature/humidity environment (80° F, 50 percent relative humidity) was utilized for longer storage periods of 56 and 84 days. The evaluation included sensitometric analysis of all films for photographic response after environmental storage.

A 90-percent or greater relative humidity was found to be unacceptable as storage conditions for the Skylab film vault. A storage temperature of 120° F or greater was determined to be unacceptable. Storage temperatures as high as 100° F were considered marginal but still acceptable for limited periods of time for most films, if low humidity is maintained. Testing for periods up to 84 days indicated a temperature of 80° F and 50-percent relative humidity to be generally an acceptable storage environment for the film types tested. Reference 4 presents details concerning the temperature/humidity test program and results on specific films tested.

Space Radiation Environment Prediction

A prediction of the film radiation doses for the corollary experiment film environment was generated. This prediction [6] takes the space radiation environment from Vette models [2] and, with a computer model, projects the attenuation caused by the configuration of the space vehicle and payload. The radiation dose behind various shield thicknesses at the film stowage and operational locations was predicted on an average daily basis.

Film Magazine Configuration

Rather heavy shielding requirements were anticipated as indicated by radiation test results and predicted radiation environments. To reduce shielding weight a minimum film stowage volume was a design goal. Early definition of film magazine configuration was, therefore, an important task. Considerable effort was expended in obtaining experiment hardware documentation and information on planned operational equipment. Although some of the equipment was not designed, best estimates of configuration have been carried forward through the program. At the time that film vault drawings were completed, detailed drawings of certain magazines were not available, and Configuration Control Board action may be required to solve future dimensional incompatibilities. Magazine envelope dimensions, approximations, and status reports were provided by the Flight Crew Integration Division (MSC) and MSFC Program Management.

Experiment Photographic Operations

During the operation of an experiment, a film magazine is not afforded the additional environmental protection of the film vault. The radiation dose while outside the vault must be considered in limiting the total accumulated radiation dose. The dose while outside the vault depends on the operational location, time at the location, and the orbital location of the spacecraft with respect to the SAA. Since detailed mission timelines for experiment operations were not available, it was assumed that the spacecraft passed through the worst daily orbits while the magazines were in use. If radiation doses are unacceptable when detailed mission timelines are available, constraints on experiment operation in the SAA may be required. Experiment Requirements Documents and Astronaut Review Sequences were examined to estimate the experiment operational characteristics and times. Radiation dose rates were estimated from predictions [6] at various locations in the spacecraft.

A computer program was developed to define the operational timelines for individual film magazines. Experiment performance times were taken from the Baseline Reference Mission (BRM) document, and photographic operations were defined from Experiment Requirements Documents and Astronaut Review Sequences. The computer program output included for each film magazine an accounting of time out of the film vault, translation time, number of translations, shoot time, waiting time, and performance locations.

Design Criteria for Portable Photographic Lamp

During the OWS Photographic Simulation Test (see the preceding section on Radiation Testing), the operational light levels in the OWS crew quarters and forward dome areas were determined to be inadequate to provide acceptable photography using Kodak EF film. The results of the test indicated that, in general, 20 ft-c of light incident on the test scenes was required for good results. This level was available only in certain areas in the crew quarters. Design criteria were developed for a portable photographic lamp and were implemented through Product Engineering and Process Technology Laboratory at MSFC. A subsequent contract with Iota Engineering, Inc., Tucson, Arizona, was initiated for the development of the lamp. Detailed specifications for this lamp are given in an end-item specification.[4]

Calculation of Radiation Shielding

The MMC film radiation test program resulted in large quantities of radiation response data for individual film types. Radiation tolerance levels for specific experiment film applications were established as a result of the test program.

The allowable radiation dose is the initial data required to establish film radiation shielding requirements. As previously discussed, there will be some image degradation from the radiation of extended missions, regardless of the film protection provided. The mass required to shield large quantities of film quickly becomes a weight factor. Although a light metal such as aluminum is one of the more efficient proton attenuators, putting several inches of thickness around a few cubic feet of film requires hundreds of pounds of aluminum. It is necessary, then, to determine the optimum amount of shielding to reasonably protect the film and at the same time be aware of the weight factor.

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4. Skylab Program End-Item Specification for High Intensity Portable Light. NASA S&E-ME-MEI, 95M 10550-1, Marshall Space Flight Center, March 16, 1970.

A procedure was developed to calculate the shielding requirements for a particular film type when given the allowable radiation limit and orbital time in and out of the film vault.[5] This procedure was refined for greater accuracy and was subsequently developed into a computer program to allow fully repeatable calculation logic and ease of recalculation for new input data. The basic logic of the shielding calculation is presented in Figure 11. Each step of the calculation procedure is discussed in Appendix C.

Film Vault Design Criteria

Preliminary Design Criteria. To integrate the film vault into the OWS hardware schedule, MSFC Program Management requested in November 1969 that the schedule for providing film vault design criteria be compressed approximately 6 months.[6] In response, a study was initiated to provide preliminary design requirements for the film vault without the benefit of the results of the planned MMC radiation, temperature, and humidity test programs. Shielding calculations based on best estimates of film radiation sensitivity were made, and temperature humidity conditions were specified in a manner that, hopefully, would preclude film damage. Other basic ground rules and design requirements were established, and the results of the study were reported in an MSFC memorandum.[7] The tradeoff studies involved various vault configurations resulting from film storage assumptions. The preliminary film vault criteria given to McDonnell Douglas Astronautics Company (MDAC) for preliminary design purposes assumed that the more sensitive film would be resupplied by the Command Module on Skylab Missions 3 and 4 (SL-3 and SL-4) and that the less sensitive film would be launched on Skylab Mission 1 (SL-1) and remain stored until used.

Final Design Criteria. At the conclusion of the MMC film test program, new shielding calculations were based on the test results; these calculations incorporated updated radiation environment predictions [7]. Meetings with Eastman Kodak personnel, discussion with other experts, and analysis of the results of the MMC temperature-humidity film tests were used to establish temperature-humidity limits for film vault design criteria.

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5. R. L. Ruffin, Jr.: Calculation of Radiation Shielding Thickness for Skylab A Experiment Film. ASD-ASTN-10784, Teledyne Brown Engineering Co., Huntsville, Ala., Sept. 30, 1970.

6. G. B. Hardy: Design Criteria for Corollary Film Stowage. NASA MSFC Memorandum PM-AA-EI-318-69, Marshall Space Flight Center, Oct. 30, 1969.

7. T. P. Isbell: Preliminary Design Requirements for Saturn V Workshop (SVWS) Film Repositories. NASA MSFC Memorandum S&E-ASTN-SD-69-99, Marshall Space Flight Center, Nov. 18, 1969.

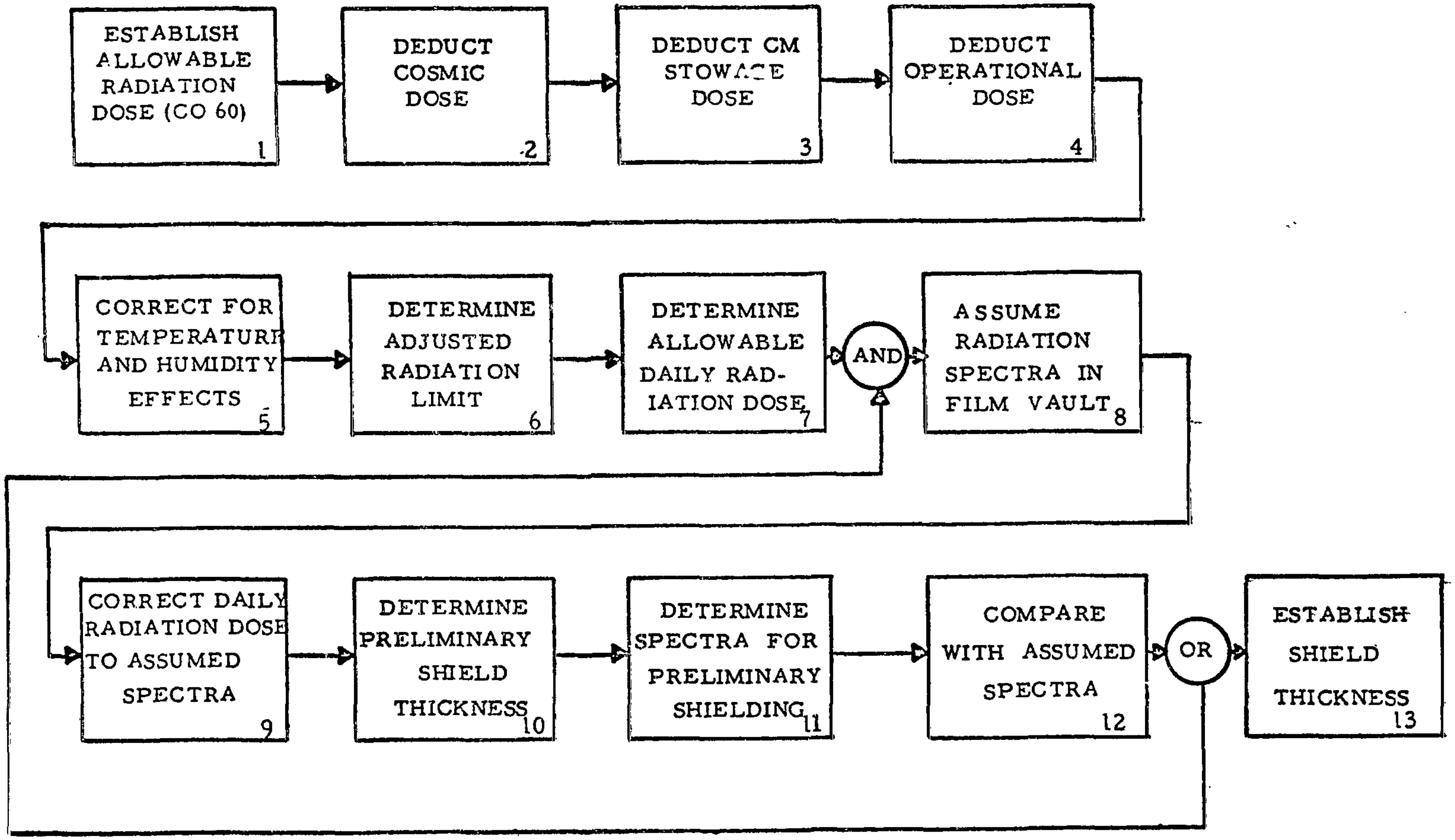

Figure 11. Skylab film vault shield thickness calculation logic.

Final design criteria were prepared during May 1970 [Engineering Change Request (ECR) No. BGNM-0131] and were forwarded to the Configuration Control Board for approval. In addition, a memorandum[8] was transmitted to Program Management documenting the analysis that was performed to develop the design criteria. The design criteria were approved by Configuration Control Board Directive (CCBD) No. 312-70-0135, dated June 1, 1970. In June several changes in film stowage were made, and these changes were incorporated in a Specification Change Notice (SCN), which was approved by CCBD No. 312-70-0198. This CCBD, representing the final design criteria for the Skylab film vault, is shown in Appendix D. The shielding requirements are shown in Table D-1. The stowage lists for 70mm and 16mm film, respectively, are given in Tables D-2 and D-3; and Table D-4 describes the configurations to be integrated into the OWS film repository.

Film Vault Design

Preliminary Design. MDAC responded to the preliminary design criteria with a preliminary film vault design which was presented at MDAC on January 21, 1970. The presentation handout defined the MDAC design approach of four equally sized vaults with three drawers, each drawer providing 0.6 in. of aluminum radiation protection. The vaults were mounted in a group on the OWS crew quarters floor next to the outer wall. Fifteen additional shielding panels would be launched, attached at various locations on the crew quarters floor, for later astronaut installation around the film vaults. These panels would provide as much as 7.8 in. total shielding for certain film magazines. This approach was necessary to reduce the maximum point loading at launch from approximately 4250 lb to approximately 1700 lb. The initial vault design included a 2-in. foam insulation barrier and an active thermal control loop from the existing refrigeration system to maintain 45 ±50° F in the vault. Humidity control was planned by using individually sealed bags for the film magazines. The vault was designed as a double-sealed pressure vessel to maintain internal pressure between 5 and 15 psia.

This preliminary design concept was reviewed during the next 5 months, and many of the initial design concepts were found to be undesirable and to require changes. MDAC began to design structural modification of the crew

8. T. P. Isbell: Design Requirements for Skylab Workshop Film Repository. NASA MSFC Memorandum S&E-ASTN-SD-70-169, Marshall Space Flight Center, May 28, 1970.

quarters floor at a new location for the film vault. A more suitable vault location was defined on the forward tank floor. A redesign of the 400-ft film magazine significantly reduced the volume of stowed film, thereby reducing the launch weight of shielding. The removable shielding panels were not only undesirable from an astronaut time standpoint, but the mission timelines would delay the installation of the panels several days after orbital habitation, thereby allowing appreciable radiation fogging for some films. The proposed film vault thermal control system was undesirable. Since the film could tolerate the predicted thermal environment during orbit but not during prelaunch, only ground cooling was required. MDAC began to design an onboard heat exchanger to provide ground cooling of the entire OWS. Because of the expected pressure variations in the film vault, the sealed film magazine bags were deleted from consideration. To preclude the necessity of qualification testing for pressure integrity, the film vault was designed to provide controlled leakage. To provide humidity control, an effort was begun to select a suitable desiccant or salt for this purpose. During this review phase of the preliminary vault design, several changes in experiment film quantities reduced the vault volumes and, thereby, the total vault weight.

Final Design. The revised design criteria presented to MDAC in May 1970 represented a reduction in film quantity and a considerable reduction in required shielding because of new film test results and new predicted radiation environments. The MDAC response was presented at MDAC on June 26, 1970.[9] MDAC found that the new criteria would allow a single large film vault to be mounted on the modified forward tank floor. One large aluminum casting with 12 drawers, 2 with 0.25 in. of shielding, 6 with 1.9 in., and 4 with 3.4 in. was designed. The total weight of the vault was reported to be 2820 lb including contingencies and 445 lb of film magazines. The foam insulation barrier was deleted. Temperature control of the vault was not required since the mission temperature profile in the OWS was considered acceptable, with the ground heat exchanger providing a prelaunch maximum of 80° F. Changes resulting from this review dealt primarily with the Experiment S190 personnel's desire to store all their film in a particular manner. This required that all S190 film magazines be located in the 3.4-in. area of the vault with three drawers to be removable as magazine handling containers. This change was accepted and, along with other minor changes, was included in a SCN approved by CCBD No. 312-70-0198 (see subheading, Final Design Criteria, under the heading, Film Vault Design Criteria) to define final design criteria.

9. Skylab A Stowage System/Systems Engineering Study Summary Presentation. McDonnell Douglas Astronautics Co., June 26, 1970.

MDAC responded to this CCBD by redesigning the vault to accommodate the Experiment S190 handling requirements and to increase shielding on one drawer from 1.9 to 2.9 in., thereby improving the allowance for any future additions of highly sensitive film to the Skylab experiment requirements. Potassium thiocyanate (KSCN) salt pads were incorporated into the vault design to control relative humidity to 45 ±15 percent throughout the Skylab missions. These and other details of the final Skylab film vault design were presented at MDAC on September 14-17, 1970, and are shown in Appendix E in Figures E-1 through E-13. An illustration of the film vault as of June 1971 is shown in Figure 12.

CONCLUSIONS

This report has described only the major tasks encountered during the effort to provide environmental protection for the Skylab corollary experiment film. A major part of the success in the effort can be attributed to the early systems definition, planning, and scheduling.

Some of the significant findings resulting from this effort were:

1. Comprehensive data do not exist on the sensitometric and physical response of specific film emulsions to radiation, temperature, humidity, pressure, or chemical environments.

2. All experimenters desired the highest possible image quality in their photographic data, but they found it difficult to define acceptable and objective limits on degradation of quality.

3. Techniques for analyzing the combined effect of various film-degrading factors had not been developed.

4. The level of confidence in predicted space radiation environments was significantly low to the extent that considerable spacecraft weight penalties resulted from shielding sensitive photographic film.

5. A trade-off was required between the shielding weight for long-term orbital storage of film and the launch payload capability for film resupply on later missions.

6. In general, films of the slowest speed compatible with experiment photographic requirements should be used to reduce sensitivity to unwanted radiation.

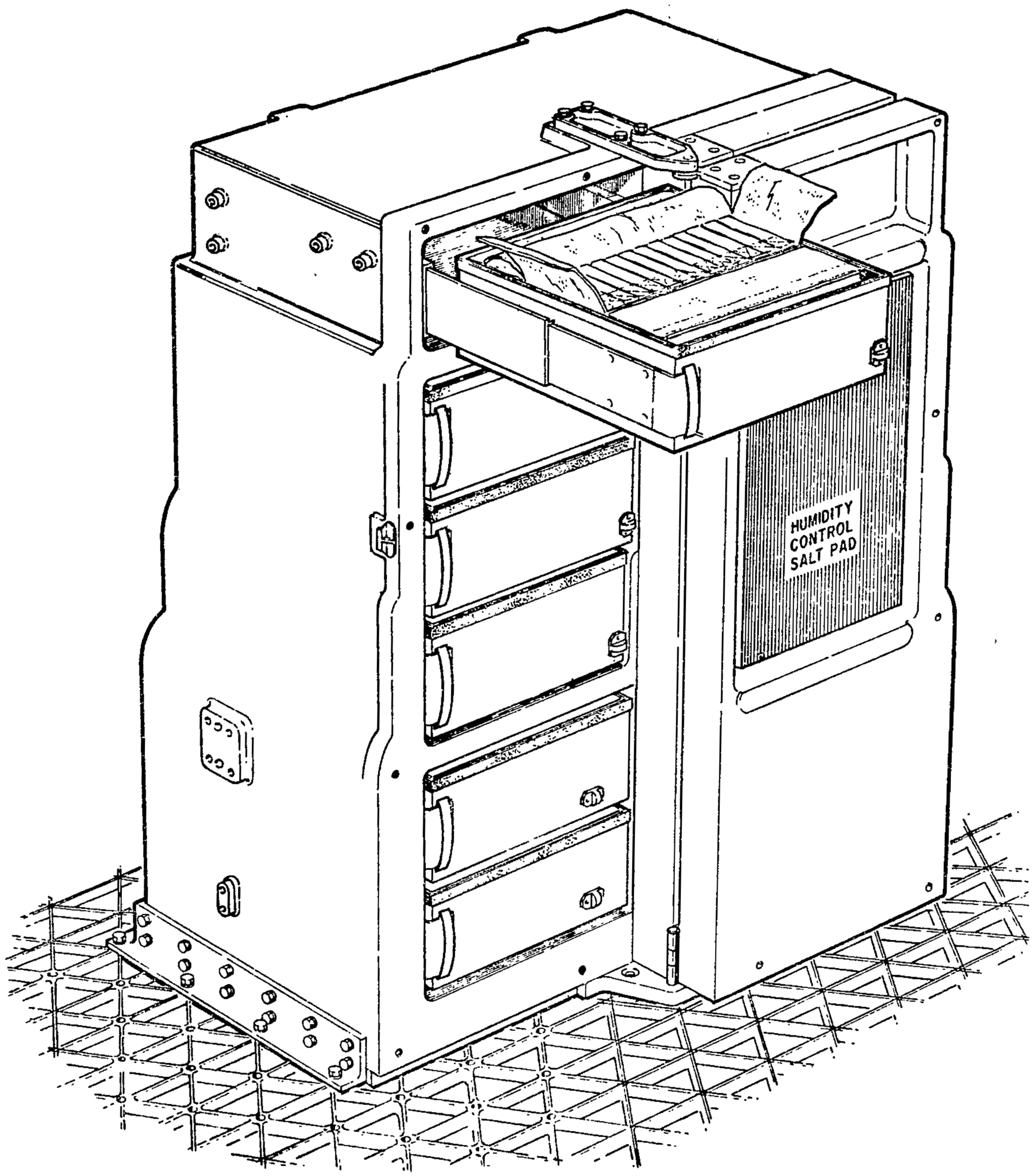

Figure 12. Skylab film vault for corollary experiment film.

7. Integration efforts to insure compatibility of photographic and spacecraft systems and adequate film protection are long lead time tasks that must be initiated at the earliest possible date in any space flight program

The capability and experience have been developed to perform the integration tasks necessary to insure compatibility of photographic and spacecraft systems and to develop film protection design criteria.

Any future space mission involving experiment photographic systems will require an early analysis of the photographic requirements and implementation of a program designed to obtain satisfactory data. It is hoped that this report has succeeded in stressing this need and the capability that has been developed to satisfy the need.

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APPENDIX A

DISCUSSION OF SELECTED PHOTOGRAPHY-RELATED TERMS

The information in the following paragraphs is intended to familiarize the reader with some of the more important system relationships, definitions, and characteristics.

RELATED CAMERA AND FILM CHARACTERISTICS

The camera, lens, film-holding mechanism, and the film form a complete information-gathering system. Just as the finest camera and lens combination cannot produce good results if the film is inadequate to give the contrast gradations or resolution required, the best film available cannot produce good results if the lens quality is not sufficiently high, the camera body is not properly adjusted, or the film-holding mechanism cannot position the film properly. The film and camera characteristics are inextricably combined in the photographic data that result. Flare in the lens causes degradation in contrast levels in adjacent areas and, consequently, loss in resolution. Spherical and chromatic aberrations also cause loss in resolution. These effects can be mitigated by a proper choice of material in the lens elements or by special coatings on the lens elements; however, they cannot be eliminated completely in a practical lens.

The relationship between camera settings and film speed can be expressed as:

$$t = \frac{Kf^2}{SL\ min},$$

where

t = exposure time (sec),

f = lens aperture in f/stop number,

S = film speed,

$L\ min$ = scene illumination (ft-L) — generally taken to be some minimum illumination that is desired to be recorded,

K = a correction factor that accounts for such items as lens flare and dimensional proportionality.

FILM DENSITY

Information is stored on the processed photographic negative in the form of deposits of metallic silver grains. The amount of silver grains present in any area of the photographic negative is proportional to the amount of light to which the area of the film was exposed. To determine the response of a film to different amounts of light or to compare the response of different films to the same amount of light, a method for measuring the quantity and quality (i. e., size and physical form) of the silver grains in a given area of the negative had to be devised. The measurement used for this purpose is called density (D).

Density is defined as the logarithm of the opacity of the silver deposit for films. Opacity (O) is derived from transmission (T), which is the ratio between transmitted light and incident light striking the film. Opacity is defined as the inverse of the transmission:

$$O = \frac{1}{T}$$

$$D = \log O = \log \frac{1}{T} \ .$$

H&D CURVES

The H&D curve, or characteristic curve, represents the relationship between optical density and the logarithm of the exposure for a given film. Such a curve is obtained by subjecting the photographic film to a series of exposures, each greater than the preceding exposure by a constant factor, and reading the resultant densities on the processed film with a densitometer. When the density of each silver deposit is plotted against the logarithm of the exposure that produced that density, a curve can be drawn through the plotted points. This curve is called the characteristic curve or the H&D curve after Hurter and Driffield, who first presented photographic data in this form in a paper published in 1890.

Figure 1 illustrates a typical characteristic curve. Because of its general shape, the characteristic curve can be divided into three distinct regions: the toe, the straight-line portion, and the shoulder. The toe begins at a level where no image density results upon development. It is characterized by a rapid increase in slope. The level of no developable image is known as the "gross fog" or base plus fog of the film. The straight-line portion of the characteristic curve, as the name implies, is a section with a constant slope. Most of the photographic information is recorded in this section. The slope of the straight-line portion of the characteristic curve is designated as gamma (γ), and the numerical value of gamma is defined as the tangent of the angle made with the exposure axis. Gamma serves as a convenient method of expressing the contrast of the film. This straight-line portion is used in some way to determine the film speed for practically all systems that are currently in use. The shoulder is characterized by a rapidly decreasing slope. It can be said to end at the point of maximum density. Exposures above this level will not produce an increase in density and may even produce a decrease in density.

APPENDIX B

GLOSSARY OF UNUSUAL TERMS

GLOSSARY

Bremsstrahlung — A continuous spectrum of x-radiation that results from the interaction of fast-moving electrons with matter. The electron source may be direct or secondary because of some other charged particle or ionizing radiation exposure.

Contrast — The term generally used to describe the gradations that a film is capable of reproducing between the lightest and darkest areas of a scene. It may be defined as a combination of the steepness or slope of the straight-line portion of a photographic film characteristic curve and the length of the straight-line portion as referred to the density axis of the curve plot.

Corollary Experiments — Those medical, scientific, and technical investigations on the Skylab missions, other than Apollo Telescope Mount (ATM) investigations, recommended by the Manned Space Flight Experiments Board and assigned to the Skylab Program by the NASA Headquarters Program Office.

Film Density — Film density is measured by the logarithm of the reciprocal of the light transmission of the developed film, the transmission being the ratio of the transmitted light (light that passes through) to the incident light impinging on the film.

Film Emulsion — The thin, light-sensitive layer that forms the active element of a photographic film.

Film Speed — A photographic film emulsion speed value is any convenient way of indicating the average sensitivities of different films and is useful in estimating the proper exposure for the best results.

Gamma (γ) — The slope of the straight-line portion of the characteristic curve. The numerical value is defined as the tangent of the angle made with the exposure axis.

Gross Fog — The sum of the densities of the film support, the suspending gelatin, and any unwanted developed grains that do not occur because of light exposure.

Hurter and Driffield Curve — The curve obtained from a plot of resultant values of density against the logarithm of the exposure [measured in meters-candles-seconds (foot-candles-seconds)] that produced the measured density for any specific film; also referred to as the characteristic curve for any specific film.

Modulation Plot — A graph comparing modulation transfer factor at a given spatial frequency to the gamma-radiation exposure of the film. The modulation transfer factor gives a relative measurement of the fidelity of reproduction of a cyclical pattern on the film.

Net Fog — The difference between the total measured density and the normal gross fog density for a given film sample, both densities being taken in areas that have no picture information.

Principal Investigator — A qualified scientist, educational institution, private industry, or Government agency that has conceived or identified an experiment aimed at advancing knowledge.

Rad — The rad is defined as the radiation-energy flux that will deposit 100 ergs/g in an absorbing material.

Sensitometry — The quantitative measurement of the relation between the image produced on a photographic material and the treatment to which it has been subjected, including exposure and development.

Skylab — A prototype earth-orbiting assembly consisting of a Multiple Docking Adapter (MDA), Apollo Telescope Mount (ATM) Airlock Module (AM), Instrument Unit (IU), and an S-IVB Stage, modified as an Orbital Workshop (OWS). Its objectives are to extend the duration of manned space flight and to carry out a broad spectrum of investigations consisting of approximately 30 medical, scientific, and technological corollary experiments and 5 ATM solar astronomy experiments.

Skylab Mission — The total Skylab flight consists of three extended duration manned missions: the first mission of up to 28 days and the second and third missions of up to 56 days with two orbital storage periods interspersed between the manned missions. The first orbital storage period will be 60 days and the second period 90 days. All three missions will evaluate the orbital assembly (OA), consisting of Skylab and the Apollo Command Service Module (CSM), as a habitable workshop and perform a number of medical, scientific, and technological experiments.

South Atlantic Anomaly — A portion of the Van Allen belts of trapped particles that are unusually close to the earth's surface because of misalignments between the geometric axis system and the magnetic field of the earth.

Van Allen Belts — Two doughnut-shaped belts of high energy charged particles trapped in the magnetic field of the earth.

Vette Data — Flux maps of the protons and electrons trapped in the Van Allen Belts compiled by J. Vette from 1962 satellite measurement and subsequently revised to include later measurements.

APPENDIX C

DISCUSSION OF FILM SHIELDING CALCULATION LOGIC

The following paragraphs provide a detailed discussion of the calculation logic, as shown in Figure 11. The paragraph numbers correspond to the blocks shown in the logic diagram.

1. Establish Allowable Radiation Dose. A final selection of allowable dose was made after evaluating the results of the Radiation Test Program and additional discussion with certain Principal Investigators (PI's). The values selected were all in terms of tolerance to an equivalent radiation dose from a Cobalt-60 source. These values are shown in Table C-1. For some experiments the allowable dose was taken as that which corresponds to a limit on change in density of the film rather than from a subjective evaluation of the test results. These cases are noted in Table C-1.

2. Deduct Cosmic Dose. Cosmic radiation or galactic primaries contribute to the accumulated radiation dose seen by the film during orbit. An effort was made to define the magnitude of this radiation source, and the results were reported.[10] The value of 0.1 rad per 30 days in orbit has been used in the calculations as the cosmic dose rate. The cosmic dose is deducted directly from the established allowable radiation dose for each experiment film since it will penetrate, without significant loss of energy, any shielding that could reasonably be provided for Skylab A. The cosmic dose is the product of the dose rate mentioned above and the orbital time for each experiment/film use.

3. Deduct Command Module (CM) Stowage Dose. A deduction was made from the allowable dose for film vault shielding for the time during which film is not stored in the vault. All film must eventually be removed from the vault and transferred to stowage in the CM for reentry. Some film is not launched in the film vault but is brought up in the CM and transferred in orbit to the film vault. The radiation dose accumulated while film is in the CM is the product of the CM dose rate and the time the film is stowed in the CM. The calculations assume that film launched in the CM will not be transferred to the film vault for 2 days and that all film will be transferred from the film vault in the CM 4 days before reentry. The actual CM stowage radiation dose is the product of the time stowed in the CM and the anticipated dose rate in the CM corrected to an equivalent Cobalt-60 dose. The dose rate in the CM was taken as 0.047 rad/day [7]. For conversion to an equivalent Cobalt-60 dose, it was assumed that the median energy was 50 MeV, and for a constant change in film density the ratio of 50 MeV to Cobalt-60 rad levels was taken from curves for each film type in the references given in footnotes 1 and 2 of this report.

10. J. A. McClendon: Galactic Primary Radiation Values for Use in Defining Film Repository Design Requirements. AVO-ASD-SHI-3, Teledyne Brown Engineering Co., Huntsville, Ala., Nov. 5, 1969.

TABLE C-1. CALCULATION DATA FOR SKYLAB EXPERIMENT FILM SHIELDING REQUIREMENTS

Film Type	Experiment	Mission Length (Days)	Cobalt-60 Rad Limit	Cobalt 60 Oper. Dose (rad)	Shielding Thickness (in.)
103-0 UV	S063	56	2.0	0.07	1.35
2485	S063	56	1.0	0.05	2.60
2485	S073	56	1.0	0.31[b]	3.40
7242	M512	30	6.0	0.5	0.10
2403	T025	56	3.0	0.04	0.32
3403	T027	30	3.0	0.26[b]	0.10
101-01	S020	30	1.5	0.06	1.15
SC5	S019	30	1.5	0.05	0.42
		56	1.5	0.05	1.75
SO168	M151, M487,	30	3.0	0.06	0.10
	M507, M508,	144	3.0	0.06	1.80
	M509, T020	230	3.0	0.06	3.00
SO168	Operational	30	3.5	0.06	0.10
		144	3.5	0.06	1.50
		230	3.5	0.06	2.70
SO168	T013	144	2.5	0.06	2.20
SO368	Operational	30	8.0	0.11[b]	0.10
		56	8.0	0.11[b]	0.10
		144	8.0	0.11[b]	1.00
		230	8.0	0.11[b]	1.70
SO180	M479	144	1.5	0.04	4.30
SO180	S190[a]	30	0.65	0.04	2.80
		56	1.35	0.04	3.20
SO121	S190[a]	30	0.35	0.04	3.80
		56	0.73	0.04	3.60
3401	S190[a]	30	1.0	0.04	0.88
		56	1.0	0.04	2.70
SO246	S190[a]	30	1.0	0.04	0.45
		56	1.0	0.04	1.90

a. Radiation limit converted from PI specification as limit on change in net density of film.
b. Detailed operational analysis to include electron and bremsstrahlung effects.

4. **Deduct Operational Dose.** Each film is removed from the film vault and transported to the experiment operational location as required. It was assumed that the film would be returned to the film vault as soon as possible after each experiment operational phase requiring photography. Experiment Requirement Documents were used along with the Experiment Task Analysis to define individual experiment operational locations and time out of the film vault. Anticipated radiation dose rates taken at the various locations were from Reference 7. The results of the computerized analysis shown in Reference 3 were used as guidelines for assumption of operational times for each experiment/film combination. In general, it was assumed for the calculation of the operational dose that all films were exposed to a typical radiation environment equivalent to that encountered during SAA passes for an average 24-hr period. It was impractical in most cases to attempt to arrive at discrete conclusions for the operational time for individual film magazines. This attempt was made for film magazines extended outside the spacecraft. As more finite operational information becomes available, the calculations should be refined to insure that adequate protection of the film is provided. Table C-1 shows the operational assumptions that were input to the computer program. The dose rates taken from Reference 7 at the various operational locations were corrected to an equivalent Cobalt-60 dose, as indicated under the previous paragraphs, except for those located outside the spacecraft, where electrons were assumed to be equal to Cobalt-60 and bremsstrahlung were assumed 10 times as damaging as Cobalt-60. The calculated doses were then subtracted from the allowable dose.

5. Correct for Temperature and Humidity Effects. It was intended that corrections would be made for fogging of the film caused by temperature and humidity effects by deducting from the allowable radiation dose an amount equivalent for each film to the density rise resulting from these temperature and humidity effects. It was found by inspection of the test data in Reference 4 that, considering the time in orbit of each film type and its sensitivity to the normal cabin environment, the fogging effects of temperature and humidity would generally be insignificant with respect to radiation fogging and would generally affect the opposite end of the sensitometric curve. Therefore, no corrections have been made in the present calculations for temperature and humidity effects. However, the calculation logic is available in the computer program, and as new films or procedures are introduced, this correction should be reviewed and possibly incorporated in the calculation.

6. Determine Adjusted Radiation Limit. The first block of the logic diagram established the allowable radiation dose of Cobalt-60 radiation for each experiment/film combination. Subsequent headings discussed deductions to be made from each of the allowable doses. The adjusted radiation limit represents for each experiment/film combination the total radiation dose that should be allowed on the film during the entire mission.

7. Determine Allowable Radiation Dose. · This step in the calculation logic allocates the accumulated allowable mission dose to a daily dose by dividing the adjusted radiation limit for each experiment/film combination by the time the film is actually in the film vault. Radiation spectra within the film are a function of the vault shielding thickness (Fig. C-1). In order to translate the preceding allowable radiation dose into the required shield thickness, the radiation spectra must be used with the matching value of shielding thickness. In order to match the two values, an iterative process must occur, beginning with assuming the spectra and calculating the required shielding, then reversing the process to determine whether the proper spectra were assumed. This iterative process is automatically cycled by the computer; however, blocks 8 through 12 will be explained to allow preliminary hand calculation of single-case shielding requirement values.

8. Assume Radiation Spectra in Film Vault. Using the relationship of radiation spectra and shielding thickness presented in Figure C-1, an iterative

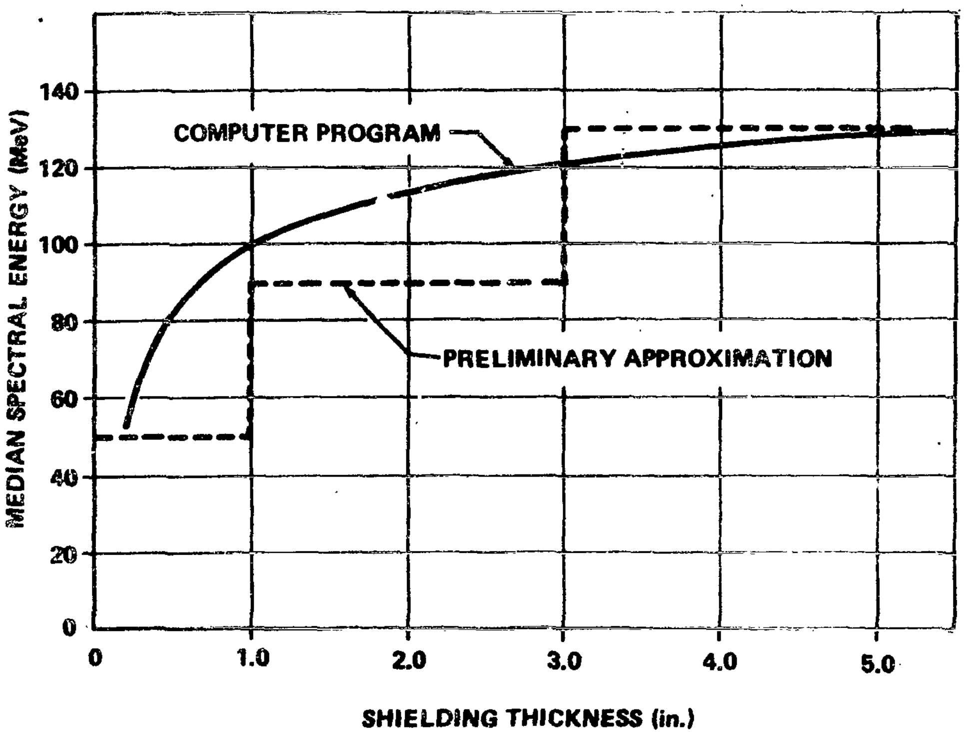

Figure C-1. Median spectral energy behind various thicknesses of aluminum shielding.

procedure is necessary to establish a desired shielding thickness. The first step in the iterative procedure is to assume radiation spectra. A shielding thickness calculation is made and compared to determine whether the relation to the assumed radiation spectra agrees with Figure C-1. The procedure is continued until agreement is reached.

9. Correct Daily Radiation Dose to Assumed Spectra. From the curves in Reference 5 and footnote 3 of this report relating film density change and accumulated radiation dose for various spectral energies, the daily radiation dose is converted from a Cobalt-60 dose to the proton dose at the median spectral energy assumed under the preceding heading. This conversion is accomplished at an equivalent density change for each film type.

10. Determine Preliminary Shield Thickness. Figure C-2 was derived from data given in footnote 9. Representative values of daily dose rate behind various shielding thicknesses were taken from the simulated film vault modeled in the reference given in that footnote. The corrected daily radiation dose having been established in the previous paragraph, a shielding thickness can be directly read from this curve.

11. Determine Spectra for Preliminary Shielding. The median radiation spectra behind the calculated preliminary shielding may be determined directly from Figure C-1. The solid line represents the relationship that has been incorporated in the computer program, and the dotted line indicates the step relationship assumed for simplification of the iterative calculation procedure used in hand calculations.

12. Compare with Assumed Spectra. At this point in the iterative calculation procedure, a comparison is made to determine whether the calculated shielding thickness and the assumed radiation spectra in the film vault agree with the relationship shown in Figure C-1. If agreement is not reached, new radiation spectra are assumed, and the calculation is repeated. If agreement is reached, a final shield thickness can be established.

13. Establish Shield Thickness. This value is actually derived as a result of the last iteration of the functions described in paragraphs 8 through 12 and does not require further manipulation.

The values of required shielding for the Skylab A film types which were derived using this calculation procedure are given in Table C-1.

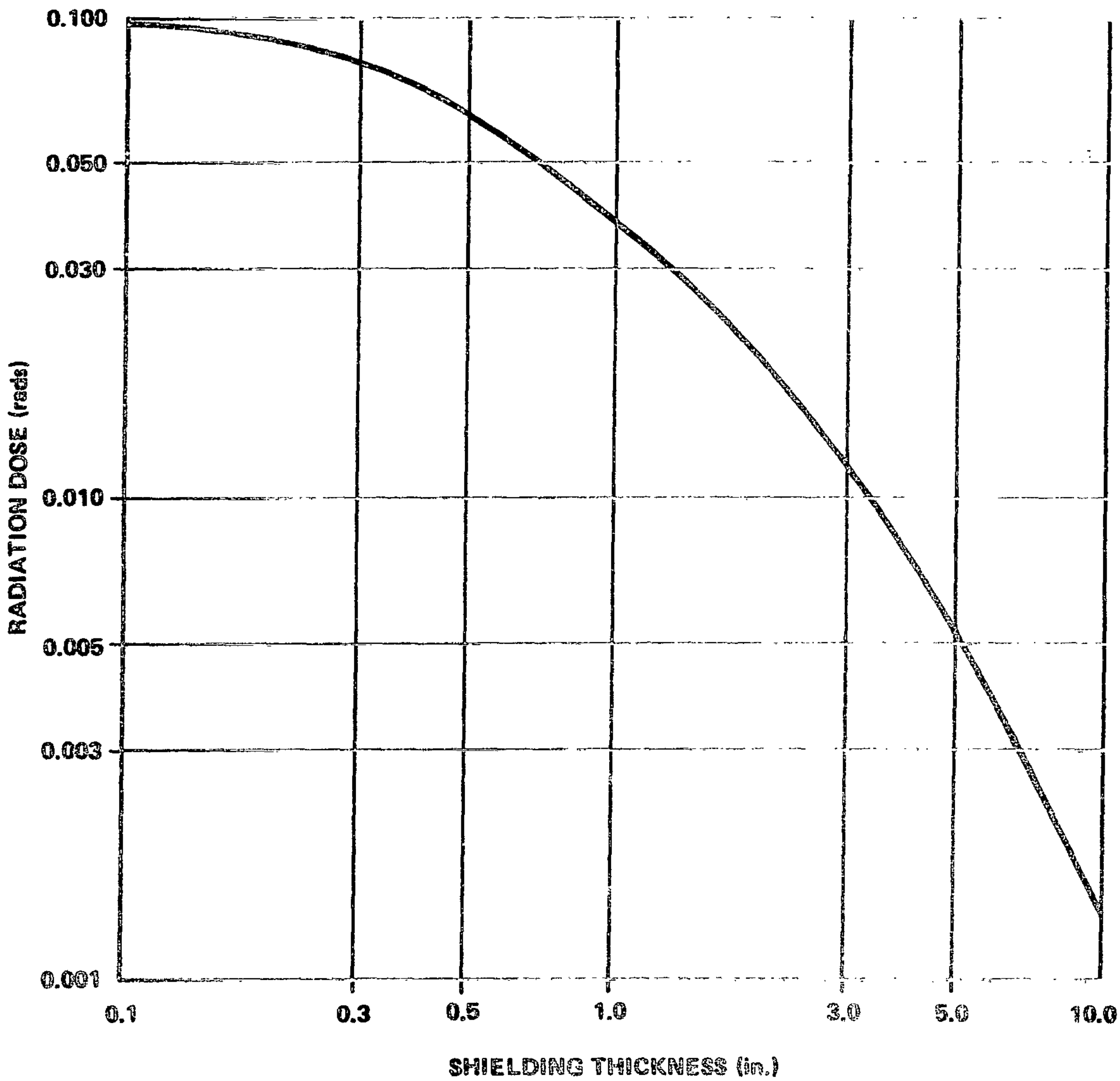

Figure C-2. Allowable daily radiation dose behind various thicknesses of aluminum shielding.

APPENDIX D

REPOSITORY DESIGN CRITERIA

(Configuration Control Board Directive No. 312-70-0198)

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CONFIGURATION CONTROL BOARD DIRECTIVE

1. CCBD NUMBER 312-70-0198	2. LEVEL III	CONFIGURATION CONTROL BOARD: Saturn Workshop Project	PAGE 1 OF 2
3. EQUIP AFFECTED ☒ FLIGHT ITEM ☐ GSE ☐ FACILITY			DATE July 31, 1970
4. CONTRACTOR MDAC-WD	5. CONTRACT NO. NAS9-6555,Sch.II	17. ECR TITLE: Provide Final Design Criteria for Orbital Workshop Film Vault	
6. ECR NUMBER ECR BGNM-0131	6(a) DATE 5/14/70		
7. SUPERSEDES ECP NUMBER N/A	7(a) DATE N/A	18. NOMENCLATURE, CONTRACT END ITEM: OWS	
8. SUPERSEDES CCBD NO. 312-70-0135 DATE 6/1/70	19. EFFECTIVITIES: OWS-1 and Backup		
9. END ITEM NUMBER DSV7-1-1			
10. END ITEM PART NUMBER N/A			
11. TCTR NUMBER AND TYPE N/A	20. SPECIAL PROCUREMENT INSTRUCTIONS REQUIRED ☒ NO ☐ YES, SEE ATTACHED SHEET		
12. PART NUMBER CHANGE ☐ YES ☒ NO	21. SPECS AFFECTED: APOLLO PROGRAM SPEC NUMBER; SATURN PROGRAM SPEC NUMBER; CEI SPEC NUMBER CP2080J1C; CRITICAL COMPONENT SPEC NUMBER		
13. SPARES AFFECTED ☐ YES ☒ NO			
14. INTERFACE REQUIREMENTS None			
15. ECP AS NOTED ABOVE IS ☐ APPROVED AS WRITTEN ☐ DISAPPROVED ☒ APPROVED WITH CHANGES AS NOTED BELOW			

REMARKS This CCBD supersedes CCBD 312-70-0135, dated 6/1/70.

DOCUMENTATION CHANGE

1. ECR BGNM-0131 is approved with changes. The changes have been incorporated in the attached PSCN. These changes to ECR BGNM-0131 are the result of memos PM-SL-EI-347-70, dated 6/11/70 and S&E-ASTN-SD-70-207, dated 7/16/70.
2. MDAC-WD shall stop all work as directed under Change Orders 20, 58, and 97.
3. MDAC-WD shall incorporate the requirements of the attached PSCN into the CEI Spec CP2080J1C.
4. The design shall be in accordance with the results of the Stowage Design Review on 6/26/70.
5. MDAC-WD shall prepare a formal ECP in accordance with the attached PSCN.

Responsible Engineer: E. Harris, 205-453-0747.

16. CCB MEMBERS	CONCUR	NON CONCUR
D. Bowden	CB	
D. Mullin	[illegible]	
D. Germany	WH	
P. Madole		
B. Davis	[illegible]	
J. King		
R. Griner	RG	
W. Bush	WB	
J. Thomas	JHT	
W.A. Clarke	[illegible]	
F. [illegible] - PW		

OTHER CENTER CCB'S	CONCUR	NON CONCUR
CCB-KSC		
CCB-MSC		

William K. Simmons [signature]
CHAIRMAN CCB

CHAIRMAN SATURN CCB

CHAIRMAN APOLLO PROGRAM CCB

MSFC - Form 2312 (December 1964)

CCB DIRECTIVE-DATA AMPLIFICATION SHEET

CCB	CCBD NUMBER AND DATE		PAGE 2 OF 2 PAGES
Saturn Workshop Project	312-70-0198	July 31, 1970	

22. CONTINUATION SECTION (REFER TO NUMBER AND TITLE OF BLOCK ON CCBD FORM):

6. MDAC-WD is directed to design and fabricate mounting provisions for the OWS film vault.

7. Next Action Required: Contractual authorization to proceed.

8. In all responses to the above, reference PCN BT-06891.

MSFC - Form 2312-1 (January 1965)

[X] PRELIMINARY [ ] FINAL	SPECIFICATION CHANGE NOTICE No. ______	Page 1 of 6 Date 5/28/70 Superseding ______
1. ECP No. N/A ECR No. N/A	2. Contract End Item No.	3. Specification No. CP2080J1C
4. Contract NAS9-6555 Schedule II	5. Contractual Authority	File Opposite Spec Page No.
6. Effectivity OWS-1 and Backup		

7. Text Change

Add the following to Paragraph 3.3.1.9.2 Film Vaults -

Provide corollary experiment and operational film protection for OWS:

1. Provide on-pad temperature control to a maximum of 80°F from the time film is loaded in the VAB through launch.

2. Provide relative humidity control to a maximum of 75 percent at all times throughout the mission.

3. Provide film radiation protection as specified in enclosure 1 during flight. The film quantity, mission assignment, and film magazine/cassette configurations are specified in enclosure 2.

4. Provide the following:

a. Fifteen (15) percent volume contingency for additional film requirements.

b. Flexibility in the internal design of the storage configuration to prevent major modification for film magazine/cassette configuration changes and provide for in-orbit reassignment of film vault locations.

c. Efficient storage of all resupply, (such as overprotection of a given film type assigned to mission 1/2, with resupply on missions 3 and/or 4. This would provide a single location with 56-day protection instead of two separate locations: one protected for 28 days and another for 56 days).

d. Assembly storage:

(1) Provide storage for two assemblies, each consisting of a 400-foot Maurer film magazine, take-up reel (400 foot) and a transport mechanism.

7. Text Change (continued)

(2) Provide storage for two assemblies, each consisting of a 600/900 Hasselblad film magazine, take-up magazine, and a transport mechanism.

e. Multiple film vaults are to be based on film shielding thickness and experiment assigned mission duration.

f. Film vaults will be assembled with necessary film installed prior to launch.

g. An identification of all film locations, by film type, experiment number, and mission assignment. This will include documentation as well as vault identification.

h. Temporary film magazine stowage (restraint) immediately adjacent to vault for temporary stowage (outside the vault), during the vault door/drawer operation.

i. Foot restraints must be provided at the vault to permit continuous use during door/drawer operation.

j. The three drawers for S190 will be made detachable and to be used as handling containers for that film. The drawer attach points to the vault will be defined by MDAC-WD and furnished to Mr. Granfield (MSC) for mounting provisions on the EREP equipment rack. (This should be a drawing that could be turned into an interface control drawing (ICD) if necessary.) These drawers to have transportation handles, be capable of positively retaining the film magazines during movement, all edges and corners rounded for crew safety.

5. Provide capability to ground monitor temperature in the film vault from the time film is loaded in the VAB prior to launch until launch (hourly sampling would be adequate).

6. MDAC-WD is to provide protection for film magazines from shock and vibration environment.

7. MDAC-WD is to provide launch vibration criteria at the interface of the film magazines and the film vault drawers.

TABLE D-1. SHIELDING REQUIREMENTS

Film Type	Experiment	Magazine[a] Quantity/Type	Aluminum Shielding Thickness (in.)
		For 30 Days	
SC-5	S019	1K	0.42
101-01	S020	1L	1.15
SO180	S190	3G	3.40
SO246	S190	6G	3.4
3401	S190	6G	3.4
SO121	S190	3G	3.4
SO168	M151, M487, M507, M508, M509, Opera	44B, 2H	0.10
SO368	Opera	2A, 2B, 2E	0.10
7242	M512	1B	0.10
3403	T027	1A	0.10
---	S009	1J	2.9
		For 56 Days	
2485	S063, S073	1E, 1A	3.40
103-OUV	S063	1E	1.35
2403	T025	1E	0.32
SC-5	S019	1K	1.70
SO180	S190	3G	3.40
SO246	S190	6G	3.4
3401	S190	6G	3.4
SO121	S190	3G	3.40
SO368	Opera	2A, 2E	0.10
		For 144 Days	
SO168	Opera	3B, 1H	1.50
SO168	T013	2B	2.20
SO368	Opera	3B, 1H	1.00
SO180	M479	7B	3.40
SO168	M487, M508, M509, M151, T020	58B	1.80
		For 230 Days	
SO168	M151, M487	23B	3.00
SO368	Opera	2B, 1H	1.70
SO168	Opera	3B, 1H	2.70

a. Tables D-2 through D-4 define the magazine type and configuration associated with the magazine codes shown.

TABLE D-2. 70mm FILM STOWAGE LIST

Experiment	Film Type	PI Requirement Mission			Packaging							
					900/600-Frame Cassette Vehicle[a]				150-Frame Cassette Vehicle[a]			
		1/2	3	4	1	2	3	4	1	2	3	4
M487	SO168EF	150[b]	150[b]	150[b]	—	—	—	—	-	—	-	—
M509	SO168EF	20[b]	0	0	—	—	—	—	-	—	-	—
T020	SO168EF	10[b]	0	0	—	—	—	—	-	—	-	—
Operational	SO168EF	750	750	750	3	0 (1)	0 (1)	0 (1)	-	—	-	—
Operational	SO368	600	600	600	3	0 (1)	0 (1)	0 (1)	-	2 (2)	2 (2)	2 (2)
D021	SO368)	8[b]	8[b]	0	—	—	—	—	-	—	-	—
D024	SO368	2[b]	2[b]	0	—	—	—	—	-	—	-	-
S063	UV (TBD)		150	0	—	—	—	—	-	—	1 (1)	—
	Visible (TBD)		150	0	—	—	—	—	-	—	1 (1)	—
T025	2403		150	0	—	—	—	—			1 (1)	
S190	Several	9000[c]	9000[c]	9000[c]	18[c]	0 (18)[c]	18 (18)[c]	18 (18)[c]	-	—	-	—
FCSD TOTAL		1540	1960	1500	6	0 (2)	0 (2)	0 (2)		2 (2)	5 (5)	2 (2)
S190 TOTAL		9000[c]	9000[c]	9000[c]	18[c]	0 (18)[c]	18 (18)[c]	18 (18)[c]	-	—	-	—
Stowage List Unassigned									3	(1)	(1)	(1)
Stowage List TOTAL					Other Film Same as Above				3	2 (3)	5 (6)	2 (3)
					No. of Magazines							
S019	SC-5 (33 × 40mm slides)	150	150	—	1	0 (1)	1 (1)	—				
S020	Type 101 (35 × 180mm strips)	2 × 10 strips	2 × 10 strips	—	2[d]	0 (2)[d]		—				
S009	Nuclear Emulsion				1	0 (1)						

a. Numbers in these columns without parentheses represent launch quantities of film magazines, and numbers with parentheses represent return quantities of film magazines.
b. This film requirement is included in operational magazine quantities.
c. S190 film magazine under development.
d. Two film magazines are contained in one film magazine stowage box for SO20.

TABLE D-3. 16mm FILM STOWAGE LIST

Experiment	Film Type	PI Requirement Mission			Packaging: 400-ft Cassette Vehicle[a]				Packaging: 140-ft Magazine Vehicle[a]			
		1/2	3	4	1	2	3	4	1	2	3	4
M151	SO168EF	9 400	11 000	8 000	72	0 (24)	0 (28)	0 (20)	-	—	—	—
M487	SO168EF	1 170	1 170	1 170	9	0 (3)	0 (3)	0 (3)	-	—	—	—
M507	SO168EF	400	0	0	1	0 (1)	—	—	-	—	—	—
M508	SO168EF	2 000	2 000	0	10	0 (5)	0 (5)	—	-	—	—	—
M509	SO168EF	3 000	7 000	0	26	0 (8)	0 (18)	—	-	—	—	—
T013	SO168EF		930[b]	0	2		0 (2)	—	-	—	—	—
T020	SO168EF	1 600	0	0	4		0 (4)	—	-	—	—	—
Operational	SO168EF	1 200	1 200	1 200	9	0 (3)	0 (3)	0 (3)	-	—	—	—
Operational	SO368	1 080	1 480	1 080	7	0 (2)	0 (3)	0 (2)	0	2 (2)	2 (2)	2 (2)
D021	SO368	130[b]	0	0	-	—	—	—	-	—	—	—
M512	7242	400	0	0	1	0 (1)	—	—	-	—	—	—
ATM-C&D	SO392	390	780	780	5	0 (1)	0 (2)	0 (2)	-	—	—	—
S073	2485		130	0	-	—	—	—			1 (1)	
T027	3403	130	0	0	-	—	—	—	1	0 (1)	—	—
M479	SO180	2 800	0	0	7		0 (7)	—	-	—	—	—
Totals		23 700	23 570	12 230	153	0 (38)	0 (75)	0 (30)	1	2 (3)	3 (3)	2 (2)
	Unassigned									1 (1)		1 (1)
Stowage List Total					153	0 (52)	0 (71)	0 (30)	1	3 (4)	3 (3)	3 (3)

a. Numbers in these columns without parentheses represent launch quantities of film magazines, and numbers with parentheses represent return quantities of film magazines.
b. 130 ft for this experiment included in operational quantities.

TABLE D-4. CONFIGURATIONS TO BE INTEGRATED INTO THE OWS FILM REPOSITORY

Code	Description	Weight (lb)	Volume[a] (ft^3)	Envelope (in.)	Part Number/Supplier[a]	
A	16mm Maurer (140-ft) Magazine	1.0	0.009	3.7 × 5.4 × 0.88	SEB33100125-203/FCSD	
B	16mm Maurer (400-ft) Cassette	1.75		6.5 × 6.5 × 1.0[d]	SEB33100279-301/FCSD	
C	16mm Maurer (400-ft) Magazine (2 Cassettes plus Transport)	3.15	0.0126	6.0 × 11.5 × 2.5[d]	Cassette part no. listed in B. Transport part no. in SEB33100278-301/FCSD	
D	Transport Only	0.8		6.0 × 8.25 × 2.5[d]		
E	70mm Hasselblad (150-frame) Magazine	1.75	0.027	3.54 × 3.35 × 3.94[a]	SEB33100082-211/FCSD	
F	70mm (500-frame) Cassette	1.5	0.045	5.0 diam × 4[c,d]	TBD/TBD	Experiment S190
G	70mm (500-frame) Magazine includes takeup reel and transporter	7.0	0.183	7.0 × 9.0 × 5.0[c,d]	TBD/TBD	Experiment S190
H	70mm (600-900 frame) Cassette	0.7	0.013	3.6 × 3.4 × 4.0[b,d]	TBD/FCSD	
I	70mm (600-900 frame) Magazine	3.6	0.081	12.0 × 4.0 × 4.0[b,d]	TBD/FCSD	
J	S009 Detector Package	30.0	0.15	5.0 × 6.0 × 8.95	TBD/TBD	
K	S019 Film Canister	13.7	1.068	9.0 × 9.0 × 8.0[a]	TBD/Northwestern University	
L	S020 Stowage Container	9.50		5.67 × 5.5 × 10.0	TBD/Naval Research Laboratory	

a. As listed in the March 31, 1970 Skylab Stowage List.
b. MSC camera project engineer estimate. Item not contracted for and is not designed.
c. Experiment S190 PI estimate. Contracted but not designed.
d. These dimensions are estimates obtained from the cognizant engineer and are considered to be the upper limit. Final envelope will not be known until design is complete.

APPENDIX E

REPOSITORY DESIGN

McDonnell Douglas Astronautics Company Presentation
September 1970

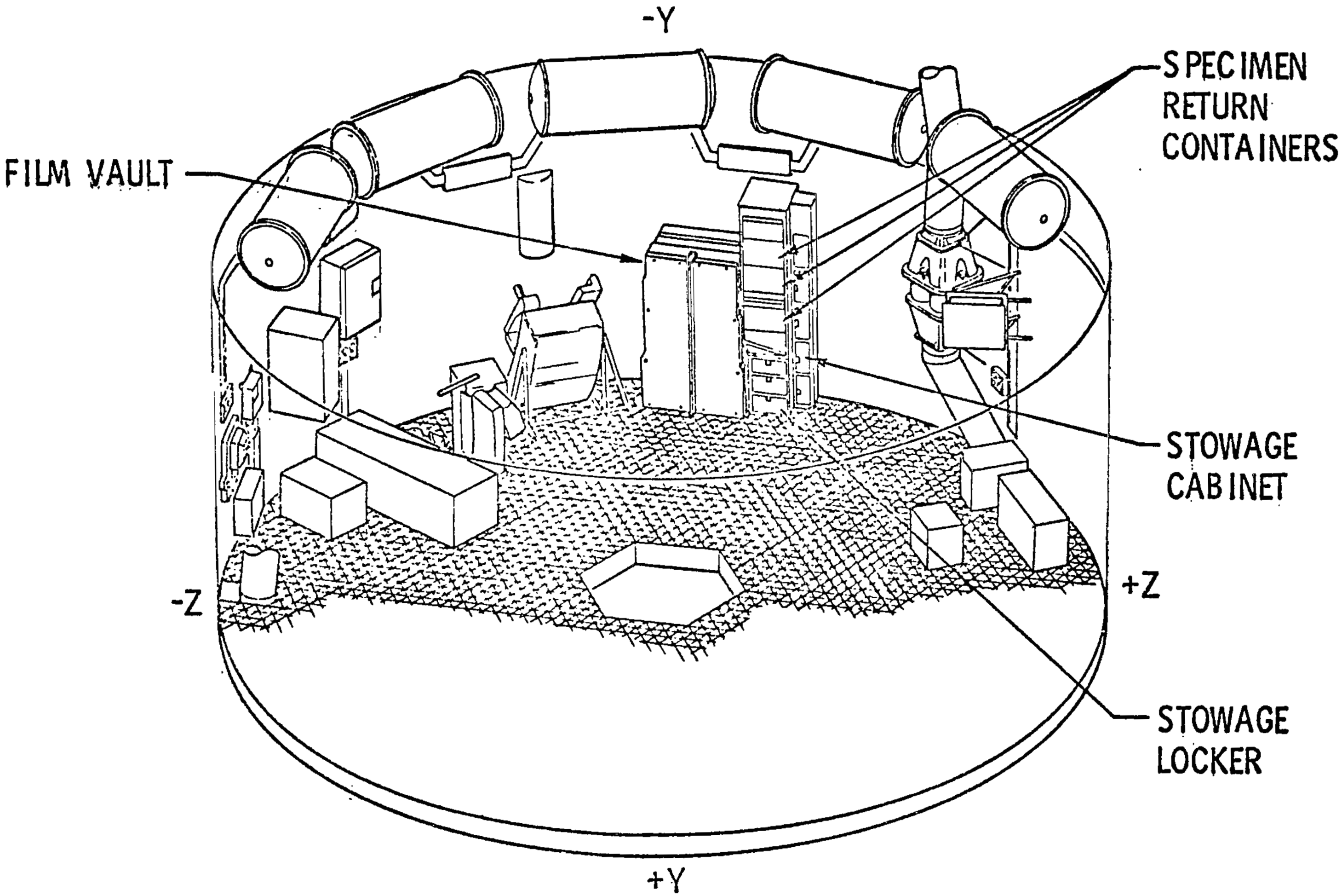


Figure E-1. Orbital Workshop stowage area on-orbit stowage.

FILM VAULT DESIGN REQUIREMENTS

- MAXIMUM 80° F VAB/ON PAD TEMPERATURE CONTROL
- MAXIMUM 75-PERCENT RELATIVE HUMIDITY CONTROL-TOTAL MISSION
- FILM RADIATION PROTECTION
- CONTINGENCY VOLUME FOR EACH VAULT COMPARTMENT
- FILM MAGAZINE/CASSETTE STOWAGE DESIGN FLEXIBILITY
- EFFICIENT STORAGE FOR REVISITATIONS
- MULTIPLE FILM VAULT COMPARTMENTS BASED ON SHIELDING THICKNESS
- (2) 400-FT MAURER MAGAZINE, TAKEUP REEL AND TRANSPORT MECHANISM STORAGE
- (2) 600/900 HASSELBLAD MAGAZINE, TAKE-UP MAGAZINE AND TRANSPORT MECHANISM STORAGE
- FILM ASSEMBLED IN VAULT DRAWERS IN BOND ROOM PRIOR TO LAUNCH
- IDENTIFICATION OF FILM LOCATION, TYPE, EXPERIMENT NO., AND MISSION ASSIGNMENT
- TEMPORARY FILM MAGAZINE STOWAGE
- FILM VAULT FOOT RESTRAINTS
- VAULT TEMPERATURE GROUND MONITORING — VAB TO LAUNCH
- DRAWERS LOADED IN BOND ROOM

Figure E-2. Orbital workshop film vault requirements.

DESIGN FEATURES

- ALUMINUM CASTING, 54 × 40 × 22 IN.
- TWO MACHINED ALUMINUM DOORS, 54 × 20 × 3.5 IN.
- FOUR VAULT COMPARTMENTS
- CENTRAL HINGE
- DOOR LATCHES
- REMOVABLE FILM DRAWERS (12)

  WELDED ALUMINUM CONSTRUCTION

  BONDED VELCRO RESTRAINTS (INTERNAL AND EXTERNAL)

  SPRING LOADED HANDLES
- BOND ROOM LOADING
- EXTERNAL VELCRO RESTRAINT (HOOK AND PILE)
- CONTENTS LABEL ON DOOR FACE
- CONTENTS LABELS ON INDIVIDUAL DRAWER FACES
- FILM STOWAGE OPTIMIZED FOR MISSION

Figure E-3. Orbital Workshop film vault.

SIZE — OVERALL

- HEIGHT — 55.5
- WIDTH — 40.0 (+3.00 FOR MOUNTING ANGLES)
- DEPTH — 25.0 (+1.50 FOR MOUNTING ANGLES)

VAULT RADIATION PROTECTION

- 1 — 0.25-IN. ALUMINUM
- 1 — 1.90-IN. ALUMINUM
- 1 — 2.90-IN. ALUMINUM
- 1 — 3.40-IN. ALUMINUM

DRAWERS 12 TOTAL IN VAULT (SIZE OF INDIVIDUAL DRAWERS)

- HEIGHT — 7.0–8.50 IN.
- WIDTH — 15.32 IN.
- DEPTH — 18.22 IN.

TOTAL AREA OF DRAWERS — APPROXIMATELY 270 $IN.^2$

Figure E-4. Orbital Workshop film vault design features.

DOCUMENT 13M13519 (EXPERIMENT AND OPERATIONAL FILM TO OWS FILM VAULT MECHANICAL INTERFACES) DEFINES:

- FILM STOWAGE REQUIREMENTS
  - FILM CONTAINER (e.g., CASSETTE, CANISTER) PHYSICAL ENVELOPE
  - FILM CONTAINER WEIGHT

WORKSHOP-IMPOSED ENVIRONMENT

- ACOUSTICAL, SHOCK AND VIBRATION
- PRESSURES
- TEMPERATURE
- HUMIDITY

Figure E-5. Orbital Workshop stowage system film-to-film vault mechanical interface.

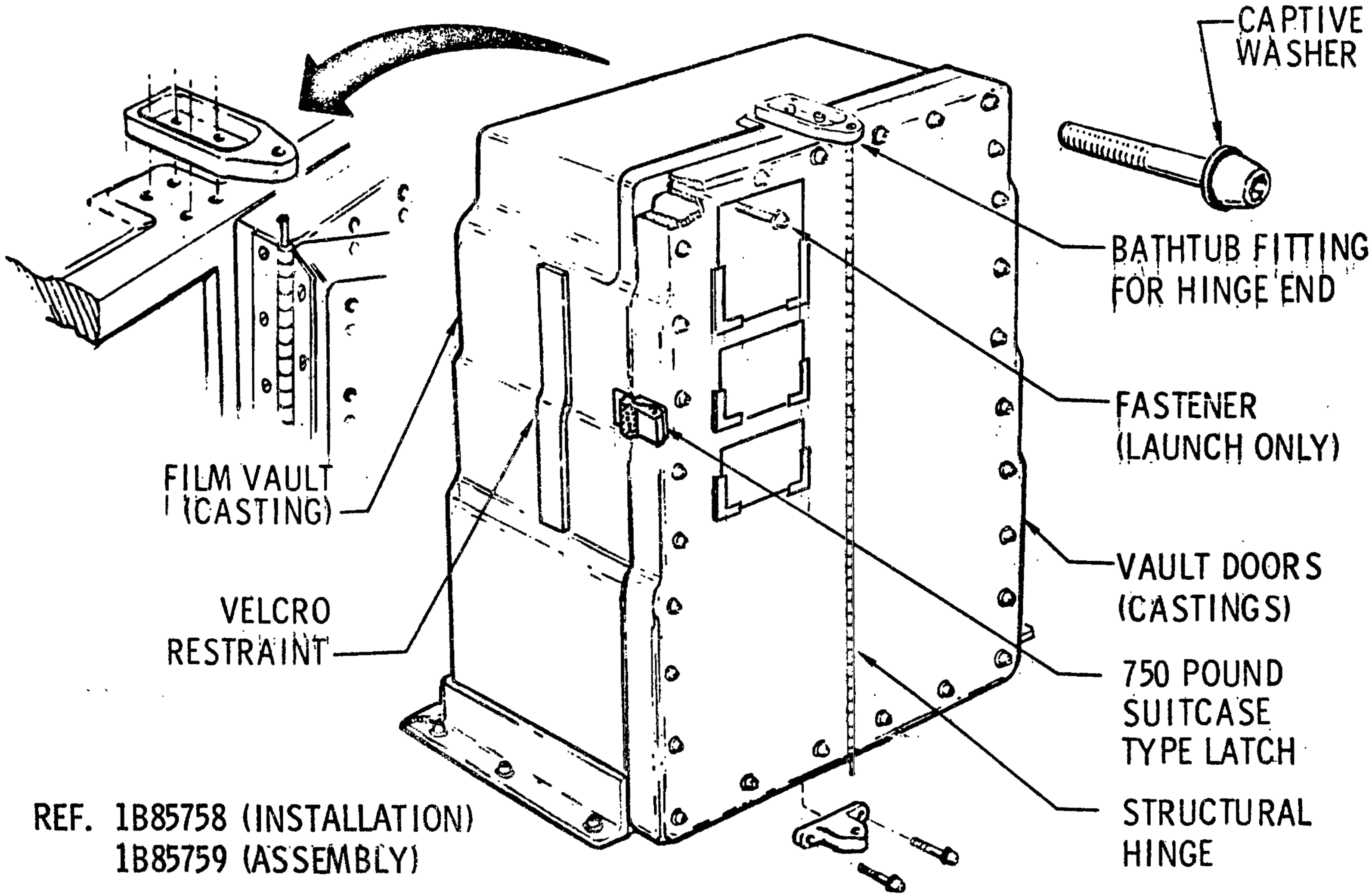


Figure E-6. Orbital Workshop film vault exterior.

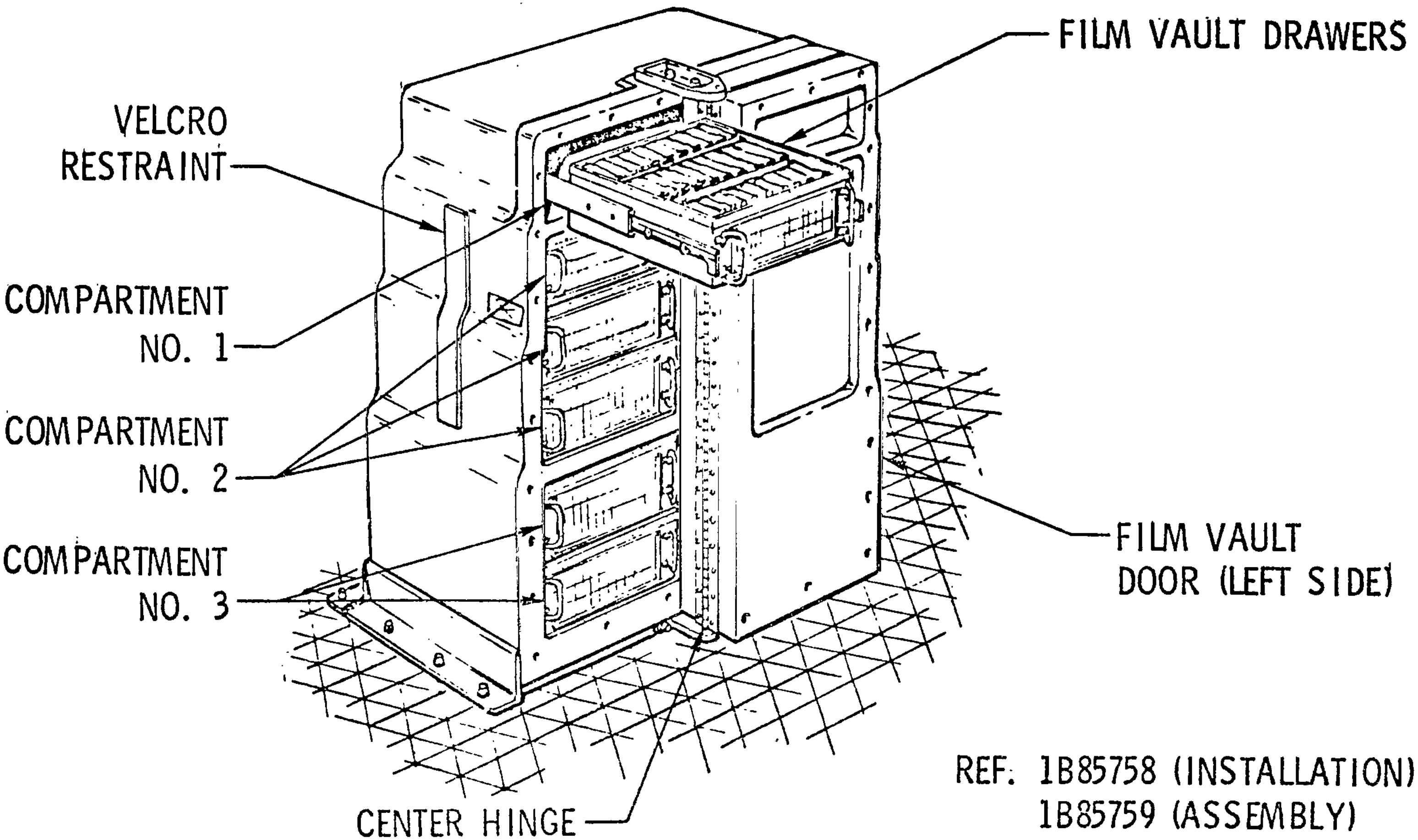


Figure E-7. Orbital Workshop film vault interior.

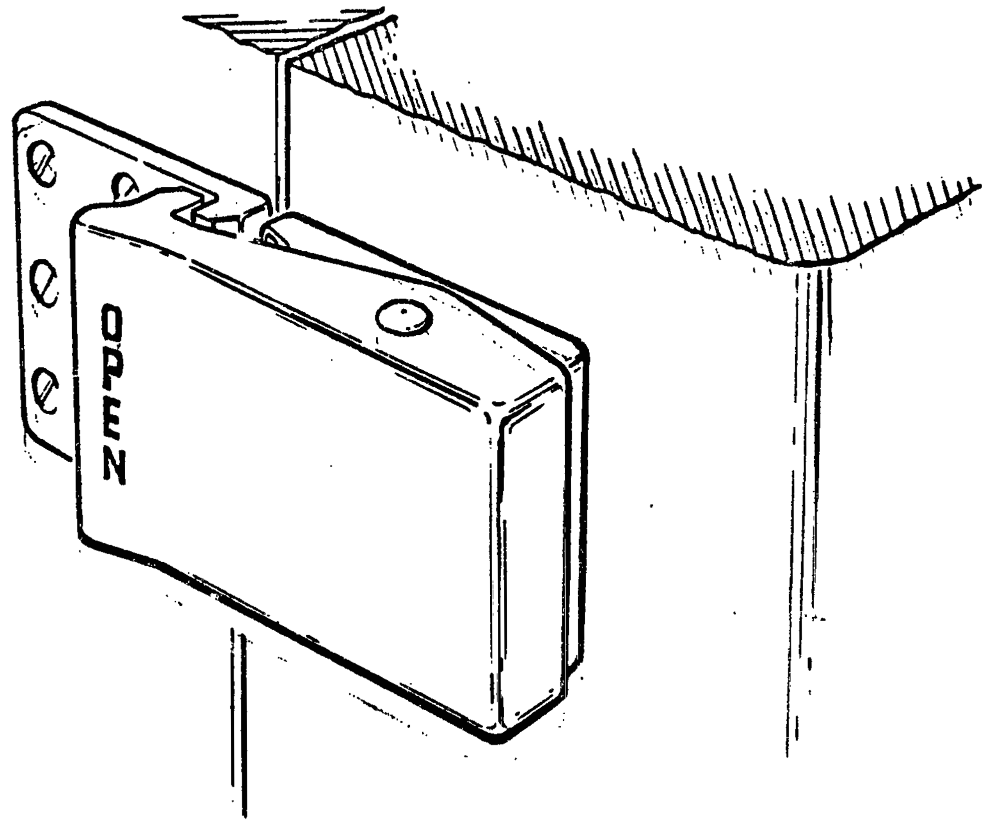


Figure E-8. Orbital Workshop stowage system film vault door latch.

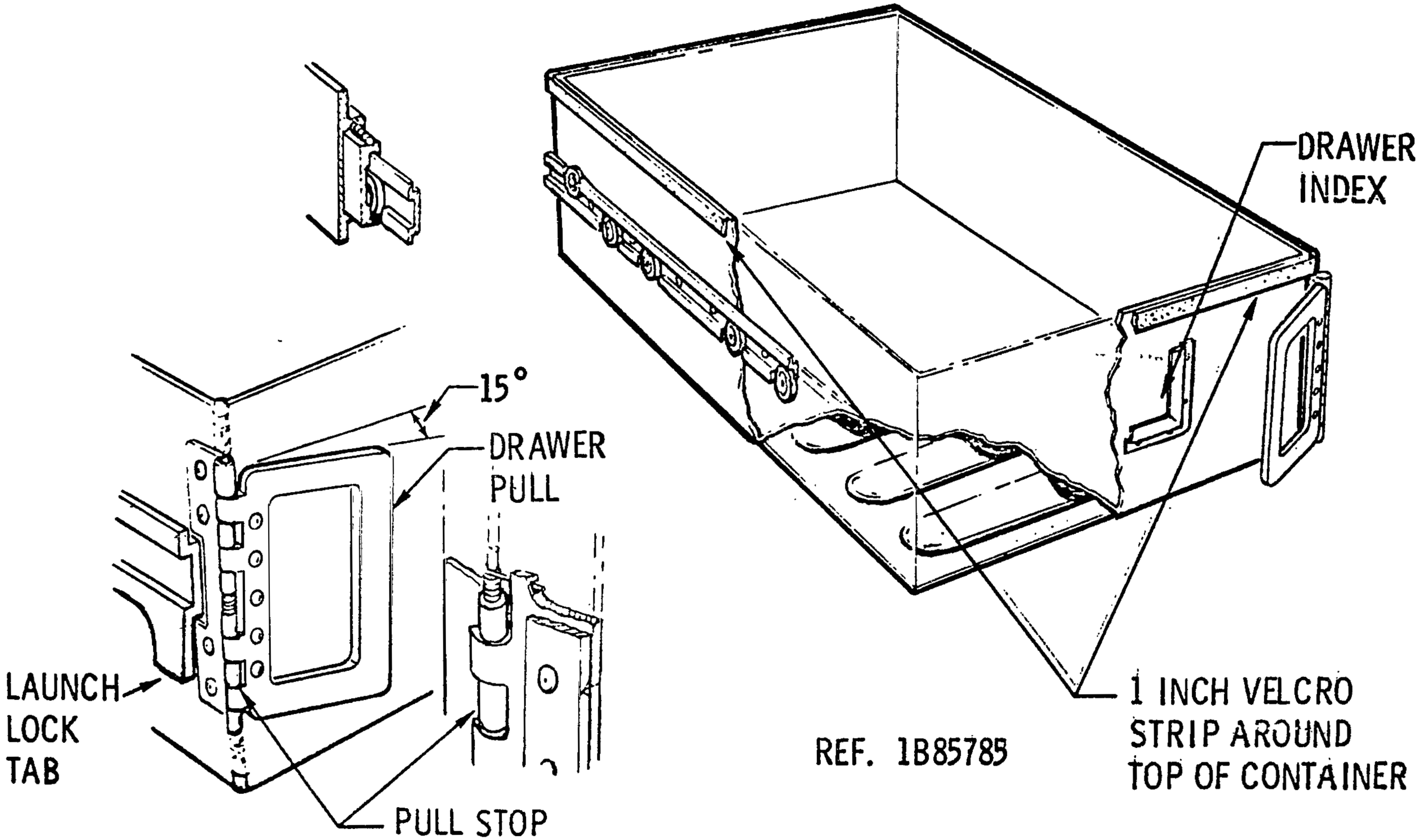
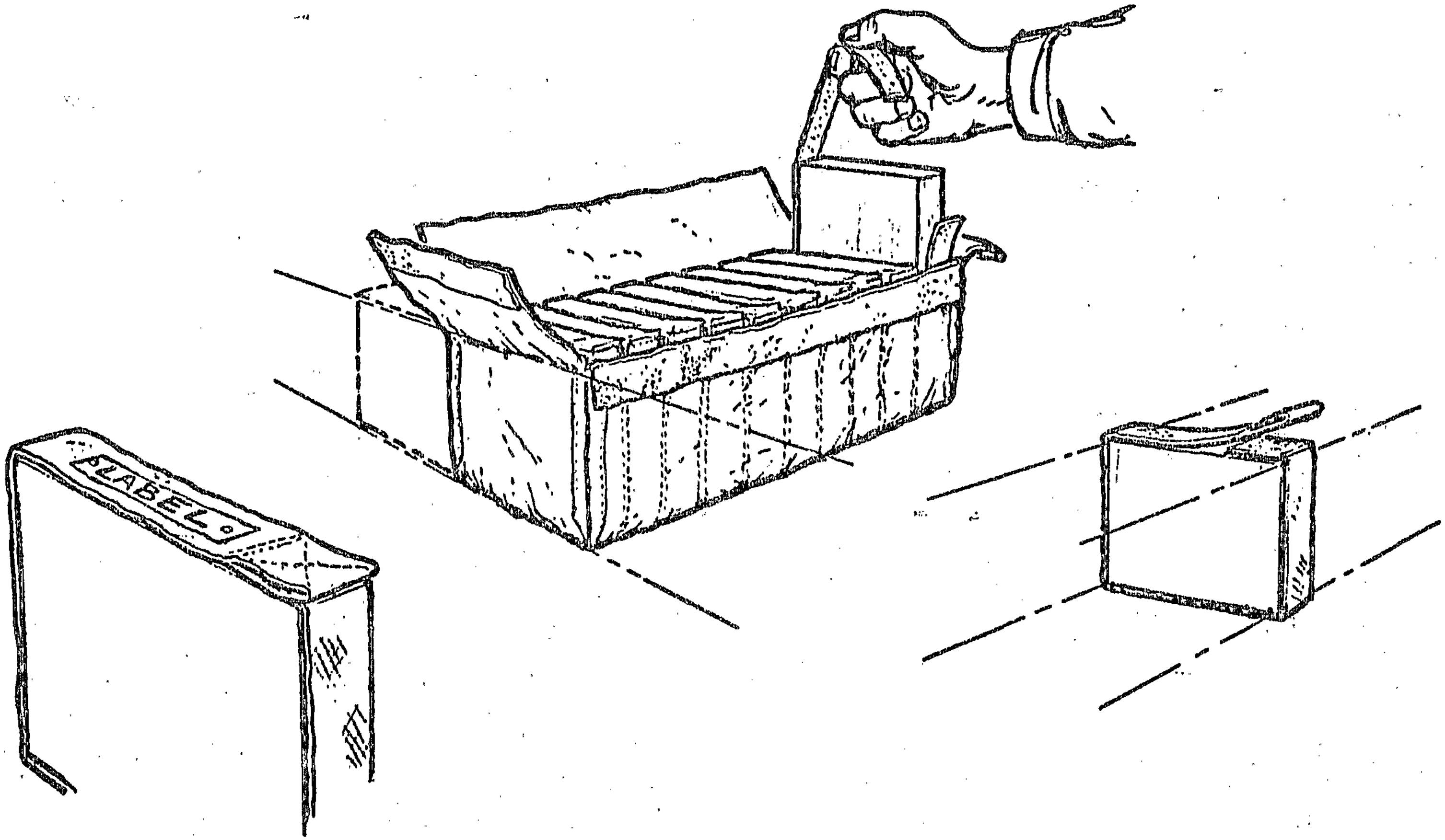


Figure E-9. Orbital Workshop stowage system vault drawer.



REF. 1B85787

Figure E-10. Orbital Workshop stowage system film stowage bag.

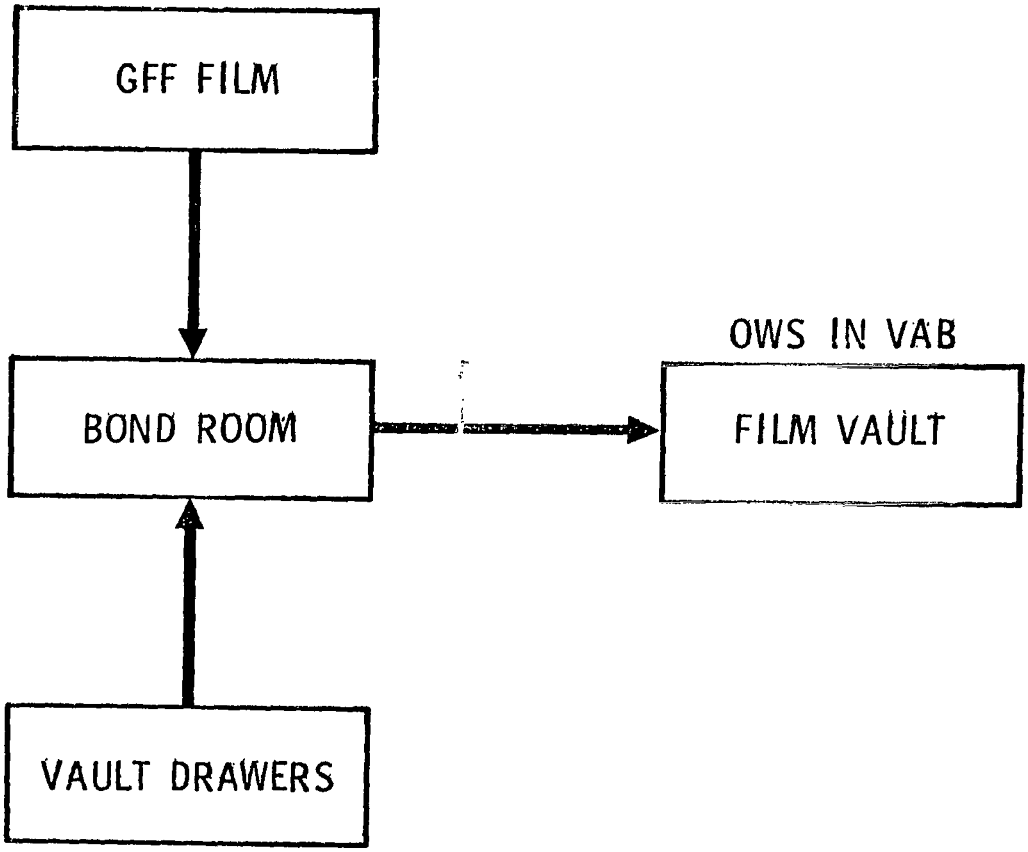
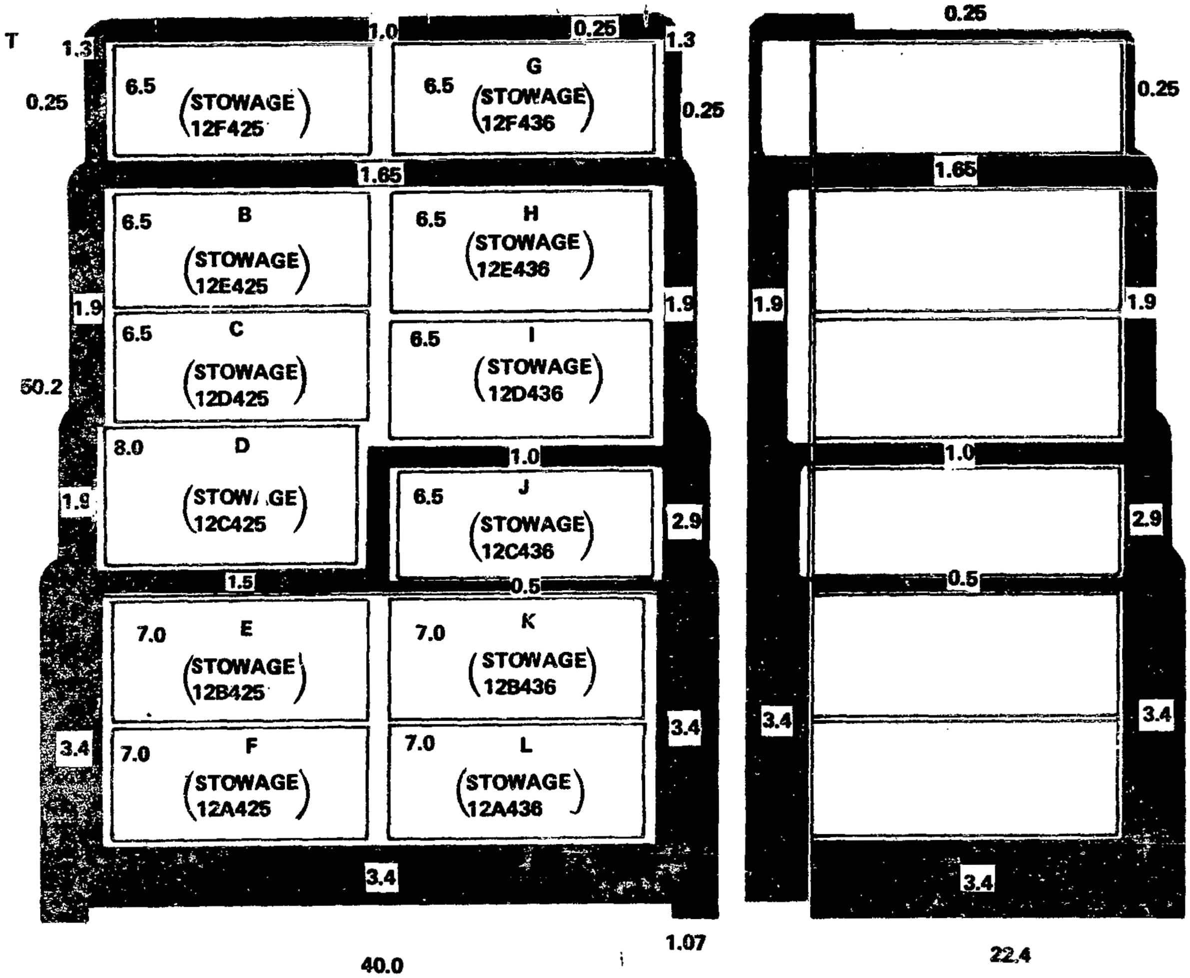


Figure E-11. Orbital Workshop prelaunch film handling.

*S190 - THREE DRAWERS, EACH OF WHICH SERVES AS A TRANSPORT CONTAINER FOR 6 FILM MAGAZINES

Figure E-12. Orbital Workshop on-orbit film location.



NOTE: ALL DIMENSIONS ARE IN INCHES.

Figure E-13. Schematic of drawer/film vault.

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APPROVAL

DEVELOPMENT OF SKYLAB ENVIRONMENTAL PROTECTION FOR PHOTOGRAPHIC FILM

By W. C. Askew, W. A. Clarke, and C. A. Best

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

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

W. C. Askew

W. C. ASKEW
Chief, Mission Development Branch

Cedar James Verhleff

T. P. ISBELL
Chief, Mechanical and Crew Systems Integration Division

Karl L. Heimburg

KARL L. HEIMBURG
Director, Astronautics Laboratory