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SPACE RADIATION HAZARDS TO PROJECT SKYLAB PHOTOGRAPHIC FILM

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16. ABSTRACT

A mathematical model of the Project Skylab cluster geometry is constructed. A radiation dose rate survey of the model is given for trapped protons, trapped electrons, and galactic cosmic radiation. Tne results of an analytical ATM film vault verification study are presented.

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FOREWORD

This technical report is submitted to the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Alabama, according to the requirements of Contract NAS8-24514. The Contract Officer's Representatives are M. O. Burrell, S&E-SSL-N, and C. A. Best, S&E-ASTN-SDI.

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ABBREVIATIONS

AM	Airlock Module, between OWS and MDA
AS&E	American Science and Engineering Corporation
ATM	Apollo Telescope Mount
CM	Apollo Command Module
CSM	CM plus SM
EVA	Extra-Vehicular Activity
GCR	Galactic Cosmic Radiation
GSFC	Goddard Space Flight Center, NASA
HAO	High Altitude Observatory
HCO	Harvard College Observatory
LM	Lunar Module
MDA	Multiple Docking Adaptor
MSC	Manned Spacecraft Center, NASA
MSFC	Marshall Space Flight Center, NASA
NASA	National Aeronautics and Space Administration
nm	Nautical Miles
NRL	Naval Research Laboratory
OWS	Orbiting Work Shop, a converted SIV B stage
RACK	LM descent stage structure
SAL	Scientific Airlock
SIV B	Third stage of the Saturn V and second stage of the Saturn IB
SM	Apollo Service Module
SSL	Space Sciences Laboratory, MSFC
STS	Structural Transition Section, between MDA and AM
SVWS	Saturn V - Launched (Dry) Work Shop

1.0 INTRODUCTION

A number of experiments in the Project Skylab program depend upon photographic film for data recording. A summary of photography requirements on November 19, 1969 includes 24 ATM cameras and 238 film magazines. Estimated shield weights are approximately 1322 pounds for ATM vaults and two tons for SVWS vaults.

Shielding requirements must be based on film damage parameters, radiation environments, and a detailed analysis of radiation transport within the complex geometry of the space vehicle, illustrated in Figure 1-1. Damage parameters are available for some of the projected films; additional film studies are underway.[7] Radiation environments are taken from the Vette models of the trapped radiation belts[12,13] and measurements of cosmic radiation levels from probes and manned space flights.[11] Radiation transport studies, reported herein, utilize the LSVDC4 computer program system.[8]

A summary of the study and recommendations are given in Section 2. The radiation environment is discussed in Section 3. The current status of the Skylab Cluster geometry model is outlined in Section 4. A dose rate survey of the cluster is presented in Section 5. Studies of Workshop film vault shielding are given in Section 6. A shielding verification analysis of the ATM vault design is shown in Section 7.

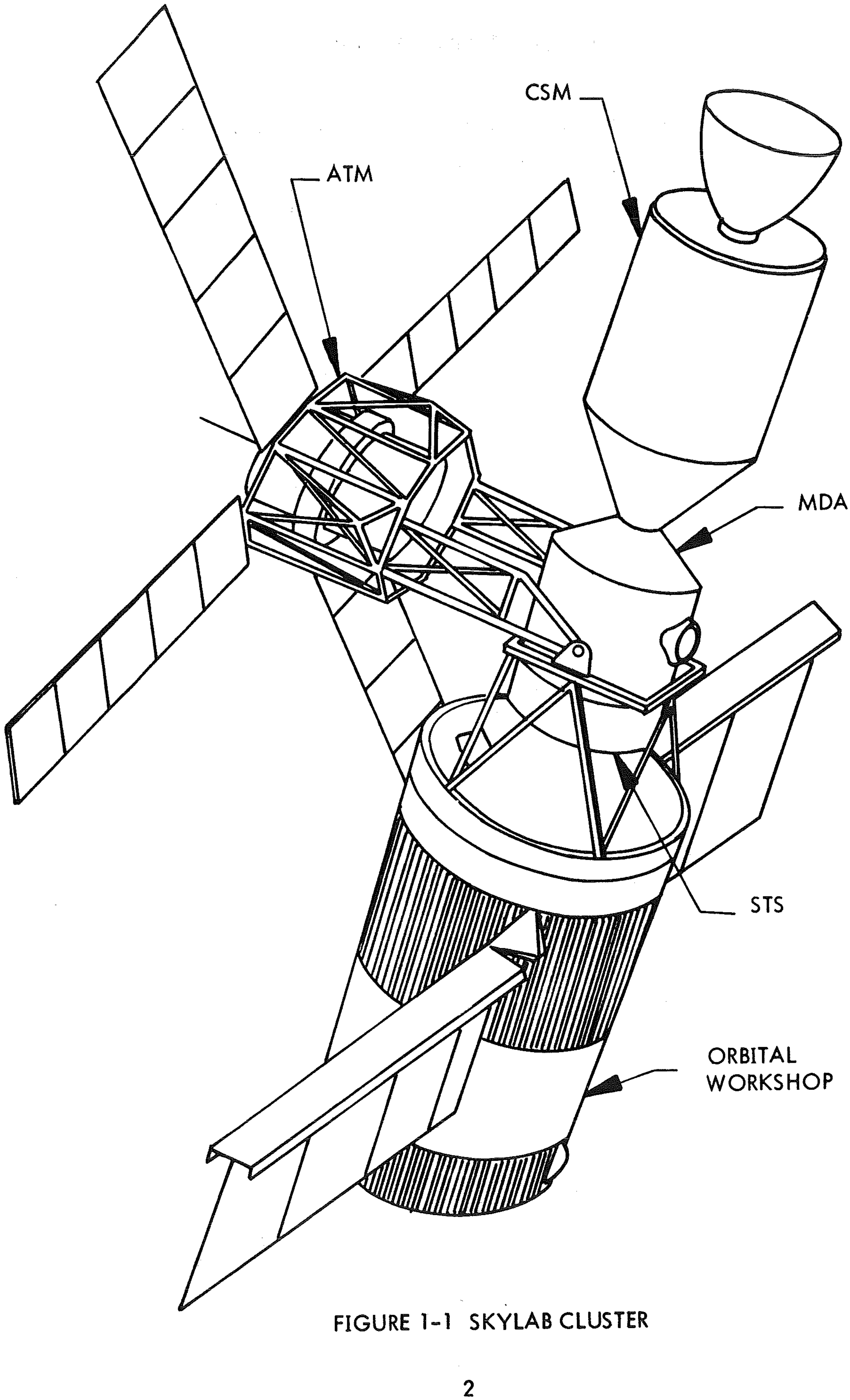


FIGURE 1-1 SKYLAB CLUSTER

2.0 SUMMARY AND RECOMMENDATIONS

The change in the Skylab orbit from 215 nm, 35 degrees to 235 nm, 50 degrees has lowered trapped proton exposure by 20 percent. Trapped electron exposure has increased one to two orders of magnitude. The contribution from galactic cosmic radiation is estimated to be on the order of .01 rad-air per day throughout the Skylab cluster.

The Skylab geometry model has been extensively revised. A detailed model of the Apollo Block II CSM received from the Manned Spacecraft Center[6] has been incorporated into the system. The MDA structure and equipment have been updated and Structural Transition Section equipment included for the first time. New Airlock Module and Workshop equipment and structure models have been constructed. The Lunar Module has been removed and the ATM/RACK moved closer to the MDA.

The addition of detailed equipment and structure to the cluster geometry model has had a significant impact on computed radiation levels. Trapped proton dose rates to bare detectors have decreased by factors of two to seven within the STS, AM, and Workshop. Dose rates within simulated film vaults are lower still. Relocation of near-by equipment may change radiation levels by a factor of two or more. These considerations show the importance of detailed modeling and the necessity of verifying the effects of configuration changes.

A dose rate survey of the Skylab cluster shows that the CM and AM offer the lowest radiation exposures, .04-.07 rad-air per day to film enclosed in a 0.1 inch aluminum magazine. Levels in the MDA, STS, and Workshop are .08 to .19 rad-air per day. Levels at the end of a 13 foot Scientific Air Lock boom are approximately 0.7 rad-air per day.

Several studies were performed to provide data for the design of the Workshop film vaults. These data may be combined with radiation damage parameters and film usage timelines to estimate vault shielding requirements.

Several studies were performed to provide data for the design of ATM camera vaults. The ATM vaults were then designed by the Martin-Marietta Corporation.[7] The design was computationally verified for radiation protection. Most of the cameras met the film fogging tolerance specification of 0.200. A few exceeded tolerance by 2 to 5 percent, well within the uncertainty of the calculation. A further study was made to examine the feasibility of reducing NRL film fogging. It was found that one vault requires 1.25 inches additional aluminum shielding.

Recommendations for future work include:

- verification of SVWS vault designs,
- examination of electron levels including their effect on EVA,
- examination of bremsstrahlung levels,
- examination of damage parameters for GCR, GCR secondaries, and bremsstrahlung,
- incorporation of damage response functions into LSVDC4,
- development of time lines for dose levels,
- updating of geometry model and radiation levels.

3.0 RADIATION ENVIRONMENT

The Skylab orbit parameters have changed significantly in the past year, i.e., from a 215 nm, 35 degree to a 235 nm, 50 degree circular orbit. The changes in altitude and inclination have compensating effects on trapped proton exposure. The net effect is a 20 to 25 percent decrease. However, exposure to trapped electrons and galactic cosmic rays has increased. These changes, together with new data on trapped protons, have led to a reevaluation of the radiation environment effects for the Skylab orbit.

3.1 TRAPPED PROTONS

The Skylab orbit is situated in a region where the gradient of flux versus altitude is very steep. Previous studies have been based on the Vette model environment AP3[12]. In December, 1969, a new model, AP7, was released.[13] The AP7 model utilizes new measurements which bracket the Skylab orbit. A comparison of portions of the AP3 and AP7 environments is shown in Figure 3-1. At 300 nm the average AP7 proton flux is double the old at both 30 and 60 degrees. The shape of the spectrum changed little. However, at 150 nm, the new spectrum is both lower and softer at the same inclinations. According to data furnished by M. O. Burrell,[3] the Skylab orbit is near the cross-over point and the spectra are within 5 percent of each other. The open circles represent proton flux at 215 nm, 35 degrees. It is evident that the orbit change reduced proton exposure by 20 to 25 percent.

3.2 TRAPPED ELECTRONS

The electron exposure used in the present study is taken from the Vette AE2 model environment projected to the end of 1968.[12] The AE2 model was developed for the August 1964 time period. The inner zone electrons were decayed to 1968 using the

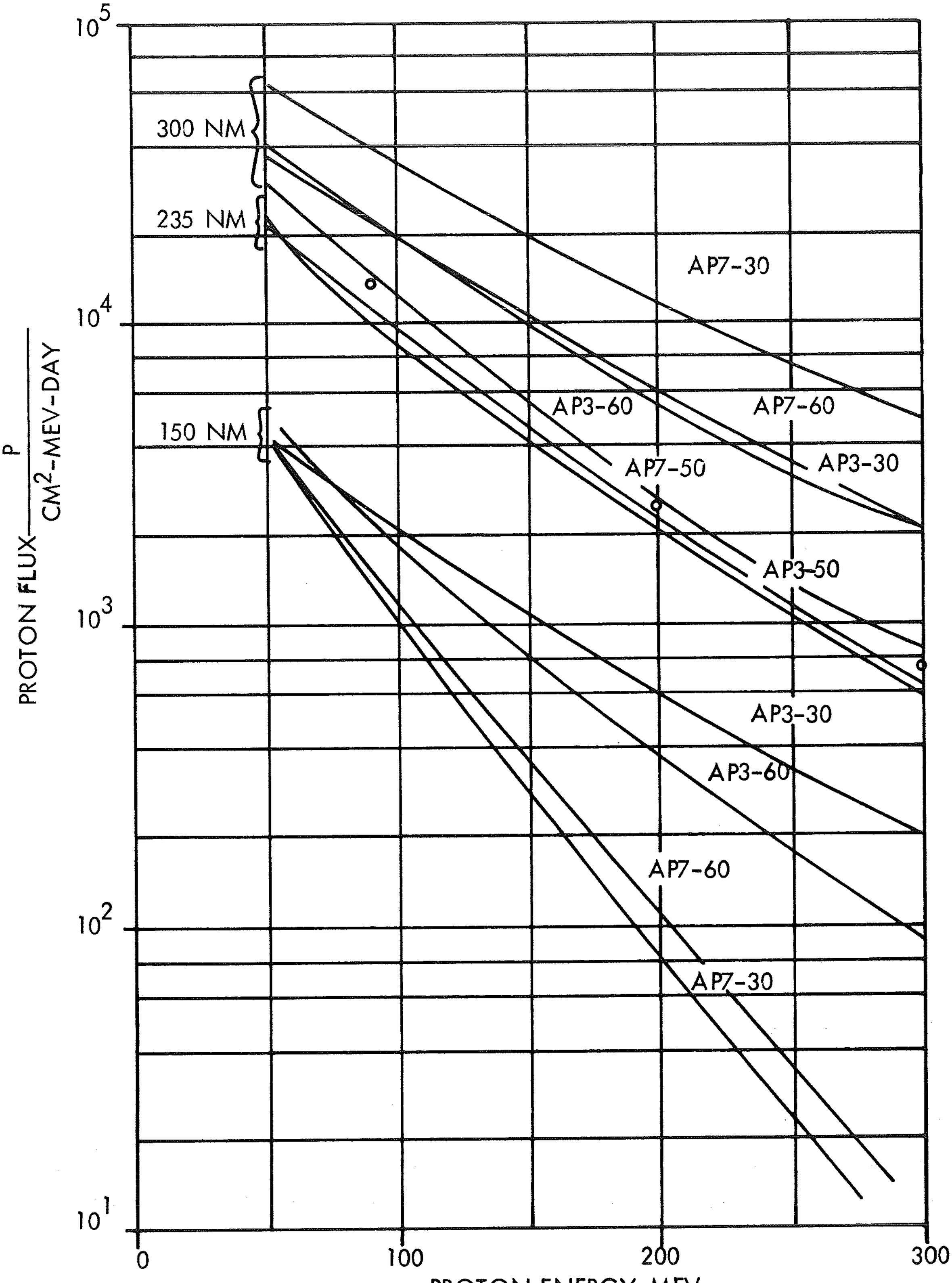


FIGURE 3-1 AP3 AND AP7 PROTON LEVELS

energy dependent decay parameters of Bostrom and Williams.[1] The outer zone electron fluxes were increased to represent estimated solar maximum conditions. These data are used herein for the Skylab cluster in the 1972-1973 time period. An updated electron model environment is scheduled to be released later in 1970.[13]

The trapped electron primaries offer no hazard to photographic film contained in film vaults. Two potential trouble areas are cameras extended on a boom through the Scientific Airlock (SAL) and x-ray telescope film in the ATM where grazing incidence electrons may reach the film. The boom-mounted camera will receive approximately equal exposures from protons and electrons averaging a total of 0.6 rad-air per day. No estimates have been made for the x-ray telescope problem.

A fraction of the electron kinetic energy is transformed into bremsstrahlung. Much of this gamma radiation is generated at low energies where it is very effective in fogging photographic film. For example, Figure 3-2 shows that gammas below 0.1 MeV are 7 to 50 times more effective in fogging film than gammas above 1 MeV.[5] Cobalt-60 gamma radiation (1.25 MeV) is 1.2 to 3 times more effective than trapped protons in fogging film on an equal dose basis. These facts indicate that 5 to 50 percent of the damage to Workshop films while outside the vaults is caused by bremsstrahlung. Dose rate estimates at several locations in the Skylab cluster are given in Section 5.

3.3 GALACTIC COSMIC RADIATION (GCR)

The GCR dose rate in free space beyond the magnetosphere is approximately .017 to .025 rad-air per day during solar minimum falling to perhaps .010 rad-air per day during solar maximum.[11] Within the magnetosphere the dose rate is much lower near the geomagnetic equator and perhaps slightly lower near the poles. Dose rate should generally increase with altitude outside the atmosphere.

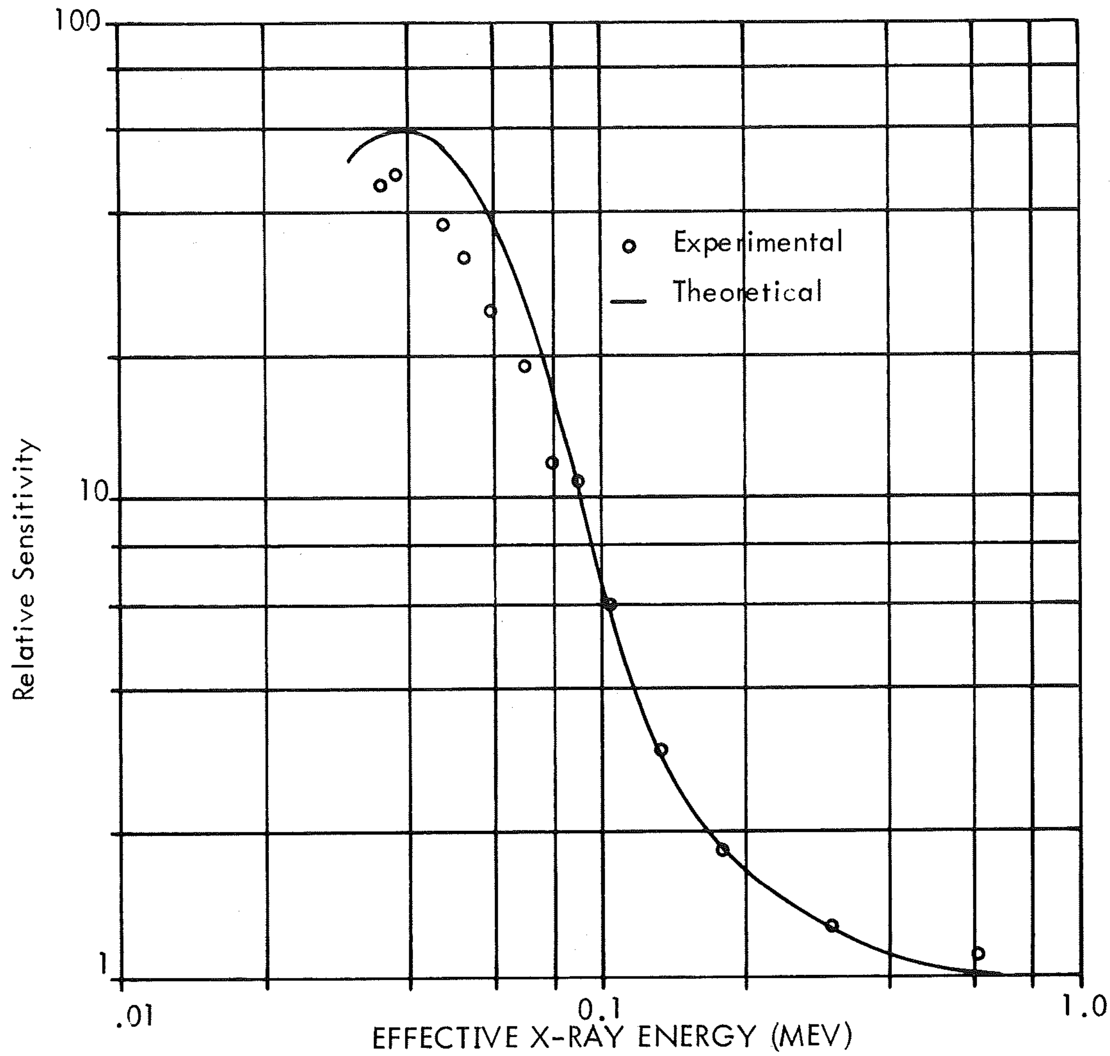


FIGURE 3-2 RELATIVE SENSITIVITY
OF ILFORD LINE FILM

One way to estimate Skylab exposure to GCR is to interpolate between the free-field measurements of Pioneer IV and V, given above, and measurements made during manned space flights. Vostok 3, 4, 5 and 6 encountered .016-.017 rad per day.[11] Most of this dose rate is attributable to GCR because the orbital inclination was 65 degrees and the orbit was too low to penetrate much of the trapped radiation belts (apogee: 120 to 137 nm; perigee: 93 to 99 nm). The Gemini IV and VI flights were at higher altitudes (apogee: 152 to 177 nm; perigee: 80 to 87 nm) but the inclination was only 30 degrees. The GCR dose rates for these flights were .0038 and .0048 rad per day.[11] These dose rates would change little behind several inches of aluminum shielding.

The dose rates given above suggest that the Skylab GCR burden may be on the order of .010 rad-air per day. Part of this exposure will be due to heavy ions which may be less damaging to film than protons on a dose basis. On one of the Vostok flights, .002 of the .017 rads per day was due to heavy ions with a quality factor of 7. The total biological dose was therefore .030 rem per day. Available data indicate the opposite effect in film fogging, that is, less sensitivity to high LET particles on an equal dose basis.[2, 10]

4.0 SKYLAB CLUSTER GEOMETRY MODEL

The geometry model of the Skylab Cluster has been extended and revised since earlier studies were reported. Some of the changes are due to availability of new data as in the case of the Apollo CSM and the ATM cameras. Some changes are due to availability of new data and configuration changes as in the case of the MDA structure and STS equipment. Still other changes are due to configuration changes only, such as the deletion of the Lunar Module.

The geometry model is now relatively complete. Most structures and major components are simulated in reasonable detail, though status dates vary. Each Lockheed-generated volume element is identified with a descriptor that simplifies configuration rearrangements. The model of each cluster module is discussed briefly.

4.1 APOLLO COMMAND AND SERVICE MODULE (CSM)

The Apollo Block II CSM model is adapted from data furnished by the Manned Spacecraft Center, NASA, Houston, Texas.[6] The data were obtained in mid-1969 and are believed to represent a 1968 status. A total of 966 volume elements are contained in the MSC model, 400 solid and 566 void.

The MSC model offers slightly less shielding than the simple model used previously. Comparisons run with the same proton spectrum show that, for a point six inches in front of the heat shield, the MSC model has a 15 percent greater dose rate than the old model.

4.2 MULTIPLE DOCKING ADAPTER (MDA)

The MDA structure has been strengthened to provide additional load-bearing capability. The model changes include skin thickening in the lower cylinder and part of the radial docking port cylinder, as well as addition of rings and stringers. One radial and one axial docking port remain. Approximately 1000 pounds of earth resource survey equipment have been added. The ATM camera models and film vaults are updated. The MDA equipment package configuration represents its January 21, 1970 status.

4.3 APOLLO TELESCOPE MOUNT (ATM)

The ATM geometry model is basically unchanged from the configuration modeled in 1969. Several camera models have been updated. The LM ascent stage has been removed from the cluster and the ATM/RACK moved closer to the MDA. The deployment truss assembly has not been incorporated into the model.

4.4 STRUCTURAL TRANSITION SECTION (STS)

A detailed geometry model of the STS structure was developed in early 1969. The present effort added thermal insulation, acoustic dampener, and inboard equipment according to an inboard profile dated October 15, 1969, and a mass properties status report dated November 3, 1969. The dose rate at two points in the STS is half the previous value as a result of additions to this module and neighboring modules.

4.5 AIRLOCK MODULE (AM)

The AM structure and equipment is completely remodeled. Approximately 80 percent of the actual weight is represented. The structure status date is mid-1969. The equipment is placed according to inboard profile drawings dated October 15, 1969. Weights are taken from a mass properties status report dated November 3, 1969.

The AM contains storage tanks for oxygen and nitrogen. These gases are assigned unique material numbers to permit a single computer run to compute upper and lower bounds on dose rate over mission duration. This difference is only 3 to 6 percent at two locations in the AM.

The greater detail available in the new model provides more realistic dose estimates in this module. As a result of these changes, dose rate levels have fallen by factors of 4 and 7 at the two locations checked. The AM and CSM provide the best shielded regions in the Skylab cluster.

4.6 SATURN V WORKSHOP (SVWS)

The SVWS structure is completely remodeled and inboard equipment added for the first time. Structural drawings used for the model bear dates ranging from 1963 to 1968. Equipment arrangements and weights are taken from the December, 1969 mass properties status report. Two Scientific Air Locks are included. The waffle-like strengthening grid on the SVWS skin is rotated 45 degrees to simplify the model. The square radiator at the base of the SVWS is omitted due to lack of data. Unique material numbers are assigned to consumables including food, water, and TACS fuel so that their effect upon dose rate may be seen.

The new model shows lower dose rates than the old. The improvement is 36 percent at one place in the forward dome and ranges from a factor of two to four at five other locations.

5.0 SKYLAB DOSE RATE SURVEY

This section reports the results of a dose rate survey at 14 locations in the updated computational model. An earlier survey published in a previous report[9] applies to a different orbit and an incomplete model. These 14 locations represent potential storage positions for photographic film.

The radiation environment considered is taken from the Vette AP7 proton model of the trapped radiation belts. The orbit is circular at 235 nm with a 50 degree inclination. The dose rates given do not include contributions from cosmic rays, trapped electrons, nor solar flares. Cosmic rays are expected to contribute on the order of .01 rad per day regardless of location and shielding. Trapped electron dose rate should be a negligible fraction of the total dose rate inside the film vaults. Outside the vaults, electron dose rate may rise to as high as 30 percent of the total for SVWS films, less for ATM films. Bremsstrahlung generated by electrons may increase the film damage appreciably in some locations. No estimates are made for solar flare radiations.

The complete geometry model is used for location 1 in the CSM. For other locations, a simple CSM model is used in place of the detailed model in order to reduce computer time. The consumables in the AM and SVWS (oxygen, nitrogen, food, water, and TACS fuel) are flagged in a special way so that the effect of removing them may be seen. The effect of CSM consumables on dose rate is not studied.

The 14 detector locations are indicated in Figure 5-1. Their coordinates in the Cartesian system shown are given in Table 5-1. The second detector is located in the center of ATM Film Vault 1. For this detector only, ATM Film Vault 1 is moved five feet toward the STS.

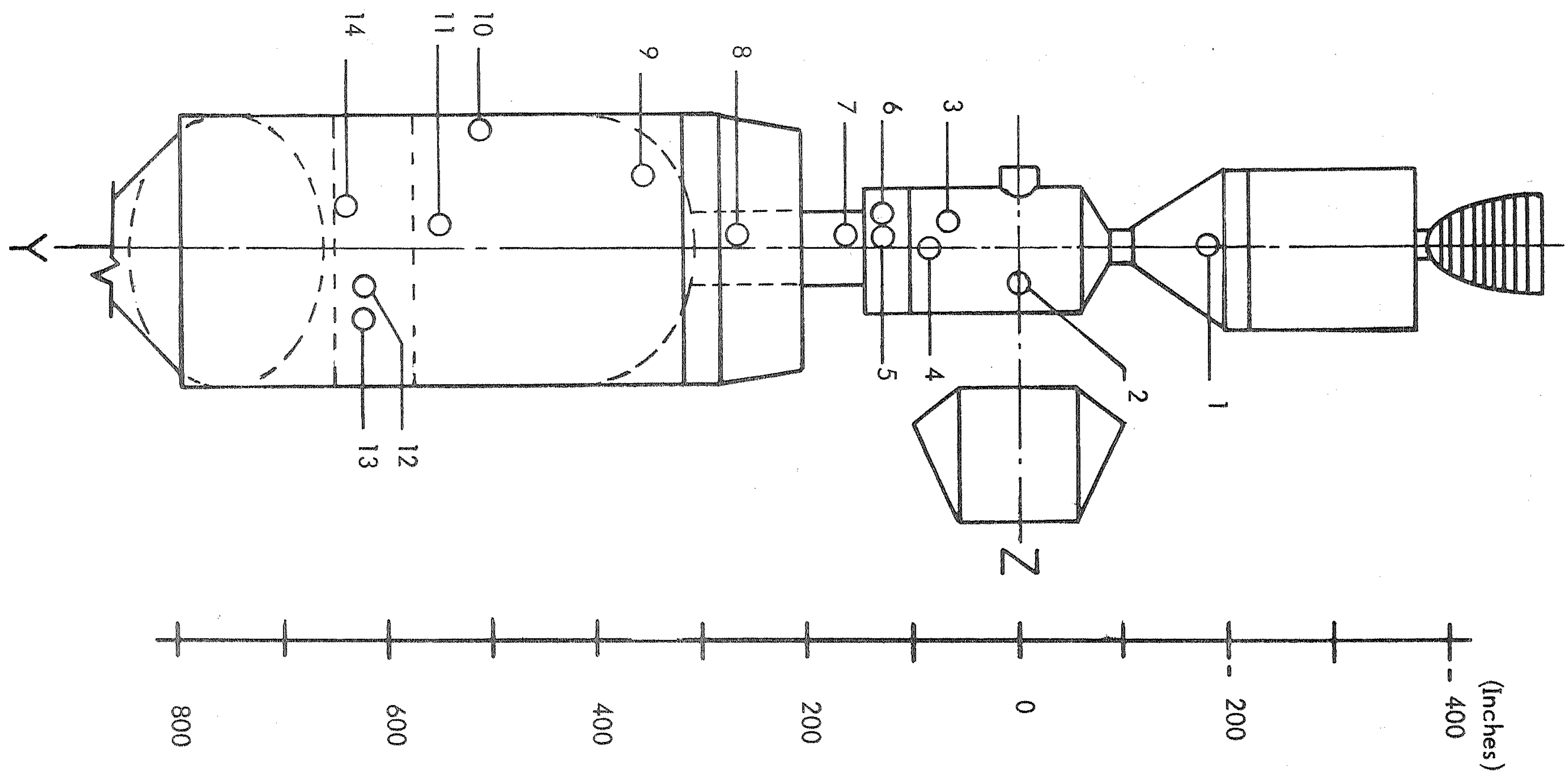


FIGURE 5-1 SKYLAB CONFIGURATION

TABLE 5-1 DOSE POINT LOCATIONS (INCHES)

Detector	Location	X	Y	Z	Radius
1	CM	0.0	-190.0	0.0	0.0
2	MDA	0.0	0.0	27.5	27.5
3	MDA	-20.5	71.0	-20.5	28.99
4	MDA	28.0	95.3	0.0	28.0
5	STS	27.21	123.03	-36.5	45.53
6	STS	-32.8	123.03	-36.4	49.0
7	AM	-11.7	163.03	-12.28	16.96
8	AM	-16.81	233.03	-10.11	19.62
9	OWS	0.0	364.24	-40.0	40.0
10	OWS	-45.0	519.74	-111.0	119.77
11	OWS	-42.26	570.92	-7.33	42.89
12	OWS	-66.5	628.74	2.9	66.56
13	OWS	-25.74	628.74	73.5	77.88
14	OWS	100.78	631.26	-54.22	114.44

The results of these computations are shown in Tables 5-2 and 5-3 for AM and SVWS consumables included and omitted respectively. The rows labeled "Bare" give the dose rates with no equipment at the detector positions. The rows labeled "Film" give dose rates to a point 0.1 inches within a 3 inch diameter roll of 16 mm film. The film is oriented so that the detector is in the most exposed position. Two similar film spools bracket the test film at a separation distance of 0.5 inches. The last four rows show the effect of placing a simple aluminum box with the indicated wall thickness around the films. The box is a cube with an internal dimension of one foot on a side.

Dose rates appear to be lowest in the Command Module and the Airlock Module. The AM, in particular, offers an attractive storage site in order to minimize shield weight. The MDA and STS are about equal to each other in shielding effectiveness. The SVWS radiation environment varies by more than a factor of two because of equipment placement. It is interesting to note that recently modeled equipment lowers dose rates in the STS by a factor of two, in the SVWS by factors of two to four, and in the AM by factors of four and seven.

With Consumable Items Included

	1	2	3	4	5	6	7
Bare	.058803	.13112	.15095	.15058	.13839	.13004	.060779
Film	.046707	.092153	.11152	.11432	.11243	.10313	.047218
0.1" Al	.042798	.082664	.097162	.099324	.096530	.088362	.043334
0.5" Al	.031684	.056909	.064605	.065388	.061943	.056792	.032349
1.0" Al	.023151	.040401	.043958	.044392	.041762	.038291	.023824
2.0" Al	.013737	.022787	.024221	.024394	.022831	.020987	.014288

	8	9	10	11	12	13	14
Bare	.046952	.21818	.18890	.12123	.10419	.12468	.14564
Film	.037891	.15122	.14297	.086039	.076418	.096218	.11397
0.1" Al	.034851	.12824	.12359	.076197	.069458	.085279	.10034
0.5" Al	.026119	.080341	.080234	.052522	.050140	.058642	.068018
1.0" Al	.019329	.053354	.053654	.036811	.035885	.040697	.046836
2.0" Al	.011681	.028670	.029048	.020592	.020748	.022871	.026057

TABLE 5-2 DETECTOR POINTS WITH CORRESPONDING DOSE RATES IN RAD-AIR/DAY

With Consumable Items Set to Zero

	1	2	3	4	5	6	7
Bare		.13119	.15111	.15110	.13936	.13090	.062368
Film		.092213	.11166	.11477	.11322	.10388	.048641
0.1" Al		.082722	.097300	.099749	.097288	.089078	.044675
0.5" Al		.057961	.064728	.065733	.062572	.057389	.033422
1.0" Al		.040448	.044065	.044663	.042264	.038775	.024656
2.0" Al		.022825	.024305	.024568	.023171	.021324	.014817

	8	9	10	11	12	13	14
Bare	.050396	.23846	.20660	.13563	.12226	.14284	.15298
Film	.040648	.16536	.15212	.097732	.090473	.11138	.11836
0.1" Al	.037475	.14048	.13195	.086807	.082307	.098975	.10438
0.5" Al	.028287	.088224	.086299	.060001	.059481	.068341	.070972
1.0" Al	.021059	.058488	.057982	.041993	.042517	.047515	.048949
2.0" Al	.012817	.031315	.031483	.023746	.024458	.026642	.027252

TABLE 5-3 DETECTOR POINTS WITH CORRESPONDING DOSE RATES IN RAD-AIR/DAY

6.0 DOSE RATES TO SVWS PHOTOGRAPHIC FILM

A large quantity of photographic film of diverse types will be carried aboard the Skylab Cluster to support experiments in the SVWS and other locations. The quantities, types, and time lines planned for these films are changing frequently. Further, radiation damage criteria have yet to be established for many of these films. For the above reasons, it is not possible to do a detailed analysis of radiation damage to SVWS films during the present study. Instead, typical dose rate levels are established within a simple vault and in several operating locations in the cluster. The vault calculations are detailed in Section 6.1; those in the operating locations are given in 6.2.

6.1 DOSE RATES INSIDE SVWS VAULTS

The simple SVWS film vault configuration chosen for the present study is shown in Figure 6-1. The internal dimensions are 10.5" x 10.5" x 11". The vault contains two large film magazines and 28 small magazines. The large magazines have walls of 0.1" aluminum and are 5" x 5" x 7". The film is on a 70 mm reel with a 3" diameter. The small magazines have walls of 0.06" aluminum and are 5" x 5" x 0.88". The 16 mm film reel has a 4.5" diameter.

The vault is placed in the forward compartment of the SVWS near the wall at Position IV. This area is on the Lockheed + X axis and the centroid is at Y = 555.633 inches (see Figure 5-1). Two food containers previously occupying this area have been removed from the model. A range of aluminum wall thicknesses are treated ranging from 0.1" to 10".

Several approximations are present in the calculation. Due to lack of data, two food containers and at least three other SVWS film vaults are missing from the geometry model. These deletions are expected to cause little error because peak load considerations will probably not allow them to be located near the vault in question. Secondly, the results are computed with all consumables in place (i.e. near mission

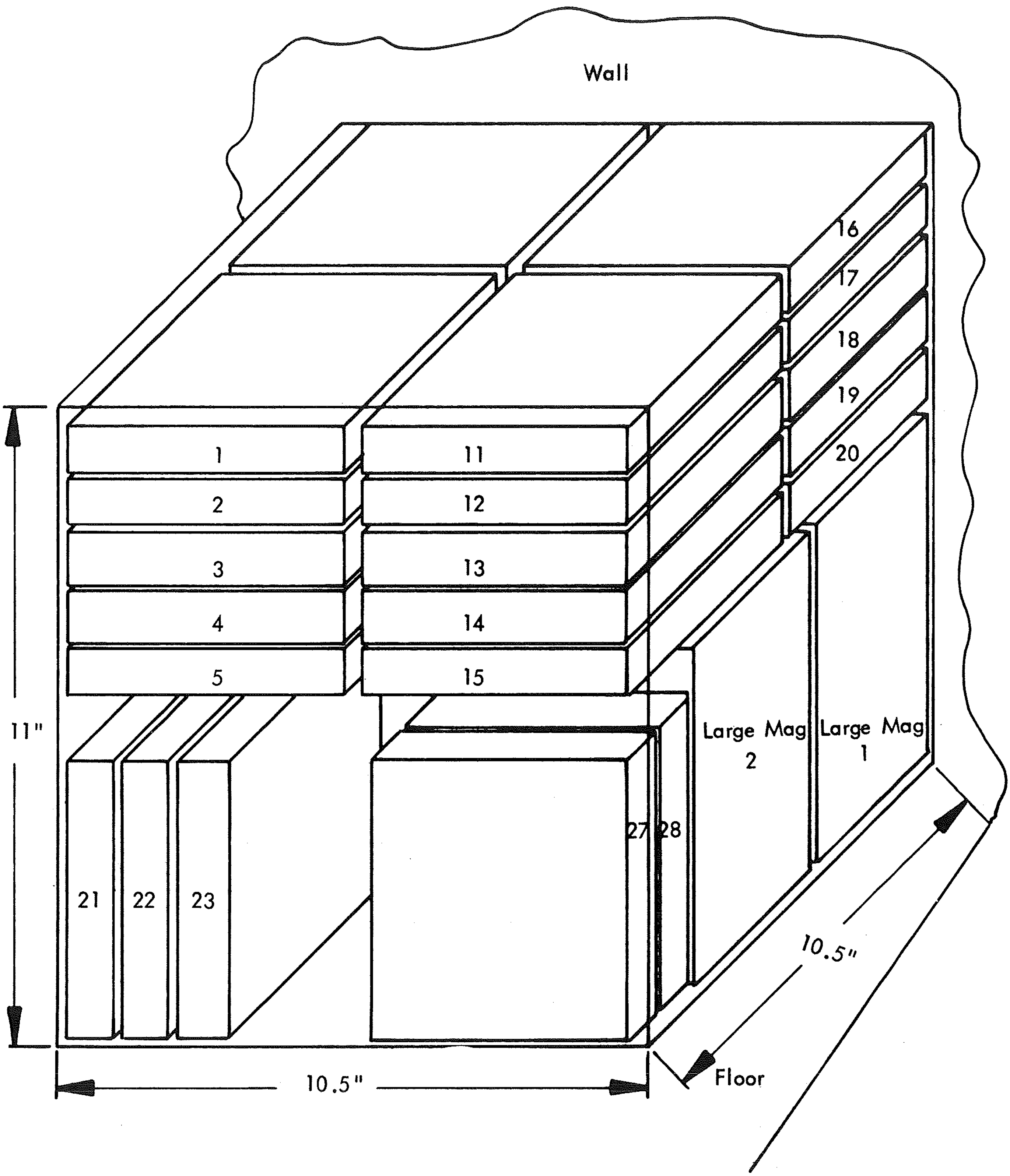


FIGURE 6-1 SVWS VAULT MODEL

start). The trapped proton dose rates may rise by 5 to 20 percent when consumables are depleted, as is seen in Section 5. Thirdly, the calculations do not include contributions from cosmic rays and electrons - see Section 3.

Dose rates 0.1" inside the film in the most exposed position are shown for five film magazines. Note that the 0.1" aluminum vault results are comparable to the results for detectors 11, 12, 13, and 14 of Table 5-2, and are significantly lower than levels for detectors 9 and 10. The 2" vault results are generally lower than those of Table 5-2 due to the presence of other films and the proximity of detectors to the wall in the present case.

The effect of using a smaller vault was examined by removing both large magazines and small magazines 21-28 of Figure 6-1, then shrinking the vault dimensions to fit the remaining magazines. The resulting dose rates are shown in Table 6-2.

It appears that 3 to 4 inches of aluminum will reduce the trapped proton dose rate to the estimated cosmic ray background. Thicker shields will continue to decrease radiation levels due to trapped protons as shown in Tables 6-1 and 6-2, but the GCR component diminishes more slowly.

6.2 DOSE RATE TO FILM OUTSIDE THE SVWS VAULT

The total radiation damage to SVWS films depends on dose received during use outside the vault as well as dose received during storage. Even with detailed timelines of film and equipment, it would be difficult to compute accurate doses for film during usage. This section provides simple estimates of out-of-vault dose rates to photographic film.

Typical average daily doses within the Skylab Cluster may be taken from Table 5-2. These

TABLE 6-1 DOSE RATE IN OWS FILM VAULT

Vault Wall Thickness (in inches Al)	Dose Rate In Air-Rads Per Day Detector 1	Detector 2	Detector 3	Detector 4	Detector 5
0.1	0.0945	0.0772	0.0937	0.0690	0.0965
0.25	0.0774	0.0651	0.0759	0.0579	0.0782
0.5	0.0590	0.0512	0.0570	0.0453	0.0589
0.75	0.0469	0.0416	0.0448	0.0367	0.0464
1.0	0.0382	0.0345	0.0363	0.0305	0.0376
2.0	0.0204	0.0191	0.193	0.0172	0.0199
3.0	0.0121	0.0116	0.0114	0.0105	0.0118
5.0	0.00559	0.00555	0.00530	0.00510	0.00542
7.0	0.00299	0.00302	0.00283	0.00281	0.00288
10.0	0.00145	0.00147	0.00137	0.00138	0.00139

Detector	Location
1	Small Magazine 24
2	Large Magazine 1
3	Small Magazine 16
4	Small Magazine 3
5	Small Magazine 6

TABLE 6-2 DOSE RATE IN SMALL OWS FILM VAULT

Vault Wall Thickness (in inches Al)	Dose Rates in Air-Rads/Day	
	Detector 3	Detector 4
0.1	0.0948	0.0718
0.25	0.0769	0.0605
0.5	0.0579	0.0475
0.75	0.0456	0.0386
1.0	0.0370	0.0320
2.0	0.0188	0.0159
3.0	0.0110	0.00950
5.0	0.00519	0.00487
7.0	0.00273	0.00262
10.0	0.00144	0.00147

Detector	Location
3	Small Magazine 16
4	Small Magazine 3

values are .03 to .04 rads per day in the CM and AM, and .07 to .14 rads per day in other modules. A camera mounted at the Scientific Air Lock might see .03 to .13 rads per day. The dose point locations are usually in moderately exposed areas, i.e., not adjacent to heavy equipment.

One camera will be extended on a boom through the SAL during portions of the mission. This situation was simulated by placing a small magazine (0.06" Al wall) thirteen feet out from the skin of the SVWS in front of the sun-side SAL. The proton dose rate 0.1 inches inside the film is 0.29 rad-air per day. The electron damage to this relatively exposed film is significant, approximately 0.3 rads-tissue per day. The air dose rate would be 12 to 13 percent lower. The electron-produced bremsstrahlung dose rate is about .005 to .01 rads per day. This low bremsstrahlung dose rate may be equivalent to 0.1 proton rads per day or more because of film's great sensitivity to low energy gammas. An example of this sensitivity is shown in Figure 3-2[5].

The boom-mounted camera exposure to trapped protons may be reduced by restricting experiments to the 12 hours per day when the orbit does not penetrate the South Atlantic magnetic analaly. Exposure to significant levels of trapped electrons occurs during approximately 20 percent of each orbit, leaving only half-hour radiation-free periods between traversals of the "horns" of the outer belt.

The magnitude of the electron and bremsstrahlung dose rate levels should be confirmed with the new electron model environments now in preparation by Dr. J. I. Vette of Goddard Space Flight Center.[13]

The dose rates outside the SVWS vault are summarized in Table 6-3.

TABLE 6-3 DOSE RATE TO FILM MAGAZINE OUTSIDE VAULT - RAD-AIR/DAY

	CM AM	OWS MDA	Inside SAL	Boom SAL
Protons	.03 - .04	.07 - .14	.08 - .13	.29
Electrons	.001	.01	.01	.3
Bremsstrahlung*	.02	.03	.05	.1
Cosmic Rays	.01	.01	.01	.01
Total	.04 - .07	.08 - .18	.09 - .19	.70

*Equivalent proton dose rate

7.0 ATM FILM VAULT VERIFICATION ANALYSES

Estimates of radiation dose and radiation-induced fogging are made for each of the 24 ATM cameras carried aboard the Skylab cluster. The purpose of this effort is to provide computational verification of vault shielding characteristics. Estimates of damage to the first load of six cameras, which are launched in place on the ATM, are included for the sake of completeness.

The trapped proton radiation dose to the film is computed with the camera in place on the ATM, in an MDA storage vault, and in the CM. The dose rates in each camera are then combined according to the time line shown in Table 7.1. Note that the effects of camera usage are taken into account. This timeline assumes that the six film-using ATM telescopes expose the first load during the 28 days of mission 1/2. A 72 day storage period ensues with loads 2, 3, and 4 in the vaults. Load 2 is exposed during the first 28 days of mission 3, then stored in the CM awaiting return the next 28 days. Load 3 is exposed the last 28 days of mission 3. The fourth load of six cameras stays in the vaults during the next 40 day storage period and the first 28 days of mission 4. The last load is returned to earth 252 days after the initial launch.

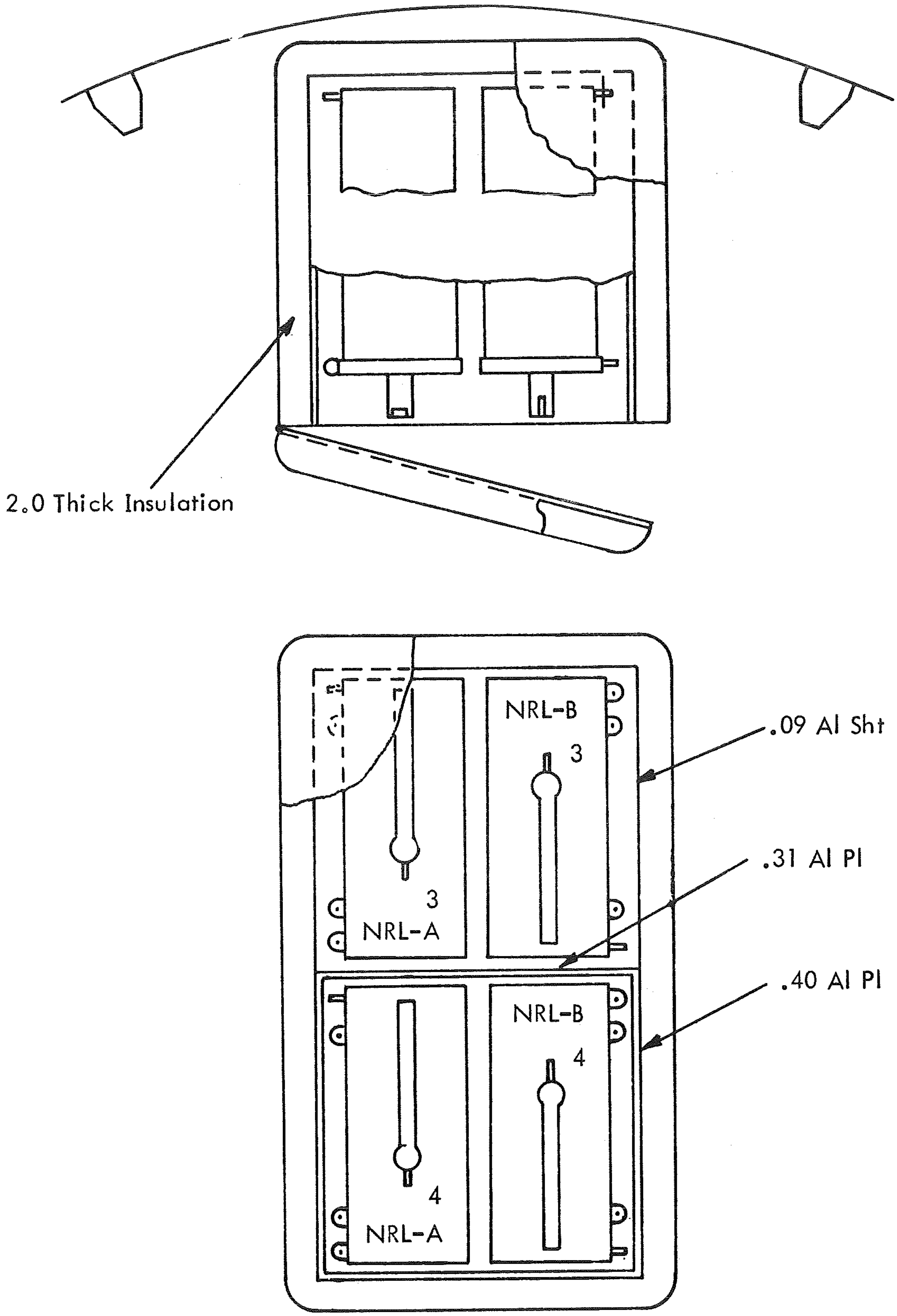
The arrangement of cameras in the four vaults is shown in Figures 7-1 through 7-4. One detector position is chosen for each film in what is thought to be the most exposed location. The Arabic numeral on each camera indicates load number.

The arrangement of cameras in the CM is not known at present. The assumed arrangement is shown in Figure 7-5.

The arrangement of telescopes on the ATM is indicated in Figure 7-6. Cameras are placed in the appropriate locations. The two NRL cameras are in relatively exposed

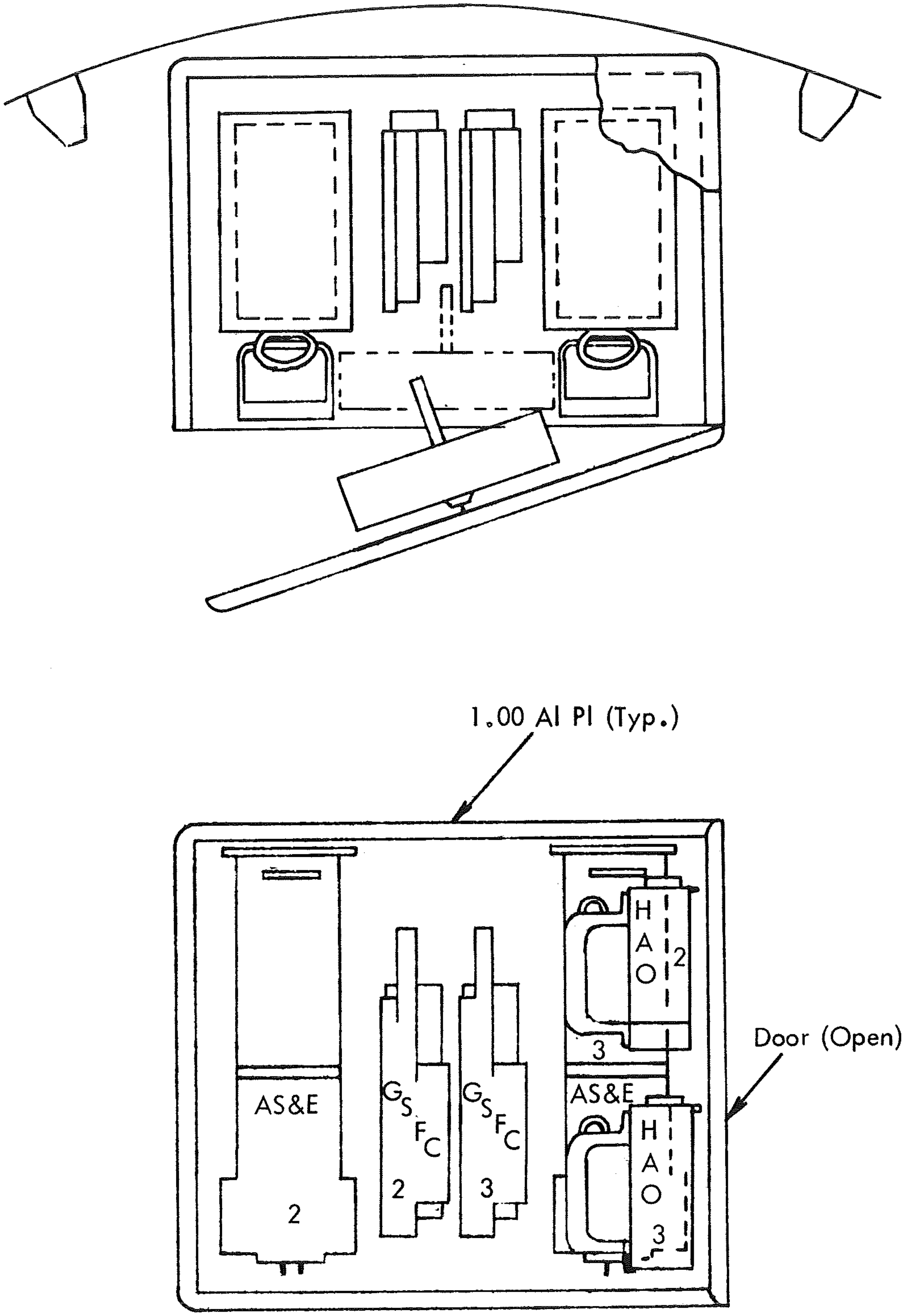
TABLE 7-1 ATM CAMERA LOCATION TIME LINE - DAYS

Camera Load	ATM	CM	Vault Storage		
			Cameras 2,3,4 Present	Cameras 3,4 Present	Camera 4 Present
1	28	--	--	--	--
2	28	28	100	--	--
3	28	--	100	28	--
4	28	--	100	28	96



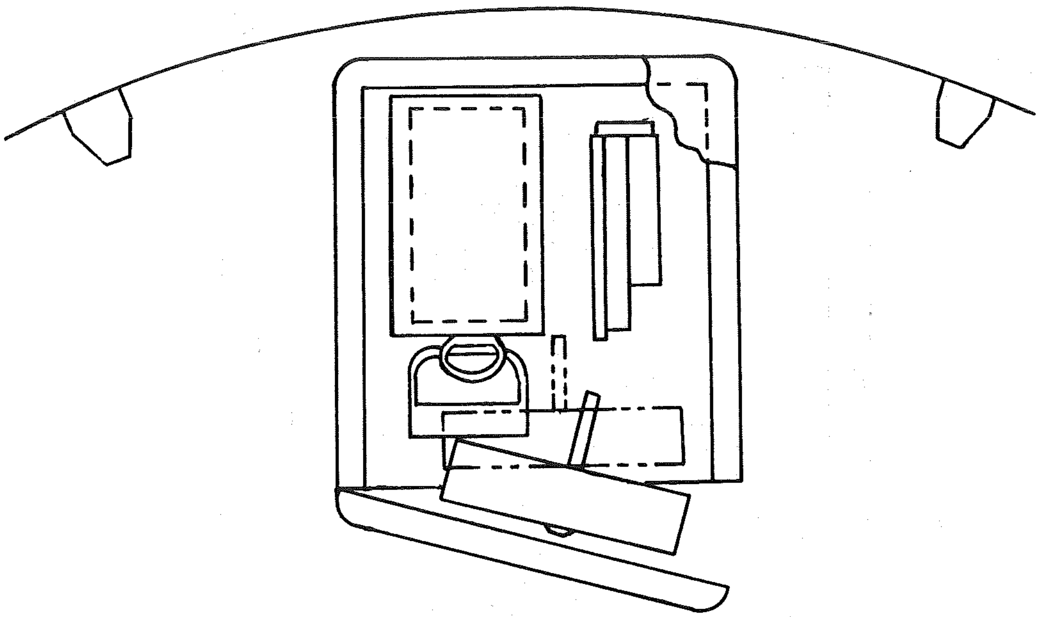
Outside Dimensions: 24.5 W x 26.8 D x 43.0 H

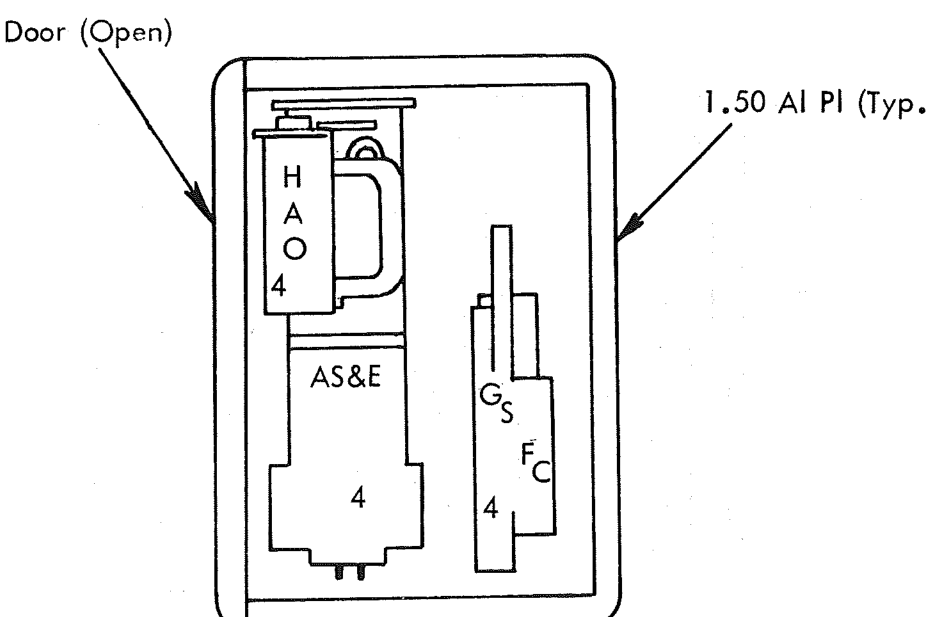
FIGURE 7-1 FILM VAULT NO. 1



Outside Dimension: 32W x 23D x 29H

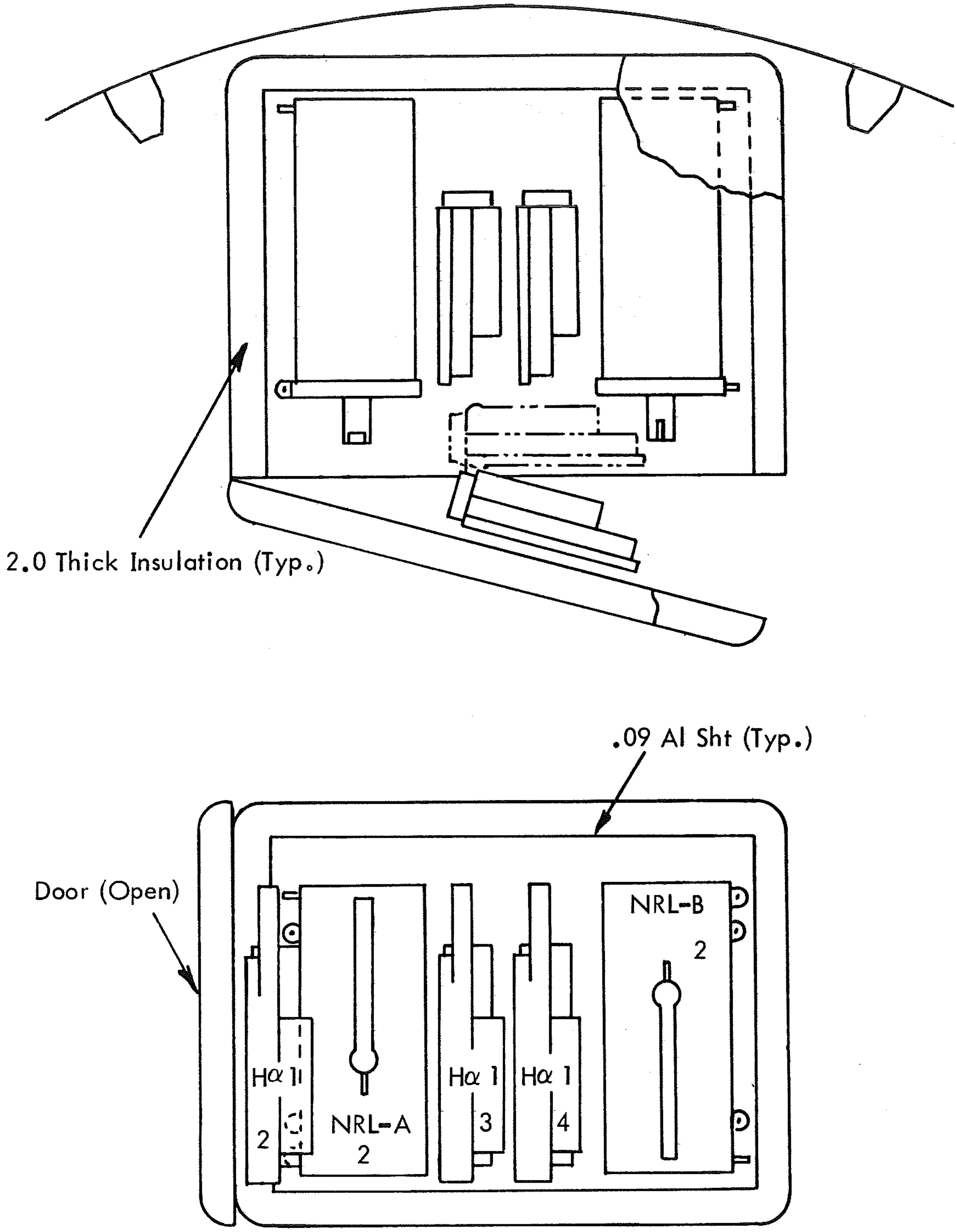
FIGURE 7-2 FILM VAULT NO. 2





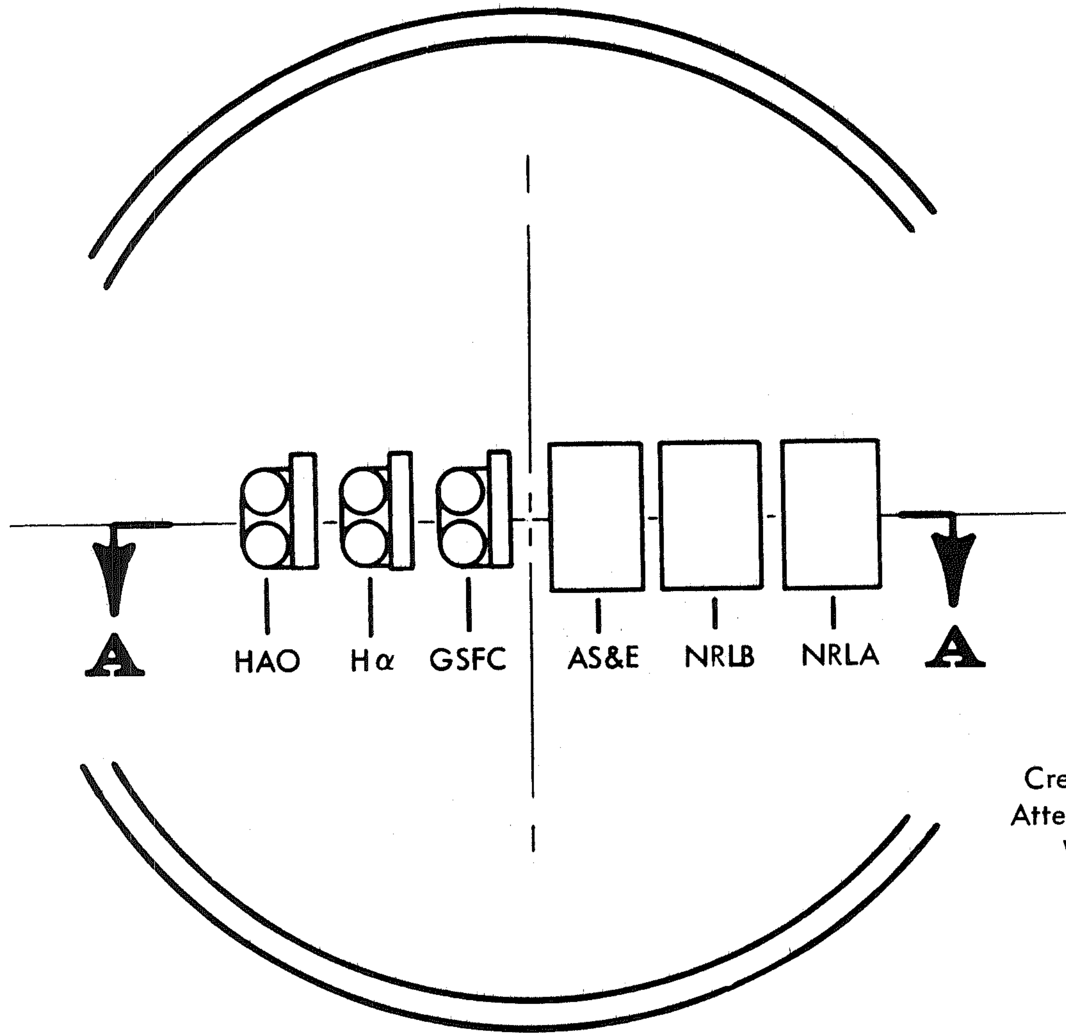
Outside Dimension: 21W x 24D x 30H

FIGURE 7-3 FILM VAULT NO. 3

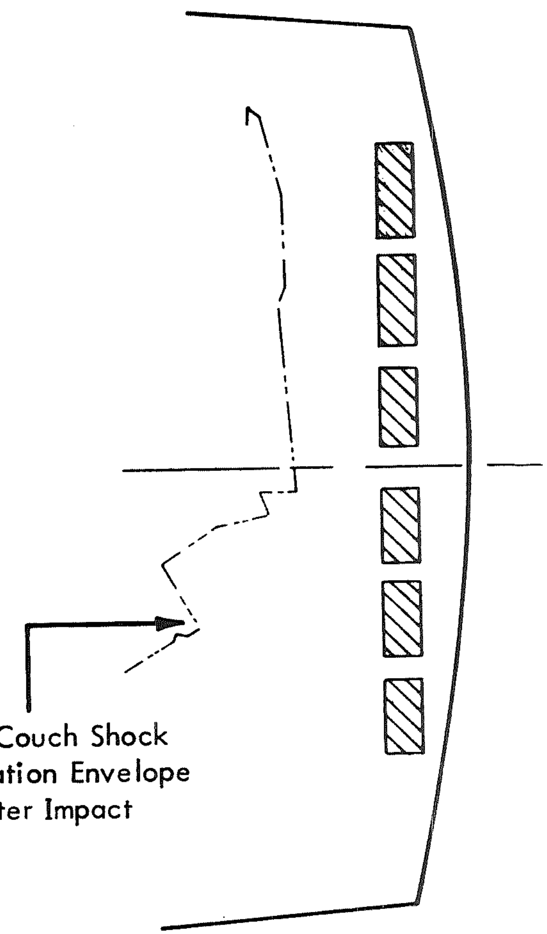


Outside Dimensions: 33.5W x 28.0D x 26.0H

FIGURE 7-4 FILM VAULT NO. 4



AFT BULKHEAD LOOKING AFT



A-A

FIGURE 7-5 CM CAMERA STOWAGE

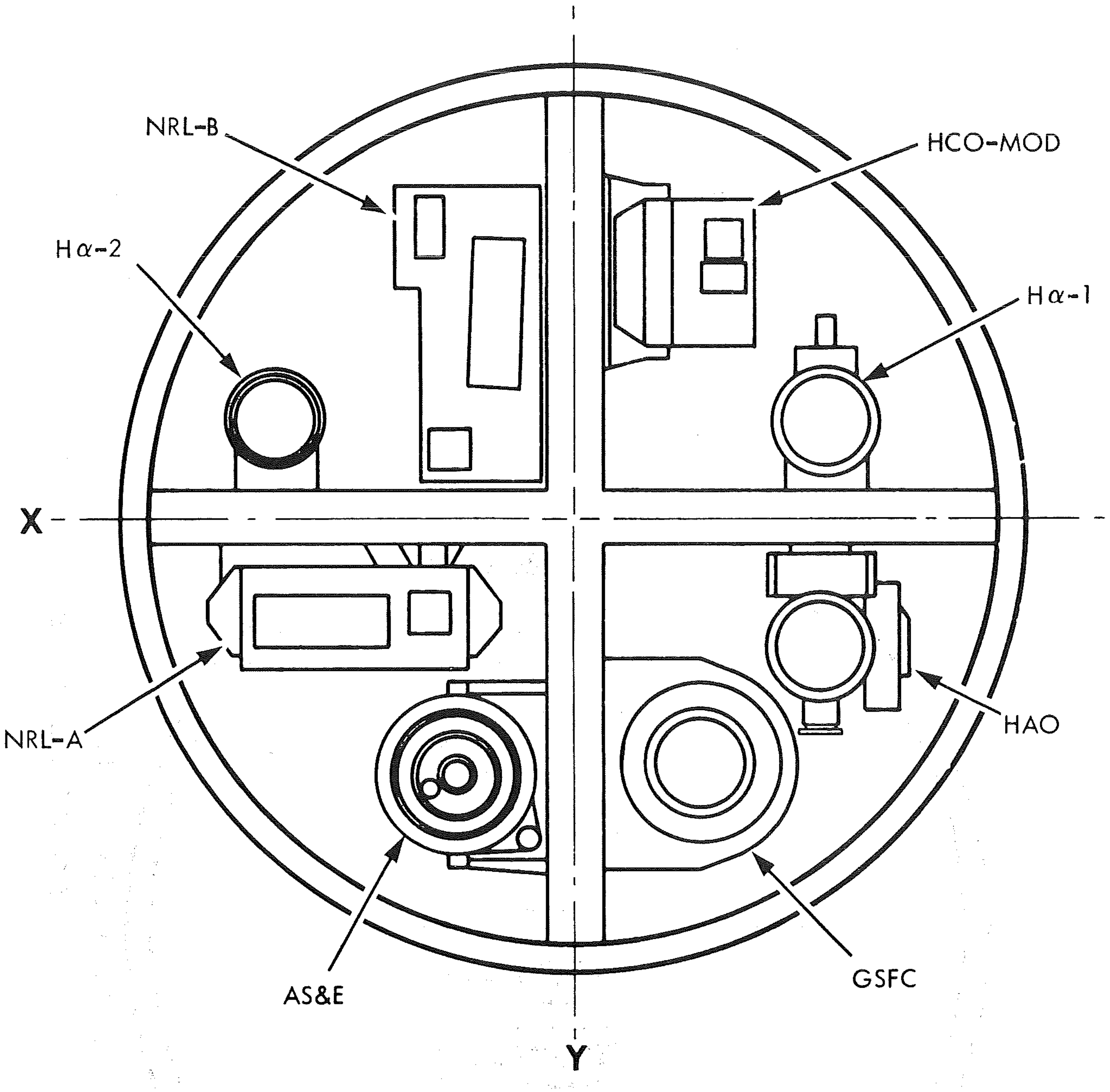


FIGURE 7-6 ATM CANISTER (SUN END)

regions near the sun end of the ATM. Two detectors are placed in each camera, one near the sun end and one next to the telescope. Each slide will occupy both positions during the exposure sequence. Dose rate is a factor of two higher at the sun end.

The NRL cameras use SWR film. The GSFC, HAO, and AS&E cameras use PAN-X film. The H-ALPHA I cameras have been changed from SO-375 to SO-392 film. Data is available on film fogging due to protons on SWR, PAN-X, and SO-375.[2,10] Estimates of proton-induced fogging to SO-392 are obtained by multiplying SO-375 values by the ratio of sensitivities to Co-60 gamma radiation- a factor of 2.3.[4]

The radiation dose and fogging to the GSFC, HAO, AS&E, and H-ALPHA 1 films are given in Table 7-2. The columns labeled "Proton Dose" and "No GCR" are due to trapped protons only. The column labeled "With GCR" includes an allowance for galactic cosmic radiation on the basis of .01 rad-air per day. No contribution from electrons and bremsstrahlung is included.

Table 7-2 shows that the first loads for these four cameras should be fogged to 10 or 20 percent of the nominal maximum tolerance of 0.2. The second and third loads receive half to three-quarters of maximum tolerance. The fourth load receives near maximum tolerance or slightly more.

The estimates for radiation dose and darkening of the NRL cameras are given in Tables 7-3 through 7-6. Tables 7-3 and 7-4 apply to trapped protons only; 7-5 and 7-6 include GCR fogging.

Tables 7-3 and 7-5, labeled "Vulnerable ATM Location", use the higher dose rate exposures from the ATM calculations. Tables 7-4 and 7-6, labeled "Protected ATM Location," use the lower ATM dose rate exposures.

The columns headed "Nominal Vault" apply to the NRL cameras in ATM vaults 1 and 4 shown in Figures 7-1 and 7-4. These nominal vaults show a maximum fogging density of 0.115, well below the baseline tolerance limit of 0.2. Because the Principal Investigator has requested a lowering of the tolerance limit, additional data are given in succeeding columns. The heading "+0.41" Al" means that .41 inches aluminum has been added to the walls of vaults 1 and 4.

The NRL experiment Principal Investigator has recently reviewed the results of radiation film testing.[7] This review established a maximum tolerance of 8 rad-air cobalt-60 gamma radiation. It is difficult to relate this dose to an equivalent proton dose because of experimental uncertainties. If the 8 rad-air level is conservatively specified for protons, the load 4 NRL cameras would require an additional 1.25 inches aluminum. Loads 2 and 3 are marginally acceptable.

TABLE 7-2 ATM FILM FOGGING DENSITY

Camera/Load		Proton Dose	Fogging Density No GCR	With GCR
GSFC	1	1.11	.018	.023
	2	4.70	.096	.133
	3	4.85	.099	.136
	4	6.72	.143	.196
HAO	1	1.76	.030	.036
	2	5.28	.108	.145
	3	5.70	.116	.155
	4	7.05	.154	.203
AS&E	1	1.33	.022	.028
	2	5.45	.110	.149
	3	5.62	.114	.153
	4	7.36	.163	.210
H-ALPHA 1	1	0.87	.009	.012
	2	6.36	.067	.088
	3	6.34	.067	.088
	4	12.16	.127	.162

TABLE 7-3 NRL FILM FOGGING DENSITY - VULNERABLE ATM LOCATION

Trapped Protons

Camera	Load	Nominal Vault		+0.41" Al		+0.91" Al		+1.41" Al		+1.91" Al		+2.41" Al	
		Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density
NRL-A	1	2.46	0.023										
	2	7.10	0.067	6.14	0.057	5.43	0.051	4.98	0.047	4.67	0.045	4.44	0.042
	3	7.32	0.069	6.13	0.057	5.24	0.049	4.66	0.044	4.25	0.040	3.95	0.037
	4	9.75	0.091	8.00	0.075	6.70	0.063	5.85	0.055	5.24	0.049	4.78	0.045
NRL-B	1	1.76	0.017										
	2	5.94	0.056	5.10	0.048	4.49	0.042	4.08	0.038	3.79	0.036	3.58	0.034
	3	5.78	0.054	4.93	0.046	4.23	0.040	3.75	0.035	3.40	0.032	3.14	0.030
	4	7.65	0.072	6.41	0.060	5.44	0.051	4.76	0.045	4.26	0.040	3.88	0.046

*Dose in RAD-AIR

TABLE 7-4 NRL FILM FOGGING DENSITY – PROTECTED ATM LOCATION

Trapped Protons

Camera	Load	Nominal Vault		+0.41" Al		+0.91" Al		+1.41" Al		+1.91" Al		+2.41 Al	
		Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density
NRL-A	1	1.38	0.013										
	2	6.02	0.056	5.06	0.047	4.35	0.041	3.90	0.037	3.59	0.034	3.36	0.032
	3	6.24	0.059	5.05	0.048	4.16	0.039	3.58	0.034	3.17	0.030	2.87	0.027
	4	8.67	0.081	6.92	0.065	5.62	0.053	4.77	0.45	4.16	0.039	3.70	0.035
NRL-B	1	0.74	0.007										
	2	4.92	0.046	4.08	0.039	3.47	0.033	3.06	0.029	2.77	0.026	2.56	0.024
	3	4.76	0.045	3.91	0.037	3.21	0.030	2.73	0.026	2.38	0.022	2.12	0.020
	4	6.63	0.062	5.39	0.051	4.42	0.042	3.74	0.035	3.24	0.030	2.86	0.027

*Dose in RAD-AIR

TABLE 7-5 NRL FILM FOGGING DENSITY - VULNERABLE ATM LOCATION
With GCR

Camera	Load	Nominal Vault		+0.41" Al		+0.91" Al		+1.41" Al		+1.91" Al		+2.41" Al	
		Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density
NRL-A	1	2.74	.025										
	2	8.66	.081	7.70	.072	6.99	.065	6.54	.061	6.23	.058	6.00	0.056
	3	8.88	.083	7.69	.072	6.80	.064	6.22	.058	5.81	.054	5.51	0.051
	4	12.27	.115	10.52	.098	9.22	.086	8.37	.079	7.76	.073	7.30	0.068
NRL-B	1	2.04	.020										
	2	7.50	.070	6.66	.063	6.05	.056	5.64	.053	5.35	.050	5.14	.048
	3	7.34	.068	6.49	.061	5.79	.054	5.31	.049	4.96	.046	4.70	.044
	4	10.17	0.095	8.93	.083	7.96	.074	7.28	.068	6.78	.063	6.40	.060

*Dose in RAD-AIR

TABLE 7-6 NRL FILM FOGGING DENSITY - VULNERABLE ATM LOCATION
With GCR

Camera	Load	Nominal Vault		+0.41" Al		+0.91" Al		+1.41" Al		+1.91" Al		+2.41" Al	
		Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density	Dose*	Fogging Density
NRL-A	1	1.66	.016										
	2	7.58	.071	6.62	.062	5.91	.055	5.46	.051	5.15	.049	4.92	.046
	3	7.80	.073	6.61	.062	5.72	.053	5.14	.048	4.73	.044	4.43	.042
	4	11.19	.104	9.44	.088	8.14	.076	7.29	.068	6.68	.062	6.22	.058
NRL-B	1	1.02	.009										
	2	6.48	.061	5.64	.052	5.03	.047	4.62	.043	4.33	.040	4.12	.039
	3	6.32	.059	5.47	.051	4.77	.045	4.29	.040	3.94	.037	3.68	.035
	4	9.15	.086	7.91	.074	6.94	.064	6.26	.059	5.76	.052	5.38	.050

*Dose in RAD-AIR

APPENDIX A

PRELIMINARY RADIATION ENVIRONMENTS IN OWS FILM REPOSITORIES

A preliminary analysis of radiation environments within an OWS (wet Workshop) film repository was made in the late summer of 1969. The objective of the study was to provide radiation levels as a function of shield thickness so that shield requirements could be estimated when film requirements and sensitivity to radiation become known. A 215 nm, 35 degree orbit is assumed. These data are superseded by Section 6.

Four of 14 available repository locations surveyed in a previous study[9] are examined. Using the notation of Figure 5-1. the selected locations are Position 4 (lower MDA), 7 (AM), 9 (upper OWS dome), and 11 (center of OWS). The cluster geometry model used in the study has no equipment in the STS and OWS, and has little equipment in the AM. For this reason, dose rate estimates within lightly shielded repositories are expected to be high in the AM and center of the OWS, and, indeed are a factor of two larger than later estimates. The other two locations receive radiation at specified detectors primarily through the adjacent vehicle wall. Repository self-shielding tends to mask the effect of other equipment in these locations.

The two repository concepts studied are labeled A and B. Repository A is shown in Figures A1 through A4; repository B, in A5 through A8. Wall thickness is varied from 0.1 to 10 inches; a 1 inch thickness is shown in the Figures. Two wall materials are studied; polyethylene (sp.gr. = 0.96) and aluminum (sp.gr. = 2.7).

Three types of film magazines, shown in Figures A9 through A11, are placed in each repository. Repository A contains 64 magazines of type 1, 20 of type 2, and 60 of type 3. Repository B contains the same plus an additional magazine of type 1 and 5 film transporters represented by hollow boxes.

Five detector points are located in each repository as indicated in Table A1. These points are embedded 0.1 inches within film in the most exposed location of the film magazines selected.

TABLE A1 - DETECTOR LOCATIONS

	Repository A		Repository B	
Detector	Magazine Type	Magazine Number	Magazine Type	Magazine Number
1	1	50	1	50
2	2	13	2	13
3	3	46	3	46
4	3	49	3	48
5	3	56	3	55

In repository A, detector 1 is centered in the layer opposite the door. Detector 2 is near the bottom edge in the same layer. The last three detectors are in the layer adjacent to the door. The third is in the center, the fourth on an edge, and the fifth in a corner adjacent to the fourth.

In repository B, detector 1 is centered on an edge rather than a face. The position of detectors 2, 3, and 4 are similar to those of repository A. Detector 5 is in a corner distant from detector 4.

The results are given in Tables A2 through A9. Tables A2 - A5 are for repository A. The first two pertain to polyethylene walls and the next two to aluminum walls. The results for repository B are arranged in a similar way.

The dose rate estimates for each detector are given in three rows labeled "A", "B", and "C". Row A gives dose rates with all film magazines present. Row B gives dose rates with approximately one third of the magazines removed. Numbers 1 through 20 of types 1 and 3, and numbers 1 through 7 of type 2 are removed. Row C gives dose rates with two thirds of the magazines removed. Numbers 1 through 40 of types 1 and 3, and numbers 1 through 14 of type 2 are removed. Note that detector 2 is in an empty part of the repositories in case C, causing an abrupt increase in dose rate from case B to C.

TABLE A2 RADIATION DOSE RATE IN REPOSITORY A - POLY (RADS PER DAY) - LOCATIONS 4&7

Detector #4		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.	Detector #7		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1	A	.1048	.0555	.0246	.0141	.0054	1	A	.0858	.0497	.0236	.0141	.00558
	B	.1066	.0569	.0254	.0147	.00567		B	.0883	.0516	.0247	.0148	.00593
	C	.1141	.0623	.0282	.0164	.00635		C	.0968	.0577	.0278	.0166	.00667
2	A	.0655	.0448	.0238	.0147	.00608	2	A	.0693	.0473	.0249	.0154	.00635
	B	.0676	.0463	.0246	.0152	.00629		B	.0716	.0489	.0258	.0159	.00654
	* C	.1675	.0882	.0391	.0221	.00819		* C	.1781	.0942	.0415	.0233	.00855
3	A	.0395	.0303	.0185	.0125	.00563	3	A	.0400	.0305	.0186	.0125	.00566
	B	.0729	.0492	.0264	.0165	.00696		B	.0810	.0532	.0278	.0171	.00710
	C	.0964	.0636	.0327	.0198	.00808		C	.1078	.0692	.0348	.0207	.00828
4	A	.0645	.0431	.0228	.0142	.00595	4	A	.0596	.0409	.0220	.0139	.00587
	B	.0818	.0542	.0279	.0169	.00686		B	.0765	.0516	.0270	.0165	.00675
	C	.1003	.0652	.0327	.0194	.00763		C	.0960	.0631	.0320	.0190	.00753
5	A	.0886	.0564	.0279	.0166	.00653	5	A	.0962	.0600	.0291	.0171	.00667
	B	.1012	.0637	.0312	.0183	.00712		B	.1069	.0668	.0324	.0189	.00726
	C	.1228	.0754	.0358	.0205	.00783		C	.1319	.0799	.0374	.0212	.00796

TABLE A3 RADIATION DOSE RATE IN REPOSITORY A - POLY (RADS PER DAY) - LOCATIONS 9&11

Detector #9		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.	Detector #11		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1	A	.1109	.0570	.0254	.0147	.00574	1	A	.1223	.0612	.0266	.0152	.00587
	B	.1133	.0589	.0264	.0154	.00605		B	.1246	.0630	.0276	.0159	.00616
	C	.1225	.0653	.0297	.0173	.00679		C	.1340	.0696	.0309	.0178	.00692
2	A	.0839	.0560	.0287	.0174	.00699	2	A	.0869	.0575	.0293	.0176	.00706
	B	.0858	.0574	.0294	.0178	.00718		B	.0895	.0594	.0303	.0182	.00730
	* C	.2102	.1097	.0472	.0262	.00940		* C	.2469	.1179	.0493	.0270	.00956
3	A	.0458	.0345	.0206	.0137	.00609	3	A	.0496	.0371	.0219	.0144	.00637
	B	.0949	.0606	.0309	.0189	.00772		B	.1059	.0663	.0332	.0200	.00805
	C	.1301	.0807	.0392	.0230	.00902		C	.1443	.0875	.0417	.0242	.00935
4	A	.0783	.0515	.0267	.0163	.00667	4	A	.0803	.0528	.0272	.0166	.00679
	B	.0994	.0646	.0326	.0194	.00768		B	.1001	.0652	.0329	.0196	.00777
	C	.1217	.0777	.0384	.0223	.00858		C	.1248	.0793	.0389	.0225	.00864
5	A	.1199	.0732	.0348	.0199	.00752	5	A	.1279	.0757	.0352	.0202	.00756
	B	.1337	.0815	.0385	.0219	.00820		B	.1409	.0833	.0385	.0219	.00817
	C	.1579	.0936	.0430	.0241	.00884		C	.1719	.0987	.0442	.0246	.00897

TABLE A4 RADIATION DOSE RATE IN REPOSITORY A - ALUMINUM (RADS PER DAY) - LOCATIONS 4&7

Detector #4			Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1		A	.0955	.0351	.0114	.00550	.00151
		B	.0973	.0362	.0119	.00578	.00158
		C	.1045	.0400	.0132	.00647	.00172
2		A	.0625	.0320	.0122	.00620	.00170
		B	.0645	.0330	.0126	.00641	.00174
	*	C	.1518	.0562	.0177	.00837	.00213
3		A	.0383	.0234	.0106	.00571	.00167
		B	.0692	.0352	.0137	.00709	.00195
		C	.0914	.0445	.0163	.00824	.00217
4		A	.0612	.0306	.0118	.00606	.00167
		B	.0776	.0379	.0139	.00699	.00187
		C	.0949	.0451	.0158	.00779	.00202
5		A	.0835	.0386	.0135	.00667	.00175
		B	.0952	.0433	.0149	.00727	.00187
		C	.1151	.0504	.0166	.00800	.00201

Detector #7			Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1		A	.0794	.0329	.0114	.00568	.00159
		B	.0818	.0343	.0121	.00604	.00167
		C	.0901	.0386	.0136	.00680	.00183
2		A	.0661	.0336	.0127	.00647	.00176
		B	.0683	.0348	.0131	.00667	.00181
	*	C	.1616	.0599	.0185	.00873	.00221
3		A	.0387	.0235	.0106	.00575	.00171
		B	.0766	.0374	.0141	.00722	.00200
		C	.1017	.0477	.0169	.00844	.00224
4		A	.0568	.0294	.0116	.00597	.00166
		B	.0728	.0365	.0136	.00687	.00185
		C	.0910	.0439	.0155	.00768	.00201
5		A	.0930	.0405	.0139	.00680	.00178
		B	.1005	.0451	.0152	.00741	.00191
		C	.1234	.0529	.0170	.00813	.00204

TABLE A5 RADIATION DOSE RATE IN REPOSITORY A - ALUMINUM (RADS PER DAY) - LOCATIONS 9&11

Detector #9		Shield Thickness - Inches				
		0.1	1.0	3.0	5.0	10.
1	A	.1001	.0363	.0119	.00583	.00158
	B	.1025	.0377	.0125	.00615	.00165
	C	.1113	.0422	.0140	.00691	.00181
2	A	.0797	.0392	.0142	.00712	.00189
	B	.0815	.0402	.0146	.00732	.00194
	* C	.1903	.0687	.0207	.00959	.00238
3	A	.0443	.0263	.0116	.00618	.00179
	B	.0894	.0421	.0155	.00785	.00211
	C	.1220	.0545	.0187	.00919	.00238
4	A	.0742	.0361	.0134	.00679	.00183
	B	.0941	.0447	.0158	.00782	.00205
	C	.1149	.0532	.0180	.00875	.00224
5	A	.1123	.0487	.0160	.00770	.00196
	B	.1252	.0541	.0175	.00836	.00211
	C	.1472	.0612	.0192	.00902	.00223

Detector #11		Shield Thickness - Inches				
		0.1	1.0	3.0	5.0	10.
1	A	.1099	.0382	.0123	.00597	.00161
	B	.1121	.0395	.0129		.00168
	C	.1212	.0442	.0144	.00705	.00184
2	A	.0824	.0401	.0144	.00719	.00190
	B	.0849	.0414	.0149		.00195
	* C	.2187	.0725	.0213	.00976	.00240
3	A	.0479	.0281	.0121	.00646	.00184
	B	.0992	.0454	.0164		.00218
	C	.1346	.0583	.0195	.00952	.00244
4	A	.0760	.0370	.0137	.00691	.00185
	B	.0947	.0452	.0160		.00207
	C	.1178	.0541	.0182	.00881	.00224
5	A	.1189	.0496	.0162	.00771	.00196
	B	.1310	.0545	.0175		.00209
	C	.1592	.0635	.0195	.00916	.00224

TABLE A6 RADIATION DOSE RATE IN REPOSITORY B - POLY (RADS PER DAY) - LOCATIONS 4&7

Detector #4		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1	A	.0924	.0548	.0259	.0150	.00572
	B	.0932	.0554	.0263	.0153	.00584
	C	.0955	.0571	.0273	.0159	.00615
2	A	.1063	.0637	.0301	.0173	.00663
	B	.1079	.0649	.0307	.0177	.00680
	* C	.2175	.1049	.0433	.0236	.00834
3	A	.0413	.0311	.0186	.0124	.00555
	B	.0779	.0515	.0268	.0165	.00682
	C	.1152	.0729	.0359	.0211	.00827
4	A	.0603	.0432	.0242	.0155	.00670
	B	.0945	.0620	.0317	.0192	.00782
	C	.1141	.0736	.0368	.0218	.00869
5	A	.0708	.0457	.0231	.0141	.00567
	B	.0762	.0491	.0246	.0149	.00596
	C	.0999	.0618	.0296	.0174	.00671

Detector #7		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1	A	.0889	.0532	.0254	.0148	.00568
	B	.0898	.0538	.0257	.0150	.00578
	C	.0926	.0559	.0269	.0158	.00610
2	A	.1014	.0623	.0299	.0173	.00666
	B	.1026	.0632	.0304	.0176	.00677
	* C	.2051	.1026	.0432	.0236	.00833
3	A	.0424	.0318	.0189	.0125	.00557
	B	.0880	.0560	.0282	.0171	.00695
	C	.1231	.0764	.0371	.0217	.00841
4	A	.0584	.0419	.0235	.0150	.00648
	B	.1027	.0653	.0326	.0194	.00775
	C	.1225	.0769	.0378	.0221	.00863
5	A	.0873	.0534	.0255	.0150	.00585
	B	.0947	.0570	.0268	.0156	.00603
	C	.1259	.0723	.0326	.0184	.00682

TABLE A7 RADIATION DOSE RATE IN REPOSITORY B - POLY (RADS PER DAY) - LOCATIONS 9&11

Detector #9		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1	A	.1167	.0654	.0295	.0167	.00619
	B	.1176	.0661	.0299	.0170	.00632
	C	.1208	.0684	.0312	.0178	.00669
2	A	.1358	.0788	.0358	.0203	.00751
	B	.1379	.0803	.0367	.0208	.00771
	* C	.2807	.1293	.0519	.0277	.00947
3	A	.0529	.0386	.0223	.0146	.00633
	B	.1090	.0679	.0333	.0200	.00798
	C	.1501	.0911	.0431	.0249	.00955
4	A	.0776	.0533	.0285	.0177	.00734
	B	.1272	.0786	.0379	.0222	.00866
	C	.1494	.0910	.0431	.0248	.00950
5	A	.1153	.0683	.0317	.0182	.00684
	B	.1235	.0731	.0337	.0192	.00719
	C	.1613	.0909	.0400	.0221	.00798

Detector #11		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1	A	.1307	.0702	.0308	.0173	.00639
	B	.1317	.0710	.0313	.0177	.00654
	C	.1347	.0733	.0325	.0185	.00690
2	A	.1354	.0780	.0355	.0201	.00750
	B	.1377	.0796	.0363	.0206	.00769
	* C	.3062	.1328	.0523	.0279	.00953
3	A	.0530	.0389	.0224	.0146	.00634
	B	.1159	.0702	.0339	.0201	.00793
	C	.1672	.0976	.0448	.0255	.00954
4	A	.0760	.0527	.0285	.0178	.00747
	B	.1342	.0812	.0389	.0227	.00884
	C	.1612	.0960	.0451	.0258	.00981
5	A	.1210	.0707	.0324	.0185	.00695
	B	.1301	.0756	.0345	.0195	.00728
	C	.1734	.0951	.0413	.0228	.00816

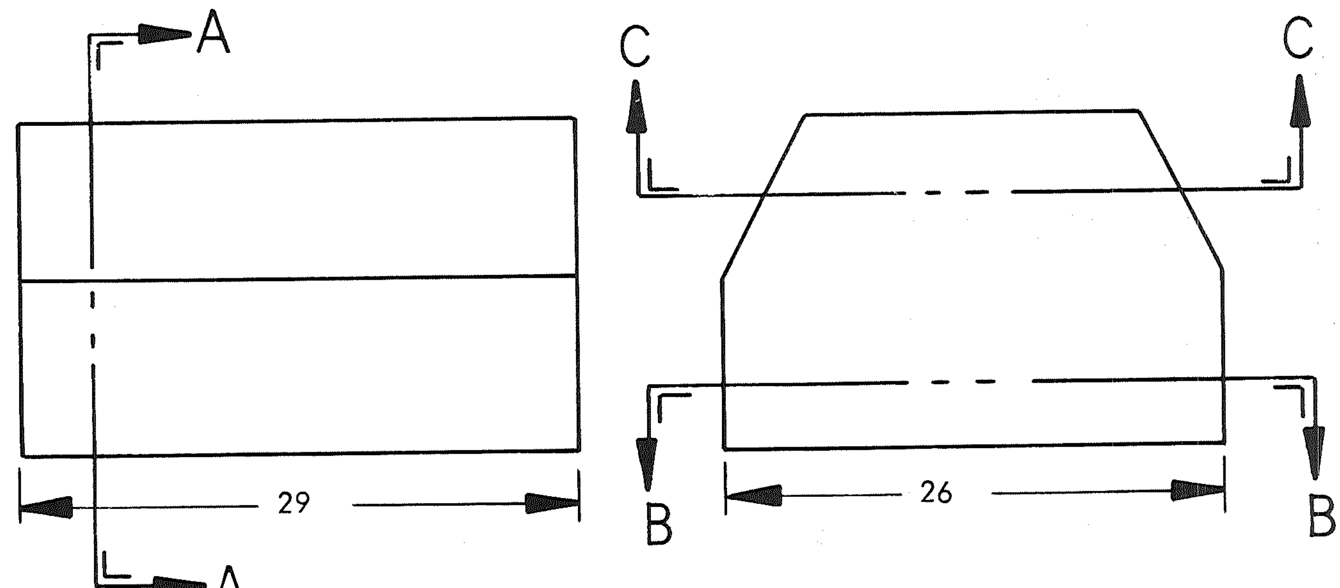
TABLE A8 RADIATION DOSE RATE IN REPOSITORY B - ALUMINUM (RADS PER DAY) - LOCATIONS 4&7

Detector #4		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.	Detector #7		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1	A	.0860	.0364	.0121	.00583	.00154	1	A	.0829	.0354	.0119	.00579	.00154
	B	.0867	.0369	.0123	.00596	.00157		B	.0837	.0359	.0122	.00589	.00156
	C	.0889	.0382	.0129	.00627	.00165		C	.0864	.0375	.0128	.00623	.00163
2	A	.0994	.0423	.0140	.00677	.00174	2	A	.0952	.0418	.0140	[illegible]	.00175
	B	.1009	.0432	.0143	.00694	.00178		B	.0964	.0425	.0143	[illegible]	.00178
	* C	.1935	.0640	.0186	.00853	.00209		* C	.1841	.0634	.0186	[illegible]	.00208
3	A	.0399	.0237	.0105	.00564	.00165	3	A	.0410	.0242	.0106	.00566	.00166
	B	.0738	.0362	.0136	.00695	.00189		B	.0828	.0385	.0140	.00707	.00193
	C	.1084	.0495	.0171	.00844	.00220		C	.1156	.0516	.0175	.00857	.00225
4	A	.0579	.0318	.0129	.00682	.00190	4	A	.0561	.0308	.0125	.00659	.00185
	B	.0895	.0433	.0157	.00797	.00212		B	.0967	.0448	.0158	.00790	.00210
	C	.1077	.0508	.0178	.00887	.00231		C	.1152	.0523	.0179	.00880	.00230
5	A	.0669	.0317	.0116	.00578	.00155	5	A	.0818	.0358	.0122	.00597	.00156
	B	.0720	.0339	.0123	.00608	.00161		B	.0885	.0379	.0127	.00615	.00159
	C	.0938	.0415	.0142	.00686	.00176		C	.1167	.0467	.0147	.00697	.00176

TABLE A9 RADIATION DOSE RATE IN REPOSITORY B - ALUMINUM (RADS PER DAY) - LOCATIONS 9&11

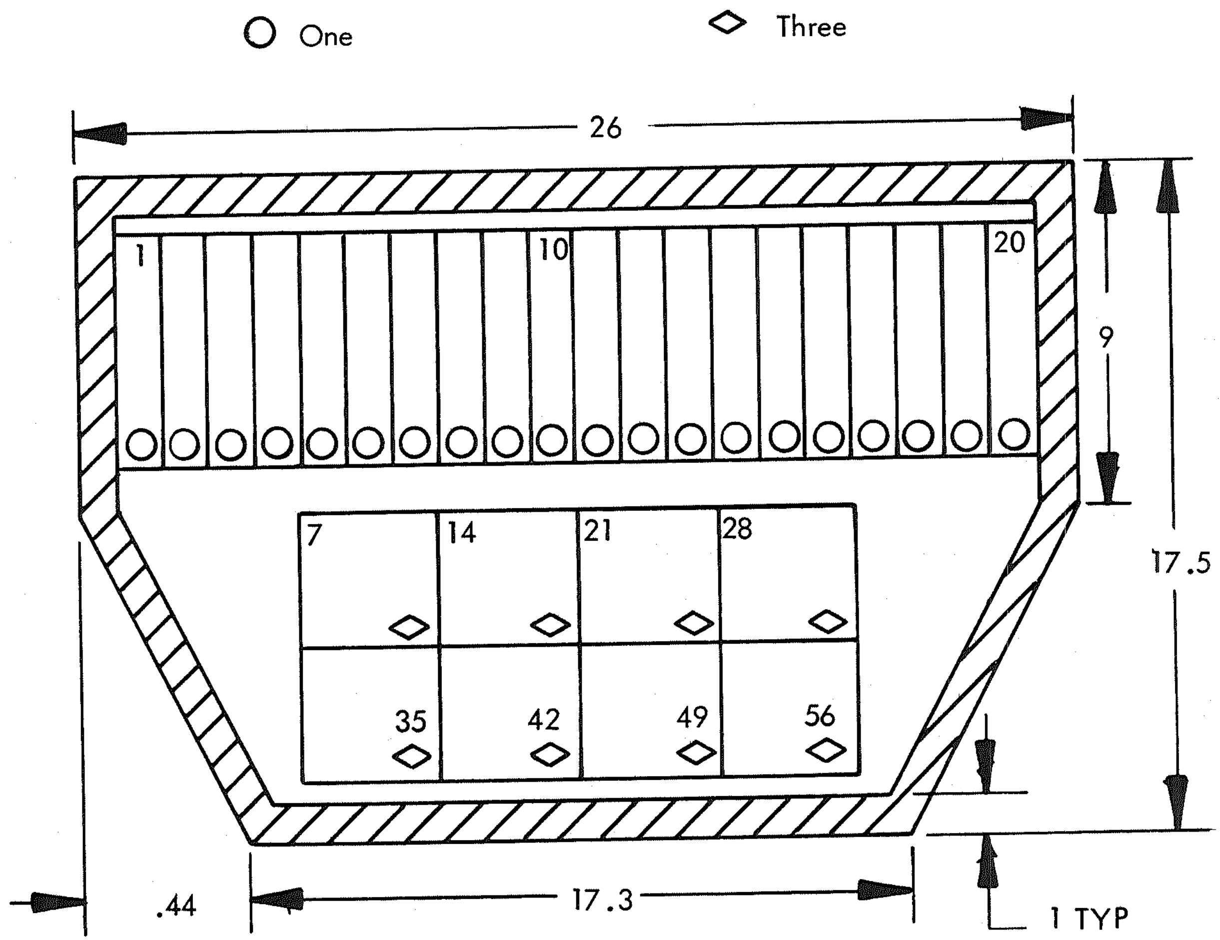
Detector #9		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1	A	.1076	.0420	.0134	.00631	.00164
	B	.1085	.0426	.0136	.00644	.00167
	C	.1115	.0443	.0143	.00682	.00175
2	A	.1260	.0510	.0162	.00766	.00192
	B	.1280	.0521	.0166	.00787	.00197
	* C	.2461	.0775	.0216	.00968	.00230
3	A	.0510	.0288	.0122	.00642	.00183
	B	.1023	.0461	.0163	.00812	.00216
	C	.1404	.0607	.0200	.00973	.00249
4	A	.0740	.0381	.0146	.00747	.00203
	B	.1192	.0530	.0180	.00882	.00228
	C	.1398	.0607	.0200	.00969	.00246
5	A	.1075	.0450	.0146	.00698	.00177
	B	.1151	.0480	.0155	.00734	.00184
	C	.1491	.0579	.0176	.00815	.00199

Detector #11		Shield Thickness - Inches 0.1	1.0	3.0	5.0	10.
1	A	.1194	.0445	.0138	.00651	.00168
	B	.1203	.0451	.0141	.00666	.00171
	C	.1233	.0468	.0148	.00703	.00179
2	A	.1255	.0506	.0161	.00765	.00193
	B	.1277	.0517	.0165	.00784	.00197
	* C	.2649	.0787	.0218	.00975	.00233
3	A	.0510	.0290	.0122	.00644	.00182
	B	.1081	.0470	.0163	.00807	.00213
	C	.1551	.0635	.0204	.00973	.00246
4	A	.0726	.0380	.0147	.00760	.00206
	B	.1252	.0543	.0183	.00900	.00233
	C	.1500	.0634	.0207	.01001	.00254
5	A	.1125	.0461	.0149	.00708	.00180
	B	.1208	.0492	.0157	.00743	.00187
	C	.1593	.0600	.0181	.00833	.00204



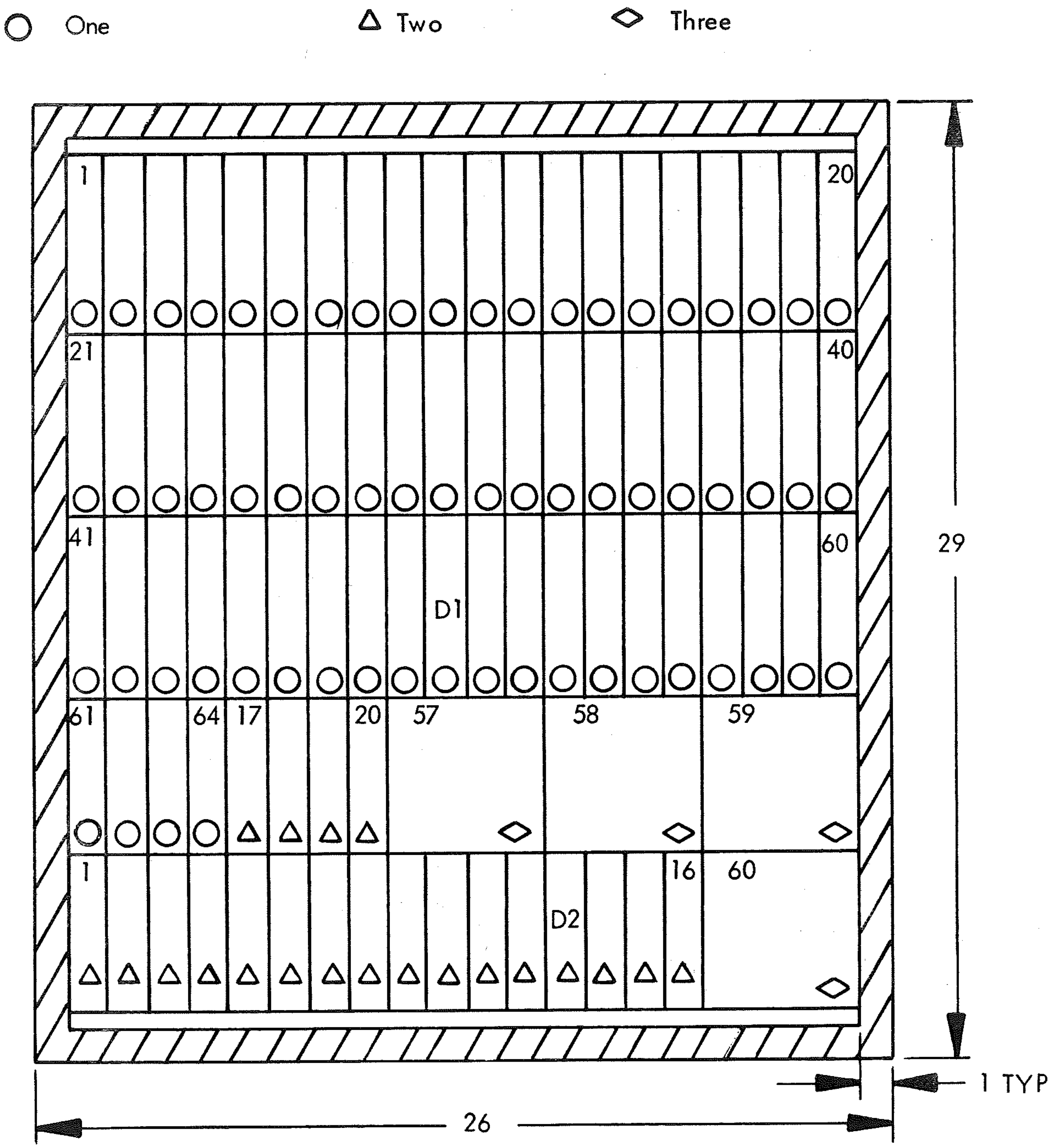
CONCEPT A

FIGURE A1 OWS FILM REPOSITORY



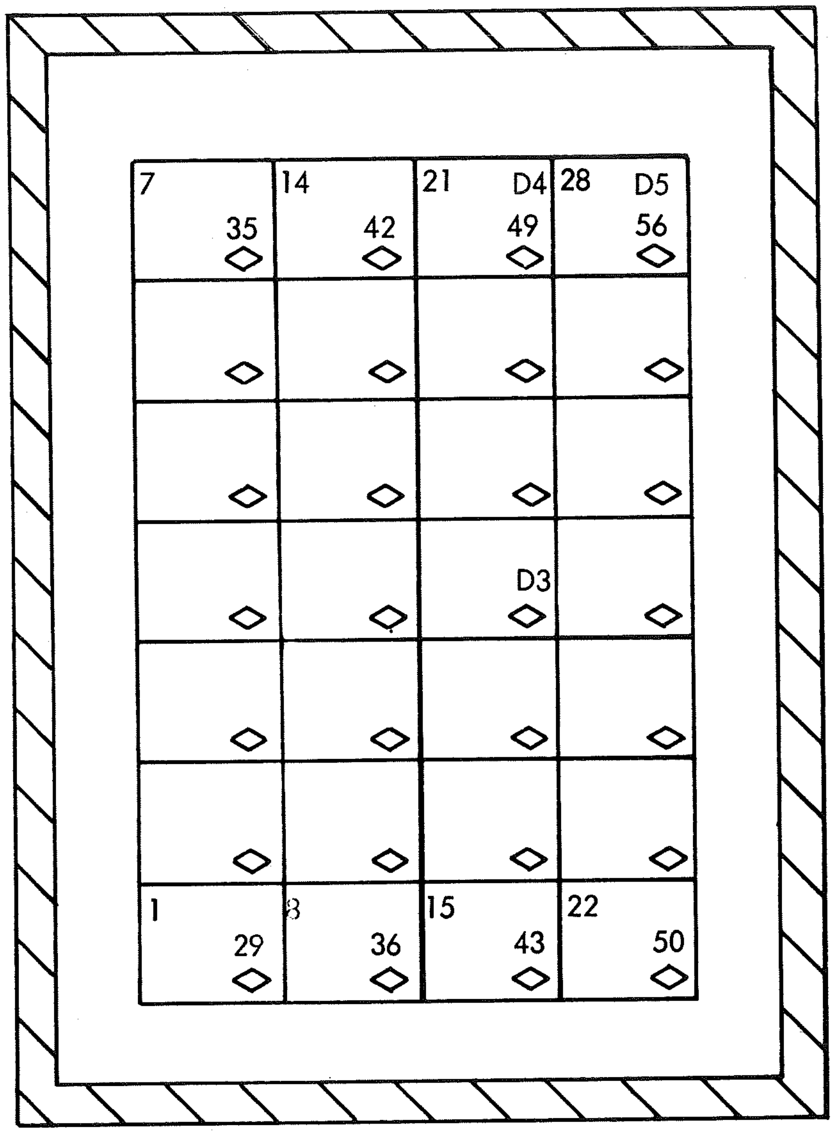
A - A

FIGURE A2


One
Two
Three
1
20
21
40
41
60
D1
61
64
17
20
57
58
59
1
16
60
D2
29
1 TYP
26

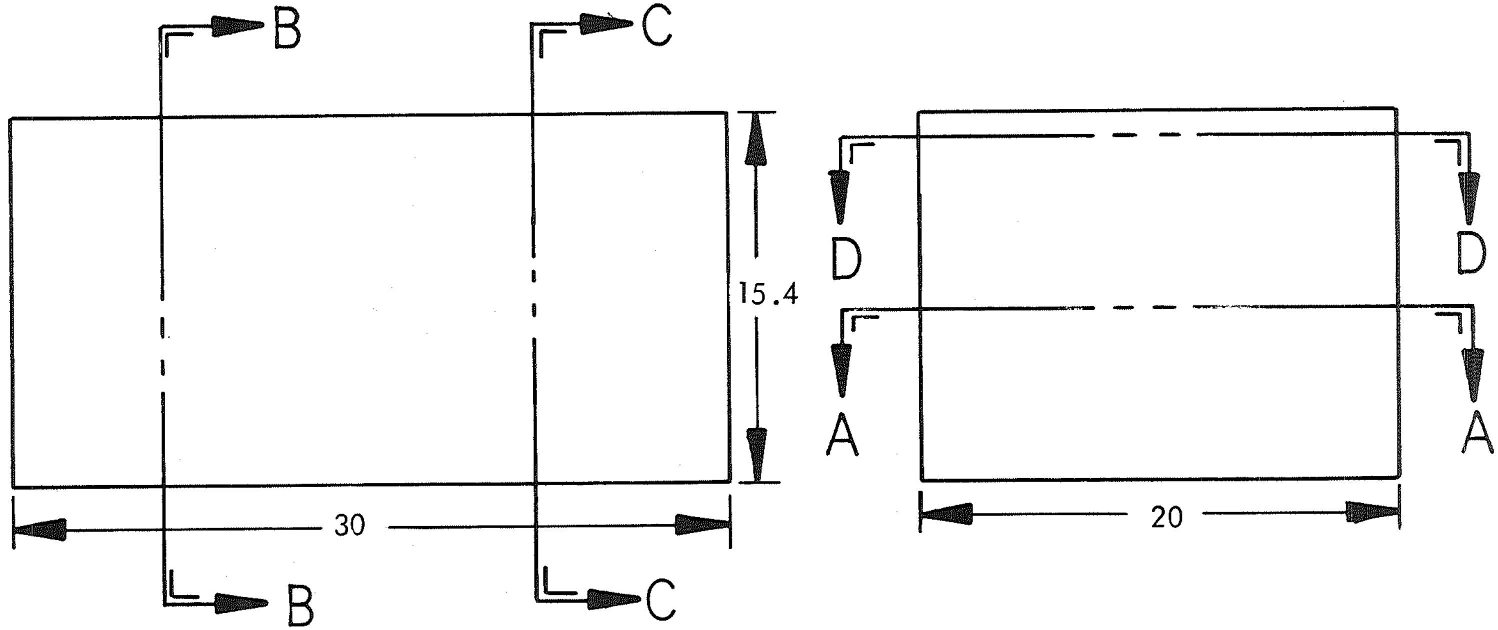
B - B

FIGURE A3



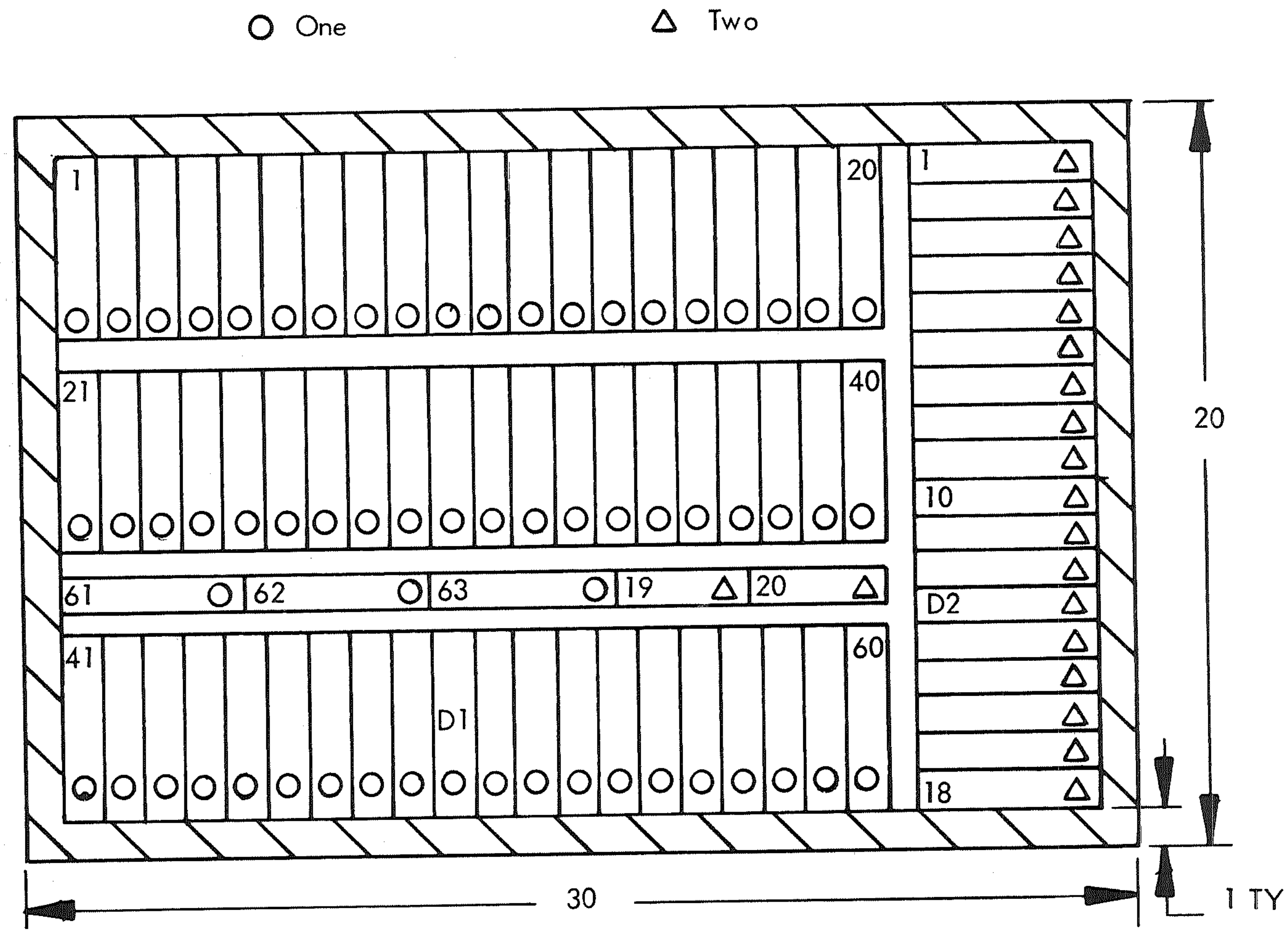
C - C

FIGURE A4



CONCEPT B

FIGURE A5 OWS FILM REPOSITORY



A-A

FIGURE A6

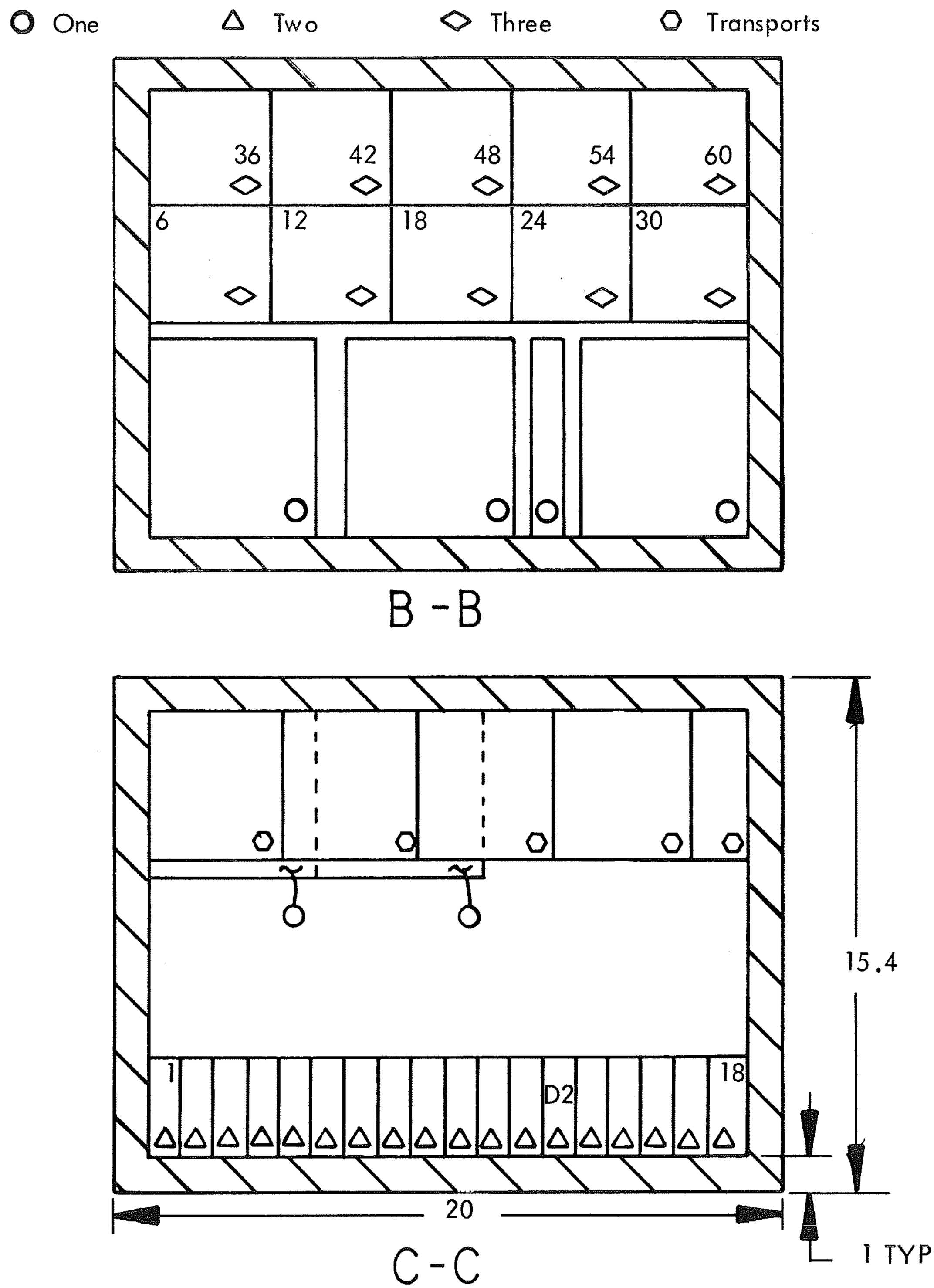
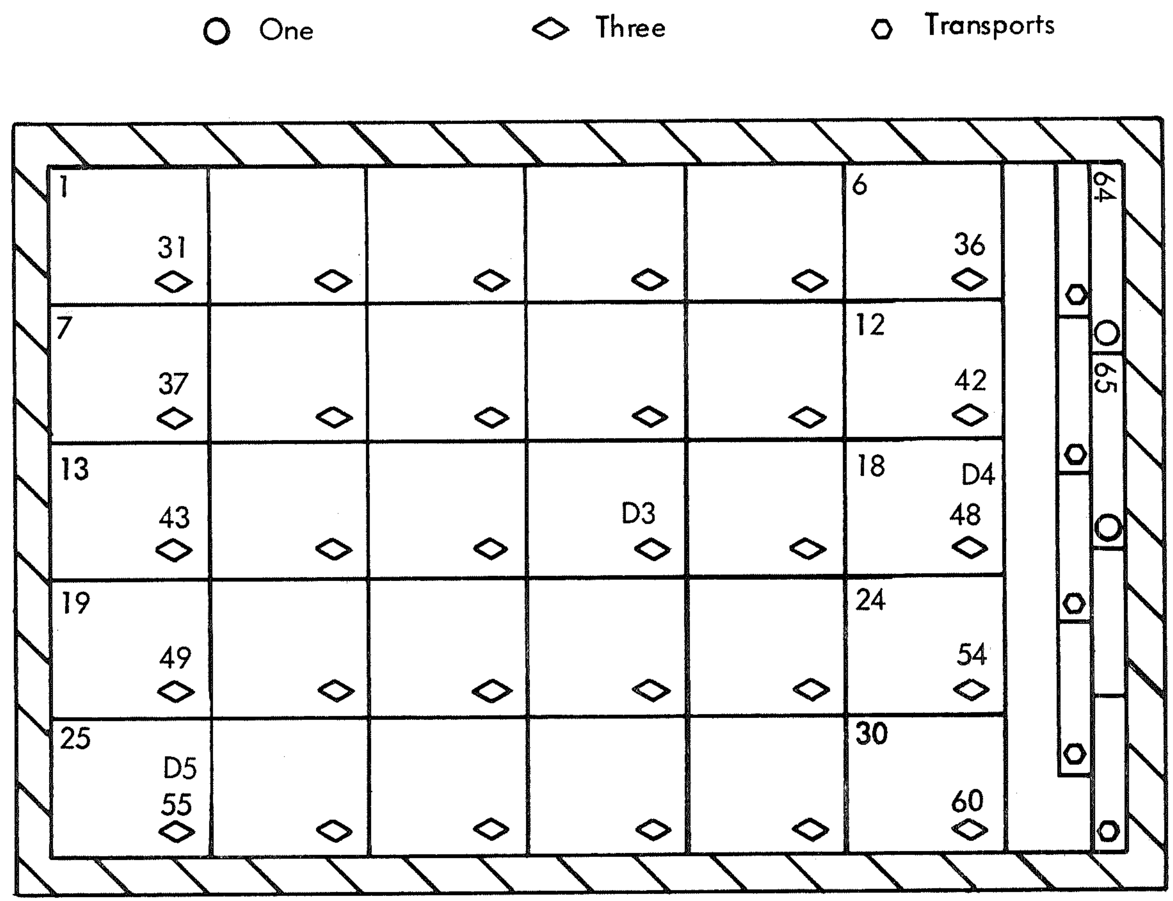
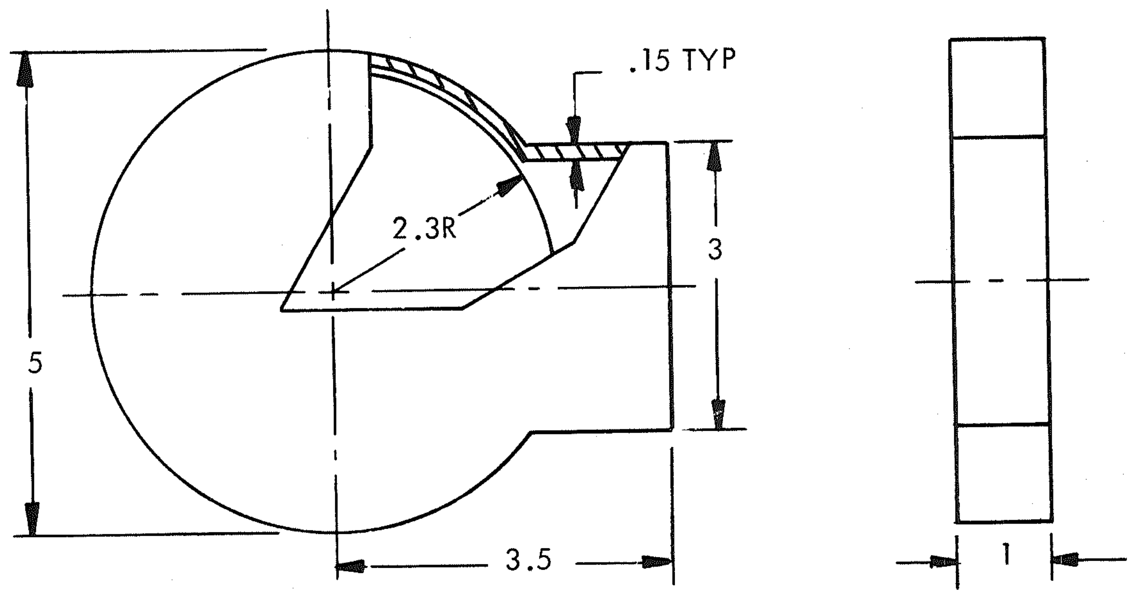

One
Two
Three
Transports
36
42
48
54
60
6
12
18
24
30
B -B
1
D2
18
15.4
20
1 TYP
C-C

FIGURE A7


One
Three
Transports
1
31
6
36
7
37
12
42
13
43
D3
18
D4
48
19
49
24
54
25
D5
55
30
60
64
65

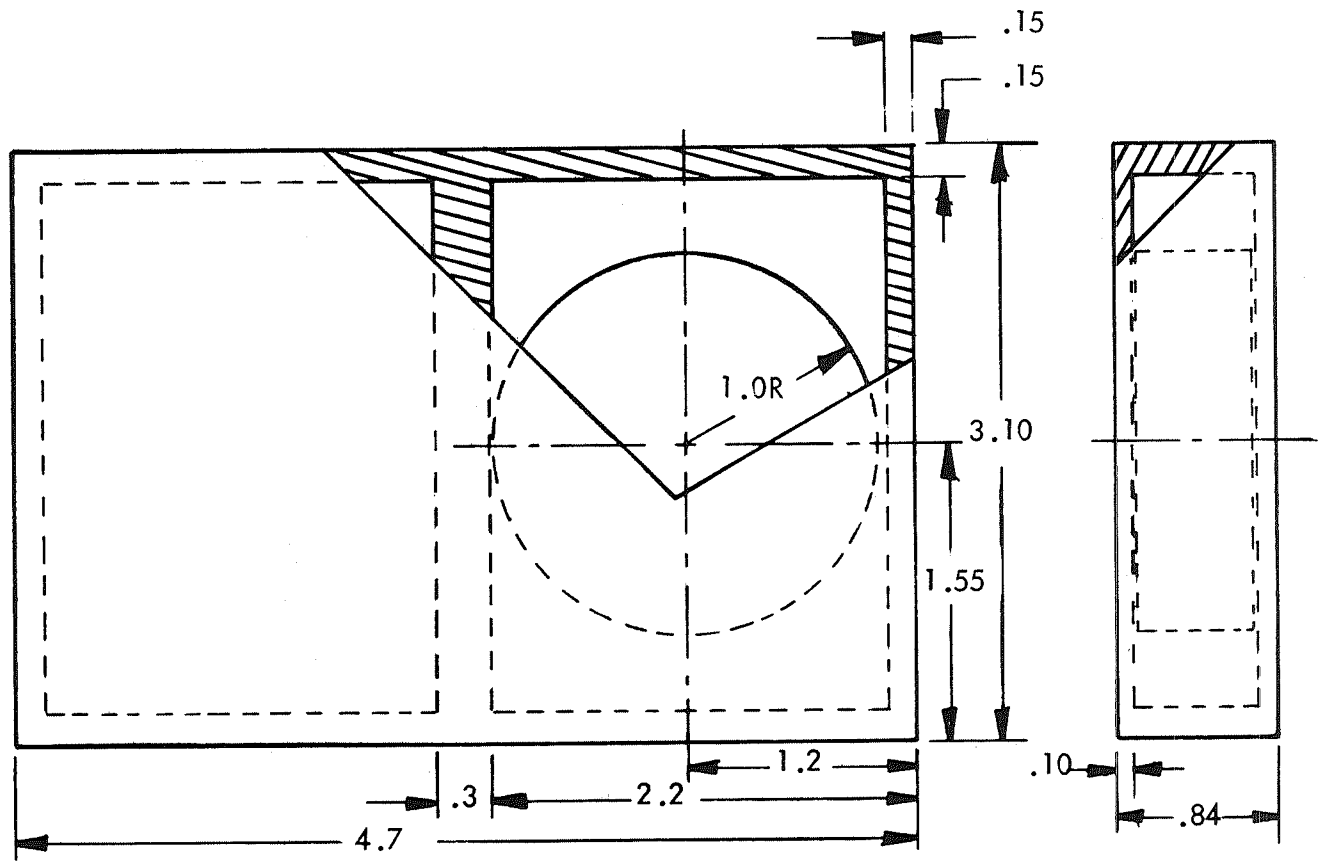
D-D

FIGURE A8



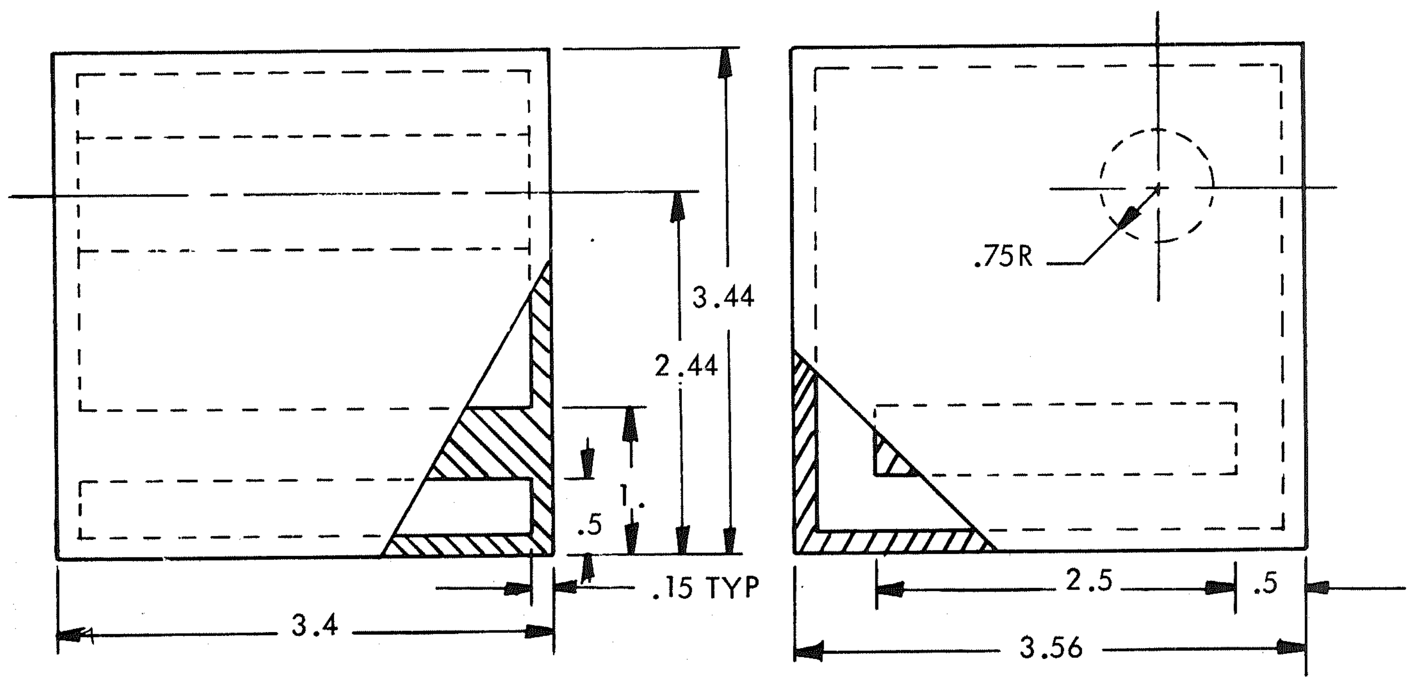
ONE

FIGURE A9 MAGAZINE ONE



TWO

FIGURE A10 MAGAZINE TWO



THREE

FIGURE A11 MAGAZINE THREE

APPENDIX B

PRELIMINARY ATM FILM STORAGE SHIELDING REQUIREMENTS

Preliminary estimates of the shielding requirements for long-term storage of ATM film were made in the fall of 1969. One potential storage site is the MDA; another, the forward skirt of the OWS. The ATM film requires shielding protection in both sites for the Dry Workshop mission profile. The weight penalty ranges from 331 to 1901 pounds in the MDA and from 647 to 2635 pounds in the OWS skirt, depending upon the film fogging criterion, exclusive of structure. Most of the weight penalty could be saved if the three types of cameras containing Pan-X film were carried on resupply vehicles for later missions. These data are superseded by Section 7.

The cluster geometric model is substantially unchanged from earlier studies[9]. Minor modifications include the removal of one docking port in the MDA, the removal of the LM, and a relocation of the ATM. Several equipment boxes have been removed from the MDA to make room for ATM film storage. The cameras are located in the MDA or, alternatively, in the OWS forward skirt as shown in Figures B1 and B2.

Four loads of film for six experiments are considered in the present study. The first load is launched aboard the ATM and is returned after 28 days. No shielding is required for the first load. Eighty-eight days after launch, the second load is moved from storage to the ATM for 28 days, then to the CM for 28 days. One hundred sixteen days after launch, the third load is moved from storage to the ATM for 28 days. Two hundred two days after launch, the fourth load is moved from storage to the ATM for 28 days.

One detector point is placed in each of the six types of cameras. They are buried 0.1 inches below the surface of the film spool or slide deck. One long container encloses the cameras along a 90 degree segment of the periphery of the OWS forward skirt. Three boxes enclose the cameras in the MDA except for the H-Alpha 1 cameras which

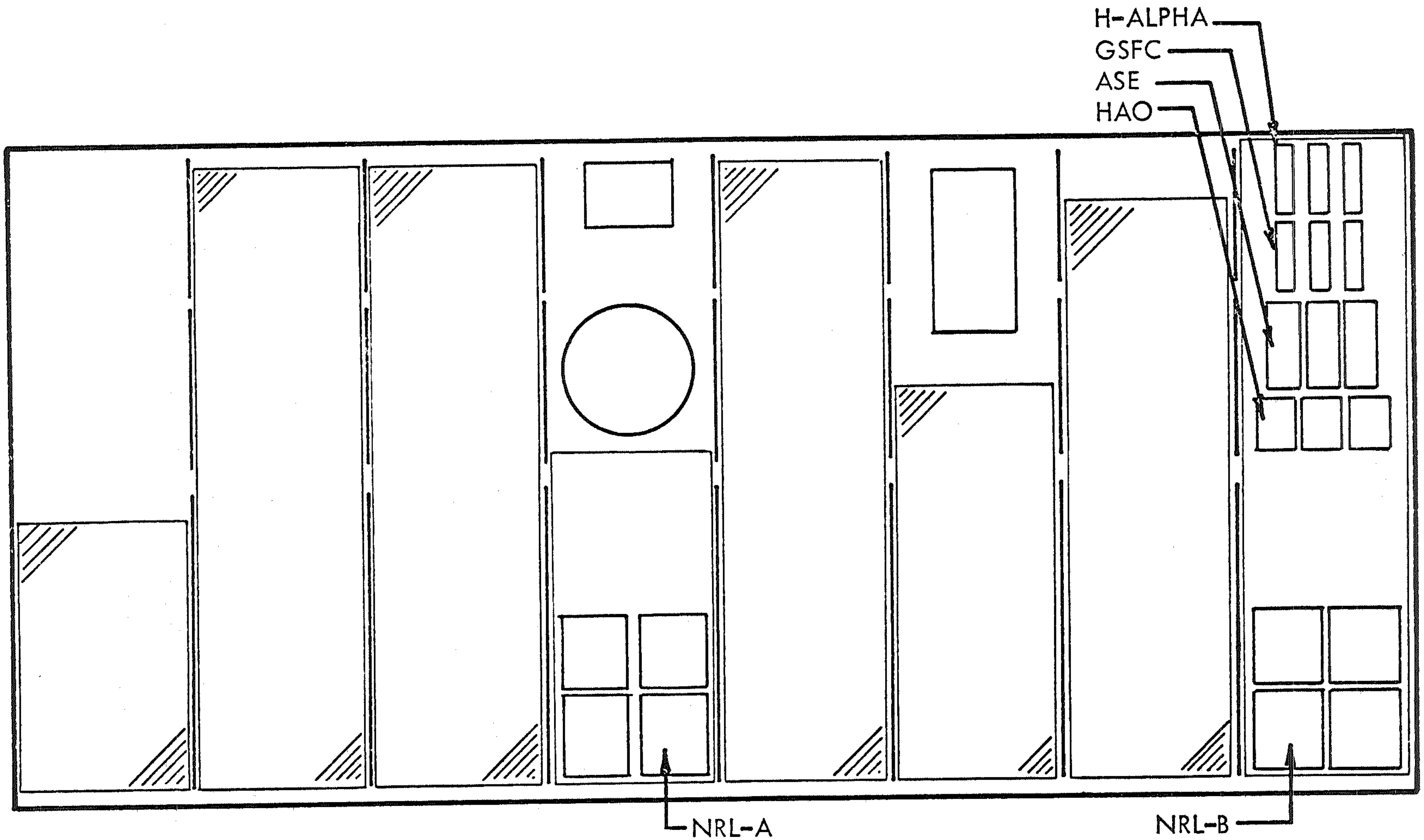


FIGURE B1 PRELIMINARY ATM CAMERA STORAGE CONCEPT DEVELOPED VIEW, MDA INTERNAL WALL (SVWS)

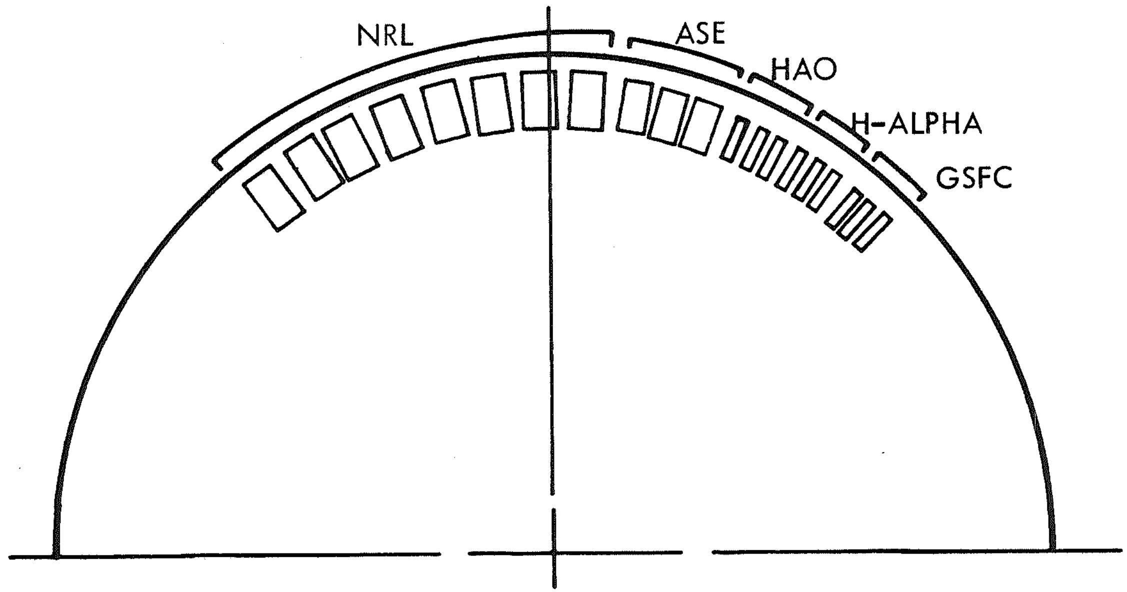


FIGURE B2. ATM FILM STORAGE ARRANGEMENT IN SVWS FORWARD SKIRT are unprotected.

Dose rates are computed for each of the detector locations in rad-air per day for a 210 nm, 35 degree orbit. A special feature of the LSVDC4[8] program system is used to compute the shielding effect of the second and third loads upon the fourth load, and also to vary box wall thickness. Results are given in Tables B1 and B2 for MDA and OWS storage, respectively. Box wall thickness varies from 0 to 6 inches aluminum. The cases labeled "A" refer to dose rates in load 4 when loads 2, 3, and 4 are in the storage site. Cases "B" are similar except that load 2 is removed. In cases "C", loads 2 and 3 are removed. GCR contributions are omitted.

The data of Tables B1 and B2 are combined with results of a previous study[9] to estimate doses to each of the four loads of film. These results are presented in Tables B3 and B4 for MDA and OWS skirt storage, respectively. The first section of each table represents doses to the first load during a 28 day period on the ATM. The second section represents doses to the second load during a 88 day storage period followed by 28 days on the ATM and 28 days in the CM. The assumption is made that dose rates are the same at the second and fourth load positions. The third section represents dose to the third load during a 88 day storage period with loads 2, 3, and 4 present; plus a 28 day storage period with loads 3 and 4 present; plus 28 days in the ATM. The fourth section represents doses to the fourth load by adding an 86 day storage period with load 4 only to the conditions of the third section. Thus, Tables B3 and B4 contain estimates of the doses received by each of the 24 ATM cameras as a function of storage box wall thickness.

Shield thickness requirements are computed for each type of film for each load at three density levels. New camera and box arrangements are devised to satisfy the shield requirements. The nine boxes could be combined to reduce weight should structural

TABLE B1 ATM FILM DOSE IN MDA – RAD/DAY

		Shield Box Thickness – Inches Aluminum							
		0	.5	1	2	3	4	5	6
1	A	.0644	.0415	.0294	.0171	.0113	.00787	.00568	.00421
NRL B	B	.0645	.0415	.0294	.0171	.0113	.00787	.00568	.00421
SWR	C	.0658	.0423	.0300	.0175	.0115	.00805	.00581	.00431
2	A	.0756	.0481	.0338	.0194	.0125	.00870	..00626	.00463
NRL A	B	.0757	.0481	.0338	.0194	.0125	.00870	.00626	.00463
SWR	C	.0771	.0489	.0343	.0197	.0128	.00886	.00638	.00473
3	A	.0647	.0430	.0308	.0180	.0119	.00826	.00594	.00441
ASE	B	.0707	.0468	.0334	.0195	.0127	.00883	.00635	.00472
PAN-X	C	.0774	.0510	.0363	.0210	.0136	.00945	.00678	.00504
4	A	.1221	.0613	.0394	.0205	.0125	.00836	.00587	.00426
GSFC	B	.1358	.0668	.0427	.0219	.0133	.00883	.00618	.00448
PAN-X	C	.1485	.0727	.0461	.0234	.0140	.00931	.00649	.00469
5	A	.1030	.0514	.0340	.0183	.0115	.00787	.00557	.00407
HAO	B	.1115	.0558	.0367	.0196	.0122	.00828	.00584	.00426
PAN-X	C	.1202	.0604	.0395	.0209	.0129	.00872	.00613	.00446
6	A	.1156	.1059	.1031	.1010	.1002	.0998	.0996	.0994
H-ALPHA	B	.1247	.1140	.1108	.1085	.1076	.1071	.1069	.1067
SO-375	C	.1353	.1226	.1191	.1165	.1154	.1149	.1146	.1144

A Loads 2, 3, 4
B Loads 3, 4
C Loads 4 Only

TABLE B2 ATM FILM DOSE IN OWS SKIRT - RAD/DAY

		Shield Box Thickness - Inches Aluminum							
		0	.5	1	2	3	4	5	6
1	A	.0707	.0434	.0302	.0173	.0113	.00786	.00566	.00417
NRL B	B	.0733	.0447	.0309	.0176	.0115	.00795	.00572	.00420
SWR	C	.0954	.0511	.0342	.0188	.0120	.00827	.00591	.00432
2	A	.0707	.0444	.0310	.0178	.0116	.00808	.00584	.00430
NRL A	B	.0787	.0477	.0329	.0185	.0120	.00830	.00598	.00439
SWR	C	.1015	.0542	.0362	.0198	.0126	.00865	.00619	.00453
3	A	.0873	.0515	.0353	.0198	.0127	.00870	.00623	.00458
ASE	B	.0912	.0531	.0363	.0202	.0129	.00882	.00631	.00463
PAN-X	C	.1015	.0564	.0380	.0209	.0132	.00903	.00645	.00473
4	A	.1730	.0891	.0577	.0303	.0183	.0123	.00874	.00640
GSFC	B	.1761	.0901	.0583	.0305	.0185	.0124	.00878	.00643
PAN-X	C	.1864	.0942	.0606	.0314	.0189	.0126	.00895	.00654
5	A	.1552	.0776	.0504	.0266	.0164	.0111	.00787	.00576
HAO	B	.1663	.0822	.0531	.0278	.0170	.0115	.00813	.00594
PAN-X	C	.1845	.0900	.0575	.0296	.0179	.0120	.00847	.00617
6	A	.1614	.0831	.0541	.0285	.0174	.0118	.00837	.00613
H-ALPHA	B	.1717	.0874	.0565	.0295	.0180	.0121	.00857	.00627
SO-375	C	.1852	.0929	.0596	.0307	.0186	.0124	.00880	.00642

A Loads 2, 3, 4
B Loads 3, 4
C Load 4 Only

TABLE B3 ATM FILM DOSE IN MDA - RAD

		Shield Box Thickness - Inches Aluminum							
		0	.5	1	2	3	4	5	6
ATM-28									
1	NRL-B	2.42							
2	NRL-A	4.04							
3	ASE	1.34							
4	GSFC	1.84							
5	HAO	2.52							
6	H-ALPHA	1.58							
MDA(A-88)ATM-28, CM-28									
1		8.79	6.78	5.71	4.62	4.11	3.82	3.62	3.49
2		11.53	9.11	7.85	6.59	5.99	5.64	5.43	5.29
3		7.67	5.76	4.69	3.56	3.03	2.70	2.50	2.37
4		13.28	7.94	6.01	4.35	3.65	3.27	3.05	2.92
5		12.14	7.60	6.07	4.69	4.10	3.78	3.57	3.44
6*		12.43	11.58	11.33	11.15	11.08	11.04	11.03	11.01
MDA(A-88, B-28), ATM-28									
1		9.89	7.24	5.83	4.40	3.73	3.34	3.08	2.91
2		12.82	9.62	7.96	6.29	5.50	5.05	4.77	4.58
3		9.01	6.43	4.98	3.47	2.75	2.31	2.04	1.86
4		16.38	9.11	6.50	4.26	3.32	2.82	2.52	2.34
5		14.71	8.60	6.54	4.68	3.88	3.45	3.18	3.00
6*		15.25	14.09	13.75	13.50	13.41	13.35	13.34	13.31
MDA(A-88, B-28, C-86)ATM-28									
1		15.55	10.88	8.41	5.91	4.72	4.03	3.57	3.28
2		19.45	13.83	10.91	7.98	6.60	5.81	5.31	4.99
3		15.67	10.82	8.10	5.28	3.91	3.12	2.62	2.29
4		29.15	15.36	10.46	6.27	4.52	3.62	3.08	2.74
5		25.05	13.79	9.94	6.48	4.99	4.20	3.71	3.38
6*		26.89	24.63	23.99	23.52	23.33	23.23	23.20	23.15

*H-ALPHA CAMERAS ARE OUTSIDE SHIELDING BOXES

TABLE B4 ATM FILM DOSE IN OWS SKIRT - RAD

	Shield Box Thickness - Inches Aluminum							
	0	.5	1	2	3	4	5	6
ATM-28								
1 NRL-B	2.42							
2 NRL-A	4.04							
3 ASE	1.34							
4 GSFC	1.84							
5 HAO	2.52							
6 H-ALPHA	1.58							
OWS(A-88)ATM-28, CM-28								
1	9.34	6.94	5.78	4.64	4.12	3.82	3.62	3.49
2	11.10	8.79	7.61	6.44	5.90	5.59	5.40	5.26
3	9.66	6.51	5.09	3.72	3.10	2.74	2.52	2.39
4	17.76	10.37	7.62	5.21	4.15	3.62	3.31	3.10
5	16.92	10.07	7.62	5.48	4.55	4.07	3.79	3.59
6	16.28	9.41	6.91	4.71	3.76	3.27	2.99	2.79
OWS(A-88, B-28), ATM-28								
1	10.69	7.49	5.94	4.44	3.74	3.34	3.08	2.91
2	12.46	9.28	7.68	6.12	5.40	4.98	4.72	4.54
3	11.58	7.36	5.46	3.64	2.82	2.35	2.06	1.88
4	21.99	12.20	8.55	5.36	3.97	3.27	2.85	2.58
5	21.02	11.81	8.55	5.70	4.47	3.84	3.45	3.20
6	20.41	11.18	7.81	4.86	3.58	2.93	2.55	2.28
OWS(A-88, B-28, C-86)ATM-28								
1	18.89	11.88	8.88	6.06	4.77	4.05	3.59	3.28
2	21.19	13.94	10.79	7.82	6.48	5.72	5.25	4.93
3	20.31	12.21	8.73	5.44	3.96	3.13	2.61	2.28
4	38.02	20.30	13.76	8.06	5.60	4.35	3.62	3.14
5	36.88	19.55	13.49	8.25	6.01	4.87	4.18	3.73
6	36.34	19.17	12.94	7.50	5.18	4.00	3.31	2.83

considerations permit. It is assumed, as a gross approximation, that the configuration rearrangement does not alter the dose estimates of Tables B3 and B4. The shield weight estimates thus obtained are presented in Tables B5 and B6.

Three density levels are investigated for several reasons. First, this approach shows the sensitivity of shield requirements to film degradation tolerance. Second, dose is computed at only one point in the film and is not necessarily the upper limit for that film. Third, some portion of the film degradation tolerance may be allotted to temperature effects, particularly for long storage times.

TABLE B5 ATM FILM SHIELD REQUIREMENTS - MDA STORAGE

Box	Contents		Internal Dimensions Inches			Fogging Density 0.10	0.15	0.20	Fogging Density 0.10	0.15	0.20
						Wall Thickness - In. Al.			Weight - Lbs		
1	NRL A, B	2	16	18	25	.12	.0	.0	27.0	.0	.0
2	NRL A, B	3	16	18	25	.26	.0	.0	59.3	.0	.0
3	NRL A, B	4	16	18	25	1.02	.22	.0	251.1	49.9	.0
4	GSFC, HAO	2	8	9	15	1.35	.49	.16	110.7	34.3	10.5
5	GSFC, HAO	3	8	9	15	1.57	.63	.25	133.9	45.3	16.7
6	GSFC, HAO	4	8	9	15	2.80	1.44	.98	293.5	120.0	75.2
7	ASE	2, 3	16	18	25	1.57	.63	.25	408.1	149.1	56.9
8	ASE	4	8	18	25	2.80	1.44	.98	606.6	266.5	171.6
9	H-ALPHA	4	4	9	15	.22	.0	.0	10.4	.0	.0
						Total Weight			1900.6	665.1	330.9

TABLE B6 ATM FILM SHIELD REQUIREMENTS – OWS STORAGE

Box	Contents		Internal Dimensions Inches			Fogging Density 9.10	0.15	0.20	Fogging Density 0.10	0.15	0.20
						Wall Thickness – In. Al.			Weight – Lbs		
1	NRL A,B	2	16	18	25	.04	.0	.0	8.9	.0	.0
2	NRL A,B	3	16	18	25	.20	.0	.0	45.3	.0	.0
3	NRL A,B	4	16	18	25	1.02	.24	.0	251.1	54.6	.0
4	GSFC, HAO	2	8	9	15	2.12	.91	.47	198.7	68.9	32.8
5	GSFC, HAO	3	8	9	15	2.20	1.10	.70	209.0	86.3	51.0
6	GSFC, HAO	4	8	9	15	3.63	2.08	1.47	433.2	193.6	123.2
7	ASE	2,3	16	18	25	2.20	1.10	.70	607.9	273.0	166.9
8	ASE	4	8	18	25	3.63	2.08	1.47	861.4	415.1	273.1
9	H-ALPHA	4	4	9	15	.38	.10	.0	18.7	4.6	.0
						Total Weight			2634.2	1096.1	647.0

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