SKYLAB D024 THERMAL CONTROL COATINGS AND POLYMERIC FILMS EXPERIMENT

William L. Lehn
Nichols Research Corporation
4141 Col. Glenn Highway
Dayton, OH 45431

Charles J. Hurley
University of Dayton Research Institute
Dayton, OH 45469

INTRODUCTION

The Skylab D024 Thermal Control Coatings and Polymeric Films Experiment (ref. 1,2) was designed to determine the effects of the external Skylab space environment on the performance and properties of a wide variety of selected thermal control coatings and polymeric films. Three duplicate sets of thermal control coatings and polymeric films were exposed to the Skylab space environment for varying periods of time during the mission. The specimens were retrieved by the astronauts during extra vehicular activities (EVA) and placed in hermetically sealed return containers, recovered, and returned to the Wright Laboratory/Materials Laboratory WPAFB, Ohio for analysis and evaluation. Post flight analysis of the three sets of recovered thermal control coatings indicated that measured changes in specimen thermo-optical properties were due to a combination of excessive contamination and solar degradation of the contaminant layer. The degree of degradation experienced over-rode, obscured, and compromised the measurement of the degradation of the substrate coatings themselves. Results of the analysis of the effects of exposure on the polymeric films and the contamination observed are also presented.The D024 results were used in the design of the LDEF M0003-5 Thermal Control Materials Experiment.The results are presented here to call to the attention of the many other LDEF experimenters the wealth of directly related, low earth orbit, space environmental exposure data (ref. 3,4) that is available from the ten or more separate experiments that were conducted during the Skylab mission. Results of these experiments offer data on the results of low altitude space exposure on materials recovered from space with exposure longer than typical STS experiments for comparison with the LDEF results.

NASA SKYLAB SATELLITE

Skylab (SL 1) was launched 14 May 1973 on a Saturn V rocket and placed in a low earth, 415 km orbit with a period of 93 minutes. It was visited by three separate astronaut crews, SL 1/2, SL 1/3, and SL 4, who occupied the facility for a total of 171 days. During this time, it completed some 3900 orbits. The flight occurred during a period of waning, low solar activity. During launch the spacecraft lost its combined micrometeorite/thermal control (heat) shield, leaving the main body and the materials used to bond the external shields exposed.This resulted in a delay in the launch of the first astronaut crew, SL 1/2, while steps were taken to develop and package the "sun shade" as shown in figure 1. This shade was deployed by the first crew to bring the temperature of the Skylab living quarters down to a habitable level. A later crew delivered and installed the "solar sail" which was necessary to further lower the vehicle temperature. One solar array wing was also damaged and lost as a result of the launch problems.

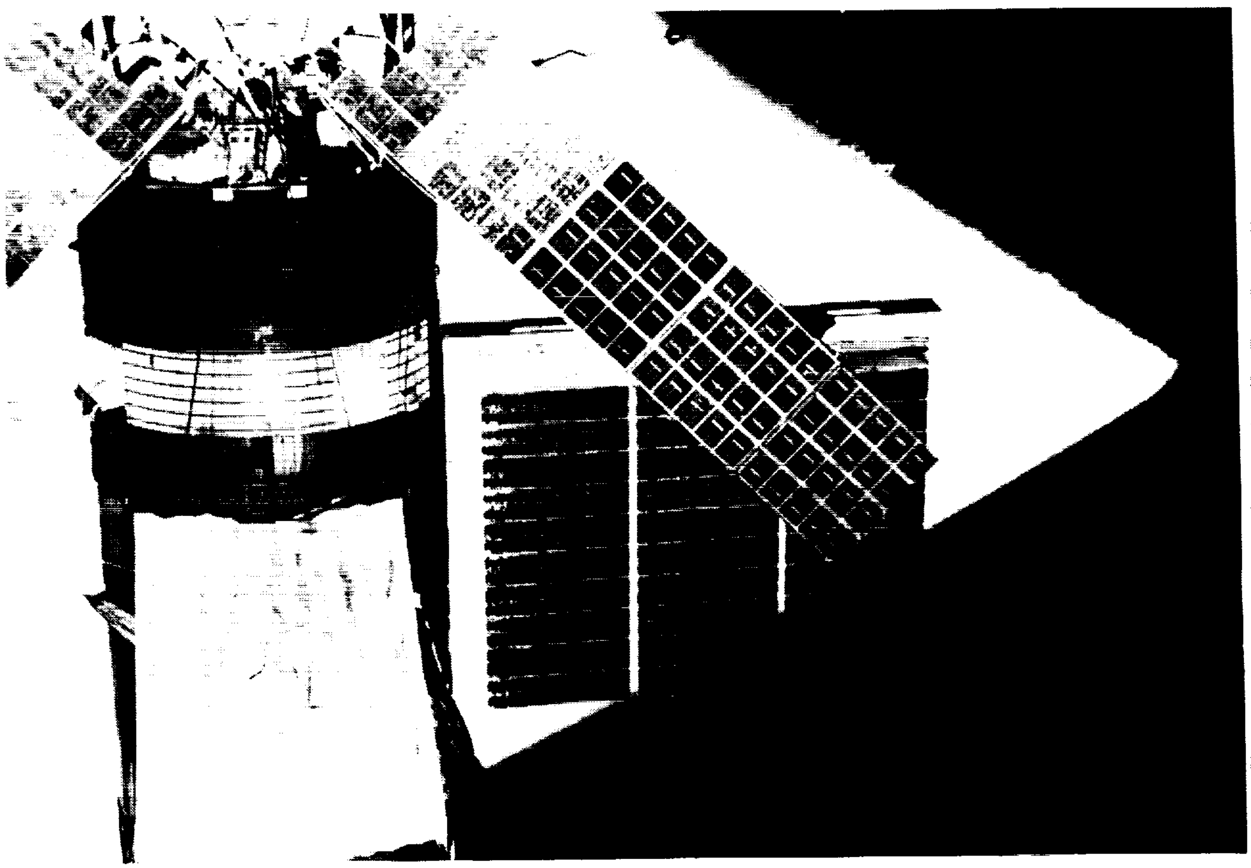

Figure 1. View of Skylab from the Command Module

DO24 EXPERIMENT LOCATION ON SKYLAB

The DO24 flight hardware consisted of four sample panels, two duplicate sample trays each containing 36 individual sample buttons coated with some 27 different selected thermal control coating materials and two duplicate sample trays each holding 8 different polymeric film specimens. The four trays along with two hermetically sealable return containers were mounted on the exterior of the Airlock Module (AM) near the Extra Vehicular Activity (EVA) hatch on the box structure at the right hand of the astronaut. The thermal control trays were mounted and oriented perpendicular to the sun vector of the solar inertially stabilized Skylab (except for selected EREP passes). In this configuration they were subjected to the maximum direct solar exposure. The polymeric films were located some 39° off axis from the solar vector. The first set of specimens, SL 1/2, were retrieved by the first crew after 35 days/550 hours of solar exposure and the second set, SL 1/3, after 131 days/2040 hours of solar exposure as shown in figure 2. The excessive contamination prompted the launch, deployment, exposure, and retrieval of a third set of samples by the SL 4 crew. These samples experienced 74 days/1150 hours of exposure. These samples were also badly contaminated.

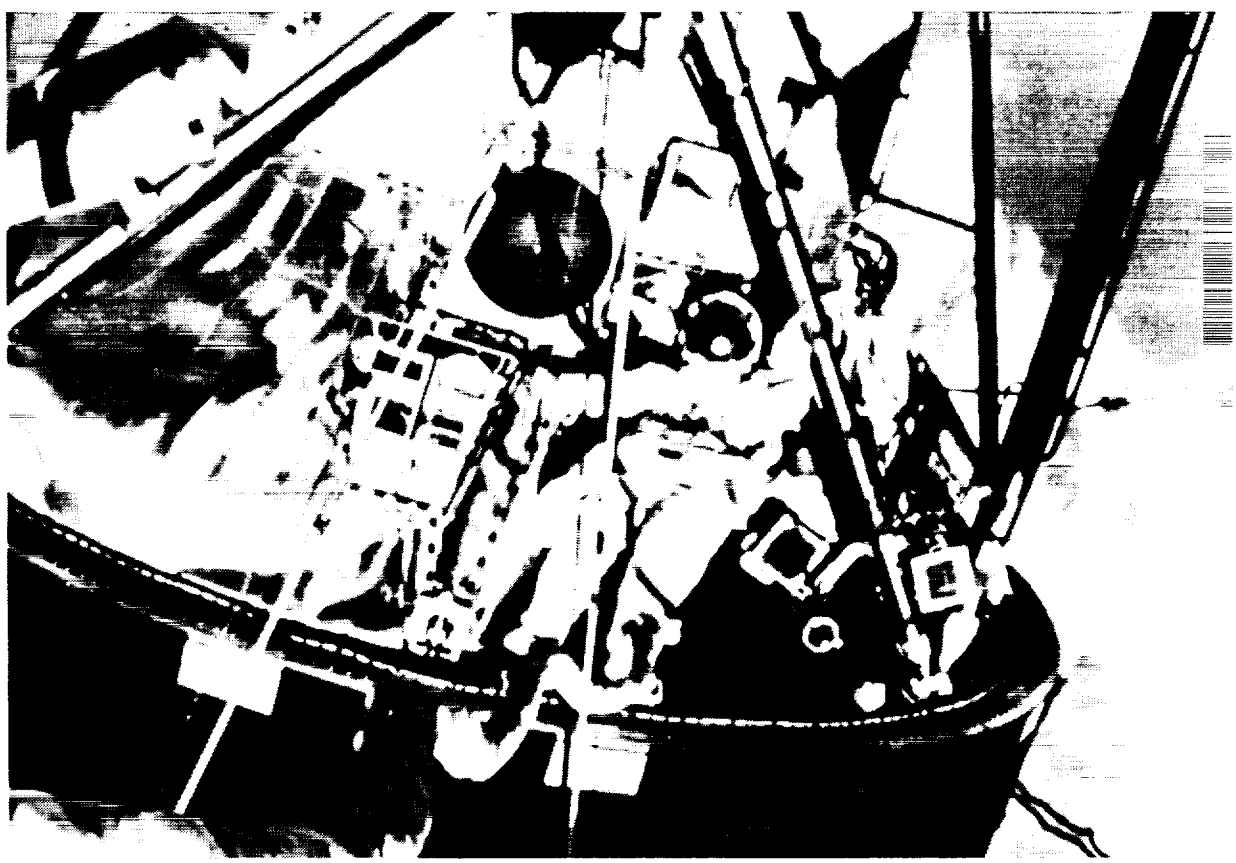

Figure 2. Astronaut Recovery of the DO24 Experiment

D024 THERMAL CONTROL COATINGS MATERIALS POST-FLIGHT SOLAR ABSORPTANCE CHANGES

The list of 36 selected thermal control coating materials flown on the D024 experiment along with the observed changes/delta in solar absorptance experienced are shown in Table 1. These changes all exceeded the expected changes based upon laboratory simulation data or values published in the literature.

MATERIAL	SL 1/2	SL4	SL 1/3
S13	0.091	0.117	0.284
S13G	0.092	0.091	0.237
Z93	0.095	0.006	0.179
SiO_2/MeSi	0.112	0.148	0.202
Eu_2O_3/MeSi	0.105	0.123	0.253
aAl_2O_3/MeSi	0.151	0.173	0.281
Anodized Al 0.5mil	0.310	0.204	0.273
FEP/Al	0.079	0.013	0.246
Fused Quartz/Al	0.057	0.006	0.208
AQ 5um	0.052	0.018	0.120
TiO_2/MeSi	0.147	0.089	0.302
3M Black Velvet	-.007	-.002	-.009
Microsheet/Ag	0.095	0.008	0.218
FEP/Ag	0.049	0.011	0.222
PV-100	0.142	0.125	0.258
aAl_2O_3/KSil	0.167	0.101	0.306
AQ 5um	0.081	0.039	0.105
AQ 5um Processed	0.052	-.018	0.120
AQ 10um	0.078	0.024	0.154
Zn_2TiO_4/MeSi	0.110	0.080	0.248
3D-QFY-Al 150 1/0	0.049	0.077	0.077
SiO_2/Al Interweave	0.064	0.034	0.080
ZrO_2/MeSi	0.211	0.247	0.314
$CaTiSiO_5$/MeSi	0.065	0.068	0.175
3D-QFY-150 1/0 VDA	0.117	0.019	0.096
FEP/Ag	0.049	0.002	0.152
Anodized Al 0.2mil	0.108	0.160	0.220
Anodized Al 0.5mil	0.131	0.204	0.273
LfgAL/SiAcrylic	0.099	0.019	0.145
S13G	0.105	0.122	0.251
Z-93	0.077	-.002	0.174
FEP/Al	0.064	0.071	0.157
3M Black Velvet	-.008	-.015	-.005
3M Black Velvet	-.011	-.006	-.006
Alzak Anodized Al	0.064	0.023	0.136
Zn_2TiO_4/MeSi	0.080	0.055	0.234

Table 1. DO24 Post Flight Absorptance Changes

D024 THERMAL CONTROL SPECIMENS AND TRAYS

The degradation/darkening of the thermal control coatings recovered by SL1/2 and SL 1/3 crews is apparent when compared with a set of preflight controls as shown in figure 3. The excessive discoloration is a result of excessive contamination followed by degradation/darkening of the contaminant layer by the solar exposure.

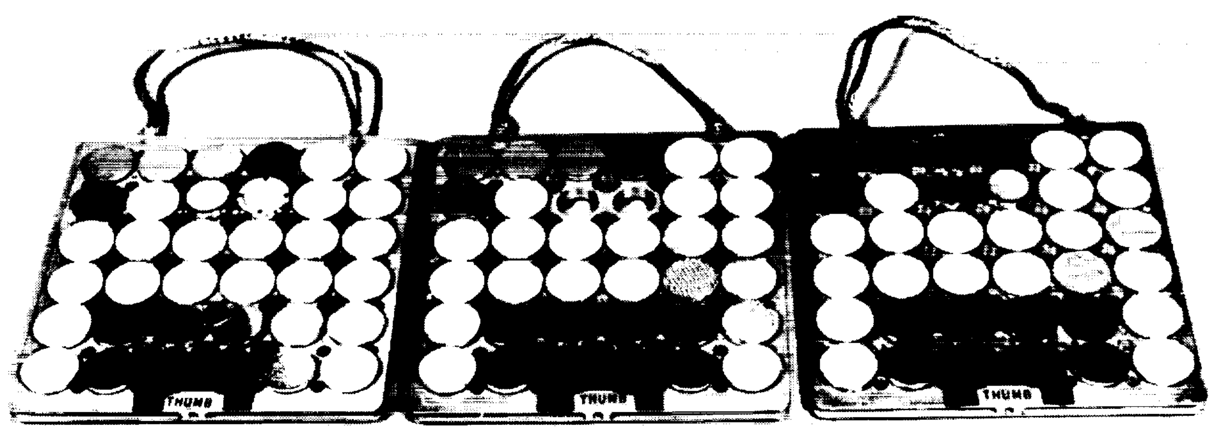

Figure 3. Comparison of DO24 Control and SL1/2 and SL1/3 Thermal Control Specimens

D024 THERMAL CONTROL TRAYS
LABORATORY CONTROL AND RECOVERED FLIGHT TRAYS

The degradation/darkening of the thermal control coatings due to contamination was also experienced on the SL 4 set of specimens and is apparent from the comparison of all three sets of specimens compared to a set of preflight controls as shown in figure 4. The SL 4 specimens were deployed after docking of the Command Module and recovered prior to undocking ruling out the Service Module Reaction Control System propellant by-products as a major source of contamination. Samples of the metallic silver coating on the surface of Sloan thickness monitor crystals exposed to the Skylab environment were badly degraded/oxidized. The reaction of the Ag with hydroxyl radicals formed due to the presence of large concentrations of water in the Skylab atmospheric "cloud" was proposed as a possible mechanism. The projected column densities of water vapor in the Skylab "cloud" also affected the sensitivity of measurements on other instruments. Atomic oxygen was mentioned but the role of "AO" in such phenomena was not really appreciated until the more recent Shuttle experiences.

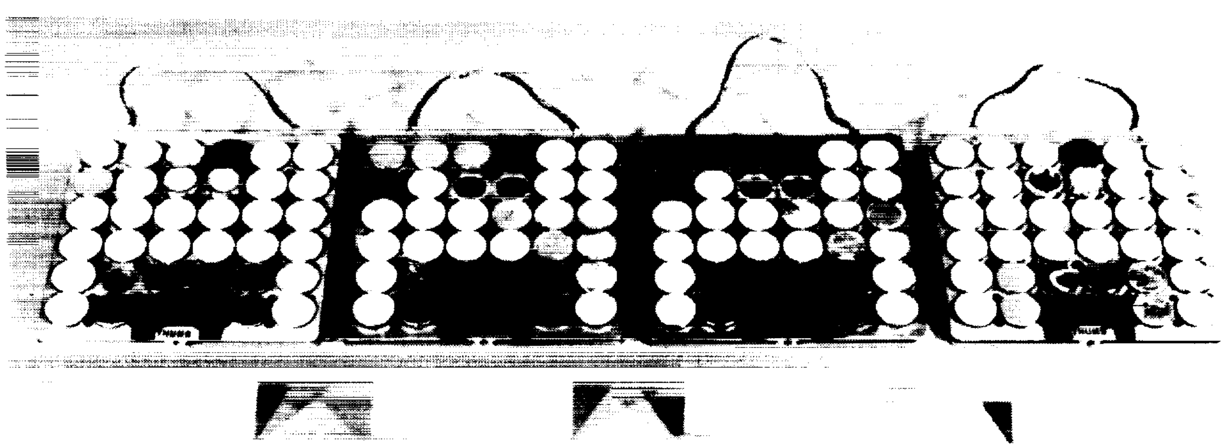

Figure 4. Comparison of Preflight and Post Flight Thermal Control Coatings Trays

SKYLAB CHANGES IN SOLAR ABSORPTANCE FOR SL1/2 - SL 4 - SL 1/3

The changes in solar absorptance for the thermal control coating materials flown on the three D024 Thermal Control Coating Trays have been plotted to show the changes which occurred and are shown in figure 5 and figure 6. The solar exposure times are: SL 1/2, 35 days/550 hours; SL 4, 74 days/1150 hours; and SL 1/3, 131 days/2040 hours. The primary increase in absorptance is due to the presence of contamination on the surfaces of the coatings. The degradation due to damage to the coating itself is largely obscured. There is some indication of the decrease in contamination level, lower values of absorptance for the SL 4 specimens. The values for the Ag and Au coated Sloan thickness monitor are not plotted. The Ag specimens were all severely oxidized all the way through the thickness to a blue/black amorphous mass. Areas of the Ag surface protected by the mechanical retaining ring were unchanged.

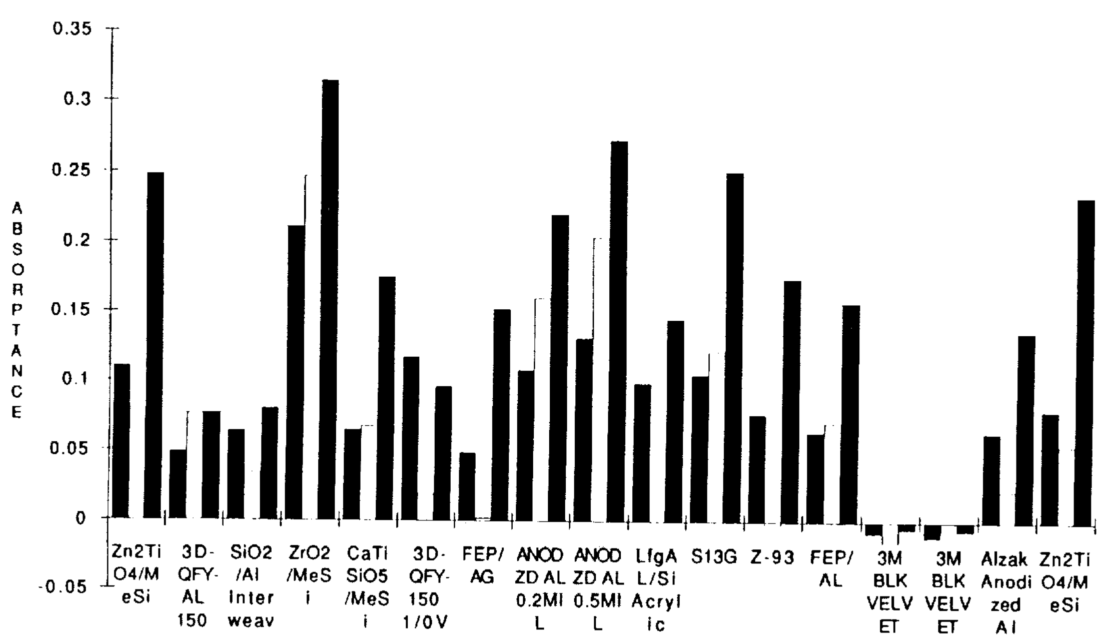

Figure 5. Solar Absorptance Changes for Thermal Control Coatings(Sl 1/2, SL 4, SL 1/3)

SKYLAB CHANGES IN SOLAR ABSORPTANCE FOR SL1/2 - SL 4 - SL 1/3

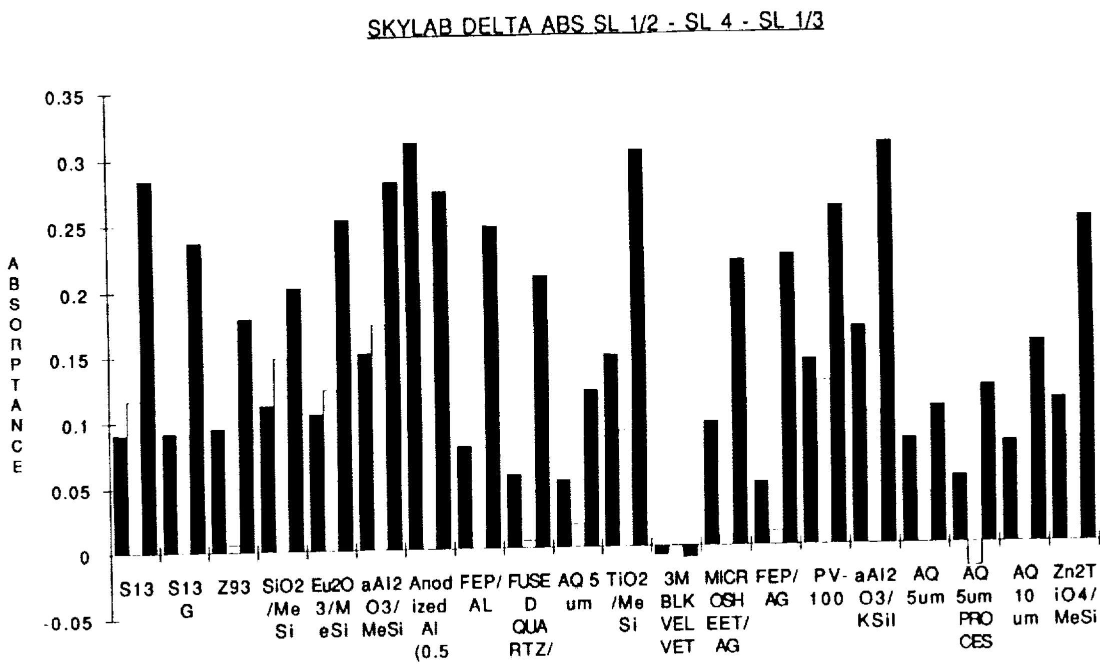

Figure 6. Solar Absorptance Changes for Thermal Control Coatings(Sl 1/2, SL 4, SL 1/3) Continued

EFFECTS OF SKYLAB EXPOSURE ON FUSED QUARTZ/AL

The effects of the Skylab exposure on a fused quartz/Al second surface mirror/OSR are shown in figure 7. The excessive degradation is attributed to the excessive contamination associated with the Skylab environment followed by further fixing and degradation of the contaminant layer by continued solar exposure.

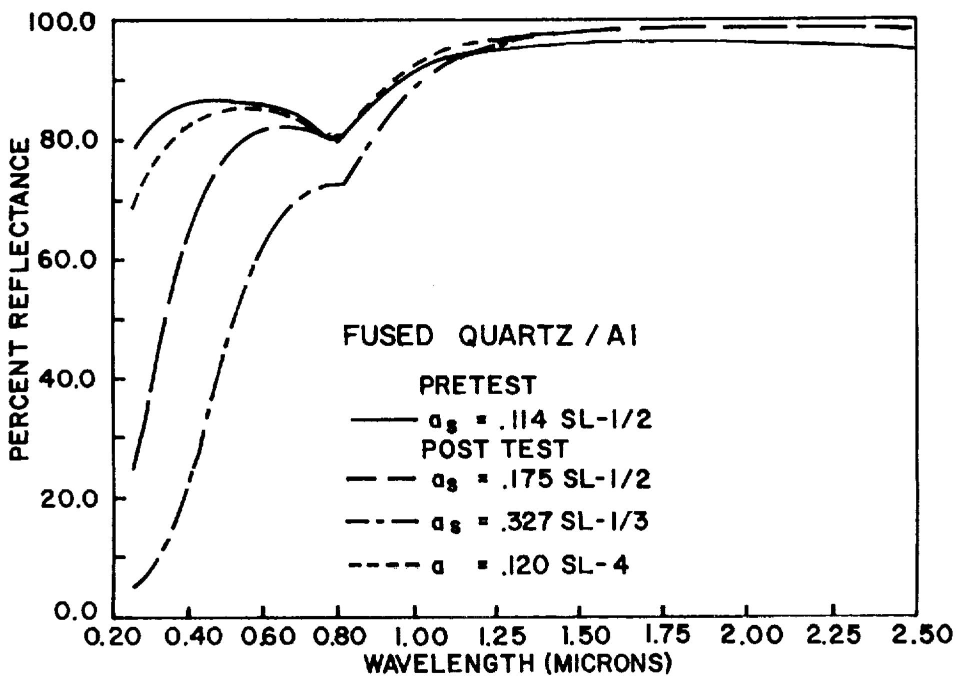

Figure 7. Effect of Skylab on Fused Quartz/Al

The degradation in transmission of a sample of FEP Type A shows the effects of the contaminant layer. Comparison with the reflectance data of samples of FEP/Ag flown on LDEF are quite similar in appearance and indicate the presence of a degraded contamination layer as shown in figures 8 and 9.

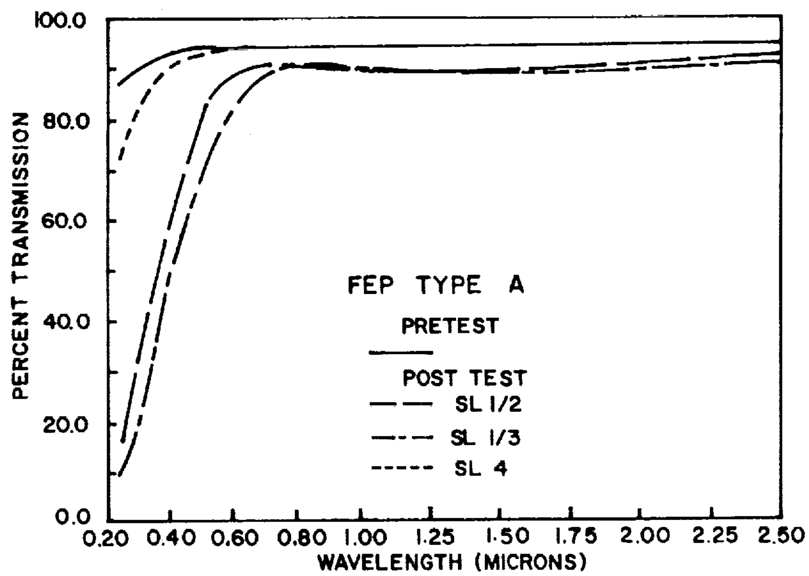

Figure 8. Effect of Skylab Exposure on FEP Type A

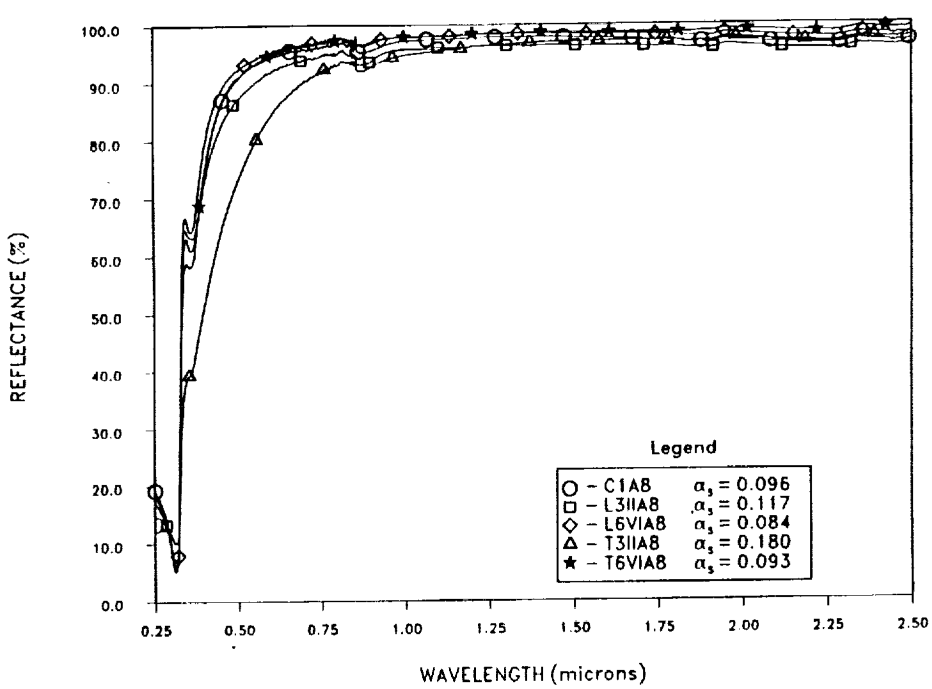

Figure 9. Effect of LDEF Exposure on FEP Type A

EFFECTS OF SKYLAB AND LDEF EXPOSURE ON S13 AND S13 GLO THERMAL CONTROL COATINGS

The pre- and post-flight reflectance spectra of samples of S13 and S13 GLO white thermal control coating paints flown on D024 and LDEF show similar changes. Contamination of these surfaces followed by degradation of the contaminant layer is proposed as the principal mechanism to account for these observed changes as shown in figures 10 and 11.

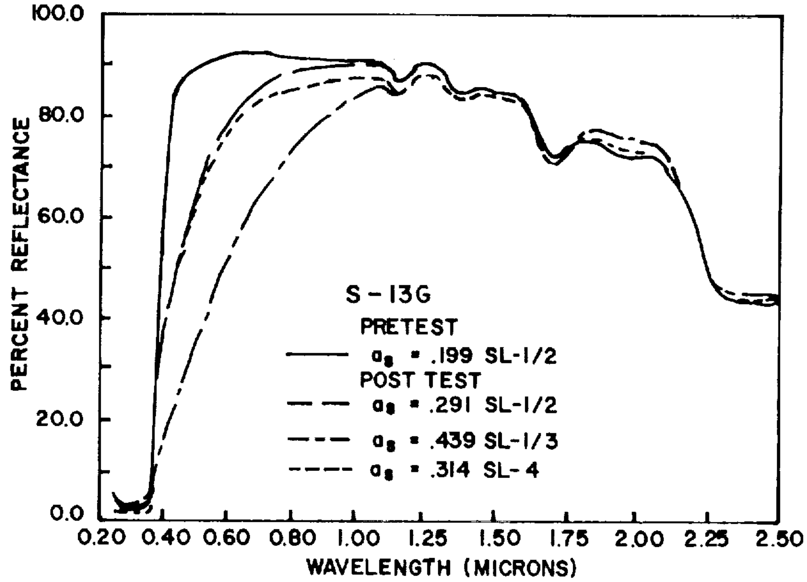

Figure 10. Effect of Skylab Exposure on S13 G

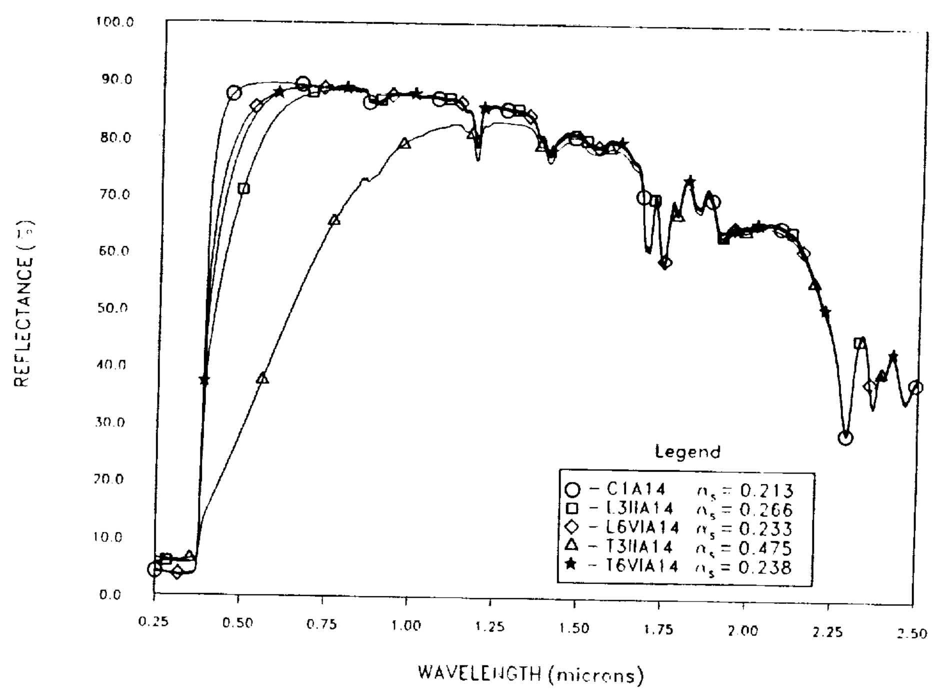

Figure 11. Effect of LDEF Exposure on S13 GLO

D024 POLYMERIC FILM STRIP TRAYS

Discrete shadow patterns of contamination were evident on all three sets of returned thermal control coating and polymeric film sample trays. They clearly demonstrated the excellent sun orientation maintained by the Skylab throughout the majority of the mission. Shadowed/clear areas exhibited only traces of contamination while the yellow/gold/brown areas showed the presence of SiOx containing contaminants. Photos of the lower areas of the Apollo Telescope Mount displayed similar effects of degradation/shadowing in those areas exposed to the sun. Low molecular weight contaminants, which outgas, were free to deposit and re-evaporate and/or migrate along the spacecraft surfaces until they reached a solar exposed area, reacted with UV, and increased in molecular weight becoming fixed/immobile. There they continued to degrade and add further amounts of contaminants as the flight continued. A comparison of a preflight tray and a flight tray are shown in figure 12.

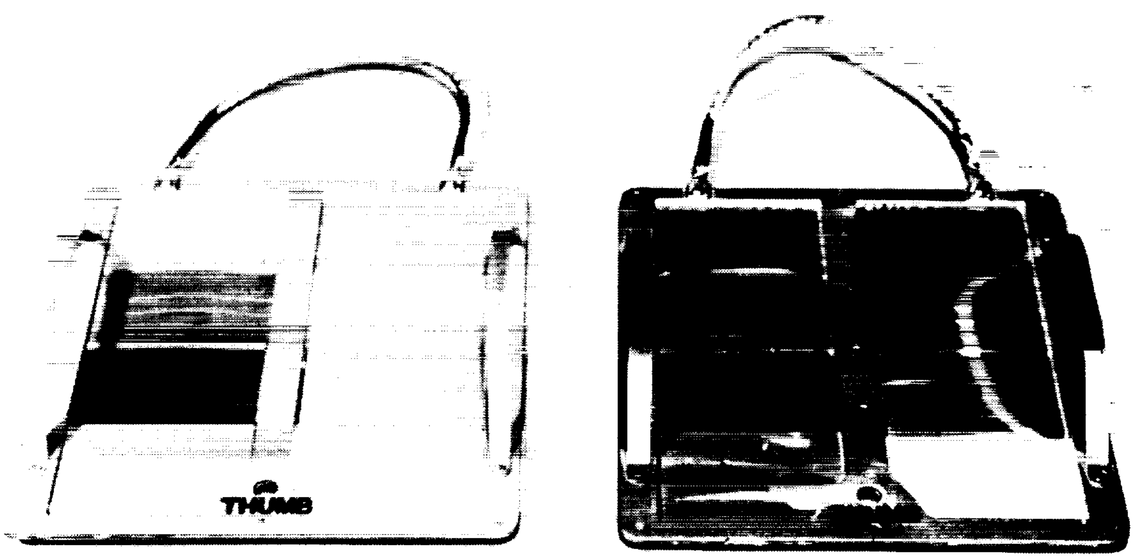

Figure 12. Comparison of DO24 Polymer Film Strip Trays

D024 RETURN CONTAINERS

The presence of contamination is clearly evident by the shadow patterns displayed on the D024 Return Containers as shown in figure 13. The sharp line on the sides marks the shadowing which occurred while the containers were mounted extending down in the box structure. The excellent-solar inertial attitude orientation of Skylab is again readily apparent as is the angle of the containers relative to the sun vector.

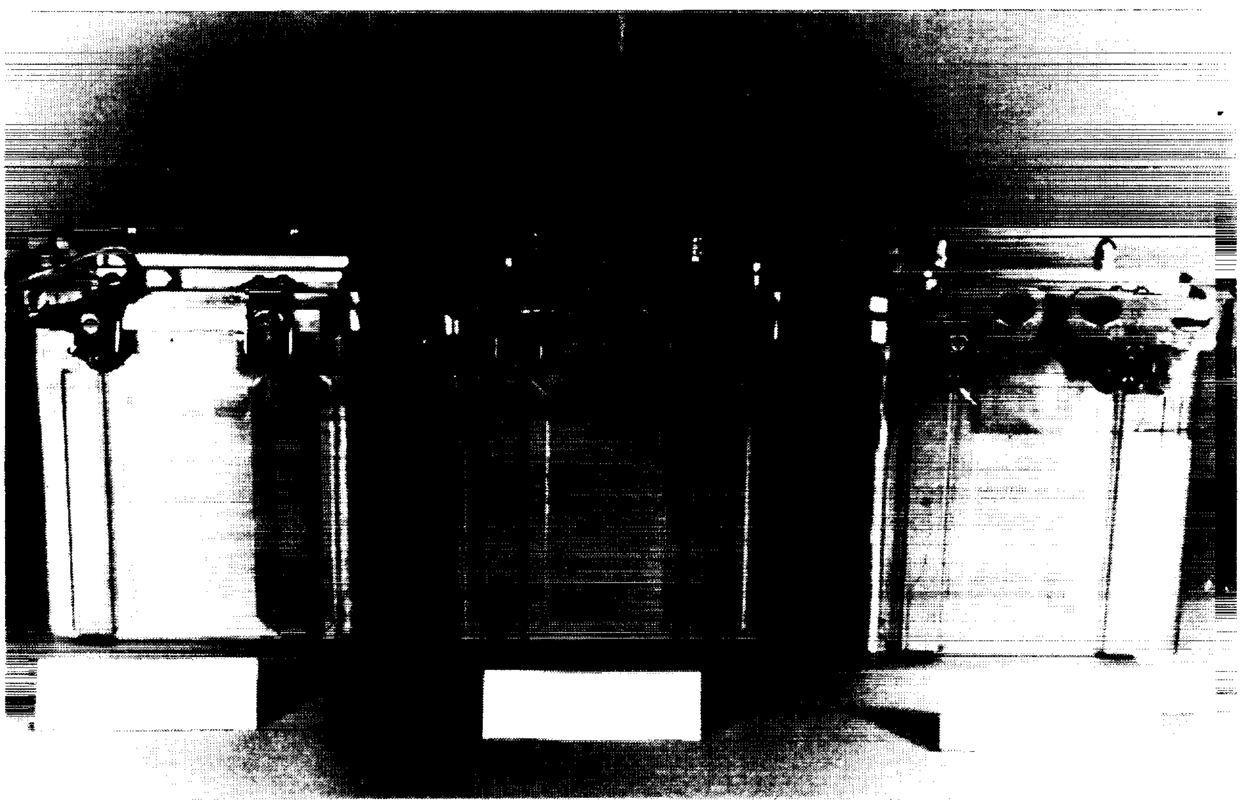

Figure 13. Comparison of DO24 Flight Experiment Containers

SKYLAB D024 POLYMERIC FILMS EXPERIMENT POST TEST SL 1/3

Results of the Skylab D024 Polymeric Films Experiment Post Test results from SL 1/3 are shown in table 2. Overall results from all three sets of returned specimens have been previously reported (ref. 2).

MATERIAL	%ELONGATION	TENSILE STRENGTH PSI X 10^3	MODULUS PSI X 10^6	YIELD PSI X 10^6	REMARKS
Nylon 6/6	49.3	5.1	.23	4.0	Severe Crosslinking
Polyimide	37.2	11.3	.19	3.2	Slight Degradation
Polyphenyl Quinoxaline	4.4	6.5	.215	4.0	Moderate Degradation
FEP Type A	224.5	1.9	.037	0.7	Mild Crosslinking
Polycarbonate	53.9	4.5	1.6	3.2	Slight Degradation
Mylar	*12.9	8.1	.31	5.8	Degradation & Crosslinking
FEPXC20	248.0	1.6	.035	0.7	Increased Crosslinking
Teflon	105.8	1.2	.04	.07	Degradation & Slight Crosslinking

* Average of three tests.

Table 2. Tensile Properties of SL 1/3 Polymeric Films

CONTAMINATION HISTOGRAM FOR SKYLAB MDA

The contamination buildup as a function of time was measured by microbalances on the Skylab docking adapter. Crystals facing along the longitudinal axis registered the highest contamination rates. Crystals that faced away from the vehicle collected deposits presumably consisting of contaminants which originated from the space station and whose molecules were back-scattered by the atmosphere around the space station. Early in the mission, the crystal facing the command module was contaminated by the steering-rocket exhaust (ref. 3). A histogram is illustrated in figure 14.

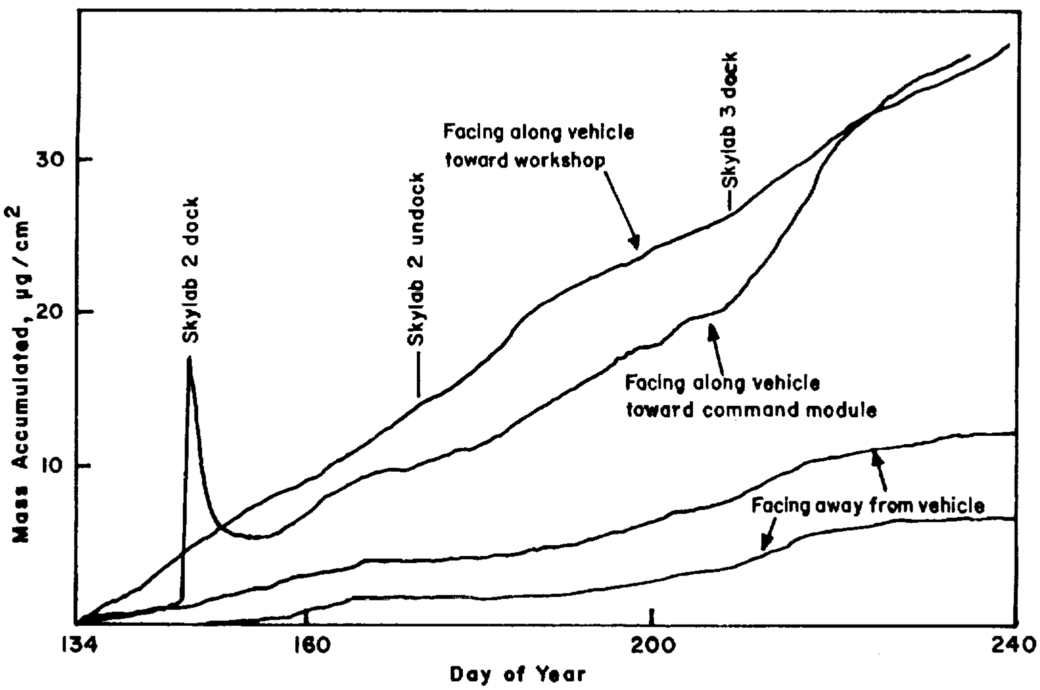

Figure 14. Histogram of Contamination for Skylab MDA

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