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**Evaluation of Certain Material Films Flown
on the Space Shuttle Mission 46, EOIM III
Experiment**

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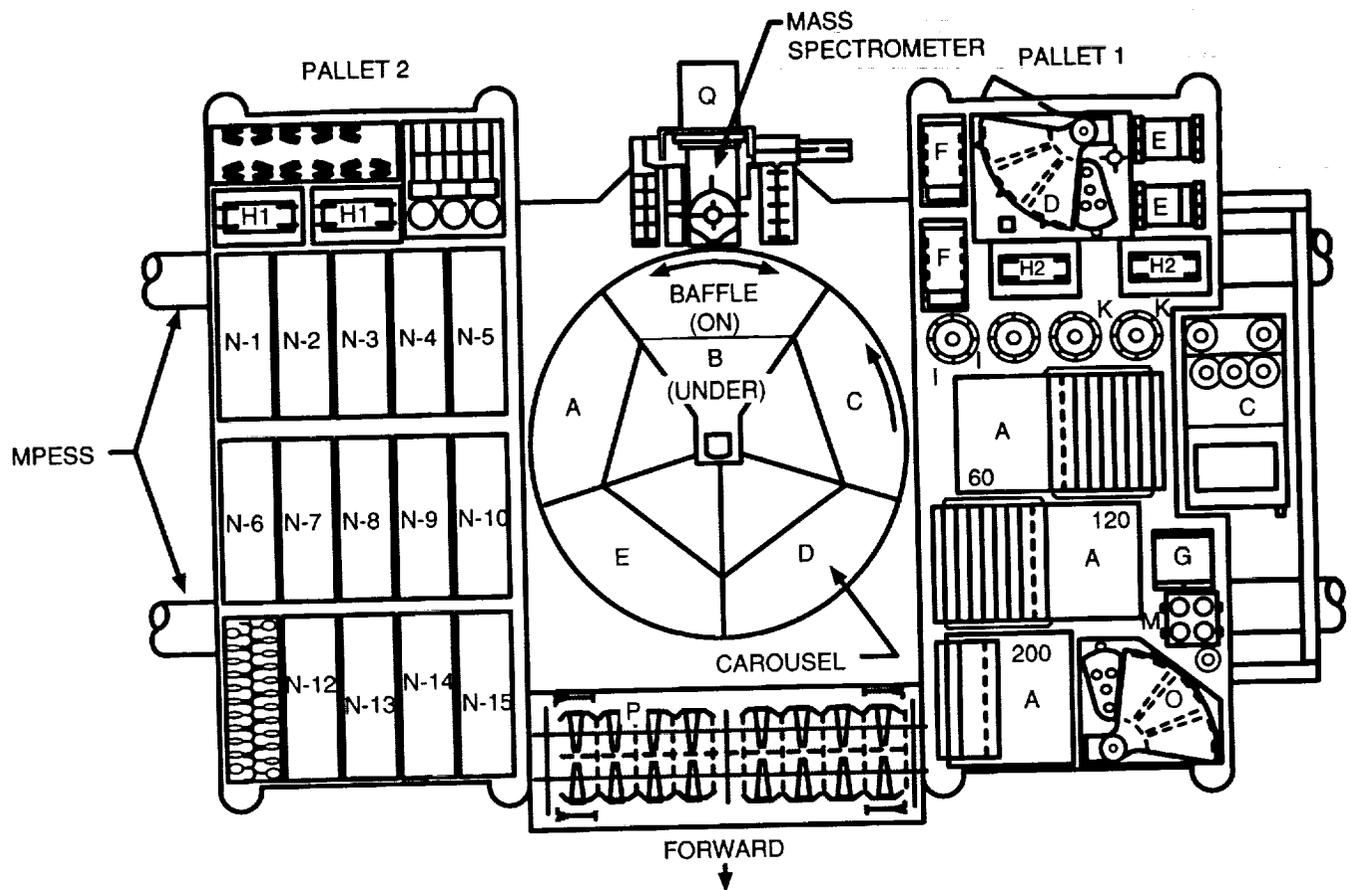
ABSTRACT

Nine film samples were carried aboard the STS-46 Atlantis shuttle to complement the "Evaluation of Oxygen Interaction with Materials (EOIM-III)" experiment to evaluate the effects of atomic oxygen on materials and to monitor the gaseous environment in the shuttle bay. The morphological changes of the samples produced by the atomic oxygen fluence of $2.07\text{E-}20$ atoms/cm² have been reported. The changes have been verified using X-ray Photoelectron Spectrometer (XPS) also known as Electron Spectroscopy for Chemical Analysis (ESCA), gravimetric measurements, microscopic observations and thermo-optical measurements. The samples including Kapton, Tefzel, Aclar, Polyacrylonitrile film, and Llumalloy films have been characterized by their oxygen reaction efficiency on the basis of their erosion losses and the fluence. Those efficiencies have been compared with results from other similar experiments, when available. The efficiencies of the samples are all in the range of E-24 gm/atom.

1.0 INTRODUCTION

The Shuttle STS Mission 46 of July/August 1992 carried in orbit a large number of experiments collectively grouped under the designation of Evaluation of Oxygen Interaction with Materials—Third Phase (EOIM-III). As indicated, the experiments had been designed: to provide atomic oxygen reactivity measurements; to gain understanding of its reaction mechanism and dynamics; and to characterize the induced environment in the shuttle bay. The instruments used to carry out these functions are indicated in figure 1. They include a mass spectrometer for measurement of the gaseous atomic fluxes and other instruments to verify the environment, the direction and energies of the various fluxes. Among these instruments, 15 were passive tray carriers, identified in the figure by the letter N, carrying samples provided by the NASA centers, the Jet Propulsion Laboratory (JPL), the Aerospace Corporation, the University of Alabama, the European Space Agency (ESA), the Canada Space Agency, and the Japan Space Agency. These trays, shown in figure 2, included nominal openings of 1/2" and 1" diameter which accommodated materials samples mounted on aluminum substrate disks. While some trays were temperature controlled, the passive trays were not. Among these passive trays, the one indicated as N-5 was provided by the Materials Branch of Goddard Space

Flight Center (GSFC). It included 49 samples prepared by GSFC, 27 by GE-Astro, 4 by IITRI, and 2 by Martin Marietta. The samples as shown in table 1 consisted of thermal control paints, films, coatings, and other assembly and construction materials. This report will cover the samples prepared by GSFC, since the guest samples were returned for analyses to their respective organizations. Of the GSFC samples, only the film samples will be reported in this paper. The analyses were carried out to evaluate the effects that the atomic oxygen flux, in conjunction with UV radiation, ionizing radiation, thermal cycling, plasma interaction, and micrometeoroid/debris, has on materials used or proposed for space applications. Those environments and especially Atomic Oxygen (ATOX) modified by orbit altitude, spacecraft inclination, and by instruments orientation, have been shown by many flight experiments to degrade materials and spacecraft performances. The characterization of those effects consists of the evaluation of the exposed material's thermo-optical properties, its surface erosion and the rates of changes of those parameters.



ATOMIC INTERACTION EXPERIMENTS:

- A - HEATED PLATE (JSC), 3EA
- B - ATOM SCATTERING EXPERIMENT (UAH), 1EA
- C - ENVIRONMENT MONITOR PACKAGE (GSFC), 1EA
- D - SOLAR UV EXPERIMENT (JSC), 1EA
- E - STATIC STRESS FIXTURE (MSFC), 2EA
- F - UNIFORM STRESS FIXTURE (MSFC), 2EA
- G - ATOMIC OXYGEN MONITOR (MSFC), 1EA
- H1 - COMPOSITE STRESS FIXTURE (LaRC), 2EA
- H2 - COMPOSITE STRESS FIXTURE (JSC), 2EA

- I - SCATTEROMETER (JPL), 2EA
- J - MECHANICAL STRESS FIXTURE (LeRC), 11EA
- K - REFLECTOMETER (LeRC), 2EA
- L - PINHOLE CAMERA (LeRC), 1EA
- M - SCATTEROMETER (AEROSPACE CORP.), 1EA
- N - PASSIVE SAMPLE CARRIERS, 15EA
- O - VARIABLE EXPOSURE TRAY, 1EA
- P - FREEDOM ARRAY MATERIALS EXPOSURE EXPERIMENT (LeRC), 1EA
- Q - QUADRUPLE MASS SPECTROMETER, 1EA

Figure 1. A line drawing of the EOIM-III payload identifying the various features. The forward edge of the payload is at the bottom of the line drawing.

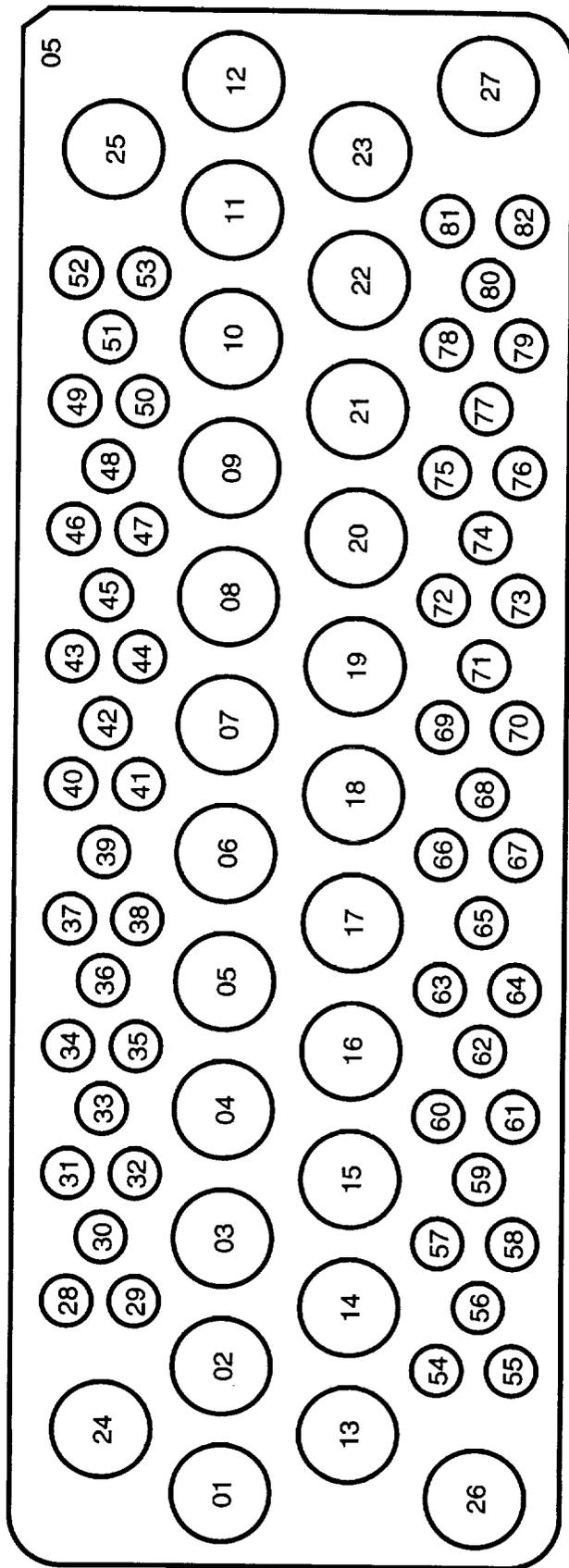


Figure 2. EOIM-III Sample Carrier Viewed in the Inverted (Loading) Position

Table 1. Material List for Tray N-5 of EOIM-III

ID NO.	MATERIALS DESIGN	CHEMICAL TYPE	USE
W-30	KAPTON 200 XC	CONDUCTIVE POLYIMIDE	FILM
X-31	ACLAR 22C	FLUOROPOLYMER	FILM
X-32	TEFZEL 500LZ	FLUOROPOLYMER	FILM
X-37	TEFZEL COATED WITH SiO _x	FLUOROPOLYMER	FILM
X-61	PAN FILM	POLYACRYLONITRILE	FILM/COATING
X-62	PAN FILM WITH COBALT CHLORIDE	POLYACRYLONITRILE WITH COBALT CHLORIDE	FILM
X-70	LLUMALLOY WITH NICKEL ALLOY COATING EXPOSED	POLYESTER WITH A NICKEL ALLOY COATING	FILM
X-44	LUMALLOY WITH POLYESTER SURFACE EXPOSED	POLYESTER WITH A NICKEL ALLOY COATING	FILM
X-43	CRYOVAC	POLYETHYLENE/ ESTER	FILM

Experimental

The STS-46 Atlantis flew at an altitude of 228-230km (123-124 miles) with an orbital inclination of 28°. The trays and other experiments were exposed for 58 hours. The material oriented for normal incidence were exposed to average oxygen fluxes of $1.5 \times 10^{15} \text{ cm}^{-2}\text{s}^{-1}$ consisting mainly of O, O₂, N₂, and H. The temperature was passively controlled and with some exceptions, it ranged between 15 °C and 40 °C. The atomic oxygen fluence was $2.07 \times 10^{20} \text{ atoms/cm}^2$. This fluence was agreement with a fluence based on the Kapton erosion and its reaction efficiency (see ref. W-30).

Prior to the flight, the samples were vacuum baked at 65 °C for 48 hours. The mass of those samples were recorded after the bakeout. An additional mass measurement was carried out at a date near the launch flight date. On return from flight, the samples were reweighed. An additional mass measurement of the sample was carried out after exposure to a vacuum for 48 hours at 20 °C. This last measurement was carried out to eliminate any contaminants which could have been deposited on the sample from the time of landing. The mass loss in orbit is then assumed to be the difference from the mass measured nearest to the launch time and the mass measured after the last vacuum exposure at 20 °C.

The results are shown in table 2. Based on this mass loss and the fluence, a reaction efficiency has been calculated. It should be noted that the samples have been protected continuously against possible contamination.

The characterization of each film sample is indicated in the following pages and it includes: the data and the measurements taken, the sample descriptions, and the sample analyses.

2.0 DATA AND MEASUREMENTS TAKEN

The effect of the space environment on these samples is indicated by providing the following descriptive parameters.

The sample weight loss, (gm), is the difference between the weight of the samples before and after the missions.

A comparison of the spectral reflectance and the integrated absorption of the coatings before and after space environment exposure—the measurements were made using the P.E. λ-9 spectrophotometer. The emittance of the non-exposed (control) sample is indicated. The emittance of the flown samples could not be measured because of their physical sizes.

Surface analysis of the samples—The surface science instrument M-Probe ESCA was used to determine elemental compositions and chemical bonding states of the samples. The ESCA is capable of analyzing the first 100 Å of surface.

Photographic and microscopic documentation—This shows the reference and flight surface appearances and related evaluation of the changes that may have occurred during space exposure.

Table 2. Summary of Oxygen Reactions

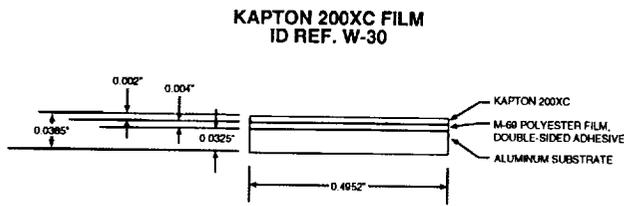
ID	FILM	THICKNESS		REACTION RATES TOTAL AREA		REACTION RATES EXPOSED AREA		REACTION RATES FROM REFERENCES		THERMO - OPTIC PROPERTIES REFLECTANCE		ABSORPTANCE	
		cm	(in.)	g/ATOM	cm ² /ATOM	g/ATOM	cm ² /ATOM	cm ³ /ATOM	REF.#	BEFORE	AFTER		
W-30	KAPTON 200XC	5.08E-3	(0.002)	2.260E-24	1.63E-24	3.48E-24	2.49E-24	1.5 - 3E-24	2	LOSS OF REFL. ~ 4% AT 300< λ<700 nm	0.923	0.959	
X-31	ACLAR 22C	0.0127	(0.005)	2.087E-24	1.03E-24	3.21E-24	1.58E-24	1.10E-24	1	LOSS OF REFL. ~ 7-8% AT 300< λ<2400 nm	0.442	0.494	
X-32	TEFZEL 500LZ	0.0127	(0.005)	1.276E-24	7.59E-24	1.97E-24	1.17E-24	1 - 1.3E-24	1	LOSS OF REFL. ~ 5% AT 300< λ<2400 nm	0.481	0.517	
X-37	TEFZEL w/SiOx			4.080E-24	2.02E-25	6.20E-25	3.07E-25	NA	NA	LOSS OF REFL. ~ 3% AT 300< λ<400 nm	0.508	0.533	
X-61	PAN*	5.08E-03	(0.002)	3.122E-24	NA	4.80E-24	NA	NA	NA	NA	NA	NA	
X-62	PAN w/C6Cl2	5.08E-03	(0.002)	1.812E-24	NA	2.78E-24	NA	NA	NA	NA	NA	NA	
X-70	LLUMALLOY		SPUTTERED	1.034E-24	NA	1.59E-24	NA	NA	NA	INTERFERENCES ELIMINATED, 5% INCREASE IN REFL.	0.762	0.723	
X-44	LLUMALLOY POLYESTER EXP.	5.08E-03	(0.002)	4.197E-24	3.10E-24	6.47E-24	4.78E-24	2.7-2.9E-24	2	INCREASE REFL. ~ 60% AT 500< λ<700 nm ~ 5% INCREASE ALL OTHER λ	0.772	0.75	
X-43	CRYOVAC	5.08E-03	(0.002)	3.334E-24	NA	5.14E-24	NA	NA	NA	LOSS OF REFL. 5-10% AT 300< λ<2400 nm	0.472	0.56	

NOTE: FLUENCE: 2.07E20 ATOM/cm²
 FLIGHT: STS-46 ATLANTIS
 ORBIT: 228-230km, 28° INCLIN.
 TOTAL AREA: 1.2449 cm²
 EXPOSED AREA: 0.810732 cm²
 * PAN (POLYACRYLONITRILE)

3.0 SAMPLE DESCRIPTIONS

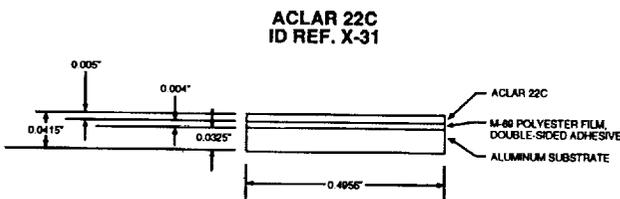
Kapton - 200 XC (Ref. W-30)

This polyimide film with conductive carbon is used as an antistatic sheet, EMI shield, and as thermal covers sheet. The physical and electrical properties are available from the Dupont Corporation. The dimensions of the sample and its composition are shown in this figure.



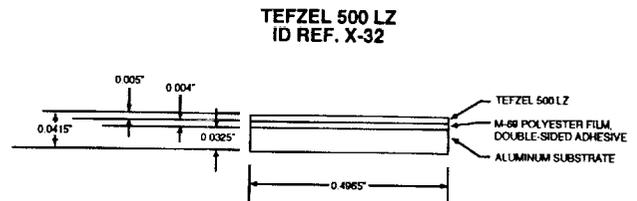
Aclar 22 C (Ref. X-31)

This is a fluoropolymer film consisting of Chlorotetrafluoroethylene (CTFE). It is used primarily as an encapsulating film for electro-luminescent lamps and is generally used for space applications and clean room packaging. It is transparent to UV, is chemically stable, is non-flammable, has a low dielectric constant, and is a moisture barrier. Its properties are available from the manufacturer—Allied Signal. The arrangement of the samples and relative dimensions are as shown here.



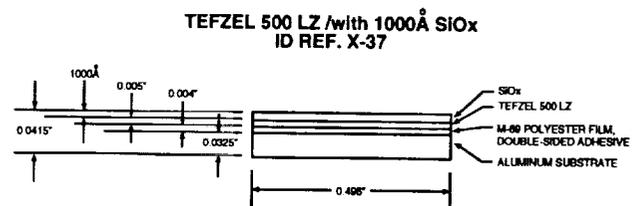
Tefzel 500 LZ (Ref. X-32)

This is a general purpose polymer film produced by Dupont. The material is a copolymer of tetrafluoroethylene. Its color ranges from clear to translucent, depending on its thickness. The sample arrangement is shown here.



Tefzel 500 LZ (SiOx) (Ref. X-37)

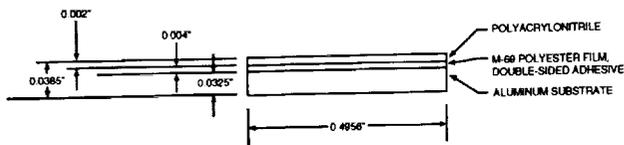
This is the same material of the Tefzel 500 LZ but includes vapor deposited SiOx on the exposed surface. This provides a film with an index of refraction of 1.51 which closely matches SiO₂ index. It is used for space application requiring the above index of refraction and protection against UV radiation. The sample arrangement is as follows:



PAN Film (Ref. X-61)

This is a polyacrylonitrile (PAN) film 0.002 inches thick. The film is usable for packaging, encapsulating, and was developed for some specific applications. It is a conductive film.

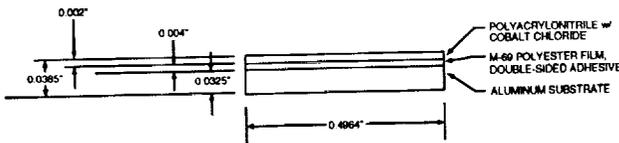
POLYACRYLONITRILE (PAN)
ID REF. X-61



PAN With Cobalt Chloride (Ref. X-62)

As with the previous PAN film, this is a variation of the polyacrylonitrile including cobalt chloride. Again, this was a film under development for use as needed.

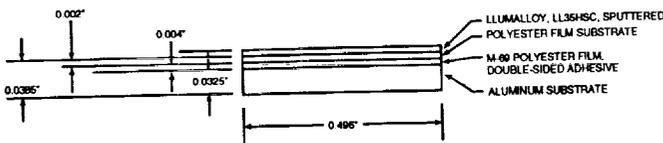
POLYACRYLONITRILE (PAN) w/ COBALT CHLORIDE
ID REF. X-62



Llualloy LL35HSC (Ref. X-70),
Llualloy Exposed to Oxygen

This is a sputtered nickel alloy on a polyester film used for electrostatic discharge packaging. The film is light transparent and optically clear with chemical compatibility characteristics. It is a product of Cortaulds Corporation.

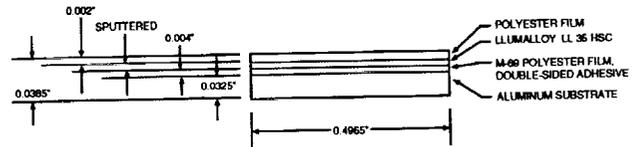
LLUMALLOY, LL35HSC, LLUMALLOY EXPOSED
ID REF. X-70



Llualloy LL35HSC (Ref. X-44),
Polyester Exposed to Oxygen

The exposed face for this sample was the polyester base of the Llualloy and the arrangement is as follows:

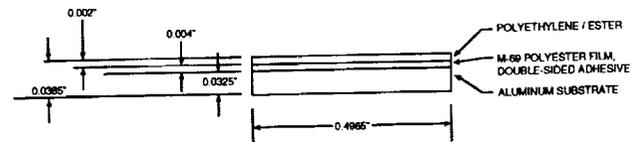
LLUMALLOY, LL35HSC, POLYESTER EXPOSED
ID REF. X-44



Cryovac (Ref. X-43)

Cryovac is a trademark for a shrink-film, transparent packaging material based on polyvinylidene chloride. It is used for packaging.

POLYETHYLENE / ESTER (CRYOVAC)
ID REF. X-43



4.0 SAMPLE ANALYSIS

Kapton 200XC (Ref. W-30)

Visual Inspection

The area shielded by the sample mounting tray is dark gray with several opaque scratches. The exposed area is velvet black with a few scratches and several minute silver particles are also shown. (See fig. 3).

High Magnification Inspection

The exposed region is darker with a rougher surface than the shielded areas. There are several very

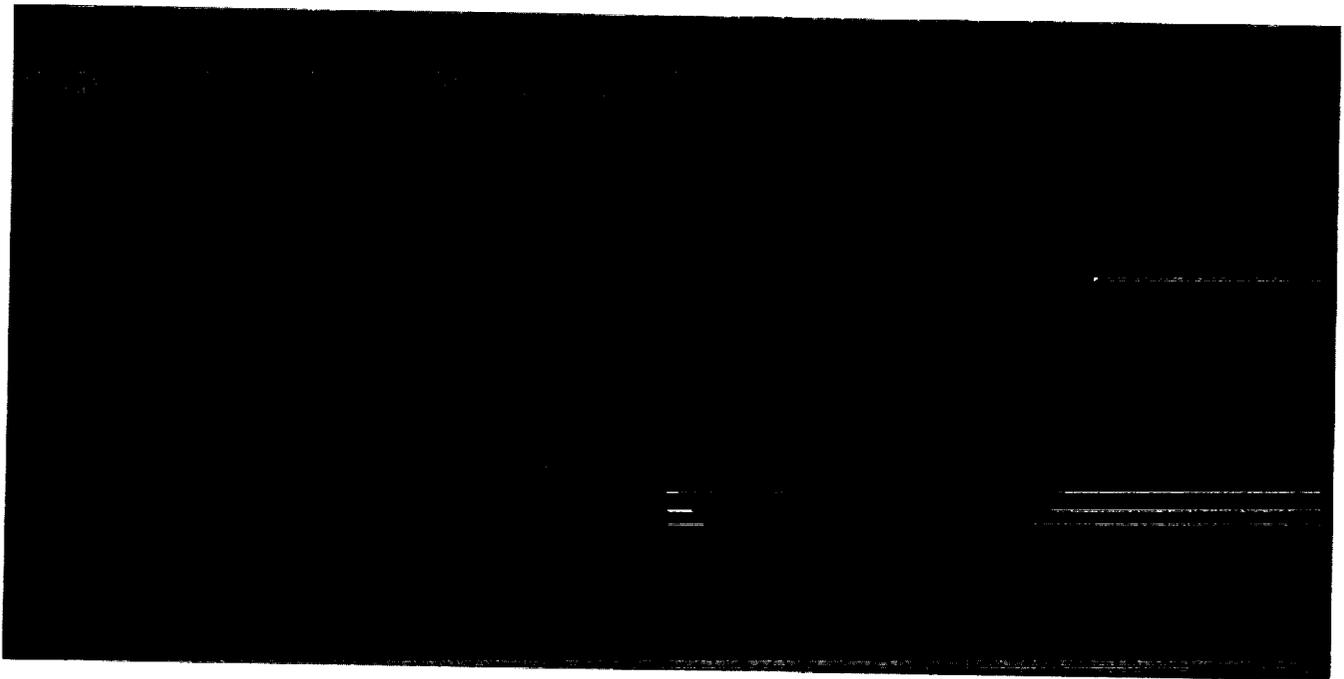


Figure 3. Kapton 200XC Photo—Left, Flight Sample; Right, Control Sample

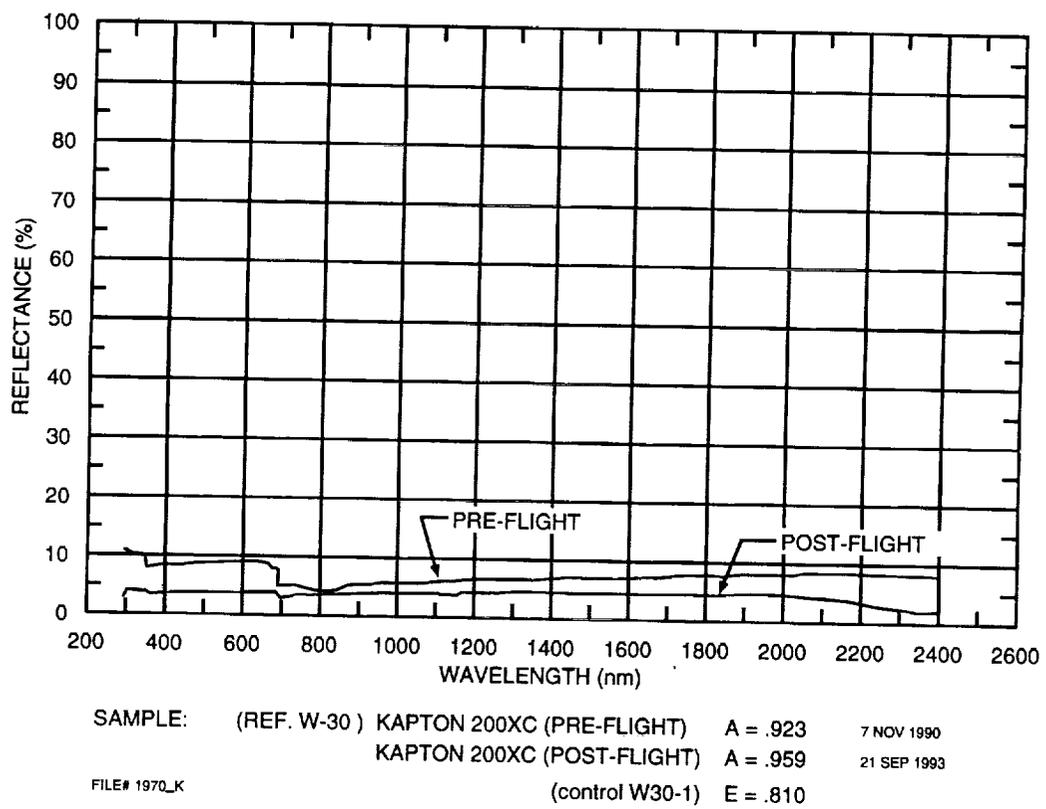


Figure 4. Kapton 200 XC—Reflectance vs. Wavelength

white powdery-appearing particles on the exposed region. Only one is in the shielded region, and that appears to be laying on the surface.

ESCA Analysis

Kapton 200XC is a carbon filled polyimide. The control material is made of carbon, oxygen, nitrogen, silicon and sulfur. The silicon and sulfur concentrations are less than 1 atomic % and are surface contaminants. The chemical state of carbon on the control specimen is 90% C-H and/or C-C bonds (it will be noted as C-(H,C) bonds) and 10% is O-C = O bonds.

The flight specimen shows carbon, oxygen, nitrogen, silicon, and tin. The tin concentration is about 0.2 atom% and is most likely a surface contamination. The carbon on the flight has 72% of C-(H,C) bonds, 18% of C-O, and 10% of O-C=O bonds. Thus, on the flight specimen, the atomic oxygen environment has led to formation of C-O bonds and sulfur is missing.

Radiative Properties

The reflectance versus wavelength are shown in figure 4. The exposed film shows an increase in absorptance from 0.923 to 0.959 and a slight change in reflectance. The emittance was calculated to be 0.816.

Physical Analysis

The mass loss of the sample was 5.84×10^{-5} gm, apparently from the 2 mil thick film. The percentage of mass change, attributed to the coating change, was estimated to be 0.168.

Oxygen Erosion

The reaction rate based on the above mass loss, the AO fluence of 2.07×10^{20} atoms/cm² and the exposed sample area of 1.2429 cm² is 2.2699×10^{-24} gm/atom. Using a Kapton density of 1.45 g/cm³, the reaction rate, in terms of volume eroded per atom, is 1.63×10^{-24} cm³/atom.

Aclar 22C (Ref. X-31)

Visual Inspection

The shielded area is clear, shiny, and uniform. The exposed area is tinted, yellow/gray, transparent near center, increasingly cloudy towards edge and raised from shielded area. (See fig. 5).

Magnification Inspection

The surface is clouded and distorted with large areas of delamination beneath the exposed surface. The exposed area is dark when compared to the shielded area. Abrasions have penetrated through this darkened surface.

ESCA Analysis

The Aclar 22C is of 5 mils of fluoropolymer film. Both control and flight specimens contained carbon, oxygen, fluorine, and chlorine. The carbon concentration on the flight specimen decreased and the fluorine concentration increased. This change in concentrations corresponds to the shift from the C-F bonding to C-F₂ bonding. The high resolution scans of the carbon 1s peak also reflect this change from C-F bonds to C-F₂ bonds. The chlorine and oxygen concentrations remained the same.

Radiative Properties

The reflectance versus wavelengths are shown in figure 6. They show an integrated absorptance of 0.444 before flight and 0.494 after flight. The drop in reflectance appears constant along the various wavelengths.

Physical Analysis

The mass loss of the sample was 5.38×10^{-5} gm. The percentage of mass loss attributable to the coating change was estimated to be 0.083.

Oxygen Erosion

The reaction ratio based on the above mass loss and the previously mentioned fluence on exposed sample area was calculated to be 2.28×10^{-24} gm/atom. The reaction rate based on a density of 2.11 gm/cm³ was calculated at 1.03×10^{-24} cm³/atom.

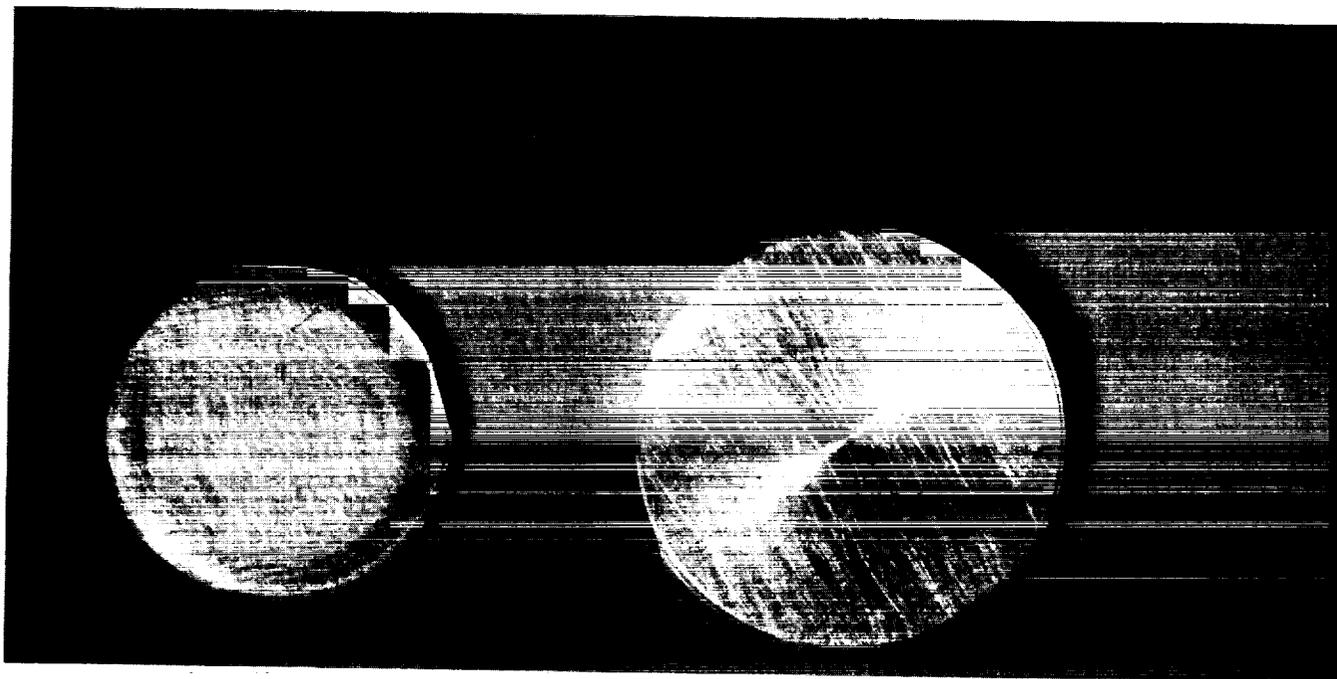


Figure 5. Aclar 22C Photo— Left: Flight Samples; Right, Control Samples

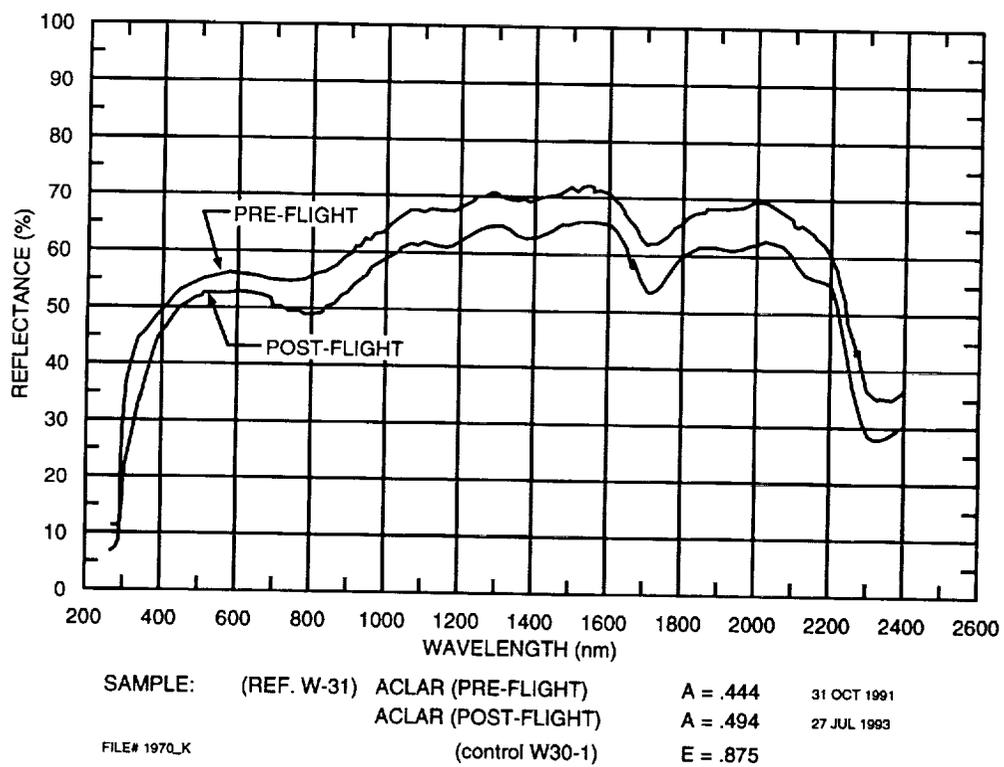


Figure 6. Aclar 22C—Reflectance vs. Wavelength

Tefzel 500LZ (Ref. X-32)

Visual Inspection

The shielded area is clear and shiny with no raised bubbles. The exposed area appears transparent with a yellowish/grayish tint and bubbles between the support material and coating. Also, the exposed area is slightly recessed from the shielded area. (See fig. 7).

High Magnification

There are slight discolorations in the exposed area, hazier (not as clear) as the control samples or the shielded region. High magnification shows darkened surface, but very superficial. It is not as dark as the abraded areas. Other areas have spotted deposits.

ESCA Analysis

This is a fluoropolymer film. The control specimen showed carbon, oxygen, and fluorine peaks. The flight specimen had carbon, oxygen, nitrogen, and fluorine. The carbon and fluorine concentrations decreased by 1.5 and 4 atomic % respectively. The oxygen concentration increased by almost 4 atomic %.

Radiative Properties

The reflectance is shown in figure 8. The post-flight absorptance was 0.517 versus a pre-flight rate of 0.483. There is a slight increase in reflectance for wavelength lower than 700 nm. The emittance of the unexposed sample was 0.898.

Physical Analysis

The mass loss of 3.3×10^{-5} gm, and attributing this loss to the film, would indicate a % change in mass of 0.055.

Oxygen Erosion

The oxygen erosion rate was 1.27649×10^{-24} gm/atom, and using a Tefzel density of 1.75 gm/cm^3 , the volumetric reaction rate is $7.59 \text{ E-}25 \text{ cm}^3/\text{atom}$.

Tefzel 500LZ with SiO_x (Ref. X-37)

Visual Inspection

The shielded area is clear and shiny. The exposed area around the edge shows bubbles between the coating and substrate. (See fig. 9).

High Magnification

Transparent, faint discoloration which cannot be documented at low magnification. High magnification shows possible impact sites with cracks radiating from center. Faint crack network at other locations.

ESCA Analysis

This is the Tefzel fluoropolymer film with a SiO_x coating. The controlled specimen has carbon, oxygen, nitrogen, silicon, and fluorine. The flight specimen has carbon, oxygen, silicon, and fluorine. The amount of fluorine was less than 1 atomic % on both specimens. The carbon concentration decreased and the oxygen and silicon concentrations increased on the flight specimen.

Radiative Properties

The reflectance remained practically unchanged with about 10% loss at about 400 nm as shown in figure 10. The absorptance changed from 0.508 to 0.533.

Physical Analysis

The mass loss was 1.04×10^{-4} gm and, attributing this loss to the film, the % mass loss was 6.73×10^{-3} .

Oxygen Erosion

The oxygen reaction rate was calculated at 4.081×10^{-25} gm/atom and in term of volume approximately $2.02 \times 10^{-25} \text{ cm}^3/\text{atom}$.

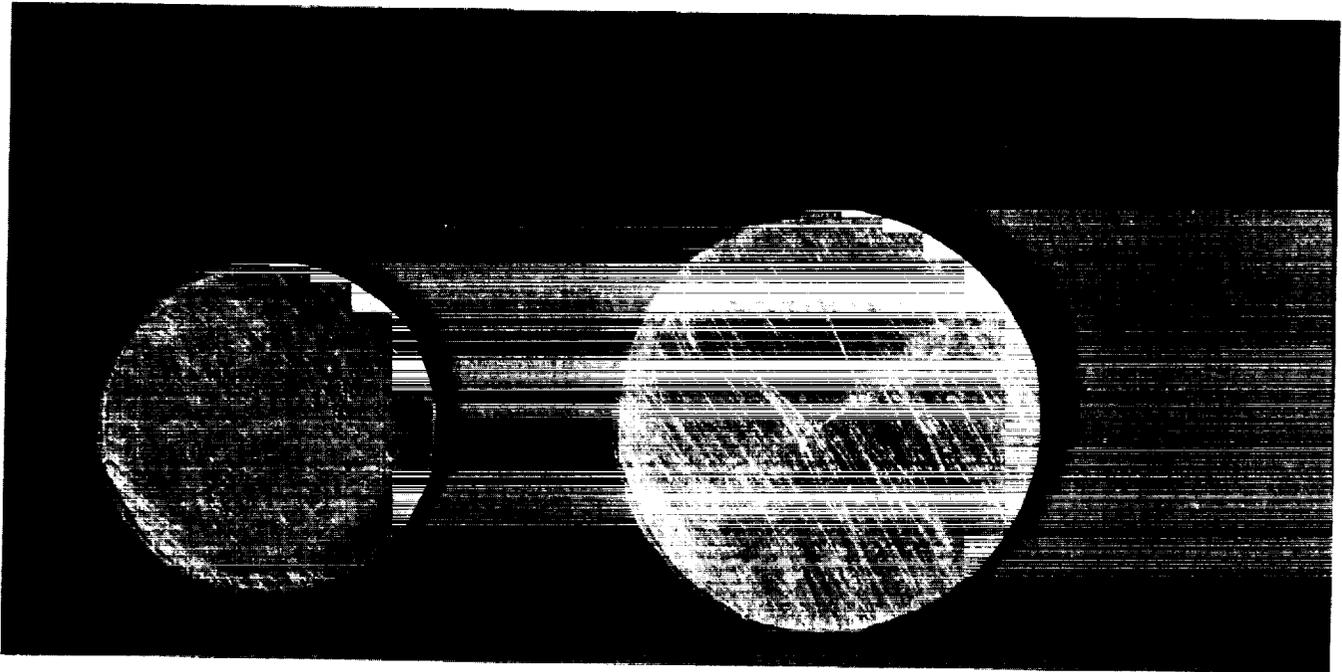


Figure 7. Tefzel 500 LZ Photo—Left: Flight Sample; Right, Control Sample

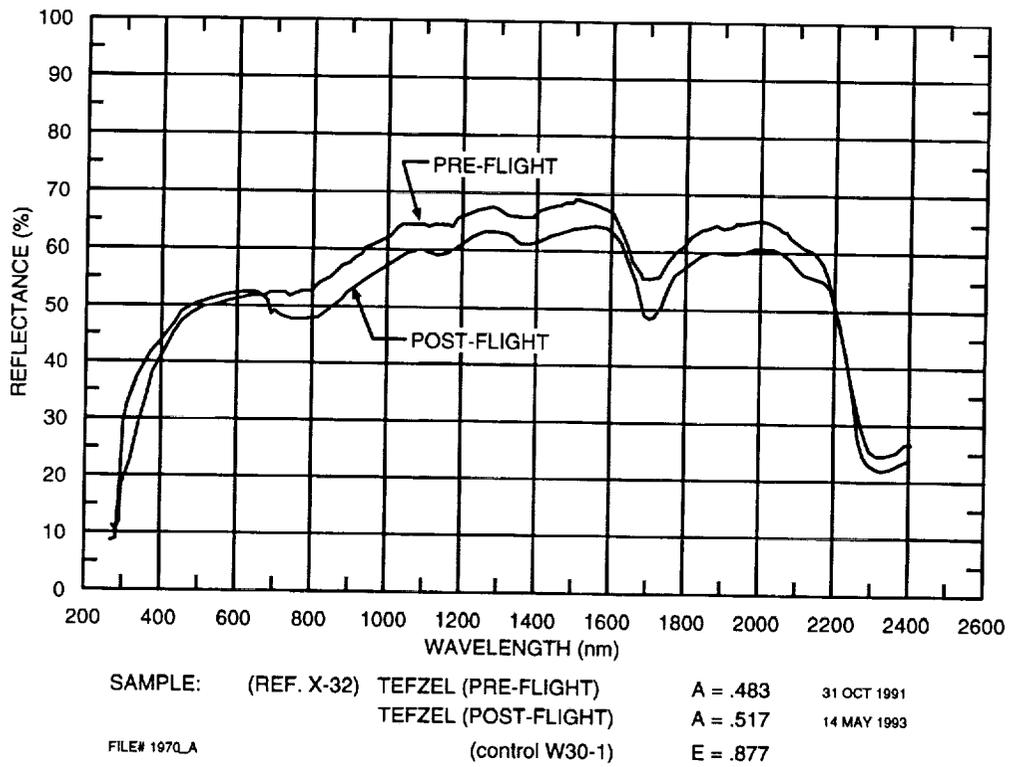


Figure 8. Tefzel 500 LZ—Reflectance vs. Wavelength

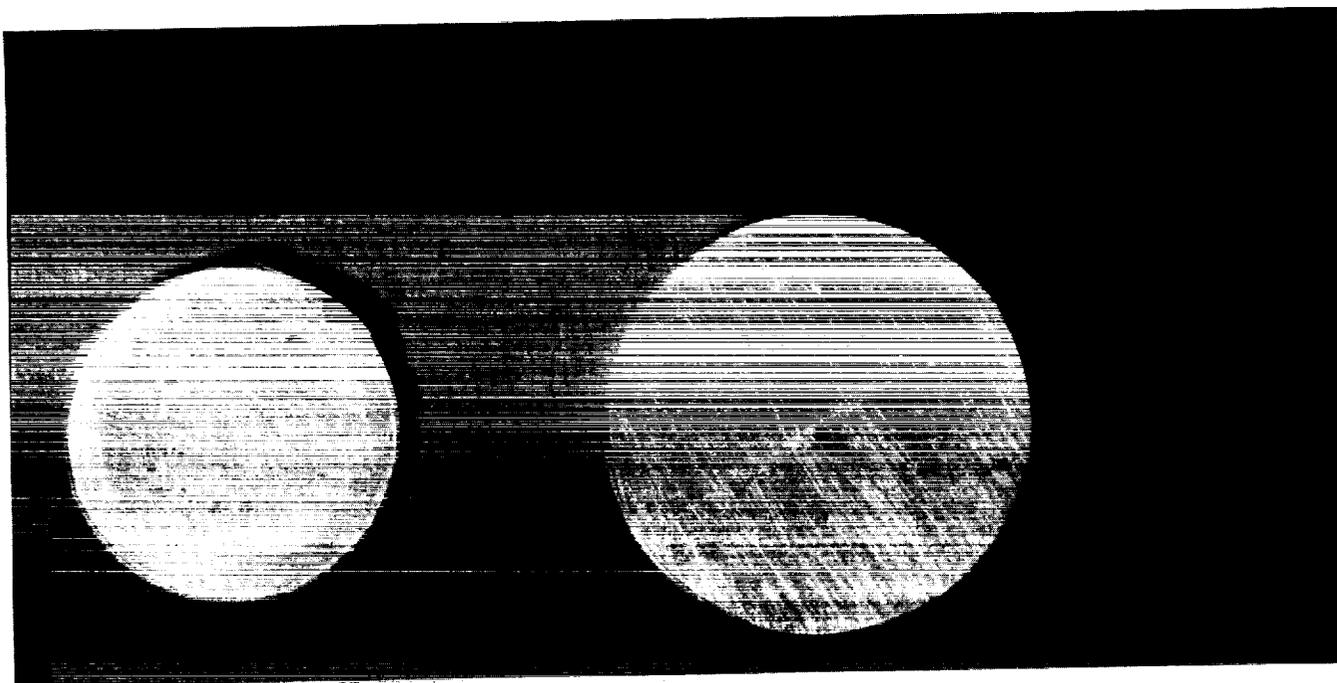
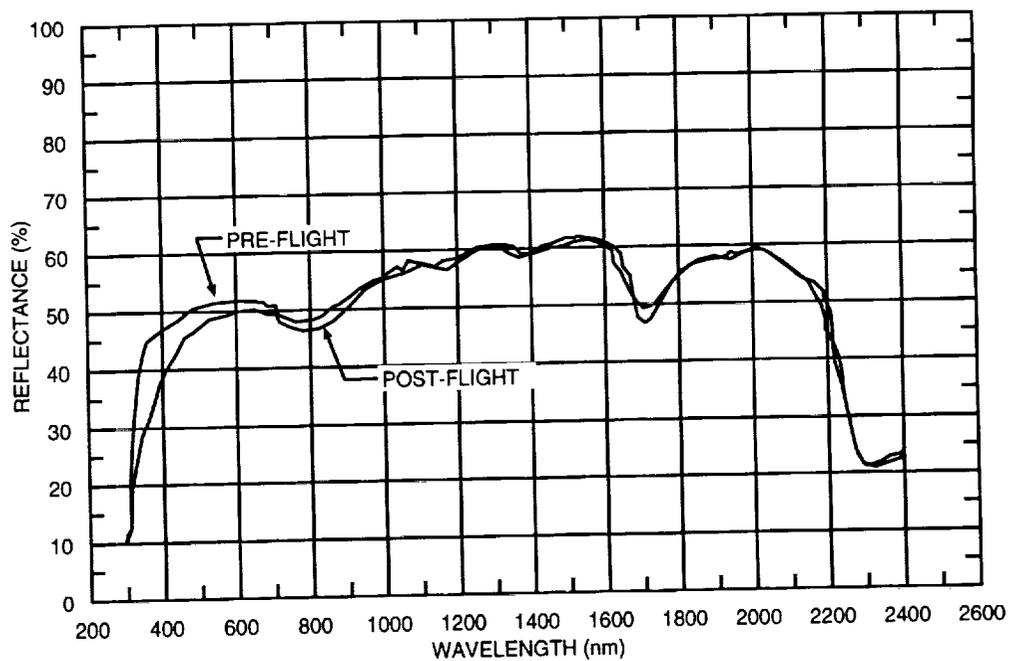


Figure 9. Tefzel 500 LZ with SiOx Photo—Left: Flight Sample; Right, Control Sample



SAMPLE: (REF. X-37) TEFZEL (PRE-FLIGHT) A = .508 30 OCT 1991
 TEFZEL (POST-FLIGHT) A = .533 13 MAY 1993
 FILE# 1970_LJ (control W30-1) E = .874

Figure 10. Tefzel 500LZ with SiOx—Reflectance vs. Wavelength

PAN Film (Ref. X-61)

Visual Inspection

The shielded area is clear and shiny. The exposed area is dull, its center is taupe and outer edge has a dark ring. There is a difference in color between shielded and exposed areas. (See fig. 11).

High Magnification

The exposed area is translucent with voids below coated surface. Shielded area is transparent and also contains voids.

ESCA Analysis

The sample is a polyacrylonitrile (PAN) film. No control specimen was available for this specimen. The unexposed area, the surface that had been shielded with the sample holder, was analyzed for comparison. The unexposed area contains carbon oxygen, nitrogen, and silicon. The 93% of carbon on the unexposed area is bonded to hydrogen and carbon, while the 7% is bonded to nitrogen.

The exposed area consists of carbon, oxygen, nitrogen, silicone, fluorine, and small amounts of sodium and sulfur. Sodium and sulfur appear to be contaminants. The exposed area shows an increase in nitrogen and oxygen concentration and a decrease in carbon concentration. It showed 60% of C-(H,C) bonds and 40% of C-O bond. Thus, it can be concluded that the atomic oxygen has altered the surface by converting the carbon triple bond with nitrogen into C-O bonds.

Radiative Properties

The radiative properties of this material were not taken.

Physical Properties

The mass loss was 8.06×10^{-4} gm. The percent change, when the loss is attributed to the film, was 0.2839.

Oxygen Erosion

The oxygen reaction rate was 3.122×10^{-24} gm/atom.

PAN Film With Cobalt Chloride (Ref. X-62)

Visual Inspection

The shielded area is clear, shiny, aquamarine, and raised. The exposed area is dull and "army green" in color with random, darker green spots. (See fig. 12).

High Magnification

Exposed area is translucent with voids below coated surface. The shielded area is transparent with a bluish color and also contains voids.

ESCA Analysis

This is a PAN Film with a CoCl_2 coating. The control specimen was not available for direct comparison. Instead, the exposed area on the flight specimen was compared with the outer edge area of the specimen where the surface had been shielded. The unexposed area has carbon, oxygen, nitrogen, silicon, and a trace amount of tin. The chemical state of carbon on the unexposed area are 7% C-O, 37% C-(O,N), and 56% C-(H,C) bonds. The exposed area contains carbon, oxygen, nitrogen, cobalt, and chlorine. The carbon bonds on the exposed area are 72% C-(N,) bonds, and 28% C-(H,C). The presence of silicon and tin on the unexposed area and the cobalt and chlorine on the exposed surface show that the atomic oxygen removed the overlayer that used to be on the surface and exposed the Pan film with its CoCl_2 layer while the shielded area still contained the surface contaminants.

Radiative Properties

The radiative properties of this material were not taken.

Physical Analysis

The mass loss was 4.67×10^{-4} gm. The % mass loss, when attributed to the film, was 0.166.

Oxygen Erosion

The oxygen reaction rate was calculated to be 1.812×10^{-24} gm/atom.

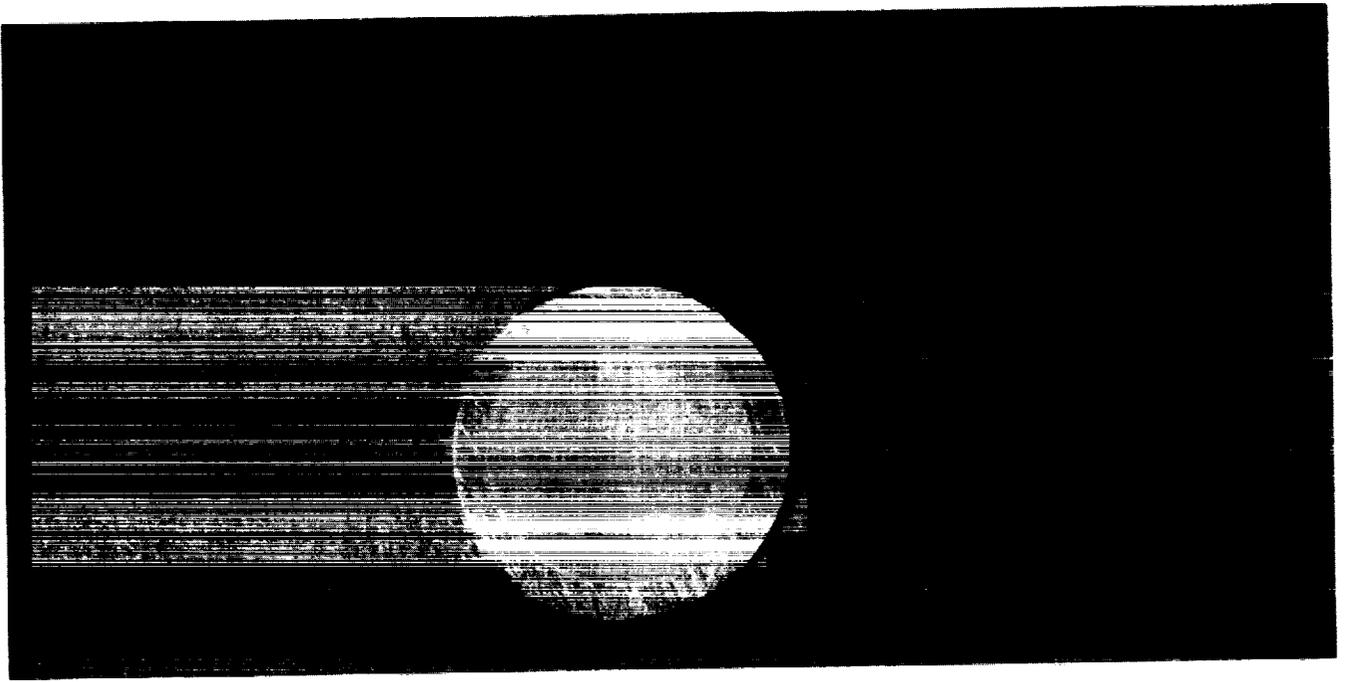


Figure 11. PAN Film Photo—Flight Sample

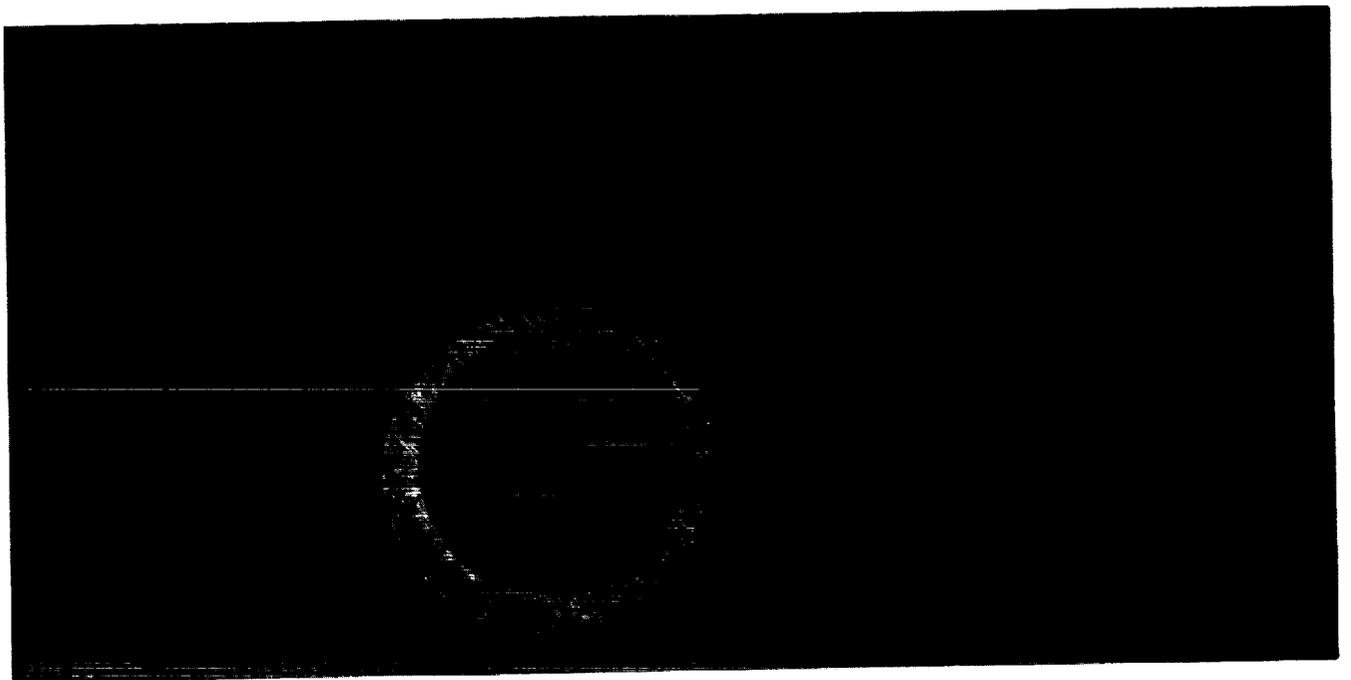


Figure 12. PAN Film with Cobalt Chloride Photo—Flight Sample

Llupalloy LL35HSC (Ref. X-70)

Visual Inspection

The entire surface is uniformly shiny. The shielded area is dark-silver colored. The exposed area shows a ring on the edge (light silver). The center is crazed. (See fig. 13).

High Magnification

The material shows a network of trapped bubbles, including some in the shielded area. The surface is smooth.

ESCA Analysis

Llupalloy is a sputtered nickel alloy on a polyester based film. The control specimen has carbon, oxygen, silicon, and chlorine. The source of chlorine is not clear. Since only a small amount of chlorine was detected, it may be a surface contaminant. The carbon state of the control specimen is 7% O-C=O, 21% C-O, and 72% C-(H,C). These bonding states correspond to the bonds found in polyesters. The flight specimen, on the other hand, has carbon, oxygen, silicon, nickel and a small amount of molybdenum. The presence of nickel indicates that the surface had not been eroded. The carbon bonding state of the flight specimen is C-(H,C). No other bonds that correspond to polyesters were detected. The flight specimen also indicates an increase in silicon and oxygen concentration.

Radiative Properties

The reflectance versus wavelength is shown in figure 14 which portrays an increase in reflectance of the post-flight sample over the pre-flight reflectance. The absorptance changed from 0.762 of the pre-flight to 0.723 after flight.

Physical Properties

The mass loss was 2.67×10^{-4} gm. When attributed to the film, the percentage loss is 0.046.

Oxygen Erosion

The oxygen reaction rate was calculated at 1.0344×10^{-24} gm/atom.

Llupalloy LL35HSC (Ref. X-44), Polyester Exposed to Oxygen

Visual Inspection

The shielded area is clear, shiny with dark silver "spots". The exposed area is dull, opaque with the outer 1/16 edge slightly brighter than the inner area. (See fig. 15).

High Magnification

The exposed surface is not as transparent as the control sample. A fine erosion is visible at 400x.

ESCA Analysis

The sample is made of a llupalloy film with polyester side up. The surface composition of the controlled specimen is carbon, oxygen and silicon, which are the elements found in polyester. The flight specimen has carbon, oxygen, silicon, and nitrogen. The nitrogen concentration is only about 1 atom%. No changes in elemental concentration or bonding state were detected.

Radiative Properties

The reflectances are shown in figure 16. The post-flight sample shows a very large increase in reflectance between 400 and 700 nm while its reflectance is lower by about 5% at all other wavelengths.

Physical Analysis

The mass change was 1.085×10^{-3} gm and, when this mass loss is attributed to the film, the percentage loss is 0.422.

Oxygen Erosion

The erosion reaction rate is 4.197×10^{-24} gm/atom and based on its density it is 3.10×10^{-24} cm³/atom.

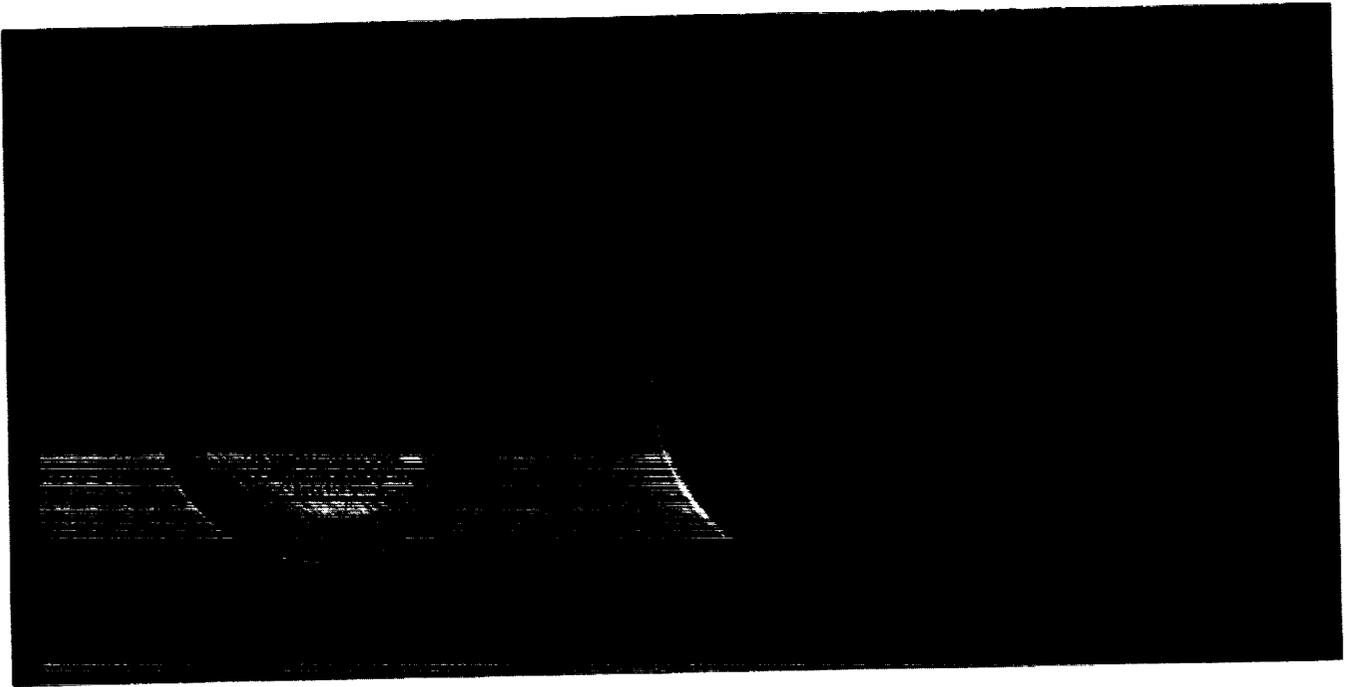
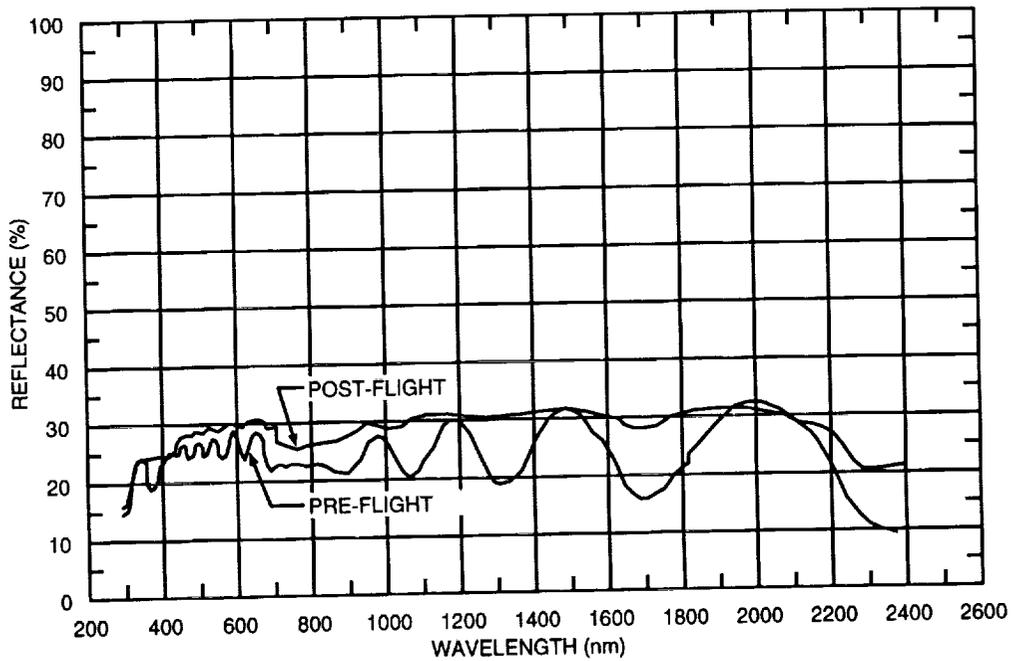


Figure 13. Llumalloy LL35HSC Photo—Left, Flight Sample; Right, Control Sample



SAMPLE: (REF. X-70) LLUMALLOY SPUTTERED (PRE-FLIGHT) A = .762 7 NOV 1991
 LLUMALLOY SPUTTERED (POST-FLIGHT) A = .723 11 FEB 1993
 FILE# 1970_F (control W30-1) E = .835

Figure 14. Llumalloy LL35HSC—Reflectance vs. Wavelength

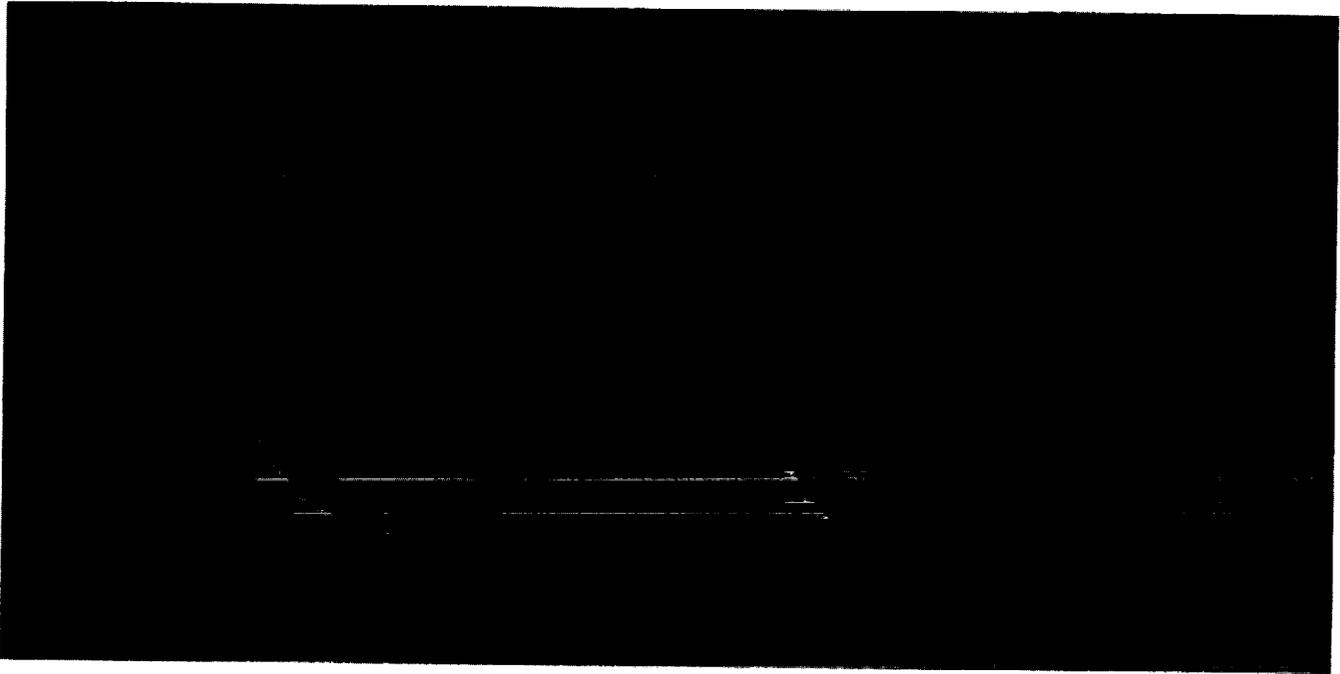
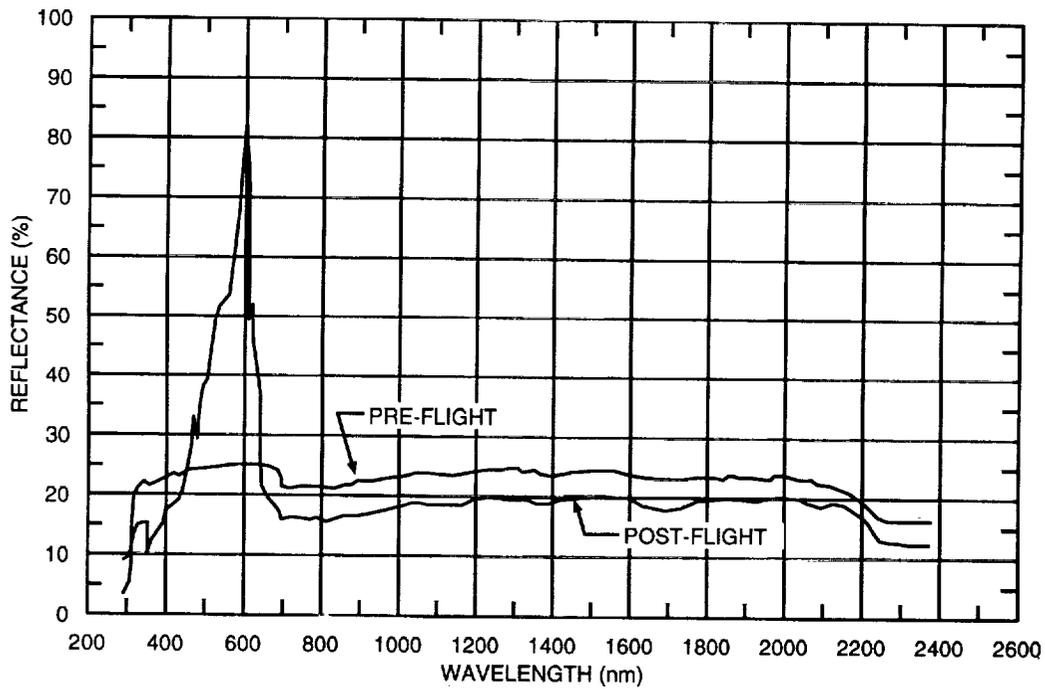


Figure 15. Llumalloy LL35HSC Photo—Left, Flight Sample; Right, Control Sample



SAMPLE: (REF. X-44) LLUMALLOY POLYESTER EXPOSED TO 0, (PRE-FLIGHT) A = .772 7 NOV 1990
 LLUMALLOY POLYESTER EXPOSED TO 0, (POST-FLIGHT) A = .750 11 FEB 1993
 FILE# 1970_F (control W30-1) E = .862

A1011.019

Fig. 8

Figure 16. Llumalloy LL35HSC—Reflectance vs. Wavelength

Cryovac Film (Ref. X-43)

Visual Inspection

The shielded area shows visible, clear dull scratches. The exposed area is cloudy, opaque, dull with apparent dark streaks under the surface. (See fig. 17).

High Magnification

The exposed surface is badly clouded.

ESCA Analysis

The Cryovac film is made of polyvinylidene chloride. The control specimen has carbon, oxygen, silicon, and fluorine. The fluorine on the control specimen appears to be surface contaminant. The flight specimen has carbon, oxygen, and silicon. The oxygen concentration is higher on the flight specimen than the control specimen. There were no changes in the chemical state which indicates that the Cryovac film is passive in the atomic oxygen environment.

Radiative Properties

The reflectances vs. wavelengths are shown in figure 18. It shows a loss of about 10% reflectance through the entire spectrum. The absorptance changed from 0.472 to 0.560.

Physical Analysis

The mass loss is 8.62×10^{-4} gm. When attributed to the film, the percentage loss is 0.286%.

Oxygen Erosion

The reaction rate is 3.334×10^{-24} gm/atom.

5.0 CONCLUSIONS

Nine different films attached to aluminum disc substrates and mounted in a tray were carried aboard the STS-46 Atlantis shuttle. They were exposed to the shuttle bay environment at an orbit of 228-230km and at a 28° inclination. These films were part of a large number of experiments on the atomic oxygen effects on materials and on the constituent and magnitude of the environment. The exposure of those films to the induced gaseous plasmas, radiation, and to a ram oxygen fluence of 2.07×10^{20} atom/cm² resulted in their erosion and morphological changes. Those changes have been verified using XPS analysis, microscopical observations, and thermo-optical measurements. The results have been tabulated. The measured reaction efficiencies based on the film mass loss expressed in gram of materials removed per O-atom or in cm³/atom when the film density was known, have been reported. The reaction efficiencies have been found to be in the E-24 g/atom range of values and to be comparable to those measured during other missions.

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- Leger L., S. L. Koontz, and J. Visentive, "An overview of the Evaluation of Oxygen Interaction with Materials - Third Phase (EOIM-III) Experiment: Space Shuttle Mission 46," *AIAA-93-0497*, 31st Aerospace Science Meeting and Exhibit, January 11, 1993, Reno, Nevada.
- Banks, B., S. K. Rutledge, J. A. Brady, and J. E. Merrow, "Atomic Oxygen Effect of Materials," *NASA Conference Publication 3035 Part 1*, NASA Langley, June 28, 1988.

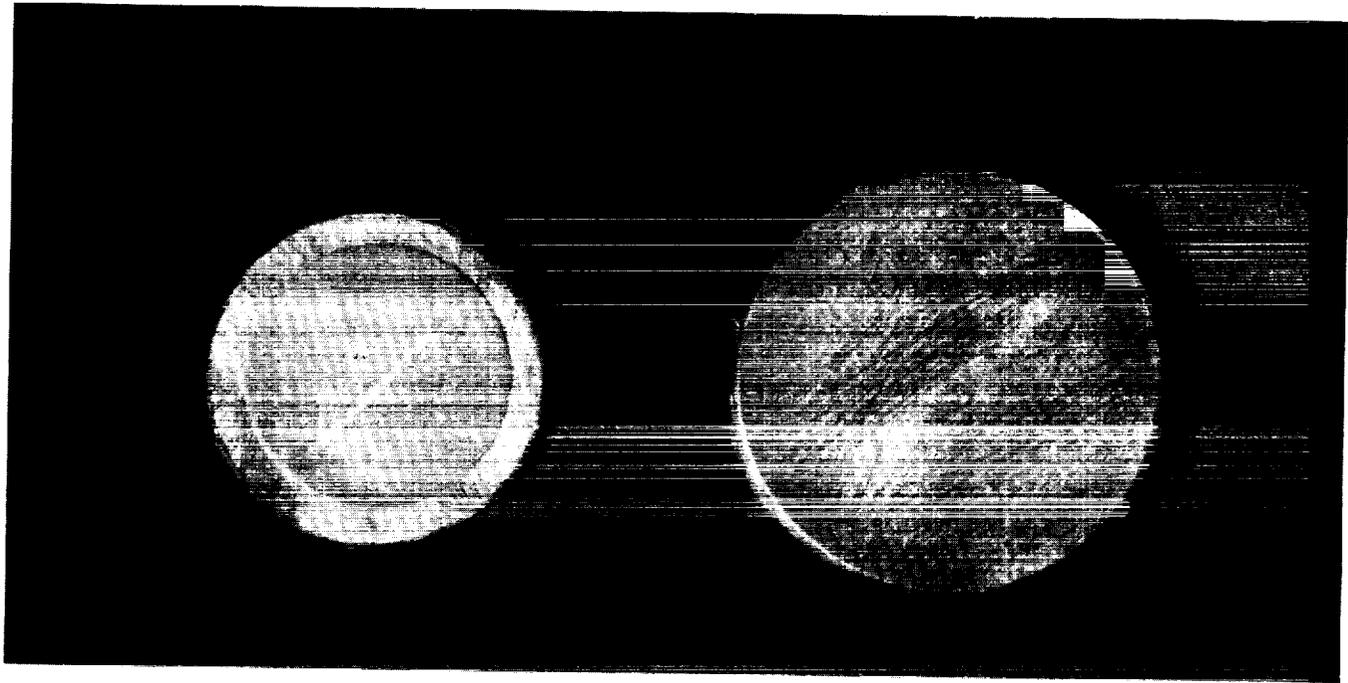


Figure 17. Cryovac Film Photo—Left, Flight Sample; Right, Control Sample

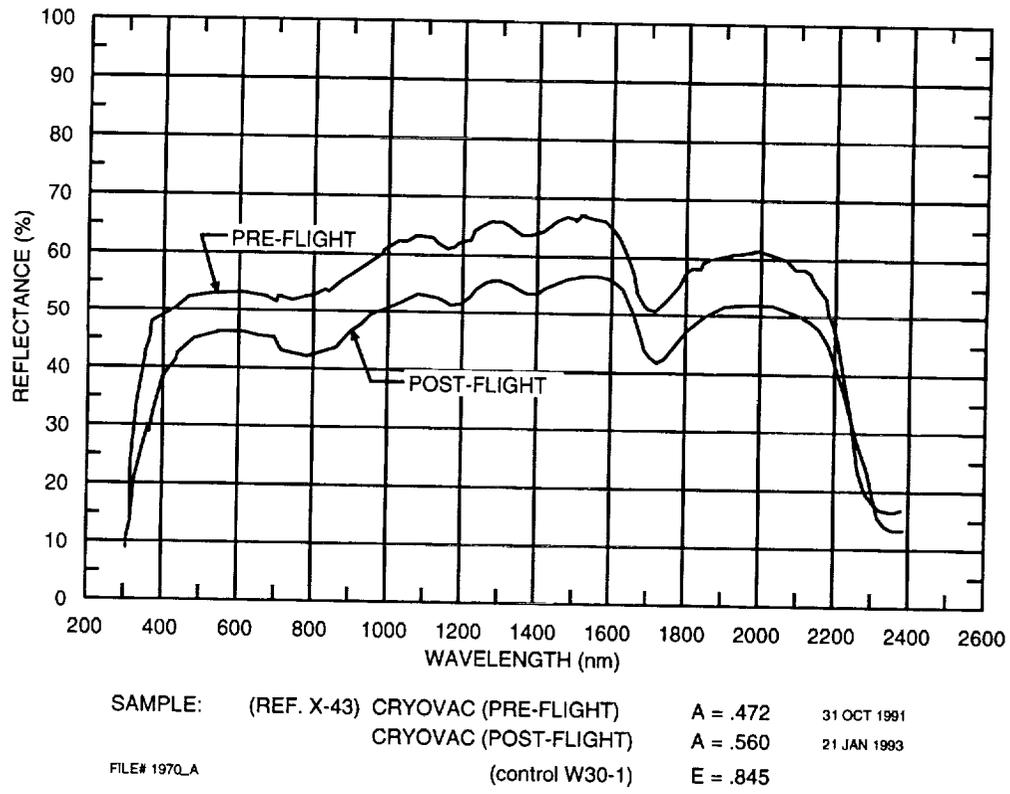
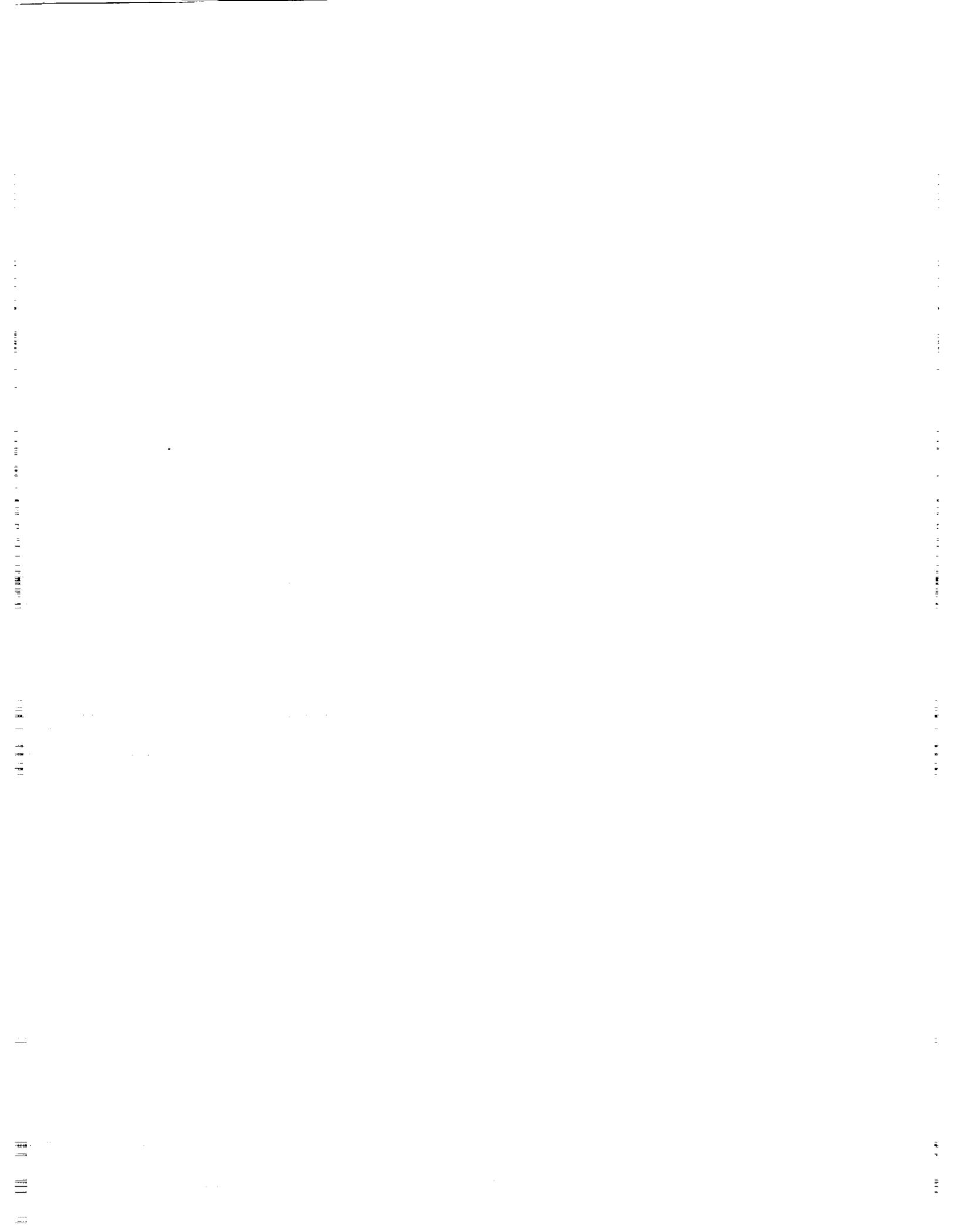


Figure 18. Cryovac Film—Reflectance vs. Wavelength







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13. ABSTRACT (Maximum 200 words) Nine film samples were carried aboard the STS-46 Atlantis shuttle to complement the "Evaluation of Oxygen Interaction with Materials (EOIM-III)" experiment to evaluate the effects of atomic oxygen on materials and to monitor the gaseous environment in the shuttle bay. The morphological changes of the samples produced by the atomic oxygen fluence of 2.07E-20 atoms/cm ² have been reported. The changes have been verified using X-ray Photoelectron Spectrometer (XPS) also known as Electron Spectroscopy for Chemical Analysis (ESCA), gravimetric measurements, microscopic observations and thermo-optical measurements. The samples including Kapton, Tefzel, Aclar, Polyacrylonitrile film, and Llumalloy films have been characterized by their oxygen reaction efficiency on the basis of their erosion losses and the fluence. Those efficiencies have been compared with results from other similar experiments, when available. The efficiencies of the samples are all in the range of E-24 gm/atom.			
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