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THE EFFECTS OF CHARGED PARTICLE AND UV RADIATION ON THE STABILITY OF SILVERED AND ALUMINIZED FEP TEFLON SECOND SURFACE MIRRORS

WALTER A. WAPPAUS

MAY 1971



GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

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ABSTRACT

A series of tests were conducted on metallized 5 mil FEP teflon film second-surface mirror thermal control coatings to determine the solar absorptance stability as a function of electron, proton and UV radiation dosage. Both silvered and aluminized FEP teflon coatings were irradiated with particle energies of 5 Kev and 25 Kev and with UV at an intensity of 5 solar constants. The combined effect of simultaneously irradiating these coatings with both UV and charged particle radiation was also investigated.

Results show that both silvered and aluminized coatings are more unstable to 25 Kev protons than to 25 Kev electrons. The combined effect of UV plus charged particle radiation produces greater instability at higher dose levels than the effect of charged particle radiation alone. The stability of the FEP teflon coatings are virtually unaffected by UV exposure in vacuum at 5 solar constants for 120 hours. The coatings are also stable to 5 Kev electrons.

THE EFFECTS OF CHARGED PARTICLE AND UV RADIATION ON THE STABILITY OF SILVERED AND ALUMINIZED FEP TEFLON SECOND SURFACE MIRRORS

INTRODUCTION

From previous screening investigations Metallized FEP⁽¹⁾ teflon⁽²⁾ Type A has emerged as a candidate material for use in thermal control of spacecraft surfaces⁽³⁻⁹⁾. When used as a second surface mirror, FEP teflon exhibits superior solar-absorptance (α_s) stability and has been successfully flight tested on OGO-6, SAS-A, Mariner V⁽¹⁰⁾ and IMP-I.

A recent study presents results of solar absorptance stability of 5 mil silver and aluminum vapor deposited FEP teflon second surface mirror thermal control coatings when irradiated with 5 Kev and 25 Kev protons and also UV radiation⁽¹¹⁾.

The purpose of the present investigation is to extend the scope of the above study to include in-situ radiation of silvered and aluminized FEP teflon second surface mirror using i) 25 Kev electrons ii) 25 Kev electrons + UV iii) 5 Kev electrons iv) 5 Kev electrons + UV and v) UV (5 solar constants, Xenon source).

Also included in the testing schedule of this study are the following in-situ radiation conditions: i) 25 Kev protons ii) 25 Kev protons + UV iii) 5 Kev protons and iv) 5 Kev protons + UV.

The in-situ reflectance of the metallized FEP teflon coatings samples is recorded before and after elementary particle radiation. Reflectance measurements are also taken before and after irradiating the samples simultaneously with UV and particle radiation. Additional reflectance data is also obtained on coating samples irradiated solely with UV.

The unreduced data yields curves which relate coating reflectance to values of wavelength of the light used to scan the coating surface⁽¹²⁾. From this data a value of solar absorptance (α_s) is obtained.

The results are plotted in graphical form showing the solar absorptance of the metallized coatings as a function of radiation dosage.

The test results involving UV only are presented in tabular form.

EXPERIMENTAL APPROACH

A recording spectrophotometer is used to plot the values of reflectivity of the coating samples as a function of wavelength. These wavelength dependent values of reflectivity are integrated to represent a value of solar absorptance, a quantity used in engineering design for specifying thermal control coatings applications.

These reflectivity measurements are obtained at chosen dosage intervals during the testing schedule, while the specimens are still in vacuum. The radiation of the samples is interrupted briefly while reflectivity measurements are taken and then resumed until the next measurement interval.

The radiation stability of the coating is gauged by the degree of change of the α_s from the pre-irradiation value.

THERMAL CONTROL COATING PREPARATION

The method of fabrication of the thermal control coating samples used in this study is one of several choices which shows promise of being selected for applications to spacecraft.

A piece of 5 mil FEP teflon film is subjected to glow discharge and then vapor deposited on one side with approximately 1000 Å of silver followed immediately with a vapor deposited layer of inonel of approximately 1000 Å in thickness. The metallized side is cemented to a 2 mil piece of aluminum foil with Solithane⁽¹³⁾ epoxy. After sufficient curing the foil side of the composite is cemented in turn to a 1 inch diameter, 1/16 inch thick aluminum disc with a mixture of Versamid⁽¹⁴⁾ 140 resin and Epon⁽¹⁵⁾ 828 epoxy prepared in the ratio of 3:2 by weight.

A similar procedure is used to prepare the aluminum type coating samples where an aluminum vapor deposition substitutes for the silver-inonel vapor deposition step previously described.

TESTING PROGRAM

The testing program is designed to compare and evaluate the stability of each type of coating after being subjected to space simulated radiation at selected energy and flux levels.

The testing schedule is divided into three phases. In the first phase only elementary particle radiation is used to bombard the thermal control coatings. The coatings are irradiated individually and mounted without adhesives on a water cooled sample holder. A cross-sectional view of the sample and sample holder is shown in Figure 1. Both silver and aluminum vapor deposited coatings are irradiated with 5 Kev protons and 5 Kev and 25 Kev electrons.

The particle introduction rate is chosen initially at 10^{11} particles/cm²/sec. This flux level is at least 1000 times in excess of actual space conditions at these energies^(16,17).

Preliminary testing with 5 Kev electrons at a flux of 10^{11} particles/cm²/sec revealed that, at a fluence level of 10^{15} particles/cm² (2.77 hours elapsed testing time), in general, small changes in α_s are observed. Due to monetary constraints precluding long term testing, all charged particle radiation rates in the entire testing schedule are increased to 10^{12} particles/cm²/sec once the 10^{15} particle/cm² fluence level is reached.

The initial reflectivity of all coatings is measured in-situ prior to irradiation. The coating reflectivity is measured primarily at fluence intervals of 10^{15} , 5×10^{15} and 10^{16} particles/cm² although other fluence levels are chosen as well.

The second testing phase is similar to the first phase with the addition of directing UV radiation at an intensity of 5 solar constants upon the coatings simultaneously with the particle radiation. Similar reflectivity measurements are recorded. The coatings are mounted in the identical manner as those included in the first testing phase. The third and final phase of testing consists of subjecting both types of coatings to prolonged UV radiation in oxygen as well as a vacuum environment. Reflectivity data is recorded for both types of these environments.

Data is taken when the coating is mounted in the apparatus but in an air environment. The system is then evacuated and another reflectance curve is recorded. The coating is in turn exposed to UV followed by a reflectivity measurement of the sample in vacuum. Final reflectance data are recorded with the sample in air.

In testing phase III, each coating sample receives 120 hours of Xenon arc source UV radiation at an intensity of 5 solar constants.

The entire testing schedule is summarized in Table I.

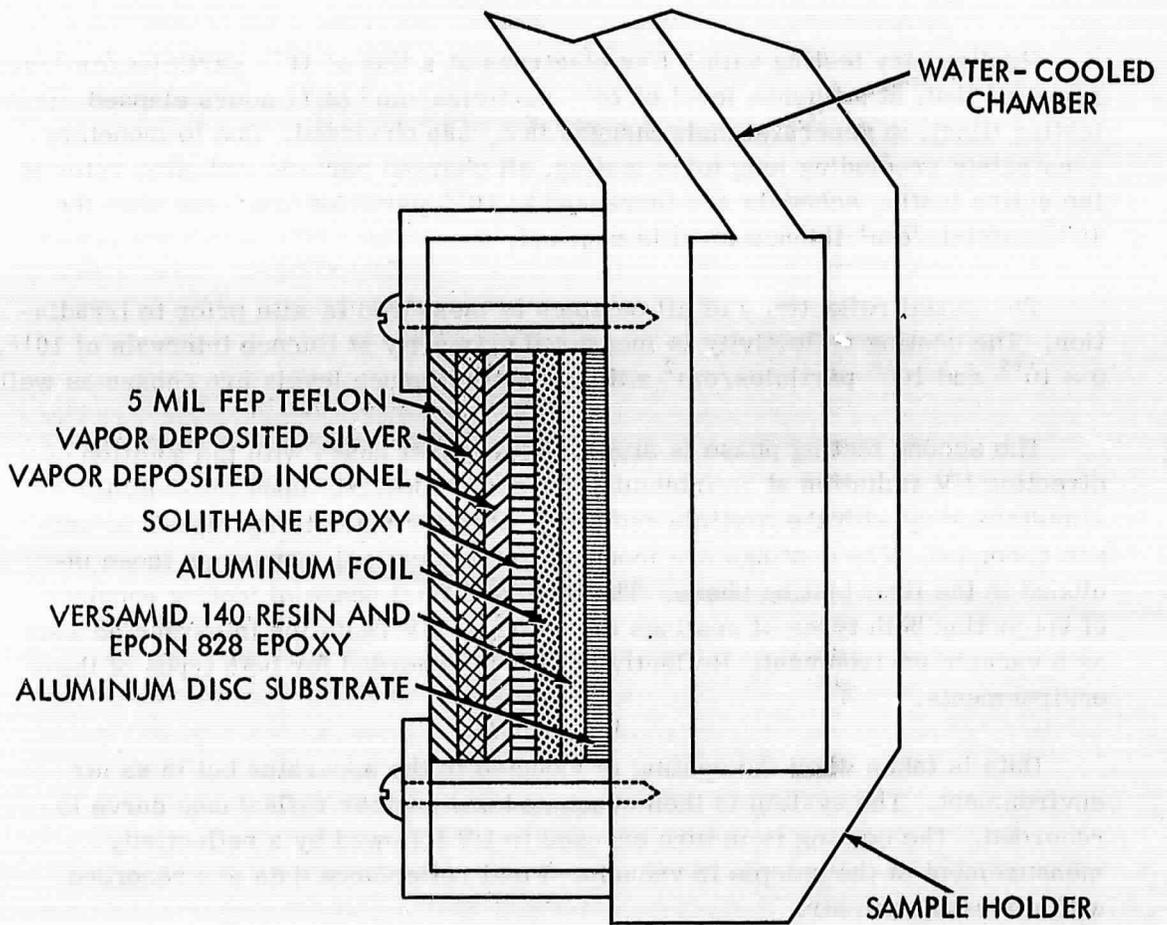


Figure 1. Cross-section of coating sample positioned in sample holder

Table I
Testing Schedule

Phase I

| Sample type | Silver | Silver | Silver | Silver | Aluminum | Aluminum | Aluminum | Aluminum |
|---|--|--|--|---|--|--|--|--|
| Radiation type | Protons | Protons | Electrons | Electrons | Protons | Protons | Electrons | Electrons |
| Energy [Kev] | 5 | 25 | 5 | 25 | 5 | 25 | 5 | 25 |
| Particle flux up to 10^{15} particles/cm ² (particles/cm ² /sec) | 10^{11} | 10^{11} | 10^{11} | 10^{11} | 10^{11} | 10^{11} | 10^{11} | 10^{11} |
| Particle flux greater than 10^{15} particles/cm ² (particles/cm ² /sec) | 10^{12} | 10^{12} | 10^{12} | 10^{12} | 10^{12} | 10^{12} | 10^{12} | 10^{12} |
| Fluence level measured at (particles/cm ²) | 10^{15} 5×10^{15} 10^{16} | 10^{15} 5×10^{15} 10^{16} | 10^{15} 5×10^{15} 10^{16} | 10^{15} 8×10^{15} 1.3×10^{16} | 10^{15} 5×10^{15} 10^{16} | 10^{15} 5×10^{15} 10^{16} | 10^{15} 5×10^{15} 10^{16} | 10^{15} 5×10^{15} 10^{16} |
| Radiation Atmosphere | Vacuum | Vacuum | Vacuum | Vacuum | Vacuum | Vacuum | Vacuum | Vacuum |
| No. of Samples | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |

Phase II

| Sample type | Silver | Silver | Silver | Aluminum | Aluminum |
|---|--|--|---|--|---|
| Radiation type | Protons + UV | Protons + UV | Electrons + UV | Electrons + UV | Electrons + UV |
| Particle energy [Kev] | 5 | 25 | 25 | 5 | 25 |
| Particle flux up to 10^{15} particles/cm ² (particles/cm ² /sec) | 10^{11} | 10^{11} | 10^{11} | 10^{11} | 10^{11} |
| Particle flux greater than 10^{15} particles/cm ² (particles/cm ² /sec) | 10^{12} | 10^{12} | 10^{12} | 10^{12} | 10^{12} |
| Fluence level measured at (particles/cm ²) | 10^{15} 5×10^{15} 10^{16} | 10^{15} 5×10^{15} 10^{16} | 10^{15} 8×10^{15} 1.3×10^{16} | 10^{15} 5×10^{15} 10^{16} | 10^{15} 3×10^{15} 1.3×10^{16} |
| UV Solar Constants | 5 | 5 | 5 | 5 | 5 |
| Total UV hours | 5.27 | 5.27 | 5.36 | 5.27 | 5.36 |
| UV Source | Xe | Xe | Xe | Xe | Xe |
| Radiation Atmosphere | Vacuum | Vacuum | Vacuum | Vacuum | Vacuum |
| No. of Samples | 1 | 2 | 1 | 1 | 1 |

Phase III

| Sample type | Silver | Silver | Aluminum | Aluminum |
|----------------------|-------------|----------------------|------------|----------------------|
| Radiation type | UV | UV | UV | UV |
| UV Solar Constants | 5 | 5 | 5 | 5 |
| Total UV hours | 120 | 120 | 120 | 120 |
| Radiation Atmosphere | Vacuum | O ₂ | Vacuum | O ₂ |
| measured in | Vacuum, air | O ₂ , air | Vacuum air | O ₂ , air |
| UV Source | Xe | Xe | Xe | Xe |
| No. of Samples | 2 | 2 | 2 | 2 |

APPARATUS

The apparatus and testing chamber used in all three phases of testing is shown in Figures 2 and 3.

In Figure 2 the diagrams show the vacuum chamber containing the sample holder along with the location of the proton and electron source and connecting drift tube which is enveloped with mu metal. Also shown are the relative positions of the UV Xenon lamp source, the associated quartz optics and the UV entrance per to the chamber. A Physicon, Model 512 beam scanner is positioned in the drift tube and is shown in detail in Figure 3. The system is evacuated by a 25 liter/sec ion pump located near the sample chamber and a 4 inch diffusion pump positioned near the elementary particle source maintaining a vacuum in the 10^{-7} torr region. Adjacent to the particle source in the drift tube is an Einzel electrostatic collimating lens and a magnetic analyzer. The elementary particle source, an Ortec Model C-SO-173 K, ionizes, using an R-F field, hydrogen gas, supplied through a palladium leak. Depending on the sense of an applied potential, protons or electrons are taken from the discharge and formed into a uniform beam by the collimating lens. The magnetic analyzer removes neutral atoms from the beam as well as ions of undesired charge-to-mass ratio. The uniform beam then passes along a four foot drift tube, while being monitored for uniformity by the beam scanner, eventually impinging on the target coatings in the sample holder chamber. The sample and holder is floated above ground and also serves as a Faraday cup permitting monitoring of the beam current.

The lower portion of Figure 2 shows a side view of the respective positions of the sample chamber, ion pump, the Gier-Dunkle integrating sphere and the Beckmen Model DK-2A recording spectroreflectometer. The sample holder may be translated for insertion into a quartz finger, permanently positioned in the integrating sphere, enabling an in-situ reflectance measurement of the coating sample to be taken. The sample is raised slightly and removed from the path of the reflectometer scan beam for a 100% reflectance measurement. For this portion of the measurement, both a reference beam and a sample beam are alternately incident on the barium sulphate coated integrating sphere wall, the sample beam traversing the quartz finger while the reference beam is positioned to miss it entirely. The two beams are diffusely reflected and detected with either a lead sulphide cell or a photomultiplier tube, depending on the wavelength of the beam. The spectroreflectometer then automatically ratios the two beam energies, and plots the result as a function of wavelength. For a coating sample measurement, the sample holder is lowered into the path of the sample beam. The sample beam is now reflected from the coating surface before it is incident on the sphere wall. With the reference beam still in the

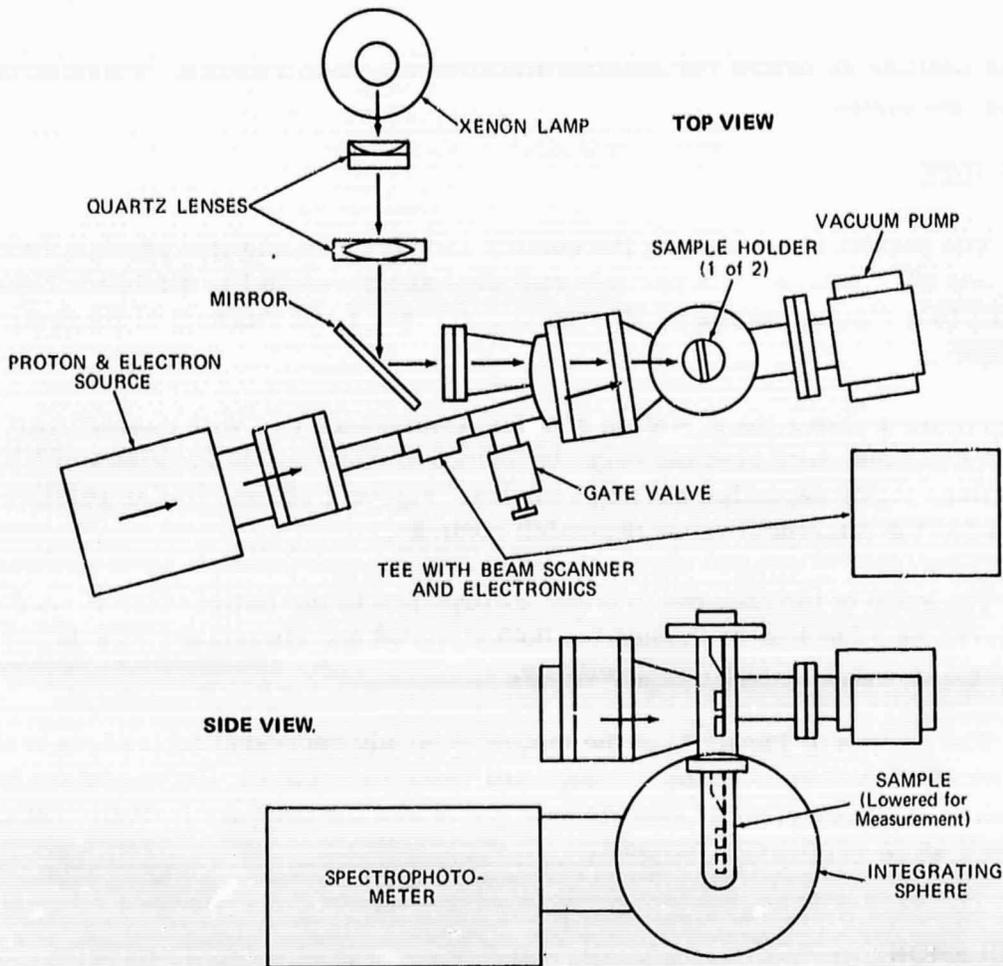


Figure 2. Diagram of in situ testing apparatus

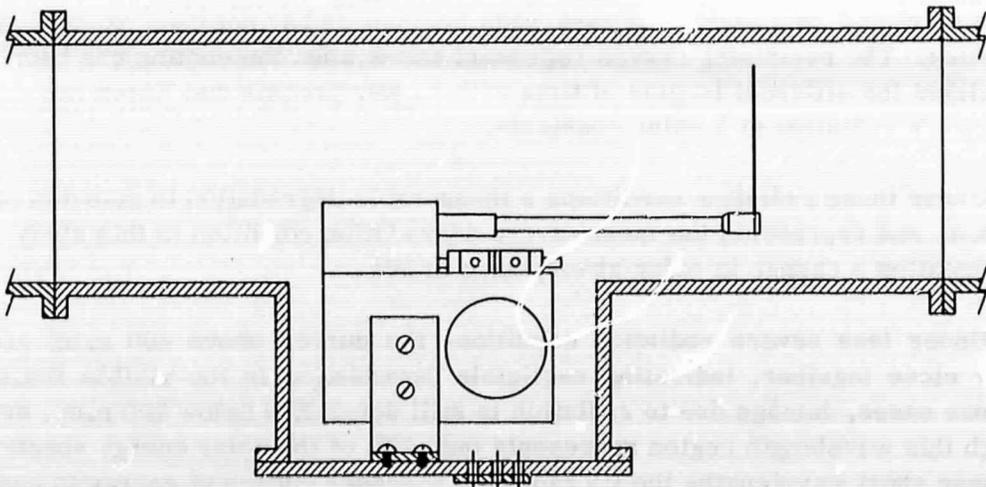


Figure 3. Diagram of beam scanner mounted in drift tube

same position as before the spectroreflectometer again ratios the energies of these two beams.

RESULTS

The results of irradiating the coating samples with charged particle radiation and UV combined with particle radiation are shown in Figure 4 thru Figure 7. All four figures represent the results of Phase I and Phase II of the testing schedule.

Figure 4 shows the variation of solar absorptance (α_s) with charged particle fluence and also with charged particle fluence combined with the effect of UV on the silver vapor deposited coating samples. Figure 5 shows similar relationships for the aluminum vapor deposited coatings.

The ratio of the changes in solar absorptance to the initial solar absorptance is shown as a function of fluence for both silvered and aluminized FEP teflon coatings in Figure 6 and 7 respectively.

The results of Phase III of the testing schedule representing the long term UV irradiation studies of the coatings are listed in Table II. Here, pre and post irradiation values of solar absorptance are shown for coatings tested in vacuum as well as an oxygen environment.

DISCUSSION

A typical family of curves representing reflectance vs. wavelength of a silvered 5 mil FEP teflon coating is shown in Figure 8. As seen in this figure, curve number 1 represents the case when the coating has not been exposed to radiation. The remaining curves represent cases when the coating has been irradiated for different lengths of time with 25 Kev protons and Xenon arc source UV radiation at 5 solar constants.

Under these radiation conditions a measurable degradation is detected at 500 n.m. and represents the most severe degradation condition in this study representing a change in solar absorptance of 30%.

Under less severe radiation conditions the curves above 400 n.m. are fairly close together, indicating negligible degradation in the visible region. In these cases, damage due to radiation is still detectable below 400 n.m., even though this wavelength region represents only 10% of the solar energy spectrum. At these short wavelengths the UV radiation possesses sufficient energy to change

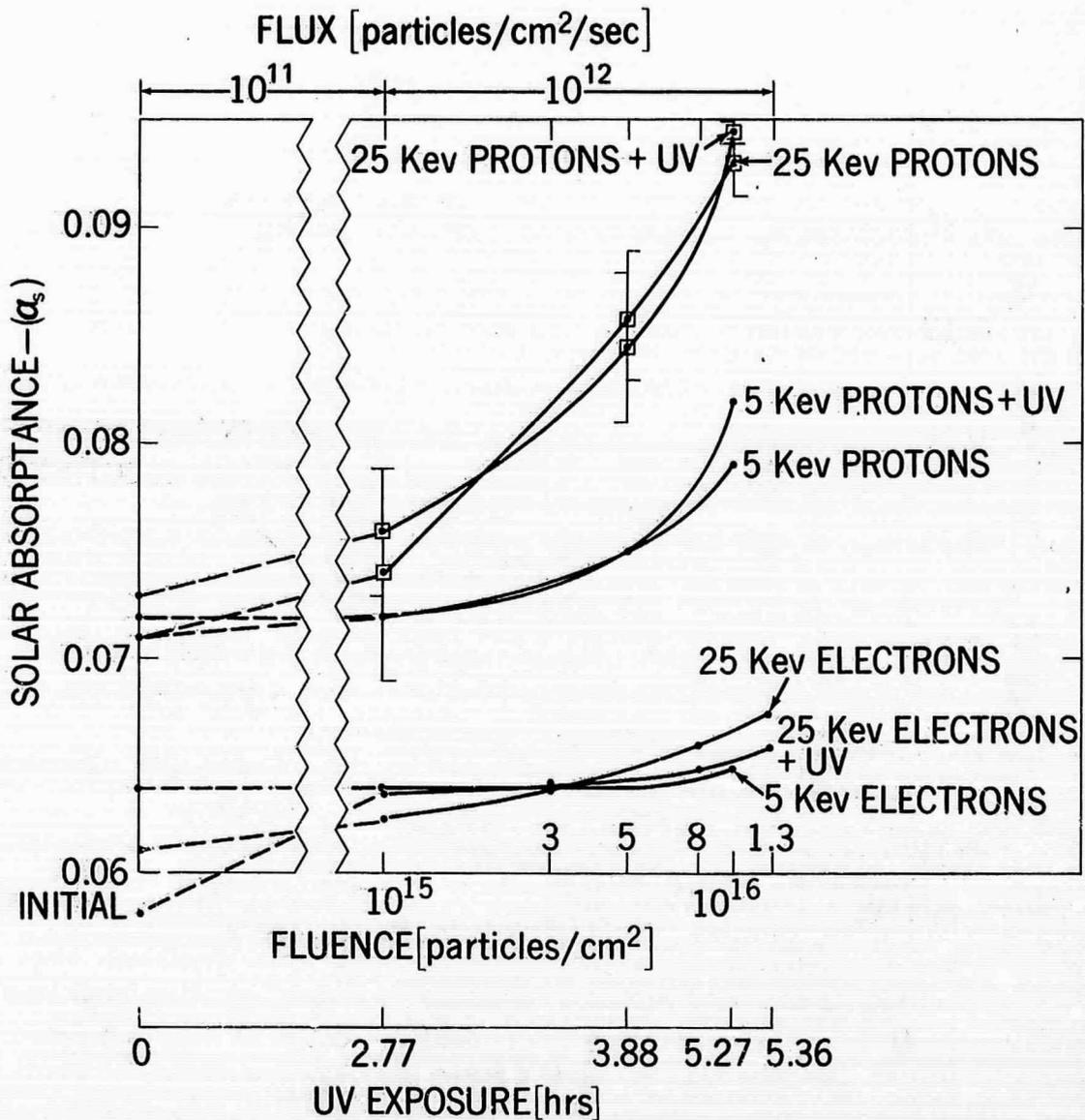


Figure 4. Relationship of solar absorbance vs particle radiation fluence and UV dosage of 5 mil FEP teflon vapor deposited with silver

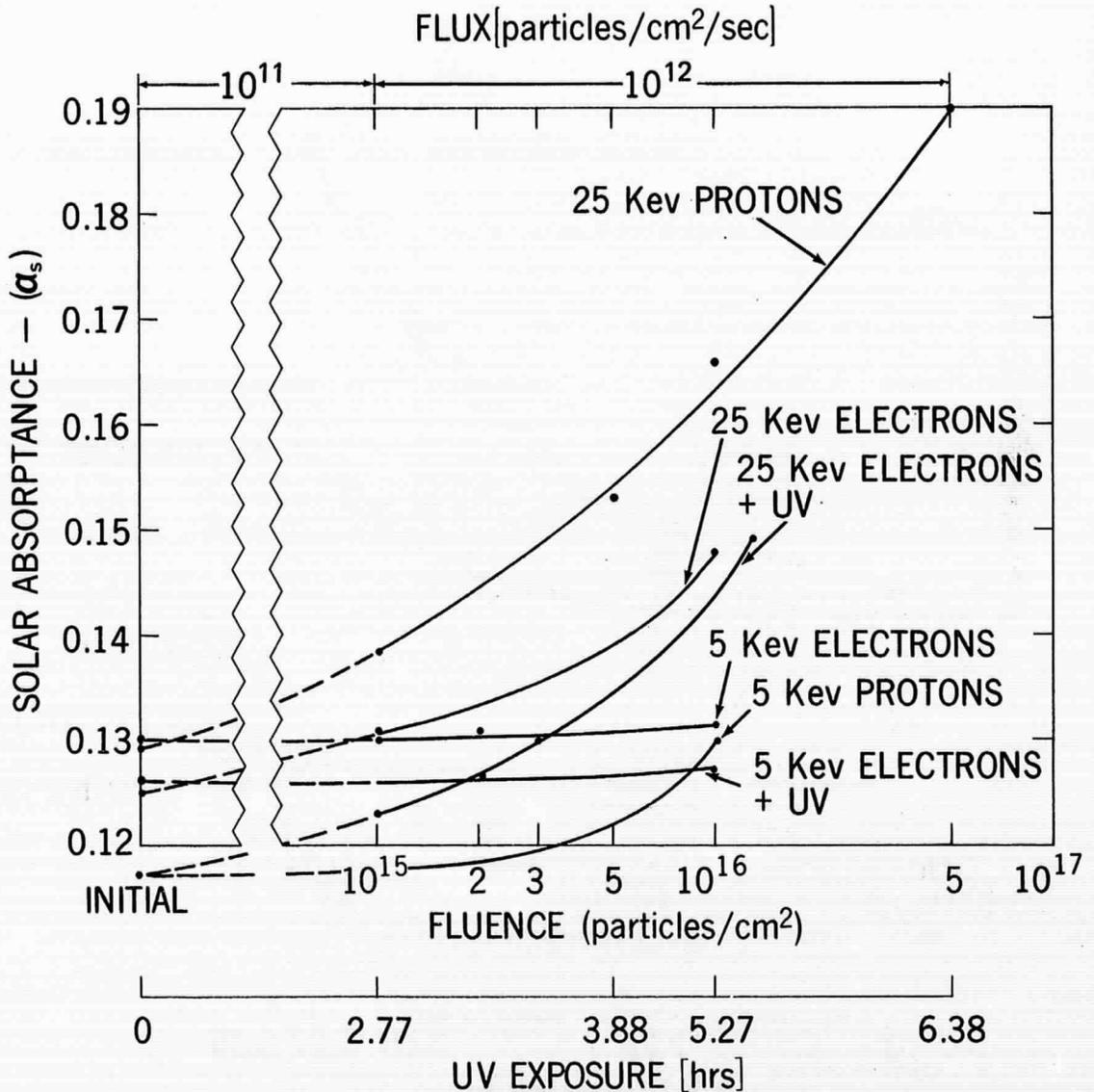


Figure 5. Relationship of solar absorbance vs particle radiation fluence and UV dosage of 5 mil FEP teflon vapor deposited with aluminum

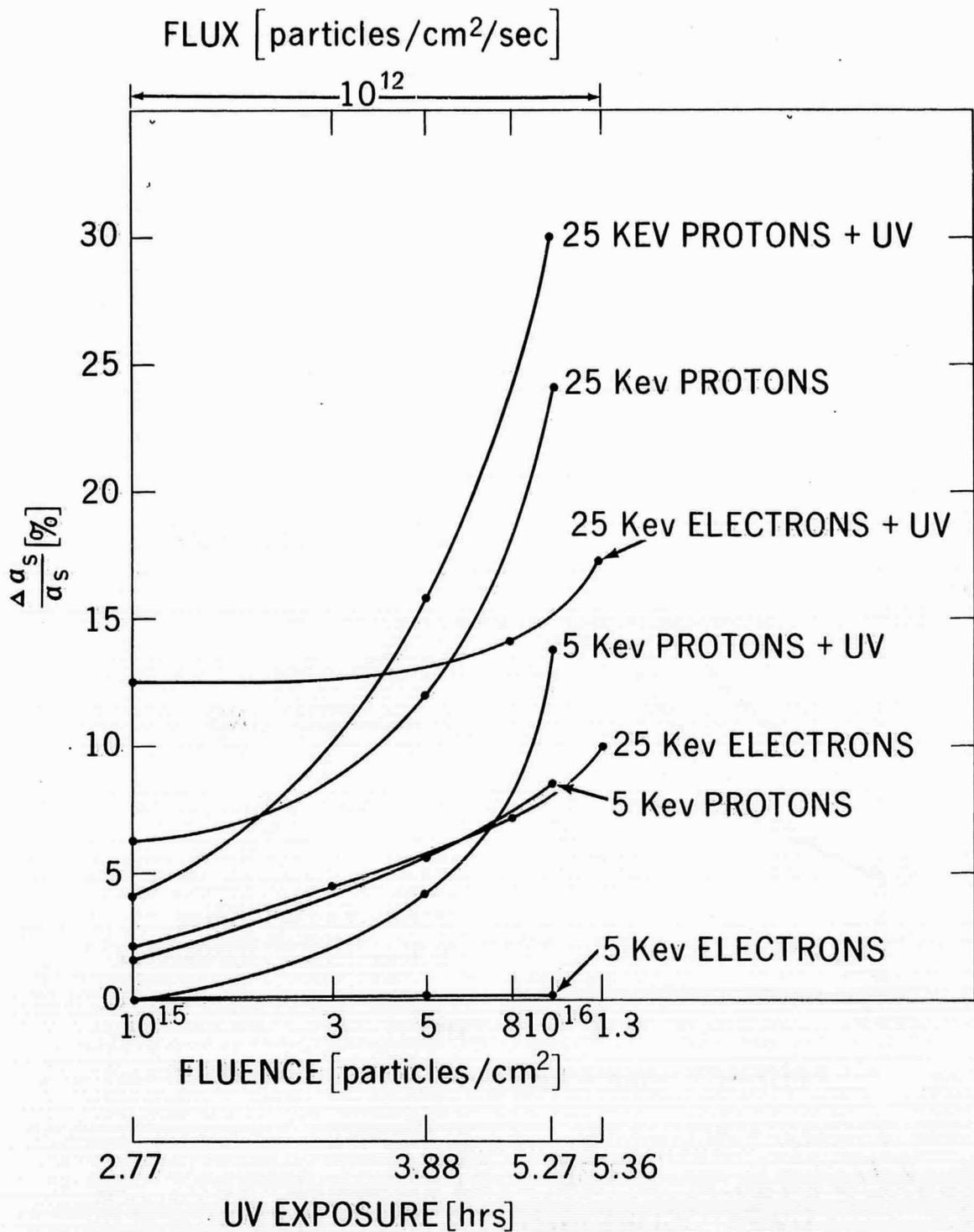


Figure 6. Relationship between the ratio of the change in solar absorptance to the initial value of solar absorptance vs particle radiation fluence and UV of 5 mil FEP teflon vapor deposited with silver

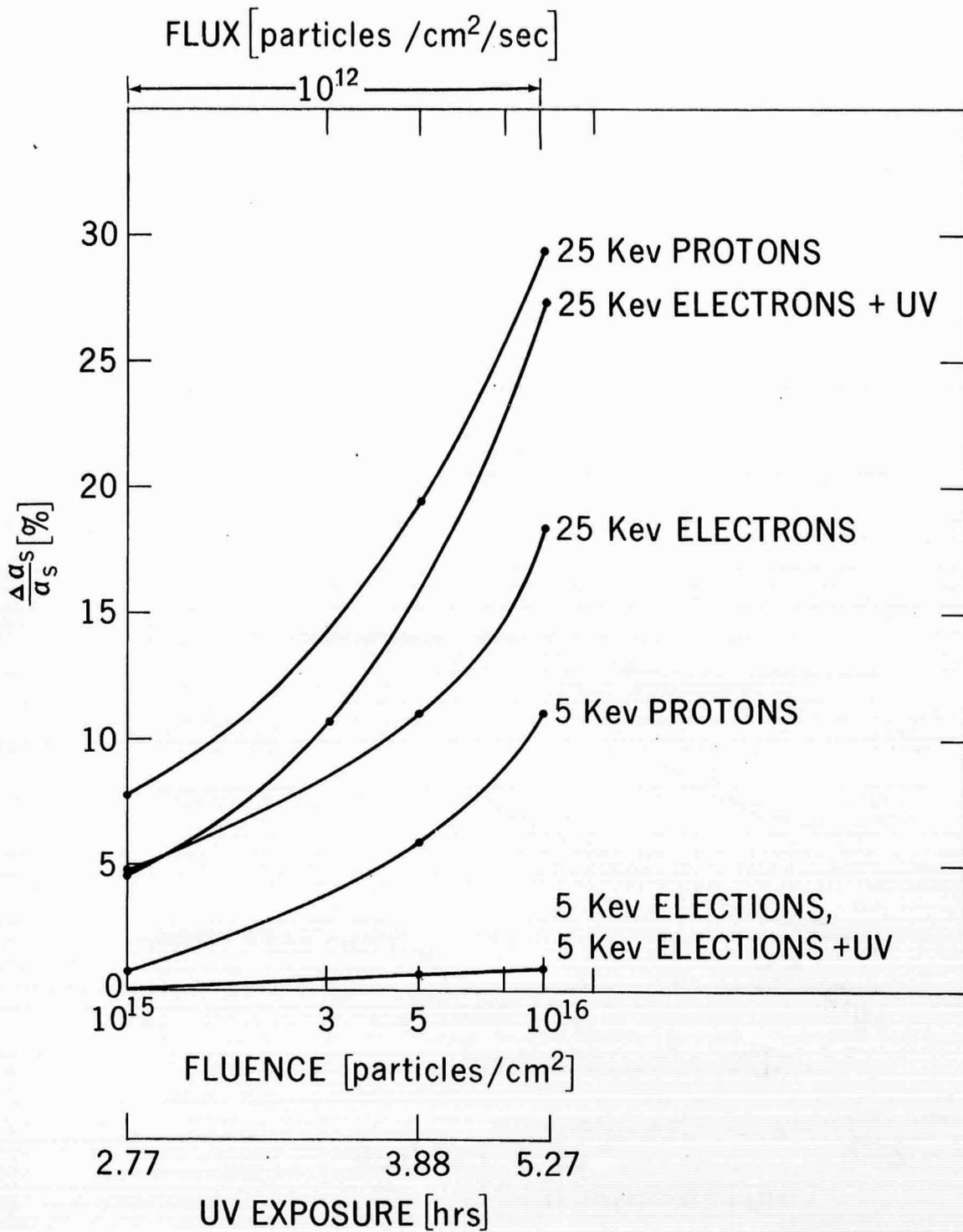


Figure 7. Relationship between the ratio of the change in solar absorptance to the initial value of solar absorptance vs particle fluence and UV dosage of 5 mil FEP teflon vapor deposited with aluminum

Table II

Initial and Final Solar Absorbance (α_s) Values of Silvered and Aluminized 5 Mil FEP Teflon Thermal Control Coatings When Exposed to Xe Source UV at 5 Solar Constants for 120 Hours in Vacuum and Oxygen Environments

| No. of Coatings Tested | Coating Type | Initial α_s (α_I) | Final α_s (α_F) | Irradiated In | Measured In | $\Delta\alpha$ ($\alpha_F - \alpha_I$) | $\frac{\Delta\alpha_s}{\alpha_s}$ (%) |
|------------------------|--------------|-----------------------------------|---------------------------------|----------------|----------------|--|---------------------------------------|
| 2 | Silver | 0.069 | 0.070 | Vacuum | Vacuum | .001 | 1.5 |
| | | 0.072 | 0.068 | Vacuum | air | -.004 | 5.6 |
| 2 | Aluminum | 0.123 | 0.116 | Vacuum | Vacuum | -.007 | 5.6 |
| | | 0.126 | 0.118 | Vacuum | air | -.008 | 6.4 |
| 2 | Silver | .076 | 0.123 | O ₂ | O ₂ | .047 | 62 |
| | | .075 | 0.125 | O ₂ | air | .050 | 67 |
| 2 | Aluminum | 0.122 | 0.112 | O ₂ | O ₂ | -.010 | 8.2 |
| | | 0.119 | 0.113 | O ₂ | air | -.006 | 5.1 |

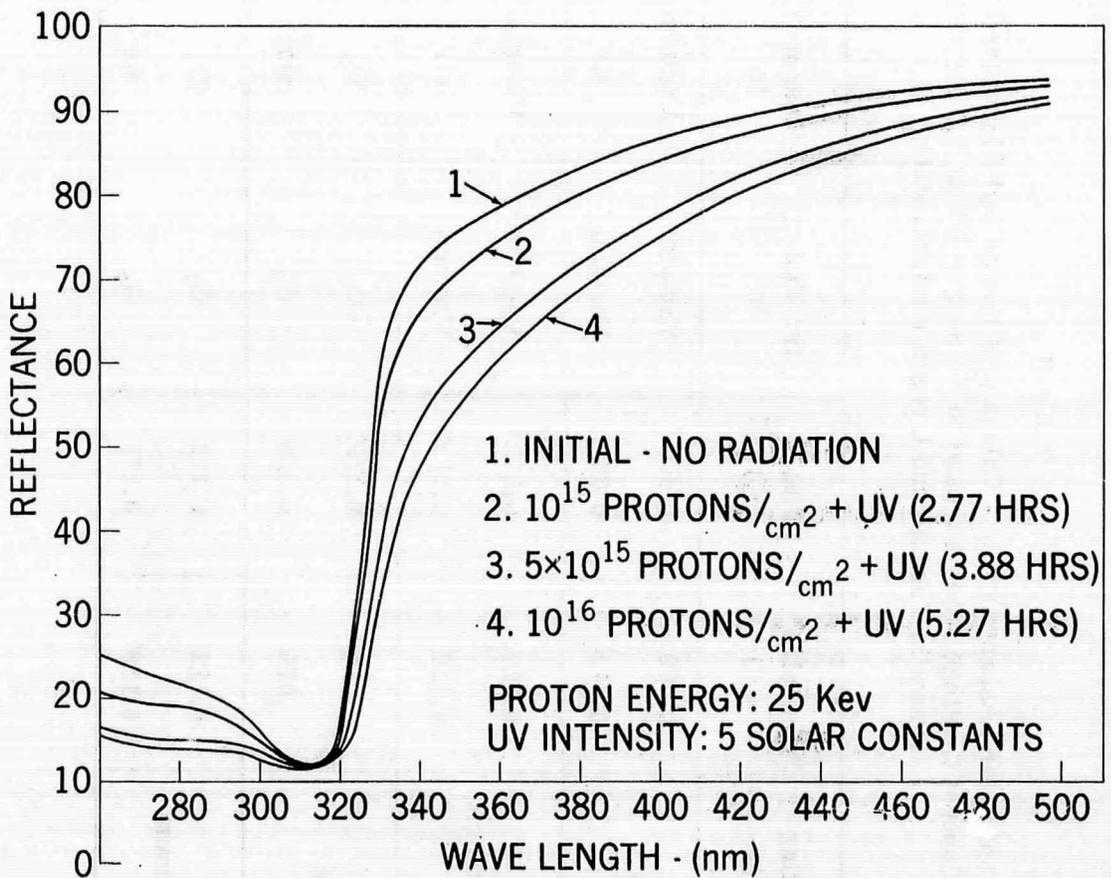


Figure 8. The reflectance of a silvered 5 mil FEP teflon coating vs wavelength when exposed to 25 Kev protons and Xenon source UV radiation at 5 solar constants

the chemical bonding in the coating material, with a resultant change in solar absorptance. However, in any type of radiation condition, UV, proton or electron, degradation is detected initially in the wavelength region below 400 nm. As the fluence of charged particle increases, at a given energy, or as the UV irradiation time increases, the reflectance curves begin to separate above 400 nm indicating degradation in the visible region as well. The most significant contribution to the increase in solar absorptance of thermal coatings occurs in the short wavelength region of the spectrum where the reflectance curves are the most widely separated.

Similar observations are made with aluminized type coatings. However, the strong absorption at 315 nm present in the silver coating reflectance curves is not observed with aluminized coatings.

Figures 4 and 5 show that both silver and aluminum type coatings are unstable to some degree with respect to solar absorptance as a result of radiation exposure.

Figure 4 shows that the most severe damage sustained by the silver vapor deposited coating results from 25 Kev protons and from 25 Kev protons + UV. Each point on these curves is an average of two data points. The spread in the two data points is designated by brackets, the extremes of the brackets representing the two data points. At the 10^{15} fluence level where the two points are the most widely separated from the mean, the spread in values of α_s represents $\pm 7\%$. The spread in values at the 5×10^{15} and 10^{16} fluence levels are correspondingly less. This spread of data precludes an assessment of the effect of the UV radiation contribution to the change in α_s of the coating.

Less severely damaged are the coatings irradiated with 5 Kev proton and 5 Kev protons plus UV. The curves show that the combined effect of UV and 5 Kev protons indicates greater damage at the 10^{16} fluence level than the 5 Kev proton radiation alone. Since only one test run per radiation condition was performed at these radiation levels and in consideration of the spread in the data of the 25 Kev proton and 25 Kev proton + UV curves, this result may be inconclusive.

Least damaged are the silvered coatings irradiated with 25 Kev electrons, 25 Kev electrons plus UV and 5 Kev electrons.

Figure 5 shows the changes in α_s of the aluminized coatings as a result of irradiation. As in Figure 4 the sample irradiated with 25 Kev protons was the most severely damaged. However, unlike Figure 4, the aluminized samples were damaged to a greater degree by 25 Kev electrons and 25 Kev electrons

+ UV than by 5 Kev protons. The 5 Kev electrons produce a negligible change in α_s from the initial values. The 5 Kev proton irradiated coating shows a significant deviation in α_s from the initial value but at the 10^{16} fluence level the degradation is comparable to the samples irradiated with 5 Kev electrons.

Proton damage is usually associated with atomic displacement and an associated vacancy type of damage whereas the predominant mechanism for electron damage is usually ionization. At a given energy level, Figures 4 and 5 show that the more massive proton changes the α_s of both the silvered and aluminized coatings at a greater rate than electrons.

With the data presented in the form shown in Figures 6 and 7, the effect of particle radiation alone compared to the effect of particle radiation plus UV radiation on the coating samples is more clearly seen. These figures show that with combined radiation testing the change in solar absorptance is greater, at the higher fluence levels, than the change in α_s when only particle radiation is directed at the coating samples.

Table II lists the results of Phase III of the testing schedule. These results represent the average values of α_s measured from two coating samples per testing condition.

The results show that silvered FEP teflon coatings are relatively unaffected by UV at an intensity of 5 solar constants when exposed in vacuum for 120 hours at room temperature. The solar absorptance decreases slightly when these coatings are measured in air.

When aluminized FEP teflon is irradiated in a similar manner and measured in vacuum as well as in air, the solar absorptance decreases from the initial value.

When silvered FEP teflon coatings are irradiated with UV in an oxygen atmosphere the solar absorptance increases drastically with the coatings showing visible signs of oxydation.

Similar testing on aluminized type coatings reveals that in an oxygen as well as a vacuum environment, the solar absorptance actually decreases. The coatings, after testing, remain highly reflective upon visible inspection. This indicates that O_2 has a profound effect, in the presence of UV, on the silvered FEP teflon coatings and that the transmissive properties of the clear FEP film is not appreciably affected in the pressure of an oxygen-UV environment.

The deterioration of the silvered FEP coatings may be due to delamination along the silver-FEP interface caused by the UV exposure with the resultant oxydation of the silvered reflecting surface. Evidence of delamination was not visible, however, upon inspection of the coatings involved.

FEP is a soft material and abrades very easily. Virtually any type of wiping motion across the surface of FEP in an attempt to clean it will cause scratches. To minimize scratches, a strip coating is used during handling. It is recommended to remove the protective coating or strip coating previously applied to the durface of the FEP teflon just prior to testing. The strip coating separates easily from the FEP and leaves no residue to impair the transmission properties.

The data shows a moderate spread in the initial value for solar absorptance. Besides small scratches and dirt acquired during handling the surface of the FEP teflon contains scratches and pinholes as it comes off the roll. The thickness of this film is controlled by the manufacturer to a tolerance at no greater than $\pm 10\%$. The variation of the values of initial α_s as measured in this report are within $\pm 10\%$.

Another source of error is the particle beam nonuniformity. The beam profile is gaussian in shape. Low energy electron beams, especially the 5 Kev beam used here, are easily deflected from external magnetic sources. Even when the drift tube is completely shielded with mu-metal, the variation in flux is probably at least $\pm 10\%$. The proton beam is much more stable in this respect.

CONCLUDING REMARKS

- 1) The change in solar absorptance of both aluminized and silvered 5 mil FEP teflon coatings is greater for protons than electrons at the 25 Kev energy level.
- 2) Except at the 5 Kev energy level, the change in solar absorptance at both silvered and aluminized 5 mil FEP teflon coatings is greater due to the combined UV and charged particle radiation, at a given energy level, than the radiation due to charged particles alone.
- 3) The distribution of the initial solar absorptance values of these coatings suggests that variations exist in the properties of the FEP teflon or in the method of sample preparation.
- 4) When comparing solar absorptance values of FEP teflon coatings, subjected to various radiation parameters, more than one run per test condition should be performed to obtain the data.

ACKNOWLEDGMENTS

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Testing was performed by S. G. Park of Electromechanical Research Inc., College Park, Md. under contract No. NAS 5-11326. F. G. Cunningham, formerly of the Thermophysics Branch initially monitored the testing schedule and reduced some of the data. Monitoring responsibility was transferred to W. A. Wappaus who produced the analysis and report of the study.

All thermal control specimens tested were prepared by R. N. Sheehy and his group of the Coatings Section.

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