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ULTRAVIOLET RADIATION EFFECTS

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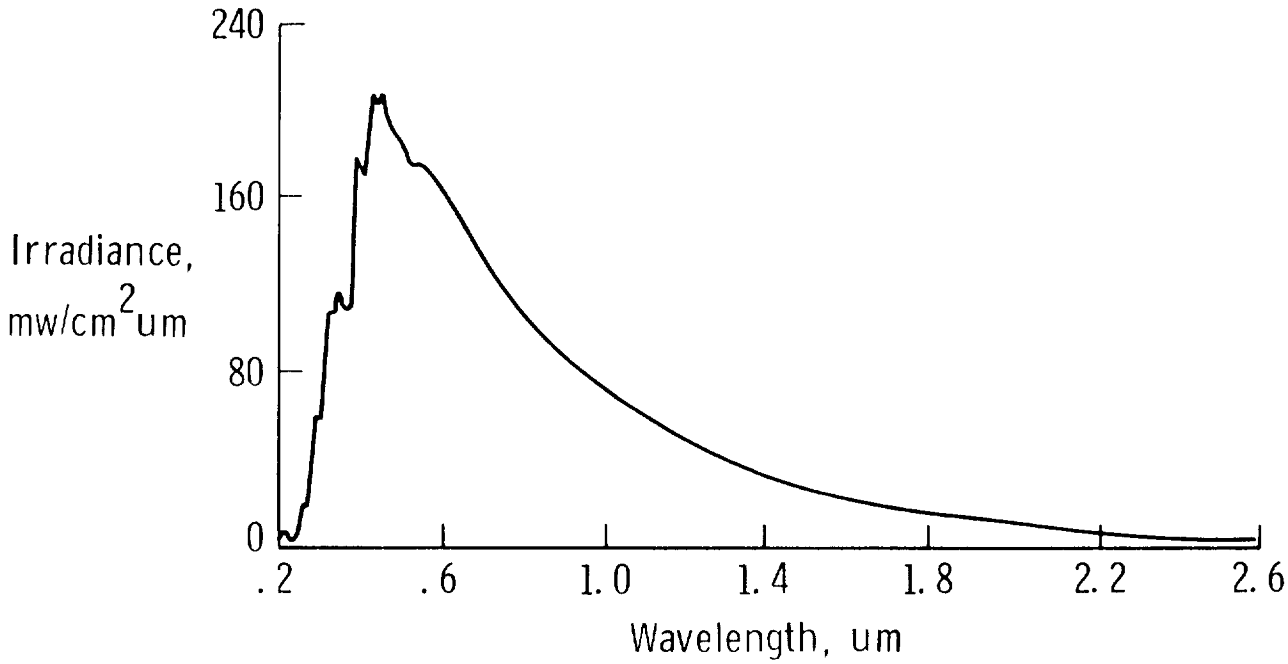
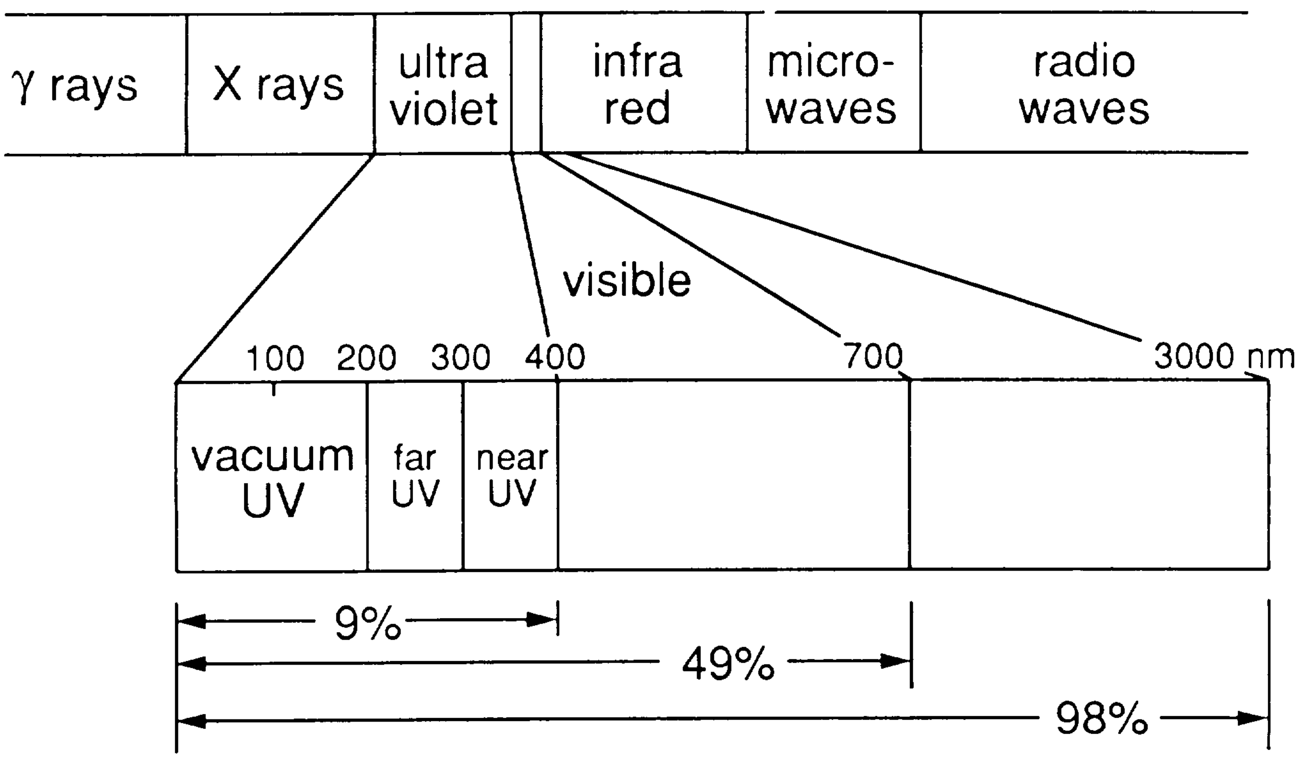
SOLAR SPECTRUM

The irradiance of the solar spectrum for air mass 0 is presented in the figure for the wavelength range of 0.2 micrometers to 2.6 micrometers.



THE ELECTROMAGNETIC SPECTRUM

The electromagnetic spectrum from gamma rays to radio waves is represented in the figure. The ultraviolet, visible, and near-infrared radiation found in the space solar spectrum is only a small part of this electromagnetic spectrum. The UV spectrum is divided into three parts--the vacuum or extreme UV below 200 nm, the far UV from 200 nm to 300 nm, and the near UV from 300 nm to 400 nm. Nine percent of the solar energy is found in the UV.



The chemical changes resulting from exposure of a polymer to ultraviolet light are illustrated in the figure. The first law states that only those radiations that are absorbed by a material can produce a chemical change. If a material does not absorb the particular wavelength of UV incident upon the material, then UV cannot cause a chemical change in the material. The second law states that each molecule taking part in a reaction absorbs one quantum ($h\lambda$) of energy. If moles are substituted in the Stark-Einstein law, the Bohr law is obtained. Since this equation is divided by wavelength, the smaller the UV wavelength, the greater the UV energy.

1) Only those radiations that are absorbed by a material can produce a chemical change (Grotthuss-Draper)

2) Energy absorbed by a reacting molecule is given by $h\lambda$ (Plank's const. x freq. of absorbed light) (Stark and Einstein)

3) Change molecules to moles (Bohr Law)

Equation: $E = Nh = N\,h\,c/2$ — **N - Avagadro's No.**

$E = 2.86 \times 10^5/\lambda$ k cal/mole — **C - Velocity of light**

λ - Wavelength, angstroms

Examples:

λ = 4000A the Einstein is 71 k cal/mole

λ = 2537A the Einstein is 113 k cal/mole

TYPICAL VALUES OF BOND ENERGIES

The typical values of bond energies are shown in this table. This illustrates that several chemical bonds can be broken by the 113 k cal/mole energy of the 2537A wavelength of UV radiation. Since the solar radiation in space extends to wavelengths as low as 1000A, most polymer bonds can be broken with UV radiation.

CHEMICAL BOND ENERGY

Bond	Bond Energy Term E (K cal./mole, 25°)
C-C	82.6
C=C	145.8
C≡C	199.6
C-N	72.8
C=N	147
C≡N	212.6
C-O	85.5
C=O aldehydes	176
C=O ketones	179
C-S	65
N-N	39
N=N	100
Si-O silicones	106?[b]

[a]All values are deduced from aliphatic compounds and are taken from T.L. Cottrell, "The Strengths of Chemical Bonds," Butterworths Scientific Publications, London, 1958, pp. 270-275.

[b]? = doubtful value

Most organic molecules lie in a singlet ground state (RH). Absorption of a photon raises the molecule to an excited singlet or triplet state (RH*). If the molecule has sufficient energy in the excited stated, bond dissociation may take place (R. + H.). This decomposition process must compete with other deexcitation processes. The excited molecule may revert to the ground state by emission of heat or energy (hν) in the form of fluorescence or phosphorescence. The later processes allow the excited molecule to return to the ground state without producing a chemical change. Revision to the ground state may also occur by the transfer of electronic energy from one group to another group in the vicinity of the excited molecule. An example of this occurs in polymethylphenylsiloxane where the phenyl group absorbs the UV energy then transfers this to the methyl group where degradation occurs.

$$RH \xrightarrow{h\nu} RH^*$$

$$RH^* \longrightarrow R. + H.$$

OTHER POSSIBLE REACTIONS

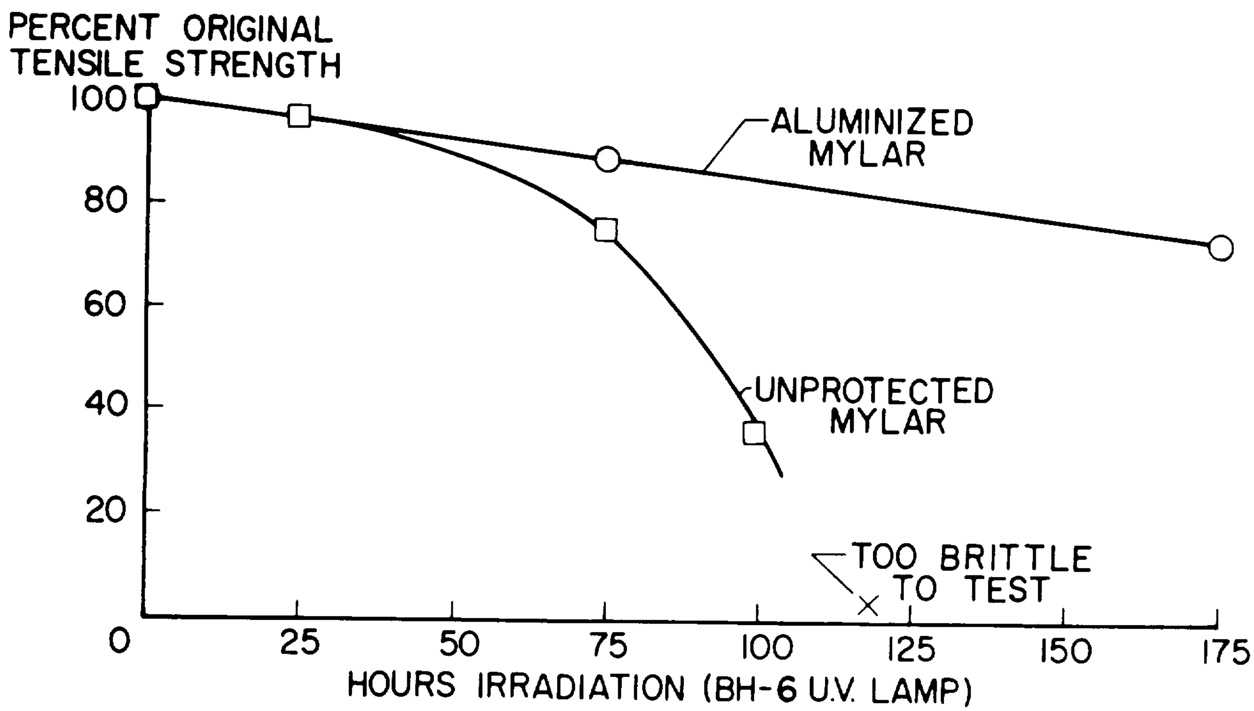
$$RH^* \longrightarrow RH + HEAT$$

$$RH^* \longrightarrow RH + h\nu \qquad \{FLUORESCENCE\ PHOSPHORESCENCE\}$$

$$M_1^* + M_2 \longrightarrow M_1 + M_2^* \qquad \{ELECTRONIC\ ENERGY\ TRANSFER\}$$

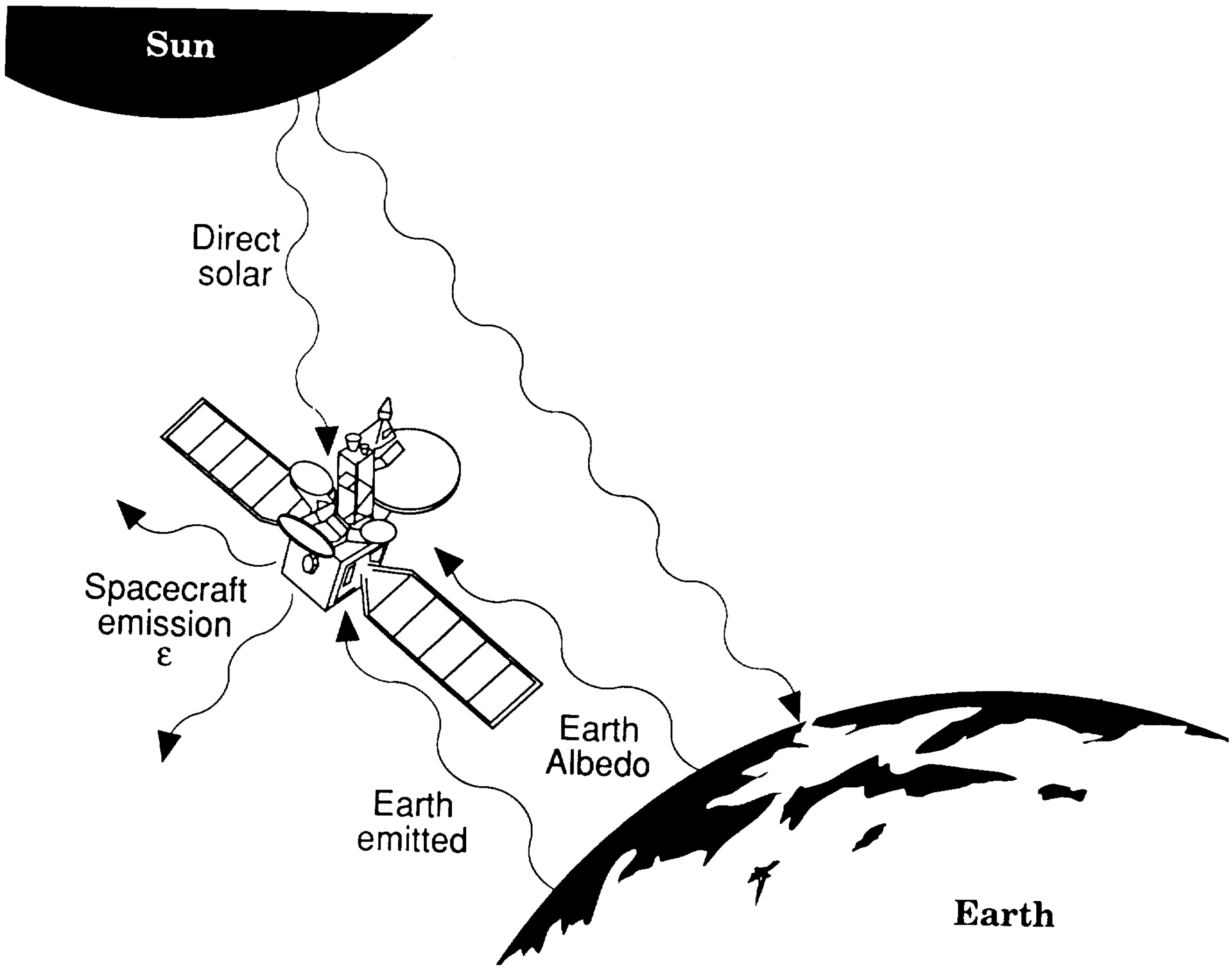
EFFECT OF ULTRAVIOLET RADIATION ON THE TENSILE STRENGTH OF MYLAR

This figure illustrates that UV radiation can degrade the mechanical properties of polymeric materials although the major research emphasis has been on changes in optical properties of polymer films.



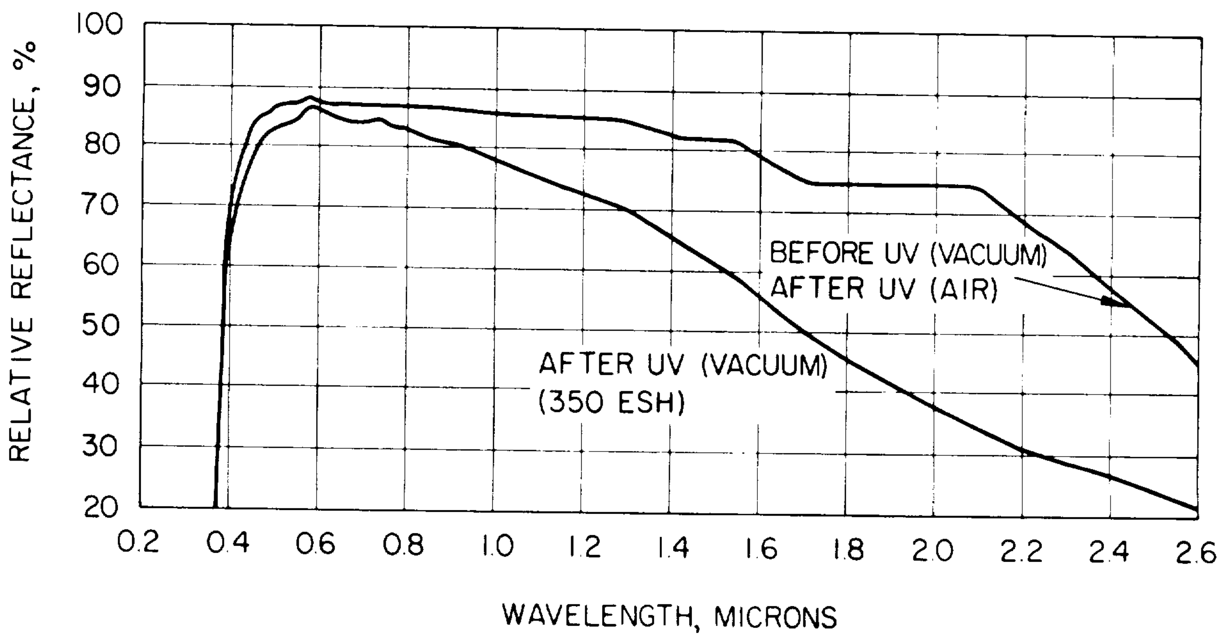
LEO SPACECRAFT THERMAL CONTROL ENVIRONMENT

The thermal control environment for a low Earth orbital satellite consists of the direct solar radiation, the Earth albedo (sunlight reflected from clouds, terain, and water), and the emitted radiation from the Earth. The absorptance of the spacecraft with its view factor to each of these heat sources is balanced against the emission of heat from the spacecraft.

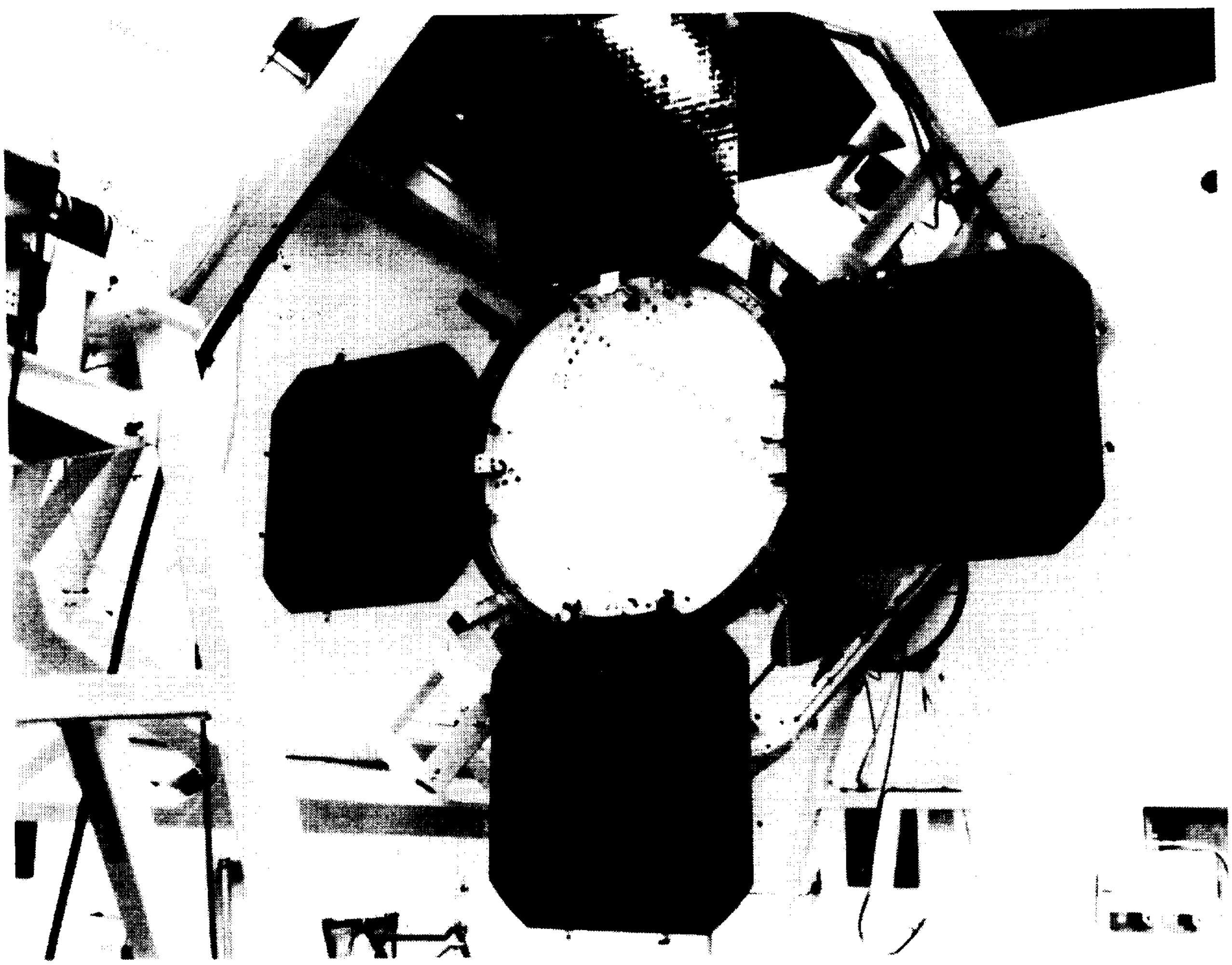


STRUCTURAL REFLECTANCE OF ZINC OXIDE-SILICONE

This figure illustrates the change in spectral reflectance due to UV exposure in vacuum for a zinc-oxide, pigmented silicone paint S-13. The figure also illustrates that upon introduction of air (oxygen) into the vacuum system, bleaching occurs which eliminates the UV degradation to this coating. This bleaching of white paints has led to the need for in situ testing of spacecraft coatings.

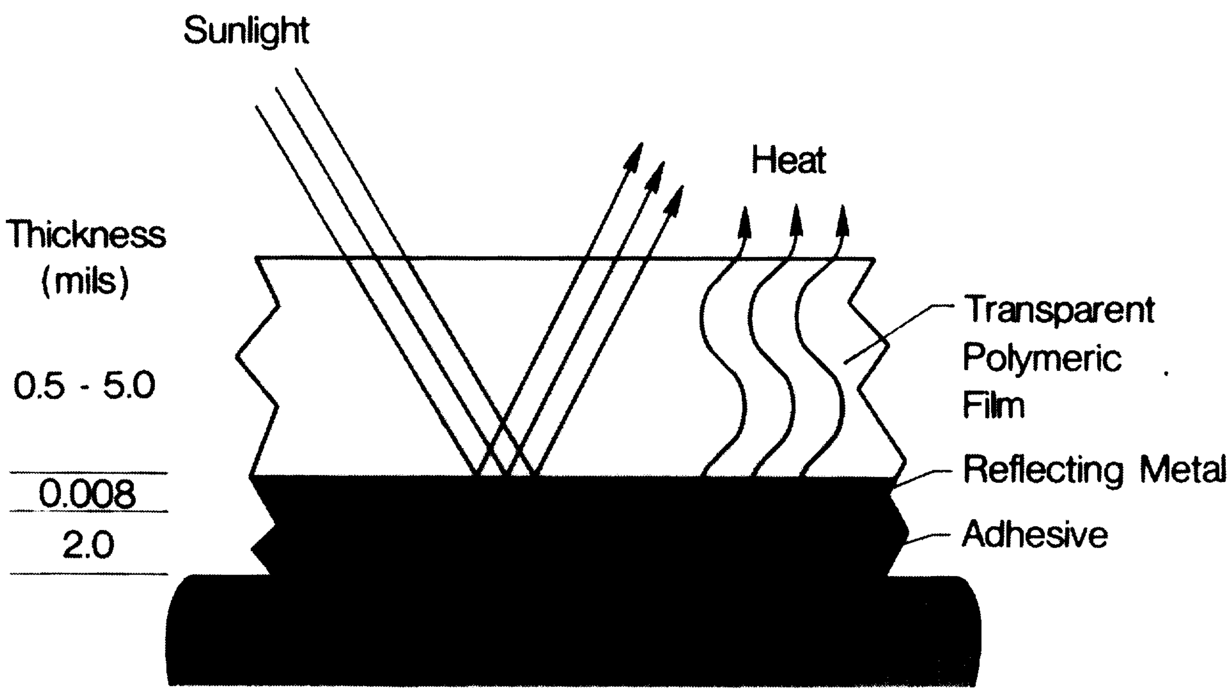


The radiator on the Lunar Orbiter spacecraft was coated with the S-13 paint before in situ testing was found to be required. Lunar Orbiters I and II experienced very dramatic temperature increases due to UV and solar wind plasma degradation of the coating. To offset the increase in solar absorptance of the white paint, about 20 percent of the radiator area on Lunar Orbiters IV and V were coated with quartz optical solar reflectors.

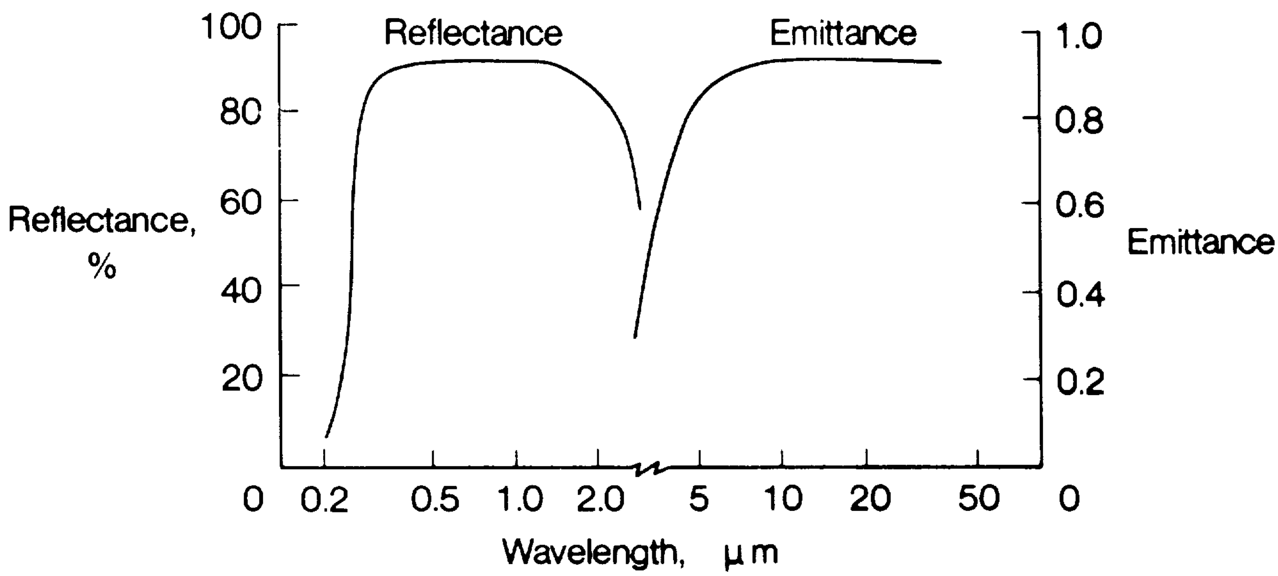


FLEXIBLE SECOND-SURFACE MIRROR (SSM) THERMAL CONTROL COATING

This figure is a schematic of a flexible second-surface mirror coating. The coating consists of a polymeric film that is transparent in the solar wavelength region and is coated on the back side with a reflecting, opaque metal like aluminum or silver. An adhesive is placed behind the metal to hold the coating to the spacecraft. Typically, the larger the thickness of the polymeric film, the stronger the absorption bands are in the infrared, out of the solar wavelength region, and therefore, the higher the emittance of the coating. An example of an SSM coating is silvered – perfluorinated ethylene propylene copolymer (FEP) Teflon.

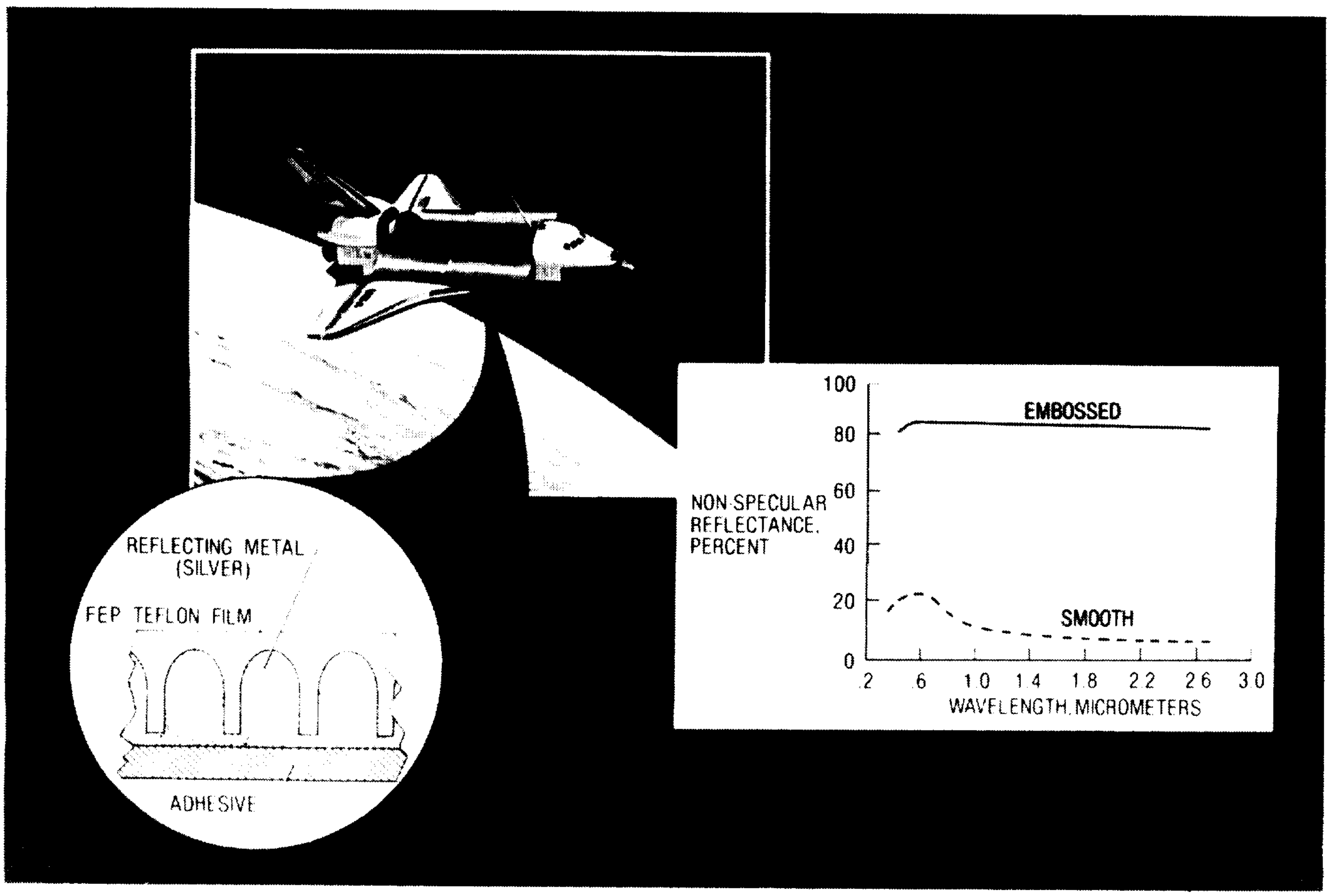


The figure helps to explain the radiation characteristics of the SSM coating in the previous figure. The reflectance of this coating and the transparency of the polymeric film must occur from 0.2 to 3.0 micrometers, the region of maximum solar energy. But the coating is radiating heat away from a spacecraft which has a maximum temperature of about 100°C; therefore, this energy is found in the infrared from 10 to 50 micrometers. The characteristic absorption bands of polymers provide this infrared emittance.



NON-SPECULAR SILVERED TEFLON

The non-specular reflecting silvered Teflon SSM coating used on the Orbiter's radiators was developed at NASA Langley. The FEP Teflon is embossed with a special roller to provide light scattering on the metal coating side leaving the outside smooth to prevent trapping contamination in the Teflon surface. The process reduces the specular reflectance to about 15 percent but maintains the 0.09 solar absorptance of the smooth silvered Teflon SSM.



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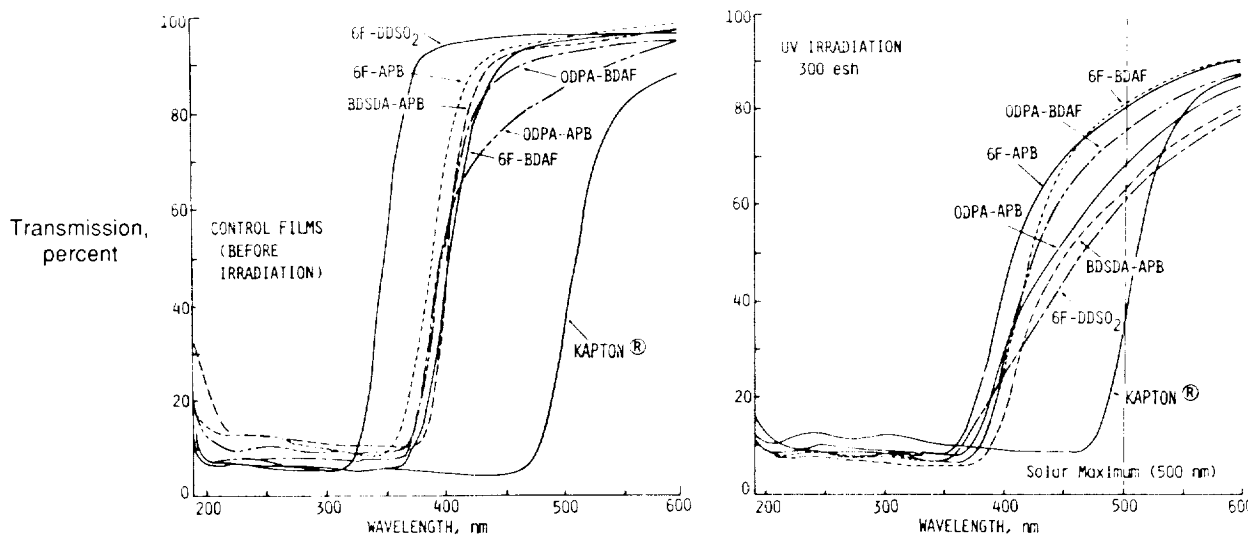
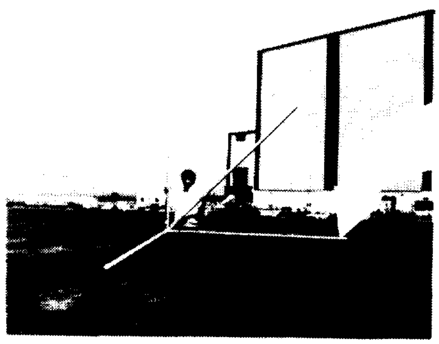
EFFECT OF UV RADIATION ON TRANSMISSION OF TRANSPARENT POLYIMIDE FILMS

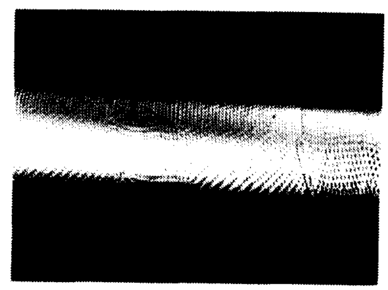
This figure illustrates some current studies being conducted at NASA Langley on highly transparent polyimide films. These films are stable to about 300°C and are soluble in the imide form, which means they are sprayable. Some of these experimental films have exhibited high stability to simulated solar UV and high energy electron radiation.



ALUMINUM FOIL COATING FOR COMPOSITE TUBES

A concept for thermal control and atomic oxygen protection for the composite tubes used as structural elements in the Space Station Freedom has been developed at NASA Langley and demonstrated under contract with Boeing Aerospace Company. Aluminum foil 0.008 cm thick is anodized or sputter coated with SiO_x to achieve the desired radiation properties of 0.3 solar absorptance and 0.65 emittance. This aluminum foil is then adhesively bonded to the exterior of the graphite/epoxy tube. Process specifications have been developed for achieving the radiation properties with chromic acid anodizing.





- Can be anodized or sputter coated to achieve desired optical properties
- Application techniques can provide a non-specular reflecting coating
- Provides atomic oxygen protection for composite tubes
- Resistant to abrasion and UV degradation
- Demonstrated on 2 inch dia. X 8 feet long P75/934 graphite epoxy composite tubes

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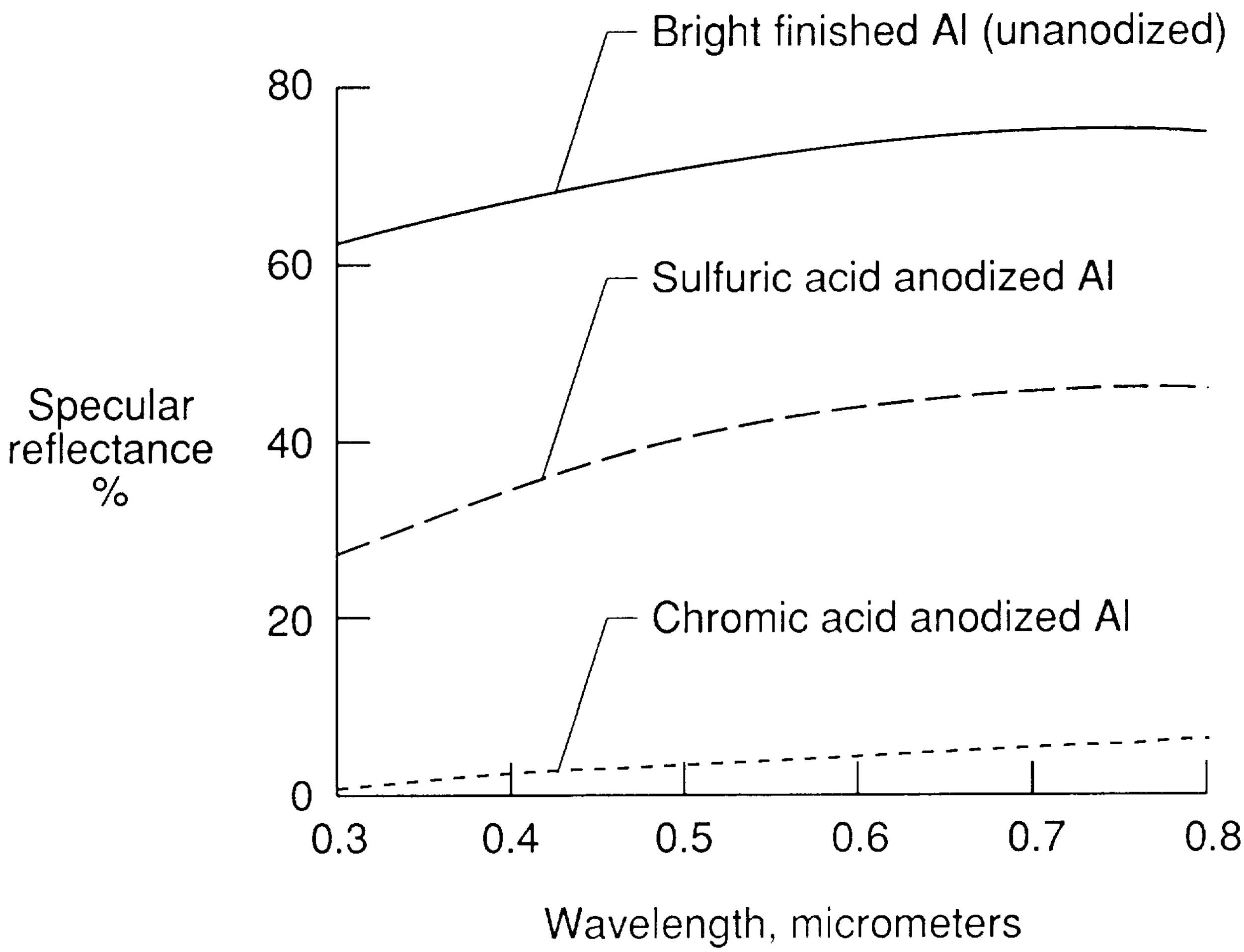
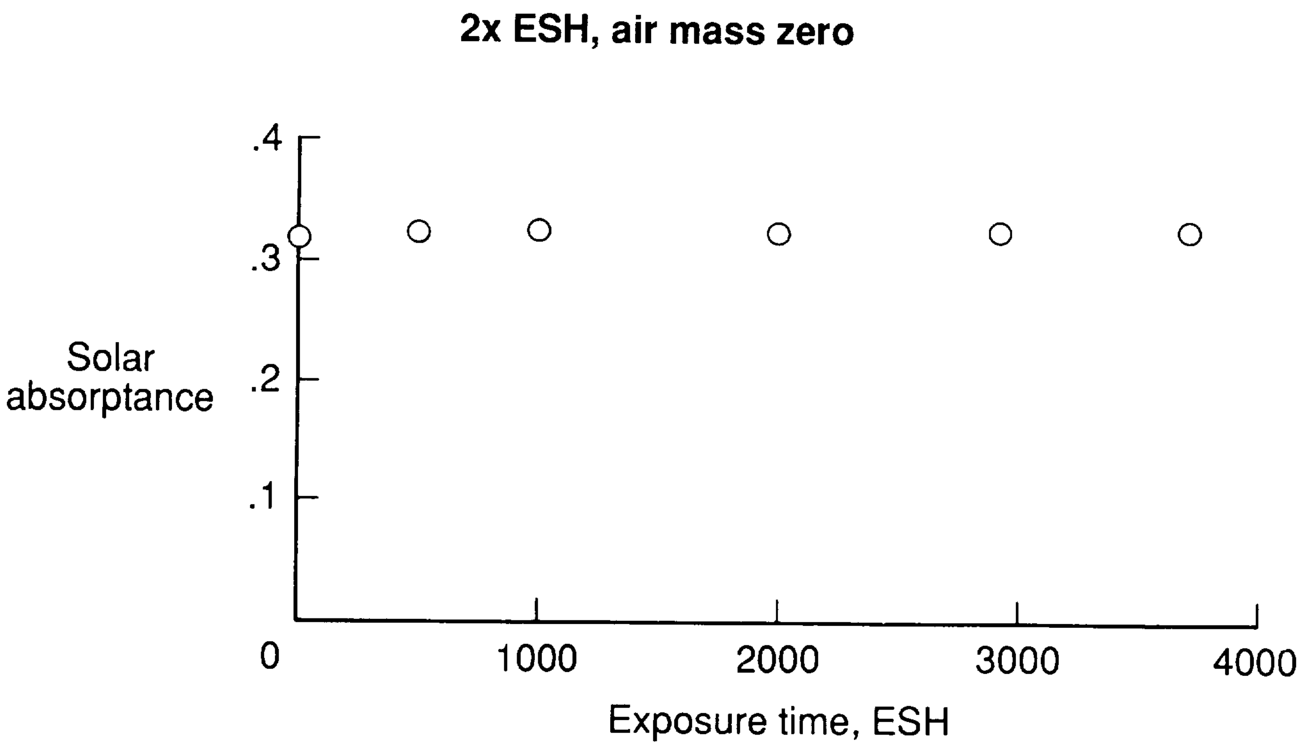
SPECULAR REFLECTANCE OF CHEMICALLY TREATED ALUMINUM

It is highly desirable to have a low solar absorptance coating on the composite structural members which would not be a specular reflector. With the large number of structural members in the Space Station Freedom, sunlight reflected from these members can interfere with optical experiments on the Freedom. This figure shows that the chromic acid anodizing process provides less than 5 percent specular reflectance at 0.5 micrometers, the peak solar wavelength, where the sulfuric acid process has nearly 40 percent specular reflectance.

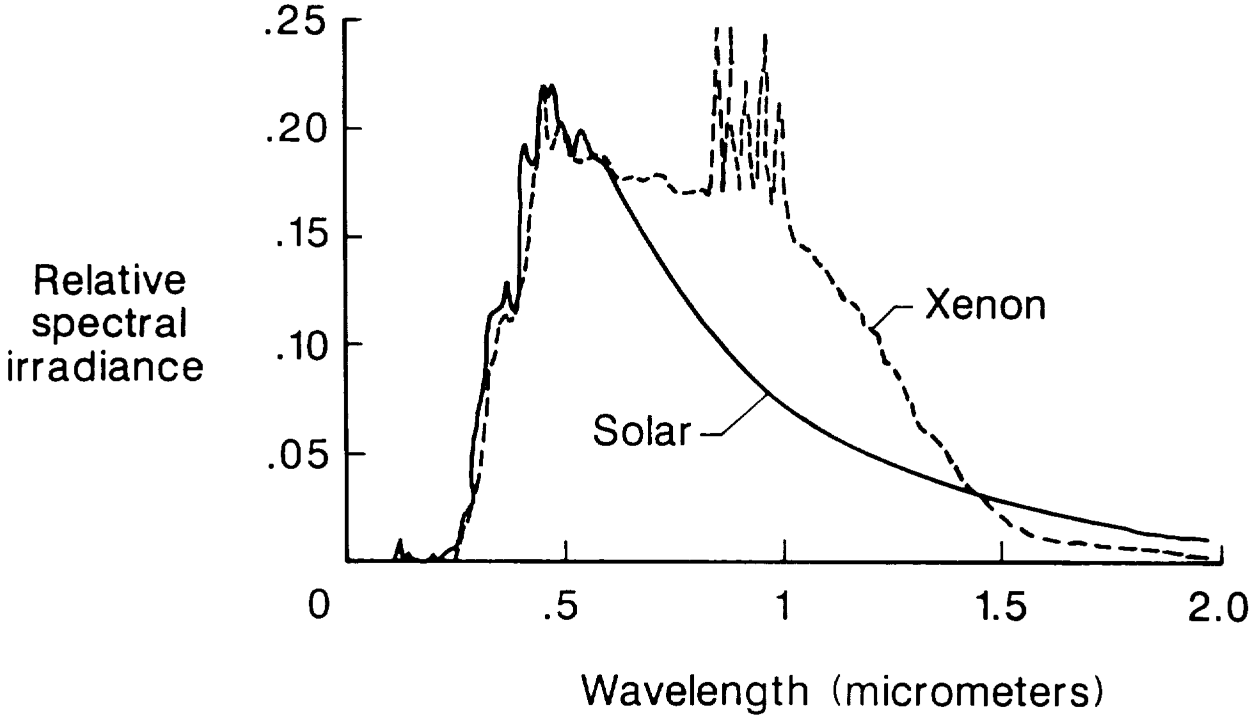


EFFECTS OF UV ON SOLAR ABSORPTANCE OF
SEALED CHROMIC-ACID ANODIZED 1145 AL 3 MIL FOIL

The chromic acid anodized aluminum foil used to coat the composite tubes for the Space Station Freedom has been exposed to simulated solar ultraviolet radiation at NASA Langley. These results show that the coating is very stable to UV radiation having only a 0.02 increase in solar absorptance in 4,000 equivalent solar hours (2,000 hours x 2 solar constants).



This figure compares the spectral irradiance of a xenon short-arc lamp with a quartz envelope to the solar irradiance at air mass zero. The figure clearly shows that xenon has a good UV solar match from approximately 0.2 to 0.7 micrometers but is much more intense in the infrared region. This IR radiation leads to over heating of test specimens when accelerated exposure is attempted. Experimental results indicate that acceleration factors of only 3X are possible without substantially overheating the test specimens.



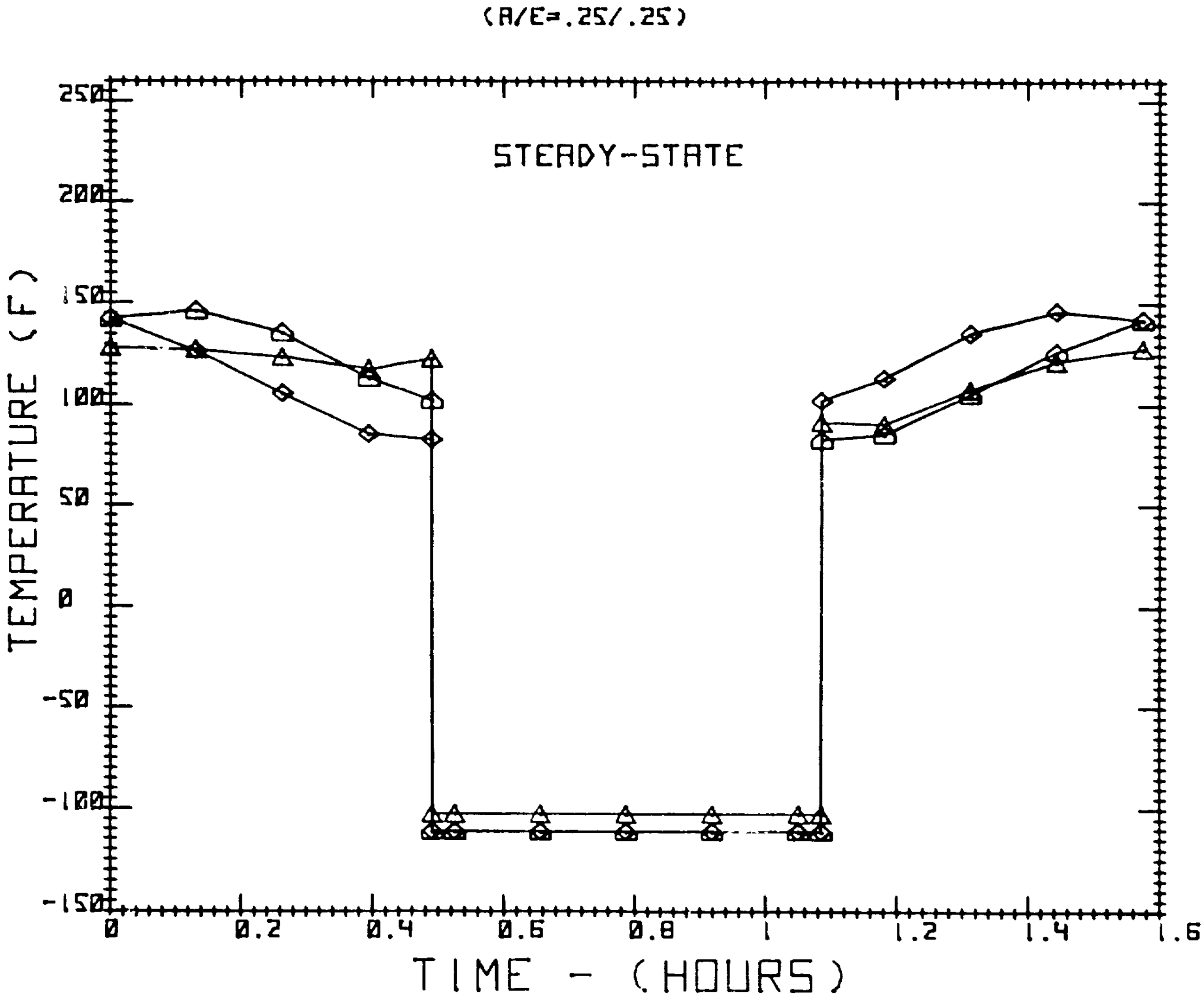
PROBLEMS ASSOCIATED WITH SOLAR SIMULATION

When most investigators expose materials to simulated solar UV, the irradiance of the UV beam is measured and referred to as a percentage of the solar irradiance at air mass 0. Since many spacecraft rotate, then this must be taken into account in calculating one solar constant. Also the shape factor for the spacecraft surface and the orbital parameters must be considered. Many spacecraft will have only 25 percent of their time in orbit in the sun. This would be a 4 to 1 acceleration factor even if the laboratory exposures were conducted at one solar constant.

- **One solar constant assumes nonrotating spacecraft in constant sunlight, but most rotate**
- **Shape factor of 1 where, in reality, shape factor is near 0.5**
- **Near Earth orbit is approximately 90 min. with about 30 min. in solar occult**
- **Reality is 25% to 40% of time in sunlight for spacecraft surfaces**

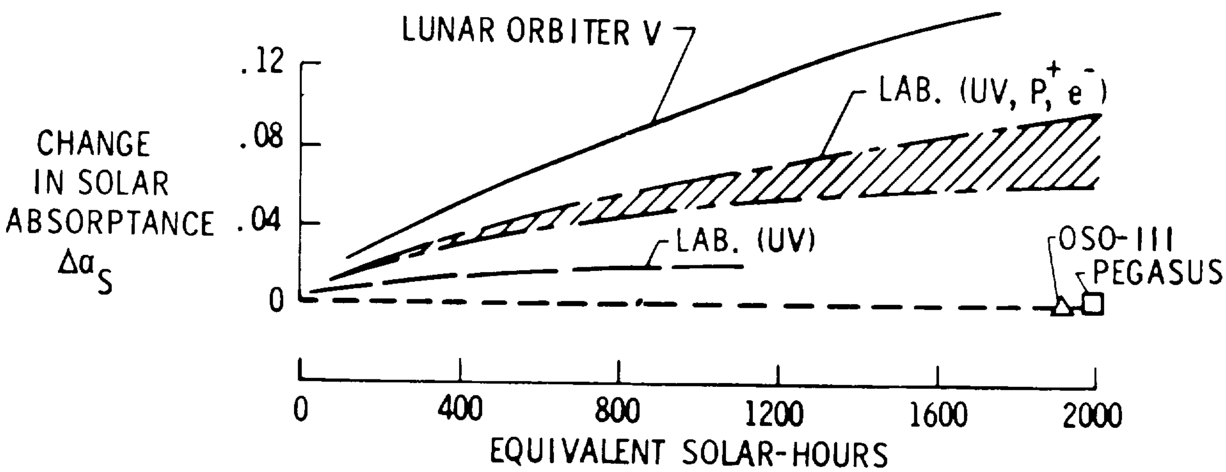
TRUSS TUBE TEMPERATURES

This is a steady state calculation for a composite tube with an α/ε of .25/.25 in the proposed Space Station Freedom orbit. This projects the thermal cycle range and shows the typical occult for these conditions.



COMPARISON OF FLIGHT AND LABORATORY DATA ON ZINC OXIDE-POTASSIUM SILICATE COATING Z-93

This figure was prepared a number of years ago from flight and laboratory data conducted using short arc xenon UV source and a 3 kev solar wind proton source with thermal electrons for charge neutralization. The combined UV and solar wind plasma experienced on Lunar Orbiter V was under simulated in the laboratory. The UV degradation experience by OSD-III and Pegasus was over simulated in the laboratory test. No changes in procedures or equipment which have been made since these tests were conducted would alter these results.



SUMMARY

Solar ultraviolet testing has not been developed which will provide highly accelerated (20 to 50X) exposures that correlate to flight test data. Additional studies are required to develop an exposure methodology which will assure that accelerated testing can be used for qualification of materials and coatings for long-duration space flight.

- **Solar UV radiation is present in all orbital environments**
- **Solar UV does not change in flux with orbital altitude**
- **UV radiation can degrade most coatings and polymeric films**
- **Laboratory UV simulation methodology is needed for accelerated testing to 20 UV solar constants**
- **Simulation of extreme UV (below 200 nm) is needed to evaluate requirements for EUV in solar simulation**