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DEGRADATION OF HUBBLE SPACE TELESCOPE METALLIZED TEFLON® FEP THERMAL CONTROL MATERIALS

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ABSTRACT

The mechanical and optical properties of the metallized Teflon® Fluorinated Ethylene Propylene (FEP) thermal control materials on the Hubble Space Telescope (HST) have degraded over the seven years the telescope has been in orbit. Astronaut observations and photographic documentation from the Second Servicing Mission revealed severe cracks of the multi-layer insulation (MLI) blanket outer layer in many locations around the telescope, particularly on solar facing surfaces.

Two samples, the outer Teflon® FEP MLI layer and radiator surfaces, were characterized post-mission through exhaustive mechanical, thermal, chemical, and optical testing. The observed damage to the thermal control materials, the sample retrieval and handling, and the significant changes to the radiator surfaces of HST will be discussed. Each of these issues is addressed with respect to current and future mission requirements.

KEY WORDS: Hubble Space Telescope, Multi-Layer Insulation, Teflon® Fluorinated Ethylene Propylene (FEP)

1. INTRODUCTION

The Hubble Space Telescope (HST) was launched in April 1990 and deployed at an orbital altitude of 598 km (320 nmi) and 28.5° orbit inclination. The Telescope's mission is to spend

15 years probing the farthest and faintest reaches of the cosmos. Crucial to fulfilling this promise is a series of on-orbit manned servicing missions to upgrade scientific capabilities. The First Servicing Mission (SM1) took place in December 1993, 3.6 years after deployment. The Second Servicing Mission (SM2) followed in February 1997, 6.8 years after deployment. Two subsequent servicing missions are also scheduled for late 1999 and early 2002.

Astronaut observations and photographic documentation from the SM2 revealed severe cracks of the multi-layer insulation (MLI) blanket outer layer in many locations around the telescope, particularly on solar facing surfaces. Two samples were retrieved during the SM2, the outer Teflon® FEP MLI layer and radiator surface, and were characterized post-mission through exhaustive mechanical, thermal, chemical, and optical testing. This paper details the observed damage to the thermal control materials, the sample retrieval and handling, and the significant changes to the radiator surfaces of HST. Each of these issues is addressed with respect to current and future mission requirements.

2. HST DESCRIPTION

As shown in Figure 1, the HST houses the five scientific instruments (SIs) and three Fine Guidance Sensors in the Aft Shroud (AS). The Support Systems Module (SSM) Bays, located directly above the AS, house the batteries, tape recorders, and house keeping equipment. The Forward Shell (FS) and Light Shield (LS) is the structure enclosing the primary and secondary mirror and stray light rejection baffles. The Aperture Door (AD) is closed only during servicing periods or safe hold modes to protect the primary and secondary mirrors from direct sun impingement and contamination.

The HST uses several thermal control materials to passively control temperatures on-orbit. These materials are of two primary types: radiators and MLI blankets. As shown in Figure 2, the radiator surfaces are the AS, Aft Bulkhead, AD, and SSM Bays and louvers on the SMM Bays. The radiator surfaces are 5 mil Teflon® FEP/Ag/Inconel bonded to the vehicle substrate (aluminum) with acrylic adhesive. All other surfaces are blanketed.

3. HST ON-ORBIT ENVIRONMENT

The HST thermal control system (TCS) is exposed to the low Earth orbit (LEO) environment which includes solar radiation, particle radiation and atomic oxygen. Solar exposure, including near ultraviolet radiation, vacuum ultraviolet radiation, and soft x-rays from solar flares, may cause surface damage in polymeric materials such as Teflon® FEP. Trapped electron and proton particle radiation may cause mechanical or chemical property changes in the bulk of the polymeric material. Atomic oxygen can erode polymeric materials such as Teflon® FEP through chemical reactions with gaseous oxide products.

Table 1 summarizes the HST environmental exposures experienced by the HST samples. The fluences shown in Table 1 do not take into account scattering of atomic oxygen or solar radiation off of other surfaces on the telescope.

Table 1. HST Sample Environmental Fluences

Sample	Equivalent sun hr (ESH)	X-ray fluence (J/m^2)	Trapped electrons and proton fluence > 40 keV (#/cm^2)	Plasma fluence (#/cm^2)	Atomic Oxygen (atoms/cm^2)
SM2 MLI	33,638	0.5-4Å: 16 1-8Å: 252.4	electrons: 2.14 x 10^{13}	electrons: 4.66 x 10^{19}	1.64 x 10^{20}
SM2 CVC	19,308	0.5-4Å: 6.1 1-8Å: 96.9	protons: 1.83 x 10^{10}	protons: 1.63 x 10^{19}	

4. THERMAL SUBSYSTEM DESCRIPTION

The HST TCS is designed to control temperatures of SSM components and the structure that interfaces with the Optical Telescope Assembly (OTA) and SIs. The TCS provides thermal control for all SSM equipment during all mission phases and is passive to the maximum extent possible. The SSM uses passive thermal control design consisting of insulation, component arrangement, and mounting configurations augmented with thermostatically controlled heaters. Louver systems are used for the battery bays.

4.1 MLI Blankets MLI blankets are used on over 80 percent of the external surface area of HST. These blankets have a FOSR (Flexible Optical Solar Reflector) outer layer (5 mil aluminized Teflon® FEP) which is reflective to energy in the solar spectrum to minimize the effect of solar orientation and day/night cycling on spacecraft temperatures. The MLI blankets insulate the structure from the external thermal environment, thus conserving heater power and minimizing temperature extremes and gradients. The baseline MLI design is 15 layers of embossed Double-aluminized Kapton® (DAK) with an outer layer of 5 mil FOSR and an inner layer of 1 mil single Aluminized Kapton® (SAK). The surface properties of this outer layer control the external blanket maximum temperatures to 20°C or less. No spacers are used between the layers since the embossing pattern reduces layer-to-layer conduction and meets the Orbiter flammability requirements.

The blankets are closed out on all four sides with a taped cap section and the layers are tied together throughout the blanket using a pattern of 10 mil acrylic transfer adhesive film. Where the blankets were cut to fit around stantions, handrails, portable foot restraint sockets, etc., the blanket was closed out by taping a cap section using 10 mil acrylic transfer adhesive film. In addition, where the blankets were vented ("X" cuts), the outer layer was reinforced using aluminized Kapton® scrim tape. Velcro® was stitched to the internal layer, which was reinforced with aluminized Kapton® scrim tape. To indicate fold lines on the SSM Bay doors blankets, the blankets were stitched through all the blanket layers.

4.2 Radiators The radiator surfaces are perforated 5 mil Silver FOSR bonded with acrylic adhesive to the (aluminum) substrate. This material was purchased in 4-inch (width) rolls with the adhesive already applied. The FOSR was applied in sections and a Teflon® wand was used to minimize air entrapment between the FOSR and the substrate. Damaged FOSR was replaced as required during the buildup of the telescope. The AD external surface is 5 mil Aluminized FOSR.

5. SM2 OBSERVATIONS

One of the objectives during the SM2 was to photo document the condition of the telescope external surfaces. During EVA (extravehicular activity) periods, photography of the telescope was performed highlighting damaged MLI areas as requested. During Crew sleep periods, the telescope was systematically photographed.

5.1 On-Orbit During the HST SM2, damage of the MLI was observed on the +V3 side (sun side) with several large cracks in the light shield MLI outer layer (above the stowed High Gain Antenna). This large crack is shown in Figure 3. Upon further visual observations of the vehicle, additional cracks were seen on all MLI surfaces. Cracking of the MLI outer layer was seen all over the telescope, with the most damage seen on the LS, SSM Bay 8, SSM Bay 7, and SSM Bay 10. The SSM Bay 8 is shown in Figure 4; the MLI is cracked around most of the bay perimeter, and the MLI appears as though it is partially detached and lifted away from the telescope.

Prior to patching the corners of the SSM Bay 8 MLI, the astronauts performed two tests: a Velcro® cycling and Teflon® FEP bend test. The Velcro®, attaching the MLI blanket to the bay, was cycled to determine its integrity – was it still attached to the telescope substrate and did the hook still hold the pile securely? The astronauts reported that the Velcro® appeared to be securely fastened to the vehicle substrate and the hook seemed to hold the pile securely. The astronauts also bent a piece of the Teflon® FEP over on itself to determine if manipulating it during the patching process would cause significant damage. The astronauts reported that the Teflon® FEP did not crack.

Although the damage to the MLI was visually dramatic, there was no measurable thermal effect due to the cracks and the exposure of the DAK to the telescope environment. However, during the SM2 mission, a program decision was made to reconfigure flown MLI patches to patch the worst of these damaged areas.

5.2 Damage Map Post mission analysis of the photographic documentation indicated that the MLI outer layer was cracked extensively on all MLI surfaces. The cracks were noticeably larger and more numerous on the sun side (+V3) of the telescope. The cracks in the FEP Teflon on the anti-sun side (-V3) of the telescope tended to start and end at stress concentration points. Whereas, the cracks on the sun side (+V3) of the telescope start at stress concentration points and either end where two cracks meet or in the middle of an MLI blanket.

Figure 5 shows a map of the MLI damage, using SM2 photo documentation (Reference 3). This map depicts the damage and notes where the cracks have opened on the LS and SSM bays. The location of the features on the map is approximate and shown for illustration purposes only. The most important item to note is that the damage is seen all over the vehicle and is noticeably worse on the sun side (+V3).

6. SAMPLE DESCRIPTION

6.1 MLI Sample An MLI sample, shown in Figure 6, was taken from the upper LS crack prior to patching the area. The LS MLI cracks are shown with patches installed in Figure 7. The sample was cut right to left with a change in the initial direction of the cut as the astronauts realized they were cutting through the sample. The sample is shown flat in Figure 8; the astronaut cuts, on-orbit cracks and handling cracks are identified. The sample was handled carefully and stored in an EVA trash bag for the duration of the EVA. The trash bag was transferred to the crew cabin and the sample was placed in a reclosable polyethylene bag and stowed in a middeck locker for the duration of the mission. The sample was requested as an early destow item and was turned over to the HST project within 6 hours of the Orbiter landing.

The sample was transferred to a poylcarbonate container and transported via over night courier service to the Goddard Space Flight Center (GSFC). Upon arrival at GSFC, a small portion of the sample was photo documented. The sample was then stored in a laboratory until testing.

6.2 Radiator Sample As part of the installation of the Near Infrared Camera Multi-Object Spectrometer, a cryogen vent line was routed through the Aft Bulkhead to expel Nitrogen boil off from the instrument. As a result, the Cryogen Vent Cover (CVC) was removed and returned to Earth at project request. The outside of the CVC (radiator surface) had been exposed to the HST ambient environment and provided a good data point for the thermal degradation of the radiator surfaces. This Aft Bulkhead (-V1) surface was exposed to direct solar incident radiation, however, it was significantly less than the MLI sample from the LS. The telescope sun angle history has been compiled and is shown in Table 1 as equivalent solar hours (ESH).

7. DISCUSSION

7.1 MLI Sample The MLI sample was characterized through exhaustive mechanical, thermal, chemical, and optical testing. The testing revealed several changes to the mechanical, chemical and thermal properties of the MLI. Details of these tests may be found in References 4-7. The on-orbit cracks are nearly featureless indicating that they occurred very slowly under low load and in the presence of a damaging environmental factor. This crack mechanism is similar to stress-corrosion cracking in metals and slow crack growth in ceramics. The material shows significant reduction in ultimate strength and elongation, indicating through-thickness embrittlement of the Teflon® FEP. The surface of the Teflon® FEP is de-fluorinated from interaction with the orbital environment. Increases in the solar absorptance of the Teflon® FEP correlate well with the number of days spent in space, rather than with equivalent solar hours. The aluminum backing is cracked in a "mud tiling" pattern due to the difference in thermal expansion of the Teflon® FEP and the aluminum and the 40,000 thermal cycles HST experienced. It is expected that the condition of the MLI will continue to degrade, and that it will be fragile by the next servicing mission.

7.2 Radiator Sample The radiator sample was characterized through exhaustive mechanical, thermal, chemical, and optical testing. Testing of the CVC sample showed that the solar absorptance of the bonded silver Teflon® FEP on the AS of HST has increased. Flight temperature data plots of the maximum and minimum temperatures over several years show an increase of the maximum temperatures to indicate a solar absorptance increase whereas the minimum temperatures remained constant to indicate no emittance change (or no Teflon® FEP thickness decrease). As with the MLI, the Teflon® FEP bonded to the aft shroud is embrittled, and the silver backing is extensively cracked. The application process used (the angle of application and rubbing to insure adhesion), has been shown to induce cracking in the metal layer. The acrylic adhesive can bleed through the cracks and then darken in the presence of UV and VUV, thus increasing the absorptance of the film. Post mission ground testing has shown that removing the release strip from the Teflon® FEP tape caused a significant amount of cracking of the silver even before application to the substrate.

Additional exposure of the CVC sample to ultraviolet radiation showed that the solar absorptance did not continue to degrade. However, newly bonded 5 mil Teflon® FEP, exposed at the same time to ultraviolet radiation experienced a significant increase in solar absorptance during the first 2000 hours of exposure. The newly bonded Teflon® FEP was bonded using both standard techniques and a "gentle" technique to minimize the cracking of the silver. The standard technique produced the largest increase in the solar absorptance; however, the "gentle" technique still produced a significant absorptance increase. This indicated that the techniques used to bond the Teflon® FEP to the substrate causes the silver to break in the application process and thus allows the adhesive to darken under exposure to ultraviolet radiation. Using a Teflon® wand to smooth the Teflon® FEP also caused localized absorptance increases. The expected degradation of the HST TCS (increase in solar absorptance) is given in Figure 9 with the CVC sample degradation indicated.

8. FUTURE REQUIREMENTS

To maintain the operational capability during HST's 15-year mission, the TCS must maintain the HST operational temperatures during all sun pointing attitudes. To continue to meet this requirement, candidate replacement materials have been selected to repair and/or replace degraded MLI during subsequent servicing missions. References 8-9, detail the evaluation of the candidate materials and the current HST metallized 5 mil Teflon® FEP. Additional testing of 5 mil aluminized Teflon® FEP will be on going to predict the expected condition of the Teflon® FEP during the future servicing missions.

9. ACKNOWLEDGEMENTS

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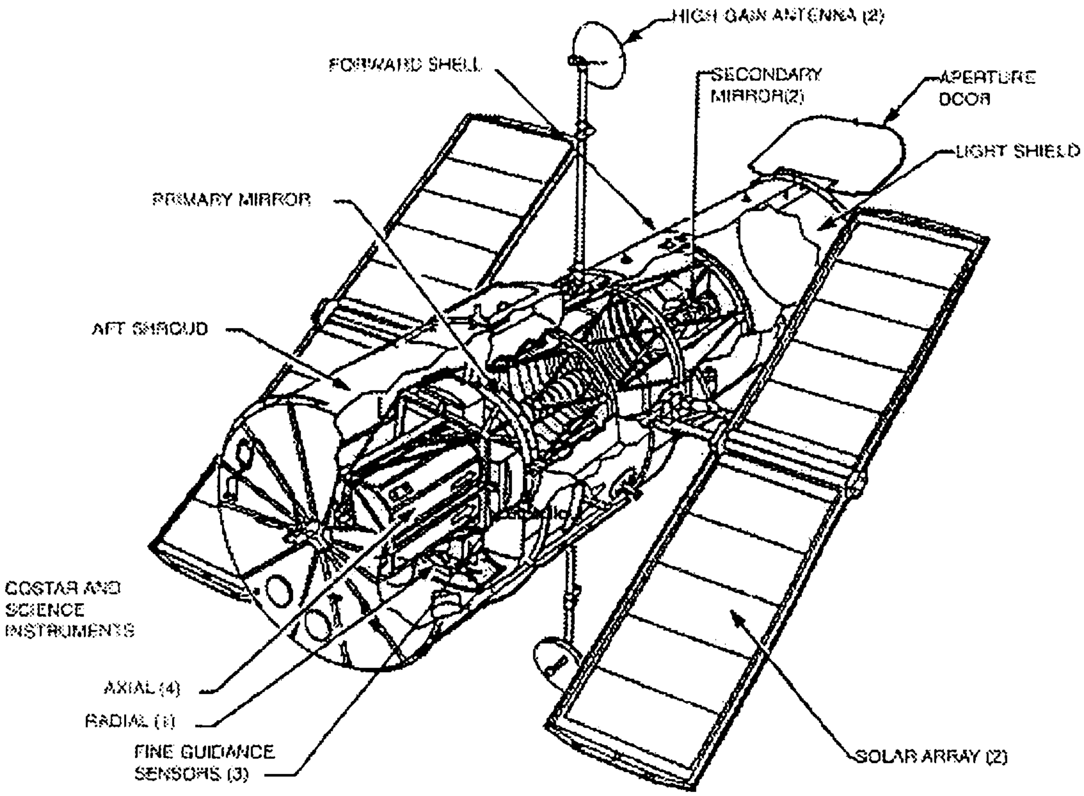


Figure 1: HST Configuration

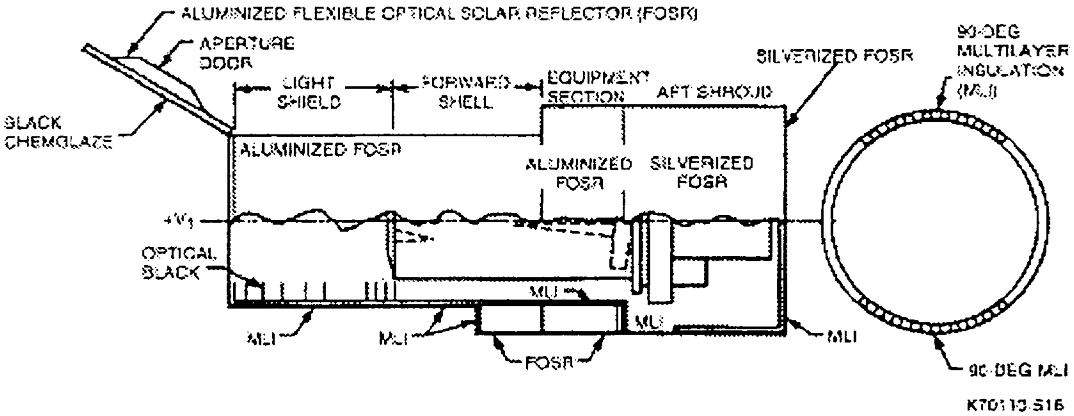


Figure 2: HST Thermal Control Subsystem Materials Location Map

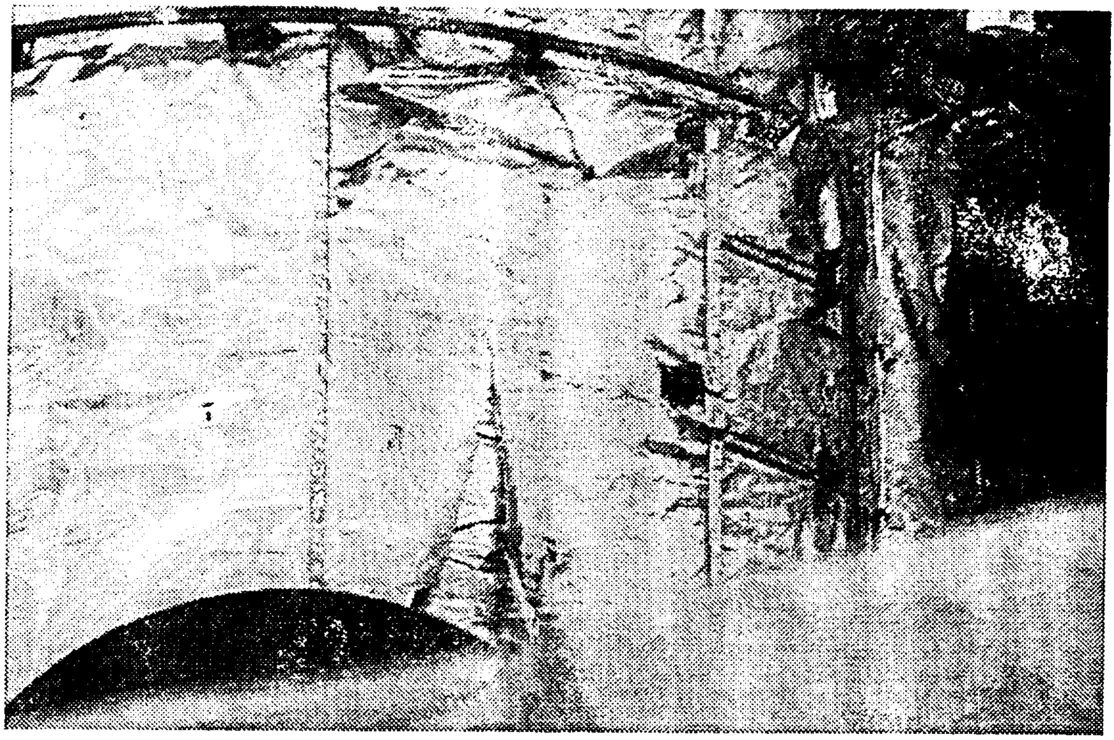


Figure 3: Light Shield MLI Cracks

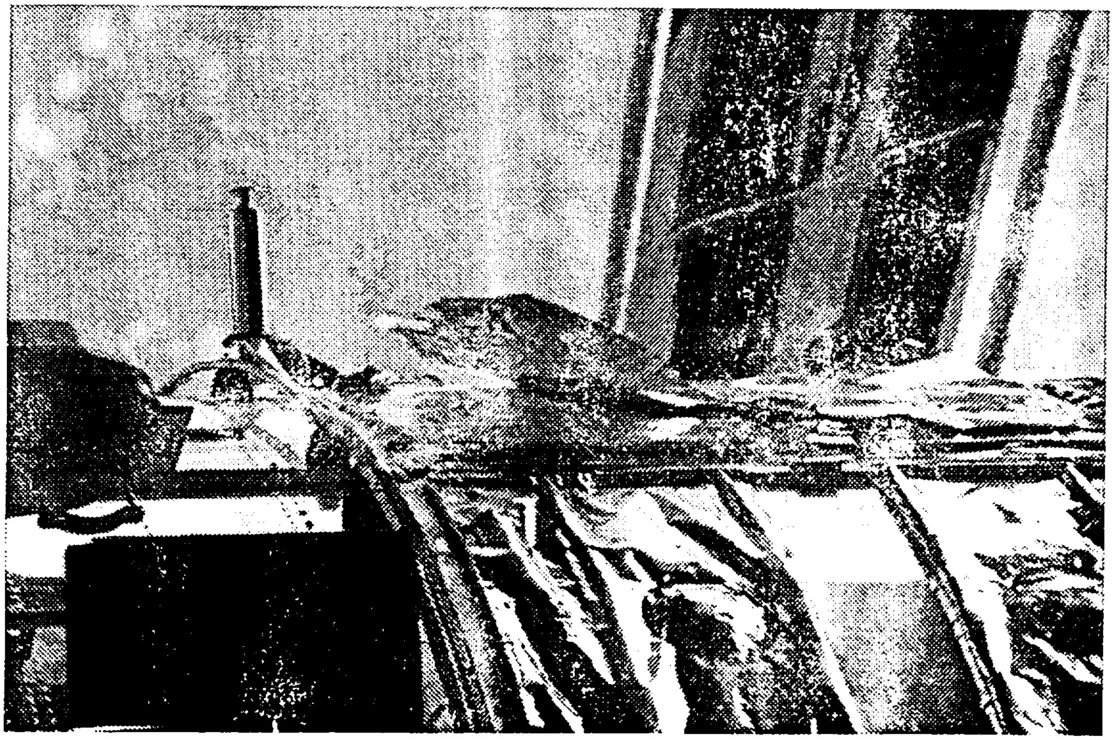


Figure 4: SSM Bay 8 MLI Crack

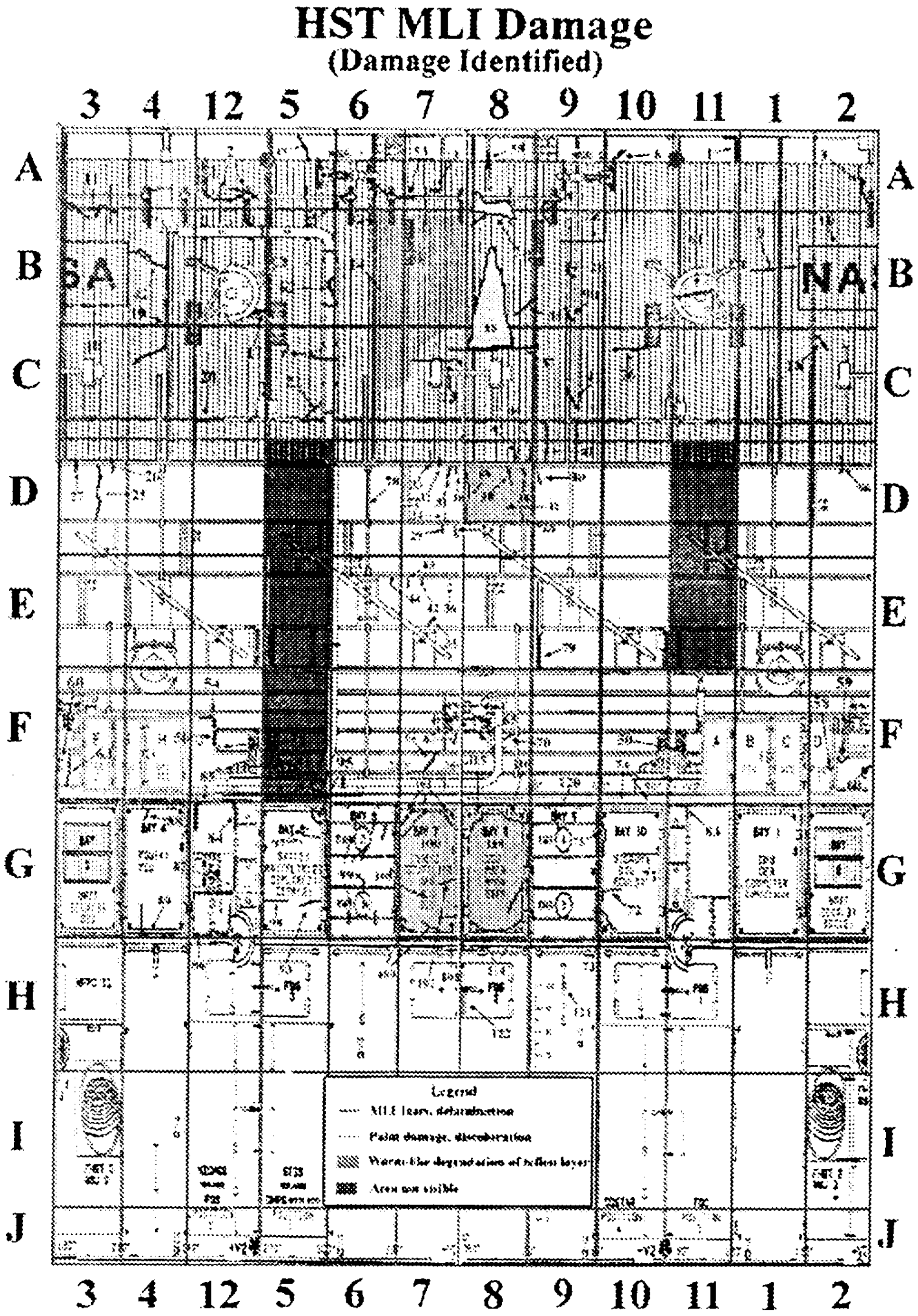


Figure 5: HST Thermal Control Subsystem Degradation Map

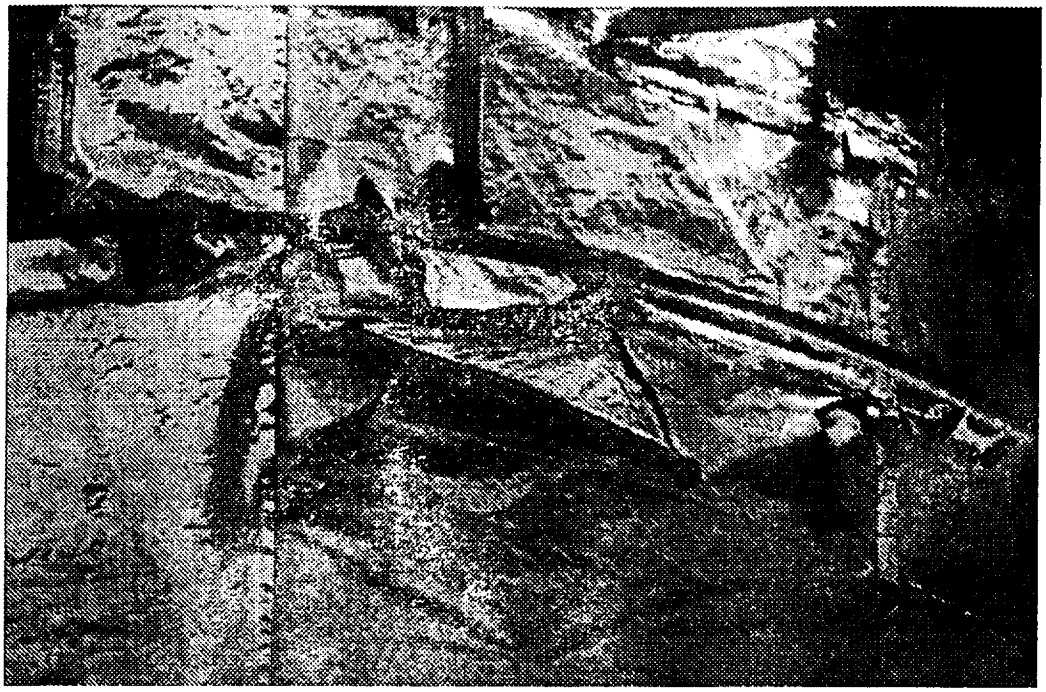


Figure 6: Upper Light Shield MLI Crack (SM2 Sample)

Figure 7: HST Light Shield MLI Cracks with Patches Installed

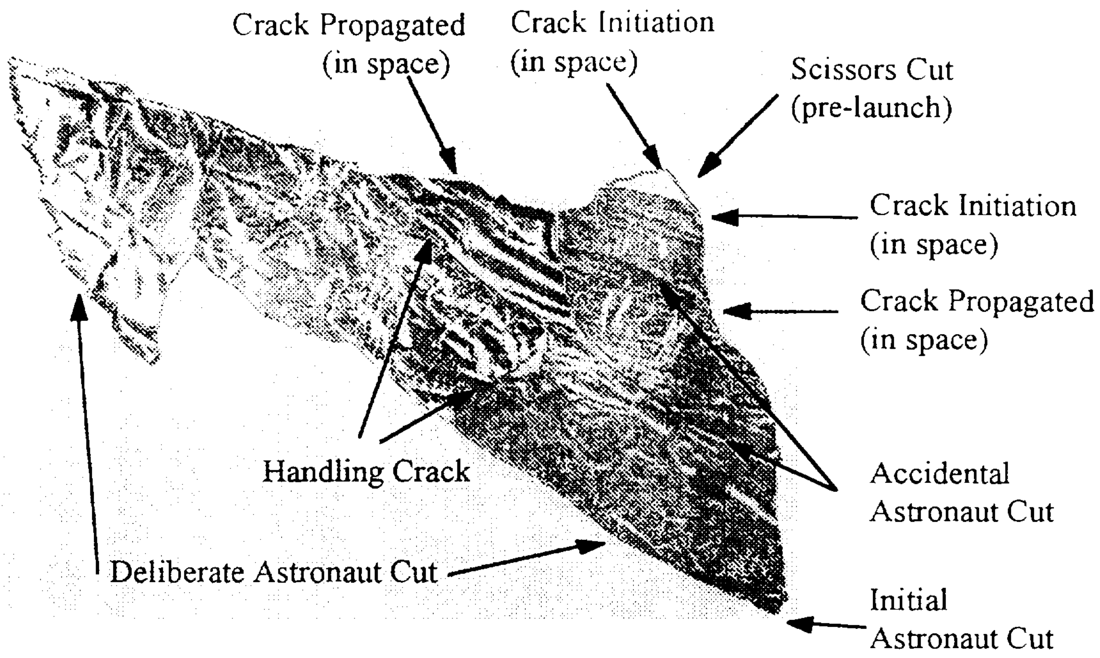
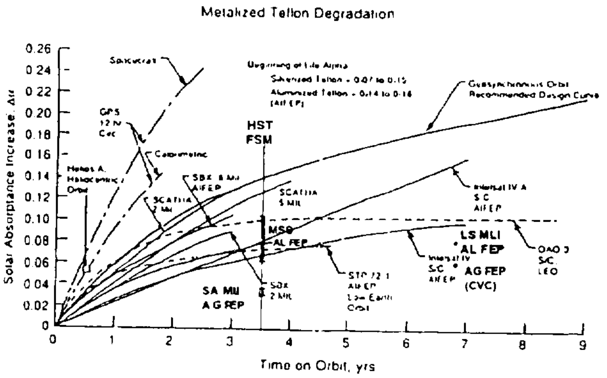


Figure 8: SM2 Teflon FEP

Sample



Metalized Teflon degradation (in geosynchronous orbit unless otherwise indicated)

Reference: "Satellite Thermal Control Handbook", D. G. Gilmore, Editor, Aerospace Corporation

Figure 9: HST Solar Absorbtance Measurements versus Predictions