THE HUBBLE SPACE TELESCOPE SERVICING MISSION 3A
CONTAMINATION CONTROL PROGRAM

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ABSTRACT *– After nearly 10 years on-orbit, the Hubble Space Telescope (HST) external thermal control materials and paint have degraded due to exposure to the low Earth orbit environment. This presented a potentially large on-orbit contamination source (particles and/or debris). Contamination mitigation techniques were developed to augment existing on-orbit servicing contamination controls. They encompassed mission management, crew training, and crew aids and tools. These techniques were successfully employed during the HST Servicing Mission 3A, December 1999.*

1 INTRODUCTION

The Hubble Space Telescope (HST) was designed and built to be periodically serviced on-orbit during its 20 year mission. The telescope was deployed in April 1990 at an altitude of 598 km (320 nmi). To date the telescope has been serviced three times as shown in Table 1.

Table 1: HST Servicing Mission history

Servicing Mission	Flight Number	Date	Duration On-orbit
1	STS-61	12/1993	3.7 yrs
2	STS-82	2/1997	6.8 yrs
3A	STS-103	12/1999	9.7 yrs

During the Servicing Mission 2 (SM2), the astronauts observed and documented severe cracking in the outer layer of the multi-layer insulation (MLI) blankets which cover over 80 percent of the telescope's external surface area. The yellow paint, identifying EVA interfaces (handrails, door knobs, latches, etc.), was also found to be degraded. These degraded materials presented a challenge both to quantify the magnitude of the contamination source and to develop on-orbit contamination control measures that would mitigate the effect of the contaminants, if generated during the SM3A servicing activities. This paper summarizes the contamination control program and mitigation techniques successfully used during the SM3A.

2 HUBBLE SPACE TELESCOPE

2.1 Thermal Control Materials

The telescope uses several thermal control materials to passively control temperature on-orbit: MLI blankets and radiator surfaces (Fig. 1). MLI blankets are used on the entire Light Shield and most of the Forward Shell and Equipment Bays (Equipment Section). Tapes are used on the Aperture Door, a few locations on Equipment Bays, the entire Aft Shroud, and Aft Bulkhead (bottom of the telescope).

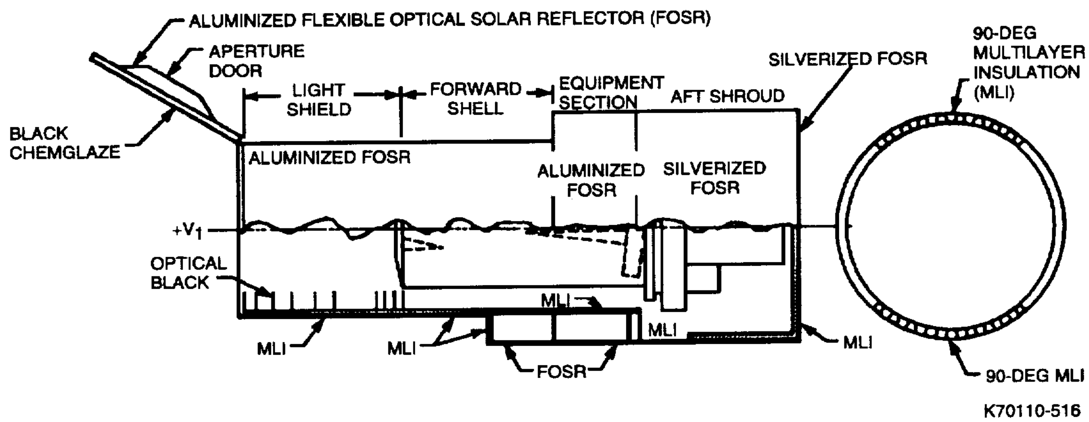

Fig. 1: HST thermal control materials location

Used over 80 percent of the external surfaces of HST, the 17-layer MLI blanket's outer layer (space-exposed) is 127 μm (0.005") Teflon® FEP (fluorinated ethylene propylene) with roughly 100 nm or vapor deposited aluminum (VDA) on the back (FEP/VDA). The inner 15 layers are embossed 8.17 μm (0.00033") double-aluminized Kapton®. The innermost (bottom) layer is 24.5 μm (0.001") single aluminized Kapton®. By embossing these inner layers layer-to-layer conduction is reduced without using spacers (a contamination source).

The blankets were closed out on all four sides with a taped cap section, and the layers were tied together intermittently throughout the blanket using spots of acrylic transfer adhesive film. Where the blankets were cut to fit around features (handrails, standoffs, etc.) the blanket was closed out again by taping the cap section. In addition, the blankets were vented with 'X' cuts and the outer layer was reinforced using aluminized Kapton® scrim tape. The entire blanket was attached to the spacecraft with Velcro stitched to the inner layer.

The radiator surfaces are perforated silver Teflon® tape bonded directly to the aluminum vehicle substrate. The space-exposed surface is 127 μm (0.005") Teflon® FEP with roughly 100 nm of vapor deposited silver (VDS) on the back (FEP/VDS). The silver side is coated with Inconel and finally with an acrylic adhesive.

The FEP/VDS material was purchased in rolls (4" width) with the adhesive already applied. The tape was applied in sections. A Teflon® wand was used to minimize air entrapment and to ensure a good bond. Material that was damaged during the integration and test phases was replaced as necessary.

2.2 Retrieved Specimens

During the SM1 and SM2, thermal control materials were retrieved during the servicing activities. Extensive analyses have been performed on these materials and reported elsewhere [Zuby 95, Town 99, Hans 98, Town 98, Deve 98, Deve 99]. The SM2 sample site is shown in Fig. 2. Only the outer FEP/VDA layer was sampled (removed). Of concern during the SM2 was exposure of the aluminized Kapton® to the environment. At the time, the exposure of the Kapton® was thought to cause a potential degradation of the telescope's thermal performance. Thus, shortly after the sample was taken, the sample site was then covered with a patch (Fig. 3). Post-mission detailed thermal analyses have shown that these cracks, while dramatic, cause very little change in the telescope's thermal performance.

Fig. 2: SM2 FEP/VDA Specimen on-orbit

The top-center of this image shows the roughly triangular SM2 LS specimen on the Light Shield at SM2 prior to retrieval. A handrail and standoffs are apparent across the top of the image. The specimen is curled very tightly, so that it is detectable here as a triangular region where the next layer of the MLI is visible. The raised feature at the bottom edge of the triangular opening contains the entire specimen that covered this triangle prior to the damage. At the bottom of the image, the tip of the largest crack on HST is seen propagating vertically towards the top of the telescope. This large crack also opened to reveal the next MLI layer.

Fig. 3: astronauts patch HST light shield during SM2

3 ON-ORBIT OBSERVATIONS

3.1 Multi-Layer Insulation

3.1.1 Servicing Mission 1

Once the telescope was grappled and captured on the Flight Support Structure (FSS), it was observed that the NASA logo was cracked (obscured 'S'). This was attributed to a mismatch in the coefficient of thermal expansion of the materials. This was the only macroscopic damage noted.

The retrieved sample – the Magnetic Sensing System MLI blanket – showed localized through-thickness cracking [Zuby 95]. These cracks were approximately 4 cm long and found in areas of high solar exposure and stress concentration [Town 99].

3.2.2 Servicing Mission 2

Once the telescope was grappled and captured on the FSS, it was observed that the NASA logo had additional cracking. The material between the 'N' and 'A' had cracked and curled, further obscuring the logo. However, the most dramatic cracks were seen on the opposite side of the telescope on the upper part of the Light Shield (Figs. 2-3). However, on closer examination of the telescope, significant damage was observed on most MLI blankets [Zuby 95, Town 99, Hans 98].

Although the damage to the telescope's MLI is dramatic, due to the large thermal margins on the forward shell and light shield, there was no effect in the telescope's performance. However, degradation of the MLI on the Equipment Bays was a concern as the scientific instruments' duty cycles were higher than that for which they were originally designed. This led to a slight increase in temperature for some of these bays with the highest duty cycles (the instrument command and data handling system, for example).

3.2 Paint

3.2.1 Servicing Mission 1

During the extra-vehicular activities (EVAs), the free-floating astronauts use the handrails on the telescope to translate to their work sites. As a safety precaution, the gloves are checked periodically throughout the EVA. There was one reported observation of yellow pigment on the EVA gloves.

3.2.2 Servicing Mission 2

During the EVAs there were observations of yellow pigment on all the EVA gloves. Photographic documentation of the painted surfaces led to the conclusion that this was indicative of degradation of the protective silicone overcoat and subsequent degradation of the paint. There was a dramatic peeling of the paint on one handrail (Fig. 4). This paint peel was dubbed "Eucalyptus Bark" due to its resemblance to the bark of a eucalyptus tree. As shown in Fig. 4, behind the handrail is an MLI blanket with beta cloth as its outer surface (not Teflon® FEP).

4. ANALYSES AND CONCLUSIONS

4.1 Multi-Layer Insulation

After the SM2, a Failure Review Board was convened to document the condition of the MLI on the telescope; analyze the retrieved specimens; and perform simulated environmental exposures. The details of these analyses are found in references 1-6. Based on these analyses and additional data from ground-based experiments, the board concluded:

> The observations of the HST MLI and ground testing of pristine samples indicate that thermal cycling with deep-layer damage from electron and proton radiation are necessary to cause the observed Teflon FEP embrittlement and the propagation of cracks along stress concentrations. Ground testing and analysis of retrieved MLI indicate that damage increases with the combined total dose of electron, proton, ultraviolet, and x-ray radiation along with thermal cycling.

Results from the SM2 sample indicated that the material's mechanical properties had been greatly compromised and would, therefore, not withstand excessive handling during future servicing missions. The number and length of cracks in the MLI blanket's outer layer had increased dramatically between SM1 and SM2. Predictions of the MLI damage for future missions, based on these observations were very conservative.

Fig. 4: Bay A degraded paint

The board concluded that the degradation of the Teflon® FEP will increase with time on-orbit. Thus, it was predicted that the Teflon® FEP will become more brittle, which for the servicing mission activities means that it will take less load to initiate new cracks and propagate existing cracks. Large and open cracks will be prevalent. Handling the MLI may cause the cracks to propagate and may cause debris when 2 or more cracks intersect.

4.2 Paint

There were no paint samples returned from EVA interfaces (e.g. handrails, standoffs, etc.). However, a Failure Review Board was convened to document the condition of the paint on the telescope; determine the degradation mechanism; predict the condition of the handrails at SM3A; and recommend corrective action.

Based on the evaluation of the HST failures and other spacecraft such as the Long Duration Exposure Facility (LDEF) the degradation was caused from the exposure of the handrail paint to the combined effects of atomic oxygen, ultraviolet radiation, and thermal cycling. Based on the location on the telescope, the handrails were expected to either have loose pigment due to primarily AO erosion or have easily visible peeling paint due to primarily UV exposure.

5. SERVICING MISSION CONTAMINATION REQUIREMENTS

The details of the telescope's cleanliness requirements and servicing mission requirements are documented [Hans 97, Hedg 94, Hans 96]. Given degraded thermal control surfaces, what mitigation techniques are necessary to preclude self-contamination during the EVAs for the SM3A? The primary objective was to mitigate additional damage to the degraded materials during the servicing mission activities and to mitigate the contamination potential of these materials. Because the EVA time is restricted due to limited on-orbit resources, the contamination mitigation techniques were developed with the intention of allowing the mission management team and the crew enough flexibility to maintain the telescope's cleanliness levels while completing the EVA tasks.

Contamination mitigation techniques that were specifically developed for the degraded materials can be group into 3 categories: Mission Management, Crew Training, and Crew Aids and Tools. Mission Management addressed the techniques which included the Orbiter, the telescope operation, and the delegation of authority. A significant portion of the HST pre-launch activities involves familiarizing the astronauts with the hardware and expected on-orbit operation. Lastly, specifically designed tools or crew aids make the astronaut's job easier.

It should be noted that debris referenced in this paper is debris generated from the HST degraded thermal control materials and painted EVA interfaces and not hyper-velocity particles (orbital debris).

5.1 Mission management

The mission management philosophy was to complete the most contamination sensitive tasks first, educate the mission operations teams on the issues, and negotiate and document broader authority for the Servicing Mission Manager. Each EVA task was evaluated, potential for debris generation assessed, and contingency actions identified. This was available in a spread sheet format. In addition, these techniques were grouped together by contamination type as shown in Table 2.

The SM3A EVAs were ordered so that the most contamination sensitive tasks were performed before activities which had significant involvement with the MLI. During the most contamination sensitive activities, that is those with the Aft Shroud doors open, an Aft Shroud debris free zone was established. There were several management options if HST generated debris was visibly determined by the crew to be in this zone. One technique delays opening the Aft Shroud doors. If the task has not begun, but the doors are open, the doors can be temporarily closed. The crew may also be asked to make a reasonable attempt to retrieve and bag the debris, then continue with their task.

To better equip the mission management teams with the background of the materials degradation and the contingencies that could arise real-time, a series of briefings were given to the Johnson Space Center and Goddard Space Center mission operations teams. Flight rules were written giving the Servicing Mission Manager broader authority to curtail an activity if the telescope's cleanliness levels were visibly at risk. These flight rules are captured in the HST Payload Integration Plan (PIP) Annex 2-2.

Table 2: Mitigation techniques by contamination type

Contamination Type	Mitigation Technique
Debris	- Aft Shroud "debris free zone" - Order EVA tasks to minimize risk - Reasonable attempt to retrieve and bag - Sweep outboard (glove or hydrazine brush)
MLI	- Avoid VDA on lifted, opened or curled cracks - Avoid intersecting cracks - Alcohol wipe of gloves at end of EVA day - Suggest alcohol wipe of suit area where VDA was contacted - Cut and bag (interferes, debris, thermal risk) - Patch

Flaking Paint	- Handrail, doorknob, handle covers
	    - 6 required around FGS site
	    - Servicing Mission Manager call for FGS translation path
	    - Contingency available for all AS and pre-AS
	    - Not use if no contact with flaking paint
	- Alcohol wipe of gloves at end of EVA day (flakes or pigment)
	- Do not remove or capture flaking paint
	- Coated tether hooks

5.2 Crew training

A standard practice for the HST servicing missions is to have the crew spend as much time with the flight hardware as possible. Crew familiarizations allow the crew to perform the EVA task with the flight hardware (and ground handling fixtures). The MLI and paint topics were added to the crew familiarizations. The crew was not only briefed on the expected condition of the MLI and paint, but also the mitigation techniques at their disposal. Because the crew is our "eyes" on-orbit, increasing their awareness of the issues, defining the vocabulary, and handling techniques made real-time communication easier. Several hands-on demonstrations gave the crew confidence that knew how to handle the degraded materials.

Maps of the current MLI degradation were incorporated into the EVA checklist, so that the astronaut, real-time, did not need to remember a specific degradation feature (e.g. cracks). The crewmember reading the checklist could give a "heads up" or verify degradation without contacting ground personnel.

5.3 Crew aids and tools

Specific crew aids and tools (CATs) were developed to make the crews' job easier. Because one of the tasks involved removing an MLI blanket, an MLI retrieval bag was developed. Because it was expected that debris would be generated, the bags were compartmentalized, allowing the crew to stow more than one retrieved blanket without opening the same compartment, possibly releasing debris.

Due to the large number of painted EVA interface surfaces, and the fact that the free floating astronaut translates to the work site and tethers at the work site using the handrails, a means of containing the paint was needed if it was found to be severely degraded (similar to figure 4). For the SM3A, the most contamination sensitive handrails were determined to be those around the Fine Guidance Sensor work site. Thus, handrail covers were employed to mitigate the generation of paint flakes during the change out activities. In addition, a Teflon® liner was added to the large waist tether hook to limit damage from the tether as it "slides" along the handrail during translation from site to site.

6 SUMMARY

Degraded thermal control materials and paint has presented a potentially large source of on-orbit contamination for the HST. Contamination mitigation techniques were developed to augment existing servicing mission contamination controls. The mission management techniques were used primarily to order the servicing mission activities, define the threshold of on-orbit contamination allowed to be generated during sensitive tasks, and document options for contingencies. Crew familiarizations with the hardware increased the crew's awareness of the contamination issues with the degraded materials. Choosing a vocabulary to describe features of degraded materials made real-time communication straightforward with little elaboration needed. Crew Aids and tools aided the crew during the EVA tasks and limited the potential for contamination generation (coated tether and compartmentalized MLI recovery bags).

While these mitigation techniques were developed specifically for the HST and its servicing mission activities, other serviceable spacecraft and platforms can use these techniques to aid their mission planning greatly increase the success of planned servicing activities. These techniques were used successfully on the HST SM3A and will be expanded for future missions as needed.

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