- **SETAS**
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- **LDEF**
  Long Duration Exposure Facility
- **MEEP**
  Mir Environmental Effects Payload
- **SARE**
  MIR Solar Array Return Experiment
- **MISSE**
  Materials International Space Station Experiment
- **AORP**
  Atomic Oxygen Resistant Polymers Experiment
- **DSPSE**
  Clementine - Deep Space Probe Science Experiment
- **ESEM**
  Evaluation of Space Environment and Effects on Materials
- **EuReCa**
  European Retrievable Carrier
- **HST**
  Hubble Space Telescope

Hubble Space Telescope

(HST) Archive System

NASA Langley Research Center
Hampton, Virginia

Overview

The purpose of the Hubble Space Telescope (HST) Hardware Archive System is to make information available concerning the returned hardware from HST on-orbit servicing missions. The Introduction of this archive gives a general background about the archive while the First Servicing Mission and Post-Retrieval Analysis sections provide explicit details regarding the on-orbit servicing mission, the people who are affiliated with the post-flight investigations of the returned hardware, and a detailed disposition of the HST hardware following its returned to Earth. Images and descriptions of the HST return hardware is discussed in the Returned Hardware section. The Technical Diciplines areas address scientific research with returned hardware, while the Photographs area provides a small sampling of on-orbit HST photographs. The Workshops section lists various workshops that included topics realtedto HST Returned Hardware, and provides the opportunity to make available data and initial results which may or may not be published or reside in the public domain. Lastly, a list of related HST online sources is provided.

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- **MIS**
  Meteoroid Impact Sensor
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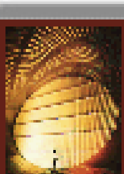
  Micro-Particle Impact Detector



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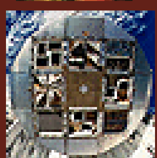

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Workshops

- HST Returned Hardware Meeting, NASA Goddard

Space Flight Center, Greenbelt, MD, January 27-28, 1994.

- HST Returned Hardware Evaluation Symposium, NASA Goddard Space Flight Center, Greenbelt, MD, December 15, 1994.
- HST Solar Array Workshop, ESTEC / ESA, Noordwijk, The Netherlands, May 30-31, 1995.
- HST Contamination Meeting, STScI, Baltimore, MD, May, 1995.

Bibliography

- References

AORP | Clementine | EuReCa | ESEM | Hubble
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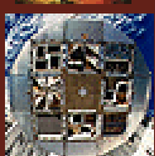 [Space Environments &Technology Archive System Home Page]

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Introduction

The Hubble Space Telescope (HST) Archive System provides access to information related to the analyses of the hardware returned during the first HST servicing mission (STS-61), which occurred in December, 1993 and it is described in the mission profile. It is the first in a series of planned missions to service the HST.

On-orbit observations of the HST's physical condition are very important to understanding the space environment and its effect on the successful, long duration operation of spacecraft. The STS-61 crew made observations of the physical condition of HST and took an extensive collection of photographs.

Plans for the post-retrieval analyses of the returned hardware were initiated prior to the servicing mission and included the participation of the HST Project , as well as other organizations with experience studying retrieved spaceflight hardware. Some of the participating organizations and their associated areas of responsibility are listed. The plans called for the returned hardware to follow the flow outlined in the logistics flow chart.

The first HST servicing mission resulted in the return of the following hardware:

- High Speed Photometer
- Wide Field Planetary Camera-I
- Solar Array

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- Solar Array Drive Electronics (SADE)
- Flight Support System
- Orbital Replacement Unit Carrier
- Orbital Replacement Units
- Eight (8) Fuse Modules
- Gyros
  - 2 Rate Sensing Units
  - 2 Electronic Control Units
- Magnetometer Multi Layer Insulation (MLI) and Side Plate
- Crew Aids and Tools

The investigations of these items have provided significant data on the environments encountered in space and the effects of these environments on spacecraft. These investigations, which were initially focused on HST Project needs, are of vital interest to the entire community of spacecraft developers and space researchers. The data obtained during analyses of HST hardware can generally be categorized according to various discipline area; this approach provides the user with one type of access route. While the data cover many areas, the following four areas have been highlighted in this archive: meteoroids & debris, contamination, materials and radiation.

A number of workshops have been held relative to the HST returned hardware and analyses. The HST Returned Hardware Evaluation Symposium, held at Goddard Space Flight Center in December, 1994, is a significant source of data. The materials presented at this symposium are included on-line in this archive. Other workshops include the initial Returned Hardware Meeting at Goddard in January, 1994, at which plans for evaluations were discussed; the Solar Array Workshop held by ESA/ESTEC in May, 1995; and the HST Contamination Meeting held by the Space Telescope Science Institute, Baltimore, MD, May, 1995.

You may also write, phone or fax:

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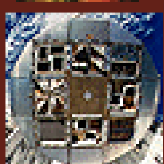
LDEF | MDIM | MEEP | MIS | MPID



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First Servicing Mission

The Hubble Space Telescope (HST) was deployed at an altitude of 331.6 nautical miles and at an inclination of 28.5 degrees on April 25, 1990. This orbit is similar to that of the Long Duration Exposure Facility (LDEF) which was returned to the Earth in January, 1990 after 5.7 years in low-Earth orbit (LEO). During HST's 3.6 years in LEO, HST was exposed to an atomic oxygen fluence estimated to be 7.59 x 10^{20} atoms/cm^2 in the velocity or ram direction.

The first HST servicing mission, STS-61, lifted off Pad 39B at 4:27 AM EST on December 2, 1993. After the Shuttle *Endeavour* followed the observatory for several orbits, HST was captured at 316.8 nautical miles by the *Endeavour* crew on December 4, 1993, where the observatory was grappled and berthed in the shuttle's cargo bay. The crew, together with the controllers at JSC and GSFC, completed all eleven servicing tasks during five EVAs. During the six day servicing mission, all of the planned goals were achieved, making this Shuttle mission arguably the most successful in Shuttle history.

The primary objective of the servicing mission was to replace the High-Speed Photometer with the Corrective Optics Space Telescope Axial Replacement (COSTAR). The installation of COSTAR allowed the HST to overcome its inherent spherical aberration flaw. COSTAR routes properly focused light to three of Hubble's five instruments. The optically-corrected Wide Field Planetary Camera (WF/PC-II) was substituted for the WF/PC-I. The WF/PC-II was designed so that the light reaching each of the instrument's four cameras was corrected by relay mirrors polished to a prescription compensating for the incorrect figure produced by Hubble's primary mirror. Eight fuse modules were replaced along with two rate sensors units (2 gyroscopes in each) and two electronic control units. New solar arrays replaced the original solar arrays, of which one solar array was returned to Earth for study and the second array was jettisoned. A new coprocessor to the DF-224 was added to the HST. Also, the new Goddard High Resolution Repair Kit and two magnetometers were installed. The old magnetometer multi-layer insulation (MLI) and side plate were returned to Earth. HST was redeployed on December 10, 1993 at 321.1 nautical miles via the Shuttle Remote Manipulator System (RMS) at 5:26 AM EST.

The next HST servicing mission is expected to occur around February, 1997. It is expected that HST will have declined to an altitude of 319 nautical miles by that time. During the second servicing mission, astronauts will install two new instruments: the Space Telescope Imaging Spectrograph, and the Near-Infrared Camera and Multi-Object Spectrograph (NICMOS). The third servicing mission is scheduled for November, 1999, during which the Hubble Advanced Camera for Exploration, which will greatly enchance the HST's imaging capabilities, will be installed.

Crew Observations

The STS-61 crew made the following general observations of HST's physical condition during the servicing mission.

Meteoroid & Debris Damage of Surfaces
Some impact-pitting was observed on HST, however, the inside of the telescope was pristine. One penetration, approximately 1/4 inch in diameter, was seen on the V3 high-gain antenna.

Painted Surfaces & Particulate Contamination
The white zinc orthotitanate (ZOT) paint on the WF/PC-I radiator appeared clean with no evidence of degradation. The yellow paint on the Orbiter handrails was observed to come off as particulate matter when force was applied to the rails. The yellow paint also appeared on the crew's gloves.

Multi-Layer Insulation (MLI)
The multi-layer installation balnkets appeared to be stretched tight. During RSU changeout, a three (3) inch square of MLI was seen floating over the starboard wing.

Photo Documentation
Over 6,000 photos were taken on-orbit for use in studying the condition of the HST.

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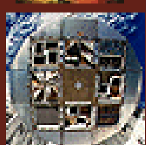 Space Environments &Technology Archive System Home Page

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Post Retrieval Analyses

Project Responsibilities
The Hubble Space Telescope Flight Systems and Servicing Project at the NASA Goddard Space Flight Center was responsible for organizing the HST first servicing mission and they assembled the HST Returned Hardware Evaluation Team. Team participation is as follows:

- NASA Goddard Space Flight Center Code 442 - HST Project Management
- NASA Headquarters - Program Management
- NASA Goddard Space Flight Center Code 300/Unisys - Materials Branch
- NASA Goddard Space Flight Center Code 717 - Optics Branch
- European Space Agency - Solar Arrays
- NASA Lewis Research Center - Solar Array Materials
- NASA Langley Research Center - Micrometeoroid Impacts
- Jet Propulsion Laboratory - Wide Field Planetary Camera
- University of Wisconsin - High Speed Photometer
- Lawrence Berkeley Laboratory - Cosmic Ray Analysis
- Swales and Associates - Contamination Materials
- Lockheed Missiles and Space - Orbital Replacement Units
- Boeing Aerospace Operations - Data Archiving

Post-Retieval Plans
The HST Flight Systems and Servicing Project identified the following priorities when developing an integrated post-retrieval analysis plan for the HST hardware:

- Understanding the cause of anomalies that occurred to HST hardware
- Preserving reusable hardware for refurbishment and requalification
- Understanding how HST hardware survived in the space environment with applications to future HST hardware
- Understanding the metrology of returned hardware
- Providing the NASA community with available samples, data, and results

Initial post-retrieval evaluations for all returned hardware began with a full visual inspection and detailed photgraphic documentation. In addition, an initial set of contamination data were collected for evaluation. Beyond this, more detailed plans were made specifically to each Techincal Discipline, including reflecting the interests of the instrument developers.

Experience from analyses of other returned space flight hardware were important in the HST hardware evaluation plans. The Long Duration Exposure Facility (LDEF) special investigation groups helped to develop and carry out analyses in areas including meteoroids & debris, systems, and materials.

Hardware Process Flow / Logistics
Follow this link to see a flow chart that visually explains the process flow or hardware logistics. A 0.5 M jpg image is also available.

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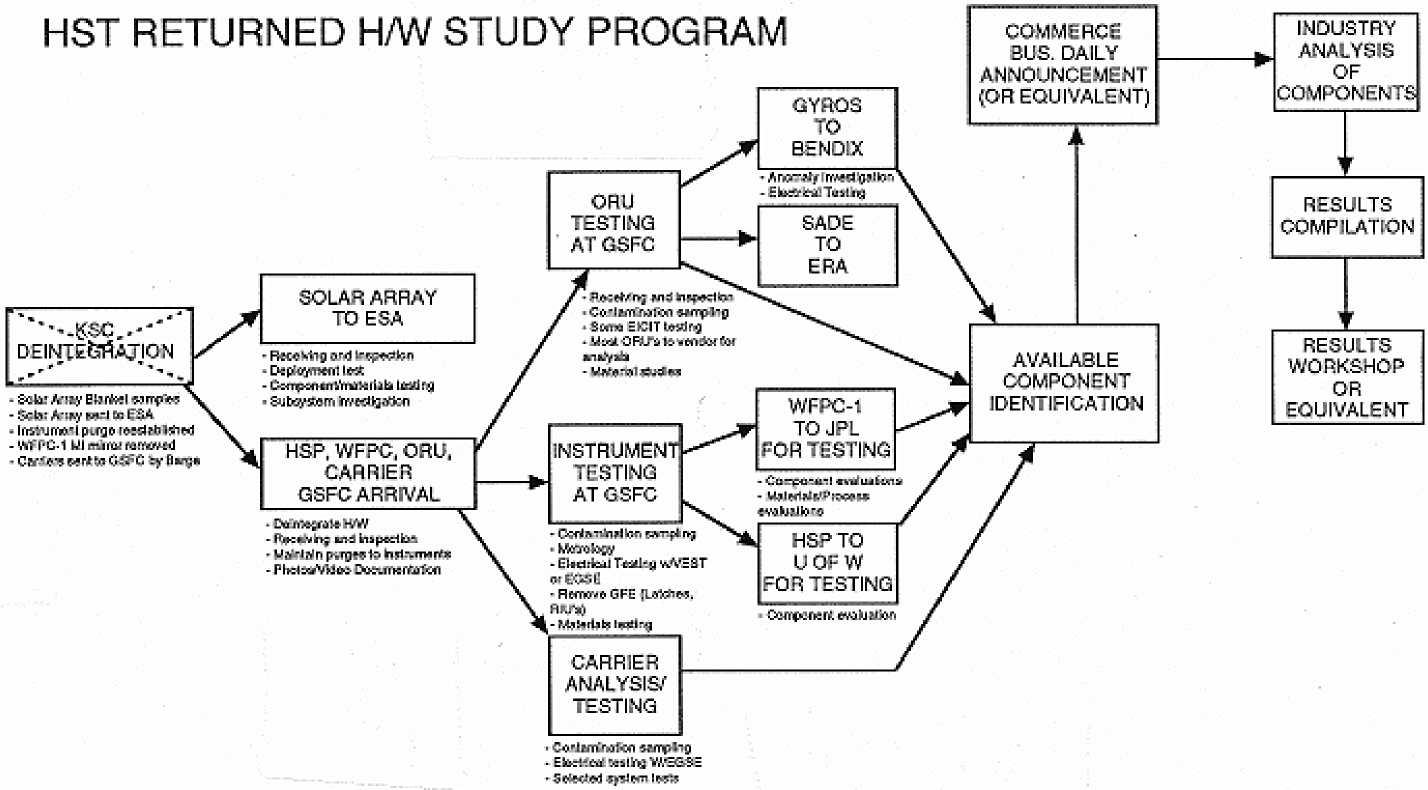
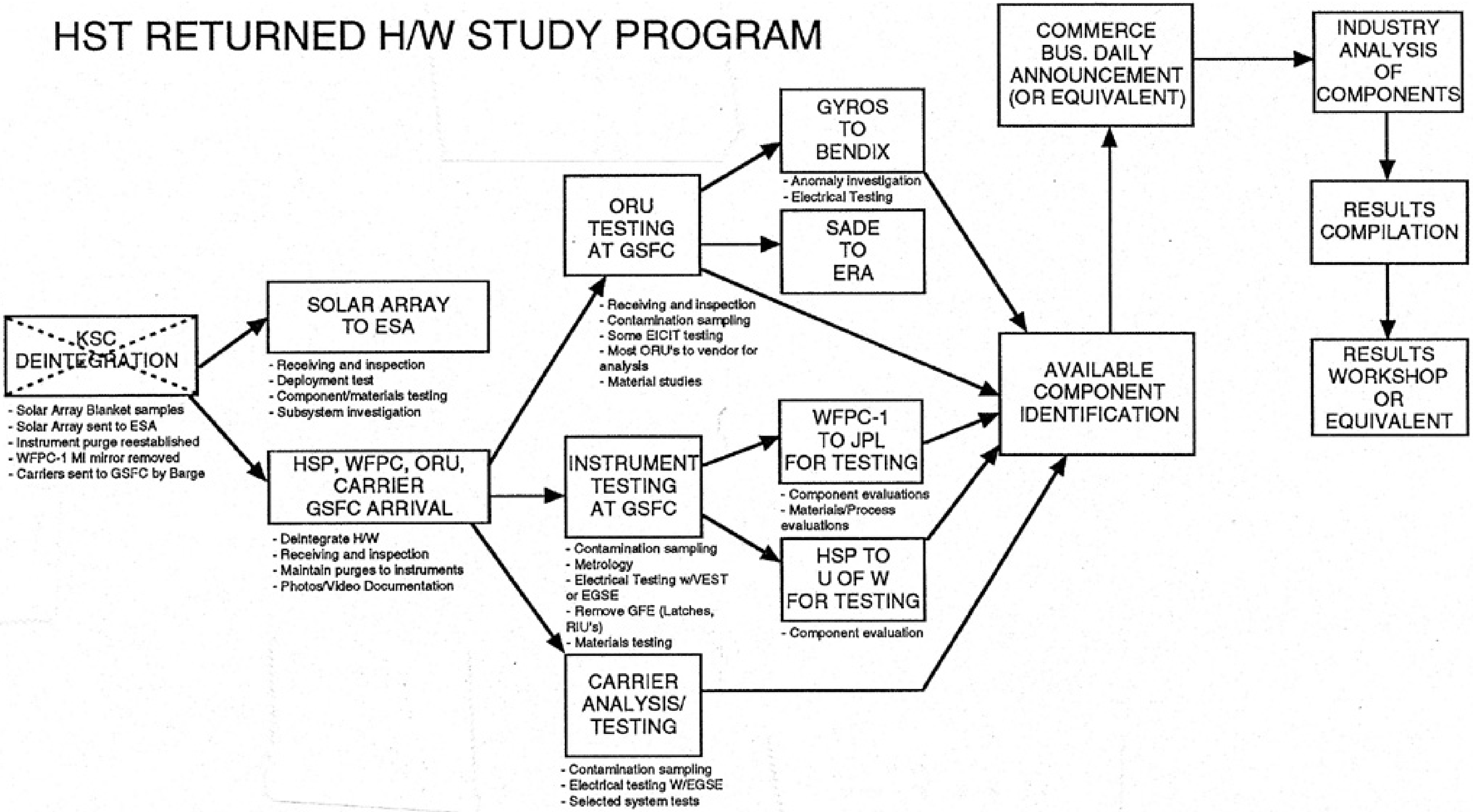
HST RETURNED H/W STUDY PROGRAM




HST RETURNED H/W STUDY PROGRAM
KSC DEINTEGRATION
- Solar Array Blanket samples
- Solar Array sent to ESA
- Instrument purge reestablished
- WFPC-1 MI mirror removed
- Carriers sent to GSFC by Barge
SOLAR ARRAY TO ESA
- Receiving and inspection
- Deployment test
- Component/materials testing
- Subsystem investigation
HSP, WFPC, ORU, CARRIER GSFC ARRIVAL
- Deintegrate H/W
- Receiving and inspection
- Maintain purges to instruments
- Photos/Video Documentation
ORU TESTING AT GSFC
- Receiving and inspection
- Contamination sampling
- Some EICIT testing
- Most ORU's to vendor for analysis
- Material studies
INSTRUMENT TESTING AT GSFC
- Contamination sampling
- Metrology
- Electrical Testing w/VEST or EGSE
- Remove GFE (Latches, RIU's)
- Materials testing
CARRIER ANALYSIS/ TESTING
- Contamination sampling
- Electrical testing W/EGSE
- Selected system tests
GYROS TO BENDIX
- Anomaly Investigation
- Electrical Testing
SADE TO ERA
WFPC-1 TO JPL FOR TESTING
- Component evaluations
- Materials/Process evaluations
HSP TO U OF W FOR TESTING
- Component evaluation
AVAILABLE COMPONENT IDENTIFICATION
COMMERCE BUS. DAILY ANNOUNCEMENT (OR EQUIVALENT)
INDUSTRY ANALYSIS OF COMPONENTS
RESULTS COMPILATION
RESULTS WORKSHOP OR EQUIVALENT

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Returned Hardware

High-Speed Photometer

Astronauts remove the HSP from HST berthed in the payload bay.

Background
The High-Speed Photometer (HSP) was designed and built by the University of Wisconsin. The HSP makes photometric measurements over visible and UV wavelengths at rates up to 105 Hz. It also measures linear polarization in the near UV.

The HSP possesses five detectors - four image dissector tubes and one photo-multiplier tube. One of these detectors suffered a throughput loss of a factor of three part way through the HST mission. The detector later recovered, however, no explanation exists for why the detector anomalously failed and recovered.

Servicing Mission
During the first HST servicing mission, the HSP was replaced with the COSTAR, the Ball Aerospace/Goddard Space Flight Center (GSFC) corrective optics. According to the shuttle crew,

the lip of the HSP rubbed on the multi-layer insulation (MLI) blanket during HSP deintegration from HST. Aside from the HSP rubbing the MLI, the HSP came out easily from the bay with a slight pitch up, which was expected. The bay of the HSP/COSTAR looked pristine and there was good visibility in the chamber with the HSP removed. The astronauts noted that the latch lubrication appeared to be fairly well distributed.

Post-flight Investigations

The HSP operated as it did during prelaunch testing with no detectable degradation. No physical change was observed in the appearance of the HSP, except for the nominal, anticipated creep of the Bray oil Rivet lubricant. The Bray oil migration was no more extensive than previously observed before launch. One of the latch fittings was nicked during either installation or removal. The interior of the HSP was in excellent condition. In addition to the visual inspection, the HSP was examined for contamination. A swab sample was taken on 1/25/94 from the top of the HSP, which reveals traces of oxides and barely detectable hydrocarbons. Tape lifts from the top and side of the HSP were similar to prelaunch findings.

Results of Completed Tests

- The HSP has undergone thorough electrical testing, including EICIT, IVT, aliveness, and short and long form functional tests using the same electrical GSE used for the preflight tests. All results were nominal, including redundant units which were never exercised during the mission, and the results were in agreement with prelaunch results.
- A throughput test was performed using a simple "flat" field source and no changes were observed.
- Both eddy current and ultrasonic tests were performed to determine if any stress corrosion cracks had appeared in the HSP structure (near the plate fittings) since similar tests were performed before launch. The HSP structure was made from 2024 Aluminum. Post-retrieval tests showed no cracks, and verified features (*e.g.* repair plug) found in previous testing.
- The HSP envelope dimensions and position of the focal plane were measured and verified. No changes were noted from preflight data.

These details about the environment and deintegration process of the HSP are important aspects of the total examination of the HSP. Other examinations include a continued external inspection. This includes rinses, tape lifts, and removal of the witness mirror from its inside protective enclosure. The latches will be inspected, a sample of the Braycote lubricant gathered and the box exterior surfaces will be closely examined, especially in the area near the aperture. This process will be videotaped for documentation. The exterior survey will be performed according to an approved procedure, a modification of the existing COSTAR metrology procedure, and will implement the AIMS systems. The aft strip, guide block mounting bracket, and all six exterior surfaces will be examined. The HSP envelope dimensions and position of the focal plane have been measured and its position verified. The internal inspection includes removal of one side panel and internal wipes, tape samples and rinses. Close inspection and photos of all filters will be completed. A witness mirror will be installed inside of HSP to monitor ground contributions to the already existing contamination. One or more flight mirrors will be removed for analysis. The side panel will be reinstalled after the internal investigation is completed.

Status as of December 1994
The HSP was shipped to the University of Wisconsin at Madison Space Astronomy Lab to undergo further testing. Prior to shipment, the HSP RIUs and latches were removed along with one filter aperture assembly which is to undergo transmission tests.

Future Plans

- Remove tape samples from front bulkhead for GSFC contamination analysis.
- Complete postflight testing and calibration.
- Verify polarizer orientation.
- Perform thermal sensor calibration.
- Perform subsystem tests.
- Test electronic boxes: function & temperature.
- Detector testing: VIS tube investigation.
- Selective internal visual inspection.

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Returned Hardware

Wide-Field Planetary Camera I

Background
The Wide-Field Planetary Camera I (WF/PC-I) was developed by the California Institute of Technology and built at the Jet Propulsion Laboratory (JPL). The WF/PC-I is a dual two-dimensional spectrophotometer with rudimetary polarimetric and transmission-grating capabilities. It is designed to operate at wavelengths between 1150-11000 Angstroms. Its field of view centers on the HST optical axis, thus providing the highest quality images possible.

First Servicing Mission
During the on-orbit removal of the Wide-Field Planetary Camera I (WF/PC-I), the astronauts noted that it was clean with no evidence of degradation. They also observed that the multi-layer insulation (MLI) located in the WF/PC-I bay was in immaculate condition. The crew saw no evidence of the MLI blooming against the axial instruments. They did notice, however, that the MLI on the right side had folded up a bit and covered the slot, making it difficult to put the cover in place during the installation of the mirror cover on the WF/PC-II.

Post-Retrieval Evaluations
The WF/PC-I was replaced by an updated version, WF/PC-II, which has new corrective optics. The WF/PC-I was operational at the time of replacement. Twelve high-velocity impact craters, located on the WF/PC-I radiator, were visible to the eye. The impacts include symmetrical and oblique craters with paint spall from the impact shock wave. There is also a brown line of undetermined origin on the radiator near its bolted edge. Brown stains, which surround the rivets, were evidenced prior to launch and are attributed to rivet lubrication creep. The WF/PC-I UV

flood mirror, M1, was external to the WF/PC-I radiator. The UV mirror was exposed to the severity of the space environment and it suffered from blistering and peeling. The mirror lost some of the MgF^2 coating which was layered on top of the aluminum coating along the outer edge of the mirror. The extremely cold sensor window exhibited unusual contamination, commonly called "measles". Measles are speculated to be crystal growth around nucleation sites. Measles may also be the initial phase of a process which results in the unusual crystal-like growth features observed on LDEF and other space missions. The pickoff mirror, located in the HST interior, was observed to be in excellent condition with some evidence of dust particles.

This optical window at the entrace aperture is of special interest because it is the seal between the HST and the WF/PC-I. The inner and outer surfaces of the mirror will provide accurate, independent characterizations of the instrument and telescope contamination environments. The M1 mirror, the pickoff mirror and the aperture window will be assessed at GSFC. Further assessments of optical elements and detectors inside the instrument enclosure will be done at JPL. JPL investigations will also include assessing the mechanisms and interior mechanical components, electrical tests of the pc boards and solder joints after dissembly of the WF/PC-I, and thermal tests which will involve heat pipe performance and TEC degradation. GSFC will also participate in the electrical testing. Electrical and electronic assessment will be done using VEST. This includes IVT, EICIT, aliveness, and functional tests. Both the A and B side circuity will be tested. All results will be compared to preflight measurements.

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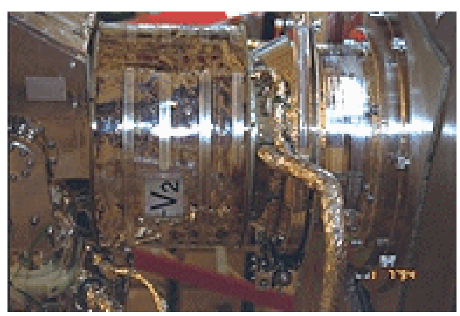
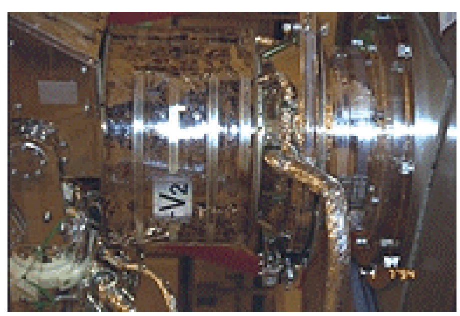
Returned Hardware

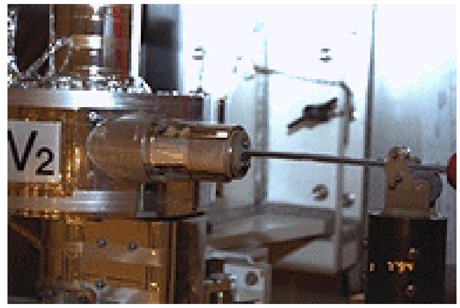
Solar Arrays
The solar arrays were replaced on-orbit due to degradation. During the repair mission, delamination of the solar array bus bars was observed and two of the hinge pins had started to creep out of the hinges. One of the arrays was returned to Earth to be studied while the second array was jettisoned into space. The returned solar array was shipped to European Space Agency.

Photographs taken during the post-flight inspection of the Solar Array





Photos of the SADM.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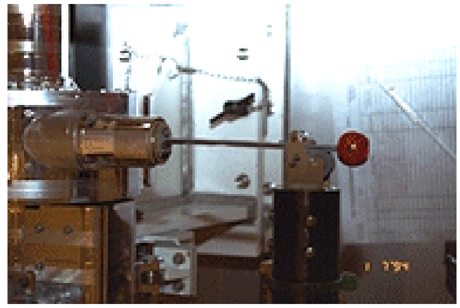
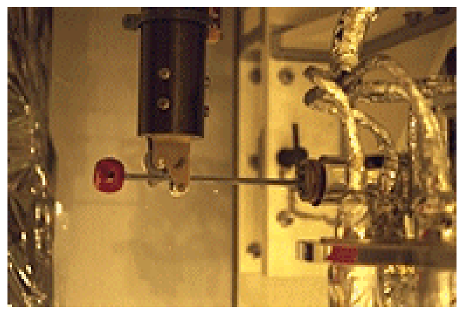
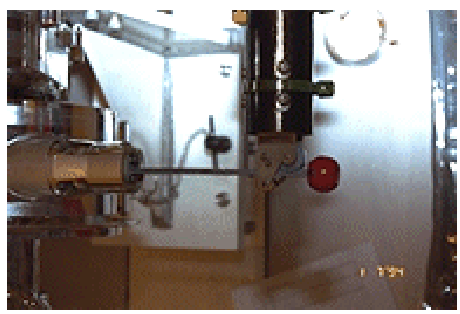
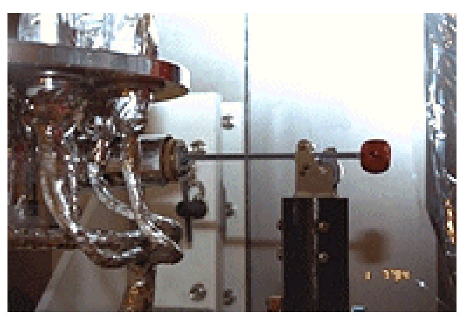
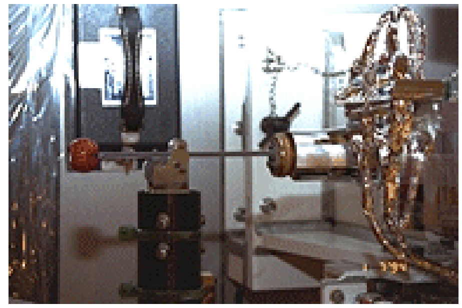


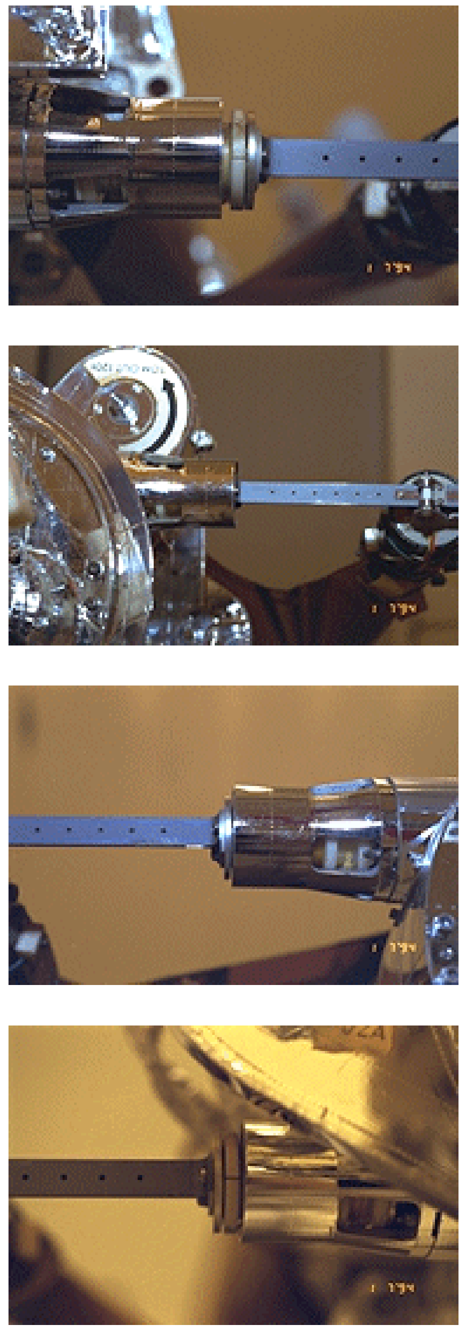




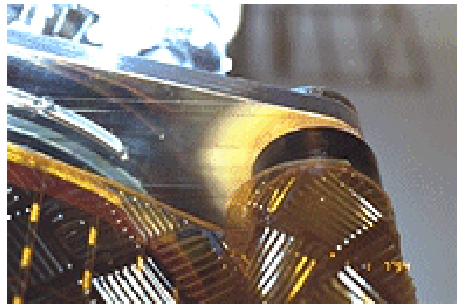


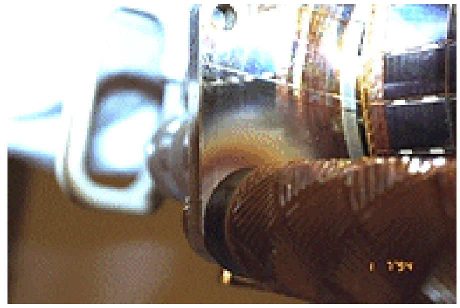


Photos of the bi-stem test procedure.

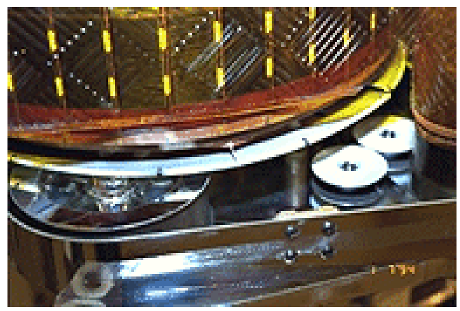


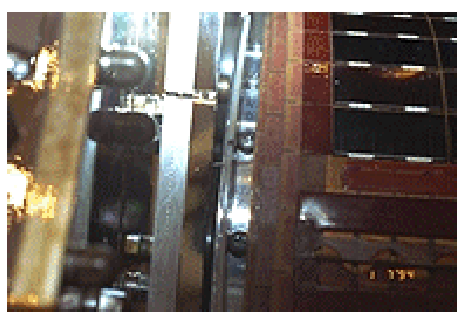
Close up photos of the bi-stem.

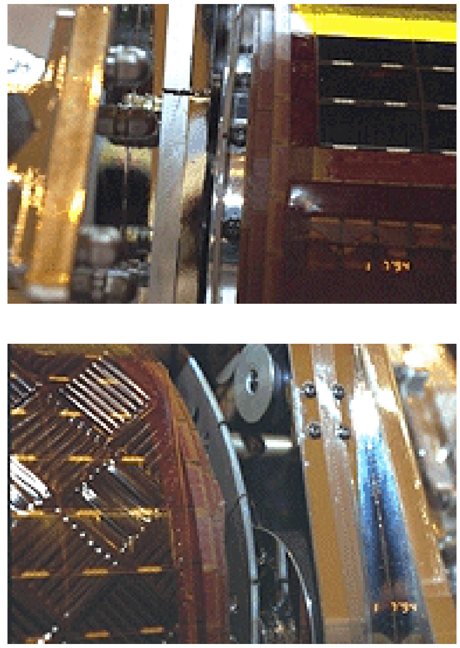




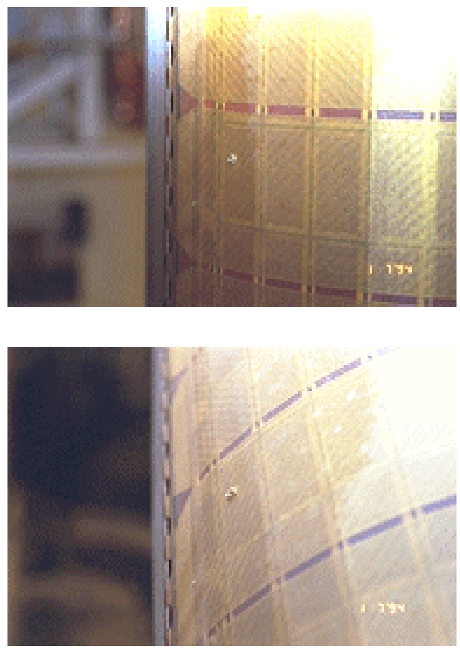
Photos of the solar array cushion and cellside.



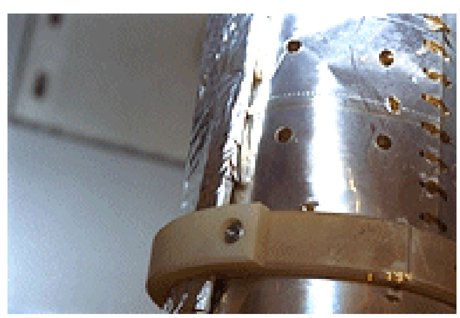


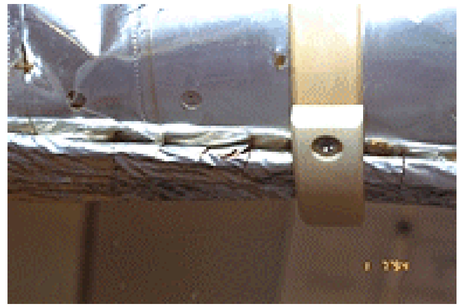


Photos of the solar array hingepin.

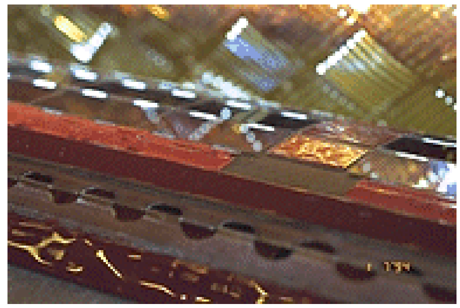


Photos of a meteoroid or debris hole in solar array.





Photos of the deterioration of the MLI plate.



Photos of the solar array RTV.

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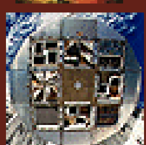

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Solar Array Drive Electronics (SADE)

Background
The SADE interfaces with the Support System Module (SSM) for exchange of operational commands and telemetry data. The SADE operates and controls the Solar Array Drive Mechanisms (SADM) for the orientation of the SAD. It also monitors the position of the arrays and the temperature of the SADM. The SADE interfaces with the SSM for exchange of operational commands and telemetry data. The SADE operates in the following modes: all motors off, one motor on each mechanism operating simulataneously in either direction of rotation (both main or both redundant), one motor on one mechanism in an operating mode as previous, and simultanious operation of both motors in either mechanism.

First Servicing Mission
During the first HST servicing mission the astronauts replaced the Solar Array Drive Electronics (SADE). The astronauts commented that the SADE change out was a challenging EVA. Astronaut Musgrave noted that the D screws were unconnected and floating in the zero-gravity environment inside the SADE unit.

Results of the SADE-1 Post-Retrieval Inspection
Two transistors (T5 and T7) and two diodes (D8 and D10) had been thermally stressed with the conformal coating discolored and charred. Solder on connections became molten and reflowed betweeen the two diodes. Failed transistors gave no indication of defective construction. All 27 Boards were inspected: seven boards were anomalous and two boards were completely replaced. Some modifications were made to SADE-1R, though the returned

SADE did not change the modifications required.

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Flight Support System

The Flight Support System (FSS) is a reusable equipment system that provides the structural, mechanical, and electrical interfaces between a spacecraft and the Orbiter for launch, retrieval, and on-orbit servicing missions. It also served as the maintenance platform holding HST in place while providing a means for rotation about two axes for correct positioning during deployment and on-orbit servicing.

The FSS configuration for spacecraft deployment or retrieval consists of three structural cradles, mechanisms for spacecraft retention and positioning, and avionics. The cradles provide the structural support for the payload and storage locations for tools and electronics. The mechanisms for retention and positioning allow the spacecraft to be docked to the FSS, serviced, and released. The FSS provides the electrical interface between the Orbiter and the HST, and between the Orbiter and the Servicing Mission payload elements. The avionics provide all necessary power, command, control, and data monitoring interfaces to support operational modes of the spacecraft. The avionics also provide for remote control of all FSS mechanisms from the Orbiter Aft Flight Deck. The configuration for on-orbit servicing typically consists of one cradle with Berthing and Positioning System, mechanisms, and avionics.

The FSS has a specific configuration for servicing the Hubble Space Telescope. The HST servicing configuration consists of a single cradle (A), avionics, mechanisms, and the Berthing and Positioning System (BAPS). Once HST is berthed to the FSS, the BAPS is used to orient the HST for servicing and to react to loads induced by reboosting the HST to a higher orbit. The avionics and mechanisms used for HST servicing are a subset of the full complement available, with additional power capability.

References

Flight Support System User's Guide: NASA Goddard Space Flight Center, HST Servicing Mission Deintegration and Test Plan, Fairchild Space Company, 1993.

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Orbital Replacement Unit Carrier

The Orbital Replacement Unit Carrier (ORUC) is a modified Spacelab Pallet which provides stowage and environmental protection for the HST orbital replacement units (ORUs) and instruments. It is a change out platform from which the EVA crew can transfer items to and from HST. The ORUC mechanical interface to the Orbiter is through one keel trunnion and four sill trunnions. The ORUC can house several ORUs.

On the first servicing mission, the WFPC-II and the COSTAR were carried in the center section in their protective enclosures. The RSUs, ECUs, and GHRS Repair Kit were mounted in a small ORU Protective Enclosure (SOPE) on the equipment shelf. The DF-224 and coprocessor were mounted in a large ORU Protective Enclosure (LOPE) on the shelf. Electrical, command and telemetry connections to the ORUC are routed via the FSS.

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Orbital Replacement Units

Hubble Space Telescope servicing missions are scheduled at approximately three-year intervals to replace scientific instruments, as well as batteries and other limited-life items. Ranging in size from a shoebox to a telephone booth, most of the items can be removed or installed with the aid of wrenches and screwdrivers. These items, called Orbital Replacement Units, include components in the guidance and control systems and in the command and data handling system, a computer, solar arrays, and the scientific instruments. Instruments, batteries, computers, and other essential components in the equipment bays are accessible through doors for easy removal and replacement.

Altogether, some 70 items in the HST can be replaced in orbit. The Orbital Replacement Units are:

1. Scientific Instrument Control and Data Handling
2. Faint Object Camera
3. Wide Field / Planetary Camera
4. Data Interface Unit for Optical Telescope Assembly
5. Data Management Unit
6. DF-224 Computer
7. Fine Guidance Electronics (3)
8. Battery (6)
9. Fixed Head Star Tracker (3)
10. Rate Sensor Unit (3)
11. Charge Current Controller (3)
12. Data Interface Unit for Support Systems Module
13. Electrical Power Thermal Control Electronics
14. Power Control Unit

15. Power Distribution Unit
16. Fuses (14)
17. Multiple Access Transponder (2)
18. Single Access Transmitter (2)
19. Faint Object Spectrograph
20. Fine Guidance Sensor (3)
21. Reaction Wheel Assembly (4)
22. Solar Array (2)
23. Low Gain Antenna
24. Sun Sensor

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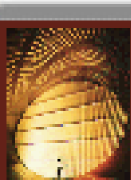

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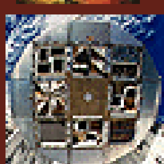

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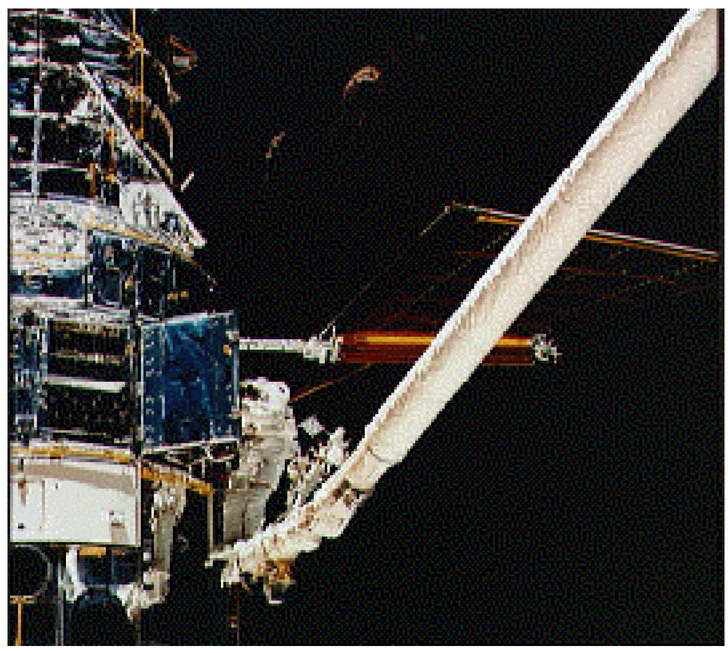
Fuses



Astronaut Hoffman replacing the fuses in HST berthed in the payload bay.

There are three different fuse-module configurations (four each) in the HST Support system Module (SSM). The P-15 and P-16 fuses were replaced with upgraded versions. Four P-15 Modules (3 and 5 amp fuses) were replaced since one had opened, and the Rate Sensing Units (RSU) fuses were increased in size from three amps to five amps. Four P-16 modules (10 and 20 amp fuses) were replaced since their configuration was questionable. Spare P-17 and Optical Telescope Assembly (OTA) fuses were carried as contingency but were not replaced. The original plugs were returned for ground examination. The fuses were visually inspected and photographically documented before the DC milliohm and high-voltage tests occurred as part of the ground examination procedure. Resistance and current characterization tests were also part of the examination.

A flight spare P-16 module was found to be miswired during ground testing. Two of the four P-16 modules replaced during the servicing mission were miswired. All 20 amp fuses in S/N's 1006 and 1007 were shunted by the twin low-resistance leads such that negligible current could flow through the fuse. Ground test verified open fuse elements in the P-15 Fuse module (S/N 1012). Ground test verified miswiring of two P-16 fuse modules (S/N's 1006 and 1007). No additional discrepancies or degradation of the modules were observed.

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Rate Sensing Units
The rate-sensing units are crucial in pointing of the Hubble Space Telescope during target acquisitions and observations. The pointing control system uses four of the six rate gyros which provide precise angular measurements for short-term stability. The rate gyros report 40 times per second and they are sensitive enough to detect position changes as small as 0.00025 arc second (7 hundred-millionths of a degree). The rate gyros give the computer information about the telescopes's orientation or attitude.

Two pairs of the gyros suffered apparent failures during the HST mission. The rate-sensing units will be visually inspected with particular attention to the connector pins. Photographs and contamination samples will be taken. Electrical interface continuity and isolation tests will be performed. The units will then be returned to Allied Signal for functional testing and evaluations. After testing is completed, the rate sensing units will be refurbished and reflown.

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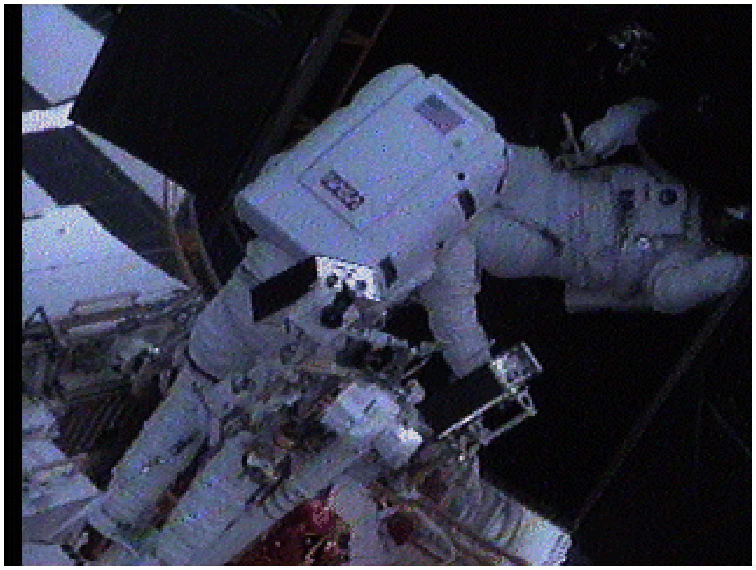
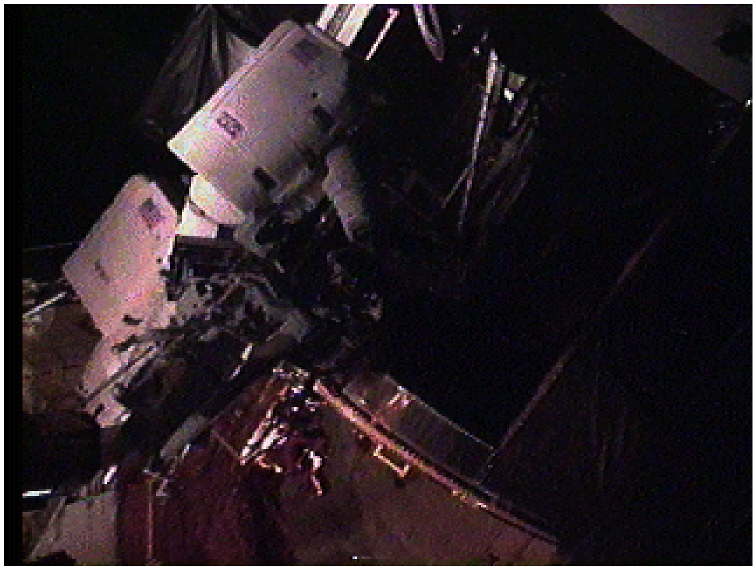


Astronauts remove RSUs during Servicing Mission.

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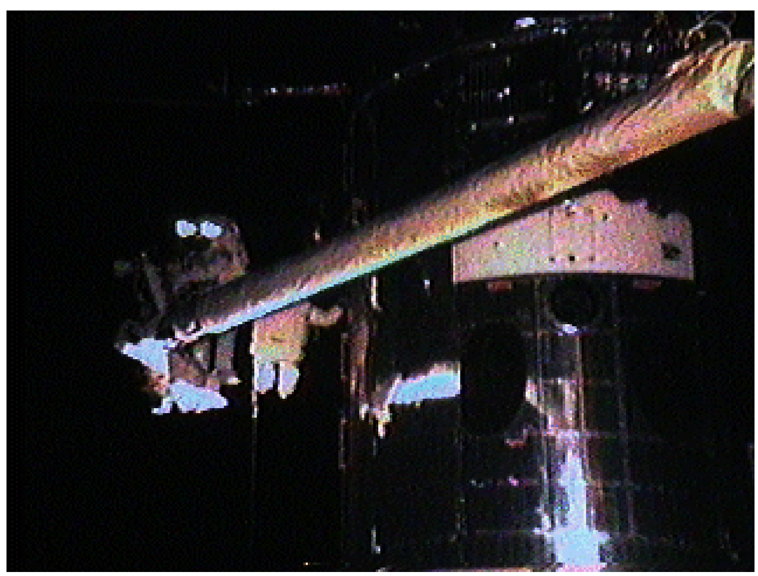
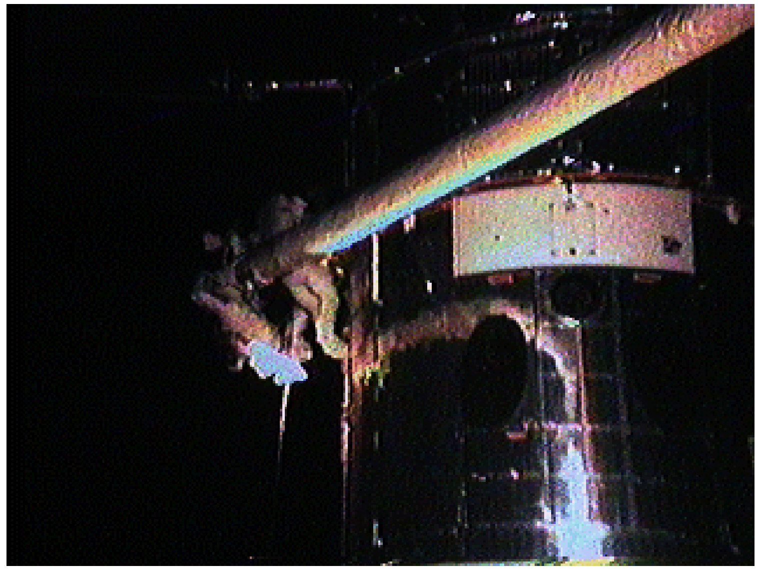
Electronic Control Units

Two Electronic Control Units (ECUs) were believed to have failed and were retrieved during the first HST servicing mission. The ECUs will be visually inspected, particularly the connector pins. While full function tests are desired, they are not planned at Goddard Space Flight Center.




Astronauts removing ECUs during servicing mission

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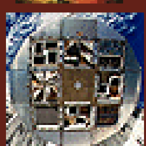

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Magnetometer Multi-Layer Insulation and Side Plate

During the first HST servicing mission the MSS kapton multi-layer insulation (MLI) was removed and replaced. The STS-61 crew noted that the MLI appeared fine at first, although it crumbled when touched.

The magnetometer MLI and side plate underwent thorough testing. These samples were chosen because they are non-optical surfaces. The experimentation was necessary in order to test the theory that the samples were contaminated by UV Earth albedo. The results of the magnetometer MLI and side plate were inconclusive.

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Tools and Crew Aids
The Hubble Space Telescope was designed to be serviced on-orbit by astronauts conducting EVA's. Most of the tool complement used on the first servicing mission were designed and developed prior to the launch of the HST in April, 1990.

After the first servicing mission, the astronaut crew detailed their experiences with the serving mission tools in their debriefing. In addition, the EVA Section of the Mission Operations Directorate (MOD) authored the STS-61 EVA Post-Flight Report in order to capture the knowledge gained from the servicing mission relative to mission operations. Based on this knowledge, MOD developed a set of recommendations for future mission successes.

The HST servicing mission required many HST-specific tools and crew aids. These included: the short and long 7/16 inch adjustable extensions, the fuse tether (commonly known as the fish stringer), multi-setting torque limiter, portable grapple fixture, and the fastener retention tools (commonly known as hairpins). Additional, less unique tools used were the push-button portable foot restraint (PFR) and articulating sockets, retractable tethers, high-speed power tool with rotary impact driver, and the large hook mini-work station end effector.

The adjustable extensions proved valuable because they enabled the astronauts to perform different HST tasks without having to use larger, bulkier hardware that could have caused a snag hazard. The fuse tether served as a device to transport the P15 and P16 fuses to the worksite as well as one to assist in the handling of multiple tools and tool caddies that were to be installed on the MFR. The multi-setting torque limiter reportedly functioned well. The portable grapple fixture was not needed during the mission, although it would have allowed the solar arrays to be jettisoned via the RMS. The fastener retention tools were used to capture the non-captive fasteners on the DF-224 computer and SADE.

The push-button PFR and articulating socket represent improvements to existing designs. The retractable tethers operated with excellent results, and are regarded as a major advancement in EVA tethers. The high-speed power tool and rotary impact driver added to the tool complement later in the development process; while they were not needed on this mission, they provide a good capability to free a stuck fastener. The EVA crew generally preferred the large hook as the end effector on the mini-work station, instead of the normal end effector.

The tools and crew aids manifested on the first servicing mission totalled approximately 200. They were tracked via a tool list that was placed under configuration control approximately six months before launch. The configuration control provided a means to define stowage requirements, responsible organizations, schedules for completion, delivery dates, and inventories of flight and training units.

During the crew debrief, several operating problems were noted with regard to the tools. These included:

- The small power driver could use a speed control.
- Power tools create RFI on the astronauts' helmet radios but the interference was tolerable.
- The power tool batteries can go dead without warning.

References
1. **STS-61 EVA Post Flight Report**, EVA Section, Mission Operations Directorate, February, 1994.

2. STS-61 Crew Debrief, December, 1993.

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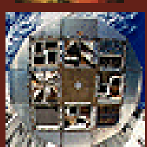 Space Environments &Technology Archive System Home Page

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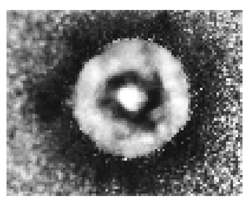
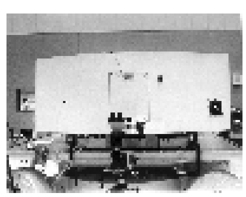
Photographs

During post-retrieval activities at Goddard Space Flight Center (GSFC) a large set of photos were taken of the returned HST hardware. At that time, the plans were to put these photographs on optical disk as part of an effort to create electronic copies of the HST photo documentation. Although not currently available through this system, it is hoped that they will be at some date. A subset of these photos have been scanned at Langley and are a part of this archive.

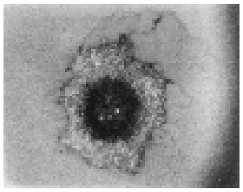
The following images were provided by Don Humes and were acquired during his meteoroid & debris impact analyses of various pieces of HST hardware. To see a larger version of the various thumbnails, select the desired format type.

GIF  JPG

1. Humes1.pit 7 - Largest crater on WF/PC-I radiator. Dimensions: lip, 980 micron diameter; at plate surface, 900 micron diameter; depth, 360 microns. Paint spall area around crater, 5400 micron diameter (not shown).

GIF  JPG

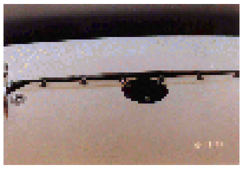
2. Humes2.setup - WF/PC-I radiator in clean room at NASA GSFC, with microscope in front.

GIF  JPG

3. Humes3.pit 61 - Crater on WF/PC-I radiator. Dimensions: lip, 500 x 540 microns; at plate surface, 370 x 460 microns; depth, 185 microns. Paint spall area around crater, 1320 microns. Cracks in paint can also be seen.

GIF  JPG

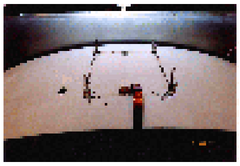
4. 94C-3052 - Wide Field / Planetary Camera - I M1 Mirror, post-flight. Magnesium fluoride coating on aluminum eroded.

GIF  JPG

5. 94C-3045 - Wide Field / Planetary Camera - I Radiator Bay 5 area, post-flight, brown discoloration evident.

GIF  JPG

6. 94C-3046 - WF/PC-I Radiator,post-flight, brown discoloration evident.

GIF  JPG

7. 94C-3041 - WF/PC-I Radiator, post-flight.

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HST Returned Hardware Evaluation Symposium

NASA Goddard Space Flight Center
December 15, 1994

Sixteen talks were presented at the Hubble Space Telescope Returned Hardware Evaluation Symposium which was held at the NASA Goddard Space Flight Center on December 15, 1994. The various presentations discussed the scientific approach and findings related to the evaluation of returned HST hardware. The following links present some of the viewgraphs and images that were presented by the various speakers.

1. Douglas B. Leviton, "Spectral Transmission Measurements of Wide Field and Planetary Camera I Optical Components Following HST FSM ".
2. June L. Tveekrem, "Optical Component Degradation Assessment Part II - Surface Chemistry Analyses ".
3. Lee Feinberg, "Optical Component Degradation Assessment and On-Orbit Implications ".
4. Tom Zuby and Kim de Groh, "Overview and

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Analysis of HST Returned FEP Insulation ".

5. L. Gerlach, "Post-Flight Investigation Program (PFIP) of HST-SA1: Investigation Logic and Results ".
6. Donald H. Humes and William H. Kinard, "Meteoroid and Debris Impacts on the WF/PC-1 Radiator ".
7. John Trauger, "WF/PC Science Filters ".
8. Mark S. Anderson, "Preliminary Wide Field Panetary Camera-1 Contamination and CCD Window "Measles" Investigation ".
9. Alan R. Smith, Donna L. Hurley, and Richard J. McDonald, "Induced radioactivities of Returned Hubble Space Telescope Parts as Indicators of Radiation Exposure to the Spacecraft ".
10. Wanda C. Peters, "Wide Field Planetary Camera-1 (WF/PC-1) Radiator Investigation ".
11. D. Hughes, "Albedo Level Photopolymerization ".
12. Evan Richards, "High Speed Photometer Evaluation and Plans ".
13. Mike Urban, "Rate Gyro Assemblies (RGAs) ".
14. Cindy Winslow, "Solar Array Drive Electronics Failure Investigation ".
15. Denis McCloskey, "Fuse Module Investigation ".
16. Brenda K. Wilson, "The LDEF Archive System - an Option for Archiving HST Returned Hardware and Data ".

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Hubble Presentations

Spectral Transmission Measurements of Wide Field and Planetary Camera I Optical Components Following HST FSM

Douglas B. Leviton / Code 717.1 Collaborators:

- Ritva Keski-Kuha / Head, Optical Research Section
- Charles Fleetwood / Optical Research Section
- June Tveekrem / Optical Research Section
- Tom French / NSI Optics Function
- Lee Feinberg / HST Project

Overview of Spectral Transmission Measurements: March 28 - June 30, 1994

Rationale

- Opportunity to study effect of exposure of optics to on-orbit environment of HST focal plane.
- Influence handling/processing considerations for next generation HST flight hardware.

Components Measured Over 920-6500 Angstroms Wavelength Range

- Flight and Flight Spare Pickoff Mirrors
- Flight MgF2 Aperture Window
- Flight and Flight Space M1 (detector UV flood) Mirrors

Measurement Approach

- Primary interest below 2000 Angstroms as contamination probe suggest vacuum setup.
- Cleanroom tabletop setup bagged / purged with dry N2 gas to transmit FUV - low

cost, fast, clean, keeps suspected contaminants from evaporating.

- Measure HST mirrors relative to reference mirror of known reflectance.
- Technique used to demonstrate COSTAR FUV throughput before FSM.

Conclusions

Substantial Degradations in FUV Transmission for:

- Flight Pickoff Mirror
- Flight MgF2 Aperture Window

Flight M1 Mirror

- Coating peeled at one end on-orbit similar to spare mirror in high temperature thermal vacuum.
- Reflectance changed little in design spectral region.

Flight Spare Optics showed little if any degradation.

Return to Hubble Space Telescope Hardware Archive System

Hubble Presentations

Optical Component Degradation Assessment Part II - Surface Chemistry Analyses

Dr. June L. Tveekrem / Optics Branch, NASA Goddard Space Flight Center

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Test Sequence and Rationale

- Nondestructive tests (e.g. microscopic inspection, photography) were performed first, then minimally destructive tests (e.g. X-ray Photoelectron Spectroscopy), then destructive tests (e.g. solvent rinse, scraping, cutting the mirror).
- The flight pickoff mirror was characterized first, then other optical elements exposed to the HST hub area were analyzed to see if they showed the same effects. The optics studied were: the flight pickoff mirror, the aperture window and several filters from the High Speed Photometer instrument.
- Since all optical elements proved to be contaminated with the same chemical species, later tests were performed on different optical elements, and the results were generalized to all the optical elements.

Micro-Photography Results

- The flight pickoff mirror, the aperture window, and the HSP filters were examined and photographed using a high-power microscope in phase-contrast (Nomarski) mode.
- The pickoff mirror showed a blue haze to the naked eye. Under the microscope, this haze was revealed to consist of numerous droplet-like features 1 to 2 microns in diameter.
- The aperture window did not appear contaminated or damaged, except for a crystalline defect in the exact center. This defect was present prior to launch.
- The HSP filters had a rough surface finish and several features which appeared to be manufacturing defects, but showed no visible contamination.

X-ray Photoelectron Spectroscopy (XPS) Results

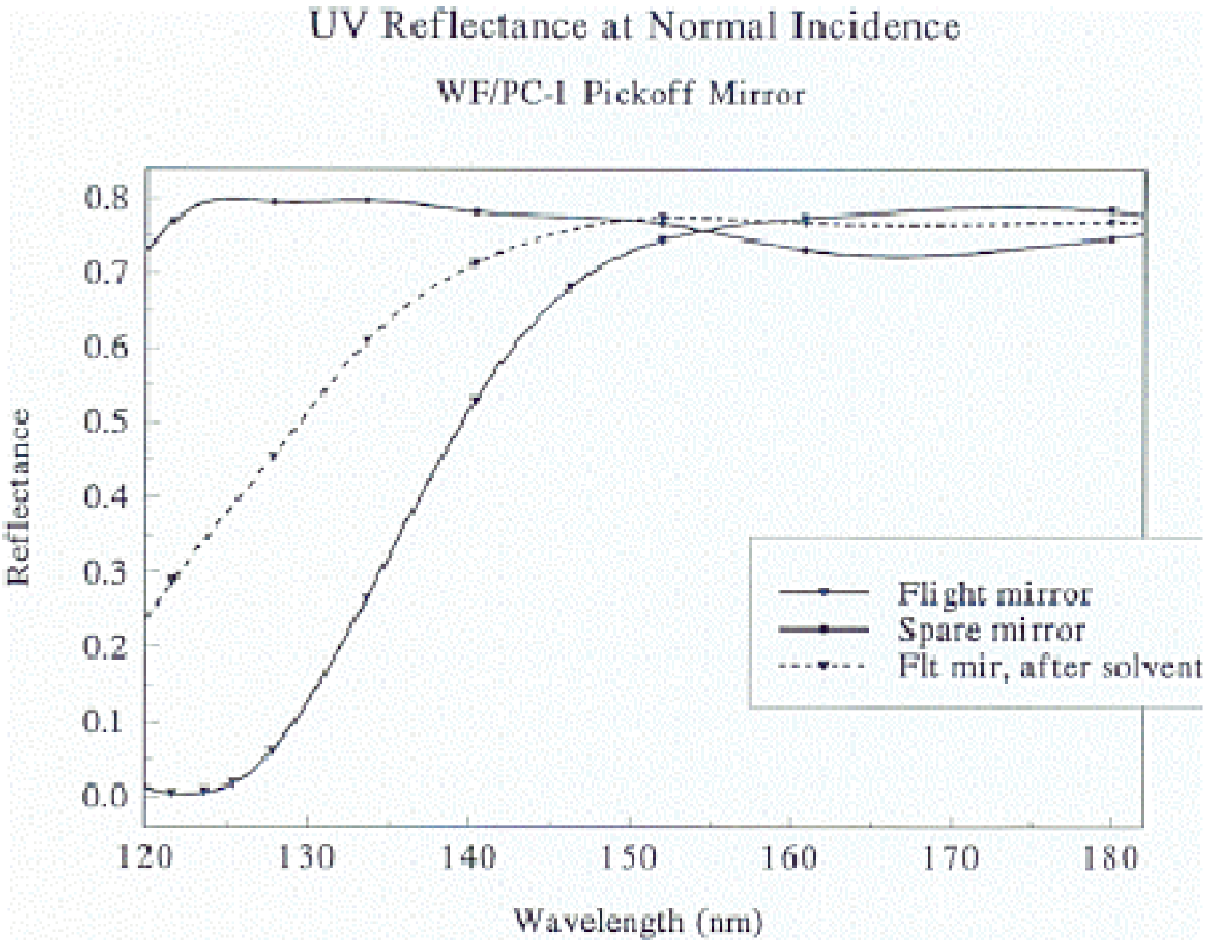
- XPS consists of irradiating a surface with X-rays, which knock electrons out of the surface via the photoelectric effect, then measuring the energy of the emitted electrons. This allows the chemical elements present in the top 50 Angstroms of surface to be identified. The chemical bonds between an atom and its nearest neighbors can also be identified.
- Chemical elements present below the surface can be identified by sputtering away the top 50 Angstroms, then analyzing by XPS again. By repeating this process many times, a depth profile of the surface is obtained.
- Depth profile of pickoff mirror revealed that the Al + MgF_2 coating was intact, but the surface was heavily contaminated with hydrocarbons, esters and silicones.
- The aperture window was also undamaged, but contained the same contamination as the pickoff mirror. The thickness of the contamination layer was 1/3 that off the layer on the pickoff mirror. Only the hub-facing side of the window was contaminated; the side facing into the WF/PC-I instrument was clean.
- Two HSP filters were analyzed; they contained the same contamination layer in the same thickness as the aperture window.
- The thickness of the contaminant was measured by sputtering a "square well" through the contamination layer on the HSP filter, then using an Atomic Force Microscope to measure the depth of the well. The result was 160 Angstroms.
- Since the aperture window and pickoff mirror were known to contain the same contaminant, the ratio of sputter times was used to deduce that the aperture window contained approximately 150 Angstroms of contamination and the pickoff mirror contained about 450 Angstroms.
- Because the contaminant did not come off in vacuum, and based on the shape of the reflectance degradation curve, an on-orbit UV-stimulated mechanism for depositing the contamination was suspected. The HST optical train is exposed to Earth-reflected UV for part of each orbit.
- The UV stimulation hypothesis is partly supported by the fact that contamination has not been found so far on hub-facing surfaces which were not exposed to UV. Investigations of such surfaces is continuing.
- To determine whether UV-assisted deposition and photopolymerization was possible, and to determine where the contamination might have come from, mass spectroscopy was performed next on the optics to better identify the chemical species of contaminants.

Surface Mass Spectroscopy Techniques

- The aperture window and the pickoff mirror were analyzed by Gas Chromatography / Mass Spectroscopy. In this technique, an area of the surface is rinsed with a strong solvent (methylene chloride), then the solution is injected into a gas chromatograph to separate the molecular types, then sent into a mass spectrometer for identification. This technique features high sensitivity, but can only detect soluble contaminants of relatively low molecular weight.
- The pickoff mirror was analyzed by Direct Probe Mass Spectroscopy and Pyrolysis Mass Spectroscopy. In these techniques, a small area of the mirror surface is scraped off, and the scrapings are heated to several hundred degrees Celsius to evaporate the sample. The evaporated molecules are directed into a mass spectrometer for identification. The advantage of this is that chemical species with high molecular weights can be detected.
- The HSP filter was analyzed by time-of-flight Secondary Ion Mass Spectroscopy. This technique consists of bombarding the surface with ions to knock molecules out of the surface, then sending the molecules into a mass spectrometer for identification. The advantage of this technique is that it is not necessary to previously remove or dissolve the contaminant from the surface. However, only the top few monolayers can be detected.

Surface Mass Spectroscopy Results

- The four mass spectroscopy techniques yielded results that were consistent with each other. The chemical species found, in order of abundance were:
    - A very high molecular weight, polymerized hydrocarbon
    - Poly dimethyl siloxane
    - Di ethyl phthalate
    - Di octyl phthalate
    - Tri phenyl phosphine oxide
    - Numerous low molecular weight hydrocarbon fragments
- The aperture window contamination was measured by XPS before and after solvent rinsing with methylene chloride. By comparing the relative strengths of the XPS peaks, it was estimated that 2/3 of the contamination layer was removed by the solvent.
- The reflectances and transmittance of the pickoff mirror and aperture window were remeasured after solvent rinsing. The aperture window results were inconclusive, but the pickoff mirror reflectance was partially restored.



Conclusions from Surface Analyses

- Reflectance degradation was caused by contamination, not optical coating damage.
- The pickoff mirror received about 450 Angstroms of contamination while the aperture window and HSP filters received about 150 Angstroms.
- The primary contaminant species detected were a polymerized hydrocarbon, polydimethylsiloxane, diethylphthalate and dioctylphthalate.
- The contaminant layer appears to be partially polymerized; some of it was removable by rinsing with strong solvents, but some was not. The part that was not removed was still enough to cause a significant reflectance degradation.
- Our leading theory is that the contamination happened during normal on-orbit HST mission operations; outgassed molecules from electronics and other hub-facing components impinged on optical surfaces and were partially polymerized there by exposure to earth-albedo UV.

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Hubble Presentations

Optical Component Degradation Assessment and On-orbit Implications

Lee Feinberg / NASA Goddard Space Flight Center

Energy Calculations

Calculations support concluding that UV-induced contamination could have occurred in HST in space:

- A calculation based on an IUE-based spectrum estimated the amount of ultra-violet energy (less than 300 nm) that could have hit the pickoff mirror while WF/PC-I was in HST and in space was 0.05 J/cm squared.
- The amount of energy required to break 2 bonds per molecule for 450 Angstroms of contaminant is approximately 0.005 J/cm squared.
  - Assumes contaminant is a phthalate.
  - This implies an approximate 10% efficiency of bond-breakage per UV photon.

Calculations also support concluding that UV-induced contamination could have occurred during the Servicing Mission:

- The amount of energy seen by the pickoff mirror in its 3.5 years in space is approximately equal to the amount of energy from 2 orbits of Earth exposure during the Servicing Mission (because of the solid angle of the Earth).
  - WF/PC-I was exposed to Earth albedo/Shuttle environment for just under 2 orbits.

Possible Outgassing Sources: Optical Telescope Assembly (OTA) and Fine Guidance Systems (FGS)

- HST "hub" contamination would likely come from either the optical telescope assembly or the three fine guidance sensors that face the WF/PC-I Pickoff Mirror.

    - Some FGS components were not baked out (including filter wheel assembly and optical subassemblies).
    - FGS and OTA subsystems were baked out until QCM at 1Hz/hr at 50-55 degrees Fahrenheit for 36 hours (much less stringent than science instruments).
    - FGSs had verification test run with QCM at hub facing aperture, QCM 18 degrees Fahrenheit below on-orbit temperature of 70 degrees Fahrenheit plus or minus 5 degree, 8 hours at 1 Hz/hr.
- Though science instruments also faced the hub, they were certified at -20 degrees Celsius at 1 Hz/hr (much cleaner) and have only a small aperture facing the hub.
- FGSs do have a few-inch gap running across the top of them in the hub.

On-Orbit Data Since Servicing Mission

- COSTAR optics deployed into the hub.
- GHRS is the most reliable on-orbit UV data for judging UV degradation to COSTAR.
- FOS data qualitatively agrees with GHRS data, FOC not accurate in desired wavelength.
- WF/PC-II data is expected December, 1994.
- Small degradation, as seen, is expected since outgassing in HST has been going on for four years. Therefore, the number of molecules is depleted.

Conclusions/Summary

- Based on results from well-controlled optical surfaces (pickoff mirror, aperture window, HSP filters) the contaminant appears to be a UV-deposited organic with soluble and non-soluble components.
    - Source of UV is believed to be Earth albedo.
- Results from non-optical surfaces (MLI, aluminum aperture plate) are inconclusive and additional samples are currently being analyzed.
    - Team is addressing question of whether any surfaces that did not see UV Earth albedo were contaminated.
    - Team is addressing issue of whether deposition occurred in HST bay during

    3.5 years in space or during the Servicing Mission.
    - Additional samples from the High Speed Photometer exterior are being collected and are expected to help resolve these issues.
- Based on existing data, scientific instruments currently in HST appear to have minimal UV degradation.
    - Work is underway to assure future instruments are also minimally affected.

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Hubble Presentations

Overview and Analysis of HST Returned FEP Insulation

Tom Zuby, NASA Goddard Space Flight Center
Kim de Groh, NASA Lewis Research Center

FEP Material Inventory

- Solar Array I Drive Arm Multi Layer Insulation (SA-I MLI)
  - 1 Sample
- Magnetic Sensing System Electronic Box Multi Layer Insulation (MSS MLI)
  - 2 Samples

Space Environment

- 3.6 years in orbit.
- Atomic Oxygen (AO) fluence in the ram direction estimated to be 7.59 x 10^20 atoms per centimeter squared.
- Solar Fluence
  - SA-I drive arm material not yet calculated but thought to be similar to the MSS calculated values.
  - MSS MLI solar fluence values calculated for the MSS MLI sample range from 0.51 to 1.90 sun years.

SA-I Drive Arm MLI

- Contamination
- Micrometeoroid or Debris
- Thickness
- Other Space Effects

SA-I Drive Arm MLI: Surface Contamination

- Contamination Aspects
    - Areas of yellow to brownish residue.
    - Water spots.
- X-ray Photoelectron Spectroscopy is to be performed on selected samples removed from this specimen.

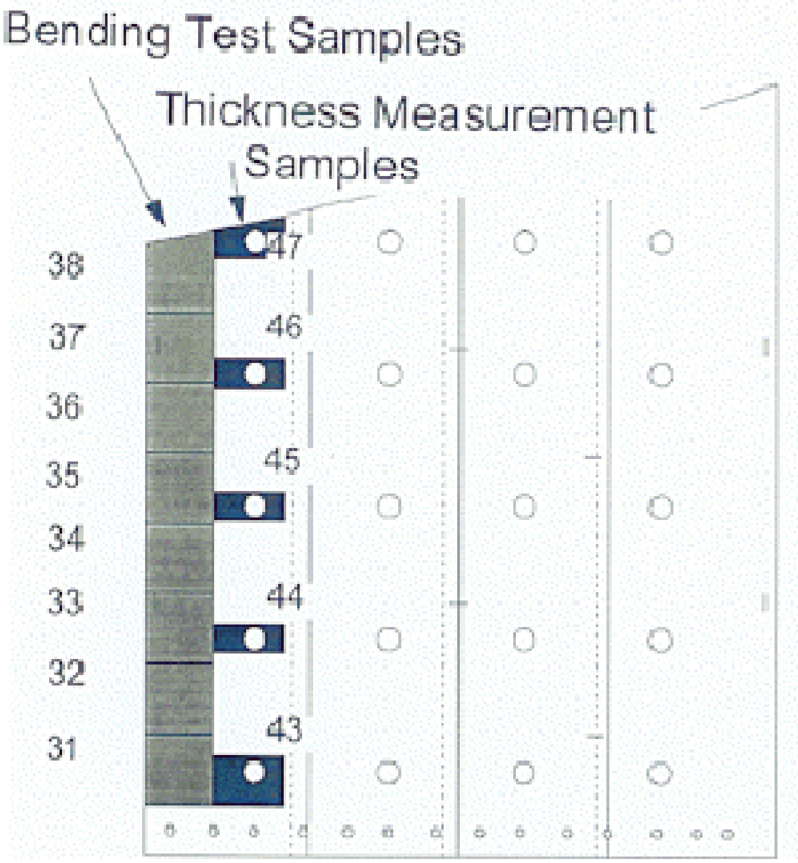
SA-I Drive Arm MLI: Micrometeoroid or Debris

- 6 impact sites identified.
- Residue not yet identified as being man-made or naturally occurring.
- Shock ring size varies with regard to penetration hole size.

SA-I Drive Arm MLI: Other Space Effects

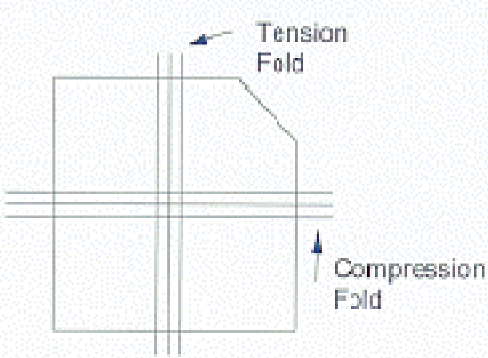
- Milky colored haziness.
- Predominant on the solar facing surfaces.
    - Darkening of the stitching materials.
    - Cracking of the FEP material.

SA-I Drive Arm MLI Sample Diagram



Bend Test Procedure

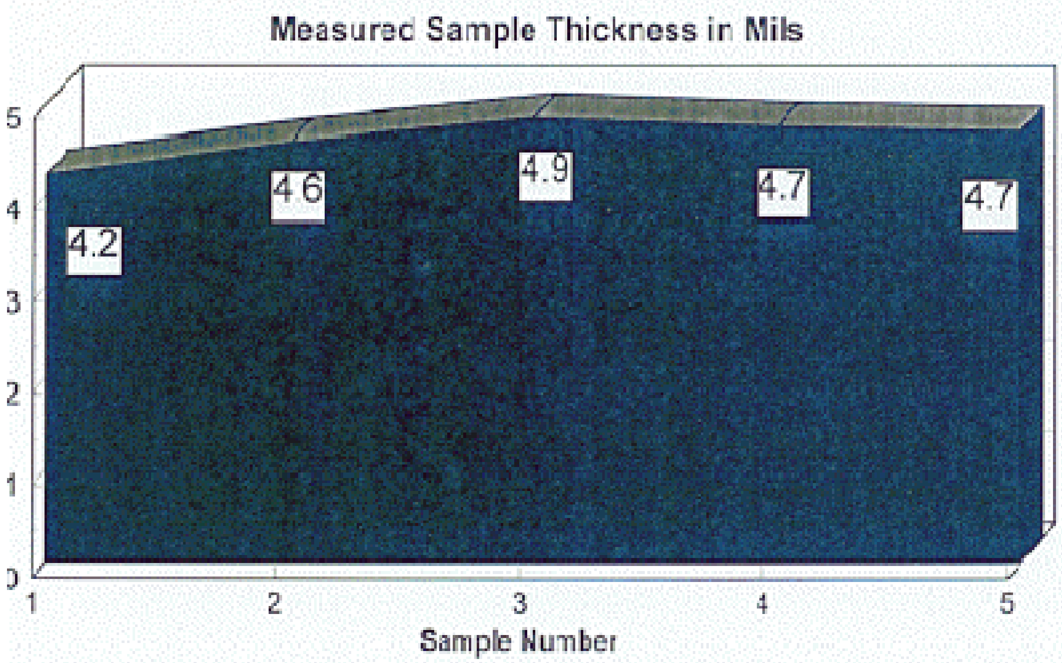
- Bending of sample
  - Sample size = 2 cm. x 2 cm.
  - 25 bends, horizontal, compression in FEP
  - 25 bends vertical, tension in FEP
  - mandrel diameter = 0.83 mm



HST SA-I Drive Arm MLI Tensile Bending Test Results

Sample #	Cracked	Notes
31, 32, 33	Yes	High solar exposure
34	Yes	Bottom half of sample cracked, top half of sample likely covered with cable bundle
35, 36	No	Likely covered with cable bundle
37, 38	No	Lower solar exposure

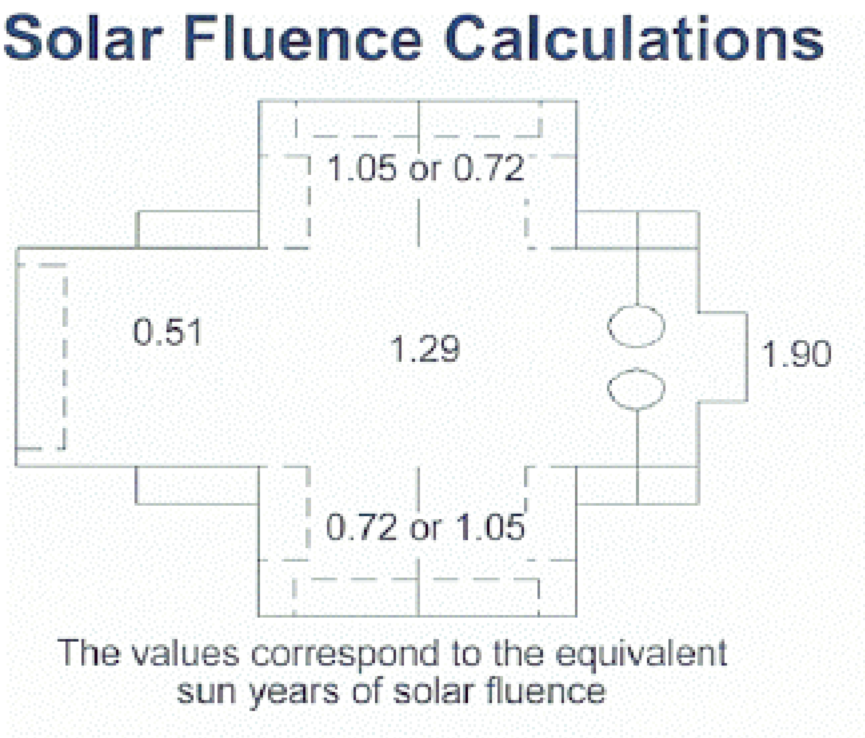
SA-I Drive Arm MLI Thickness Measurements



Non-Exposed Sample Thickness Measured to be 5.1 mils

MSS Electronics Box MLI

- Contamination
- Micrometeoroid or Debris
- Thickness
- Tensile and Elongation
- Other Space Effects



MSS MLI Surface: Contamination

- Very brown areas.
  - Around cable holes.
  - Along edges of Velcro.
- Darkening seems only to occur in proximity to underlying acrylic adhesive layer.

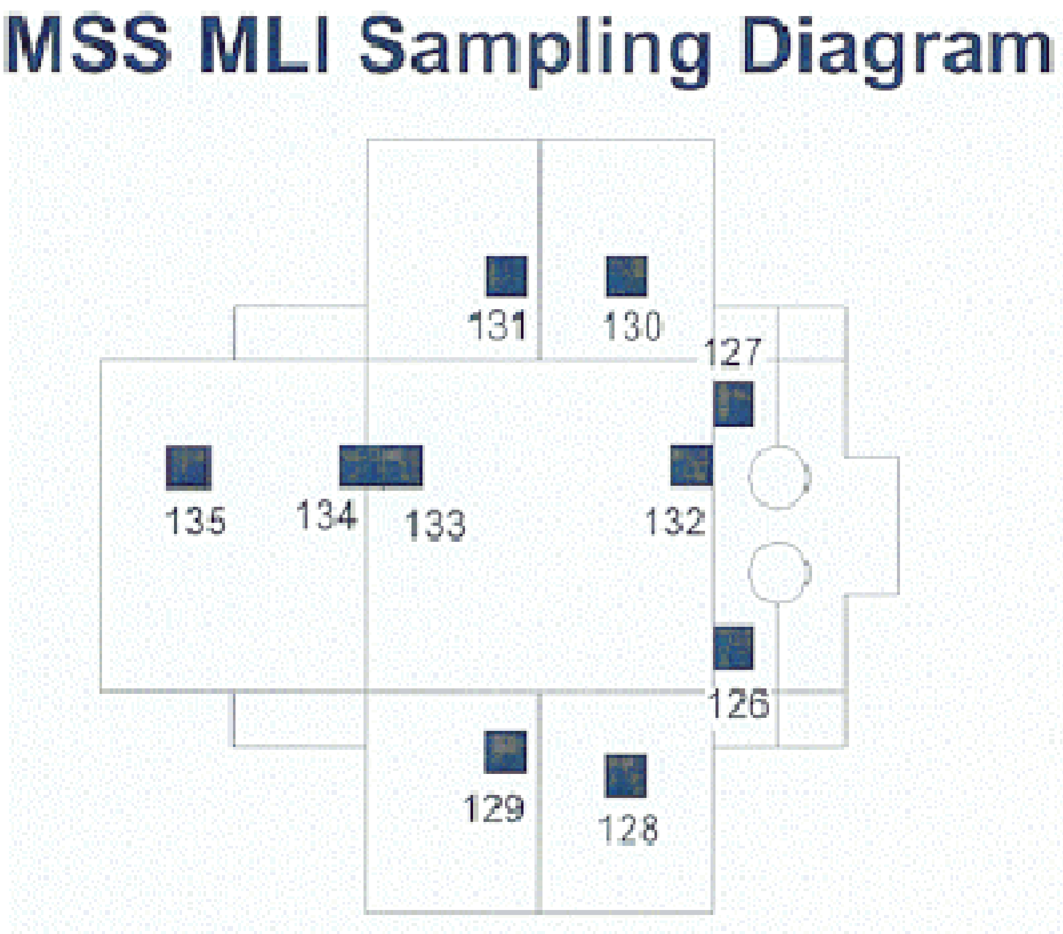
MSS MLI Surface: Micrometeoroid or Debris

- 3 impact sites identified

- Micro-photographs of these sites are still pending.
    - Site 1: 6 layers penetrated
    - Site 2: 4 layers penetrated
    - Site 3: 8 layers penetrated
- Residue to be identified as man-made or naturally-occurring.

MSS MLI Surface: Other Space Effects

- Milky colored haziness.
- Cracking is evident on the material with high solar fluence.
- Adhesive failure is noted for the FEP/Acrylic interface.
- Increase of surface hardness.

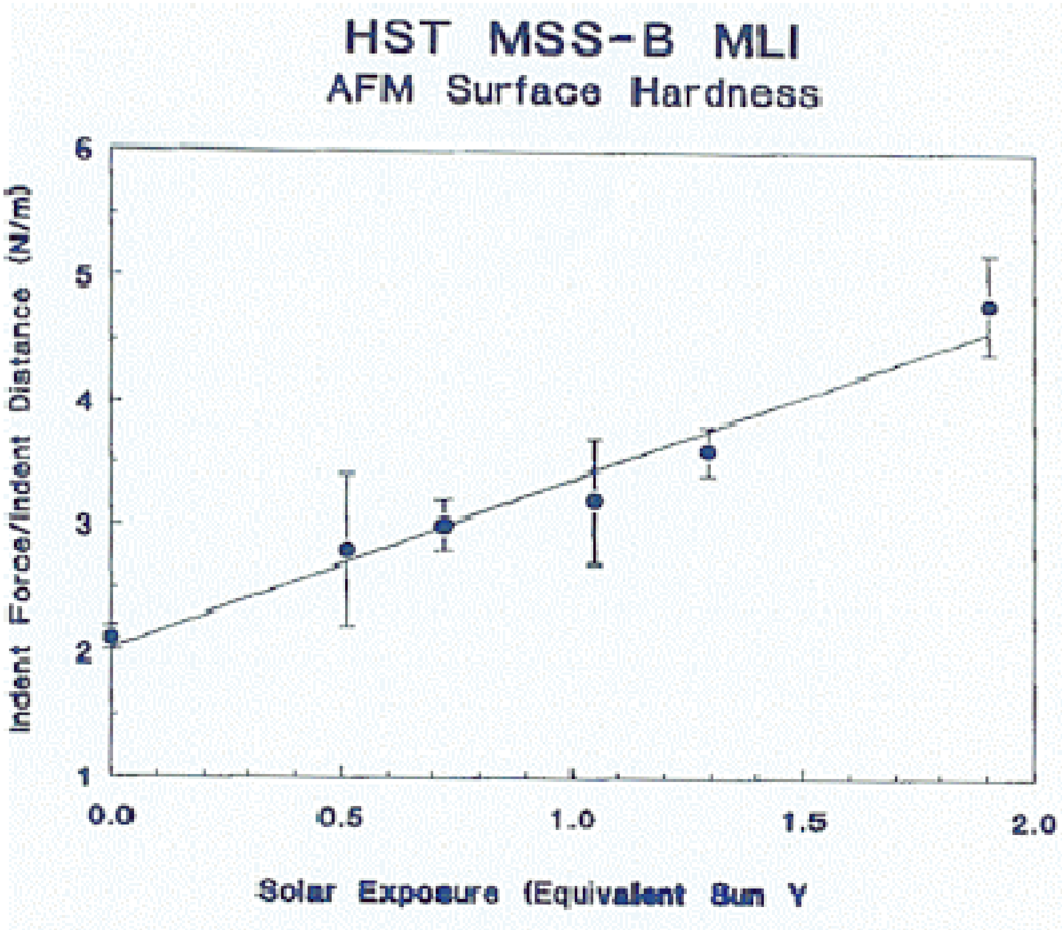


HST MSS MLI

As Received Condition

Sample #	Solar Exposure*	Received Condition
134, 135	0.511	bent, not cracked
128, 129	.0722 or 1.049	slightly bent, few cracks
130, 131	1.049 or 0.722	bent, extensive cracking
132, 133	1.294	slightly bent, little to extensive cracking
126, 127	1.903	bent, extensive cracking

*Solar exposure given in equivalent sun years


HST MSS-B MLI
AFM Surface Hardness
Indent Force/Indent Distance (N/m)
6
5
4
3
2
1
0.0
0.5
1.0
1.5
2.0
Solar Exposure (Equivalent Sun Y

Tensile and Elongation Measurements

Sample	Yield Strength (lbs)	Ultimate Load (lbs.)	Elongation (relative to Stock Material)
Stock Material	1.4	2.6	100
Sample 1	1.3	1.5	57
Sample 2	1.3	1.3	33

Samples taken from the area designated with 1.29 years of solar fluence.

Conclusions

- FEP MLI shows damage from space environmental exposure.
  - Cracking occurrences increase with increased solar exposures.
  - Increased hardness and reduced elongation was observed in areas of high solar fluence.
  - Erosion yield appears to be greater for higher solar fluence surfaces and is an order of magnitude greater than LDEF values.
- FEP is still acceptable as a thermal blanket material provided:
  - No insitu deformation occurs.
  - A suitable backing is adhesively applied to the FEP layer to maintain structural integrity.

Further Study

- Determine accurate AO fluences for erosion yield calculations.
- Contamination evaluation.
  - X-ray Photoelectron Spectroscopy.
  - Scanning electron microscopy with energy dispersive spectroscopy.
- Measure optical properties to determine changes in thermal control.
- Surface topography analysis with atomic force and scanning electron microscopy.
- Cross sectioned material analysis.
  - Crack depth measurement
  - Atomic force microscopy hardness as a function of distance from surface.
- Comparison of HST samples with both LDEF and ground-based samples.

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Hubble Presentations

Post-Flight Investigation Programme (PFIP) of HST-SA1: Investigations Logic and Results

L. Gerlach / ESTEC

General

- Planning for HST-SA1 PFIP started in 1991.
- STSA-1 PFIP to be seen in connection with EURECA-SA PFIP.
  - ST-SA1: flexible array, 43.3 months in orbit.
  - EURECA-SA: rigid panel design, 10.8 months in orbit.
- Smooth Transition from EURECA-SA to HST-SA1 PFIP
  - EURECA-SA PFIP: July 1993 - Decmber 1994.
  - HST-SA1 PFIP: December 1994 - May 1995.
    - Final Report: July 1995.
- General investigation approach is identical for both programs.
- Experience from EURECA PFIP helped to further optimize the HST-SA1 Investigation Program.

Investigation Program Objectives

- Evaluation of system performance
  - In-flight performance against specification (mechanical, electrical)
  - Comparison of data (pre-flight, on-orbit, post-flight)
- Evaluation of changes in materials properties
  - Insulation strengths, embrittlement, µ-cracks, alpha, epsilon, etc.
- Explanation of on-orbit failures
  - Short / open circuits, boom buckling, tension sensor, etc
- Evaluation of design related degradation mechanisms
  - Power, loss factors, low cycle fatigue of connectors, etc.
- Refinement of models for space environment
  - Radiation, ATOX, µ-meteorite, etc.
- Design recommendations for future solar arrays

Investigation of Mechanisms (SDM, PDM and SAD)

- Deployment/Retractions
    - Comparison of performances
    - Electrical continuity during deployment
    - Synchronization, blanket tensions
- Inspection of Bi-Stem Booms
    - Surface condition, marks, deformations, particles
- Gear Wear, Wear of Ceramic Gear Carrier
- Assessment of Lubricants, Fluid Reservoirs, Fluid Creep
- Static Adhesion
- Fretting on all Clamps/End Stops
- Electrical Contacts, Brush/Commutators
- Motor Currents, Speed Torque Characteristic

Results from Wing Level Investigations: Visual Inspection

- Thermal / ATOX Protective Coatings
    - Generally all coatings and surface finishes showed discolorations, where exposed to Sun (except aluminized Kapton material).
    - Top layer of one MLI segment on PDM arm experienced splitting starting from nitting and venting holes.
    - Teflon® tape used for PDM harness cracked in some areas (sun direction only).

Results from Wing Level Investigations: First Results from Activities on Mechanisms

- Secondary Deployment Mechanism
    - Deployment/retraction went very smooth.
    - 3 stops were implemented for synchronization measurements.
    - Total deployment time 6 minutes 34 seconds (both microswitches operated).
    - Handling error during retraction triggered microwitch (float).
    - Bi-stem boom diameter increased by 2%.
    - Bi-stem boom showed evidence of radial movement between elements.
- Primary Deployment Mechanism (PDM)

    - Primary deployment/retraction function and PDM locking device test successful.
    - EGSE glitch during PDM deployment operation (EGSE drive electronics for the motor).

Results from Blanket Investigations: Visual Inspection

- No delamination of the GFRP stiffeners.
- The piano hinges are in good shape.
    - No rupture of hinge loops was observed.
    - 3 hinge pins moved towards blanket in board end.
    - In one case the hinge rod penetrated the sliding protection substrate (no protection on BDA/IBA pins).
- No degradation/delamination of insulation strip/tape.
- All bridge pieces are in good shape.
    - No sign of degradation.
    - No sign of overstressing or distortion.
    - No evidence of ATOX attack.
- No sign of substrate degradation/delamination (bubbling).
- All solder joints are in good condition (no sign of degradation).
- All repair techniques were successful (no sign of degradation).

Results from Blanket Investigations: Visual Inspection (Atomic Oxygen Protective Coatings)

- All coatings have been successful in protecting from ATOX.
- RTV-S 691 (silicone adhesive, front side).
    - Bus Bars (silver) overcoat has darkened in color from fairly bright red to a brownish tinge.
    - Meander bars (silver) overcoat has darkened in color from fairly bright red to a brownish tinge.
    - Blanket and edge stiffeners (GFRP) changed as the silver overcoat, but darkening is more pronounced.
- DC 93500 (silicone adhesive, front and rear side).
    - There is no obvious degradation of substrate integrity.
    - There is no obvious change in appearance where the substrate is shielded from direct sunlight.
    - Areas directly exposed to sunlight (UV) caused in some areas severe

darkening of DC 93500 (i.e. IBA).

Particle Impacts on HST-SA1: Preliminary Results

- Survey of both blankets and mechanisms.
    - Scanned area is approximately 65 squared.
    - More than 40000 impacts of particles > 10 µm expected.
    - More than 1000 impacts of particles > 80 µm expected.
    - SPAs were inspected by Mare Crisium (MC) and DASA, using different inspection methods.
    - Data evaluation in progress.
- MC results
    - 672 impact features greater than or equal to 1.2 mm recorded on SPA front sides.
    - Solar-cell grid finger spacing is 1.2 mm.
    - 270 impact features recorded on rear-side.
- DASA results
    - 3862 impact features recorded on SPA front sides.
    - Blanket rear side recording difficult due to different surface morphology (only > 500 µm particles recorded).
    - 738 solar cells (silicon) damaged.
    - 149 solar cells with "dents" in silicon due to rear side hits (no cracks).
    - 1316 cracked cover slides (crater with no further damage not considered as a crack).

First Results and Conclusions

- The blankets and solar cell network is in good condition.
- The blankets are in a good bonding state.
    - No delaminations of the carrier substrate were visible (test planned in vacuum).
- Exposed RTV coatings how different degrees of discoloration.
- No significant change of thermo-optical properties.
    - i.e. SCA, rear sides.
- SCA interconnectors are in good shape.
- No surprise concerning the number of broken cells.

- The electrical degradation of solar cells was somewhat less than expected.
    - For future power predictions loss factors should be revised.
- The post-flight system performance of the mechanisms was smooth and as expected.
- Materials and coatings for the protection against ATOX and UV are suitable for long duration missions in LEO.
    - FEP requires special integration precautions when used (procedure TBD).
- Unexpected Findings (until now).
    - Radial movement of bi-stem elements.
    - Cracking of flexible data harness on OBA/DBA interface.
- Thousands of particle impacts were recorded on the arrays with almost 200 penetrating the blankets.
- Despite the numerous clearly visible impacts there is no indication that any meteoroid or debris impact has caused any of the observed failures or other unusual power degradation.
- The results from the PFIPs is a great help in refining the environmental models and the understanding of damaging effects of impacting particles.
- PFIP is on Schedule.
- SA-PFIPs for EURECA and HST have already proven to be very valuable for ESA and its future solar-array projects.

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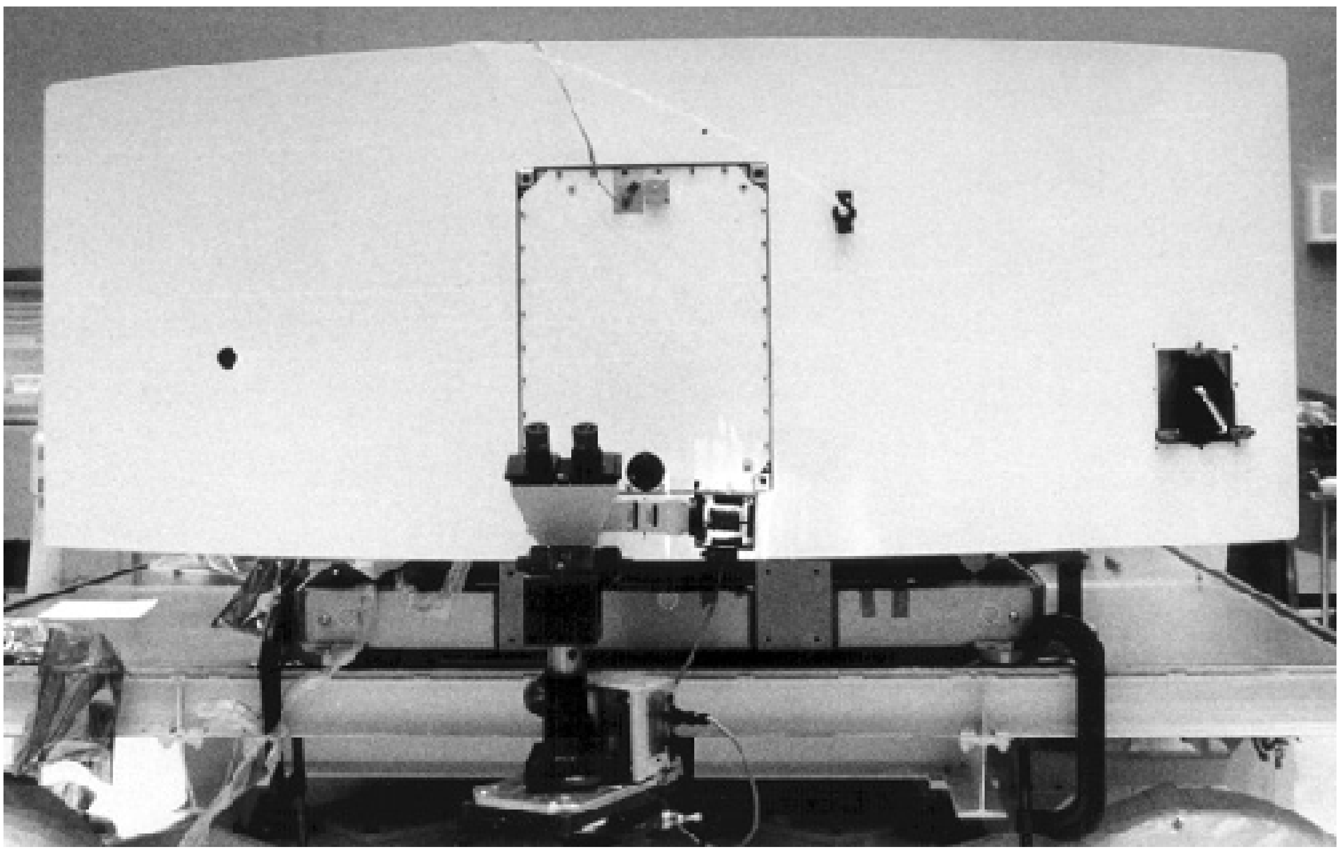
Hubble Presentations

Meteoroid and Debris Impacts on the WF/PC I Radiator

Donald H. Humes / NASA Langley Research Center
William H. Kinard / NASA Langley Research Center

We spent two days in the clean room at Goddard examining the WF/PC-I radiator with a microscope to measure the damage done by meteoroids and man-made orbital debris during its 3.6 years in orbit.

It was a difficult job - moving the microscopes around on a heavy stand, positioning it close to the WF/PC I radiator while never touching it, and looking through the microscopes while in awkward positions on the steps of a ladder.



WF/PC-I radiator in clean room at NASA GSFC, with microscope in front.

I (Don Humes) looked at every impact site examined, but Mark Kulick, a Lockheed meteoroid and debris researcher, made all the measurements. Only a few photographs were taken because of the difficulty in taking them in the short time we had.

We were aided immensely by the survey done at Goddard using theodolites to obtain the location of possible impact sites. Goddard provided the coordinates of 100 possible impact sites, assigned a number to each, and rated them by size on an arbitrary scale of 1 to 10 (10 being the largest).

Outline

- Crater Flux
- Spallation of Paint
- Rings in Paint (LDEF)
- Crater Shape
- Summarizing Remarks

I will talk about (1) the crater flux based on the number of craters of various sizes found in the aluminum radiator plate, (2) the spallation of the ZOT paint in an area around the craters, (3) rings seen in paint on the LDEF but not seen in the ZOT paint and (4) the shape of the craters in the aluminum.

Comparison of the damage seen on the WF/PC I radiator to damage seen on the LDEF will be made throughout the talk.

Crater Flux

The theodolite survey data was given to me by Henry Sampler and also had the name of Jerry Gay on it. They did a great job - finding impact sites with craters as small as 270 microns, that is .011 inches.

We examined 72 of the 100 possible impact sites and found 53 to be true impacts and 18 to be deposits of gooey particles or to be scrapes in the paint. At one site we found nothing. We examined all the size 4 to size 10 impact sites, and half of the size 1 to size 3 sites.

Radiator Surface

The WF/PC-I radiator was an aluminum plate, 0.160 inch thick, that was painted with ZOT paint. ZOT paint is a ceramic thermal control paint that gives a <0.18 and $e>0.85$ in the 0.28 to 2.50 micron range. The pigment is zinc orthotitanate and the binder is potassium silicate. The specs call for the ZOT to be 3 - 6 mils thick. A pre-flight inspection report lists the thickness as 6.8 mils. We measured a thickness of 4.3 mils at one place.

Large Impact Craters

The large craters in the aluminum were slightly to moderately irregular in shape and had pits (or sub-craters) of different depths inside the primary cavity.

The lips were not well formed like those in unpainted aluminum - having broken off or never developed.

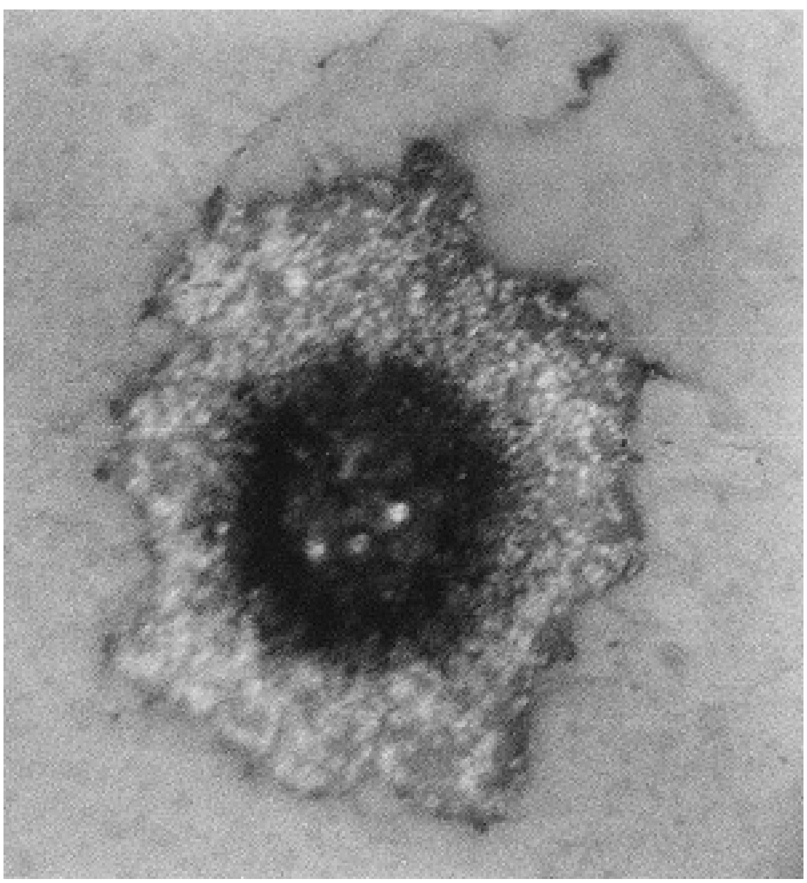
There was a dark area around the crater where the raised lips would have been.

Condensed molten droplets, apparently of aluminum, were common near the top of the craters and at all depths.

The ZOT paint spalled off the aluminum plate in a large area around the craters.

The spall area was irregular in shape too.

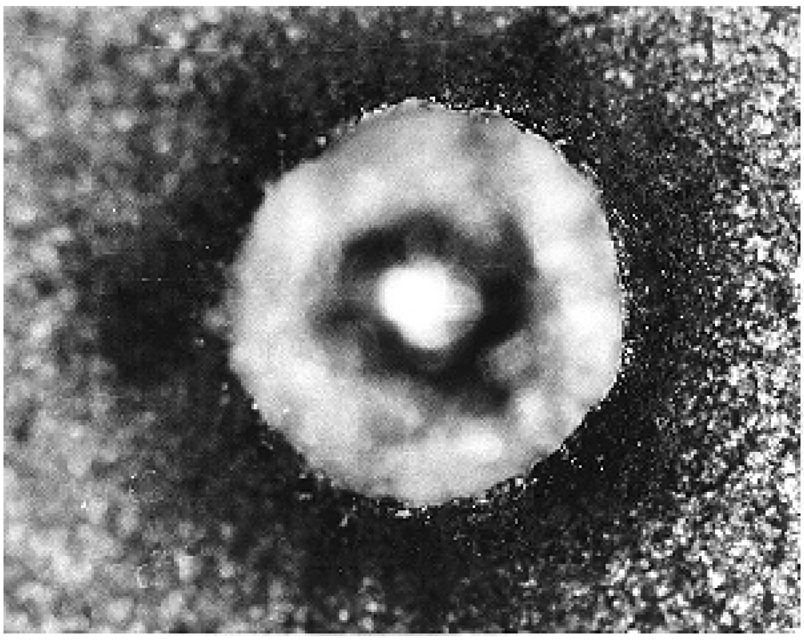
The 14 impact sites that had craters with a diameter greater than 450 microns (measured at the aluminum plate surface) were of the type classified here as large craters. They had a single crater that, while not usually round, was not extended in any direction.



Crater on WF/PC-I radiator. Dimensions: lip, 500 x 540 microns; at plate surface, 370 x 460 microns; depth, 185 microns. Paint spall area around crater, 1320 microns. Cracks in paint can also be seen.

The very largest craters had nearly round rims, but with irregular bottoms.

The largest crater found in the WF/PC I radiator was 900 microns in diameter. It is nearly round and resembles craters found in unpainted aluminum on the LDEF, except that the lips are poorly developed.



Largest crater on WF/PC-I radiator. Dimensions: lip, 980 micron diameter; at plate surface, 900 micron diameter; depth, 360 microns. Paint spall area around crater, 5400 micron diameter (not shown)

Small Impact Damage Sites

Craters smaller than about 450 microns (there is no clear cutoff size) were highly irregular in shape with a number of cavities that were sometimes connected and sometimes not.

It appeared as if the ZOT paint acted like a meteoroid bumper, shattering the impacting particle before it hit the aluminum plate, and allowing the fragments to disperse somewhat. The surprising thing is that the fragments could disperse so much in such a short distance - the thickness of the paint.

Perhaps this shows that many meteoroids are a loose aggregate, a porous and fragile assemblage of grains, as Brownlee has suggested in a recent study of the densities of captured stratospheric meteoroids.

And I do suspect that most of the impacts on the WF/PC I radiator were caused by meteoroids and not by man-made debris, as I will discuss later.

Crater fields like this were seen on the LDEF plates also, but only very rarely (less than 1 percent of the impacts). Those crater fields were usually linear and showed evidence of the impact direction and seemed to be caused by highly oblique impact angles (greater than 80 degrees from the normal). Those impacts also suggested that many meteoroids are loose aggregates. The ZOT paint seemed to enhance the breakup and dispersion. The painted aluminum plates on the LDEF did not exhibit the type of cratering seen on the WF/PC-I radiator.

But there are other possibilities.

Secondary particles created when meteoroids and debris were fragmented while penetrating the solar panels could have struck the radiator. That would explain the dispersion of the fragments. But I think it is unlikely that the ejecta would have created small clusters of craters so widely separated from each other.

There was a highly irregular spall area around the crater field.

Measurements

The measurements we made were (1) the diameter of the crater at the aluminum plate surface, (2) the diameter at the top of the raised lips, when they existed in any form, (3) the depth from the plate surface to the deepest point and (4) the diameter of the spall area around the crater.

Because the large craters and their spall areas were irregular in shape, the diameters measured are crude measurements but did not require much judgement in assigning a representative diameter.

On the other hand, the measurement of the crater diameter at the small impact sites did require a judgement.

The depth was straightforward, and the spall diameter was straight-forward, but the crater diameter was not.

We chose to imagine a circle surrounding most of the crater field and call that the crater diameter. This may overestimate the size of the crater that would have produced in an unpainted plate - but that is what we measured.

In some cases the crater field was extended in one direction and the width and length of the crater field was measured.

There is a correlation between the Goddard size estimate and our measured crater diameter, although it is not perfect. A few entries are out of place.

We can expect that all the large craters were found and measured and that, in fact, essentially all the craters in the aluminum were found, although some were not examined.

Impacts that only damaged the paint and did not produce spallation would not have been found during the Goddard theodolite survey and hence were not examined by us.

Many size 1,2, and 3 possible impact sites were not examined. We can estimate from the statistics of those that were examined how many probably are impact sites and what size they probably are. Having done that we can estimate the flux of various size craters in the radiator.

Here then is the cumulative crater flux as a function of crater diameter, i.e. the number of craters larger than some limiting size per unit area per unit time.

The previous discussion about the Goddard size estimate and the correlation to our measured crater diameters was included to show that we have not made the best flux measurements that we could have made. We guessed at what size craters we would have found at some sites because we did not have time to look at them.

The production of small craters in the aluminum, those with a diameter less than the paint thickness, was probably inhibited by the presence of the paint.

But we expect that the diameters of the largest craters were not affected much by the paint and that the flux measurements for the three largest threshold crater sizes are close to what the crater flux in an unpainted aluminum plate would have been. We have evidence to support that from a painted aluminum plate from the LDEF.

LDEF EPDS Thermal Cover - Row 12

Crater Flux

The painted plate was on Row 12 of the LDEF. The cumulative flux of various threshold crater sizes on the that plate had 90 percent confidence limits.

The crater flux in the painted aluminum on Row 12 matched the crater flux in the bare aluminum on Row 12 for craters with a diameter greater than the paint thickness, and did not for a crater diameter less than the paint thickness.

In other papers, it is argued that most of these craters were caused by meteoroids, greater than 80 percent. That argument is based on the distribution of craters around the LDEF, on the chemical analyses of residue found in LDEF craters, and on measurements on the particulate environments in the 1960s when man-made debris presumably was not abundant.

And since the craters in the WF/PC I radiator are in the same size range and in the same flux range, we assume they also were caused mostly by meteoroids.

The paint on the LDEF was not the same as that on the WF/PC-I and I'll talk more about that later.

Crater Flux on Radiator

The fluxes were measured in unpainted aluminum on various sides of the LDEF. The HST was at the same altitude and inclination as the LDEF so the meteoroid fluxes should be directly comparable for the three largest crater flux measurements.

The problem is - we don't know what the orientation of the WF/PC I radiator was. If we knew its orientation history we could see if the WF/PC I radiator experienced the same flux as the LDEF.

If it turns out that the WF/PC I radiator was effectively randomly oriented or slightly more protected than a randomly oriented surface (protected by its orientation or by the solar panels) - then the crater fluxes on the radiator would be in agreement with the LDEF data, and then we could conclude that the LDEF and that secondary particles generated when the solar panels were penetrated were not significant. But that all hinges on knowing the orientation history of the HST.

Spallation of Paint

I would like to compare the spallation areas in the paint seen around the craters on the WF/PC I radiator with paint spallation areas seen on a plate from the LDEF.

The EPDS thermal cover on Row 12 of the LDEF was an aluminum plate painted with Chemglaze A276. The specs called for a thickness of 4.5 mils. We measured 2 - 4 mils at various locations.

Spallation of the paint on this LDEF plate usually occurred in one of three ways with a spall diameter two to nine times the crater diameter.

About sixty percent had a near circular spall area with no radial cracks outside the spall zone.

About nineteen percent had an inner spall diameter and incomplete spallation for a larger spall diameter - but with no cracks seen where spallation was incomplete.

About eight percent had a small spall diameter with both radial and circumferential cracks where an outer spallation zone was nearly formed.

Of the remainder of the spallation sites, less than four percent had irregularly shaped craters (none like those seen on the WF/PC-I radiator) and irregular spall areas. About six percent had paint in the crater. About two percent were dings - chipped off paint with no crater.

A typical irregular crater and spall area accounted for less than four percent of the impacts of the LDEF EPDS thermal cover. These craters were single, oblong cavities and did not resemble the multiple-cavity craters seen on the WF/PC-I radiator.

A spall on the WF/PC-I radiator look a lot like one of the LDEF spalls previously shown - a small spall area and radial and circumferential cracking outside the spall area. The WF/PC-I radiator spall area is not as round as that usually seen in the A276 paint on the LDEF.

On the LDEF plate, the diameter of the spall area, in proportion to the crater diameter, varied with crater size. The ratio of spall diameter to crater diameter decreasing with increasing crater size.

For the ZOT paint on the WF/PC I radiator the diameter of the spall area was also two to ten times the crater diameter.

But the spall area for large craters was much larger for the ZOT paint than for the A276 on the LDEF.

Also, the proportionate size of the spall area increased with increasing crater size for the ZOT paint - just the opposite of the trend for A276.

Ring of Chemglaze 9924 Primer Around the Crater

On the LDEF, there was a ring of the red Chemglaze 9924 primer around the crater where the raised lips would have been on an unpainted aluminum plate. While the two coats of white A276 did spall off the primer coat did not. Every where else in the spall area the primer coat spalled off the plate. The large craters on the WF/PC-I radiator also had dark rings around them where the raised lips would have been, but we could not tell if this was the primer paint.

A feature seen in the A276 paint on the LDEF but not seen in the ZOT paint on the WF/PC I radiator was a series of perfectly circular concentric rings around the crater, far outside the spall zone - perhaps 15 to 30 times the diameter of the crater.

The rings do not show up under normal room lighting. They only show up when lit from the side at an extreme angle and the room lighting is not too bright.

We looked for rings in the ZOT paint and did not find any, but we could not produce the lighting that would show them up best while we were in the clean room. We only had a flashlight to use for the extreme angle lighting.

However, we do not expect that such rings exist in the ZOT paint. The theory on the rings in the A276 is that atomic oxygen attacked the organic binder in the paint and it was removed, leaving the powedered white pigment on the surface. Shock waves created during an impact then reflected off the two surfaces of the aluminum plate and interferred, sometimes contructively, sometomes destructively, and caused the pigment to be thrown off at particular distances from the crater. The surface certainly has a white powder on it. You can see where it was wiped off near the edges of the plate during handling.

The ZOT paint may not be affected by atomic oxygen this way.

Crater Shape

Craters in unpainted aluminum are nearly hemispherical with lips that rise above the plate surface. Large craters are very nearly hemispherical, while small craters are slightly deeper than hemispheres.

Small craters in unpainted aluminum have a wide range of shapes that have a mean P/D of about 0.6, but as the craters get bigger they have little variation from hemispheres - at least at this location, which was Row 10 on the LDEF, near the RAM direction.

Some sides of the LDEF, like the space end, did not show this strong funnel shaped data field.

The craters in the painted aluminum on the LDEF were shallower than those in unpainted aluminum, as you would expect because of the thickness of the paint penetrated.

The small craters in the aluminum on the WF/PC-I radiator were very shallow compared to the diameter. That is related to the way the "diameter" was defined for the collection of cavities that were typical of the small impact sites on the radiator. This further illustrates that the small craters on the WF/PC-I radiator were very different from those on the painted aluminum plate from the LDEF.

Summarizing Remarks

- The WF/PC-I radiator appears to have a normal (expected) number of impact craters.
- The ZOT paint affected the impacting particles greatly, even more than A276 on the LDEF.
- The ZOT paint caused dispersion of particles that were fragmented by the paint so that multiple cavities were created in the aluminum plate instead of a single cavity as seen under A276 paint.
- Large areas of the ZOT paint spalled off the radiator around the craters, similar in size to the spall areas seen on a painted aluminum plate from the LDEF, but with a different variation with crater size.
- The impacts were probably nearly all from meteoroids with few man-made debris impacts.
- Secondaries from the solar panels probably did not produce much damage to the radiator.
- Many of the meteoroids that struck the radiator were apparently loose aggregates - porous and fragile.
- Further examination on the WF/PC I radiator impact sites is suggested.

HST WF/PC-I

Suggested Future Work on Radiator

Complete examination of possible impact sites identified by GSFC.

Look for impact craters in ZOT paint.

Obtain good photographs of impact damage.

Measure thickness of ZOT paint at many locations.

Obtain orientation history of HST prior to First Servicing Mission.

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Hubble Presentations

WF/PC-I Science Filters

John Trauger / Jet Propulsion Laboratory

WF/PC-I Science Filters

- Proposal for handling and initial characterizations of returned WF/PC-I optical filters was distributed in July 1994 (J. Trauger memo, 7/9/94), and amended to include testing of one additional filter (J. MacKentry memo).
- All proposed initial characterizations have been completed at JPL. The filters remain in dry N2 purge in JPL bonded stores.
- Filter passband and blocking curves are now available in digital files available over the Internet. These have been made available to the STScI and the WF/PC-I and WF/PC-II science teams.
- Further work will be carried out as required in response to specific requests.

WF/PC-I Filters - Initial Characterization

- The WF/PC-I optical filters came to JPL installed in the SOFA mechanism, and under nitrogen purge.
- SOFA wheels were removed from the SOFA housing at Schaeffer Magnetics, in a manner minimizing exposure of the mechanism and filters to air and humidity.
- Filters were removed from the SOFA wheels by an experienced JPL technician familiar with the handling of optical filters and the SOFA mechanism.
- Prior to removing the filters from the SOFA wheels, the JPL technician inspected the filters visually, and noted the orientation of the filter in the wheel.
- Filters were visually inspected following removal and immediately placed in a nitrogen-purged storage container which protects the filters from physical change.
- A selected subset of filters was initially characterized at JPL for the spectral profile of the passband at five positions (filter center and center of the four sides) and in the blocking band (logarithmic scale accurate to 10^-6), in the same manner as the WF/PC-II filters.

- This filter subset includes narrowband filters F673N, F658N, F656N, F664N, F631N, F502N, F588N, F469N, F517N and F1042N.
- Also the photometric filters F336W, F439W, F555W, F675W and F791W.
- The filters are now in nitrogen-purged storage, and preserved for further testing by the WF/PC-I and/or WF/PC-II science teams.

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Hubble Presentations

Preliminary Wide Field Planetary Camera I Contamination and CCD Window "Measles" Investigation

Mark S. Anderson / Jet Propulsion Laboratory

WF/PC-I SOFA Inspection

WF/PC-I: Molecular Contamination Analysis

- Chemical Analysis Methods.
- Pre-Launch Molecular Contamination Summary.
- Post-Flight Solvent Wipe Analysis Results.
- Optical Microscopy of CCD's #5 and #6.
- Future/Ongoing Work.

WF/PC-I SOFA Inspection

- Pre-disassembly electrical testing of SOFA performed by Schaeffer Magnetics Inc. showed no change in electrical parameters and no change in motor torques from original values.
- During disassembly of SOFA the following was noted:
  - Some filters showed evidence of delamination (see filter report by John Trauger).
  - Air gaps between rotors and staters all in specification.
  - No visible evidence of contamination seen on any mechanical parts or filters.
  - All bearings free running (note: bearing disassembly/inspection not performed as yet - will occur after January 1995).
  - No evidence of wear seen on any mechanical parts.
- To date Schaeffer Magnetics personnel have seen nothing that would preclude a recommendation to refly as is.

Chemical Analysis Methods

- Optical and Electron Microscopy
- Fourier Tansform Infrared (FTIR) Spectroscopy
  - Chemical Functional Groups, Quantitative Analysis.

    - Diffuse Reflectance (DRIFT) for trace analysis of solvent wipe samples.
    - FTIR Microscope for identification of non-metallic particles.
- Gas Chromatography/Mass Spectroscopy (GC/MS)
    - GC separation and MS chemical analysis.
    - Individual chemical components identified.
- X-Ray Photoelectron Spectroscopy (XPS)
    - Chemical Functional Group and Elemental Analysis.
    - Thin Film Analysis (sub-monolayer sensitivity).
- Size Exclusion Chromatography (HPLC/SEC)
    - Polymer Analysis: Modecular Weight Distribution.
- Atomic Force Microscopy (AFM)
    - Very high resolution 3-D surface imaging.
    - Thin organic films can be interactively imaged and manipulated to determine film thickness.

WF/PC-I Prelaunch Molecular Contamination

- Major Components:

    1. Esters (Aliphatic/Aromatic). This is a broad class of materials. The most common source is plasticizers (phthalate esters).
    2. Silicone (polydimethysilozane). Many possible sources. A major component of RTV silicone rubbers. Vacuum pump oils.
    3. Hydrocarbon Oils. Common contamination that has many sources (lubricants, outgassing components of polyolefin materials). Typically have a broad distribution of molecular weights.
- Minor Components:

    1. Amines are typically from Epoxy and Polyurethane curing agents.
    2. Organic Acid Salts. Typically from RTV accelerators and possibly from ethanol residue.
- Contamination Levels:
    - Molecular Contamination was generally less than ~1 microgram per square centimeter (1 µg/cm squared=~1 mg/ft squared=~10 nanometer film). Vent Tube 0.15 µg/cm squared or 1.5 nm film.

Post-Flight Molecular Contamination Analysis

- Analytical Method:
    - FTIR infrared spectroscopy, Diffuse Reflectance (DRIFT). Solvent

(Freon/IPA) rinse using porous Teflon® wipes.

- Quantitative/Semi-quantitative.
  - Sensitivity (nanograms, monolayer films) depends on sample area.
- Areas Tested
  - Vent Tube 0.82 µg/cm squared (0.15 before launch) ~20% Ester, trace amine, ~80% silicone.
  - Blanket (Light Pipe) 0.041 µg/cm squared (0.65 before launch) ~10% Ester, 80% silicone
  - Side Panel 0.077 µg/cm squared ~15% Ester, ~85% Silicone.
- Conclusions:
  - Post-flight surfaces are generally cleaner.
  - The ester (and amine) based components tend to be the most volatile.

CCD Lens Surface Contamination Optical Microscopy

- CCD (#5, #6) Window Surface Particles
  - Flatfield Images.
  - Haze on CCD #5.

WF/PC-I CCD #5 & #6 Contamination: Preliminary Results

- Optical Microscopy: CCD (#5,#6) Window surfaces.
  - Particles imaged on both CCD's.
  - Au particles, translucent particles and fibers.
  - Structured haze seen on #5.
- CCD Gold Cover and Thermal Shields (Near CCD window).
- XPS: The adjacent Au surface next to the CCD window has C-O and C=O functional groups present. CCD #5 has more residue and additional trace C-N functionality. No Si found (less than 0.1 monolayer).
- FTIR: The infrared spectra of rinses from the CCD thermal shield and baffles show silicone, ester and amines. The level is ~0.35 ug/cm squared for both #5 and #6.
- AFM: Shows the film thickness to be ~5.0 nanometers on the #6 CCD Au surface.
- Conclusion:
  - The material on the Au surfaces near the CCD windows is mainly ester and a lesser amount (on #5) of N-C material (i.e. possible amine). This is consistent with the previous wipes analysis showing that the ester components are

volatile.

Future/Ongoing Work

- Precisely correlate flatfield images to particles on the CCD windows.
- Complete FTIR, XPS and AFM on CCD surfaces.
- Analyze the residue on the CCD window by GC/MS and Size Exclusion Chromatography for component identification.

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Hubble Presentations

Induced Radioactivities of Returned Hubble Space Telescope Parts as Indicators of Radiation Exposure to the Spacecraft

Alan R. Smith / Lawrence Berkeley Laboratory
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Richard J. McDonald / Lawrence Berkeley Laboratory

Abstract

We present a summary of results obtained at the Lawrence Berkeley Laboratory's Low Background Facility on the (mainly) proton-induced radioactivities in several parts from the Hubble Space Telescope (HST) modules that were returned to Earth in the recent repair mission. These induced-activity measurements permit us to estimate the integrated radiation exposure to the telescope during its 3 1/2 years in orbit. The estimates are based on comparisons of results from our very small data set with the much more extensive analysis done for the LDEF satellite mission. The analysis of additional samples in combination with relevant mission parameters will greatly improve confidence in these preliminary estimates of the HST radiation exposure.

Much information of value to future spaceflights was gained from radiometric analysis of materials obtained from the Long Duration Exposure Facility (LDEF) satellite after its return to Earth's surface in early 1990. In that mission a limited number of special material samples were on board for the express purpose of post-flight radiometric analysis, which results would permit independent estimates for the integrated exposure of the satellite to energetic nuclear particles from the solar wind and galactic cosmic rays. Of equal, or perhaps greater value than results obtained from these "intentional samples", were results obtained from radiometric analysis of spacecraft parts, including items made of aluminum alloy, titanium alloy, stainless steel, and lead. (Note that a number of small but very sensitive integrating passive nuclear radiation dosimeters were also onboard the LDEF.)

The radiometric analysis of LDEF materials has been accomplished over the past several years through a multi-laboratory collaboration (Ref. 1,2,3) headed by Dr. Thomas Parnell of the Marshall Space Flight Center (MSFC), Huntsville, Alabama. Since the radioactivities to be measured were typically at very weak intensities, much of this work could only be done with heavily shielded detector systems in which the "no-sample" or background (BKG) response is two to three orders of magnitude lower than the "unshielded in the laboratory" response -- the so-called "low-background" systems. The detector system of choice for such measurements (used by all the participants in this program) is the high-resolution high-purity Ge-crystal gamma-ray spectometer. Our Low Background Facilities (LBF) at the Lawrence Berkeley Laboratory (LBL) have played a major role in this program (see contributions or A.R. Smith and D.L. Hurley in Ref. 1,2,3), mainly as a consequence of the exceptional low-level counting capability existing at the underground Oroville Facility: a gamma-ray spectrometer system called "MERLIN II", which has both the highest sensitivity and the lowest BKG among the systems used by the participants in this program. And additional background reduction factor of 10 to 100 has been achieved with the MERLIN detector.

Hardware returned from the Hubble Space Telescope (HST) Repair Mission constitutes another potential treasure trove of materials to be analyzed for mission-induced radioactivities. Given the opportunity to analyse samples of aluminum and/or stainless steel, these HST activities can be compared to those measured in LDEF samples, and because of the comprehensive analysis done for the LDEF mission, may then be translated into approximate radiation exposures to the HST parts. The missions were of comparable duration: the returned HST items were in orbit for 3 1/2 years, whereas the LDEF voyage lasted 5 1/2 years, most of which time was spent at a similar altitude.

In Autumn 1993 we established contact with Dr. Lee Feinberg of the HST Office at Goddard Space Flight Center (GSFC) to explore the availability of suitable samples for this purpose. Following successful completion of the repair mission, we have so far received and analyzed three items from the returned modules:

1. Four stainless steel screws from the exterior surface of the Wide Field Planetary Camera (WF/PC) module, weight 11.2 grams.
2. An INVAR mirror mount from the WF/PC, weight 75 grams.
3. A handle from the DF224 Module, at an interior location on the HST, weight 245 grams.

The screws and the mirror mount are alloys in which the major element is Fe; the handle is an alloy in which the major element is aluminum. Fe and Al are the major target elements for reactions that produce the two most important radionuclides discussed here (Mn-54 and Na-22), both of which are produced predominantly by energetic proton interactions. Results of the radiometric analyses are summarized here, and are interpreted in terms of radiation exposure by comparison to the LDEF experience.

The Merlin II Detector System

The Lawrence Berkeley Laboratory's Low-Background Facility operates low-level counting installations as two sites: at the LBL Berkeley site and in the underground power plant of the Oroville Dam (a multi-purpose facility of the California Department of Water Resources). At Oroville the 600-ft overhead thickness of bedrock reduces the surface Cosmic Ray intensity by 1000-fold, and is significantly lower than can be achieved at surface sites. The MERLIN II detector is operated at our underground Oroville site, to take advantage of this additional factor in BKG reduction.

The detector is a very large n-type high purity Ge-crystal, of dimensions 80 mm diameter by 85 mm length; its rated "efficiency" is 115%, which actually means it is 115% as effecient as the "standard" NaI(TI) scintillation crystal of dimensions 3" diameter by 3" length, under specific source-detector conditions. The cryogenic vacuum system is constructed of carefully selected low-radioactivity materials. The local shielding that surrounds the detector cavity is built of low-activity lead and copper. The detector cavity is a space 7" x 7" cross section by 18" height,that is shared by the centrally positioned 4" diameter detector cryostat and the various size samples.

The radiometric data are collected in the format of energy spectra which cover the gamma-ray energy range of 10 to 3600 kev, and contain 4000, 9000 or 16000 channels (bins). Our "peakprint" analytic technique utilizes sharp peaks in spectral data that represent total absorption of discrete-energy gamma-rays. The energies of "signature" peaks are used to identify the radionuclides, while their intensities provide data from which radionuclide quantities can be calculated.

Data and Experimental Results

The four screws from the WF/PC module were located on the exterior surface of the module. Each screw head was in space, while the shank and threaded portions were somewhat shielded by the screw head and the material in which it was seated. The screws are stainless steel, 8-32 x 5/8" with special socket heads. Total weight of the 4 screws is 11.2 grams -- a sample of very small mass for this sort of work.

The screws contained measurable amounts of the radionuclides Sc-46, Mn-54, Co-56, Co-57, Co-58, Co-60, determined in a one-week count time with the MERLIN system at Oroville. A plot of (almost) the entire spectrum is shown on Figure 1. The peaks of interest, as well as the BKG peaks, appear as narrow vertical lines rising from a slowly descending smooth continuum.

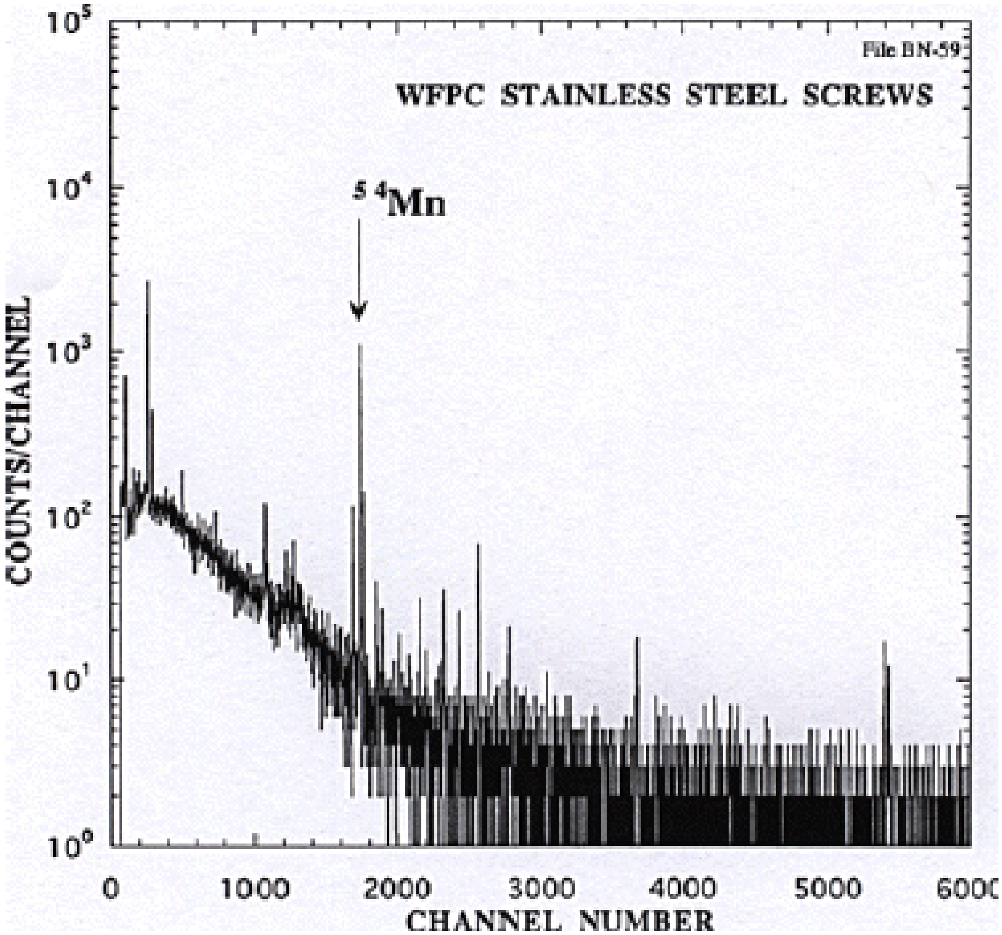

Figure 2 shows a narrow interval from this spectrum, on which four peaks of interest and one BKG peak are indicated. Detailed characteristics of the data can be seen here, including the shapes of peaks and the nature of the continuum. Table I lists the rates in diagnostic peaks for the above nuclides as observed at counting time. (No decay corrections have been applied to these values.) Uncertainties are expressed as single standard deviations on the actual data.

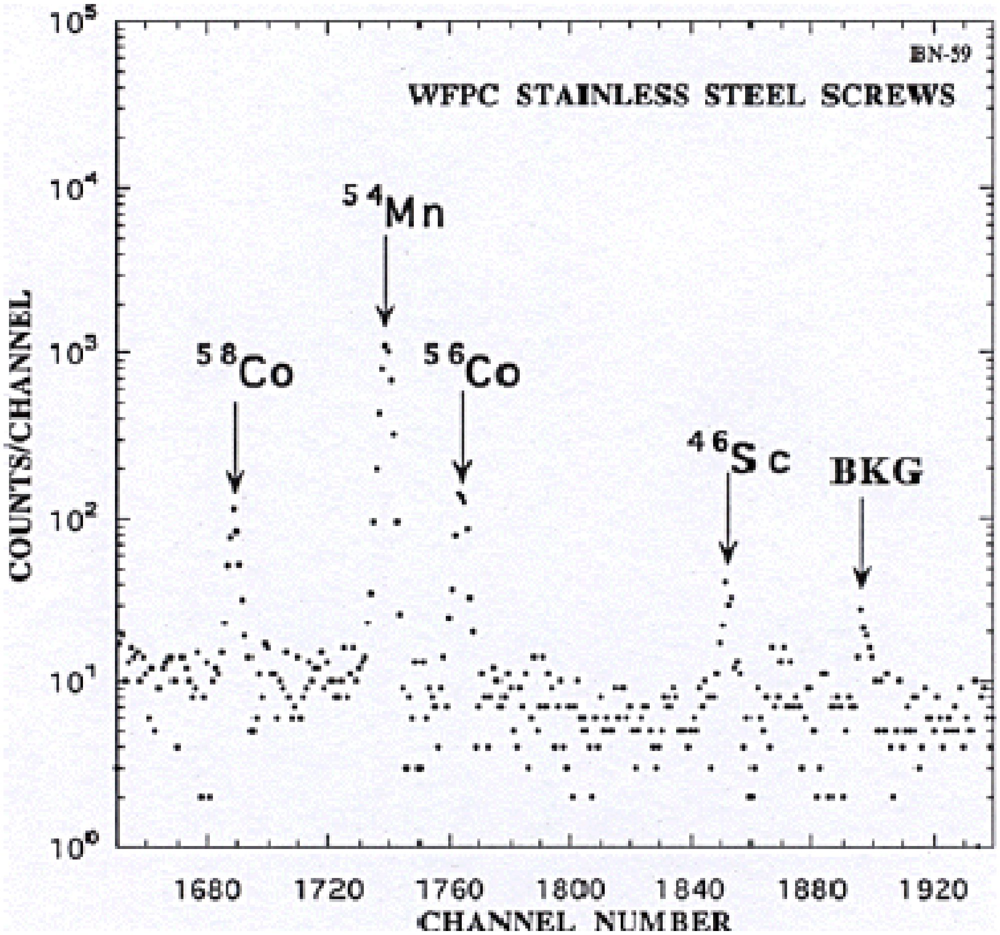

Table I

Nuclide: Sc-46, Diagnostic Peaks (KeV): 889+1120, WFPC Screws Observed Peak c/min: 0.029 +-0.002, Mirror Mount Observed Peak c/min: 0.029+-.004

Nuclide: Mn-54, Diagnostic Peaks (KeV): 834, WFPC Screws Observed Peak c/min: 0.515 +-0.008, Mirror Mount Observed Peak c/min: 1.24+-.02

Nuclide: Co-56, Diagnostic Peaks (KeV): 847, WFPC Screws Observed Peak c/min: 0.067 +-0.003, Mirror Mount Observed Peak c/min: 0.088+-.005

Nuclide: Co-57, Diagnostic Peaks (KeV): 122, WFPC Screws Observed Peak c/min: 0.962 +-0.001, Mirror Mount Observed Peak c/min: 2.51+-.03

Nuclide: Co-58, Diagnostic Peaks (KeV): 811, WFPC Screws Observed Peak c/min: 0.039 +-0.002, Mirror Mount Observed Peak c/min: 0.148+-.007

Nuclide: Co-60, Diagnostic Peaks (KeV): 1173+1332, WFPC Screws Observed Peak c/min: 0.010 +-0.002, Mirror Mount Observed Peak c/min: 0.041+-.004

All these induced-activity nuclides can be produced by reactions of energetic particles (mostly protons) on the major constituents of stainless steel -- iron and nickel. The dominant component of the activating flux is expected to be solar protons of energies in the range of a few 10's to many 100's of MeV. Activation by the more energetic galactic cosmic ray component, although contributing to the observed radionuclide inventory, is of minor importance for these surficial samples. Galactic cosmic ray activation plays a more dominant role in objects that are well-shielded from space-facing surfaces.

We also note the (unexpected) presence of Y-88. Although the evidence consists of very low-intensity peaks, both major peaks from decay of this radionclide are observed, and with appropriate relative intensities. This nuclide cannot be produced by reactions on the major constituents of stainless steel. Its presence could be explained if the screw contain Y, Zr, Nb, or Mo. Otherwise, it must be presumed to be associated with some exotic contaminant. Additonal information from the HST personnel or contractors may provide a solution to this puzzle.

Useful comparisons can be made between the level of activities measured in the WF/PC screws and those observed in samples from one of the LDEF stainless steel trunnions. (Samples had been taken at various depths in the solid 3.25-in diameter trunnion to provide a depth profile of induced activities.) The most useful is the comparison between activities of 312-day halflife Mn-54, an isotope that is produced mainly by reactions of protons on Fe in steel. The Mn-54 level in the WFPC screws is about three-fold greater than was observed in comparably located LDEF samples (see Table III). The smaller LDEF activities may be due partly to the decaying orbit, in the sense that the activating flux decreased as the satellite moved to lower altitudes during its final year aloft.

The WF/PC mirror mount is roughly an "oblong" shape, about 2 1/2" in maximum length and 2" maximum width, weight 75 grams. It is made from the dimensionally-stable alloy INVAR, which has a composition 64% Fe and 36% Ni. Observed induced activity nuclides are Sc-46, Mn-54, Co-56, Co-57, Co-58, and Co-60, as were seen in the WF/PC screws. The specific activity of Mn-54 is about 1/2 that seen in the screws. There is no evidence of Y-88 in this sample.

One aluminum alloy sample, the DF224 Module handle from an interior location in the HST, has also been analyzed at Oroville. The handle is of welded construction, made from both tubular and plate stock, and is 16" in length. Because of its "unusual" size a special calibration was required to permit conversion of observed peak intensities into absolute activity rates. The only induced-activity radionuclide observed is 2.62 year halflife Na-22, which can be prduced in aluminum by protons with energies greater than about 30 MeV. Most of the other gamma-ray peaks seen in this spectrum (Figure 3) belong to the Th-232 series of natural terrestrial radionuclides. Shown on Table II are the only major peaks that accompany Na-22 decay, and two of the peaks (of many) that are commonly used to measure

Th-series concentrations. Although the 511 kev peak is the more intense of the pair, it cannot always be used as diagnostic for Na-22, as it arises from positron annihilation -- a phenomenon common to the decay of many other radionuclides.

Table II

Nuclide: Na-22, Diagnostic Peaks (KeV) 511, DF224 Handle Observed Peak c/min: 2.58+-0.02

Nuclide: Na-22, Diagnostic Peaks (KeV) 1274, DF224 Handle Observed Peak c/min: 0.724+-0.011

Nuclide: Th-232, Diagnostic Peaks (KeV) 583, DF224 Handle Observed Peak c/min: 0.490+-0.010

Nuclide: Th-232, Diagnostic Peaks (KeV) 911, DF224 Handle Observed Peak c/min: 0.414+-0.008

The Th-232 mass concentration in the handle is about 4 ppm, a value that falls toward the high end of the expected range for the Th-content of aluminum alloys.

Again, comparisons can be made with the Na-22 activities in LDEF aluminum alloy samples. The HST sample is from an interior (shielded) location in contrast to the LDEF samples which were all from the satellite's exterior surface. This difference in shielding makes interpretation of the Na-22 activities not as direct as was the case for Mn-54 activities in the stainless steel samples. Comparisons of both Mn-54 and Na-22 activities are shown on Table III, where all activities have been corrected to the times of return to Earth.

Table III

Mn-54 in Stainless, WFPC Screws: 380 pCi/Kg, 1500 Rads, LDEF Trunnion: 83-171 pCi/kg, 500 Rads

Na-22 in Aluminum, DF224 Handle: 250 pCi/Kg, 1000 Rads, LDEF Keel Plate: 86-140 pCi/kg, 500 Rads

Specific activities for the LDEF samples are double-valued, to indicate the magnitude of differences we observed in activation of north-facing and south-facing surface samples on this attitude-stablized satellite. The Hubble Space Telescope, on the other hand, points toward whichever astronomical object is currently being viewed. We use an average of each pair of LDEF activity values to correlate with the radiation dose integrals measured during the satellite's voyage (Ref. 4). The radiation dose to the HST can then be estimated. From these approximations we can make the following comparisons:

1. The dose integral to the exterior of the HST was about 3 times larger than that delivered to the LDEF exterior, as determined from the induced activity of Mn-54 in stainless steel.
2. The dose integral to the "interior" HST site was about 2 times larger than that delivered to the LDEF exterior, as determined from the induced activity of Na-22 in aluminum.

These two statements appear to be consistent, but need more evidence from the HST and the environment in which it travelled, in order to provide stronger confirmation (or refutation). High on a list of such items are: more complete details about the samples already analyzed; additional HST samples from locations with known duration that includes relevant experimental data, and comparison of the results of the HST modelling with similar studies done for the LDEF flight. The HST appears to have received a larger dose integral in a shorter time than did the LDEF. The 11-year solar cycle needs to be taken into account, as well as the sudden appearance of the anomalous long-lived low-altitude "Van Allen" radiation belt during the HST mission.

SUMMARY

We have presented results from measurements of induced-activity radionuclides in several parts from Hubble Space Telescope modules that were returned to Earth in the recent successful repair mission. Since the intensities of these radioactivities are quite weak, sophisticated gamma-spectrometry systems operated in very low background environments are required to achieve successful radioassay. The underground Oroville installation of the LBL Low Background Facility is particularly well suited for this type of analysis. It was used for these HST samples, as it had been used previously for many samples from the LDEF mission.

The HST sample results, when compared to the extensive analysis performed on the LDEF mission, are interpreted to provide a preliminary estimation of integrated radiation exposure to the telescope during its first 3 1/2 years in orbit. Our estimate indicates the HST received a larger integrated dose in a shorter time than did the LDEF satellite. An extension of the work reported here can produce a much more accurate estimate for the HST radiation exposure; in addition, this more accurate estimate will add significantly to the validation of using induced-activity measurements for radiation dosimetry purposes. This capability is especially important when no "actual" radiation dosimeters are on board a spacecraft.

Acknowledgements

We are very appreciative of the opportunity to participate in analysis of returned HST parts, and thank the HST team at Goddard MSFC headed by Dr. Frank Ceppolina for making it possible. Special thanks are due Dr. Lee Feinberg, who first of all took our initial request seriously, who then provided us with samples, and without whose support we could not have attended this conference. We are truly indebted to Dr. Al Schultz (CSC/STScI, Baltimore), who got us in touch with the right people at the outset.

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1. Various authors: Space Environments, Ionizing Radiation, in First LDEF Post-Retrieval Symposium, NASA CP-3134, conference proceedings, pp 199- 396, 1991.
2. Various authors: Space Environments, Ionizing Radiation, in Second LDEF Post-Retrieval Symposium, NASA CP-3139, conference proceedings, pp 67-274, 1992.
3. Various authors: Space Environments, Ionizing Radiation, in Third LDEF Post-Retrieval Symposium, NASA CP-, conference proceedings, in press, 1993.
4. A. L. Frank, E. V. Benton, T. W. Armstrong, and B. L. Colborn, Second LDEF Post-Retrieval Symposium, NASA CP-3139, conference proceedings, pp 163-170, 1992.

Figure Captions

- Figure 1. Gamma-ray spectrum from WFPC stainless steel screws.
- Figure 2. Section of gamma-ray spectrum from WFPC stainless steel screws, showing details of several diagnostic peaks.
- Figure 3. Gamma-ray spectrum from aluminum handle of DF224 module.

This work was supported by the U.S. Department of Energy under contract No. DE-AC03-76SF00098 and by the Hubble Space Telescope Project, Code 442, Goddard Space Flight Center, Greenbelt, MD.

Return to Hubble Space Telescope Hardware Archive System

Hubble Presentations

Wide Field Planetary Camera I (WF/PC-I) Radiator Investigation

Wanda C. Peters / Swales & Associates, Inc.

WF/PC-I Radiator History

- WF/PC-I Radiator
    - Painted at Jet Propulsion Laboratory (JPL)
    - Pre-flight thermal measurements made by JPL
    - Post-flight thermal measurements made by GSFC
- Thermal Control Paint
    - Name: YB-71 White Paint
    - Pigment: Zinc Orthotitanate (ZOT)
    - Pigment Supplier: IIT Research Institute (IITRI)
    - Binder: Potassium silicate (PS-7)
    - Binder Supplier: Sylvania Electric Products Company
- Painting Completion Date
    - End of August 1985

JET PROPULSION LABORATORY (JPL) PRE-FLIGHT DATA

JPL Radiator Pre-Flight Thermal Measurements

- Solar Absorptance [alpha(s)]
    - Gier-Dunkle Instruments Inc. Solar Reflectometer Model MS-251 was used to measure pre-flight reflectance.

    - JPL records indicate that the [alpha(s)] values were influenced by the curvature of the surface and separation of 0.5 inch between the ZOT surface and the instrument used for measurement.

- Inspection (witness) sample painted along with the radiator. The sample measured an [alpha(s)] value of 0.19 prior to vacuum bake. The inspection sample measured an [alpha(s)] value of 0.17 after vacuum bake.

- The flight radiator was vacuum baked prior to solar absorptance measurements.

Normal Infrared Emittance [epsilon(n)]

- Gier-Dunkle Instruments Inc. Infrared Reflectometer Model DB-100 was used to measure pre-flight normal emittance.

- Pre-flight inspection sample measured within specifications of greater than or equal to 0.85.

JPL Radiator Pre-Flight Inspection Report Observations

- Chassis Electronics Subassembly (Bay5)
  - ZOT paint was chipped at right center edge of panel approximately 0.5 inch and at the left edge of the panel.
  - Some difficulty was incurred during repair of ZOT surface.
- Paint Thickness
  - Measured 0.0068 inch.
  - Inspection sample measured within safe limits per specification requirements (0.003 to 0.006 inch).

GODDARD SPACE FLIGHT CENTER POST-FLIGHT DATA

GSFC Radiator Post-Flight Thermal Measurements

- Solar Absorptance [alpha(s)]

- AZ Technology Laboratory Portable SpectroReflectometer (LPSR) 200 was used to measure post-flight reflectance.

- The instrument touched the surface of the ZOT paint during reflectance measurements.

- The radiator was measured at GSFC on February 22, 1994.

- The radiator was measured again at JPL on August 10, 1994.

* Normal Infrared Emittance [epsilon(n)]

  - Gier-Dunkle Instruments Inc. Infrared Reflectometer Model DB-100 was used to measure post-flight normal emittance.

  - Normal emittance measurements were only performed by GSFC on February 22, 1994.

Status of Discoloration Investigation

- Stains were still present after the ZOT paint was sanded and cleaned with ethyl alcohol. It appears that stains penetrate through the paint material.
- JPL suspects that the source of discoloration is the epoxy Eccobond 57C used in the installation of the saddle when it was riveted to the radiator.
- Chemical analysis of the stains by NASA-GSFC Materials Branch have not been completed due to instrument failure.

Concluding Remarks

- Due to the unsuccessful search by JPL to locate the inspection samples of the ZOT paint applied to WF/PC-I, a direct comparison between pre-flight and post-flight thermal values cannot be made.
- Pre- and post-flight measurements cannot be directly compared due to the differences in the method and the instrumentation used to measure the [alpha(s)] values.
- Assuming JPL pre-flight [alpha(s)] value from the inspection sample is representative of the pre-flight radiator's [alpha(s)] values, it appears that there is an

increse in [alpha(s)].

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Hubble Presentations

Albedo Level Photopolymerization

D. Hughes / Swales and Associates, Inc.

Background

- WF/PC-I Pickoff Mirror is contaminated.
- Throughput at Lyman-Alpha is negligible.
- STIS and other advanced instruments will view the Lyman-Alpha wavelength.
- Contaminant may be polymerized.
- Polymerization during the Servicing Mission is not a concern, but polymerization during HST operations would be.

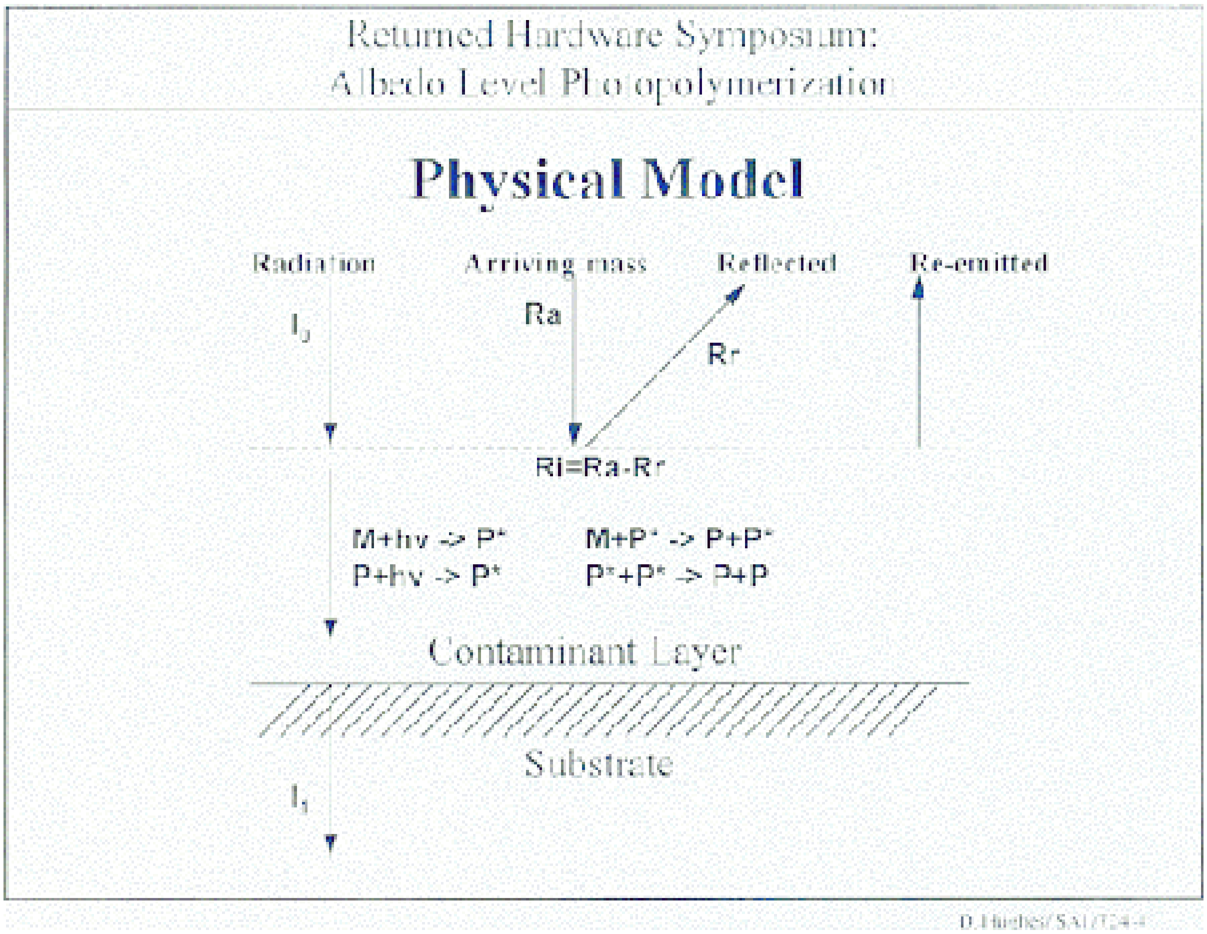
Poylmerization Premise

- Ultraviolet radiation causes polymerization of hydrocarbon contaminants.
- The rate of polymerization is dependent upon radiation level and mass flux.
- Two exposures of the WF/PC-I Pickoff Mirror occurred: albedo levels during operations and direct sun during the Servicing Mission.
- Testing may reveal which is the likely cause.

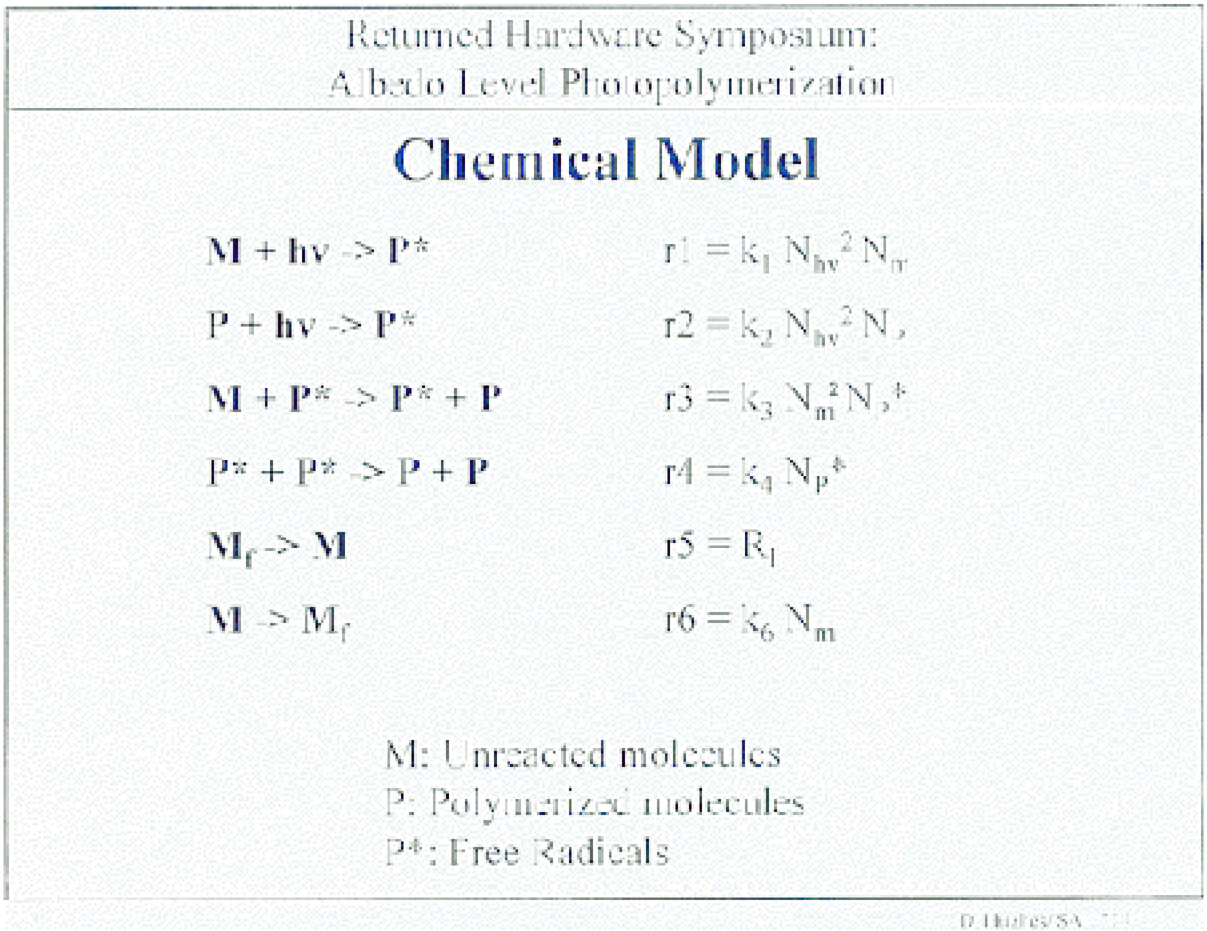
Previous Research

- A simple model was able to predict accumulation within a factor of 2.
  - Valid for 1 sun intensity.
  - Prediction made for spacecraft using tested materials.
- Model suggests linear extrapolation to other mass fluxes; data does not confirm this.

Physical Model



Chemical Model



Test Objectives

- Determine the reaction rate as a function of mass flux and light intensity.
- Use this knowledge to set test parameters when attempting to duplicate WF/PC-I POM contamination.

Test Requirements

- Low background contamination levels.
  - Cold chamber shroud.
  - Open test configuration (one bounce).
- Variable light source.
  - Pinhole filters to adjust to low light levels.
  - Deuterium and Krypton lamps.
- UV detector and calibration method.

    - Photomultiplier and NO detectors.
    - Movable MgF_2 window for calibration.
- QCMs for deposition and reemission measurements.
- Effusion cell with a shutter for rapid on-off capability.

Test Methods

1. Find the rate constants using a pure material (to simplify analysis).
2. Repeat for different UV intensities and mass fluxes:
    - Internal to the HST.
    - Servicing Mission on-orbit.
    - Intermediate.
3. Extrapolate to the required lamp intensity, given the mass flux available from a candidate source.
4. Use the candidate source to contaminate a window. Verify the parameters were correct with a QCM.
5. Analyze the window contamination.

Status

Mechanical and thermal systems are working.

Pure source (phthalate) and candidate on-orbit source have been identified.

Data Acquisition System is in place.

UV detector is performing poorly.

Results expected in early February 1995.

Hubble Space Telescope Archive Return to Hubble Space Telescope Hardware Archive System

Hubble Presentations

High Speed Photometer Evaulation and Plans

Evan Richards / University of Wisconsin

Overall Conclusion to Date

- HSP operates as it did pre-launch with no detectable degradation. Physical appearance is as it was with no change, except for the nominal, anticipated creep of the Bray oil rivet lubricant.

Tests and Inspections Performed

Visual inspection & photographic documentation

- The exterior surfaces appeared to be in good condition with no damage or degradation. (One of the latch fittings was later nicked during installation/removal from the HFMS). The Bray oil migration (creep) was no more extensive than previously observed before launch. Interior condition of the HSP was excellent.

Close inspection and photos of all filters

- No changes from pre launch condition.

Contamination inspection and tests

- Ref: HST FSM Contamination Report P442-0667 and Colony memo to Greenberg dated 1/31/94.

- Swab sample taken 1/25/94 from HSP top found traces of oxides and barely detectable hydrocarbons.

- Tape lifts from HSP top & side were similar to pre-launch findings.

Electrical Interface Tests

- A complete verification of the electrical interface (EICIT and IVT) was performed, including redundant units. All results were nominal.

Functional Tests (including thruput)

- A complete set of functional tests were run using the HSP EGSE. All functions were nominal and in agreement with pre-launch results. The redundant electronics were also tested for the first time since pre- launch functional tests were completed (The redundant electronics were never exercised during the mission.) A thruput test was performed using a simple "flat" field source, and no changes were observed.

Flaw Detection Tests

- Ref: Lugmayer Associates Report #LAJ-1850-94.

- Tests conducted 4/4/94 to 4/14/94.

- Both eddy current and ultrasonic tests performed to determine if any stress corrosion cracks had appeared in the HSP structure (near the latch fittings) since similar tests were performed before launch. HSP structure is made from 2024 aluminum (a "table 3" material). Tests showed no cracks, and verified features (e.g. repair plug) found in previous testing.

Quarter panel test

- The HSP envelope dimensions and position of the focal plane were measured and verified. No changes noted from pre-flight data.

Ship to UW-Madison

- Before shipment, HSP RIUs and Latches removed, one filter aperture assembly removed for transmission tests.

- Shipped from GSFC to UW Space Astronomy Lab for further testing. Chamberlin Hall freight elevator failure marooned the HSP on the sixth floor before it was removed from the shipping container. Activities on hold.

Plan

- Remove HSP from shipping container (must install hoist on 6th floor).

- Move to SAL cleanroom.
- Remove tape samples from front bulkhead for GSFC contamination analysis.
- Complete postflight testing and calibration.
  - Verify polarizer orientation.
  - Perform thermal sensor calibration.
- Perform subsystem tests.
  - Test electronic boxes: functional, temperature.
  - Detector testing: VIS tube investigation.
  - Selective internal visual inspection.

Return to Hubble Hardware Archive System

Hubble Presentations

Rate Gyro Assemblies (RGAs)

Mike Urban / NASA Goddard Space Flight Center

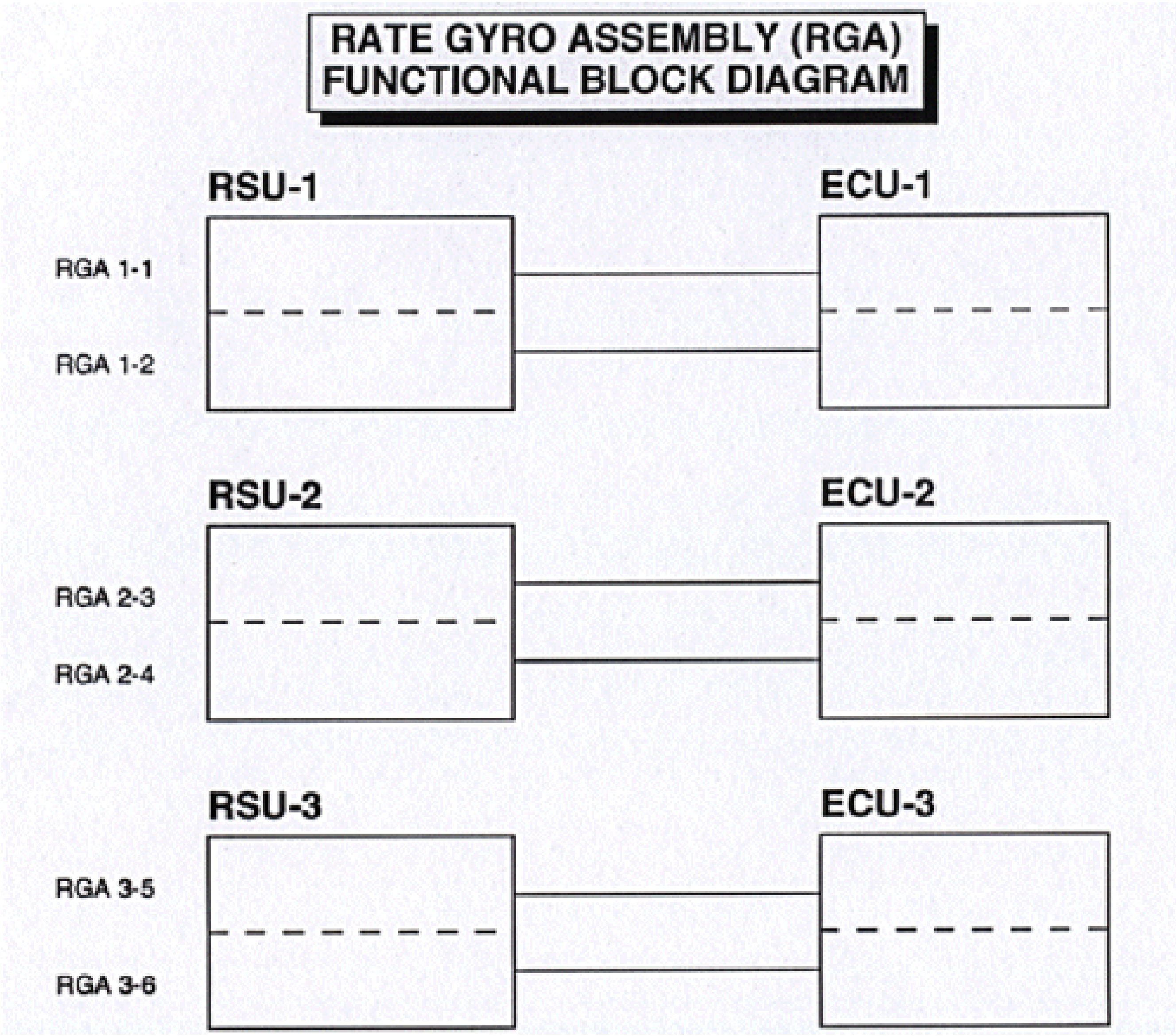
Summary

- No failure, degradation, or aging mechanisms attributable to the space environment.
- No significant change in design or materials in response to observed failures.
- Observed failures mitigated by process controls.
- Lube patch formation a random event (personal opinion).
- Flexlead corrosion an aging mechanism.

Description

- Six rate gyros
  - Rate gyro channels functionally separated into electronics control unit (ECU) and rate sensor unit (RSU).
  - Rate gyro channels packaged two per ECU and two per RSU. No cross strapping.
- Three channels required for normal vehicle control.
- Four channels typically used for fail operational capability.

Rate Gyro Assembly (RGA) Functional Block Diagram



Background

- Three channels failed prior to first servicing mission; fourth showed anomalous behavior.
- Post servicing mission evaluation of returned hardware isolated failure sites.

Failure Summary

- Rate gyro channel 1
  - Signature: Motor current to zero (failure).
    - Source: Shorted capacitor in ECU.
- Rate gyro channel 4
  - Signature: Gyro output to saturation (failure).

        - Source: Failed hybrid circuit card in RSU.
- Rate gyro channel 5
    - Signature: High mode scale factor transient (anomaly).
        - Source: Foreign particle in flotation fluid in RSU.
    - Signature: Motor current increase (anomaly).
        - Source: "Lube patch" on gas bearing in RSU.
- Rate gyro channel 6
    - Signature: Gyro output to saturation (failure).
        - Source: Failed hybrid circuit card in RSU.
    - Gyro motor spindown (failure).
        - Source: Open flexlead in RSU.

Lube Patch

- Lubricant is applied to reduce bearing stiction at wheel startup.
- Lubricant can accumulate on bearing surface resulting in increased stiction.
- Mechanism not well understood but appears to be related to run time.
- Gyro 5 lube patch accumulated to the point where bearing dynamic friction affected; requiring increased motor torque (e.g., motor current) to maintain wheel speed.
- Previously observed problem:
    - HEAO 1, 2, 3: 5 of 16 gyros fail to restart (4 of these recovered after repeated restart attempts).
    - IUE: 2 of 6 gyros have failure signatures consistent with lube patch accumulation.
    - Lube patch accumulation is major source of rejection during gyro screening.
- Processes already in place to mitigate lube patch problem.

    - Change lubricant from sodium stearate to tri-ethyl amine stearate (TEAS).
    - Controlled micro-pitting of bearing surface.
    - Increased motor startup voltage.
    - Screening: Measure variations in required startup voltage after wheel run-in.
- Current status
    - Lube patch problem is still with us.

    - Corrective actions seem to have mitigated its consequences if not its occurrence.
        - Gyro 5 continued to operate on-orbit.
        - Gyro 5 successfully restarted on the ground after return.
    - Further corrective action (all procedural).

        - Don't operate gyro for extended periods until you're ready to use it.
            - Lube patch accumulation appears to be function of operating time.

        - Once you've started using it, don't stop.
            - Can't guarantee motor will restart.

Flexlead Failure

- Output axis rotation facilitated by encapsulating the wheel assembly plus necessary electronics (e.g., float) and immersing it in a viscous "flotation" fluid.
- Motor current and output axis rebalance torque signals delivered to the float by thin conductive ribbons (e.g., flexleads).
    - Four flexleads carry motor current (two motor phases; two leads per phase).
    - Three flexleads carry output axis torque commands (plus and minus and a common return).
- Flexleads are immersed in the flotation fluid.

- Flotation fluid
    - Bromo tri-fluoro ethylene (BTFE); contains covalently bonded halogens (bromine, fluorine, chlorine).
        - Selected to satisfy viscosity and density requirements: float must be neutrally buoyant.
- Flexleads
    - 85% silver 15% copper aggregate.
        - Selected for conductivity/mechanical characteristics (flexibility, tensile strength).
    - Copper and (to a lesser extent) silver corrode in the presence of BTFE.
        - Extensive corrosion observed on flexleads of all returned gyros.

    - Corrosion/failure mechanism
        - Residual halides react with copper phase of the flexlead aggregate.
            - With copper (15% of material) gone, material is embrittled and tensile strength reduced 98%.
        - Corrosion continues at slower rate on silver phase.
        - Ultimate failure due to either fracture of embrittled silver lead or complete corrosion of silver.

    - Residual halides an inevitable byproduct of fluid manufacture.
    - Exacerbated by:
        - Moisture (forms acids).

        - Oxygen (replaces halogens in the polymer).
        - Light and heat (accelerate polymer decomposition).
        - Residual chlorides from solder flux and solvent.

      .
    - Indirect evidence that fluid lot used for all four returned gyros was a "bad" batch.

    - Corrective action
        - Specifications/screening for halide and moisture content of floation fluid.
        - Modify fill procedures to eliminate exposure to air (oxygen) during fill process.
        - Manage gyro operating time as a consumable.
        - Gyro operates at increased temperature.
        - Flexlead corrosion rate increases with temperature.

Hubble Space Telescope Archive Return to Hubble Space Telescope Hardware Archive System

Hubble Presentations

Solar Array Drive Electronics Failure Investigation

Cindy Winslow / Lockheed Missiles and Space Corporation

SADE Description

- Task of SADE is to interface with the SSM for exchange of operational commands and telemetry data.
- Operate and control the SADM for the orientation of the SA and monitor the position of the arrays and the temperature of the SADM.
- SADE shall operate in the following modes
  - All motors off.
  - One motor on each mechanism operating simultaneously in either direction of rotation (both main or both redundant).
  - One motor on one mechanism in an operating mode as above.
  - Simultaneous operation of both motors in either mechanism.

Overview of Transistor Overstress Problem

- Analysis shows that transistors 2N5153 and 5154 are allowed to dissipate up to 2.2W each before reaching its junction temperature limit of 115 degrees Celsius when SADE electronics are in the maximum temperature environment of 40 degrees Celsius.
  - Expected dissipations are 700mW which will be equivalent to approximately 68 degrees Celsius in vacuum.
- The transisitors T4 and T6 mounted on PCB NO.5 are allowed to dissipate 57 mW without additional means and up to 89mW with a black anodized T018 housing with 115 degrees Celsius upper junction temperature limit.
  - When the transistor case is molded in an AlO2 carrier, thus connected to the PCB, the junction temperature is 75 degrees Celsius (89 mW).

Results of SADE-1 Inspection

- Two transistors, T5 and T17 severely thermally stressed, conformal coating discolored and charred.
- Two diodes, D8 and D10, severely thermally stressed, conformal coating discolored and charred.

- Solder on connections became molten and reflowed between the two diodes.
- Failed transistors gave no indication of defective construction.
- All 27 boards inspected.
    - Seven boards with anomaly.
    - Two boards competely replaced.
- The heat sink will dissipate the heat and protect the transistors.
    - Same modification made to SADE-1R.
    - Returned SADE did not change modifications required.

PCB 916-220 110.0A, Resolver Decoder A

- The upper right corner of the heat sink layer is partially lifted.

PCB 916-220 510.0C, Multispeed Decoder

- Dark discoloration on the lower right part of the assembly.
- Dark discoloration on contacts of PCB connector.
- Dark discoloration on lower area of solder side.
- Coating is damaged.

PCB 916-220 350.00.0C Compensation Network Filter

- Solder splashes on lower right area of assembly side.
- Six discolored points along one PCB retainer near left border on solder side.

PCB 916 220.400.00.0/1C, Sine Converter Oscillator Divider

- Dark discoloration on components on lower right side.

Motherboard 916-220 400.00.0C, PCB Retainer Guides

- Brown deposit and solder splashes in area of the slot for the oscillator board.
- Dark deposit near PCB retainer board.

Additional Reading

- Inspection report for the SADE-1, IR-SA-DO/01/F1, March 1994.
- Non-compliance report, MRB-SAR-500, March 1994.
- Minutes from SADE MRB at Dorner, 23 March 1994.
- Failure investigation of Hubble Space Telescope solar array drive electronics, ESA report 2083, March 1994.
- Metallurgy report, MGl2102, Oct. 1994.
- Visual examination and analysis of rubber compound strip and PCB side edge guide, report #2084, Aug. 1994.

Return to Hubble Space Telescope Hardware Archive System

Hubble Presentations

Fuel Module Investigation

Denis McCloskey / Lockheed Missiles and Space Corporation

Fuse Module Description

- There are three different fuse module configurations (4 each) in the HST SSM.
- Four P-15 modules (3 and 5 Amp fuses) were replaced since one had opened and the RSU fuses were increased in size from three Amps to five Amps.
- Four P-16 modules (10 and 20 AMP fuses) were replaced since their configuration was questionable.
- Spare P-17 and OTA fuses were carried as contingency but were not replaced.

Returned Hardware Testing

- Visual inspection/photographs.
- Baseline Milli-Ohm test per NSI 36-02-1152.
- Baseline high voltage test per NSI 36-02-1152.
- Resistance versus current tests.
- Destructive tests.

Overview of P-16 Wiring Problem

- A flight spare P-16 module was found to be miswired during ground testing.
- Two of the four P-16 modules replaced during the servicing mission were miswired.
- All 20 AMP fuses in S/N's 1006 and 1007 were shunted by the twin low resistance leads such that negligible current could flow through the fuse.

Conclusions

- Ground test verified open fuse elements in the P-15 fuse module (S/N 1012).
- Ground test verified miswiring of two P-16 fuse modules (S/Ns 1006 and 1007).
- No additional discrepancies or degradation of the modules were observed.

Return to Hubble Space Telescope Hardware Archive System

Hubble Presentations

The LDEF Archive System - an Option for Archiving HST Returned Hardware and Data

Brenda K. Wilson / Boeing Aerospace Operations, Inc.

Introduction

The studies of HST returned hardware have resulted in significant data on the environments encountered in space and the effects of these environments on spacecraft.

Spacecraft developers and researchers need access to these data and returned hardware.

The Archive System initially established for LDEF can be used to provide the needed access to the HST returned hardware data.

The objectives of this presentation are to describe the LDEF Archive System and how data from other sources can be included in it.

LDEF Archive System

Designed to provide single point access to LDEF and other resources, which include data, photographs, reports, hardware and test specimens.

Includes electronic and physical archives, distributed among research locations.

Access to the archives is provided through Internet.

Key features:

- Widely accessible.
- User-friendly/easy browsing and retrieval methods.
- Minimization of costs - public domain software.
- Flexibility to add new data models and network connections.

LDEF Archive System Access

Electronic Archive:

User needs Internet address and World Wide Web (WWW) reader or client, such as NCSA Mosaic. WWW is an Internet information access initative. The NCSA is the National Center for Supercomputing Applications, and its Mosaic is public domain software.

System address, or uniform resource locator (URL) is:

http://setas-www.larc.nasa.gov/setas

Physical Archive:

An index of the physical archive is contained in the electronic archive.

To obtain materials from the physical archive:

- Electronic communication - w.h.kinard@larc.nasa.gov
- Postal service, phone, fax, personal visit -
  - William H. Kinard
  - NASA Langley Research Center
  - M/S 188B
  - Hampton, VA 23681-0001
  - phone (804) 864-3796
  - fax (804) 864-8094

Concluding Remarks

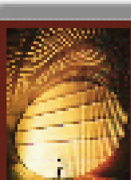
Significant space environments and effects data have resulted from the studies of the HST returned hardware.

Spacecraft developers and researchers need access to these and other space environments and effects data. To satisfy this need, all such data should be archived.

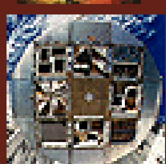
The LDEF Archive System is an option for archiving the HST returned hardware data.

Archiving of space environments and effects data should be considered early in the planning cycle for the second HST servicing mission.

- SETAS
  Overview - Home Page
- HST
  Hubble Space Telescope



Langley Home Page



Space Environments & Technology Archive System Home Page

Space Environments & Effects Home Page

NASA Home Page

Hubble Space Telescope

(HST) Archive System

NASA Langley Research Center
Hampton, Virginia

HST Contamination Meeting

Space Telescope Science Institute
Baltimore, Maryland
May, 1995

The HST Contamination Meeting covered contamination-related topics relevant to the operation of the HST scientific instruments. The first presentation is the only one discussed in this archive section, as it provides results from WF/PC-I contamination studies, and other returned hardware. It is a confirmation of the data reported at the HST Returned Hardware Evaluation Symposium held at GSFC in December, 1994.

WF/PC-I Pickoff Mirror Contamination
Failure Review Board Findings
Lee Feinberg/NASA GSFC Code 442

Background

- As part of the HST Returned Hardware Program, the 1216-1608 Angstrom reflectivity of the WF/PC-I pickoff mirror was found to be degraded. It was measured in an ambient (nitrogen) tent and in vacuum.

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SETAS Request Information

Responsible Parties:
Page Content: William H. Kinard
Page Construction: Thomas H. See
Last Updated undefined

- A Tiger Team and then a Failure Review Board were appointed to study the impact to HST.
- This section summarizes key Failure Review Board findings.

Transmission / Reflectivity Measurements

- Flight WF/PC-I Pickoff Mirror:
  - Showed large degradation below 1600 angstroms
  - Measured at 45 degrees and normal incidence
  - Measured first in nitrogen tent, then in vacuum
  - Spare pickoff mirror also measured
  - Compared to pre-flight data
- Flight Aperture Window:
  - Showed some degradation below 1600 angstroms
  - Measured in nitrogen tent
  - Compared to pre-flight data

Other FRB Findings

- Energy calculations indicate Earth albedo UV strong enough to photopolymerize the contaminants of the pickoff mirror (Based on IUE data)
- Contaminants did not come off in vacuum, and had a reflectivity curve consistent with UV polymerization
- Contaminants were removable under high temperature or with certain cleaning methods (evidence of partial polymerization)
- Contaminant chemistry generally consistent with results from spare FGS outgassing test
- No historical data that support charged particles as energy source

FRB Recommendations

- General:
  - Minimize exposure of UV optics to the bright Earth during servicing mission instrument changeout. For the 1997 mission, it is important that the open STIS instrument aperture not be unnecessarilly pointed at the bright Earth.
  - Characterize, as well as possible, the environment to which the science instruments are subjected during a servicing mission with witness mirror(s) and/or with onboard QCM measurements. The time resolution of the QCM measurement would provide considerably more information regarding potential contamination sources.
- If the Spare Fine Guidance Sensor is Flown:
  - Clean it to the same cleanliness level that the original Fine Guidance Sensors are at now after five years of outgassing.
  - Perform UV monitoring of STIS, WF/PC-II, and the remaining COSTAR channel as part of the Servicing Mission Orbital Verification (SMOV). The monitoring should occur frequently enough to assess build up of contaminants soon after the mission is complete.
  - If an FGS is removed, its pickoff mirror should be preserved both during the servicing mission and during ground processing. This includes minimizing exposure of this mirror to the bright Earth during the

servicing mission.

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Hubble Space Telescope

(HST) Archive System

NASA Langley Research Center
Hampton, Virginia

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Hubble Space Telescope

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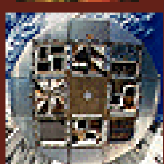

Space Environments &Technology Archive System Home Page

Space Environments &Effects Home Page

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References

1. NASA Goddard Space Flight Center, "Hubble Space Telescope First Servicing Mission Post Mission Deintegration Plan," 1993.
2. Returned Hardware Meeting Presentations, meeting hosted by HST Flight Systems and Servicing Project, NASA GSFC, January 1994.
3. Telecons, HST Returned Hardware Activities Team, hosted by GSFC, February-March 1994.
4. "Exploring the Universe with the Hubble Space Telescope," NASA NP-126.
5. White, R. L., Space Telescope Science Institute, "Hubble Space Telescope High Speed Photometer Instrument Handbook," Version 2.0, May 1990.
6. MacKenty, J. W., *et al.*, Space Telescope Science Institute, "Hubble Space Telescope Wide Field - Planetary Camera Instrument Handbook," Version 3.0, April 1992.
7. British Aerospace, "Description Handbook of the Solar Array Drive (Electronics Part)," Doc. No. TN-SA-DO27, June 1980.
8. Fairchild Space Company, "Flight Support System User's Guide."

9. HST Returned Hardware Evaluation Symposium, NASA GSFC, December 1994.
10. STS-61 EVA Post Flight Report, EVA Section, Mission Operations Directorate, February 1994.
11. NASA Press Releases, 1993-1994.

HST Home Page

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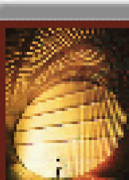

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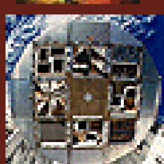

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Hubble Space Telescope

(HST) Archive System

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Technical Disciplines

Follow the links to access information pertaining to the various data sets or analyses performed on HST return hardware related to the Technical Discipline areas.

Meteoroid & Debris

- On-orbit observations of HST Physical Condition
- Meteoroid & debris impacts on the WF/PC I Radiator, Humes *et al.*

Contamination

- Wide Field Planetary Camera 1
- HST Contamination Meeting, May, 1995

Radiation

- Induced Radioactivities of Returned Hubble Space Telescope Parts as Indicators of Radiation Exposure to the Spacecraft, *A. Smith, et. al.*

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Materials

- Overview and Analysis of HST Returned FEP Insulation, Zuby and deGroh.

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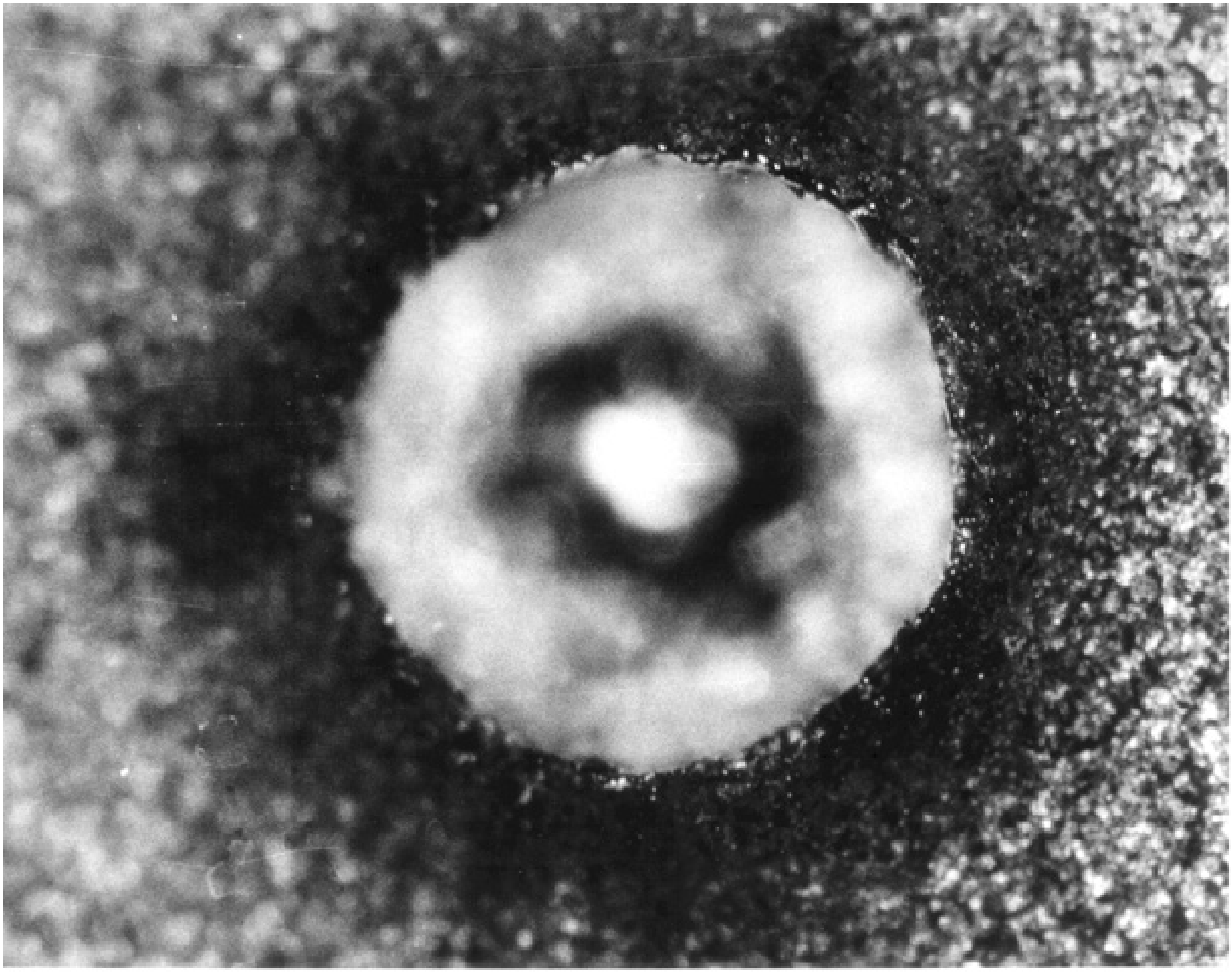

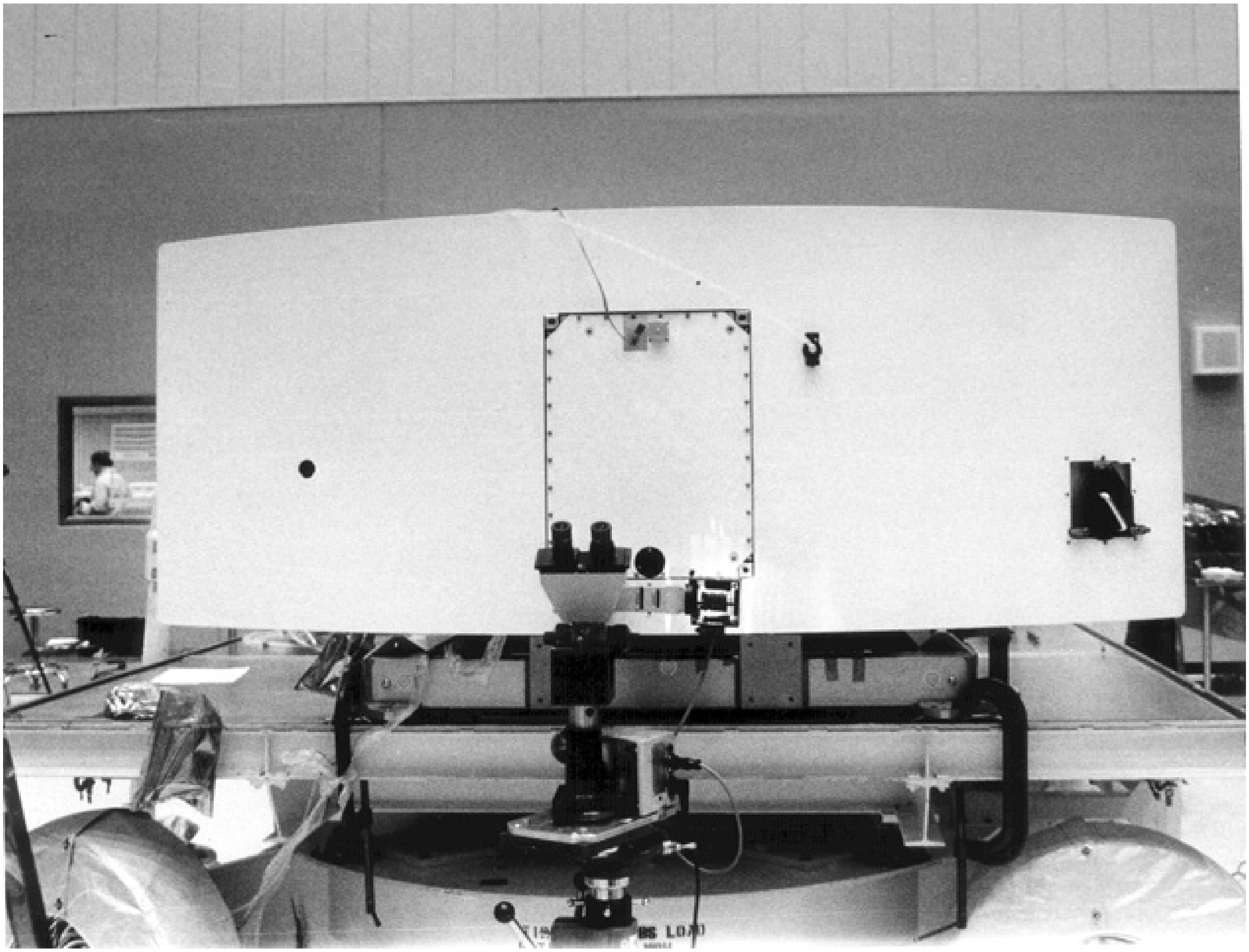

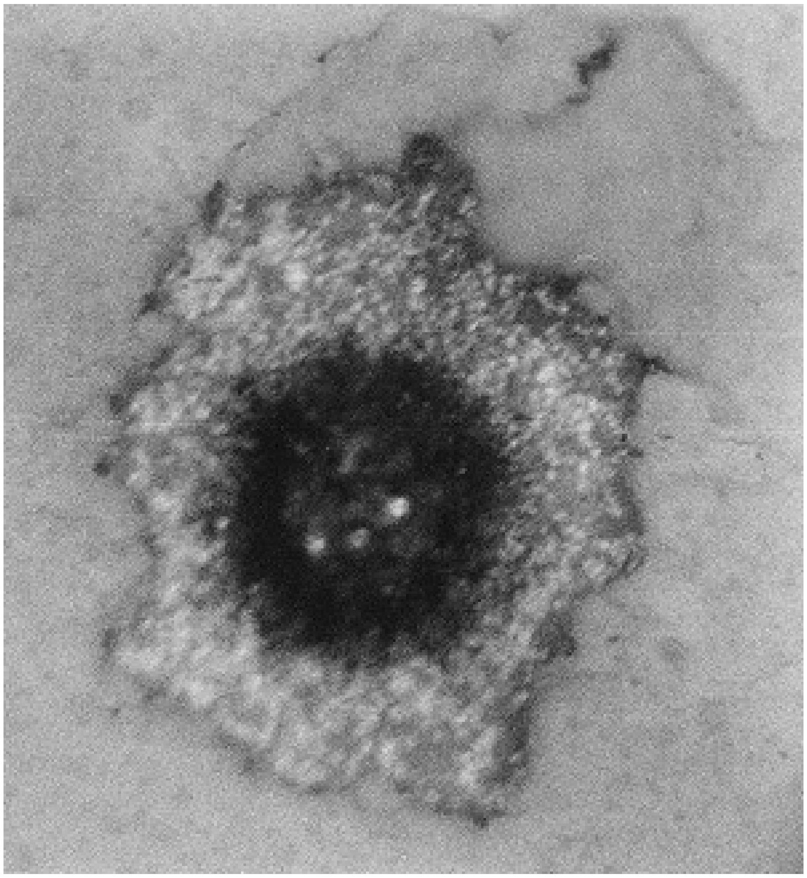

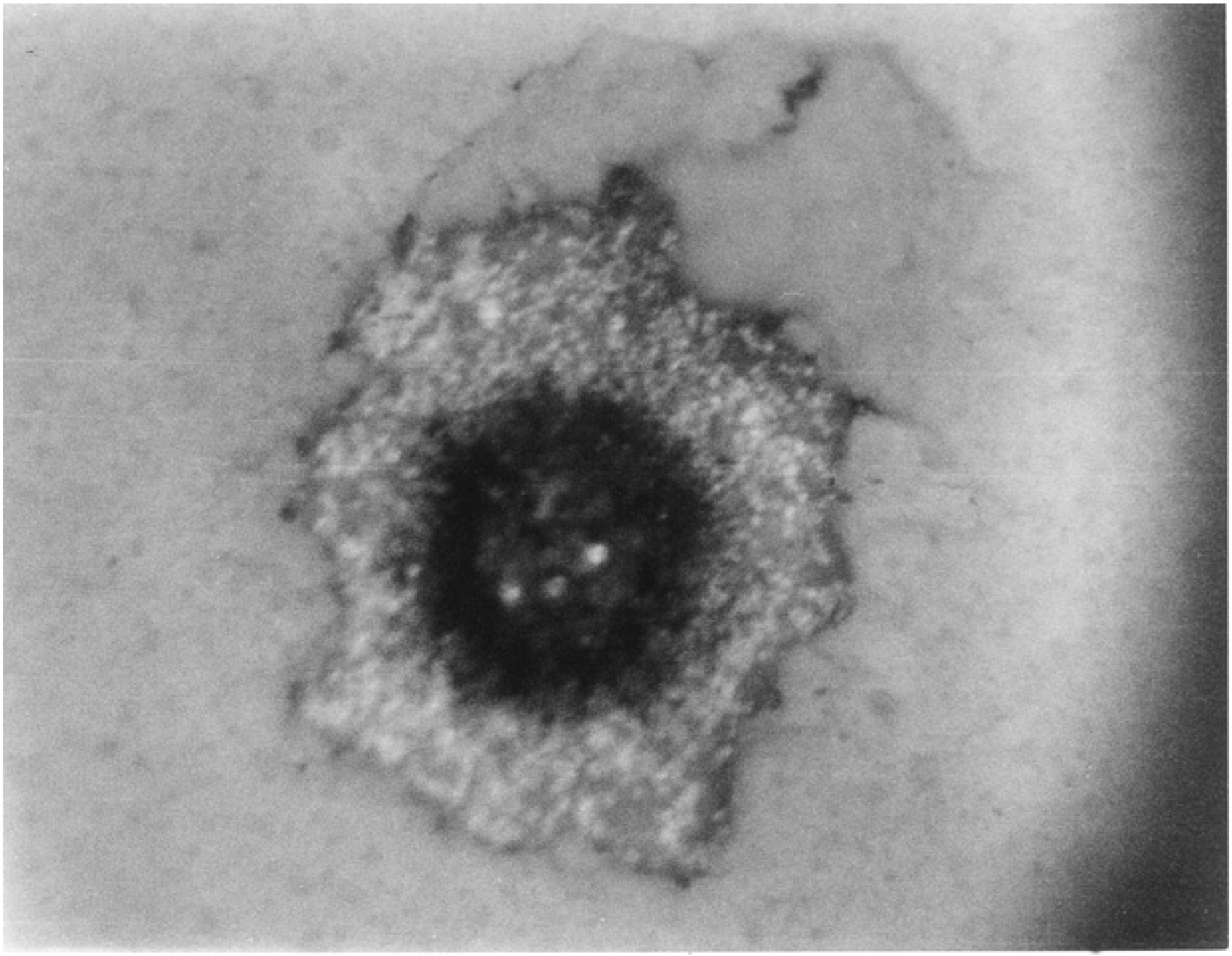

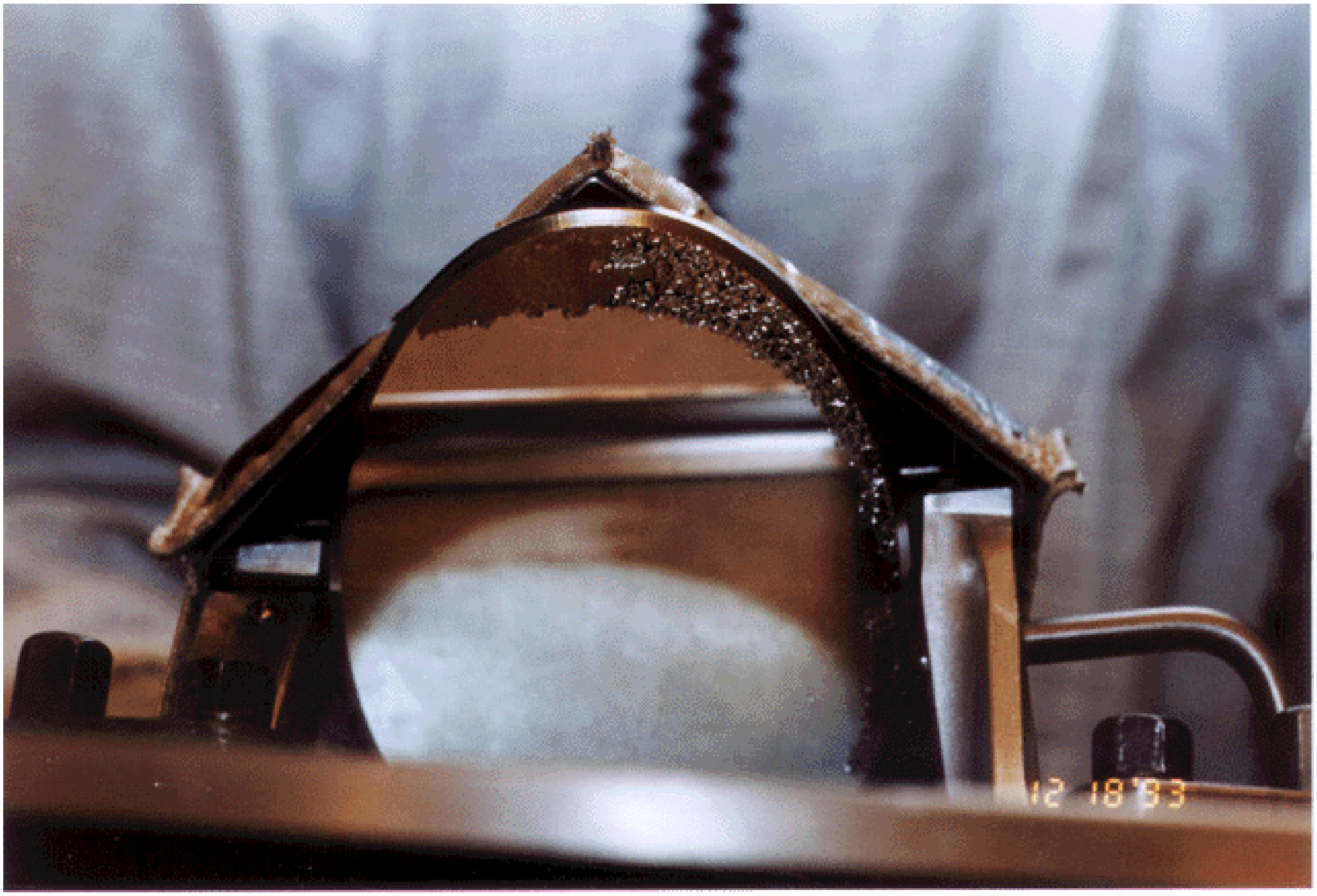
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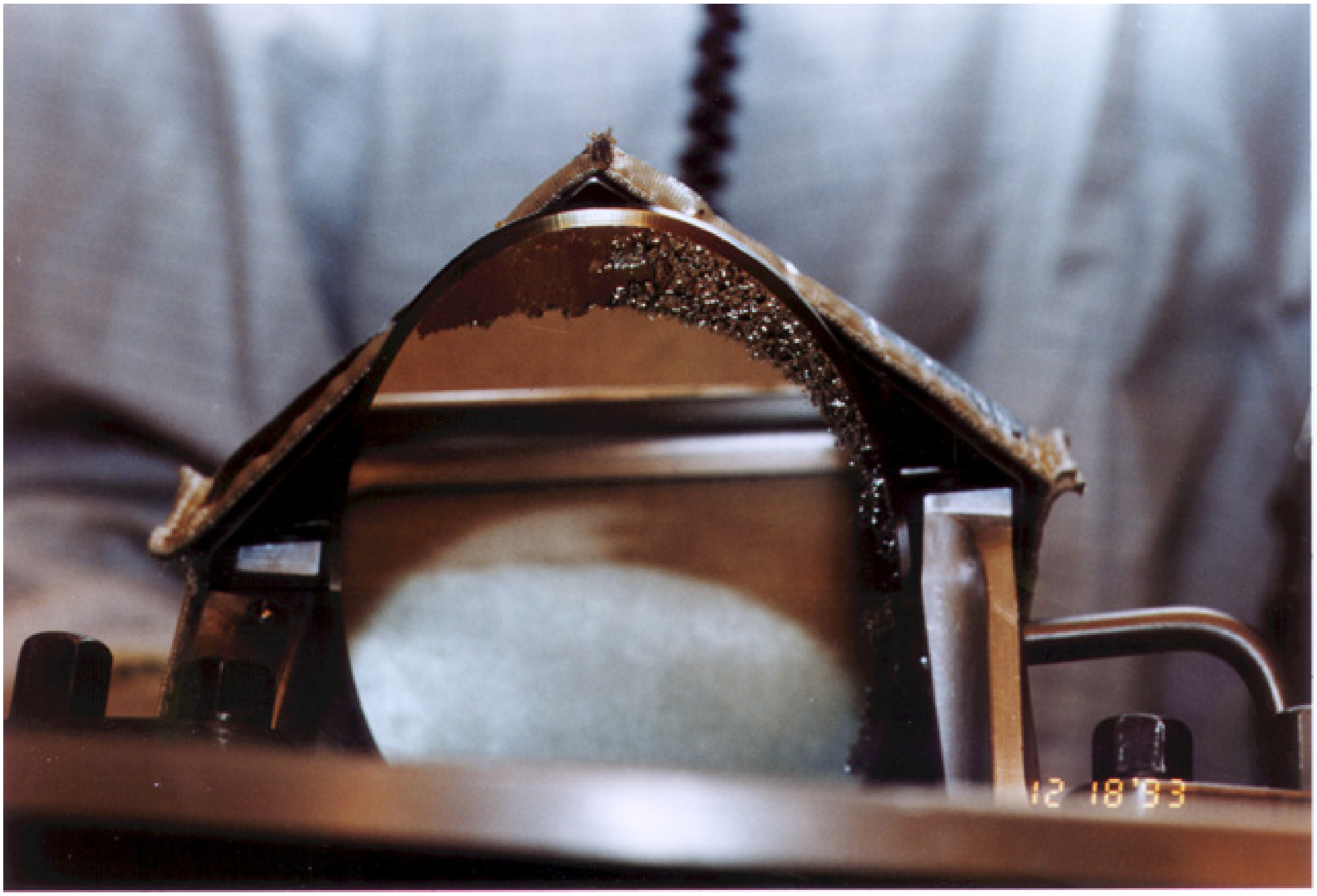
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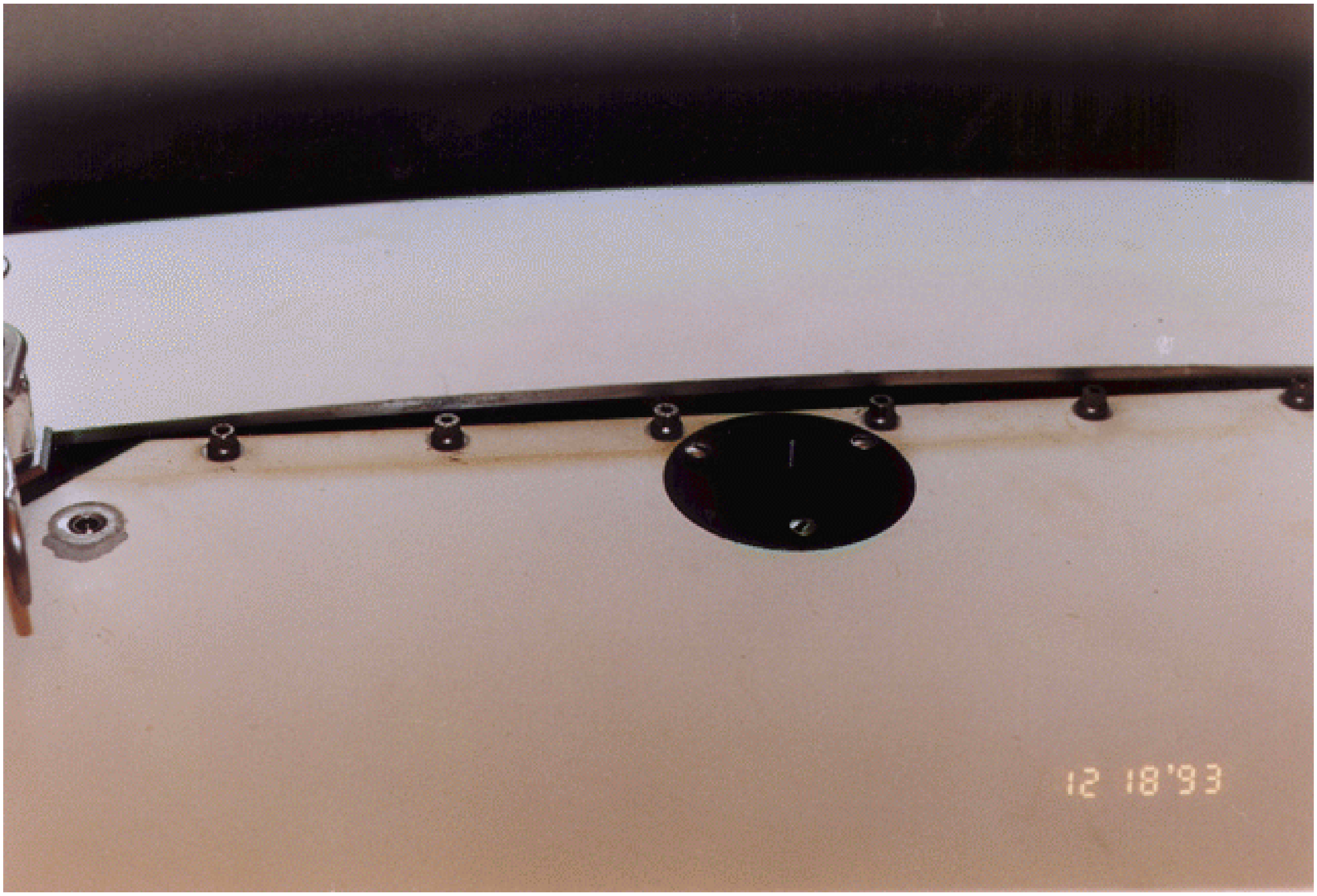
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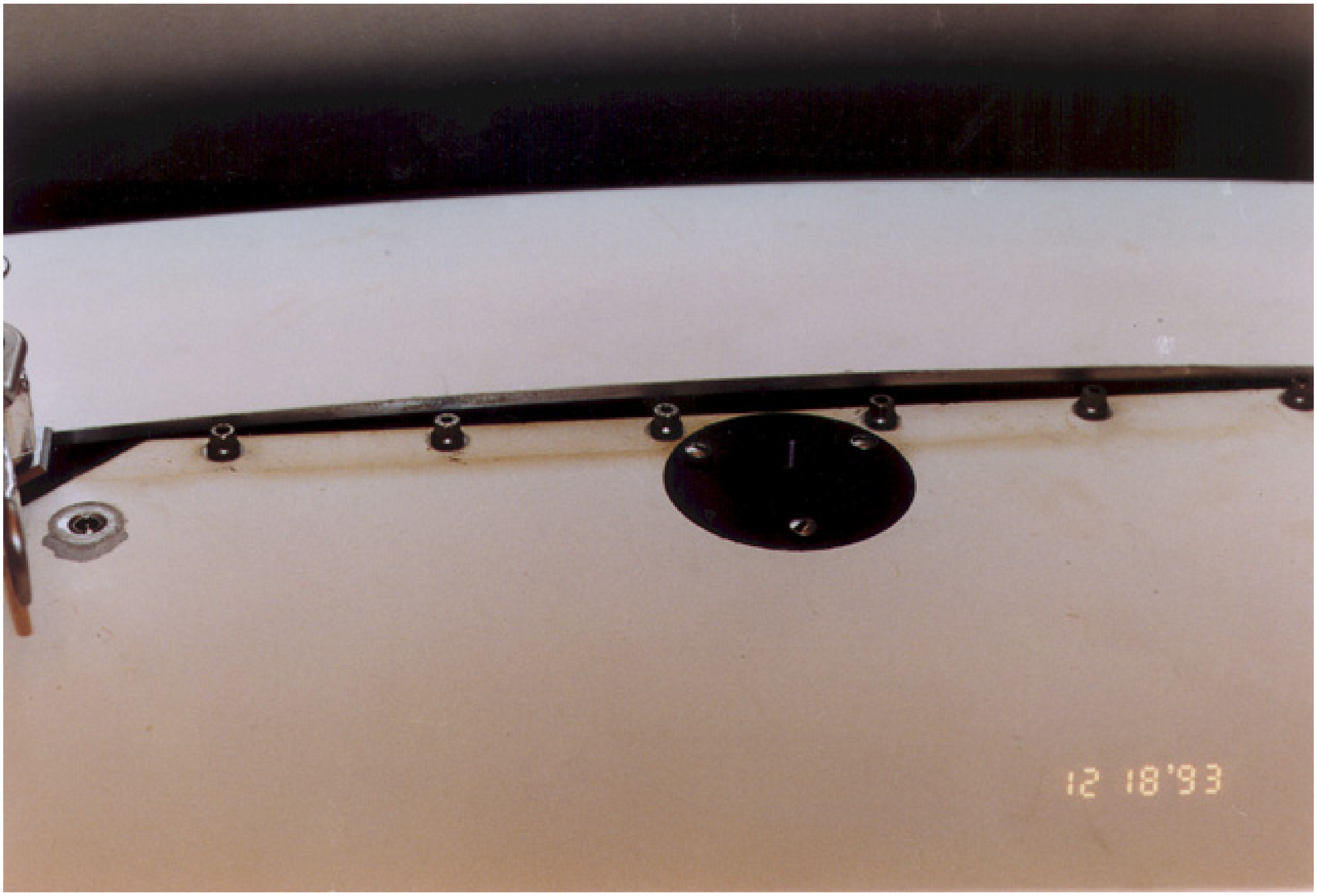
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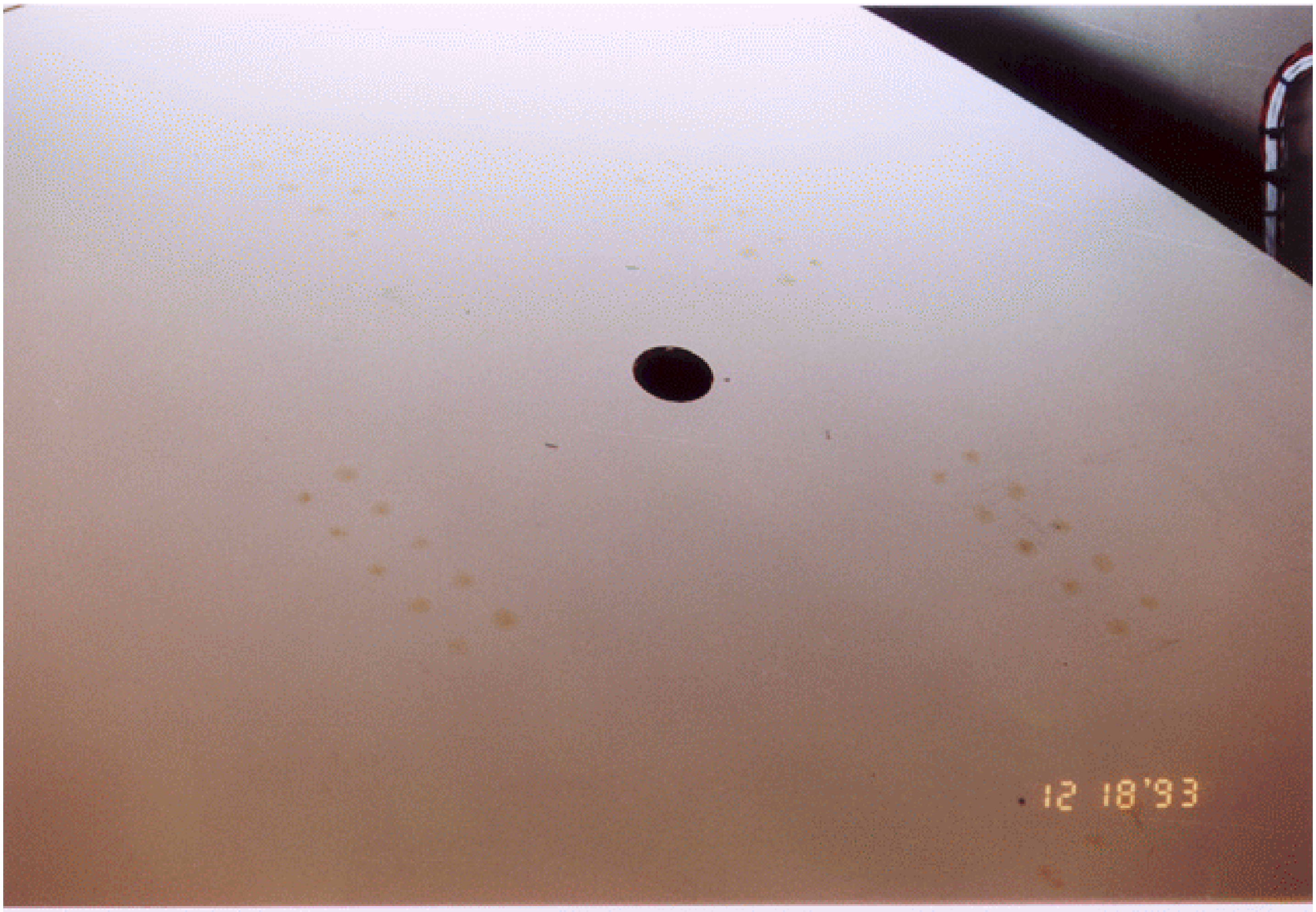
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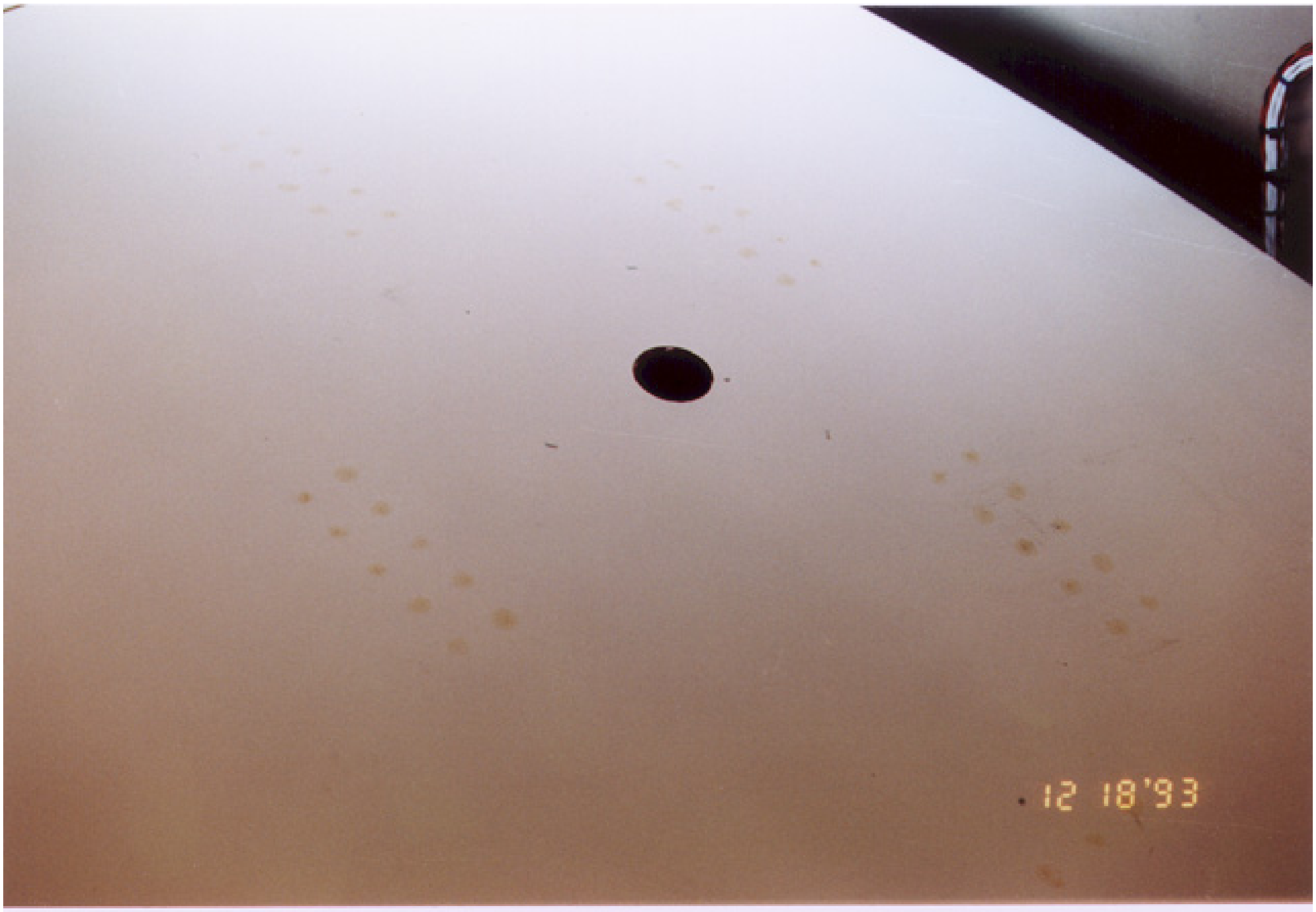
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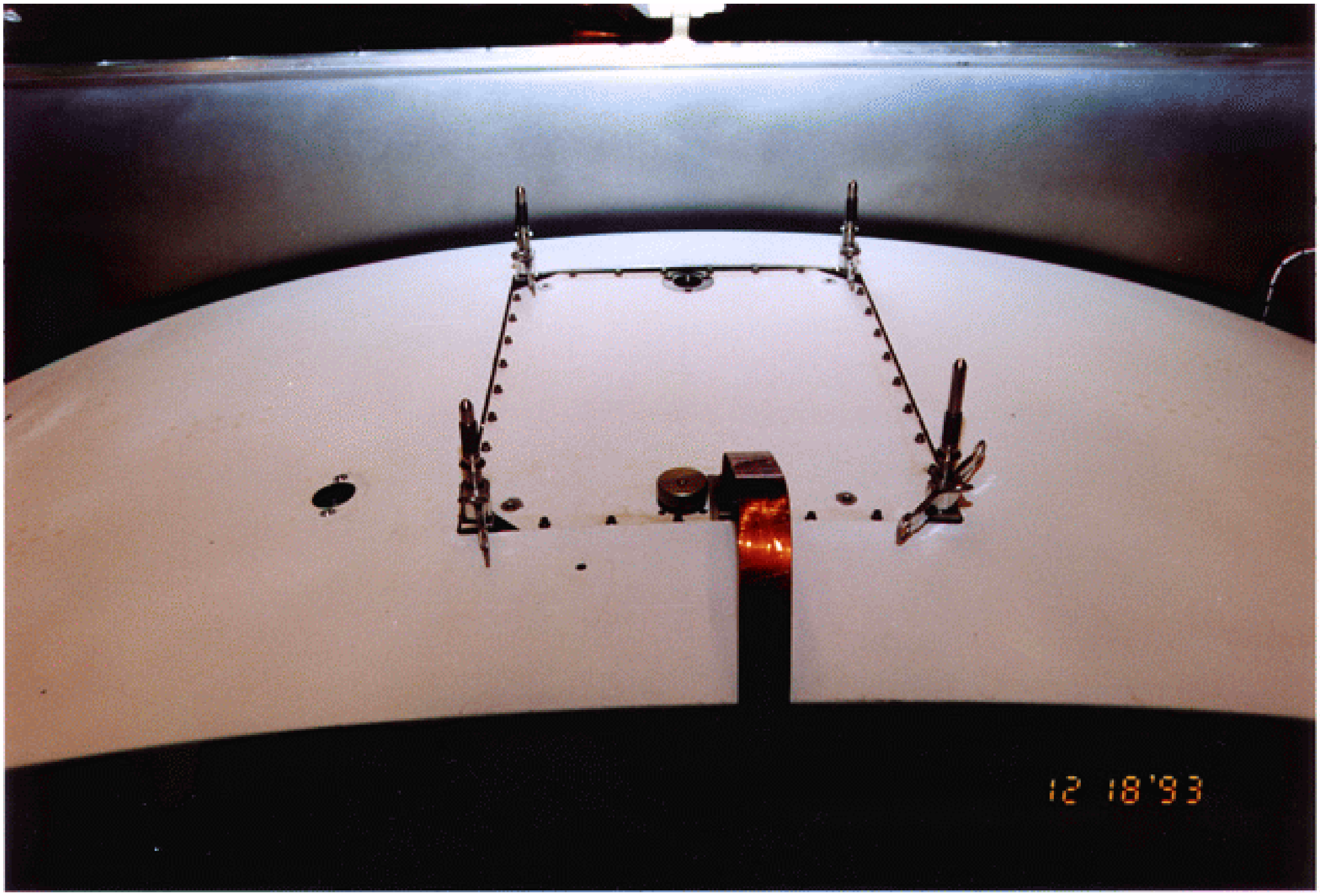
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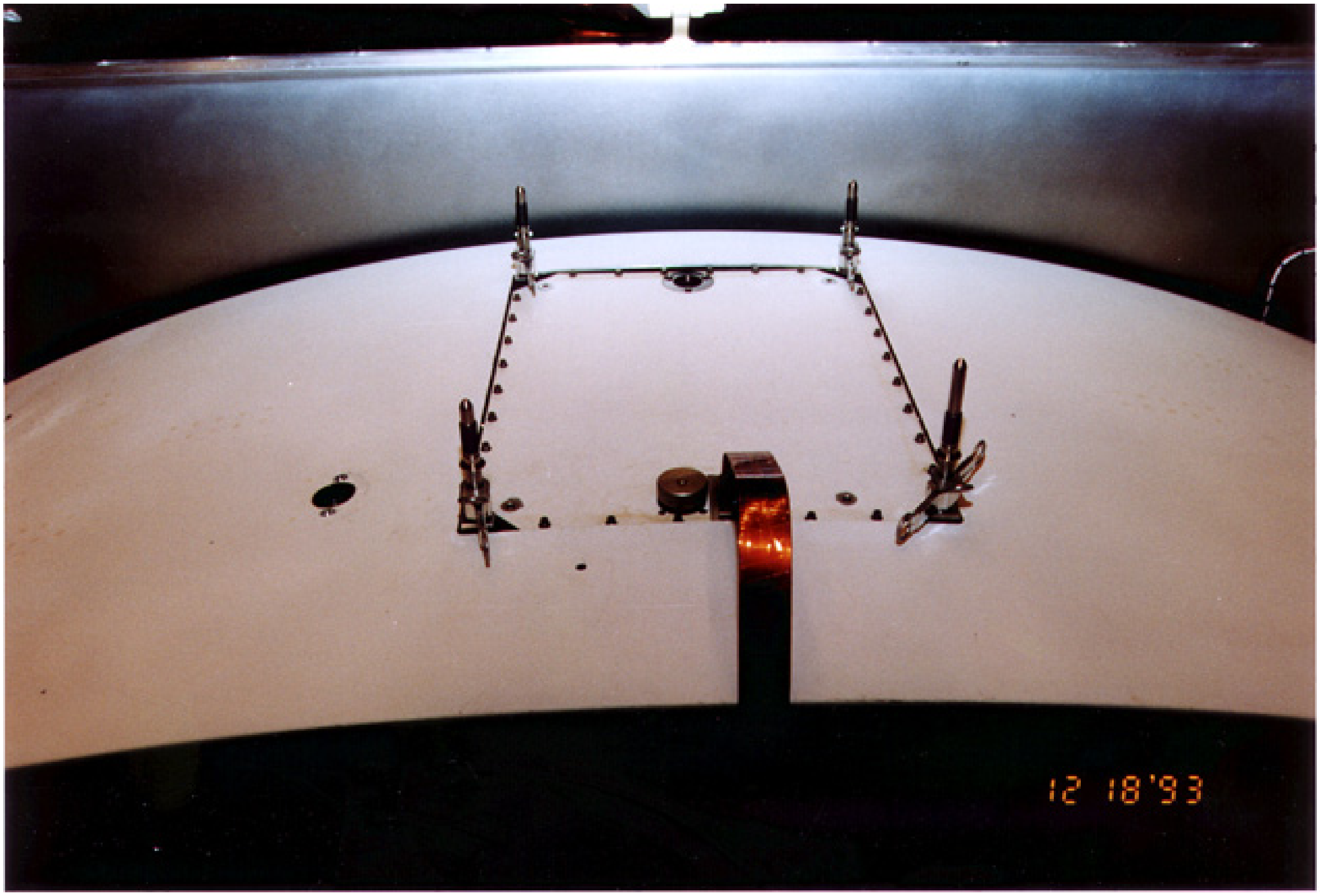
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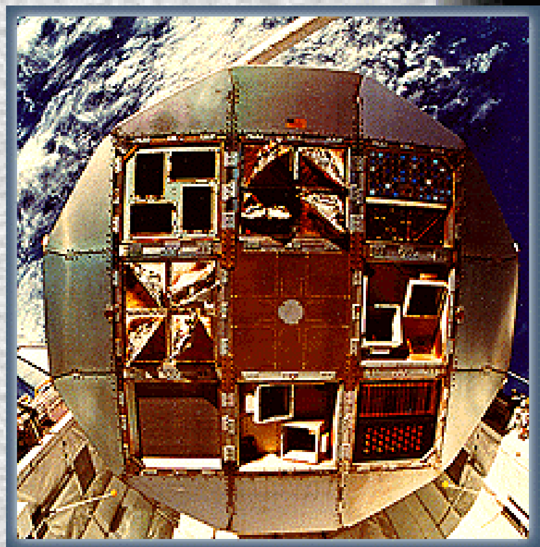


Space Environments and Technology Archive System (SETAS)

NASA Langley Research Center
Hampton, Virginia

- What's New
  Recently Added Information

Overview

- LDEF
  Long Duration Exposure Facility
- MEEP
  Mir Environmental Effects Payload
- SARE
  MIR Solar Array Return Experiment
- MISSE
  Materials International Space Station Experiment
- AORP
  Atomic Oxygen Resistant Polymers Experiment
- DSPSE
  Clementine - Deep Space Probe Science Experiment

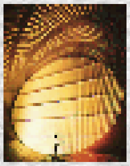
Overview

The Space Environments and Technology Archive System (SETAS) has been established to preserve and provide easy access to the diverse collection of space environments and technology (SET) resources. The resources are organized according to technical disciplines and data sources.

The technical disciplines are meant to encompass the varied aspects of the space environment and their effects. These include ionizing radiation, meteoroids and debris, neutral external contamination, plasmas and fields, thermal and solar, electromagnetic effects, materials and processes, and systems.

The data sources refer to space missions and experiments, including the Long Duration Exposure Facility (LDEF), Hubble

- **ESEM** Evaluation of Space Environment and Effects on Materials
- **EuReCa** European Retrievable Carrier
- **HST** Hubble Space Telescope
- **MDIM** Meteoroid and Debris Impact Monitor
- **MIS** Meteoroid Impact Sensor
- **MPID** Micro-Particle Impact Detector



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Space Environments &Technology Archive System Home Page

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Space Telescope (HST), the European Retrievable Carrier (EuReCa), and Clementine / Deep Space Probe Science Experiment (DSPSE). It is planned that this list will be expanded to include all available data sources.

Resources are planned to include:

- SET data, analysis, documentation, photographs and publications from in-space and terrestrial laboratory experiments
- Simplified models of the space environment and effects - for use in conceptual and preliminary design studies to identify environment-related concerns and design options
- Descriptions of high fidelity models of space environments and effects - for use in final spacecraft design and operational phases. Contacts responsible for execution and analysis of the models are to be included as well.
- Guidelines for spacecraft design
- Space flight hardware and ground test specimens that have value to future SET-related investigations
- SET research test facilities and descriptions
- SET technology development

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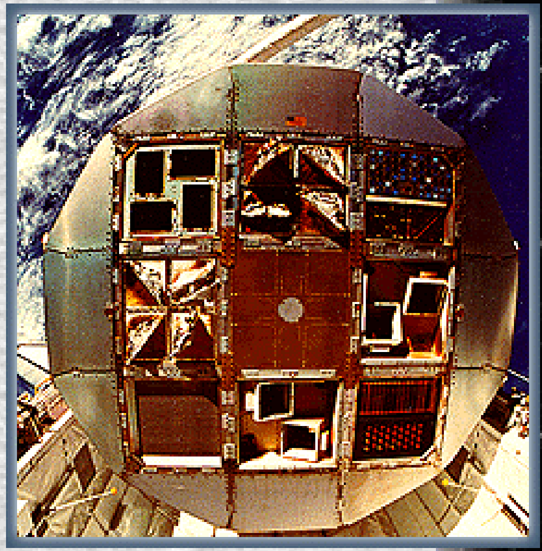
programs, current and planned

LDEF | Hubble | EuReCa | Clementine | MEEP



Space Environments and Technology Archive System

(SETAS)

NASA Langley Research Center
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  Long Duration Exposure Facility
- MEEP
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  MIR Solar Array Return Experiment
- MISSE
  Materials International Space Station Experiment
- AORP
  Atomic Oxygen Resistant Polymers Experiment
- DSPSE
  Clementine - Deep Space Probe Science Experiment

March, 2000
Mir Environmental Effects Payload (MEEP) - One-Year Reports
Orbital Debris Collector

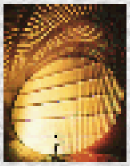
August, 1999
NASDA ESEM - Final Report

June, 1999
NASA ESEM - Final Report

February, 1999

- Sunsat successfully launched on February 23, 1999
- Stardust successfully launched on February 7, 1999
  and on course for January 2, 2004 encounter with Comet Wild-2!

- ESEM
  Evaluation of Space Environment and Effects on Materials
- EuReCa
  European Retrievable Carrier
- HST
  Hubble Space Telescope
- MDIM
  Meteoroid and Debris Impact Monitor
- MIS
  Meteoroid Impact Sensor
- MPID
  Micro-Particle Impact Detector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December, 1998

Mir Environmental Effects Payload (MEEP) - One-Year Reports

- Passive Optical Sample Assembly I (POSA I)

November, 1998

SARE - MIR Solar Array Returned Experiment

February, 1998

MEEP PPMD - Craters in the Aluminum Alloy (6061-T6) Plate

Mir Environmental Effects Payload (MEEP) - 30-Day Reports

- Orbital Debris Collector (ODC)
- Passive Optical Sample Assembly I (POSA I)
- Passive Optical Sample Assembly II (POSA II)
- Polished Plated Meteoroid Detector (PPMD)

LDEF | **Hubble** | **EuReCa** | **Clementine** | **MEEP**

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- Overview
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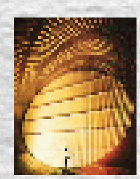
  - Meteoroid & Debris
  - Contamination
  - Atomic Oxygen
  - Solar & Thermal
  - Materials & Processes
  - Systems



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Long Duration Exposure Facility

(LDEF) Archive System

NASA Langley Research Center
Hampton, Virginia

Overview

The Long Duration Exposure Facility (LDEF) Archive System is designed to provide spacecraft designers and space environment researchers a single point access to all available resources from LDEF. These include data, micrographs, photographs, technical reports, papers, hardware and test specimens, as well as technical expertise. Furthermore, the LDEF Archive System is planned such that it could be the foundation for the NASA Space Environments and Technology (SET) Archive System, with the addition of other spaceflight, laboratory and theoretical space environments and effects data and associated materials.

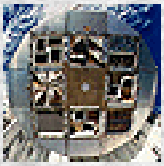
NASA's Long Duration Exposure Facility (LDEF) was designed to provide long-term data on the space environment and its effects on space systems and operations. It successfully carried science and technology experiments that have revealed a broad and detailed collection of space environmental data. The LDEF concept evolved from a spacecraft proposed by NASA Langley Research Center (LaRC) in 1970 to study the meteoroid

environment, the [Meteoroid and Exposure Module (MEM)].

LDEF had a nearly cylindrical structure, and its 57 experiments were mounted in 86 trays about its periphery and on the two ends. The spacecraft measured 30 feet by 14 feet and weighed ~21,500 pounds with mounted experiments, and remains one of the largest Shuttle-deployed payloads. The experiments involved the participation of more than 200 principal investigators from 33 private companies, 21 universities, seven NASA centers, nine Department of Defense laboratories and eight foreign countries. The post-flight special investigations and continued principal investigator research have increased the total number of investigators to between 300 - 400.

LDEF was deployed in orbit on April 7, 1984 by the Shuttle *Challenger*. The nearly circular orbit was at an altitude of 275 nautical miles and an inclination of 28.4 degrees. Attitude control of the LDEF spacecraft was achieved with gravity gradient and inertial distribution to maintain three-axis stability in orbit. Therefore, propulsion or other attitude control systems were not required, and LDEF was free of acceleration forces and contaminants from jet firings.

LDEF remained in space for ~5.7 years and completed 32,422 Earth orbits; this extended stay increased its scientific and technological value toward the understanding of the space environment and its effects. It experienced one-half of a solar cycle, as it was deployed during a solar minimum and retrieved at a solar maximum.



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LDEF was retrieved on January 11, 1990 by the Shuttle *Columbia*. By the time LDEF was retrieved, its orbit had decayed to ~175 nautical miles and was a little more than one month away from reentering the Earth's atmosphere. *Columbia* landed at Edwards Air Force Base and was ferried back to NASA Kennedy Space Center (KSC) on January 26, 1990.

Following the deintegration of each experiment tray from the spacecraft at KSC, research activities included a radiation survey, infrared video survey, meteoroid & debris survey, contamination inspection, and extensive photo documentation. After these post-deintegration activities the experiment trays were shipped or hand-carried directly from KSC to the principal investigators' laboratories.

Chronology of LDEF covering the twenty-three years between 1970 and 1993.

Related LDEF Information at JSC

- **SETAS** Overview - Home Page
- **LDEF** Long Duration Exposure Facility
- **MEEP** Mir Environmental Effects Payload
- **SARE** MIR Solar Array Return Experiment
- **MISSE** Materials International Space Station Experiment
- **AORP** Atomic Oxygen Resistant Polymers Experiment
- **DSPSE** Clementine - Deep Space Probe Science Experiment
- **ESEM** Evaluation of Space Environment and Effects on Materials
- **EuReCa** European Retrievable Carrier
- **HST** Hubble Space Telescope

MIR Environmental Effects Payload

(MEEP) Archive System

NASA Langley Research Center

Hampton, Virginia

MEEP: 1-Year Post-Retrieval Reports

ODC | POSA I | POSA II | PPMD

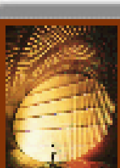
MEEP: 30-Day Post-Retrieval Reports

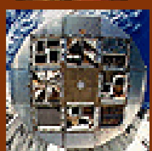
ODC | POSA I | POSA II | PPMD

Overview

The Mir Environmental Effects Payload (MEEP) is an International Space Station Phase 1 Risk Mitigation Experiment that will provide an assessment of baseline and candidate Space Station materials for the intended operational environment of the International Space Station. MEEP will also fulfill the need to examine the occurrence and effects of man-made debris and natural micrometeoroids through capture and impact studies. The MEEP was deployed on the Mir/Shuttle Docking Module via an Extravehicular Activity (EVA) from the shuttle on STS-76, and was retrieved during STS-86.

MEEP consists of a family of four science experiments that are deployed on a common carrier. Langley Research center has the overall responsibility for the MEEP experiment as well as the development of the common carrier. The organizations responsible for each of the science experiments are listed in the descriptions below pertaining to each of the four experiments.

 [Langley Home Page](#)

 [Space Environments & Technology Archive System Home Page](#)

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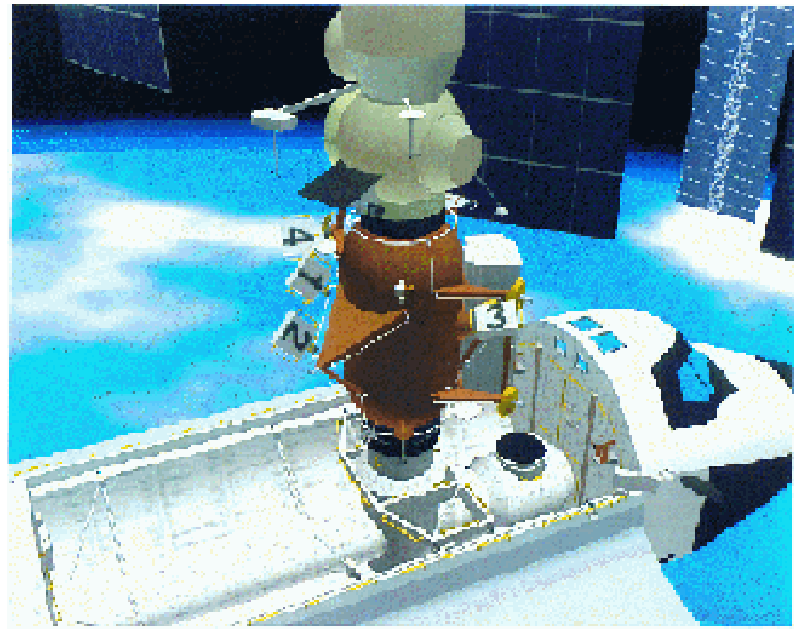
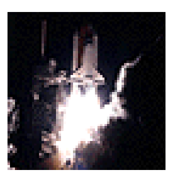


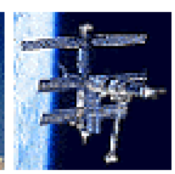
Information concerning the Passive Experiment Carrier and the four MEEP experiments.

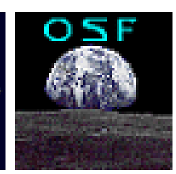
- Passive Experiment Carrier (PEC)
- Polished Plate Micrometeoroid and Debris (PPMD)
- Passive Optical Sample Assembly I (POSA I)
- Orbital Debris Collector (ODC)
- Passive Optical Sample Assembly II (POSA II)

Related Links

 Deployment STS-76

 Retrieval STS-86

 Space Station MIR

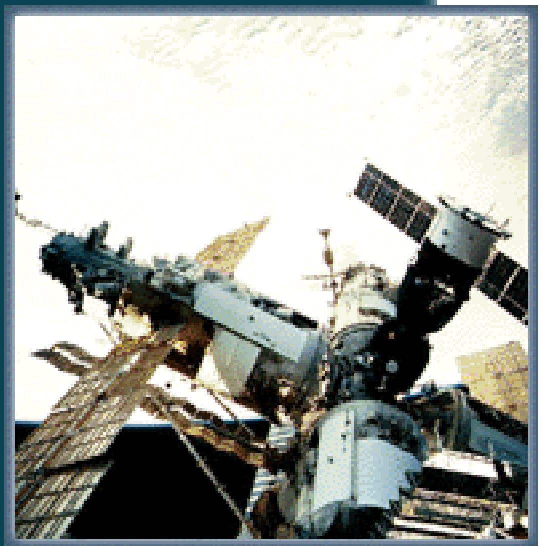


Office of Space Flight

 OSF / STS-76 Press Kit

Technical content for the MIR Environmental Effects Payload (MEEP) Web site was provided by Greg Stover. Please address comments regarding the technical content to g.stover@larc.nasa.gov.

MEEP | PEC | PPMD | POSA I | ODC | POSA II
MEEP / Mir Photographs
Page 1 | Page 2



MIR Solar Array Returned Experiment

(SARE) Archive System

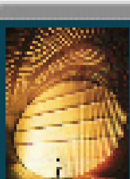
NASA Langley Research Center
Hampton, Virginia

Introduction

During November 1997, a solar array panel was removed from the non-articulating PV (Photovoltaic) array on the Mir core module by Russian cosmonauts. This panel, which was exposed to the orbital space environment for a period of ten years, consists of eight foldable sections and was ~6.0 meters in length and ~1.3 meters in width. The length and width dimensions of each foldable section within the panel were 760 mm and 1300 mm, respectively. After removal from the PV Array, the solar array panel was placed in a protective bag, sealed, and stowed within the Mir core module.

During the STS-89 mission, which rendezvoused

- **DSPSE** Clementine - Deep Space Probe Science Experiment
- **ESEM** Evaluation of Space Environment and Effects on Materials
- **EuReCa** European Retrievable Carrier
- **HST** Hubble Space Telescope
- **MDIM** Meteoroid and Debris Impact Monitor
- **MIS** Meteoroid Impact Sensor
- **MPID** Micro-Particle Impact Detector



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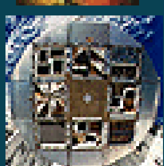

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with Mir in January 1998, the solar array panel was removed from the Mir core module and stowed aboard the U.S. Spacehab module for return to Earth and laboratory studies of the effects of the prolonged space exposure. After the Orbiter was returned to its processing facility at the Kennedy Space Center (KSC), the Spacehab module was removed and taken to the Spacehab Laboratory at the Kennedy Space Complex for post-flight processing. The solar array panel was subsequently removed from the Spacehab module and placed in an adjacent clean room for visual and microscopic examination. During these examinations, the intact panel underwent scientific inspections and preliminary tests by a joint team of U.S. and Russian investigators. One section of the panel (*i.e.*, panel 8) was removed by the Russians and given to U.S. scientist for further inspection, study, and laboratory analysis. The remaining seven sections of the panel were returned to RSC Energia for inspection, study, and further analysis by Russian investigators.

Photodocumentation - Images of the Solar Array and examination activities at Spacehab Laboratory.

Analyses of Mir Solar Array Handrail Samples - Kim K. de Groh, NASA Lewis Research Center and Terry R. McCue, Dynacs Engineering

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MIR Solar Array Return Experiment
U.S. & Russian Team Participants

Investigator	Affiliation/ Company	Specialty / Field
James Visentine	Boeing	U.S. Project Manager
David Brinker	LeRC	Power Degradation Studies

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Thomas H. See	Lockheed-Martin JSC	MM/OD Impact Studies
James Zwiener	MSFC	Molecular Contamination Analysis
Gale A. Harvey	LaRC	Molecular Contamination Analysis
Keith Albyn	JSC	Optical Property Measurements
Bruce Banks	LeRC	Atomic Oxygen Studies
Alexander Markov	RSC-E	RSC-E Project Manager
Dmitriy Surin	RSC-E	Power Degradation Studies
Viktor Konoshenko	RSC-E	MM/OD Impact Studies
Stanislav Naumov	RSC-E	Molecular Contamination Analysis

For further information on the activities and results related to the MIR Solar Array Return Experiment, please contact James (Jim) Visentine.

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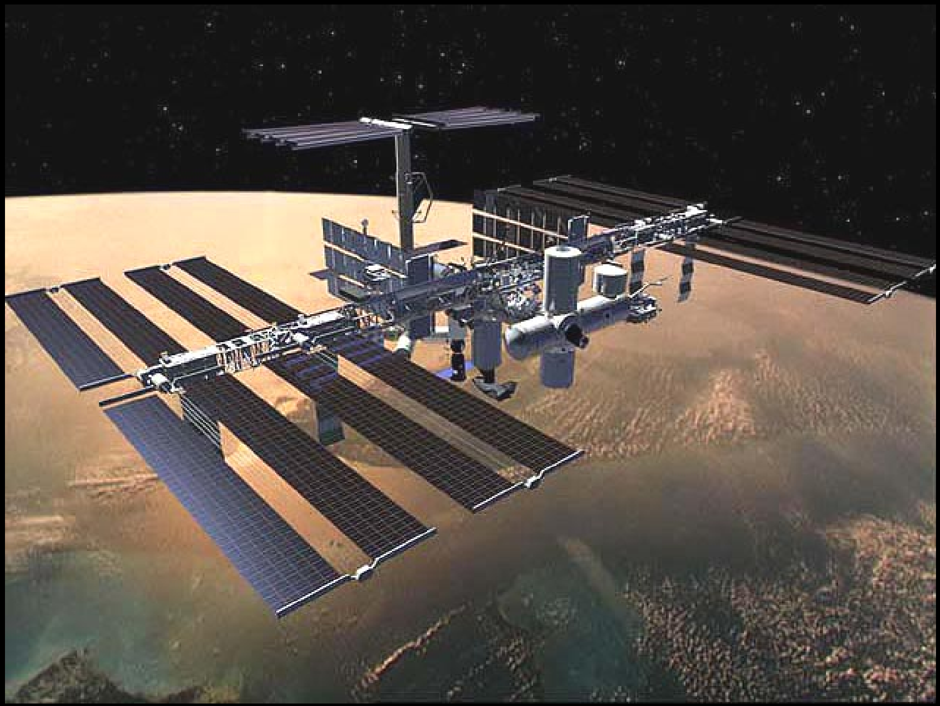
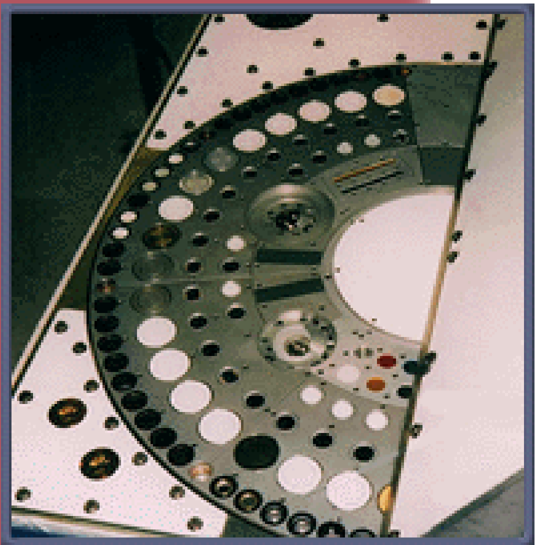
IN SPACE

DATA ANALYSIS

MATERIALS INTERNATIONAL SPACE STATION EXPERIMENT





Atomic Oxygen Resistant Polymers Experiment

(AOP) Archive System

NASA Langley Research Center

Hampton, Virginia

- **SETAS** Overview - Home Page
- **LDEF** Long Duration Exposure Facility
- **MEEP** Mir Environmental Effects Payload
- **SARE** MIR Solar Array Return Experiment
- **MISSE** Materials International Space Station Experiment
- **AORP** Atomic Oxygen Resistant Polymers Experiment
- **DSPSE** Clementine - Deep Space Probe Science Experiment
- **ESEM** Evaluation of Space Environment and Effects on Materials
- **EuReCa** European Retrievable Carrier

COLLEGE OF WILLIAM & MARY - NASA/LaRC

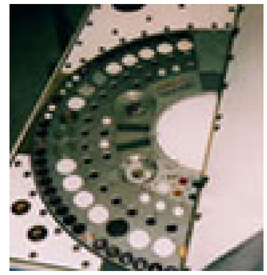
ATOMIC OXYGEN RESISTANT POLYMERS EXPERIMENT

The W&M - NASA/LaRC Atomic Oxygen Resistant Polymers (AORP) experiment is one of the experiments carried by the Optical Properties Monitor (OPM) which is currently attached to the exterior of the Russian MIR space station. The AORP experiment objective is to measure the performance of atomic oxygen resistant polymers when exposed to the space environment for approximately one year. The OPM is then retrieved from MIR and the material samples are analyzed by the experiment investigators. These materials also flew on the STS-85 shuttle mission payload "Evaluation of Space Environment and Effects on Materials (ESEM)" and have previously flown on shuttle missions STS-46 and STS-51.

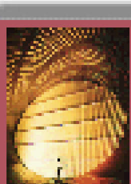
This experiment is supported by the Space Environments and Effects Program (SEE).

Experiment Principal Investigators are Professor Richard L. Kiefer, Professor Robert A. Orwoll and Dr. Sheila A. Thibeault

- **HST** Hubble Space Telescope
- **MDIM** Meteoroid and Debris Impact Monitor
- **MIS** Meteoroid Impact Sensor
- **MPID** Micro-Particle Impact Detector



STS-46 | STS-51 | AORP Image



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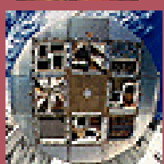

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AORP | Clementine | EuReCa | ESEM | Hubble
LDEF | MDIM | MEEP | MIS | MPID

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Clementine Deep Space Probe Science Experiment

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- **ESEM**
  Evaluation of Space Environment and Effects on Materials

Overview

Clementine, a joint project between the Ballistic Missile Defense Organization and NASA, was launched on January 25, 1994 from Vandenburg Air Force Base aboard a Titan IIG rocket. Clementine was the first of a new class of spacecraft designed to enable long-duration, deep-space missions at reduced cost. Its principal objective was to qualify lightweight imaging sensors and component technologies for the next generation of spacecraft. Clementine's secondary mission was to make scientific observations of the Moon and the near-Earth asteroid 1620 Geographos. These observations included imaging at various wavelengths (*e.g.*, ultraviolet and infrared), laser ranging altimetry, and charged particle measurements for the purposes of assessing the surface mineralogy of the Moon and Geographos, obtaining lunar altimetry from 60N to 60S latitude, and determining the size, shape, rotational characteristics, surface properties, and cratering statistics of Geographos.

After two Earth flybys, lunar insertion of Clementine was achieved on February 19, 1994. Mapping of the Lunar surface took place over a two

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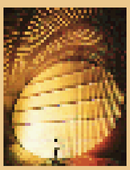

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month period in two systematic mapping passes over the Moon. The first part consisted of a five hour elliptical polar orbit with a perihelion of about 400 km at 28 degrees S latitude. After one month the orbit was rotated to 29 degrees N latitude, where it remained for the second month. These two orbital inclinations provided global imaging, as well as altimetry coverage from 60 degrees S to 60 degrees N.

After leaving lunar orbit, a malfunction in one of the on-board computers on May 7, 1994 caused one of the thruster to fire and continue to burn until it had depleted all of its fuel, leaving the spacecraft spinning at rate of about 80 RPM. Unfortunately, this made the continuation of the mission, a planned flyby of the near-Earth asteroid Geographos, impossible. However, the spacecraft remained in a geocentric orbit and testing the various spacecraft components continued until the end of mission.

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5. The Natural Meteoroid Environment Near Earth as Indicated by Data From the Orbital Meteoroid and Debris Counting Experiment on the Clementine Interstage Adapter Spacecraft, Kinard, W.H. and Humes, D.H., *AAS/AIAA Spaceflight Mechanics Meeting, AAS 95-128*

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- Description
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Other Internet Sites with Clementine Information, Data, and Images

- Lawrence Livermore National Laboratory
- Goddard Space Flight Center
- Lunar & Planetary Institute
- Naval Research Laboratory
- US Geological Survey
- National Space Science Data Center; GSFC

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