HUBBLE SPACE TELESCOPE SERVICING MISSION
SCIENTIFIC INSTRUMENT PROTECTIVE ENCLOSURE
DESIGN REQUIREMENTS AND CONTAMINATION CONTROLS

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ABSTRACT

The Scientific Instrument Protective Enclosures were designed for the Hubble Space Telescope Servicing Missions to provide a benign environment to a Scientific Instrument during ground and on-orbit activities. The Scientific Instruments required very stringent surface cleanliness and molecular outgassing levels to maintain ultraviolet performance. Data from the First Servicing Mission verified that both the Scientific Instruments and Scientific Instrument Protective Enclosures met surface cleanliness level requirements during ground and on-orbit activities.

INTRODUCTION

The 15 year mission of the Hubble Space Telescope (HST) is to provide scientific data on the constituents of our universe. Collectively, the HST scientific objectives are to determine: "the constitution, physical characteristics, and dynamics of celestial bodies; the nature and processes which occur in the extreme physical conditions existing in stellar objects; the history and evolution of the universe; and whether the laws of nature are universal in the space-time continuum".[1] On-orbit manned servicing missions are critical in fulfilling these objectives. The successful December 1993 Space Transportation System (STS) 61 mission was the first step in upgrading the HST Scientific Instrument (SIs) and restoring the scientific capabilities of the HST through the installation of Orbital Replacement Units (ORUs). The ORUs consisted of two SIs [the Wide Field and Planetary Camera-2 (WFPC-2) and the Corrective Optics Space Telescope Axial Replacement (COSTAR)], Solar Arrays (SAs), Solar Array Drive Electronics, magnetometers, a coprocessor for the DF-224 flight computer, two rate sensor units, two gyroscope electronic control units, several fuse plugs, and a Goddard High Resolution Spectrograph redundancy kit.

The First Servicing Mission (FSM), shown in Figure 1, used a three Carrier system configuration that included: the Solar Array Carrier (SAC), the Orbital Replacement Unit Carrier (ORUC), and the

Flight Support System (FSS). The 15' x 15' x 15' SAC functioned as a load isolation system for the SAs, and it was used for temporary stowage of the replaced SAs during Extravehicular Activity (EVA). The 12' long x 15' wide x 15' high ORUC, shown in Figure 2, was the most contamination sensitive Carrier. The ORUC housed the WFPC-2 and COSTAR in Scientific Instrument Protective Enclosures (SIPEs). The two SIPEs, the Radial SIPE (RSIPE) for WFPC-2 and the Axial SIPE (ASIPE) for COSTAR, provided a thermal environment equivalent to that inside of the HST, and they were mounted on a load isolation system which provided a low-g vibration environment to the SIs. The warm thermal environment not only ensured that the SIs would remain within their temperature limits during the EVA, but also ensured that any outgassing inside the SIPEs, which could otherwise affect optical performance, would not condense on the SIs. The 5' long x 15' wide x 15' high FSS was used as the maintenance platform to berth the HST to the Shuttle throughout the mission.

The SIPEs were designed to provide a protective environment for the SIs during activities which posed a particulate and molecular degradation threat to the SIs. The RSIPE design, shown in Figure 3, was the most complex design, and as such, this paper will focus on the RSIPE design requirements and the contamination controls which were implemented to preserve the cleanliness and optical performance of the SIs. Similar design requirements and contamination controls were also implemented for the ASIPE. The SI contamination requirements will be described as the basis for the SIPE design requirements. Verification of the contamination cleanliness levels for the SIs and SIPE will be presented.

SIPE DESIGN

The RSIPE provided structural interfaces for mounting to the ORUC and ASIPE; access for EVA removal and insertion of the SI; protection of the SI from mechanical damage during an EVA; controlled thermal, acoustical, and contamination environments; and an electrical interface to the SI. The SIPE was made of an aluminum honeycomb composite. This design used a large amount of adhesive in the manufacturing process; therefore, contamination control methods were incorporated in the design and processing phases to control and reduce outgassing.

The candidate bonding adhesives for the panel facesheets, inserts, and edge member closeouts were initially screened to determine the outgassing rates at the on-orbit predicted temperatures. FM 73 adhesive, by American Cyanamid Company, was used for the RSIPE and FM 123 LVC, by American Cyanamid Company, was used for the ASIPE. For both samples, initial outgassing test yielded acceptable results. To further reduce the honeycomb panel outgassing and increase venting for more efficient vacuum baking, the exterior facesheets were perforated with 0.028 inch diameter holes approximately one inch apart on center. The interior facesheets were not perforated. The facesheet perforations allowed for directional venting away from the SI during Orbiter ascent and on-orbit operations. Prior to the buildup of the SIPEs, the honeycomb panels were vacuum conditioned to decrease outgassing during system certification.

A monitoring system was incorporated into the SIPE designs to effectively verify the surface cleanliness of the SIPEs. Figure 4 shows the RSIPE baseplate contamination witness plates, and vertical and flat optical witness mirrors (OWMs). The witness plate is a 9" x 9" aluminum surface used to measure surface molecular cleanliness levels. The oblique and viewing port mirrors are shown in Figure 5. These OWMs were used to measure surface ultraviolet reflectance and particulate levels. The SIPE was designed so that the OWMs were accessible without opening the RSIPE to preclude compromising the cleanliness level of the RSIPE or the SI. The viewing port was incorporated into the RSIPE design for the insertion of a Quartz Crystal Microbalance (QCM) during the system level vacuum outgassing test to measure the total outgassing rate of the RSIPE with all the hardware installed.

Because the WFPC-2 required a dry purge at all times, the RSIPE design incorporated a purge interface as shown in Figure 6. The purge system, which is attached to the RSIPE baseplate, utilized stainless steel tubing for controlling moisture and surface cleanliness levels. The purge gas entered the RSIPE through a port at the bulkhead fitting location interfacing with the WFPC-2 pick-off mirror cover after installation of the WFPC-2 into the RSIPE.

A vent filter system, detailed in Figure 7, was developed to sustain an effective purge, control particulate migration from the external environment into the RSIPE, allow for pressure differentials during launch and ascent, and reduce molecular backstreaming into the RSIPE. The location of the vent on the RSIPE is shown in Figure 3 in the middle of the protective cover assembly. The mounting frame was a 10" x 10" component that contains a stainless steel filter element (nominal 30 micron pore size) and protective screen to preclude damage to the filter element. A restrictor plate, equipped with a purge flow monitor (not shown), covered the entire mounting frame. This plate increased the efficiency of the purge to the WFPC-2 by reducing molecular backstreaming into the RSIPE.[2]

SIPE CLEANLINESS REQUIREMENTS

The SI cleanliness requirements evolved from the HST Aft Shroud (AS) cleanliness requirements which were driven by the Faint Object Spectrograph detector operating temperature. To preclude potential cross-contamination between the SIPEs and the SIs, the SIPEs were subject to the AS outgassing requirements and surface cleanliness level requirement of 400B per MIL-STD-1246.

SI Cleanliness Requirements

For the Servicing Missions, the SIs are the critical elements for establishing the overall contamination requirements and budgets. The SIs are directly exposed to the SIPEs during ground and on-orbit operations, and therefore the SIPEs were assessed for the cleanliness impact to the SIs. The SI requirements dictated the necessity for a continuous gaseous purge to maintain a dry, hydrocarbon-free environment for internal SI surfaces.

The science goal for WFPC-2 was to experience no greater than a one percent loss in UV throughput in any 30 day period at a wavelength of 1470 Å. Mass transport modelling determined that this goal equates to less than or equal to 4.7 Å accumulation on a -70°C charge couple device (CCD). To meet this goal significant improvements were made to the WFPC-2 and are discussed in detail in

References 3 and 4. External WFPC-2 surface cleanliness level requirements were much less stringent than the CCD requirement evolving from the HST AS cleanliness requirements. The WFPC-2 external surface outgassing requirement is less than 1 Hertz (Hz) per hour measured by a 15 MHz QCM set at -20° C. The external surface cleanliness level is Level 400B (i.e., less than 2.0 mg/ft^2) per MIL-STD-1246.

The COSTAR science specification required the M1 and M2 mirror end-of-life spectral throughput of 56 percent at 1216 Å, equating to a 12 Å deposition for a 1 percent reflectance loss for every 1.5 Å deposited. The external COSTAR surface cleanliness level requirements were much less stringent than the M1 and M2 mirror requirements, and as with WFPC-2 its cleanliness requirements evolved from the HST AS cleanliness requirements. The COSTAR external surface outgassing requirement was less than 1 Hz per hour measured by a 15 MHz QCM set at -20° C. The external surface cleanliness level was Level 400B.

SI Purge Requirements

To preserve the WFPC-2 ultraviolet performance, an ultra-clean gaseous nitrogen purge was instituted from the completion of system thermal vacuum testing through integration and testing to launch. For simplicity, the WFPC-2 purge requirements, the most stringent of the nitrogen purge requirements, were instituted as the FSM purge requirements. The WFPC-2 purge requirements are shown in Table 1.

Table 1. WFPC-2 Purge Gas Requirements

Outlet Gas Specification	Requirement
Purity	99.5% (5000 ppm total impurities)
Purge Line Particulate	Level 21 per MIL-STD-1246 (< 15 particles of > 5 microns shed per SCF)
Total Hydrocarbons (as CH_4)	< 1.0 ppm
Dew Point (at 21°C, 760 mm Hg)	> -73.4°C
Water	< 1.5 ppm (molar fraction)

A gaseous nitrogen purge was implemented to ensure an ultra-clean environment for the SIs during the long period of testing and integration prior to launch. Gaseous nitrogen was chosen as the purge gas due to its low cost and ready availability, at relatively high purity, at both Goddard Space Flight Center's (GSFC) integration and test facilities and at Kennedy Space Center's (KSC) launch integration facilities. To meet the WFPC-2 purge requirements additional filtration was required. This was provided by a series of portable filtration units, purge carts, which provided the SIs with isolation from molecular contamination sources, including those within the already clean purge supply gas.

A total of six purge carts were ultimately required to support the continuous purge requirements of the SIs and SIPEs. Two carts were required for each instrument, (one active, one backup), with two remaining for the carriers and transport containers. Continuous purge was defined as no more than a one hour outage, for any reason, before clean gas flow was re-established. Implementing this requirement was the most challenging part of the purge operation. Multiple backups were established including in-place spare purge carts, with redundant parallel filtration, and backup purge gas supplies, (K-bottle 6 packs), with pressure actuated shuttle valves to automatically provide backup in case of facility outage. In addition a computer system radio-paged project personnel if the nitrogen supply pressure was lost.

The purge carts provided a gaseous nitrogen purge not only during integration activities in the NASA cleanroom, but also during transport between facilities (GSFC to KSC, payload cannister transport between KSC facilities, and in the Orbiter). One purge cart actively supplied an SI while another purge cart was staged and certified in the next facility to be occupied by the SI. This method ensured that a fully tested, certified purge gas supply was ready for an SI immediately upon its arrival to a facility and allowed for a straight forward transfer from facility purge to transport purge and back to facility purge (a frequent, if irregular, occurrence).

FSM MONITORING RESULTS

The SIPE surface cleanliness level (particle and molecular) degradation was budgeted from the end of system level thermal vacuum testing through Orbiter integration and on-orbit activities. As shown in Figure 8, periodic cleaning of the RSIPE was scheduled to maintain cleanliness levels during integration and test. The particle level excursions shown in Figures 8-9 were the result of crew training which involved inserting mass model instruments into the respective SIPEs. This training was conducted in a Class M 5.5 cleanroom, but due to the number of excess people observing the activity, the particle levels of the SIPE grossly exceeded the requirement. As a result of this monitoring, the instrument insertion procedure was modified to minimize personnel in the SIPE area.

Monitoring, using image analysis of the SIPE OWMs and tapelifts, provided a particle fallout measurement while the SIs were installed in the SIPEs. The modified procedure minimizing personnel resulted in a clean SIPE and SI, well within the HST budget. Figures 8 and 9 provide the particulate and molecular budgets for the RSIPE and ASIPE, respectively. Post-mission data, image analysis of the OWMs and tapelifts verified that the particle level inside the SIPEs did not exceed the HST requirement of particle level 400. Rinse data, prior to the installation of the SIs into the RSIPE and post-mission, show that the molecular contamination level was less than 0.5 mg/ft^2, well within the HST budget.

The WFPC-2 external particulate level budget shown in Figure 10 was based upon HST AS particle level requirements, and the pick-off mirror particle level was imposed by obscuration requirements dictated in the WFPC-2 contamination control plan. Actual particle level results on external surfaces, shown in Figure 10, were determined by tape lift sampling and/or image analysis. Figure 11 shows the WFPC-2 molecular level budget and the actual data as determined by chemical analyses and/or OWM reflectance measurements. The WFPC-2 exterior surface particulate and molecular cleanliness levels, Level 300 and 0.1 mg/ft^2, respectively, were much less than the HST requirement of Level 400 and 2.0 mg/ft^2.

Figure 12 shows the budgeted particulate contamination allocations for the COSTAR M1 and M2 mirrors. The COSTAR exterior surface particulate contamination level was less than Level 200, well below the HST requirement of Level 400. An OWM program was used to monitor the M1 and M2 degradation; verification was performed throughout the COSTAR build-up, testing, integration, and launch activities. Figure 13 details the COSTAR molecular contamination budget for the external surfaces and M1 and M2 mirrors. The actual obscuration for the M1 and M2 mirrors (not shown) ranged from 0.5 to 3.5 percent.

CONCLUSION

As a result of incorporating important cleanliness controls early in the design phase of the SIPEs, an effective program for fabricating a protective enclosure to preclude degradation of the FSM SIs was developed. The design strategy included material screening beyond ASTM E595 selection criteria, high temperature component bakeouts, honeycomb panel directional venting, a purge system and vent design, and a monitoring scenario using witness plates, molecular rinses, tapelifts and OWMs. The implementation strategy employed stringent contamination controls during the SIPE fabrication, integration, test, instrument integration, Orbiter integration, and on-orbit activities to minimize potential surface contamination of the FSM SIs.

REFERENCES

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2. M. Peterson and B. Choudhury, "HST/SM SIPE Contamination Analysis", LMSC Memorandum EM: SPS 644A, 5 February 1992.
3. J.B. Barengoltz, J.M. Millard, T. Jenkins, and D.M. Taylor, "Modeling of Internal Contaminant Deposition on a Cold Sensor", SPIE 1329: 337-351, 1990.
4. J.B. Barengoltz, S. Moore, D. Soules, and G. Voecks, "The Wide Field/Planetary Camera 2 (WFPC-2) Molecular Adsorber", JPL Publication 94-001, 15 January 1994.

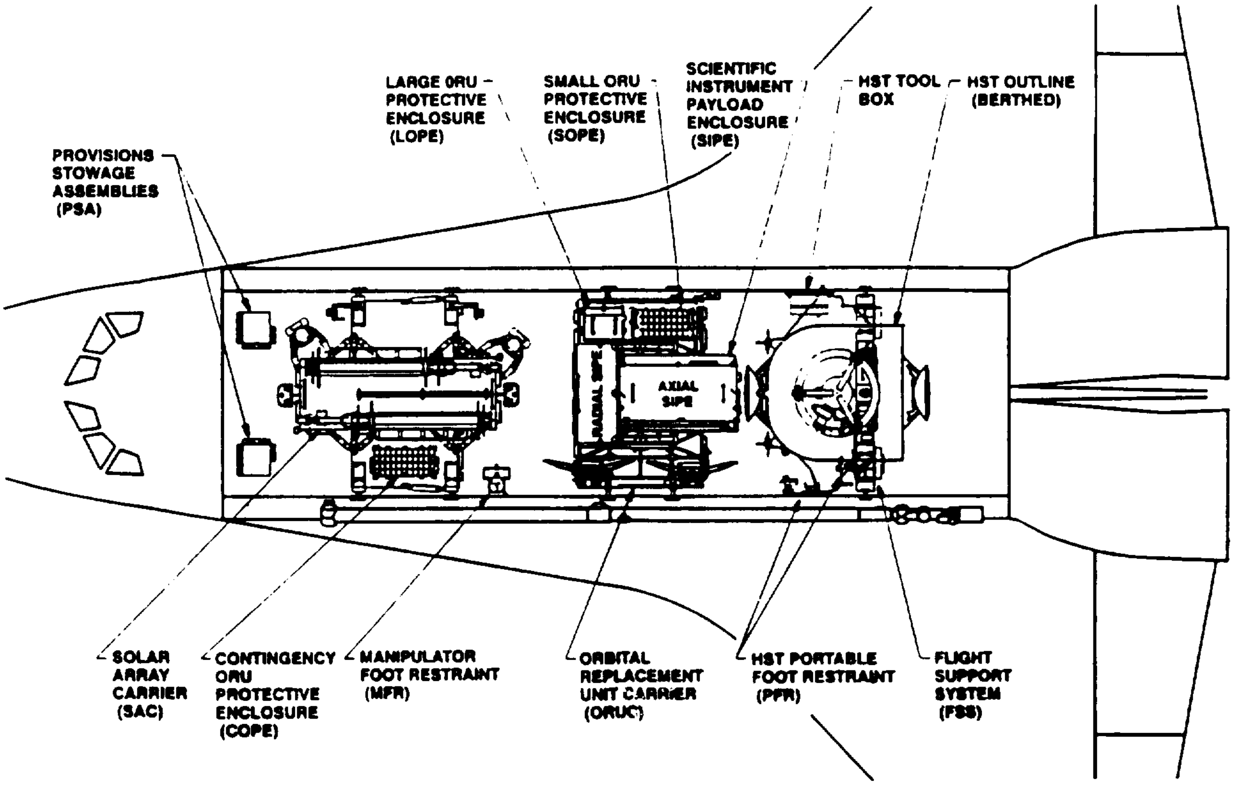

Figure 1. HST First Servicing Mission (STS-61) Cargo Configuration

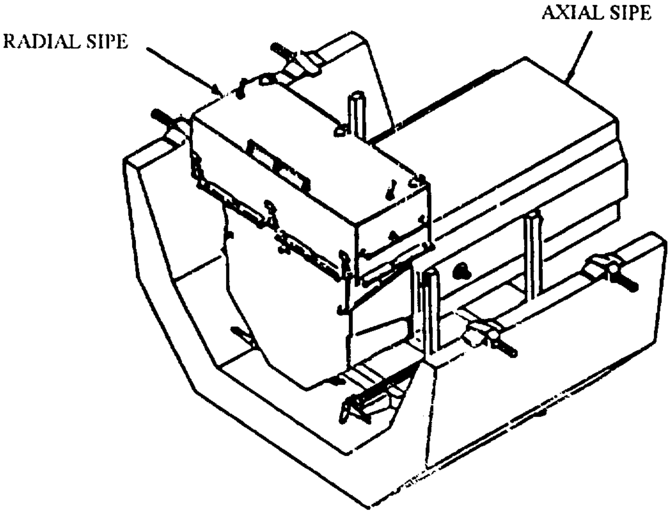

Figure 2. ORUC with SIPEs Integrated

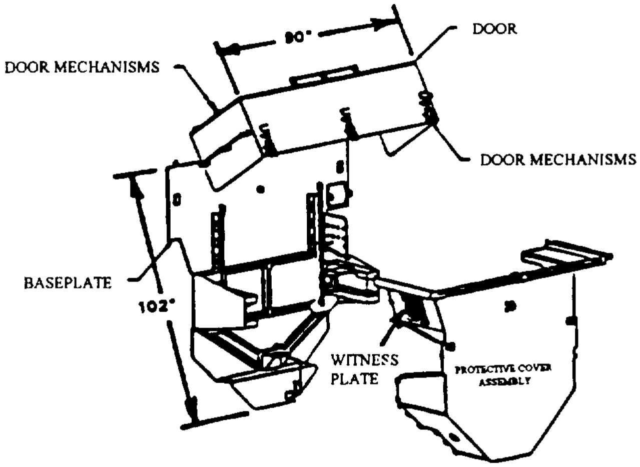

Figure 3. RSIPE Components

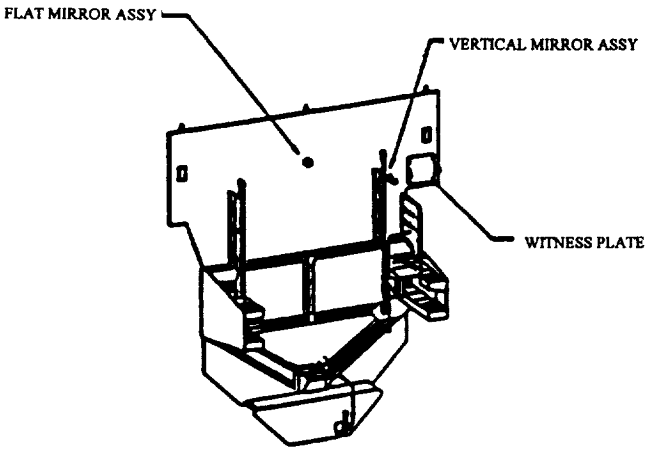

Figure 4. RSIPE Baseplate Contamination Monitors

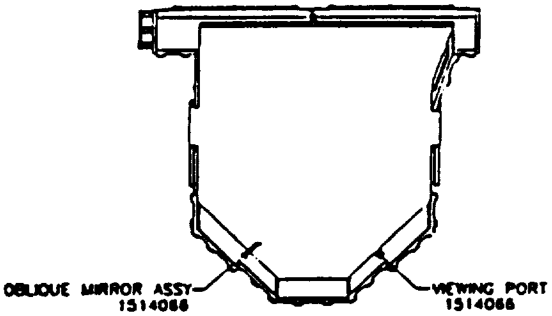

Figure 5. RSIPE Oblique Mirror and QCM Port

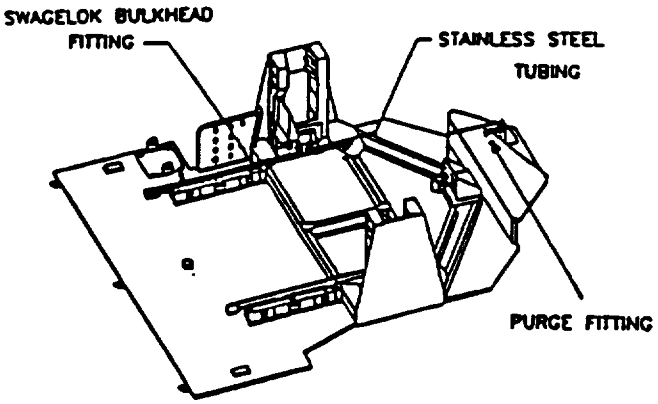

Figure 6. RSIPE Purge System

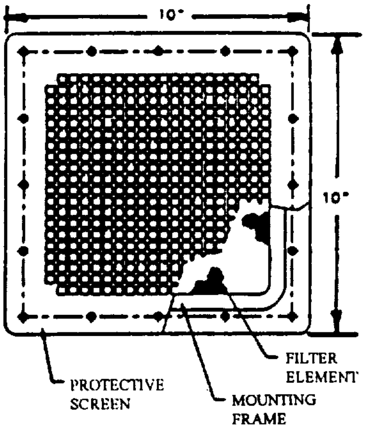

Figure 7. SIPE Vent Filter Design

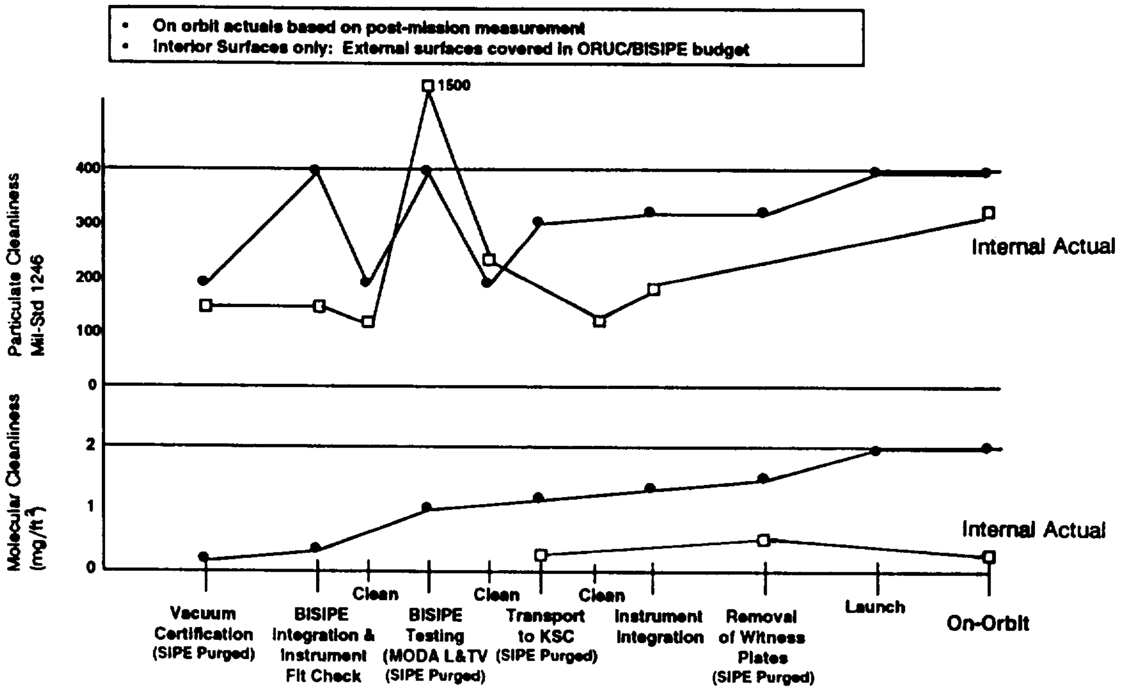

Figure 8. RSIPE Contamination Budget

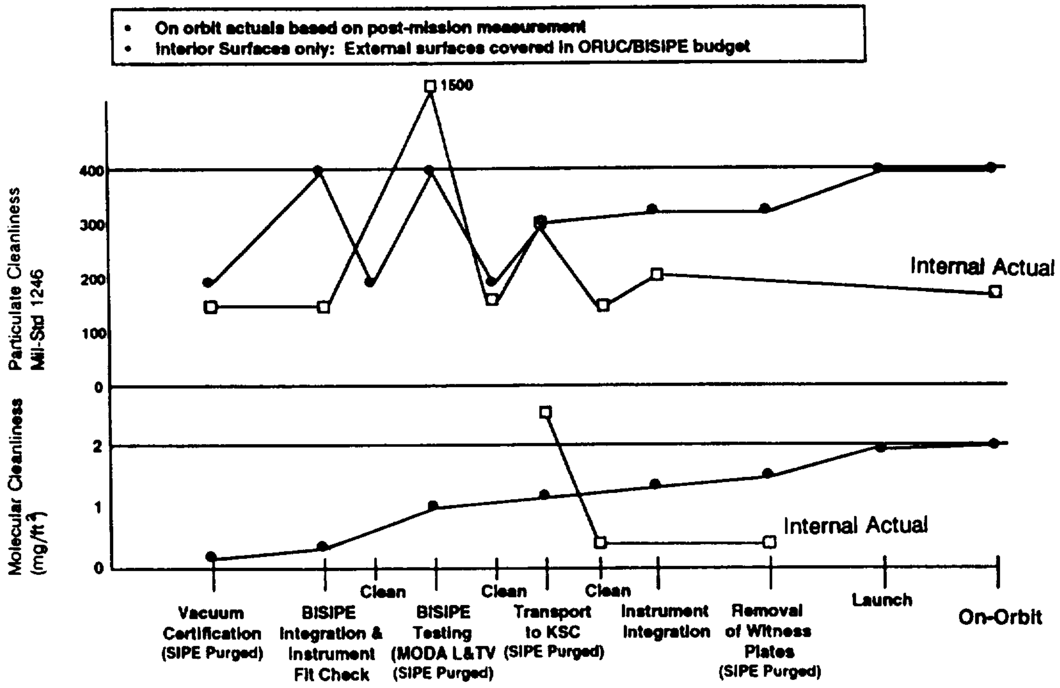

Figure 9. ASIPE Contamination Budget

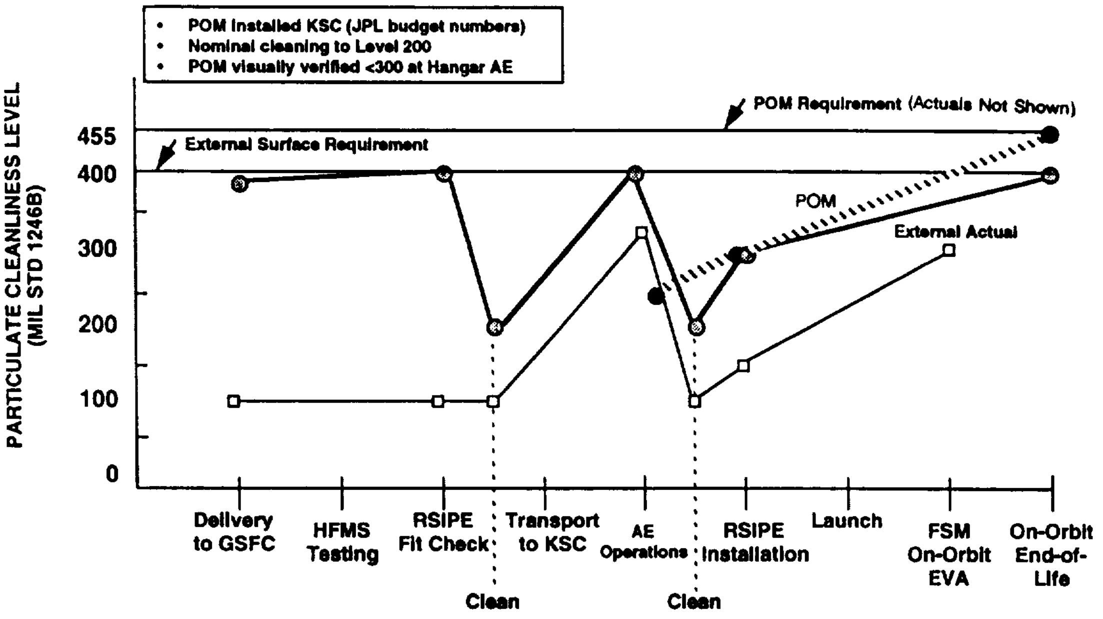

Figure 10. WFPC-2 Particulate Contamination Budget

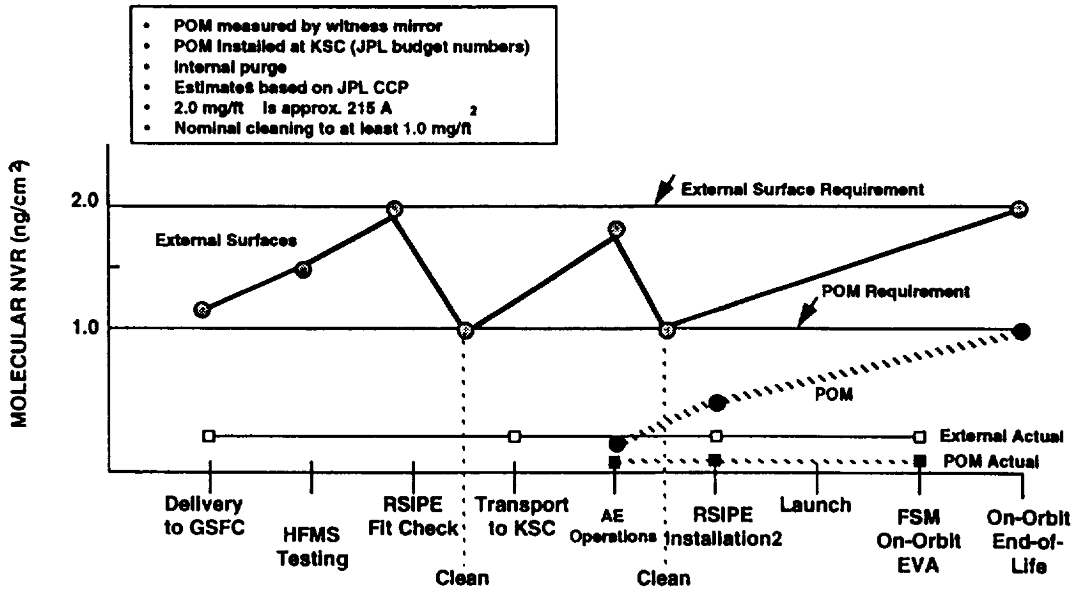

Figure 11. WFPC-2 Molecular Contamination Budget

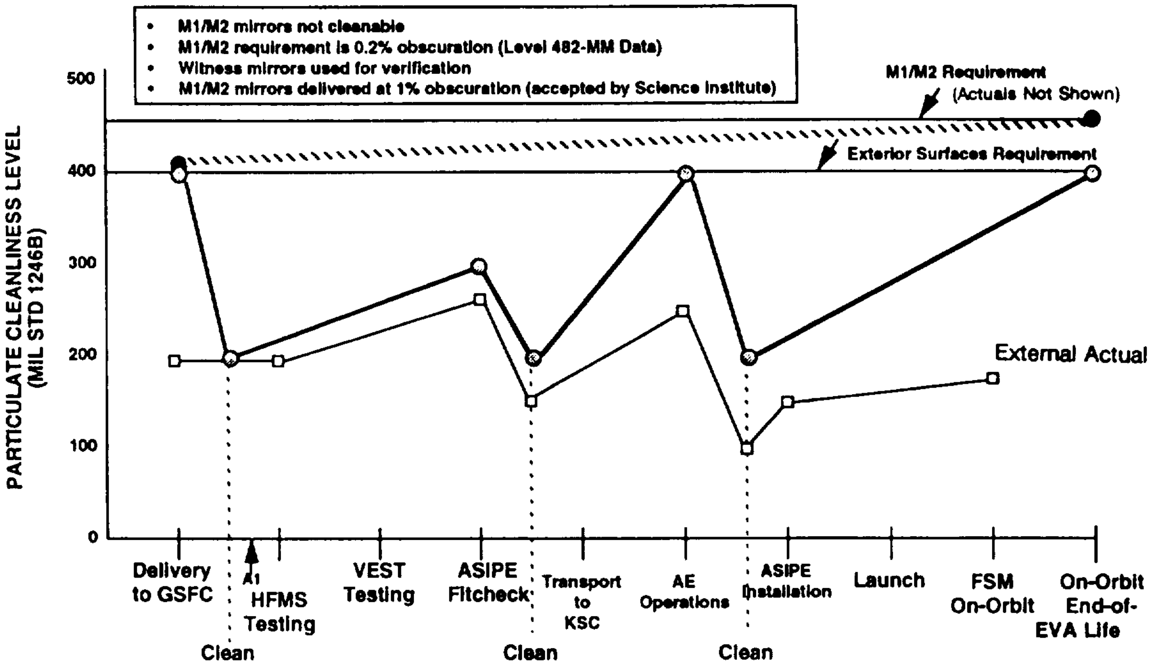

Figure 12. COSTAR Particulate Contamination Budget

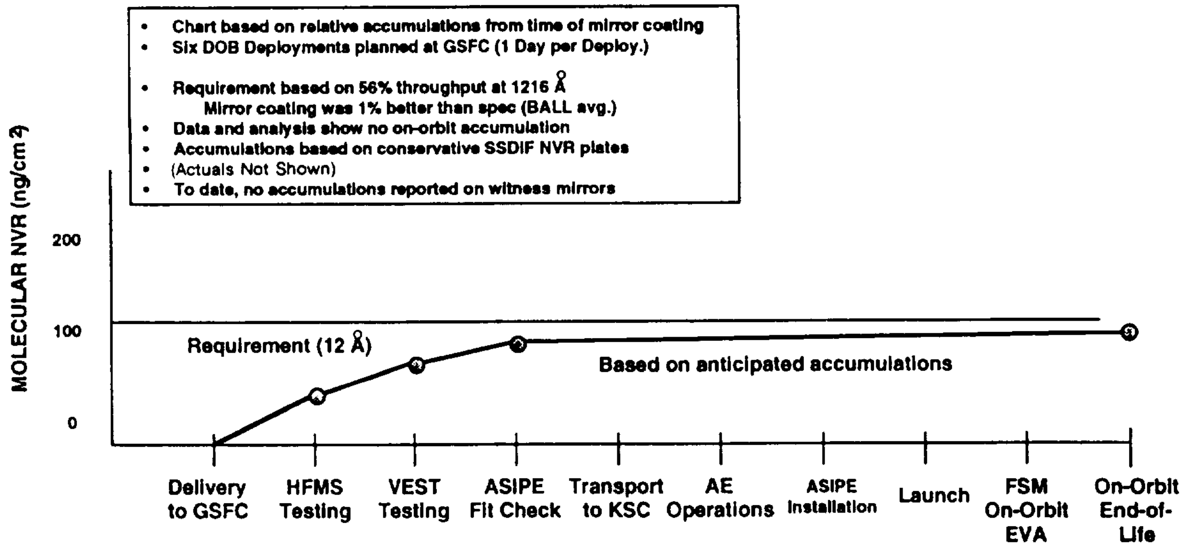

Figure 13. COSTAR Molecular Contamination Budget