Mir Contamination Observations and Implications to the International Space Station

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ABSTRACT

A series of external contamination measurements were made on the Russian Mir Space Station. The Mir external contamination observations summarized in this paper were essential in assessing the system level impact of Russian Segment induced contamination on the International Space Station (ISS).

Mir contamination observations include results from a series of flight experiments: CNES Comes-Aragatz, retrieved NASA camera bracket, Euro-Mir '95 ICA, retrieved NASA Trek blanket, Russian Astra-II, Mir Solar Array Return Experiment (SARE), etc. Results from these experiments were studied in detail to characterize Mir induced contamination.

In conjunction with Mir contamination observations, Russian materials samples were tested for condensable outgassing rates in the U.S. These test results were essential in the characterization of Mir contamination sources.

Once Mir contamination sources were identified and characterized, activities to assess the implications to ISS were implemented. As a result, modifications in Russian materials selection and/or usage were implemented to control contamination and mitigate risk to ISS.

Keywords: contamination, Mir, space station, spacecraft, materials outgassing

1. INTRODUCTION

As international agreements on the Russian participation in the International Space Station (ISS) program were finalized, the integration of Russian hardware with the ISS configuration became critical to the program. In the area of external contamination, it became necessary to assess the compatibility of Russian hardware with the ISS system level requirements[1]. Of primary importance was to maintain the environment specified in these requirements as ISS hardware and payloads are designed to operate within this environment.

In order to assess Russian hardware compatibility, it was first necessary to characterize the contamination sources in the Russian hardware, analyze the contamination induced by these sources onto ISS contamination sensitive hardware, assess compliance with requirements and implications.

The Russian space station Mir was the focal point of initial investigations on the induced contamination environment.

[1] NASA, Space Station External Contamination Control Requirements, NASA SSP 30426 Revision D, 1994.

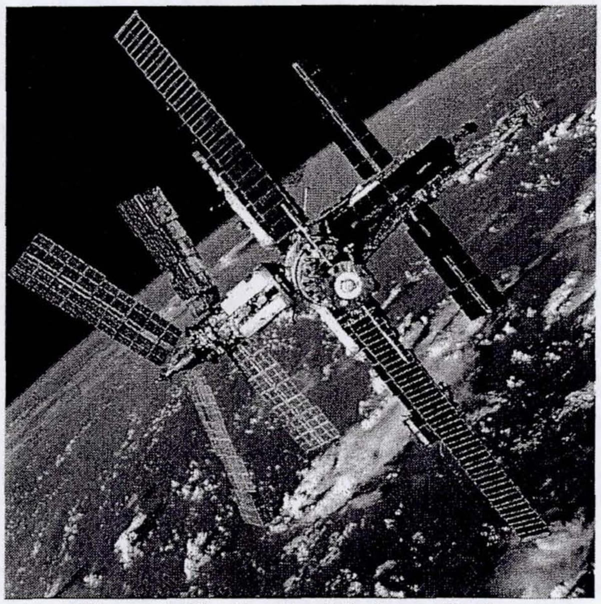


Figure 1: The Russian Mir Space Station

Mir contamination observations were made during the 14 year lifetime of the station. These observations stem from a series of flight experiments: CNES Comes-Aragatz, NASA STS-74 camera bracket, Euro-Mir '95 ICA, retrieved NASA Trek blanket, Russian Astra-II, Mir Solar Array Return Experiment (SARE), and many others. Some of these experiments were flow during the NASA Phase 1 program, also known as the Shuttle-Mir program. External contamination data was collected during each of the 11 Space Shuttle flights which span a four-year period.

2. CNES COMES-ARAGATZ FLIGHT EXPERIMENT

The Comes-Aragatz flight experiment[2] was deployed and retrieved during spacewalks 13 months apart (from December 9, 1988 to January 11, 1990). The experiment was returned to earth on February 19, 1990.

During most of this timeframe the Mir station consisted of only the Base Block and the Kvant modules. The Kvant 2 module was only mated to the complex on December 1989. It is important to note the size of Mir, and its implications to the Comes-Aragatz observations, when comparing results with other Mir flight experiments.

This flight experiment consisted of four panels; which exposed samples on both sides. One side was identified as the "V" side and the other side was identified as the "R" side. The materials exposure experiment was mounted on the Mir Base Block (also referred to as the Mir Core Module), on the narrow conical section near the center of the Mir Core Module.

The temperature range for the panels is estimated to be from -60°/-70°C (coldest, experiment in shadow) to +10°/+30°C for the V side, and from -60°/-70°C to +50°/+60°C on the R side. The atomic oxygen fluence is estimated to range from 3.6×10^{20} to 5.9×10^{20} atoms/cm^2 for the R side, and from 3.7×10^{18} to 7.3×10^{19} atoms/cm^2 for the V side. The solar vacuum ultraviolet (VUV) radiation exposure is estimated at 2850 ESH for the V side and 1900 ESH for the R side.

The resulting contaminant deposit was identified as an SiOx layer superposed with a carbon/oxygen layer of unspecified thickness:

- Average contaminant deposit thickness measured on the R side was 350 ± 50 Å
- Average contaminant deposit thickness measured on the V side was 780 ± 50 Å

These results are consistent with the estimated exposure to solar ultraviolet radiation and atomic oxygen: The V side received the least amount of atomic oxygen fluence and the highest amount of UV, maintaining lower temperatures.

[2] Guillaumon, J.C. and Paillous, J.M., "Flight and Laboratory Testing of Materials in Low Earth Orbit,"

3. NASA STS-74 CAMERA BRACKET

During the Phase 1 program (Shuttle-Mir), a camera bracket was mounted on the docking module for 4 months. The bracket was exposed to the Mir contamination environment from November 19, 1995 through March 27, 1996.

The camera bracket side with the heaviest amount of contamination had a view of the Spektr module. The side with the lowest amount of contamination had a view of the docking module and the Krystal solar array, with a peripheral view of the Soyuz, Kvant and Mir Core Module.

The camera bracket was exposed to one Mir solar cycle (period with no time in shadow lasting several days) on January 6, 1996. Temperature, atomic oxygen fluence and solar UV exposure were not estimated for the camera bracket. The bracket was made of aluminum coated with A-276 white paint.

X-Ray Photoelectron Spectroscopy (XPS), performed at the NASA White Sands Test Facility, showed a contaminant deposit identified as an SiO_x layer consistent with polymethylsiloxane and SiO_2. The measured contaminant deposit thickness was 12,000 Å (sample 001B). This is equivalent to a condensable outgassing rate of approximately 1×10^{-11} g/cm^2/sec.

The camera bracket exposed samples showed a substantial layer composed of primarily silicon and oxygen in an atomic ratio of 1 to 2. There was a carbon layer at the interface between the top layer and the bulk material.

Sample 001B showed a thick layer composed of silicon and oxygen with a carbon-rich layer at the interface with the bulk material. Sample 002B showed two distinct layers composed of silicon and oxygen separated by a carbon layer.

4. EURO-MIR '95 ICA FLIGHT EXPERIMENT

Euro-Mir '95 began in September 1995 and was completed in March 1996. ICA QCM mission data was available from October 1995 through January 1996. ICA was part of the Euro-Mir '95 ESEF platform. ICA was located on the end-cone of Spektr module.

Two Quartz Crystal Microbalances (ICA QCMs 1 and 2) were directed along the Spektr module axis (at the time thought to be facing ram). One QCM (ICA QCM 3) was directed perpendicular to the Spektr axis (thought to be facing the nadir direction).

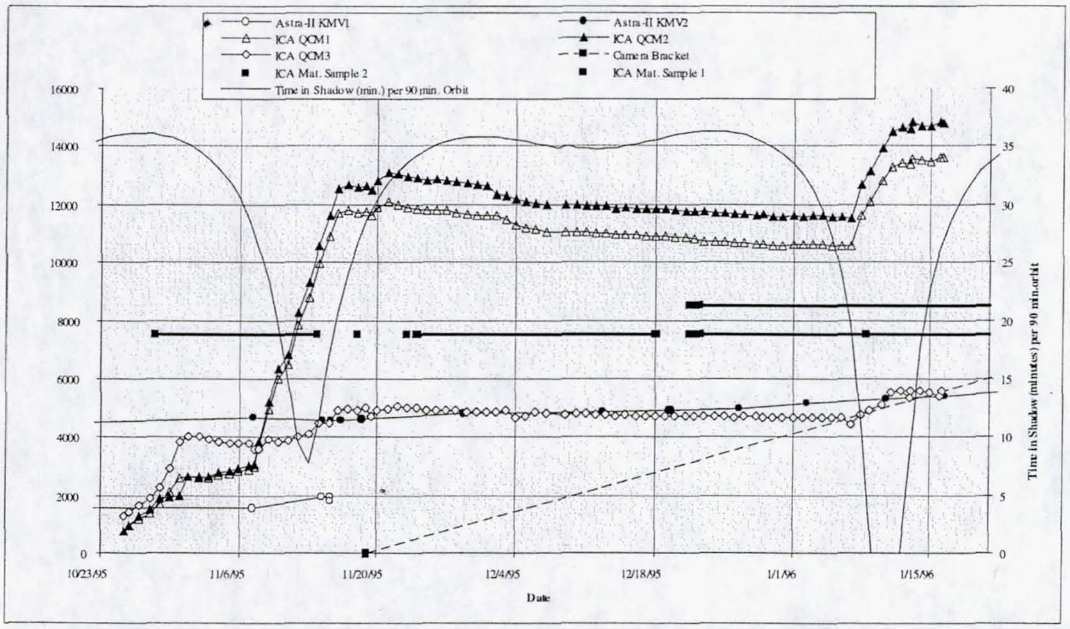


Figure 2: Euro-Mir '95 ICA QCM Measurements and Mir Time in Shadow

Significant increases in ICA QCM frequency measurements correlate well with Mir attitude data and increase in temperature due to "solar cycles" (time in shadow). Pressure readings from within the Spektr endcone indicate significant materials outgassing from within the non-pressurized endcone.

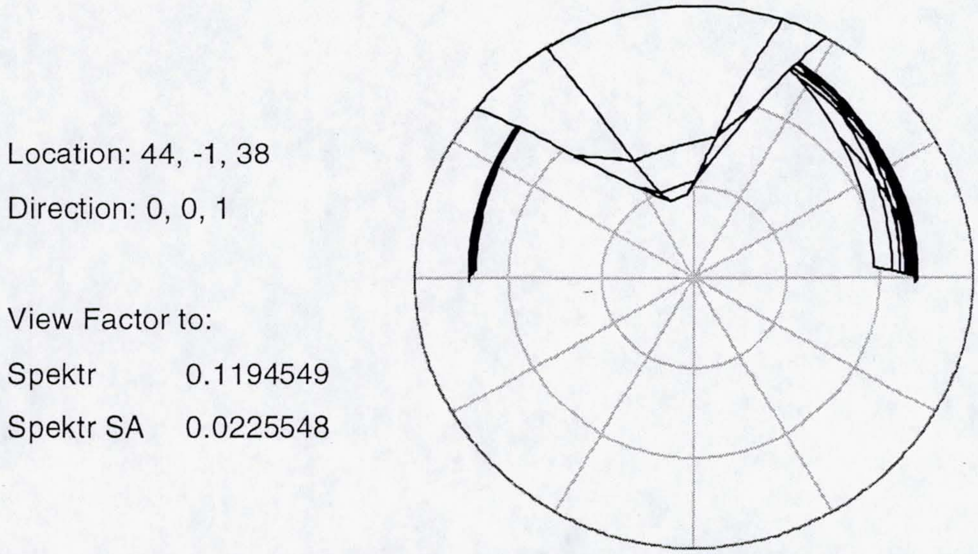


Figure 3: View from ICM QCMs 1 and 2 and Viewfactors to Spketr Module and Solar Arrays

Dates	Nov. 7-16, 1995	Jan. 7-11, 1996
QCM 1 deposition rate ($g/cm^2/sec$)	1.2×10^{-10}	7.8×10^{-11}
QCM 2 deposition rate ($g/cm^2/sec$)	1.3×10^{-10}	8.5×10^{-11}
QCM 1 derived Spektr outgassing rate ($g/cm^2/sec$)	**1.0×10^{-9}**	**6.5×10^{-10}**
QCM 2 derived Spektr outgassing rate ($g/cm^2/sec$)	**1.1×10^{-9}**	**8.0×10^{-10}**

Table 1: ICA QCMs 1 and 2 Deposition Rates and Derived Spektr Module Outgassing Rates

Dates		Nov. 7-16, 1995	Jan. 7-11, 1996
Observed	QCM 1 deposition rate ($g/cm^2/sec$)	1.2×10^{-10}	7.8×10^{-11}
	QCM 2 deposition rate ($g/cm^2/sec$)	1.3×10^{-10}	8.5×10^{-11}
	QCM 3 deposition rate ($g/cm^2/sec$)	1.8×10^{-11}	3.0×10^{-11}
Derived	QCM 1 derived Spektr outgassing rate ($g/cm^2/sec$)	**1.0×10^{-9}**	**6.5×10^{-10}**
	QCM 2 derived Spektr outgassing rate ($g/cm^2/sec$)	**1.1×10^{-9}**	**8.0×10^{-10}**
	QCM 3 derived Spektr outgassing rate ($g/cm^2/sec$)	**8.9×10^{-10}**	**1.5×10^{-9}**

Table 2: ICA QCMs 1 and 2 Deposition Rates and Derived Spektr Module Outgassing Rates

5. RUSSIAN ASTRA-II FLIGHT EXPERIMENT

The Astra-II QCMs have been operating since June 1995. Disruption due to Progress impact. Astra-II is located on the end-cone of Spektr module, on the opposite side from the ICA flight experiment.

One Crystal Microbalances (KMV 2) is directed along the Spektr module axis, facing the Mir core. The second QCM (KMV 1) was directed perpendicular to the Spektr axis (Zenith direction).

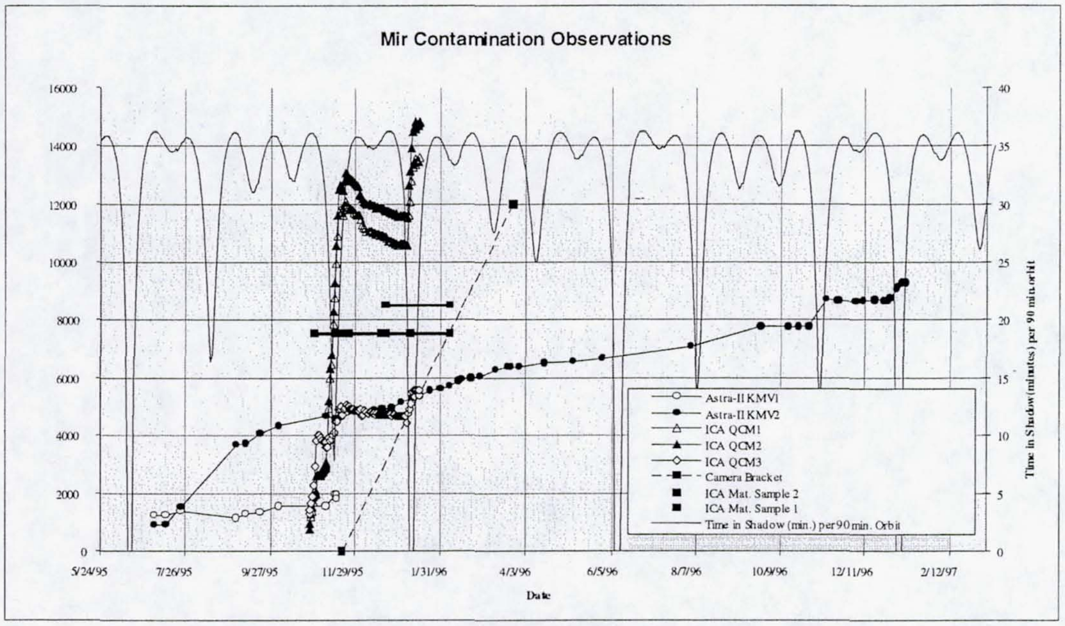


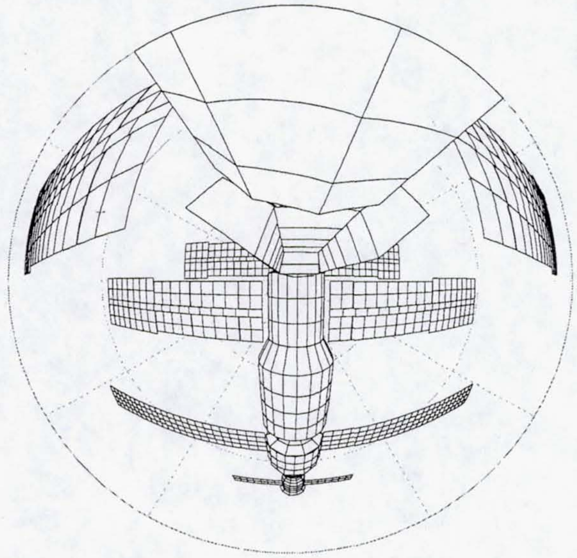
Figure 4: Astra-II QCM Measurements and Mir Time in Shadow

Location: 31, 1, 30

Direction: 0, 0, -1

View Factor to:

Spektr	0.2771924
Spektr SA	0.0413169
Core	0.0845588
Core SA	0.0652032
Kvant	0.0068475
Kvant SA	0.0215639
Progress	0.0011795
Progress SA	0.0012173
Priroda SA	0.0300060



View Factor to Spektr/Core/Kvant: 0.3685985

Figure 5: View from Astra-II KMV2 QCM and Viewfactors to Mir Hardware

Dates	KMV2 deposition rate ($g/cm^2/sec$)	KMV2 derived Spektr/Core/Kvant outgassing rate ($g/cm^2/sec$)
7/22/95-9/1/95	6.0×10^{-12}	1.6×10^{-11}
5/29/96-8/2/96	7.0×10^{-13}	1.9×10^{-12}
8/2/96-9/24/96	1.5×10^{-12}	4.1×10^{-12}
10/29/96-11/12/96	8.3×10^{-12}	2.3×10^{-11}
12/27/96-1/7/97	6.6×10^{-12}	1.8×10^{-11}

Table 3: Astra-II KMV2 QCM Deposition Rates and Derived Spektr/Core Module/Kvant Outgassing Rates

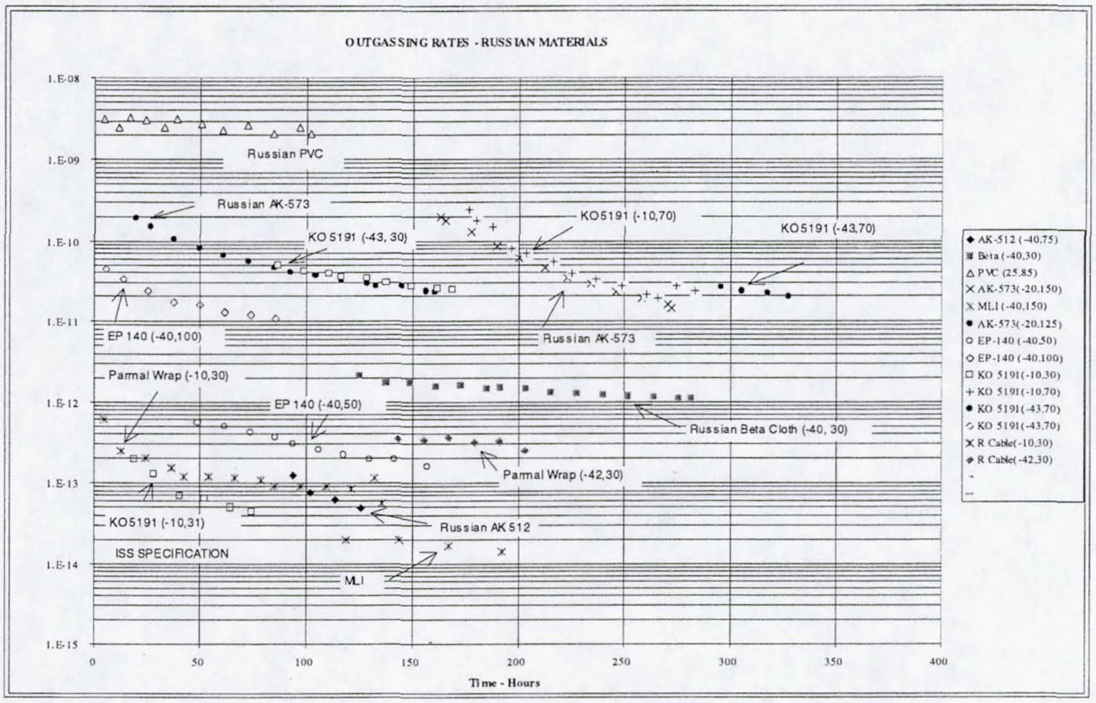
6. MIR SOLAR ARRAY RETURN EXPERIMENT (SARE)

The Mir Solar Array Return Experiment assessed long-term degradation of Mir solar arrays, as well as external contamination and orbital debris environment.

7. MIR CONTAMINATION SOURCES

Russian vacuum exposed materials used in large-surface area applications were identified, and further tested for chemical composition and characterization of condensable outgassing rates.

Materials condensable outgassing rate testing was performed according to ASTM E 1559. The tests were of long duration, typically 144 hours. Condensable outgassing rates were measured for a range of temperatures (material sample and QCM receivers). The outgassing rate data was curve fitted to account for time decay due to long on-orbit residence times.



8. ANALYSIS OF MIR CONTAMINATION OBSERVATIONS

Comes-Aragatz and Camera Bracket:

The effective outgassing rates to produce the contamination observed on the Comes-Aragatz experiment were estimated at 3.2×10^{-11} g/cm^2/sec for the R side and 7.1×10^{-11} g/cm^2/sec for the V side. The effective outgassing rate to produce the contamination observed on the camera bracket was estimated at 1.2×10^{-10} g/cm^2/sec. These results are consistent with typical large surface area Mir materials and coatings (such as KO-5191).

KO-5191 (organic silicone based paint) probably was the major source of contamination since it coated a large composite section on the Mir Core Module that was viewed by the Comes-Aragatz experiment. Another silicone contamination source, although a lower order of magnitude contributor, is AK-573 (organic silicone based paint).

The PVC cable insulation and the BF-4 impregnated mesh (solar arrays) also contribute to contamination, but these are hydrocarbon contamination sources.

The Mir complex was considerably smaller during the time frame of the Comes-Aragatz experiment. This is consistent with the lower contamination measurements observed on the Comes-Aragatz samples. Further, results from the Comes-Aragatz experiment are consistent with the estimated exposure: V side received the least amount of atomic oxygen fluence and the highest amount of UV, maintaining lower temperatures.

The higher rate inferred from the camera bracket contaminant deposit layer is consistent with the higher source temperatures due to the Mir solar cycle and the fact that the Spektr module was a recent addition at that time.

ICA Flight Experiment (Euro-Mir '95) and Russian Astra-II Flight Experiment:

The significant increases in ICA QCM frequency measurements correlate well with Mir attitude data and increase in temperature due to "solar cycles" (time in shadow). The effective outgassing rates required to produce the observed contamination are consistent with typical PVC rates. PVC is used for electrical cable insulation on the Spektr module.

The pressure readings from within the Spektr endcone indicate significant materials outgassing from within the non-pressurized endcone.

Correlation of ICA QCM frequency readings with Mir attitude data and pressure measurements from within the Spektr endcone indicate that materials outgassing and contaminant deposit re-release due to surface heating are the sources of contamination.

9. IMPLICATIONS TO THE INTERNATIONAL SPACE STATION

The ISS External Contamination Team performed an assessment of Mir external contamination observations, including analysis of data from several sources. Participants in analysis activities included Boeing, NASA, ESA/ESTEC and RSC-Energia.

External contamination analysis was performed for every identified contamination source and deposition estimates were obtained for sensor and sample surfaces on Mir.

Results were instrumental in ISS Russian segment changes to ensure compliance with ISS external contamination requirements, for example:

- Cable insulation on ISS Russian segment: Teflon instead of PVC
- Replace high-outgassing KO-5191 and AK-573 with AK-512
- Solar array lubricant: fluorocarbon instead of silicone

10. CONCLUSIONS

Once Mir contamination sources were identified and characterized, activities to assess the implications to ISS were implemented. As a result, modifications in Russian materials selection and/or usage were implemented to control contamination and mitigate risk to ISS.

These activities also demonstrate that the external contamination methodology developed by the ISS External Contamination Team is successful in identifying contamination sources and mitigating risks to the program. This methodology has been documented in previous publications (Reference 8).

External contamination analysis is performed for every identified contamination source and deposition estimates are obtained for all ISS contamination sensitive surfaces. The External Contamination Master Verification Database summarizes cumulative estimated deposition rates for all ISS sensitive surfaces. It is also instrumental in identifying any potential issues.

Optical property degradation models have been developed to account for long on-orbit residence time and VUV exposure. These models are semi-empirical (based on laboratory and flight data).

11. REFERENCES

1. NASA, Space Station External Contamination Control Requirements, NASA SSP 30426 Revision D, 1994.
2. Guillaumon, J.C. and Paillous, J.M., "Flight and Laboratory Testing of Materials in Low Earth Orbit,"
3. Comes-Aragatz
4. Camera Bracket
5. Euro-Mir '95 ICA
6. Astra-II
7. Russian materials test data
8. STAIF-99 paper