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# DEGRADATION OF OPTICAL COMPONENTS IN A SPACE ENVIRONMENT

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## SUMMARY

Phillips Laboratory's LDEF optical experiment is designed to determine the adverse effects of the natural space environment on laser optical component and coating materials. The experiment consists of 10 sample sets, each containing six different material samples. The materials were chosen because of their common use in laser optical components. Sample characterization is divided into three phases. Phase I testing is limited to visual and optical performance evaluation. Phase II tests investigate the fundamental causes of the performance degradation quantified in Phase I. During Phase III, selected samples will be cleaned and some Phase I measurements repeated to determine if acceptable optical performance can be restored, and laser damage testing will be performed on a small number of samples. Performance deteriorations will be correlated to exposure duration, sample location on the LDEF, atomic oxygen levels, and other space environment conditions. Preliminary results obtained on the optical samples are discussed in this paper.

## EXPERIMENT DESCRIPTION

The Phillips Laboratory (PL) experiment consists of 60 samples organized into 10 identical sets of 6 samples each. The samples are finished on both sides, so a total of 120 surfaces are available for characterization and analysis. Each set includes one sample each of: 1) uncoated fused silica, 2) magnesium fluoride coated fused silica, 3) uncoated molybdenum, 4) molybdenum coated with chromium, silver and thorium fluoride, 5) diamond turned copper, and 6) diamond turned nickel plated copper. Two sample sets were never flown (ground control samples), one set was flown on the trailing edge but was not exposed (flight control samples), and one set was flown on the leading edge and exposed for 70 months. The remaining six sets were exposed for 3, 6, and 9 months on both the leading and trailing edges. The Phillips Laboratory optical experiment is unique in that identical samples were exposed for various durations of time on both the leading and trailing edges of the LDEF.

All but one of the PL flown sample sets were located in Environmental Control Canisters (ECC). The canisters were not opened during the first 14 days in orbit when the immediate environment contained a heavy concentration of contamination introduced by the Shuttle [1]. Also, after 9 months, the canisters were closed, preventing sample exposure to the high fluxes of atomic oxygen encountered late in the mission. The canisters still possessed a partial vacuum when disassembly was performed in the clean room environment at Kennedy Space Center. The ECC samples should be relatively contamination free compared to the samples exposed on the leading edge for 70 months. It is anticipated that observed differences in optical performance degradation will be seen between those samples exposed for 3, 6, 9 and 70 months.

## CHARACTERIZATION PROGRAM

Phillips Laboratory has developed a three phase characterization plan to determine sample optical performance degradation and correlate measured degradation with space exposure. Phase I is restricted to visual, microscopic and optical evaluation. Phase II tests are designed to gain an understanding of fundamental material changes affecting optical performance, and Phase III will include laser damage testing and optical component cleaning. Results from all phases will be correlated with sample exposure location and duration. It is anticipated that samples flown on the leading edge (LE) will have suffered more performance degradation than samples on the trailing edge (TE). It is also feasible that samples exposed to the space environment for longer periods of time will show more performance degradation than those exposed for shorter periods of time.

Phase I measurements are nondestructive and include, but are not limited to: 1) full surface photography, 2) high resolution microscopy and photography, 3) absorption, 4) transmission and reflectance, 5) ellipsometry, 6) scatter (BRDF), and 7) an impact site count. A detailed surface map will also be made of each surface. The surface mapping consists of a visual and microscopic examination which provides a qualitative measure of the types of damage sustained by each sample and is being used to locate and identify unusual damage sites.

Phase II analysis will determine surface morphology and chemistry, film depth profiles, atomic population density, erosion depth and mass loss. Techniques designed to investigate the fundamental reasons for performance degradation are in many cases intrusive and will not be undertaken until Phase I measurements are complete.

During Phase III, selected samples will be cleaned according to standard optical cleaning and/or innovative procedures. Selected Phase I tests will be repeated to determine if the sample's performance can be restored to an acceptable level. A small number of samples will be laser damage tested.

## PRELIMINARY CHARACTERIZATION RESULTS

Full Surface Photography. Full surface photography has proven to be a valuable tool for surface mapping and is a simple technique in which the sample is placed in a dark room, illuminated by a high intensity light at a high angle of incidence, and photographed. The photograph shows surface irregularities as points of scattered light. All full surface photographs were taken in a class 100 clean environment. Each sample surface (front and back) has been photographed twice, once with the sample fiducial mark at zero degrees to the direction of illumination and again at 90 degrees. The photographs reveal that surface contamination and damage vary greatly from sample to sample.

Figure 1 is a full surface photograph of a diamond turned, nickel plated copper, flight control sample. The sample surface was coated at the time of manufacture with a protective film that was not removed until just before the sample was photographed. The photograph shows a clean surface devoid of scatter sites. Figure 2 is a photograph of a magnesium fluoride coated fused silica ground control sample. There are several scatter sites on the surface showing that even the ground control samples, which were stored under good conditions, display some contamination. Figure 3 is a photograph of a molybdenum sample which was flown on the LDEF trailing edge and exposed for 3 months. There are significantly more scatter sites on this sample than the control sample, implying that the LDEF space environment significantly increased surface contamination and/or damage. The increase in contamination/damage becomes even more apparent in photographs of samples exposed for longer periods of time. A coated molybdenum sample exposed for 70 months is shown in Figure 4. The scattered light from this surface identifies a rather large ($\approx$ 1 cm diameter) damage site.

The scatter sites shown in the full surface photographs are being investigated with a Nomarski microscope, and photomicrographs are being made for unusual contamination areas and impact sites. Optical measurements are being made on the highly blemished surface areas as well as on the cleaner areas.

Microscopy. Initial microscopy on the PL optical samples was performed by The Aerospace Corporation at the time the samples were removed from the trays. Phillips Laboratory is performing a final microscopic evaluation on each sample. The full surface photographs which have been taken of each surface are assisting in locating some sites requiring careful examination in Phase I and Phase II characterization.

The damaged area of the coated Mo sample discussed above (Figure 4), upon high levels of magnification, appears as shown in Figure 5. It is obvious that the overall damage area is many times the diameter of the crater. The mechanism for the coating failure in the vicinity of the strike is probably thermal or shock related or possibly a synergistic combination of both. It is evident from the photograph that the damage is quite severe and of considerable spatial extent. This type of damage has a pronounced effect, from a systems standpoint, on scatter. It is anticipated that the damage site will also have a significant effect on absorption.

The extent of debris and micrometeoroid caused damage varies. Figure 6 shows a strike on $MgF_2$ coated fused silica (LE, 9 month exposure) where the damage is relatively constrained. In contrast to Figure 6, Figure 7 documents an impact on uncoated fused silica (LE, 70 month exposure) which produced localized chipping and fracture zones extending many particle diameters. Figure 8 is a dark field photograph of a 1 mm diameter area on a fused silica sample which was exposed on the LE for 70 months. Each bright spot is light being scattered off a damaged area. When the dark field is removed, typical chipping associated with impact sites can be seen in the damaged areas. This sample will be photographed under higher magnification to verify that these damaged areas are impact sites. Optics with damaged areas such as these are potentially high scatter and high absorption optics.

Scatter Measurements. BRDF measurements made on the optical samples are being made on a research grade scatterometer, High Resolution Scatter Mapping Instrument (HRSMI), operated in the PL Optical Components Branch. The HRSMI is capable of high resolution scatter measurements and surface scatter mapping. All scatter data reported in this paper was taken at 6328 Angstroms. It is anticipated that samples flown on the leading edge and/or exposed for longer periods of time may be more highly scattering than samples flown on the trailing edge and/or exposed for shorter periods of time.

A scatter map of a fused silica sample is shown in Figure 9. The sample surface was exposed on the LE for 70 months; therefore, we anticipated that this surface would be highly scattering. The scatter map shows scatter varying two orders of magnitude across the sample surface.

The effects of micrometeoroid damage are important for brittle materials. Investigators have found fracture lines extending 2 cm from impact sites [2]. Figure 10 is a scatter map of an impact site on the LE, 70 month, fused silica sample. Scatter intensity from the center of the crater is five orders of magnitude greater than the sample background. Fracture lines extending from the crater are high scatter sites on the surface and are indicated in the mapping by rows of peaks. The intensity of the peaks is between one and three orders of magnitude greater than the surface background. This map demonstrates the severe scatter effects of impact damage on brittle materials.

A graph of scattered intensity versus detector angle for various uncoated fused silica samples is shown in Figure 11. Eleven measurements were taken across each sample, and the eleven data points for a given detector angle were averaged to give one data point on the graph. The line defined by "+" symbols is scatter measured from a clean superpolished substrate which is not part of the LDEF sample set. The other four graphs represent data from uncoated fused silica samples. The data shows the expected trend between TE and LE samples. The ground control sample and the TE, 3 month sample are the lowest scattering of the four samples, while the LE samples are the most highly scattering. The two LE data curves have the same shape implying that the contamination and/or contributing to scatter is the same on both surfaces. It is interesting to note that the measured scatter of both the 70 month and 9 month exposed samples is the same. Two possible explanations for this phenomena are: 1) whatever is causing the scatter reached a condition where scatter is no longer affected, or 2) contamination on the 70 month sample was removed by atomic oxygen, radiation, or some other type of scrubbing effect which lowered the scatter to a level comparable to the 9 month exposure sample.

A preliminary attempt to determine the presence and magnitude of scattering from surface contamination was made. Scatter from the unexposed side of the LE, 70 month, uncoated fused silica sample was measured; and the data, represented by squares in Figure 12, shows that the surface is highly scattering. The surface was then blown with an air brush in an attempt to remove contamination, and the scatter measurement was repeated. The data, represented by triangles in Figure 12, shows that the surface scatter was not reduced. An alcohol drag was then performed twice on one-half of the surface, and the scatter was remeasured. The data, represented by diamonds, shows that cleaning the surface reduced the scatter three orders of magnitude. This is a significant reduction in scatter, indicating that there is considerable contamination on the sample surface.

Preliminary scatter data has also been collected on selected $MgF_2$ coated fused silica samples (Figure 13). Again, we anticipated that the LE samples would be more highly scattering than TE samples. The data, however, shows the complete opposite trend - TE samples are more highly scattering than LE samples. The reverse trend may possibly be attributed to the sample's coating. It has been shown that coating an optic increases its surface scatter; therefore, if the coatings on the LE samples have been removed by the space environment then the LE samples will be less scattering than the TE samples. All ten samples in this sample set will be measured to verify the preliminary data, and tests will be performed to determine each coating's condition.

## CONCLUSIONS

The Phillips Laboratory optical experiment is unique. Identical samples were flown on both the leading and trailing edge and were exposed for variable lengths of time. Therefore, the potential exists to correlate optical performance to exposure duration and position.

Preliminary investigations indicate that these samples have experienced severe contamination and damage levels. Initial scatter data has shown that there is a potential relationship between sample exposure position and duration and surface scatter. These observations indicate that optical systems which are critically impacted by high scatter levels or high local absorption may be adversely affected by space environments similar to that experienced by LDEF.

## REFERENCES

1. LDEF - 69 Months in Space, First Post-Retrieval Symposium, Part I, June 2-8, LDEF Science Office, NASA Langley Research Center, 1991.

2. "Meteorite and Debris Impact Features Documented on the Long Duration Exposure Facility." Preliminary Report, NASA Publication #94 (Aug 1990).

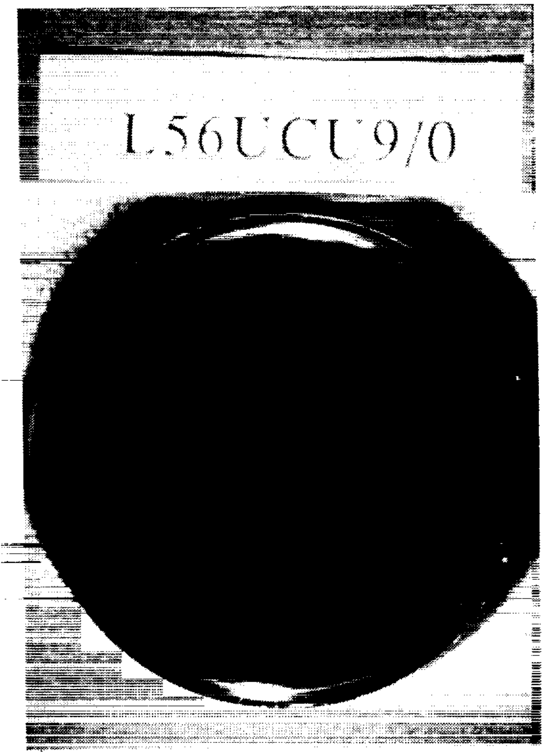

FIGURE 1: Full surface photograph of a clean optical surface. Sample is nickel plated copper.

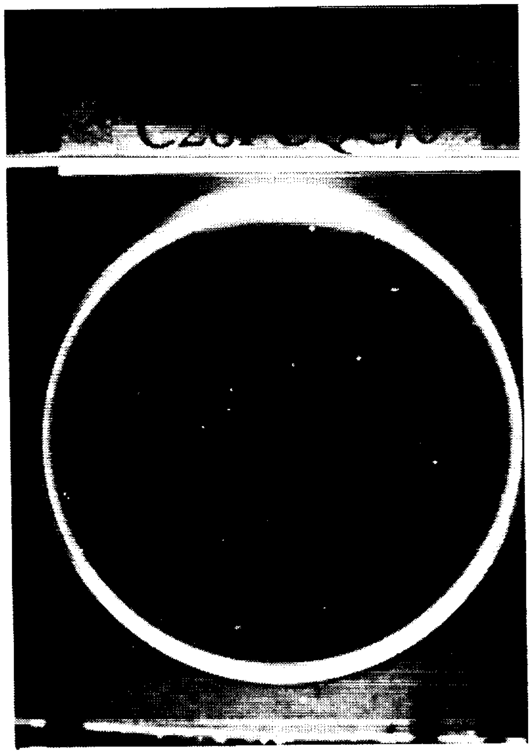

FIGURE 2: Full surface photograph of $MgF_2$ coated fused silica control sample.

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FIGURE 3: Full surface photograph showing many scatter sites on a molybdenum sample.

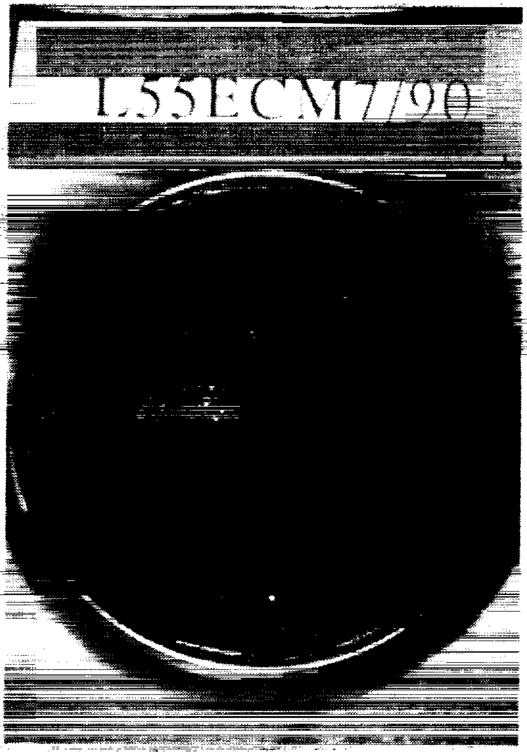

FIGURE 4: Full surface photograph showing a large damage site on a coated molybdenum sample.

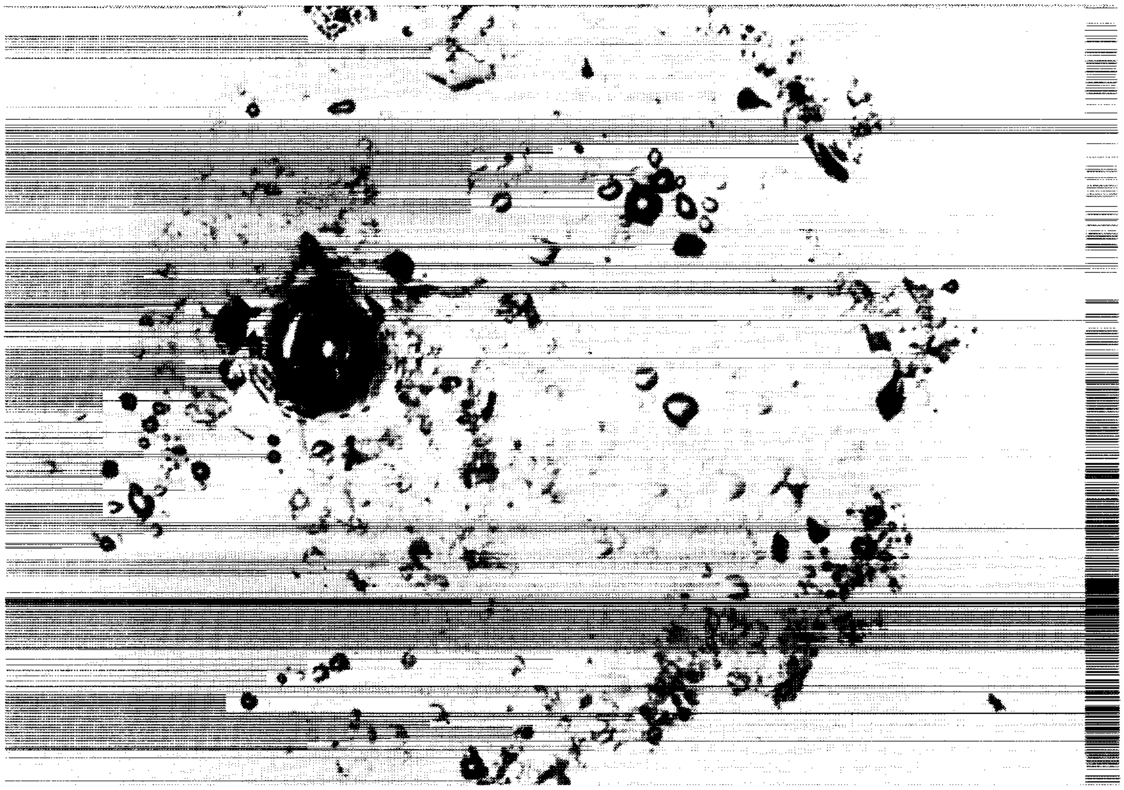

FIGURE 5: Micrometeoroid impact site surrounded by localized damage.*

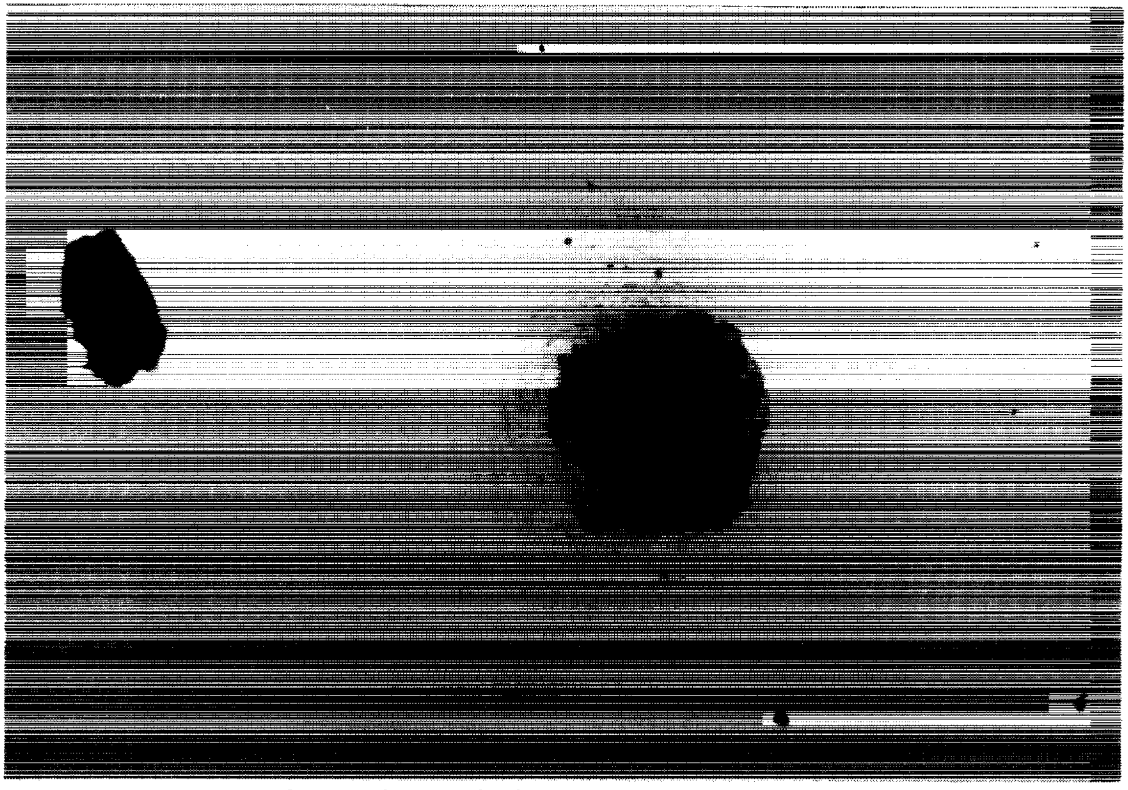

FIGURE 6: Impact site with limited localized damage on $MgF_2$ coated fused silica.*

*Photograph Courtesy of The Aerospace Corporation.

FIGURE 7: Micrometeoroid impact site surrounded by localized damage.*

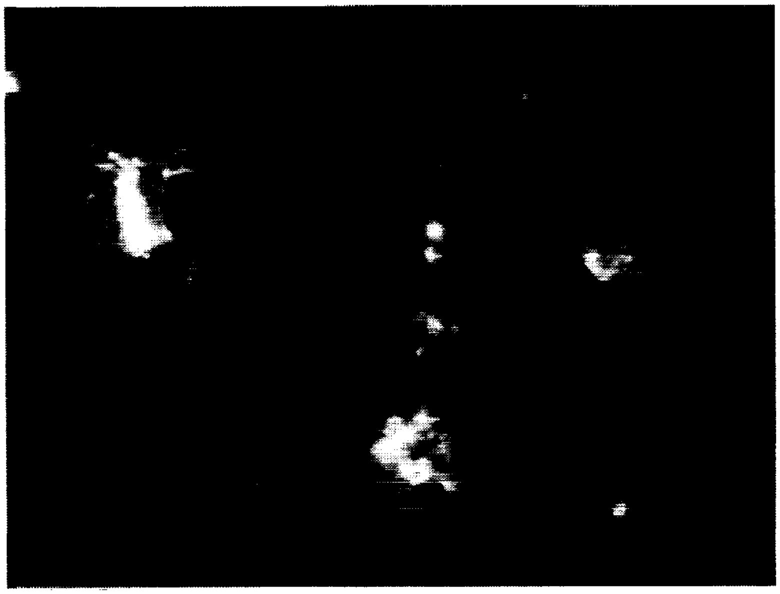

FIGURE 8: Dark field photograph showing fracture zones on a fused silica surface.

*Photograph Courtesy of The Aerospace Corporation.

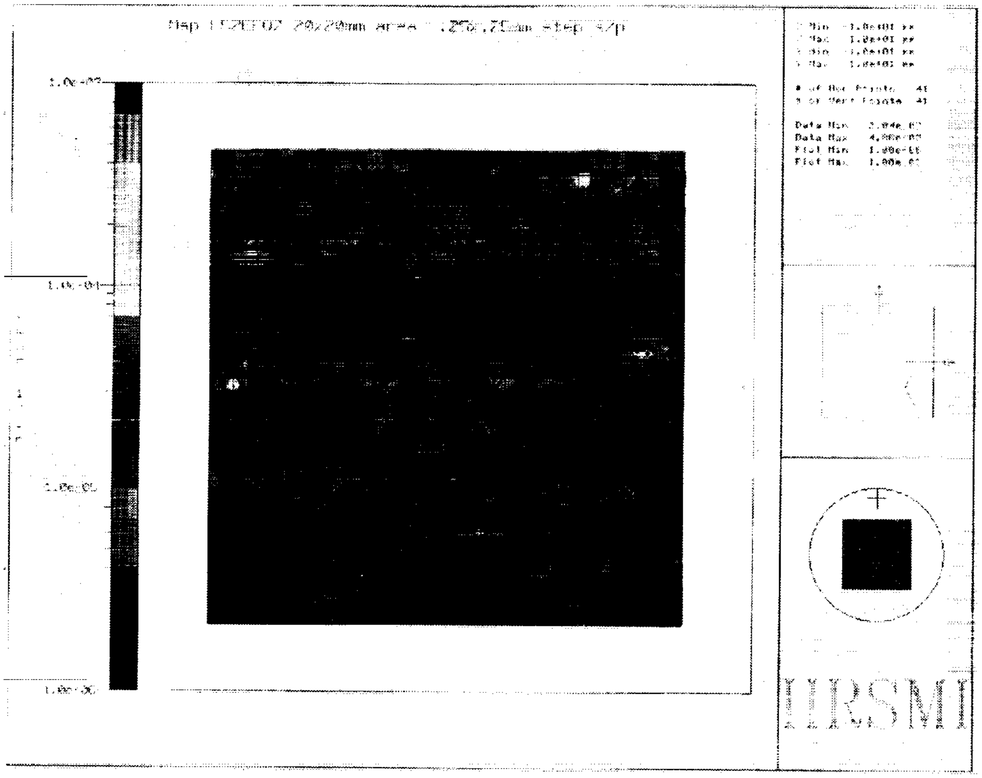

**FIGURE 9**: Scatter map of fused silica sample.
See color photograph on page 1563.

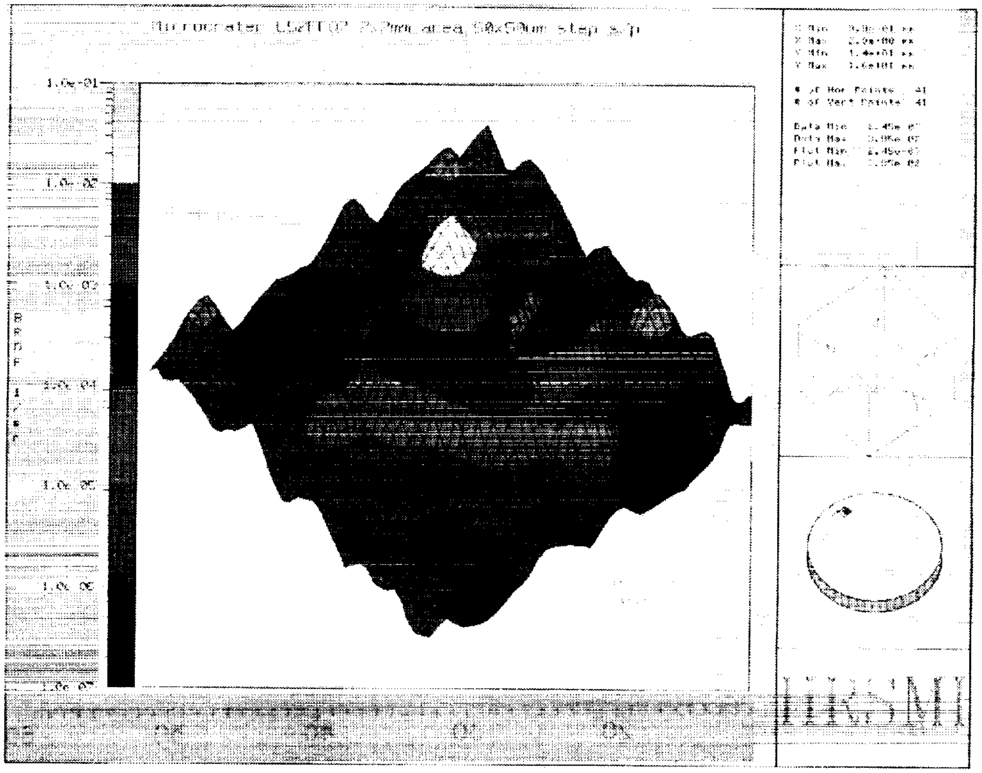

**FIGURE 10**: Scatter map of a micrometeoroid impact site on fused silica.
See color photograph on page 1564.

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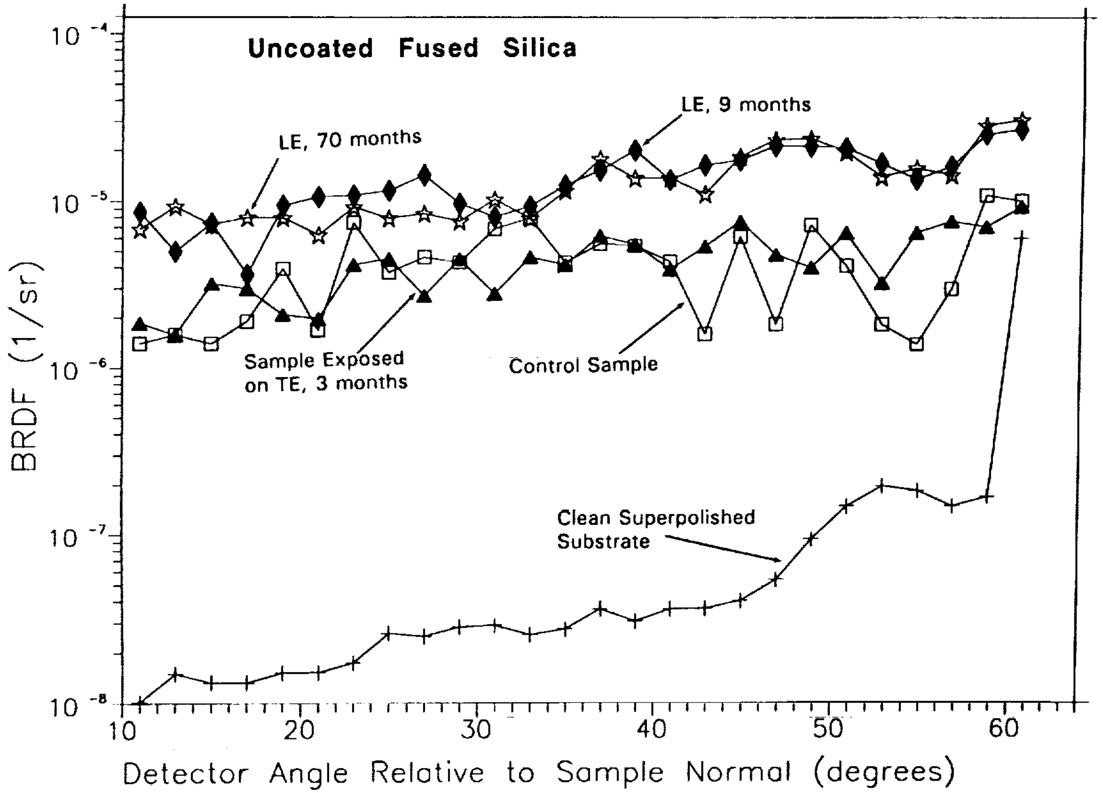

FIGURE 11: Graph of scattered intensity versus detector angle for four fused silica samples.

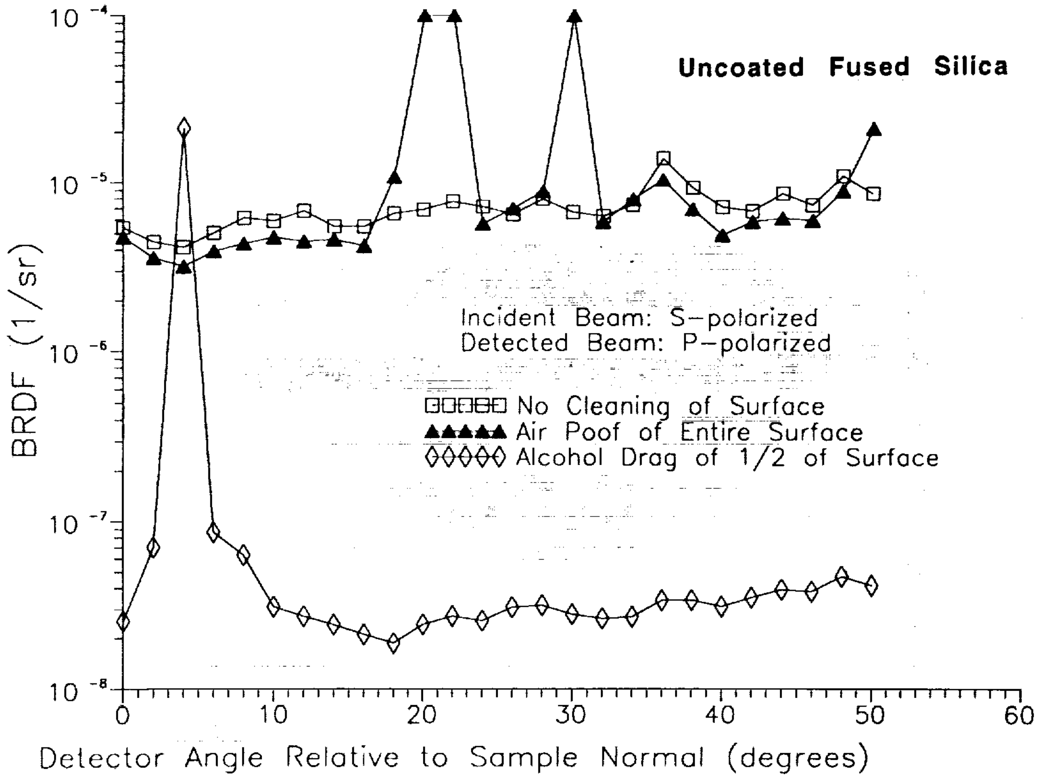

FIGURE 12: Scatter data showing effects of surface cleaning on fused silica sample.

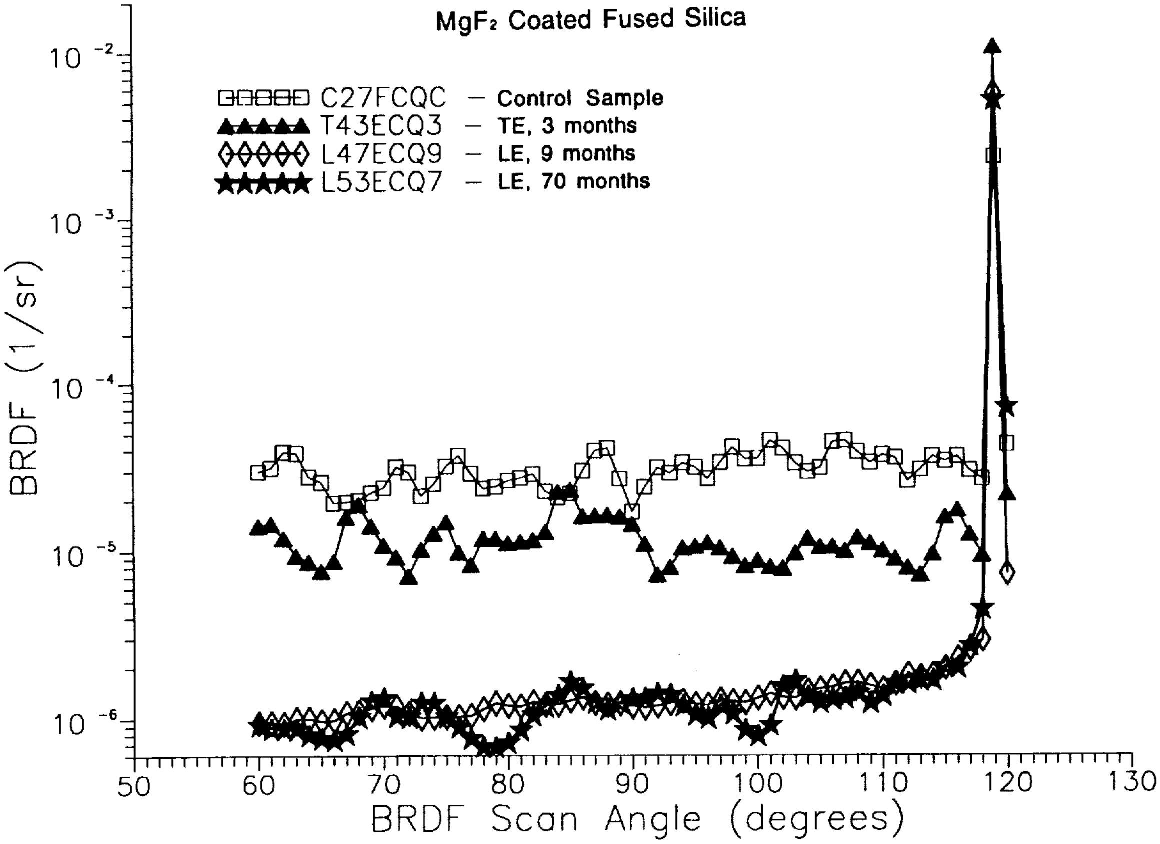

FIGURE 13: Graph of scattered intensity versus detector angle for four $MgF_2$ fused silica samples.