N92-23286

PARTICLE TYPES AND SOURCES ASSOCIATED WITH LDEF*

E. R. Crutcher and W. W. Wascher
Boeing Defense and Space Group
Seattle, WA 98124-2499
Phone: 206/773-7002, Fax: 206/773-1473

SUMMARY

The particulate contamination history of LDEF is evident through the particles, the surfaces on which the particles are found, and the most probable sources for the types of particles found. The particles were identified as residues from fabrication, residues from assembly, cross-contamination from integration or launch, orbit generated debris, cross-contamination from reentry or ground operations up to Kennedy, and contamination at Kennedy. It was easy to distinguish between the particles present during orbit and those deposited during or following recovery by the shielding of the surface provided by particles present during orbit. On the ram facing trays particles protected the surface from atomic oxygen erosion. On the trailing trays particles shielded the surface from the deposition of outgassed materials. Once it had been determined if the particle was present prior to orbit or introduced following orbit possible sources could be sought. In this manner the raw material for a history of LDEF contamination was collected.

When LDEF entered orbit it carried a variety of contaminants from assembly operations and from the shuttle bay itself. Residues from fabrication and assembly included abrasives, abrasion generated metal, plastic, wood dust, spray paint, wear metals, and other debris. General fallout and handling debris such as skin flakes, paper and clothing fiber, natural minerals, etc. were also included with the assembly contaminants. Shuttle tile material and the bay liner Beta Cloth materials were used as indicators of cross-contamination between the payload and the Shuttle Bay. Once LDEF entered orbit the contaminants on the surface of LDEF began interacting with the environment. Most particles appear to have been associated with an outgassing phase, probably water, that created a local 'high pressure' zone. These zones were evident around the particle as an area where molecular films from other sources could not deposit. The effect was to create an optical inhomogeneity much larger than the original particle's obscuration area. Some particles were associated with a condensable outgassing material and generated a halo around themselves. This also resulted in an optical effect larger than the particle's obscuration value. A third mechanism in which a particle created an enlarged optical footprint was the actual movement of the particle creating shadows in more than one area. This movement appears to have been the result of thermal effects and of impacts near the particle.

New particulate contaminants were generated in orbit by impacts with micrometeorites or space debris. These contaminants were predominantly LDEF materials shattered, ejected as molten metal, or ejected as a gas phase that could then redeposit on LDEF. Many examples of such deposition were evident on LDEF.

The exposure to atomic oxygen in orbit eroded carbon based materials leaving 'ash' and jagged remnants of what had been solid sheets of plastic. Plastic films with vapor deposited metal backing were reduced to flakes of very thin metal foil. Paint films became a layer of free pigment particles protecting the remaining paint film beneath them. These materials were reasonably stable in orbit but with the

*Work done under NAS 1-18224, Task 12

repressurization of the Shuttle Bay during reentry they became free moving particles contaminating the interior of the Shuttle Bay and the surface of LDEF. Small fragments of the molecular films created in orbit on the surface of LDEF were also blown free and became particulate contaminants in the Shuttle Bay.

During ground operations from the OPF through SAEF-2 additional particulate contaminants accumulated on the surface of LDEF. This photoessay provides documentation of many of these particle types and of the surface effects mentioned above. LDEF provided the first opportunity to quantify contaminants over the entire surface of a satellite and to document the effects of contaminants on that surface.

INTRODUCTION

This paper is a brief photoessay of the particulate contaminants found on the various surfaces of LDEF with a description of their probable source and the methods used to establish that source. It includes photographs taken directly from LDEF surfaces in SAEF-2 as well as those taken later in the laboratory. Photographs of tapelift samples collected from the surface of LDEF, the shuttle bay, and from different Kennedy facilities or fixtures associated with LDEF are also included.

Determining the source of a particle on a surface necessarily involves some knowledge of the history of the sources to which the surface was exposed and the duration or conditions of that exposure. In the case of LDEF there were a number of well documented events that had an effect on the exposure of the satellite to surface contaminants (Ref. 1). Photographic evidence documenting those effects along with a description of the criteria used to establish both the time of the arrival for particles at the surface of LDEF and their probable source are included here.

DETERMINING PARTICLE ARRIVAL TIME

One of the early concerns regarding the interpretation of the contamination history of LDEF was the ability to distinguish new contaminants from those that were present on the surface during orbital exposure. The first microscopic examination of the Teflon blanket material revealed a remarkably well recorded chronology of events in the tracks of deposited molecular films. The surface of the Silver/Teflon blanket from the first tray removed, the seeds experiment tray F-02, was examined the day of its removal using the Nomarski microscope station adjacent to the LDEF satellite in the SAEF-2 clean room. The pattern of shadows characteristic of particles on the surface during the orbital exposure and the non-shadowed "new" particles were documented that same day (see Photograph 1). The patterns seen on the surface beneath the particles tended to indicate the time at which the particle had arrived at the surface. Particles with no "shadow" had clearly arrived after the "shadowing" event. On tray F-02 this was the deposition of molecular contaminants and the ultraviolet modification of the Teflon surface. Absence of both shadow effects indicated that these particles arrived at their current location during recovery or subsequent activities. Particles with shadows could be placed in two groups; those with shadows of their projected area and those with shadows much larger than their projected area. Cellulose particles tended to have shadows much larger than their fiber diameter. Cellulose also has the tendency to retain large amounts of water absorbed into its structure. With elevated temperature or vacuum it tends to give up the absorbed water. This relatively high partial pressure of water vapor may be responsible for the extensive "protected" area or shadow seen around cellulose particles. Any particle at rest on a surface for extended intervals of time tends to adsorb water at the interface between the particle and the surface. The extended shadow of minerals or other non-absorbing particles may be due to this effect. These particles would then be those that were present on the surface of LDEF prior to launch. Particles with only a sharp silhouette would be new arrivals at the time LDEF went into orbit. These would be the particles that relocated during the launch and orbit insertion events. Photograph 1 illustrates mineral particles with extended shadows around the particle, those without extended shadows (discounting the "comet tail"), shadows without particles indicating where a particle had been during orbit but that moved sometime during recovery, and new particles with no shadow (including no comet tail).

Row 2 was a trailing row (as were rows 1, 3, 4, and 5), and was not exposed to any significant level of atomic oxygen. The leading rows (rows 7, 8, 9, 10, and 11) exhibited a different pattern when the surface was protected by particulate contaminants. Areas of uneroded surface material projected above the eroded surface of carbon based materials (see Photographs 2, 3, and the second photo of Figure 1). A few particles on the leading row trays moved while in orbit. The particles left an eroded pattern of their silhouette where they had been and created a new silhouette on the eroded surface that they then protected (Photograph 4 and Figure 2 tray C-08 photographs). The relative time the particle spent in each position could be deduced by the relative amount of atomic oxygen erosion that had occured at each location. As some carbon based surfaces were eroded metal oxide ash was left in proportion to the trace metals present as part of catalysts, antioxidants, inorganic fillers, or contaminants present in the material. Resin systems were often coated with a fine white ash resulting from atomic oxygen erosion as can be seen in the background of Photograph 3, a carbon fiber/resin composite. Some particulate contaminants were carbon based and did not survive the atomic oxygen exposure on the leading rows but left their outline as a slightly less eroded pattern on the surface (see Figure 1, photograph 3). Particles that had moved while in orbit as opposed to those that were carbon based and had been eroded away by the atomic oxygen left different patterns in the underlying eroded surface. When a particle moved it exposed edges that began eroding rapidly resulting in rounded rather than sharp edges. Eroded particles left an inert ash behind, often concentrated near the edges of the particle, with the result that the edges were often less eroded than the area where the main body of the particle had been. Photograph 6 is a good example of this effect.

Three types of shadows characterized the presence of particles on the exterior surface of LDEF during its orbital exposure; molecular film, atomic oxygen, and ultraviolet light. Molecular film shadows are shown in Photograph 1 and Figure 2, photograph 1. Molecular film shadows often exhibit what appears to be an outgassing positive pressure zone around the particle that prevents local deposition of films. This is most pronounced around particles with significant amounts of water to outgas as is the case with cellulose fibers (Figure 2, photograph 1). Atomic oxygen shadows were characterized by less surface erosion as seen dramatically in carbon based systems and to a lesser degree on other surfaces. The ultraviolet shadow effect is seen in Figure 1, photograph 2. The smooth surface of glass fiber and the ultraviolet transmission of some glasses created an atomic oxygen shadow but not an ultraviolet shadow. The ultraviolet modification of the Teflon surface under the fibers on tray C-08 shown in figure 2 may have contributed to their final movement . Because of the position of the tray with respect to the ram direction the ray path through the fiber would not have been normal to the surface of the Teflon. As a result the ultraviolet modification of the Teflon surface under the fiber would have been asymmetric, increasing the instability of the fiber's position.

The particles themselves often exhibited the evidence of orbital exposure. Photographs 9 and 10 show two organic fibers modified by their exposure to atomic oxygen and energetic ultraviolet light. In Photograph 9 the straight chain nylon polymer has been reorganized through disruption of the bonding along the chain and the generation of crosslinkages. This is evident by the change in the electron density distribution indicated by the change in the color effects exhibited when the fiber is viewed between crossed polarizing filters. In Photograph 10 both atomic oxygen and ultraviolet light exposure effects are evident on a cellulose fiber.

Secondary evidence based on the identification of contaminants found on the surface, the location of those contaminants, and their most likely source or sources was used to elaborate on the chronology established by the direct evidence. For example a cellulose particle found on a leading edge tray surface could not have survived the atomic oxygen exposure of orbit. It would have to have arrived at the surface during or after recovery. The position of LDEF in the Shuttle bay during nearly all of the ground operations had row 12 facing upward. This row has special significance for monitoring fallout while LDEF was on the ground and in the Shuttle Bay. Just prior to and during launch the space end of LDEF was facing upward to collect fallout characteristic of those events. Once in orbit the Shuttle Bay doors were opened and row 12 was the first part of LDEF to receive ultraviolet radiation. Information of this type has been providing and will continue to provide evidence to evaluate various contamination scenarios.

Contaminants created by impacts with space debris or micrometeorites constituted a special class of materials. Figure 3 illustrates a few specific impacts. One of these impacts was the result of a micrometeorite impact with a bolt on a tray clamp of tray E-10. Molten metal droplets were ejected to a distance of about a centimeter onto the tray clamp. Many examples of the transport of molten metal contaminants have been seen on LDEF. On tray H-06, molten droplets were spattered over the bottom of the tray more than 10 centimeters from an impact. Figure 3 also shows impacts with Teflon surfaces, painted surfaces, and anodized aluminum surfaces.

IDENTIFICATION OF CONTAMINANTS AND THEIR SOURCES

The contaminants found on LDEF were from a variety of sources and represented a complex variety of materials. The analytical compound light microscope is the most effective analytical tool available for this type of work and was used extensively for this study. Microchemical tests, microphysical tests, micro-FTIR spectroscopy, electron microscopy, X-Ray fluorescence microscopy, and other techniques were used as appropriate. Below are a few examples of the kind of information used to differentiate particle types during the analysis.

The first example of this type of analysis is that of the variety of glass fibers present and their sources. The glass fiber from the shuttle bay liner has a refractive index of approximately 1.55, a very constant diameter of 15 micrometers, and a gentle wave set into each fiber by the weave of the fabric (Photograph 7 and Figure 1, lower set photograph 2). Shuttle tile fiber has a refractive index of approximately 1.48, is highly variable in diameter, and irregular in shape (Photograph 8 and Figure 1, lower set photograph 1). Glass fiber from fiberglass is a third type present. This material has a refractive index of approximately 1.52, a diameter of about 25 micrometers, and the individual fibers are very straight. Glass fiber from insulation blankets have a refractive index of about 1.52, are highly variable in diameter, and tend to be irregular in shape though not as variable as the Shuttle tile fiber. HEPA filter glass fiber has a refractive index of about 1.5, is variable in diameter but the diameter is less than 10 micrometers and often less than one micrometer, and the fibers tend to be short and straight. These first level discriminators can then be refined further by more accurate characterization of the refractive index or other parameter to identify different sources of the same type of glass fiber.

The Shuttle Bay liner fiber was found widely distributed over the surface of LDEF and on the samples from the Shuttle Bay not collected from the liner. The tapelifts from the liner material contained very large amounts of this fiber and the associated Teflon material. Teflon was found associated with this fiber only on a few occasions from samples collected from the surface of LDEF. These were presumably new materials deposited during recovery. There was no evidence that these particular specimens had seen extended LDEF exposure. Many of the bay liner type of fiber were found on LDEF surfaces with atomic oxygen or molecular film shadows beneath them indicating they were present during orbit. These particles were presumably deposited on LDEF during launch or payload integration. Most of these particles are under 500 micrometers in length.

Glass fiber from insulation batting and glass fiber from glass fiber/resin composites were also common on LDEF. The frequency of encountering these types of fiber varied by location and by proximity to sources on LDEF. Variations in the refractive indices of the glass fiber from composite materials indicated at least four sources. These sources include fiber freed by atomic oxygen erosion of LDEF materials (Photograph 11), a glass fiber/phenolic material, and two glass fiber/epoxy materials. The atomic oxygen freed fibers were redistributed on the surface of LDEF during reentry pressurization and during other pressurizing events in the Shuttle Bay. Glass fiber insulation also was present from multiple sources as indicated by variations in refractive indices.

HEPA filter fiber is very regular in its properties and different HEPA filter sources are more difficult to distinguish though the HEPA source is well characterized (Photograph 12). HEPA filter fiber was found in the Shuttle Bay samples as well as on LDEF. During a layover in the ferry flight the Shuttle was connected to a new HEPA filter purge air cart that had not been blown down. HEPA fiber may have been blown onto LDEF at that time but it was not the only source of such fiber. HEPA fiber concentrations never exceeded the trace level.

No glass fiber attributable to an impact with a ceramic or optic was seen in any of these samples. Glass fiber is a very common contaminant that can provide much information with respect to contaminant sources if it is properly identified as to type. If it is not so characterized the presence of glass fiber indicates little due to the wide variety of potential sources.

Organic fibers illustrate additional morphological and optical properties useful for the identification or characterization of particles. Organic fibers exhibit two different refractive indices. In synthetic polymer fibers one refractive index is characteristic of the polymer crosslinkages and the other of the bonding along the backbone of the polymer. The manufacturing process tends to align the polymer molecule so that crosslinkages are aligned at right angles to the length of the fiber and the core of the molecule is aligned with the length. These indices can be measured separately by using a single linear polarizing filter on the light microscope. With two refractive indices the orientation of the higher refractive index, parallel or perpendicular to the length, becomes a useful characteristic called the sign of elongation. Orlon has a negative sign of elongation, the high refractive index is perpendicular to the length, and nylon has a positive sign of elongation, the high refractive index is parallel to the length. The absolute difference in the two refractive indices is another property called the birefringence of the fiber. The birefringence is low for Orlon (0.002), moderate for Saran, and high for polyester (0.18). Morphological properties include the lumen (tube) down the center of plant fibers, cuticle scales characteristic of mammalian hair, linear striations of crenelate plastic fiber, black specks of rutile in plastic fibers, clay sizing on the surface of paper fiber, and other characteristic structures.

Most of the organic fibers found on LDEF were clothing or paper fibers. Polyester, nylon, and rayon fiber has been used in clean room garments but not Saran, Orlon, polyethylene, cotton, wool, or Teflon fiber. Intensely colored fibers of polyester, nylon, or rayon also generally indicate street clothing and not clean room garments. Trilobate nylon, a common rug fiber, was also found on LDEF. Some of these fibers had been exposed to the orbital environment. Photographs 9 and 10 show modifications due to that exposure. On the leading row trays these fibers were eroded by atomic oxygen leaving only tracks as in upper photograph 3 of Figure 1. These types of fibers are one of the most common Shuttle Bay contaminants. An analysis of the HEPA vacuum bag sample collected from the Shuttle Bay door prior to opening indicated these types of fibers were present at high concentrations along the door joint. The Interim Orbiter Contamination Monitor (IOCM) monitoring the Shuttle Bay at the time of the Shuttle Bay door opening in the OPF indicated the most intense contamination response of the entire mission at that time. These types of fibers were rather common on LDEF surfaces both during orbit and as sampled in SAEF-2. Paper fibers were the most common type of fiber added to LDEF during its stay in SAEF-2. Paper fiber is often associated with "sizing" material such as starch, clay, or plastic.

CONCLUSION

The particulate contamination history of LDEF can be resolved by careful analysis of particle types, the LDEF time line, evidence of the relationship between particles and the surface of LDEF, and a consideration of probable sources. This work is far from complete but has been initiated as part of the characterization of the condition of experimental trays that have been returned to principal investigators for their analysis. The work presented in this photo essay is continuing and will be updated in subsequent reports to NASA and at future technical meetings.

REFERENCES

1. Crutcher, E. R., L. S. Nishimura, K. J. Warner, and W. W. Wascher: Migration and Generation of Contaminants From Launch Through Recovery: LDEF Case History. First LDEF Post-Retrieval Symposium, NASA CP-3134, 1992.

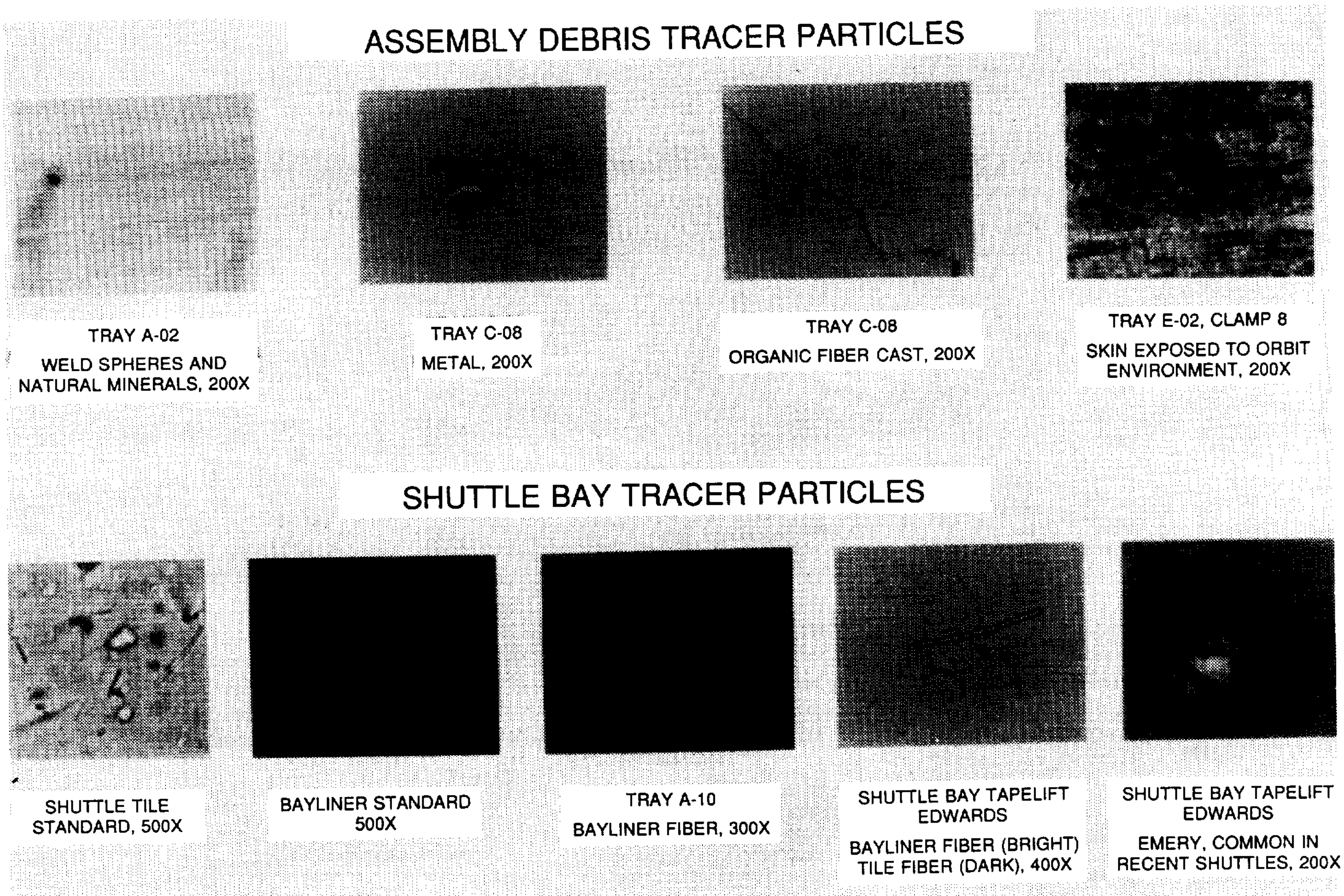


Figure 1: Particles Used To Trace Sources

Upper Set of Photographs: Assembly Debris

Photograph 1: Tray A-02, Silver/Teflon blanket showing a magnetite sphere typical of welding or cutting iron alloys and a natural mineral particle that were present on this blanket when LDEF entered orbit as indicated by the comet tail shaped molecular film shadow.

Photograph 2: Tray C-08, Silver/Teflon blanket showing a crescent shaped wear metal particle that was present on this blanket when LDEF entered orbit and the smooth topped Teflon island that indicates that fact.

Photograph 3: Tray C-08, Silver/Teflon blanket showing the cast of an organic fiber that was consumed by atomic oxygen. The parts of the fiber that were in intimate contact with the surface left concentrations of ash on the surface that further slowed the AO attack of the Teflon surface. Where the fiber was not in intimate contact the ash was more dispersed when it reached the surface or failed to reach the surface so provided less protection. Where the fiber was not in intimate contact it did not provide any protection from ultraviolet light. This also would reduce the net benefit of the shielding provided by this part of the fiber.

Photograph 4: Tray E-02, clamp 8, chromic acid anodized aluminum with UV browned skin flake.

Lower Set of Photographs: Shuttle Bay Tracers

Photograph 1: Shuttle tile fiber standard.

Photograph 2: Shuttle bay liner fiber standard.

Photograph 3: Tray A-10, Silver/Teflon blanket showing bay liner fiber with two AO Shadows.

Photograph 4: Tapelift from the Shuttle bay at Edwards. Shuttle tile fiber and bay liner fiber.

Photograph 5: Tapelift from the Shuttle bay.

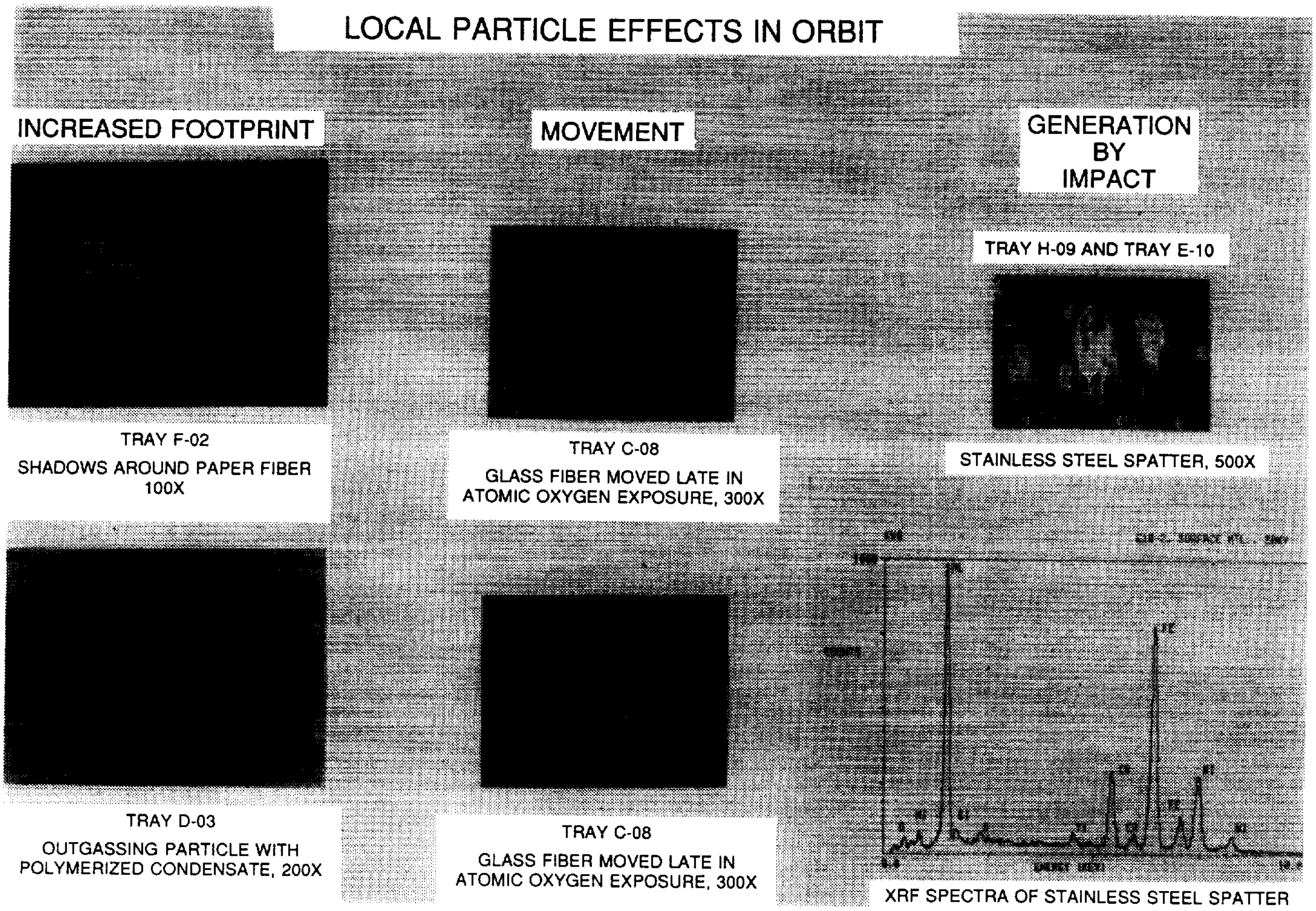


Figure 2: Local Particle Effects

Photograph 1: Tray F-02, Silver/Teflon blanket showing the 'positive pressure' effect seen as the clear area around the cellulose fiber. The roughened areas are a molecular film deposit. The comet tail type shadow is also seen in this photograph.

Photograph 2: Tray C-08, Silver/Teflon blanket showing two AO shadows made by the same glass fiber. The upper lighter shadow was the last location of the fiber.

Photograph 3: Tray E-10, stainless steel splatter on the surface of anodized aluminum from an impact with a tray clamp bolt.

Photograph 4: Tray D-03, Carbon fiber /epoxy composite showing the outgassing deposit from a particle on its surface.

Photograph 5: Tray C-08, Silver/Teflon blanket showing two AO shadows made by the same glass fiber.

Photograph 6: Tray E-10, clamp 2, X-Ray fluorescence analysis of the metal splatter from bolt A on the anodized aluminum.

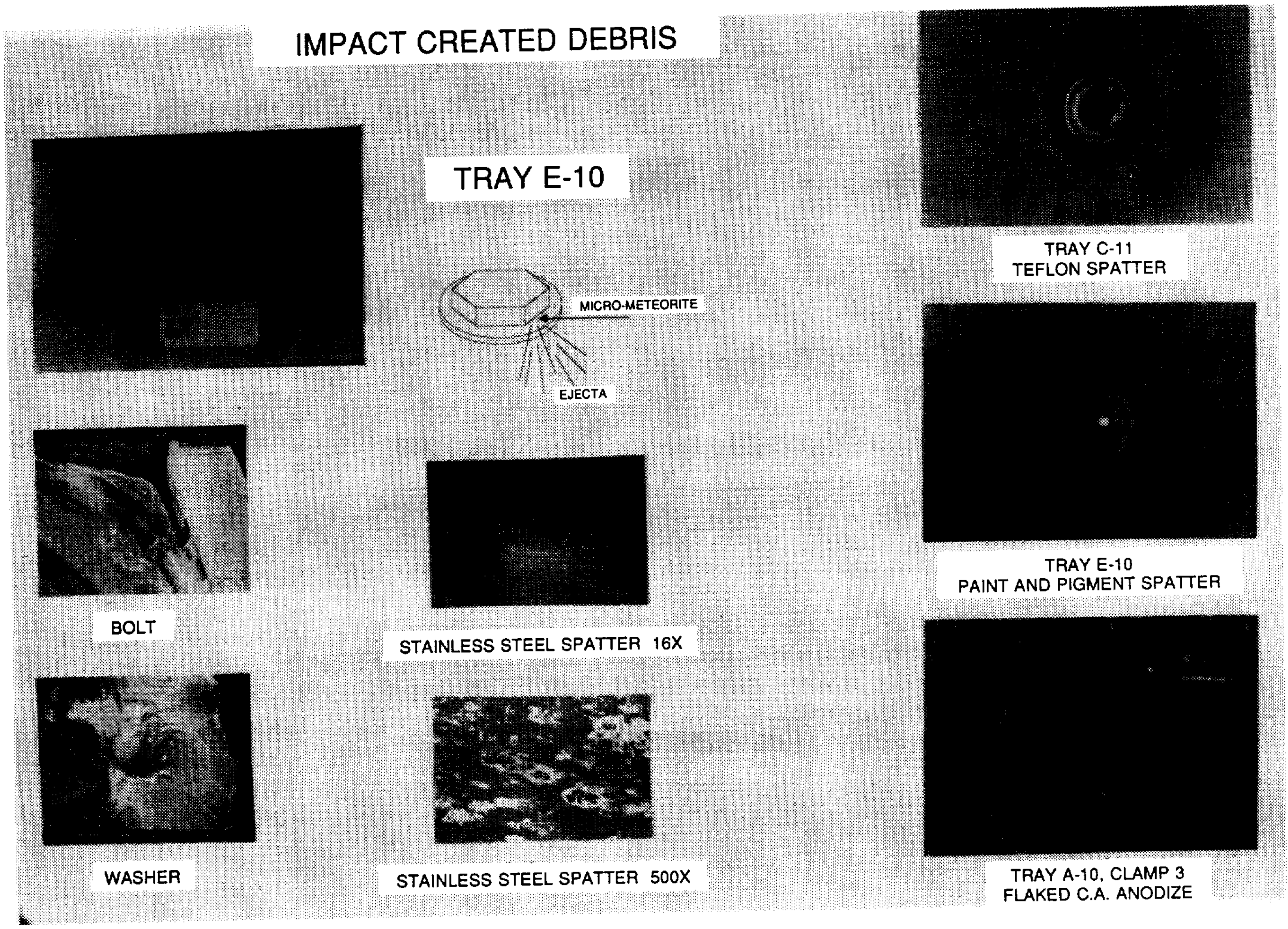


Figure 3: Impact Created Debris

Photograph 1: Tray E-10, clamp 2, showing the stainless steel ejecta field on the clamp from the impact.

Photograph 2: Illustration of the impacted bolt and washer of tray E-10, clamp 2 showing the direction of the impact and the path of the ejected material.

Photograph 3: Tray C-11, Silver/Teflon blanket showing the splattering of Teflon from an impact.

Photograph 4: Tray E-10, clamp 2, bolt A showing the impact site on the bolt using electron microscope.

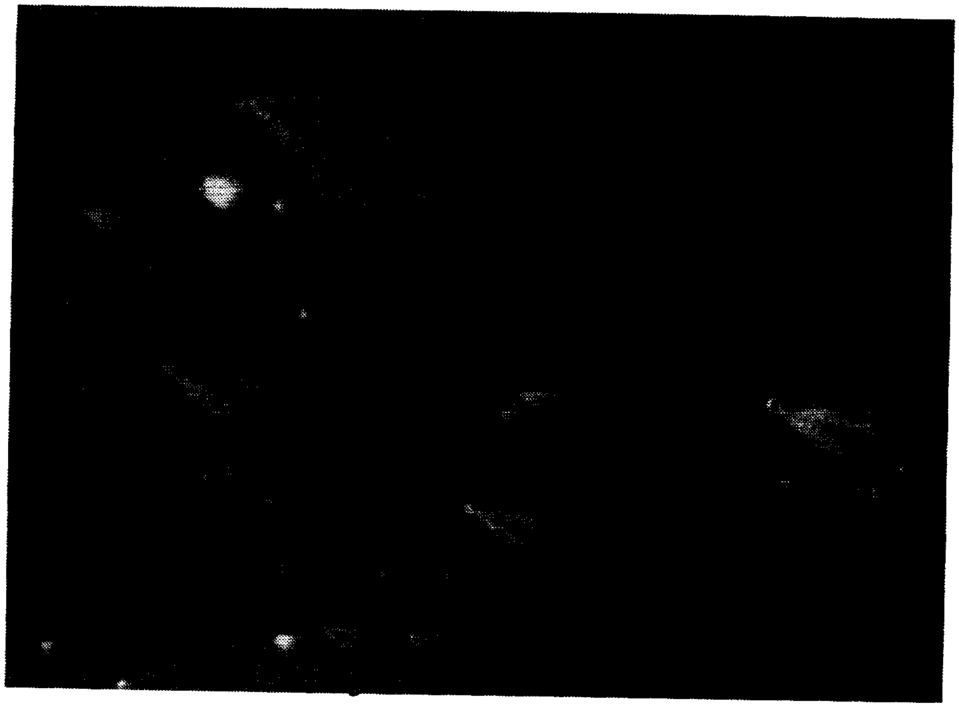
Photograph 5: Tray E-10, clamp 2 showing the field of ejected material using the electron microscope.

Photograph 6: Tray E-10, clamp 6, paint button showing an impact that released an outer ring of AO freed pigment particles and an inner ring of paint flakes. Oblique toplight illumination.

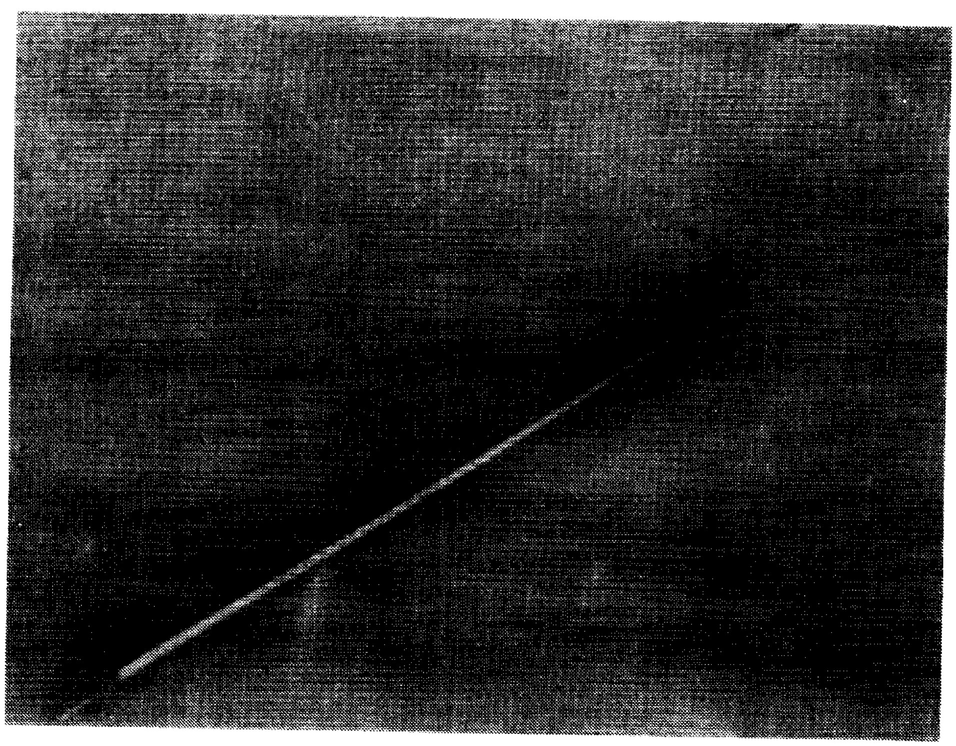
Photograph 7: Tray E-10, clamp 2, washer A showing the impact site on the washer using electron microscope.

Photograph 8: Tray E-10, clamp 2, stainless steel splatter on the surface of anodized aluminum from an impact with bolt A. Scanning electron microscopy photograph at about 500x.

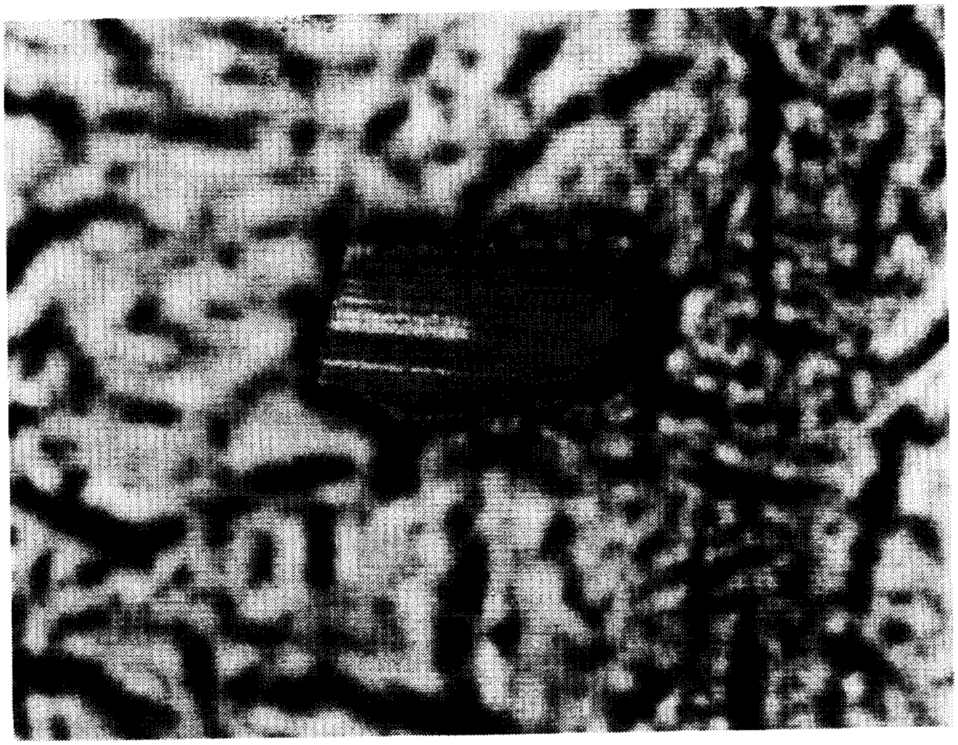
Photograph 9: Tray A-10, clamp 2 showing flaking of anodized coating caused by impacts in orbit.



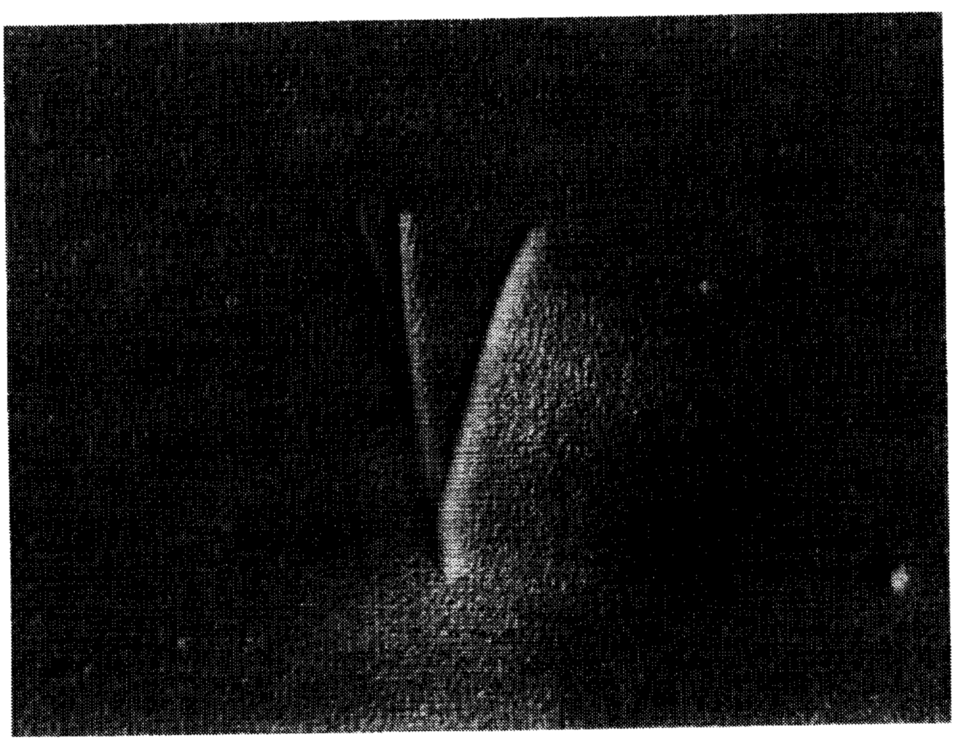
Photograph 1: Tray F-02, Silver/Teflon blanket showing particle shadows in the molecular film (comet tails), relocation or new particles with no shadows, and particles now missing that had been present during orbit (white patches with no black particles present). This photograph was taken in SAEF-2 using brightfield episcopic illumination so that all particles appear black and smooth clear surfaces appear white. 125x magnification.



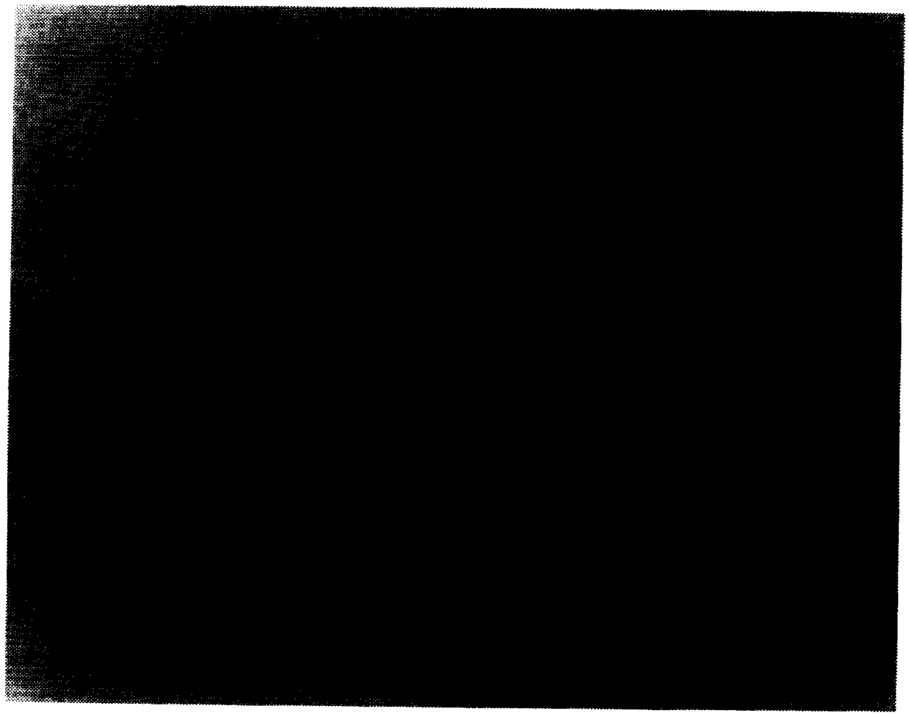
Photograph 2: Tray A-10, Silver/Teflon blanket showing a glass fiber cast. The fiber was in place during the entire orbital exposure as is indicated by the smooth surface of the cast. 125x magnification.



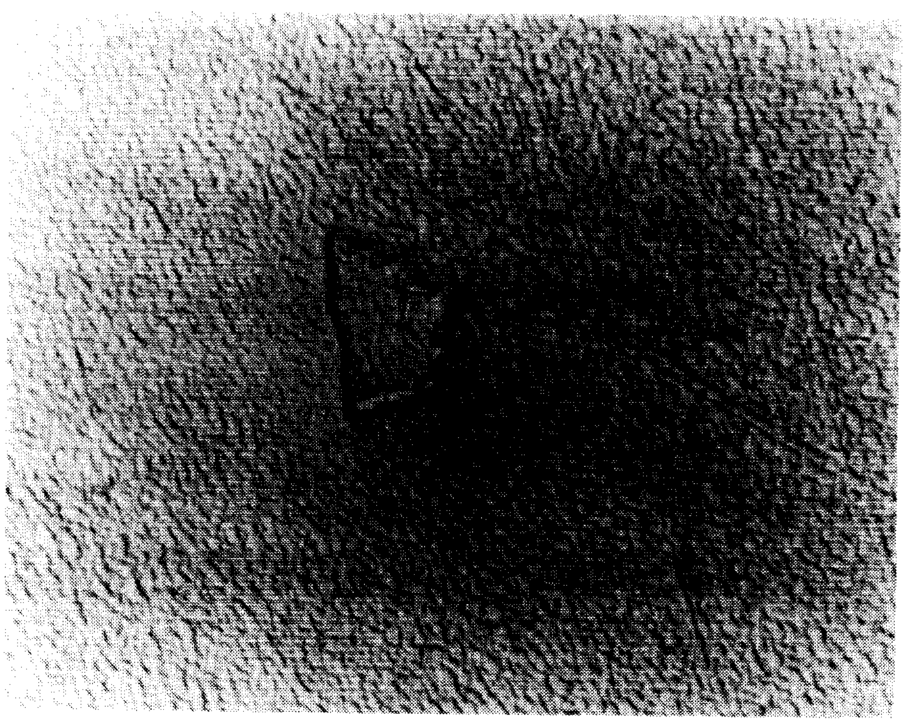
Photograph 3: Tray D-09, Carbon fiber/epoxy composite sample, L3-4-8-65-10, showing a particle protected island that projects 65 micrometers above the atomic oxygen eroded surface. 320x magnification.



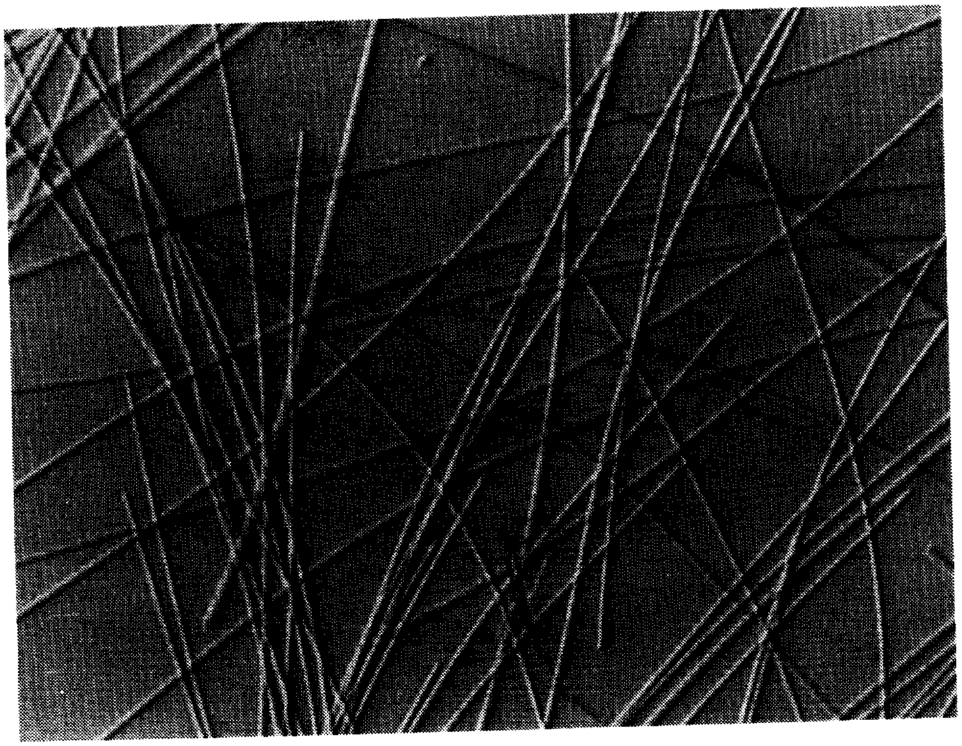
Photograph 4: Tray A-10, Silver/Teflon blanket showing a bay liner fiber (note gentle curve and diameter) with two AO shadows. The actual fiber is the center image of the three linear images and extends above the surface of the Teflon. 575x magnification.



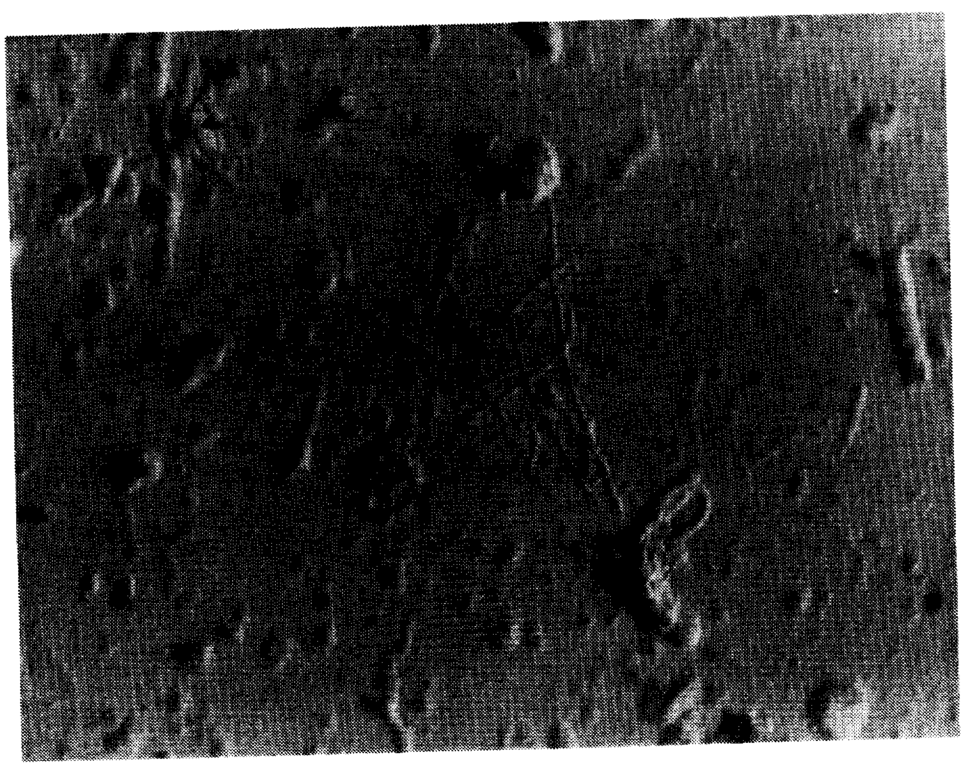
Photograph 5: Tray E-10, Silver/Teflon blanket showing a pattern from a tangle of fibers. The fibers protruded above the surface resulting in only partial protection for part of the surface.



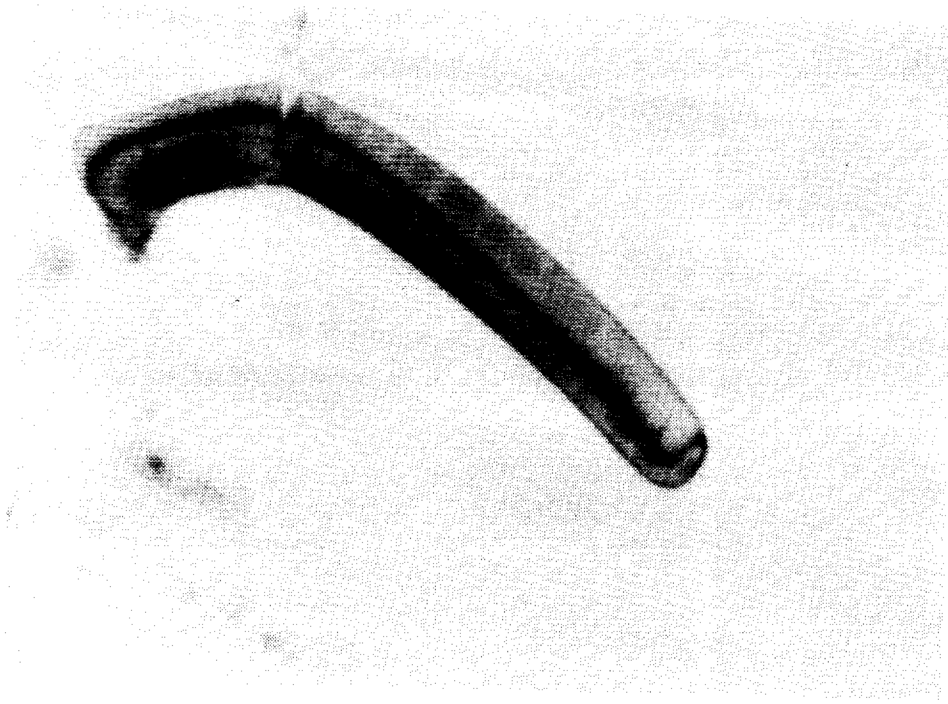
Photograph 6: Tray C-08, Silver/Teflon blanket showing the pattern left by an organic particle that was consumed by atomic oxygen. It provided some protection of the surface while it was being burned away and its ash provided additional protection, at the edge especially. 575x magnification.



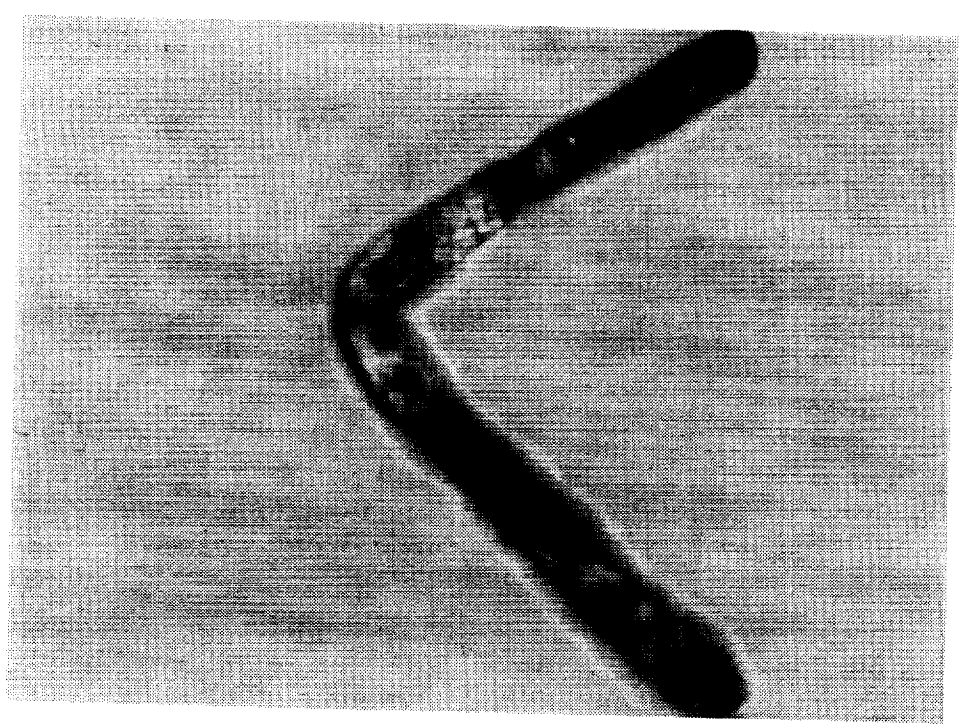
Photograph 7: Bay liner fiber standard from the Columbia showing the gentle curve of the fiber and constancy of the diameter. 320x magnification.



Photograph 8: Shuttle tile fiber standard from a shuttle tile removed from Columbia during preparation for flight. Note the variability in diameter, irregular shapes, and fiber tangles. 320x magnification.

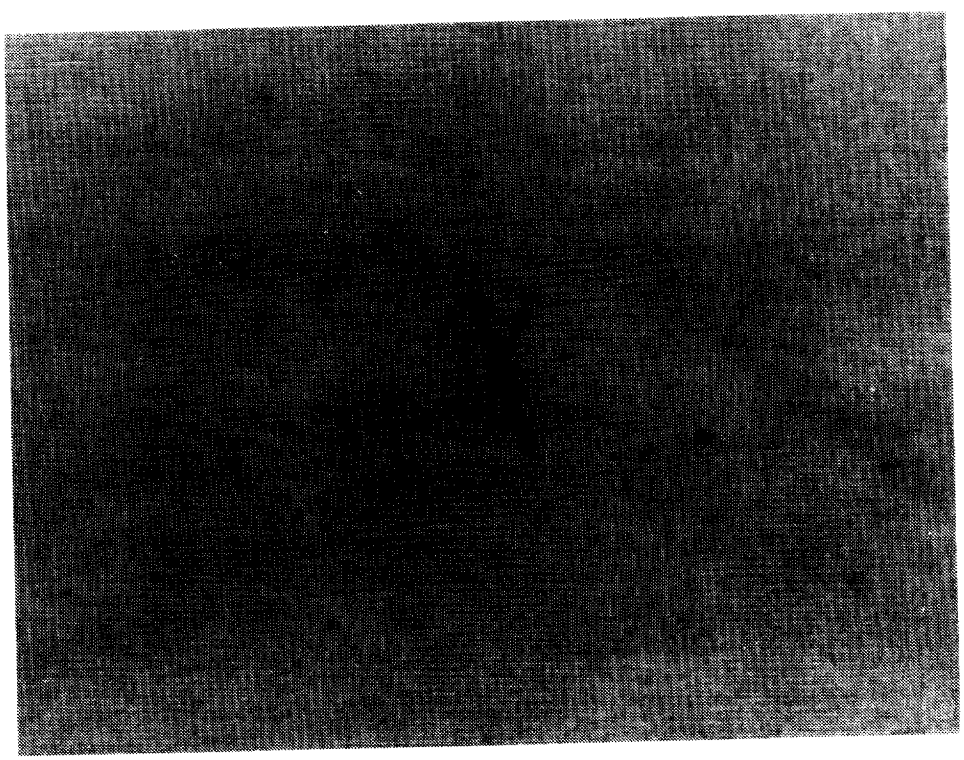


Photograph 9: Tapelift from the Shuttle Bay at Edwards showing ultraviolet modified nylon fiber. The photograph was taken using polarizing filters 15 degrees off crossed. 955x magnification.

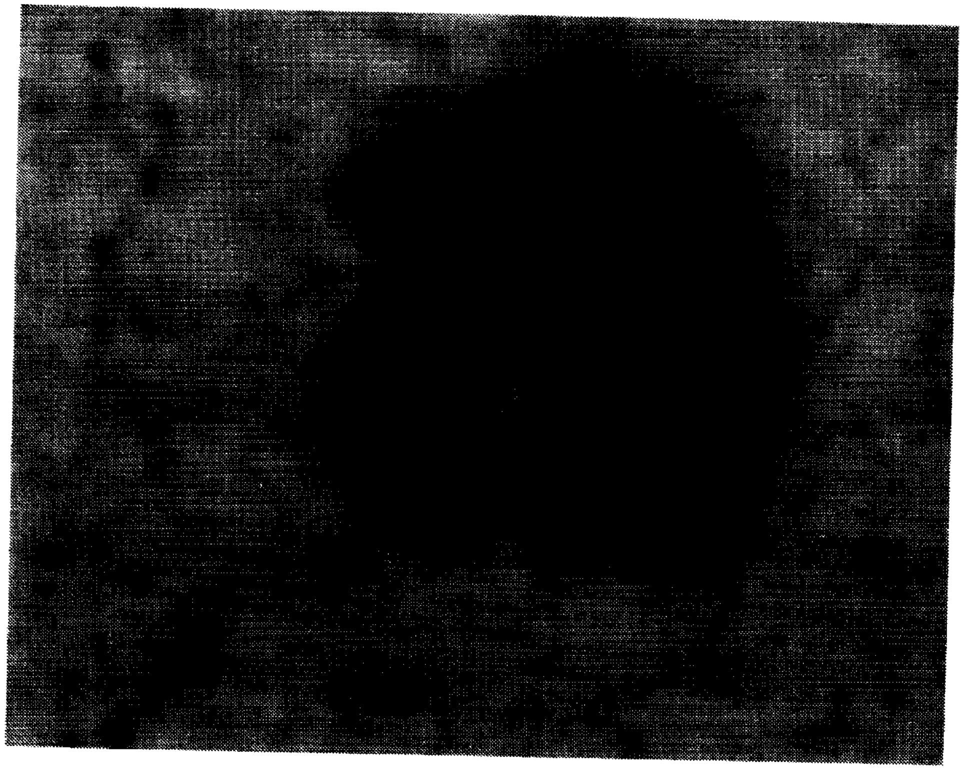


Photograph 10: Tapelift from the Canister under LDEF showing an atomic oxygen and ultraviolet modified cellulose fiber. The photograph was taken using polarizing filters 15 degrees off crossed. 255x magnification.

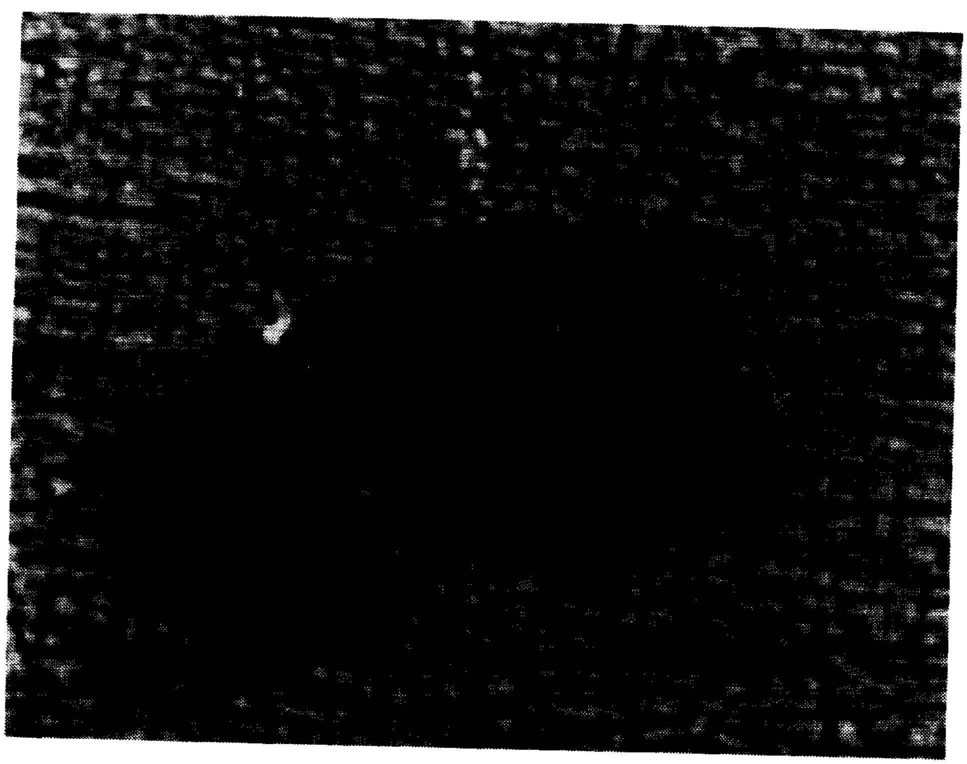
Photograph 11: Tray D-09 showing glass fiber freed by atomic oxygen erosion of a glass fiber reenforced adhesive. 320x magnification.



Photograph 12: Tray C-11, Silver/Teflon blanket showing HEPA filter fiber. 285x magnification.

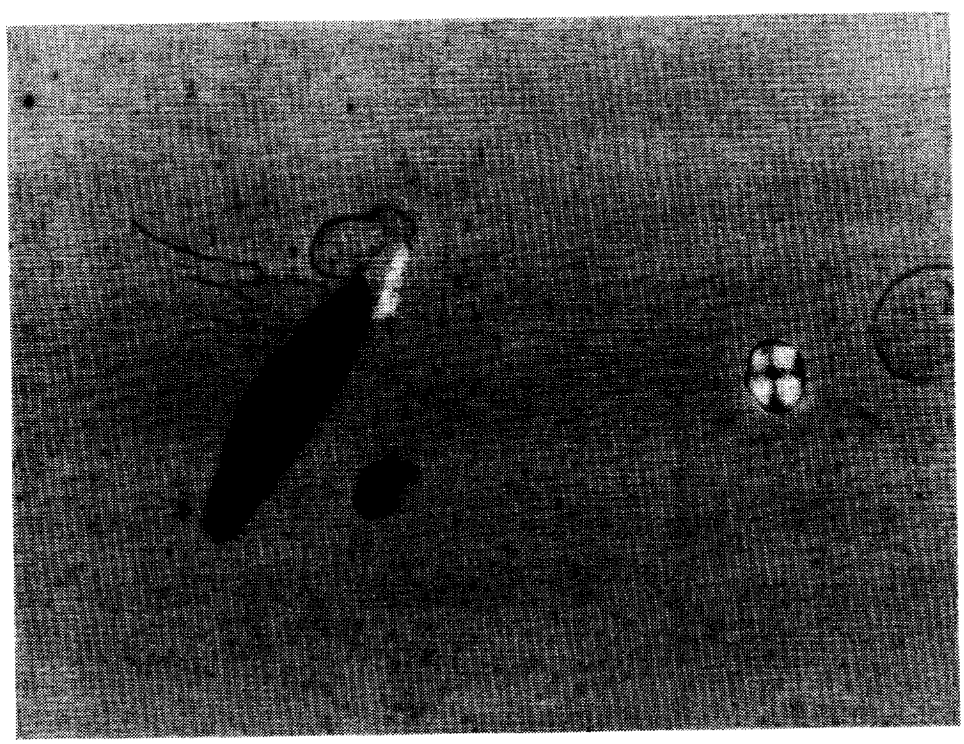


Photograph 13: Tray B-07, clamp 7 showing brown film particle that relocated to the surface of a paint button. 445x magnification.

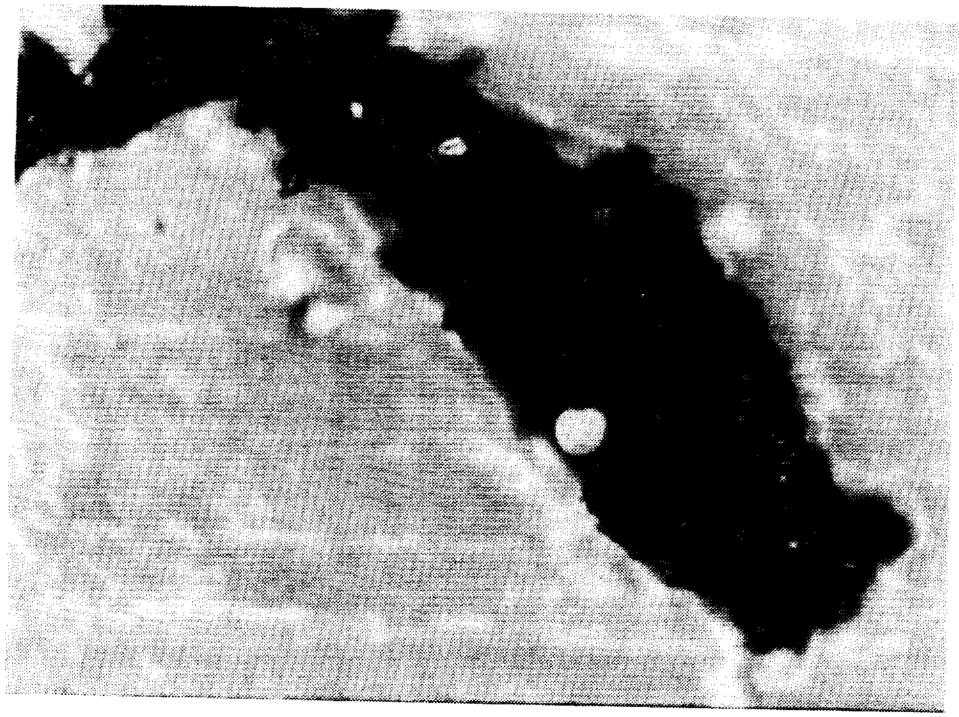


Photograph 14: Tray D-09 showing an antenna particle created by atomic oxygen erosion of the Kapton substrate upon which the vapor deposited aluminum array of half millimeter squares had been placed. These squares were found distributed all over LDEF, the shuttle bay, and the LATS. 70x magnification.

Photograph 15: Tray B-07, clamp 7, showing the fluid flow erosion of the edge of a paint button and the deposition of white pigment on the rough surface of the adjacent black paint. 110x magnification.

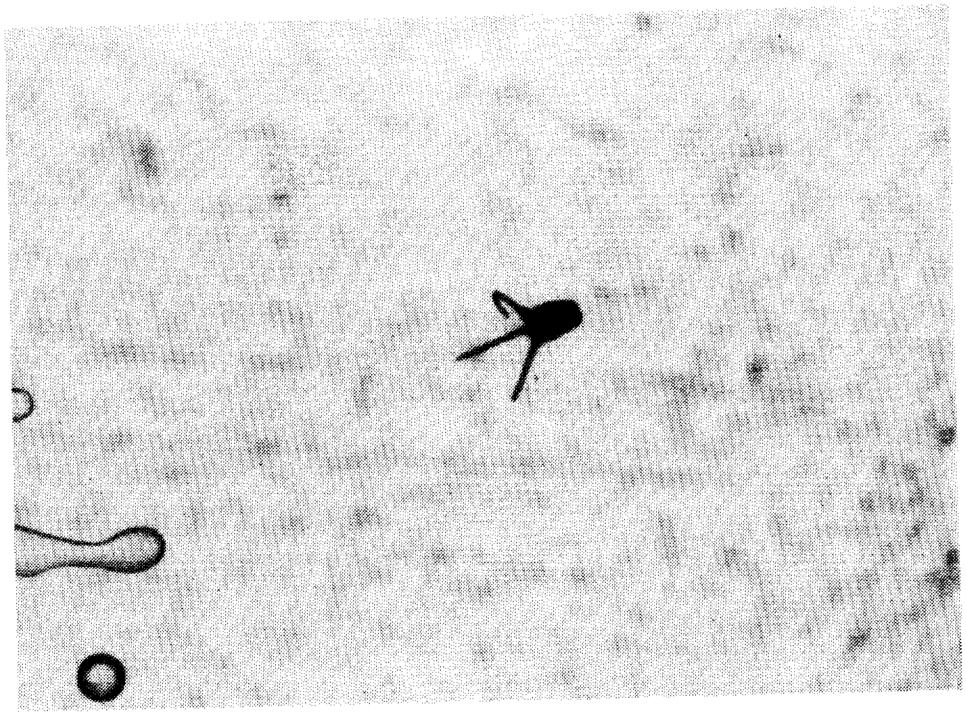


Photograph 16: Tapelift from the SYNCOM Cradle after transport of LDEF in the O&C building. A multichambered fungal spore, latex spheres, a starch grain, AO eroded Kapton fragment, skin, and a clay particle are shown. The photograph was taken using polarizing filters 15 degrees off crossed. 320x magnification.

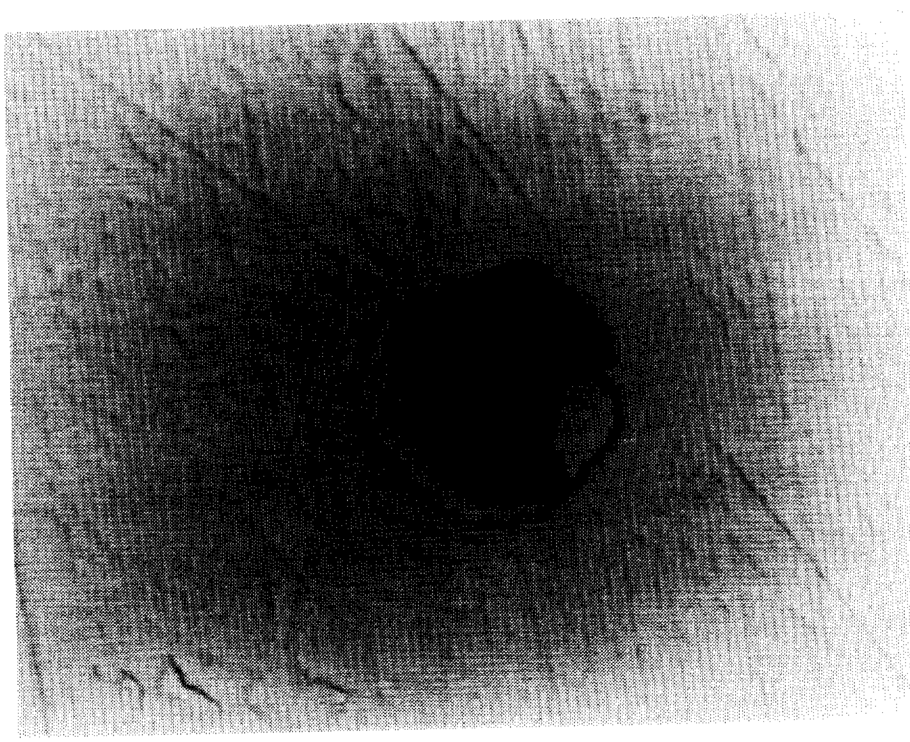


Photograph 17: Tapelift from kit 22, M0002 edge showing rubber wear with attached pine pollen and other debris. Rubber wear may be from the crane or from another tire source. 110x magnification.

Photograph 18: Paper fiber standard showing cellulose fiber with clay sizing. The photograph was taken using polarizing filters 15 degrees off crossed. 320x magnification.



Photograph 19: Tapelift from the shuttle bay at Kennedy, OPF, showing insect foot. 255x magnification.



Photograph 20: Tray A-04, Silver/Teflon blanket showing mica protecting the Teflon surface from atomic oxygen and ultraviolet light degradation. 1100x magnification.