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CONTAMINATION ON LDEF: SOURCES, DISTRIBUTION, AND HISTORY

Gary Pippin and Russ Crutcher
Boeing Defense & Space Group
Seattle, WA 98124-2499
Phone: 206/773-2846, Fax: 206/773-4946

In this paper we present an introduction to contamination effects observed on the Long Duration Exposure Facility (ref 1). The activities reported here are part of Boeing's obligation to the LDEF Materials Special Investigation Group (ref 2).

The contamination films and particles had minimal influence on the thermal performance of the LDEF. Some specific areas did have large changes in optical properties. Films also interfered with recession rate determination by reacting with the oxygen or physically shielding underlying material. Generally, contaminant films lessen the measured recession rate relative to "clean" surfaces. On orbit generation of particles may be an issue for sensitive optics. Deposition on lenses may lead to artifacts on photographic images or cause sensors to respond inappropriately. Particles in the line of sight of sensors can cause stray light to be scattered into sensors. Particles also represent a hazard for mechanisms in that they can physically block and/or increase friction or wear on moving surfaces.

LDEF carried a rather complex mixture of samples and support hardware into orbit(ref. 3) The experiments were assembled under a variety of conditions and time constraints and stored for up to five years before launch. The structure itself was so large that it could not be baked after the interior was painted with chemglaze Z-306 polyurethane based black paint. Any analysis of the effects of molecular and particulate contamination must account for a complex array of sources, wide variation in processes over time, and extreme variation in environment from ground to launch to flight. Surface conditions at certain locations on LDEF were established by outgassing of molecular species from particular materials onto adjacent surfaces, followed by alteration of those species due to exposure to atomic oxygen and/or solar radiation.

Venting during ascent and prior to development was the initial opportunity for large scale mass transfer of volatile species. Distinct layers of materials in selected areas is evidence of short term variation in outgassing rates as LDEF traversed the earth shadow during each orbit. Over the long term the rate may be altered as the materials degrade under exposure to the space environment. Solar ultraviolet radiation(UV), and in leading edge locations, atomic oxygen exposure, affect the long term state of the outgassed deposits.

The environmental exposures also varied over time with short wavelength radiation intensity about 50% to 100% greater at the end of the mission relative to the start. The relative increase was even greater for certain wavelengths. A majority of the oxygen exposure occurring in the last six months.

Figure 1 is a schematic mission time line to define the types of exposure. Time periods 1,6,8, and 10 are ground environments, and 3 and 4 are deployment from, and retrieval by, the shuttle. The mission may be usefully divided into three categories of contamination exposure periods. First, the preflight exposures include all the ground based processing, which created particles and films which were subsequently carried into orbit. Second, the on-orbit exposure, venting, outgassing and deposition, and subsequent degradation produced new particles and films whose composition varied with time. Third, the post flight environments included additional particulate deposition, moisture absorption, and molecular film formation. Events during the first two periods must be evaluated for their effects on spacecraft performance. The third time period, post flight exposure, is not typical for payloads because most spacecraft are not retrieved. Therefore contamination from this time period must be viewed simply as an artifact to be factored out of analysis of material performance in flight.

Contamination sources can be grouped according to particulates, and two types of molecular sources, carbon based films and silicone based films. Particulate sources include fibers, pollen, dust, manufacturing debris and salt deposits from ground operations and exposures. While individual items certainly caused profound effects on a local microscopic scale, particulate sources did not have a significant effect on the overall thermal control performance of the satellite and its systems. The level of surface particulate contamination was extensive enough to be of concern for spacecraft with optical sensors.

Sources of carbon based molecular films include paint solvents, polymeric thin films, and organic composite materials, which outgassed on-orbit, as well as organic dust and solvent present during manufacturing, or used for cleaning, such as cetyl alcohol used a lubricant for bolts and alcohols used to wipe down surfaces.

Potential silicone based film sources include as manufactured coating on support hardware, adhesive materials, coatings on test specimens, solar cells, paints, and the orbiter.

The final disposition of contaminant films was determined by the specific on-orbit conditions at each location. Two types of competing processes are occurring. Removal is possible by thermal cycling and/or oxidation to volatile species. Simultaneously, fixing of selected contaminant species in place by UV induced bond rupture, and crosslinking between polymer chains, oxidation to non volatile species.

The end of mission surface products which remain are thermodynamically stable, non-volatile materials or species which are physically trapped by silica coatings formed by oxidation of outgassed siloxanes. The trapped species have likely undergone change due to UV subsequent to deposition onto the exposed surfaces.

There were major differences in environmental effects creating contaminants on-orbit. Leading edge exposure conditions caused certain materials to deteriorate and/or fail, creating a number of particle sources. Trailing edge conditions allow creation of thin films as materials outgassed and redeposited, but exposure to solar UV did not lead to catastrophic failure of any materials.

Figure 2 shows examples of surface contamination on tray A2. At the top of the photo is skin tissue, identified under a microscope by its cellular structure, and which was deposited subsequent to recovery. The lower right location is skin tissue which was exposed to space, as evidenced by the outgassing patterns around the location. The lower left corner shows a weld sphere from a manufacturing process. Figure 3 shows layering of contaminant films from Tray C-12. This pattern is indicative of thermal cycling causing intermittent deposition and likely occurred early in the mission.

A brown discoloration was observed in many locations on external aluminum surfaces. This film was formed by relatively complex processes. Outgassed organic molecules deposit on the surface where they were degraded by solar UV permanently fixed to the surface and further crosslinked and polymerized. For leading edge surfaces silicones co-deposited with the organics were oxidized to silica and trap underlying organic molecules, which then darken over time due to the solar UV Heat from thermal cycling may also accelerate degradation for part of each orbit.

Figure 4 shows shadow patterns forming the silhouettes of nuts and bolts from an interior location on LDEF. This shadowing is due to external environmental factors effecting molecular fixing, and not localized outgassing. The edges of the "shadow" patterns are quite distinct and well aligned with one another.

The areas not protected by the bolts appear to have lightened rather uniformly, probably due to intermittent UV exposure through a small opening on the opposite side of the spacecraft. Figure 5 shows a NASA photo taken in SAEF 2 during deintegration. This is the corner of trays A9 and A10, the longeron and tray clamps between and part of the black coated cover plate for the earth end of the LDEF. The black covered plates are slightly raised relative to the structure. Dark brown deposits can be seen on the aluminum structure next to the black plate. This was a vent path from the interior of LDEF and shows that volatile species form the interior can be directed parallel to the exterior surfaces. This plot shows deposition only near the vents because there surfaces are essentially oriented into the ram direction and have been "cleaned" by atomic oxygen. Figure 6 shows an on-orbit photo with large scale deposition of molecular contaminants clearly visible in tray E12. Darkened areas are visible around each electrical feed through and in particular corrosion of the tray.

However, while significant areas do have a substantially increased absorptance, the overall absorptance to emittance ratio on this satellite is only slightly influenced by the contaminant films. This is because the large majority of the surface of this satellite is anodized aluminum, which showed only slight changes in a/e, and silverized FEP, which was virtually unchanged.

Figure 7 is an on-orbit photo of tray D8 and part of tray D9 taken by NASA astronauts during retrieval of LDEF. The lower portion of the photograph shows a considerable amount of particulate debris spread over tray D9, created as the hardware from one of the experiments on this tray failed and lost its mechanical integrity. Tray D8 shows no visual evidence of migration of these particles from D9 even though this tray is in close proximity. The distribution pattern of this contamination and any anomalies it may have caused in the analysis of the nearby specimens must be inferred from the on-orbit photos. Re-entry turbulence removed this loose debris and distributed some of the very small pieces of aluminum all around the spacecraft.

Images from NASA's video downlink have been examined and image enhanced using a computer. Figure 8 shows one frame from the downlink and individual debris particles are seen in the LDEF wake. These particles are visible on the video as they reflect sunlight in the direction of the camera, then disappear as they rotate, and then reappear on a later frame. This debris has collected in the wake of LDEF. No particles were visible on the ram side. Individual particles may be moving away from the LDEF structure at very low relative velocities, taking weeks or months to leave the vicinity of the spacecraft, until they trail LDEF by such a distance that they are back in the ambient environment.

Net momentum changes due to impact with the ambient environment would be away from the satellite direction of motion and once in the wake there would be no additional impacts to further change the velocity. This condition was only being observed during the short period of time before recovery, so long term changes were not seen. In addition, effects due to electrostatic charging have not been considered and details of processes by which the particles left the location of the material failure and moved around the spacecraft are completely unknown. Figure 9 shows results from computer enhancement of the particle images. The left side of the figure shows one frame and the right half shows the sum of several frames with the background averaged out of the box in the center. Only images which persist for several frames appear in the enhanced image. Enhanced video shows many more particles are present than are seen in any individual frames. The significance of these particles being present is that they are a significant potential source of interference to experiments done with a wake shield facility and could interfere with optical sensors or telescopes observing either the earth or other objects of interest to astronomers. It is particularly relevant for space station, which will fly in a series of constant orientations.

Long term outgassing of materials is subject to many influences, local temperature cycles, geometry of hardware around the source, and orientation of the source with respect to environmental factors. Even space qualified materials can outgas significant total amounts of material. Materials which are rated as vacuum stable may in fact break down very slowly, but at a relatively constant rate, and have an essentially infinite outgassing time. Outgassed material has complex interactions with the environment and it is the changes subsequent to material deposition on a surface which dominate the surface conditions. For organic contaminants, oxygen atoms can clean surfaces by producing volatile reaction products.

LDEF contamination was extensive but very site specific. Films deposited were essentially from line of sight sources with slight enhancement for specific geometries due to scattered species.

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References

1. See papers from section on LDEF mission and induced environments in NASA CP 3134, LDEF-69 Months in Space, First Post-Retreival Symposium, Part 1, A.S. Levine, ed., Jan. 1992.

2. NASA CP-3162, LDEF Materials Workshop '91, Parts 1 and 2, B.A. Stein and P.R. Young, eds., Sept. 1992.

3. NASA SP-473 The Long Duration Exposure Facility. See also articles from references 1 and 2.

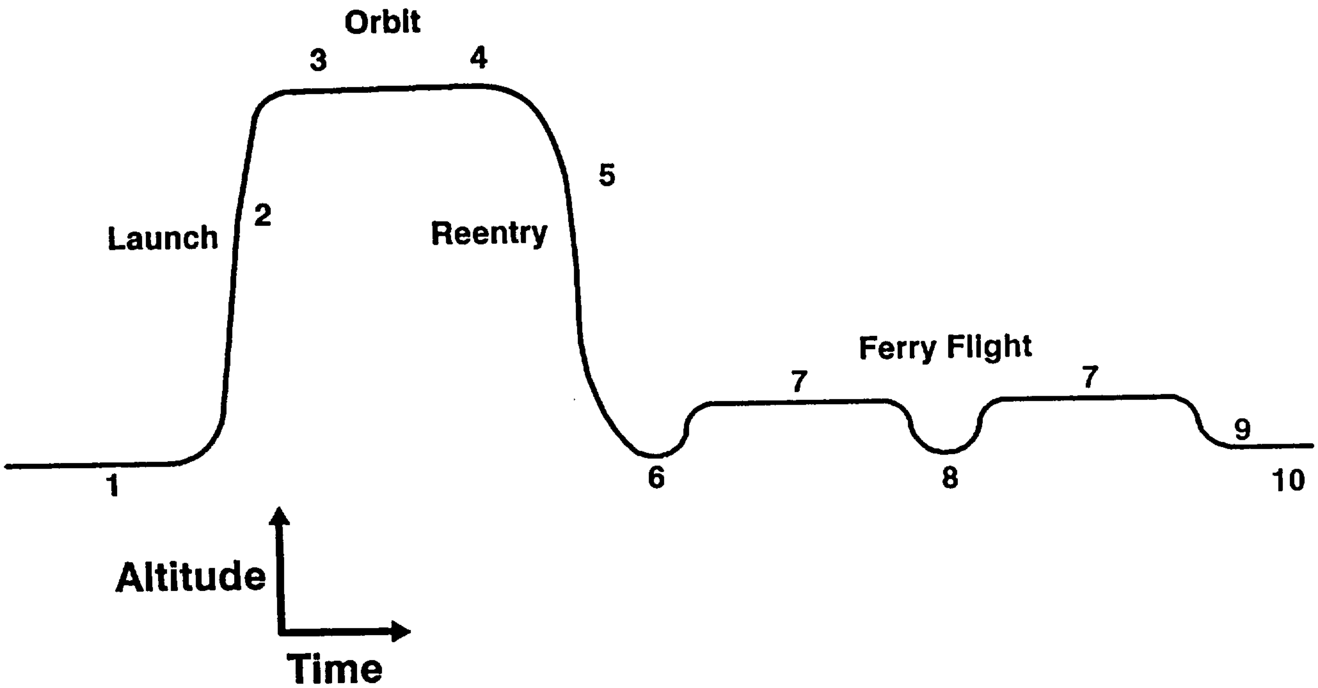

Figure 1. LDEF Contamination Exposure History

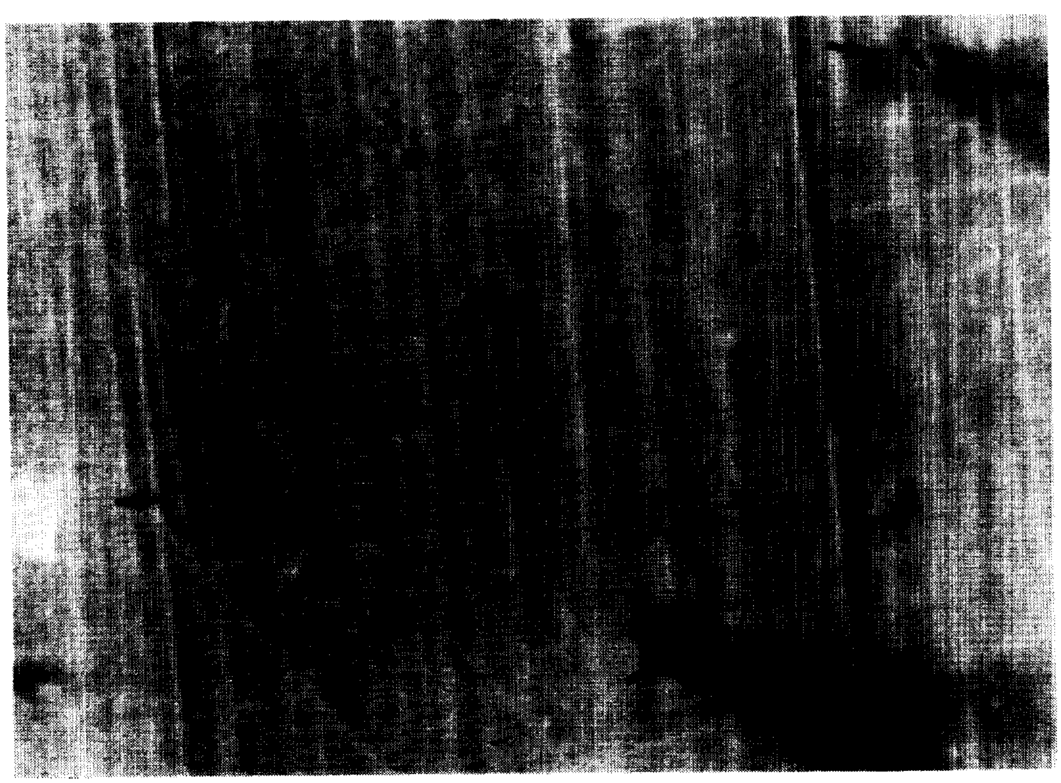

Figure 2. Particulate Contamination Examples on LDEF

Figure 3. Layered Contaminant Films from Tray C12
(Color version of black and white photograph shown on page 1247.)

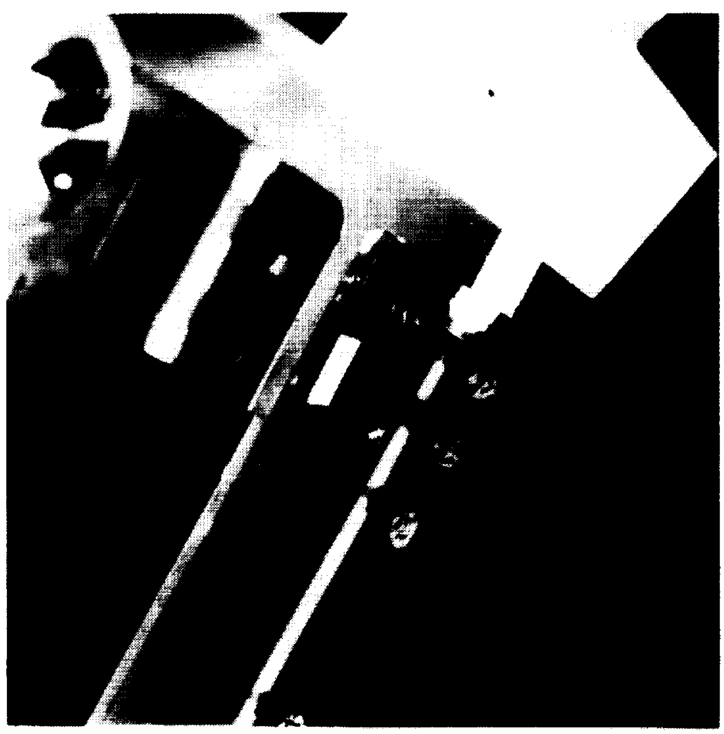

Figure 4. Shadowing from External Environmental Factors at LDEF Interior Locations

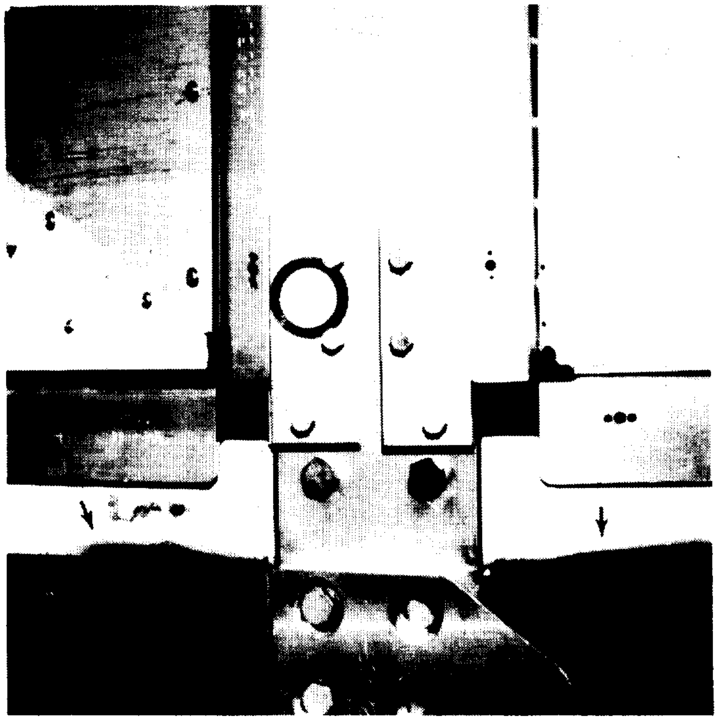

Figure 5. Outgassed Material on LDEF Structure Near Vents from Interior
(Color version of black and white photograph shown on page 1247.)

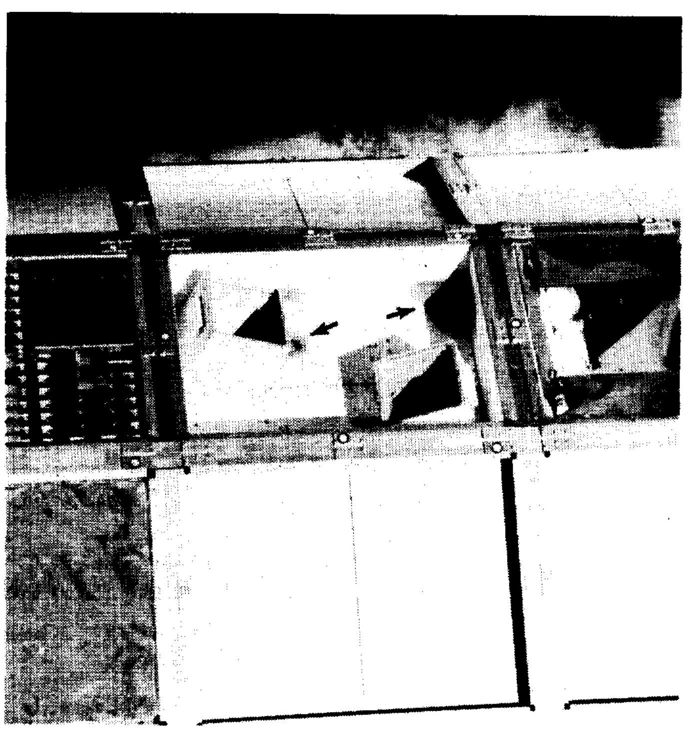

Figure 6. On-Orbit Photo of Tray E12 Showing Molecular Contamination Patterns

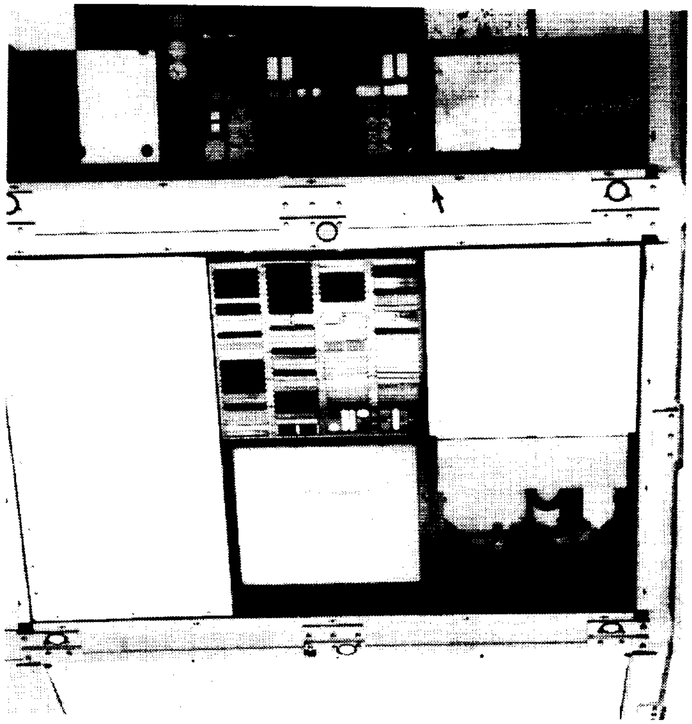

Figure 7. On-Orbit Photo of Trays D8 and D9(partial) Showing Particulate Debris from Degraded Hardware

Figure 8. Image made from one Frame of NASA Video Downlink During LDEF Recovery. Particles Observed in LDEF Wake are Visible

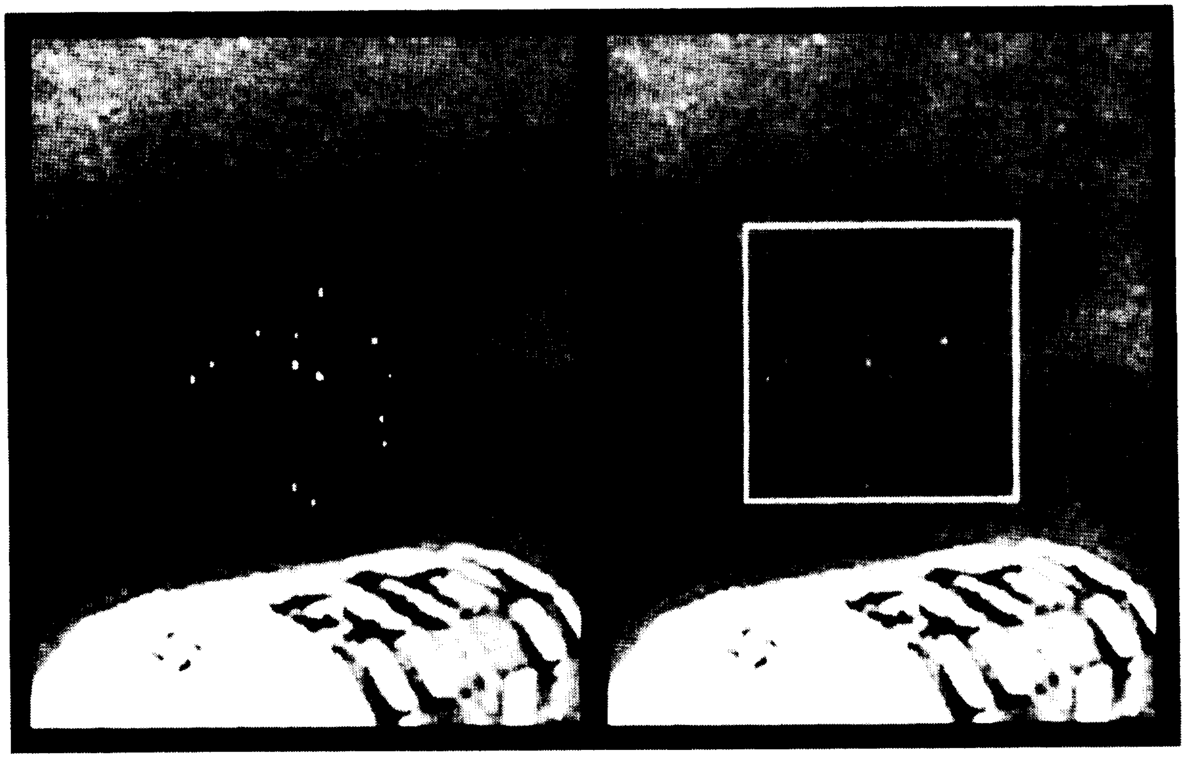

Figure 9 Computer Enhancement of Particle Images. Image with Dark Background in Center is Computer Enhanced Average of Several Frames