MIR ENVIRONMENTAL EFFECTS PAYLOAD AND RETURNED MIR SOLAR PANEL CLEANLINESS

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ABSTRACT

The MIR Environmental Effects Payload (MEEP) was attached to the Docking Module of the MIR space station for 18 months during calendar years 1996 and 1997 (March 1996, STS 76 to October 1997, STS 86). A solar panel array with more than 10 years space exposure was removed from the MIR core module in November 1997, and returned to Earth in January, 1998, STS 89. MEEP and the returned solar array are part of the International Space Station (ISS) Risk Mitigation Program. This space flight hardware has been inspected and studied by teams of space environmental effects (SEE) investigators for micrometeoroid and space debris effects, space exposure effects on materials, and electrical performance. This paper reports changes in cleanliness of parts of MEEP and the solar array due to the space exposures. Special attention is given to the extensive water soluble residues deposited on some of the flight hardware surfaces. Directionality of deposition and chemistry of these residues are discussed.

KEY WORDS: Space Environment, Cleanliness, Mir

1. INTRODUCTION

This paper presents preliminary results of the space-flight-hardware surface-cleanliness studies of MEEP and a returned MIR solar array. The MEEP consisted of four experiment containers which housed the experiment trays. The experiment containers were closed until after they were attached to hand-rails on the MIR docking module. These four Passive Experiment Containers (PECs) were opened during the MEEP deployment extravehicular activity (EVA) of STS 76, and the experiments inside were exposed to the space environment in the vicinity of the MIR space station for 18 months. The PECs were closed during the STS 86 MEEP EVA and returned to Earth. Two of the four PECs, housing the Polished Plate Micrometeoriod Detector (PPMD) and the Passive Optical Sample Array II (POSA II) had readily apparent residue spots of about 0.1 to 5 mm diameter on two sides of each of these PECs. The other two PECs, housing

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the POSA I and the Orbital Debris Collector (ODC) experiments did not have any similar residue spots. Brown spots on the docking module handrail near PPMD and on an alignment target near POSA II are present in photographs taken during the STS 86 EVA. The POSA I PEC did have an unspotted, silicon rich film on the front side.

The returned MIR solar array was inspected by a team of SEE investigators in February 1998 at the Spacehab facility in Florida. Visual inspection of the array for cleanliness evaluation was performed, photographs of each of the 8 panels were taken, and tapelifts for electron microscope studies of four large (~1 cm diameter) brown residue spots were taken. Panel 8 of the solar array was removed and shipped to Langley Research Center where it was inspected with a 6x comparitor, and with a brightfield microscope at 50x to 500x. Brilliant colors in varied patterns were seen when the solar cells were viewed through a brightfield microscope. Color shifts of thin films viewed through a brightfield microscope are discussed in reference 1.

The first objective of the LaRC cleanliness evaluations of the solar array was study of water soluble residue similar to that on PPMD and POSA II. A second objective was to obtain an overall cleanliness evaluation. A third objective was analysis of the color patterns observed by brightfield microscopy.

2. MEEP EXPERIMENT

The four space environment experiments of MEEP attached to the MIR docking module are shown in Figure 1. The flight hardware consisted of four identical PECs and four dissimilar experiments. The PECs were 2-feet by 2-feet by 6-inches deep anodized aluminum suitcase-like containers which protected the experiment trays before and after exposure to the MIR space environment while attached to the docking module handrails. Prior to launch the PECs were cleaned to MIL Standard 1246C Cleanliness Level 200 A/10 at the Langley Research Center in September 1995. The cleaning was done by ultrasonification in Freon 113 followed by a rinse with perfluorocarbon 5060. A syringe (flush) of the PECs with analytical grade isopropyl alcohol was performed for the cleanliness measurement. Similar cleaning was performed for the PPMD experiment hardware and similar cleanliness levels (200 A/8) were attained. The PECs were bagged in approved bagging material, except when the experiments were integrated and deintegrated into the PECs in cleanrooms.

The PECs were bagged immediately after removal from the Orbiter upon return from space. The readily apparent spots and splashes on the PPMD experiment and on the PPMD PEC (Figure 2) were initially reported on at the ISS/MIR Space Environment Effects Workshop in Houston, TX in January 1998. The probable source of the water soluble residues on the PPMD was thought at that time to be Orbiter fluid waste dumps.

2.1 RESIDUE APPEARANCE AND CHEMISTRY

The residue deposits on the PPMD was in the form of circular spots, elongated spots, and streaks (Figure 3). Material scraped from spots on the front of the PPMD PEC dissolved in deionized water. The residue deposits on the POSA II PEC were in the form of circular spots on two sides of the PEC (Figure 4), and of streaks (Figure 5) on the bottom lips of the PEC.

Aluminum coupons specifically designed for scanning electron microscope (SEM) energy dispersive spectroscopy (EDS) chemical analyses were part of the contamination witness plates of the PPMD experiment. The EDS (Figure 6) of a residue spot on one of these coupons revealed that the major elements of the residue were sulfur, sodium and phosphorus. EDS of dozens of spots on the calcium fluoride optical witness plate, and on the zinc and gold experiment plates all gave the same major three elements, but in varying ratios to one another. This indicates that several different mixtures of water soluble material were deposited on PPMD. Direct comparison EDS spectra were obtained of normal urine, Orbiter fluid waste, detergents, and other compounds. Chlorine and potassium were major elements in all samples of urine and Orbiter fluid waste. The closest EDS chemical match of the residues on PPMD was with a laboratory detergent.

The aluminum identification plate (Figure 7) of the POSA II PEC was placed in a SEM and an EDS of one of the residue spots is shown in Figure 8. Spectra of twelve of the largest spots on the identification plate were almost identical to each other in the ratios of sulfur to sodium to phosphorous with no other elements present. This indicates that only one mixture of water soluble material was deposited on POSA II. A small amount of silicon is on the identification plate. No chlorine or potassium is present, indicating the residue is not dried urine.

2.2 DIRECTIONALITY AND DISPERSION

The presence of dense residue deposits on only two sides of each of two of the four PECs indicates that the source of the residue was near the PPMD and POSA II. If the source was at some distance there would probably be residue spots on the POSA I and ODC carrier sides pointing in the same direction as the spotted sides of PPMD and POSA II. The sides of PPMD and POSA II with the residue spots, and the surfaces of the docking module handrail and alignment target with spots were all facing down into the Orbiter payload bay and toward the back of the Orbiter. The Orbiter fluid waste nozzle is located just under the front edge of the front payload bay door on the starboard side, and not in a line-of-sight to the deposits on PPMD and POSA II.

A streak of residue on one side of the PPMD PEC, see Figure 9, indicates an angle of deposition of 17 degrees above the plane of the experiment trays (which is almost vertical down into the payload bay) and parallel to that side of the PPMD PEC. The angle of elongated residue drops, measured from the side of the PEC, on the experiment plates varied from about one degree on one side to 23 degrees on the opposite side 0.6 meter away. The 22 degrees angle of divergence indicates an apparent source about two meters from PPMD.

The streaks of residue on the lip of POSA II PEC (Figure 5) are all about 30 degrees to the front surface on one side and about 44 degrees to the front surface on the opposite side 0.6 meter away. The 14 degrees angle of divergence indicates an apparent source about three meters from POSA II.

All three types of directional information (1. surfaces spotted, 2. direction of streaks, and 3. divergence of streaks) indicate sources of residues in the vicinity of the rear of the payload bay and behind the docking module adapter. A 1995 STS manifest (reference 2) lists Spacehab on all MEEP exposure missions (76, 79, 81, 84, and 86). Double Spacehab modules were flown on all of these missions except STS 76 which had a single module. Both the Extreme Temperature

Translation Furnace (ETTF) and The Active Rack Isolation System (ARIS) underwent multiple ventings during STS 79 while docked to MIR. It is concluded that the water soluble residues on two of the MEEP experiments was vented from Spacehab modules.

Attempts to obtain specific information about the ventings during STS 79 were unsuccessful. No information about the cleaning process or the chemistry of the cleaning solutions used for the Spacehab vent plumbing was obtained. There appears to be a restricted information policy by some space flight offices which contrasts markedly with the open and enthusiastic assistance of Shuttle operations at KSC.

3. RETURNED SOLAR PANEL

An on-orbit photograph of the solar array returned from MIR is shown in Figure 10. Figure 11 is a photograph of the returned solar array panel at the Spacehab facility in Florida. Each of the eight sections of the returned panel is 70 cm by 120 cm. Figure 12 is a head-on photograph of the lower half of section 1 of the returned panel. Most of the cells are 4.0 cm by 4.8 cm, however some of the solar cells along the edge of the end sections are 4.0 cm by 2.4 cm. Variability in hue or color of individual cells can be seen in this photograph. Most of the color differences seen in Figure 12 result from differences in reflected light from individual cover glasses, different hues of individual silicon wafer antireflection (AR)coatings, and creep of silicone polymer material from the edge of cells onto the cover glasses. This surface thin film of silicone polymer material was oxidized to silica by atomic oxygen. Figure 13 is a photograph taken with a flash illuminating the solar cells at a small angle of incidence. This photograph shows more backscatter of light along the edges of the cells than from the center of the cells, indicating that the backscatter is from the oxidized polymer that crept onto the cover glasses.

The Russian Returned Solar Array Team was very helpful in providing information on the construction and materials of the returned solar array.

3.1 APPEARANCE AND CHEMISTRY

Four large (~ 1 cm diameter) thick brown spots were observed on sections 1, 2, 3, and 5 of the returned solar panel. Figure 14 shows the largest (1.1 cm diameter) of these spots (on section 1). Figure 15 is a SEM EDS of the spot residue. This residue (mostly sulfur, phosphorous, and sodium) chemically matches the water soluble residues on PPMD and POSA II.

A microextraction of one of the residue spots with deionized water was attempted. The one mm drop of deionized water instantly wetted (formed a very thin film of ~ 1° contact angle) the residue spot and surrounding area. This indicates the solar cell surface was very polar immediately after return from space. Water usually beads at a large contact angle on most flight hardware surfaces because of the very thin (~ 0.01 micron thick) film of organic contamination.

Section 8 (Figure 16) was removed from the solar panel and sent to Langley Research Center for microscopic examination and measurements of micrometeoroids and space debris impacts, and for cleanliness evaluation and contamination analyses. Section 8 was first examined visually with a six power comparitor (magnifying glass) and hand held illumination at oblique angles. About 95% of the solar cells have visible white backscatter on at least one edge of the cover glass. The white backscatter is mostly due to creep of the polymer potting between adjacent solar cells onto the cover glasses, and from fine spray ejecta from discharges within the potting material. Amber and black particles are ejected from many of the discharge sites in addition to the fine spray (which is dark under normal [90°] illumination). However, many of the darker cells result from a darker silicon wafer within the cell rather than a coating or film on the cover glass. The brightness of the cells near the center of Figure 16 is an artifact of reflected light from the camera's flash.

Forty-seven brown residue spots of 0.2 mm to 3.5 mm diameter were located on section 8. Two of these residue spots are shown in Figures 17 and 18. An EDS spectrum of the residue spot in Figure 17 is presented as Figure 19. This residue consists mostly of sodium, sulfur, and phosphorus.

Two of the residue spots either overlapped into the micrometeoroid spalled surface, or were deformed by the spalled surface. This indicates these residue spots were deposited after the micrometeoroid impact and hence were not preexisting to deployment in space.

The EDS (figure 20) of spot in Figure 18 shows only cadmium and potassium. The source of the cadmium and potassium is unknown.

3.2 MICROPHOTOGRAPHY

More than 200 microphotographs have been taken of section 8 of the returned solar panel. The opaque residue deposits and other interesting features were examined and photographed at 50x, 100x and 200x with a brightfield microscope. This microscope projects light through the microscope objective, and collects reflected and scattered light through the same lens. Hence the light is almost normal (90°) to the object surface and the microscope serves as a low resolution interferometer in which some colors constructively interfere (are bright) and some colors destructively interfere (are dark) in thin films. Vivid colors are seen on most of section 8's solar cells when viewed through the brightfield microscope. These color patterns can be seen in Figures 21 and 22. These color patterns are typically a few hundred microns across. An out-of-focus electrical grid on top of the silicon wafer and the cover glass silicone adhesive can also be seen in Figures 21 and 22. Cover glasses were removed from several solar cells and the vivid color patterns were no longer visible through a brightfield microscope. This indicates these patterns result from optical interference in the combination of cover glass, silicone adhesive, and antireflection (AR) coated silicon wafer. Clear thin films (~ 1 micron thick) were observed on both the back side of the cover glass and the top of the zinc sulfide AR coating on the silicon wafer.

Additional thin transparent films of several types are shown in Figures 23 and 24. Some of these thin films or water marks have lots of very fine particles (similar to airborne dust) which are visible with darkfield illumination, intrapped in the thin molecular film and some of the films have little or no trapped dust. Many of the thin films are circular or ring shaped, suggesting droplets or bubbles. Most of the thin films are irregular in shape, possibly indicating pronounced wetting by an incident droplet. The thin film color shifts or enhancements due to deposition of molecular material on the cover glasses is similar to the color shifts due to erosion of optical-coated thin-films reported in reference 1.

Numerical surface cleanliness of the returned solar panel can be estimated by using MIL Standard 1246C. The largest spot of thick residue on section 1 is about 1.2 cm in diameter. Treating this spot as a particle on the 0.85 m^2 surface gives a cleanliness level of about 7500. Several dozen of the 4 cm by 4.8 cm solar cells on section 8 of the returned panel have spots of about 1 mm diameter. This corresponds to a cleanliness level of about 2000.

The minimum molecular film thickness can be estimated by the color shifts seen through a brightfield microscope. A difference in color of about 0.1 microns (i.e. blue and yellow, or yellow and red) is caused by a film of (n-1) x d where n is the index of refraction and d is the film thickness. Assuming an index of refraction of n=1.5 indicates a film thickness of about 0.2 microns for blue to yellow or yellow to red color shifts. This corresponds to level H molecular film in MIL Standard 1246C.

Venting of gases (i.e. cabin air) is a possible significant source of external contamination on the MIR space station. Moisture and fine particles would be released in these ventings, whether they were intentional or accidental. The moisture subsequently could condense into mist or droplets because of the cooling due to expansion of the venting gas. Clean droplets with little organic compounds would wet or sheet polar surfaces leaving irregular films after the water completely evaporated. Droplets with more organic content would tend to bead up and leave circular films after the water completely evaporated.

4. CONCLUSIONS

A large number of water soluble residues were found deposited on the MEEP PPMD and POSA II experiments and PEC housings. These residues probably resulted from ventings from Spacehab modules during STS 79 which released residual aqueous cleaning solutions. The residues consisted mostly of sulfur, sodium, and phosphorous, typical ingredients of detergents.

Large (greater than 1 cm diameter) and small (less than 1 mm diameter) thick brown spots were observed on the returned solar array. These water soluble residues consisted mostly of sulfur, sodium, and phosphorous, and could have originated from space craft module releases during the ten years of space exposure. Some of the residue films also contained fine particles. Many of the films are ring shaped, suggesting droplets or bubbles. This suggests venting of gases as a source of these residues. The cleanliness level of the returned array is about 2000 H, using Mil Standard 1246 C.

An unexpected category of external contamination (water soluble residues) dominated the MEEP experiment and was also present on the returned solar array. Water soluble residues will probably be a significant, but unplanned for category of external contamination for long duration manned spacecraft such as the ISS. The multitude and complexity of operations performed by relatively independent organizations has much more potential for vent-related contamination accidents than previous missions. The non-disclosure of requested information concerning contamination related operations and equipment can make meaningful study of contamination processes or accidents difficult or impossible. A policy of open disclosure of relevant information regarding significant contamination incidents should be adapted for the ISS.

The unexpected type and extent of contamination on MEEP shows that the space environment with interacting manned vehicles and operations is not highly predictable. Early monitoring of the ISS during the construction stages with MEEP preflight-type experiments is highly desirable. The use of returned flight hardware such as the Mir solar array for space environment studies is extremely cost effective and should be encouraged and expanded.

5. REFERENCES

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William H. Kinard is a Materials Scientist with 44 years experience at the Langley Research Center. He is the Chair for the Micrometeoroid and Space Debris Group of the NASA Space Environmental Effects Program, and is a principal investigator for the Mir/ISS Risk Mitigation Program. He received a BS in mechanical engineering and an honorary Doctor's degree from Clemson University.

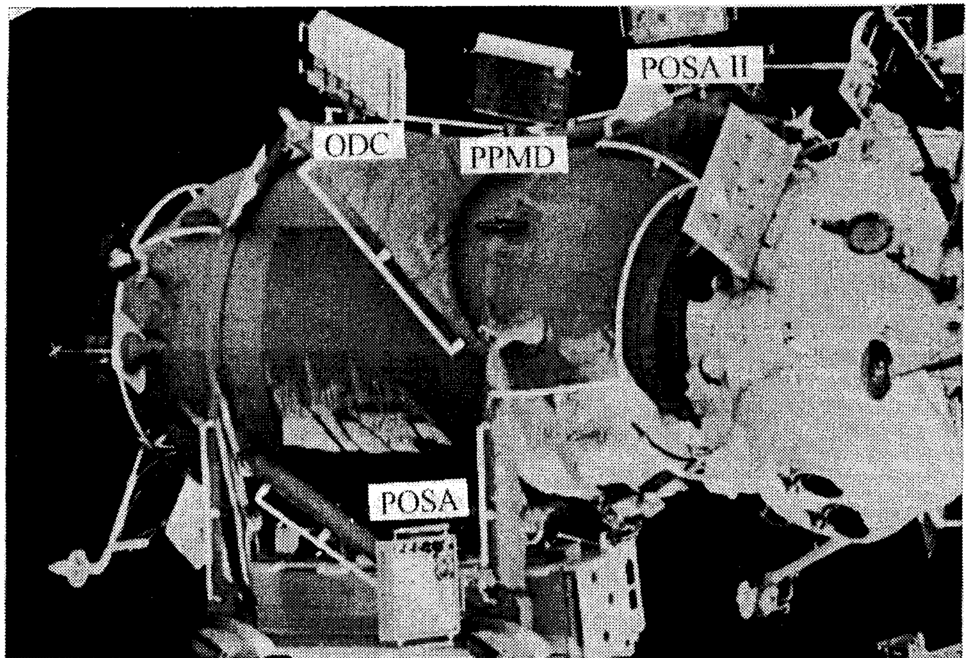


Figure 1.- STS 81 photograph of MEEP on Mir Docking Module.

Figure 2.- STS 86 photograph of brown spots on PPMD and handrail.

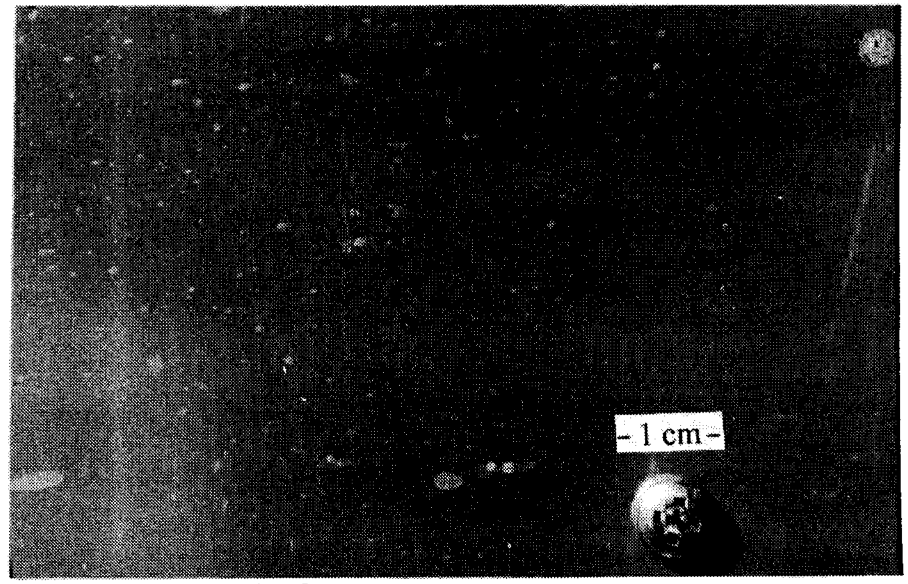


Figure 3.- Photograph of PPMD zinc plate #7.

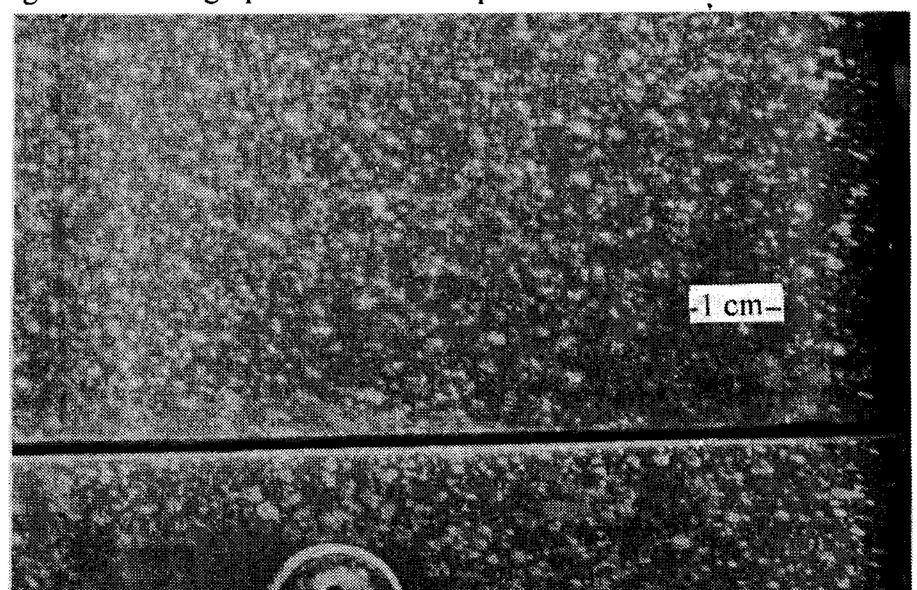
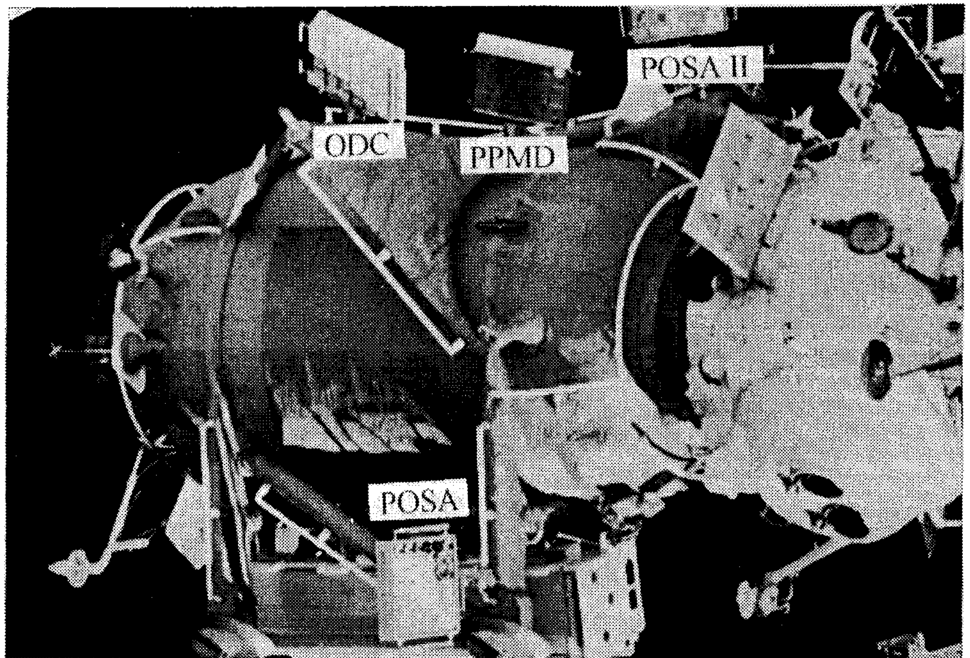


Figure 4.- Ultraviolet light photograph of spots on POSA II.



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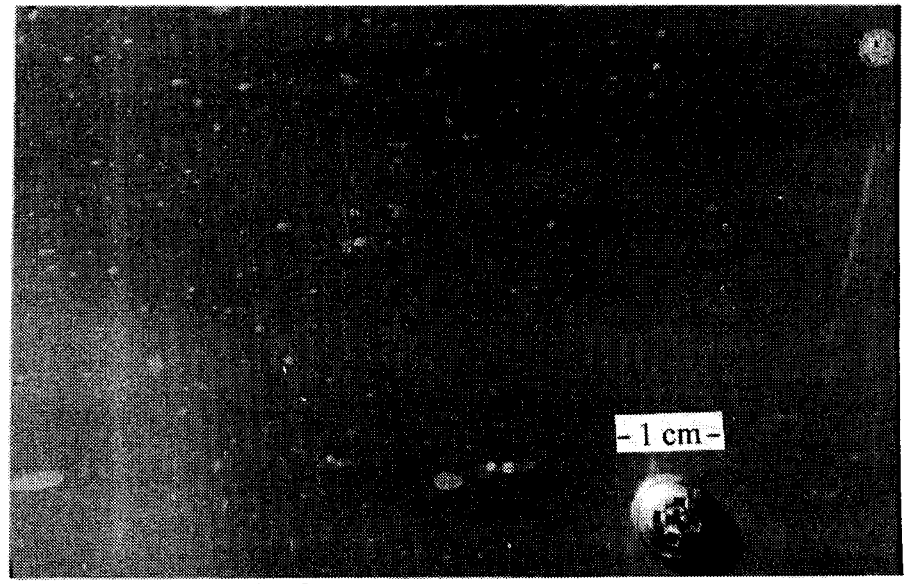

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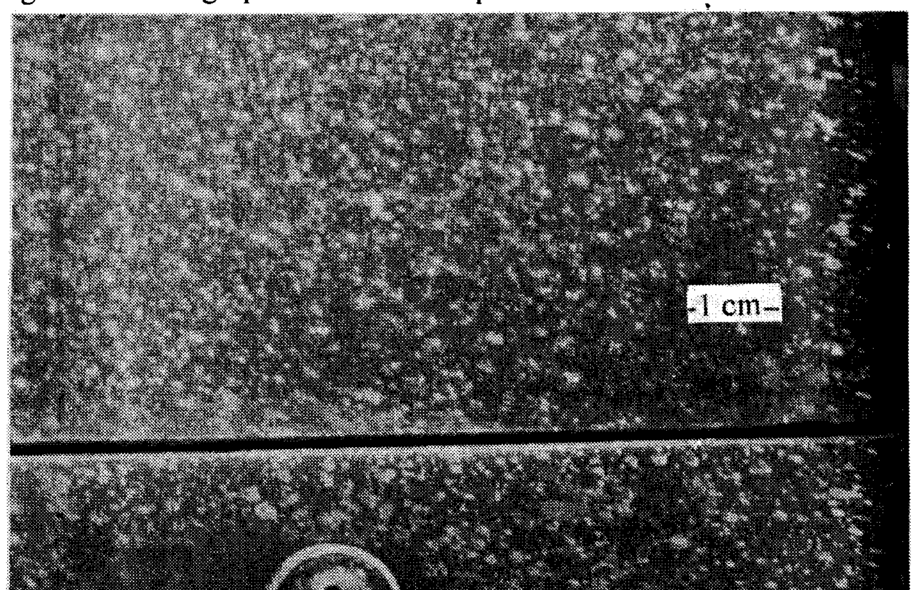

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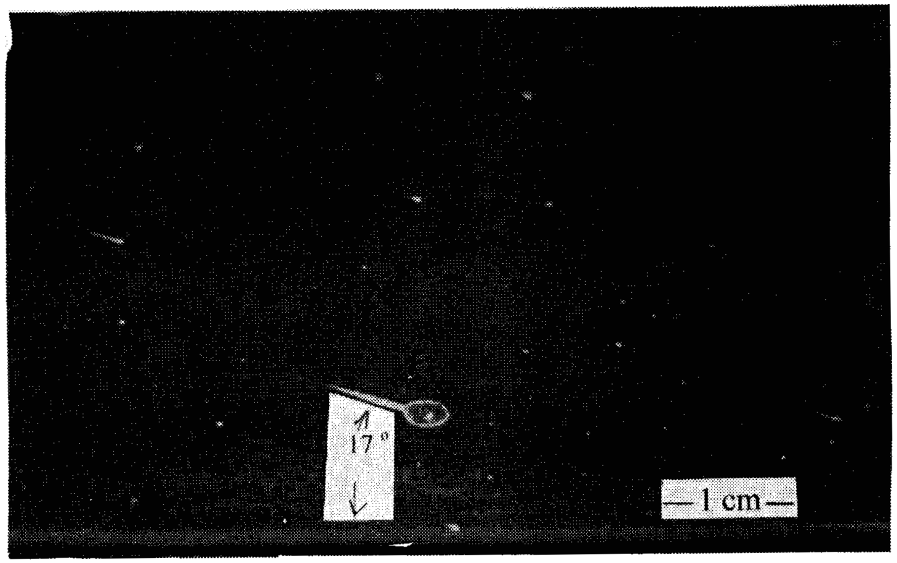

Figure 9.- Streak 17⁰ from experiment surface on PPMD PEC.

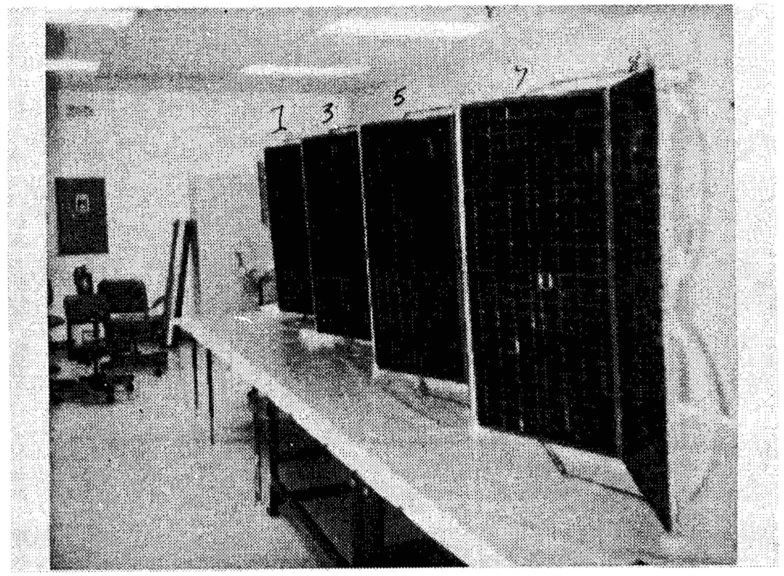

Figure 11.- Returned solar array in Spacehab facility.

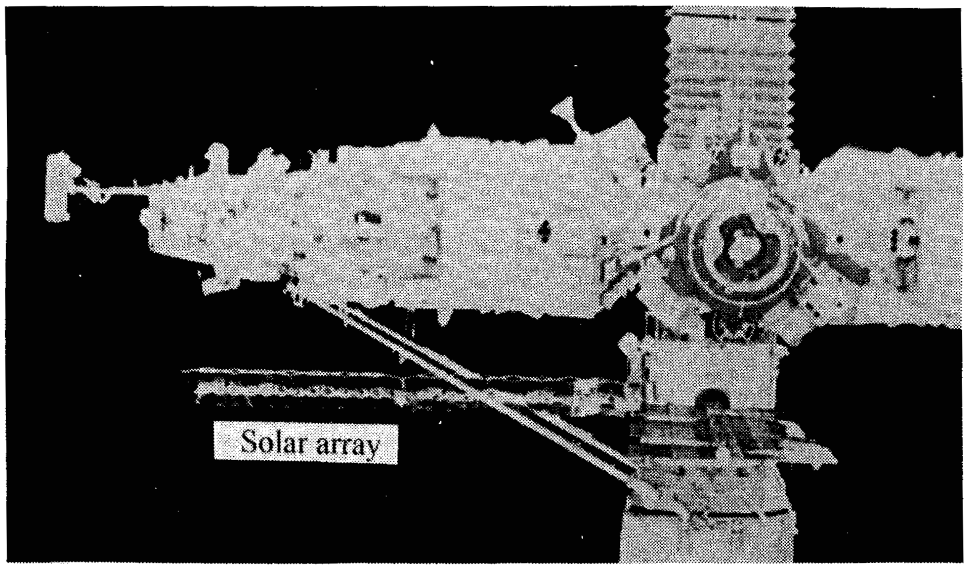

Figure 10.- Photograph of solar array on Mir.

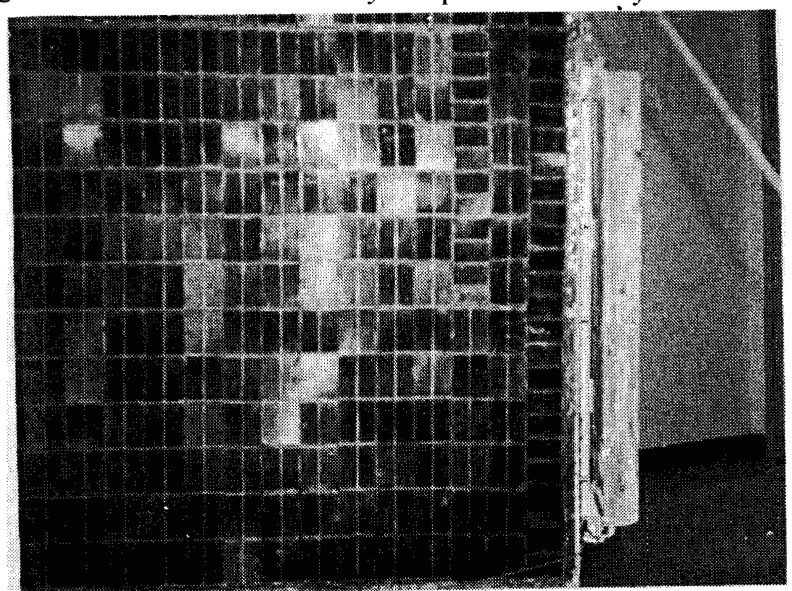

Figure 12.- Section 1 of returned solar panel.

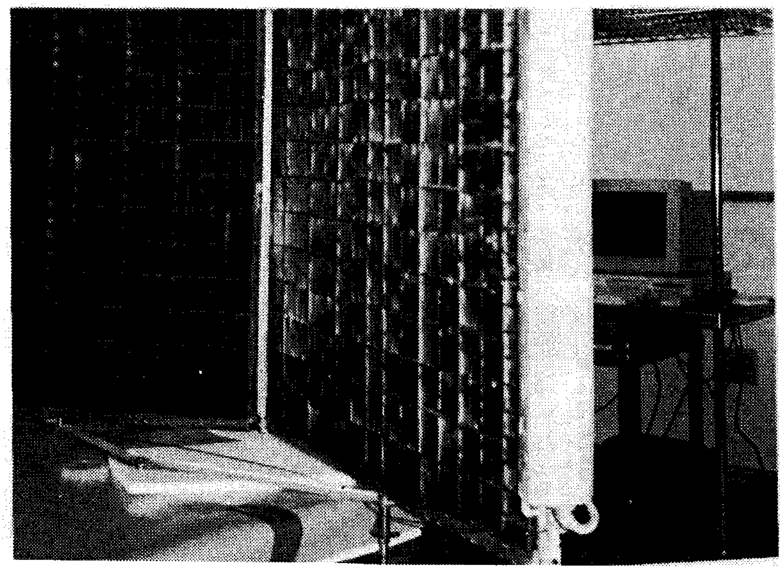

Figure 13.- Backscattered light from the edges of the solar cells.

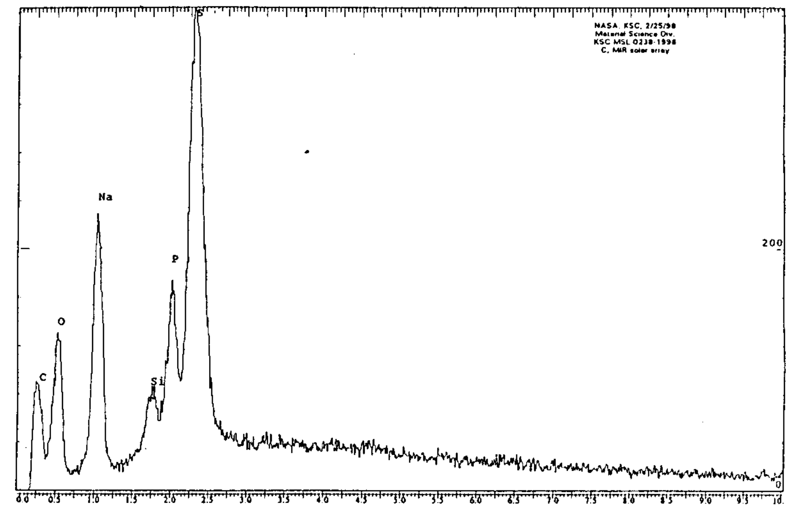

Figure 15.- EDS of 1.1 cm brown spot residue.

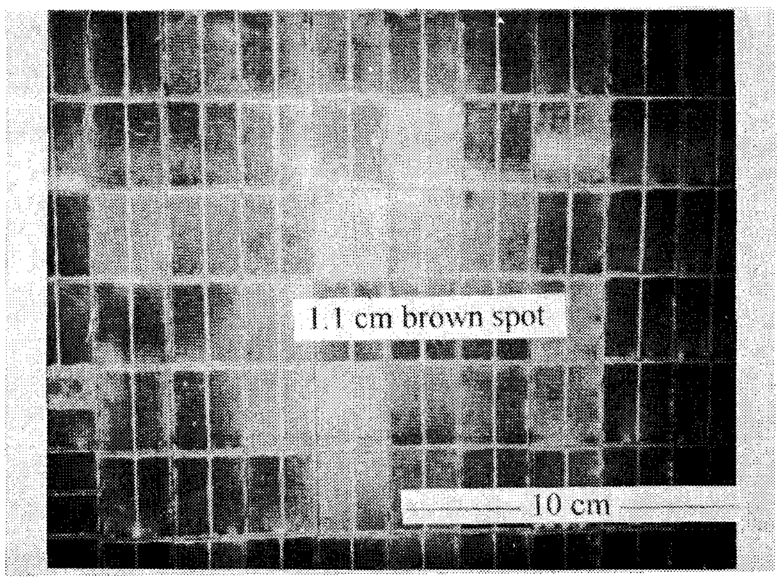

Figure 14.- Photograph of 1.1 cm brown spot on panel 1.

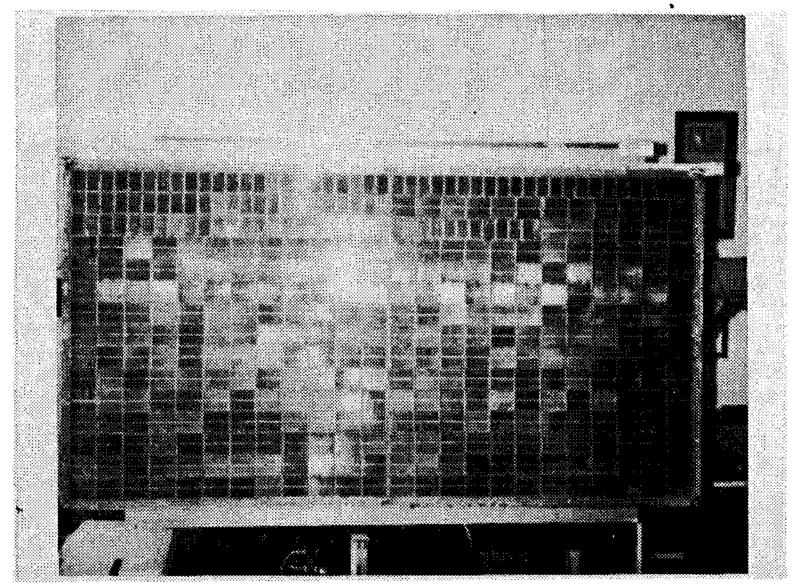

Figure 16.- Photograph of section 8 of returned solar panel.

Figure 17.- 50x microphotograph of largest residue spot on panel 8.

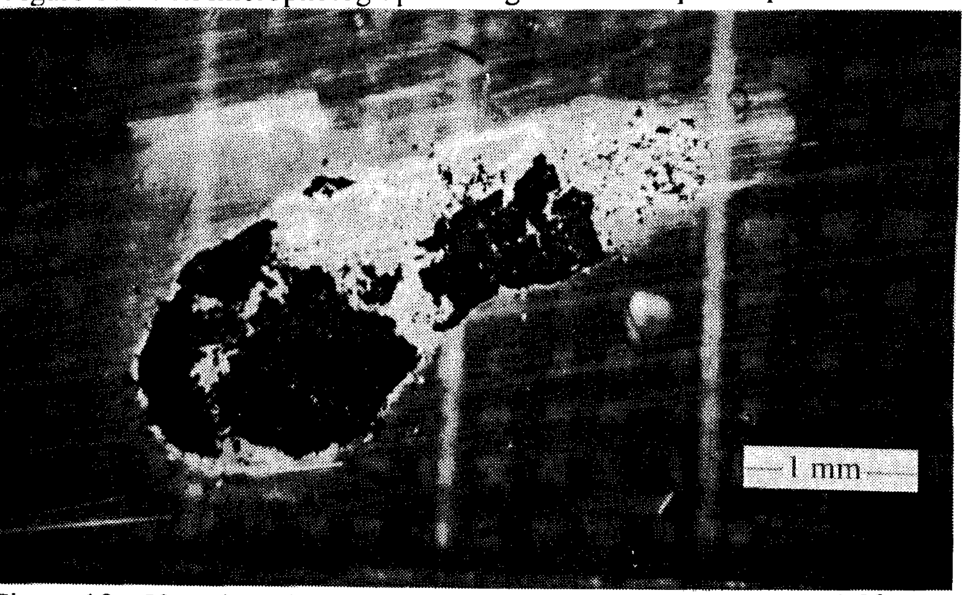

Figure 18.- 50x microphotograph of cadmium residue on cell 8-14-22.

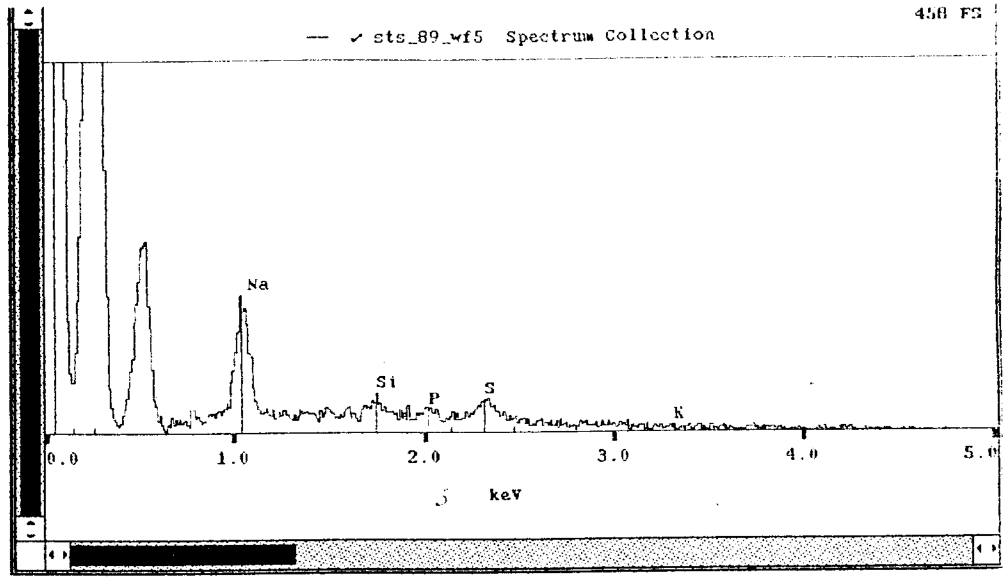

Figure 19.- EDS of largest residue spot on panel 8.

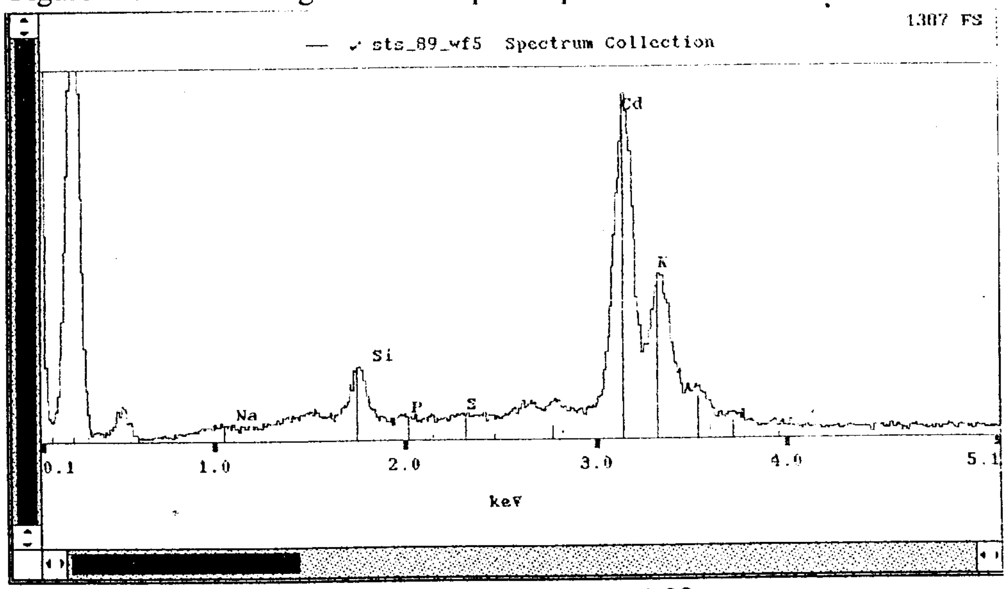

Figure 20.- EDS of cadmium residue on cell 8-14-22.

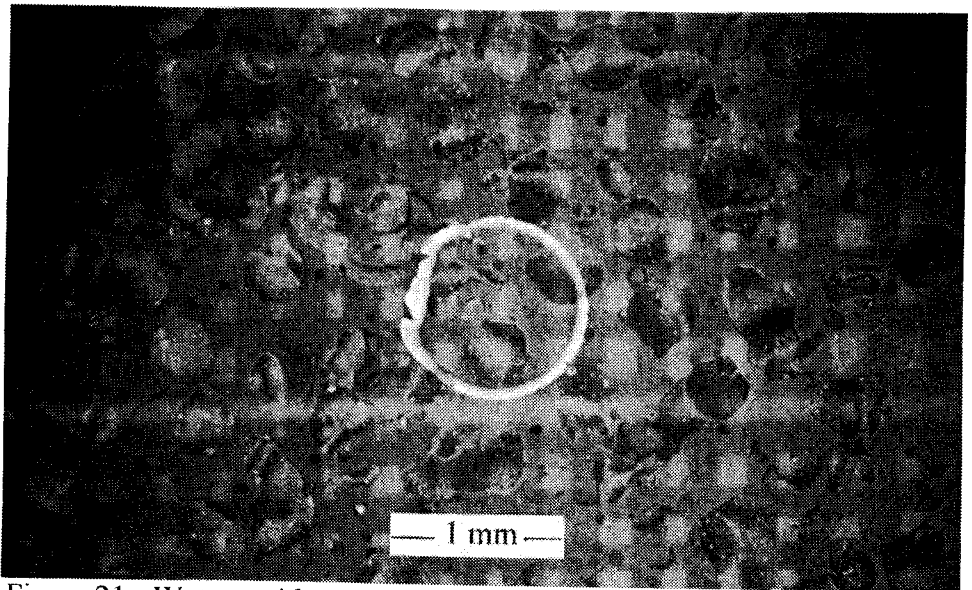

Figure 21.- Water residue marks on solar cell 8-1-14.

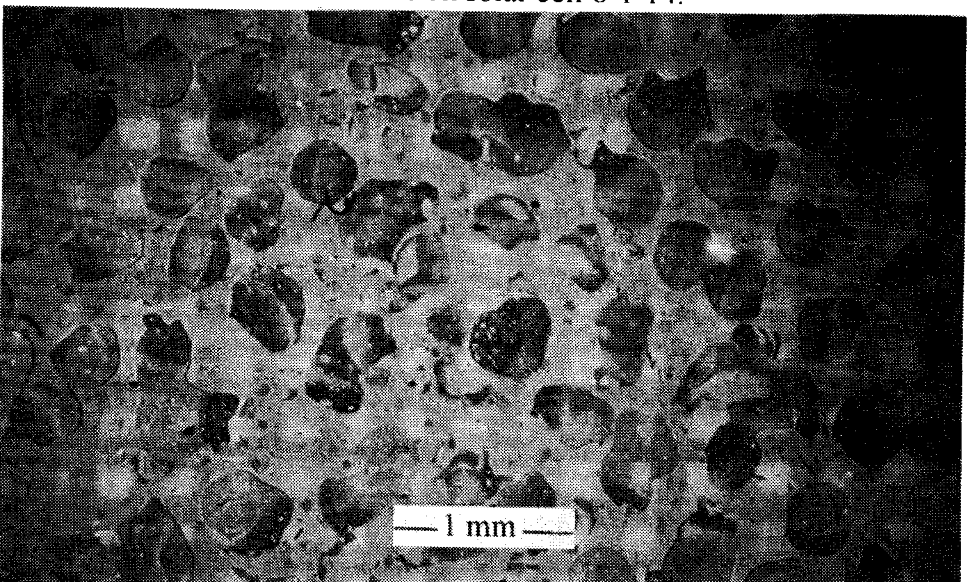

Figure 22.- Water residue marks on solar cell 8-1-14.

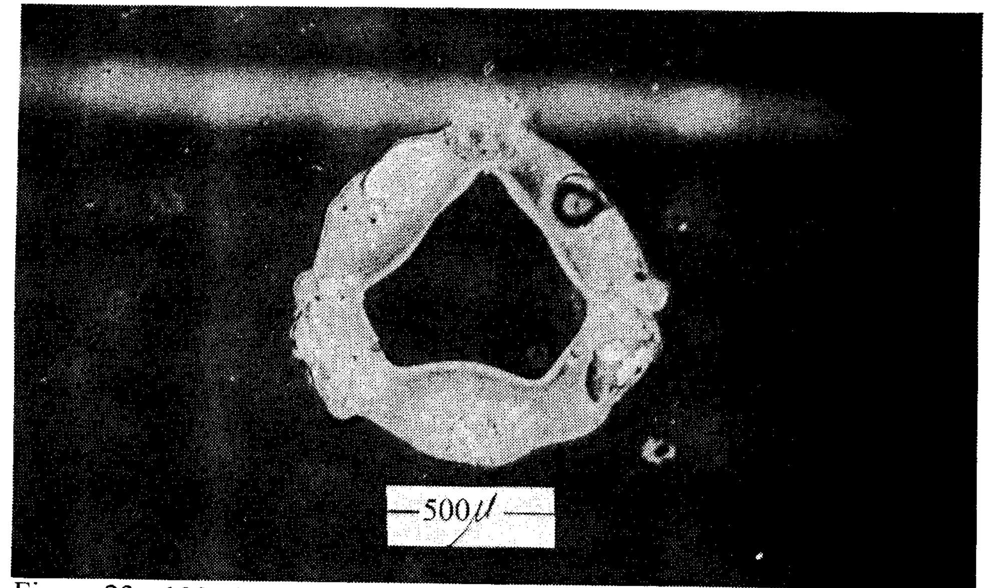

Figure 23.- 100x brightfield photograph showing variable thickness residue.

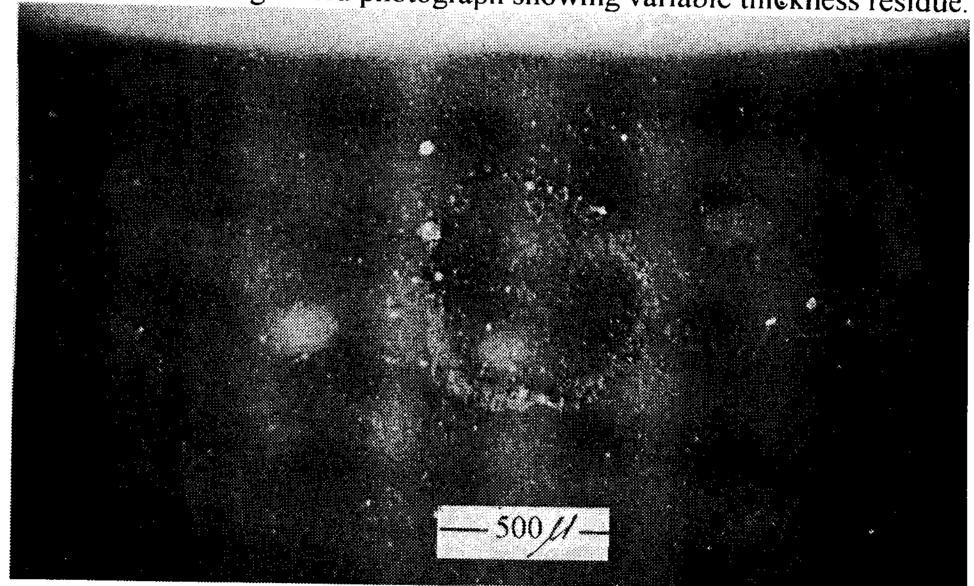

Figure 24.- 100x darkfield photograph showing many fine particles.