Mir Solar Array Return Experiment

by -

James Visentine, Boeing; William Kinard, Langley Research Center; David Brinker, David Scheiman, and Bruce Banks, Lewis Research Center; James Zwiener, Marshall Space Flight Center; Keith Albyn, Johnson Space Center; and Thomas See, Lockheed-Martin

Prepared
for -

1998 Space Environments and Effects Program

Flight Experiments Workshop

Huntsville, Alabama

June 23-25, 1998

Mir SARE (Solar Array Return Experiment)

- *Shuttle-Mir Program has provided unique opportunity for U.S. and Russian investigators to visually inspect, characterize, & assess condition & operational performance of returned Russian space hardware*

- *Experiment designed to characterize external contamination and orbital debris environments and assess degradation in solar array power performance*

- *SARE PV Panel, which consisted of eight foldable sections, was operated aboard Mir and exposed to low Earth orbital space environment for ~10 years*

- *SARE PV Panel was first installed & later removed from Mir core module by suited Russian cosmonauts during June 1987 & November 1997, respectively*

- *Panel was returned in Spacehab Module by Space Shuttle during STS-89 Mission (January 1988). U.S. and Russian visual inspections & initial power performance tests commenced at Spacehab facilities during February 1998*

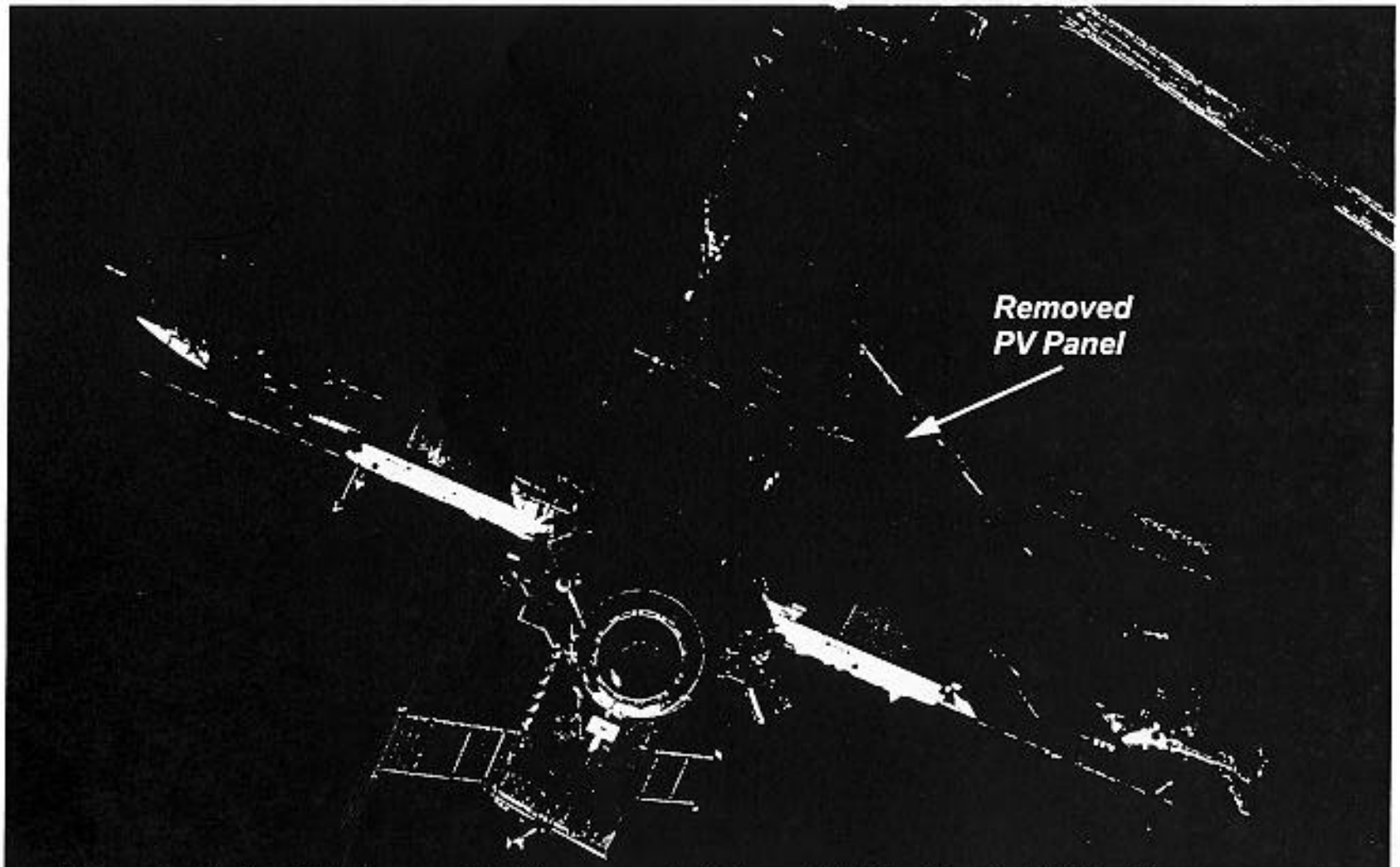


Figure 1. Photovoltaic Array on the Mir core module from which the Russian PV Panel was removed.

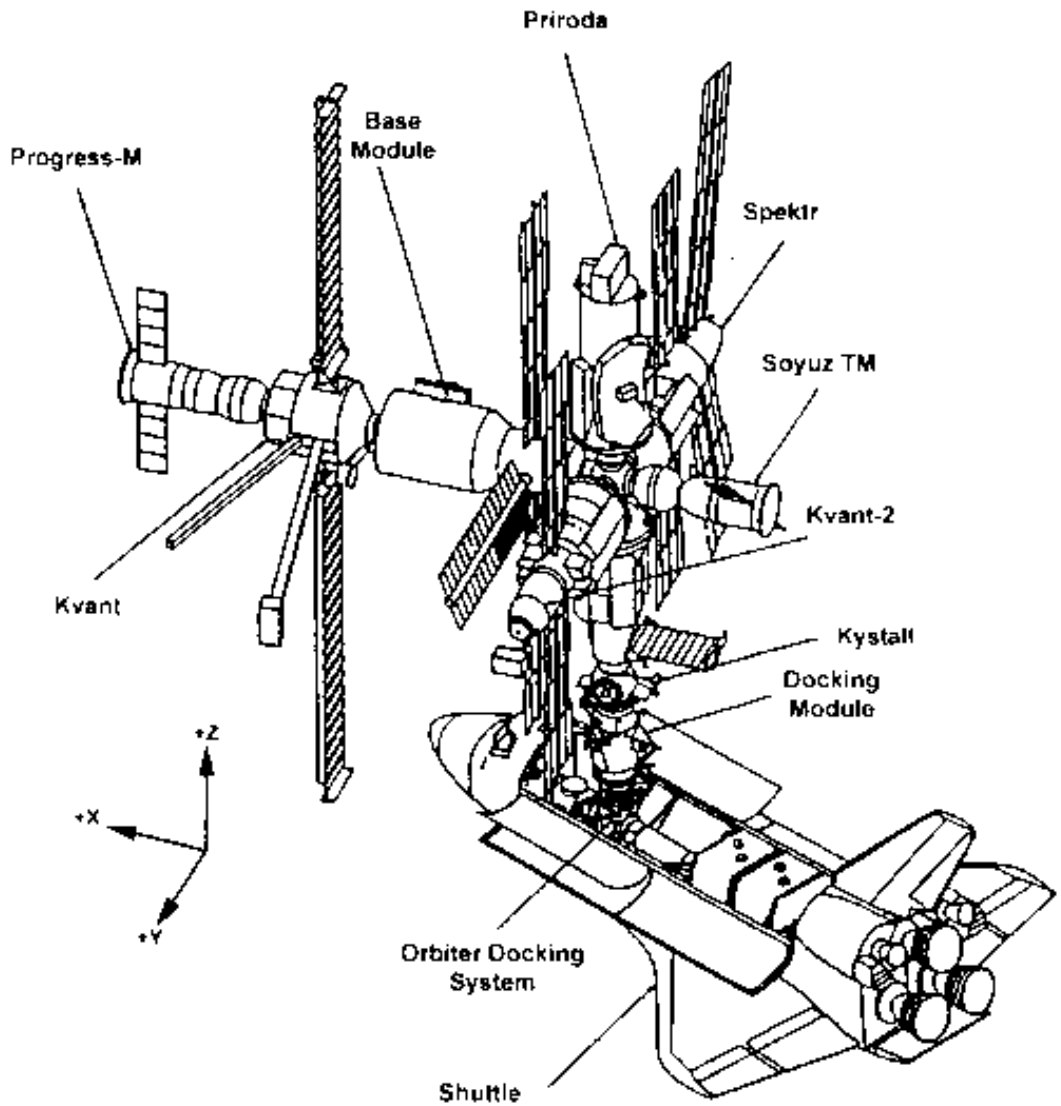


Figure 2. Illustration showing the configuration of the PV Array after the Russian Panel was removed.

Mir SARE Solar Cell Configuration

- Each solar cell has cover glass with anti-reflection coating to improve light transmission properties. All spacings and joints between cells filled & sealed with organic potting material.
- Cover glass is bonded to layer of fabric mesh which is tightly woven and impregnated with organic adhesive
- Solar cells are each bonded to this fabric layer and to a second layer of fabric mesh which which is attached to backside of each cell within panel sections
- Bonded to backside of second layer of fabric is an Optical Solar Reflector
- OSR's used to reject heat from two adjacent solar cells attached to its surface and to minimize heat input into PV array when exposed to reflected, or direct sunlight
- Polymer backside netting, large open-weave organic fabric, was physicially attached between cells with organic threads which tied all three fabric layers together. Netting fabric supported cells during manufacturing process and provided mechanical strength during launch, ascent, and array deployment

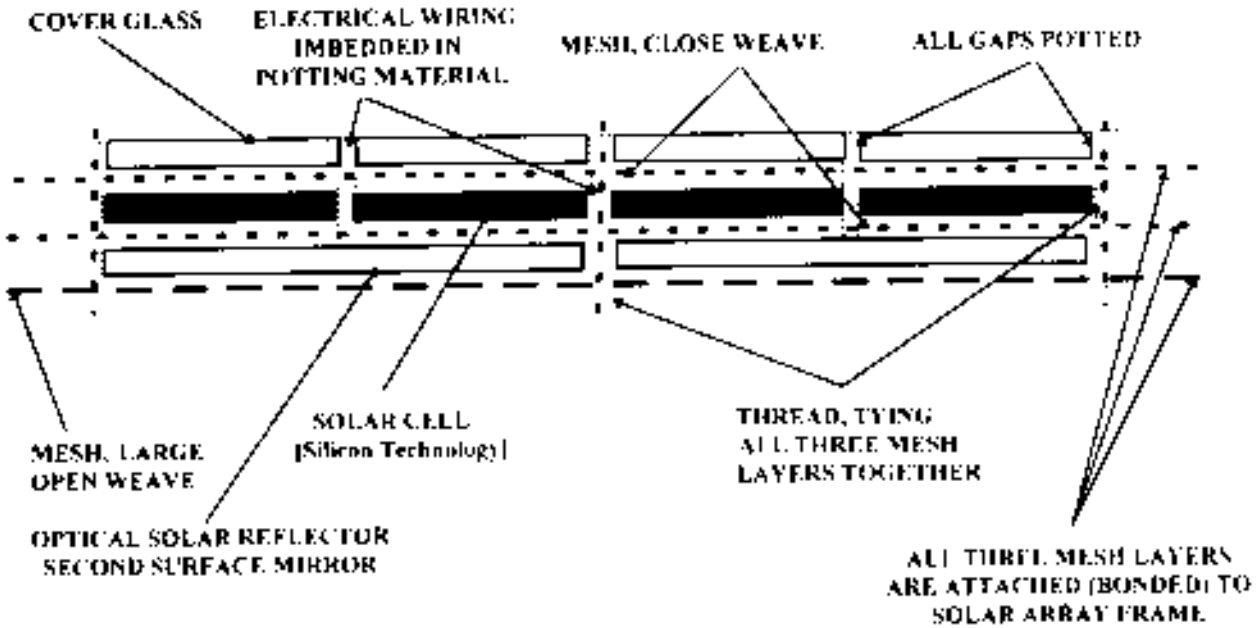


Figure 4. Cross section of the returned Russian solar array.

SARE Visual Inspections

- Visual examinations of array surfaces during post-flight inspections revealed they were highly contaminated by opaque white film deposited non-uniformly along length of the panel on both the cover slides, handrails, and the optical solar reflectors

- Molecular film deposits on edges of cover slides appear to have originated from holes due to reinforcement threads which penetrated potting material between the cells

- Deposits were most visible when viewed obliquely from the surface and visually appeared as a series of white dots (light reflections) on edges of cover slides

- Several localized regions of the eight panel sections were highly blackened, and silicon cells within these regions appear to have been damaged by electrical arcing

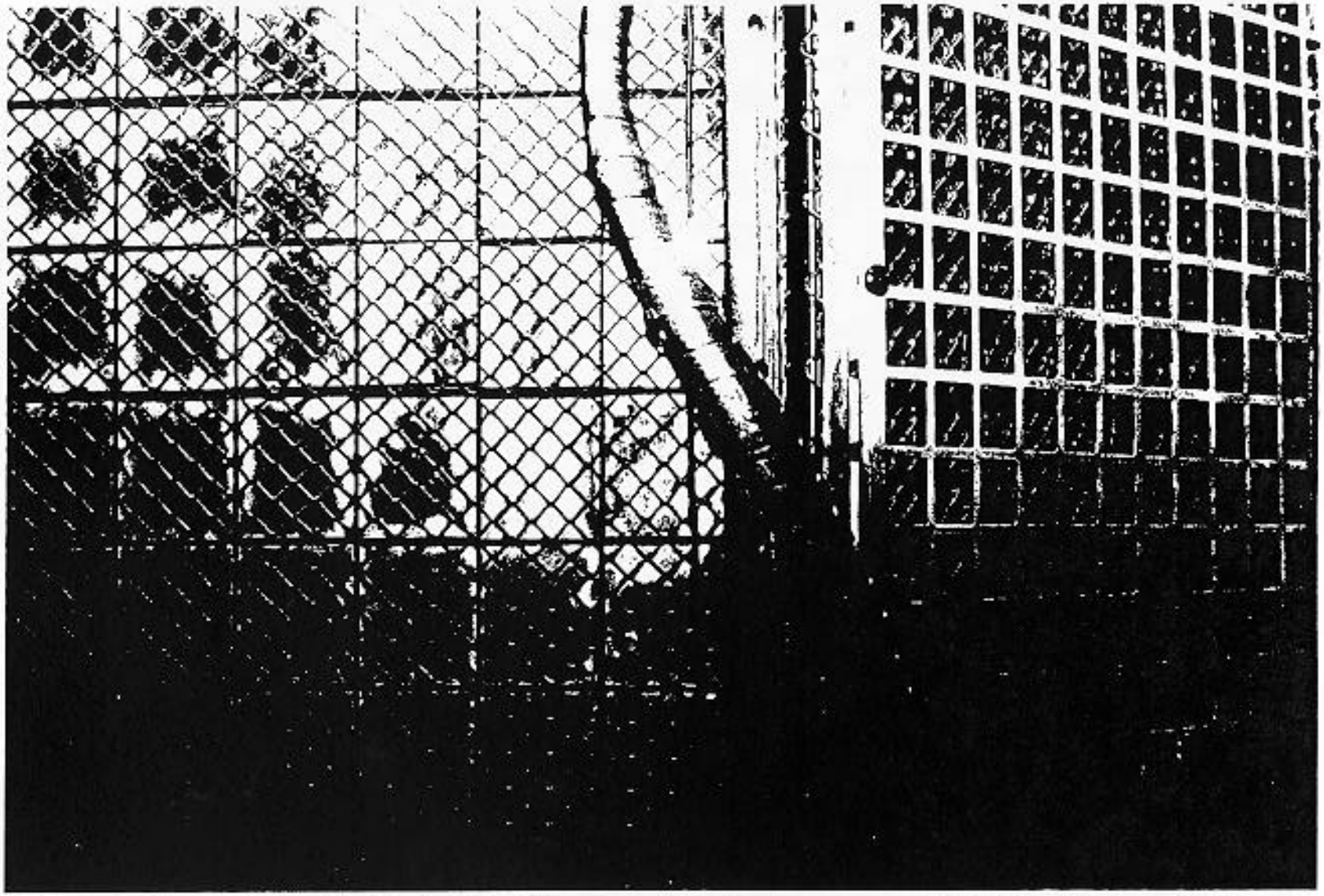


Figure 6. Photograph of the back side of the array showing the opaque, white film which coated the Optical Solar Reflectors.

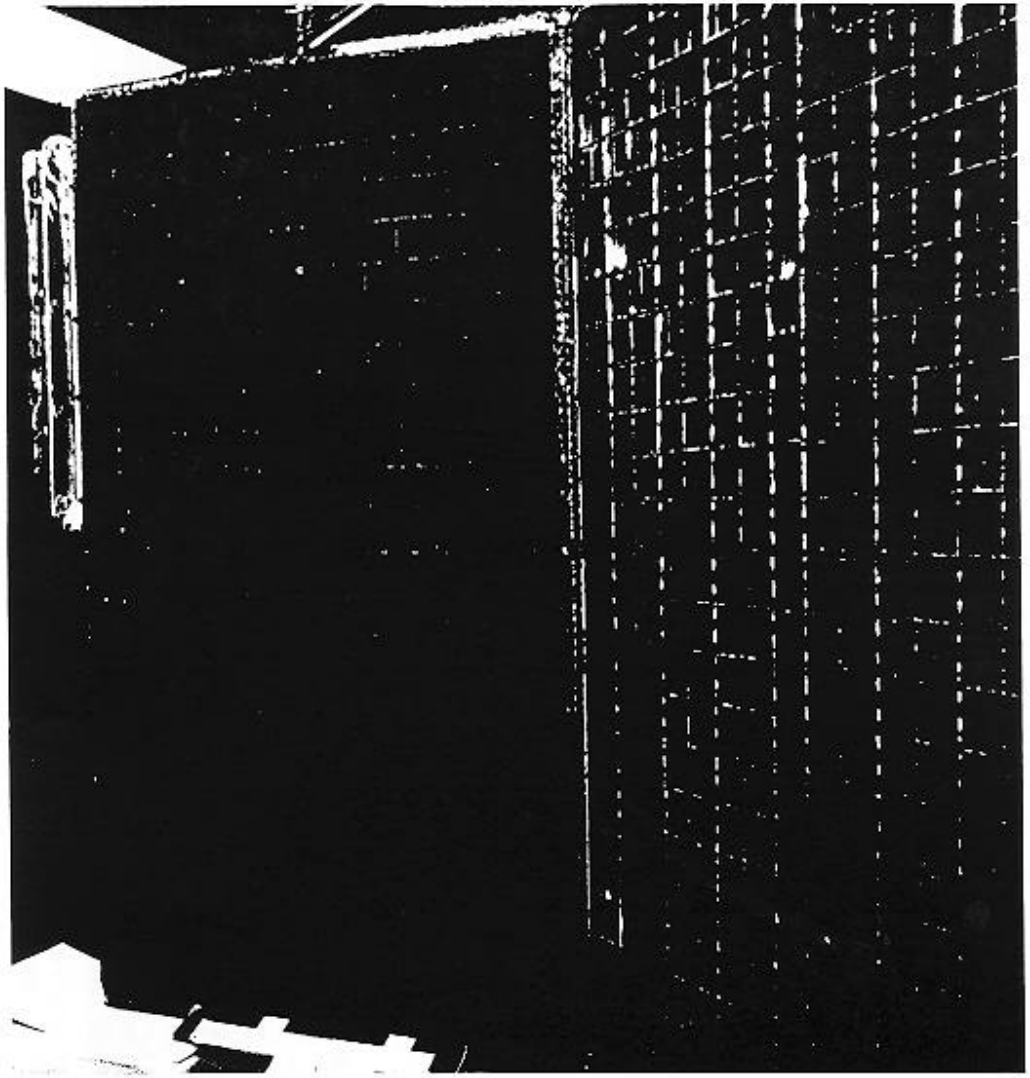
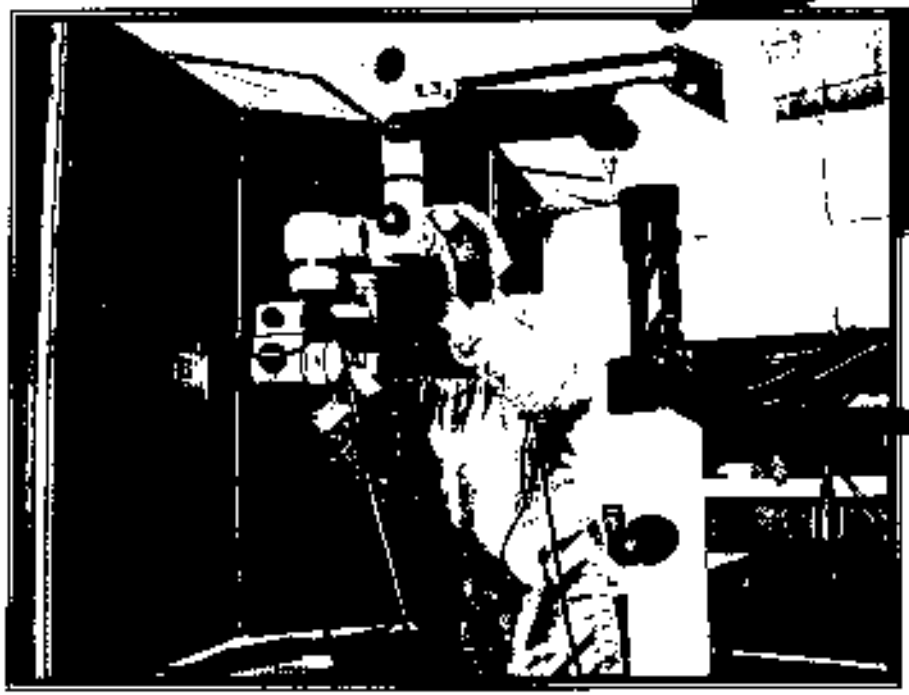


Figure 5. Photograph of the front side of panels 1 & 2 showing the opaque, white material that coated the edges of the solar array cover slides. The source of this contaminant appears to have originated where the reinforcement threads penetrated the epoxy material between the cells.

All Panels Visually Scanned & Photographed at KSC

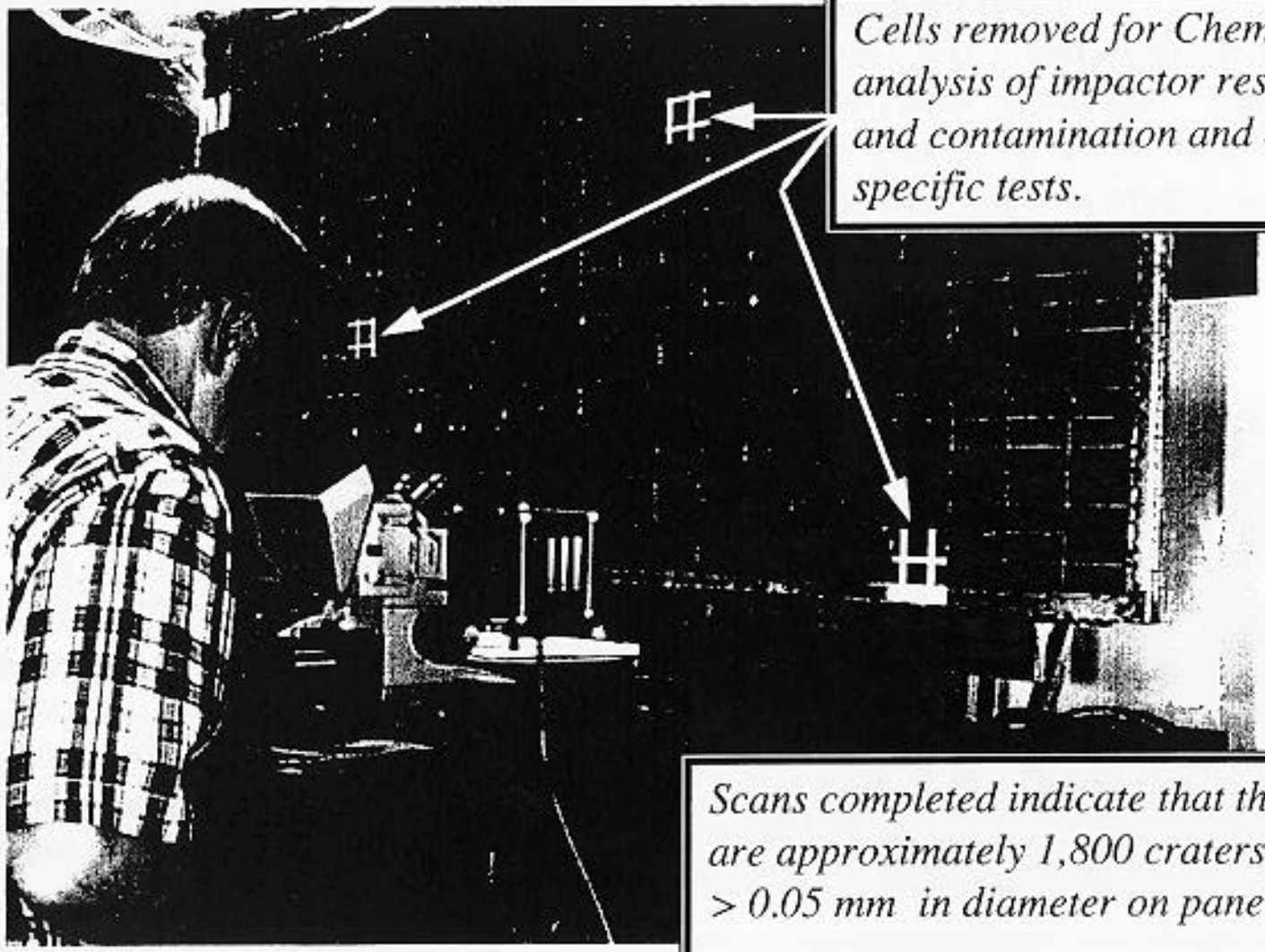
- *Visual scans counted and identified locations of craters. Found -*
  - *a. 1748 small craters > 0.3 mm diam.*
  - *b. 47 medium craters > 3 mm diam.*
  - *c. 15 large craters > 5 mm diam.*

Total - 1810 craters > 0.3 mm diam.



- *Digital images obtained through a microscope of 200 small, medium and large impact sites. Images have been recorded on Photo Compact Disks.*

Panel #8 Microscopically Scanned at LaRC (50X)

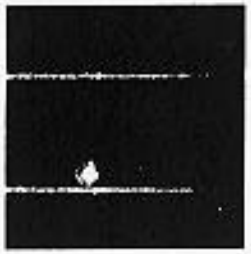


Cells removed for Chemical analysis of impactor residue and contamination and other specific tests.

Scans completed indicate that there are approximately 1,800 craters > 0.05 mm in diameter on panel #8.

Typical Craters in Mir Solar Panels

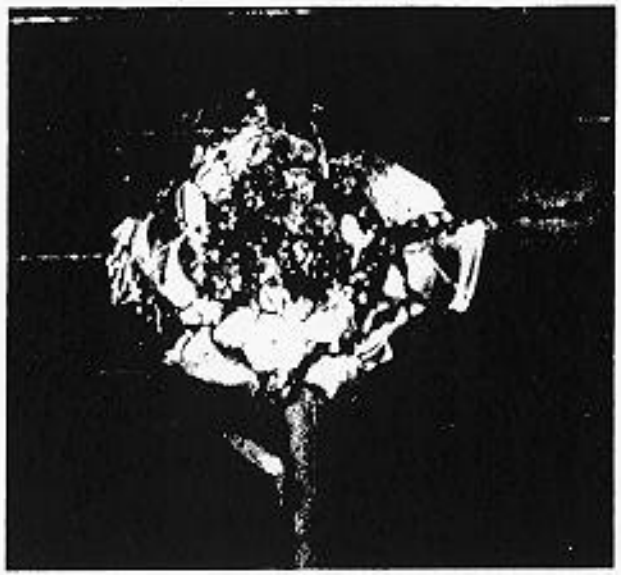
Small



> 0.3 mm Diam.

Penetration limited to cover glass.

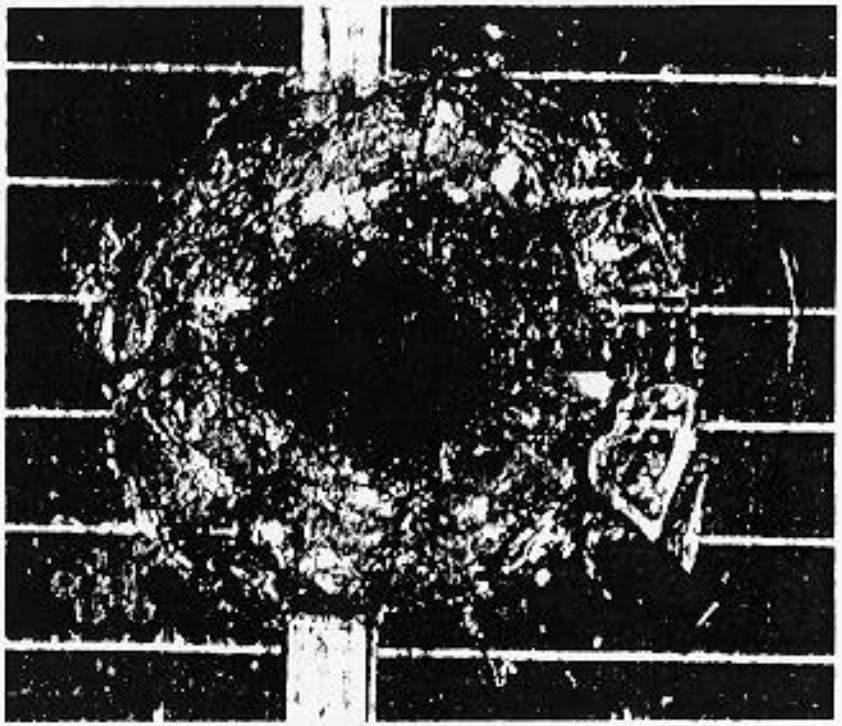
Medium



> 3 mm

Penetrated multi-layers (cover glass, fabric, solar cell and possibly rear reflector).

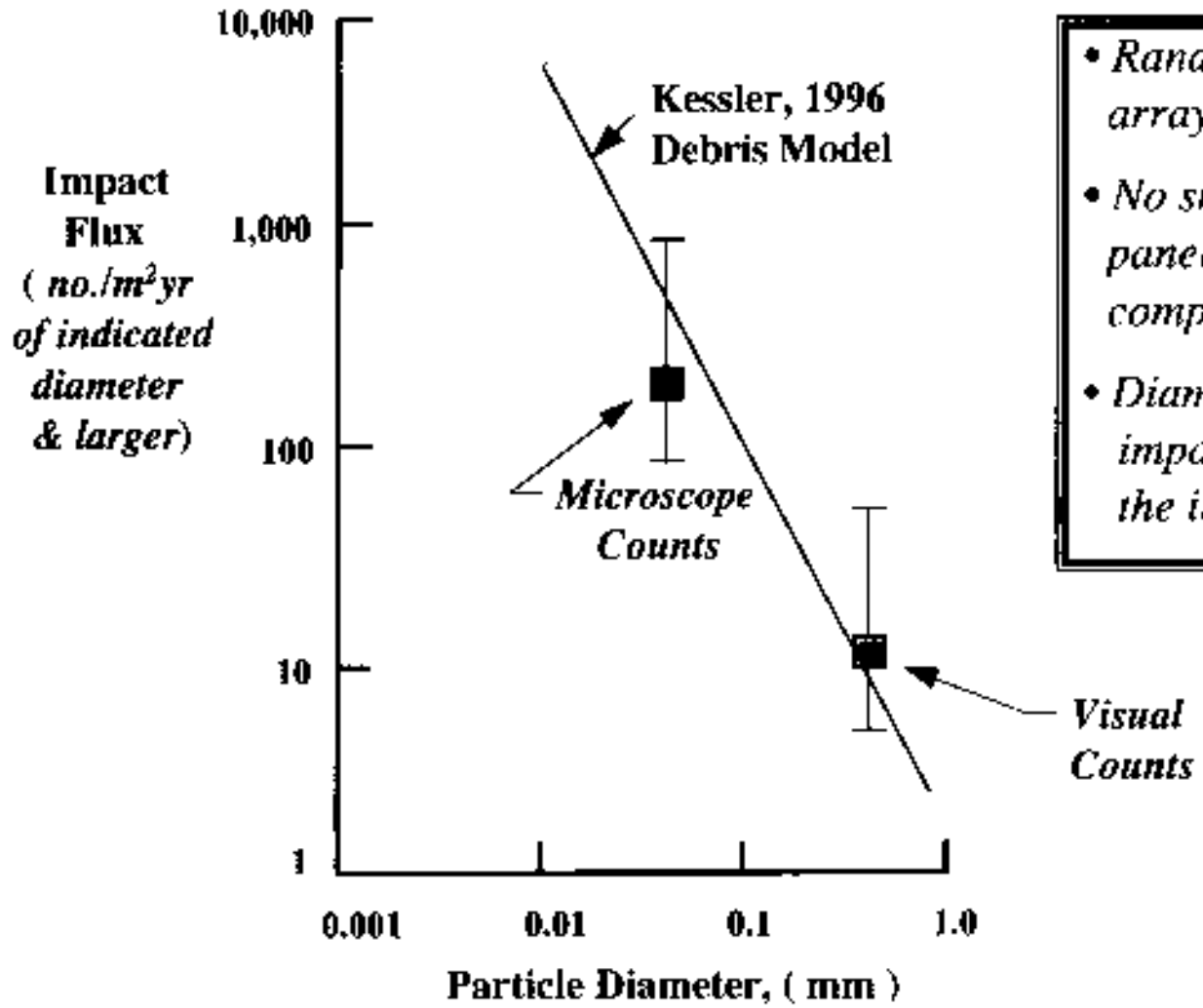
Large



> 5 mm

Penetrated multi-layers, often, the complete solar array.

Debris Impact Fluxes Indicated by Crater Counts



Assumptions -

- *Random orientation of array panel.*
- *No shielding of array panel by other Mir components.*
- *Diameter of damage at impact sites is 10 times the impactor diameters.*

SARE Power Degradation Studies

- SARE PV panel section was inspected, tested, and evaluated by U.S. specialists at NASA Lewis Research Center

- Evaluation tests consisted of illuminating entire panel section with one sun solar radation intensity and measuring power output performance

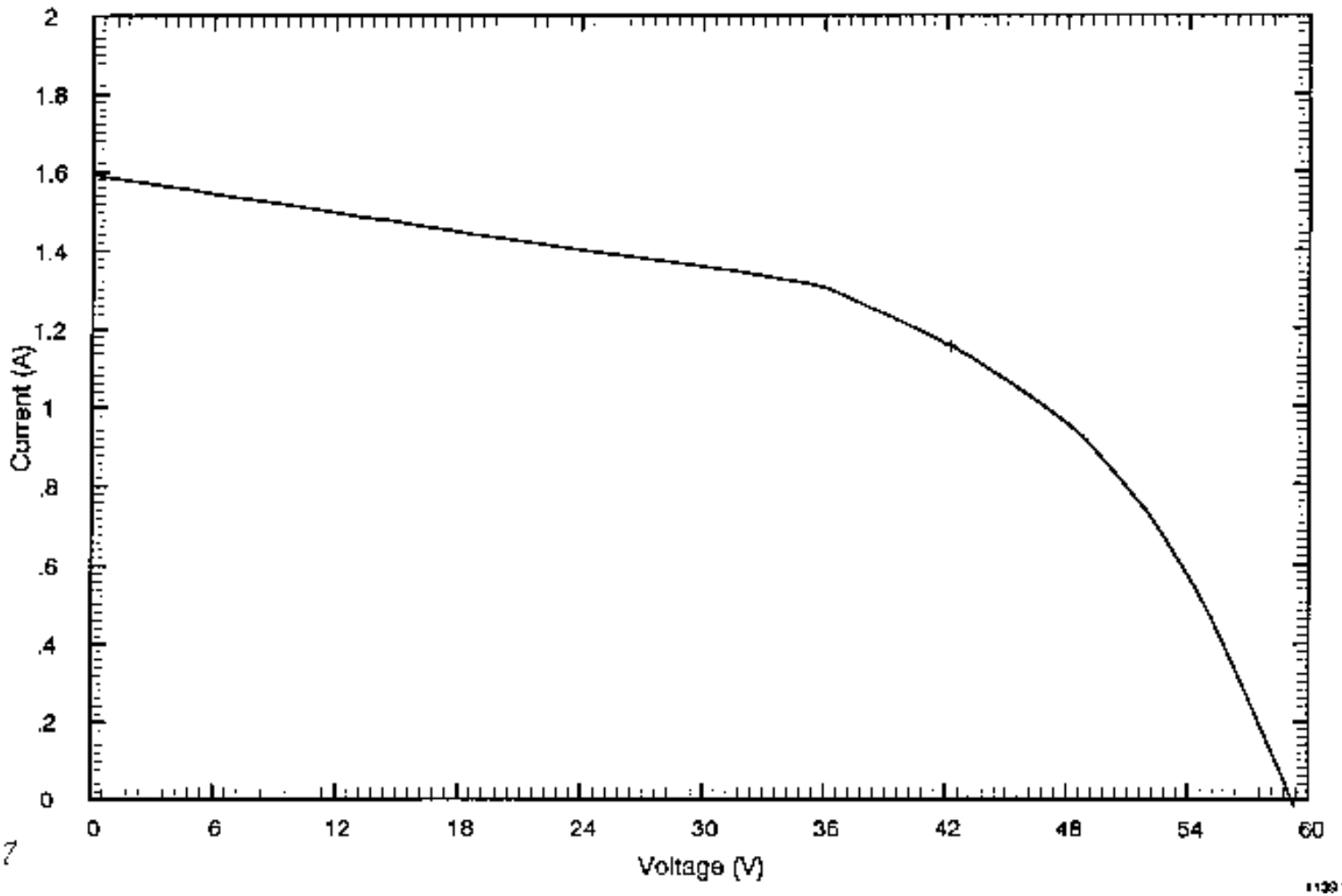
- Test Measurement Results:
  - Panel Operating Temperature: 25 °C
  - Panel Area: 7,409 cm^2
  - Short Circuit Current: 1,595 mA
  - Open Circuit Voltage: 59 Volts
  - Maximum Power Output: 48.7 W (1,153 mA @ 42.2 V)
  - Fill Factor: 0.516 (Original F/F was probably 0.70 - 0.75)
  - Power Efficiency: 4.81% (Original P/E was probably 10-12%)

- Component tests are presently underway to measure the performance and efficiency of ten solar cells individually removed from SARE panel section

NASA

Lewis Research Center

Cell ID	: Panel 8	I_{sc}	=	1595.2 mA
Date	: 04-23-1998	V_{oc}	=	59.158 V
Area	: 7409 cm^2	I_{max}	=	1153 mA
Temperature	: 25 °C	V_{max}	=	42.212 V
Data is not temp corrected		P_{max}	=	48.672 W
10 years on MIR		F.F.	=	.516
File : LAP1139.I_V		Eff.	=	4.81 %



17

1139 LAPSS

Project Status and Future Laboratory Studies

STS-89 Returned Russian Solar Array Experiment

Activity Name	Item	Start Date	Finish Date
	1	2/23/98	2/27/98
• Optical Properties Report (K. Albyn)	2	4/5/98	Complete
• Residue Analysis Report (S. Harvey)	3	3/27/98	Complete
• MM/OD Impact Survey Report (W. Kinard)	4	4/12/98	Complete
• Power Degradation Report (D. Brinker)	5	4/12/98	Complete
Remove Panel #8 Handholds & Handrails and transport to JSC	6	2/27/98	3/2/98
Perform JSC/WSTF Chemical Analysis of Panel #8 Handholds and Handrails	7A	3/3/98	5/1/98
JSC to Prepare and Ship Handholds & Handrails to LeRC/LaRC for Analysis	8A	5/4/98	5/8/98
LeRC/LaRC to perform Chemical Analysis of Panel #8 Handholds and Handrails	9A	5/11/98	5/29/98
Spacehab to Prepare & Ship Solar Array Panel #8 to NASA LaRC	10	3/2/98	3/6/98
LaRC to Perform MM/OD Analysis	11	3/9/98	4/9/98
LaRC to Prepare & Ship Solar Array Panel #8 to NASA LeRC	12	4/10/98	4/15/98
LeRC to Perform Power Degradation Studies of Solar Array Panel	13	4/15/98	5/1/98
LeRC to Remove 10 Solar Array Cells & Polymer Backside Netting from Panel #8	14	5/4/98	5/11/98
LeRC to Perform Power Degradation Studies of 10 Solar Cells	15	5/11/98	6/19/98
LeRC to Analyze Solar Cell Netting (Edge Cells) and panel metal frame coating	16	5/11/98	6/19/98
LeRC to Ship Polymer Backside Netting to JSC for Vacuum Outgassing Tests	17	6/8/98	6/15/98
JSC to Conduct Condensable Outgassing Rate Studies of Polymer Backside Netting	18	6/15/98	8/1/98
LeRC to Prepare & Ship 10 Solar Cells (2 cells each) to five NASA Centers (LaRC, MSFC, JSC, WSTF, KSC) for analysis	19	6/15/98	6/19/98
Each Center Rotates Cells & Performs Chemical Analysis of all ten Solar Cells	20	5/22/98	8/26/98
Participants Select & Return three Solar Cells to NASA JSC for Sectioning	21	8/31/98	9/4/98

J. T. Visentine
Boeing/HS-11
Date 4/21/98

STS-89 Returned Russian Solar Array Experiment

Activity Name	Item	Start Date	Finish Date
JSC to section each Solar Cell and WSTF to perform Chemical Analysis of Elements	22	9/7/98	10/16/98
JSC to Prepare & Ship three Solar Cell Elements to three NASA Centers (MSFC LaRC, KSC) for Inspection & Analysis	23	10/19/98	10/23/98
MSFC LaRC, & KSC to perform Chemical Analysis of Elements	24	10/26/98	11/5/99
Each Center Rotates Elements & Performs Chemical Analysis of all three Elements	25	11/9/98	12/11/99
LaRC returns Solar Array Panel #8 to LaRC for continued MM/OD Analysis	25A	5/4/98	5/6/98
LaRC to complete MM/OD Analysis	25B	5/11/98	7/10/98
Other NASA Centers return Solar Array Panel, Handrails, Cells, & Elements to JSC	26	12/14/98	12/18/98
JSC to return Solar Array Cells, Elements Handrails, & Panel #8 to Russia for Analysis	27	12/21/98	1/8/99
JSC to Prepare and Issue final Analysis Report w/inputs from all NASA Centers	28	1/11/99	2/26/99

J. T. Visentine
Boeing/HS-11
Date 4/21/98

Future Laboratory Studies

- Selected solar cells recently removed from SARE PV panel section will be sent to six NASA centers for more detailed laboratory studies

- FTIR (Fourier Transform Infrared) Spectroscopy will be used to identify molecular constituents on solar cell surfaces

- Thicknesses of film deposits on cover glass and OSR surfaces (front & back) will be determined from ellipsometer measurements

- EDX (Energy Dispersive X-Ray) measurements will be performed in SEM (Scanning Electron Microscope) to determine elements comprising films

- Other investigations will include XPS (X-Ray Photoelectron Spectroscopy) and TOF/SIMS (Time of Flight/Secondary Ion Mass Spectroscopy) to further identify elements and compounds present