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LONG DURATION EXPOSURE FACILITY (LDEF) CONTAMINATION STUDY

FINAL REPORT

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Prepared by:

Karen P. Scott
Optical Sciences Center
UA 353380
University of Arizona

SUMMARY

This report describes the optical measurements that were taken of LDEF surfaces during the deintegration of LDEF from February to April 1990. This project was one part of an overall effort conducted by Boeing Aerospace to determine and track contamination on LDEF.

The purpose of this portion of the contamination project was to provide early documentation of the contamination level on LDEF experiments before shipment and disassembly by the principle investigators (PI). 35% of experiment trays located on all areas of LDEF were examined to, in particular, catalogue global differences in contamination depending on tray location.

The optical measurements were performed with a Model BHMJ Nomarski microscope which had also darkfield and oblique lighting capabilities. The optical measurements were documented by video and 35-mm cameras that could be attached to the microscope. Approximately 15 hours of video and 17 rolls of film (24 exposure) were taken. A full list of all trays and experiments observed is presented in Appendix C. Due to the high volume of data, a short 10-min. video has been compiled to illustrate the different contamination processes observed on LDEF.

LONG DURATION EXPOSURE FACILITY

The Long Duration Exposure Facility (LDEF) was a free-flying cylindrical structure that accommodated 86 experiment trays containing 57 experiments. The LDEF was launched in April 1984 at an orbit of 257-nmi and at an inclination of 28.5 degrees by the Space Shuttle Challenger on mission STS 41-C. The LDEF was retrieved in January 1990 at an altitude of 179-nmi on mission STS-32 by the Space Shuttle Columbia. Originally the LDEF mission was only scheduled for one year, but due to launch delays and the Challenger accident, the mission was extended to five years and nine months. This delay did have some catastrophic effects on some of the experiments.

The 30 foot by 14 foot diameter structure contained experiments belonging to four main experiment categories: 1) materials, coatings, and thermal systems; 2) power and propulsion; 3) science; 4) optics and electronics. A description of all experiments can be found in reference 1.

Since the LDEF was in a passively stabilized orbit, the experiments were exposed to very consistent conditions that depended on tray location. Trays were located around the LDEF in 12 rows with six trays in each row. Trays were also located on both ends of LDEf. The LDEF structural configuration and experiment location are illustrated in figure 1 (ref 1, pg. 3).

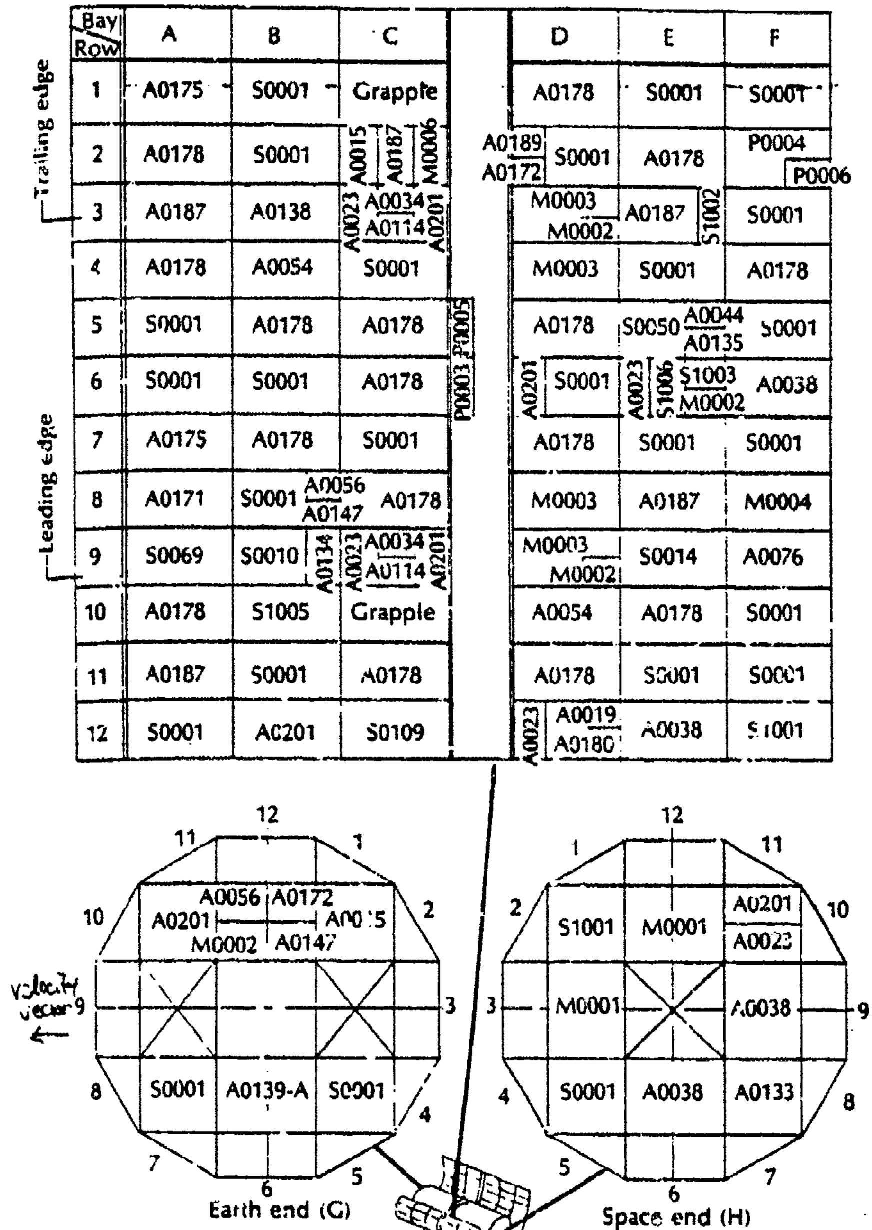

Figure 1: LDEF Experiment Model

Throughout this report, experiment location will be given by bay (A-F) and row number (1-12). For example, position A-9 signifies experiment S0069 as seen in fig. 1. Positions to particularly note are rows 3 and 9, which correspond to the trailing edge (very little exposure to atomic oxygen) and the leading edge (very high exposure to atomic oxygen), and positions starting with G (earth end) and H (space end). The correlation of experiment number, title, and tray locations are listed in Appendix A (ref 2, pp. 15-19).

LDEF DEINTEGRATION

After Columbia landed at Edwards Air Force Base it was ferried across the U.S. by a Boeing 747 to Kennedy Space Center (KSC). Upon arrival the LDEF was removed from the Shuttle and eventually moved to a clean room in the SAEF II building. The deintegration of the experiment trays started on February 23 and was completed on March 27, 1990. The procedure to deintegrate a tray was to remove it from the LDEF structure and circulate it through three locations. The first stop was in a special area to conduct a detailed photographic survey. Next the tray was moved to the Meteoroid and Debris Special Investigation Group (M/D SIG) which conducted a systematic scan of outer structures for impacts. Finally the tray was moved to the Systems SIG (with principal investigator (PI) approval) for a noncontact contamination evaluation using a Nomarski microscope. Since optical elements are often the most affected by contamination and were also the most effectively observed with a Nomarski microscope, experiments containing optical elements were pursued. After deintegration of each tray, the PIs received them and arranged for shipment to their laboratories.

LDEF CONTAMINATION PROGRAM

Four Special Investigation Groups (Meteoroid and Debris, Systems, Materials, and Radiation) were created, before the LDEF recovery, to investigate effects of low earth orbit (LEO) on material samples and systems that were not specifically being studied by the PIs. For example, the Systems SIG was chartered to analyze the performance of LDEF systems and experiment systems (including optical systems). The subject of contamination was more difficult to place in a specific SIG so the duties were shared between the Materials and Systems SIGs. A contamination committee was formed to raise awareness of contamination problems and insert procedures to reduce these problems in the deintegration effort and to measure contamination that had already occurred. Boeing Aerospace was commissioned to monitor contamination levels in the deintegration building (SAEF II) as well as trace the entire contamination history from prelaunch, retrieval, to deintegration. The observation of experiments with the Nomarski microscope was one part of an overall effort to determine and track contamination on LDEF.

THE NOMARSKI MICROSCOPE OBSERVATIONS

The purpose of the Nomarski portion of the contamination project was to provide early documentation of the contamination level on LDEF experiments before shipment and disassembly by the principle investigators (PI). 35% of experiment trays located on all areas of LDEF were examined to, in particular, catalogue global differences in contamination depending on tray location. It was also thought that the video could serve as an early permanent detailed record of experiment conditions upon arrival at KSC, before shipment and possible exposure to damage. The video is one of the few records that contains observations made of many different experiments (at high magnification) located on all areas of LDEF.

The optical measurements were performed with an Olympus Model BHMJ Nomarski microscope which had also darkfield and oblique lighting capabilities. This instrument was chosen because it was lightweight and portable, and could make observations of objects in a vertical orientation. A source transmitted by a 7-mm flexible light-guide was used to increase flexibility in illuminating a given experiment. It was possible to point the light-guide directly at an experiment surface to do oblique lighting studies. The microscope had a 10x binocular eyepiece and five different objectives to allow a magnification range of 50x to 800x. The optical measurements were documented by video and a 35-mm camera that were borrowed from Boeing Aerospace. A portable boom stand was also purchased to hold the microscope and allow a variety of vertical positions. An additional rail system was designed and built by NASA personnel to allow the whole microscope to be moved along an experiment tray during observation (see appendix B).

The procedure for a typical tray observation went as follows. Our group was usually asked if we would want to do observations on a given tray that was passing through the deintegration process. If any part of the tray contained optics samples, or had a surface conducive to observations with a Nomarski, we would ask the PI for permission to analyze the tray. Next the tray would be rolled over with a tray stand and placed next to the microscope in a vertical position. Normally we were given only 0.5 to 2 hours to observe a tray, so the work had to move very quickly. Notes were written rapidly correlating observations with the video tape counter number. A television monitor assisted in the note taking. An experiment would be scanned until something of interest was found, then the magnification was increased for a more detailed analysis. All magnification changes and observations were written in the experiment notes. For particularly interesting features, the 35-mm camera was substituted for the video head and slides were taken. It was often necessary to make maps of experiment samples because neither our group nor the PI knew what sample material we were observing. Sometimes there would be up to 30 samples, so we did our best to number them and observe them all in the short time we had with each experiment. In all, approximately 15 hours of video and 17 rolls of film (24 exposure) were taken. A full list of all trays and experiments observed is listed in Appendix C.

NOMARSKI OBSERVATION RESULTS

This part of the contamination study was noncontact as stated. The data obtained was only a first step in a lengthy process to determine the types and sources of contamination present on LDEF. At no time was the purpose of the study to analyze individual PI experiments. Much of the data collected was used to guide other parts of the study (tape lifts, witness plates, microchemical tests, electron microscopy, and other contact analysis tests of actual experiments) that were able to collect more quantitative data. As one example, the Nomarski observations revealed that there was a high population of glass fibers on all experiments, but the source was unknown. Later, through the other analyses discussed above, several sources of glass fibers were found including: 1) shuttle bay liner; 2) shuttle tile fiber; 3) glass fiber from glass fiber/resin composites; 4) HEPA filter fiber (ref. 3, pp. 104-105).

There were many early observations, like the example given above, made using the Nomarski microscope. Following is a numbered list of some of these other observations that will be referred to later when discussing the overview video that has been created for this report.

1) One of the early observations made was the presence of shadows behind particles and fibers on experiment surfaces. The shadows were a result of local shielding of the surface material from some external event. For example, on the silver/Teflon (Ag/FEP) thermal control blankets (A0178) on the leading edge, the particulates shielded the Teflon blankets from atomic oxygen erosion of the surface. On the trailing edge the particulates shielded the Ag/FEP surface from the deposition of molecular contamination due to nearby outgassing events (shielding from ultra-violet exposure also created this same type of shadowing). However, on the same Teflon surfaces, there was debris present that had no nearby shadowing which indicated that the debris had arrived during recovery or deintegration. This phenomenon became a very important discovery because it revealed when contaminants had entered the system. Furthermore, there were shadows with no particles present, and debris that were displaced from their shadows. This type of information indicated how much particulates had been displaced during recovery and deintegration.

2) In scanning over many experiment surfaces, it became clear that there was a lot of organic fibers. The main sources were from clothing (cotton, polyester, wool etc.), wood fiber from nonclean-room paper, rug fiber, etc. Most of the sources were determined by other tests, though the polyester fiber was easily identified because of it's high birefringence which was observed by rotating the polarizer on the microscope. From the shadowing, it was clear that all these types of contaminants were present before launch, but also had entered during deintegration. Other sources of "people" contaminants included skin flakes, hair, finger prints, sneeze particles, and residual water contaminants.

3) A special class of contaminants were created from meteoroid and debris (M/D) impacts. These contaminants were caused when an impact would occur on a bolt or part of a mount near an optic. The result of the impact was to spray molten metal across the nearby sample. Other effects of impacts were to cause localized damage or fracture of a sample as will be shown in the video.

4) Molecular contamination was observed through out LDEF. In some areas it was quite thick. The Nomarski could detect the presence of this type of contamination, but other methods had to be used to determine its composition.

5) There were indications of cross contamination, not only from the shuttle and other external sources, but also from experiment to experiment. Because of the longer than expected exposure in space, some of the experiments disintegrated and eventually contaminated other experiments. The cross contamination was certainly aggravated during the LDEF recovery and shuttle landing. Aluminized mylar, Kapton (many sources), and radar camouflage materials (M0003) were some of the contaminants found on other experiment surfaces indicating cross-contamination.

OVERVIEW VIDEO

Due to the high volume of data, a short 10-minute video has been compiled to illustrate the different contamination processes observed on LDEF and discussed above. A short description of each video subject will follow below that will include the experiment number-tray location (for example A0023-C9), field-of-view size and video elapsed time in parenthesis. There are three sections of the video that are titled: 1) Fiber, Particulate, and Misc. Contamination; 2) Meteoroid and Debris Impacts; 3) Atomic Oxygen Erosion of Organic Composites.

FIBER, PARTICULATE, AND MISC. CONTAMINATION

1) Fiber ball, Exp. A0023-C9, FOV = 2-mm, (0-34 seconds).

2) Unidentified red contamination with halo (oblique lighting shows the color). This material was found on several experiments. Exp. A0201-C3, FOV = 2-mm and 1-mm, (34 sec. to 2-min.).

3) Evaporated liquid with some left over residual material. Could be salt mist or a sneeze particle. Both were found in other studies. Exp. A0201-C3, FOV = 1-mm, (2:02 to 2:23).

4) This frame shows the shadowing phenomenon on a Silver Teflon blanket. The familiar comet tails were seen all over LDEF. The frame stops at an imbedded fiber that was obviously present throughout the mission. Exp. A0178-A4, FOV = 2-mm and 1-mm, (2:24 to 2:47).

5) Fibers and a meteoroid hit, Exp. A0187-C2, FOV = 2-mm, (2:48 to 3:05).

6) This frame shows some of the aluminized mylar foil that was found everywhere including floating in SAEF II. Exp. A0147-B8, FOV = 2-mm and 0.5-mm, (3:07 to 3:27).

7) More evaporated liquid probably salt mist, Exp. A0147-B8, FOV = 2-mm and 0.5-mm, (3:28 to 3:53).

8) Imbedded fiber with some shadowing, Exp. M0004, FOV = 2-mm, (3:54 to 4:13).

9) Another fiber with very localized shadowing just under the fiber. Exp. M0004-F8, FOV = 0.5-mm, (4:14 to 4:37).

10) More of the red contamination like the material described in frame #2 yet found on a different experiment. Exp. M0004-F8, FOV = 2-mm and 0.5-mm (4:39 to 5:10).

METEOROID AND DEBRIS IMPACTS

11) Impact on a Silver Teflon blanket, the fissures radiating from the impact are quite distinct. Exp. A0178-A4, FOV = 0.5-mm, (5:22 to 6:23).

12) M/D impact with impact spray on to nearby sample. Next move up to nearby imbedded fiber. Exp. A0187-2-C2, FOV = 2-mm, (6:24 to 7:26).

13) Demonstrates meteoroid hit on a mesh. Exp. S0010-B9, FOV = 0.5-mm, (7:27 to 7:43).

14) Dramatic edge impact with molten metal spray. Exp. A0056-B8, FOV = 2-mm and 0.5-mm, (7:45 to 8:15).

15) Impact on a germanium sample, Exp. A0056-B8, FOV = 2-mm, (8:17 to 8:51).

ATOMIC OXYGEN EROSION OF ORGANIC COMPOSITES

16) Atomic oxygen erosion of a graphite epoxy composite. Loose glass fibers are shown everywhere. Exp. S0010-B9, FOV = 2-mm and 1-mm, (9:04 to 10:05).

CONCLUSIONS

This report has discussed the contamination study done with the Nomarski microscope during the deintegration of LDEF at KSC. As has been stated, this was a first step in a comprehensive contamination program to determine the history of contamination on

LDEF. For a complete report on the full results of this study compiled by Boeing Aerospace, the reader is referred to references 3-5. A video is included with this report as a sample of the 15 hours of video that was taken.

REFERENCES

1) The Long Duration Exposure Facility (LDEF) Mission 1 Experiments, NASA SP-473, 1984.

2) O'Neal, R. and Lightner, E., "Long Duration Exposure Facility - A General Overview", LDEF 69 Months in Space - First Post-Retrieval Symposium, June 1991.

3) Crutcher, E.R. and Wascher, W., "Particle Types and Sources Associated with LDEF", LDEF 69 Months in Space - First Post-Retrieval Symposium, June 1991.

4) Crutcher, E.R., et al., "Migration and Generation of Contaminants From Launch Through Recovery: LDEF Case History", LDEF 69 Months in Space - First Post-Retrieval Symposium, June 1991.

5) Crutcher, E.R., et al., "Quantification of Contaminants Associated With LDEF", LDEF 69 Months in Space - First Post-Retrieval Symposium, June 1991.

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APPENDIX A

Table 1.- LDEF experiment complement

EXP. NO.	TITLE	TRAY NOS.
A0015	Free-Flyer Biostack Experiment Institute fur Flugmedizin, DFVLR	C2, G2
A0019	Influence of Extended Exposure in Space on Mechanical Properties of High-Toughness Graphite-Epoxy Composite Material University of Michigan	D12
A0023	Multiple Foil Microabrasion Package University of Kent	C3, C9, D12, E6, H11
A0034	Atomic Oxygen Stimulated Outgassing Southern University/NASA-MSFC	C3, C9
A0038	Interstellar Gas Experiment NASA-JSC/University of Bern	E12, F6, H6, H9
A0044	Holographic Data Storage Crystals for LDEF Georgia Institute of Technology	E5
A0054	Space Plasma High Voltage Drainage TRW Space and Technology Group	B4, D10
A0056	Exposure to Space Radiation of High-Performance Infrared Multilayer Filters and Materials Technology Experiments University of Reading/British Aerospace	B8, G12
A0076	Cascade Variable Conductance Heat Pipe McDonnell Douglas Astronautics Company	F9
A0114	Interaction of Atomic Oxygen with Solid Surfaces at Orbital Altitudes University of Alabama in Huntsville/NASA-MSFC	C3, C9
A0133	Effect of Space Environment on Space Based Radar Phased Array Antenna Grumman Aerospace Corporation	H7
A0134	Space Exposure of Composite Materials for Large Space Structures NASA-LaRC	B9

Table 1.- (continued)

EXP. NO.	TITLE	TRAY NOS.
A0135	Effect of Space Exposure on Pyroelectric Infrared Detectors NASA-LaRC	E5
A0138-1	Study of Meteoroid Impact Craters on Various Materials CERT/ONERA-DERTS	B3
A0138-2	Attempt at Dust Debris Collection with Stacked Detectors CERT/ONERA-DERTS	B3
A0138-3	Thin Metal Film and Multilayers Experiment CNRS/LPSP	B3
A0138-4	Vacuum Deposited Optical Coatings Experiment Optical Division, Matra S. A.	B3
A0138-5	Ruled and Holographic Gratings Experiment Inst. SA/JOBIN-YVON Division	B3
A0138-6	Thermal Control Coatings Experiment CERT/ONERA-DERTS, CNES/CST	B3
A0138-7	Optical Fibers and Components Experiment CERT/ONERA-DERTS	B3
A0138-8	Effect of Space Exposure of Some Epoxy Matrix Composites on Their Thermal Expansion and Mechanical Properties Space Division, Matra S. A.	B3
A0138-9	The Effect of the Space Environment on Composite Materials Aerospatiale	B3
A0138-10	Microwelding of Various Metallic Materials Under Ultravacuum Aerospatiale	B3
A0139A	Growth of Crystals from Solutions in Low Gravity Rockwell International Science Center Technical University of Denmark	G6

Table I.- (continued)

EXP. NO.	TITLE	TRAY NOS.
A0147	Passive Exposure of Earth Radiation Budget Experiment Components The Eppley Laboratory, Inc.	B8, G12
A0171	Solar Array Materials Passive LDEF Experiment NASA-MSFC/NASA-LeRC/NASA-GSFC Jet Propulsion Laboratory	A8
A0172	Effects of Solar Radiation on Glasses NASA-MSFC/Vanderbilt University	D2, G12
A0175	Evaluation of Long-Duration Exposure to the Natural Space Environment on Graphite-Polyimide and Graphite-Epoxy Mechanical Properties Rockwell International Corp. (Tulsa Facility)	A1, A7
A0178	A High Resolution Study of Ultra-Heavy Cosmic Ray Nuclei Dublin Inst. for Advanced Studies, ESA-ESTEC	A2, A4, A10, B5, B7, C5, C6, C8, C11, D1, D5, D7, D11, E2, E10, F4
A0180	The Effect of Space Environment Exposure on the Properties of Polymer Matrix Composite Materials University of Toronto	D12
A0187-1	Chemistry of Micrometeoroids NASA-JSC/Univ. of Washington, Rockwell Int. Science Center	A3 A11
A0187-2	Chemical and Isotopic Measurements of Micrometeoroids by Secondary Ion Mass Spectrometry McDonnell Center for the Space Sciences Max-Planck Institute fur Nuclear Physics Munich Technical University Ernst-Mach Institute Dornier System Manufacturing Company	C2, E3, E8
A0189	Study of Factors Determining the Radiation Sensitivity of Quartz Crystal Oscillators Martin Marietta Laboratories	D2
A0201	Interplanetary Dust Experiment Institute for Space Science and Technology NASA-LaRC North Carolina State University	B12, C3, C9, D6, G10, H11

Table 1.- (continued)

EXP. NO.	TITLE	TRAY NOS.
M0001	Heavy Ions in Space Naval Research Laboratory	H3, H12
M0002-1	Trapped Proton Energy Spectrum Determination AF Geophysics Laboratory	D3, D9, G12
M0002-2	Measurement of Heavy Cosmic-Ray Nuclei on LDEF University of Kiel, Federal Republic of Germany	E6
M0003	Space Environment Effects on Spacecraft Materials The Aerospace Corporation	D3, D4, D8, D9
M0004	Space Environment Effects on Fiber Optics Systems AF Weapons Laboratory	F8
M0006	Space Environment Effects AF Technical Applications Center	C2
P0003	LDEF Thermal Measurements System NASA-LaRC	Center ring
P0004-1	Seeds in Space Experiment George W. Park Seed Company, Inc.	F2
P0004-2	Space-Exposed Experiment Developed for Students (SEEDS) NASA Headquarters	F2
P0005	Space Aging of Solid Rocket Materials Morton-Thiokol, Inc.	Center ring
P0006	Linear Energy Transfer Spectrum Measurement Experiment University of San Francisco/NASA-MSFC	F2
S0001	Space Debris Impact Experiment NASA-LaRC	A5, A6, A12, B1, B2, B6, B8, B11, C4, C7, D2, D6, E1, E4, E7, E11, F1, F3, F5, F7, F10, F11, G4, G8, H5

Table I.- (concluded)

EXP. NO.	TITLE	TRAY NOS.
S0010	Exposure of Spacecraft Coatings NASA-LaRC	B9
S0014	Advanced Photovoltaic Experiment NASA-LeRC	E9
S0050	Investigation of the Effects of Long Duration Exposure of Active Optical System Components Engr. Exp. Station, Georgia Inst. of Technology	E5
S0050-1	Investigation of the Effects of Long Duration Exposure on Active Optical Materials and UV Detectors NASA-LaRC	E5
S0069	Thermal Control Surfaces Experiment NASA-MSFC	A9
S0109	Fiber Optic Data Transmission Experiment Jet Propulsion Laboratory	C12
S1001	Low Temperature Heat Pipe NASA-GSFC/NASA-ARC	F12, H1
S1002	Investigation of Critical Surface Degradation Effects on Coatings and Solar Cells Developed in Germany Messerschmitt-Bolkow-Blohm Space Division	E3
S1003	Ion Beam Textured and Coated Surfaces Experiment NASA-LeRC	E6
S1005	Transverse Flat Plate Heat Pipe Experiment NASA-MSFC/Grumman Aerospace Corporation	B10
S1006	Balloon Materials Degradation Texas A&M University	E6

APPENDIX B

APPENDIX C

TRAY NUMBER	EXPERIMENTS
A01	A0175
A04	GROUND STRAP AND A0178
A07	A0175
B03	A0138
B08	S0001, A0056, A0147
B09	A0134, S0010
B11	S0001
C02	A0187-2, A0015
C03	A0034, A0201
C05	A0178
C08	A0178
C09	A0034, A0023, A0201, A0114
D02	A0172
D07	A0178
D11	A0178
D12	A0180
E05	S0050-1
E06	M0002, S1003
E08	A0187-2
F02	Ag/FEP MATERIAL OVER SEEDS
F08	M0004
G02	A0015
G10	A0201, A0056
G12	M0002
H06	A0038
H07	A0133-8
MISC. GROUND CLIPS, KNURLED KNOBS, PAINT BUTTONS	