NASA Conference Publication 10046

LDEF Materials Data Analysis Workshop

(NASA-CP-10046) PROCEEDINGS OF THE LDEF MATERIALS DATA ANALYSIS WORKSHOP (NASA)

289 p

Unclassified

Compiled by
Bland A. Stein
and Philip R. Young

Langley Research Center
Hampton, Virginia

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July 1990

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225
FOREWORD

The National Aeronautics and Space Administration Long Duration Exposure Facility (LDEF) was launched into low-Earth orbit (LEO) from the payload bay of the Space Shuttle Orbiter Challenger in April 1984. It was retrieved from orbit by the Columbia in January 1990. The original flight plan called for a 1-year mission. The extended time in orbit, some 4 years and 10 months longer than originally planned, generally enhanced the value of the 57 LDEF experiments which covered the disciplines of materials, coatings, and thermal systems; power and propulsion; space science; and electronics and optics. LDEF was designed to provide a large number of economical opportunities for science and technology experiments that require modest electrical power and data processing while in space and which benefit from post-flight laboratory investigations of the retrieved experiment hardware on Earth. Most of the materials experiments were completely passive; their data must be obtained in post-flight laboratory tests and analyses.*

The 5-year, 10-month flight of LDEF greatly enhanced the potential value of most LDEF materials, compared to that of the original 1-year flight plan. NASA recognized this potential by forming the LDEF Space Environmental Effects on Materials Special Investigation Group (MSIG) in early 1989 to address the expanded opportunities available in the LDEF structure and on experiment trays, so that the value of all LDEF materials data to current and future space missions would be assessed and documented. (Similar Special Investigation Groups were formed for the disciplines of Ionizing Radiation, Systems, and Meteoroids/Debris.) MSIG was chartered to investigate the effects of the long LEO exposure on structure and experiment materials which were not originally planned to be test specimens and to integrate the

results of this investigation with data generated by the Principal Investigators of the LDEF experiments into the LDEF Materials Data Base. This LDEF Materials Data Analysis Workshop addressed the plans (and those of other LDEF groups) resulting from that charter (and similar charters for the other disciplines). The workshop ran concurrently with the activities surrounding the successful return of the LDEF spacecraft to the NASA Kennedy Space Center. This document is a compilation of the visual aids utilized by the speakers at the workshop.*

The LDEF Materials Data Analysis Workshop had several objectives. Session 1 summarized current information on analysis responsibilities and plans; this information was aimed at updating the workshop attendees: the LDEF Advisory Committee, Principal Investigators (PIs), Special Investigation Group Members, and others involved in LDEF analyses or management. Workshop Sessions 2 and 3 addressed materials data analysis methodology, specimen preservation/shipment/archival, and initial plans for the LDEF Materials Data Base. An equally important objective of this workshop was to stimulate interest and awareness of the opportunities to vastly expand the overall data base by considering the entire spacecraft as a materials experiment. To this end, the voluntary contribution and sharing of samples between PIs and MSIG were encouraged. These samples include both materials on experiment trays which were not intended to be test specimens and material test specimens which are available after the original test objectives have been achieved.

The synergistic effects of atomic oxygen, ultraviolet and particulate radiation, thermal cycling, and vacuum in the 5-year, 10-month LEO exposure of materials on LDEF will produce a data base unparalleled in the history of space environmental effects. Data of this type will not be available again until Space Station Freedom has deployed a materials exposure experiment for more than 6 years. Thus, the LDEF Principal Investigators and Materials Special Investigation Group now have the unique opportunity and responsibility to significantly contribute to spacecraft design, verification of analysis models based on previous in-space and Earth laboratory data on space materials, and planning of space research and development for the 1990s and into the 21st century. This workshop served as one step toward the realization of that opportunity.  

_Bland A. Stein and Philip R. Young_  
Co-Chairmen, LDEF Materials Data Analysis Workshop

*Notes: These charts reflect general understanding of space environmental effects on materials, prior to specific analyses of LDEF materials specimens. The LDEF materials analysis plans presented herein are subject to revision as the analyses proceed during the next several years.
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INTRODUCTION

BLAND A. STEIN

NASA - LANGLEY RESEARCH CENTER
WORKSHOP CO-CHAIRMAN

LDEF
MATERIALS DATA ANALYSIS
WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
LONG DURATION EXPOSURE FACILITY

LDEF
MATERIALS DATA ANALYSIS WORKSHOP

NASA - KENNEDY SPACE CENTER
BUILDING M7-351, TRAINING AUDITORIUM
FEBRUARY 13 & 14, 1990

LONG DURATION EXPOSURE FACILITY
MATERIALS DATA ANALYSIS WORKSHOP

INTRODUCTION

BLAND A. STEIN
NASA - LANGLEY RESEARCH CENTER,
WORKSHOP CHAIRMAN

LDEF MATERIALS DATA ANALYSIS WORKSHOP
NASA - KENNEDY SPACE CENTER
FEBRUARY, 1990
LDEF Retrieval.

LDEF Launch.
LDEF INSPECTION TEAM

LDEF RETRIEVAL OBSERVATIONS FROM DOWNLINK VIDEO, IN-SPACE PHOTOGRAPHS, AND INITIAL KSC OBSERVATIONS

GENERAL

• NO STRUCTURAL DAMAGE
• NO UNANTICIPATED PHENOMENA
• DAMAGE TO THIN FILMS, COATINGS, AND THERMAL BLANKET MATERIALS ON EXPERIMENT TRAYS, PREDOMINANTLY ON:
  - LEADING EDGE
  - SPACE END
• FLOATING DEBRIS VISIBLE NEAR LDEF, ESPECIALLY AFTER GRAPPLE
• MINIMAL DEBRIS IN CARGO BAY; SOLAR CELL MODULE ONLY LARGE PIECE OF DEBRIS FOUND
• LOCALIZED CONTAMINATION ON LDEF SURFACES IN SEVERAL AREAS

LDEF INSPECTION TEAM

LDEF RETRIEVAL OBSERVATIONS FROM DOWNLINK VIDEO, IN-SPACE PHOTOGRAPHS, AND INITIAL KSC OBSERVATIONS (CONTINUED)

MECHANISMS AND SYSTEMS

• ALL FIVE EXPERIMENT EXPOSURE CONTROL CANISTERS (EECCs) ON LDEF CLOSED, AS PLANNED
• A CLAMSHELL CANISTER IS OPEN (PROBABLY CLOSED AND REOPENED)
• MSFC THERMAL CONTROL SURFACES EXPERIMENT (A0069) MECHANISMS APPEAR TO HAVE FUNCTIONED CORRECTLY.

MICROMETEOROID AND DEBRIS EFFECTS

• SIGNIFICANT MICROMETEOROID AND DEBRIS IMPACTS OBSERVED ON EXPERIMENT TRAYS; IMPACTS GENERALLY CONSISTENT WITH EXPECTATIONS.
• NO LARGE, CATASTROPHIC IMPACT EVENTS DETECTED.
• MORE MICROMETEOROID/DEBRIS DAMAGE APPARENT ON LEADING EDGE THAN ON TRAILING EDGE.
• IMPACTS ALSO OBSERVED ON LDEF STRUCTURE.
LDEF INSPECTION TEAM

LDEF RETRIEVAL OBSERVATIONS FROM DOWNLINK VIDEO, IN-SPACE PHOTOGRAPHS, AND INITIAL KSC OBSERVATIONS (CONCLUDED)

ATOMIC OXYGEN EFFECTS
- Significant atomic oxygen degradation observed on most leading edge experiments.
- More than 0.005-inch degradation of Kapton and Mylar films on leading edge experiments.
- Surfaces of silver/teflon thermal blankets on leading edge turned "milky" white.
- Thermal control paint "target spots" remained white on entire leading face of LDEF.

ULTRAVIOLET RADIATION EFFECTS
- Thermal control paint target spots discolored on trailing face, earth end, and space end of LDEF.

INDUCED RADIATION EFFECTS
- Induced radiation surveys show measurable radioactive activity.
- No threats to human health.

LDEF MATERIALS DATA ANALYSIS WORKSHOP

SESSION 1: LDEF DATA ANALYSIS RESPONSIBILITIES AND PLANS

OBJECTIVE: Understanding of the breadth and potential of LDEF experimental and analytical data by LDEF Advisory Committee, Principal Investigators, Special Investigation Groups, and other Workshop Attendees

APPROACH: Presentations and Interactive discussions on
- LDEF
- LDEF Science Office and NASA HQ Management
- Supporting Data Group plans
- Special Investigation Group plans
- Principal Investigator Plans
OBJECTIVE: Stimulate interest and awareness of the opportunities to expand the LDEF data base through:
  • Understanding the potential of data synergism
  • Voluntary contribution of materials which:
    were not originally planned to be test specimens
    or
    were duplicate specimens in the experiment
    or
    are specimens whose initial experiment objectives have been satisfied

APPROACH: Interactive discussions on analysis methodology
  • Characterization
  • Surface science
  • Atomic oxygen
  • Contamination
  • Other parameters which define (or obscure) the data
  • Specimen preservation and shipment
NASA
LONG DURATION EXPOSURE FACILITY

NASA HEADQUARTERS
PERSPECTIVE

ROBERT J. HAYDUK

NASA HEADQUARTERS
LDEF SCIENCE PROGRAM MANAGER

LDEF
MATERIALS DATA ANALYSIS WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
NASA HEADQUARTERS PERSPECTIVE
OF
LONG DURATION EXPOSURE FACILITY

BY

ROBERT J. HAYDUK
LDEF SCIENCE PROGRAM MANAGER
OAST, MATERIALS & STRUCTURES DIVISION

LDEF MATERIALS DATA ANALYSIS WORKSHOP
NASA KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990

LDEF SCIENCE ORGANIZATION

OAET
OAET - RM
LANGLEY

LDEF INSPECTION TEAM

STRUCTURES DIRECTORATE
MATERIALS DIVISION

LDEF ADVISORY COMMITTEE
LDEF SCIENCE OFFICE

SPECIAL INVESTIGATION GROUPS
SUPPORTING DATA GROUPS
PRINCIPAL INVESTIGATORS
LDEF HISTORY

- LDEF Announcement of Opportunity (OAET-76-1)

- "Solicited Research Experiments in Long Duration Testing in Space" in Areas of Interest to OAET, OSSA, & OSF

- Open to NASA, Universities, Industry, U.S. Government Agencies, & Foreign Participants

- AA OAET Selected Experiments

LDEF - EARLY 80's

- "Laboratory in the Sky"

- Many Flight Opportunities

- Sequential Plan of Experiments
  - Flights: A, B, C, etc.
  - Experiments: Based on Experiments of Prior Flights
  - Develop Large Data Base
LDEF - LATE 80's

- One Flight Opportunity

- LDEF Spacecraft & Experiments
  - Have Higher Interest & Potential-Payoff

- Significant Changes in Science Plan
  200 Principal Investigators
  Plus
  Special Investigation Groups
  - Materials
  - Environmental Stability
  - etc.

LDEF SCIENCE PROGRAM

OBJECTIVE

- Maximize Science Return From LDEF Mission

APPROACH

- Integrated Plan for Data Analysis
- Documentation and Timely Dissemination of Data
- Science Team of International Stature
LDEF SCIENCE

SUMMARY

- LDEF IS A UNIQUE OPPORTUNITY TO OBTAIN SCIENTIFIC AND TECHNOLOGICAL INFORMATION IN COLLABORATION WITH PRINCIPAL INVESTIGATORS FROM THE UNITED STATES AND NINE OTHER COUNTRIES, FOUR SPECIAL INVESTIGATION GROUPS, AND THREE SUPPORTING DATA GROUPS.

- AN LDEF DATA BASE WILL BE ASSEMBLED AND MANAGED TO COLLECT ALL SCIENTIFIC AND TECHNOLOGICAL RESULTS. THIS DATA BASE WILL BE ACCESSIBLE TO THE INTERNATIONAL SCIENTIFIC COMMUNITY.

- LDEF RESULTS WILL BE OF SIGNIFICANT BENEFIT TO FUTURE SPACE SYSTEMS.
NASA
LONG DURATION EXPOSURE FACILITY

LDEF DATA ANALYSIS
PROJECT OFFICE OVERVIEW

DARREL R. TENNEY

NASA - LANGLEY RESEARCH CENTER
CHIEF, MATERIALS DIVISION

LDEF
MATERIALS DATA ANALYSIS WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
LONG DURATION EXPOSURE FACILITY

• Launched - April 1984 Retrieval - January 1990

• 57 Technology, Science, and Applications Experiments (More than 10,000 test specimens)

• Participants
  - P.I.'s: >200
  - Industry: 33
  - NASA Centers: 7
  - Special Investigation Groups (Approx. 60 participants) (Materials, Systems, Meteoroid/Debris, & Radiation)
  - Countries: 9
  - Universities: 21
  - DOD Labs: 9
LDEF EXPERIMENTS (57 TOTAL)

- MATERIALS AND COATINGS (20 TOTAL)
  - NASA, 11
  - INDUSTRY, 2
  - DOD, 1
  - FRANCE, 4
  - CANADA, 1
  - TEXAS A&M, 1

- PROPULSION, POWER, AND ENERGY (8 TOTAL)
  - NASA, 5
  - WEST GERMANY, 1
  - MORTON THIOKOL, 1
  - MCDONNELL DOUGLAS, 1

- INFORMATION SCIENCES AND HUMAN FACTORS (14 TOTAL)
  - NASA, 7
  - UK, 1
  - DOD, 2
  - FRANCE, 4

- SCIENCE (15 TOTAL)
  - NASA, 6
  - DOD, 2
  - UK, 1
  - GERMANY, 2
  - NETHERLANDS, 1
  - FRANCE, 2
  - PARK SEED, 1

LDEF SCIENCE ORGANIZATION

- OAET
  - OAET - RM
    - LANGLEY
      - LDEF INSPECTION TEAM
      - STRUCTURES DIRECTORATE
      - MATERIALS DIVISION
        - LDEF ADVISORY COMMITTEE
          - LDEF SCIENCE OFFICE
            - SPECIAL INVESTIGATION GROUPS
            - SUPPORTING DATA GROUPS
            - PRINCIPAL INVESTIGATORS
LDEF DATA ANALYSIS GROUPS AND FUNCTIONAL RESPONSIBILITIES

LDEF Advisory Committee
- Technical critique of data analyses plans and strategies

LDEF Program Manager
- NASA Hq.s. coordination
- Programmatic issues
- International cooperation
- External affairs

LDEF Inspection Team
- Critical inspection of LDEF

Data Analyses Project Office
- Planning and implementation of data analyses

Experiment PI's
- Analyses & reporting of results

Supporting Data Groups
- Quantitative definition of LDEF environment

Special Investigation Groups
- Central analyses & discipline data bases

LDEF ADVISORY COMMITTEE

Membership, February, 1990

- Chairman: J. Garibotti, Ketema
- Executive Secretary: R. Hayduk, NASA Hq.

U.S. Spacecraft Industry
- J. Blumenthal, TRW
- E. Littauer, Lockheed
- S. Greenberg, Aerojet
- H. S. Greenberg, Rockwell

NASA - User Community
- J. Moacanin, JPL
- K. Faymon, LeRC
- A. Edwards, Space Station Freedom

Science Community
- J. Wightman, Va. Tech
- J. Lewis, U. Arizona
- R. Naumann, MSFC

Department of Defense
- A. Young, SDIO
- M. Minges, USAF-WRDC
LDEF INSPECTION TEAM

Assess "Normality" of LDEF Spacecraft & Science Experiments

Membership

Chairman - Darrel R. Tenney - LaRC

Bland A. Stein - LaRC
Bill Kinard - LaRC
Lubert Leger - JSC
Ann Whitaker - MSFC
Tom Parnell - MSFC

Dr. William Lehn - WRDC
Lt. Dale Atkinson - AF Weapons Lab.
Bob Hayduk - NASA Headquarters
Jim Mason - GSFC

LONG DURATION EXPOSURE FACILITY INSPECTION TEAM

REPORT TO OAET MANAGEMENT

DARREL R. TENNEY

NASA - KENNEDY SPACE CENTER
FEBRUARY 8, 1990
PI RELATIONS

- MOU/MOA's - (1) Trays Returned to PI's
  (2) PI's provide data to NASA/Science Community

- Addendum's to MOU/MOA's (Planned)
  -- Identify specific samples/data SIG's require

SUPPORTING DATA GROUPS

Environments: William Kinard, LaRC

2. Particle Fluxes - Gene Benton, San Francisco State Univ.
3. Atomic Oxygen Fluxes - Lubert Leger, JSC
4. Meteoroid and Space Debris Fluxes
   - Don Humes, LaRC; Don Kessler, JSC
5. Contamination - Lubert Leger, JSC
6. Time Line of Operational Events - Larry Brumfield, LaRC

Spacecraft Thermal: William M. Berrios, LaRC

Orbit and Orientation: Mel Kelly, Analytical Mechanical Associates
LDEF Special Investigation Groups

SPECIAL INVESTIGATION GROUPS
(SIG)

STRATEGY

- Four working groups established (Jan. 1989) to address key technology areas which are broader than individual experiments
- Technical expertise was the principal criteria for selection of participants
- LDEF facilities and experiments studied to identify samples and systems of key interest from a total LDEF perspective
- Contracts established to provide central analyses of samples with state-of-the-art analyses techniques and procedures
- SIG's providing key mechanism to implement cooperative activities between P.I.'s, NASA, and DOD
## LDEF DATA ANALYSIS

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### Major milestones

1. LDEF retrieval & "quick-look-inspection" findings
2. Supporting data packages to PI's & SIG's
3. LDEF investigator workshop to compare preliminary data
4. LDEF data conference
5. LDEF data & space environmental effects models symposium
6. LDEF materials, systems, & debris effects data bases documented

## SHUTTLE FLIGHTS WITH SAMPLE RETURNS

- First shuttle launch: 4/81
- LDEF launch: 4/84
- Space Station Launch: 3/95
- 1980: STS-3, 3/82
- EOIM-I (STS-5), 11/82
- EOIM-II (STS-8), 9/83
- Solar Max repair, 4/84
- EOIM-III, 1991
- LDEF retrieval, 1/90
- TDMX-2011 ~1996
- 1990: 41-G (STS-17), 10/84
- EOIM-III
- 2000
LDEF DATA ANALYSIS TEAM & SUPPORTING DATA GROUP

**LDEF Data Analysis Team**

Team Leader
William H. Kinard
LDEF Chief Scientist

**Team Leader**
William H. Kinard

**Supporting Data Groups**

- **Orbit and Orientation Data Manager**
  - G. Mel Kelley

- **Environments Data Manager**
  - TBD

- **Spacecraft Thermal Manager**
  - William M. Berries

- **Meteoroid and Space Debris Group Leader**
  - William H. Kinard

- **Induced Radiation Group Leader**
  - Tom Parnell

**Environmental Effects on Materials Group Leader**
Bland A. Stein

**Environmental Effects on Systems Group Leader**
James B. Mason

**LDEF FIRST MISSION EXPERIMENTS**

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ENvironments data

LDEF ENvironments Data Group

- Timeline of Operations
- Solar & Planetary Fluxes
- Particle Radiation
- Atomic Fluxes
- Meteoroid & Debris
- Contamination

Orbit and Orientation data

- Initial Orbit -
  - Inclination
  - Perigee Altitude
  - Apogee Altitude
  - Semi-major Axis Altitude

- Time History of Semi-major Axis Altitude Decay

- Orientation and Range of Oscillations About Each Axis
NASA
LONG DURATION EXPOSURE FACILITY

LDEF SUPPORTING DATA GROUP PLANS
- SPACECRAFT THERMAL

WILLIAM M. BERRIOS
NASA - LANGLEY RESEARCH CENTER
MEMBER, SUPPORTING DATA GROUP

LDEF MATERIALS DATA ANALYSIS WORKSHOP
NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
LONG DURATION EXPOSURE FACILITY
LDEF

LDEF THERMAL DATA

LDEF THERMAL

TOPICS OF DISCUSSION

- OBJECTIVE
- APPROACH
- EFFECTS OF EXTENDED MISSION
- DATA REDUCTION PLAN
- STATUS
LDEF THERMAL

OBJECTIVE

- VALIDATE THE LDEF THERMAL MODEL
- ASSESS THE EFFECTS OF THE EXTENDED MISSION ON THE LDEF PREDICTED TEMPERATURES
- UPDATE THE LDEF END OF MISSION CALCULATED TEMPERATURES
- PROVIDE SCIENCE COMMUNITY WITH DATA DESCRIBING THE THERMAL ENVIRONMENT EXPERIENCED BY THE LDEF EXPERIMENTS

LDEF THERMAL

APPROACH

- UPDATE THERMAL MODEL ORBITAL PARAMETERS
- COMPARE AND VALIDATE BEGINNING OF MISSION THERMAL MODELS WITH RECORDED FLIGHT TEMPERATURE DATA
- SURVEY THE LDEF SURFACES END OF MISSION A/E PROPERTIES
- UPDATE THE LDEF THERMAL MODELS WITH END OF MISSION A/E PROPERTIES
- RUN END OF MISSION THERMAL MODELS
- PREPARE AND DISTRIBUTE THE LDEF THERMAL DATA PACKAGES
LDEF THERMAL

DATA PACKAGE
• BOUNDARY CONDITIONS
  BEGINNING/END OF MISSION
  ORBITAL PARAMETERS
  HEAT FLUXES
  SURVEY OF THERMAL COATINGS
  LDEF STRUCTURE TEMPERATURES
• CALCULATED LDEF TEMPERATURES
  BEGINNING OF MISSION
  DEPLOYMENT ALTITUDE
  NEW COATINGS
  HOT & COLD CASES
  1 YEAR BETA ANGLE TRACKING
  END OF MISSION
  RETRIEVAL ALTITUDE
  DEGRADED COATINGS
  HOT & COLD CASES
  1 YEAR BETA ANGLE TRACKING

LDEF THERMAL

EFFECTS OF EXTENDED MISSION
• Temperature data recorded for the first year of the LDEF mission. There are no active measurements of the LDEF temperatures for the remainder of the extended mission.

• Data mismatch. There are no recorded end of mission temperatures to correlate with the measured end of mission coatings.

• Uneven degradation of coatings will require increased sampling of thermal coatings in order to characterize their behavior.

• Role of coatings interaction effects on their thermal control performance needs to be characterized.

• On-board passive attitude detectors may be saturated at this time.
**LDEF THERMAL**

**DATA REDUCTION PLAN**

- Begin measurement of A/E properties by February 20, 1990
- Begin update of thermal model A/E values by February 23, 1990
- Complete end of mission survey of thermal surfaces A/E properties by end of March 1990
- Receive flight temperature data by end of March 1990
- Preliminary report by Summer 1990
- Final report by Winter 1990

**LDEF THERMAL**

**DATA REDUCTION STATUS**

- Acquired new instrumentation for measurement of solar absorptance
- Located instrumentation in the SAEF II clean room area
- Located operations center on support trailer 633
- Opened data line to LaRC computing facilities
- Performed instrumentation check-out
- Performed A/E measurements of thermal panels removed from the facility
- Performed A/E measurements of silvered teflon surfaces on locations A10 & B11
- Ready for measurement of LDEF thermal coatings during deintegration schedule
LDEF THERMAL
DATA REDUCTION PLAN

DATA
PRE-FLIGHT
- COATINGS
- ORBIT PARAMETERS
- ATTITUDE

POST-FLIGHT
- MEASURED COATINGS
- ATTITUDE

FLIGHT TEMPERATURES
+ ACTIVE
+ PASSIVE

REVISED LDEF THERMAL MODEL

REVISED CALCULATED TEMPERATURES

COMPARE

REVISED CALCULATED TEMPERATURES

CALCULATE

FINAL LDEF TEMPS

NO

UPDATE

UPDATE

YES

REVISE
NASA
LONG DURATION EXPOSURE FACILITY

SPECIAL INVESTIGATION GROUP
PLANS
- METEOROID AND DEBRIS SIG

WILLIAM H. KINARD
NASA - LANGLEY RESEARCH CENTER
CHAIRMAN, M&DSIG

LDEF
MATERIALS DATA ANALYSIS
WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
To exploit the wealth of M&D data recorded on the LDEF during the 5 1/2 year space exposure in space by:

- Ensuring that natural meteoroid and man-made debris craters in retrieved LDEF and experiment hardware, which were not originally intended to be meteoroid & debris test specimens, are identified, investigated, and archived for future investigations.

- Coordinating the data obtained by the LDEF meteoroid & debris experiment P.I.'s with the data obtained by this SIG into a single LDEF METEOROID & DEBRIS DATA BASE for use by engineers and scientists in future studies.

MEMBERS OF LDEF M&D SIG

Dr. William H. Kinard (Group Leader)
Mail Stop 356
NASA Langley Research Center
Hampton, VA 23665-5225

Lieut. Dale Atkinson
Air Force Weapons Laboratory/NTCAS
Kirtland Air Force Base, NM 87117-6008

Dr. Donald H. Brownlee
University of Washington
Seattle, WA 98102

Dr. Theodore E. Bunch
Mail Stop 399-4
NASA Ames Research Center
Moffett Field, CA 94035

Dr. Vladimir Chobotov
The Aerospace Corporation
M4-948
2350 E. El Segundo Blvd.
P. O. Box 92957
Los Angeles, CA 90245

Mr. Richard Engstrom
POD Associates, Inc.
1850 Tramway Terrace Loop Ave.
Albuquerque, NM 87122

Dr. Fred Horz
Code SN21
NASA Johnson Space Center
Houston, TX 77058

Mr. Don H. Humes
Mail Stop 493
NASA Langley Research Center
Hampton, VA 23665-5225

Mr. Donald J. Kessler
Code SN31
NASA Johnson Space Center
Houston, TX 77058

Mr. Michael J. Mirich, Jr.
Mail Stop 16-1
NASA Lewis Research Center
Cleveland, OH 44135

Mr. Roy A. Taylor
Code EH15
NASA Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Mr. Robert E. Zinner
Washington University
One Brookings Drive
St. Louis, MO 63130

Ms. Martha Albright
S-CUBED
2501 Yale SE, Suite 300
Albuquerque, NM 87108

Dr. Michael Zolensky
Code SN2
NASA Johnson Space Center
Houston, TX 77058

Mr. J-C. Mandeville
CERTONERA-ERTS
Toulouse
FRANCE

Ms. Sally L. Little
Code SSO
Space Station Freedom Program Office
10701 Parkridge Boulevard
Reston, VA 22091

Dr. Jerry Weinberg
Space Astronomy Laboratory, ISST
1810 NW 6th Street
Gainesville, FL 32609

Mr. Thomas M. See
C23
Lockheed/JSC
2400 NASA Road 1
Houston, TX 77058-3711

Mr. Charles G. Simon
Washington University
Campus Box 1105
1 Brookings Drive
St. Louis, MO 63130

Mr. Herbert A. Zook
Code SN31
NASA Johnson Space Center
Houston, TX 77058
NASA
LONG DURATION EXPOSURE FACILITY

SPECIAL INVESTIGATION GROUP
PLANS
- SYSTEMS SIG

JAMES B. MASON
NASA - GODDARD SPACE FLIGHT CENTER
CHAIRMAN, SSIG
AND
JOEL EDELMAN AND HARRY DURSCH
SSIG SUPPORT

LDEF
MATERIALS DATA ANALYSIS
WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
LDEF SYSTEMS SIG

CHARTER

INVESTIGATE THE EFFECTS OF THE NEARLY SIX YEAR EXPOSURE IN SPACE ON LDEF AND EXPERIMENT SYSTEMS.

COORDINATE THE DATA FROM THE ANALYSIS OF THE LDEF AND EXPERIMENT SYSTEMS INTO A SINGLE LDEF SYSTEMS DATA BASE.

LDEF SYSTEMS SIG

OBJECTIVE

- DEVELOPMENT OF THE LDEF SYSTEMS DATA BASE
SYSTEMS SIG

ROLE OF LDEF SYSTEMS SIG:

- DEFINE LDEF DATA BASE REQUIREMENTS
- DEFINE LDEF SYSTEMS FOR ANALYSIS AND MEASUREMENT
- DEFINE MEASUREMENT PROGRAM FOR SELECTED SYSTEMS
  - LDEF STRUCTURE AND SUBSYSTEMS
  - EXPERIMENT TRAYS
  - MATERIAL USED IN BUILDING OF LDEF AND EXPERIMENTS (e.g., SPARES)
- DEVELOP INSPECTION, HANDLING, TESTING AND REPORTING PLANS AND PROCEDURES
- COORDINATE WITH AND SUPPORT PROJECT, SIGs, AND EXPERIMENTER ACTIVITIES
- COLLECT AND DOCUMENT SYSTEMS DATA BASE

THREE INVESTIGATION PHASES

I. PLANNING EFFORT

II. KSC OPERATIONS

III. POST-KSC TESTING AND DATABASE DEVELOPMENT
LDEF SYSTEMS SIG INVESTIGATION PLAN

1.0 Introduction
2.0 Requirements
   2.1 Objectives, Rationale, Prioritization Considerations
   2.2 Data
      2.2.1 Data Development
      2.2.2 Data Management and Dissemination
   2.3 Hardware Systems Identification
   2.4 Standard Test Plans
3.0 Implementation
   3.1 Implementation Team
   3.2 Implementation Timeline
      3.2.1 Pre-inspection Activities
         3.2.1.1 KSC-provided Equipment
         3.2.1.2 Boeing-provided Equipment
      3.2.2 General Inspection
      3.2.3 Experiment and LDEF Systems Deintegration
      3.2.4 Post KSC Operations
   3.3 Configuration Management

Appendix A  KSC Operations Procedures
Appendix B  Individual Experiment Test and Implementation Plans/Procedures
Appendix C  System SIG/Boeing Personnel
Appendix D  Nomarski Analysis

SYSTEMS SIG
DATA BASE CONTRIBUTORS

DATA SOURCES

SYSTEM SIG DATA
SYSTEM SIG-INSPIRED OUTSIDE DATA
DATA BASE
PIs, DATA GROUPS, OTHER SIGs DATA

DATA SOURCES

DATA BASE

SYSTEM SIG DATA

SYSTEM SIG-INSPIRED OUTSIDE DATA

DATA BASE

PIs, DATA GROUPS, OTHER SIGs DATA
LDEF SYSTEMS FLIGHT HARDWARE

STANDALONE

- LDEF STRUCTURE
- VISCUS MAGNETIC DAMPER
- TRUNNIONS/GRAPPLE FIXTURE
- EXPERIMENT INITIATE SYSTEM (EIS)
- EXPERIMENT INITIATE BOX (EIB)

SHARED

- STANDARD EXPERIMENT POWER AND DATA SYSTEM (EPDS):
  - DATA PROCESSOR CONTROL ASSEMBLY (DPCA)
  - MAGNETIC TAPE MEMORY UNIT (MTM)
  - LiS02 BATTERY POWER SOURCE
- EXPERIMENT EXPOSURE CONTROL CANISTER (EECC): WITH LiS02 BATTERIES
- EXPERIMENT TRAYS (CLAMPING ARRANGEMENT)

LDEF EXPERIMENT SYSTEMS

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STANDARD TEST PLAN OUTLINE

I. GENERAL
   A. Review and Inspection
      1. Preliminary Review
      2. Visual Inspection
      3. Initial Data Review
   B. Calibration
      1. General
      2. Calibration Certification
      3. Accumulative Errors
      4. Statement of Accuracy
   C. Contamination

II. ELECTRICAL
   A. Electrical Systems
      1. Component examination and failure analysis
      2. Systems and subsystems functional testing
      3. Circuit board evaluation
   B. Power
      1. Batteries
      2. Solar Cells
      3. Power management and control components
      4. High voltage insulators/dielectrics
   C. Wire Harnesses

III. OPTICAL
   A. Glasses/Substrates/Filter
   B. Sources/Detectors/Radiometers
   C. Fiber Optics

IV. MECHANICAL
   A. Structures
   B. Mechanisms
   C. Electro-Mechanical/Servo
   D. Instrumentation

V. THERMAL
   A. Insulation
      1. Non-metallic insulators
      2. Thermal blankets
   B. Surfaces
   C. Instrumentation
LDEF SYSTEMS SIG
DATA BASE COMPOSITION

- Vendor and OEM specifications for systems, assemblies, parts and materials
- As-built drawings, schematics, and parts lists
- Pre-flight procedures
- Pre-flight parts screening and failure analysis data
- Pre-flight acceptance, qualification and performance test data
- Pre-flight control sample test data and storage history data
- Environmental data from supporting data groups
- Flight operational history
- Support equipment calibration data
- Post-flight test plans, procedures, and supporting data
- Post-flight failure/degradation analysis reports
- Post-flight measured data

LDEF DATA ANALYSIS REPORT
OUTLINE

1 Introduction and Background

1.1 LDEF Systems SIG
1.1.1 Investigation Plan
1.1.2 Data Package Format

2 Investigation Results

2.1 General Systems
2.1.1 Summary of the Investigation
2.1.2 Abstracts of Specific Studies
2.1.3 LDEF Systems
2.1.4 Experimenter Samples
2.2 Electrical Systems
2.2.1 Summary of the Investigation
2.2.2 Abstracts of Specific Studies
2.2.3 LDEF Systems
2.2.4 Experimenter Samples
2.3 Mechanical Systems
2.3.1 Summary of the Investigation
2.3.2 Abstracts of Specific Studies
2.3.3 LDEF Systems
2.3.4 Experimenter Samples
2.4 Optical Systems
2.4.1 Summary of the Investigation
2.4.2 Abstracts of Specific Studies
2.4.3 LDEF Systems
2.4.4 Experimenter Samples
2.5 Thermal Systems
2.5.1 Summary of the Investigation
2.5.2 Abstracts of Specific Studies
2.5.3 LDEF Systems
2.5.4 Experimenter Samples

3 Cross Reference Tables and Indices

4 Assessment of the Investigation Plan
MONTHLY REPORT

OBJECTIVES

• DISSEMINATION

• SOLICITATION

MONTHLY REPORT

CONTENTS

• DATABASE STATUS

• RECENT EVENTS AND OBSERVATIONS

• PROGRAM/PROJECT COMMENTARY AND NEWS

• SIG(s) STATUS REPORT(s)

• SDIO COMMENTARY AND NEWS

• EXPERIMENTER PUBLICATION NOTICES/ABSTRACTS/NEWS

• SCHEDULE/EVENTS/MEETINGS

• PEOPLE/TRANSITIONS
LDEF SYSTEMS

PRIMARY STRUCTURE:

INTEGRATE SSIG-DEVELOPED PLANS INTO PROJECT OFFICE PROCEDURES

- VISUAL INSPECTION, WELD INSPECTION, BOLT REMOVAL
- LDEF COMPONENTS FOR STRUCTURAL ANALYSIS AT BOEING
- NO POST-FLIGHT MODAL, WEIGHT AND ALIGNMENT MEASUREMENTS

EXPERIMENT INITIATE SYSTEM (EIS)

SSIG PROPOSED VERIFICATION OF EIS RELAY STATUS PRIOR TO TRAY REMOVAL

- DISCONNECT OUTPUT CABLE AT EIS, PERFORM CONTINUITY TESTS
- MULTIMETER WILL NOT ACTIVATE RELAYS
- ALL TEST RESULTS RELEASED TO P.O.
- FOUR EXPERIMENTS PER CONNECTOR
- NEED PI CONSENT

LDEF SYSTEMS

ENVIRONMENTAL EXPOSURE CONTROL CANISTER (EECC)

- PI'S WITH CANNISTERS HAVE BEEN CONTACTED AND COMMENTS INCORPORATED
- CANNISTER INTERNAL PRESSURE, SURGE CURRENT, SEAL, MECHANISM, HARNESS AND CONNECTORS

EXPERIMENT POWER AND DATA SYSTEM (EPDS)

- START-UP, FUNCTIONAL TESTING

VISCOUS DAMPER

- LDEF PROCEDURE FOR REMOVAL
- JSC AND/OR OEM (GE) WILL PERFORM POST-FLIGHT TESTING

GRAPPLE (ACTIVE & PASSIVE)

- JSC AND/OR OEM (SPAR) WILL PERFORM POST-FLIGHT TESTING

BATTERIES

- PROJECT OFFICE PROCEDURES GOVERN REMOVAL
- DISCHARGE EVALUATION ADDED TO NO-LOAD TESTING
INDIVIDUAL EXPERIMENT AND IMPLEMENTATION PLANS

- EXPERIMENT NO. AND TITLE
- NAME & PHONE NO. OF PI CONTACTED
- LOCATION OF EXPERIMENT ON LDEF
- DESCRIPTION OF HARDWARE OF SYSTEM SIG INTEREST
- RESULTS OF DISCUSSIONS WITH PI
- PROPOSED TEST PLAN FOR EVALUATION OF SYSTEM HARDWARE AT KSC
- POST KSC TEST PLAN AND SCHEDULE
- IDENTIFICATION OF PREFLIGHT AND CONTROL HARDWARE
- NECESSARY ACTION ITEMS PRIOR TO THE GENERAL INSPECTION AT KSC
- EDITORIAL COMMENTS
LONG DURATION EXPOSURE FACILITY
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)

MATERIALS DATA ANALYSIS PLAN

BLAND A. STEIN
NASA - LANGLEY RESEARCH CENTER,
CHAIRMAN, LDEF MSIG

LDEF MATERIALS DATA ANALYSIS WORKSHOP
NASA - KENNEDY SPACE CENTER
FEBRUARY, 1990

LONG DURATION EXPOSURE FACILITY
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)

CHARTER

• INVESTIGATE THE EFFECTS OF THE 5.5-YEAR EXPOSURE IN LEO ON LDEF STRUCTURAL AND EXPERIMENT MATERIALS WHICH WERE NOT ORIGINALLY PLANNED TO BE TEST SPECIMENS

• INTEGRATE THE DATA/ANALYSES FROM THE MATERIALS EXPERIMENT TEST SPECIMENS (GENERATED BY THE PIs) WITH THE MATERIALS DATA GENERATED BY MSIG INTO AN LDEF MATERIALS DATA BASE
MEMBERSHIP OF LDEF MSIG  
February, 1990

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<th>NAME</th>
<th>AFFILIATION</th>
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<td>NASA - MSFC</td>
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LDEF
MATERIALS SPECIAL INVESTIGATION GROUP

ANALYSIS AND DOCUMENTATION PLAN

• SYSTEMATICALLY EXAMINE IDENTICAL MATERIALS IN MULTIPLE LOCATIONS AROUND LDEF TO ESTABLISH DIRECTIONALITY OF ATOMIC OXYGEN EROSION, THERMAL EFFECTS, AND ULTRAVIOLET RADIATION DEGRADATION

• ANALYZE SELECTED SAMPLES FROM LDEF "NON-MATERIALS" EXPERIMENTS

• ESTABLISH CENTRAL MATERIALS ANALYSIS CAPABILITY
  - STANDARDIZED, NON-CONTAMINATING PROCEDURES FOR SAMPLING/SHIPPING/ARCHIVING
  - UNIFORM TEST/ANALYSIS PROCEDURES
  - BASIS FOR ASSESSMENT OF LABORATORY-TO-LABORATORY VARIATIONS IN MATERIALS DATA

• FOCAL POINT FOR COORDINATION OF ALL LDEF MATERIALS ANALYSES
  - SPONSOR LDEF MATERIALS WORKSHOPS/SYMPOSIA
  - GENERATE UNIFIED LDEF MATERIALS DATA BASE, INCLUDING DATA FROM PRINCIPAL INVESTIGATORS, SUPPORTING DATA GROUPS, AND SPECIAL INVESTIGATION GROUPS
## LDEF DATA ANALYSIS

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<tr>
<th>THRUSTS</th>
<th>FY-89</th>
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<tr>
<td>LDEF RETRIEVAL</td>
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<td>• EARLY ASSESSMENT OF SPACE ENVIRONMENTAL EFFECTS</td>
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<td>• EFFECTS OF LDEF EXPOSURE ON MATERIALS AND SYSTEMS</td>
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<td>• ENHANCED MODELS FOR SPACE ENVIRONMENTAL EFFECTS</td>
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<td>DOCUMENTATION</td>
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<td></td>
<td>• SPACE ENVIRONMENT EFFECTS HANDBOOKS FOR LOW EARTH ORBIT EXPOSURES</td>
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</tbody>
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### MAJOR MILESTONES

- LDEF RETRIEVAL AND "QUICK-LOOK INSPECTION" FINDINGS
- SUPPORTING DATA PACKAGES TO PIs AND SIGs
- LDEF INVESTIGATOR WORKSHOP TO COMPARE PRELIMINARY DATA
- LDEF DATA CONFERENCE
- LDEF DATA AND SPACE ENVIRONMENTAL EFFECTS MODELS SYMPOSIUM
- LDEF MATERIALS, SYSTEMS, AND DEBRIS EFFECTS DATA BASES DOCUMENTED
LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)
- KEY MILESTONES -

• SELECT MSIG PARTICIPANTS, JANUARY 1989; HOLD 4 MEETINGS IN 1989

• ADOPT MSIG PHILOSOPHY, MARCH 1989

• RECOMMEND SECURITY POLICY REGARDING MATERIALS INFORMATION TO LDEF PROGRAM OFFICE, APRIL 1989

• SELECT CONTRACTOR, INITIATE TASK CONTRACT FOR MATERIALS TESTS AND ANALYSES, MAY 1989:
  - IDENTIFY ANALYSIS TECHNIQUES, JULY 1989
  - DEVELOP SPECIMEN SELECTION PLANS, AUGUST 1989
  - DEVELOP INITIAL SPECIMEN PRESERVATION PLANS, OCTOBER 1989
  - PRE-/POST-RETRIEVAL LIAISON WITH PIs, MAY 1989 - MARCH 1990

• SUGGEST CONTAMINATION MONITORING METHODOLOGY TO LDEF PO, SEPTEMBER 1989

• PROVIDE ATOMIC OXYGEN FLUX ESTIMATES AND PHOTOGRAPHIC SURVEY RECOMMENDATIONS TO LDEF PO, OCTOBER 1989

• DEVELOP MSIG DETAILED TEST PLAN, OCTOBER - DECEMBER 1990

LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)
- KEY MILESTONES (Continued) -

• PLAN LDEF MATERIALS DATA ANALYSIS WORKSHOP, NOVEMBER - DECEMBER 1989

• DETERMINE UTILITY OF NASA-MSFC MAFTIS DATA BASE CAPABILITY FOR LDEF MATERIALS DATA BASE, JANUARY 1990

• RETRIEVE LDEF; FERRY TO KSC; INITIAL INSPECTIONS, JANUARY - FEBRUARY 1990

• CHAIR LDEF MATERIALS DATA ANALYSIS WORKSHOP AT KSC, FEBRUARY 1990

• OBTAIN MSIG SPECIMENS, FEBRUARY - MARCH 1990

• DATA GENERATION, DATA ANALYSIS, AND DATA BASING, 1990 - 1992

• MSIG REPORTS AT LDEF AND OTHER CONFERENCES, 1990 - 1993

• DEFINE, WITH PIs AND OTHER SIGs, MATERIALS DATA BASE, 1991 - 1992

• COLLATE AND DOCUMENT LDEF MATERIALS DATA BASE, 1992 - 1993
LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)

- TEST PLAN OUTLINE -

• GOALS AND PROCEDURES
• PRE-RECOVERY PREPARATIONS
• NASA - KSC OPERATION REQUIREMENTS
• ON LINE/OFF LINE EXAMINATION PROCEDURES
• IDENTIFICATION OF PRIORITY MATERIALS
• ANALYSIS/TEST PLAN FOR EACH MATERIAL TYPE
• SAMPLE HANDLING/PACKAGING/SHIPPING
• CONTAMINATION CONTROL
• LDEF MATERIALS DATA BASE
• KEY PERSONNEL
• SCHEDULE

* SEE TEST PLAN DOCUMENT FOR DETAILS
LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)
TEST PLAN

- GOALS AND PROCEDURES* -

GOALS

- INVESTIGATE THE EFFECTS OF LDEF EXPOSURES ON SPACECRAFT MATERIALS, ESPECIALLY THOSE NOT ORIGINALLY INTENDED TO BE MATERIAL SPECIMENS
- DEVELOP ENGINEERING DATA FOR SPACECRAFT DESIGN
- DEFINE MECHANISMS OF MATERIAL DEGRADATION

* COORDINATE DATA FROM PIs, MSIG, AND OTHER SIGs INTO LDEF MATERIALS DATA BASE

- EFFECTS OF POSITION ON LDEF, ORIENTATION OF LDEF, POSITION ON EXPERIMENT TRAY
- COMPARISONS WITH CONTROL SPECIMEN DATA
- LABORATORY-TO-LABORATORY DATA VARIABILITY

PROCEDURES

- ESSENTIAL TASKS AT KSC DE-INTEGRATION
  - DETAILED PHOTOGRAPHIC AND HIGH-RESOLUTION VIDEO SURVEYS OF SURFACES
  - DEFINE CONTAMINATION
  - WORK CLOSELY WITH OTHER SIGs AND PIs
  - COLLECTION AND PRESERVATION OF SOME SPECIMENS
  - DEFINITION OF ADDITIONAL MSIG SPECIMENS

* EXTENSIVE TESTING AND ANALYSES AT BOEING AEROSPACE UNDER CONTRACT NAS1-18224, TASK 12
* COMPUTERIZED DATA BASES PLUS HANDBOOK(S)

* SEE TEST PLAN DOCUMENT FOR DETAILS
LDEF MATERIALS SPECIAL INVESTIGATION GROUP (MSIG) TEST PLAN

- PRE-RECOVERY PREPARATIONS* -

- Preparation of contamination tapelift kits, documentation, and indexing procedures
- Arrange for photo and video documentation equipment
- Obtain photographs and video from on-orbit retrieval activities
- Define specimen labeling key; arrange for labeled packaging materials and documentation forms
- Define storage and shipping arrangements for MSIG specimens
- Define KSC-provided equipment and facilities
- Define MSIG/Boeing-provided equipment and facilities
- Establish KSC coordination team and Boeing analysis teams
- Plan LDEF materials data analysis workshop during "LDEF inspection week" at KSC

* See test plan document for details
ON-LINE EXAMINATIONS
• DON'T GO IN WITH PRECONCEIVED CONCLUSIONS. OBSERVE FROM A MODERATE DISTANCE, OBSERVE FROM CLOSE DISTANCE, STEP BACK AND OBSERVE AGAIN. TRY TO "LISTEN TO LDEF'S STORY".
• ASSURE PHOTOGRAPHIC/VIDEO DOCUMENTATION OF ENTIRE LDEF AND CLOSEUPS OF ALL REGIONS OF PARTICULAR INTEREST
• COLLECT TAPELIFTS FROM STRUCTURAL SURFACES, INDEX AND DOCUMENT
• ASSURE ACCESS TO CONTAMINATION WITNESS PLATE DATA
• DOCUMENT ALL REMOVED PARTS

OFF-LINE ACTIVITIES
• COORDINATE AND PARTICIPATE IN LDEF MATERIALS DATA ANALYSIS WORKSHOP
• COORDINATE PHOTO/VIDEO SURVEYS WITH JSC/M&D SIG TEAM
• NEGOTIATE WITH PIs AND OTHER SIGs FOR HARDWARE OF INTEREST TO MSIG
• MONITOR DE-INTEGRATION; PACKAGE AND SHIP INITIAL MSIG SPECIMENS

* SEE TEST PLAN DOCUMENT FOR DETAILS

---

LDEF Orbital Orientation Model.
LDEF ENVIRONMENTS

LDEF SPACE ENVIRONMENT

• ATOMIC OXYGEN
• METEOROIDS, MICROMETEOROIDS, AND SPACE DEBRIS
• COSMIC DUST AND HEAVY COSMIC-RAY NUCLEI
• HEAVY IONS
• SOLAR ELECTROMAGNETIC ENERGY AND ENERGY VARIATIONS
• PROTON AND ELECTRON RADIATION

LDEF EARTH, LAUNCH, RETRIEVAL, AND FERRY ENVIRONMENTS

• ATMOSPHERIC GASES (DRY AIR)
• HUMIDITY (BUT NOT CONDENSATION)
• CONTAMINANT GASES
• CONTAMINANT PARTICLES

PRELIMINARY APPROACH TO SPECIMEN SELECTION FOR MATERIALS ANALYSIS AND DATA BASE CREATION

MSIG SPECIMENS

• Materials not of primary interest to PIs
• Availability of extra exposed specimens
• Availability of extra control specimens

PI SPECIMENS

• Experiments with desirable locations
• Experiments with diverse materials

ANALYSIS ASSESSMENT

• Assessment of lab-to-lab variations
- EXAMPLES OF "NON-MATERIALS EXPERIMENT" MATERIALS SOURCES* -

- TRUNNIONS AND SCUFF PLATES
- SHUTTLE PAYLOAD BAY DEBRIS
- REFLECTORS
- TRAY FASTENERS, BOLTS, WASHERS, NUTS, PLATES, ETC.
- MATERIALS AND COATINGS IN SYSTEMS EXPERIMENTS
- MATERIALS AND COATINGS IN SCIENCE EXPERIMENTS
- THERMAL BLANKET AND OTHER PROTECTION MATERIALS
- ELECTRONIC COMPONENT MATERIALS

* SEE TEST PLAN DOCUMENT FOR DETAILS

**LDEF MATERIALS FOR ANALYSIS**

**Materials**
- Polymeric films and composites
- Metal-matrix composites
- Polished metals
- Glasses, optical filters and fibers
- Ceramics
- Solar cell materials
- Solid rocket materials

**Coatings**
- Black and white paints
- Anodized aluminum
- Sputter deposited coatings
- Metallic coatings
- Second-surface mirrors
- Optical solar reflectors
LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)
TEST PLAN

- PRIORITY MATERIALS FOR MSIG ANALYSIS* -

MATERIAL TYPES

- KAPTON
- COATED AND UNCOATED TEFON
- THERMOSETS
- THERMOPLASTICS
- ANODIZED ALUMINUM
- STAINLESS STEEL
- BLACK AND WHITE THERMAL CONTROL PAINTS

TRAY LOCATIONS

- LEADING EDGE/TRAILING EDGE
- SPACE END/EARTh END
- 90° TO LEADING EDGE

* SEE TEST PLAN DOCUMENT FOR DETAILS

LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)
TEST PLAN

- MATERIALS OF INTEREST FOR MSIG ANALYSIS* -

MATERIAL TYPES

- POLYMERS
- METALS
- COMPOSITES
- CERAMICS
- COATINGS
- INSULATION
- LUBRICANTS
- ELASTOMERS/ADHESIVES/POTTING COMPOUNDS

LDEF LOCATIONS/ENVIRONMENTS OF INTEREST

- RAM EDGE/AO, UV, SOLAR WIND, THERMAL CYCLING, M&D IMPACTS
- 30°, 60°, AND 90° TO RAM EDGE/LESS AO, UV, SOLAR WIND, TC, M&D
- TRAILING EDGE/UV, SOLAR WIND, TC, M&D IMPACTS
- 30° AND 60° FROM TRAILING EDGE/UV, SOLAR WIND, M&D IMPACTS
- SPACE END/UV, SOLAR WIND, TC, M&D IMPACTS
- EARTH END/UV, SOLAR WIND, TC, M&D IMPACTS, EARTH RADIATION
- INTERNAL AND PROTECTED AREAS/VACUUM, LESS TC, RELATIVE CONTAMINATION

* SEE 18 PAGES OF TEST PLAN DOCUMENT FOR DETAILS
LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)
TEST PLAN

- NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES* -

ULTRASONIC
- PULSE ECHO
- HIGH FREQUENCY
- SURFACE WAVE

EDDY CURRENT

COMPUTED TOMOGRAPHY
- X-RAYS
- MULTIPLANE RECONSTRUCTION

* SEE TEST PLAN DOCUMENT FOR DETAILS

LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)
TEST PLAN

- TESTS FOR MATERIAL CATEGORIES* -

COMMON PROCEDURES FOR MOST MATERIALS
- VISUAL INSPECTION
- DETERMINE WEIGHT AND DIMENSIONS
- OPTICAL PHOTOMICROGRAPHY
- SURFACE ROUGHNESS (PROFIOMETER OR NOMARSKI MICROSCOPE)
- SOLAR ABSORBANCE (UV-VIS/NIR SPECTROMETER, ASTM E-424 A)
- INFRARED EMITTANCE (DB-100 IR REFLECTOMETER, ASTM E-408 A)
- TOTAL HEMISPHERICAL REFLECTANCE (UV-VIS/NIR AND FTIR SPECTROMETERS)
- OUTGASSING (STANDARD TESTS PLUS PYROLYSIS GAS CHROMATOGRAPHY)
- COATING ADHESION PEEL TESTS

ADDITIONAL TESTS FOR ORGANICS
- THERMAL CHARACTERIZATION (TGA, TMA, DMA, DSC)
- CREEP
- HARDNESS (SHORE A AND D)
- DIELECTRIC CONSTANT AND STRENGTH (MIL-STD-202)
- ELECTRICAL RESISTANCE (MIL-P-13949)
- CONFORMAL COATING ANALYSIS (MICRO-IR, DSC, TGA, ETC.)
- SOLUTION PROPERTIES (HPLC, GPC)

* SEE TEST PLAN DOCUMENT FOR DETAILS
LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)
TEST PLAN
- TESTS FOR MATERIAL CATEGORIES* (CONTINUED) -

ADDITIONAL TESTS FOR METALS

- HARDNESS (ROCKWELL AND ROCKWELL SUPERFICIAL)
- SURFACE ANALYSIS (SEM, EDS, AUGER, ESCA, X-RAY DIFFRACTION)
- RESIDUAL STRESS (X-RAY DIFFRACTION)
- MECHANICAL PROPERTIES (TENSILE, IMPACT, FRACTURE TOUGHNESS)
- FRACTURE ANALYSIS (OPTICAL MICROSCOPY, SEM, EDS)
- BULK CHEMICAL ANALYSIS (SPECTROCHEMICAL, EDS)
- METALLOGRAPHY
- OPTICAL AND THERMAL PROPERTIES (REFLECTIVITY, EMMITANCE, HEAT TRANSFER)

ADDITIONAL TESTS FOR CERAMICS AND GLASSES

- ELEMENTAL ANALYSIS (AUGER, ESCA, SIMS)
- CRYSTALLINITY (X-RAY DIFFRACTION)
- TRANSMISSION ELECTRON MICROSCOPY
- IN-SITU TRANSMITTANCE AND REFLECTANCE (CETF)
- BIDIRECTIONAL REFLECTANCE DISTRIBUTION (CETF)

* SEE TEST PLAN DOCUMENT FOR DETAILS

LDEF
MATERIALS SPECIAL INVESTIGATION GROUP (MSIG)
TEST PLAN
- TESTS FOR MATERIAL CATEGORIES* (CONTINUED) -

ADDITIONAL TESTS FOR COMPOSITES

- SURFACE EROSION AND MICROCRACKING (OPTICAL MICROGRAPHY AND SEM)
- SPECIFIC GRAVITY
- DELAMINATIONS (NDE TECHNIQUES, MICROSCOPY, AUGER, MICROPROBE)
- MECHANICAL PROPERTIES (FLEXURE, COMPRESSION, SHEAR, TOUGHNESS)
- OPTICAL PROPERTIES (EMITTANCE, ABSORPTION, REFLECTANCE)
- FIBER CONTENT, RESIN CONTENT, VOID CONTENT (RESIN BURNOUT, CALCULATION)
- THERMAL EXPANSION, THERMAL CONDUCTIVITY (TMA, DILATOMETRY, ASTM D1225)
- GLASS TRANSITION TEMPERATURE (DTA, ASTM D1225)
- SPECIFIC HEAT (DSC)
- OUTGASSING, VOLATILES, CONDENSIBLES (TGA, ASTM E595)
- CHEMICAL ANALYSIS (INFRARED SPECTROSCOPY)

ADDITIONAL TESTS FOR INSULATION MATERIALS

- THERMAL CONDUCTIVITY (DYNATECH, HEAT FLOW METER)
- SPECIFIC HEAT (DSC)
- COMPRESSIBILITY/RESILIENCY
- WETTABILITY/CONTACT ANGLE (GONIOMETER)
- ELECTROSTATIC CHARGING (SURFACE ELECTRICAL POTENTIAL, CONDUCTIVITY)

* SEE TEST PLAN DOCUMENT FOR DETAILS
ADDITIONAL TESTS FOR LUBRICANTS

- CREEP (VISUAL/OPTICAL EXAMINATION, INFRARED ANALYSIS)
- WEAR AND LUBRICANT CONDITION (TRIBOMETER, CHROMATOGRAPHY, SPECTROMETRY)
- PEEL (FOR SOLID FILM LUBRICANTS)

ADDITIONAL TESTS FOR THERMAL CONTROL COATINGS

- SURFACE ANALYSIS/ROUGHNESS, CRACKING (SEM, NOMARSKI MICROSCOPY)
- SURFACE ANALYSIS/CHEMISTRY (FTIR, X-RAY PHOTOELECTRON SPECTROSCOPY)
- TOTAL INTEGRATED SCATTER AND BIDIRECTIONAL REFLECTANCE DISTRIBUTION (LASER ILLUMINATION, VARYING SOURCE AND DETECTOR ANGLES)
- IN-SITU SOLAR ABSORPTANCE (COMBINED RADIATION EFFECTS TEST CHAMBER, DOUBLE PASS REFLECTANCE)
- COATING THICKNESS (PROFILOMETRY)

* SEE TEST PLAN DOCUMENT FOR DETAILS

ADDITIONAL TESTS FOR ELASTOMERS, ADHESIVES, AND POTTING COMPOUNDS

- VISUAL APPEARANCE (LOW MAGNIFICATION)
- CHEMICAL ANALYSIS (FTIR)
- SOLUTION PROPERTIES (HPLC, GPC)
- HARDNESS (SHORE A OR D, ASTM 2240)
- THERMAL CHARACTERIZATION (TGA, TMA, DMA, DSC)
- DIELECTRIC CONSTANT AND STRENGTH (MIL-STD-202)
- ELECTRICAL RESISTANCE (MIL-P-13949)

* SEE TEST PLAN DOCUMENT FOR DETAILS
LDEF
ENVIRONMENTAL EFFECTS ON MATERIALS
SPECIAL INVESTIGATION GROUP

- ACCOMPLISHMENTS THROUGH FEBRUARY, 1990 -

• MEETINGS HELD AT LaRC, WILLIAMSBURG, BOEING/KENT, AND KSC; MARCH, MAY, AUGUST, AND OCTOBER, 1989 (AND FEBRUARY, 1990)

• BRIEFINGS TO LDEF PRINCIPAL INVESTIGATORS, OTHER SPECIAL INVESTIGATION GROUPS, SPACE STATION M&P WORKING GROUP, SDIO/AEROSPACE CORP., AND NASA HQ

• MSIG PHILOSOPHY ADOPTED:
  - DEVELOP ENGINEERING DATA AS FIRST PRIORITY
  - DEVELOP MECHANISTIC DATA AS HIGH PRIORITY

• SECURITY POLICY REGARDING MATERIALS INFORMATION RECOMMENDED TO LDEF PROGRAM OFFICE; LDEF INSPECTION TEAM FORMED

• CONTRACTOR SELECTED, TASK CONTRACT INITIATED FOR MATERIALS TESTS AND ANALYSES
  - PRELIMINARY ANALYSIS TECHNIQUES IDENTIFIED
  - APPROACHES TO SPECIMEN SELECTION DEVELOPED
  - PLANNING, ANALYSIS, AND DOCUMENTATION TASKS INITIATED

• SPECIAL FY89 FUNDING REQUESTED FROM NASA ASSOCIATE ADMINISTRATOR FOR AERONAUTICS AND SPACE TECHNOLOGY; JULY 1989

• MSIG CHAIRMAN INSPECTED LDEF-RELATED FACILITIES AT KSC TO ASSESS CONTAMINATION POTENTIAL; JULY 1989

• MSIG CONTAMINATION MONITORING SUGGESTIONS SENT TO LDEF PO; SEPT. 1989

• ATOMIC OXYGEN/PHOTOGRAPHIC SURVEY SUGGESTIONS SENT TO LDEF PO; OCT. 1989

• LDEF MATERIALS DATA-BASING OPTIONS REVIEWED; NASA-MSFC MAAPTS DATA BASE SELECTED FOR INITIAL ASSESSMENT; AUGUST - OCTOBER 1989

• LDEF MATERIALS DATA ANALYSIS WORKSHOP PLANNED; NOVEMBER 1989 TO JANUARY 1990

• MSIG TEST PLAN DEVELOPED AND DOCUMENTED; TRANSMITTED TO LDEF PROJECT OFFICE; DECEMBER 1989
LDEF
ENVIRONMENTAL EFFECTS ON MATERIALS
SPECIAL INVESTIGATION GROUP

- ACCOMPLISHMENTS THROUGH FEBRUARY, 1990 -
(Concluded)

• SUPPORT OF LDEF INSPECTION TEAM DURING DOWNLINK VIDEO, IN-SPACE
  PHOTOGRAPHY, AND INITIAL KSC INSPECTIONS; JANUARY AND FEBRUARY 1990

• PRELIMINARY IDENTIFICATION OF LDEF LEADING EDGE POSITION, FEBRUARY 1990

• MSIG SPECIMEN IDENTIFICATION; FEBRUARY AND MARCH 1990

• ASSUMED RESPONSIBILITY FOR TOTAL LDEF CONTAMINATION IDENTIFICATION
  AND DOCUMENTATION; FEBRUARY 1990
  - PARTICULATE CONTAMINATION (PRE-DEINTEGRATION)
  - MOLECULAR CONTAMINATION (POST-DEINTEGRATION)
NASA
LONG DURATION EXPOSURE FACILITY

SPECIAL INVESTIGATION GROUP
PLANS
- IONIZING RADIATION SIG

THOMAS A. PARNELL
NASA - MARSHALL SPACE FLIGHT CENTER
CHAIRMAN, IRSIG

LDEF
MATERIALS DATA ANALYSIS WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
LDEF IONIZING RADIATION
SPECIAL INVESTIGATION GROUP
KSC 2-13-90

- Objectives of IRSIG
- Review Team Members
- Radiation Measurements in LDEF Experiments
- Improvements in Radiation Environments Knowledge Anticipated from LDEF
- IRSIG Plans
  - Predictions Booklet
  - Calculations Plan
  - P0006 Measurements and Analysis
  - Induced Radiation Measurements and Analysis
  - Radiations Effects Coordination
  - Coordination with Experimenters and Other SIG's
- Status

LDEF IONIZING RADIATION SIG
REVIEW TEAM

Thomas A. Parnell
Marshall Space Flight Center

E.V. Benton
University of San Francisco

Gerald J. Fishman
Marshall Space Flight Center

Robert L. Kinzer
Naval Research Lab

Allan R. Smith
Lawrence Berkeley Lab

Jacob I. Trombka
Goddard Space Flight Center

James H. Adams (DOD Contract)
Naval Research Laboratory

John W. Watts
Marshall Space Flight Center

Alex Thompson
Dublin Institute for Advanced Studies

Tony Armstrong
SAIC

James H. Derrickson
Marshall Space Flight Center

Wolfgang Heinrich
University of Siegen

C. Lewis Sneed
Brookhaven National Lab

Clive S. Dyer (ESA Contact)
Royal Aerospace Establishment

Rodney Piercey
Mississippi State University

Denis O'Sullivan
Dublin Institute for Advanced Studies

James C. Ritter (SDIO Rep)
Naval Research Laboratory

Richard Scott (SSIG Rep)
Jet Propulsion Laboratory

Paul Sagalyn (MSIG Rep)
Army Materials Lab, Watertown, Mass.

W.H. Kinard (M&DSIG. Rep)
Langley Research Center
LDEF IONIZING RADIATION SIG CHARTER

1. Provide Radiation Environment Predictions (Booklet)

2. Analyze Supporting Radiation Data and Induced Radio-Activity and Compare to Calculations.


4. Compare Radiation Data, when Available, from Experiments with Calculations.

5. Disseminate Results of 2-4 as Available.


7. Provide Calculations/Estimates for Specific Locations in LDEF, or for Specific Components with Suspected Radiation Effects.


IMPROVEMENTS IN RADIATION ENVIRONMENT KNOWLEDGE/CALCULATION METHODS WITH LDEF

• Effects of Directional Properties of Trapped Protons
  - Measurements of Dose with TLD's and Activation Around Flight-Direction Stabilized Spacecraft.
  - Calculations with Directional Proton Model as a Function of Position and Depth in LDEF, HETC Calculation of Activation Using Directional Proton Flux.

• Accurate Neutron Fluence and Spectrum

• Measurement of Linear Energy Transfer Spectrum Beyond the "Iron Peak" in Cosmic Rays

• Fluence, LET Spectra, and Dose of Low Energy Target Spallation Nuclides or "Star" Particles.
  - Some New Measurements
  - HETC Calculations

• More Accurate Levels of AP8 Proton Fluxes at Solar Minimum
  - Measurements of Dose with TLD's and Activation at Various Spacecraft Locations and Depth. Enhanced by Flight Direction Stability of LDEF.
  - Requires Application of Directional Proton Model (as AP8 Post Processor) and HETC Calculations. Also Requires Maximum Use of TLD's and Activation Materials in LDEF.
### Radiation Detectors on LDEF

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<th>TLD'S</th>
<th>PNTDS</th>
<th>Activated Materials</th>
<th>Fission Foils</th>
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<td>Absorbed Dose (RADS)</td>
<td>Heavy Ion Fluence &amp; LET Spectra</td>
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### Radiation Measurement Principal Categories

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IONIZING RADIATION

L D E F

PREDICTION BOOKLET — OUTLINE
THE LONG DURATION EXPOSURE FACILITY
IONIZING RADIATION PREDICTIONS (BOOKLET)

I. • INTRODUCTION -- VALUE OF LDEF MEASUREMENT -- LIST OF LDEF RADIATION MEASUREMENTS

II. • DESCRIPTION OF TRAPPED PARTICLES AND COSMIC RAYS IN LDEF ORBIT (REFERENCES)

III. • RADIATION ABSORBED DOSE -- DEPTH DOSE AND GENERAL DESCRIPTION OF DIRECTIONAL EFFECTS

IV. • LET SPECTRA AND GENERAL DESCRIPTION OF "SINGLE HIT" ASPECT OF PARTICLES -- DISCUSSION OF SOURCE OF PARTICLES IN VARIOUS PARTS OF LET SPECTRUM

V. • NEUTRONS AND DISCUSSION OF OTHER SECONDARIES

VI. • EQUIVALENT DOSE (APPROXIMATE)

VII. • ACTIVATION OF MATERIALS

VIII. • RADIATION EFFECTS (GENERAL)

IX. • RADIATION MEASUREMENT AND ANALYSIS PLAN FOR LDEF

X. • REFERENCES
External Environment Calculations

- Geomagnetically trapped protons and electrons differential fluxes
  (Vette AP8MIN proton and AE8MIN electron environment)
- Directional proton flux
  (AP8 post-processor (Watts-MSFC))
- Galactic cosmic radiation (GCR) differential flux
  (CREME GCR environment)
- Albedo neutrons flux from atmosphere (T. Armstrong)
- Magnetic field Model

First Order Internal Environment Calculations

- Dose and dose equivalent versus shield thickness for trapped particles
  (Burrell "straight-ahead, continuous slowing down" proton dose program)
  (MSFC electron dose program based on fits to ETRAN)
- Dose and dose equivalent versus shield thickness for GCR
  (CREME)
- Let spectra for trapped protons versus shield thickness
  (CREME)
- Let spectra for GCR/anomalous component versus shield thickness
  (CREME)
Models of LDEF

- Vector mass model for dose and fluence calculations at shielding depths
- Radioactivity model from sample/mass model calculations

Activation Calculations using HETC

- Activation of experiment samples
- Activation of materials available in other experiments
- Activation of spacecraft structure samples
- Activation for a simple total spacecraft model

Secondaries Calculations using HETC

- Secondary proton spectra
- Secondary neutron spectra

Approach for LDEF Calculations
### Dose LDEF Mission due to Trapped Protons and Electrons
Behind a Plane Aluminum Slab with Infinite Backing

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<th>Proton (rads)</th>
<th>Total (rads)</th>
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### Dose LDEF Mission due to Trapped Protons and Electrons
Center of a Spherical Aluminum Shell

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Trapped Proton Fluence for LDEF

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<td>3.52x10⁷</td>
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<td>3.15x10⁷</td>
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<td>2.29x10⁷</td>
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Trapped Electron Fluence for LDEF

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<td>$1.95 \times 10^{13}$</td>
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<td>0.25</td>
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<tr>
<td>0.50</td>
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<tr>
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<td>3.75</td>
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![Trapped Proton Fluence for LDEF](image-url)
Integral LET Spectra for LDEF

- Insertion - Recovery of LDEF
- 481.5 km, 730.4 km circular
- 28.5° inclination

Spectra includes:
- Cosmic rays (Z = 1-29)
- Trapped protons (near min.)
- Anomalous component (Z = 1)

Precipitation levels:
- Geomagnetic cutoff included
- No magnetic disturbance
- Earth's shadow included
- No shielding

Average proton dose rates for 38.5° orbit for a detector behind a 5 g/cm² aluminum shield with infinite backing with the plane facing in the specified directions relative to the geographic coordinates.
DATA ANALYSIS PLAN

for

LDEF EXPERIMENT P0006

Linear Energy Transfer Spectrum Measurements Experiment

October 1989

E.V. Benton
Composition of the top and bottom modules of the POGO experiment.
OBJECTIVES

THE MAJOR SCIENTIFIC OBJECTIVES OF THE PO006 EXPERIMENT ARE AS FOLLOWS:

1. MEASURE LET SPECTRA DUE TO HZE PARTICLES AT DIFFERENT SHIELDING DEPTHS

2. OBTAIN HIGH LET (>100 keV/µm) PORTIONS OF LET SPECTRA WITH SUPERIOR STATISTICAL ACCURACY

3. MEASURE TOTAL MISSION RADIATION DOSE, NEUTRON FLUENCES AND ACTIVATION OF METAL SAMPLES

4. PERFORM VECTOR SHIELDING CALCULATIONS TO DETERMINE COMPLEX SHIELDING DISTRIBUTIONS OF LDEF EXPERIMENTS

5. CALCULATE LET SPECTRA, TOTAL RADIATION DOSES AND NEUTRON FLUENCES FOR COMPARISON WITH EXPERIMENTAL LDEF RESULTS

6. DEVELOP CALCULATIONAL METHODS TO EXTRAPOLATE THE DATA TO OTHER ORBITS

7. PERFORM CALCULATIONS OF RADIATION FIELD FOR THE SPACE STATION ORBIT

8. FROM LET SPECTRA, DETERMINE FLUENCE OF HIGH ENERGY DEPOSITION EVENTS (IN SILICON) THAT CAUSE SINGLE EVENT UPSETS (SEU) IN MICROCIRCUITS IN LDEF ORBIT

9. MEASURE FLUENCE OF RECOIL NUCLEI IN SILICON CAUSED BY PROTONS IN THE SOUTH ATLANTIC ANOMALY (NEW METHOD)

10. DETECT RADIATION EFFECTS ON BULK OR MECHANICAL PROPERTIES OF MATERIALS (LiF, POLYCARBONATE, POLYEsters)
OTHER LDEF EXPERIMENTS HAVING UNIVERSITY OF SAN FRANCISCO RADIATION DETECTORS

I. POOD6: LINEAR ENERGY TRANSFER SPECTRUM MEASUREMENT EXPERIMENT
   (UNIVERSITY OF SAN FRANCISCO)

   A. PMTs
      1. CR-39 (PURE)
      2. CR-39 (WITH DOP PLASTICIZER)
      3. TUFFAK POLYCARBONATE
      4. SHEFFIELD POLYCARBONATE
      5. MELINEX POLYESTER

   B. MUSCOVITE MICA

   C. TLDs

   D. FISSION FOIL DETECTORS
      1. 238U/MICA
      2. 232Th/MICA
      3. 209Bi/MICA
      4. 181Ta/MICA
      5. 6LiF/CR-39, with and without Gd

   E. ACTIVATION FOILS
      1. Ni
      2. Ta
      3. In
      4. V

   F. SILICON WAFERS WITH CR-39

II. POOD4-1: SEEDS IN SPACE EXPERIMENT
    (G. PARK SEED CO.)

   A. PMTs
      1. CR-39
      2. TUFFAK POLYCARBONATE

   B. TLDs

   C. 6LiF/CR-39, with and without Gd
III. 50004-2: SPACE EXPOSED EXPERIMENT DEVELOPED FOR STUDENTS
(NASA HEADQUARTERS)

A. PNTDs
   1. CR-19
   2. TUFFAK POLYCARBONATE

B. TLDs
   5. LiF/CR-19, with and without Gd

IV. 50015: FREE-FLYER BIOSTACK EXPERIMENT
(OFVLR)

A. PNTDs
   1. CR-19
   2. SHEFFIELD POLYCARBONATE
   3. TUFFAK POLYCARBONATE

B. MUSCOVITE MICA

C. TLDs

D. FISSION FOIL DETECTORS
   1. 238U/MICA
   2. 232Th/MICA
   3. 209Pt/MICA
   4. 181Ta/MICA
   5. LiF/CR-19, with and without Gd

I. 50004: SPACE ENVIRONMENT EFFECTS IN FIBER OPTICS SYSTEMS
(AFVL)

A. PNTDs
   1. CR-19
   2. TUFFAK POLYCARBONATE
   3. SHEFFIELD POLYCARBONATE
   4. MELINEX POLYESTER

B. TLDs
$SCHEDULE -- P0006 ANALYSIS PLAN$

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*disassemble experiment early because of activation materials
LDEF INDUCED RADIOACTIVITY ANALYSIS PLAN

- FULL SPACECRAFT MEASUREMENTS
- INDIVIDUAL SAMPLE MEASUREMENTS
- CALCULATIONS OF SAMPLE AND SPACECRAFT MATERIAL RADIOACTIVITY AND COMPARISONS WITH MEASUREMENTS
- MASS MODEL AND RADIOACTIVITY MODEL OF SPACECRAFT
- CALCULATION OF GAMMA FLUX AND SPECTRA AT DETECTOR POINTS OF FULL SPACECRAFT MEASUREMENTS
- EXTRAPOLATION OF CALCULATIONS TO OTHER ORBITS

GAMMA-RAY SPECTRUM - PACKET NO. 2. The activation gamma-ray peaks are identified; all other peaks are due to background gamma-ray lines. A strong background continuum is also apparent.
TABLE 1. MEASURED INDUCED RADIOACTIVITY (SKYLAB DEBRIS)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>gm MASS</th>
<th>ISOTOPE</th>
<th>ENERGY (keV)</th>
<th>HALF-LIFE</th>
<th>NET COUNTS/1000 sec</th>
<th>RE-ENTRY PLUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (6)</td>
<td>150</td>
<td>Na 22</td>
<td>1278</td>
<td>2.8 yr</td>
<td>0.50 ± 0.15</td>
<td>3 - 6 wks</td>
</tr>
<tr>
<td>SS (7)</td>
<td>367</td>
<td>Co 58</td>
<td>811</td>
<td>71d</td>
<td>0.49 ± 0.13</td>
<td>3 - 6 wks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn 54</td>
<td>835</td>
<td>303d</td>
<td>4.32 ± 0.24</td>
<td>3 - 6 wks</td>
</tr>
<tr>
<td>SS (11)</td>
<td>175</td>
<td>Co 56</td>
<td>847</td>
<td>77d</td>
<td>0.90 ± 0.16</td>
<td>3 - 6 wks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn 54</td>
<td>835</td>
<td>71d</td>
<td>0.41 ± 0.15</td>
<td>3 - 6 wks</td>
</tr>
<tr>
<td>SS (15)</td>
<td>117</td>
<td>Co 56</td>
<td>847</td>
<td>303d</td>
<td>2.83 ± 0.28</td>
<td>3 - 6 wks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn 54</td>
<td>835</td>
<td>77d</td>
<td>0.91 ± 0.18</td>
<td>3 - 6 wks</td>
</tr>
<tr>
<td>SS (16)</td>
<td>281</td>
<td>Co 56</td>
<td>847</td>
<td>303d</td>
<td>4.14 ± 0.30</td>
<td>3 - 6 wks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn 54</td>
<td>835</td>
<td>77d</td>
<td>0.50 ± 0.26</td>
<td>5 months</td>
</tr>
</tbody>
</table>

SS = STAINLESS STEEL  () SAMPLE NUMBER

TABLE 2. TYPICAL SPECIFIC ACTIVITIES OF SKYLAB DEBRIS SAMPLES

<table>
<thead>
<tr>
<th>SAMPLE MATERIAL</th>
<th>ISOTOPE</th>
<th>SPECIFIC ACTIVITY* (AT RE-ENTRY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALUMINUM</td>
<td>Na 22</td>
<td>1.1 DISINTEGRATIONS/sec/kg</td>
</tr>
<tr>
<td>STAINLESS STEEL</td>
<td>Co 56</td>
<td>0.8 DISINTEGRATIONS/sec/kg</td>
</tr>
<tr>
<td>STAINLESS STEEL</td>
<td>Mn 54</td>
<td>3.0 DISINTEGRATIONS/sec/kg</td>
</tr>
<tr>
<td>STAINLESS STEEL</td>
<td>Co 56</td>
<td>1.5 DISINTEGRATIONS/sec/kg</td>
</tr>
</tbody>
</table>

*ESTIMATED ACCURACY: ±30 PERCENT

LDEF
Long Duration Exposure Facility

INDUCED RADIOACTIVITY EXPERIMENT

Target Types:
I. Intentional Samples
   - Metal Targets, 2" x 2" : Ni, Co, Ta, V, In
   - Contained in : A0114 Atomic Oxygen (Gregory/Peters)
     P0006 LET Spectra (Benton)
     M0001 Heavy Ions (Adams)
     M0002 Trapped Proton Spectra (AFCRL)

II. Spacecraft Structure/Components
   - Stainless Steel Trunions
   - Lead ballast Plates
   - Aluminum Structural Components

III. Components of Other Experiments Desired:
   - Samples of Metals or Alloys of High Atomic No. (>30)
     with weights over 1/2 oz.
OBJECTIVES

I. Measurements of Induced Radioactivity in Spacecraft and Experiment Materials in Low Earth Orbit
   A. Spacecraft Materials: Aluminum Alloys, Stainless Steels
   B. Experiment Materials: Copper, Germanium, Structural Alloys
   C. Activation vs. depth in a large spacecraft
   D. Activation vs. orientation in a gravity-gradient stabilized spacecraft

II. Characterization of the Nuclear-Active Particle Environment in Low Earth Orbit
   A. Proton Flux and Spectra Above 20 MeV
   B. Neutron Flux and Coarse Spectral Measurements
   C. Separation of Trapped Proton and Cosmic Ray Proton Fluxes
   D. Proton Anisotropy Measurements

III. Experimental Verification of Spacecraft Activation
    Computer Codes Developed for Future Programs
    A. Space Station
    B. Lunar Base
    C. Manned Mars Mission
### Targets/Reactions/Gamma Ray Energy/Half Lives

<table>
<thead>
<tr>
<th>TARGET MATERIAL</th>
<th>MAJOR PRODUCTION MODE</th>
<th>RADIOACTIVE NUCLIDE</th>
<th>GAMMA ENERGY MeV</th>
<th>HALF LIFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>$A_1^{27}(p,-)$</td>
<td>Na$^{22}$</td>
<td>1.28</td>
<td>2.6 y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Be$^{7}$</td>
<td>.478</td>
<td>53 d</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>$Ni^{58}(n,p)$</td>
<td>Co$^{58}$</td>
<td>.810</td>
<td>71 d</td>
</tr>
<tr>
<td></td>
<td>$Ni^{58}(p,2p)$</td>
<td>Co$^{57}$</td>
<td>.122</td>
<td>270 d</td>
</tr>
<tr>
<td></td>
<td>$Ni^{58}(p,2pn)$</td>
<td>Co$^{56}$</td>
<td>.847</td>
<td>77 d</td>
</tr>
<tr>
<td></td>
<td>$Fe^{56}(p,2pn)$</td>
<td>H$^n_54$</td>
<td>.835</td>
<td>313 d</td>
</tr>
<tr>
<td>Nickel</td>
<td>$Ni^{58}(n,p)$</td>
<td>Co$^{58}$</td>
<td>.810</td>
<td>71 d</td>
</tr>
<tr>
<td></td>
<td>$Ni^{58}(p,2p)$</td>
<td>Co$^{57}$</td>
<td>.122</td>
<td>270 d</td>
</tr>
<tr>
<td></td>
<td>$Ni^{58}(p,2pn)$</td>
<td>Co$^{56}$</td>
<td>.847</td>
<td>77 d</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Co$^{59}(n,\gamma)$</td>
<td>Co$^{60}$</td>
<td>1.173, etc.</td>
<td>5.26 y</td>
</tr>
<tr>
<td>Tantulum</td>
<td>Ta$^{181}(n,\gamma)$</td>
<td>Ta$^{182}$</td>
<td>1.211</td>
<td>115 d</td>
</tr>
<tr>
<td></td>
<td>W$^{181}$</td>
<td>1.153, etc.</td>
<td>113 d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hf$^{181}$</td>
<td>.482</td>
<td>43 d</td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td>Ti$^{46}(n,p)$</td>
<td>Sc$^{46}$</td>
<td>.899</td>
<td>84 d</td>
</tr>
<tr>
<td></td>
<td>Ti$^{48}(p,n)$</td>
<td>V$^{48}$</td>
<td>.983</td>
<td>16 d</td>
</tr>
<tr>
<td>Indium</td>
<td></td>
<td>Cd$^{115}$</td>
<td>.940, etc.</td>
<td>43 d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In$^{114}$</td>
<td>.72, etc.</td>
<td>50 d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cd$^{113}$</td>
<td></td>
<td>14 y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sn$^{113}$</td>
<td></td>
<td>118 d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ag$^{110}$</td>
<td></td>
<td>260 d</td>
</tr>
</tbody>
</table>

Copper
Vanadium
Germanium
Gold
LDEF
Induced Radioactivity
Short-Lived isotopes

Remaining Activity

Days After Recovery

Bi^{209}, Ni^{54}, Ag^{104}, Mn^{57}, Bi^{201}
LDEF INDUCED RADIOACTIVITY
REQUEST FOR LOAN OF OTHER EXPERIMENT MATERIALS
FOR GAMMA RAY COUNTING

<table>
<thead>
<tr>
<th>EXP. NO.</th>
<th>MATERIAL</th>
<th>DESCRIPTION</th>
<th>SIZE/WT</th>
</tr>
</thead>
<tbody>
<tr>
<td>M0003*</td>
<td>Gallium Arsenide</td>
<td></td>
<td>2 x 2 x .09</td>
</tr>
<tr>
<td>M0003*</td>
<td>Molybdenum</td>
<td>Optical Mirrors (2)</td>
<td>114g</td>
</tr>
<tr>
<td>M0003*</td>
<td>Copper</td>
<td>Dia. Turned</td>
<td>100g</td>
</tr>
<tr>
<td>M0006</td>
<td>CdSe</td>
<td>Semiconductors (2)</td>
<td>1&quot; Dia.</td>
</tr>
<tr>
<td>M0006</td>
<td>GaAs</td>
<td>Semiconductors (7)</td>
<td>1&quot; Dia.</td>
</tr>
<tr>
<td>A0056</td>
<td>BaF₂</td>
<td>Substrate</td>
<td>25mm</td>
</tr>
<tr>
<td>A0056</td>
<td>Cd Telluride</td>
<td>Substrate</td>
<td>25mm dia. x 1.2mm</td>
</tr>
<tr>
<td>A0056</td>
<td>Thallium</td>
<td>Substrate</td>
<td>1&quot; Dia.</td>
</tr>
<tr>
<td>A0056</td>
<td>Bromoiodide</td>
<td>Substrate</td>
<td></td>
</tr>
<tr>
<td>A0056</td>
<td>Germanium</td>
<td>Substrate</td>
<td>25mm</td>
</tr>
<tr>
<td>A0139A</td>
<td>Copper OFHC</td>
<td>Instrumentation</td>
<td>&lt;100g</td>
</tr>
<tr>
<td>A0189</td>
<td>Copper OFHC</td>
<td>Instrumentation</td>
<td>&lt;100g</td>
</tr>
<tr>
<td>S0014</td>
<td>Gallium Arsenide</td>
<td>APEX Sample</td>
<td>1.6cm x 1.3cm</td>
</tr>
<tr>
<td>S0014</td>
<td>Copper OFHC</td>
<td>Instrumentation</td>
<td>&lt;100g</td>
</tr>
<tr>
<td>S0014</td>
<td>GaAlAs/Ga/As</td>
<td>APEX Samples (2)</td>
<td></td>
</tr>
<tr>
<td>P0003</td>
<td>Copper</td>
<td>Plate, Radiometer</td>
<td>115g</td>
</tr>
<tr>
<td>A0114</td>
<td>Copper</td>
<td>Disc.</td>
<td>1&quot; Dia.</td>
</tr>
<tr>
<td>EXP. NO.</td>
<td>MATERIAL</td>
<td>DESCRIPTION</td>
<td>SIZE/WT</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------</td>
<td>-------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>A0114</td>
<td>Germanium</td>
<td>Disc.</td>
<td>1&quot; Dia.</td>
</tr>
<tr>
<td>A0114</td>
<td>Silver</td>
<td>Single Crystal Disc.</td>
<td>1&quot; Dia.</td>
</tr>
<tr>
<td>A0114</td>
<td>Silver</td>
<td>Solid Disc.</td>
<td>1&quot; Dia.</td>
</tr>
<tr>
<td>A0114</td>
<td>Titanium Alloy</td>
<td>6A-4B Alloy Disc.</td>
<td>1&quot; Dia.</td>
</tr>
<tr>
<td>A0114</td>
<td>Titanium</td>
<td>75 A Disc.</td>
<td>1&quot; Dia.</td>
</tr>
<tr>
<td>A0187</td>
<td>Gold</td>
<td>Detector</td>
<td>?</td>
</tr>
<tr>
<td>A0178</td>
<td>Iridum</td>
<td>Foil</td>
<td>0.5mm thick</td>
</tr>
<tr>
<td>S1002</td>
<td>Titanium Alloy</td>
<td>Alloy 6V4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>AMS 4911B</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>AMS 4928D</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>VFN 13307/20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LN 9247</td>
<td></td>
</tr>
<tr>
<td>S1002</td>
<td>Copper</td>
<td>Electrolytic</td>
<td>?</td>
</tr>
<tr>
<td>S1001</td>
<td>Silver</td>
<td>Diode Heat Pipe</td>
<td>?</td>
</tr>
</tbody>
</table>

* NOTE 1: All samples on #M0003 have matching unexposed samples attached to the bottom of the tray. Also, since #M0003 is on four different trays, there may be more than one set of materials.

NOTE 2: These samples are desired for counting with low background gamma ray detectors as soon as feasible following de-integration of the experiments, since many nuclides of interest have short half lives. The samples can be shipped and analyzed in thin, low background radioactivity, hermetic enclosures (if required). A few materials will have some long lived radio-nuclides allowing useful analysis for several months or more following deintegration. The desired loan period for gamma ray counting is two weeks minimum. The availability of a ground control samples of the material would considerably enhance the analysis.
List of LDEF spacecraft structural and systems materials suitable for induced radioactivity studies.

This table contains only major parts; numerous other minor components such as fasteners, and small structural parts would also be of value for the induced radioactivity studies.

<table>
<thead>
<tr>
<th>Description</th>
<th>Material</th>
<th>Wt. (lbs.)</th>
<th>Ref. No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunnion pins:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main (middle) (2)</td>
<td>SS 17-4 PH</td>
<td>85.4</td>
<td>815934-E</td>
</tr>
<tr>
<td>End (2)</td>
<td>SS 17-4 PH</td>
<td>52.3</td>
<td>815835-B</td>
</tr>
<tr>
<td>Keel (1)</td>
<td>SS 17-4 PH</td>
<td>61.6</td>
<td>815950-C</td>
</tr>
<tr>
<td>Ballast plates (ap. 18 total)</td>
<td>Lead</td>
<td>7.5-10</td>
<td>819225</td>
</tr>
<tr>
<td>Ballast cover plates (18)</td>
<td>Alum., 6061</td>
<td>1.9, 2.8</td>
<td>819226</td>
</tr>
<tr>
<td>Keel plate</td>
<td>Alum., 6061</td>
<td>7.75</td>
<td>815947</td>
</tr>
</tbody>
</table>
Results from 16 hours of counting with one detector on the SPACE end of LDEF compared to a background taken in the SAEF-11 high bay with no LDEF present. The line at 1274 keV comes from nuclear reactions between the aluminum on LDEF and the high-energy proton flux encountered in orbit.
Sensitivity of Various Components to the Ionization Effects of Radiation

LDIF IRSIG TAP 2/13/90

LDIF - RADIATION EFFECTS

- Detailed knowledge of radiation environment in LDIF will be supplied by IRSIG.
- The IRSIG will arrange consultants to advise concerning potential radiation effects in systems and materials.
- Special calculations will be made for components with suspected effects.
- If post-flight radiation testing is desired the IRSIG will advise on particle beams to use and arrange radiation effects consultation to design the tests.
- It is recommended that any required radiation effects ground tests for SEU's, optical properties effects, displacement damage in crystalline materials etc. be performed by the relevant experimenter or SIG.
LDEF SEEDS
Preliminary Estimate
Absorbed Radiation Dose
Trapped Protons and Electrons
Omnidirectional AP8 and AE8
Spherical Shield
LDEF`IONIZING RADIATION INFORMATION REQUEST

1. Originator: __________________________ Phone: __________________________

2. Organization/Address: __________________________________________________

3. LDEF Experiment/System/Component/Material: __________________________

4. Tray Number/Location: _________________________________________________

5. Anticipated/Observed Effect: __________________________________________

6. Suspected Radiation Component (Total Dose, High LET Particles, Neutrons, etc.)
   ________________________________________________________________

7. Other Justification for Radiation Analysis: _________________________________

8. Desired action by Ionizing Radiation SIG (Radiation calculations at suspect site, recommendation for post-flight testing, radiation effects references, etc.)
   ________________________________________________________________

9. Please supply detailed drawing showing component in tray and materials identification so that shielding model may be developed.

10. Requestor Signature: _________________________________________________
    SIG Signature: ______________________________________________________

Add continuation sheets as necessary, send copies to the following:

(1) LDEF Project Office, Code 356, NASA, LaRC, Hampton, VA 23665-5225
(2) T.A. Parnell, ES62, NASA, Marshall Space Flight Center, AL 35812

NOTE: The LDEF IRSIG does not plan to perform experimental radiation effect studies on materials/components. It does plan to supply accurate information on radiation dose, flux, secondary components at suspect sites. It will also supply references to relevant literature on radiation effects, and advice concerning post flight radiation testing.
LDEF IRSIC STATUS

- IRSIG PLANS COMPLETE
- PRELIMINARY DOSE, FLUENCE AND LET MEASUREMENTS COMPLETE AND CIRCULATED
- PREDICTIONS BOOKLET IN PRESS - DISTRIBUTION 3/15/90
- RADIATION CALCULATIONS PLAN COMPLETE
- PO006 ANALYSIS PLANS COMPLETE
- INDUCED ACTIVITY ANALYSIS PLANS COMPLETE
- MEASUREMENTS OF FULL SPACECRAFT INDUCED ACTIVITY IN PROGRESS
- INDUCED ACTIVITY CALCULATIONS PLANS COMPLETE
- RADIATION EFFECTS CONSULTING PLAN IN PROGRESS

* AWAITING FUNDING
NASA
LONG DURATION EXPOSURE FACILITY

OVERVIEW OF PRINCIPAL INVESTIGATOR PLANS

JAMES L. JONES, JR.
NASA - LANGLEY RESEARCH CENTER
LDEF SCIENCE MANAGER

LDEF MATERIALS DATA ANALYSIS WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
PI EXPERIMENT ACTIVITIES

KSC OPERATIONS
PI EXPERIMENT

EXPT. DEINTEGRATION
PI FACILITY

DATA ANALYSIS

DATA PUBLICATION

NON PLEXPTS.
- SYSTEMS
- COMPONENTS
- SAMPLES

DATA ANALYSIS

DATA PUBLICATION

SIG REQUESTS
- MATERIAL
- SYSTEM
- MICROMETEROID
- RADIATION

PI/SIG
UNDERSTANDING

RETRIEVAL PLANS (COMPLETED)

- TRAY/EXPERIMENT PROCESSING

DE-INTEGRATE
(IF NECESSARY)

PHOTOGRAPH
FRONT & BACK

INSTALL TRAY COVERS

PACK FOR SHIPPING

DELIVER FOR SHIPPING

BATTERY REMOVAL

SELECTED EXPERIMENT C/O OPERERS.

DE-INTEGRATE
(IF NECESSARY)

EXPERIMENT POWER & DATA SYS. ACT.

OFF-LINE STS

REMOVE TO FLOOR

REMOVE TRAY COVERS

96

C.J.
EXPERIMENTS A0134 AND S0010—BEFORE INTEGRATION ON LDEF STRUCTURE.
EXPERIMENT S1001—BEFORE INTEGRATION ON LDEF STRUCTURE.

EXPERIMENT A0054—BEFORE INTEGRATION ON LDEF STRUCTURE.
INTEGRATED TRAY C-3—BEFORE INTEGRATION ON LDEF STRUCTURE.

EXPERIMENT A0178—BEFORE INTEGRATION ON LDEF STRUCTURE.
INTEGRATED TRAY D-12—BEFORE INTEGRATION ON LDEF STRUCTURE.

EXPERIMENTS M0002 AND M0003—BEFORE INTEGRATION ON LDEF STRUCTURE.
TRAY G10—BEFORE INTEGRATION ON LDEF STRUCTURE.

EXPERIMENT S0014—BEFORE INTEGRATION ON LDEF STRUCTURE.
INTEGRATED TRAY E-6—BEFORE INTEGRATION ON LDEF STRUCTURE.

EXPERIMENT M0004—BEFORE INTEGRATION ON LDEF STRUCTURE.
EXPERIMENT A0138—BEFORE INTEGRATION ON LDEF STRUCTURE.
NASA
LONG DURATION EXPOSURE FACILITY

SDIO OVERVIEW

WAYNE E. WARD
U.S.AIR FORCE SYSTEMS COMMAND
MEMBER, MSIG

LDEF
MATERIALS DATA ANALYSIS WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
SDIO ASSESSMENT OF THE NASA LONG DURATION EXPOSURE FACILITY (LDEF)

IDENTIFICATION OF DATA/SAMPLES DESIRED

NASA/LDEF WORKSHOP
KSC
13 - 14 FEBRUARY 1990
WAYNE E. WARD
WRDC/MLBT
WRIGHT-PATTERSON AFB,
OHIO 45433-6533

SPACE ENVIRONMENTAL EFFECTS
PROGRAM OBJECTIVES

PROVIDE SELECTED, CRITICAL SPACE ENVIRONMENTAL EFFECTS DATA ON MATERIALS IN THE FORM TO ASSIST MORE CONFIDENT DESIGN OF LONG LIFE SDS SPACECRAFT

TWO PHASE EFFORT

- UTILIZE EXISTING NATIONAL RESOURCES AND CURRENT OR CURRENTLY DEVELOPMENTAL MATERIALS TO ACQUIRE ESSENTIAL DATA FOR PHASE ONE SYSTEM DESIGNS (e.g. BSTS, SSTS)

- ENHANCE AND INTEGRATE NATIONAL TESTING CAPABILITIES FOR LONG LIFE IN ALL ENVIRONMENTAL CONDITIONS

- EXPAND TESTING TO INCLUDE MATERIALS NOW IN EARLY DEVELOPMENT

- COMPLY WITH LONG LEAD TIME REQUIREMENTS BY IMMEDIATELY INITIATING SPACE FLIGHT PLANNING TO ACQUIRE ESSENTIAL DATA
<table>
<thead>
<tr>
<th><strong>SPACE ENVIRONMENTAL EFFECTS SUMMARY</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>WRDC / ML: SERVE AS EXECUTING AGENT</td>
</tr>
<tr>
<td>* TO PLAN AND EXECUTE THE SPACE ENVIRONMENTAL EFFECTS PROGRAM</td>
</tr>
<tr>
<td>* TO MANAGE A COORDINATED NATIONAL EFFORT</td>
</tr>
<tr>
<td>* TO PROVIDE SELECTED SPACE ENVIRONMENTAL EFFECTS INFORMATION FOR MATERIALS SELECTION, PERFORMANCE AND END OF LIFE PREDICTIONS FOR NEAR TERM AND FUTURE SDS SPACECRAFT</td>
</tr>
<tr>
<td>* TO FILL CRITICAL VOIDS IN THE TRANSITION OF NEW MATERIALS AND STRUCTURES TECHNOLOGY TO SDS SPACECRAFT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>SPACE ENVIRONMENTAL EFFECTS NEEDS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>* SPACE ENVIRONMENTAL EFFECTS ON MATERIALS PROPERTIES / PERFORMANCE MUST BE QUANTIFIED</td>
</tr>
<tr>
<td>• GROUND SIMULATION</td>
</tr>
<tr>
<td>• COMBINED EFFECTS</td>
</tr>
<tr>
<td>• ORBITAL DEPENDENCE</td>
</tr>
<tr>
<td>• ORBITAL EXPERIMENTS / DATA</td>
</tr>
<tr>
<td>• LDEF, DELTA STAR, OTHERS</td>
</tr>
<tr>
<td>• MATHEMATICAL MODELING</td>
</tr>
<tr>
<td>• COMBINED EFFECTS</td>
</tr>
<tr>
<td>• ENHANCED DATA BASE</td>
</tr>
<tr>
<td>• STANDARDIZED TEST METHODS AND PROCEDURES</td>
</tr>
<tr>
<td>• ACCELERATED TESTING</td>
</tr>
<tr>
<td>* SPACE ENVIRONMENTAL EFFECTS ON HARDNESS MUST BE QUANTIFIED</td>
</tr>
<tr>
<td>• COMBINED ENVIRONMENTAL / HARDNESS TESTING</td>
</tr>
<tr>
<td>* RESULTS MUST BE CORRELATED FOR EASY ACCESS BY SYSTEMS DESIGNERS</td>
</tr>
<tr>
<td>* GUIDE MATERIALS DEVELOPMENT</td>
</tr>
</tbody>
</table>
## SPACE ENVIRONMENTAL EFFECTS
TECHNOLOGY INSERTION WORKING GROUP (TIWG)

### MEMBERSHIP

<table>
<thead>
<tr>
<th>Organization</th>
<th>Name</th>
<th>Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR FORCE</td>
<td>DR. WAYNE WARD</td>
<td>WRDC/ML, CHAIRMAN</td>
</tr>
<tr>
<td></td>
<td>DR. ED MURAD</td>
<td>AFGL/PHK</td>
</tr>
<tr>
<td></td>
<td>LT. DALE ATKINSON</td>
<td>AFWL/NTCAS</td>
</tr>
<tr>
<td></td>
<td>LT. BRIAN LILLIE</td>
<td>AFSTC/XLA</td>
</tr>
<tr>
<td>SDIO</td>
<td>LTC RICHARD YESENSKY</td>
<td>SDIO/TNK</td>
</tr>
<tr>
<td></td>
<td>DR. AINSLIE YOUNG</td>
<td>SDIO/TNK</td>
</tr>
<tr>
<td></td>
<td>LTC CHIP HILL</td>
<td>SDIO/TNK</td>
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<tr>
<td>NAVY</td>
<td>MR. AL BERTRAM</td>
<td>NSWC/WL</td>
</tr>
<tr>
<td>NASA</td>
<td>DR. DARREL TENNEY</td>
<td>Langley Research Center</td>
</tr>
<tr>
<td></td>
<td>DR. LUBERT LEEGER</td>
<td>Johnson Space Center</td>
</tr>
<tr>
<td>W.J. SCHAFFER</td>
<td>MR. ROBERT TURNER</td>
<td>CPL</td>
</tr>
<tr>
<td>Aerospace Corp.</td>
<td>DR. GRAHAM ARNOLD</td>
<td>MSL</td>
</tr>
<tr>
<td></td>
<td>DR. MIKE MESHISHNEK</td>
<td></td>
</tr>
<tr>
<td>JET PROPULSION LAB</td>
<td>DR. RANTY LIANG</td>
<td>Space Materials S&amp;T</td>
</tr>
<tr>
<td></td>
<td>DR. JOHN SCOTT-MONCK</td>
<td>Space Materials S&amp;T</td>
</tr>
</tbody>
</table>

## LDEF: OBJECTIVES OF SDIO EFFORT

- Identify SDIO data analysis requirements and sample needs
- Set SDIO priorities
- Develop input for NASA - LDEF SIG Chairmen
- Sort requirements by benefiting program offices
PRIORITIES

I. CRITICAL TO SDIO SYSTEMS AND TECHNOLOGY PROGRAMS.

II. ESSENTIAL TO SDIO DATA GENERATION AND GROUND-TO-SPACE CORRELATIONS.

III. SUPPORTS GENERIC RESEARCH NEEDS.

SDIO PARTICIPATION IN NASA-LDEF ORGANIZATION CHART

SDIO
(LTC YESENSKY/DR. YOUNG)

SDIO COORDINATOR
(R. TURNER)

NASA-HQ
(J. AMBRUS)

LARC PROJECT
(W. KINARD/B. LEIGHTNER/J. JONES)

MATERIALS SIG
(B. STEIN)

SYSTEMS SIG
(J. MASON)

M&D SIG
(W. KINARD)

RADIATION SIG
(T. PARNELL)

SDIO REP
(C. BERSCH)/IDA

SDIO REP
(R. MERCER/SDIO)

SDIO REP
(LT D. ATKINSON/WL)

SDIO REP
(J. RITTER/NRL)

SDI SYSTEMS REQUIREMENTS
(L. McCreight/AEROSPACE)
- SBI
- BP
- SSTS
- NPB

SDI TECHNOLOGY REQUIREMENTS
- Materials (W. Ward/WRDC)
- Power (T. Wheeler/WJSA)
- Survivability (Lt D. Atkinson/WL)
- Optics (K. Scott/AEROSPACE)
- Electronics (W. Dudney/USASDC)
- Thermal Management (W. Ward/WRDC)
SDIO PARTICIPATION IN NASA-LDEF RESPONSIBILITIES

SDIO SIG REPRESENTATIVES
- Coordinates NASA-LDEF Requirements/Preparation
- Provides coordinated SDIO requirements to NASA SIG's
- Provides cost estimates
- Prioritize requirements

SDIO SDI SYSTEMS AND TECHNOLOGY REPRESENTATIVES
- Reviews experiments/LDEF spacecraft data opportunities
- Provides SDIO SIG representatives with requirements for assigned area
  - Data needs per NASA format
  - Sample needs
  - Estimate costs

SDIO - LDEF COORDINATOR
- POC for NASA LDEF project
- Shepherds action timeline
- Supports coordination of SDIO activities, resolution of issues

STATUS OF SDIO PLANNING EFFORT

- SDIO REQUIREMENTS DEFINED
- MATERIALS OR SYSTEMS ANALYSES AND PRIORITIES ARE IDENTIFIED BY LDEF EXPERIMENT
- SAMPLE NEEDS AND TEST SEQUENCES ARE IDENTIFIED BY LDEF-EXP
- FURTHER COORDINATION NEEDS ARE IDENTIFIED BY LDEF EXPERIMENT
- NEED TO IDENTIFY IMPLEMENTATION APPROACHES
  - DATA ANALYSES
  - SAMPLE COLLECTION

110
### LEVEL III SUMMARY OF TYPE OF MATERIALS OR SYSTEMS REQUESTED AND TESTS REQUIRED

<table>
<thead>
<tr>
<th>SDIO CODE</th>
<th>TRAY #</th>
<th>TYPE OF MAT/SYS NAME/COMPANY</th>
<th>PRIORITY</th>
<th>PRIORITIZED 1 THRU n TEST/SAMPLE REQUIREMENT</th>
<th>ADDITIONAL INFORMATION NEEDED</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYS 04</td>
<td>M0006</td>
<td>Vacuum canister</td>
<td>I</td>
<td>Stiction, lube condit, migration</td>
<td>Dry lubricant specifications</td>
</tr>
<tr>
<td>SYS 05</td>
<td>M0006</td>
<td>Detectors &amp; shielding mat.</td>
<td>II</td>
<td>Performance (13)</td>
<td>Preflight data, control samples</td>
</tr>
<tr>
<td>SYS 06</td>
<td>M0006</td>
<td>Mechanisms</td>
<td>I</td>
<td>Contamination degradation (16)</td>
<td></td>
</tr>
<tr>
<td>SYS 07</td>
<td>M0006</td>
<td>Clocks, opt. filters, substs</td>
<td></td>
<td>Neutral particle beam surv.</td>
<td>Preflight, post-flight test data</td>
</tr>
<tr>
<td>SYS 07</td>
<td>M0006</td>
<td>Thermal paints, thermocplis</td>
<td></td>
<td>AGT and laser survivability</td>
<td>Preflight, post-flight test data</td>
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<tr>
<td>DEB01</td>
<td>M0006</td>
<td>Mirrors-fused Si &amp; Be</td>
<td>I</td>
<td>Evaluate Impacts (1)</td>
<td>Orig. Specs., Chars. (1)</td>
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<tr>
<td>MAT 02</td>
<td>M0006</td>
<td>Mirrors-Be</td>
<td>I</td>
<td>Optical Properties / Samples</td>
<td>Collaboration with M0003</td>
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<tr>
<td>MAT 06</td>
<td>M0006</td>
<td>Electro Optics</td>
<td></td>
<td>Optical and T/C Tests (1)</td>
<td>Control Sample Info (1)</td>
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<tr>
<td>MAT 07</td>
<td>M0006</td>
<td>Electronics (9)</td>
<td></td>
<td>Materials degradation data</td>
<td></td>
</tr>
</tbody>
</table>

### LEVEL III NOTES FOR SUMMARY OF TYPE OF MATERIALS OR SYSTEMS REQUESTED AND TESTS REQUIRED

<table>
<thead>
<tr>
<th>SDIO CODE</th>
<th>TRAY #</th>
<th>TYPE OF MAT/SYS NAME/COMPANY</th>
<th>PRIORITY</th>
<th>PRIORITIZED 1 THRU n TEST/SAMPLE REQUIREMENT</th>
<th>ADDITIONAL INFORMATION NEEDED</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAT 06</td>
<td>Note (1)</td>
<td></td>
<td></td>
<td>If not performed by PI, perform the following tests. For more complex tests obtain samples from PI when his prior testing is complete:</td>
<td>If available, obtain control samples corresponding to exposed samples provided by the PI. Where critical tests are performed by PI, review his data and if values or calibrations uncertain, request flight and control samples be submitted to SIG for retest.</td>
</tr>
</tbody>
</table>

- Visual examination under varying lighting conditions
- Contamination collection, analysis, and identification
- Total integrated scatter measurements before and after contamination removal
- Reflectance/transmittance measurements
- Analysis of defects of and causes for:
  - separations
  - flaking
  - peeling
  - other surface anomalies
- Nomarski tests of selected surfaces.
<table>
<thead>
<tr>
<th>LEVEL III</th>
<th>NOTES TO SUMMARY OF TYPE OF MATERIALS OR SYSTEMS REQUESTED AND TESTS REQUIRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIG: DEBRIS</td>
<td></td>
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<tr>
<td>SDIO CODE</td>
<td>TRAY #</td>
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<tr>
<td>Note (1)</td>
<td></td>
</tr>
<tr>
<td>Note (2)</td>
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</tr>
</tbody>
</table>

**ADDITIONAL INFORMATION NEEDED**

- Original specifications and optical characteristics (TIS, BRDF, TMR, etc.), post retrieval optical measurements on control samples

**LIMITATIONS TO THE DEFINITION OF SDIO NEEDS**

- DEPTH OF REQUIREMENTS DEFINITION -- ID LIMITED BY AVAILABLE INFORMATION.
- TYPES OF MATERIALS ARE IDENTIFIED, NOT SPECIFIC SPECIMENS IN MOST CASES
- "ASSUMES" ALL TRAYS WILL BE ANALYZED
- REQUIREMENTS ARE NOT SEPARATED RELATIVE TO WHAT IS BEING DONE BY SIGs AND PIs VERSUS SDIO SPECIFIC NEEDS
- CONFLICTS / OVERLAPS BETWEEN SIGs NOT RESOLVED
- TIMELINESS OF AVAILABILITY OF DATA TO IMPACT SDI SYSTEMS
- INTERESTED IN "LEADING EDGE" SAMPLES OR BEST ALTERNATIVE
## EXPERIMENTS OF INTEREST TO SDIO

<table>
<thead>
<tr>
<th>EXPERIMENT</th>
<th>LOCATION</th>
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<tbody>
<tr>
<td>A0019</td>
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<tr>
<td>A0034</td>
<td>A0038</td>
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<td>A0044</td>
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</tr>
<tr>
<td>A0056</td>
<td>A0076</td>
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<tr>
<td>A0114</td>
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<tr>
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<td>A0135</td>
</tr>
<tr>
<td>A0138</td>
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<tr>
<td>A0187</td>
<td>A0189</td>
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<tr>
<td>A0201</td>
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## EXPERIMENTS OF INTEREST TO SDIO

<table>
<thead>
<tr>
<th>EXPERIMENT</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0019 (D12)</td>
<td>A0023 (various)</td>
</tr>
<tr>
<td>A0034 (C3,C9)</td>
<td>A0038 (various)</td>
</tr>
<tr>
<td>A0044 (E5)</td>
<td>A0054 (B4,D10)</td>
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<tr>
<td>A0056 (B8,G12)</td>
<td>A0076 (F9)</td>
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<tr>
<td>A0114 (C3,C9)</td>
<td>A0133 (H7)</td>
</tr>
<tr>
<td>A0134 (B9)</td>
<td>A0135 (E5)</td>
</tr>
<tr>
<td>A0138 (B3)</td>
<td>A0139 (G8)</td>
</tr>
<tr>
<td>A0147 (B8,G12)</td>
<td>A0171 (A8)</td>
</tr>
<tr>
<td>A0172 (D2,G12)</td>
<td>A0175 (A1,A7)</td>
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<tr>
<td>A0178 (various)</td>
<td>A0180 (D12)</td>
</tr>
<tr>
<td>A0187 (various)</td>
<td>A0189 (D2)</td>
</tr>
<tr>
<td>A0201 (various)</td>
<td></td>
</tr>
</tbody>
</table>
FUTURE DIRECTION AND COORDINATION

- NEED TO INTERACT FURTHER WITH SIGs AND PIs
  - IDENTIFY PLANNED PI TESTS AND ANALYSES
  - IDENTIFY PLANNED SIG TESTS AND ANALYSES
  - IDENTIFY ANY MISMATCHES BETWEEN SDIO AND NASA PLANS

- NEED TO LAYOUT A MUTUALLY AGREEABLE PROCESS FOR INTERACTION

- SOME DETAIL MISSING FOR SOME REQUIREMENTS

IMPLEMENTATION PLAN

- SDI SPACE ENVIRONMENTAL EFFECTS (SEE) PROGRAM MANAGER RESPONSIBLE FOR COORDINATION OF SDI/LDEF ACTIVITIES
  - ESTABLISH SDI/LDEF ADVISORY PANEL (SEE TIWG & SDIO SIG REPS)

- IMPROVE COORDINATION WITH NASA
  - INCREASED PARTICIPATION IN SIG ACTIVITIES
  - HELP IDENTIFY/RESOLVE DATA/SAMPLE QUESTIONS AMONG PIs/SIGs/SDI
    - DUPLICATIONS, CONFLICTS, TEST SEQUENCING, etc.

- COMMUNICATE WITH PIs
  - PI INTERESTS/DATA GENERATION PLANS
  - SDI INTERESTS/DATA AND/OR SAMPLES DESIRED

- ENSURE COOPERATIVE APPROACH
  - MAXIMIZES BENEFITS FROM RESOURCE EXPENDITURES
  - BEST WAY TO PROTECT EVERYONE’S RIGHTS AND INTERESTS
HOW CAN SDI ACQUIRE DESIRED DATA/SAMPLES?

- EXPERIMENTS/SAMPLES BELONG TO PIs
  - TWO KINDS OF DATA: "GENERAL INTEREST" AND "SDI UNIQUE"
    - "GENERAL INTEREST"
      - IS PI PLANNING TO GET IT?
        - IF YES
          - ASSURE COMPATIBILITY OF PIs PLANS WITH "GLOBAL" PLANS
            - KEEP IN TOUCH (THROUGH SIGS)
          - IF NO
            - CAN/WOULD PI GET IT IF ASKED?
              - IF NO
                - WOULD PI AGREE TO LOAN/GIVE A SAMPLE FOR DATA GENERATION
                  - BY SIG/BOEING
                  - BY SOMEONE ELSE (TBD)
                  - PI GETS PUBLICATION RIGHTS
                    - IF YES
                      - KEEP IN TOUCH
                    - IF NO
                      - "????"
        - IF NO
          - KEEP IN TOUCH

HOW CAN SDI ACQUIRE DESIRED DATA/SAMPLES?

- "SDI UNIQUE" DATA (e.g. SURVIVABILITY)
  - REQUEST SAMPLES FROM PIs
    - SUITABLE FOR TESTING
    - MAY NOT BE RETURNED (DEPENDS ON TESTS TO BE PERFORMED)
    - CONTROL SAMPLES MAY BE NEEDED FOR CORRELATION
    - DATA GENERATED MAY NOT BE RELEASED (MAY BE CLASSIFIED)
  - COOPERATIVE EFFORT TO MAXIMIZE DATA WHICH CAN BE OBTAINED FROM UNIQUE LDEF OPPORTUNITY
LONG DURATION EXPOSURE FACILITY

MATERIALS DATA ANALYSIS METHODOLOGY

OVERVIEW

BLAND A. STEIN
NASA - LANGLEY RESEARCH CENTER,
CHAIRMAN, LDEF MSIG

LDEF MATERIALS DATA ANALYSIS WORKSHOP
NASA - KENNEDY SPACE CENTER
FEBRUARY, 1990

LDEF launch
LDEF MATERIALS CHARACTERIZATION OPPORTUNITIES

UNIQUE MATERIALS DATA

• 5.5-year exposure in low Earth orbit
• Well-defined environmental parameters
  - Natural environment
  - Induced environments (e.g.-contamination, debris)
• Large variety of materials in materials experiments, systems experiments, and science experiments

BENEFICIAL MATERIALS DATA

• Design data base for NASA, DoD, and Commercial missions
  - Space Station Freedom
  - In-Space Experiments
  - Global Change Technology Platforms/Experiments
  - SDI systems
  - Communications satellites
  - Concept studies for advanced missions
• Design data for space-based operations
• Verification of space materials environmental degradation models
• Fundamental understanding of space environmental effects
COORDINATION OF LDEF MATERIALS DATA

MATERIALS SPECIAL INVESTIGATION GROUP TASK:

>>> CONSIDER ENTIRE SPACECRAFT AS AN EXPERIMENT<<<

(Synergism: The whole is greater than the sum of its parts)

MSIG APPROACH:

• Provide central data analysis laboratory

• Encourage voluntary contribution of P.I. experiment materials for documentation, mapping, analysis, archival, and/or determination of laboratory-to-laboratory variability

• Specimen requirements
  - 75% of objective can be accomplished with 10mg of sample
  - 95% of objective can be accomplished with 100 - 500mg

• All experimental and analytical data will be shared with contributor

LDEF MATERIALS DATA ANALYSIS WORKSHOP

SESSION 2: MATERIALS DATA ANALYSIS METHODOLOGY DISCUSSIONS
SESSION 3: MATERIALS ANALYSIS, DATA BASE, AND PRESERVATION

OBJECTIVE: Stimulate interest and awareness of the opportunities to expand the LDEF data base through:

• Understanding the potential of data synergism
• Voluntary contribution of materials which:
  were not originally planned to be test specimens or
  were duplicate specimens in the experiment or
  are specimens whose initial experiment objectives have been satisfied

APPROACH: Interactive discussions on analysis methodology

• Characterization
• Surface science
• Atomic oxygen
• Contamination
• Other parameters which define (or obscure) the data
• Specimen preservation and shipment
NASA
LONG DURATION EXPOSURE FACILITY

POLYMERIC MATERIALS
CHARACTERIZATION

PHILIP R. YOUNG
NASA - LANGLEY RESEARCH CENTER
MEMBER, MSIG

LDEF
MATERIALS DATA ANALYSIS
WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
CHARACTERIZATION OPPORTUNITIES

- UNIQUE ENVIRONMENTAL EXPOSURE
- LARGE VARIETY OF MATERIALS
- DIRECT APPLICATION TO CURRENT AND FUTURE SPACE ACTIVITIES
- VERIFICATION OF ENVIRONMENTAL PERFORMANCE MODELS
- FUNDAMENTAL INSIGHTS INTO SPACE ENVIRONMENTAL EFFECTS
POLYIMIDE (KAPTON, PMR-15)
EPOXY (934/5208/3501)
POLYESTER (MYLAR, DACRON)
AROMATIC POLYAMIDE (KEVLAR)
POLYAMIDE (NYLON 6/6, ZYTEL)
POLYSULFONE (P-1700)
POLYCARBONATE (LEXAN)
BISMALEIMIDE (V378A)
ACRYLIC (PLEXIGLASS)
ACETAL (DELRIN)
TEFLON (FEP)
KYNAR (TFE)
VITON (POLYHEXAFLUOROPROPYLENE)
GRAPHITE FIBER (PAN)
PYRRONE

POLYOLEFIN:
POLYETHYLENE
BLACK POLETHYLENE
POLYPROPYLENE
VINYL:
POLYVINYL CHLORIDE
POLYVINYL FLUORIDE (TEDLAR)
POLYVINYLIDENEFLUORIDE
POLYSTYRENE
POLYURETHANE
POLYPARAXYLENE
PHENOLIC
CELLULOSE NITRATE
POLYDIMETHYLISOXANE
SILICONE RUBBER
BUNA N RUBBER
NEOPRENE RUBBER
WHAT ELSE SHOULD WE DO?

- WHAT CAN BE LEARNT ABOUT SPACE ENVIRONMENTAL EFFECTS THAT HAS LASTING VALUE?
- WHAT "GOOD" SCIENCE CAN WE DO?
- WHAT ADDITIONAL WORK SHOULD BE PERFORMED TO ASSURE THAT THE "CORRECT" SCIENCE IS BEING DONE?
- WHAT IS THE "BEST" ANALYTICAL CHARACTERIZATION PLAN?

CHARACTERIZATION OF LDEF MATERIALS

OBJECTIVE: STIMULATE INTEREST AND AWARENESS OF OPPORTUNITY TO EXPAND THE LDEF DATA BASE BY CONSIDERING THE ENTIRE SPACECRAFT AS AN EXPERIMENT.

APPROACH: PRESENT DISCUSSIONS ON CHEMICAL CHARACTERIZATION, SURFACE SCIENCE, ATOMIC OXYGEN, CONTAMINATION, AND OTHER PARAMETERS WHICH DEFINE (OR OBSCURE) THE INFORMATION OF INTEREST.
OUTLINE

- RESPONSE OF POLYMERIC MATERIALS TO SPACE ENVIRONMENT
- ANALYTICAL CHARACTERIZATION
  - MOLECULAR WEIGHT
  - CHROMATOGRAPHY
  - DIFFUSE REFLECTANCE-FTIR
  - THERMAL ANALYSIS
  - MODEL COMPOUNDS

- RECOMMENDED CHARACTERIZATION PLAN

ANALYTICAL CHARACTERIZATION

MUST FOCUS ON

- DEVELOPMENT OF NEW AND IMPROVED MATERIALS
- THE LONG-LIFE CERTIFICATION OF SELECTED MATERIALS
- FUNDAMENTAL INFORMATION AT THE MOLECULAR LEVEL
  - STRONG AND WEAK CHEMICAL LINKS
  - IMPROVEMENTS TO MOLECULAR STRUCTURE
  - DEGRADATION MECHANISMS
CHARACTERIZE RESPONSE OF POLYMERIC MATERIALS TO LDEF ENVIRONMENT

- ATOMIC OXYGEN
- THERMAL CYCLING
- ULTRAVIOLET RADIATION
- IONIZING RADIATION ($e^- p^+$)
- COSMIC RADIATION
- METEOROID AND DEBRIS
- VACUUM
- SYNERGISTIC EFFECTS

### ABSORPTION OF RADIATION

<table>
<thead>
<tr>
<th>Primary processes</th>
<th>Secondary reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial effects:</strong></td>
<td></td>
</tr>
<tr>
<td>$P \rightarrow P^+ + e^-$</td>
<td>Ionization</td>
</tr>
<tr>
<td>$\rightarrow P^+$</td>
<td>Excitation</td>
</tr>
<tr>
<td>$e^- \rightarrow e_{ih}$</td>
<td>Energy loss</td>
</tr>
<tr>
<td>$P^+ + e_{ih} \rightarrow P$</td>
<td>Recombination</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Subsequent effects:</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$P^+ \rightarrow R^+_1 + R^+_2$</td>
<td>Homolytic cleavage</td>
</tr>
<tr>
<td>$P^+ \rightarrow A^+ + B^+$</td>
<td>Heterolytic cleavage</td>
</tr>
<tr>
<td>$P^+ \rightarrow C^+ + D^+$</td>
<td>Decomposition</td>
</tr>
<tr>
<td>$P^+ + P \rightarrow PX + D^+$</td>
<td>Ion-molecule</td>
</tr>
</tbody>
</table>

$R^+ + R^-' H \rightarrow R - H + R^-$  \text{ Abstraction}

$R^+ + R^-' Cl \rightarrow R - Cl + R^-$  \text{ Heterolytic cleavage}

$R^+ + CH_2 = CHR \rightarrow RCH_2 - CHR'$  \text{ Addition}

Decomposition $\rightarrow$ Small molecules

(\text{CO}_2, \text{HCl} ...)

Chain scission and crosslinking

$P$ = Polymer
$R$ = Radical
$A, B, C, D$ = Other molecular species
PHOTOCHEMICAL EFFECTS

ENERGY ABSORBED BY A MOLECULE:

\[ E = h \nu \]
\[ = \frac{hc}{\lambda} \]

\( h \) = PLANCK'S CONSTANT
\( c \) = VELOCITY OF LIGHT
\( \nu \) = FREQUENCY
\( \lambda \) = WAVELENGTH
\( N \) = AVAGADRO'S NUMBER

CONVERT MOLECULES TO MOLES:

\[ E = \frac{Nhc}{\lambda} \]

IF \( \lambda = 4000\text{"Å}, E = 71.5 \text{ Kcal/mole} \)
IF \( \lambda = 2500\text{"Å}, E = 114.4 \text{ Kcal/mole} \)

TYPICAL BOND ENERGIES (Kcal/mole):

<table>
<thead>
<tr>
<th>Bond</th>
<th>Energy (Kcal/mole)</th>
</tr>
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<tbody>
<tr>
<td>C-H</td>
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</tr>
<tr>
<td>C-C</td>
<td>83</td>
</tr>
<tr>
<td>C=O</td>
<td>179</td>
</tr>
<tr>
<td>C=O</td>
<td>100</td>
</tr>
<tr>
<td>SiO</td>
<td>100</td>
</tr>
<tr>
<td>C-N</td>
<td>70</td>
</tr>
<tr>
<td>C-Cl</td>
<td>79</td>
</tr>
<tr>
<td>C=N</td>
<td>212</td>
</tr>
<tr>
<td>C-O</td>
<td>84</td>
</tr>
<tr>
<td>C-Cl</td>
<td>79</td>
</tr>
<tr>
<td>C=N</td>
<td>212</td>
</tr>
</tbody>
</table>

RESPONSE OF POLYMERS TO EXPOSURE

- SMALL MOLECULE GENERATION
- STRUCTURAL CHANGES
- CROSSLINK
- DEGRADE (CHAIN SCISSION)
INDUCED CHEMICAL CHANGES

1. CROSSLINKING
   - INCREASE IN MOLECULAR WEIGHT
   - MACROSCOPIC NETWORK
   - SOLUBLE FRACTION DECREASES WITH DOSE

2. CHAIN SCISSION
   - DECREASE IN MOLECULAR WEIGHT
   - DECREASE IN TENSILE AND FLEXURAL STRENGTH
   - EMBRITTLEMENT
   - DISSOLUTION RATE INCREASES

3. SMALL MOLECULE PRODUCTS
   - RESULTS FROM SCISSION FOLLOWED BY ABSTRACTION/RECOMBINATION
   - INFORMATION ON DEGRADATION MECHANISMS
   - CRACKING AND CRAZING (CO₂, H₂ ...)
   - CONTAMINATION (HCl ...)

4. STRUCTURAL CHANGES
   - FOLLOWS PRODUCTION OF SMALL MOLECULES AND OTHER REACTIONS
   - CHANGE IN COLOR
   - LOSS OF CRYSTALLINITY
   - MICRO- AND MACROSCOPIC DIMENSIONAL CHANGES

RESPONSE TO RADIATION DEPENDS ON STRUCTURE

VINYL POLYMERS (CROSSLINK) | VINYLIDENE POLYMERS (RUPTURE)
---|---
\[
\text{POLYETHYLENE} \quad \text{POLYSTYRENE} \\
\text{POLYVINYL CHLORIDE} \quad \text{SARAN} \\
\text{KYNAR}
\]
EFFECT OF AROMATICITY ON RADIATION STABILITY

![Graph showing the effect of aromaticity on radiation stability.](image)

VISCOSITY $[\eta]$ vs DOSE IN MEGARADS

INSOL. AT 1000 Mr

INSOL. AT 500 Mr

PEN

PE-HT

PET


EFFECT OF UV RADIATION ON TENSILE STRENGTH OF MYLAR FILM

![Graph showing the effect of UV radiation on tensile strength of Mylar film.](image)

PERCENT ORIGINAL TENSILE STRENGTH vs HOURS IRRADIATION (BH-6 UV LAMP)

ALUMINIZED MYLAR

UNPROTECTED MYLAR

TOO BRITTLE TO TEST

EFFECT OF e\textsuperscript{−} RADIATION ON TENSILE STRENGTH OF PYRRONE FILM

![Graph showing the effect of dose of 3 MeV electrons on yield strength of pyrrone film.]

EFFECT OF SPACE EXPOSURE ON T\textgreek{g} OF POLYMER FILMS

![Graph showing the effect of space exposure on T\textgreek{g} of different polymer films.]

MOLECULAR WEIGHT

SINGLE MOST IMPORTANT PARAMETER GOVERNING PROPERTIES OF POLYMERS

SILICONE OIL  →  SILLY PUTTY  →  SUPER BALL

(VERY LOW Mw)  (LOW Mw, LIGHTLY CROSSLINKED)  (HIGH Mw)

THE ELEMENTAL ANALYSIS OF ALL THREE MATERIALS IS IDENTICAL.

DISTRIBUTION OF MOLECULAR WEIGHT IN A TYPICAL POLYMER

\[ \bar{M}_n = \frac{\sum M_i N_i}{\sum N_i} \]

\[ \bar{M}_w = \frac{\sum M_i^2 N_i}{\sum M_i N_i} \]

\[ \bar{M}_v = \frac{\sum M_i (1 + s) N_i}{\sum (M_i N_i)^{1/s}} \]
**MOLECULAR WEIGHT CHARACTERIZATION**

**LIGHT SCATTERING (LALLS)**

- INCIDENT BEAM
- POLYMER

\[ I(0°) = I(180° - \theta) \]

\[ M_w = f(\text{scattering}) \]

**CHROMATOGRAPHY**

- PUMP
- COLUMN
- INJECTOR

**GPC-LALLS, GPC-DV**

**VISCOMETRY (DV)**

- GPC IN
- \( M_v = f(\text{viscosity}) \)

**OSMOMETRY**

- OSMOTIC PRESSURE (\( \pi \))

\[ \pi V = M_n RT \]
**SELECTED PARAMETERS AS DETERMINED BY SEVERAL TECHNIQUES ON THE SAME POLY(ARYLENE ETHER KETONE) SAMPLE**

<table>
<thead>
<tr>
<th>Technique</th>
<th>$M_n$ (g/mole)</th>
<th>$M_w$ (g/mole)</th>
<th>$M_v$ (g/mole)</th>
<th>$[\eta]$ (dL/g)</th>
<th>$M_w/M_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane Osmometry</td>
<td>31,700 ± 300$^8$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static LALLS</td>
<td></td>
<td>58,000 ± 3000$^2,8$</td>
<td></td>
<td></td>
<td>1.8</td>
</tr>
<tr>
<td>GPC-LALLS$^4,9$</td>
<td>26,200 ± 100</td>
<td>52,400 ± 100</td>
<td></td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>GPC-DV$^5,9$</td>
<td>10,500 ± 600</td>
<td>45,000 ± 2000</td>
<td>38,000 ± 2000</td>
<td>0.52 ± 0.02</td>
<td>4.2</td>
</tr>
<tr>
<td>GPC$^8,9$</td>
<td>19,100 ± 1000</td>
<td>69,200 ± 900</td>
<td></td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td>Solution Viscosity$^7$</td>
<td></td>
<td></td>
<td></td>
<td>0.545 ± 0.002$^8$</td>
<td></td>
</tr>
</tbody>
</table>

$^1$Four concentrations in anisole.
$^2$Seven concentrations in chloroform; $dn/dc = 0.221 ± 0.001$.
$^3$Five concentrations in chloroform; $dn/dc = 0.221 ± 0.001$.
$^4$Two analyses, two concentrations.
$^5$Three analyses, two concentrations.
$^6$Three analyses, two concentrations; relative to polystyrene.
$^7$Five concentrations in chloroform.
$^8$Uncertainty in $y$-axis intercept at zero concentration.
$^9$Chloroform mobile phase.
EFFECT OF PROCESSING ON VARIOUS MOLECULAR WEIGHT PARAMETERS FOR A POLYSULFONE

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>$\bar{M}_w$</th>
<th>$\bar{M}_n$</th>
<th>$\bar{M}_v$</th>
<th>$\bar{M}_w/\bar{M}_n$</th>
<th>$[\eta]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEAT RESIN$^1$</td>
<td>52,300</td>
<td>15,800</td>
<td>45,700</td>
<td>3.31</td>
<td>0.424</td>
</tr>
<tr>
<td>FRACTURED RESIN$^2$</td>
<td>50,600</td>
<td>15,400</td>
<td>44,000</td>
<td>3.29</td>
<td>0.428</td>
</tr>
<tr>
<td>SOLVENT CAST FILM$^2$</td>
<td>50,200</td>
<td>14,900</td>
<td>43,600</td>
<td>3.38</td>
<td>0.427</td>
</tr>
<tr>
<td>SOLVENT COATED PREPREG$^3$</td>
<td>54,900</td>
<td>15,900</td>
<td>46,800</td>
<td>3.44</td>
<td>0.430</td>
</tr>
<tr>
<td>HOT MELT PREPREG$^3$</td>
<td>53,200</td>
<td>16,300</td>
<td>45,500</td>
<td>3.27</td>
<td>0.409</td>
</tr>
<tr>
<td>COMPOSITE$^3$</td>
<td>53,200</td>
<td>15,900</td>
<td>45,700</td>
<td>3.34</td>
<td>0.422</td>
</tr>
<tr>
<td>NEAT RESIN MOLDING$^3$</td>
<td>54,600</td>
<td>16,700</td>
<td>47,500</td>
<td>3.27</td>
<td>0.402</td>
</tr>
</tbody>
</table>

$^1$AVERAGE OF 5 ANALYSES
$^2$AVERAGE OF 2 ANALYSES
$^3$SINGLE ANALYSIS

POLYSULFONE MOLECULAR WEIGHT DISTRIBUTION FOR POLYSULFONE RESIN

![Molecular Weight Distribution Diagram](image-url)
MOLECULAR WEIGHT DISTRIBUTIONS
FOR EIGHT POLY(ARYLENE ETHER KEYTONES)

DISTRIBUTION
DIFFERENTIAL
WEIGHT
FRACTION

SOLUBILITY OF POLYVINYLIDINE FLUORIDE IN DMAc
AS A FUNCTION OF DOSE

ANALYTICAL CHROMATOGRAM OF AP-22

CHROMATOGRAPH: ALC202/R401
COLUMN: PORASIL
SOLVENT: 0.5% MeOH/CH₂Cl₂
RATE: 1.5 ml/min
SIZE: 1 µl (5 µg/µl)
DETECTOR: UV (254 nm)

RADIATION EFFECTS IN T300/934 COMPOSITE

THERMOMECHANICAL ANALYSIS

THERMAL VACUUM WEIGHT LOSS

DIFFUSE REFLECTANCE SPECTROSCOPY

INCIDENT

DIFFUSE COMPONENT

SAMPLE

ELLIPSOIDAL MIRRORS

SAMPLE

SLIDING SAMPLE MOUNT

TO DETECTOR

MIRROR 1

FROM INTERFEROMETER

MIRROR 2

DR-FTIR SPECTRA OF GRAPHITE/POLYSULFONE COMPOSITE
BEFORE AND AFTER RADIATION EXPOSURE

SAMPLE: Celion 6000/P-1700

\[
\text{SAMPLE: Celion 6000/P-1700} \\
\text{CH}_2 - \text{O} - \text{CH}_2
\]

10^5 rads at RT (1 mev e^-)
UNIRRADIATED

2000 1800 1600 1400 1200 1000
WAVENUMBERS, cm^{-1}

ABSORBANCE
DR-FTIR SPECTRA OF 2-Ply T300/5208 Composite Exposed to Space Environment

DR-FTIR SPECTRA OF GRAPHITE/EPOXY COMPOSITE BEFORE AND AFTER THERMAL AGING

SAMPLE: AS/3501-5

WAVENUMBERS, cm⁻¹
SPECTRA OF MODIFIED POLYESTER
BEFORE AND AFTER SPACE EXPOSURE

DR-FTIR SPECTRA OF CELION 6000/LARC-160 COMPOSITE
BEFORE AND AFTER THERMAL AGING
DR-FTIR SPECTRA OF THERMALLY CYCLED PMR-15 COMPOSITE

DR-FTIR SPECTRA OF BIS-NADIMIDE MODEL COMPOUND
EFFECT OF THERMAL AGING ON NADIMIDE MODEL COMPOUND

**ISOTHERMAL WEIGHT LOSS AT 500°F**

- **WEIGHT LOSS, 5.0 PERCENT**
- **TIME, HOURS**

![Graph showing isothermal weight loss at 500°F with a weight loss of 5.0 percent over time.](image)
MOLECULAR LEVEL EFFECTS

[Chemical structure image]

DIMENSIONS

<table>
<thead>
<tr>
<th>ATOM</th>
<th>X</th>
<th>DISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>C — N</td>
<td>-CH₃</td>
<td>17.95 Å</td>
</tr>
<tr>
<td>C — C — O</td>
<td>-CH₃</td>
<td>17.46 Å</td>
</tr>
<tr>
<td>C — N</td>
<td>C = O</td>
<td>19.18 Å</td>
</tr>
</tbody>
</table>

GEOMETRY

<table>
<thead>
<tr>
<th>X</th>
<th>BOND ANGLE</th>
<th>TORSIONAL ANGLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>-CH₃</td>
<td>109.54°</td>
<td>-43.3°</td>
</tr>
<tr>
<td>C = O</td>
<td>120.21°</td>
<td>-35.5°</td>
</tr>
</tbody>
</table>

RECOMMENDED CHEMICAL CHARACTERIZATION

- **SOLUTION PROPERTIES**
  - **HPLC**
  - **GPC**
  - **LALLS/OSMOMETRY/ VISCOSITY**
  - Separates molecular mixtures into individual components
  - Separates large molecules according to size
  - Molecular weight and molecular weight distribution determination

- **SPECTROSCOPY**
  - **MASS**
  - **UV-VIS-NIR**
  - **IR**
  - **MAGNETIC RESONANCE**
  - Identification of molecular species
  - Electronic spectra, chromophore composition, transparency, excited state behavior.
  - Vibrational spectra, chemical structure, conformational, chemical modification.
  - ¹H & ¹³C NMR: chemical structure, tacticity, conformation, chemical modification.
  - ESR: radicals, triplet state structure and behavior.

Detects changes at the molecular level.
RECOMMENDED PHYSICAL CHARACTERIZATION

- THERMAL/ THERMOMECHANICAL
  - DSC - $T_g, T_m, \text{HDT, CRYSSTALLINITY}$
  - TBA - $T_g, T_m, \text{MECHANICAL SPECTRUM}$
  - TMA - CTE, HDT, $T_g, T_m$
  - DMA - $\text{RELAXATIONS, DAMPING COEFFICIENTS, MECHANICAL SPECTRUM}$
  - TGA - VOLATILE PRODUCTS

DETECTS CHANGES IN POLYMER MACROSTRUCTURE.

CHARACTERIZATION PLAN - CONTINUED

ANALYTICAL RESULTS WILL DICTATE DIRECTION OF ADDITIONAL RESEARCH:

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>TECHNIQUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SURFACE CHEMISTRY</td>
<td>ESCA, $\alpha_\delta/E$, EDAX, AUGER</td>
</tr>
<tr>
<td>SURFACE MORPHOLOGY</td>
<td>SEM, STEM</td>
</tr>
<tr>
<td>METAL ION MIGRATION</td>
<td>ATOMIC ABSORPTION, ICP</td>
</tr>
<tr>
<td>SURFACE MOLECULAR AND ATOMIC RESOLUTION</td>
<td>SCANNING TUNNELING MICROSCOPY</td>
</tr>
<tr>
<td>THERMOSET SOLUBLE FRACTION</td>
<td>HPLC</td>
</tr>
<tr>
<td></td>
<td>MASS SPEC/ PYROLYSIS</td>
</tr>
<tr>
<td></td>
<td>GC/ PYROLYSIS</td>
</tr>
</tbody>
</table>

OBJECTIVE: MOLECULAR LEVEL RESPONSE TO ENVIRONMENTAL EXPOSURE.
**CHARACTERIZATION PLAN - THERMOSETS**

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>MEASUREMENT</th>
<th>TECHNIQUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILMS</td>
<td>TRANSPARENCY, ELECTRONIC STRUCTURE</td>
<td>UV-VIS-NIR %T</td>
</tr>
<tr>
<td></td>
<td>MOLECULAR STRUCTURE</td>
<td>%T FTIR, $^1$H $^{13}$C-NMR</td>
</tr>
<tr>
<td>COMPOSITES/</td>
<td>MOLECULAR STRUCTURE</td>
<td>DIFFUSE REFLECTANCE-SOLID STATE NMR</td>
</tr>
<tr>
<td>SOLIDS</td>
<td>DEGRADATION/VOLATILE PRODUCTS</td>
<td>SOLVENT EXTRACTION/TGA</td>
</tr>
<tr>
<td>ALL</td>
<td>$T_g$, CTE, HDT, DEGREE OF CURE ...</td>
<td>DSC/TMA</td>
</tr>
<tr>
<td></td>
<td>ELEMENTAL COMPOSITION</td>
<td>CHNO</td>
</tr>
<tr>
<td></td>
<td>CRYSTALLINITY</td>
<td>X-RAY DIFFRACTION</td>
</tr>
<tr>
<td></td>
<td>SURFACE CONTAMINATION</td>
<td>MASS SPEC/BAKEOUT</td>
</tr>
</tbody>
</table>

**CHARACTERIZATION PLAN - THERMOPLASTICS**

IN ADDITION TO STANDARD THERMOSET ANALYSES:

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>TECHNIQUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROSSLINK DENSITY</td>
<td>GEL FRACTION</td>
</tr>
<tr>
<td>MOLECULAR WEIGHT: $M_n$</td>
<td>MEMBRANE OSMOMETRY</td>
</tr>
<tr>
<td></td>
<td>LOW ANGLE LASER LIGHT SCATTERING (LALLS)</td>
</tr>
<tr>
<td>$M_w$</td>
<td>DIFFERENTIAL VISCOMETRY (DV)</td>
</tr>
<tr>
<td>$M_v$</td>
<td>VISCOMETRY</td>
</tr>
<tr>
<td>[$\eta$]</td>
<td>GPC/LALLS, GPC/DV</td>
</tr>
</tbody>
</table>
### KAPTON

<table>
<thead>
<tr>
<th>ROW: 9(RAM)</th>
<th>3(TRAIL)</th>
<th>6/12(±90°)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Film</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A0134</td>
<td>S1002</td>
<td>S1001</td>
</tr>
<tr>
<td>A0076</td>
<td>M0002</td>
<td>S1001</td>
</tr>
<tr>
<td><strong>Insulation Aluminized</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A0076</td>
<td>M0003</td>
<td>S1003</td>
</tr>
<tr>
<td>S0010</td>
<td>M0002</td>
<td></td>
</tr>
<tr>
<td>M0002</td>
<td>M0003</td>
<td></td>
</tr>
<tr>
<td>M0003</td>
<td>S1001</td>
<td></td>
</tr>
<tr>
<td><strong>Tape Washers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S0069</td>
<td>S1001</td>
<td>A0180</td>
</tr>
</tbody>
</table>

(Also row 10 S0115 at A0178 at 16 locations)

### TEFOLON

<table>
<thead>
<tr>
<th>ROW: 9(RAM)</th>
<th>3(TRAIL)</th>
<th>6/12(90°)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teflon, PTFE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A0076</td>
<td>A0187</td>
<td>A0180</td>
</tr>
<tr>
<td>A0201</td>
<td>A0201</td>
<td>S1001</td>
</tr>
<tr>
<td>S0014</td>
<td>S1002</td>
<td>A0201</td>
</tr>
<tr>
<td><strong>Teflon</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M0003</td>
<td>M0003</td>
<td>M0002</td>
</tr>
<tr>
<td>S0014</td>
<td>A0138</td>
<td>S1001</td>
</tr>
<tr>
<td><strong>Aluminized Silvered</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A0076</td>
<td>(also row 8, A0147 and row 2, A0172)</td>
<td>A0038</td>
</tr>
<tr>
<td><strong>SSM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S0010</td>
<td>(also A0178 at 16 locations)</td>
<td></td>
</tr>
<tr>
<td><strong>Kel F</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S0114</td>
<td>(also space end, A0054)</td>
<td></td>
</tr>
<tr>
<td><strong>FEP AI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FEP</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M0003</td>
<td>M0003</td>
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<tr>
<td>A0134</td>
<td>M0003</td>
<td>S1003</td>
</tr>
<tr>
<td>M0002</td>
<td>M0002</td>
<td></td>
</tr>
<tr>
<td><strong>Viton</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A0134</td>
<td>A0138</td>
<td>A0180</td>
</tr>
<tr>
<td><strong>Tedlar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M0003</td>
<td>M0003</td>
<td>S1001</td>
</tr>
<tr>
<td><strong>PVF</strong></td>
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<td></td>
</tr>
<tr>
<td>A0134</td>
<td>S1002</td>
<td></td>
</tr>
<tr>
<td><strong>PVF₂</strong></td>
<td></td>
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### THERMOSETS

<table>
<thead>
<tr>
<th>Material</th>
<th>Code1</th>
<th>Code2</th>
<th>Code3</th>
<th>Code4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMR-15</td>
<td>A0175</td>
<td>M0003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LARC-160</td>
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</tr>
<tr>
<td>Kapton</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Vespel</td>
<td>S1002</td>
<td>S0014</td>
<td>M0003</td>
<td></td>
</tr>
<tr>
<td>Gr/5208</td>
<td>A0019</td>
<td></td>
<td>A0134</td>
<td>A0180</td>
</tr>
<tr>
<td>Gr/3501-6</td>
<td>M0003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr/934</td>
<td>A0180</td>
<td>A0171</td>
<td>A0134</td>
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</tr>
<tr>
<td>Pyrrone</td>
<td>A0134</td>
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</tbody>
</table>

**already noted**

### THERMOPLASTICS

<table>
<thead>
<tr>
<th>Material</th>
<th>Code1</th>
<th>Code2</th>
<th>Code3</th>
<th>Code4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mylar, film</td>
<td>A0139A</td>
<td>P0003</td>
<td>A0023</td>
<td>A0187</td>
</tr>
<tr>
<td>velcro</td>
<td>P0004</td>
<td>M0002</td>
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<td>Polysulfone, film</td>
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<td>composite</td>
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<td>M0002</td>
<td>A0015</td>
<td>M0003</td>
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<td></td>
<td>A0178 at 16 locations</td>
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<td>Teflon</td>
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## Desirable Samples from Materials Experiments

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<th>Request</th>
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<tr>
<td>1. A0019 D12</td>
<td>5208/T300</td>
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<tr>
<td>2. A0175 Al &amp; A7</td>
<td>LARC-160 PMR-15 934 F178</td>
<td>Primarily, mechanical properties</td>
<td>Broken samples</td>
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<td>3. A0180 12</td>
<td>Epoxy, Kevlar Kapton</td>
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<td>4. S1006 E6 E6</td>
<td>Nylons, PE Mylar, Kevlar</td>
<td>Space exposure of balloon materials</td>
<td>Redundant films</td>
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<tr>
<td>5. S1003 E6</td>
<td>FEP, Kapton</td>
<td>α_2/c (no chemistry)</td>
<td>Buttons after testing</td>
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<tr>
<td>6. S1001 F12/H1</td>
<td>Kapton, Acrylics Urethanes, Silicones Epoxy, Polycarbonate PVF, Teflon</td>
<td>Heat pipe, plus films added for A0 exposure</td>
<td>Any redundant films</td>
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### Other General Requests

- **Polyethylene**
- **Poly(Ethylene Terephthalate)**
- **Polystyrene**
- **A0178 - Duplicate 16 times on vehicle**
## PAINTS

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<td>9924 (PRIMER)</td>
<td>S-13G</td>
<td>3M NEXTEL</td>
<td>ASTRAL P123</td>
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<td>A-276 (WHITE)</td>
<td>S-13GLO</td>
<td>CATALAC</td>
<td>DuPONT 46971</td>
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<td>DC 92-007</td>
<td>IITRI D-111</td>
<td>Zn CHROMATE</td>
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<td>Z-202 (WHITE)</td>
<td>YB-71</td>
<td>3M 101-C10</td>
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<td>Z-302 (WHITE)</td>
<td>Zn O-TITINATE</td>
<td>3M CR-110</td>
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<td>II-AS71 (RED)</td>
<td>MS-74</td>
<td>3M 401-C10</td>
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<td>9951 (THINNER)</td>
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## ADHESIVES

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<td>EPON 828 (SHELL)</td>
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<td>EPI BOND (FURANE)</td>
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<td>WASATCH UH-3119</td>
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SUMMARY

- UNIQUE CHARACTERIZATION OPPORTUNITY
- MOLECULAR LEVEL INFORMATION ON POLYMERIC BEHAVIOR
- SAMPLE ARCHIVAL/DOCUMENTATION IS CRITICAL
- VOLUNTARY PARTICIPATION/CONTRIBUTION IS ENCOURAGED
NASA
LONG DURATION EXPOSURE FACILITY

SURFACE CHEMISTRY

JAMES WIGHTMAN
VIRGINIA TECH
MEMBER, LDEF ADVISORY COMMITTEE

LDEF
MATERIALS DATA ANALYSIS
WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
SURFACE ANALYSIS USING X-RAY PHOTOELECTRON SPECTROSCOPY (XPS OR ESCA)

J. P. WIGHTMAN
CHEMISTRY DEPARTMENT
VIRGINIA TECH
BLACKSBURG, VA  24061

PHONE   703-231-5854
FAX      703-231-3971

LDEF WORKSHOP
NASA - KSC
FEBRUARY 14, 1990
ACKNOWLEDGEMENTS

Alcoa  Boeing  Elf Aquitaine  Johnson Wax
NASA-LaRC (6)  NSF  Tioxide Intl

Virginia

Mr. P. Commerçon  Dr. M. E. Counts
Dr. T. A. DeVilbiss  Dr. J. G. Dillard
Dr. D. Dwight  Dr. J. Filbey-Arney
Dr. J. O. Glanville  Dr. J. S. Jen
Dr. Y. Kang  Dr. C. U. Ko
Mr. T. Lin  Dr. D. J. Moyer
Ms. K. Phillips  Ms. K. A. Sanderson
Dr. R. Seals  Dr. E. J. Siochi
Dr. J. A. Skiles  Mr. H. F. Webster

OUTLINE

INTRODUCTION

SEM
△ EXAMPLES

XPS or ESCA

△ PRINCIPLES
△ EXPERIMENTAL
△ APPLICATIONS

Metals
Particles/Fibers
Polymers/Composites

IRS

△ EXPERIMENTAL
△ APPLICATIONS

Polymers/Composites

SUMMARY
### Key to acronyms and entries

<table>
<thead>
<tr>
<th>Acronym</th>
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<td>AEAPS</td>
<td>Auger-electron appearance-potential spectroscopy</td>
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<td>AEM</td>
<td>Auger-electron microscopy</td>
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<tr>
<td>AFS</td>
<td>Auger-electron spectroscopy</td>
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<tr>
<td>AIM</td>
<td>Adsorption isotherm measurements</td>
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<tr>
<td>APS</td>
<td>Appearance-potential spectroscopy</td>
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<tr>
<td>ASW</td>
<td>Acoustic surface-wave measurements</td>
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<tr>
<td>ATR</td>
<td>Attenuated total reflectance</td>
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<tr>
<td>BIS</td>
<td>Berekstrahung isochromat spectroscopy</td>
</tr>
<tr>
<td>CIS</td>
<td>Characteristic isochromat spectroscopy</td>
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<td>CL</td>
<td>Cathodoluminescence</td>
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<tr>
<td>COL</td>
<td>Cathodoluminescence, IR, visible, UV, X-ray, and g-ray absorption spectroscopy</td>
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<tr>
<td>CPD</td>
<td>Contact potential difference (work function measurements)</td>
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<td>DAPS</td>
<td>Disappearance-potential spectroscopy</td>
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<td>Disappearance-potential spectroscopy</td>
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<tr>
<td>ELD</td>
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<td>ESDD</td>
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<td>Laser microprobe</td>
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<td>MBRS</td>
<td>Molecular-beam reactive scattering</td>
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<td>MOSS</td>
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<td>NIRS</td>
<td>Neutral impact radiation spectroscopy</td>
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<td>Nuclear magnetic resonance</td>
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<td>NRS</td>
<td>Nuclear reaction spectrometry</td>
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<td>PD</td>
<td>Photo-desorption</td>
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<tr>
<td>PEM</td>
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<td>PES</td>
<td>Photoelectron spectrometry</td>
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<tr>
<td>SES</td>
<td>Rutherford back scattering spectroscopy</td>
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<td>RHEED</td>
<td>Reflection high-energy electron diffraction</td>
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<td>SC</td>
<td>Surface capacitance</td>
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<td>SDDM</td>
<td>Scanning desorption molecular microscopy</td>
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<td>SEM</td>
<td>Secondary electron emission</td>
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<td>SI</td>
<td>Surface extended X-ray absorption fine structure</td>
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<td>Secondary ion imaging mass spectrometry</td>
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<td>Secondary ion mass spectrometry</td>
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**PARTIAL LISTING OF SURFACE ANALYSIS TECHNIQUES—C. J. POWELL.**

**ORIGINAL PAGE IS OF POOR QUALITY**
SEM PHOTOMICROGRAPHS OF CARBON FIBER/POLYIMIDE MATRIX COMPOSITES—MOYER & WIGHTMAN.
SEM PHOTOS OF PRETREATED SURFACES

Oxygen Plasma 1 min 100,000X  Oxygen Plasma 5 min 100,000X

Oxygen Plasma 10 min 100,000X  Oxygen Plasma 20 min 100,000X

SEM PHOTOMICROGRAPHS OF CARBON FIBER/POLYIMIDE MATRIX COMPOSITES—MOYER & WIGHTMAN.
SEM PHOTOMICROGRAPHS OF KAPTON BEFORE AND AFTER EXPOSURE TO ATOMIC OXYGEN—STS 8—McGRATH.

SEM PHOTOMICROGRAPHS OF POLYIMIDE—SILOXANE BEFORE AND AFTER EXPOSURE TO ATOMIC OXYGEN—STS 8—McGRATH.
SCHEMATIC DIAGRAMS OF THE FOUR WORKHORSE SURFACE ANALYTICAL TECHNIQUES—D. M. HERCULES/J. S. JEN.

ENERGY LEVEL DIAGRAM FOR X-RAY PHOTOELECTRON SPECTROSCOPY (XPS)—D. M. HERCULES.

Electronic Relaxation Processes for Atom with 1s Vacancy
- Hercules
SCHEMATIC DIAGRAM FOR XPS TECHNIQUE—DuPONT.

SCHEMATIC DIAGRAM OF XPS SPECTROMETER—DuPONT.

ORIGINAL PAGE IS OF POOR QUALITY
Figure 8 Wide scan XPS spectrum of Sample F1001.


WIDE SCAN XPS SPECTRUM OF CESIUM DOPED TUNGSTEN FILAMENT—JEN & WIGHTMAN.
Narrow scan ESCA spectrum of W in Sample #1001.

NARROW SCAN XPS SPECTRUM OF THE TUNGSTEN 4F REGION—JEN & WIGHTMAN.

ORIGINAL PAGE IS OF POOR QUALITY
XPS ANALYSIS OF CHROMIC ACID ANODIZED TITANIUM 6-4 (Ti 6-4) ALLOY—FILBEY & WIGHTMAN.

AUGER ELECTRON SPECTROSCOPY (AES) SURVEY SCAN OF PRETREATED Ti 6-4 ADHERENDS—DITCHEK et al.
AES DEPTH PROFILE ANALYSIS OF CHROMIC ACID ANODIZED Ti 6-4 ALLOY—FILBEY & WIGHTMAN.
AES DEPTH PROFILE ANALYSIS OF ACID ETCHED Ti 6-4 ALLOY—FILBEY & WIGHTMAN.
## ATOMIC COMPOSITION OF ANODIZED Ti 6-4 SAMPLES

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<td>#1</td>
<td>#2</td>
<td>#3</td>
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<tr>
<td>F 1s</td>
<td>1.2</td>
<td>0.4</td>
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<tr>
<td>O 1s</td>
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<td>23.6</td>
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<tr>
<td>N 1s</td>
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<td>C 1s</td>
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<td>Cl 2p</td>
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*NSP - No significant peak

---

XPS ANALYSIS OF UNBONDED (#1) AND FAILED T-PEEL SAMPLE (#2 & #3) OF Ti 6-4 ALLOY BONDED WITH EPOXY—MARCEAU, SKILES & WIGHTMAN.
XPS ANALYSIS OF DEGREASED AND FAILED LAP SHEAR SAMPLE (METAL AND ADHESIVE SIDES) OF GALVANIZED STEEL BONDED WITH EPOXY—COMMERÇON & WIGHTMAN.
AES SURVEY (TOP) AND DEPTH PROFILE ANALYSIS OF GALVANIZED STEEL SUBSTRATE PRIOR TO BONDING—COMMERÇON & WIGHTMAN.
AES SURVEY (TOP) AND DEPTH PROFILE ANALYSIS OF ADHESIVE SIDE OF GALVANIZED STEEL BONDED WITH EPOXY FOLLOWING LAP SHEAR FAILURE—COMMERÇON & WIGHTMAN.
AES SURVEY (TOP) AND DEPTH PROFILE ANALYSIS OF METAL SIDE OF GALVANIZED STEEL BONDED WITH EPOXY FOLLOWING LAP SHEAR FAILURE—COMMERÇON & WIGHTMAN.

ORIGINAL PAGE IS OF POOR QUALITY
DIAGRAMS SHOWING LOCUS OF FAILURE FOR THREE GALVANIZED STEEL (GH, MS, A527) BONDED WITH EPOXY—COMMERÇON & WIGHTMAN.

SEM PHOTOMICROGRAPH OF SHUTTLE EXHAUST PARTICLES COLLECTED BY AIRCRAFT ON A NUCLEOPORE FILTER—COFER & WIGHTMAN.
Al 2p Photopeak—NASA 75-A-20—Raw Data and Deconvoluted Components

Al 2p Photopeak—NASA 75-A-47—Raw Data

Al 2p Photopeak—NASA 75-A-47—Raw Data and Deconvoluted Components

XPS CURVE-FITTED ALUMINUM 2P PHOTOTEAKS OF SHUTTLE EXHAUST PARTICLES—COFER & WIGHTMAN.
SEM PHOTOMICROGRAPHS OF MOUNT ST. HELENS (MSH) ASH—KANG & WIGHTMAN.
XPS (ESCA) ANALYSIS OF MSH ASH—KANG & WIGHTMAN.

WETTING OF COAL—GLANVILLE & WIGHTMAN.
XPS CURVE FITTED CARBON 1S PHOTOPEAKS OF COAL HEATED TO DIFFERENT TEMPERATURES IN AIR—PHILLIPS & WIGHTMAN.

OXYGEN/CARBON RATIO OF COAL DETERMINED BY XPS (ESCA) AS A FUNCTION OF PRETREATMENT TEMPERATURE—PHILLIPS & WIGHTMAN.
XPS ANALYSIS OF COMMERCIALLY AVAILABLE CARBON FIBERS—DeVILBISS & WIGHTMAN.

XPS WIDE SCAN SPECTRUM OF NITROCELLULOSE LACQUER—WEBSTER & WIGHTMAN.
XPS CURVE FITTED CARBON 1S PHOTOPEAKS OF
POLYETHYLENETEREPHTHALATE—DWIGHT, McGRATH & WIGHTMAN.

XPS CURVE FITTED CARBON 1S AND OXYGEN 1S PHOTOPEAKS FOR
POLYMETHYL METHACRYLATE—WEBSTER & WIGHTMAN.
XPS SPECTRA OF METALLIZED KATPON
TOP—CHROMIUM AND ALUMINUM PHOTOPeAKS ON CHROMIUM SIDE
BOTTOM—CHROMIUM AND ALUMINUM PHOTOPeAKS ON ALUMINUM SIDE
—WIGHTMAN.

ORIGINAL PAGE IS OF POOR QUALITY.
CARBON 1S AND SULFUR 2P XPS PHOTOPEAKS FOR POLYSULFONE (PSF) FILM (TOP SPECTRA) AND PSF FILM SPUTTERED WITH ARGON (NEXT SPECTRA)—KO & WIGHTMAN.

ORIGINAL PAGE IS OF POOR QUALITY
SCHEMATIC DIAGRAM FOR ANGLE DEPENDENT XPS STUDIES—WEBSTER.

ESCA ANALYSIS OF POLYMER FILMS

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<td>90°</td>
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<td>0.997</td>
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<td>90°</td>
<td>0.002</td>
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<td>0.998</td>
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<td>EXPOSED</td>
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<td>90°</td>
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<td>0.972</td>
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<td>11°</td>
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XPS (ESCA) ANALYSIS OF POLYOLEFIN FILMS BEFORE AND AFTER EXPOSURE TO OXYGEN PLASMA—WIGHTMAN.
SILICON 2P AND SULFUR 2P XPS PHOTOPEAKS IN SILOXANE CONTAINING POLYMER—LIN, McGrath & Wightman.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>C/O</th>
<th>C/F</th>
<th>C/S</th>
<th>C/Al</th>
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<tbody>
<tr>
<td>NYEXAR</td>
<td>6.8</td>
<td>1.2</td>
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<td>7.1</td>
<td>1.4</td>
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<td>TEFLON</td>
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<td>TFE-3A-0.2</td>
<td>13.3</td>
<td>1.0</td>
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<td>-</td>
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<tr>
<td>POLYSULFONE</td>
<td>6.3</td>
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<td>27.0</td>
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<td>PSF-9A-0.2</td>
<td>6.0</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>PMMA-3B-0.2</td>
<td>3.5</td>
<td>-</td>
<td>-</td>
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<tr>
<td>CONTROL</td>
<td>1.2</td>
<td>-</td>
<td>2.6</td>
<td>4.3</td>
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<tr>
<td>C-5-0.2</td>
<td>1.2</td>
<td>-</td>
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</table>

XPS RATIOS BEFORE [POLYMER NAME ONLY] AND AFTER [NUMBER DESIGNATION] ROAD EXPOSURE OF COATED PLATES MOUNTED ON AUTO—SIOCHI & WIGHTMAN.
SILICONE/FLUORINE RATIO AS DETERMINED BY XPS FOR SILICONE OIL MIGRATION ACROSS POLYMER SUBSTRATE—WEBSTER & WIGHTMAN.
ESCA SPECTRA OF C1s PHOTOPEAKS OF OXYGEN PLASMA PRETREATED COMPOSITES

XPS (ESCA) RESULTS OF OXYGEN PLASMA TREATED COMPOSITES—MOYER & WIGHTMAN.

ORIGINAL PAGE IS OF POOR QUALITY
ESCA RESULTS OF OXYGEN PLASMA PRETREATED COMPOSITES

XPS (ESCA) SPECTRA OF CARBON 1S PHOTOPAKS OF OXYGEN PLASMA TREATED COMPOSITES—MOYER & WIGHTMAN.
(a) ATR - IRE
(b) specular - multiple reflections
(c) specular - single reflection
(d) specular - grazing angle

ELLIPSOIDAL MIRRORS
SAMPLE
MOVABLE
SAMPLE
MOUNT
FROM
INTERFEROMETER
MIRROR 1
MIRROR 2
TO
DETECTOR

(e) diffuse reflectance

SRS attachments.

DIAGRAMS OF VARIOUS REFLECTANCE INFRARED ACCESSORIES—HONEYCUTT, WEBSTER, YOUNG AND WIGHTMAN.
Reflectance infrared spectrum of Sample Imp3-516.

PEAK ASSIGNMENTS OF STRIPS OF FRACTURE SURFACES

\[ \nu (\text{cm}^{-1}) \quad \text{Assignment} \]

580 \quad \text{SAH}^*

700 \quad \text{SAH}

735 \quad \text{C-H rock}

840 \quad \text{SAH}

920 \quad \text{SAH}

970 \quad \text{SAH}

1035 \quad \text{SAH}

1230 \quad \text{SAH}, \text{SAH}

1270 \quad \nu_2 \text{C-O}

1370 \quad \nu_1 \text{N-H}

1730 \quad \text{O-CHE}_2, \nu_2 \text{C-O}

3000 \quad \text{C-H stretch}

*SAH - skeletal aromatic rock

Reflectance IR spectrum of failed Titanium Lap Shear Sample bonded with Polyimide Adhesive—Counts & Wightman.
REFLECTANCE IR SPECTRA OF UNEXPOSED (TOP) AND ROAD EXPOSED (BOTTOM) FLUOROPOLYMER COATED PLATES—SIOCHI & WIGHTMAN.
REFLECTANCE IR SPECTRA OF TWO THICKNESSES OF POLYMETHYL METHACRYLATE ON CHROME STEEL—WEBSTER & WIGHTMAN.
170Å POLYSULFONE FILM - BEFORE EXPOSURE

AFTER EXPOSURE - ~100Å

DIFFERENCE SPECTRA

REFLECTANCE IR SPECTRA OF POLYSULFONE FILMS BEFORE AND AFTER EXPOSURE TO OXYGEN PLASMA—WEBSTER & WIGHTMAN.
SUMMARY

XPS (ESCA) is a sensitive surface analytical technique par excellence giving atomic composition. The technique

△ is moderately fast
△ is sample forgiving
△ has good sensitivity for all elements
△ does discriminate between valence states
△ does minimal sample damage

Auger electron spectroscopy is a useful ancillary technique for non-polymeric substrates giving depth profiles

Infrared spectroscopy is another complementary technique for polymer substrates giving group identification
NASA
LONG DURATION EXPOSURE FACILITY

ATOMIC OXYGEN

BRUCE A. BANKS
NASA - LEWIS RESEARCH CENTER
MEMBER, MSIG

LDEF
MATERIALS DATA ANALYSIS
WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990

PRECEDING PAGE BLANK NOT FILMED
ATOMIC OXYGEN INTERACTION WITH MATERIALS ON LDEF

Bruce A. Banks
NASA Lewis Research Center
(216) 433-2308 FTS 297-2308

LOW EARTH ORBITAL ENVIRONMENT

![Graph showing the number density of various gases vs. altitude.](image)
LDEF (Long Duration Exposure Facility) Atomic Oxygen Fluence on Forward-Facing Surfaces

100 250
Od
E
E
O
x
c
l
9
O
x
0
m
E
0
<
50
10
5
Space Station AO Fluence:
1.5 x 10^9 atoms/cm^2
(Constant Density Flight Profile)

Space Station AO Fluence:
3.6 x 10^22 atoms/cm^2
(Constant Altitude Flight Profile)

EOIM-2 AO Fluence:
3.5 x 10^19 atoms/cm^2
(Forty Hours Exposure at 120 n.m.l.)

LDEF Mission Days (x10^2) from 7/15/88

Atomic Oxygen Fluence x 10^21, atoms/cm^2

Fluence Altitude

Altitude, n. m.

193
LDEF EXPERIMENT INTEGRATION MODEL.

<table>
<thead>
<tr>
<th>Bay Row</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<td>S0109</td>
<td>A0019</td>
<td>A0180</td>
<td>A0038</td>
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</tbody>
</table>

Earth end (G)

Space end (H)
LOW EARTH ORBITAL
ATOMIC OXYGEN ENERGY DISTRIBUTION

Number of Oxygen Atoms of Energy E

Energy E, eV

ATOMIC OXYGEN RAM ENERGY

Altitude, km

Energy, eV
ATOMIC OXYGEN IMPACT VELOCITY RELATIVE TO SPACECRAFT SURFACES
(AT 333 km = 180 nmi)

- Orbital Ram Velocity, \( \vec{v}_o \)  
  - Magnitude and direction varies around orbit due to inclination, latitude and altitude
  - Reduces normal incident ram fluence by 11%
  - Fluence effects cancel to first order on surfaces 90° to ram

- Atmospheric Rotation Velocity, \( \vec{v}_a \)  
  - Magnitude and direction varies around orbit due to inclination, latitude and altitude
  - Reduces normal incident ram fluence by 5.6%

- Random Maxwellian Thermal Velocity, \( \vec{v}_T \)  
  - Maxwellian tail allows atomic oxygen impact on surfaces >90° to ram
  - Average value is 0.41 km/sec

- Total Impact Velocity, \( \vec{v}_* \) = \( \vec{v}_o \) + \( \vec{v}_a \) + \( \vec{v}_T \)
  - Evidence of atomic oxygen attack on IDEF at 105° to ram

ATOMIC OXYGEN FLUENCE DEPENDENCE ON ARRIVAL ANGLE

\[ \text{Relative Fluence} = \frac{\text{Fluence at } \theta}{\text{Fluence at } 0°} \]

\[ \cos \theta \]

\[ \text{Angle from ram, } \theta, \text{ degrees} \]

\( C-3 \)
CALCULATED ATOMIC OXYGEN FLUENCE BY SPACECRAFT ROW.

<table>
<thead>
<tr>
<th>Bay Row</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Atomic Oxygen fluence, atoms/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A0175</td>
<td>S0001</td>
<td>Grapple</td>
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<td>S0001</td>
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<td>0</td>
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<td>S0001</td>
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<td>5.7 x 10¹⁷</td>
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<td>M0003</td>
<td>S0001</td>
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<td>8.3 x 10²¹</td>
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<td>A0178</td>
<td>S0001</td>
<td>M0003</td>
<td>S0001</td>
<td>A0178</td>
<td>3.9 x 10²¹</td>
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<td>4.0 x 10²¹</td>
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<td>1.4 x 10²¹</td>
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<td>S0109</td>
<td>A0019</td>
<td>A0038</td>
<td>S1001</td>
<td></td>
</tr>
</tbody>
</table>

Ram ➔ 9

Earth end (G)

Space end (H)
ATOMIC OXYGEN SURFACE INTERACTION PROCESSES

ATOMIC OXYGEN REACTION MECHANISMS

ALKANES

\[
\text{RCH}_2\text{CH}_3 + \text{O} \rightarrow \text{R'O} + \text{R'CH}_2\text{CH}_3. \quad \text{recombination/further reaction/fragmentation} \rightarrow \text{volatiles (CO, H}_2\text{O, HCO, C}_{2}\text{H}_4 \text{etc.)}
\]

\[
\text{RCH}_2\text{CH}_2. + \text{OH} \rightarrow 2 \text{RCH}_2\text{CH}_2. + \text{HOH}
\]

ALKENES

\[
\text{R} = \text{C} = \text{C} - \text{H} + \text{OH} \rightarrow 2 \text{R} = \text{C} - \text{C} - \text{H} + \text{HOH}
\]

\[
\text{RCH}_2\text{CH}_2. + \text{OH} \rightarrow \text{RCCH}_2. + \text{H} (\text{volatiles})
\]

\[
\text{RCCH}_2. + \text{H} \rightarrow \text{RCCH}_3. \rightarrow \text{fragmentation (volatiles)}
\]
# Atomic Oxygen Erosion Yields of Various Materials

**Material** | Erosion Yield, \(10^{-24}\) cm\(^3\)/Atom
--- | ---
Kapton H polyimide | 3.0
Mylar polyester | 2.7 - 3.9
Polyethylene | 3.3 - 3.7
Epoxy | 1.7
Polycarbonate | 2.9 - 6.0
Polystyrene | 1.7
Polysulfone | 2.4
Urethane (black, conductive) | 0.3
Silver | 10.5
Carbon | 0.9 - 1.7
Chemglaze Z306 (flat, black) | 0.35
FEP Teflon | 0.037
Aluminum | 0.0
Copper | 0.0
Gold | 0.0
Platinum | 0.0
SiO\(_2\) | 0.0

## Material Thickness Loss
From Oxidation by Atomic Oxygen

<table>
<thead>
<tr>
<th>(\mu m)/mils</th>
<th>Erosion Yield</th>
<th>(cm^3)/atom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fluence, atoms/cm(^2)</strong></td>
<td>(9)</td>
<td>(8 &amp; 10)</td>
</tr>
<tr>
<td>1.05 (\times 10^{22})</td>
<td>9.08 (\times 10^{21})</td>
<td>5.25 (\times 10^{21})</td>
</tr>
</tbody>
</table>
| Polyethylene | 347 / 13.6 | 300 / 11.8 | 173 / 6.8 | 13.6 / 0.54 | 3.3 \(\times 10^{-24}\)
| Kapton polyimide | 315 / 12.4 | 272 / 10.7 | 158 / 6.2 | 12.4 / 0.49 | 3.0 \(\times 10^{-24}\)
| Epoxy | 179 / 7.0 | 154 / 6.1 | 89 / 3.5 | 7.0 / 0.28 | 1.7 \(\times 10^{-24}\)
| Graphite | 125 / 5.0 | 106 / 4.3 | 63 / 2.5 | 4.9 / 0.19 | 1.2 \(\times 10^{-24}\)
| FEP Teflon | 3.9 / 0.15 | 3.4 / 0.13 | 1.9 / 0.08 | 0.15 / 0.01 | 3.7 \(\times 10^{-25}\)
### Erosion Yields of Various Materials Exposed to Atomic Oxygen in Low Earth Orbit

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>EROSION YIELD, $\times 10^{-24}$ cm$^2$/ATOM</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina (150 Å)</td>
<td>0.0</td>
<td>1</td>
</tr>
<tr>
<td>Aluminum-coated Kapton</td>
<td>0.01</td>
<td>2</td>
</tr>
<tr>
<td>Aluminum-coated Kapton</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>&lt; 0.025</td>
<td>3</td>
</tr>
<tr>
<td>Al$_2$O$_3$ (700 Å) on Kapton H</td>
<td>&lt; 0.02</td>
<td>4</td>
</tr>
<tr>
<td>Apiezon greasy 2μm</td>
<td>&gt; 0.625</td>
<td>5</td>
</tr>
<tr>
<td>Aquadag E [graphite in an aqueous binder]</td>
<td>1.23</td>
<td>6</td>
</tr>
<tr>
<td>Carbon</td>
<td>1.2</td>
<td>7, 1, 8, 9</td>
</tr>
<tr>
<td>Carbon (various forms)</td>
<td>0.9 - 1.7</td>
<td>10</td>
</tr>
<tr>
<td>Carbon/Kapton 1000ÅC37</td>
<td>1.5</td>
<td>11</td>
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<tr>
<td>401-C10 (flat black)</td>
<td>0.30</td>
<td>12</td>
</tr>
<tr>
<td>Chromium (123 Å)</td>
<td>partially eroded</td>
<td>14</td>
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<tr>
<td>Chromium (125 Å) on Kapton H</td>
<td>0.006</td>
<td>15, 16</td>
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<tr>
<td>Copper (bulk)</td>
<td>0.0</td>
<td>17</td>
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<tr>
<td>Copper (1,000 Å) on sapphire</td>
<td>0.007</td>
<td>15, 16</td>
</tr>
<tr>
<td>Copper (1,000 Å)</td>
<td>0.0064</td>
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<td>Diamond</td>
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<td>Electrodag 402 (silver in a silicone binder)</td>
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<td>6</td>
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<td>Electrodag 106 (graphite in an epoxy binder)</td>
<td>1.17</td>
<td>6</td>
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<tr>
<td>Epoxy</td>
<td>1.7</td>
<td>10, 16</td>
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<tr>
<td>Fluoropolymers:</td>
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<tr>
<td>FEP Kapton</td>
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<td>10</td>
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<tr>
<td>Kapton F</td>
<td>&lt; 0.05</td>
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<tr>
<td>Teflon, FEP</td>
<td>0.037</td>
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<td>Teflon, FEP</td>
<td>&lt; 0.05</td>
<td>10</td>
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<td>&lt; 0.05</td>
<td>10, 6</td>
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<td>Teflon, FEP and TFE</td>
<td>0.0 and 0.2</td>
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<td>Teflon</td>
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<td>EROSION YIELD, $x 10^{-24}$ cm$^3$/ATOM</td>
<td>REFERENCE</td>
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<tr>
<td>--------------------------------------</td>
<td>----------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Gold (bulk)</td>
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<td>17</td>
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<td>Gold</td>
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<td>20</td>
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<td>Graphite Epoxy:</td>
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<tr>
<td>1034 C</td>
<td>2.1</td>
<td>10</td>
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<td>5208/T300</td>
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<td>10</td>
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<td>GSFC Green</td>
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<td>1</td>
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<tr>
<td>HOS-B75 (bare and preox)</td>
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<td>1, 26</td>
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<tr>
<td>Indium Tin Oxide</td>
<td>0.002</td>
<td>15, 16</td>
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<td>Indium Tin Oxide/Kapton (aluminized)</td>
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<td>2</td>
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<tr>
<td>Iridium Film</td>
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<td>17</td>
</tr>
<tr>
<td>Lead</td>
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<td>1, 26</td>
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<td>Magnesium Fluoride on glass</td>
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<td>Siloxane Polyimide (25% Sx)</td>
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<td>Silver</td>
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<td>Tantalum</td>
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<td>Tedlar (clear)</td>
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<td>Trophet 30 (bare and preox)</td>
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<td>YB-71 (ZOT)</td>
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<tr>
<td>Z302 (glossy black)</td>
<td>3.9</td>
<td>26</td>
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EROSION YIELD TABLE

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8. University of Alabama at Huntsville


11. British Aerospace

12. Whitaker, A. F. LEO atomic oxygen effects on spacecraft materials.

13. Martin Marietta

14. Lewis Research Center


16. Jet Propulsion Laboratory

References


20. Goddard Space Flight Center

21. Johnson Space Center

22. Washington University


25. Aerospace Corporation


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<tr>
<th>Material</th>
<th>Change in Optical Properties due to AO/VO</th>
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<td>Solar Absorptance</td>
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<td>Al2O3</td>
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<td>Al2O3/Al(Le)</td>
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<td>Aluminized FEP Teflon, second surface mirror (0.025 mm thick)</td>
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<td>Al Kapton</td>
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<td>Al Kapton</td>
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<td>Aluminized Kapton, second surface mirror, uncoated (0.050 mm thick)</td>
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<td>Aluminum (150 Λ)</td>
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<td>Aluminum (chronic acid oxidized)</td>
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<td>Black, carbon-filled PTFE impregnated fiberglass (0.127 mm thick)</td>
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### Change in Optical Properties due to A/O

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<tr>
<th>Material</th>
<th>Change in Optical Properties due to A/O</th>
<th>Solar Absorptance</th>
<th>Emittance</th>
<th>Reflectance</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Z302 with RTV-670 overcoat</td>
<td>-0.004</td>
<td>-</td>
<td>0.4</td>
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<td>Z306</td>
<td>0.022</td>
<td>0.0</td>
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<tr>
<td>Z306 (flat black)</td>
<td>0.028</td>
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<tr>
<td>ZB53, glossy yellow with MM41-1104-O overcoat</td>
<td>0.011</td>
<td>-</td>
<td>-</td>
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<td>ZB53, yellow</td>
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<tr>
<td>401 - C10 flat black</td>
<td>0.005</td>
<td>-</td>
<td>-</td>
<td>L</td>
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</table>

**NOTE:**

* More reflective as a result of the exposed Mo substrate.
** Low absolute reflectance (-0.5 to 1%)
*** Contrast in different spectra between STS-8 and control. Possible aging effects on controls.
**** Aging effects similar in STS-8 and control. No exposure effect.
REFERENCES

A. NASA Goddard Space Flight Center

B. NASA Marshall Space Flight Center

C. NASA Langley Research Center

D. Whitaker, Ann F. LEO Atomic Oxygen Effects on Spacecraft Materials.

E. NASA Lewis Research Center

F. NASA Langley Research Center

G. Martin Marietta


ATOMIC OXYGEN TEXTURED FEP TEFON BY DIRECTED BEAM EXPOSURE AT UNIVERSITY OF TORONTO.
ATOMIC OXYGEN IN PLASMA ASHERS.

ATOMIC OXYGEN EXPOSURE BY DIRECTED BEAMS.
MASS LOSS OF FIBERGLASS EPOXY COMPOSITES AND KAPTON AS A FUNCTION OF EFFECTIVE ATOMIC OXYGEN FLUENCE (KAPTON BASED).
ANTICIPATED SURFACE PROFILE FOR THICK ORGANIC LDEF SAMPLES.

THIN POLYMER FILMS (<5 mils)
THIN POLYMER FILMS (<5 mils)
WITH ATOMIC OXYGEN PROTECTIVE COATINGS

[Diagram of thin polymer films with atomic oxygen protective coatings]
ANTICIPATED LDEF SURFACE PROFILES FOR PROTECTED THICK POLYMERS.

ANTICIPATED UNDERCUTTING CAUSED BY SCATTERING FROM BACK SIDE METALLICATION AT DEFECT SITES.
NASA
LONG DURATION EXPOSURE FACILITY

MATERIALS SPECIAL INVESTIGATION GROUP
MATERIALS ANALYSIS

GARY PIPPIN
BOEING AEROSPACE AND ELECTRONICS CO.
MSIG SUPPORT

LDEF
MATERIALS DATA ANALYSIS WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
LONG DURATION EXPOSURE FACILITY MATERIALS DATA ANALYSIS

BOEING MATERIALS TEAM AT KSC DURING DEINTEGRATION PROCESS

Dr. Gary Pippin-Environmental Effects on Materials
Syl Hill-Adhesives, Composites
Roger Bourassa-TCC, Composites, Lubricants, Environmental Effects Modeling
Dr. Johnny Golden-TCC, Paints, Al Anodizing
Russ Crutcher-Particular and Molecular Analysis, Contamination Control
Harry Dursch-Tech Leader Boeing Tasks for SSIG
Bob Roper-Composites, Adhesives, Program Support
GOALS:

TO BE ABLE TO PREDICT THE PERIOD OF TIME A GIVEN MATERIAL WILL SURVIVE IN LEO

TO BE ABLE TO ESTIMATE THE ENGINEERING PERFORMANCE LIFETIME IN LEO OF SPECIFIC MATERIALS

TO UNDERSTAND THE DEGRADATION MECHANISMS IN ORDER TO PRODUCE MATERIALS MORE INHERENTLY RESISTANT TO THE LEO ENVIRONMENT

MSIG KSC WORKSHOP - FEB 1990

Tasks:

- Make Quantitative measurements of the effects of the low earth orbit environment on materials.

- Report results for inclusion into LDEF materials data base
SPECIMEN/SYSTEM ENVIRONMENTAL EXPOSURE

SPECIMEN EXPOSURE DEPENDENT ON LOCATION

12 Sides + 2 ends

Modules with/without lids

"Shadow" effects
  Depth of tray
  Oscillation of spacecraft

"Edge" effects
  Side, front of specimens

Secondary scattering

MSIG KSC WORKSHOP - FEB 1990

Unique Specimens

- One time opportunity

- Procedures selected to maximize information value

- Careful documentation of each step
HARDWARE CONDITION WILL DRIVE INVESTIGATION

COMPARISON- OPTICAL IMAGE SUBTRACTION

QUALITATIVE-TRENDS

QUANTITATIVE-NUMERICAL VALUE

SPECIFIC ITEMS

SILVER BACKED TEFiTON BLANKETS
ALUMINUM PLATES WITH A-276 & Z-306 COPPER GROUNDING STRIPS
COMPOSITES
KAPTON(POLYIMIDES)
"TEFİONS"- MANY VARIETIES
PIECES OF OTHER THERMAL CONTROL BLANKETS
LEXAN, PAINTS, ADHESIVES
FLUORINATED MATERIALS

PAINTS
A276
Z306
S13
YELLOW PAINT ON TRUNNIONS

ALUMINUM, STEEL

KAPTON
POLYCARBONATE(LEXAN)

COMPOSITES

COMPLETE SET ALUMINUM PLATES, TCC DISKS, BOLTS, WASHERS
AT LEAST ONE FROM EACH TRAY LOCATION (TWO PREFERRED)

PHOTODOCUMENT ORIENTATION BEFORE REMOVAL

VARIETY OF MATERIALS WITH COMMON LOCATION DISTRIBUTION

DETAILED OPTICAL AND SURFACE CHARACTERIZATION
SURVEY CONDITION OF TEFLON MATERIALS ON LDEF

DIMENSIONAL CHANGES WHERE POSSIBLE

SURFACE TEXTURE
COLOR-OPTICALS

OUTGASSING, CHEMICAL IDENTITY
IR SPECTRA

COPPER GROUNDING STRIPS
INTACT

WITH PIECE OF THERMAL CONTROL BLANKET ADHESIVELY ATTACHED
COPPER GROUNDING STRIPS
STRUCTURE TO AO178 TRAY

EXPERIMENTAL MEASURE OF ATOMIC OXYGEN FLUX TO EACH ORIENTATION

CONTOUR OF EACH STRIP SHOWS VARIATION
MEASURE THICKNESS, DENSITY, OXIDE SPECIES, OPTICALS
PRESERVE ORIENTATION OF EACH STRIP

OPTICAL PROPERTIES

SURFACE CHEMISTRY
FUNCTIONAL GROUPS
ELEMENTAL ANALYSIS-
OXIDATION STATE
MICROCRACKING
TEXTURE
RECESSION, THICKNESS
BULK PROPERTIES
MECHANICAL
THERMAL
OUTGASSING
# Properties of Interest-Composites

## Non-Experimental Materials

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<thead>
<tr>
<th>Property</th>
<th>Test</th>
<th>Purpose</th>
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<tr>
<td>Mechanical Properties</td>
<td>Tensile strength, modulus</td>
<td>Determine end-of-life structural capability by comparing with specification requirements &amp; historical data</td>
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<td>Compression strength, modulus</td>
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<td>Shear strength</td>
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<tr>
<td>CTE</td>
<td>Quartz tube or laser dilatometer</td>
<td>Determine effects on dimensional stability</td>
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<tr>
<td>Depth effects &amp; microstructure</td>
<td>Chemical/analytical, microscopy</td>
<td>Determine degradation vs depth, extent that UV, AO are self-limiting &amp; thermal cycling effects</td>
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## Experimental Materials

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<td>Depth effects &amp; microstructure</td>
<td>Chemical/analytical, microscopy</td>
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<tr>
<td>CTE</td>
<td>Laser dilatometer</td>
<td>Determine effects of exposure &amp; one-surface degradation</td>
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</table>
LDEF Thermal Control Coatings

- Engineering Properties
  - Thermal Vacuum Stability
  - Optical Characteristics
  - Adhesion
  - Abrasion Resistance

- Basic Properties
  - Chemical Changes
    - Molecular Weight
    - Dehydration
    - Oxidation State
  - Morphological Changes
    - Crystallinity or Phase Changes
    - Defects

THERMAL EMITTANCE
CORRECT TO HEMISPHERICAL

SOLAR ABSORPTANCE

SURFACE TEXTURE-SEM

SURFACE CHEMISTRY
AUGER
REFLECTANCE, IR
ESCA
Physical/Chemical Changes

- Outgassing
- Average molecular weight distributions
- Pyrolysis GC

Examine Surface of Metals For Oxidation

- Aluminum
  Depth - XPS
- Chrome - Plating on trunnions
- Steel - bolts
Insulation Materials

Optical ---- Surface properties

Thermal conductivity

Specific heat

Compressibility/resiliency

Wettability/contact ----- surface roughness, actual area

If PI requests and NASA approves, Boeing will conduct measurements on PI hardware/specimens

Test equipment not available/planned for by PI

Lab to Lab comparison

Results back to PI to publish; also included in LDEF data base
Request to PI's

- Schedule of availability of hardware/specimens
- Commitment from each PI regarding which specimens/hardware will be made available for MSIG analysis

This list is an expression of the interests of the LDEF Special Investigation Groups (SIGs). These groups were established by NASA to maximize the scientific return from the LDEF experiments, in view of LDEF's extended space exposure. At this time, the materials noted above have merely been identified for consideration by the Project. The Principal Investigators' (PIs) cooperation will be solicited in this extended research. Either the PIs could provide samples for analysis to the SIGs, or the PIs could perform the additional research with guidance provided by the SIGs.
MATERIALS OF INTEREST TO MSIG

MSIG CONTACT:  DR. H. GARY PIPPIN  (206)393-3584
EXPERIMENT:  STRUCTURE  NASA

MATERIAL DESCRIPTION
S13/LO, Disk Coatings
Al & SS, Disk plates and fasteners
Cr-Plated Steel, Trunion Pins
Z306, Thermal Control Paint
Cr-Plated Steel, Keel Pin

QUESTIONS

NOTES

DATA BASE

- By Experiment
- By System
  - Quantitative Data From Measurements
  - "Lessons Learned" Text Summaries
  - Recommended Practices
  - Undesirable/Forbidden Practices
  - Relate To Space Environment
NASA
LONG DURATION EXPOSURE FACILITY

MSIG/MAPTIS DATA BASE

JOHN M. DAVIS
NASA - MARSHALL SPACE FLIGHT CENTER
MEMBER, MSIG

LDEF
MATERIALS DATA ANALYSIS
WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
MAPTIS GENERAL INFORMATION

1. MAPTIS is a collection of databases giving information about materials and processes.

2. Databases are relational databases written with the ORACLE Database Management System.

3. MAPTIS is accessible from anywhere by user with an account.

4. MAPTIS is constantly changing – with updates and improvements. Ex. New Graphics Package will be added within one year.

5. New material information is added every day.
MATERIALS & PROCESSES TECHNICAL INFORMATION SYSTEM
METALS PROPERTIES DATABASE

• Alloy Information
  - Density
  - Poisson Ratio
  - Melting Range
  - Alternate Designation
  - UNS Designation
  - Category

• Composition Information
  - Elements
  - Average Percentage
  - Minimum/Maximum Composition

• Specification Data
  - Alloy
  - Condition
  - Form
  - Material Code (MSFC Assigned Easy Reference)
  - Specification Number

• Mechanical Properties
  - Elongation
  - Tensile Strength
  - Bearing Strength
  - Bearing Yield
  - Compressive Strength
  - Bend Radius
  - Fatigue Strength
  - Hardness
  - Hydrogen Embrittlement

• General Comments on Properties
  - Corrosion Resistance
  - Formability
  - Heat Treatment & Stress Relief by Plastic Stretching
  - Machineability
  - Surface Treatment
  - Weldability

• Much More..........................................................
MATERIALS & PROCESSES TECHNICAL INFORMATION SYSTEM

NONMETALS PROPERTIES DATABASE

- Identification Information
  - Designation
  - Manufacturer
  - Color
  - Description

- Chemical Classification
  - Composition
  - Category
  - Compound
  - Generic ID
  - Material Code
  - Process Method
  - Specifications (MIL Spec., etc)

- Component Parts Information
  - Designation
  - Description
  - Generic Type
  - Form
  - Mix Ratio

- Cure Information
  - Cure Cycle
  - Temperature
  - Time

- Material Properties
  - Use Temperature Range
  - Shelf Life
  - Compressive Strength
  - Shear Strength
  - Viscosity

- ETC.........................................................
MATERIAL SELECTION HANDBOOK DATABASE

- Material Information
  - Material Code
  - Designation
  - Composition
  - Cure
  - Use Type
  - Specifications
  - Manufacturer

- Test Results and Data
  - Corrosions
  - Liquid Oxygen
  - Hydrazine
  - High Pressure Hydrogen
  - Low Pressure Hydrogen
  - Gaseous Oxygen
  - Nitrogen Tetraoxide
  - Flammability
  - Toxicity
  - TVS

- ETC

MATERIALS & PROCESSES TECHNICAL INFORMATION SYSTEM

MAPTIS MAIN MENU

1. Properties
2. Materials Selection Handbook
3. Standards
4. Foreign Alloy Cross Reference
5. Material Usage Agreement (MUA)
6. Where Used
7. Valve and Component
8. Manufacturer Codes
9. Resource Database

Enter choice:
PRINT ALL SKewed SELECTION LIST DATA FOR ALL MATERIALS WHICH HAVE DESIGNATIONS LIKE \"RTV\".

********* MAPISS SELECTION LIST DATA FOR MTRL CODE: 00128 ********* 31-JAN-90

MTRL CODE: 00128
DESIGNATION: RUBBER SILICONE RTV 102
COMPOSITION: 
GENERIC ID: 
USE TYPE: RUBBER

MIN USE TEMP: -10 f  MAX USE TEMP: 350 f

SPECIFICATION: MB0120-041

MANUFACTURER: GENERAL ELECTRIC

FLAMMABILITY DATA

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<th>BURN</th>
<th>THICK</th>
<th>TOR</th>
<th>SSTR</th>
<th>THICK</th>
<th>SUBSTRATE MTRL</th>
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<th>SUBSTRATE MTRL</th>
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G SEE TOX CURE

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<th>ODOR</th>
<th>TEST BASIS</th>
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### THERMAL VACUUM STABILITY DATA

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**MATERIALS AND PROCESSES TECHNICAL INFORMATION SYSTEM**

---

**DESIGNATION:** RTV-102  
**MANUFACTURER:** ALLIED RESINS CORP  
**DESCRIPTION:** READY TO USE ADHESIVE/SEALANT USES-SEALING. AEROSPACE (EXTREME TEMPERATURE)  
**CATEGORY:**  
**COMPOUND:**  
**GENERIC ID:** ABDXXXX  
**MATERIAL CODE:** 00128  
**PROCESS METHOD:**  
**COLOR:** WHITE

---

**COMMENT:**  
**COMPOSITION:**

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**CURE:**

**MATERIAL SPECIFICATIONS:** MIL-A-46106

**PROPERTIES:**

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RESISTANCE CHARACTERISTICS:

PRINT ALL DATA FOR MATERIALS WHICH HAVE MATERIAL CODES LIKE 10233

--------------------- MATERIALS AND PROCESSES TECHNICAL INFORMATION SYSTEM --------------------- 31-JAN-90

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SPECIFICATION: MB0160-037

SUPPORT DATA: 2 N204 + MDZE 10078

PROPERTY DATA

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### General Data for FE 304L

**Alloy Type:**
- **Alloy:** FE 304L
- **Composition:** Low Carbon 18-8 Stainless Steels
- **Density:** 0.068g/cm³
- **Melting Range:** 2550 - 2650°F

**Alloy Designation:**
- **USS-Designation:** A286
- **Category:** FEA

### Composition Data for Alloy: FE 304L

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### Composition Property Comments for: FE 304L

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- **Form:**

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**** Property values for all the forms and conditions were only those that were available in the recommended references.

** The condition codes for steels, when not available, were created solely for use in this database.

### Abbreviations That May Be Used in the Following Tables

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<th>Abbreviation</th>
<th>Meaning</th>
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<td>DRBH</td>
<td>Drawn</td>
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<tr>
<td>E/D</td>
<td>Ratio of edge distance to hole diameter</td>
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<tr>
<td>FIO</td>
<td>For information only</td>
</tr>
<tr>
<td>GMS</td>
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<td>GPS</td>
<td>Grams per square inch</td>
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<td>International annealed copper standard</td>
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<td>KGRT</td>
<td>KSI square root of inch</td>
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<td>TYP</td>
<td>Average for all sizes, thicknesses, forms and method of manufacture.</td>
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### Basis Definitions

** Basis Definition **

241
A. At least 95 percent of the population of values is expected to equal or exceed the "A" basis mechanical property allowable, with a confidence of 95 percent.

B. At least 90 percent of the population of values is expected to equal or exceed the "B" basis mechanical property allowable, with a confidence of 95 percent.

C. This typical property value is an average value, no statistical assurance being associated with it. However, these typical properties have been based on consistent results of tests on three or more lots of material and are useful in design. Since there are well-known methods for reducing them to minimum values, the manner in which these property values are to be used will be specified in the detailed structural requirements of the procuring or certification agency and are thus beyond the scope of this database.

D. This typical property value is an average value, no statistical assurance being associated with it. However, these typical properties have been based on consistent results of tests on three or more lots of material and are useful in design.

E. For information only.

S. The S basis mechanical property allowable is the minimum value specified by the appropriate federal, military, SAE aerospace or ASTM specification for the material. The statistical assurance associated with this value is not known.

References that may be used in the following tables:

1. AEROSPACE STRUCTURAL METALS HANDBOOK
2. MIL HANDBOOK 5
3. AMERICAN SOCIETY FOR METALS, METALS HDBK, 9TH EDT., VOL. 1
5. AMERICAN SOCIETY FOR METALS, METALS HDBK, 9TH EDT., VOL. 3
6. STRUCTURAL ALLOYS HANDBOOK
| PROPERTY NAME          | PROP VALUE | PROP UNIT | EXP TEMP | TEST TEMP | TEST DUR | A S E | S Q R. THICK | MIN THICK | MAX THICK | THICK VAL | L/D CONC | CYCL VAL | R | CREEF | R | RUP | COM | R |
|-----------------------|------------|-----------|----------|-----------|----------|------|-------------|-----------|-----------|-----------|---------|-----------|   |      |     |     |     |   |
| Bearing              | 150.0      | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Strength - DRY PIN VALUES | 50.0      | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Compressive          | 28000.0    | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Elastic Modulus      | 27.0       | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Compressive          | 27.0       | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Yield Strength       | 40.0       | %         |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Elongation           | 45.0       | %         |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Shear Rigid Modulus  | 12500.0    | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Shear Strength       | 50.0       | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Tensile Elastic      | 29000.0    | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Tensile Yield        | 30.0       | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |
| Ultimate Tensile     | 7.5        | ksi       |          |           |          |      |             |           |           |           |         |           |   |      |     |     |     |   |

**Condition:** A  **Form:** SHEET
### Mechanical Property Data for: Fe 304L

**Condition:** A  
**Form:** Sheet

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<th>Max</th>
<th>Temp</th>
<th>Time</th>
<th>Temp</th>
<th>Time</th>
<th>B</th>
<th>Crep</th>
<th>Strs</th>
<th>Pct</th>
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<td>Lt</td>
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No Magnetic Records Found for: Fe 304L

**Form:** Sheet

### Corrosion/Stress Corrosion Data for: Fe 304L

**Condition:** A1  
**Form:** Sheet

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<th>Max</th>
<th>Temp</th>
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<th>Exp</th>
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<th>Pit</th>
<th>Inter-</th>
<th>E</th>
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No H2 Brittle Records Found for: Fe 304L

**Form:** Sheet

No Mechanical Records Found for: Fe 304L

**Form:** Sheet

No Magnetic Records Found for: Fe 304L

**Form:** Sheet
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<th>Dip</th>
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<th>Test Thick Max</th>
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<th>Test Temp</th>
<th>Exp Time</th>
<th>Test Environment</th>
<th>Exp Stress</th>
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**CORROSION/STRESS CORROSION DATA FOR: FE 304L**

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<td>DEG-F</td>
<td>TEMP INCH</td>
<td>DEG-F</td>
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**CONDITION:** A4

**CORROSION RATE:** 8.9 MPY

**ENVIRONMENT:** NITRIC-DICHROMATE

**NO H2 EMBRITTLEMENT RECORDS FOUND FOR: FE 304L**

**MECHANICAL PROPERTY DATA FOR: FE 304L**

**PROPERTY**

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<th>PROPERTY NAME</th>
<th>PROP TESTING</th>
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**CONDITION:** CR

**CROSS SECT SECT**

**FORM:** SHEET

**CROSS SECT SECT**

**FORM:** SHEET

**CROSS SECT SECT**

**FORM:** SHEET

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**ULTIMATE TENSILE STRENGTH**

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**NO MAGNETIC RECORDS FOUND FOR: FE 304L**

**CR**

**SHEET**
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<tr>
<td>CORROSION RESISTANCE</td>
<td>GENERAL CORROSION RESISTANCE OF THIS STEEL TO VARIOUS ATMOSPHERES, MOST ACIDS, HOT PETROLEUM PRODUCTS AND STEAM AND COMBUSTION GASES IS VERY GOOD. INTERGRANULAR CORROSION IN TYPE 304L WHEN SUBJECTED TO A NITRIC-DICHROMATE SOLUTION IS ASSOCIATED WITH THE PRESENCE OF CONTINUOUS GRAIN BOUNDARY PATHS OF EITHER SECOND PHASE OR SOLUTE-SEGREGATED CYCLES. THE SUSCEPTIBILITY OF THESE TYPES TO INTERGRANULAR CORROSION MAY BE SUBSTANTIALLY REDUCED BY SUITABLE HEAT TREATMENTS. TYPE 304L WILL BECOME SENSITIZED ONLY AFTER PROLONGED HEATING IN THIS TEMPERATURE RANGE, BUT ITS USE OVER 800 °F IS NOT RECOMMENDED BECAUSE OF ITS RELATIVELY LOW STRENGTH. COMPLETE IMMUNITY FROM INTERGRANULAR CORROSION IS OBTAINED ONLY IN THE STABILIZED TYPES 321 AND 347. DEEP OCEAN BEHAVIOR OF TYPE 304L VARIES, BUT LOCAL ATTACK OFTEN TAKES PLACE. IT IS SUSCEPTIBLE TO STRESS CORROSION IN SALT DILUTE CHLORIDE SOLUTIONS. THE PRESENCE OF OXYGEN IN THE SOLUTION INCREASES THE TENDENCY TO STRESS CORROSION. MAKING THE STEELS ANODIC ACCELERATES STRESS CRACKING, WHILE CATHODIC CURRENTS PREVENT IT. THE BEST CORROSION RESISTENCE COMES FROM A CLEAN SURFACE FREE OF ALL ORGANIC AND METALLIC CONTAMINANTS. SUCH SURFACES CAN BE OBTAINED BY A THOROUGH DECREASING TREATMENT AND A NITRIC ACID RINSE. NITRIDING SIGNIFICANTLY INCREASES THE RESISTANCE TO STRESS CORROSION CRACKING. OXIDATION RESISTANCE OF THIS STEEL IS GOOD UP TO 1700 °F FOR CONTINUOUS SERVICE AND UP TO 1600 °F FOR INTERMITTENT SERVICE. THE PRESENCE OF HIGH PRESSURE HYDROGEN DURING LOADING TO FAILURE LEADS TO A MARKED REDUCTION IN THE TENSILE STRENGTH AND DUCTILITY OF TYPE 304L AT ROOM TEMPERATURE. THIS REDUCTION IN STRENGTH IS DEPENDENT UPON THE STATE OF STRESS AT THE ROOT OF THE NOTCH, INCREASING BOTH WITH INCREASING NOTCH SEVERITY AND WITH INCREASING HYDROGEN PRESSURE.</td>
</tr>
<tr>
<td>FORMABILITY</td>
<td>THIS STEEL HAS EXCELLENT FORMABILITY IN THE ANNEALED CONDITION. ALTHOUGH OTHER STRAIGHT 18-8 GRADES MAY BE PREFERRED FOR CERTAIN OPERATIONS, IT HAS A LOW YIELD STRENGTH AND HIGH STRAIN HARDENING CAPACITY AND REQUIRES CONSIDERABLY MORE POWER THAN CARBON STEELS. SEVERE FORMING OPERATIONS MAY REQUIRE INTERMEDIATE ANNEALS AND A FINAL ANNEAL IMMEDIATELY AFTER FORMING SHOULD BE APPLIED TO PREVENT STRESS CRACKING. STARTING FORGING TEMPERATURE 2300 °F MAXIMUM, FINISHING TEMPERATURE 1500 °F MINIMUM. SEVERE REDUCTIONS BELOW 1700 °F SHOULD BE AVOIDED. THE CASTING CHARACTERISTICS OF THIS ALLOY ARE EXCELLENT. MOST OF THE CASTERS USE THIS COMPOSITION AS A BASE FOR MAKING COMPARISONS OF CASTING CHARACTERISTICS.</td>
</tr>
<tr>
<td>GENERAL</td>
<td>TYPE 304L IS A LOW CARBON MEMBER OF THE STRAIGHT 18-8 AUSTENITIC STAINLESS STEEL FAMILY, WITH 0.03 PERCENT MAXIMUM CARBON. IT HAS PROPERTIES SIMILAR TO THOSE OF TYPE 302 BUT THEIR CORROSION RESISTANCE IS SLIGHTLY HIGHER BECAUSE OF THE LOWER CARBON AND THE INCREASED CHROMIUM AND NICKEL CONTENTS. THE SUSCEPTIBILITY OF THIS STEEL TO INTERGRANULAR CORROSION DECREASES CONSIDERABLY WITH DECREASING CARBON CONTENT, ALTHOUGH LONG EXPOSURE TO ELEVATED TEMPERATURES MAY EVEN SENSITIZE TYPE 304L. TYPE 304L IS AVAILABLE IN ALL COMMON WROUGHT FORMS AND ALSO AS CASTINGS UNDER THE DESIGNATIONS OF CF-8 AND CF-3, RESPECTIVELY. THE WROUGHT FORMS POSSESS VERY GOOD FORMABILITY AND THE STEELS CAN BE READILY WELDED BY ALL COMMON METHODS.</td>
</tr>
<tr>
<td>HEAT TREATMENT</td>
<td>A CONDITION HEAT TREATMENT. ANNEAL AT 1800 DEG F FOR 30 MINUTES TO 1 HOUR PER INCH THICKNESS, 2 HOURS MINIMUM FOR PLATE. AIR COOL OR QUENCH DEPENDING ON SECTION SIZE. COOLING TO 800 DEG F MAXIMUM SHOULD BE WITHIN 3 MINUTES. A1 CONDITION HEAT TREATMENT. ANNEAL AT 1920 DEG F FOR 2 HOURS WATER QUENCH. A2 CONDITION HEAT TREATMENT. ANNEAL AT 1920 DEG F FOR 2 HOURS WATER QUENCH AND HEAT TO 1650 DEG F FOR 2 HOURS WATER QUENCH.</td>
</tr>
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</table>
**GENERAL COMMENTS FOR ALLOY: FE 304L**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>COMMENTS</th>
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<tbody>
<tr>
<td>HEAT TREATMENT</td>
<td>A3 CONDITION HEAT TREATMENT. ANNEAL AT 1920 °F FOR 8 HOURS WATER QUENCH AND HEAT TO 1170 °F FOR 2 HOURS WATER QUENCH. A4 CONDITION HEAT TREATMENT. ANNEAL AT 1920 °F FOR 8 HOURS WATER QUENCH AND HEAT TO 1110 °F FOR 2 HOURS WATER QUENCH. CH CONDITION IS 50 PERCENT COLD ROLLED.</td>
</tr>
<tr>
<td>MACHINABILITY</td>
<td>BECAUSE OF ITS HIGH STRAIN HARDENING, MACHINING OF AUSTENITIC STAINLESS STEELS REQUIRES POSITIVE FEEDS, CORRECTLY CONTOURED AND SHARP TOOLS AND AN AMPLE SUPPLY OF COOLANT. WHILE COMPARISON WITH OTHER MATERIAL VARY WITH THE OPERATION. SPECIAL MEASURES, SUCH AS CHIP CURLERS, ARE REQUIRED TO HANDLE THE VERY LONG CHIPS FORMED BY THIS STEEL.</td>
</tr>
<tr>
<td>SURFACE TREATMENT</td>
<td>CLEANING PRIOR TO HEATING AND WELDING SHOULD INCLUDE THOROUGH REMOVAL OF CARBONACEOUS MATERIAL AND OF ANY PICKUP OF ZINC OR LEAD FROM DIES. CONTAMINATION FROM THESE SOURCES MAY REDUCE THE CORROSION RESISTANCE. CAUSE EMBRITTLEMENT AND SUSCEPTIBILITY OF INTERGRANULAR ATTACK DURING SERVICE OR PROCESSING.</td>
</tr>
<tr>
<td>WELDABILITY</td>
<td>THIS STEEL CAN BE WELDED READILY BY ANY OF THE COMMON WELDING METHODS. FUSION WELDING OF SHEET UP TO 0.125 INCH THICK IS GENERALLY DONE BY THE INERT GAS TUNGSTEN ARC (TIG) METHOD. THE SHIELDED METAL ARC WELDING PROCESS IS PREFERRED FOR SHEET OVER 0.125 INCH THICK AND OTHER PRODUCTS. TYPE 308 FILLER ROD AND ELECTRODES ARE USED. TYPE 304L WILL BECOME SUSCEPTIBLE TO INTERGRANULAR CORROSION ONLY IF SUBJECTED TO HEATING AT ABOUT 1200 °F FOR A LONG TIME.</td>
</tr>
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</table>
NASA
LONG DURATION EXPOSURE FACILITY

MATERIALS SPECIMEN
PRESERVATION AND
CONTAMINATION AVOIDANCE

RUSSELL CRUTCHER
BOEING AEROSPACE AND ELECTRONICS CO.
MSIG SUPPORT

LDEF
MATERIALS DATA ANALYSIS
WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
CONTAMINATION ANALYSIS

CONTAMINATION CONTROL, AND

MATERIALS SPECIMEN HANDLING

WHY

- Ground contamination control effects Orbital performance

- Orbit generated cross contamination effects Orbital performance
QUESTIONS ANSWERED: WHAT ARE -

- Effects of Ground Contaminants
- Effectiveness of Ground Cleaning Activities
- Molecular Effects of Non-Approved Materials
- Contaminating Effects of Atomic Oxygen
- Cleaning Effects of Atomic Oxygen
- Contaminating Effects of Micrometeorites and Debris

ENVIRONMENTS

- Prelaunch and Launch
- Orbital
- Re-entry and Edwards Operations
- Ferry Flight Operations
- Orbital Processing Facility
- O&C Operations
- SAEF-II
- P.I. Laboratory Clean Room
OTHER QUESTIONS: WHERE ARE -

- Effects of Reentry on Payload
- Effects of Ferry Flight on Payload
- Effects of Terrestrial Environment upon Orbit

    Activated Materials

EXOLUTION

- Recovering prelaunch through Orbital data
- Identifying recovery generated debris
- Identifying recovery generated artifacts
- Identifying recent terrestrial debris
TOOLS

- Tapelift
- Witness plates
- Airborne particle counts
- Volumetric air samples
- Temperature and relative humidity data
- Swabs (NVR)
- Direct surface IR for NVR analysis
- Optical Values
- Photographic Documentation

MATERIALS CONTAMINATION CONTROL

SOURCE APPORTIONMENT

- Reference samples
- Analytical characterization
- Assemblage analysis
CONTAMINANT ANALYSIS

REFERENCE SAMPLES

- Photographs of trays
- Fines from known environments
  - Edwards
  - Debris from Shuttle Bay
  - Kennedy Space Center
- Tapelifts from known environments
- Plasticizers from tray materials
- Films from known sources
- Identification tables for knowns
TAPE LIFT SAMPLES - ALL SLIDES IN KIT 01

KIT-01 SLIDE-01  BLANKET ABOVE PURGE DUCT INITIAL SAMPLING STARBOARD.
KIT-01 SLIDE-02  BLANKET ABOVE PURGE DUCT INITIAL SAMPLING PORT.
KIT-01 SLIDE-03  BLANKET BELOW PURGE DUCT INITIAL SAMPLING PORT.
KIT-01 SLIDE-04  SLIDE-01 RESAMPLING AFTER DRYDEN PLB OPERATIONS
KIT-01 SLIDE-05  SLIDE-02 RESAMPLING AFTER DRYDEN PLB OPERATIONS
KIT-01 SLIDE-06  SLIDE-03 RESAMPLING AFTER DRYDEN PLB OPERATIONS
KIT-01 SLIDE-07  BLANKET STARBOARD SIDE NEAR ADAPTER PLATE INITIAL SAMPLING PRE-FERRY FLIGHT
KIT-01 SLIDE-08  STARBOARD BLANKET CENTRAL SQUARE ONE AWAY FROM PSA LOCKER INITIAL SAMPLING PRE-FERRY FLIGHT
KIT-02 SLIDE-09  PORT SIDE BLANKET NEAR OPTICAL TARGET INITIAL SAMPLING PRE-FERRY FLIGHT
KIT-02 SLIDE-01  SLIDE-08 RESAMPLE AFTER LIFTING OPS AT OPF
KIT-02 SLIDE-08  SLIDE-09 RESAMPLE AFTER LIFTING OPS AT OPF
KIT-02 SLIDE-02  SAMPLE NEAR AFT PSA BLANKET AFTER LIFTING OPS AT OPF

*SAMPLE INVALID- TOUCHED PURGE DUCT ON WAY UP.

^^^NOT RESAMPLED

ALL DRYDEN OPERATION SAMPLES ARE ON XO 576 BULKHEAD

ALL PRE AND POST FERRY OPERATIONS WERE PERFORMED ON BAY ONE SURFACES.
TAPELIFT KIT #9
2-1-90

Tapelifts taken prior to LDEF arrival in SAEF II

SLIDE #   AREA SAMPLE
1  Laminar flow bench work surface
2  Tile floor, middle area
3  Concrete floor, middle area
4  Floor of 8' platform
5  Equipment locker, W wall, S. room
6  Tray hoist
7  Stairs of 12', slamd
8  Tone alarm "push to talk" mike boxes, E. wall
9  Krypton vent pipe, S. wall
10 LN2 tanks for Ge(Li) detectors
11 Floor tile in front of observation window, E. wall
12 Video camera and stand near air shower
13 Forklift, battery operated
14 Floor in front of airlock door, N. wall
15 Top of blue box, W. wall, 12" X 18" X 36" approx
16 Top of ladder platform, W. wall
17 Top of check-out unit, W. wall
18 Floor in front of radiation detectors (Ge(Li))
19 Floor, 10' in front of observation window
20 Floor, W. side, LDEF outline
21 Sole of clean room shoe after SAEF II tapelifts

TAPELIFT KIT #10
2-9-90

Tapelifts taken in SAEF II DURING IMAX FILMING

SLIDE #   AREA SAMPLE
1  Floor, just inside airlock door, W. wall
2  Floor, E. wall near observation window
3  Floor, W. area near air return
4  LATS, between LDEF rows D & E, E. side
5  LATS, LDEF row D, W. side
6  Floor, edge of LATS, W. side
7  Laminar flow bench work surface (bench has been turned off)
8  M&D work station, table top, at door, w. wall
9  Concrete floor, E. wall, near phone
10 Sole of Tom See's clean room shoe, during SAEF II work
11 Work table top, W. wall, near emergency exit
12 Work table, IMAX camera stuff, NW. corner
13 Video camera and stand near air shower
14 Fiber on LDEF equipment box #175B, near air shower
15 Floor of 8' platform by LDEF boxes, NW. corner
CONTAMINANT ANALYSIS

ANALYSIS

• Begins with sample selection
• Synergism - Key to cost effectiveness
• Samples are cheaper than analysis

MATERIALS CONTAMINATION CONTROL

ANALYTICAL CHARACTERIZATION

• Optical crystallographic data
  - Color
  - Crystal type
  - Refractive indices (real and estimated imaginary)
  - "Texture"
• Morphological data
  - Shape type
  - Size
• Elemental data
CONTAMINANT ANALYSIS (Proposed)

- IR image mapping of LDEF
- Selected "Swab" samples - IR and other
- Selected interface film thickness measurements
- Direct surface IR - ATR
- Selected control areas

CONTAMINANT ANALYSIS

- LDEF Preflight Photos
- Astronauts Flight Photos
- KSC Team
  - Macro Documentary
  - Surface Texture Study
  - Debris Distribution Study
  - "Shadow" Study
  - Discoloration Study
- JSC Team
  - Microvideo
  - Macrovideo
- SDIO Optical Surfaces and Contaminants Study
- IMAX Documentary
- Thermal (IR) Video
CONTAMINATE SOURCE APPORTIONMENT

APPROACH

Witness Samples → CENTRAL FILE AND CONTAMINANT BANK
Tape Lifts
Source Samples

→ Light Microscopy
→ Electron Microscopy
→ IR Analysis
→ Other

CONTAMINATE SOURCE APPORTIONMENT

Concept
Terrestrial with Orbital Artifacts
Terrestrial without Artifacts
Extraterrestrial Impact and Surface Collection
CONTAMINATION CONTROL

- Minimize Dilution
- Minimize Cost
- Minimize Loss of Data

MATERIALS CONTAMINATION CONTROL

ISSUES

- Avoidance
- Monitoring
- Source apportionment
- Criteria for relief
MATERIALS CONTAMINATION CONTROL

AVOIDANCE

- Collection protocol
- Specimen isolation
- Specimen contamination monitoring
- Specimen inventory control
- People Control

MATERIALS CONTAMINATION CONTROL

MONITORING

- Environments
- Surfaces
- Kits to PIs
CONTAMINATION CONTROL

At Kennedy Space Center

1. Witness Plates
2. Selected Area Tape Lifts
3. Environmental Monitoring
4. Limited Exposure (Cover)
5. Packaging to Ship
6. Electrostatics

CONTAMINATION CONTROL

At Boeing

1. Clean Room Preparation of Samples
   Class 100,000 to Class 10 available
2. Clear View or Close-up Video to Outside
3. Intercom between Clean Room and Outside
4. Sample Collection and Preliminary Analysis Station
CONTAMINATION CONTROL

At P.I. Laboratories

1. Witness Plates
2. Selected Area Tape Lifts

MATERIALS CONTAMINATION CONTROL

Environments

- Controlled
  - Records available for facility
  - Exposure log for hardware (time out of container)
  - Surface samples (tapelifts)

- Uncontrolled
  - Exposure log for hardware (time out of container)
  - Surface samples (tapelifts)
CONTAMINATION CONTROL

SURFACES

- Tapelifts
  - Samples collected regularly
  - Samples processed as required
  - Samples archived with hardware until processed

- NVR Witness Plate or Surface
  - Flushed or wiped at weekly intervals or longer

MATERIALS CONTAMINATION CONTROL

KITS TO PIs

- Low cost
  - Glass slides
  - 3M magic tape
  - Acetone
  - Beaker
  - Mountant
  - Storage box

- Small storage volume
  - 7" x 10" x 1-1/4" per 100 samples

- Simple procedure
  - Apply tape and lift
  - Soak in acetone
  - Mount in medium

- Available for detailed analysis of single particles
CONTAMINATION CONTROL

- Surface Analysis Complete

- Remaining Tests for Bulk Properties

ISSUES

- Tray handling and specimen isolation
- Documentation of precise origin
- Packaging
- Sample control
- Short term storage
- Archival preservation of samples
MATERIALS SPECIMEN CONTROL

TRAY HANDLING

- Special cart for tray
- Holding fixtures for cover, etc.
- Always two persons
- Removed from container in clean room

SPECIMEN ISOLATION

- Class 10,000 clean room or better
- Two persons, one for documentation
- Specimens labelled and packaged in clean room

MATERIALS SPECIMEN CONTROL

DOCUMENTATION OF ORIGIN

Tray Identifier
Bay A-F
Row J-12
End G-H by nearest vertical row, horizontal row

Specimen Identifier
Level I, II, III, IV, V, etc.
Position 12-36 (short axis from bottom) - (long axis from left) (in inches)
MATERIALS SPECIMEN CONTROL

PACKAGING

• Container selection
• Prelabelled containers
  - At KSC
  - To PIs
• Contingency containers
• Tapelifts
• Vacuum collection

MATERIALS SPECIMEN CONTROL

CONTAINER SELECTION

• Bags (least expensive)
• Boxes (large or heavy object support)
• Vials (small delicate object support)

ACCESSORIES

Styrofoam cushions
Dry nitrogen purge
Exterior supports
MATERIALS SPECIMEN CONTROL

SAMPLE CONTROL

- Single storage facility (temperature controlled)
- Single custodian
- Log-in, log-out procedure
- Indexed file for all samples - hard copy and computer history
LDEF SPECIMEN BOEING ENTRY LOG

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PREPARED BY: 
Name: Organization: Laboratory: Phone #:

DATE: TIME: DURATION OF PART EXPOSURE: SIGNATURE:

RECEIVED BY: 
Name: Signature: Date: Time:
# LDEF SPECIMEN REQUEST FORM

## ITEMS

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270
# LDEF SPECIMEN DISPOSITION FORM

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MATERIALS SPECIMEN CONTROL

SHORT TERM STORAGE

- Samples bagged to preserve condition
- Stored in single dedicated room or locker
- Stored in controlled environment $72^\circ \pm 7^\circ$
- Single custodial responsibility

CONTAMINANT ANALYSIS

DATA TO BE PROVIDED

- Recovery to deintegration background
- Update reports
- Final report: Prelaunch to Deintegration

CONTAMINANT ANALYSIS

CURRENTLY NOT FUNDED

- Detailed NVR analysis
NASA
LONG DURATION EXPOSURE FACILITY

STORAGE AND ARCHIVAL OF EXTRATERRESTRIAL MATERIAL

MICHAEL E. ZOLENSKY
NASA - JOHNSON SPACE CENTER
MEMBER, M&DSIG

LDEF
MATERIALS DATA ANALYSIS WORKSHOP

NASA - KENNEDY SPACE CENTER
FEBRUARY 13 & 14, 1990
PLANETARY MATERIALS CURATION

RESPONSIBILITY: THREE COLLECTIONS PLUS
LUNAR - APOLLO & LUNA
ANTARCTIC METEORITES
COSMIC DUST PARTICLES
RETURNED SPACECRAFT PARTS

PURPOSE:
PRESERVE & PROTECT SAMPLES
CHARACTERIZE SAMPLES - CLASSIFY, DOCUMENT, PUBLICIZE
PROVIDE APPROPRIATE SAMPLES FOR SCIENTIFIC RESEARCH
PROVIDE SUPPORT FOR COMPLEX SAMPLING & CONSORTIA STUDIES
PROVIDE MATERIAL & INFORMATION FOR PUBLIC DISPLAY & EDUCATION

SCOPE: LUNAR
79,200 SAMPLES & SUBSAMPLES
11,000 PETROGRAPHIC THIN SECTIONS
CURRENTLY STUDIED IN 48 US AND 20 FOREIGN LABORATORIES
ABOUT 70 REQUESTS & 800 SAMPLE ALLOCATIONS PER YEAR
RESPONSIBILITY FOR SAMPLES RETURNED AFTER STUDY
LUNAR SAMPLE NEWSLETTER MAILED TO 1100 RECIPIENTS

SCOPE: METEORITES
NEW METEORITES RECEIVED & CHARACTERIZED YEARLY (670 IN 89)
21,800 SAMPLES & SUBSAMPLES
4,060 PETROGRAPHIC THIN SECTIONS
STUDIED IN 133 US AND 66 FOREIGN LABORATORIES
ABOUT 80 REQUESTS AND 700 SAMPLE ALLOCATIONS PER YEAR
ANTARCTIC METEORITE NEWSLETTER MAILED TO 500 RECIPIENTS

SCOPE: COSMIC DUST
137 COLLECTION SURFACES; 1350 CHARACTERIZED PARTICLES
CURRENTLY STUDIED IN 11 US & 9 FOREIGN LABORATORIES
76 REQUESTS SINCE 1982
LARGE AREA COLLECTORS NOW IN USE
PERFORM SOLAR MAX & LDEF PARTICLE CHARACTERIZATION
COSMIC DUST CATALOGS & NEWSLETTERS MAILED TO 300 RECIPIENTS

SCOPE: RETURNED SPACECRAFT PARTS
SOLAR MAX PARTS (DUST ON THERMAL BLANKETS & LOUVERS)
SOLAR MAX DUST SAMPLES DISTRIBUTED TO 6 INVESTIGATORS
LDEF EXPERIMENTS (PROCESSING LABORATORY IS READY)
SECTION V*

PROCEDURES FOR MEASURING IMPACT FEATURES

This section outlines the types of information and measurements, and the procedures for their acquisition for features of interest to the M&D SIG. Information acquired following the procedures outlined below will permit such data to be of significant use and compatible with similar data generated by the M&D SIG laboratories.

1.0 OPTICAL CHARACTERIZATION

1.1 Minimum Characterization -- Minimum characterization consists of acquiring a good quality color photograph of the feature(s) of interest at the earliest possible time.

1.2 Detailed Characterization -- Detailed characterization consists of acquiring various measurements on the feature(s) of interest, in addition to the color photography outlined in Paragraph 1.1. Feature measurement standards are available from the M&D SIG. Contact Michael E. Zolensky [(713) 483-5128] or Thomas H. See [(713) 483-5027] to request temporary loan of impact-feature standards.

1.2.1 Diameter -- Acquire the diameter measurement at the original target/material surface (see Figure 4). Measure and report the major and minor axes of elliptical features.

1.2.2 Depth -- Make the depth measurement from the original target/material surface (see Figure 4) to the bottom (lowest point) of the feature. When measuring the depth of an elliptical feature report the location of the deepest point within the feature; such data could then be utilized to provide directionality of the impactor. If a rim is present, provide a measurement of its height (if possible) from the original target/material surface (see Figure 4).

1.2.3 Halos -- Characterize halos by utilizing oblique lighting. Note halo type (e.g., dark, bright, spalled, etc.) and width. If the feature is non-circular, characterize its variability. A color photograph of such features should be made when ever possible.

1.2.4 Impactor Residue -- Describe impactor residues in detail. Include color, location (e.g., whether residue is within or around the impact feature, or both), size of individual grains or particles, as well as any unusual features of the material (e.g., dendritic pattern, vesicularity, etc.).

2.0 CHEMICAL CHARACTERIZATION

The material of interest for chemical characterization is the impactor or impactor residues. Such materials will generally be molten in appearance and found adhering to the target/substrate. Contamination particles, on the other hand, generally should appear as discrete, loosely adhering particles or grains predominantly located outside an impact feature, although they may be found inside as well.

An issue of extreme importance to the M&D SIG is the amount, type, and composition of any post-recovery contaminants that may have come into contact with, or may now reside on the LDEF spacecraft and/or experiment trays due to recovery, ferrying operations associated with the flight of STS-32, and/or processing of the orbiter or LDEF spacecraft. Thus, the witness plates that fly on the STS-32 mission, those placed in the payload bay during the ferrying operation from Edwards AFB to KSC, those exposed in the Vertical Processing Facility (VPF) and the LDEF Assembly & Transportation System (LATS), as well as any other witness plates that may be utilized during the LDEF processing and deintegration activities will contain vital information to which the M&D SIG must have access. Ideally, the M&D SIG would like to analyze all or a portion of each witness plate. At an absolute minimum, the M&D SIG must obtain the results of the analyses performed on the various witness plates.

2.1 Minimum Characterization -- A minimum chemical characterization consists of qualitative analysis of the impactor residue and/or grains. Report the actual chemical constituents rather than simply referring to the materials as either "meteoritic" or "man-made debris".

2.2 Detailed Characterization -- Detailed chemical characterization consists of quantitative analysis of the impactor residue and/or grains. Extremely long counts may be necessary for small particles (e.g., several thousand seconds at 20 kV) in order to minimize interference from the target/substrate materials. If possible, obtain a set of analytical standards from the M&D SIG by contacting Michael E. Zolensky [(713) 483-5128] or Thomas H. See [(713) 483-5027] to request temporary acquisition of these analytical standards.

2.2.1 Procedures -- Provide a detailed description of the analytical procedures employed in obtaining the analyses (e.g., analytical instrument, count times, accelerating voltage, beam size, standards used with an analysis of each, detector crystals, etc.).

2.2.2 Composition -- Report the weighted average of the composition of the impactor residue(s).

2.2.3 Contamination -- If recognizable particles of contamination are present, report their composition.

Should a PI or institution decide to loan or donate any materials to the M&D SIG, or should questions arise as to techniques and/or procedures listed in this document, please contact the appropriate personnel at the Johnson Space Center in Houston, Texas, or the LDEF Project Office in Hampton, Virginia. A list of M&D SIG contacts can be found in Section IX.
SECTION VII*  
LDEF DATABASE  

1.0 SAMPLE NUMBERING  

The examination of the LDEF spacecraft for features of interest to the M&D SIG will consist of two phases. First, a preliminary examination will take place at KSC while the spacecraft is still intact and during the deintegration activities where features of about 1 mm in size or larger will be identified and documented. During the second phase, individual pieces will be transferred to JSC for microscopic examination in the Facility for the Optical Inspection of Large Surfaces (FOILS). During the secondary examination phase, features of much smaller size may be identified. For some features, the preliminary examination may be the only one possible.

In either case, the locations of the features on LDEF must be documented carefully so that their frequency, size, and distribution may be correlated with the orientation of the spacecraft, its direction of travel, and the type of surface on which the feature occurs.

The LDEF spacecraft is a 14-faced (12 sides and two ends), open-grid structure on which a series of rectangular trays used for mounting experiment hardware are attached. All parts of the spacecraft, including experiment trays, framework, and hardware will be examined for the presence of features of interest. A numbering scheme for the satellite grid has been established, in which components are identified using "Bay" and "Row" numbers (Figure 6). The geometry of the two end pieces is more complex than that of the 12 sides, and the existing numbering scheme provides for identifying only the grids to which experiment trays are affixed. The current scheme may be expanded to include the end grids by assigning row numbers in a clockwise (Earth-facing end) or counter-clockwise (space-facing end) direction.

The examination and disassembly of LDEF will yield three different types of objects which need to be tracked and described.

1.1 Primary Surfaces -- *Primary surfaces* consist of all space-exposed hardware from the LDEF spacecraft. They may represent an entire experiment tray, a piece of hardware (e.g., screw, clamp, etc.), or a piece of the spacecraft's structure (e.g., frame, support beam, etc.).

The primary-surface ID will consist of four parts. The first two parts indicate the Bay (A-H) and Row (01-25) of the LDEF grid from which the primary surface was removed (see Figures 6 and 7), while the third part represents the spacecraft component. The following codes are proposed for the different components from the LDEF spacecraft:

- **E** - Experiment Tray
- **B** - Support Beam
- **F** - Frame
- **C** - Clamp
- **S** - Screw
- **J** - Joint
The fourth part of the primary-surface number represents the individual component number and may be a sequentially assigned number, or it may delineate a specific orientation, as will be the case for the experiment-tray clamps (see below).

In the case that an entire experiment tray is designated to be a primary surface, the component number "00" will be assigned to it (e.g., C04E00). Any pieces of hardware constituting the framework of the spacecraft will be assigned the bay and row numbers of the tray adjacent to them (e.g., C04F00). If two trays share the same pieces of framework, as will be the case in most instances, the hardware to the left and bottom of the tray will be assigned the corresponding bay and row numbers.

All experiment trays are mounted to the LDEF spacecraft by clamps. A series of eight clamps affix the experiment trays on the 12 sides of LDEF, while experiments occupying the two ends are held in place by 12 clamps (Figure 8). In order to document an individual clamp's location around an experiment tray, the numbering scheme illustrated in Figure 8 will be utilized. Thus, if the M&D SIG were to obtain the clamp that occupies position 6 (Figure 8) on the experiment tray from C04 (Figure 7), that clamp would receive primary-surface number C04C06. Should clamps be acquired from configurations other than those depicted in Figure 8, a drawing will be made of the clamp configuration in order to illustrate the clamp's relationship with the experiment tray.

1.2 Features -- A feature is a hole, crater, or other type of impact structure which is identified on a primary surface. As features are identified, they are assigned a specific number. The numbering sequence for features begins with 1 for each primary surface. The primary-surface number plus the specific number constitute the feature number (e.g., C04E00,8; Figure 7).

1.3 Cores -- A core is a piece which has been removed from a primary surface on which one or more features have been identified and numbered (i.e., pieces removed from a primary surface which have no features identified are assigned component numbers; see Primary Surfaces, above). Core numbers are assigned sequentially as they are generated, regardless of the primary surface from which the core was removed. The core number consists of two parts: the "LD" prefix, which is the spacecraft identifier, and a sequential number beginning with 1 (e.g., LD-1; Figure 7).
In summary, two distinct numbering systems are proposed for these objects in order to avoid ambiguity in their curation and among scientists. One system is for the primary surfaces and features, with features being a subset of the primary surfaces; the other is for the cores, or pieces which have been removed from primary surfaces.

Primary surfaces are the objects on which features are identified and from which cores are removed. Features are the objects which will be examined and described by the scientific community and in the FOILS laboratory; cores are the means by which they will be divided and transported. Once features have been identified on a surface, any piece removed, regardless of its size, will be assigned a core number. This procedure ensures that correlation between the primary-surface and feature number is maintained. Since the features will be the basic units of scientific interest, it is proposed that the LDEF grid number and component type be included in their identity so that the number will impart some information about a feature's location on LDEF. Cores will be numbered sequentially as they are produced, regardless of the primary surface from which they are removed.

2.0 DATA FILES

2.1 Primary-Surfaces File -- The primary-surfaces file will contain one record for each primary surface generated. For example, a primary-surface number will be assigned to each experiment tray, screw, clamp, or other spacecraft component which is removable as a separate unit; the shape of the component may be square, rectangular, round, oval, trapezoidal, or irregular. The orientation of the component, relative to the other components removed from the spacecraft, is recorded (the specific nomenclature for the orientation must be determined), as are the longest and shortest dimensions. The substrate is determined by the material of which the surface is made, or the material on the surface of the tray (e.g., gold, aluminum, type of plastic). The location in this column refers to one of the various NASA centers (e.g., LaRC, JSC, etc.). Fields for the original and current masses of the surface (grams) are included for accountability of the gold surfaces (Table 1).

2.2 Features File -- The features file will contain one record for each feature identified. If a feature is removed from the primary surface, the number of the core which contains the feature is recorded. The X,Y-coordinates of the feature, as determined by the scanning process are recorded as fixed units from the (0,0) reference point. Optical observations for each feature are recorded to the extent possible; not all features will be cored, and detailed descriptions regarding sizes, impact types, quantity of material, rims, and halos may not be feasible for all features.

2.3 Cores File -- The cores file will contain one record for each piece or core removed from a primary surface. The principal function of this file is to track the cores with regard to location and container. A field for the mass (grams) of the core is included for accountability of the gold surfaces (Table 1).

2.4 Allocation File -- The allocation file will contain one record for each distribution of a primary surface or core to a PI. The number of the material (primary surface or core), the name of the PI, and the date the material was allocated are recorded.

2.5 Images File -- The images file will contain one record for each image recorded during the preliminary examination of the LDEF spacecraft at KSC, as well as during subsequent processing at JSC. The image type may be a photograph, a digital image, or a video tape. The number will be the NASA photo number, or an assigned unique number or file name which identifies a video tape or digital-
image file. Fields for feature number and core number are included (Table 1) so that cross-referencing with the other LDEF database files may be implemented; however, data will not be recorded in these fields unless such information applies directly to the photograph, image file, or video tape. A field for a more detailed description is also included.

2.6 Notes File -- The notes file will be used for recording comments about trays, primary surfaces, features, and cores. Separate fields for feature and core number are included (Table 1) for cross-referencing. Only those fields relevant to particular parts need be completed (for example, if a note is about a primary surface, only the bay, row, and component fields would be completed). Fields for the name of the person entering the note and the date are included.

2.7 Chemistry File -- The chemistry file will be used to record, for individual features, the elemental composition of projectile residues, surface materials, and possible contaminants. Fields for the feature number, element, the part analyzed, the analyst, and the date of the analysis are included (Table 1). Two separate fields are included for recording the amount of element present. One is for expressing the amount as the weight percent of the element, while the other is for expressing the amount in parts per million. Data in the field for the part analyzed is restricted to specific keywords, such as "IMPACTOR", "SURFACE", or "CONTAMINATION", so that records pertaining to each of these materials may be collected and sorted by element for calculation of elemental composition. The file may contain many records for some elements for a feature and none for others.

Table 1. LDEF Database File Interaction

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3.0 SOFTWARE REQUIREMENTS

The following are the requirements which should be considered in order to implement the proposed database system:

3.1 Multi-User Access -- Although the number of persons accessing the database will be limited initially, more than one person should be able to access the database at one time for both updating and reporting purposes. Record-locking should be used in the event that several people attempt to access the same record for writing at the same time.

3.2 Menus -- Access to the database should be configured so that updating the files and generating reports is accomplished through menus, which permit the user to have little to no knowledge of how the database software actually operates.

3.3 Multi-File Access -- The proposed design divides the data into a number of different files, with redundancy only in the identifiers for the different types of objects. The database software must have the capability of synthesizing information from one or more of these files into a single report (for example, one requirement might be to list all the features in the custody of a PI, even though locations of samples are recorded for core numbers only).

3.4 Graphics -- The data must be able to be selected and sorted to produce a variety of plots for data recording, analysis, and presentation. For example, a plot of the features on a primary surface based on the X,Y-coordinates recorded by the FOILS scanner provides a means for correlating core and feature numbers. Plots of size distribution versus frequency of impact were requirements resulting from studies of the Solar Maximum spacecraft; similar plots will be necessary for LDEF.

3.5 Weight Balancing -- If weight accountability for gold surfaces is a requirement, the software must be capable of prohibiting entry of updates for these surfaces until masses of the primary surface and cores removed from that surface total the same before and after the transaction.

3.6 Expandability -- In order to meet new requirements as they are identified, the database must be capable of being expanded or adapted, either by means of additional data files or by reformatting of existing ones.

3.7 Commonality -- The data must be usable by different types of computers and applications (e.g., mainframes, PC's, MAC's).

3.8 Access -- The database will be accessible via SPAN. Details on the procedures for gaining access to the LDEF M&D SIG database can be obtained by contacting C.B. Dardano, T.H. See, or M.E. Zolensky, at JSC.

Should a PI or institution decide to loan or donate any materials to the M&D SIG, or should questions arise as to techniques and/or procedures listed in this document, please contact the appropriate personnel at the Johnson Space Center in Houston, Texas, or the LDEF Project Office in Hampton, Virginia. A list of M&D SIG contacts can be found in Section IX.
LONG DURATION EXPOSURE FACILITY

WORKSHOP AGENDA

LDEF

MATERIALS DATA ANALYSIS

WORKSHOP

NASA - KENNEDY SPACE CENTER
BUILDING M7-351, TRAINING AUDITORIUM

FEBRUARY 13 & 14, 1990
LDEF
MATERIALS DATA ANALYSIS WORKSHOP

NASA - KENNEDY SPACE CENTER
BUILDING M7-351, AUDITORIUM

FEBRUARY 13 & 14, 1990

CO-CHAIRMAN: MR. BLAND A STEIN, CHAIRMAN LDEF MSIG, NASA-LARC

CO-CHAIRMAN: DR. PHILIP R. YOUNG, NASA-LARC

AGENDA

FEBRUARY 13, 1990

8:00 A.M. Registration

Session 1 - LDEF Data Analysis Responsibilities and Plans

8:30 A.M. Workshop Introduction B. Stein, Workshop Co-Chairman

8:45 A.M. NASA Headquarters Perspective R. Hayduk, LDEF Coordinator, NASA Headquarters

8:55 A.M. LDEF Data Analysis Project Office Overview D. Tenney, Chief, Materials Division, NASA-LaRC

9:15 A.M. LDEF Project Operations B. Lightner, LDEF Manager

9:30 A.M. Supporting Data Group Plans:
- Environments
- Orbit and Orientation W. Kinard, LDEF Chief Scientist

W. Kinard, LDEF Chief Scientist
February 13, 1990

Session 1 - LDEF Data Analysis Responsibilities and Plans (continued)

10:00 A.M. Special Investigation Group Plans:
- Meteoroid and Debris SIG  W. Kinard, Chairman, M&DSIG

10:50 A.M. Storage and Archival of Extraterrestrial Material
M. Zolensky, NASA-JSC

11:00 A.M. Supporting Data Group Plans (Continued):
- Spacecraft Thermal  W. Berrios, NASA-LaRC

11:45 A.M. Lunch

1:00 P.M. Special Investigation Group Plans (continued):
- Systems SIG  J. Mason, Chairman, SSIG
- Materials SIG  B. Stein, Chairman, MSIG
- Induced Radiation SIG  T. Parnell, Chairman, IRSIG

4:00 P.M. Overview of Principal Investigator Plans  J. Jones, LDEF Science Manager

4:40 P.M. SDIO Overview  W. Ward, WRDC/MLBT

February 14, 1990

Session 2 - Materials Data Analysis Methodology Discussions

8:30 A.M. Overview  B. Stein, NASA-LaRC

8:45 A.M. Discussion Topics and Leaders:
- Polymeric Materials Characterization  P. Young, NASA-LaRC
  - Surface Chemistry  J. Wightman, Virginia Tech
  - Atomic Oxygen  B. Banks, NASA-LeRC

11:45 A.M. Lunch
February 14, 1990

Session 3 - Materials Analysis, Data Base, and Specimen Preservation

1:00 P.M. MSIG Materials Analysis
G. Pippln, Boeing Aerospace

1:40 P.M. MSIG/MAPTIS Data Base
J. Davis, NASA-MSFC

2:20 P.M. Materials Specimen Preservation and Contamination Avoidance
R. Crutcher, Boeing Aerospace

3:20 P.M. General Discussion
All participants

4:00 P.M. Adjourn
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The 5-year, 10-month flight of the Long Duration Exposure Facility (LDEF) greatly enhanced the potential value of most LDEF materials, compared to the original 1-year flight plan. NASA recognized this potential by forming the LDEF Space Environmental Effects on Materials Special Investigation Group in early 1989 to address the expanded opportunities available in the LDEF structure and on experimental trays, so that the value of all LDEF materials to current and future space missions would be assessed and documented. The LDEF Materials Data Analysis Workshop served as one step toward the realization of that responsibility and ran concurrently with activities surrounding the successful return of the spacecraft to the NASA Kennedy Space Center. This document is a compilation of visual aids utilized by speakers at the workshop.

Session 1 summarized current information on analysis responsibilities and plans and was aimed at updating the workshop attendees: the LDEF Advisory Committee, Principle Investigators, Special Investigation Group Members, and others involved in LDEF analyses or management. Sessions 2 and 3 addressed materials data analysis methodology, specimen preparation, shipment and archival, and initial plans for the LDEF Materials Data Base. A complementary objective of the workshop was to stimulate interest and awareness of opportunities to vastly expand the overall data base by considering the entire spacecraft as a materials experiment.