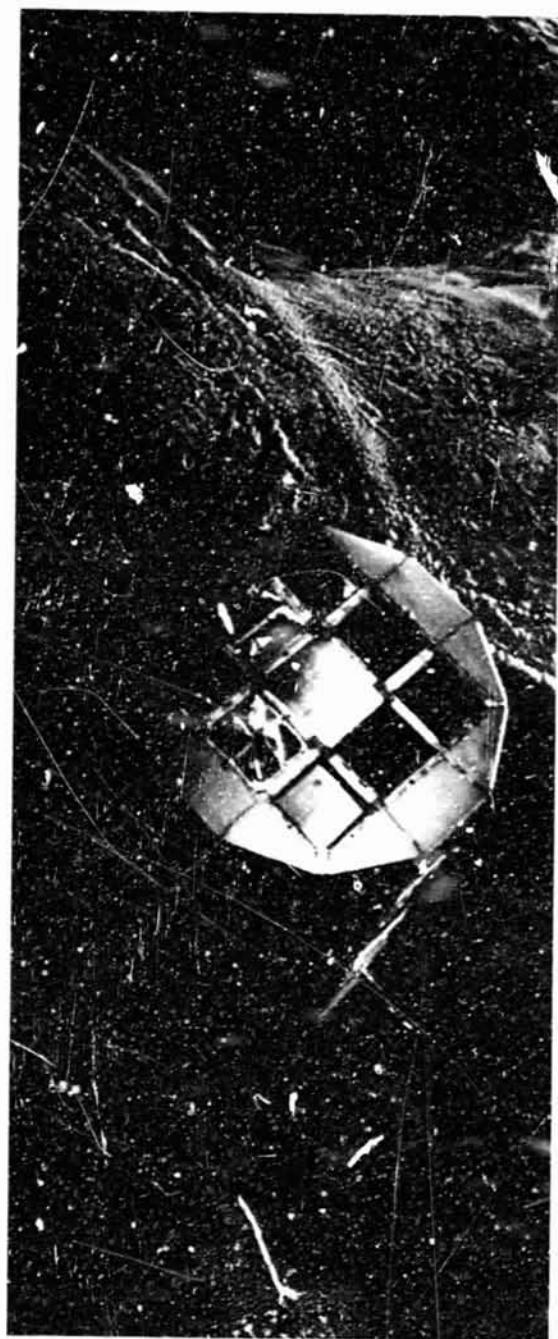


(NASA-CP-10097) SECOND LDEF POST-RETRIEVAL
SYMPOSIUM ABSTRACTS Abstracts Only (NASA)
133 p

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NASA Conference Publication 10097



Second LDEF Post-Retrieval Symposium Abstracts

June 1-5, 1992

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Hampton, Virginia 23665-5225

American Institute of
Aeronautics and Astronautics



*Second
Post-Retrieval
Symposium*

*Compiled by
Arlene S. Levine
NASA Langley Research Center
Hampton, Virginia*

*Abstracts of a symposium sponsored by the
National Aeronautics and Space Administration
Washington, D.C. and the American Institute of
Aeronautics and Astronautics, Washington, D.C.,
and held in San Diego, California
June 1-5, 1992*

FOREWORD

Nineteen hundred and ninety-two has been designated as the International Space Year (ISY) and is the 500th Anniversary of Christopher Columbus's discovery of the New World. It is also the 75th Anniversary of the Langley Research Center, the home of the Long Duration Exposure Facility (LDEF). In addition, 1992 marks the second anniversary of the retrieval of LDEF and the first anniversary of the First Post-Retrieval Symposium. The LDEF principal investigators, co-investigators, and collaborating investigators have had an additional 12 months to analyze and interpret the data from LDEF's 57 onboard experiments and to come to a better understanding of the space environment (ionizing radiation, meteoroids, space debris and atomic oxygen in the upper atmosphere) and the effects of prolonged exposure in this environment on future spacecraft such as large low-earth orbit (LEO) platforms, earth-orbiting spacecraft, and on future manned and unmanned spacecraft to the Moon and to other planets.

The results of the second year of LDEF studies will be addressed at the Second LDEF Post-Retrieval Symposium, to be held at the Town and Country Hotel, San Diego, California, June 1 to 5, 1992. This Symposium is co-sponsored by NASA Langley Research Center and the American Institute of Aeronautics and Astronautics. This volume contains the investigator prepared abstracts for the Second Symposium. Registration, poster and display set-up, and the opening night reception will be held on Monday, June 1. Tuesday, June 2, will include invited review papers on ionizing radiation, meteoroids and debris, environmental effects on materials, environmental effects on systems, and archiving the LDEF data. Papers on the LDEF mission and induced environments, as well as microgravity, will also be presented. Wednesday and Thursday, June 3 and 4, will include concurrent sessions on ionizing radiation, meteoroids and debris, space effects on materials and systems. On Friday, June 5, a session on the future will be held. The full-length papers will be printed in the fall of 1992, in a NASA conference publication.

In June 1991, over 400 LDEF investigators and data users convened in Kissimmee, Florida for the First LDEF Post-Retrieval Symposium. The results of the First LDEF Post-Retrieval Symposium (a total of 130 papers) are printed in a three-part NASA conference publication, LDEF-69 Months in Space: First LDEF Post-Retrieval Symposium, January 1992, (CP 3134.) The LDEF Science Office plans to hold a third symposium in the spring of 1993. Additional information on these symposia may be obtained by contacting:

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* Poster Presentation

† Oral and Poster Presentation

Mission And Induced Environments

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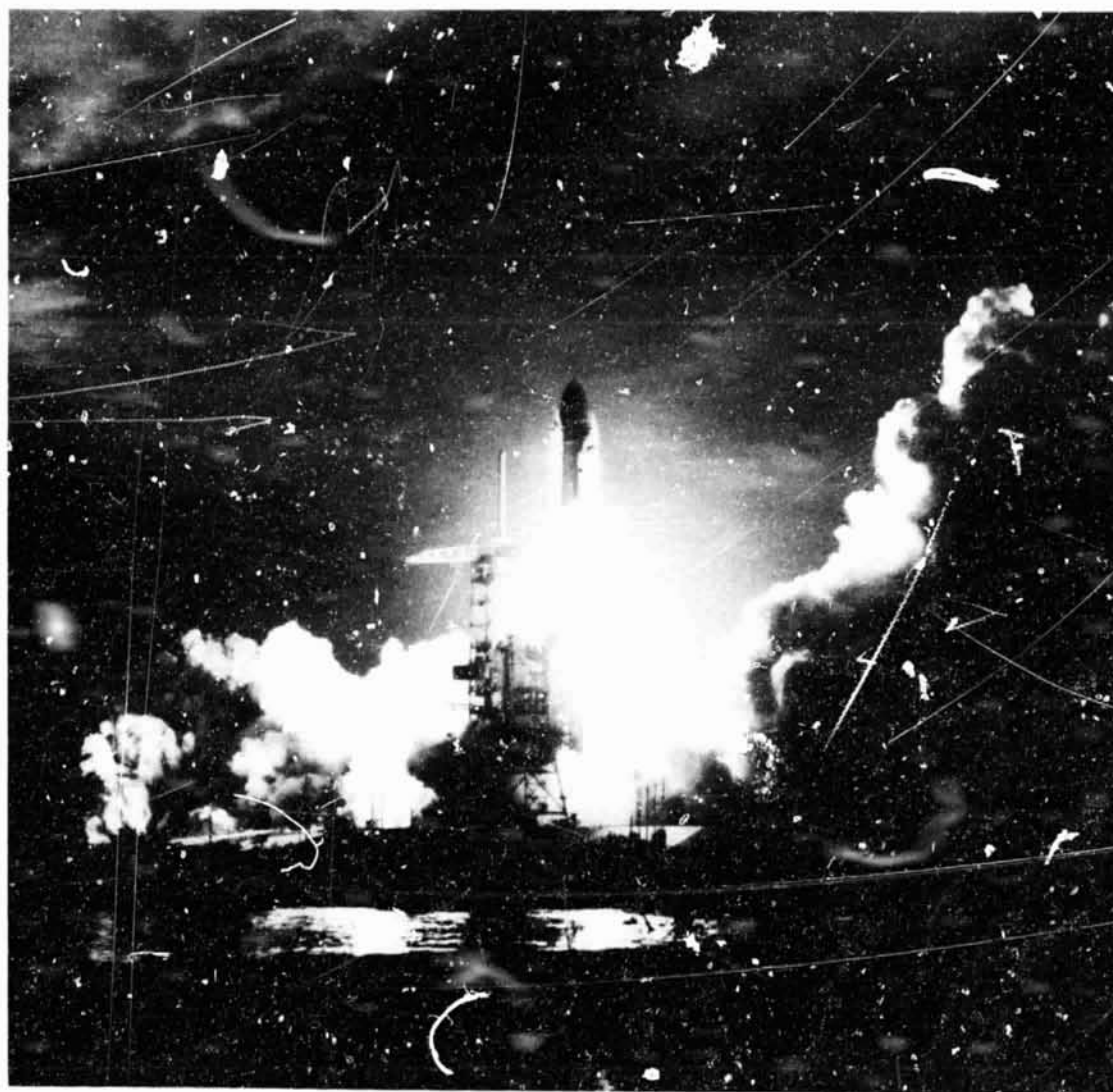


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ATTITUDE STABILITY OF LDEF: REFINEMENT OF RESULTS
FROM THE SILVER PINHOLE CAMERA

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ABSTRACT

We have described (1) a measurement of the angular offset and attitude stability of the LDEF spacecraft using a simple pinhole camera device in the UAH experiment A0114. This device uses a silver surface to record the impact zone of atmospheric atomic oxygen passing through a small pinhole on the front surface of the satellite. The shape and size of this zone are well defined if the satellite velocity and gas temperature are known. The circular symmetry of the zone would be distorted by oscillation of the LDEF about its stable attitude, or by the effect of the co-rotation of the Earth's atmosphere for cases of satellites in non-equatorial orbits. The observed ellipticity (1) of 1.05 with the major axis in the yaw direction is equivalent to an oscillation of ± 0.2 deg about the stable attitude. The uncertainty in that measurement was estimated at about 0.1 deg.

A refined analysis based on summing distributions of flux versus incidence angle for a large number of orbital positions, and including a co-rotating atmosphere, indicates that the combined distributions produce a result consistent with the measured exposed spot. It is suggested that, within the precision of the measurements, no actual oscillation of the LDEF is required to produce the results. Thus, the LDEF may have maintained a stable attitude to better than 0.1 deg, even under conditions of maximum aerodynamic perturbation when the silver oxygen record was made. This error is some two orders of magnitude lower than the predicted uncertainty in yaw oscillation and may indicate that the predict methodologies are too conservative.

1. J.C. Gregory and P.N. Peters, "Measurement of the Passive Attitude Control performance of a Recovered Spacecraft" Journal of Guidance, Control and Dynamics, AIAA, Vol. 15, No. 1, Jan-Feb 1992, pages 282-284.

N92-27220

LDEF MICROENVIRONMENTS, OBSERVED AND PREDICTED

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ABSTRACT

Complex protrusions and surface indentations on spacecraft equipment alter exposure environments by casting shadows, producing reflections and scattering incident atomic oxygen flux and ultraviolet radiation. A computer model is being developed to predict these effects. The model accounts for any arbitrary shape, size, orientation, or curvature of exposed objects. LDEF offers a unique opportunity to compare model predictions with observations. For this purpose a study is underway on twelve of LDEF's copper grounding straps. These straps were exposed at various angles from the ram vector during the LDEF flight. Microenvironment variables include shadowing and reflections from clamps and fasteners, and varying exposure caused by bending of the straps. Strap measurements include optical properties, surface film composition by ESCA, and film thickness measurements by optical interference techniques. The features of the microenvironments model and the analytical methods used to examine the straps are discussed. Data are presented showing predicted microenvironmental variations. These variations are compared with observed point to point differences in surface properties of the straps.

N92-27221

**A GENERALIZED APPROACH TO THE THERMAL ANALYSIS OF THE LONG
DURATION EXPOSURE FACILITY'S FLIGHT EXPERIMENTS.**

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ABSTRACT

The generalized method used in the thermal analysis of the Long Duration Exposure Facility's (LDEF) flight experiments is presented. The approach consists of developing a mathematical lumped parameter node representation of the experiment; defining the source and sink temperature boundary conditions; calculating the albedo, infrared, and solar orbital heating fluxes; and solving with a finite difference technique. The temperature predictions can be made either on a per orbit basis or for any length of mission time using a daily averaged calculated composite flux. The thermal analysis of the Ultra-Heavy-Cosmic Ray Experiment (UHCRE-A0178) is presented as an example of this approach.

N92-27222

ENVIRONET: AN ON-LINE ENVIRONMENT DATA BASE FOR LDEF DATA

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ABSTRACT

EnvironNET is an on-line, free-form data base intended to provide a centralized depository for a wide range of technical information on environmentally induced interactions of use to Space Shuttle customers and spacecraft designers. It provides a user-friendly, menu-driven format on networks that are connected globally and is available twenty-four hours a day - everyday. The information updated regularly, includes expository text, tabular numerical data, charts and graphs, and models. The system pools space data collected over the years by NASA, USAF, other government facilities, industry, universities, and the European Space Agency. The models accept parameter input from the user and calculate and display the derived values corresponding to that input. In addition to the archive, interactive graphics programs are also available on space debris, the neutral atmosphere, radiation, magnetic field, and ionosphere. A user-friendly informative interface is standard for all the models with a pop-up window, help window with information on inputs, outputs and caveats. The system will eventually simplify mission analysis with analytical tools and deliver solution for computational intense graphical applications to do "What if..." scenarios. A proposed plan for developing a repository of LDEF information for a user group concludes the presentation.

Space Environments - Ionizing Radiation

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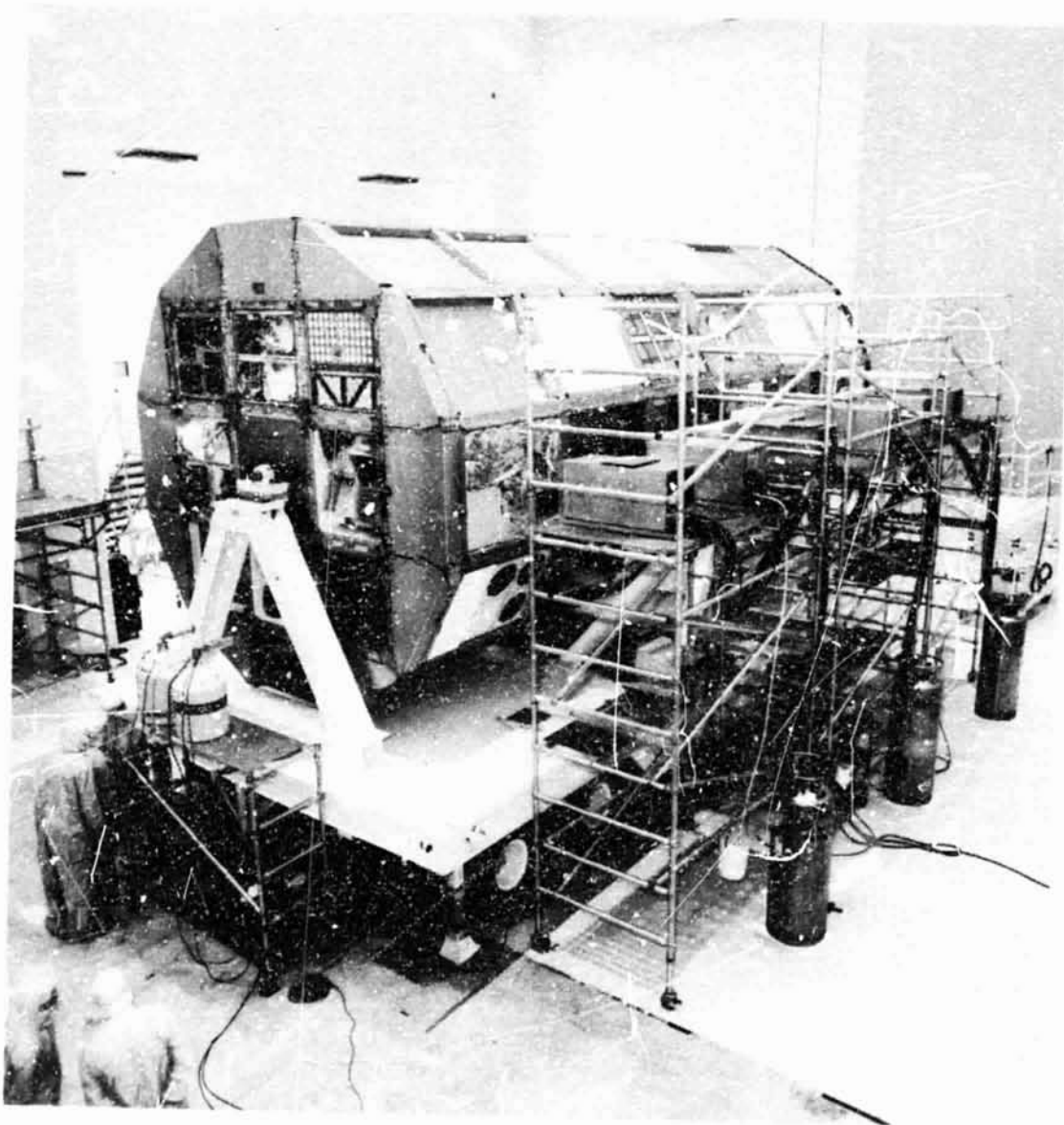


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STATUS OF LDEF IONIZING RADIATION
MEASUREMENTS AND ANALYSIS

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ABSTRACT

The LDEF-1 results from the particle astrophysics, radiation environments and dosimetry measurements on LDEF-1 are summarized, including highlights from presentations at the Second Symposium. Progress in using LDEF data to improve radiation environment models and calculation methods is reviewed. Radiation effects, or the lack thereof are discussed. Future plans of the LDEF Ionizing Radiation Special Investigation Group are presented.

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**SENSITIVITY OF LDEF FOIL ANALYSES USING ULTRA-LOW BACKGROUND
GERMANIUM VS. LARGE NaI(Tl) MULTIDIMENSIONAL SPECTROMETERS**

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ABSTRACT

Cobalt samples were analyzed for cosmic-ray induced ^{60}Co with both an ultra-low background germanium gamma-ray spectrometer and with a large NaI(Tl) multidimensional spectrometer utilizing electronic anticoincidence shielding. Aluminum samples were analyzed for ^{22}Na . The results are presented along with the relative sensitivities and precisions afforded by the two methods.

N92-27225

RADIOACTIVITIES INDUCED IN SOME LDEF SAMPLES

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ABSTRACT

Final activities are reported for gamma-ray-emitting isotopes measured in 35 samples from LDEF. In 26 steel trunnion samples, activities of ^{54}Mn and ^{57}Co were measured and limits set on other isotopes. In five aluminum end support retainer plates and two aluminum keel plate samples, ^{22}Na was measured. In two titanium clip samples, ^{22}Na was measured, limits for ^{46}Sc were obtained, and high activities for impurity uranium and daughter isotopes were observed.

Four sets of depth-versus-activity profiles were measured for the D sections of the trunnion. For all 4 profiles, the activities first decreased with increasing distance from the surface of the trunnion but were fairly flat near the center. These profiles are consistent with production by both the lower-energy (~ 100 MeV) trapped particles and high-energy (~ 10 GeV) galactic-cosmic-ray particles. For the near-surface samples, the earth quadrant had more ^{54}Mn than the space quadrant. For the D sections, there was less ^{54}Mn in the east trunnion than in the west trunnion.

Comparisons are made among our samples and with activities measured by others. The limit for ^{46}Sc in the titanium clips is compared with the activities of ^{54}Mn produced in the steel pieces by similar reactions. Activities predicted by several models are compared with the measured activities.

A PHOTON-PHREAK DIGS THE LDEF HAPPENING

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ABSTRACT

Extension of the Long Duration Exposure Facility (LDEF) voyage to nearly 6 years proved a bonanza to most on-board experiments. This has been especially true for investigators of the gamma-emitting induced radioactivities in both intentional samples and spacecraft parts. The long time greatly enhanced our ability to detect some of the longer-lived nuclides, including: 2.6-yr Na-22 in Al and Fe; 5.3-yr Co-60 in Co, Ni, and In; 2.9-yr Rh-102 in In; and 35-yr Bi-207 in Pb. These radionuclides, along with such others as 33-yr Ar-42 in Ti, Fe, or Ni and 47-yr Ti-44 in the same elements, would be appropriate monitors of the high-energy space radiation field on long round-trip voyages in the solar system. Additional candidate radionuclides will also be discussed.

Radiometric analysis of the LDEF samples was a substantial effort among a dedicated group of experts in low-level counting, and highlights several important aspects of the procedures needed to achieve success in this kind of endeavor. Among these are the following items. Reaction product half-lives should be matched to mission duration, so to enhance measurement precision and facilitate interpretation of results: did we measure a particle flux integral, or a particle flux rate? Samples of larger mass are needed to improve precision and/or decrease count times. Many LDEF samples needed a week's count time; a 10-fold increase in sample mass (from the typical 50 grams) often would have produced nearly the same increase in count rate, and a corresponding decrease in count times or an increase in precision. Sample retrieval time from a 7 to 10 day mission should be no more than a few hours, and no more than a few days from any mission, however long its duration.

Target elements should be chosen to differentiate between neutron- and proton-induced reactions, whenever this is feasible. Reactions should be chosen with a wide range of energy thresholds, to enable calculation of both intensity and energy spectra of the particle fluxes. We note that as reaction energy thresholds increase into the 10's of MeV, it becomes less and less important to choose single-isotope target elements. Several decades-worth of relevant experience in this high-energy regime exists at LBL, as well as at other high-energy particle accelerator laboratories. Target materials must be thoroughly checked for "BKG" activities prior to a mission, and earthbound control samples must be carefully tended during a mission in case subsequent testing becomes necessary.

Our analysis of LDEF samples can serve as a priceless guide to planning similar efforts in the future. Then, the next time around will be much more efficient and productive, whether it be for a returned Mars Mission, a retrieval of Apollo Program machinery left on the lunar surface twenty years ago, or a long-orbiting "dead" satellite brought back to earth for comprehensive analysis.

N92-27227

**Collection, Analysis, and Archival
of LDEF Activation Data**

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Samples intentionally placed aboard the Long Duration Exposure Facility (LDEF) and samples obtained from the LDEF structure have been studied at Marshall Space Flight Center and seven national laboratories to determine the radioactivity produced in orbit. The gamma-ray spectra from these studies have provided information concerning the type and quantity of radioactive nuclei produced by various activating particles. The gamma-ray spectra, the resulting activation, and the experimental arrangements are being collected at Marshall Space Flight Center and Eastern Kentucky University for review, further analysis, and future archival. An overview of this process and the type of information that will be available for future reference will be given. This information includes the samples studied, the location of the samples on LDEF, the amount and type of covering material, the types of detector systems, the format of the gamma-ray spectra and the corrections for geometry, self-absorption, detector efficiency and background needed to obtain accurate specific activations (activation per kilogram) of material. Plans will be given as to the archival of the data for such future reference and how other scientific investigators or spacecraft designers can access the data.

INDUCED ACTIVATION STUDY OF LDEF

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ABSTRACT

Analysis of the induced radioactivity of LDEF is continuing with extraction of specific activities for various spacecraft materials. Data and results of activation measurements from eight national facilities are being collected for interpretation at Eastern Kentucky University and NASA/Marshall Space Flight Center.

The major activation mechanism in LDEF components is the proton flux in the South Atlantic Anomaly inner radiation belt. This flux is highly anisotropic, and exposes the west side of the spacecraft to higher radiation doses. The directionally-dependent activation due to these protons has clearly been observed in the data from aluminum experiment tray clamps (isotope ^{22}Na), steel trunnions (isotope ^{54}Mn and others) and is also indicated by the presence of a variety of radioisotopes in other materials. A secondary production mechanism, thermal neutron capture, has been observed in two materials having large capture cross sections, cobalt (isotope ^{60}Co) and tantalum (isotope ^{182}Ta). The neutrons could be thermalized in nearby low Z material, although this has yet to be verified. Other mechanisms which activate spacecraft material and are not as easily separable from SAA proton activation, such as galactic proton bombardment and secondarily-produced fast neutrons, are being investigated by comparison to radiation environmental calculations¹. Deviations from one-dimensional activation models indicate that these mechanisms are more important at greater shielding depths.

We present specific activities for a number of materials which show SAA effects and thermal neutron capture. We will also examine trends in the measured results that illustrate the effect of shielding and non-SAA-related activation.

1. T. W. Armstrong and B. L. Colborn, these conference proceedings.

N92-27229

REVISED PREDICTIONS OF LDEF EXPOSURE TO TRAPPED PROTONS¹

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ABSTRACT

Initial estimates of LDEF exposure to the trapped proton environment have been reported previously to aid in the interpretation dosimetry data and in conjunction with dosimetry response predictions. These previous estimates have been made using the standard NASA AP8 trapped proton model for two sets of assumed conditions: (a) the omnidirectional flux spectra have been calculated with the LDEF altitude and solar activity variations taken into account², and (b) the MSFC anisotropy model has been applied to obtain directional spectra, but only for solar minimum conditions and at a single altitude³.

In the present paper the directional trapped proton fluence spectra is calculated considering both the altitude variation and solar activity during the LDEF mission. These additional results represent an extension of previous calculations to provide a more definitive description of the LDEF trapped proton exposure.

¹ Work partially supported by NASA Marshall Space Flight Center, Huntsville, Alabama, Contract No. NAS8-38566.

² John W. Watts, Jr., et al. "The Ionizing Radiation Environment of LDEF: Prerecovery Predictions", Proc. First LDEF Post-Retrieval Symposium.

³ T. W. Armstrong, B. L. Colborn, and J. W. Watts, Jr., "Ionizing Radiation Calculations and Comparisons with LDEF Data", Proc. First LDEF Post-Retrieval Symposium.

**MEASUREMENTS OF THE RADIATION DOSE TO LDEF
BY MEANS OF PASSIVE DOSIMETRY**

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ABSTRACT

We fielded a very simple experiment on LDEF to measure the energetic radiation dose by means of passive dosimetry. It consisted of two identical packets of 16 LiF thermoluminescent dosimeters (TLD) arranged in planar arrays. One array was placed on the leading edge of the spacecraft, the other on the trailing edge. These arrays were installed in opaque packets of 1 mil aluminum foil and Kapton tape mounted behind an aluminum plate of 30 mils thickness. The nominal energy thresholds were 14 MeV for protons and 650 keV for electrons. In addition to the flight arrays, two control arrays were prepared which were kept with the flight arrays as long as possible during experiment integration and then stored in our laboratory. The flight and control arrays were read out alternating in groups of four; it was found that the control dose was negligible. The flight and control detectors were exposed to a 55 MeV proton beam at the Lawrence Berkeley 88" Cyclotron in order to provide a re-calibration of the detectors. It was found the the post-flight and pre-flight calibrations were in good agreement.

The LDEF flight doses were found to be:

$$\text{Leading Edge} = 88.9 \pm 11.5 \text{ Rads} \quad (1)$$

$$\text{Trailing Edge} = 147 \pm 21.1 \text{ Rads} \quad (2)$$

$$\text{Dose Ratio} = 1.65 \pm 0.32 \quad (3)$$

A comparison of our results with the predictions shows that the measured dose was a factor of 4 to 5 low. It is possible that there was in-flight annealing of the TLDs as a result of the long mission and perhaps temperature excursions of the sensors. The East-West effect was larger than expected. The ratio of 1.65 is approximately what was expected for protons alone. Electrons should reduce the dose ratio since electrons add equally to the leading and trailing edge dose. A possible explanation is that the electron dose was negligible compared to the proton dose.

N92-27231

LDEF: DOSIMETRIC MEASUREMENT RESULTS
(AO 138-7 EXPERIMENT)

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ABSTRACT

One of the objectives of the AO 138-7 experiment on board the LDEF was a total dose measurement with Thermo Luminescent Detectors (TLD 100) removed after flight.

Two identical packages, both of them including five TLDs inside various aluminum shields (thicknesses: 0.3, 1.0, 2.0, 3.0 and 4mm), are exposed to the space environment in order to obtain the absorbed dose profile induced.

Radiation fluence received during the total mission length has been computed, taking into account the trapped particles (AE8 and AP8 models during solar maximum and minimum periods) and the cosmic rays; due to the magnetospheric shielding the solar proton fluences are negligible on the LDEF orbit.

The total dose induced by these radiations inside a semi infinite plane shield of aluminum are computed with the radiation transport codes available at DERTS. The dose profile obtained is in good agreement with the evaluation by T. PARNELL.

TLD reading are performed after flight; due to the mission duration increase a post flight calibration was necessary in order to cover the range of the flight induced dose. The results obtained, similar ($\pm 30\%$) for both packages, are compared with the dose profile computation.

For thicknesses 2.0, 3.0 and 4.0mm it seems that the measurements exceed the forecast (factor lower than 1.4). That can be due to a cosmic ray and a trapped proton contributions coming from the backside (assumed as perfectly shielded by the LDEF structure in the computation), or to an underestimate of the proton or cosmic ray fluences. A fine structural shielding analysis should be necessary in order to determine the origin of this slight discrepancy between forecast and in flight measurements.

For the less shielded dosimeters (0.3 and 1.0mm), mainly exposed to the trapped electron flux, a likely overestimate of the dose (less than a factor 1.4) appears. Due to the dispersion of the TLD's response, this cannot be confirmed.

In practice these results obtained on board LDEF, with less than a factor 1.4 between measurements and forecast, reinforce the validity of the computation methods and models used for the long term evaluation of the radiation levels (flux and dose) encountered in space on low inclination and altitude Earth orbits.

ABSORBED DOSE MEASUREMENTS AND PREDICTIONS ON LDEF¹

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ABSTRACT

The overall radiation environment of LDEF was determined in part through the use of thermoluminescent detectors (TLDs) which were included in several experiments. The results given here are from four experiments (A0015 Bio-stack, M0004 Fiber Optics Data Link, P0004 Seeds in Space, and P0006 Linear Energy Transfer Spectrum Measurement) and represent a large fraction of existing absorbed dose data. The TLDs were located on the leading and the trailing edges and the Earth end of the spacecraft under various shielding depths (0.48 to 15.4 g/cm²). The measured absorbed doses were found to reflect both directional dependence of incident trapped protons and shielding.

At the leading edge, doses ranged from 2.10 to 2.58 Gy under shielding of 2.90 to 1.37 g/cm² Al equivalent (M0004). At the trailing edge, doses varied from 3.04 to 4.49 Gy under shielding of 11.7 to 3.85 g/cm² (A0015), doses varied from 2.91 to 6.64 Gy under shielding of 11.1 to 0.48 g/cm² (P0004), and a dose range of 2.66 to 6.48 Gy was measured under shielding of 15.4 to 0.48 g/cm² (P0006). At the Earth end of the spacecraft, doses from 2.41 to 3.93 Gy were found under shielding of 10.0 to 1.66 g/cm² (A0015). The effect of the trapped proton anisotropy was such that the western side of LDEF received about 5 times the dose of the eastern side at shielding depths of \approx 1 gm/cm². These data are being utilized to evaluate the accuracy of models currently in use for predicting ionizing radiation environments for low Earth orbit missions.

¹Work partially supported by NASA Contract No. NAS8-38610 (NASA-Marshall Space Flight Center, Huntsville.)

A0015
 M0004
 P0004
 EXPERIMENT NOS. P0006

N 9 2 - 2 7 2 3 3

CHARGE, ENERGY AND LET SPECTRA MEASUREMENTS OF CHARGED PARTICLES
IN P0006 EXPERIMENT OF LDEF¹

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ABSTRACT

Measurements are under way of the charged particle radiation environment of the LDEF satellite using stacks of plastic nuclear track detectors (PNTDs) placed in different locations of the satellite. In the initial work the charge, energy and linear energy transfer (LET) spectra of charged particles were measured with CR-39 double layer PNTDs located on the west end of the satellite (P0006). Primary and secondary stopping heavy ions as well as relativistic galactic cosmic rays (mostly iron particles) were measured separately.

The results from the P0005 experiment will be compared with similar measurements in other locations on LDEF with different orientation and shielding conditions.

The remarkably detailed investigation of the charged particle radiation environment of the LDEF satellite will lead to a better understanding of the radiation environment of the Space Station Freedom. It will enable more accurate prediction of single event upsets (SEUs) in microelectronics and, especially, more accurate assessment of the risk — contributed by the different components of the radiation field (GCRs, trapped protons, secondaries and heavy recoils, etc.) — to the health and safety of crew members.

EXPERIMENT NO. P0006

¹Work partially supported by NASA grant No. NAG8-168 (NASA-Marshall Space Flight Center, Huntsville)

V92-27234

LIGHT-HEAVY ION MEASUREMENTS IN CR-39 LOCATED ON THE EARTH SIDE OF
LDEF¹

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ABSTRACT

The azimuthal angle distribution and the charge and energy spectra of selected light-heavy ($3 \leq Z \leq 8$) stopping particles were measured in a single layer of CR-39 plastic nuclear track detector (PNTD) from the stack of the A0015 experiment located on the Earth-end of the satellite. The directional incidence of the trapped protons is studied by comparing the azimuthal angle distribution of selected recoils, obtained in the LDEF detectors, to that obtained through calibrations of PNTDs with exposures performed with 200 MeV proton beams from different directions. Similar measurements will be performed in a CR-39 sample exposed on the space-end of the LDEF satellite for intercomparison. The experimental results will also be compared to theoretical calculations.

EXPERIMENT NO. A0015

¹Work partially supported by NASA contract No. NAS8-38610 (NASA-Marshall Space Flight Center, Huntsville)

N92-27235

THREE-DIMENSIONAL SHIELDING EFFECTS ON CHARGED PARTICLE FLUENCES
MEASURED IN THE P0006 EXPERIMENT OF LDEF¹

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ABSTRACT

The azimuthal and polar angle distribution of the galactic cosmic ray particles (mostly relativistic iron) was measured in the main stack and four side stacks of the P0006 experiment located on the west end of the LDEF satellite. A clear shadowing effect of the shielding of the LDEF satellite is found.

The total fluence of stopping protons (mostly primary, trapped particles) was measured as a function of the position in the main and side stacks of the P0006 experiment. Experimental results are compared with theoretical calculations and the effect of the strong location dependence of particle fluences is explained by the three-dimensional shielding model of the P0006 stack.

Through comparisons between experimental results and calculations, this work will lead to the refinement of the radiation environment computational models.

EXPERIMENT NO. P0006

¹Work partially supported by NASA grant No. NAG8-168 (NASA-Marshall Space Flight Center, Huntsville)

N 9 2 - 2 7 2 3 6

DEVELOPMENT AND APPLICATION OF A 3-D GEOMETRY/MASS MODEL
FOR LDEF SATELLITE IONIZING RADIATION ASSESSMENTS¹

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ABSTRACT

A computer model of the three-dimensional geometry and material distributions for the LDEF spacecraft, experiment trays, and, for selected trays, the components of experiments within a tray has been developed for use in ionizing radiation assessments. The model is being applied to provide 3-D shielding distributions around radiation dosimeters to aid in data interpretation, particularly in assessing the directional properties of the radiation exposure. Also, the model has been interfaced with radiation transport codes for 3-D dosimetry response predictions and for calculations related to determining the accuracy of trapped proton and cosmic-ray environment models.

This paper will describe the methodology used in developing the 3-D LDEF model and the level of detail incorporated. Basically, all major components of the spacecraft structure are modeled, each experiment tray is modeled separately, and a detailed description of the contents of several experiment trays containing radiation dosimeters is incorporated. Currently, the trays modeled in detail are F2 (containing Exps. P0004 and P0006), F8 (Exp. M0004), and H12 and H3 (Exp. M0001).

Applications of the model which will be discussed include the 3-D shielding distributions around various dosimeters, the influence of shielding on dosimetry responses, and comparisons of dose predictions based on the present 3-D model vs those from 1-D geometry model approximations used in initial estimates.

¹ Work supported by NASA Marshall Space Flight Center, Huntsville, Alabama, Contract No. NAS8-38566.

RADIATION MODEL PREDICTIONS AND VALIDATION USING LDEF DATA¹

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ABSTRACT

Radiation dosimetry aboard LDEF, as well as post-flight measurements of the radioactivity induced in numerous LDEF spacecraft components, provide unique data for evaluating the accuracy of current models for predicting both the space radiation environments (trapped proton intensity, spectra, and directionality; cosmic-ray fluence) and the radiation environments induced in spacecraft components (fluence, energy spectra, secondary particles, LET spectra, etc.). By determining the accuracy of such models using LDEF data, and with model updates where required, improved radiation environment predictions can be made for future missions, which in turn allows improved predictions for specific radiation effects for future spacecraft components (single-event upsets of microelectronics, radiation damage to focal plane arrays, noise in sensitive instrumentation, etc.).

In this paper the status and results from radiation model predictions and comparisons with LDEF data will be given. The calculations are made using radiation transport codes coupled with a 3-D geometry/mass model of LDEF, together with current models of the space radiation environment. Calculations are compared with TLD measurements of the absorbed dose at various tray locations and shielding depths, fluence and spectra from PNTD dosimeters, induced radioactivity in metal samples placed in experimental trays, and induced radioactivity of various LDEF spacecraft components. Assessments of the comparisons are in terms of the accuracy of current space radiation models for low Earth orbit missions and the models and methods for predicting radiation environments internal to the spacecraft.

¹ Work supported by NASA Marshall Space Flight Center, Huntsville, Alabama, Contract No. NAS8-38566.

CRITICALITY OF Be⁷ CONCENTRATION IN LDEF

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ABSTRACT

In the First Post-Retrieval Symposium of the Long Duration Exposure Facilities (LDEF), a number of papers reported the detection of high Be⁷ concentration in the LDEF. It sounded alarming for space flight in the LDEF orbit, since Be⁷ is a radioactive nuclide with a half life of 54 days and emits gamma rays of 0.48 MeV which is ionizing radiation. Hence two questions arise: (a) Is this high concentration harmful to spacecraft crews? and (b) Is this concentration damaging to electronic components used on spacecraft? To answer these questions, we need to estimate the dosage of this concentration and compare the value of the allowed limits. As a result, we calculated the dosage of 0.03 rad. When this is compared with the human limit of 25 rads and the susceptibility requirement of 800 rads, the Be⁷ amount should not be considered critical. The calculation of Be⁷ dosage is detailed below.

According to Fishman, the concentration of Be⁷ in the air was calculated as 3.8×10^6 atoms/(gm of air). Consider each Be⁷ atom emits a gamma photon of 0.48 MeV. The energy deposited in 1 gram of air is seen to be

$$3.8 \times 10^6 \times 0.48 = 1.8 \times 10^6 \text{ MeV/(gm of air)}$$

In terms of rad which is equal to 100 ergs/gm or 6.25×10^7 MeV/gm, the energy deposited in 1 gram of air is

$$1.8 \times 10^6 \text{ MeV/gm} / (6.25 \times 10^7 \text{ MeV/gm}) 1 \text{ rad} \approx 0.03 \text{ rad}$$

which is negligible as compared with the limit of 25 rad for human beings and the 800 rads radiation susceptibility of electronic components which are the values selected for use in spacecraft operation.

COSMOGENIC RADIOISOTOPES ON LDEF SURFACES

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ABSTRACT

The radioisotope ^7Be was discovered in early 1990 on the front surface, and the front surface only, of the LDEF, (Fishman et al, Nature, 349, 1991, pp678-680). Our working hypothesis is that the isotope, which is known to be mainly produced in the stratosphere by spallation of nitrogen and oxygen nuclei with cosmic ray protons or secondary neutrons, diffuses upward and is absorbed onto metal surfaces of spacecraft. The upward transport must be rapid, that is, its characteristic time scale is similar to, or shorter than, the 53 day half-life of the isotope. It is probable by analogy with meteoritic metal chemistry in the atmosphere, that the form of the Be at a few 100 km altitude is as the positive ion Be^+ which is efficiently incorporated into the ionic lattice of oxides, such as Al_2O_3 , Cr_2O_3 , Fe_2O_3 , etc., naturally occurring on surfaces of Al and stainless steel. Other radioisotopes of Be, Cl and C are also produced in the atmosphere, and we have begun a search to discover these. Of principal interest are ^{10}Be and ^{14}C for which the production cross-sections are well-known. The method of analysis is accelerator mass-spectrometry. Samples from LDEF clamp-plates are being chemically extracted, purified and prepared at Rutgers University for an accelerator run at the University of Pennsylvania.

PROGRESS REPORT ON THE HEAVY IONS IN SPACE (HIIS) EXPERIMENT

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ABSTRACT

The Heavy Ions In Space (HIIS) experiment has two primary objectives: (1) to measure the elemental composition of ultraheavy Galactic cosmic rays, beginning in the tin-barium region of the periodic table; and (2) to investigate heavy ions which arrive at LDEF below the geomagnetic cutoff, either because they are not fully stripped of electrons or because their source is within the magnetosphere. Both of these objectives have practical as well as astrophysical consequences.

The HIIS experiment used eight thick stacks of plastic track detectors mounted in two trays on the space-facing end of LDEF. Since the last LDEF symposium, we have increased the statistics of our observations and have extended the analysis to a second stack and to detector sheets near the top of a stack. We report new results on the detector resolution and on the observations of both stopping and relativistic particles.

EXPERIMENT NO. M0001

**PROGRESS REPORT ON THE ULTRA HEAVY
COSMIC RAY EXPERIMENT (A0178)**

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ABSTRACT

The Ultra Heavy Cosmic Ray Experiment (UHCRE) is based on a modular array of 192 side-viewing solid state nuclear track detector stacks. These stacks were mounted in sets of four in 48 pressure vessels employing sixteen peripheral LDEF trays. The extended duration of the LDEF mission has resulted in a greatly enhanced scientific yield from the UHCRE. The geometry factor for high energy cosmic ray nuclei, allowing for Earth shadowing, was $30 \text{ m}^2\text{sr}$, giving a total exposure factor of $170 \text{ m}^2\text{sr y}$ at an orbital inclination of 28.4 degrees. Scanning results indicate that about 3000 cosmic ray nuclei in the charge region with $Z > 65$ have been collected. This sample is more than ten times the current world data in the field (taken to be the data set from the HEAO-3 mission plus that from the Ariel-6 mission) and is sufficient to provide the world's first statistically significant sample of actinide ($Z > 88$) cosmic rays.

Results to date are presented including a sample of ultra heavy cosmic ray nuclei, analysis of pre-flight and post-flight calibration events and details of track response in the context of detector temperature history. The integrated effect of all temperature and age related latent track variations cause a maximum charge shift of $\pm 0.8e$ for uranium and $\pm 0.6e$ for the platinum-lead group. The precision of charge assignment as a function of energy is derived and evidence for remarkably good charge resolution achieved in the UHCRE is considered. Astrophysical implications of the UHCRE charge spectrum are discussed.

Experiment No. A0178

**FUTURE DIRECTIONS FOR LDEF IONIZING RADIATION
MODELING AND ASSESSMENTS¹**

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ABSTRACT

Data from the ionizing radiation dosimetry aboard LDEF provide a unique opportunity for assessing the accuracy of current space radiation models and in identifying needed improvements for future mission applications. This paper will (a) detail the LDEF data presently available and forthcoming for radiation model evaluations, (b) give the current status of model comparisons with LDEF data, (c) indicate future directions of planned modeling efforts and data comparison assessments, and (d) outline the methodology related to modeling being employed to help insure that the LDEF ionizing radiation results can be utilized to better address ionizing radiation issues for future missions.

In general, the LDEF radiation modeling work to date has emphasized quick-look predictions using simplified methods to make comparisons with absorbed dose (thermoluminescent detector) measurements and induced radioactivity measurements of emissions from both intentionally placed samples and various spacecraft components. This work has provided an evaluation of the accuracy of external radiation environment models for predicting the radiation exposure of low Earth orbit, mid-inclination spacecraft. Future modeling efforts will focus on evaluating models for predicting induced environments by performing comparisons with LDEF linear-energy-transfer (LET) and secondary particle (neutron) measurements. These comparisons will be based on detailed radiation transport methods (e.g., 3-D Monte Carlo codes) coupled with a 3-D LDEF mass model to account for shielding variations.

Modeling and LDEF data comparisons related to LET spectra are of particular importance for several reasons: (a) LET spectra are of fundamental importance in predicting "single hit" radiation effects, such as single-event upsets in microelectronics and biological damage, and are of key practical importance in spacecraft/payload design and mission planning, (b) the long duration LDEF mission allowed LET measurements of unprecedented statistical accuracy, particularly for the high-LET component which is important in assessing certain radiation effects, and (c) LET represents a stringent test of modeling methods for simulating both the external environment (trapped and galactic sources) and radiation transport (interactions including secondary particle effects), more so than for integral results such as absorbed dose and induced radioactivity.

This paper will discuss the planned modeling and LDEF data comparisons for LET spectra, including components of the LET spectra due to different environment sources (trapped vs. galactic radiation), contribution from different production mechanisms (primary particles vs. target fragments), and spectra in plastic detectors (representative of tissue) vs. silicon (representative of microelectronics). Of particular importance are modeling efforts to aid in understanding the directional features exhibited by some of the LDEF LET data.

¹ Work supported by NASA Marshall Space Flight Center, Huntsville, Alabama, Contract No. NAS8-38566.

Space Environments - Meteoroid And Debris

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Photo Number
L-91-2527
KSC-390C-1938.02

SUMMARY OF ACTIVITIES OF THE METEOROID AND DEBRIS SPECIAL INVESTIGATION GROUP

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ABSTRACT

The LDEF Meteoroid and Debris Special Investigation Group (hereafter M&D SIG, see listing of members below) was formed to maximize the data harvest from LDEF by permitting the characterization of the meteoroid and space debris impact record of the entire satellite. Thus, our work is complementary to that of the various M&D PIs, all of whom are members of the SIG. This presentation will summarize recent M&D SIG activities. We will also present discussions dealing with four critical goals:

CLASSIFICATION OF IMPACTORS: We will present general sets of criteria permitting discrimination of natural meteoroids from space debris based upon chemistry of the impactor residues. We will then present specific criteria applicable for use on different LDEF exposed substrate materials (*i.e.* Al, Ge, steel, etc.).

CALIBRATION: This topic involves the cratering and penetration formulas presently used by the M&D investigators. We will discuss the advantages, disadvantages, and uncertainties of the various approaches used to convert raw impact feature data into projectile dimensions and masses.

CHARACTERIZATION OF VERY SMALL CRATERS: While the M&D SIG was successful in documenting the 4500 largest impact features on the entire LDEF during satellite deintegration, analysis of much smaller impact features continues today. Results from these studies are critical to a full understanding of particulate flux.

PARTICULATE FLUX: We will present a preliminary synthesis of observations from LDEF PIs and the SIG, and discuss the present uncertainties which remain.

The M&D SIG members are: William Kinard, Martha Allbrooks (POD Assoc.), Dale Atkinson, Don Brownlee (Univ. Washington), F Buhler (Univ. Bern), Ted Bunch (NASA ARC), Vladimir Chobotov (Aerospace Corp.), Cassandra Coombs (POD Assoc.), Gunther Eichhorn (Space Telescope Sci. Inst.), Miria Finckenor (NASA MSFC), Fred Horz (NASA JSC), Donald Humes (NASA LaRC), Don Kessler (NASA JSC), J-C Mandeville (CERT-ONERA), J A M McDonnell (Univ. Kent), Michael Mirtich (NASA LRC), J D Mulholland (Inst. Space Sci. Tech.), Thomas See (Lockheed-ESC), Charles Simon, Robert Walker (Washington Univ.), Jerry Weinberg (Inst. Space Sci. Tech.), Ernst Zinner (Washington Univ.), Michael Zolensky and Herb Zook.

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MICROMETEORIDS AND DEBRIS ON LDEF

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ABSTRACT

Part of the LDEF tray allocated to French experiments (FRECOPIA) has been devoted to the study of dust particles. The tray was located on the face of LDEF directly opposed to the velocity vector. Two passive experiments have been flown : one composed of a set of glass and metallic samples and one composed of multilayer thin foils detectors. Crater size distribution has made possible the evaluation of the incident microparticle flux in the near environment. Comparisons are made with measurements obtained on the other faces of LDEF and with results of a similar experiment flown on the MIR space station.

Of peculiar interest was the study of impact features on stacked thin foil detectors. The top foil acted as a shield, fragmenting the projectile and spreading the fragments over the surface of the thick plate located underneath. EDS analysis has provided evidence of impactor fragments. Detectors consisting of a thin shield and thick bottom plate appear to offer a significantly higher return of information concerning chemical analysis of impactor residues than single plate detectors. Focus has been made on the discrimination between extraterrestrial particles and man-made debris, however until now, no evidence for impact caused by artificial particles has been found, which is consistent with the location of the our experiment on LDEF.

The samples of various materials offer an unique opportunity for the study of the many processes involved upon hypervelocity impact phenomena; peculiarly, the characteristic ratio for impacts on thin targets (crater diameter/target thickness) has been evaluated and compared with laboratory simulations.

EXPERIMENTS AO 138-1/2

DETAILED EXAMINATION OF LDEF'S FRAME AND THE A0178 THERMAL BLANKETS
BY THE METEOROID & DEBRIS SPECIAL INVESTIGATION GROUP

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ABSTRACT

INTRODUCTION: A major responsibility of the Meteoroid & Debris Special Investigation Group (M&D SIG) is to define the hypervelocity particle environment encountered by LDEF during its 5.7 year stay in low-Earth orbit (LEO). Last year we reported [1,2] on the frequency of craters $\geq 500 \mu\text{m}$ and penetration holes $\geq 300 \mu\text{m}$ in diameter for LDEF's frame and Teflon thermal blankets, respectively. During the past year the M&D SIG has been examining these surfaces, in much greater detail, in the Facility for Optical Inspection of Large Surfaces (FOILS) laboratory at the Johnson Space Center.

LDEF's 6061-T6 aluminum frame and the Teflon/silver-inconel/paint thermal blankets represent large surface areas (~ 15.4 & $\sim 20.4 \text{ m}^2$, respectively) that were widely distributed around the spacecraft. Here we report the results of high-resolution scans of ~ 0.36 and $\sim 0.31 \text{ m}^2$ for the intercostals and thermal blankets, respectively.

DATA ACQUISITION: Surfaces are examined on an X,Y scanning table, to which is mounted a Leitz M8 stereo-microscope [2,3,4]. The hardware permits systematic scanning of surfaces at magnifications ranging between 2.5 to 250x; the data reported here were acquired at 40x which permitted the identification of all features $\geq 30 \mu\text{m}$ in diameter (i.e., rim-crest-to-rim-crest [D_r]).

RESULTS: The cumulative size-frequency distributions of craters and penetrations holes are illustrated in Figs. 1 and 2, respectively. Note that features $\leq 200 \mu\text{m}$ in diameter in Fig. 2 are generally craters, rather than penetration holes, because increasingly smaller particles are unable to completely penetrate the $\sim 180 \mu\text{m}$ thick thermal blankets.

The average crater frequencies for the the five forward-facing (i.e., F07, F08, E09, F09, & E10) and two rearward-facing (i.e., C03 & E05) intercostals can be seen in Fig. 1. The change in the slopes for the intercostal data between 500 and 1000 μm , and the convergence of these data toward the larger craters is most likely an artifact of the limited surface areas offered by the intercostals. For comparison, data from the bays A03 and A11 (experiment A0187) represent crater frequencies on the Al 6061-T6 experiment-tray lips [5], while the B03 (experiment A0138 [6]) data were obtained from counts on unspecified "aluminum" surfaces. The A11 data are in good agreement with this investigation for the general, forward-facing intercostals. As expected, the A03 and B03 data show significant decreases in crater densities and exhibit similar slopes to that of the forward-facing population, supporting the earlier conclusion that the changes in slope is related to the limited surface area of the intercostals.

Fig. 2 depicts thermal-blanket data obtained from the forward-facing (E10) and rearward-facing (E02 & F02) directions. Because of the large surface area and crater/penetration-hole population we did not try to quantitatively count features down to 30 μm in diameter, but instead used a cut-off diameter of 100 μm , which explains the flattening in the slope for the curve below 100 μm . Also in Fig. 2 are data from the A0023 experiment [7] that depicts penetration-hole frequency in aluminum foils of specific and variable thicknesses. These data sets are in excellent agreement for both the forward and rearward-facing directions and could be joined into curves that would characterize the relative frequency of micron to millimeter-sized projectiles.

DISCUSSION: Our current findings are in qualitative agreement with existing model-predictions that suggest highly differential bombardment histories for surfaces pointing into specific directions relative to the velocity vector of a non-spinning platform in LEO [8]. The production rates for craters $\geq 50 \mu\text{m}$ in diameter in aluminum and penetration holes $\geq 100 \mu\text{m}$ in diameter in thin foil materials (Teflon; 180 μm thick) differ by more than a factor of 10 between forward and rearward-facing surfaces. These are substantial differences that must be considered during the design of future, large-scale, long-duration platforms in LEO (e.g., most immediately the Space Station Freedom).

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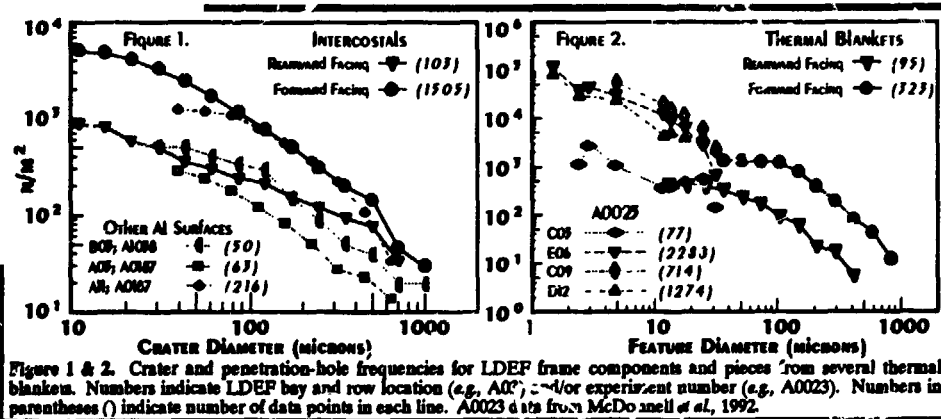


Figure 1 & 2. Crater and penetration-hole frequencies for LDEF frame components and pieces from several thermal blankets. Numbers indicate LDEF bay and row location (e.g., A03) or experiment number (e.g., A0023). Numbers in parentheses () indicate number of data points in each line. A0023 data from McDonnell et al., 1992.

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LDEF EXPERIMENT M0003 METEOROID AND DEBRIS SURVEY

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ABSTRACT

A survey of the meteoroid and space debris impacts on LDEF experiment M0003 has been performed. The purpose of this survey was to document significant impact phenomenology and to obtain impact crater data for comparison to current space debris and micrometeoroid models. The survey consists of photomicrographs of significant impacts in a variety of material types, accurate measurements of impact crater coordinates and dimensions for selected experiment surfaces and databasing of the crater data for reduction, manipulation and comparison to models. Large area surfaces which were studied include the experiment power and data system (EPDS) sunshields, environment exposure control canister (EECC) sunshields and the M0003 Signal conditioning unit (SCU) covers. Crater diameters down to 25 microns were measured and catalogued. Both leading (D8) and trailing (D4) edge surfaces were studied and compared. The EPDS sunshields are aluminum panels painted with Chemglaze A-276 white thermal control paint, the EECC sunshields are chromic acid-anodized aluminum, and the SCU covers are aluminum painted with S13GLO white thermal control paint. Typical materials which have documented impacts are metals, glasses and ceramics, composites, polymers and electronic materials. The results of this survey demonstrates the different response of materials to hypervelocity impacts. Comparison of the survey data to curves derived from the Kessler debris model and the Cour-Palais micrometeoroid model indicates a marked tendency for overprediction of small impacts (< 100 microns) and underprediction of large impacts (>1000 microns) with there being fair-to-good agreement for the medium-sized impacts. Comparison of the impact distributions among the various surfaces indicates significant variations which may be a function of material response effects. Representative photographs and summary graphs of the impact data will be presented.

EXPERIMENT NO. M0003

DAMAGE AREAS DUE TO IMPACT CRATERS ON LDEF ALUMINUM PANELS

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ABSTRACT

Because of its exposure time and total exposed surface area, the LDEF provides a unique opportunity to analyze the effects of the natural and man-made particle populations in Low Earth Orbit (LEO). This study concentrated on collecting and analyzing measurements of impact craters from seven painted aluminum surfaces at different locations on the satellite. These data are being used to (1) update the current theoretical micrometeoroid and debris models for LEO, (2) characterize the effects of the LEO micrometeoroid and debris environment of satellite components and designs, (3) help assess the probability of collision between spacecraft in LEO and already resident debris and the survivability of those spacecraft that must travel through, or reside in, LEO, and (4) help define and evaluate future debris mitigation and disposal methods.

Measurements were collected from one aluminum experiment tray cover (Bay C-12), two aluminum grapple plates (Bays C-01, C-10), and four aluminum experiment sun-shields (Bay E-09), all of which were coated with thermal paint. These measurements were taken at the Facility for Optical Interpretation of Large Surfaces (FOILS) Lab at NASA Johnson Space Center.

Virtually all features >0.2 mm in diameter possessed a spall zone in which all of the paint was removed from the aluminum surface, and which varied in size from 2-5 crater diameters. The actual craters vary from central pits without raised rims to morphologies more typical of craters formed in aluminum under hypervelocity impact conditions for larger features. Most craters exhibit a shock zone that varies in size from ~ 1 -20 crater diameters. In general, only the outer-most layer of paint was affected by this impact-related phenomenon, with several impacts possessing ridge-like structures encircling the area in which this outer-most paint layer was removed. Overall, there were no noticeable penetrations or bulges on the underside of the trays. One tray from the E-09 bay exhibited a spallation zone on the backside, approximately equal in size to that on the front side.

Results from this study demonstrate that the impact damaged areas extend far beyond the actual craters in coated or painted surfaces. While the cratering damaged $\ll 1\%$ of the total surface area, the total impact damage area exceeded 3%.

N92-27247 ;

**MECHANICAL PROPERTIES OF GLASSES
IMPACTED BY DEBRIS OR MICROMETEORITES**

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ABSTRACT

Mechanical strength measurements on five glasses and one glass ceramic exposed on LDEF have revealed no damage exceeding experimental limits of error after exposure. The measurement technique subjected less than 5% of the sample surface area to stresses above 90% of the failure strength. Seven micrometeorite or space debris impacts occurred at locations which were NOT in that portion of the sample subjected to greater than 90% of the applied stress. In consequence of this the impact events on the sample were not detected in mechanical strength measurements. The physical form and structure of the impact sites has been carefully examined to determine the influence of those events upon stress concentration associated with the impact and the resulting mechanical strength influence. The size of the impact site insofar as it determines flaw size for fracture purposes was examined. Surface topography of the impacts reveals that six of the seven sites display impact melting. The classical melt crater structure is surrounded by a zone of fractured glass. Residual stresses arising from shock compression and from cooling of the impact fused zone cannot be included in fracture mechanics analyses based on simple flaw size analyses. Strategies for refining estimates of mechanical strength degradation by impact events will be presented.

Experiment No. A0172

N92-27248

ANALYSIS OF LDEF MICROMETEOROID/DEBRIS DATA AND DAMAGE
TO COMPOSITE LAMINATES

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ABSTRACT

This report presents a nomogram based on the number/distribution of micrometeoroid/debris hits recorded on LDEF. The nomogram permits the user to estimate the total number of impacts that a space structure would encounter as a function of time in orbit, exposed area and angular location relative to the 'ram' direction. The data base for this nomogram is valid for the LEO parameters associated with LDEF. Examples are presented on the application of the nomogram to satellites and space structures of different cross-sections to that of LDEF. The effects of altitude and orbit inclination are also discussed. To further demonstrate the usefulness of this nomogram, results are compared to impact data measured on the UTIAS polymer matrix composite experiment (AO180). This report also examines the impact damage occurring on these composite materials and presents data on hole size, penetration depth and delamination area.

N92-27249

LDEF'S MAP EXPERIMENT FOIL PERFORATIONS YIELD HYPERVELOCITY IMPACT
PENETRATION PARAMETERS

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ABSTRACT

The space exposure of LDEF for 5.75 years , forming a host target in LEO orbit to a wide distribution of hypervelocity particulates of varying dimensions and different impact velocities, has yielded a multiplicity of impact features. although the projectile parameters are generally unknown and, in fact not *identical* for any two impacts on a target, the great *number* of impacts provides statistically meaningful basis for a valid comparison of the response of different targets. Given sufficient impacts for example, a comparison of impact features (even *without* knowledge of the project parameters) is possible between

- (i) differing material *types* (for the same incident projectile distribution)
- (ii) differing target *configurations* (e.g. thick and thin targets for the same material projectiles) and
- (iii) different *velocities* (using LDEF's different faces).

A comparison between different materials is presented for infinite targets of Aluminium, Teflon and Brass in the same pointing direction; the maximum finite-target penetration (ballistic limit) is also compared to that of the penetration of similar materials comprising a semi-infinite target. For comparison of impacts on similar materials at different velocities, use is made of the pointing direction relative to LDEF's orbital motion; first, however, care must be exercised to separate the effect of spatial flux anisotropies from those resulting from the spacecraft velocity through a geocentrically referenced dust distribution.

Data comprising thick and thin target impacts, impacts on different materials, and in different pointing directions is presented; hypervelocity impact parameters are derived.

Results are also shown for flux modelling codes developed to decode the relative fluxes of Earth orbital and unbound interplanetary components intercepting LDEF.

Modelling shows the west and Space pointing faces are dominated by interplanetary particles and yields a mean velocity of 23.5 kms⁻¹ at LDEF, corresponding to a V_∞ Earth approach velocity of = 20.9 km s⁻¹. Normally resolved average impact velocities on LDEF's cardinal point faces are shown in Table 1. As "excess" flux on the East, North and South faces is observed, compatible with an Earth orbital component below some 5 microns in particle diameter.

<u>East</u>	<u>West</u>	<u>North/South</u>	<u>Space</u>
V = 21.5	V = 11.1	V = 15.7	V. = 15.7

Table 1. Mean normally resolved velocity (kms⁻¹) of impacting interplanetary particles incident on LDEF's faces (true pointing) for geocentric particle velocity 23.5 kms⁻¹.

**HYPERVELOCITY IMPACT FACILITY FOR SIMULATING
MATERIALS EXPOSURE TO IMPACT BY SPACE DEBRIS**

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ABSTRACT

The Space Power Institute at Auburn University has constructed an electromagnetically driven particle accelerator for simulating the effects of space debris on the materials for use in advanced spacecraft. The facility consists of a capacitively driven accelerator section, a drift tube and a specimen impact chamber. The drift tube is sufficiently long that all electrical activity has ceased prior to impact in the specimen chamber. The impact chamber is large enough to allow a wide range of specimen geometries, ranging from small coupons to active portions of advanced spacecraft.

The electric drive for the accelerator consists of a 67 kJ, 50 kv capacitor bank arranged in a low inductance configuration. The bank is discharged through an aluminum armature/plastic ablator plate/projectile load in roughly 1.2 μ sec. The evaporation of the ablator plate produces an expanding gas slug, mostly H₂, traveling at a velocity of some 60 km/sec. Because of the pressure and local density, the expanding gas cloud accelerates projectiles due to plasma drag. To date, we have utilized projectiles consisting of 100 μ SiC, 100 and 400 μ Al₂O₃, 100 and 145 μ olivines. Since many particles are accelerated in a given experiment, there is a range of velocities for each shot as well as some particle breakup. Advanced diagnostics techniques allow determination of impact coordinates, velocity and approximate size for as many as 50 individual impacts in a given experiment. We routinely measure velocities in the range 1-15 km/sec. The fastest particle velocity measured to date has been 25 km/sec.

We have used this facility to study a variety of impact generated phenomena on coated surfaces, both paint and plastic, thermal blanket material, solar cell arrays and optical materials such as glass and quartz lenses.

This paper will describe in detail the operating characteristics of the gun, the advanced diagnostic scheme and the results of studies of crater morphology. Projectile residue analysis, as a function of impact velocity for the materials listed above, will also be discussed. Wherever possible, these results will be compared to those obtained by LDEF investigators and future experiments suggested which could help to explain unique features associated with LDEF impacts.

METEOROID & DEBRIS SPECIAL INVESTIGATION GROUP; STATUS OF 3-D CRATER ANALYSIS FROM BINOCULAR IMAGERY

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ABSTRACT

During the three month deintegration of LDEF, the M&D SIG generated approximately 5000 digital color stereo image pairs of impact related features from all space exposed surfaces. Currently these images are being processed at JSC to yield more accurate feature information (e.g., the depth and diameter of the crater with respect to the original target surface). An earlier paper (1) describes the theory and practice of determining this 3-dimensional feature information from stereo imagery. In practice, matching data points (tiepoints) are selected by an analyst from each of the images for several points on the original target surface so that corrections may be made for differences between the system focal plane and the target surface (i.e., rotations and offsets). Then tiepoints for impact related features are selected and heights for each point are calculated with respect to the original target surface. Work is currently underway to determine the minimum number of data points necessary to parametrically define impact crater morphologies in order to minimize the man-hour intensive task of tiepoint selection.

Initial attempts at deriving accurate crater depth and diameter measurements from binocular imagery were based on the assumption that the crater geometries were best defined by a paraboloid (a 3-dimensional parabola). We made no assumptions regarding the crater depth/diameter ratios but instead allowed each crater to define its own coefficients by performing a least-squares fit based on user-selected tiepoints. Initial test cases resulted in larger errors (on the order of 10%) than desired, so it was decided to test our basic assumption that the crater geometries could be parametrically defined as paraboloids. The method for testing this assumption was to carefully slice test craters (experimentally produced in an appropriate aluminum alloy) vertically through the center resulting in a readily visible cross-section of the crater geometry. Initially, five separate craters were cross-sectioned in this fashion. A digital image of each cross-section was then created, and the 2-dimensional crater geometry was then hand-digitized to create a table of XY positions for each crater.

A 2nd order polynomial (parabolic) was fitted to the data using a least-squares approach. (Note: A first order term was left in the equation to compensate for any rotation in the digital image.) The differences between the fit equation and the actual data were fairly significant, and easily large enough to account for the errors found in the 3-D fits. The differences between the curve fit and the actual data were consistent between the craters (i.e., the curve fit was always 6%-9% deeper at the base, narrower in the middle, and 6%-10% wider at the ambient surface). This consistency suggested that the differences were due to the fact that a parabola did not sufficiently define the generic crater geometry. Fourth order and sixth order equations were then fitted to each crater cross-section, and significantly better estimates of the crater geometry were obtained with each fit. (No attempt was made to fit odd order equations due to the assumption that the crater geometries are axially symmetric.) It should be noted that the fourth order fits resulted in consistent differences between the fit equations and the actual data (3%-4% shallower and 1%-2% wider), while the sixth order curve fits resulted in inconsistent differences (+/- 2% depth and +/- 1% diameter), implying that a sixth order curve fit best describes the crater geometry. Work is presently underway to determine the best way to make use of this new parametric crater definition.

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CHARACTERISTICS OF HYPERVELOCITY IMPACT CRATERS
ON LDEF EXPERIMENT S1003 AND IMPLICATIONS
OF SMALL PARTICLE IMPACTS ON REFLECTIVE SURFACES

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ABSTRACT

The Ion Beam Textured and Coated Surfaces Experiment (IBEX) was designated S1003 on LDEF at a location 98 degrees relative to the ram direction. Thirty-six diverse materials were exposed to the micrometeoroid (and some debris) environment for 5.8 years. Optical property measurements indicated no changes for almost all of the materials except S-13G, Kapton, and Kapton-coated surfaces, and these changes can be explained by other environmental effects. From the predicted micrometeoroid flux of NASA SP-8013, no changes in optical properties of the surfaces due to micrometeoroids were expected. However, there were hypervelocity impacts on the various diverse materials flown on IBEX. The characteristics of these craters were documented using scanning electron microscopy (SEM) and are presented in this paper.

Interest in placing large solar concentrator/solar dynamic systems in space for power generation has again brought up a concern for maintaining the integrity of the optical properties of highly specular reflecting surfaces in the near-Earth space environment. It has been shown that highly reflective polished metals and thin film coatings degrade when exposed to simulated micrometeoroids in the laboratory. At NASA Lewis Research Center, a shock tube was used to simulate the phenomenon of micrometeoroid optical properties of surfaces exposed to this impact were then evaluated. A calibrated sensor, 2,000Å Al/stainless steel, was developed to not only detect the small size micrometeoroid environment, but also to evaluate the degradation of the optical properties of thin aluminum films in space. This sensor was flown on LDEF experiment S1003 and also on the OSO III and SERT II satellites that were launched in 1967 and 1970, respectively. No changes in the optical properties of the highly reflective surface sensor on SERT II were measured during 20 years in space. The results, as determined by the accuracy of the sensor, indicate that a highly reflective surface should lose less than 1 percent of its specular reflectance in near-Earth orbit during 20 years.

N92-27253

LONG DURATION EXPOSURE FACILITY (LDEF) ATTITUDE MEASUREMENTS
OF THE INTERPLANETARY DUST EXPERIMENT

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ABSTRACT

The LDEF Interplanetary Dust Experiment (IDE) was unique in providing a time history of impacts of micron-sized particles on six orthogonal faces of LDEF during the first year in orbit. The value of this time resolved data depended on and was enhanced by the proper operation of some basic LDEF systems. Thus the value of the data is greatly enhanced when the location and orientation of LDEF is known for each time of impact. The location and velocity of LDEF as a function of time can be calculated from the "two-line elements" published by NASA Goddard Space Flight Center during the first year of the LDEF mission. The attitude of LDEF was passively stabilized in a gravity-gradient mode and a magnetically anchored viscous damper was used to dissipate roll, pitch, and yaw motions. Finally the IDE used a standard LDEF Experiment Power and Data System (EPDS) to collect and store data and also to provide a crystal derived clock pulse (1 count every 13.1072 seconds) for all IDE time measurements. All that remained for the IDE was to provide a system to calibrate the clock, eliminating accumulative errors, and also verify the attitude of LDEF.

The IDE used solar cells on six orthogonal faces to observe the LDEF sunrise and provide data about the LDEF attitude. The data was recorded by the EPDS about 10 times per day for the first 345 days of the LDEF mission. This data consist of the number of IDE counts since the last LDEF sunrise and the status of the six solar cells (light or dark) at the time of the last IDE count. The EPDS determined the time that data was recorded and includes with each record the master EPDS clock counter (1 count every 1.6384 seconds) that provided the range and resolution for time measurements. The IDE solar cells provided data for an excellent clock calibration, meeting their primary purpose, and this paper will present the time resolved LDEF attitude measurements that can be gleaned from this data.

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EXPERIMENT NO. A0201

LONG-TERM PARTICLE FLUX VARIABILITY INDICATED BY COMPARISON OF
INTERPLANETARY DUST EXPERIMENT (IDE) TIMED IMPACTS FOR LDEF'S FIRST
YEAR IN ORBIT WITH IMPACT DATA FOR THE ENTIRE 5.75-YEAR ORBITAL LIFETIME

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ABSTRACT

The electronic sensors of the Interplanetary Dust Experiment (IDE) recorded precise impact times and approximate directions for submicron to ~100-micron size particles on all six primary sides of the spacecraft for the first 346 days of the LDEF orbital mission. Previously-reported analyses of the timed impact data have established their spatio-temporal features, including the demonstration that a preponderance of the particles in this regime are orbital debris and that a large fraction of the debris particles are encountered as megameter-size clouds, some of which persist for long times. Short-term fluxes within such clouds can rise several orders of magnitude above the long-term average. These findings are consistent with the results of the first catastrophic hypervelocity laboratory impacts on a real satellite, recently reported in the press.

Analysis continues on the geometric and evolutionary characteristics of these clouds, as well as on the isolation and characterization of the natural micrometeoroid component in the IDE data, but the unexpectedly large short-term variations in debris flux raises the question of how representative an indication of the multi-year average flux is given by the nearly one year of timed data. It has therefore always been one of the goals of IDE to conduct an optical survey of the craters on the IDE detectors, to obtain full-mission fluxes for comparisons with the timed data. This work is underway, and the results presently in hand are significant. Optical scanning of the ram and wake (East and West) panels is complete, and it is clear that the first year was in some respects not representative of the subsequent years. The 5.75-year average flux on East panel was 90% of the value predicted by the average flux recorded during the first year, while it was only 34% on West panel. This suggests that western hemisphere spacecraft launches are a major contributor to the long-term flux and that their contribution is primarily in the smaller end of the size distribution. This conclusion follows from the fact that a closely-spaced series of launch failures (Titan, Delta, Ariane, Challenger) caused a virtual hiatus in launch activity during a large part of the later years of the LDEF mission. We hope to provide a quantification of the particle size distribution function in this case. The optical survey is underway on Space and Earth panels, and these should be complete by June. Partial results will also be available on North and on South.

EXPERIMENT N° AO201

ELEMENTAL ANALYSES OF HYPERVELOCITY MICRO-PARTICLE IMPACT SITES ON INTERPLANETARY DUST EXPERIMENT SENSOR SURFACES.

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ABSTRACT

The Interplanetary Dust Experiment (IDE) had over 450 electrically active ultra-high purity metal-oxide-silicon impact detectors located on the six primary sides of the Long Duration Exposure Facility (LDEF). Hypervelocity micro-particles (~0.2 to ~100 μm diameter) that struck the active sensors with enough energy to breakdown the 0.4 or 1.0 μm thick SiO_2 insulator layer separating the silicon base (the negative electrode), and the 1000 \AA thick surface layer of aluminum (the positive electrode) caused electrical discharges that were recorded for the first year of orbit. These discharge features, which include 50 μm diameter areas where the aluminum top layer has been vaporized, facilitate the location of the impacts. The high purity Al-SiO₂-Si substrates allow detection of trace (ppm) amounts of hypervelocity impactor residues.

After sputtering through a layer of surface contamination, secondary ion mass spectrometry (SIMS) is used to create two-dimensional elemental ion intensity maps of micro-particle impact sites on the IDE sensors. The elemental intensities in the central craters of the impacts are corrected for relative ion yields and instrumental conditions and then normalized to silicon. The results are used to classify the particles' origins as "manmade", "natural" or "indeterminate". The last classification results from the presence of too little impactor residue (a frequent occurrence on leading edge impacts), analytical interference from high background contamination, the lack of information on silicon residue, the limited usefulness of data on aluminum in the central craters, or a combination of these circumstances.

Several analytical "blank" discharges were induced on flight sensors by pressing down on the sensor surface with a pure silicon shard. Analyses of these blank discharges showed that the discharge energy blasts away the layer of surface contamination. Only Si and Al were detected inside the discharge zones, including the central craters, of these features. (limitation is based on availability of the SIMS instrument of one day per week for LDEF work.)

At the time of this writing, a total of 35 impacts on leading edge sensors and 22 impacts on trailing edge sensors have been analyzed. Of the leading edge impacts, 4 were classified as manmade particles, 9 were classified as natural, and 22 were classified as indeterminate. Of the trailing edge impacts, 4 were from classified as manmade particles, 5 were classified as natural, 3 were classified as indeterminate, and 10 have not been classified yet. Indeterminate classifications may change as data analysis continues.

Current plans call for the analysis of a total of 246 impact sites on sensors from all six locations on LDEF. This will provide a statistically significant set of micro-particle impactor analyses that can be compared to other LDEF and historical data.

EXPERIMENT NO. AO201

**SCANNING ELECTRON MICROSCOPE/ENERGY DISPERSIVE X-RAY ANALYSIS
OF IMPACT RESIDUES ON LDEF TRAY CLAMPS**

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ABSTRACT

To better understand the nature of particulates in low-Earth orbit (LEO), and their effects on spacecraft hardware, we are analyzing residues found in impacts on LDEF tray clamps.

LDEF experiment trays were held in place by 6 to 8 chromic-anodized aluminum (6061-T6) clamps that were fastened to the spacecraft frame using three stainless steel hex bolts. Each clamp exposed an area of approximately 58cm² (4.8cm X 12.7cm X .45cm, minus the bolt coverage). Some 337 out of 774 LDEF tray clamps have been archived at JSC and are available through the Meteoroid & Debris Special Investigation Group (M&D SIG).

Optical scanning of clamps, starting with Bay/Row A01 and working toward I 05, is being conducted at JSC to locate and document impacts as small as 40 microns. These impacts are then inspected by Scanning Electron Microscopy/Energy Dispersive X-ray Analysis (SEM/EDXA) to select those features which contain appreciable impact residue material. Based upon the composition of projectile remnants, and using criteria developed at JSC, we have made a preliminary discrimination between micrometeoroid and space debris residue-containing impact features. Presently, 13 impacts containing significant amounts of unmelted and semi-melted micrometeoritic residues were forwarded to Centre National d'Etudes Spatiales (CNES) in France. At the CNES facilities the upgraded impacts were analyzed using a JEOL T330A SEM equipped with a NORAN Instruments, Voyager X-ray Analyzer. All residues were quantitatively characterized by composition (including oxygen and carbon) to help understand interplanetary dust as possibly being derived from comets and asteroids.

**COMPOSITIONAL ANALYSIS OF PROJECTILE RESIDUES
ON LDEF INSTRUMENT AO187-1**

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ABSTRACT

Impact craters $>30\mu\text{m}$ and associated projectile residues have been analyzed by Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Analysis (EDXA). Objectives were to analyze a statistically significant number of projectiles to evaluate their chemical variability and possible clustering into discrete particle types. Bay A11 exposed six collector surfaces of anodized 1100-T4 ($>99\%$ pure) aluminum sheets, 0.32 cm thick, yielding an exposed surface area of 1.1 m^2 . Four of the six panels have been retained at JSC, and were optically scanned, one (A11E00E) was prepared for SEM/EDX analysis. Bay A03 was occupied by high purity (99.99%) gold sheets, 0.5 mm thick, yielding an exposed surface area of 0.85 m^2 . Sample processing included the optical scanning (6X), labeling, and dislodging (by a punch-die device) of each individual impact greater than $75\mu\text{m}$ for the aluminum and $30\mu\text{m}$ for the gold. 209 craters were dislodged from A11E00E, having crater diameters up to $3500\mu\text{m}$. Optical examination of the gold surfaces detected 238 craters, 198 of which were retained at JSC and analyzed via SEM/EDX. The analytical procedures included maximizing the geometric efficiency (take-off angles), using relatively long count times (500-1000 sec) and sufficiently high accelerating currents (25-30Kev). Despite diligent examination, a large number of craters did not exhibit measurable signals above background. Detectable residues were classified as either micrometeoritic or as man-made debris.

MICROMETEORITIC: Approximately 35% of the A11 impacts were determined to be natural micrometeoritic in origin. Subclasses of natural particles were also established as: (1) "chondritic"; (2) Monomineralic silicates of olivine and pyroxene; (3) Fe-Ni rich sulfides. Tray A03 contained 57 impacts classified as natural, all of which fell into the three subclasses. Furthermore, a significant portion of natural residues are present as relatively large, unmelted particles, which will permit detailed phase studies via Transmission Electron Microscopy or other methods.

ORBITAL DEBRIS: Man-made debris is present as Fe, Ni, Cr (stainless steel), Ti, Zn, Cl (spacecraft paint), Ag and Cu (electrical components). About 8% of the craters from A11E00E fall into this classification. The trailing edge surfaces revealed 30 craters (15%) produced by man-made particles. The dominant species (80%) reveals only aluminum lines in EDXA; the remaining 20% are akin to the man-made particles on the A11 collectors. The significant number of aluminum projectiles detected on the gold surfaces makes us suspect that many aluminum impactors will remain undetectable on our A11 collectors and other exposed surfaces comprised of aluminum.

NO RESIDUE: Less than 50% of the impacts into these (metallic) infinite half-space targets yield sufficient quantities of projectile material to permit detection. Some possess morphologies indicative of very high encounter speeds, this would significantly reduce the initial projectile mass needed and dilute residues present in the impact feature. Also, in such collisions much of the projectile may be completely vaporized and/or ejected beyond the local region of the resulting crater.

N92-27258

INTERPLANETARY METEOROID DEBRIS IN LDEF METAL CRATERS

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ABSTRACT

The extraterrestrial meteoroid residue found lining craters in LDEF aluminum and gold targets is highly variable in both quantity and type. In typical craters only a minor amount of residue is found and for these craters it is evident that most of the impacting projectile was ejected during crater formation. Less than 10% of the craters $>100\mu\text{m}$ contain abundant residue consistent with survival of a major fraction of the projectile. In these cases the residue can be seen optically as a dark liner and it can easily be analyzed by SEM-EDX techniques. Because they are rare, the craters with abundant residue must be a biased sampling of the meteoroids reaching the earth. Factors that favor residue retention are low impact velocity and material properties such as high melting point. In general the SEM-EDX observations of crater residues are consistent with the properties of chondritic meteorites and interplanetary dust particles collected in the stratosphere. Except for impacts by particles dominated by single minerals such as FeS and olivine, most of the residue compositions are in broad agreement with the major element compositions of chondrites. In most cases the residue is a thin liner on the crater floor and these craters are difficult to quantitatively analyze by EDX techniques because the electron beam excites both residue and underlying metal substrate. In favorable cases the liner is thick and composed of vesicular glass with imbedded FeNi, sulfide and silicate grains. In the best cases of meteoroid preservation the crater is lined with large numbers of unmelted mineral grains. The projectiles fragmented into micron sized pieces but the fragments survived without melting. In one case the grains contain linear defects that appear to be solar flare tracks. Solar flare tracks are common properties of small interplanetary particles and their preservation during impact implies that the fragments were not heated above 600C. We are investigating the meteoroid fragments in LDEF metal craters to determine the properties of interplanetary dust and to determine if there are meteoroid types that are overlooked or otherwise undetected in cosmic dust collections obtained from the stratosphere and polar ice.

EXPERIMENT NO. A0187-1

**SIMS CHEMICAL ANALYSIS OF EXTENDED IMPACTS ON THE LEADING
AND TRAILING EDGES OF LDEF EXPERIMENT AO187-2**

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ABSTRACT

LDEF Experiment AO187-2 consisted of 237 capture cells, 120 on the leading edge and 117 on the trailing edge. Each cell was made of polished Ge plates covered with 2.5 μm thick mylar foil at 200 μm from the Ge. Although all leading edge cells and 105 trailing edge cells had lost their plastic covers during flight, optical and electron microscope examination revealed extended impacts in bare cells from either edge that apparently were produced by high velocity projectiles while the plastic foils were still in place.

Detailed optical scanning yielded 53 extended impacts on 100 bare cells from the trailing edge that were selected for SIMS chemical analysis. Lateral multi-element ion probe profiles were obtained on 40 of these impacts. Material that can be attributed to the incoming projectiles was found in all analyzed extended compact features and most seem to be associated with cosmic dust particles. However, LDEF deposits are systematically enriched in the refractory elements Al, Ca and Ti relative to Mg and Fe when compared to IDPs collected in the stratosphere and to chondritic compositions. These differences are most likely due to elemental fractionation effects during the high velocity impact but real differences between interplanetary particles captured on LDEF and stratospheric IDPs cannot be excluded.

Recently we extended our studies to cells from the leading edge and the covered cells from the trailing edge. The 12 covered cells contain 20 extended impact candidates. Ion probe analysis of 3 yielded results similar to those obtained for impacts on the bare cells from the trailing edge. Optical scanning of the bare leading edge cells also reveals many extended impacts (42 on 22 cells scanned to date), demonstrating that the cover foils remained intact at least for some time. However, SIMS analysis showed elements that can reasonably be attributed to micrometeoroids in only 2 out of 11 impacts. 8 impacts have residues dominated by Al and one dominated by Ti, indicating a preponderance of orbital debris in leading edge impacts.

FURTHER ANALYSIS OF LDEF FRECOPA MICROMETEROID REMNANTS

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Experiments dedicated to the detection of interplanetary dust particles (IDPs) have been exposed within the FRECOPA payload, installed on the face of LDEF directly opposed to the velocity vector (west facing direction, location B3). We were mainly interested in the analysis of hypervelocity impact features of sizes $\leq 10 \mu\text{m}$, found in thick Al targets devoted to the research of impact features, a few cm^2 of which were loaned to us by J.C. Mandeville, P.I. of the FRECOPA experiment. In the 15 craters found in the scanned area ($\sim 4 \text{cm}^2$), the chemical analysis suggests an extraterrestrial origin for the impacting particles: the main elements we identified are usually referred to as "chondritic" elements: Na, Mg, Si, S, Ca and Fe are found in various proportions, intrinsic Al being masked by the Al target; we notice a strong depletion in Ni, never observed in our samples. Furthermore, C and O are present in 90% of the cases; the C/O peak height ratio varies from 0.1 to 3 (1).

Impactor simulations by light gas gun hypervelocity impact experiments have shown that meaningful biogenic element and compound information may be obtained from IDP residues below impacts of critical velocities, that are $\leq 4 \text{km sec}^{-1}$ for particles larger than $100 \mu\text{m}$ in diameter (2). Our results obtained for the smaller size fraction IDPs suggest that at such sizes, the critical velocity could be higher by a factor of 2 to 3, as chemical analysis of the remnants were possible in all the identified impact craters, performed on targets possibly hit at velocities $\geq 7.5 \text{km/s}$, which is the spacecraft velocity (3).

These samples are now subjected to an imagery and analytical protocol that includes FESEM (field emission scanning electron microscopy) and LIMS (laser ionization mass spectrometry). The LIMS analyses were performed using the LIMA-ZA instrument at CHARLES EVANS & ASSOCIATES. The instrument was first operated in the single laser probe mode, allowing for an atomic identification. On some particular events, characterised by a high C/O ratio, the instrument will be operated in the double laser probe mode, allowing for a molecular identification.

Results will be presented, clearly indicating that such small events show crater features analogous to what is observed at larger sizes; our first analytical results, obtained for 2 events (called P6 and P10) suggest that N is present in the IDPs remnants in which C and O have been identified by EDX analysis. In one case (P6), enrichment in K and P is observed. Surface contamination by NaCl is evident on the FRECOPA surfaces.

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N 9 2 - 2 7 2 6 1

PREDICTED AND OBSERVED DIRECTIONAL DEPENDENCE OF
METEOROID/DEBRIS IMPACTS ON LDEF THERMAL BLANKETS

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ABSTRACT

The number of impacts from meteoroids and space debris particles to the various LDEF rows is calculated using ESABASE/DEBRIS, a 3-D numerical analysis tool. It is based on the latest environment flux models and includes geometrical and directional effects.

A detailed comparison of model predictions and actual observations is made for impacts on the thermal blankets which covered the USCR experiment. Impact features on these blankets have been studied intensively in European laboratories and hypervelocity impacts for calibration have been performed.

The thermal blankets were located on all LDEF rows, except 3, 9, and 12. Because of their uniform composition and thickness these blankets allow a direct analysis of the directional dependence of impacts and provide a unique test case for the latest meteoroid and debris flux models.

OBSERVATION OF FULLERENES (C₆₀-C₇₀) ASSOCIATED WITH LDEF CRATER #31.

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ABSTRACT

We report in this communication the presence of fullerenes in and around LDEF crater #31. This crater has a high C level associated with it, and is interpreted as having been produced by the impact of a C-rich micrometeoroid.¹ Fullerenes are large three-dimensional C structures, among which the species C₆₀ (MW 720) and C₇₀ (MW 840) are preminent.² Fullerenes have several UV absorption bands, hence fullerenes should be detectable using UV laser ionization time-of-flight mass spectrometry.³

We used the LIMA-2A instrument at CHARLES EVANS & ASSOCIATES with pulsed UV laser (266nm) to search for high mass C species associated with LDEF crater 31. The mass range was 0 to 1200 amu. Low ablating laser power levels were used ($\leq 5 \times 10^7$ W \cdot cm⁻²); 200 mass spectra were acquired and summed. We observed high mass signals near m/z 720, exhibiting 24 amu separation, which is characteristic of fullerenes.⁴ Alkali ion signals were also observed. Little or no C clusters of intermediate mass were observed. We interpret the signals around m/z 720 as fullerenes, mainly C₆₀⁺ with lower levels of C₇₀⁺. We propose that the mechanism that produces these signals is resonant multiphoton ionization (REMPI).⁵ This selective mechanism explains why low mass C cluster ions are not observed along with the fullerenes, since they have much higher ionization potentials.

This finding is unexpected, since up to now the search for fullerenes in extraterrestrial materials has not been successful.⁶ We rule out instrumental artifacts, having tested the LIMA 2A instrument with a carbon target under a variety of laser power conditions, without detecting fullerene signals. We also rule out laboratory contamination of the sample, since (a) this crater was always under controlled conditions from the time it was cored from LDEF, (b) its companion, crater #74, does not exhibit fullerene signals, and (c) fullerene distribution decreases radially outward from crater 31 suggesting a crater ejection origin. We conclude that the fullerenes became associated with crater #31 in space. Two alternative (and exciting) scenarios are being considered at this time, i.e., either the fullerenes were carried by the C-rich projectile that formed #31, or the fullerenes formed upon impact with LDEF. We will show the results of experiments at the NASA Ames Vertical Gun Facility, which may establish some constraints on the origin of the fullerenes.

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ASTEROIDAL VERSUS COMETARY METEOROID IMPACTS ON THE LONG DURATION
EXPOSURE FACILITY (LDEF)

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ABSTRACT

Meteoroids that enter the Earth's atmosphere at low velocities will tend to impact the apex side (that surface facing the spacecraft direction of motion) of a spacecraft at a very high rate compared to the rate with which they will impact an antapex-facing surface. This ratio -- apex to antapex impact rates -- will become less as meteoroid entry velocities increase. The measured ratio, apex to antapex, for 500 micron diameter impact craters in 6061-T6 aluminum on LDEF seems to be about 20 from the work of the meteoroid SIG group and from the work of Humes that was presented at the first LDEF symposium. Such a ratio is more consistent with the meteoroid velocity distributions derived by Erickson and by Kessler, than it is with others that have been tested. These meteoroid velocity distributions have mean entry velocities into the Earth's atmosphere of 16.5 to 16.9 km/s.

Jackson and Zook (in a paper submitted to *Icarus*) have numerically simulated the orbital evolution of small dust grains emitted from asteroids and comets. For those asteroidal grains small enough (below about 100 microns diameter) to drift from the asteroid belt to the orbit of the Earth, under P-R and solar wind drag, without suffering collisional destruction, the following results are found: as their ascending or descending nodes cross the Earth's orbit (and when they might collide with the Earth), their orbital eccentricities and inclinations are quite low ($e < 0.3$, $i < 20^\circ$), and their mean velocity with respect to the Earth is about 5 or 6 km/s. When gravitational acceleration of the Earth is taken into account, the corresponding mean velocities relative to the top of the Earth's atmosphere are 12 to 13 km/s. This means that, at best, these small asteroidal particles can not comprise more than 50% of the particles entering the Earth's atmosphere. And when gravitational focussing is considered, they cannot comprise more than a few percent of those in heliocentric orbit at 1 AU. The rest are presumably of cometary origin.

ORIGIN OF ORBITAL DEBRIS IMPACTS ON LONG DURATION
EXPOSURE FACILITY'S (LDEF) TRAILING SURFACES

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ABSTRACT

Orbital debris tracked by the U. S. Space Command is mostly in near circular orbit around the Earth. If small debris were in the same types of orbits, there would be very few orbital debris impacts on LDEF's trailing surfaces. However, at least 15% of the impacts found on the trailing A03 Gold surface was found to be orbital debris impacts. This measurement suggests that the orbital distribution of small debris is not the same as that of larger debris. Although this is not a total surprise, since modeling of satellite breakups has predicted different distributions, it does raise questions as to what types of orbits could be responsible for these impacts.

A model was developed to explain these LDEF results. The model calculates the expected debris impact crater distribution around LDEF, as a function of debris orbital parameters. The results show that only low inclination and highly elliptical orbits could be responsible for these impacts. The most common object left in this type of orbit is an orbital transfer stage, used by the U. S. and ESA to place objects into geosynchronous orbit. These stages typically have orbits with their perigee in low Earth orbit, apogee near geosynchronous orbit, and inclinations near 28 and 7 degrees for the U. S. and ESA, respectively. Even large fragments from satellites, which break up in these types of orbits, are difficult to observe from the ground; consequently, little is known about the number and characteristics of breakups in these orbits. The LDEF data suggest that these objects are breaking up. The LDEF data also suggest that the ratio of the contribution of small debris from this type of orbit to the contribution from circular orbits is about an order of magnitude larger than the same ratio for debris tracked by the U. S. Space Command.

MODELLING THE NEAR-EARTH SPACE ENVIRONMENT USING LDEF DATA

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ABSTRACT

Near-Earth space is a dynamic environment, that is currently not well understood. In an effort to better characterize the near-Earth space environment, this study compares the results of actual impact crater measurement data and the Space Environment (SPENV) program developed in-house at POD, to theoretical models established by Kessler (NASA TM-100471, 1987) and Cour-Palais (NASA SP-8013, 1969). With the continuing escalation of debris there will exist a definite hazard to unmanned satellites as well as manned operations. Since the smaller non-trackable debris has the highest impact rate, it is clearly necessary to establish the true debris environment for ALL particle sizes. Proper comprehension of the near-Earth space environment and its origin will permit improvement in spacecraft design and mission planning, thereby reducing potential disasters and extreme costs.

Results of this study directly relate to the survivability of future spacecraft and satellites that are to travel through and/or reside in Low Earth Orbit (LEO). More specifically, these data are being used to (1) characterize the effects of the LEO micrometeoroid and debris environment on satellite designs and components, (2) update the current theoretical micrometeoroid and debris models for LEO, (3) help assess the survivability of spacecraft and satellites that must travel through or reside in LEO, and the probability of their collision with already resident debris, and (4) help define and evaluate future debris mitigation and disposal methods. Combined model predictions match relatively well with the LDEF data for impact craters larger than ~0.05 cm, diameter; however, for smaller impact craters, the combined predictions diverge and do not reflect the sporadic clouds identified by the Interplanetary Dust Experiment (IDE) aboard LDEF. The divergences cannot currently be explained by the authors or model developers. The mean flux of small craters (~0.05 cm diameter) is overpredicted by Kessler and underpredicted by Cour-Palais. This divergence may be a result of β -meteoroid fluxes, elliptical orbits or a combination of the two.

The results of this study illustrate the definite need for more intensive study of the near-Earth space environment, particularly the small particle regime, as it is the most degrading to spacecraft in LEO.

"THE INTERSTELLAR GAS EXPERIMENT: ANALYSIS IN PROGRESS"

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ABSTRACT

The interstellar gas experiment (IGE) exposed thin metallic foils in order to collect neutral interstellar particles which penetrate the solar system due to their motion relative to the sun. These atoms were entrapped in the collecting foils along with precipitating magnetospheric ions and with ambient atmospheric atoms. For the entire duration of the LDEF mission, seven of the foils collected particles arriving from seven different directions as seen from the spacecraft. In the mass spectrometric analysis of the trapped noble gas component, we detected the ^3He , ^4He , ^{20}Ne , and ^{22}Ne isotopes.

In order to infer the isotopic ratios in the interstellar medium from the measured concentrations found in the foil piece, several lines of investigation had to be initiated. The flux of incident noble gas atoms from the ambient atmosphere was estimated by detailed calculations. The contributions proved to be negligible, supporting the experimental evidence. Foil and machine backgrounds for the four isotopes which were measured had to be assessed individually. While this was easy for ^4He , spurious foil background of ^3He had to be monitored carefully by analyzing unflown foil pieces. Trapped Ne concentrations are not far above background.

During the flight, a stuck electrical relay precluded the foil-trays from sequencing as designed. Therefore, we could not use the seasonal variation of the direction of the incoming interstellar atoms to make the distinction between interstellar and magnetospheric components of the trapped particles. Instead, we had to try the method of stepwise heating to extract the interstellar component at lower temperatures than we use to extract the magnetospheric component (the interstellars hit the foil with lower energies than most of the magnetospherics).

New limiting values for the isotopic composition of the interstellar medium, unavailable yet from any other method of measurement, are emerging from this analysis.

**NEW METEOROID MODEL PREDICTIONS FOR
DIRECTIONAL IMPACTS ON LDEF**

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ABSTRACT

An extensive body of data, from meteors, zodiacal light, spacecraft-borne impact detectors (Helios, Pioneer, Galileo, Ulysses), and other sources, forms the basis of a new numerical model for the distributions of interplanetary meteoroids. For each of the five populations in this model it is possible to evaluate meteoroid concentration and flux for oriented surfaces or detectors having arbitrary position and velocity in interplanetary space (Divine, 1992, in preparation). For a spacecraft in geocentric orbit the effects of gravitational focussing and shielding by the Earth have been newly derived with full attention to the directionality of the particles, both on approach (i.e., relative to a massless Earth) and at the target. This modeling approach has been exercised to provide an estimate of meteoroid fluence for each of several oriented surfaces on LDEF.

This research was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Space Environments - Microgravity



Photo Number
L-90-10468
S32-85-08

**FOLLOW UP ON THE CRYSTAL GROWTH
EXPERIMENTS OF THE LDEF**

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The 4 solution growth experiments on the LDEF were presented thoroughly elsewhere. The CaCO_3 -experiment, and to a certain extent also the TTF-TCNQ-experiments yielded useful results.

In January 1992 the next series of solution growth experiments were sent to ESA for shipment to NASA, KSC. As on the LDEF, the SGF (Solution Growth Facility) of the EURECA-1 contains 4 large experiments. From the beginning the planning and development of the SGF was based on the LDEF package, but a number of changes and improvements were introduced. Still the basic concept has been maintained, and the CaCO_3 -experiment, that showed the best results on the LDEF, will now be repeated with improved technology and in a larger scale on the EURECA-1.

The contents of the 4 SGF experiments are as follows:

1. **Growth of Calcium-Carbonate Crystals.**
2. **Formation and Transformation of Tri-Calcium-Phosphate.**
3. **Growth of Zeolite Crystals.**
4. **Soret Coefficient Measurements (Diffusion).**

The scientific background for the choice of experiments and the major improvements of the SGF will be reviewed.

Furthermore some ideas on basic microgravity solution growth experimentation from ESA's newly established EWG (Expert Working Group) on solution growth will be reported.

Space Environmental Effects - Materials

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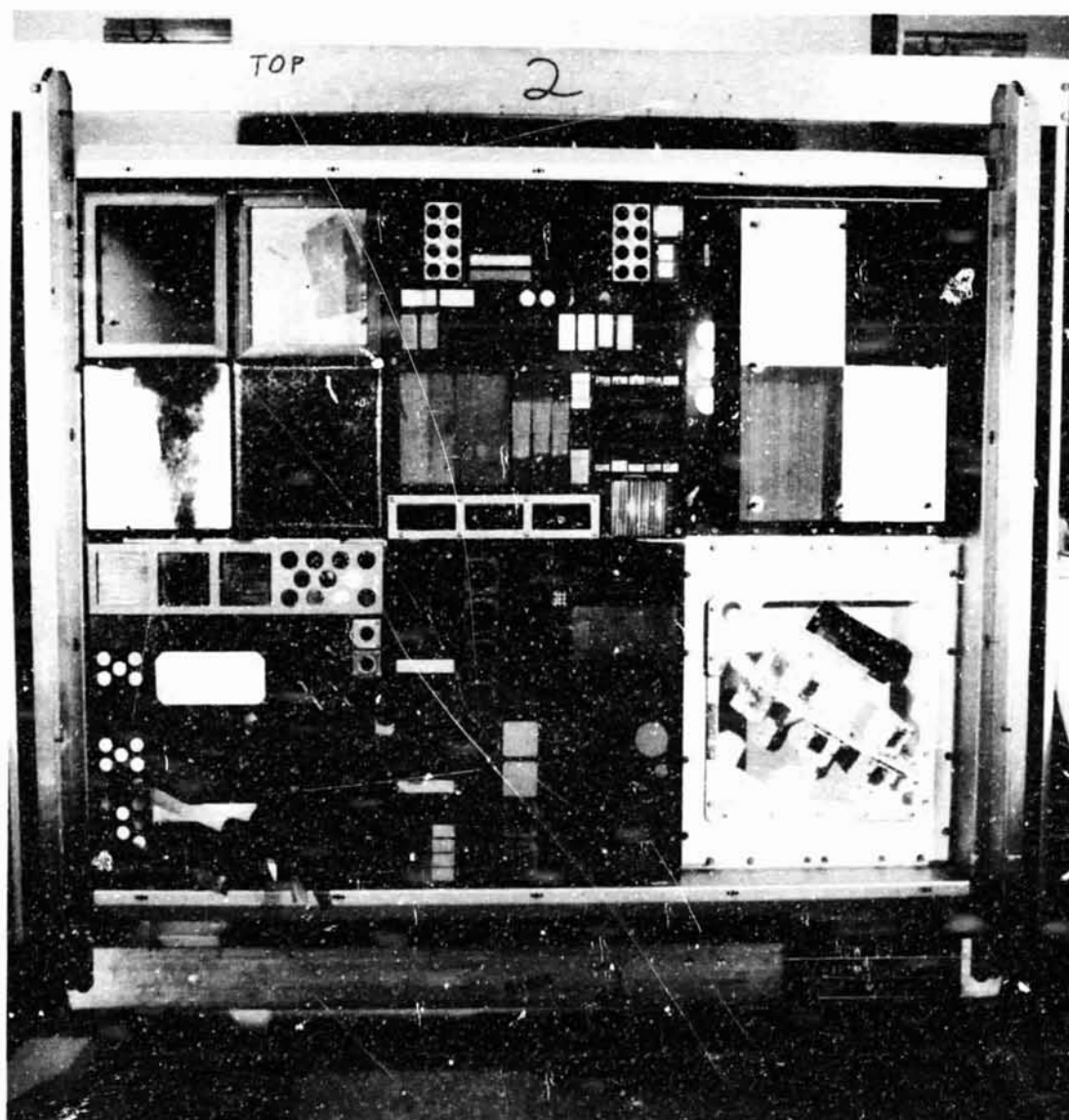


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KSC-290C-1529.03

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LDEF MATERIALS OVERVIEW

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ABSTRACT

The flight and retrieval of the National Aeronautics and Space Administration's Long Duration Exposure Facility (LDEF) provided an opportunity for the study of the low-Earth orbit (LEO) environment and long-duration space environmental effects (SEE) on materials that is unparalleled in the history of the U.S. space program. The 5-year, 9-month flight of LDEF greatly enhanced the potential value of all materials on LDEF to the international SEE community, compared to that of the original 1-year flight plan. The remarkable flight attitude stability of LDEF enables specific analyses of various individual and combined effects of LEO environmental parameters on identical materials on the same space vehicle. NASA recognized this potential by forming the LDEF Space Environmental Effects on Materials Special Investigation Group (MSIG) to address the greatly expanded materials and LEO space environment parameter analysis opportunities available in the LDEF structure, experiment trays, and corollary measurements, so that the combined value of all LDEF materials data to current and future space missions will be addressed and documented.

This presentation provides an overview of the interim LDEF materials findings of the principal investigators and the Materials Special Investigation Group. These revelations are based on observations of LEO environmental effects on materials made in-space during LDEF retrieval and during LDEF tray deintegration at the Kennedy Space Center, and on findings of approximately 1.5 years of laboratory analyses of LDEF materials by the LDEF materials scientists. These findings were extensively reviewed and discussed at the MSIG-sponsored LDEF Materials Workshop '91. The results are presented in a format which categorizes the revelations as "clear findings" or "confusing/unexplained findings" and resultant needs for new space materials developments and ground simulation testing/analytical modeling, in seven categories: Materials/Environmental Parameters and Data Bases; LDEF Contamination; Thermal Control Coatings and Protective Treatments; Polymers and Films; Polymer-Matrix Composites; Metals, Ceramics, and Optical Materials; Lubricant, Fastener, Seal, and Adhesive Materials. The utilization of LDEF materials data for future low-earth orbit missions will also be discussed, concentrating on Space Station Freedom.

In general, the LDEF data is remarkably consistent; LDEF will provide a "benchmark" for materials design data bases for satellites in low-Earth orbit. Some materials were identified to be encouragingly resistant to LEO SEE for 5.8-years; other "space qualified" materials displayed significant environmental degradation. Molecular contamination was widespread; LDEF offers an unprecedented opportunity to provide a unified perspective of unmanned LEO spacecraft contamination mechanisms. New material development requirements for long-term LEO missions have been identified and current ground simulation testing methods/data for new, durable materials concepts can be validated with LDEF results. LDEF findings are already being integrated into the design of Space Station Freedom.

 **LDEF**
MSIG
MATERIALS
SPECIAL INVESTIGATION GROUP

DATABASES FOR LDEF RESULTS

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ABSTRACT

One of the objectives of the team supporting the LDEF Systems and Materials Special Investigative Groups is to develop databases of experimental findings. These databases identify the hardware flown, summarize experimental results, conclusions, and provide a systems for acknowledging investigators, tracing sources of data, and future design suggestions. To date, databases covering the Optical experiments, and Thermal Control materials (chromic acid anodized aluminum, silverized Teflon blankets, and paints) have been developed at Boeing. We used the Filemaker Pro software, the database manager for the Macintosh computer produced by the Claris Corporation. It is a flat, text-retrievable database that provides access to the data via an intuitive user interface, without tedious programming. Though this software is available only for the Macintosh computer at this time, copies of the databases can be saved to a format that is readable on a personal computer as well. Further, the data can be exported to more powerful relational databases, capabilities, and use of the LDEF databases and describe how to get copies of the database for your own research.

Experiment No.: Compilation of several experiments

N92-27271

MATERIALS AND PROCESSES
TECHNICAL INFORMATION SYSTEM
(MAPTIS)
LDEF MATERIALS DATABASE

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ABSTRACT

The Materials and Processes Technical Information System (MAPTIS) is a collection of materials data which has been computerized and is available to engineers in the aerospace community involved in the design and development of spacecraft and related hardware. Consisting of various database segments, MAPTIS provides the user with information such as material properties, test data derived from tests specifically conducted for qualification of materials for use in space, verification and control, project management, material information, and various administrative requirements. A recent addition to the project management segment consists of materials data derived from the LDEF flight. This tremendous quantity of data consists of both pre-flight and post-flight data in such diverse areas as optical/thermal, mechanical and electrical properties, atomic concentration surface analysis data as well as general data such as sample placement on the satellite, A-O flux, equivalent sun hours, etc. Each data point is referenced to the primary investigator(s) and the published paper from which the data was taken. The MAPTIS system is envisioned to become the central location for all LDEF materials data.

This paper will consist of multiple parts, consisting of a general overview of the MAPTIS System and the types of data contained within, and the specific LDEF data element and the data contained in that segment.

192-27272

LDEF MATERIALS DATA ANALYSIS: REPRESENTATIVE EXAMPLES

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ABSTRACT

This talk will present results of measurements on silverized teflon, heat shrink tubing and nylon tie downs on the wire harness clamps, silvered hex nuts, and contamination deposits. We will interpret the results in terms of our microenvironments exposure model and locations on the LDEF. Distinct changes in the surface properties of FEP were observed as a function of UV exposure. Significant differences in outgassing characteristics were detected for hardware on the interior of row 3 relative to identical hardware on the interior of row 3 relative to identical hardware on nearby rows. The implications for in service performance will be reviewed.

N 9 2 - 2 7 2 7 3

LONG DURATION EXPOSURE FACILITY EXPERIMENT
M0003 DEINTEGRATION OBSERVATION DATABASE

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ABSTRACT

The four trays of the M0003 materials experiment on LDEF contained 1274 samples from 19 subexperiments. The complete sample complement represented a broad range of materials, including thin film optical coatings, paints, polymer sheets and tapes, adhesives, and composites, for use in various spacecraft applications including thermal control, structures, optics, and solar power. Since some subexperiments included duplicate samples exposed on the leading and trailing edge trays, for 9 week, 19 week, 40 week, and 58 month durations on both the leading and trailing edges, comparisons provided a valuable time history of degradation. During the deintegration of the subexperiments from the M0003 trays, each sample was examined using bright field, dark field, and Normarski light microscopy techniques. Over 3,000 color macrographs and photomicrographs were made of the condition of M0003 trays and the individual samples. Records of the condition of the samples, photographic records, and all available references of publications on postflight analyses on each sample were collected in a database. The photographs provide a visual comparison of the response of materials common to various subexperiments in different LDEF environments. Aerospace Corporation is distributing the database records and photographs to the general community. Information on how to access and receive copies of the photographs and written records on materials of interest from the database will be given in this presentation.

N92-27274

THERMAL CONTROL SURFACES EXPERIMENT (TCSE) MATERIALS
ANALYSIS

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ABSTRACT

Materials on the Thermal Control Surfaces Experiment (TCSE) underwent changes in their properties during the 5.8 years of exposure to the combined space environment. The analysis of these materials is continuing and current results will be discussed. Some materials were significantly degraded such as silver Teflon, S13GLO, and Z302; while others such as Z93 and YB71 were stable. Time dependent flight data is provided, along with preflight and postflight measurements. Results are compared with other experiments, demonstrating the atomic oxygen (AO) ram effect. Atomic oxygen texturing of silver Teflon varies with incident angle. Even indirect exposure to atomic oxygen appears to be involved with surface texturing on the interior of the TCSE. Localized contamination occurred at discrete locations both inside and on exterior surfaces. Most of the visible deposits were the result of the classical photo-enhanced contamination deposition. The synergism of combined space environmental effects is demonstrated by the specific localization of contamination caused by photo-enhanced deposition versus AO removal. Optical degradation measurements of these contaminated areas, utilizing a new portable reflectometer, will be presented.

EXPERIMENT NO. S0069

N92-27275

THERMAL CONTROL PAINTS ON LDEF: RESULTS OF SUB-EXPERIMENT 802-18

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ABSTRACT

Several thermal control paints were flown on LDEF, including the white paints Chemglaze A276, S13GLO, and YB-71, and the black paint D-111. The effects of low earth orbit, which includes UV radiation and atomic oxygen, varied significantly with each paint and its location on LDEF. For example, samples of Chemglaze A276 located on the trailing edge of LDEF darkened significantly due to UV-induced degradation of the binder, while leading edge samples remained white but exhibited severe atomic oxygen erosion. Although the response of S13GLO to low earth orbit is much more complicated, it also exhibited greater darkening on trailing edge samples as compared to leading edge samples. In contrast, YB-71 and D-111 remained relatively stable and showed minimal degradation.

This paper will examine the performance of these paints as determined by changes in their optical and physical properties, including solar absorptance, surface chemical changes, and changes in surface morphology. It will also provide a correlation of these optical and physical property changes to the physical phenomena that occurred in these materials during the LDEF mission.

EXPERIMENT NO. M0003

LDEF THERMAL CONTROL COATINGS POST-FLIGHT ANALYSIS

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ABSTRACT

The optical, physical, and chemical properties of selected spacecraft thermal control coatings exposed for 10 months and 5.8 years on the leading edge (Row 9) of LDEF are reported. Coatings include: quartz/silver optical solar reflector; silvered FEP Teflon; S-13GLO, YB-71, and A-276 white paints; Z-306 black paint; and sputter deposited coatings over graphite-epoxy composite substrates.

The solar absorptance, total normal emittance, scanning electron and X-ray photoelectron microscopy, and X-ray diffraction analyses will be compared for the control, 10-month exposed and 5.8-year exposed specimens. Data suggests that the high atomic flux over the last 6 months of the LDEF mission may have substantially influenced the results from this coatings experiment.

N92-27277

SELECTED RESULTS FOR LDEF THERMAL CONTROL COATINGS

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ABSTRACT

The investigation of space environmental effects on LDEF thermal control coatings by the Materials Special Investigation Group is continuing. Analyses of chromic acid anodize, A276 white paint, and Z306 black paint have been conducted, assessing performance as functions on environmental exposure. Test results from additional coatings, such as on scuff plates, M003, and the black chromium plate solar absorber, have been obtained. Guidelines for the use of these materials and comparisons to ground based test data will be presented.

N92-27278 !

FLUORESCENCE MEASUREMENTS OF THE THERMAL CONTROL COATINGS
ON
LDEF EXPERIMENTS S0069 AND A0114

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ABSTRACT

Strong fluorescence emissions were observed, during post flight ultraviolet light inspection of experiments S0069 and A0114, from some of the surfaces exposed to the space environment. Subsequent wavelength measurements of the fluorescence emission characteristics, indicated large changes occurred between controls and exposed materials. Black urethane based coatings, especially ones having a silicone atomic oxygen protective overcoat, appear bright yellow under ultraviolet exposure. Measurements showed that the urethane based coatings had their emission spectra shift into the visible wavelength range. In contrast, zinc oxide pigment type coatings showed a different effect, which was a quenching or reduction of their fluorescence versus exposure time. Silver Teflon bonded to aluminum with acrylic adhesive also showed a slight measurable fluorescence, which subsequent ground testing indicates to originate from the acrylic adhesive.

EXPERIMENT NO. S0069 & A0014

N92-27279

ATOMIC OXYGEN EFFECTS ON THERMAL CONTROL AND MIRROR COATINGS:
EVALUATION OF EXPERIMENT A0034

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ABSTRACT

Evaluation of the degradation attributed to contamination of the collector mirrors in Experiment A0034 exposed to various thermal control coatings on the Leading and Trailing Edges of the LDEF has provided some evidence for outgassing of coatings stimulated by atomic oxygen. Effects of the natural space environment on the coatings and mirrors, including particularly the effects of incident and re-directed atomic oxygen flux, have been investigated to determine the degrees of relative influence of the natural and induced environments on mirror degradation. The effects of exposure of the coatings and mirrors have been evaluated by optical, surface profiling, chemical, and SEM measurements and analyses. Preliminary results of these analyses are discussed for application to both the issues of mirror and coating stability to the natural environment and the specific issue of atomic oxygen stimulated outgassing.

N92-27280 !

ATOMIC OXYGEN EFFECTS ON LDEF EXPERIMENT A0171

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ABSTRACT

Mass and thickness changes measured in thin film, composites, polymers, metals, and paints from LDEF Experiment A0171 will be presented. Atomic oxygen accommodation and reactivity numbers along with morphology features are shown for a variety of A0171 materials. The validity of predicting long term erosion rates will be assessed from short term environmental exposures.

N 9 2 - 2 7 2 8 1

**MONTE CARLO MODELING OF ATOMIC OXYGEN ATTACK OF
POLYMERS WITH PROTECTIVE COATINGS ON LDEF**

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ABSTRACT

Characterization of the behavior of atomic oxygen interaction with materials on the Long Duration Exposure Facility (LDEF) will greatly assist in understanding the mechanisms involved, and will lead to improved reliability in predicting in-space durability of materials based on ground laboratory testing. A computational simulation of atomic oxygen interaction with protected polymers has been developed using Monte Carlo techniques. Through the use of assumed mechanistic behavior of atomic oxygen and results of both ground laboratory and LDEF data, a predictive Monte Carlo model has been developed which simulates the oxidation processes that occur on polymers with applied protective coatings that have defects. The use of high atomic oxygen fluence-directed ram LDEF results has enabled mechanistic implications to be made by adjusting Monte Carlo modeling assumptions to match observed results based on scanning electron microscopy. Modeling assumptions, implications, and predictions will be presented, along with comparison of observed ground laboratory and LDEF results.

N92-27282 !

LDEF POLYMERIC MATERIALS: 10 MONTHS VS. 5.8 YEARS OF EXPOSURE

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and

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ABSTRACT

The chemical characterization of several polymeric materials which received both 10 months and 5.8 years of exposure on a Row 9 experiment (A0134) is reported. Specimens include polysulfone film, polysulfone matrix/graphite fibers reinforced composites, and coated and uncoated epoxy matrix/graphite fiber reinforced composites. The effect of 10 months of exposure of an experimental silicon-containing polyimide copolymer film is also reported.

The results of infrared, thermal, x-ray photoelectron, and scanning electron microscope analyses will be compared for the two exposures. Solution property measurements on the thermoplastic polysulfone resin will also be presented. Molecular level effects attributable to exposure and present in 10-month specimens are not present in 5.8-year specimens. This suggests that increased atomic oxygen fluence toward the end of the mission may have eroded selected environmentally-induced changes in surface chemistry for 5.8-year specimens.

N 9 2 - 2 7 2 8 3

**THE VISCOELASTIC CHARACTERIZATION OF POLYMER MATERIALS
EXPOSED TO THE LOW-EARTH ORBIT ENVIRONMENT**

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ABSTRACT

Recent accomplishments in our research efforts have included the successful measurements of the thermal mechanical properties of polymer materials exposed to the low earth orbit environment. In particular, viscoelastic properties have been recorded using the Rheometrics Solids Analyzer (RSA II). Dynamic moduli (E' , the storage component of the elastic modulus, and E'' , the loss component of the elastic modulus) were recorded over three decades of frequency (0.1 to 100 rad/sec) for temperatures ranging from -150°C to 150°C . Although this temperature range extends beyond the typical use range of the materials, measurements in this region are necessary in the development of complete viscoelastic constitutive models. The experimental results have been used to provide the stress relaxation and creep compliance performance characteristics through viscoelastic correspondence principles. Our results quantify the differences between exposed and control polymer specimens. The characterization is specifically designed to elucidate a constitutive model that accurately predicts the change in behavior of these materials due to exposure. The constitutive model for viscoelastic behavior reflects the level of strain, the rate of strain, and the history of strain as well as the thermal history of the material.

EXPERIMENT NO. S1006

OXYGEN ISOTOPES IMPLANTED IN THE LDEF
SPACECRAFT

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Depth profiles of ^{16}O and $^{18}\text{O}/^{16}\text{O}$ have been measured on stainless steel nuts and copper sheet (from a grounding strap) recovered from the leading edge of LDEF (Tray E10). The measurements were obtained using dynamic SIMS (secondary ion mass spectrometry) using a VG Isolab 54 ion microprobe. Plots of $^{18}\text{O}/^{16}\text{O}$ against time, which is equivalent to depth assuming steady state conditions, show large depletions of up to a factor of 2 compared to the $^{18}\text{O}/^{16}\text{O}$ value at sea level, at the metal surface and then rise to normal values in the bulk metal. The ^{16}O current decreases by 2 orders of magnitude in the interior of the metal and the corresponding profile of anomalous ^{16}O is strongly peaked in the outer few tens of nanometers of the surface. This depth scale is however a tentative one based on estimated sputtering rates.

Plots of $^{18}\text{O}/^{16}\text{O}$ against $1/^{16}\text{O}$ should be linear if two isotopically distinct components, one of variable concentration (orbital component) and one of fixed concentration (normal oxygen) are mixed. Data to be presented at the meeting show departures from linearity which result from variability in the concentration of normal oxygen, but may also arise from the implantation of oxygen with a range of fractionation due to the decaying orbit of LDEF, sputtering of the surface by atomic oxygen and the different momenta of the two isotopes due to their equal velocities.

The potential for using this method as a means of identifying exposure to low Earth orbit, de-convoluting the effects of space exposure from terrestrial contamination and using the implanted anomalous oxygen as a means of studying the atomic oxygen density and upper atmosphere temperature height profile will be discussed at the meeting.

N 9 2 - 2 7 2 8 5

SILAZANE TO SILICA

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ABSTRACT

Thin film silica and/or methyl silicone have been detected on most external surfaces of the retrieved LDEF. Known sources of silicone in or on the LDEF appear inadequate to explain the ubiquitous presence of the silica and silicone films. Hexamethyldisilazane (HMDS) was used as the Challenger tile waterproofing compound for the Challenger/LDEF deployment mission. HMDS is both volatile and chemically reactive at STP. In addition, HMDS releases NH_3 which depolymerizes silicone RTV's. Polyurethanes are also attacked. Much of the silica/silicone contamination of LDEF resulted from HMDS.

STABILITY AND REACTIVITY OF DIMETHYLETHOXYSILANE

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ABSTRACT

Dimethylethoxysilane (DMES) is currently used to retreat HRSI shuttle tiles to provide a hydrophobic surface on the silica. DMES is a volatile, reactive silane that incorporates two reactive sites, the ethoxy group and the silica-hydride group. The work reported in this paper focused on the reactivity of these two groups with silica, water, quantitative reagents and within DMES itself.

From this preliminary study, it is concluded that the major reaction of the DMES with silica is through the ethoxy group although if a base is present, the hydride group can react also. This was confirmed by analyzing infrared spectra of the bonded DMES. DMES can react with free moisture on the silica surface producing a volatile compound that is easily removed from the surface. Decomposition of DMES produces tetramethyldisiloxane, diethoxydimethylsilane, dimethylsilane and silicone polymers. Therefore the stability of DMES with time is limited. These products were confirmed with GCMS techniques. Several analytical methods to quantify the amount of DMES either in solution or on silica by titrating the silica-hydride group were developed.

The reactivity of DMES is significant to long-term use of HRSI tiles or other silica surfaces coated with this material and further work on the chemical reactivity is warranted.

An ESR Study of the UV Degradation of FEP

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Spacecraft in low earth orbit are subjected to significant levels of high energy radiation, including UV and VUV wavelengths. The effects of UV radiation are enhanced over those at the surface of the earth, where the only incident wavelengths are greater than 290 nm. In low earth orbit the incident UV wavelengths extend below 290 nm into the VUV region, where the Lyman α -emissions of atomic hydrogen occur at 121 nm. In addition to electromagnetic radiation, in low earth orbit polymer materials may also be subjected to atomic oxygen particle radiation, which will result in direct oxidation of the polymer.

Thus, polymeric materials for space applications must exhibit a resistance to radiation damage of this type. One class of materials which have this characteristic are the fluorinated ethylene-propylene copolymers (FEP). FEP is produced commercially with a composition of 6:1 ethylene to propylene. These copolymers are semi-crystalline thermoplastics (crystallinity 50-60%). The polymers absorb radiation in the UV-VUV region with the low energy tail extending to wavelengths of approximately 300 nm.

Absorption of UV or VUV radiation can lead to the formation of excited states or radicals. Radicals are formed as a result of bond scission, which may involve one of the bonds in the main carbon chain, in which case the molecular weight of the polymer may be reduced, or a bond to one of the other atoms of the polymer, in which case the polymer may undergo crosslinking reactions.

Radicals are very reactive species. They will readily undergo reactions with oxygen to form peroxides, for example. These polymeric peroxides are thermally and photolytically unstable and can be responsible for chain reactions leading to extensive polymer degradation and other post-irradiation effects. The primary radicals may also react with polymer additives, such as antioxidants or UV stabilizers.

In this paper we describe an ESR study of the radicals produced by the UV irradiation of FEP granules and a commercially available FEP polymer film. The nature of the radicals formed in the polymers has been investigated and their reactions with oxygen and additives examined. The thermal stabilities of the polymer radicals have also been investigated to assess the importance of possible post-irradiation and ageing effects.

LDEF RESULTS FOR POLYMER MATRIX COMPOSITE EXPERIMENT AO 180

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ABSTRACT

This report presents a summary of the results obtained to-date on a polymer matrix composite experiment (AO 180) located at station D-12, about 82" off the "ram" direction. Different material systems comprised of graphite, boron and aramid (Kevlar®) fiber reinforcements have been studied. Although previous results have been presented on in-situ thermal-vacuum cycling effects, particularly dimensional changes associated with outgassing, additional comparative data will be shown from ground-based tests on control and flight samples. The system employed was fully automated for thermal-vacuum cycling using a laser interferometer for monitoring displacements. Erosion of all three classes of materials due to atomic oxygen (AO) will also be discussed, including angle of incidence effects. Data from this experiment will be compared to published results for similar materials in other LDEF experiments. Composite materials' erosion yields will be presented on an AO design nomogram useful for estimating total material loss for given exposure conditions in low Earth orbit (LEO). Optical properties of these materials will also be compared with control samples.

A survey of the damage caused by micrometeoroids/debris impacts will be addressed as they relate to polymer matrix composites. Correlations between hole size and damage pattern will be given. Reference to a new nomogram for estimating the number distribution of micrometeoroid/debris impacts for a given space structure as a function of time in LEO will be addressed based on LDEF data.

HIGH-TOUGHNESS GRAPHITE/EPOXY COMPOSITE MATERIAL EXPERIMENT

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ABSTRACT

Specially toughened T300 graphite / 5208 epoxy composites were fabricated with 7- μ m thick layers of Mylar interspersed between the prepreg plies to increase fracture toughness. The extent of bonding between adjacent plies is adjusted by changing the area fraction of a matrix of evenly spaced 1.1-mm diameter holes punched in the Mylar.

This LDEF experiment was designed to measure the effects of near-earth exposure on this class of composites over a range of properties. All specimens are 8 plies thick, with one of two different cross-ply angles and with one of four different values of bonding fraction between plies. The mechanical properties of interest are toughness, strength, and elastic modulus. Six toughness specimens and nine strength/modulus specimens were manufactured and flown.

Two additional sets of ground control specimens were manufactured concurrently with the flight specimens: a zero-time set, tested shortly after the LDEF launch, and a full-time set tested after LDEF retrieval at the same time as the flight specimens.

Although some degradation from exposure was observed, test results suggest that, within the limits set by the small number of specimens, properly coated graphite/epoxy composites of exceptional toughness can maintain useful mechanical properties for at least 5.8 years in near-earth orbit at altitudes of the order of 400 km.

EXPERIMENT NO. A0019

N 9 2 - 2 7 2 9 0 !

**SPACE ENVIRONMENTAL EFFECTS ON LDEF COMPOSITES: LEADING
GRAPHITE/EPOXY PANEL, SELECTED TRAILING EDGE SPECIMENS**

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ABSTRACT

The composite electronics module cover for the leading edge (row D9) experiment M0003-8 was fabricated from T300 graphite/934 epoxy unidirectional prepreg tape in a multi-oriented layup. This panel contained thermal control coatings in three of the four quadrants with the fourth quadrant left uncoated as a control. The composite experienced different thermal cycling extremes in each quadrant due to the differing optical properties of the coatings. Results will be presented on microcracking and other LEO effects on the coated panel substrate.

Experiment M0003-10 included graphite/epoxy, graphite/polymide and graphite polysulfone from the leading and trailing edges of LDEF. Results of a comparative study of these specimens will be presented.

N92-27291

EVALUATION OF LONG-DURATION EXPOSURE
TO THE NATURAL SPACE ENVIRONMENT
ON THE MECHANICAL PROPERTIES OF CARBON-
REINFORCED EPOXY AND POLYIMIDE COMPOSITES

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ABSTRACT

Experiment AO175 involved passive exposure -- on oblique leading and trailing faces of LDEF -- of carbon-fiber-reinforced laminates of epoxy, bismaleimide, and polyimide resins. Post-flight evaluation included: optical examination of exposed surfaces and polished cross-sections, panel weight and distortion measurements, ultrasonic c-scan inspection, and conventional mechanical testing of coupons machined from the panels.

The principal effects on the condition of these materials from the almost six-year exposure to the low-earth-orbit environment were: (1) superficial erosion of the resin-rich surface by atomic oxygen; and (2) the development, or increase in density, of microcracks through the thickness of the laminates.

The primary conclusion from the evaluation is that the structural performance of these materials was not measurably affected by the exposure. The observation of some evidence of atomic oxygen erosion, together with the knowledge that this erosion was much more pronounced in similar materials located on the leading edge of LDEF, confirms the need for some measure of protection for resin-matrix composites intended for long-term low-earth-orbit missions. Likewise, the evidence of increased microcracking provides a mechanism for structural degradation in these materials which could become critical under certain types of loading or longer periods of exposure.

EXPERIMENT NO. A0175

EFFECTS OF THE LOW EARTH ORBIT SPACE ENVIRONMENT ON THE SURFACE
CHEMISTRY OF KAPTON POLYIMIDE FILM: AN XPS STUDYMyung Lee, William Rooney, James WhitesideGrumman Corporate Research Center
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ABSTRACT

Kapton H (DuPont Trademark) polyimide specimens exposed to the low earth (LEO) space environment on LDEF experiment AO133 suffered significant weathering with surface erosions approximately 8.0 μm . Despite these effects no significant changes in bulk chemistry have been observed. X-ray photoelectron spectroscopy (XPS) was used to determine local changes induced from approximately 25% (nominal bulk is 17%) in 1980 vintage ground control specimens to nearly 53% in space exposed specimens. The greatest increase was observed for the divalent oxygen moieties, although a slight increase in carbonyl oxygen was also measured. Furthermore, the chemical shifts of all XPS peaks of space exposed Kapton are shifted to higher energy. This is consistent with a higher oxidation state of the space exposed surface. Finally, space exposed specimens had distinct silicon peaks (2p 100 eV and 2s 149 eV) in their XPS spectra in agreement with widespread reports of silicon contamination throughout the LDEF satellite. These results are discussed in terms of surface reactivity of the polyimide exposed to the LEO environment and the chemical nature of contaminants deposited on flight surfaces due to satellite outgassing.

SURFACE ANALYSES OF COMPOSITES EXPOSED TO THE SPACE ENVIRONMENT ON
LDEF

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ABSTRACT

We have conducted a series of surface analyses on carbon fiber/polyarylacetylene matrix composites that were exposed to the space environment on the Long Duration Exposure Facility (LDEF) satellite. These composite panels were arranged in pairs on both the leading edge and trailing edge of LDEF. None of the composites were catastrophically damaged by nearly six years of exposure to the space environment. Composites on the leading edge exhibited about 5 mils of surface erosion, but trailing edge panels exhibited no physical appearance changes due to exposure.

Scanning electron microscopy (SEM) was used to show that the erosion morphology on the leading edge samples was dominated by crevasses parallel to the fibers with triangular cross sections 10 to 100 μm in depth. The edges of the crevasses were well defined and penetrated through both matrix and fiber. The data suggest that the carbon fibers are playing a significant role in crevasse initiation and/or enlargement, and in the overall erosion rate of the composite. X-ray photoelectron spectroscopy (XPS) and energy dispersive X-ray spectroscopy (EDS) results showed the presence of silicone and hydrocarbon contamination from in-flight sources. The role of contamination in crevasse initiation and enlargement is unknown at this time.

These LDEF results demonstrate that the prediction of long term atomic oxygen erosion morphology for composite materials from erosion data obtained on short Space Shuttle missions is difficult. A better understanding of other factors such as thermal cycling and UV exposure which may influence erosion is necessary to improve the accuracy of the predictions.

EXPERIMENT NO. M0003

"THERMAL EXPANSION BEHAVIOR OF LDEF METAL MATRIX COMPOSITES"

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ABSTRACT

The effects of space environment on the thermal expansion stability of metal matrix composites (graphite/Al and graphite/Mg) will be presented. A sample from each category of metal matrix composites mounted on the leading and trailing edge were chosen for analysis of the temperature-time-thermal strain histories. Typical thermal expansion curves over the same range of temperature were selected at the beginning, mid, and end of the recording duration. The thermal expansion of selected post-flight LDEF samples were measured over the same range of temperature in laboratory using Michelson laser interferometer. The thermal strains were monitored concurrently from laser interferometer and a mounted strain gage to derive apparent

**SPECTRAL INFRARED HEMISPHERICAL REFLECTANCE MEASUREMENTS FOR
LDEF TRAY CLAMPS****Bobby E. Wood****Calspan Corporation****Arnold Air Force Base, TN 37389****Phone: 615/454-7719, FAX : 615/454-6348****Brian K. Cromwell, Charles W. Pender****Sverdrup Technology, Inc.****Arnold Air Force Base, TN 37389****Phones: 615/454-4746, 454-4649****Capt. Seth D. Shepherd****US Air Force, DOT****Arnold Air Force Base, TN 37389****Phone: 615/454-6517****ABSTRACT**

This paper describes infrared hemispherical reflectance measurements (2 - 15 μm) that were made on 58 chromic acid anodized tray clamps retrieved from the LDEF spacecraft. These clamps had been used for maintaining the experiments in place and had been located at various locations about the spacecraft. Changes in reflectance of the tray clamps at these locations were compared with atomic oxygen fluxes at the same locations. There doesn't seem to be a correlation between the two. A decrease in absorption band depth was seen for the surfaces exposed to space indicating that there was some surface layer erosion. In all of the surfaces measured very little evidence of contamination was observed and none of the samples showed evidence of the brown nicotine stain that has been seen so prominently in other experiments. Total emissivity values were calculated for both exposed and unexposed tray clamp surfaces. Only small differences, usually less than 1%, were observed. The spectral reflectances were measured using a hemi-ellipsoidal mirror reflectometer matched with an interferometer spectrometer. The rapid scanning capability of the interferometer allowed the reflectance measurements to be made in a timely fashion. The ellipsoidal mirror has its two foci separated by 2" and located on the major axis. A blackbody source was located at one focus while the tray clamp samples were located at the conjugate focus. The blackbody radiation was modulated and then focused by the ellipsoid onto the tray clamps. Radiation reflected from the tray clamp was sampled by the interferometer by viewing through a hole in the ellipsoid. A gold mirror (reflectance ~98%) was used as the reference surface.

N 9 2 - 2 7 2 9 6 1

SURFACE ANALYSIS OF ANODIZED ALUMINUM CLAMPS FROM NASA-LDEF SATELLITE

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ABSTRACT

Surface analysis results of selected anodized aluminum clamps containing black (Z306) and white (A276) paints which received nearly six years of LEO exposure on the Long Duration Exposure Facility are reported. Surface analytical techniques including x-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy (AES) and scanning electron microscopy/energy dispersive analysis by x-ray (SEM/EDAX) showed significant differences in the surface composition of these materials depending upon the position on the LDEF. Differences in the surface composition are attributed to varying amounts of atomic oxygen and vacuum ultraviolet radiation (VUV). Silicon containing compounds were the primary contaminant detected on these materials. [Research supported by NASA-LaRC]

N92-27297

CONTAMINATION ON LDEF SOURCES: DISTRIBUTION AND HISTORY

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ABSTRACT

An overview description of contamination sources from preflight, mission and post flight environments is presented. Examples of contamination events and processes from each stage of the LDEF mission are given. IR and XPS data characterizing some of the contaminant films will be shown. Property changes on surfaces due to contaminant films, and post-desposition changes in the contaminant films due to the space environment will be reported.

CONTAMINATION MEASUREMENTS ON EXPERIMENT M0003

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ABSTRACT

The contamination monitors on the M0003 experiment consisted of passive sample collectors to measure molecular and particulate deposition. The collectors were placed in the leading and trailing edge trays of M0003. The objective was to quantify the contaminants and determine how contamination affected the other materials in the trays. Duplicate collectors were placed inside the vacuum canisters that provided protection from the launch, ascent, deployment, and recovery environments.

The sample collectors and the analyses performed are listed below:

Sample Collector Material	Measurement Technique	Quantity Measured
Low Scatter, Black Glass Mirror	Light Scatter	Optical Effects of Particles
Aluminized, Fused Silica Mirror, Front Surface	Scanning Electron Microscopy (SEM), Electron Dispersive X-Ray (EDX)	Particle Numbers, Sizes, & Composition
Low Scatter, Nickel Mirror	SEM/EDX	Particle Numbers, Sizes, & Composition
Low Scatter, Gold Coated Nickel Mirrors	SEM/EDX	Particle Numbers, Sizes, & Composition
Gold on Copper Mirror	SEM/EDX	Particle Numbers, Sizes, & Composition
KRS-5 & Zinc Selenide Multiple Internal Reflectance Elements	Infrared Spectroscopy	Composition of Molecular Deposits
Aluminized, Fused Silica Mirror, Second Surface	Spectral Reflectance	Solar Absorptance

Analyses of the samples show small quantities of molecular deposition on both the leading and trailing edge trays. Silicone deposits are negligible. The aluminized, fused silica, second surface mirrors showed small changes in solar absorptances. This is consistent with the small quantities of molecular deposits deduced from the FTIR measurements. The conclusions that can be made are as follows:

- 1) Molecular contamination from local sources in the SSD-802 trays was small.
- 2) Return flux of LDEF outgassed products to the leading edge was small or consisted of hydrocarbons that were removed by atomic oxygen in the atmosphere.
- 3) In contrast to some other LDEF experiments, negligible silicone deposition was observed.
- 4) Silicone contamination from the Shuttle Orbiter during launch and deployment or recovery was negligible.

The paper will also present the results of particle deposition, light scatter, and a micrometeoroid (or debris) impact.

This work was performed under contract F04701-88-C-0089 with the Air Force Space Systems Division, AFSC, El Segundo, California

EXPERIMENT NO. M0003

N92-27299

EVALUATION OF SEALS, LUBRICANTS, AND ADHESIVES USED ON LDEF

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ABSTRACT

A wide variety of seals, lubricants, and adhesives were used on LDEF. This paper will discuss the ongoing Materials SIG investigation into the effect of the long term exposure of these various materials to the LEO environment. This investigation includes the testing of hardware at Boeing, documenting and collating experimenter test results, and deriving "lessons learned."

SPACECRAFT THERMAL CONTROL COATINGS
COMPARISON BETWEEN FLIGHT RESULTS OBTAINED ON LDEF AND MIR.

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ABSTRACT

Two flight experiments dedicated to the study of the performance of materials in space have been carried out. Material samples have been exposed passively to the LEO environment then retrieved for laboratory study.

The first experiment was conducted in the framework of the FRECOPA project and was flown on the trailing edge of LDEF (exposure to vacuum and UV radiation for 5.5 years).

The experiment COMES was installed outside of the MIR space station during an extravehicular activity; it was exposed to vacuum, O-atoms and UV radiation for 1.1 year; it was brought back to earth by cosmonauts. Due to a lack of knowledge in the actual spacecraft attitude, there is a large uncertainty in the O-atom fluence and UV dose experienced by COMES; moreover a large amount of contaminants of different origins has been observed on the COMES samples after retrieval.

In spite of that, the difference in exposure conditions and the use of transparent filters protecting some samples of COMES enable to differentiate the effects of UV radiation and oxygen atoms.

The degradations measured after these two flight experiments on several thermal control coatings (paints, metallized polymeric films with and without ITO) are compared.

The results show that:

- a) erosion is lower when contaminants layers are present on the sample surface,
- b) for some thermal control coatings (PSB and A276 paints) the degradation of optical reflectance is less important when UV and O-atoms are acting together; on some other materials (PSG120 FD and SG11 FD white paints, PU1 and Z306 black paints, aluminized Kapton) the degradation seems to be higher under their combined effect.
- c) on one of the faces of COMES, the erosion of FEP is approximately equal to that of Kapton; on the other face it corresponds to only one tenth of the erosion of Kapton.
- d) a clear emissivity change is observed on polyurethane black paints (specially on the conductive paints pigmented with graphite) when O-atoms are received.

EXPERIMENT AO 138-6

ANGULAR DISTRIBUTIONS OF 5eV ATOMIC OXYGEN
SCATTERED FROM SOLID SURFACES
ON THE LDEF SATELLITE

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ABSTRACT

The angular distribution of 5eV atomic oxygen scattered off several smooth solid surfaces was measured by the UAH experiment A0114 which flew on board the Long Duration Exposure Facility (LDEF). Target surfaces were silver, vitreous carbon and lithium fluoride crystal. The apparatus, which was entirely passive, has been described by Gregory and Peters⁽¹⁾. It uses the property of silver surfaces to absorb oxygen atoms with high efficiency; the silver being converted to optically transmissive silver oxide. A collimated beam of oxygen atoms is allowed to fall on the target surface at some pre-set angle. Reflected or re-emitted atoms are then intercepted by a silver film placed so that it subtends a considerable solid angle from the primary beam impact point on the target surface. The silver films are evaporated onto flexible optically-clear polycarbonate sheets which are scanned later to determine oxygen uptake. The device was previously tested on the STS-8 flight of the Space Shuttle⁽¹⁾.

While the silver detector cannot measure atom velocity or energy, its physical configuration allows easy coverage of large angular space both in the beam-plane (that which includes the incident beam and the surface normal), and in the azimuthal plane of the target surface.

The LDEF vehicle, which was passively stabilized in 3 axes, has been shown⁽²⁾ to have maintained attitude-stability to within a few tenths of a degree throughout the portion of the flight during which the majority of the oxygen fluence was experienced. This occurred late in the flight as the orbit decayed, which fact is known because the attitude-measuring device also used the silver-oxygen reaction⁽²⁾.

The UAH experiment, LDEF A0114, entitled "The Interaction of Atomic Oxygen with Solid Surfaces at Orbital Altitudes"⁽³⁾ carried 3 reflectometers with Ag, C and LiF targets. The devices were designed for nine months exposure, rather than the 5.75 years actually experienced. In spite of the heavy exposure, it has proven possible to extract the scattering information, and results on the 3 target surfaces will be discussed and compared.

1. J.C. Gregory and P.N. Peters, "A Measurement of the Angular Distribution of 5eV Atomic Oxygen Scattered off a Solid Surface in Low Earth Orbit" Rarefied Gas Dynamics 15 (1), 644-656, (1986).
2. J.C. Gregory and P.N. Peters, "Measurement of the Passive Attitude Control performance of a Recovered Spacecraft" Journal of Guidance, Control and Dynamics (1992), in press.
3. J.C. Gregory and P.N. Peters, "The Interaction of Atomic Oxygen with Solid Surfaces at Orbital Altitudes" in The Long Duration Exposure Facility, eds. W. Kinard and D. Carter, NASA SP-473, p.14, (1984).

INTERACTION OF ATOMIC OXYGEN WITH THIN FILM AND BULK COPPER:
AN XPS, AES, XRD AND PROFILOMETER STUDY

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ABSTRACT

The University of Alabama in Huntsville (UAH) experiment A-0114 was designed primarily to study degradation of material surfaces due to LEO atmospheric oxygen. The experiment contained 128 one inch circular samples; metals, polymers, carbons and semiconductors. Half of these samples were exposed on the front and remaining on the rear of LDEF.

Among metal samples, copper has shown some interesting new results. Two types of copper samples : a film sputter coated on fused silica and a bulk piece of OFHC copper were characterized employing a variety of techniques such as X-ray and Auger electron spectroscopies, X-ray diffraction and high resolution profilometry. Cu 2p core level spectra were used to characterize the presence of Cu₂O and CuO in addition to Cu Auger LMM lines. These results are supported by our recent X-ray diffraction studies which clearly establish the presence of Cu oxides which we were unable to prove in our earlier work. Profilometry showed an increase in thickness of the thin film sample where exposed to 106.7 ± 0.5 nm from an initial thickness of 74.2 ± 1.1 nm. Further studies with SEM and ellipsometry are underway.

Experiment No: A-0114

Space Environmental Effects - Systems

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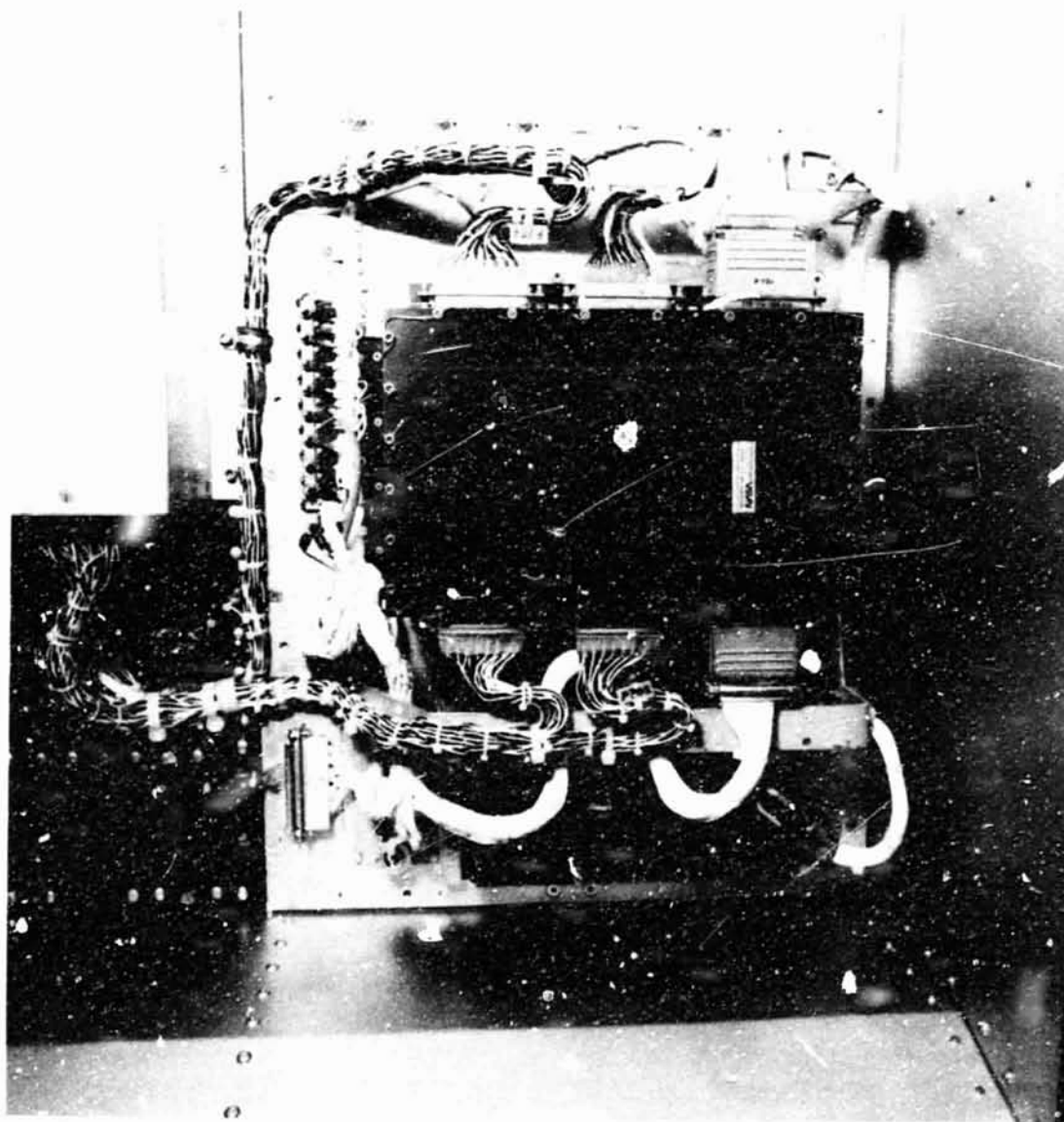


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OVERVIEW OF THE SYSTEMS SPECIAL INVESTIGATION

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ABSTRACT

The Systems Special Investigation Group (SIG), formed by the LDEF Project Office to perform post flight analysis of systems hardware, was chartered to investigate the effects of the extended LDEF mission on both satellite and experiment systems and to coordinate and integrate all systems analyses performed in post flight investigations.

The LDEF carried a remarkable variety of electrical, mechanical, thermal, and optical systems, subsystems, and components. Nineteen of the 57 experiments flown on the LDEF contained functional systems that were active on-orbit. Many of the other experiments possessed at least a few specific components of interest to the Systems SIG, such as adhesives, seals, fasteners, optical components, thermal blankets.

Almost all of the top level functional testing of the active experiments has been completed, but many components are still under investigation by either the Systems SIG or individual experimenters. Results reported to date have been collected and integrated by the Systems SIG and an overview of the current results and the status of the Systems Investigation are presented in this paper.

N 9 2 - 2 7 3 0 4 !

NEW RESULTS FROM FRECOPA ANALYSIS

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ABSTRACT

Given LDEF new situation (5,8 years mission), CNES decided to set up a team to analyse FRECOPA Systems (AO 138). After the results presented in Orlando at the first post retrieval conference, this paper summarizes our last appraisals.

We studied first the kinematic system. We observed damage on DELRIN gears and lubricant ageing. The results are based on comparative appraisals between components after flight and those stored on ground in laboratory conditions. We observed also the aluminium surface treatment in the exposed areas and we measured the thermo-optical properties changes. We examined after, the welding ageing of the structure.

The second point is the analyse of shadows observed on the tray. One, inside (canister shadow) and three on the back side of the tray (bolt, rivets and wire shadows). We used surface analysis means as X Ray and R.B.S. to determine the origin of this contamination. We worked with the same means on teflon glass fabric used on the back to find also the presence of contamination.

Now, with all the results stored, we try to give a ruling on the use of FRECOPA materials in space environment (LEO orbit).

N92-27305

MECHANISMS FLOWN ON LDEF

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ABSTRACT

A wide variety of mechanisms were flown on LDEF. These include canisters, valves, gears, drive train assemblies and motors. This report will provide the status of the Systems SIG effort into documenting, integrating, and developing "lessons learned" for the variety of mechanisms flown on LDEF. Results will include both testing data developed by the various experimenters and data acquired by testing of hardware at Boeing.

N92-27306 !

DEGRADATION OF ELECTRO-OPTIC COMPONENTS ABOARD LDEF

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ABSTRACT

Remeasurement of the properties of a set of electro-optic components exposed to the low-earth-orbit environment aboard LDEF indicates that most components survived quite well. Typical components showed some effects related to the space environment unless well protected. The effects were often small but significant. Results for semiconductor infrared detectors, lasers, LED's, filters, mirrors, and black paints will be presented. Semiconductor detectors and emitters were scarred but reproduced their original characteristics. Spectral characteristics of multi-layer dielectric filters and mirrors were found to be altered and degraded. Increased absorption in black paints indicates an increase in absorption sites, giving rise to enhanced performance as coatings for baffles and sunscreens. We find plastics and multi-layer dielectric coatings to be potentially unstable. Semiconductor devices, metal, and glass are more likely to be stable.

EXPERIMENT NO. S0050

N92-27307

DEGRADATION OF OPTICAL
COMPONENTS IN A SPACE ENVIRONMENT

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ABSTRACT

The objective of the Phillips Laboratory (PL) LDEF experiment is to determine the adverse effects of the natural space environment on laser optical component and coating materials. The LDEF experiment provides a unique opportunity for the study of optical material response to an extended low earth orbit space exposure.

The PL (Formerly the Air Force Weapons Laboratory) samples consist of 10 sets of the six materials each. These materials are uncoated fused silica, magnesium fluoride coated fused silica, uncoated molybdenum, molybdenum coated with chromium, silver and thorium fluoride, diamond turned copper, and diamond turned nickel plated copper. These samples are unique among the LDEF optical samples as they were housed in shuttered containers and each set received a different space exposure. Of the 10 sample sets, two sets were never flown (controls), 1 set was flown and not exposed, and the other sets were exposed for 3, 6, 9 and 70 months. Four sets were located on the spacecraft leading edge and four sets on the trailing edge.

Testing of the samples is divided into two phases. Phase I is restricted to visual, microscopic and optical evaluation. Phase II tests are designed performance degradation quantified in Phase II. Performance degradation will be correlated to establish trends between sample location, duration of exposure, atomic oxygen exposure and other space environment conditions.

This paper discusses the results of the tests thus far performed on the LDEF samples and the plans for the future.

EXPERIMENT NO. M0003-2

OPTICAL CHARACTERIZATION OF CONTAMINANT FILM

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ABSTRACT

The so called "nicotine stain" documented at many locations on the LDEF is still unexplained as to the exact origin and mechanism of deposition, although enough is known to have some understanding of the conditions coincident for the formation of the deposits. Direct and scattered atomic oxygen flux, and solar UV radiation interacting with materials outgassing products have all been implicated in the formation of the dark brown contamination deposits. The nicotine stain represents a potential of performance degradation for spacecraft designed for long term operation in low Earth orbit and therefore, a need exists to characterize this form of spacecraft self-contamination and quantify the impact on thermal/optical systems.

Optical property measurements in the spectral range of 2 to 10 microns were performed on specimens of the contaminant film taken from below the flange of an experimental tray located on row 10 of the LDEF. Reflectance measurements of the contaminant film as deposited on the surface and as free standing films are presented along with transmission spectra for the bulk material. Thickness measurements and micrographic examination of the cross section of the deposit reveal the layered structure of the deposit which further implicates solar illumination as a factor in the deposition mechanism.

N 9 2 - 2 7 3 0 9

IN ORBIT DEGRADATION OF UV OPTICAL COMPONENTS
FOR THE WAVELENGTH RANGE 10-140 μm .
AO 138.3 (FRECOPA)

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ABSTRACT

Optical components (thin film filters and multilayered mirrors) for use in the wavelength range 10-140 μm were included in the vacuum tight container FRECOPA in preparation for the SOHO mission. They were exposed during 9 months at the beginning of the LDEF flight. One batch of components was exposed to the sun, while another one was shielded from solar radiation.

The results of optical transmission measurements of the flight components and of a groundbase reference set, made at the ORSAY Synchrotron radiation light source are presented.

N92-27310 !

STUDIES OF EFFECTS ON OPTICAL COMPONENTS AND SENSORS:
LDEF EXPERIMENTS AO-147 (ERB COMPONENTS) AND S-0014 (APEX)

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ABSTRACT

Some of the results of testing of optical filters and window materials and thermopile sensors of the two experiments will be presented.

N92-27311

**EFFECTS OF LONG TERM SPACE ENVIRONMENT
EXPOSURE ON OPTICAL SUBSTRATES AND COATINGS
(S0050-2)**

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ABSTRACT

The experiment consisted of Fused Silica and Ultra Low Expansion (ULE(tm)) glass samples which were either uncoated or had high reflectance silver, antireflectance, or solar rejection coatings. A set of duplicate control samples was manufactured and stored in a controlled environment for comparison purposes. We will present spectral curves for the glass and coatings which define pre-flight, post-flight, and post-cleaning performance. Data on the analysis of the contaminate deposited on the samples and stress measurements in the glass will also be presented. Some results of particular interest are that the contaminate composition varied between different types of samples, and no darkening of the ULE(tm) glass occurred due to the radiation exposure.

N92-27312-1

LDEF SPACE OPTICS HANDBOOK

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ABSTRACT

There is a need to present design guidelines derived from the LDEF space optics experiments to hardware designers. In response to this need, a small study program has just been started by SAIC and POD Associates for the Phillips Laboratory. The objective is to prepare a top-level review of available results on the behavior of certain optical components in the LDEF space experiments. The optics interest centers on optical surfaces and coatings, and fabrication processes for laser windows and mirrors. The program has two main parts: the first phase, one-year long, consists of identifying and acquiring data from the appropriate investigators. The second phase, ending in December 1993, comprises report preparation as well as selected, prioritized, additional characterization of certain samples, coordinated with the principal investigators and the Phillips Laboratory. This short paper outlines the program under way.

N 9 2 - 2 7 3 1 3

**RULED AND HOLOGRAPHIC EXPERIMENT
(A0 138-5)**

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Fax n°33.1.69.09.07.21

ABSTRACT

The A0 138-5 experiment has been designed, via the FRECOPA (FRench COoperative PAYload) experiment with the aim to study the optical behaviour of different diffraction gratings submitted to space vacuum long exposure and solar irradiation.

Samples were ruled and holographic gratings, masters or replica, and some additional control mirrors with various coatings.

The experiment was located on the B3, trailing edge of the L.D.E.F and has been protected against Atomic Oxygen flux. The experienced thermal cycling has been evaluated from - 23°C to 66°C during the flight, 34 000 orbits.

The samples (two batches of four pieces) were located on a dedicated plate, by pair of equivalent gratings or mirrors, optical faces located on the external side. The plate was inside a cannister, which had been opened in space for ten months. When the satellite returned to K.S.C., the remaining vacuum in the cannister was still correct.

The analysis has been focussed on the triple point characterization including light efficiency, wavefront flatness quality and stray light level.

Tests were conducted on control mirrors and gratings (ruled and holographic master or replica) loaded but not exposed to cosmic dust or direct solar irradiations. They did not show any significative variations.

Solar exposure had damaged the coating (aluminum and platinum) reflectivity in the Ultra-Violet region, the degradation is higher with the gratings, in terms of efficiency. However, wavefront flatness quality and stray light level tests revealed no additional changes.

N92-27314

HOLOGRAPHIC DATA STORAGE CRYSTALS FOR THE LDEF

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ABSTRACT

Lithium niobate is a significant electro-optic material, with potential applications in ultra high capacity data storage and processing systems. Lithium niobate is the material of choice for many integrated optical devices and holographic mass memory systems. For crystals of lithium niobate were passively exposed to the space environment of LDEF. Three of these crystals contained volume holograms. Although the crystals suffered the surface damage characteristic of most of the other optical components on the Georgia Tech tray, the crystals were recovered intact. The holograms were severely degraded because of the lengthy exposure, but the bulk properties are being investigated to determine the spaceworthiness for space data storage and retrieval systems.

V92-27315

**CHARACTERIZATION OF A SPACE ORBITED
INCOHERENT FIBER OPTIC BUNDLE**

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ABSTRACT

The purpose of this paper is to report the results of a study performed to determine the effects of adverse space environments on a bundle of 1300+ optical fibers space orbited for 69 months. Experimental results are presented on an incoherent fiber optic bundle oriented in low earth orbit aboard the Long Duration Exposure Facility (LDEF) satellite as part of the Space Environment Effects Experiment (M0006). Measurements were performed to determine if space induced radiation effects changed the bundle characteristics. Data demonstrating the success of this light transmitting fiber optical bundle to withstand the adverse space environment are presented.

EXPERIMENT No. M0006

N 9 2 - 2 7 3 1 6 |

**ANALYSIS OF SPACE ENVIRONMENT EFFECTS ON ACTIVE
FIBER OPTIC LINKS ORBITED ABOARD THE LDEF**

E. W. Taylor

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ABSTRACT

This interim analysis correlates the results of the "Preliminary Analysis of WL Experiment #701, 'Space Environment Effects on Operating Fiber Optic Systems' " (NASA Report CP-3134) with space simulated post retrieval terrestrial studies performed on the M0004 experiment. Temperature cycling measurements were performed on the active optical data links for the purpose of assessing link signal to noise ratio and bit error rate performance some 69 months following the experiment deployment in low earth orbit. The early results indicate a high correlation between pre-orbit, orbit recorded, and post orbit functionality of the first known and longest space demonstration of operating fiber optic systems.

EXPERIMENT No. M0004

N92-27317

RADIATION AND TEMPERATURE EFFECTS ON LDEF
FIBER OPTIC CABLE SAMPLES

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ABSTRACT

This paper will concentrate on results obtained from the JPL Fiber Optics LDEF Experiment since the June 1991 Experimenters Workshop. Radiation darkening of laboratory control samples will be compared to the LDEF flight samples. The results of laboratory temperature tests on the flight samples extending over a period of about nine years including the preflight and postflight analysis periods will be described.

N92-27318 !

LONG DURATION EXPOSURE FACILITY (LDEF)
LOW-TEMPERATURE HEAT PIPE EXPERIMENT PACKAGE (HEPP)
FLIGHT RESULTS

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ABSTRACT

The Low Temperature Heat Pipe Flight Experiment (HEPP) is a fairly complicated thermal control experiment that was designed to evaluate the performance of two different low temperature ethane heat pipes and a n-Heptane Phase Change Material (PCM) canister. A total of 388 days of continuous operation with an axially grooved aluminum fixed conductance heat pipe of axially grooved stainless steel heat pipe diode was demonstrated before the EPDS batteries lost power. The inability of the HEPP's radiator to cool below 190°K in flight prevented freezing of the PCM and the opportunity to conduct transport tests with the heat pipes. Post flight tests showed that the heat pipes and PCM are still functioning.

This paper presents a summary of the flight data analysis for the HEPP and its related support systems. Pre and Post-flight thermal vacuum test results are presented for the HEPP thermal control system along with individual heat pipe performance and PCM behavior. Appropriate SIG related systems data will also be included along with a "Lessons Learned" summary.

POST-FLIGHT ANALYSES OF THE CRYSTALS FROM THE M0003-14
QUARTZ CRYSTAL MICROBALANCE EXPERIMENT

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ABSTRACT

Quartz Crystal Microbalances constructed by QCM Research were flown on the leading and trailing edges of LDEF as one of the sub-experiments of M0003. Response of the crystals coated with 150 Å of $\text{In}_2\text{O}_3\text{Zn}$ was recorded during the first 424 days of the mission. A second QCM with crystals coated with 150 Å was also flown but not monitored. The flight data and temperature profiles will be presented.

After the flight, the QCM's were disassembled and analyzed in The Aerospace Corporation laboratories. The samples included the crystals from the leading and trailing edge samples of both types of coatings along with the reference crystals which were inside the QCM housing. Analyses were performed by scanning electron microscopy, energy dispersive X-ray analyses, X-ray photoelectron spectroscopy, ion microprobe mass analysis, and reflectance spectroscopy in the infrared and UV/visible region.

The crystals are contaminated predominantly with silicone compounds. The contamination is higher on the leading edge than on the trailing edge and higher on the exposed crystals than on the reference crystals. No significant differences in composition of the In_2O_3 crystal were noted. Differences in the reflectance spectra and surface analysis of the ZnS crystals will be discussed.

EXPERIMENT NO. M0003

N 9 2 - 2 7 3 2 0

STUDY OF FACTORS DETERMINING THE RADIATION SENSITIVITY
OF QUARTZ CRYSTAL OSCILLATORS (A0189)

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ABSTRACT

Previous post-flight tests of quartz resonators indicated that resonators fabricated from swept premium Q quartz were affected by the space radiation environment experienced on the LDEF flight. Resonators fabricated from natural quartz material were not. The resonant frequency of the swept premium Q material exposed to the space radiation exhibited a change in frequency that was significantly larger than that of the controls or the natural quartz material and the frequency change was attributed to a recovery of damage to the quartz material sustained during the LDEF flight. Further tests of the resonators, currently in progress, are being conducted to verify this conclusion, the results of which will be presented at the LDEF Symposium.

Experiment No. A0189

V92-27321

**THE EFFECT OF THE LOW EARTH ORBIT ENVIRONMENT ON SPACE SOLAR CELLS:
RESULTS OF THE ADVANCED PHOTOVOLTAIC EXPERIMENT (S0014)**

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ABSTRACT

The Advanced Photovoltaic Experiment (APEX), containing over 150 solar cells and sensors, was designed to generate laboratory reference standards as well as to explore the durability of a wide variety of space solar cells. Located on the leading edge of LDEF, in position E9, APEX received the maximum possible dosage of atomic oxygen and ultraviolet radiation, as well as an enormous number of impacts from micrometeoroids and debris. The effect of the LEO environment on the solar cells and materials of APEX will be discussed in this paper. The on-orbit performance of the solar cells, as well as a comparison of pre-flight and post-flight laboratory performance measurements, will be presented.

LEO EFFECTS ON CANDIDATE SOLAR CELL COVER MATERIALS

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ABSTRACT

The LDEF (Long Duration Exposure Facility) test samples discussed herein are part of SAMPLE (Solar-Array-Materials Passive LDEF Experiment) which included contributions from NASA-MSFC, NASA-LeRC, NASA-GSFC and JPL. Only the JPL portion is described in this paper.

The JPL test plate, measuring approximately 24x36 cm², contains 30 individual thin silicon solar cell/cover samples. Each cell/cover assembly has silver plated Invar tabs attached for before and after flight electrical performance measurements. It was the intent of the experiment to evaluate the stability and protective capability of various cover materials such as conventional fused silica and potential alternative materials such as Teflon, silicone RTVs, glass resins, polyimides and a copolymer encapsulant.

Examination of the recovered experiment shows extensive physical changes have occurred. Approximately 150 micrometeorite/debris impacts were noted, including some directly incident on solar cells. Numerous photographs have been obtained to illustrate interactions with cover, solar cell, interconnector and the substrate insulation. Of particular interest are the result of UV and atomic oxygen interactions with the various candidate cover materials.

Initial results show that the conventional fused silica cover is the most stable and protective cover material, with the performance of the other materials varying widely. Electrical measurements of the cell/cover samples are presented as part of the evaluation of the ability of the various cover materials to adequately protect the cells in the LEO environment.

Space Environmental Effects - Biology

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



Photo Number
L-90-9942

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FINAL RESULTS OF
SPACE EXPOSED EXPERIMENT DEVELOPED FOR STUDENTS
(SEEDS)
P-0004-2

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Space Exposed Experiment Developed for Students (SEEDS), a cooperative endeavor of NASA Headquarters, the NASA Langley Research Center, and the George W. Park Seed Company, resulted in the distribution of over 132,000 SEEDS kits in 1990. The kits, sent to every state and 30 foreign countries, contained Rutgers tomato seeds that had flown on LDEF as well as seeds that had been stored in a climate-controlled warehouse for the same time period. Student researchers from kindergarten through university compared germination and growth characteristics of the two seeds groups and returned data to NASA for analysis. This data, along with anecdotal information, is contained in *SEEDS: A Celebration of Science* which has been published and distributed by NASA Headquarters. The scientific information gained was important as students shared the excitement of taking part in a national project. Of greater importance was the subsequent interest generated in science education.

N 9 2 - 2 7 3 2 4 1

CONTINUED RESULTS OF THE SEEDS IN SPACE EXPERIMENT

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ABSTRACT

Two million seeds of 120 different varieties representing 106 species, 97 genera and 55 plant families were flown aboard the Long Duration Exposure Facility (LDEF). The seed were housed on the Space Exposed Experiment Developed for Students (SEEDS) tray in the sealed canister number 6 and in two small vented canisters. The tray was in the F-2 position. The seed were germinated and the germination rates and development of the resulting plants compared to the control seed that stayed in Park Seed's seed storage facility.

The initial results were presented in a paper at the First LDEF Post-Retrieval Symposium. There was a better survival rate in the sealed canister in space than in the storage facility at Park Seed. At least some of the seed in each of the vented canisters survived the exposure to vacuum for almost six years. The number of observed apparent mutations was very low. In the initial testing, the small seeded crops were not grown to maturity to check for mutation and obtain second generation seed. These small seeded crops are now being grown for evaluation.

EXPERIMENT NO. P0004-1

Future

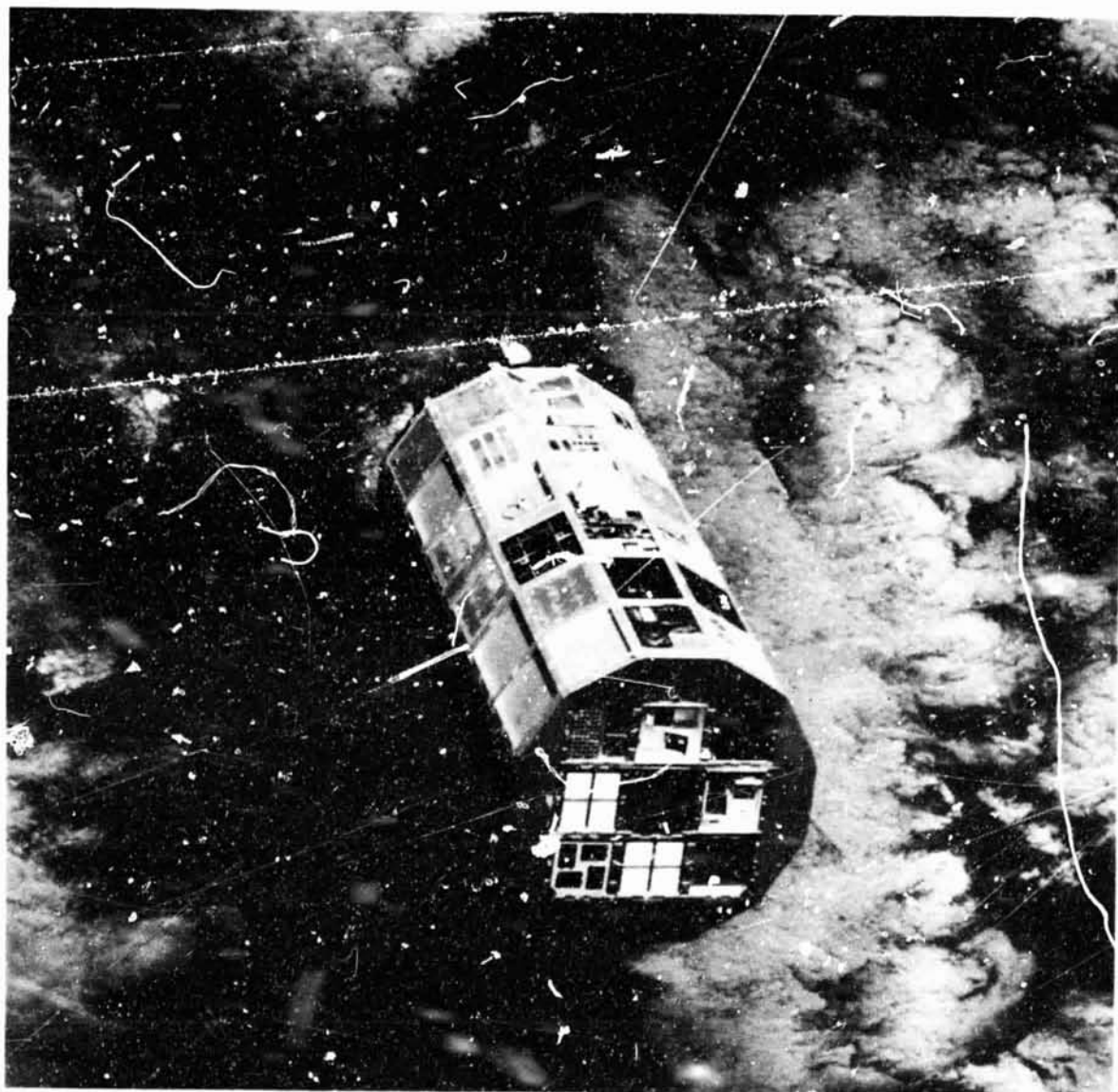


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L-84-04318

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LDEF ARCHIVAL SYSTEM PLAN

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ABSTRACT

The LDEF Science Office is developing a comprehensive archival system to enable access to LDEF data, analysis, publications and hardware for further research and design applications. The archival system will be a space environmental effects resource designed to encompass other data relevant to the space environment in addition to that which has resulted from LDEF. Elements of the archival system will include electronically stored data, hardcopies, photographs, hardware and samples. Currently LDEF data and analytical results are being recorded by principal investigators and special investigation groups in many forms and for both inhouse uses and outside distribution. It is intended that the LDEF archival system will include access to some of these independent sources of information as part of the complete archives. Other systems exist in the broader areas of space and planetary sciences which have similar goals of preserving data and materials in the furthering of space environment understanding, and these systems are being studied in the development and implementation of the LDEF archival system. This paper will discuss the LDEF archival system, including the procedures for acquiring information and hardware.

N92-27326 J.

RETRIEVABLE PAYLOAD CARRIER
--NEXT GENERATION LONG DURATION EXPOSURE FACILITY: UPDATE '92--

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ABSTRACT

Access to space and cost have been two major inhibitors of low Earth orbit research. The Retrievable Payload Carrier (RPC) Program is a commercial space program which strives to overcome these two barriers to space experimentation. The RPC Program's fleet of spacecraft, ground communications station, payload processing facility, and experienced integration and operations team will provide a convenient "one-stop shop" for investigators seeking to use the unique vantage point and environment of low Earth orbit for research. The RPC is a regularly launched and retrieved, free-flying spacecraft providing resources adequate to meet modest payload/experiment requirements, and presenting ample surface area, volume, mass, and growth capacity for investigator usage. Enhanced capabilities of ground communications, solar-array-supplied electrical power, central computing, and on-board data storage pick up on the path where NASA's Long Duration Exposure Facility (LDEF) blazed the original technology trail. Mission lengths of 6-18 months, or longer, are envisioned. The year 1992 has been designated as the "International Space Year" and coincides with the 500th anniversary of Christopher Columbus's voyage to the New World. This is a fitting year in which to launch the full scale development of our unique ship of discovery whose intent is to facilitate retrieving technological rewards from another new world: space. Presented here is an update on progress made on the RPC Program's development since the November 1991 LDEF Materials Workshop.

NEXT GENERATION OPTICAL INSTRUMENTS
AND SPACE EXPERIMENTS BASED ON
THE LDEF THERMAL CONTROL SURFACES EXPERIMENT
(S0069)

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ABSTRACT

The Thermal Control Surfaces Experiment (TCSE) on the LDEF was a very effective experiment to study the effects of the space environment on thermal control surfaces. Three current programs have benefited from the TCSE experimental concept and optical instrument--the Optical Properties Monitor (OPM) experiment, the Laboratory Portable SpectroReflectometer (LPSR) and the Space Portable SpectroReflectometer (SPSR). The OPM expands the TCSE optical measurement and environmental monitoring capability to address a wide range of materials including optics, optical coatings, thermal control surfaces, solar array materials, etc. The OPM is a multipurpose optical laboratory in space providing the measurement of spectral total hemispherical reflectance, two color Total Integrated Scatter (TIS), and vacuum ultra-violet (VUV) transmission/reflectance. The OPM is being developed under the NASA In-Space Technology Experiments Program (IN-STEP) and is planned to fly aboard the European Space Agency EURECA 3 mission.

The LPSR is a hand-held instrument developed to measure the spectral total hemispherical reflectance of small and large surfaces in the field. The LPSR is based on the TCSE reflectometer and provides measurements over the 250 to 2500 nm wavelength range. The spectral data is integrated by the instrument to provide an accurate value for solar absorptance.

The SPSR is a space application of the LPSR and TCSE technologies with the same measurement capability. Two versions of the SPSR are being developed under the NASA SBIR program--a hand held model for astronaut use and a remotely operated version for use with the Remote Manipulator System (RMS). The SPSR will provide the capability to characterize the external surfaces of operational spacecraft such as Space Station Freedom.

Experiment No. S0069

THE CANADIAN SPACE AGENCY, SPACE STATION, STRATEGIC TECHNOLOGIES FOR
AUTOMATION AND ROBOTICS PROGRAM
TECHNOLOGY DEVELOPMENT ACTIVITY IN
"PROTECTION OF MATERIALS FROM THE LOW EARTH ORBIT
SPACE ENVIRONMENT"

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ABSTRACT

The Strategic Technologies in Automation and Robotics (STEAR) program, of the Canadian Space Agency's Space Station Program, is managing a number of development contracts to improve the protection of spacecraft materials from the Low Earth Orbit (LEO) space environment. The project is structured in two phases, to be conducted over 3 to 4 years with a budget of between 3 to 4 million dollars.

Phase I is a competitive phase involving 6 contracts with Canadian industry. It is designed to demonstrate the technical feasibility and commercial potential of a coating/substrate system and its associated application process. A mandatory test program using standardized space quality substrates is implemented to generate technical results which are on a common basis for comparison. The test program involves: a 2.2 eV atomic oxygen and ultraviolet radiation (AO+UV) exposure using an in-situ mass loss sensor, thermal cycling, outgassing, solar absorptivity and emissivity before and after AO+UV exposure, SEM topography before and after AO+UV exposure, SEM defect density before and after thermal cycling, adhesion before and after thermal cycling, and bending. An independent study of the defect density and coating residual stress will also be conducted through an undercutting type test using a thermal atomic oxygen facility. The space quality substrates are Graphite/Epoxy, Graphite/PEEK, Aluminized Kapton, Aluminized Teflon and Beta cloth.

Three Phase I contractors will be selected to each perform a 1 million dollar, 2 to 3 year Phase II. Its objective is to demonstrate a prototype fabrication capability using a full scale component of a commercially viable process for the protection of materials and surface finishes from the LEO space environment, and to demonstrate compliance with a set of performance requirements. This prototype fabrication process must demonstrate that, using representative spacecraft materials/components, the process will yield the same quality performance as obtained in the lab scale process. A series of performance requirements has been established as to generate the information required by the spacecraft community to assess the coating/substrate system and the associated process.

The performance of the technologies developed in Phase I will be discussed briefly.

**INSTRUMENTATION FOR NEAR-EARTH MEASUREMENT OF ORBITAL DEBRIS AND
COSMIC DUST PARTICLES**

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ABSTRACT

Dust instrumentation based on polyvinylidene fluoride (PVDF) dust sensor arrays is described which will measure the masses, fluxes, velocities and trajectories of orbital debris particles and natural micrometeoroids. Orbital debris particles are distinguished from natural particles (cosmic dust) by means of the velocity/trajectory information. The instrumentation will measure particle trajectory with a mean error $\sim 7^\circ$ (for isotropic flux) and is designed for measurements over the particle diameter range $\sim 2\mu\text{m}$ to $200\mu\text{m}$.

For future missions having Earth-return capabilities, arrays of capture cell devices positioned behind the PVDF trajectory system would provide for Earth-based chemical and isotopic analysis of captured dust.

FUTURE RADIATION MEASUREMENTS IN LOW EARTH ORBIT

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ABSTRACT

The first LDEF mission has demonstrated the value of the LDEF concept for deep surveys of the space radiation environment. This paper will survey the kinds of measurements that could be done on a second LDEF mission.

One of the most surprising discoveries on LDEF I was the ${}^7\text{Be}$ that was found imbedded on the windward surfaces of LDEF. This discovery was not made by a planned LDEF experiment, but as a result of a test conceived prior to retrieval. A second LDEF mission could follow up on this discovery and search for evidence of other cosmogenic nuclei from the atmosphere below LDEF using carefully planned experiments.

A second discovery on LDEF I is the presence of energetic heavy ions below the geomagnetic cutoff. The origin of these ions has not yet been established. A second experiment could be designed to investigate these ions in more detail.

Data collected on LDEF I will permit the investigation of heavy ions trapped in the earth's radiation belts. Since LDEF I, we have seen the discovery of trapped anomalous cosmic rays as well as the discovery that inner belt protons are redistributed by large magnetic storms. A second LDEF mission could be used to follow up these discoveries.

The first LDEF mission carried experiments to measure the elemental composition of galactic cosmic rays beyond Fe. These experiments had >10 times the exposure of previous ultraheavy cosmic ray experiments. They will allow the major features of cosmic ray composition to be discovered. Improvements in track detectors since LDEF I now make it possible to look in detail at the elemental abundances. The abundances of radionuclides, like technetium and the actinides, measure the various lifetimes of cosmic rays while the rare earths measure the matter traversed by cosmic rays. The relative abundances of rare earths can also be used to search for evidence that cosmic rays are accelerated in episodes which occur throughout their propagation in the interstellar medium.

Additional investigations of induced radioactivity and radiation doses, including doses from fast neutrons, could be made on a second LDEF mission. Further investigations of radiation effects could also be undertaken.

A second LDEF mission also offers the opportunity for new investigations such as measurements of the cosmic ray differential energy spectrum to ultrahigh energies. These and other ideas will be discussed.

REPORT DOCUMENTATION PAGE			Form Approved OMB No 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204 Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 1992	3. REPORT TYPE AND DATES COVERED Conference Publication		
4. TITLE AND SUBTITLE Second LDEF Post-Retrieval Symposium Abstracts			5. FUNDING NUMBERS WU 196-88-00-03	
6. AUTHOR(S) Arlene S. Levine (Compiler)				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, Virginia 23665-5225			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING / MONITORING AGENCY REPORT NUMBER NASA CP-10097	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 99			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This volume is a compilation of abstracts submitted to the Second Long Duration Exposure Facility (LDEF) Post-Retrieval Symposium. The abstracts represent the data analysis of the 57 experiments flown on the LDEF. The experiments include materials, coatings, thermal systems, power and propulsion, science, (cosmic ray, interstellar gas, heavy ions, micrometeoroid, etc.), electronics, optics, and life science.				
14. SUBJECT TERMS space experiments, LDEF, shuttle			15. NUMBER OF PAGES 143	
			16. PRICE CODE A07	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	