CURRENT ACTIVITIES AND RESULTS OF THE LONG DURATION EXPOSURE FACILITY METEOROID & DEBRIS SPECIAL INVESTIGATION GROUP; Thomas H. See*, Kimberly S. Leago*, Jack L. Warren*, Ronald P. Bernhard* and Michael E. Zolensky**, * C23, Lockheed-ESC and **SN2, NASA/JSC, all in Houston, Texas 77058.

INTRODUCTION: Fiscal Year 1994 will bring to a close the initial investigative activities associated with the Long Duration Exposure Facility (LDEF). LDEF was a 14-faced spacecraft (*i.e.*, 12-sided cylinder and two ends) which housed 54 different experimental packages in low-Earth orbit (LEO) between April, 1984 to January, 1990 (*i.e.*, for ~5.75 years). Since LDEF's return, the Meteoroid & Debris Special Investigation Group (M&D SIG) has been examining various LDEF components in order to better understand and define the LEO particulate environment. Members of the M&D SIG at the Johnson Space Center (JSC) in Houston, Texas have been contributing to these studies by carefully examining and documenting all impact events found on LDEF's 6061-T6 aluminum *Intercostals* (*i.e.*, one of the spacecraft's structural frame components). Unlike all other hardware on LDEF, the frame exposed significantly large surface areas of a single homogeneous material in all (*i.e.*, 26) possible LDEF pointing directions. To date, 28 of the 68 *Intercostals* in the possession of the M&D SIG have been documented. This data, as well as similar information from various LDEF investigators, can be accessed through the M&D SIG Database which is maintained at JSC.

IMPACT FREQUENCY: Figure 1 shows the cumulative size-frequency distribution for craters as determined from examination of the *Intercostals* carried out in the Facility for the Optical Inspection of Large Surfaces (FOILS) at JSC. For the sake of clarity, only the average flux for the four cardinal pointing directions of LDEF are plotted. Each curve represents the average flux for the primary row (*i.e.*, 3, 6, 9 & 12) from each cardinal direction, along with the adjacent rows on either side (*i.e.*, East represents the average flux for Rows 8, 9 & 10). LDEF's forward-facing rows continue to reveal the highest cratering frequencies, while the rearward-facing rows exhibit the lowest. The northern facing rows (1, 12 & 11) exhibit a slightly higher overall flux than do their southern-facing counterparts, at least for craters >30 μm in diameter. The minor differences between these two pointing directions are most likely due to the fact that LDEF's velocity vector was yawed ~8^{o} toward the Row-12 direction (*i.e.*, Rows 1, 12, and 11 pointed ~8^{o} more into the velocity vector, while Rows 5, 6, and 7 were ~8^{o} further removed from the velocity vector [1]). However, as data from more impact features are accumulated, the overall differences between the northern- and southern-facing *Intercostals*, excluding the difference below ~30 μm, have become smaller, to the point where the impact frequency for these surfaces are essentially the same. The elevated flux for impact features below 30 μm on the southern-facing rows is due to the unusually high frequency of small features documented on *Intercostal* F07F02.

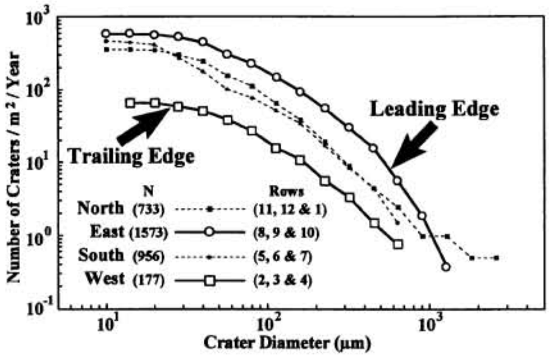

Figure 1. Average cumulative size frequency distributions for the four cardinal pointing directions on LDEF. Row 9 was the leading edge of the spacecraft in its gravity-gradient stabilized orbit.

The ratio of the production rate of impacts on the leading edge to that on the trailing edge seems to vary slightly depending on the impact-crater diameter. Comparing the averages of the east- and west-facing directions the ratios range from ~8:1 to ~10:1 for the smallest size bins, and drops to ~6:1 for the larger features. Is the large-particle population more isotropically distributed, are these differences related to the sources, and hence the associated velocities of the different particle-population sizes, or is this simply a statistical effect from the reduced number of impacts at successively larger diameters? We are currently investigating these possibilities.

INTERCOSTAL F07F02: High-magnification optical examination of 28 *Intercostals* has revealed an anomalous number of craters ≤40 μm in diameter on *Intercostal* F07F02 [2]. In an effort to understand this phenomenon and to identify the source of these features, the M&D SIG has analyzed some of these craters, the associated projectile residues, and associated contamination by Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Analysis (EDXA). The objectives were to evaluate the chemical variability and possible clustering of discrete particle types and determine their source(s). Detectable projectile residues were classified as either micrometeoritic or as man-made debris, while sources of surface contamination were identified whenever possible.

The occurrence of the various projectile types resulting from this investigation has been tabulated in histogram form and is illustrated in Figure 2, which displays the relative frequencies of micrometeoritic, man-made debris particles (*i.e.*, paint and electrical components), indeterminate, and contaminated impacts for the smaller size bins. We analyzed 251 of the 540 craters from F07F02, or ~46%. A higher occurrence of all types of particles is evident in the 20 to 40 μm size range. However, there is a particular increase in the relative amount of paint-type residues as compared to residues found on tray clamps and the gold surfaces from experiment A0187-1 [3, 4]. SEM examination of impact-feature morphology shows that the depth to diameter ratios, the crater rim characteristics, and the residue remnants are similar within this suite of impact features. The chemistry of the paint-impact residues tend to be Si-, Cl-, Ti-rich paint, all exhibiting an absence of Zn. This may indicate that the projectiles originated from a common source, yet the exact nature of this source remains unknown. One possibility is that the paint particles may have been traveling as a dense cloud or group of orbital debris; if so, the occurrence of this phenomenon on LDEF has only been found in this one very localized area thus far. In fact, *Intercostals* C07F02 from the other end of the same row, and F08F02 from the adjacent row do not exhibit this anomalous flux behavior. An orbiting debris cloud would have to have been extremely compact to have caused such a localized phenomenon. The craters could represent secondaries from some localized impact event. However, attempts to identify a source related to LDEF have been unsuccessful. This leads us to believe that the primary source for these particles was an impact event into a painted Shuttle surface (*e.g.*, the Remote Manipulator System or arm), which occurred either during deployment or retrieval of LDEF.

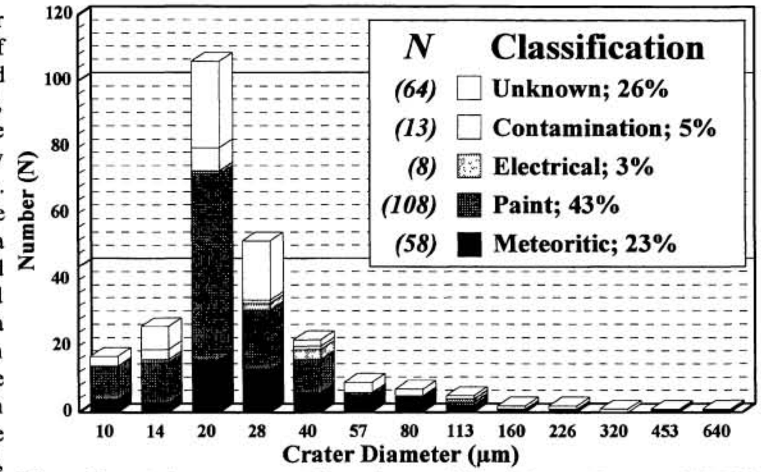

Figure 2. Relative occurrence of the various particle residues on *Intercostal* F07F02. Percentages given are for all crater sizes.

M&D SIG ACTIVITIES FOR FY 94: With FY 94 bringing to a close the initial investigative phases of LDEF, the M&D SIG is active on several fronts. In a continuing effort to make all M&D data available to the general user community, the M&D SIG at JSC is constantly updating the M&D Database with data from all possible sources, including data generated at JSC, as well as data provided by various LDEF investigators. However, the M&D SIG would like to receive more data from all potential sources and are requesting that anyone having such data forward it to T.H. See or M. Zolensky.

Members of the M&D SIG at JSC continue to gather data from the detailed scans of the LDEF *Intercostals*; these activities will continue as long as funding permits. In related matters, the past year saw the return of the EURECA spacecraft, as well as the Hubble Space Telescope (HST) repair mission. The M&D SIG has already acquired sections of EURECA's thermal insulation materials and plans to scan or examine this hardware during the upcoming months. Prior to the HST repair mission the M&D SIG had requested pieces of the return solar panels for examination. However, during the repair activities one of the two solar panels would not completely fold to a configuration permitting it's return to Earth, and thus, was jettisoned over the side of the Shuttle. Whether or not the M&D SIG will still acquire any of this material for examination has yet to be determined. Nevertheless, LDEF will serve as a useful baseline or snap shot of the LEO particulate environment for the time period of April, 1984 to January, 1990. Future data will be compared to the data acquired from LDEF to evaluate how the LEO particulate environment is evolving with time.

Another activity presently underway at JSC involves the long-term storage and availability of the ~4,500 stereo images of various LDEF impact features taken during the initial deintegration and examination of LDEF at the Kennedy Space Center, as well as all of the subsequent images acquired at JSC. All of these images have been converted to a TIFF file format and are being transferred on to CD-ROM. Copies of these CDs are available on a temporary loan basis from the Office of the LDEF Curator at JSC. In addition, the LDEF Science Office located at Langley Research Center, Hampton, Virginia is considering doing the same thing with the on-orbit LDEF survey and general-view pictures, and the post-flight deintegration and experiment tray stand pictures for the purpose of long-term archiving and general access. The exact format in which these files will be written to CD has not been determined. Finally, along this same line, the M&D SIG plans on archiving all LDEF M&D data it can acquire on CDs. This will only occur if the various LDEF investigators provide the M&D SIG with their data.

Lastly, the M&D SIG is in the process of putting together a final report summarizing all results, and what they mean to the survivability of both manned and unmanned spacecraft in LEO. This report will include recommendations for further M&D-type activities and investigations on future spacecraft, as well as a long-term outlook as to ways in which the population of LEO particles can be monitored, as well as possible mitigation of it's orbital-debris components.

FUTURE ACTIVITIES: Although FY 94 will conclude the initial LDEF activities, it will not mean an end to M&D-type studies and investigations. At the recently held 3rd LDEF Post-Retrieval Symposium in Williamsburg, Virginia, NASA Headquarters and the LDEF Science Office presented plans for the formation of a Space Environments & Effects (SEE) program. This program would encompass the various LDEF SIGs, as well as private industry and academia, and would be customer-oriented, focusing on issues related to designing, placing and safely maintaining both manned and unmanned payloads into orbit.

REFERENCES: 1) Peters and Gregory, 1993 Att. Stab. LDEF: Ref Resu. from the Silver Pinhole Cam. *LDEF - 69 Mths Sp. 2nd Post-Ret. Sym., NASA CP-3194*, p. 3-12. 2) See *et al.*, 1994, Comp. Anal. of Proj. Res. on LDEF Inter. F07F02, *3rd LDEF Post-Ret. Sym., Abstracts*, p. 54. 3) Bernhard and Zolensky, 1994, Anal. of Imp. Res. on LDEF Clamp Sur. by SEM, *3rd LDEF Post-Ret. Sym., Abstracts*, p. 56. 4) Hörz *et al.*, 1994, Comp. and Freq. of Hyper. Part. <1 mm in LEO, *3rd LDEF Post-Ret. Sym., Abstracts*, p. 57.