19950017478

N95- 23898

Recent Results from Long Duration Exposure Facility Materials Testing*

H.G. Pippin and H.W. Dursch
Boeing Defense & Space Group
Seattle, WA. 98124-2499
(206) 773-2846

S2-25
399903
11P

The overall goals of the Long Duration Exposure Facility (LDEF) investigations, established by the Materials Special Investigation Group (MSIG) prior to LDEF retrieval, are to provide useful engineering data to people designing and building spacecraft and, secondarily, to obtain data of potential interest to materials researchers.

The specific objectives are to support predictions of materials lifetimes under the various low earth orbit (LEO) environments to determine how long the material will physically survive; to estimate the engineering performance lifetimes of these same materials under specific LEO exposures; to identify materials and processes by which given materials degrade; and to provide insights into development of new, more inherently LEO environmentally resistant materials.

To achieve the established objectives, two criteria were established to select which materials had the highest priorities for analyses. The first criteria was to examine materials which are still being used on new spacecraft. The second priority was to examine materials with multiple exposure locations on LDEF, because this provided opportunity to develop predictions on how a material will behave as the exposure environment varies.

The goals as defined led to the identification of silverized Teflon TM (Ag/FEP), chromic acid anodized aluminum, and certain thermal control paints used on LDEF as the material types of highest priority for examination. Ag/FEP was chosen because of an excellent a/e ratio (extremely low), and extensive flight history. Also influencing the decision was the fact that the Hubble Space Telescope uses Ag/FEP as its primary passive thermal control system (and was launched shortly after LDEF retrieval) and that a number of other spacecraft are using, or considering this material for use. The various forms of Ag//FEP were used on virtually every side of the LDEF except the earth end. The potential uses of this material, and the location distribution and therefore, exposure conditions, have provided the rationale and opportunity for a comprehensive study of this material.

The performance of anodized aluminum is of significance to Space Station because of the planned wide use of treated aluminum to achieve desired optical properties. The anodizing process allows good control and tailoring of optical properties (Ref. 1). Aluminum is widely used on spacecraft because of its relative inertness and low density.

A276, S13/GLO, and a variety of additional thermal control paints were used on selected experiments and flown as test specimens on other experiments. These paints are used for many spacecraft, under many different exposures, and continue to be considered for future missions. The many observed changes seen on LDEF post-flight have raised concerns about the suitability of a number of these materials for longer term missions and is the reason for the high priority in characterizing the observed degradation.

*These activities were supported by NASA Langley Research Center under contract NAS1-19247

PRECEDING PAGE BLANK NOT FILMED

554

A number of additional types of materials were flown in-service or as specimens in multiple locations. These materials include various composites, copper, stainless steel, and a variety of different adhesives, seal materials, and lubricants. These materials all have practical significance for spacecraft design and have been examined and reported on by various investigators.

Materials present in only one or a very few locations were considered lowest priority for MSIG activities. A number of optical materials, one of a kind coating materials, hardware used on only one experiment tray, and materials in well shielded areas fall into this category.

Reports on specific materials are being completed describing our investigations on chromic acid anodized aluminum, thermal control coatings, materials from internal locations, seals and lubricants, adhesives, silverized Teflon, composites and metals flown on LDEF. In addition, user guides are being prepared for existing models which predict atomic oxygen and solar ultraviolet radiation fluences at arbitrary, but specific, locations on spacecraft.

The primary atomic oxygen model used to predict the direct fluence to LDEF surfaces has also been used to make estimates for a nominal space station trajectory.

The microenvironments atomic oxygen (AO) fluence model has been applied to selected surfaces on the LDEF and to two other spacecraft, the Tropical Rainfall Measurement Mission (TRMM) and the All-Composite Experimental Spacecraft Structure (ACESS). The LDEF applications include predicting exposures on a space end clamp and bolts, a pair of specimens from A0171, an angle bracket on A0076, a copper grounding strap, selected areas on blankets from trays B7, D7 and D11, the S0069 experiment tray and a module from the M0001 experiment. Figure 1 shows the results of the AO microenvironments model calculation on a representative ACESS geometry structure.

The solar UV model has been applied to the LDEF to determine the equivalent sun hours (ESH) of solar radiation, including both direct solar and earth albedo contributions. These results were compared with an earlier analytical calculation of the ESH and are in agreement. The solar model was also used for the TRMM spacecraft, and for S0069 and M0001 experiments on LDEF. Thermal models have also been applied to an M0003 composite panel and to tray clamps from rows 9 and 4 to examine thermal loads on the adhesive holding the paint buttons on these clamps.

Boeing Defense & Space Group has produced both IBM Compatible and Macintosh™ versions of data bases covering four material types from LDEF. The subjects are thermal control paints, optical material, Ag/FEP, treated aluminum, and LDEF environments. These data bases are complete through the 2nd Post Retrieval Symposium and include some information from the 1992 Huntsville LDEF materials conference and are available to the user community free of charge.

Materials analysis continued on a variety of LDEF materials in 1993. These materials included a copper grounding strap, unanodized aluminum, yellow paint surfaces on the scuff plates, stainless steel bolts, DC6-1104 adhesive, heat shrink tubing and additional Ag/FEP from the S1005, M0001 and S1002 experiments.

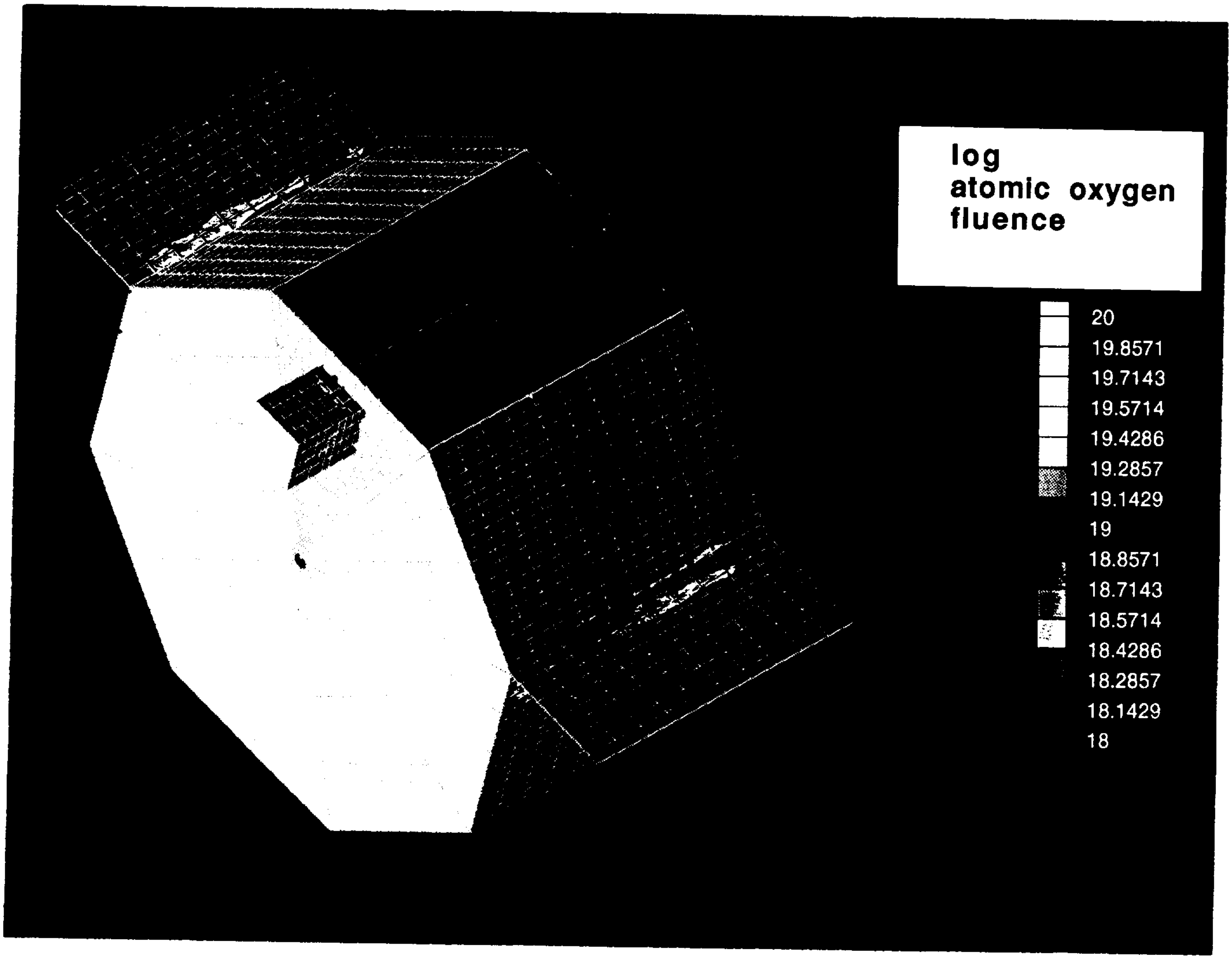

Figure 1. Computer generated plot of the atomic oxygen exposure over the surface of the All-Composites Experimental Spacecraft Structure (ACESS). The atomic oxygen microenvironments model used for this prediction was verified through comparisons with LDEF flight data.

Materials from "interior" locations, which were only directly exposed to vacuum and mild thermal cycling conditions, generally appeared in excellent condition post-flight. All the heat shrink tubing, nylon grommets, Teflon-coated wire bundles and multi-layer insulators (MLI) were intact and functioning. A slight increase in brittleness was observed for the nylon grommet flight specimens relative to ground control material. Selected fiberglass shims associated with the heat shrink tubing were evaluated and had slightly lower Total Mass Loss (TML) and Collectable Volatile Condensable Materials (CVCM) in comparison with ground specimens. These results are detailed in a NASA Contractor Report on LDEF Internal Materials.

Figure 2 shows the points of attachment of the velcro fastening material with the AO178 tray frame from location C11. The DC6-1104 RTV silicone adhesive used showed significantly increased TMLs relative to a ground reference value. The CVCMs were virtually identical for flight and ground specimens. For selected LDEF locations, samples were taken from both the vacuum exposed bond line of flight specimens and the center of the velcro covered area on these same specimens. No difference could be determined between outgassing properties of pairs of samples from different areas of the same adhesive specimen.

Figure 3 shows a photo of aluminum wire harness clamps partially covered with heat shrink tubing, nylon grommets and a wire harness bundle.

Outgassing data for heat shrink tubing specimens are shown in figures 4 and 5. The results show no significant difference in CVCM for flight vs. ground specimens, although the average for each flight location is slightly lower than for the ground control specimens. The average TML's for two distant flight sample populations, samples from rows 3, 4, 8, and 9 compared with specimens from all other locations (different to >95% confidence level), are about 30% lower than the ground control TML. One Earth end clamp showed anomalously high results. An additional set of specimens were run on this particular clamp and showed the same high TML as the original measurement. The reason for the anomaly is not known.

The surface of Ag/FEP specimens from a M0001 module on the space end and the Environmental Exposure Control Canister (EECC) from experiment S0002 on tray E03 showed the expected changes in structure associated with solar exposure. The relative environmental susceptibility of functional groups under LEO exposure conditions, in increasing order, is CF to CF_2 to CF_3. Changes in relative amounts of CF, CF_2 and CF_3 functional groups vs. solar exposure are summarized in figures 6 and 7. The results indicate that changes in the FEP structure accelerate over the UV exposure range for which data is available. It cannot be assumed that the trend towards more rapid degradation will continue indefinitely because the cross-linked structure may achieve more stability with time. In addition, the sequence of environmental exposures is critical; an initial exposure to a relatively high dose of atomic oxygen is probably less damaging to this material than an equivalent dose later in a mission. By contrast, under high particulate radiation environments, such as the SCATHA experiment flown at geosynchronous altitudes, this material changed a by ~0.2 over 10 years (Ref. 3).

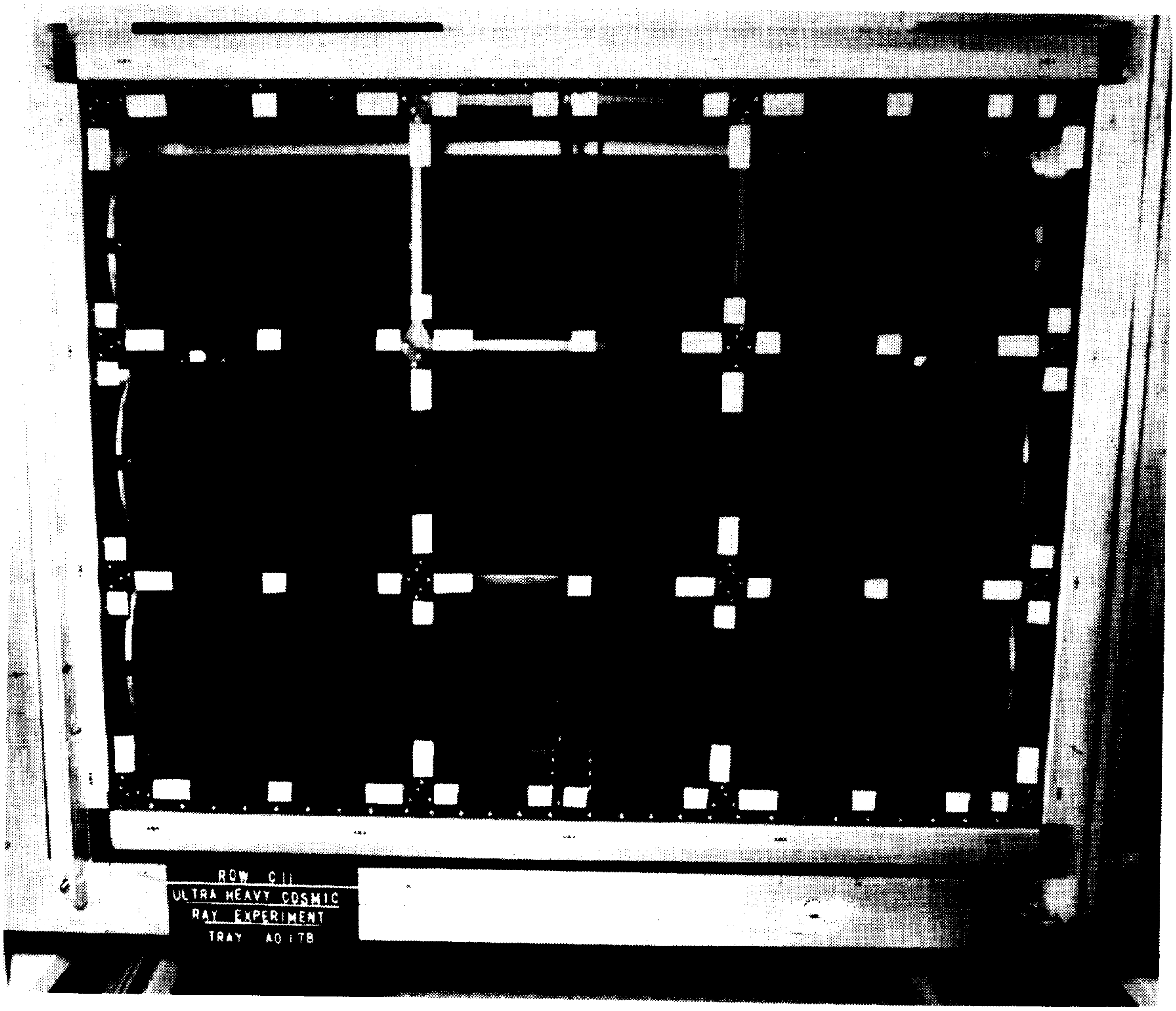

Figure 2. NASA photograph of open tray from location C11 showing the points of attachment of the thermal control blanket to the tray. The white rectangular areas are the velcro strips attached to the tray frame.

Figure 3. NASA photograph of a portion of the LDEF interior showing the wire harness bundles, nylon grommets, aluminum clamps, and heat shrink tubing on the aluminum wire harness bundle clamps.

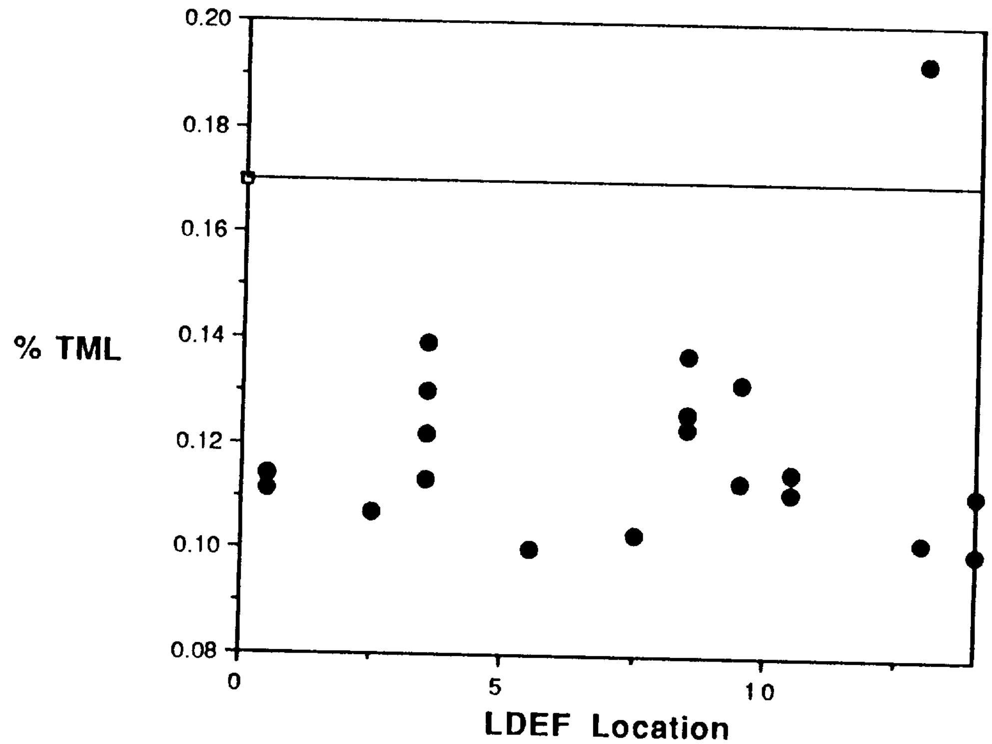

Figure 4. Total Mass Loss (%TML) of heat shrink tubing as a function of location on the LDEF interior. The horizontal line at 0.17% is the TML average for the ground control specimens.

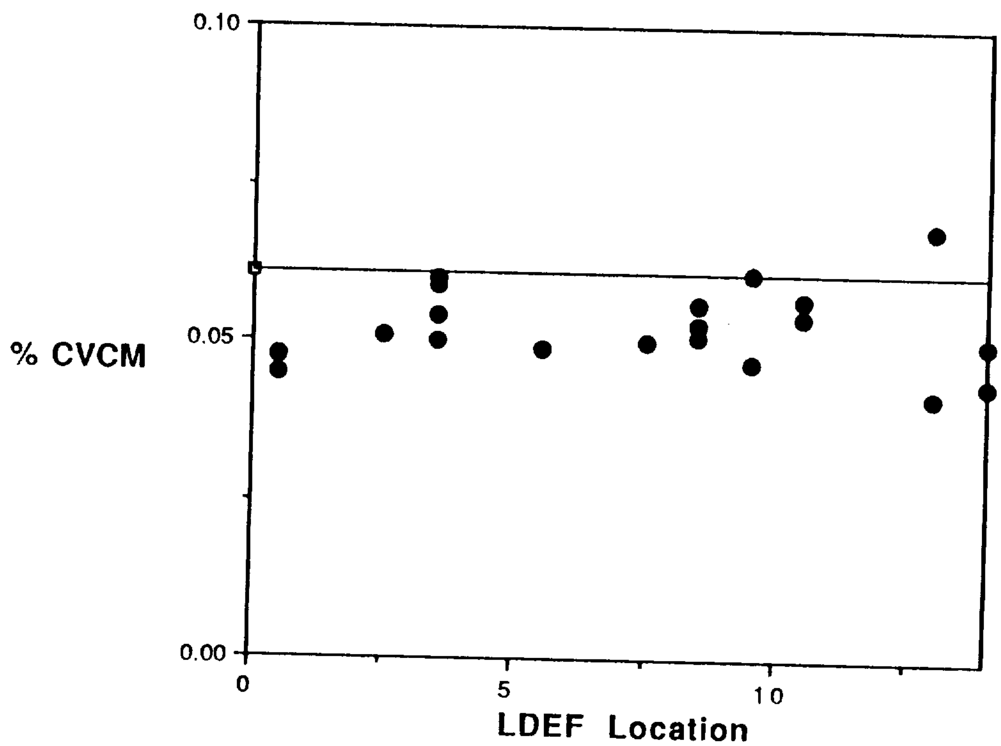

Figure 5. Collectable Volatile Condensable Materials (%CVCM) of heat shrink tubing as a function of location on the LDEF interior. The horizontal line at ~0.06 is the average % CVCM for the ground control specimens.

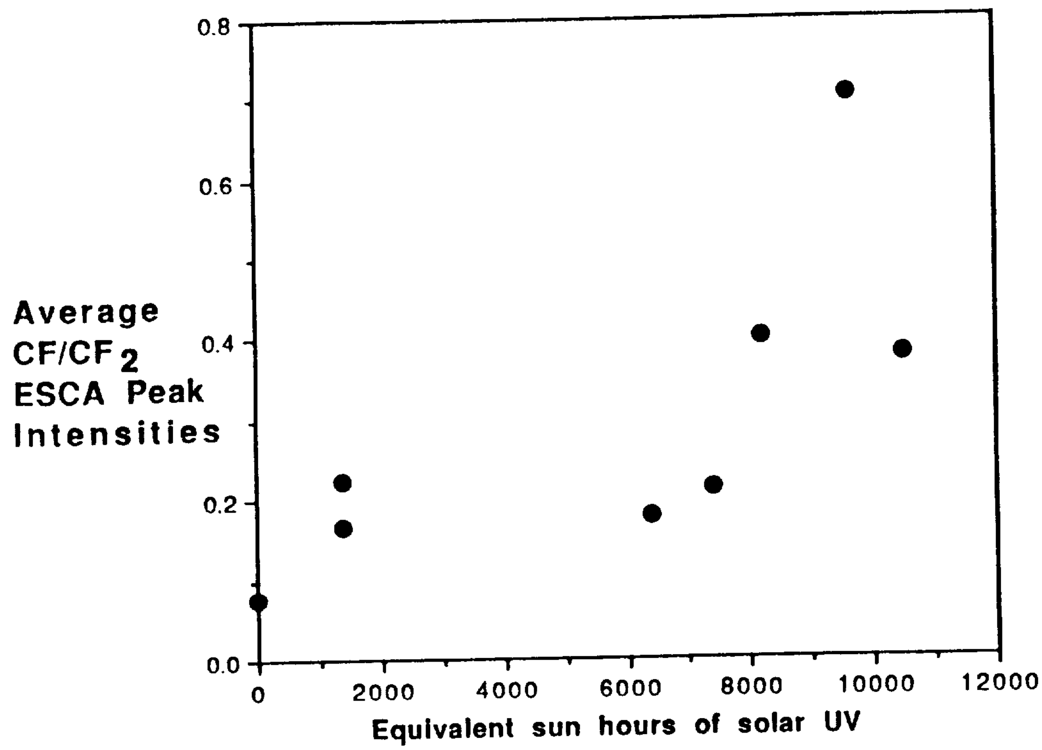

Figure 6. Ratio of CF to CF2 ESCA peak heights as a function of hours of solar exposure.

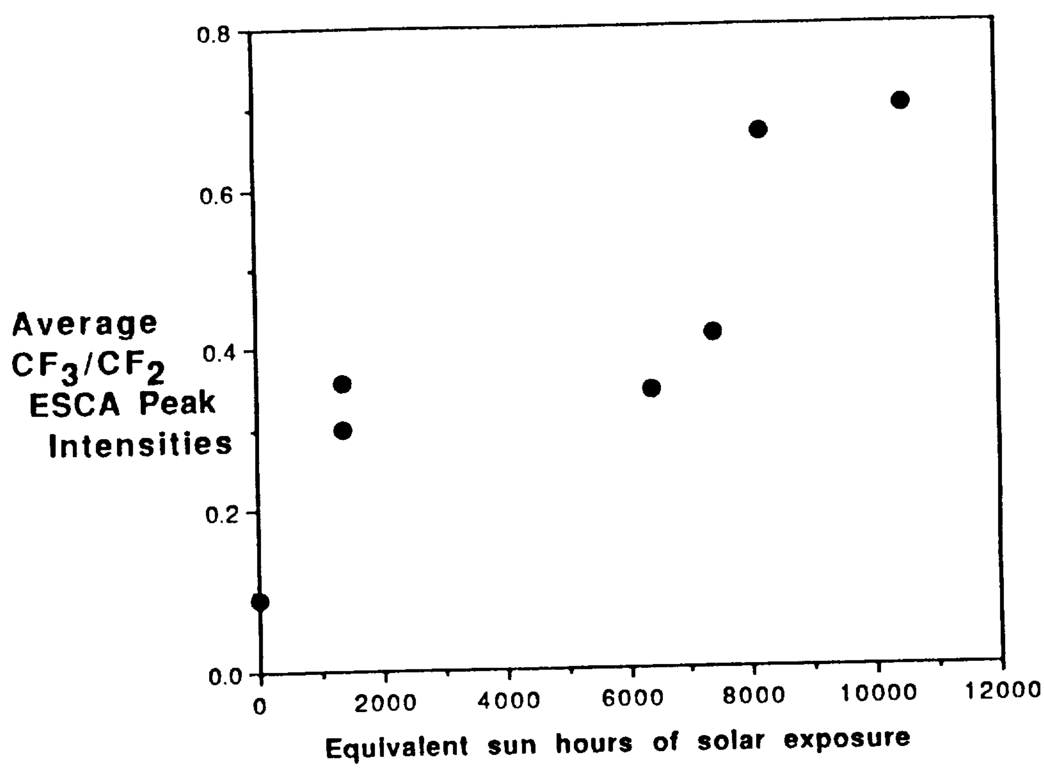

Figure 7. Ratio of CF3 to CF2 ESCA peak heights as a function of hours of solar exposure.

Because the exposure cycle was different on the Solar Max Satellite than for LDEF, the Solar Max Ag/FEP specimens may have high information content regarding environmental effects on materials. This depends partially on how well the orbit and satellite motions can be estimated.

Goddard Space Flight Center also flew vapor deposited aluminum coated FEP tape on rows 9 and 12. The row 9 specimen exposed side shows less carbon and increased oxygen relative to the shielded side. Row 12 specimens show silicon contamination on exposed surfaces and small amounts of silicon on shielded surfaces.

The effects of contaminant film range from optical properties changes to influencing the apparent recession rate of other materials. The chromic acid anodized aluminum surfaces on the trailing edge appeared slightly darkened and showed a 3-4% increase in absorbency relative to the control specimens. This increase is attributed to solar darkened contaminant films and is not considered a significant engineering change. Localized deposits of outgassed products from silicone adhesive increased the absorbency of Ag/FEP from 0.07 up to 0.25 in a few areas. Similar changes were also seen on Solar Max specimens (Ref. 2). Severe darkening was also associated with small areas around vent paths from interior locations. While the discoloration is severe, and these areas appear visibly dark, the total area is a small fraction of the surface.

Deposited material lowers the apparent recession rate of the substrate material by acting as a sacrificial material which consumes oxygen and may also physically block the oxygen from reaching some reactive sites.

Degraded materials are also potential sources of particles which may block lenses, mirrors and thermal control surfaces. These films may also alter properties on these critical surfaces.

Silicone has been detected on many LDEF surfaces. These surfaces include each stainless steel bolt head examined, both exposed and shielded FEP surfaces on the trailing edge, 22 of 24 aluminum tray clamps examined using ESCA, numerous clamps examined using IR spectroscopy, stainless steel bolt tips and silver coated hex nuts on the interior of LDEF, each copper strap examined, and on the surface of specific experiments.

A number of potential sources have been identified, but in every case determined to date, the outgassing source has been very localized and/or the contaminant was present from the manufacturing process.

The adhesive used on AO178 and P0004 experiment trays to fasten velcro to the tray frame and back side of the thermal control blankets outgassed and left stains around the corners and sides of these trays and on the surfaces of the blankets themselves. The bicycle reflectors and a number of specimens from certain experiments were silicone coated. The area around the reflectors was not analyzed for Si content. Where specimens adjacent to silicon containing specimens were examined, any silicon based contamination was shown to be extremely local. Small amounts of silicon based adhesive used on specific experiments contaminated areas on those same experiments. There is no evidence of serious cross contamination from one tray to another.

The copper grounding straps were made by bonding two strips of adhesive-backed copper tape together. This tape as manufactured has a silicon based release coating on the cover paper protecting the adhesive. When the tape is rolled this paper comes in contact with the copper side and a thin silicone film is deposited on the copper. The shuttle is also a potential source of silicon. However, the results of our examination of the stainless steel bolts were not conclusive because the silicon levels were small and any films were extremely thin. The A286 type alloy stainless steel bolts, as manufactured, contain about 1% silicone by weight. The presence of this source and the carbon based contamination on the bolt heads mask the deposition of Si on orbit.

Property changes observed on LDEF are a function of the specific environmental exposure. The Ag/FEP optical properties did not change under AO and UV exposure. The structural changes in the FEP increased with UV exposure in a non-linear fashion.

The discoloration of the A276 paint buttons due to UV exposure is irreversible. The damage to this material is to the resin system. By contrast, the "bleaching" of paints in air, after vacuum exposure to protons, electrons, and UV, is a result of changes of the pigment.

The total amount of Si on LDEF surfaces is quite small. There were a number of localized sources.

There are specific materials and surfaces on LDEF which still have a high information content. The Ag/FEP specimens from the M0001 modules and the AO069 experiment, and the A276 paint binders all contain materials whose chemical structure has been altered and could provide clues as to the actual UV damage mechanisms. Most of the time resolved exposures on LDEF have not yet been analyzed. The inside surfaces of canisters which were opened in stages provide time resolved information about the deposition of contaminant films.

Application of the AO and UV microenvironments models continue to show that for complex shaped surfaces, the indirect scattering makes a significant contribution to the total intensity. This is significant because the interpretation of materials data from the LDEF only has meaning in the content of the specific environmental exposure.

Post flight measurements are integrated results which reflect the net changes induced by several uncontrolled environments. The sequencing of the exposure conditions determines the observed results.

References

1. Duckett, R.J. and Gilliland, C.S., Variable Anodic Thermal Control Coating on Aluminum, AIAA 18th Thermophysics Conference, June 1-3, 1983, AIAA-83-1492.

2. Proceedings of the SMRM Degradation Study Workshop, May 9-10, 1985, NASH-GSFC, 408-SMRM-79-0001.

3. Hall, D.F. and Fote, A.A., 10 Year Performance of Thermal Control Coatings at Geosynchronous Altitude, AIAA 26th Thermophysics Conference, June 24-26, 1991, Honolulu, Hawaii.