N93-10592

SYSTEM RELATED TESTING AND ANALYSIS OF FRECOPA

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SUMMARY

This paper presents a new part of the results from FRECOPA system analysis. It was one of the numerous experiments which were flown on the LDEF satellite. In our flight configuration (LEO orbit, trailing edge), the environment was a better vacuum than the leading edge, with many thermal cycles (32000) and U.V. radiations (11100 equivalent sun hours). The satellite was also bombarded by mainly natural micro-particles. It saw a low atomic flux and minor doses of protons and electrons.

INTRODUCTION

The subjects of our analyses are the studies of: canisters and their seals, organic and metallic fasteners, and the study of adhesion between two metallic parts. The canisters were used to protect samples during launch and return to Earth. The butyl seal provided vacuum tightness. The glues were used to bond metallic fasteners and the velcro tapes to fix the thermal blankets. The adhesion phenomenon was found between a small steel spring and an aluminium plate used to fix samples. At the end, we will show two contamination phenomena which will be the subject of our future investigations. The following results are based on comparisons between components after flight and those stored on ground in laboratory conditions.

SEALS

Butyl rubber seals were used to provide vacuum tightness inside the canisters. The seal was bonded to one of the face-plates of the half canisters as seen in figure 1. In the closed position (during launch and return to earth) a compression force was exerted on the canister to guarantee global cohesion. An aluminium shield was placed on the top of the canister to protect the seal during opening (10 months). According to this position, their exposure was limited to hard vaccum and thermal conditions. We performed two tests on the seal:

- Micro-Hardness M.H. (NF-T 46-003)
- Compression Set C.S. (NF-T 46-011) 22 hours, 100°C and 25% set

We measured

	M.H.(DIDC)	C.S.(%)
Flight model B3	55	5.5
Reference model B6	53	8.3

The increase in micro-hardness values show a slight ageing of the seal confirmed by the decrease in compression set values.

We conclude good behaviour; the seal is still in good working order, and it adheres efficiently to the metal and has not changed aspect.

CANISTER

Measurements of pressures inside the canisters 70 days after return of FRECOPA show the excellent behaviour of canister n°5 which has an improved vacuum, 0.045 mbar for 0.66 mbar equivalent nitrogen before flight. Canisters 3 and 4 have pressures of approximately 1.6 and 4.1 mbar respectively, slightly less than at the beginning. We performed leak tests after removal of the samples with a new pressure in the canister of 10^{-3} mbar. We measured:

- canister 3 after 500 hours, 4 10^{-6} mbar.dm^3.s^{-1} equivalent N_2
- canister 4 after 800 hours, 2 10^{-6} mbar.dm^3.s^{-1} equivalent N_2
- canister 5 after 500 hours, 3 10^{-6} mbar.dm^3.s^{-1} equivalent N_2

For canister 4 after 7200 hours we had the value of 3 10^{-7} mbar.dm^3.s^{-1} equivalent N_2.
This value shows the good behaviour of the butyl seal. The pressure differences between

canisters after flight can be explained by the fact that canisters 3 and 4 contained organic materials which may have outgassed even after the canisters were closed.

This technique for protecting samples operated correctly, but the thermal conditions inside the canisters after they were closed may have contributed to the materials' ageing.

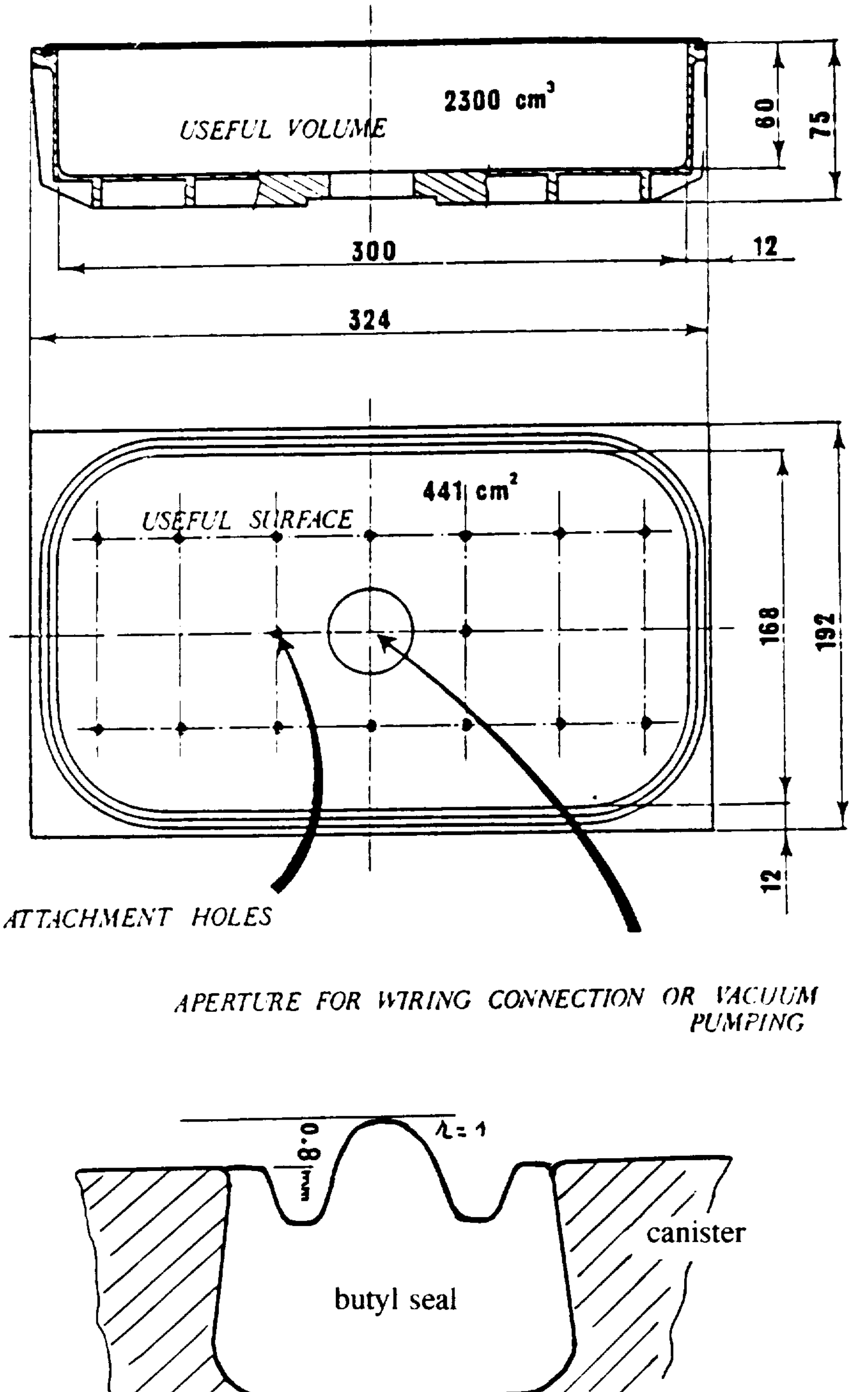


Figure 1. Canister dimensions and Butyl seal cutting out

VELCRO TAPES

The behaviour of the velcro tapes was highly satisfactory when used to attach flexible shields. Qualitative tests carried out upon disassembly showed a high level of resistance for assemblies using these materials. Quantitative tests show no change in tensile strength but a decrease of 50 % in opening strength. Visual observations show a change in color (yellowing as seen in figure 2). Analysis of surface constituents (R.B.S.) reveals silicon contamination, along with the presence an other element not yet definitely identified (as seen in figure 3). Thermal analysis (D.S.C.) shows no significant change in transition temperature (3%) but a second peak appears on the flight sample curves (as seen in figure 4). The type of transition or the element producing it are not yet known.

GLUES

All structure attachements were secured by bonding (bolts, screws). The Velcro strips were bonded to the structure by EC 2216 glue. Traces of adhesive, although cleaned for assembly, reappeared under the effect of U.V. (as seen in figure 2). The adhesives themselves changed color (grey to green) but variations in their transition temperature (Tg) depended on the type of support and the thermal conditions to which they were subject (as seen in figure 5*).

SILVER-PLATED BOLTS

All the screw torques were nominal during disassembly but we detected a pollution on certain bolts holding the batteries. Sulfur and oxygen were detected in the layer of silver, and this had a granular appearance (as seen in figure 6). This may be due to in-flight contamination by other experiments. Contamination after the return of FRECOPA is also possible, as the satellite travels in the cargo bay of the space shuttle and this is not sealed. This pollution is only slight but it could generate small conductor particles on the bolts. These are harmful not only to electronics and components but more generally to any manned flight.

In our flight conditions, these attachment techniques were proved to be high performance. This would not be the case on the side exposed to atomic oxygen.

*Photographs are not shown in color.

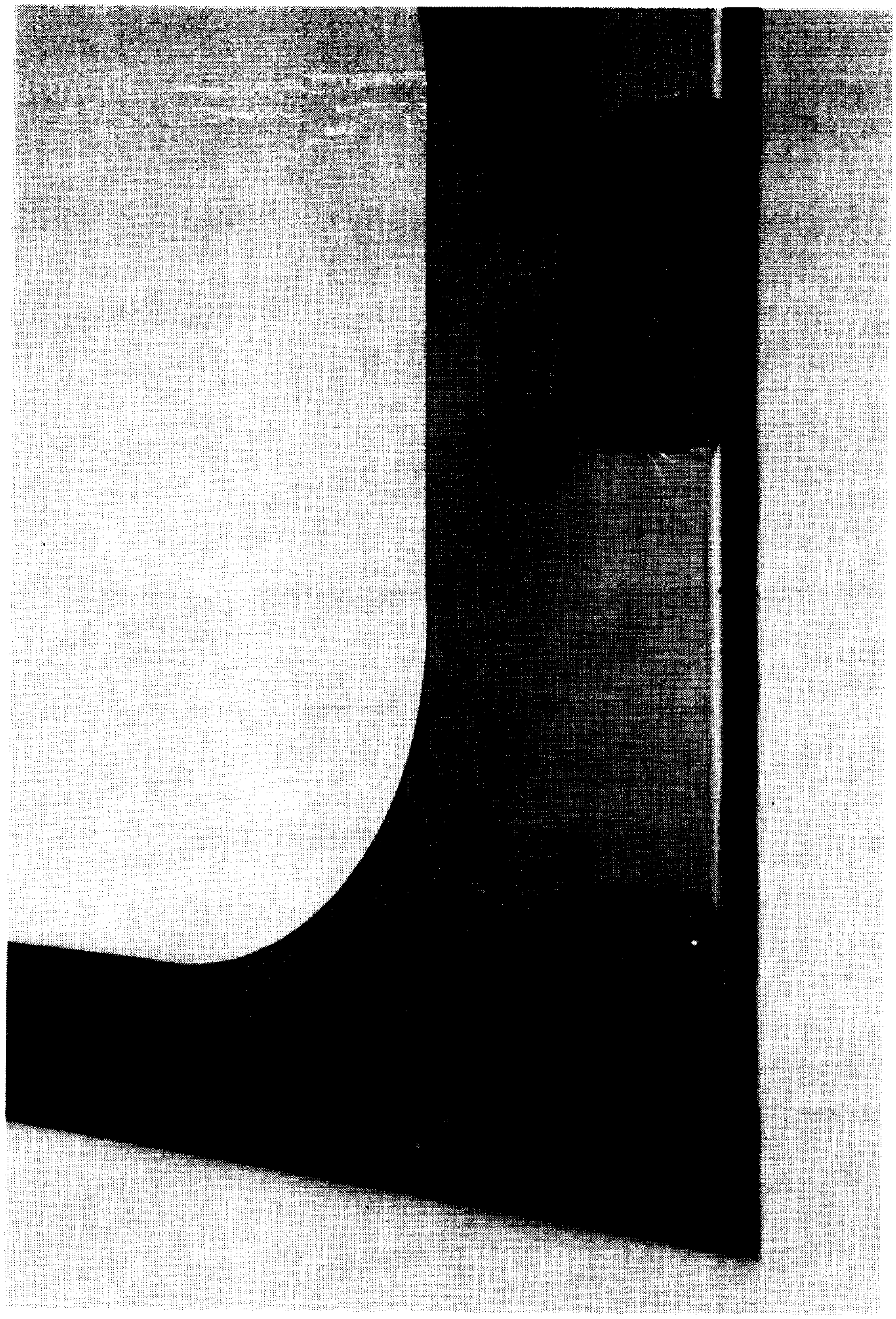
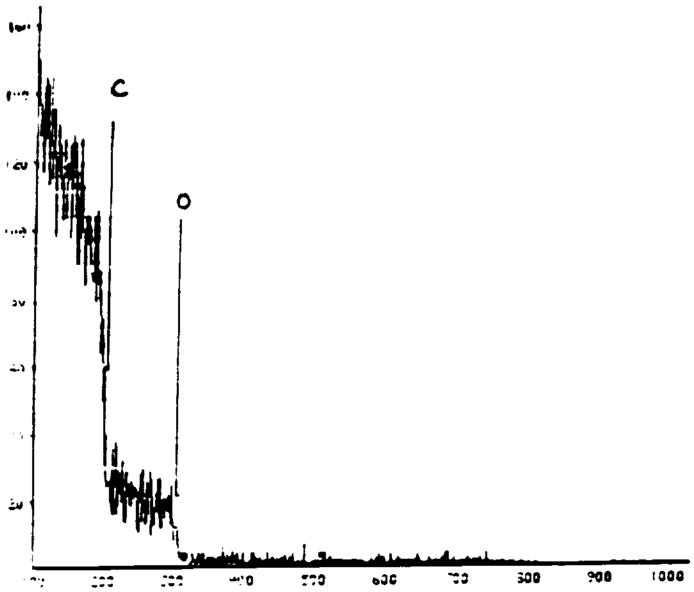


Figure 2. Velcro color change and glue trace on rigid shield

Reference



Flight

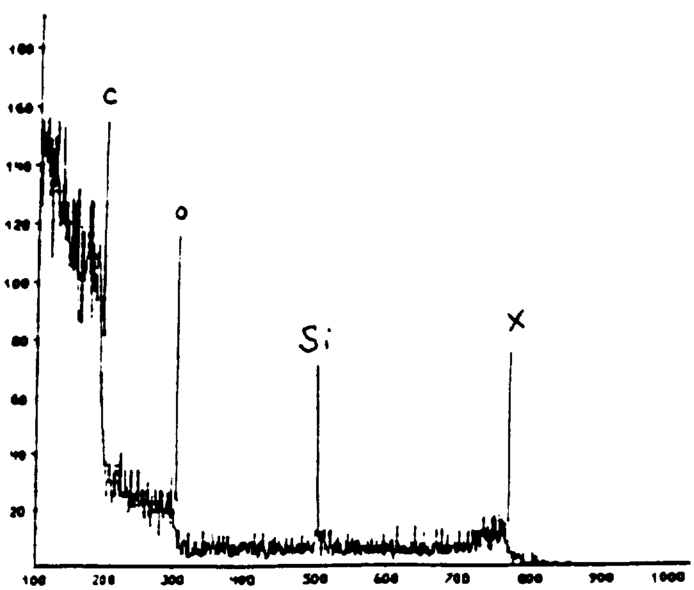
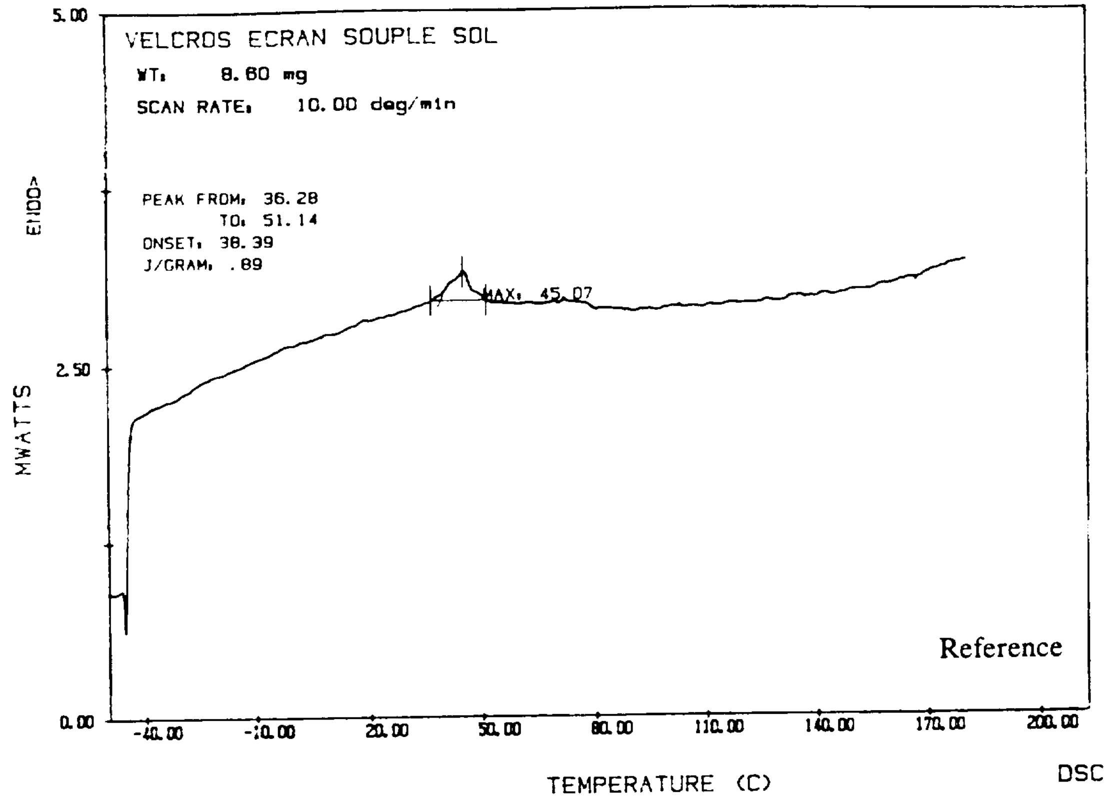


Figure 3. R.B.S. results on velcro tapes



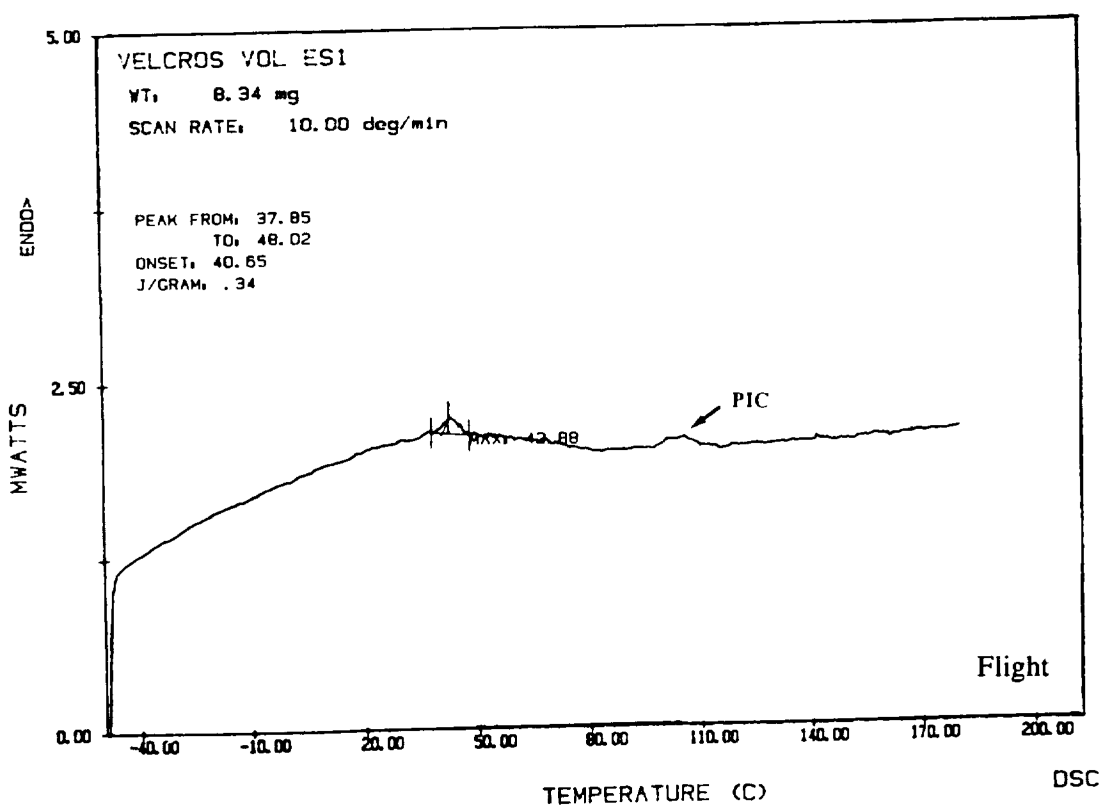
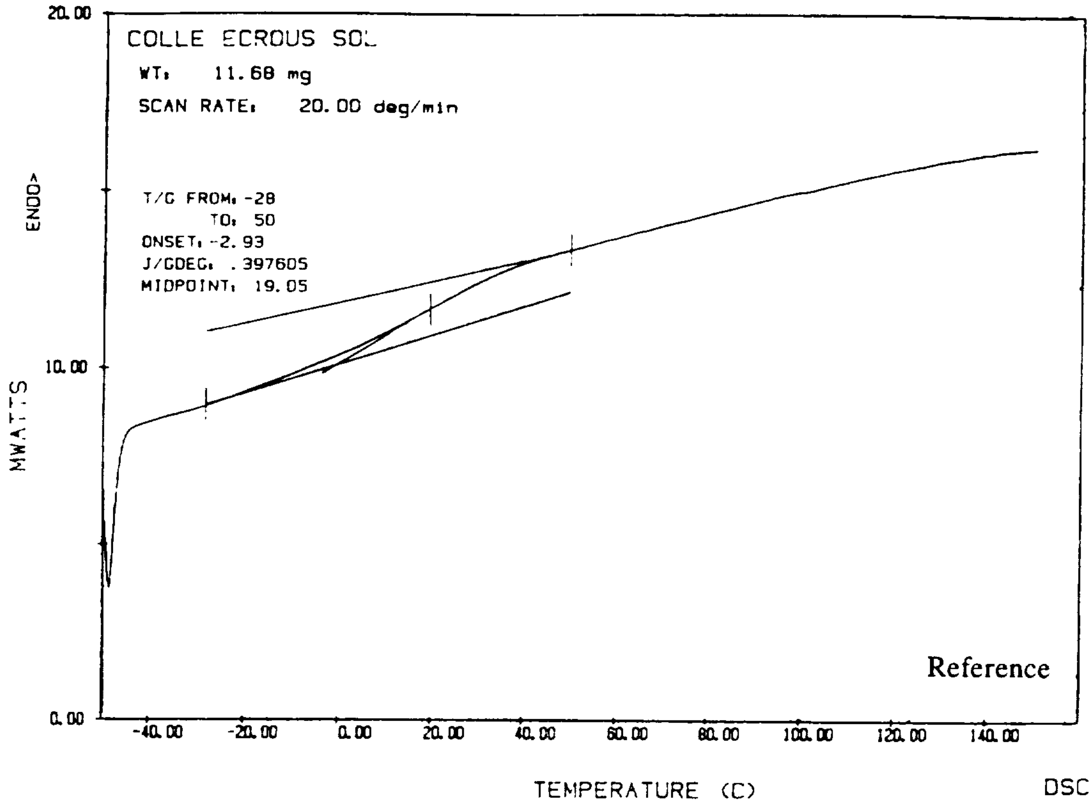


Figure 4. D.S.C. results on velcro tapes



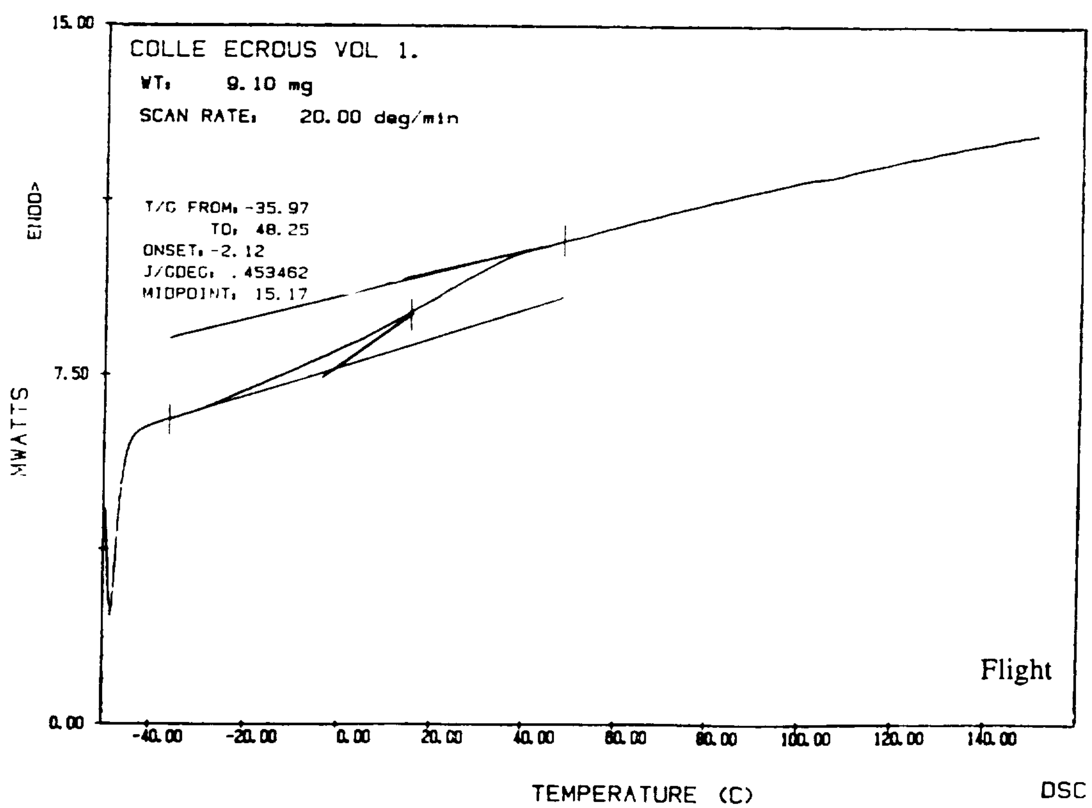
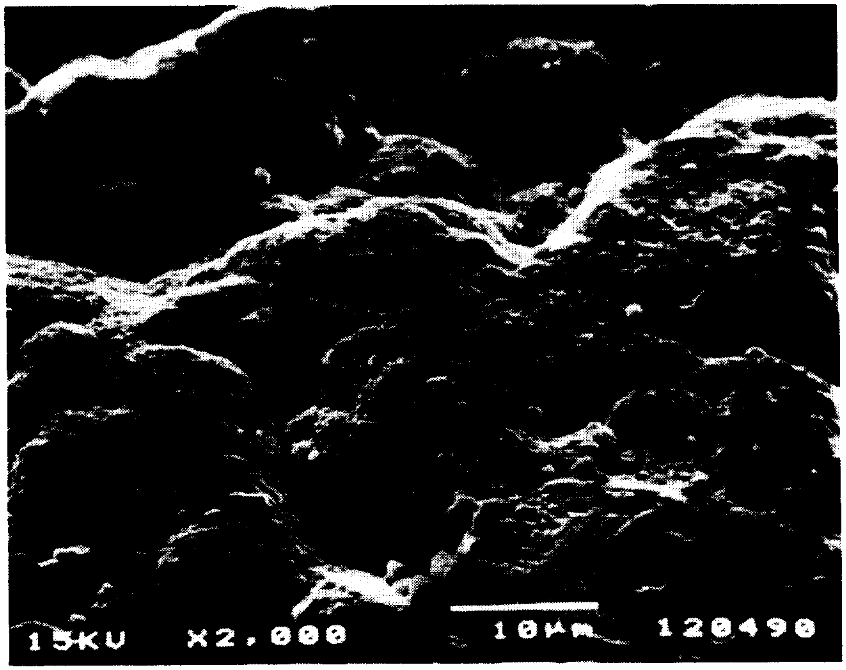


Figure 5. D.S.C. results on glue



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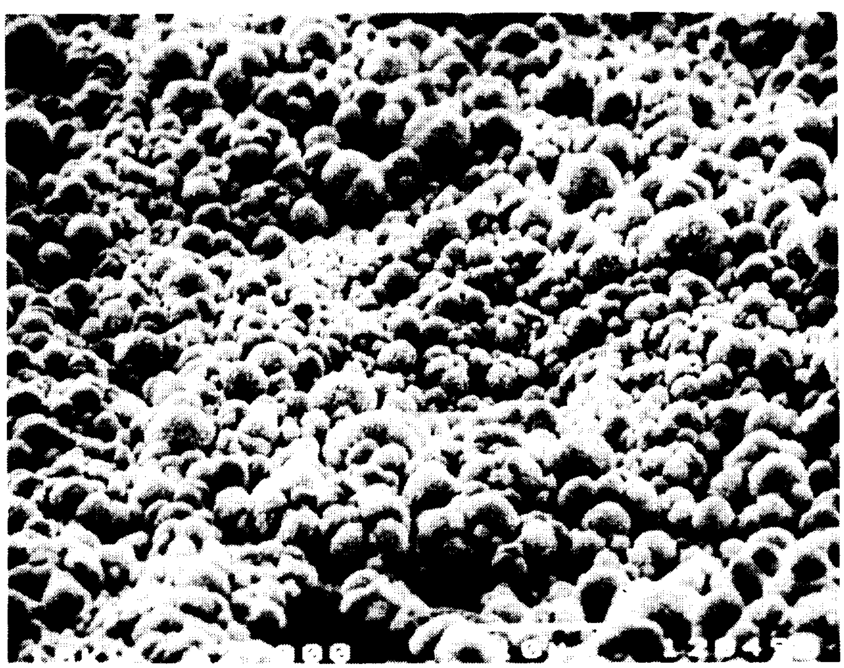


Flight

Figure 6. Contamination aspect on silver-plated bolt

ADHESION PHENOMENON

This phenomenon concerns a welding problem. We noticed the adhesion between a steel spring and a small aluminium plate. The disassembly force was very slight and we only observed a single outright case of bonding. These items come from experiment AO138-1 or AO138-6 and were used to support the samples (as seen in figure 7). Visual inspection reveals local shiny marks on the spring (as seen in figure 8). X analysis and the electronic microscope reveal a transfer of aluminum material to the steel (as seen in figure 9). This phenomenon could have been produced by a machining problem (unevenness of the spring), which, under launch and environment constraints, was locally "welded" to the aluminum.

This last paragraph highlights the importance of choosing the right metallic and organic materials, and the possible consequences in terms of pollution and/or faulty mechanical operation.

WORK IN PROGRESS

The former phenomenon concerns the shadow of a canister which can only be seen on one side of the plate (as seen in figure 10). We put its origin down to the outgassing of organic materials in vacuum and to the thermal conditions. The products of evaporation were condensed over all the cold surfaces of FRECOPA during the night. At sunrise, one side of the plate was more rapidly illuminated. The combined action of this illumination and U.V.'s radiations led to polymerization of these products. On the opposite side, which was slower to heat up, the contaminants had time to re-evaporate before polymerization by the U.V.'s.

When studying this contamination problem, we also noted the shadows of a connector wire, a bolt and of rivets on the FRECOPA structure (as seen in figure 11). This time, orientation of the contaminating flows seems to come from inside the LDEF towards space. It is far more difficult to explain this phenomenon. A study will be carried out, along with surface analysis.

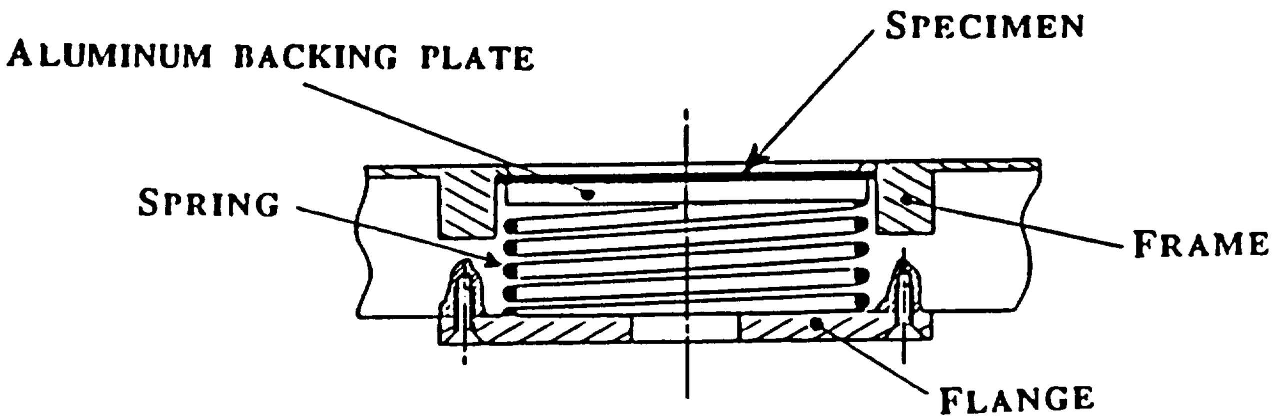


Figure 7. Steel spring and aluminum plate configurations

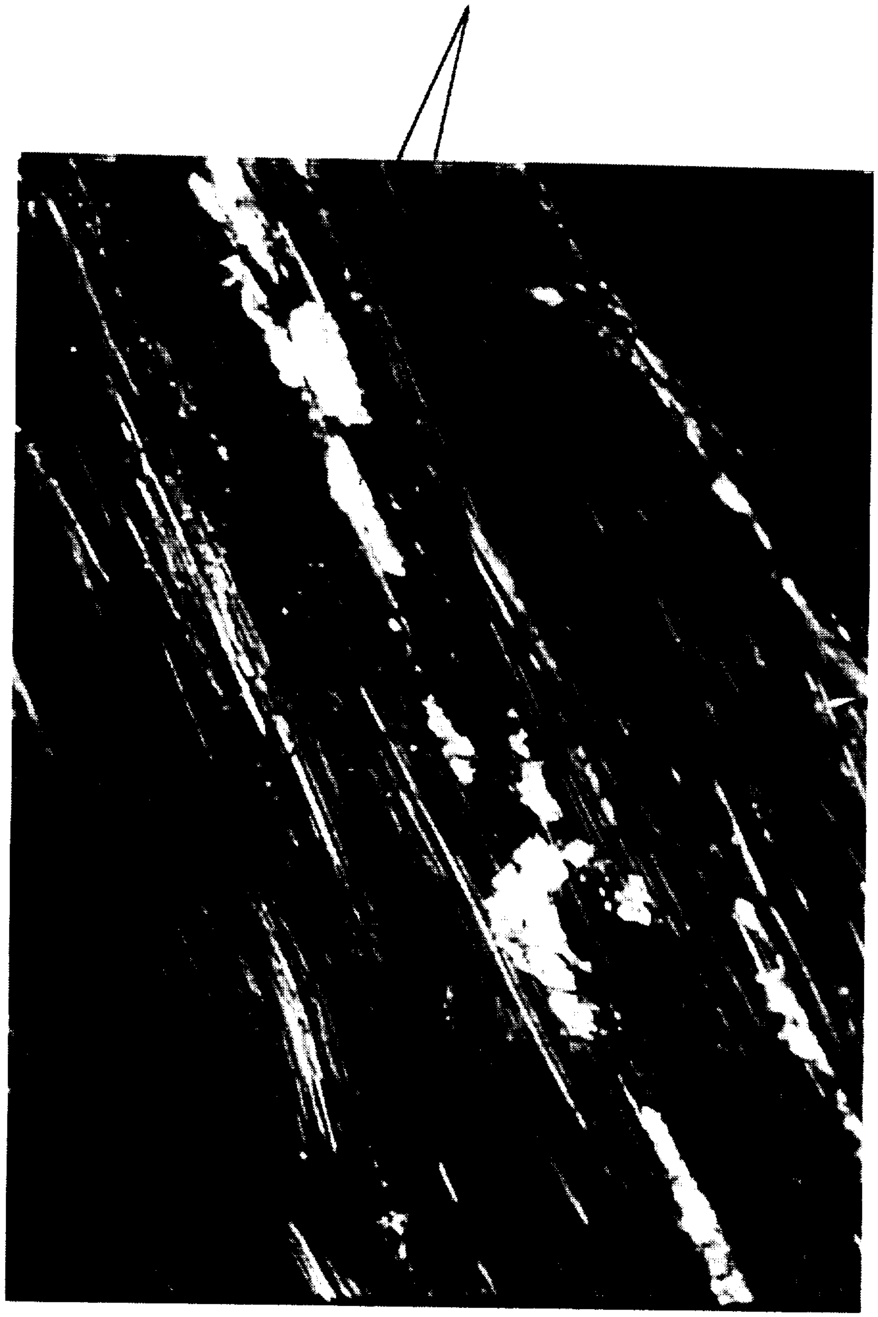
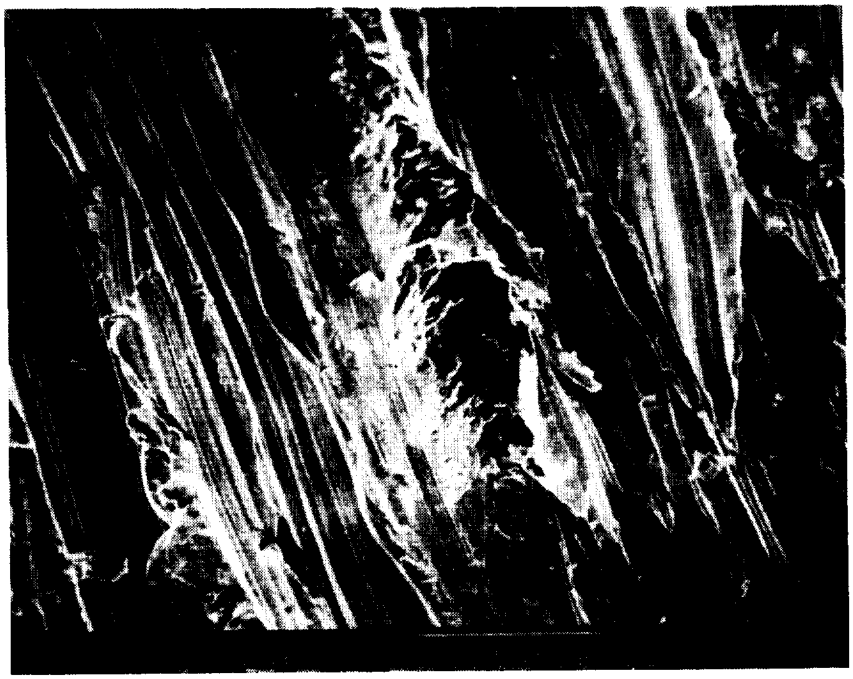
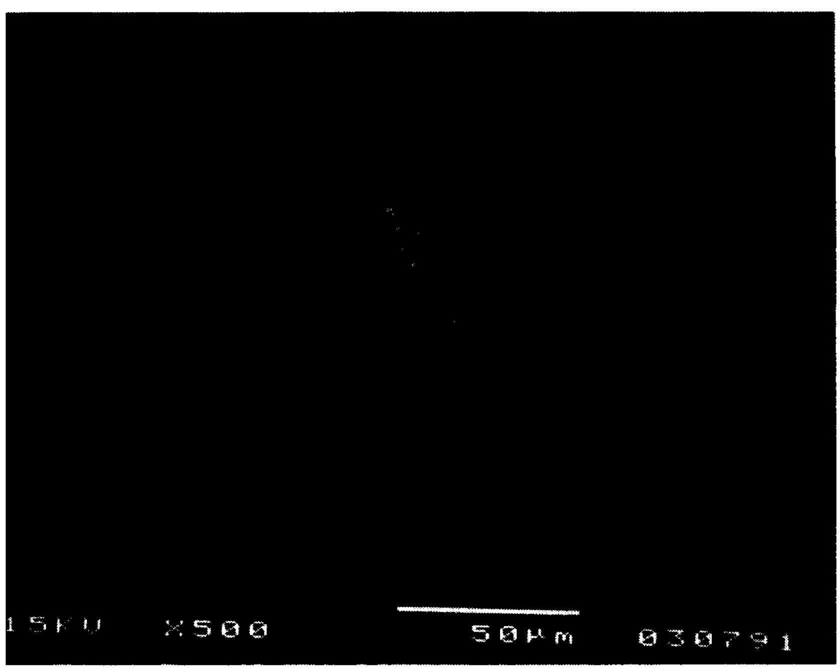


Figure 8. Aluminum transfer on steel spring



SEM picture



Aluminum element map

Figure 9. Aluminum transfer on steel spring (SEM)

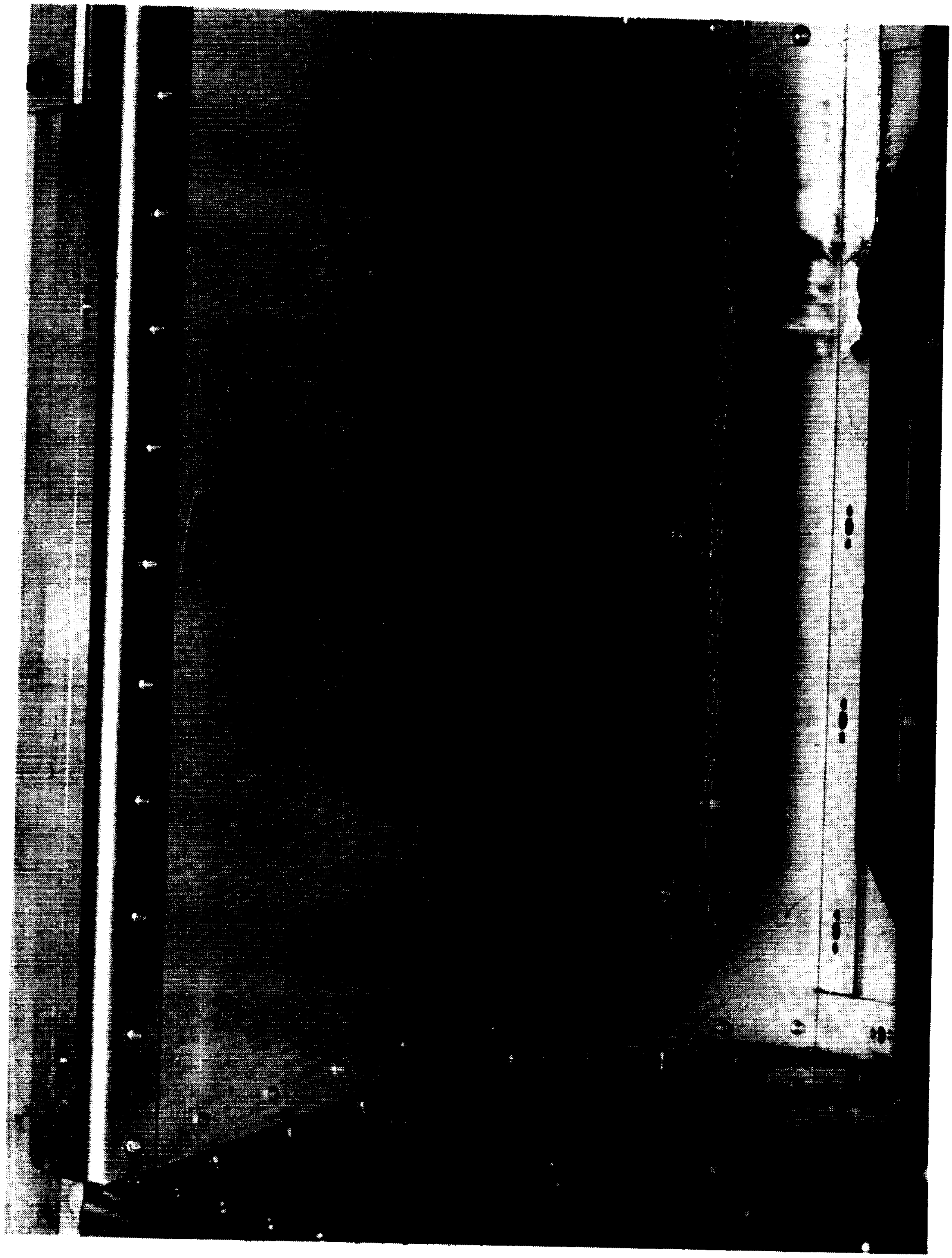


Figure 10. Canister shadow inside the tray

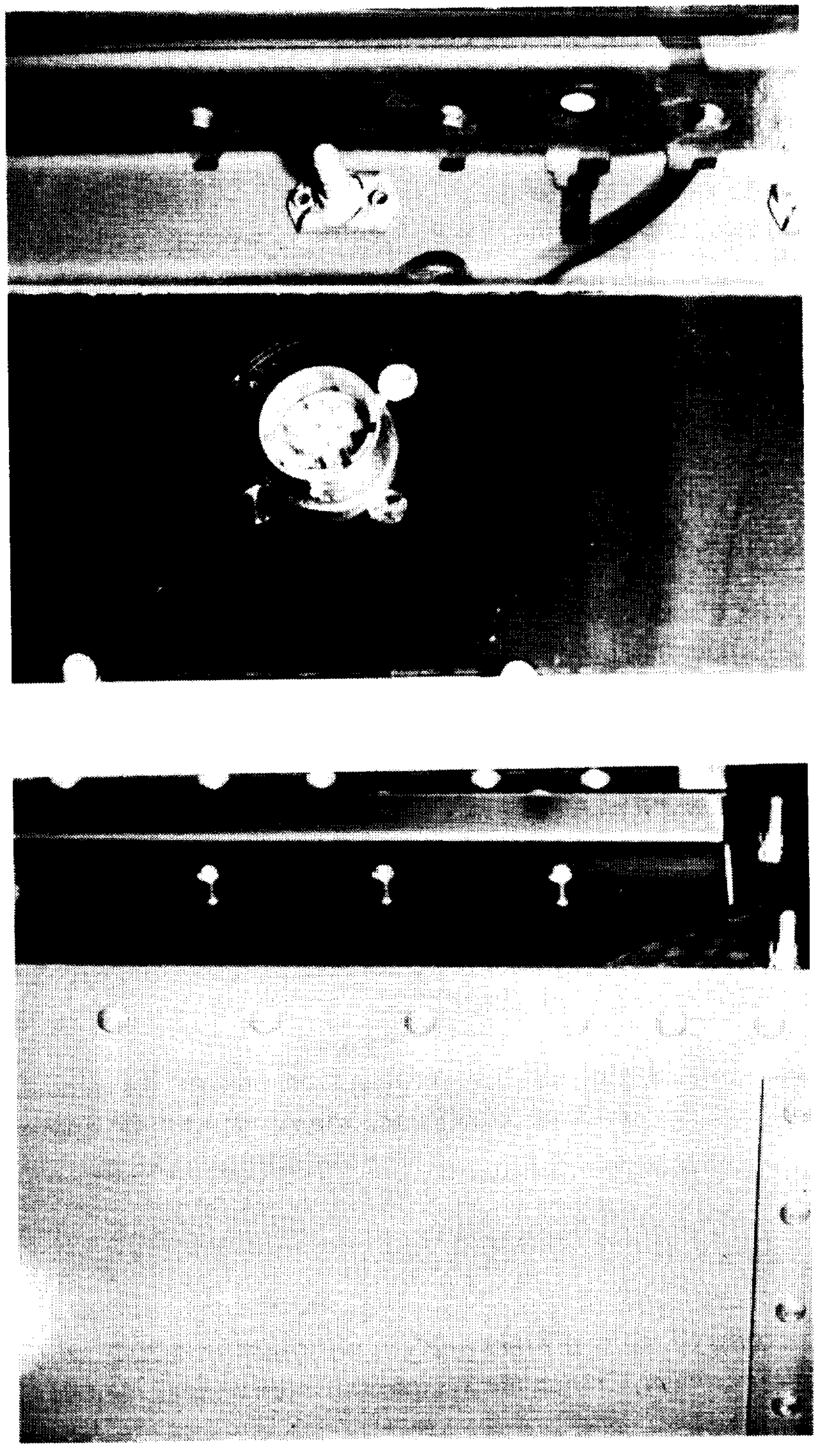


Figure 11. Bolts, wire and rivet shadows on the back of the tray

CONCLUSIONS

The FRECOPA experiment was a success. All systems operated correctly. The mechanisms and electronics of the sealed canisters worked correctly and provided ten months' exposure as planned. The extension to the mission enabled us to study the behaviour of a large number of materials after nearly 6 years' exposure. The overall result is positive. Materials resisted well in the environment, even if some of them show evidence of ageing which could have been harmful to a longer mission. We must use the results obtained to improve dimensioning or to protect the materials used for longer missions.

We noticed the good behaviour of the butyl seal despite a slight ageing.

For organic materials (velcro tapes, glues) we observed an ageing and some noticeable changes in mechanical and physico-chemical properties. We also noted a contamination by Si. The mechanical functions have been nevertheless executed.

Certain combinations of metallic materials must be prohibited, as local welding phenomena may occur under certain mechanical and/or environmental conditions. Combinations such as the organic/metallic used for FRECOPA gears might be a solution. Machining of parts are also important conditions affecting the appearance of this phenomenon.

Despite selection and the tests carried out, organic materials produce contamination which is likely to polymerize on cold surfaces. Protection and stringent outgassing tests before flight are the only remedies for using these materials.

Validation through tests is perhaps not sufficient at present for modelling the synergic complexity of all space environment parameters, which can only be approached through in-orbit tests.

References

1. Ch. DURIN, *Results of the post flight analysis on system materials for the LDEF/FRECOPA experiment,* Cinquieme Symposium International, Sep 91 Cannes-Mandelieu, France.

2. J.GUILLIN, *Les matériaux en environnement Spatial,* Cinquieme Symposium International, Mandelieu, France, Septembre 1991.

PANEL DISCUSSION SUMMARY

THEME PANEL DISCUSSION TOPICS

Bland A. Stein and Philip R. Young
Workshop Coordinators
NASA - Langley Research Center

Considering your theme / discipline, how have initial LDEF results affected:

- Potential space applications of specific classes / types of materials?
- Understanding of environmental parameters / synergism?
- Understanding of mechanisms of materials degradation?
- New materials development requirements?
- Ground simulation testing requirements?
- Space environmental effects analytical modeling requirements?

Considering your theme / discipline:

- What are the LDEF data-basing requirements? How would you like to see the data compiled / presented?
- What are the general needs for future flight experiments?
- What level of information should be presented for this discipline (and in what format should it be presented) at the Second LDEF Post-Retrieval Symposium, June 1992?

Considering your theme / discipline:

- Which LDEF findings are clear, indisputable, unambiguous?
- Which LDEF findings are confusing, ambiguous, obscure?
- Additional comments, concerns, recommendations?

LDEF Materials, Environmental Parameters, and Data Bases

Co-Chairmen: Bruce Banks and Mike Meshishnek
Recorder: Roger Bourassa

Consistent with the theme assigned, a wide range of topics was discussed by the Panel. The consensus of opinions and comments expressed by the various part-time and full-time panel attendees are summarized herein.

Initial LDEF results have affected and will continue to affect the application of specific classes of materials to spacecraft design. Unprotected polymers were shown to be unsuitable for long duration exposure in low earth orbit. The need has been shown for protective coatings for organic materials. The results also show that other materials may be employed with greater confidence than was realized before. For example, silicate binder Z-93 and YB-71 thermal control coatings survived and functioned well even under severe exposure conditions. LDEF data indicates both spatial and temporal nonuniformity in debris and micrometeoroid impact rates. This finding may significantly affect Space Station *Freedom* reliability assessments.

The availability of actual material samples exposed to low earth orbit environment for laboratory examination has both answered questions and raised new questions. Understanding of environmental parameters has been expanded to include synergistic effects that were not widely known outside the research laboratories. For example, atomic oxygen flux and ultraviolet radiation interact in degradation of silver/FEP and silicone materials. These interactions verify ground simulations and thus help to validate research methods. However we do not understand the mechanisms of atomic oxygen reactions with polymers. LDEF samples show that materials with volatile oxides develop surfaces textured with conical shapes. No satisfactory explanation has been advanced.

Differences between leading and trailing surfaces of LDEF reveal a role for atomic oxygen in contamination. Atomic oxygen is active in both depositing contamination layers and in their subsequent chemical change and removal. We do not understand how contamination layers are deposited. At this juncture LDEF is supplying clues that will help to focus future research.

No cold welding of fastener mating surfaces was observed on LDEF which could be attributed to space exposure. Only the occasional galling of threaded surfaces, commonly associated with assembly operations, was observed on post-flight examination of fasteners. However, the possibility that cold welding may occur between cleaned surfaces or between surfaces of threaded fasteners assembled and disassembled in space is not ruled out.

A few instances of adhesive failures on LDEF have been documented. These failures may be associated with thermal cycling. But, for the most part adhesives employed on LDEF functioned satisfactorily.

The need for on-board monitoring of several material properties and flight parameters has been revealed. These measurements include solar absorptance, thermal emittance, temperature, impacts, strain, yaw, pitch and roll because time dependent factors are important to analysis. Also, post-flight degradation of samples occurs. The need is evident for even more careful preparation and preflight handling of samples than was the practice for LDEF.

New material needs demonstrated by LDEF include: (1) protective coatings for organic materials; (2) a replacement for silver/FEP thermal control film; (3) a flexible white paint replacement for S13G/LO; (4) a durable flexible polymer electrical insulation; and (4) improved bumper designs for increased micrometeoroid and debris impact tolerance.

The panel recommends that ground simulation test requirements include synergistic effects. Analytical means need to be developed to extrapolate from ground testing to in-space performance of materials. Acceleration artifacts, ultraviolet radiation, atomic oxygen, thermal cycling and ground facility contamination effects are items of concern. Comparative ground testing of materials flown on LDEF is recommended. The environments simulated in ground facilities must be better characterized.

Modeling requirements for space behavior of materials depends on reliable reporting of LDEF exposures and are dependent on observed behavior of materials. As of now, not all data is available. Thermal models appear adequate. Return flux and trailing edge contamination effects must be modeled to accurately predict results. All models must be user friendly, accessible, and accepted by the user community.

Data bases developed for LDEF must acknowledge the divergent needs of different user groups; scientists, engineers, designers, etc. The user community needs to be able to electronically alert MAPTIS when the need for data updating is identified. The medium and procedures for forwarding data for inclusion in MAPTIS need to be defined. The data base must include sources and references for information. LDEF photographs need to be archived and the location of LDEF hardware needs to be made available to users.

Throughout the LDEF post-flight investigation a requirement has existed for individual investigators to collate and exchange results in a simple data base prior to more careful checkout and incorporation of data into MAPTIS. While not presented in this session, such a data base was reported on by the Systems Special Investigation Group, Optics Study and is worthy of note for use by others.

Recommendations by the Panel for future flight experiments are as follows: (1) provide for on-board measurement of spacecraft health and time dependent test parameters; (2) continue testing of actively monitored solar cells; (3) standardize test practices for characterization of materials; (4) allow for development of methods for extrapolation of test results; (4) test new higher performance, more durable materials to meet the critical needs identified by LDEF; (5) include validation as well as phenomenology levels of test; and, (6) be responsive to LDEF lessons learned.

At the Second LDEF Post-Retrieval Symposium, the Panel recommends that results and interpretations be presented in concurrent, narrow discipline sessions. Presentations on lessons learned and recommendations for LDEF data users should be prepared. Presentations should focus on quantitative results and new information. Qualitative overviews should be omitted. A view graph format should be followed and advanced copies of view graphs should be handed out at the start of the conference. Photographs should have scale bars. Appropriate acknowledgements should be made for materials used. The Second Symposium should feature a MAPTIS data base presentation.

Of the various LDEF findings the Panel noted that those most clear, indisputable and unambiguous are the following: (1) all polymers including organic paint binders are attacked by atomic oxygen; (2) most metal oxides protect materials from atomic oxygen attack; (3) silicate binder Z-93 and YB-71 thermal control coatings are durable in low earth orbit; (4) silicones are crazed on exposure in low earth orbit; (4) the Space Shuttle produces debris; (5) the majority of impacts occur in temporal bursts; and, (6) synergistic contamination and environmental effects are significant to materials behavior. The Panel also noted that there were unanticipated bond failures, these occurring with acrylic adhesives. The most confusing, ambiguous, and obscure finding was the extensive surface contamination of experiments and structure. What is the source of this contamination and by what mechanism is it deposited?

Concerns and recommendations for LDEF included the following items: (1) that LDEF lessons learned be captured and summarized; (2) the need for selectivity in deciding what to do with limited funding; (3) that completion of testing be timely because of aging of retrieved samples; (4) that the preflight condition of samples including processing details be more carefully documented; (5) that the location of LDEF control samples be documented; and, (6) that LDEF's value be recognized for ultraviolet radiation effects, thermal cycling, micrometeoroid and debris impact as well as for atomic oxygen effects.

LDEF MATERIALS, ENVIRONMENTAL PARAMETERS, AND DATA BASES

Bruce Banks and Mike Meshishnek, Co-Chairmen
Roger Bourassa, Recorder

+ Spacecraft on-board monitoring needed for (α, ε, T, impacts strain, yaw, pitch, roll) monitors needed
- Post-flight degradation occurs
- Preflight and post-flight handling is important

• New Materials Development Requirements

- Potassium silicate binder paints are durable for α, ε (Z-93, YB-71)
- Protective coatings are needed for long term durability of organic materials
- Bumpers or improved designs needed for micrometeoroid and debris tolerance
- Large new data base is emerging from flown LDEF materials which may be baseline for future spacecraft
- AO durable flexible polymer (electrical insulation)
- Replacement for Ag/FEP with low α/ε
- Flexible white paint replacement for S13G/LO

• Ground Simulation Testing Requirements

- Must be capable of simulating observed LDEF results
- Synergistic effects must be included (simultaneous or sequential)
- How do you extrapolate from ground testing to predict in-space performance?
- Acceleration artifacts for UV, AO, thermal cycling--How much is okay?
- Ground facility contamination effects must be considered
- Ground facility comparative testing on materials flown on LDEF
- Better characterization of ground facilities

• Space Environmental Effects Analytical Modeling Requirements

- Data must be available to be modeled - not all is available yet
- Exposures must be reliably reported for LDEF
- Models must predict observed results
- Return flux, trailing edge contamination effects must have models which accurately predict results
- Models must be user-friendly and accepted by the user community
- Thermal models appear adequate

- Potential Space Applications
  - SSF, EOS
- Understanding of Environmental Parameters
  - Debris, spatial and temporal non-uniformity may have big impact on SSF reliability
  - AO-UV synergism not previously known especially for Ag/FEP and silicones
- Understanding of Mechanisms
  - AO Mechanisms not understood (details of micro-cone structure)
  - Contamination mechanisms not understood
  - + Leading-Trailing surface contamination differences
  - + AO/UV silicone interactions verify ground simulations
  - + Thermal cycling effects in space
    - No cold welding possibly due to contamination
    - Adhesive failures
- LDEF Data-Basing Requirements
  - Need for LDEF community to be able to electronically alert MAPTIS that data needs updating
  - Two kinds of users' needs should be met
    - Scientists
    - Engineers, Designers
  - LDEF data needs to be sent to
    - ➧ Joan Funk, NASA LaRC, for MAPTIS inclusion in any form (hard copy, magnetic disk)
  - Data base must have data source and paper title identified
  - Archiving of photos needs to be carried out
  - Knowledge of location of all LDEF hardware must be capable of being made available to those who may have need it
- General Needs For Future Flight Experiments
  - Monitoring of spacecraft
  - Study effects of active vs passive solar cells

- Separation of synergistic phenomena
- List of "LDEF Lessons Learned" must be considered in future spacecraft designs
- Use standard recommended test practices for characterization of materials
- Need to know how to extrapolate results of short flight experiments to long duration
- Need to test new, higher performance, more durable materials
- Need validation as well as phenomenology tests

• Presentations At Second LDEF Post-Retrieval Symposium
  - Results and interpretations be presented in narrow discipline, concurrent sessions
  - Organization committee should have presentations on:
    - lessons learned
    - recommendations for users
  - Presentation of quantitative results (new data) not qualitative overviews
  - Advance copy of transparencies should be handed out at start of conference
  - Suggested viewgraph format (include scale bars and appropriate acknowledgments
  - MAPTIS data base presentation

• Confusing, ambiguous findings
  - Sources of contamination
  - Mechanisms--what caused what

• Additional Recommendations, Concerns
  - Need to be selective in deciding what to do with limited funds
  - LDEF's value for combined UV, thermal cycling, micrometeoroid, and debris, etc. needs to be recognized
  - Timeliness of aging material samples
  - Initial conditions (preflight) of samples be more carefully documented
  - Processing details are important
  - Capture LDEF lessons learned
  - Location of LDEF control samples needs to be documented

LDEF Contamination

Co-Chairmen: Wayne Stuckey and Steve Koontz
Recorder: Russell Crutcher

The contamination panel consisted of nineteen individuals representing a variety of NASA, DOD, and corporate centers (see attached). The meeting commenced at 12:55 PM, November 21, 1991. This session covered the following agenda topics:

1. What have we learned?
   What are we sure of and what is still in question?

2. How have initial results affected Aerospace Technology?

3. How should the data generated be stored to facilitate retrieval?

4. What future requirements have been indicated?

The items listed under what we had learned included things confirmed by LDEF, new information from LDEF, and things suggested by LDEF with data from, other projects strengthening the inference.

WHAT HAVE WE LEARNED

Most of the molecular film deposition was not line of sight. The deposits exhibited a geometry that did not point toward any specific outgassing source. Much of the contaminant film was found deposited on surfaces that faced outward from LDEF, indicating some of the deposition was the result of return flux. The interesting geometry seen in the deposited films were all related to the 'fixing' mechanisms, ultraviolet radiation and atomic oxygen, and not to an obvious surface collection mechanism. The infrared spectra of the most common molecular films indicated that the film was a mixture of functional groups from the variety of materials found on LDEF with modification as would be expected from the ultraviolet and atomic oxygen exposure. Urethane and silicone modalities were very common along with various other nitrogen containing functional groups and carbonyls. Large amounts of urethane paint, Z306 and A276, and silicone containing materials had been used on LDEF. The outgassing products from these materials, if blended and modified, would be consistent with what has been found using infrared analysis. This leads to the conclusion that most of the molecular contamination was outgassed from material intentionally used on LDEF. Infrared analysis of residues under tray clamps and shims and under materials fixed in location prior to flight indicated the presence of silicones and organics. Witness plates in the shuttle bay on other missions have indicated a deposition of silicones and organics during payload integration and vertical assembly. It is reasonable to assume that the molecular contaminants present prior to launch included both organic and silicone films and that these materials may have been widely distributed.

Silicones were a significant part of the final molecular film seen on LDEF surfaces. Atomic oxygen reacted with these molecular films removing most of the carbon and creating an oxidized silicon film. On surfaces with high atomic oxygen exposure the resultant film was thoroughly oxidized and became an invisible, porous, glassy layer. With less atomic oxygen exposure the characteristic brown film persisted underneath the silicon oxide surface layer. All exposed surfaces were contaminated with this film except for those being eroded by atomic oxygen.

The initial deposition of the molecular film was cyclic in nature, depositing the film with as many as 34 discrete layers as seen on tray C-12 and Earth and Space end films. Deposition patterns on the sample canisters indicate that most of the molecular film deposition occurred in the first thirty days though materials continued to accumulate throughout the mission at a reduced rate. A Quartz Crystal Microbalance active over the first 400 days of orbit on the trailing edge tray D-3 recorded a steady accumulation of mass. This is consistent with the experience of other satellites with sensors in a trailing or UV shadowed orientation.

The film was not uniformly distributed. Inside LDEF the film was concentrated wherever ultraviolet light could penetrate as LDEF came out of the earths shadow. These surfaces were oriented toward the ram direction so they also received atomic oxygen. The vent openings tended to have heavy deposits on the more ram directed sides. The films over much of LDEF were thin and often perforated. Atomic oxygen, ultraviolet light, the thermal condition of the surface and the cyclic inter-relationships of these parameters influenced deposition. Different surfaces also exhibited different collection efficiencies. Particulate contaminants on the surface of LDEF created holes in the contaminant film nearly an order of magnitude greater in area than that of the particle. This was exhibited as halos of relatively "clean" surface or "clean" shadows associated with the presence of particlulate contaminants.

Cross contamination from the Shuttle to LDEF and from LDEF to the Shuttle was evident based on particle types collected from the surface of both. Many of the Shuttle particle types found on LDEF were present while LDEF was in orbit. These particles were deposited on LDEF prior to and during launch. Others were not associated with orbital artifacts and may have been deposited post orbit during the recovery operations. LDEF was a major source of contamination for the Shuttle bay during recovery. There may have also been molecular cross contamination both during the original preorbit exposure of LDEF to the Shuttle bay and during the recovery. Current evidence from the HALO program suggests a low level of silicones may have deposited on LDEF prior to release into orbit from the silicones used on the Shuttle Bay liner and the Shuttle tiles.

Small circular deposits made by liquid aerosols have been found on every tray and most of the tray clamps of LDEF's surface. The concentration of these deposits varies widely from hundreds per square inch in a few locations to less than one per square inch in other areas. The deposits also vary in size from about a millimeter in diameter or larger to a few micrometers. Some of these materials were deposited prior to integrating the trays to LDEF and are consistent with "sneeze" droplets. These exhibite the highest local concentrations. Others are more complex and exhibit a pattern characteristic of an orbital environment. Some of these on the ram surfaces are oxidized and have no residual organic compounds. Others on the ram surface contain significant amounts of organics and could not have been present for any extended duration during the free orbit of LDEF.

The importance of contamination control plans and the need for detailed material reviews have been reemphasized as a result of the LDEF findings. Contaminants generated in any one area of LDEF contributed to the contamination of the entire structure. The concept of having sensitive surfaces out of the line of sight of contaminating materials is not sufficient to protect sensitive surfaces.

There are a number of questions that are not yet resolved. The sources of the silicone component of the molecular films have not all been identified. Many materials have been suggested but no detailed inventory of silicone containing materials has been produced. The Z306 black paint contained a very low level of silicones (0.05% or less). There were silicone contaminant films on the surface of some trays prior to launch. Silicone RTV's were used to stabilize some components so that they could better tolerate launch vibration; a ring of silicone contamination was deposited on every tray by the gasket of the tray covers; cross-contamination of silicones used on the shuttle to payload surfaces has been suggested with some support based on witness plate studies. The relative contribution of all these sources to the final film has not been determined.

Another unresolved question is the time and the mechanism of molecular film deposition. There was a major deposition sequence early in the mission but deposition continued over at least the first 400 days and probably over the entire mission. Atomic oxygen and ultraviolet light degraded more stable materials creating new outgassing species throughout the mission. The proportion of the outgassing materials that returned to LDEF as a stable surface film has not been determined nor has the mechanism for creating the film in its various locations. Ultraviolet light and atomic oxygen are both implicated as important to the creation of the film but the relative role of each has yet to be resolved.

There still remains much work to be done in quantifying the amount and distribution of the molecular films on LDEF. Models for the return flux and for the effects of vent geometry cannot be validated without such a detailed map. Electrical or magnetic field effects and other possible effects also need such a map to be adequately investigated.

INITIAL EFFECTS ON AEROSPACE TECHNOLOGY

Aluminized Kapton has been used frequently for low earth orbit (LEO) applications. On LDEF Kapton used on the ram surfaces eroded on exposure to atomic oxygen, leaving a very thin layer of aluminum foil. Some of the residual foil migrated in orbit, obscuring areas of previously exposed surface. Use of this material for future low earth orbit missions should be reconsidered in the light of the LDEF experience. The Z306 paint and its primer was one of the major contributors to the molecular film deposit on LDEF. The Z306 has a very favorable volatile/condensible material (VCM) rating based on the NASA standard outgassing test. This should not be considered a reasonable measure of the VCM during nearly six years of actual orbital exposure. Large areas on the interior and some of the exterior surface of LDEF were covered with this paint, so even low VCM values could contribute significant amounts of condensed material. The primer had a much higher VCM value and the volatile species did diffuse through the Z306, which also contributed to the total material outgassing from the painted surfaces. A more general concern is the possible formation of volatile condensible materials by the interaction of ultraviolet (UV) light and atomic oxygen (AO) on exterior exposed polymers. The frequency with which fluorine, presumably from the Teflon blankets on LDEF, was found by surface elemental analysis on surfaces far removed from any Teflon suggests such a mechanism. A list of likely reaction products from ultraviolet and atomic oxygen exposure for most polymer materials also includes many materials that could condense on surfaces in an orbital environment.

LDEF provides an opportunity to better understand the environment in low earth orbit and the synergistic relationships between the various environmental parameters. One example is the apparent UV enhanced atomic oxygen erosion rate of Teflon materials in LEO. Teflon surfaces exposed to UV alone exhibited surface modification and texturing that suggests chemical modification.

Another example is the AO cleaning effect. On ram surfaces that were attacked by AO there was no accumulation of molecular contaminants. On ram oriented metal or ceramic surfaces a contaminant film was present, though it tended to be invisible, making the surface appear 'clean'. When a surface analysis was performed on such materials, a layer of silicate contamination was invariably found. This silicate layer is the oxidized remnant of the molecular film found elsewhere on LDEF.

LDEF underscored the importance of synergistic effects in the performance of materials in LEO. Molecular films were not found necessarily on the most efficient collection surface or on surfaces that experienced the greatest exposures to outgassing materials but rather on surfaces where the conditions were conducive to the formation of stable films. These were surfaces that were cool at the time of their exposure to ultraviolet light and that had direct or indirect exposure to atomic oxygen. The relative role of UV and AO to the formation of these films may be indicated by the distribution of the film on LDEF but they have not yet been deciphered. The migration of particles during orbit has been documented on LDEF, but the conditions that cause the movement away and back or along the surface have not been determined. The distribution of debris from impacts to other surfaces on the satellite is another well documented effect on LDEF. Impact generated, spattered molten metal has been found on the surface of LDEF tens of centimeters from its source.

The whole field of combined effects needs to be more closely examined in light of LDEF findings. UV, AO, thermal effects, charging, field effects, outgassing and offgassing rates, the path of impact ejecta, degradation product yield in response to UV, AO, and combined UV-AO at various surface temperatures are environmental parameters that require more evaluation as indicated by the distribution and flight dynamics of contaminants on LDEF. Other parameters such as electrical fields, magnetic fields, and plasma may also have left distinguishable marks on LDEF.

The LDEF findings have emphasized the desirability of eliminating silicones and of minimizing organic materials on spacecraft. Exterior surfaces are the most susceptible to degradation caused by the exposure of silicones or organics to UV and AO. Venting from the interior of LDEF was responsible for much of the exterior deposit. Careful design of vents would help eliminate these problems as would the reduced application of organic or silicone materials on the interior of the spacecraft.

LDEF verified the need for greater flexibility in the testing of materials for specific orbital applications. ASTM E595 is a step in the right direction but more is needed. Combined exposure testing is needed for surfaces exposed to UV and AO. After all the components have been evaluated, a system level test would show the result of the interaction between contaminants from different components and their joint response to the environment. The panel stressed that acceptable performance of a material in these tests does not eliminate the concern for contamination; it simply helps to quantify the risk. Current materials carefully used can be acceptable, provided all recommended guidelines for restricted use and special processing are followed. The term "Space Qualified" for materials that meet a particular performance level should not be interpreted as license to use such a material freely.

LDEF results have also had an effect on contamination modeling. Most of the molecular deposition occurred at surfaces where the conditions were conducive to the formation of a stable film and not in the direct line of sight from specific sources. Current models model condensation on surfaces and not 'fixing' of the condensed materials to surfaces. Return flux was also an important contributor to the surface film. The role of vent configuration needs more detailed consideration. Larger trailing edge vents on satellites could reduce return flux. On the ground the poor correlation between airborne monitoring, small area fallout collection plates, and the actual accumulation of contaminants on the surface of large spacecraft was again verified.

DATA BASE REQUIREMENTS

The effects of contaminants on LDEF materials need to be documented by material type and/or system. Optical, thermal control surfaces, solar cells, and other key references must be one mode of access. The effects must also be accessible by type of contaminant, source of contaminant, time of contamination, and analytical method. The analytical method should be cross referenced to results from other methods of analysis. The test methods used to measure the changes in the material and those to identify and quantify the contaminant must be specified along with the raw data, the time of the analysis, sample preparation, conditions of storage prior to the test, and any other information that would have an effect on the measurements taken.

Much valuable information about the dynamics of contaminants on Shuttle missions and on the dynamics of contaminants in low earth orbit has been gained by the study of LDEF, but there is much more that can still be learned. LDEF has been a rare opportunity to glimpse the actual dynamics of contaminants in low earth orbit. These lessons learned must now be communicated to the aerospace community in general. The database is an important part of that communication but so also are the papers being generated by the various LDEF conferences. Much of the analytical work already accomplished has yet to be evaluated and disseminated. The upcoming June, 1992 LDEF meeting will be an opportunity to continue to disseminate the lessons learned from LDEF to the entire community and not just to those in our own particular area of aerospace technology.

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LDEF CONTAMINATION

Wayne Stuckey and Steve Koontz, Co-Chairmen
Russell Crutcher, Recorder

DISCUSSION TOPICS

- What Have We Learned?
  - Clear
  - Needed
- How Have Initial LDEF Results Affected
  - Potential Space Applications
  - Understanding of Parameters/Synergisms
  - Materials Degradation
  - New Materials Development
  - Ground Simulation Testing
  - Analytical Models
- Data Bases
- Future Requirements

WHAT HAVE WE LEARNED (Clear, Indisputable)

Not Line-of-Sight - Notable return flux
Self Contaminating
Confirmed environmental interactions - Atomic Oxygen,UV, Temperature
Silicone Contamination
Contamination continued to accumulate
Non-Uniform deposition - Not always visible
Contamination layers present
Importance of Multiple Sources
Leading Edge deposits are more transparent
Cross Contamination from Shuttle Sources
Droplets from pre- and post-orbit operations

Importance of Contamination Control Plans and Materials Review

WHAT HAVE WE LEARNED (Needs Clarification)

Sources of Silicones/Silicates
Deposition profile for entire mission
Deposition Mechanisms
Thickness, Amounts of Contaminants on LDEF Surfaces
Contribution of AO Degradation Products
Models for Return Flux, Vents
Sources of Other Contaminants from LDEF Interior
Electrical Interaction with Contaminant Deposition

How Have Initial LDEF Results Affected

Potential Space Applications

Aluminized Kapton
Erosion may be Contaminant Source

How Have Initial LDEF Results Affected

Understanding of Environmental Parameters/Synergisms

Particulate Migration
UV Enhanced Deposition
AO/UV Synergism for Deposition
AO "Cleaning" or Deposition
Impact Debris
Non Line-of-Sight Deposition
Other Parameters to be considered
- Electrical Fields
- Plasma
- Magnetic Fields

Particulates from AO/UV Interactions

How Have Initial LDEF Results Affected

New Materials Development Requirements

Alternate Non-Silicone Materials
Current Materials generally acceptable with proper usage/processing

How Have Initial LDEF Results Affected

Ground Simulation Testing Requirements

Verified Need for Materials Testing for Contamination (E595)
New ASTM Method Available for Materials
Need for Combined Exposure Testing
System Level Contamination Tests

"Space Qualified" (E595) does not eliminate contamination concern

How Have Initial LDEF Results Affected

Space Environmental Effects Analytical Modeling

Line-of-Sight versus Monte Carlo - Importance of Return Flux
Venting Source Analysis Needed
Airborne particulate results do not correlate with surface cleanliness

How Have Initial LDEF Results Affected

Data Base Requirements

- Effects of Contamination on Materials Performance
  - Optics
  - Thermal Control
  - Others
- Document Results and Analysis Technique
- Analyze Reference Areas by Multiple Techniques
- Note Potential Sources
- Note Contamination Analysis and Effects of Contamination
- Include other relevant data whenever possible
- Time of Analysis, Storage Conditions, Removal, Sample Preparation, History
- Document Lessons Learned

Thermal Control Coatings, Protective Coatings, and Surface Treatments

Co-Chairmen: Ann Whitaker and Wayne Slemp
Recorder: Johnny Golden

Applicability of Results:

The initial LDEF results on thermal control coatings have direct applicability to all LEO spacecraft. The environmental conditions provided by LDEF, including the contamination environment, will also be partially applicable to other spacecraft working altitudes.

Understanding Of Environment/Synergism:

Although the LDEF results greatly increased our knowledge of long-term LEO effects on materials, we still do not fully understand the LEO environment in terms of synergistic effects. This deficiency is largely due to the lack of firm single environmental parameter effects data from LDEF. Most measured changes in thermal control materials have been related to combined environmental effects due to the nature of the LDEF mission.

Understanding of Degradation Mechanisms:

The mechanisms of materials degradation are likewise not well understood. Degradation (chemical) mechanisms are determined by understanding rate effects. However, the effect of temperature and thermal cycling has been largely ignored in the initial LDEF results. The temperature dependence of AO and UV effects must be ascertained to complete our understanding of materials degradation mechanisms. For LDEF in particular, we also need to express how contamination effects have interacted with surfaces when we interpret degradation mechanisms.

Materials Development Required:

LDEF results and recent world-wide focus on environmentally conscious manufacturing have affected requirements for new materials development. The inorganic white coatings Z93 and YB-71 were confirmed through LDEF data to have stable optical properties in the LEO environment. However, a new source for the silicate binder used in these coatings must be obtained. The requalification process is presently underway at IITRI. LDEF results indicate that thin silicates as overcoatings should be developed for AO protection of less stable thermal control surfaces. The continued use of organic coatings for passive thermal control will require the development and qualification of materials with environmentally compliant levels of volatile organic compounds (VOCs). Need was expressed for the development of new conductive and partially conductive coatings with acceptable optical properties. Finally, the UV degradation of silver/Teflon adhesive observed on LDEF warrants the evaluation and publication of an appropriate application procedure to avoid future problems.

Ground Simulation Testing:

The ability of ground simulation testing to be accelerated and still provide results comparable to that observed on long-life spacecraft is the ultimate goal of performance life prediction. Examples where prediction did not meet performance, most notably with S-13G/LO, have been observed with LDEF. The ability to conduct combined effects testing is indicated, involving combined AO plus UV exposure at controlled temperature with in situ reflectance measurements. Serious work concerning the proportionality of AO and UV for such a system, in addition to the type of UV source, needs to be done. The use of calorimetry to obtain real time α/ε measurements would be an enhancement. The addition of electrons and protons to ground testing is also recommended.

Analytical Modelling:

The LDEF results have illustrated the need for adequate modelling of the contamination environment, to determine the sources and sinks of molecular contamination, and how this will affect the performance of thermal control coatings. The most useful contamination model would include interactions with AO and UV.

Data-Basing Requirements:

Data-basing of LDEF thermal control coating experience is essential. A format like that developed for the optical systems data, presented at the workshop, would be acceptable when modified to support thermal control coatings key words. However, it must be recognized that such a database will require a commitment for continued financial support in order to be maintained adequately.

Future Flight Experiments:

Future flight experiments suggested by the results of LDEF thermal control coatings analysis would be an "LDEF"-like vehicle and orientation, flown in polar or highly elliptical orbits. Such experiments would allow more separation of the individual environmental factors for elucidation of degradation mechanisms and synergisms, and would also provide enhanced particulate radiation for the study of spacecraft charging effects on thermal control coating degradation.

Second LDEF Post-Retrieval Symposium:

Information presented at the Second LDEF Post-Retrieval Symposium should draw conclusions and make recommendations. It is also preferable to see more comprehensive presentations, which provide data for materials considering the various environmental exposures available on LDEF when applicable. Another factor in these comprehensive presentations would be that they also include comparisons to ground test results reported in the open literature.

Clear Findings:

Clear findings from LDEF were few, but it is apparent that the silicate-based coatings Z93 and YB-71, and the chromic acid anodized aluminum are stable thermal control coatings for long-term space flight in LEO. Another clear finding is that for paints which are vulnerable to AO and UV degradation, such as in polyurethane paints (A276), the coating performance is principally controlled by AO erosion.

Confusing Findings:

Several results from LDEF appear confusing at this time. Urethanes, silicones, and epoxies exhibited changes in their fluorescence spectra after LDEF exposures, with reflectance of a UV illumination source shifting from the ultraviolet region to the visible region. LDEF AO fluence modelling has shown that most of the AO exposure occurred in the latter stages of the LDEF mission. It is not completely clear how this relatively rapid increase in AO flux has affected thermal control coating results. It is also apparent that we do not understand the degradation of the black chromium solar absorber coating, when it exhibited very stable optical properties in some areas but changed in other areas where the environment should not have been substantially different. And finally, has contamination contributed to some of the results which are not compatible with STS measurements? There is some confusion in determining which LDEF results are due to contamination, which are due to the "natural" space environment, and which involve interactions that protect or degrade the performance of thermal control coatings.

Other Concerns:

Several other concerns and comments were raised in the thermal control coatings theme panel discussion. One concern was post-flight handling, and how this has affected the data. Comment was made about the FEP Teflon AO erosion rate appearing to have been accelerated above STS predictions due to UV exposure, and if electron and proton radiation could also play a role in this effect. It was also observed that the S-13G/LO coating exhibited varying degrees of degradation, all within what could be considered as comparable environmental exposure conditions. There is some question as to how much of such effects are due to formulation and application technique, as opposed to contamination and environmental exposure.

THERMAL CONTROL COATINGS, PROTECTIVE COATINGS, AND SURFACE TREATMENTS

Ann Whitaker and Wayne Slemp, Co-Chairmen
Johnny Golden, Recorder

THERMAL CONTROL COATINGS

- Applications: Data directly applicable to all LEO spacecraft - partially applicable to some higher orbits without high radiation fluences
- Understanding of environment/synergism: Not fully understood - Need single parameter effects data mechanisms dependent upon rate effects - Need dependence data for AO, UV at temperature. Need contamination effects interaction data
- Materials development required: Thin silicates as overcoats for AO protection - Need source of silicate for Z-93 and requalification of coating
- Materials development: Evaluation and publication of application process for silvered Teflon
- Ground simulation testing: In-situ measurement capability for AO and UV testing, addition of electrons and protons to ground testing, and achievement of same results for long-life spacecraft
- Analytical modeling: Ability to model contamination and its effect on coatings

- Data-basing requirements: Optical systems data base is acceptable - use thermal control coating key word
  - This Data Base will need continued financial support to be maintained!
- Future flight experiments: Need polar and elliptical orbit data with high particulate radiation
- Information should draw conclusions and make recommendations - need more comprehensive presentations looking at all environments on LDEF
- Clear Findings:
  - Chromic acid anodized aluminum and Z-93, YB-71 paints are stable for long-term space flight
  - AO erosion is major factor in coating performance where paints are vulnerable to UV and AO degradation. Example--A276 (urethane binders)

- Confusing Findings:
  - Urethanes, silicones and epoxies change fluorescence spectrum after UV and AO exposure
  - Since LDEF had most of its AO exposure at end of life - how does this effect the results?
  - Black chromium had stable optical properties in some areas but changed in others where environment should be the same
  - How does contamination effect AO and UV degradation? What changes on LDEF are due to contamination vs natural space environment?
- Concerns:
  - How did post-flight handling affect data?
  - FEP Teflon coating AO erosion rate appears to accelerate with UV exposure. Do electron and proton radiation also play a role in this acceleration?
  - The S-13GLO exhibited varying degrees of degradation - Is this caused by formulation, application, or contamination and environmental exposure?

Polymers and Films
(Including Ag/FEP)

Co-Chairmen: Philip R. Young and David Brinza
Recorder: Gary Pippin

This theme panel is conveniently separated into two subtopics, silvered teflon (Ag/FEP) and other thin film polymeric materials.

Potential Space Applications

The Ag/FEP blankets remained functional as a thermal control system over the lifetime of the LDEF. Several changes were observed which will limit the lifetimes of the blankets. The recession due to atomic oxygen will eventually leave the FEP layer thin enough so that the emissivity will decrease. Solar ultraviolet and vacuum ultraviolet radiation caused degradation of mechanical properties. Delamination zones were observed around all the impact sites. The above effects acted in concert at certain locations. Any one, or combination of these effects may ultimately limit the lifetime for a given application. The large number of thermal cycles endured by the spacecraft may have enhanced the delamination. The silver layer in the adhesive-backed Ag/FEP was cracked during the application onto the aluminum substrate, causing "bleed-through" and subsequent darkening of the adhesive under solar exposure. While this process increased the solar absorptance to thermal emittance ratio, the resulting temperature increases were not excessive. The roughening of the surface texture of the FEP layer dramatically increased the diffuse component of reflectance. The resulting increase in light scattering means that care should be taken when atomic oxygen susceptible materials are used near sensitive optics.

Unprotected, non-silicone containing organic polymers were heavily attacked by atomic oxygen. At least 0.010" thickness of Kapton was removed from near leading edge locations.

Siloxane containing materials are self-protecting as thin silicon dioxide layers are formed under atomic oxygen exposure. These materials outgas, and if the outgassed materials deposit on other surfaces, the surface optical properties can change.

Understanding of Environmental Parameters

The erosion rate of Ag/FEP was greater than rates observed on short-term shuttle flights. One possibility is that increased UV exposure will break bonds and provide more and more active sites for oxidation events. There is evidence for heating on a number of film specimens. The texture of some regions of the FEP, as viewed under SEM, looks like material which has been melted at some time. Some remaining strips of thin film materials are twisted and curled and appear to be shrunk. The thermal cycling can influence the erosion rate for oxidation processes which have some activation energy. The measured recession rates are global averages over the complete range of conditions, but the actual rates may have varied widely during even single orbits. Localized heating appears to have occurred where particles with particular optical properties have migrated onto surfaces with different optical properties. The Earth and space end thermal panels were coated differently, and the bicycle reflector near the trailing edge and at the Earth end of LDEF was severely eroded and very different in appearance from any of the other reflectors. On Ag/FEP blanket A4 there is evidence of indirect atomic oxygen scattering from the underside of a nearby scuff plate which extended beyond the end of the LDEF structure and was exposed to ram atomic oxygen. Surface roughening on the tucked edge portions of Ag/FEP blankets near the leading edge was also observed, implying oxygen was scattered from tray and clamp edges. LDEF represents the first examination of material which has been exposed under all conditions of the solar cycle, from solar min to solar max. The solar vacuum ultraviolet radiation flux varies over the solar cycle. The influence of this variation on the thin polymer film samples has not been well characterized.

Understanding of Degradation Mechanisms

The erosion of Kapton is apparently linear with AO fluence; the observed recession on LDEF can be generally predicted by multiplying the STS-8 erosion yield with the calculated LDEF AO fluence. Significantly greater erosion yields are observed for FEP, polystyrene, and PMMA from LDEF in comparison with shuttle results, suggesting a strong atomic oxygen/ultraviolet radiation synergism in the degradation mechanism for these materials. The mechanical properties of FEP were affected by exposure to UV. The data indicate chain scission processes followed by crosslinking in the polymer under UV exposure. For the specimens which were highly eroded due to atomic oxygen exposure, little chemical change was observed relative to ground specimens. This suggests that UV may prepare free radical sites on or near the surface. The oxygen reacts at these sites, producing volatile species which then leave, exposing fresh material. There is concern that there may be post-retrieval material degradation; peroxide radicals may form on surfaces and continue oxidation and volatiliation processes.

New Materials Development Requirements

LDEF confirmed the need for both atomic oxygen and ultraviolet radiation stabilized materials for long term missions. Polysiloxane modified materials and thermoset siloxane materials with high (> 200C) glass transition temperatures offer possibilities for atomic oxygen stabilized materials. Fluorocarbons have extended lifetimes relative to polyimides and hydrocarbons. Use of phosphate pendant groups on polymer chains should enhance oxidative stability because the phosphate group is already oxidized and is large enough to block access to main chain atoms. For ultraviolet stabilization, candidates include polyphosphazenes, UV stabilized fluorocarbons such as perfluorophenyls, low color polyimide polymers (UV transparent), and aromatic polyimides.

Ground Simulation Testing Requirements

The types of capabilities needed from test facilities are high fluence atomic oxygen exposure testing with directed beams, high fluence UV/VUV testing, simultaneous atomic oxygen/ultraviolet (including vacuum ultraviolet wavelengths) radiation exposures, in situ properties measurements, thermal cycling/temperature control and monitoring, and "large" exposure areas (perhaps 100 cm^2 or greater). Materials flown on LDEF which appear to be good candidate material types for use in calibration of test facilities include FEP, the type of polymers flown on experiment AO114, the graphite fiber/organic resin composites, and the polyurethane based A-276 white thermal control paint. This is a good range of pure materials and mixtures which degrade by a variety of mechanisms and will give a good gauge of the effectiveness of a space simulation test bed.

Space Environmental Effects Analytical Modeling Requirements

Spacecraft environmental models should be able to predict overall effects on satellites, atomic oxygen and UV flux, and particle impact rates vs location, and should be able to predict local effects, temperature variations, outgassing, and shadowing from nearby structures. Both direct and indirect scattering of atomic oxygen should be modeled. Experimental results from the LDEF provide a means to verify models for virtually every LEO environmental parameter. The orbit data generated by NORAD observations of LDEF can be used to test models of the atmosphere, particularly density predictions, to improve our knowledge of satellite drag coefficients. Materials degradation models can be produced from LDEF for several materials. We can make some empirical predictions about erosion yields for materials with up to six years exposure. Detailed mechanistic models will require more effort. The specific dependence of degradation and recession on atomic oxygen and ultraviolet fluxes varies by material type. These effects are likely strongly time and temperature dependent, activation energies will vary for different processes, and the fluxes of vacuum ultraviolet radiation and atomic oxygen change drastically over the solar cycle. At different times, different parameters likely dominate the rate limiting processes. This is a complex, material specific area. The goal is to be able to make accurate lifetime performance predictions for materials with specific applications. This would improve the reliability of spacecraft and therefore their chances of enduring and performing their missions over the long term. Good models would also minimize the cost of testing by guiding selection of test parameters to focus on critical conditions.

Data Basing Requirements

The following information is the minimum required for an effective compilation of materials data from LDEF. The trade name of the material; its chemical composition and structure; the locations on LDEF, including exposure details such as direct, indirect, internal, and likely thermal conditions; and availability of controls for each are desired, as well as a list of investigators who flew a particular material as part of their experiment, either as specimens or supporting hardware. A compilation of general observations should be obtained and should include notes on contamination, meteoroid and debris impacts, physical integrity of the hardware, and any evidence of melting or other visual changes. The available numerical data, with estimates of the uncertainty (error bars!) is of interest. Measurements of erosion are needed, as well as a surface analysis to obtain elemental analysis and to identify the functional groups present. Surface morphology should be documented, and a thermal analysis is needed to obtain glass transition temperatures, coefficient of thermal expansion, heat capacities, and melting temperatures. Mechanical and optical properties of interest are the moduli, strength, % elongation, solar absorptance, thermal emittance, and diffuse reflectance. Outgassing and weight loss of material should be included. Reports of measurements should include the laboratory and the date of analyses so that any terrestrial degradation may be accounted for. A reference list of photographs of SEM, AFM, and STM images should be compiled. A list of references to other flight data, laboratory data, and investigators working with this material for space applications should be compiled for each material.

Future Flight Experiments

There are several near term flight opportunities which may provide materials performance data. Shuttle flight STS-046 will contain the Energetic Oxygen Interaction with materials-3 (EOIM-3) experiment, which will provide a 40 hour exposure. This flight will also launch the EURECA free flyer experiment which will remain in orbit for between 6 and 11 months. The LDCE (gas can) sponsored by Case Western Reserve University, the IOCM and other gas can experiments represent additional opportunities. The SAMMES experiment will be an active experiment with telemetered data. Future opportunities may include other free flyers, RPC, and Space Station Freedom.

Measurement techniques on EOIM-3 will include recession measurements vs weight loss, stressed and loaded materials, temperature effects, thin films on reflective surfaces, UV synergism, and variable exposure. The SAMMES and OPM will have in situ monitoring of critical properties such as absorptance, emittance, and thickness, and SAMMES will have an in situ environment monitor. The SAMMES mission will be an extended duration exposure of between 6 and 18 months. Canister experiments will offer the advantage of controlled environments.

Suggestions for the Next Symposium

Submission of data packages at the symposium for data basing should be required. The presentations by the principal investigators should be detailed and include interpretations of their observations. The presentations by the special investigation groups should focus on the consequences of the observed condition of the hardware, a compilation of engineering lessons learned, and predictions for use by future missions. There should be plenary sessions for environments and for each of the special investigation groups. The conference should include a poster session and a mixer. Discussion periods are essential, and concurrent sessions should be conducted for the different subject themes and disciplines.

Summary of LDEF Findings

The clear findings are that the LDEF was retrieved, the funding was inadequate for postflight analysis, and the results were needed rapidly. The effects of atomic oxygen and solar ultraviolet acting in concert were evident for many materials. Contamination was widely present on this spacecraft. The effects of the thermal velocity component of atomic oxygen were verified by examination of FEP and Kapton films.

The LDEF findings that are not so clear are the impact of contamination, post-retrieval aging effects, thermal effects, and the atomic oxygen fluence estimate. We have several comments, concerns, and recommendations. This community of workers needs more access to each others' data and materials for additional testing. The methods of storage of materials, both flight and controls, may not have prevented aging effects. Both time and money are critical for obtaining the maximum information from this rather unique opportunity. We should try to target end-users for support and advocate continued investigations. Prime contractors on SSF should consider supporting these efforts with IR&D funding; we should also continue to solicit support from DoD and SDIO.

POLYMERS AND FILMS (INCLUDING AG/FEP)

Phil Young and David Brinza, Co-Chairmen
Gary Pippin, Recorder

- Potential space applications of materials affected by LDEF results
  - Ag/FEP:

    Blankets remained functional over LDEF mission

    AO erosion may limit life; diffuse reflectance may impact systems sensitive to light scattering

    UV/VUV effects on FEP mechanical properties

    Enhanced propensity for delamination of Ag/FEP can impact thermal control performance

    "Bleed-through"/aging of bonded Ag/FEP affects α

  - Non-silicone-containing, unprotected polymers heavily attacked by AO (i.e. ~ 0.010" Kapton eroded)
  - Siloxane - modified materials are self-protecting
    survive AO attack
    outgassing concerns...chemical incorporation rather than blends
    effects on surface optical properties are a concern

- Understanding of environmental parameters/synergisms affected by LDEF results
  - Greater than expected erosion noted for some materials
    Enhanced UV/AO fluence ratio effect?
  - Indirect (scattered) AO effects observed
    Reflection from LDEF tray surfaces on Ag/FEP films
  - Extensive heating of films witnessed (melting of polyethylene)
    Effects on degradation due to UV/VUV exposure
    Effects on AO attack of carbon films
  - Local thermal effects noted
    Particles/surface debris on materials
    Earth, space end panels (melted bicycle reflector)
  - Variability of UV/VUV with solar cycle
- Understanding of mechanisms of materials degradation affected by LDEF results
  - Erosion of Kapton apparently linear with AO fluence data. Observed recession predicted by previous erosion yield from LDEF AO fluence
  - Significantly greater erosion yields for FEP, polystyrene, PMMA... suggests strong AO/UV synergism

- Mechanical properties significantly affected by UV
  - Crosslinking, chain scission processes in FEP, polyethylene
- Little chemical changed noted in highly eroded materials;
  - Exception: ESCA of FEP
    - C8 - nearly same as control (+0.5% Oxygen)
    - C5 - CF, CF_3 enhanced with respect to control
    - C6 - intermediate to C8, C5
- Data for materials in canisters important for leading edge
  - Enhanced AO/UV fluence ratio
- Materials degrading since retrieval
  - Peroxide radical chemistry?

• New materials development requirements affected by LDEF results

- Materials intrinsically stable against AO attack needed

  Siloxane - modified polymers (polysiloxane/polyimides)
  Thermoset siloxane materials - High Tg (>200°C)
  Fluorocarbons have extended life compared to polyimides, hydrocarbon polymers

- UV--stabilized materials

  Fluorocarbons with pendent and chain perfluoroaromatics
  Aromatic polyimides
  Colorless/low color polyimides
  Polyphosphazines
  Phosphate pendant groups on polymer chains

• Ground simulation testing requirements affected by LDEF results

- High fluence AO testing (directed beam)
- High fluence UV/VUV testing
- Simultaneous AO/UV exposure testing
- Quantify acceleration factors for testing
- Large exposure areas - mechanical testing
- Thermal cycling
- Temperature effects
- Potential "benchmarks":

  A276 paint
  Polymers being studied at UAH
  FEP
  Composite materials (matrices)
  Canister materials

- Space environmental effects analytical modeling requirements affected by LDEF results
  - Environment definition - global and local environments
    - AO fluence estimates: direct, indirect (scattered AO)
    - UV/VUV fluence
    - Thermal environment
  - Degradation models
    - Empirical, simple models (erosion yield, optical and mechanical property changes, etc.)
    - Detailed mechanistic models
      - Dependent on:
        - AO fluence
        - UV/VUV fluence
        - Materials
        - Temperature
        - Time
        - Load

          .

          .

          .

        Lifetime performance prediction - Complex!

- LDEF Data base needs, format, search strategy
  - Specimen:
    * Trade Name, MAPTIS ID
    * Chemical composition, structure
    * LDEF location
    * Investigator(s)
    * Availability of flight, control materials
  - Analytical data: (with error bars as appropriate)
    * Erosion (recession) ⇨ erosion yield
    * Surface analyses: ESCA, IR (functional groups, spectra references)
    * Mechanical property changes (moduli, strength, percent elongation, etc.)
    * Thermal analyses (Tg, Tm, Cp,CTE, ΔH fusion, decomposition)
    * Optical properties (α, ε)

      Mass loss (outgassing characteristics)

      Reference (index) of photos, SEM, STM, AFM

      Laboratories, techniques and dates of analyses
  - General observations:

    Contamination, M&D impacts, melting, etc.
  - References to other flight, laboratory simulation data with dates and investigators

  * Search keywords

- Needs for future flight experiments

  Opportunities:

  - Imminent:

    Shuttle: EOIM-3 STS-46 (AO, 40+ hr.)
    LDCE-1 (GAS canister) STS-46 (AO, 40+ hr.)
    Other - IOCM, Canadian experiment (STS-52)

    Free-flyers: EURECA-1 (STS-46, 6-11+ mo.)

  - Future:

    Shuttle: EOIM-4 ?
    LDCE, GAS can

    Free-flyers: RPC ?
    MATLAB ?
    SSF ?

    Active: SAMMES (SDIO) ?
    OPM (AZ-Tech) ?

Techniques, Approach:

EOIM-3: Recession measurements vs weight loss
Stressed, loaded materials
Temperature effects
UV synergism
Variable exposure

SAMMES, OPM: In situ measurements (α/ε, erosion, environmental monitoring)

Extended exposure - SAMMES, Free-flyers, SSF
Returned specimens - Canisters, controlled environment

- Suggestions for 2nd LDEF post-retrieval symposium
  - Invited presentations:

    P.I.'s - Details, interpretations, consequences
    SIG's - Lessons learned, predictions for future missions

  - Submission of data packages for data basing activities
  - Relevant ground simulations, flight experiment results
  - Plenary sessions for environments, SIGS

- Concurrent sessions for disciplines
- Opportunities for discussion essential

  Interpretation
  Future focus of analyses, follow-on efforts
  Mitigation of environmental degradation

- Poster session / mixer

• LDEF Findings: Clear, indisputable, unambiguous

  - General

    LDEF retrieved
    Funding inadequate
    Results needed yesterday

  - AO/UV effects evident for many materials
  - Contamination evident
  - Thermal velocity of AO effects verified on Kapton, FEP films

• LDEF Findings: Confusing, ambiguous, obscure

  - Impact of contamination
  - Post-retrieval aging effects
  - Thermal effects
  - AO fluence estimates ⇨ erosion yields

• Comments, concerns, recommendations

  - Access to data, materials (additional testing)
  - Storage/disposition of flight and control materials
  - Time, $ critical
  - Target end-users for advocacy/support
    SSF prime contractors, IRAD
    Material vendor analyses
    DoD, SDIO Support

Metals, Ceramics, and Optical Materials

Co-Chairmen: Roger Linton and John Gregory
Recorder: Gail Bohnhoff-Hlavacek

Q. How have initial LDEF results affected potential space applications of specific optical, metals and ceramic materials?

LDEF is providing pertinent and previously unattainable information of long-term environmental effects on metals, optics, and ceramics for diverse space mission applications. For example, silver oxidation data from LDEF Experiment A0171 provided timely input to the Intelsat VI retrieval mission assessment study. Additional materials included in this and other LDEF experiments are contributing to the baseline selection of materials for future solar arrays and solar concentrators, optical telescope and sensors, and structure metals. Experiment A0114 is providing pertinent data for the selection of AXAF primary mirror coatings in the results for gold, nickel, and irridium coatings. The damage assessment of meteroid and debris impacts, including ejecta deposit patterns, is providing data needed for evaluating the integrated optical performance.

Q. How have inital LDEF metal/optical/ceramic results affected the understanding of space environmental parameters and synergism?

New information was made possible by the unexpected long duration of LDEF in space. Several metallic materials whose oxidation or space environmental stability was either unknown or undetectable for short term exposure, were found to be measureably affected. For example: 1) the unexpected degree of copper and silver oxidation; 2) potential evidence of slight, though perceptible, reactivity in gold and, 3) evidence of natural environment degradation in the fluoride compound protective or antireflection coatings (e.g. MgF_2 and CaF_2).

Other results described the localized effects found on LDEF including the synergistic effects of atomic oxygen, solar UV, and contamination, resulting in polymerization and discrete flow patterns of contaminant deposits. Despite severe limitations on the utility of Trailing Edge specimens due to contamination, the range of LDEF results indicates that the microenvironment of individual experiments, resulting from environmental factors such as contamination and thermal excursions, are critical factors needing further study for Leading Edge and Trailing Edge experiments.

Finally, other very useful data, are the timed exposures on LDEF trays ranging from months to over five years. The timed intervals provided a new set of empirical data points along the LDEF five-year timeline, not available in the past. This proved useful in the comparisons for validation of ground-based environmental exposure simulations.

Q. How have LDEF optical/metal/ceramic results affected new material requirements?

LDEF underscores the need for new material research on environmental stability and protection schemes for long-term space exposed hardware. Few materials on LDEF were found to be completely unaffected, whether due to the extended exposure or the increased sensitivity of state-of-the-art analysis instrumentation. Even for those LDEF materials or optical elements whose degradation cannot presently be clearly attributed to specific environmental factors, the need for further study is apparent. Some new, post-LDEF results were discussed concerning the apparent effectiveness of CVD-diamond coatings for optical element protection. LDEF also demonstrated the importance of ensuring quality and uniformity in the manufacturing of space hardware, since slight variations in hardware fabrication and materials processing can change performance. Evidence for this was seen in the results of selected solar cells.

Q. How have initial LDEF results affected analytical modeling?

LDEF initial results have provided new tools for analytical modeling and classifying materials. Radiation and meteroid/debris damage are being incorporated into both empirical and analytical models. The degree and patterns of contamination, including the tray vent-hole deposition "plumes", the apparent cleaning of Leading Edge surfaces, and the general distribution of deposition around the LDEF are providing invaluable input to analytical modeling for contamination.

Q. What are the LDEF database requirements?

An LDEF database should have an accessible format that is easy-to-use, so that the distribution of LDEF findings will be timely, and enhance communication between principal investigators and space hardware designers. The Optical Experiments Database developed by the Optical Systems Special Investigative Group, provided essential information about the various optical experiments including: what optical materials flew, who was the principal investigator, results summaries, conclusions, the environmental conditions the samples were exposed to, future design considerations, and additional sources of information. It was developed as a library research tool, to enable researchers to quickly locate pertinent optical information from LDEF experiments. The database does not contain extensive data tables, graphs, etc. on each experiment; instead it summarizes many of the results and then directs researchers to the original source of information for details. The database layout is highly focused, using terminology and search queries that are appropriate for the optical applications. The data can also be easily downloaded into other types of files for reports and spreadsheets, or other more powerful databases.

Q. What are the general needs for future flight experiments?

Several topics were discussed including: 1) ensuring the statistical design of experiments with sample controls and preflight measurements; 2) requiring screening methodolgies for outgassing materials on spaceborne hardware; 3) providing on-orbit monitoring (including temperature, radiation flux, UV, AO, contamination); 4) utilizing more active experiment measurements; and 5) completing a thorough recovery and post-flight examination. Without all of this information, it is difficult to make conclusions concerning which effects are due exclusively to space exposure on samples flown in space.

Q. What level of information should be presented for this discipline (and in what format should it be presented) at the second LDEF Post-Retrieval Symposium, June 1992?

Several panel members suggested that the proceedings from the November Materials Conference be available prior to the symposium. Secondly, they suggested that we emphasize the technical content, and suggested that speakers give more back-up information about their hypothesis to allow the audience to form their own opinions and ask specific questons. Along that same line, the panel thought concurrent sessions would be most appropriate to allow time for the questions and discussion. The panel requested that speakers use a standardized experiment description (one viewfoil) prior to their talk, to assist first-time attendees. The viewfoil should include the experiment number, experiment title, principal investigators, location on LDEF, and the space environmental conditions it experienced.

METALS, CERAMICS, AND OPTICAL MATERIALS

Roger Linton and John Gregory, Co-Chairmen
Gail Bohnhoff-Hlavacek, Recorder

- Potential Space Applications
  - Interference filter and detectors
    - visible wavelength transmission altered
    - increased IR throughout
    - erosion/contamination caused "detuning"
  - Reflecting films
    - oxidation of metals (Ag, Cu, Au?)
    - mass changes
    - thicknesses determined
  - Environmental parameters
    - time intervals of exposure
    - microenvironments
    - comparison to ground simulation data
- New Materials Development
  - LDEF results underscore the need for new protection schemes
  - black coatings get more absorbing

- Ground simulation
  - LDEF enhances reliability
  - wide range of goals for new ground simulation
- Analytical modeling
  - provides new tools
  - classifying materials
  - considers M&D impacts
    - size distribution
    - density
    - damage
- Data Base Requirements
  - accessible format
  - electronic
  - easy to use
  - materials usage limitations
- Level of Information for Second LDEF Conference
  - proceedings from this conference available prior to next conference
  - emphasize technical content
  - standardize experiment description

- Findings

  <u>Clear</u>
  - Presence of contamination

  <u>Unclear</u>
  - Source of contamination

- General needs for future flights

  - Control samples
  - Preflight measurements
  - On-orbit monitoring
    - temperature
    - radiation flux
    - UV, AO
    - contamination
  - Active measurements

Polymer Matrix Composites

Co-Chairmen: Gary Steckel and Rod Tennyson
Recorder: Pete George

This summary narrative details summary charts from the Polymer Matrix Composites (PMC) theme panel discussion. The charts present the issues and preliminary conclusions from LDEF PMC test results and experiences. This narrative attempts to assign significance, supporting discussions, and priorities for the issues and conclusions.

Polymer matrix composite materials used in low earth orbit (LEO) applications with lengthy direct atomic oxygen (AO) exposure will likely require protective coatings. This conclusion was largely anticipated prior to the retrieval of LDEF based on ground based simulation and on orbit shuttle payload bay experiments. Graphite reinforced PMCs displayed 3 to 5 mils of erosion for leading edge (perpendicular to direction of orbit) exposure conditions on LDEF.

The AO erosion occurred over 5 3/4 years of flight exposure, during which the LDEF was loosing altitude (thus entering higher AO concentrations). LDEF AO erosion data combined with ground based simulation and modeling can be used by designers to make the decision whether AO protective coatings will be required for their specific application. Leading edge applications for PMCs may not need a protective coating if only insignificant material loss to AO erosion is expected over its useful life. Factors such as resin content, fiber orientation of exposed plies and load bearing directions must be considered for PMC materials in direct AO environments. In addition, the potential contaminating effects of the erosion on the overall space system must be considered.

PMCs located on LDEF's trailing edge and in other AO shielded positions did not display any significant reductions in mechanical properties. Based on LDEF results, specific matrix and fiber systems appear suitable for non-AO-exposed LEO applications without protective coatings. Coatings may be required for thermal stability or other reasons.

PMC experiments have not provided any special insights to date into understanding LDEF environmental parameters or possible synergistic effects. However, cause and effect relationships have been fairly well established. Surface erosion with an accompanying reduction in mechanical properties is a direct effect of AO exposure. Some darkening of the PMC matrices has been observed for trailing edge exposed specimens and has been attributed to ultraviolet exposure. Although synergistic effects between AO and ultraviolet (UV) radiation are suspected for some polymer systems, none have been identified based on LDEF PMC experiment results.

A reversible shrinkage of LDEF PMCs was measured by inflight strain gauge instrumentation. This dimensional change has been attributed to moisture loss due to the microvacuum and thermal cycling environments. The thermal cycling environment is also believed to be responsible for increased microcrack levels (compared to control specimens) which were reported for some multidirectional carbon fiber reinforced PMCs. Other than during the periods of shrinkage mentioned above, no changes in thermal expansion coefficients were reported. However, most of the post-flight thermal expansion data reported to date were acquired using techniques insufficient to resolve small CTE changes in low expansion materials. There is a need for more precise thermal expansion measurements.

The morphology of the AO eroded PMC surfaces does not resemble that of pure polymer specimens of similar chemistry as the PMC matrix resin. For example, surface morphology for AO eroded polyimide films reveals a rough surface with up to 5 μm features verses up to 75 μm features for graphite reinforced polyimides. Other graphite reinforced PMCs display similar size features. Also, "ash" like "residues" have been reported for most of the AO eroded PMC surfaces. These findings, along with some reported surface chemistry changes for AO eroded PMCs, may provide some insights into the AO erosion mechanism.

The need for AO protective coatings and scale up of coating processes for high AO flux LEO polymer matrix composite applications has been strongly confirmed by LDEF test results. The AO protective coatings which flew on LDEF were applied to small coupons. The viability of scale up should be investigated to determine which coatings offer the most promise. Optical properties as well as coating durability are also important factors. Flexible structures such as PMC springs may require the development of flexible AO protective coatings.

Since LDEF integration over 10 years ago, significant advancements in materials for space applications have occurred. Evaluation of these new materials including PMCs using the the LDEF environment as a benchmark will help to identify potential performers while possibly avoiding costly material development programs.

Concerning ground based simulation the general consensus at the PMC theme panel discussion was that existing techniques are adequate for individual effects testing. However, availability and sample size capacity for quality AO exposure are inadequate. Ground based simulation testing will be necessary to validate models developed from LDEF experiences. LDEF AO recession rates can be used as a benchmark for future ground based studies. Atomic oxygen ground based simulation testing of LDEF UV exposed specimens which were shielded from AO during flight may help to identify AO/UV synergistic effects including a possible UV "induction" period.

Since AO erosion, microcracking, and dimensional stability properties appear to be the most significantly affected for PMCs, it is logical to concentrate analytical modeling efforts in these areas. Continuation of the existing efforts for development of local geometry AO fluence simulation with addition of reflection factors will hopefully allow experimenters to evaluate PMC specimens which may have been subjected to local geometry effects onboard LDEF. Also, application of a model as described above to simulated inhomogeneous materials such as PMCs with reactivities assigned to the separate components may help explain the unique surface morphologies which have been observed. LDEF and ground based test results should be combined with analytical modeling in the areas of dimensional stability, microcrack density and thermal expansion properties. These properties are related and can be combined with other properties and orbital environment inputs for a comprehensive model. The output from this model could be subsequently used as input for fatigue life, structural and dimensional stability models. A general call for validation and refinement of LDEF AO environment modeling was also expressed during the discussion.

Data base requirements were discussed during the theme panel with the conclusion that both comprehensive archive and design data formats should be developed as separate but cross referenced databases. The archive should include property data, photos, and phenomenology. This database should have multiple path accessibility through material type, property range and application requirements. Also, an evaluation of the data including test methods, conflicting results etc. should be included to alert the database user to the confidence level associated with the reported values.

LDEF polymer matrix composite data which shows consistency and can be confidently interpolated and/or extrapolated to the ranges of concern for the designer in areas such as AO fluence, altitude, and exposure time. should be presented in a design handbook format. Both hard and electronic copies would present this data as design curves as a function of the above mentioned conditions.

During the PMC theme panel discussions the general needs for future flight experiments were discussed. On orbit measurement of AO flux vs. time would provide means for very accurate AO recession rate determination. In situ measurement of critical specimen properties would avoid the problems associated with retrieval and deintegration. Also, self opening and closing canisters, like the ones used on some LDEF trays, should be the preferred format for exposure duration critical experiments.

Comparison of LDEF data from experiment to experiment has been difficult. Future flight experiments should incorporate standard specimen configurations as well as standard methods for contamination, handling, and testing. Critical properties and their test methods should be identified and agreed upon prior to integration to allow consistent zero time control specimen testing. Strong integration guidance will be required to achieve these goals.

The second post retrieval symposium should have a full day session dedicated to polymer matrix composites. This session should include investigators presentations of test results as well as initial work on model development. Standard data formats for properties to be included in data basing should be established prior to the call for papers. A comprehensive summary paper for PMCs with integrated test results, space systems relevance and additional test requirements should be presented.

Among the clear, indisputable initial LDEF findings for polymer matrix composites are susceptibility to material loss and surface roughening due to atomic oxygen for leading edge exposed PMCs. As a result of the material loss, mechanical property reductions have been observed. The surface roughening and perhaps the presence of "ash" has affected the optical properties for leading edge exposed graphite reinforced PMCs. Trailing edge PMCs did not display any measurable change in mechanical properties. Glass reinforced PMCs displayed significantly less AO erosion due to the AO resistant nature of the glass fiber reinforcement. Glass reinforced PMCs did display significant changes in optical properties. Micrometeoroid and debris impact damage did not result in any catastrophic failures of PMCs. However, through penetrations and reverse side spallation damage were observed at some impact sights. Polymer property changes were only "skin deep". No changes were found for bulk polymer properties.

Among the more confusing and obscure findings are the variations in color and texture of AO eroded PMC surfaces. Variations in graphite fiber reinforced PMC AO eroded surface morphologies were observed by scanning electron microscopy as a function of fiber modulus. Also, "ash" levels varied from PMC type to PMC type. In one case AO erosion characteristics varied within individual T300 graphite/934 epoxy specimen creating light and dark banding on the surface. Also, the effects of contamination on erosion rates and other properties are not clear.

In summary, the panel members felt that good progress was being made by the individual investigators. Areas in which additional data are required include microcracking analysis, detailed surface chemistry analysis of AO eroded surfaces, and precise thermal expansion measurements. There was a consensus that at this point greater emphasis should be placed on compiling and comparing the data from the different experimenters in order to identify trends, relationships, synergisms, and data gaps. More coordinated test planning and cooperative efforts should then follow.

POLYMER-MATRIX COMPOSITES

Gary Steckel and Rod Tennyson, Co-Chairmen
Pete George, Recorder

THEME PANEL DISCUSSION

- How have initial LDEF results affected:

  1. Potential space applications of specific classes/type of materials

     A. Specific graphite reinforced composites for non AO LEO structural applications (both external and internal).

     B. Coated composites for direct AO exposure LEO applications

     C. Uncoated Composites for certain leading edge applications

  2. Understanding of environmental parameters/synergism

     A. AO causes mechanical properties degradation

     B. UV causes darkening of PMC matrix surfaces

     C. Thermal cycling can cause microcracking

     D. No synergistic effects identified to date

     E. Sequential environmental effects of micrometeoroid impact/AO erosion observed on coated specimens

- How have initial LDEF results affected:

  3. Understanding of mechanisms of material degradation?

     A. Thermal cycling/microcracking mechanism understood from previous efforts in general composites activities

     B. Differences in AO eroded surface morphology, "ash" composition, and surface chemistry have been identified and may provide insights into AO erosion mechanisms

     C. No specific mechanisms identified for AO or UV to date

- How have initial LDEF results affected:

  4. New materials and processes development requirements?

     A. Coatings to protect composites - scale up of coating process to full scale parts

     B. Flexible coatings for protection of composite springs, other flexible composite structures

     C. Evaluation of post-LDEF-integration-developed materials

- How have initial LDEF results affected:

  5. Ground simulation testing requirements?

A. Existing simulation techniques adequate for individual effects

B. Capacity and sample size for quality AO simulation currently inadequate

C. AO, UV, thermal cycling, vacuum, contamination simulation testing including synergistic effects

D. Use LDEF recession rates, etc. as benchmarks

E. AO simulation on UV degraded LDEF specimens etc.

- How have initial LDEF results affected:

6. Space environmental effects analytical modeling requirements?

   A. Validate/Improve AO environment modeling

   B. Continue development of local geometry AO fluence simulation with addition of reflection factors. Apply to textured AO eroded surface geometry, post damaged composites

   C. Microcrack density prediction modeling based on optical properties, thermal coupling, solar exposure, etc. Plug results into fatigue life, structural, and dimensional stability models

- DATA BASE REQUIREMENTS

  - Archive

    Comprehensive LDEF Results

    Property Data
    Photos
    Phenomenology

    Multiple Access

    Material Type
    Property Range
    Application

    Data Evaluation

  - Handbook Data

    Hardcopy/Electronic Copy present data as design curves; properties function of AO fluence, altitude, exposure time

- General Needs for Future Flight Experiment
    - On Orbit Measurements
        - Environmental Factors
            - AO, other species, UV, Thermal
        - In situ property measurement
        - Orbital parameters
    - Standardized samples
    - Standardized handling of controls
    - Strong integration/guidance contamination control
- 2nd Symposium Coverage
    - One day session
    - Investigators' presentations
    - Comprehensive summary paper
        - Integrated results
        - Space Systems Relevance
        - Additional Test Requirements

- CLEAR, INDISPUTABLE FINDINGS
    - PMC's on leading edge susceptible to material loss/surface roughening due to AO
    - No degradation of mechanical property except on leading edge from AO
    - Graphite/polymers show no changes in optical properties except on leading edge
    - Glass/polymers composites do show optical property changes
    - No catastrophic failures from impact damage
    - No bulk polymer property changes except outer skin
- CONFUSING, OBSCURE FINDINGS
    - Presence of stripes on T300/934 with 5 mil tape (experiment A0134)
    - Differences in AO erosion morphology
    - Differences in appearance and amount of "ash" on AO erosion surfaces
    - Effects of contamination on AO erosion rates and other properties

- <u>ADDITIONAL COMMENTS</u>
  - Need to compile, compare and "filter" data to identify trends, relationships, gaps, and synergisms
  - Use above results to establish test plan and integrated cooperative effort
  - Need further data for
    - Thermal cycling/microcracking
    - AO Erosion surface chemistry
    - Precision CTE measurements
    - Interpretation of AO erosion mass loss data

Lubricants, Adhesives, Seals, Fasteners, Solar Cells, and Batteries

Co-Chairmen: James Mason and Joel Edelman
Recorder: Harry Dursch

General Findings:
Spacecraft designers need to consider both the effects of the space environment on materials or components and the effects of the material or component on the surrounding space environment. Examples of this include lubricant outgassing, location of high voltage power supplies, or the impact of degrading materials that could contaminate optics.

What one spacecraft designer might view as common knowledge might not be common knowledge to another designer. One LDEF related example was an experimenter changing his fastener assembly lubricant from MoS2 dry film lubricant to cetyl alcohol. This change was made to avoid possible volatilization and contamination while on-orbit. However, it led to severe galling of the fasteners. To some designers, it would have been obvious that fastener seizure would result from the switch of lubricants but it wasn't "common knowledge" to the experimenter. This illustrates the need for timely and accurate development and distribution of design guidelines. LDEF presents a unique opportunity to make common knowledge more common.

Clear, Indisputable Findings:
Adhesives - Most adhesives that were flown on LDEF performed as designed. When PI's were contacted about the condition of adhesives used on their experiment, the vast majority stated that "it is still stuck, even though the adhesive turned brown". However, there have been two notable exceptions to the successful use of adhesives on LDEF. Four solar cells became disbonded and were lost sometime during the LDEF mission and several PI's noted darkening of solar cell coverglass adhesives, causing a loss of light to the solar cells. In addition, following the Theme Panel presentation, several additional adhesive failures were mentioned by members of the audience.

Seals - A wide variety of seals were flown on LDEF. No failures attributable to exposure to the space environment occurred. However, all seals were shielded from direct exposure to the space environment. The only known failure occurred on the ten LiCF batteries. Due to extended exposure to the electrolyte gas, the o-ring lost its resiliency, causing leakage of the electrolyte gas. This failure had no effect on the battery performance and similar failures occurred on control LiCF batteries.

Lubricants - There was a wide variety of lubricants flown on LDEF. All lubricants shielded from direct exposure to the space environment performed as designed. The lubricants that were unprotected from the space environment underwent viscosity changes, had organic binders disappear or disappeared completely. This points out the need to thoroughly test lubricants in a simulated combined effects chamber (including dynamic effects) to enable determination of service lifetimes.

Fasteners - As with the adhesives, seals, and lubricants, there was a variety of fasteners used on LDEF. During de-integration, there were widespread reports of fastener related anomalies. Instances of sheared fasteners, severely damaged nut plates, and excessive breakaway and/or prevailing torques were reported. To date, all anomalies have been attributed to galling due to poor pre-flight installation practices and/or incorrect selection of lubricants. The most important finding has been the absence of any coldwelding.

Solar cells - Over 350 solar cells were flown on LDEF. The vast majority of the cells were silicon, but several GaAs cells were flown. While over half of the cells were actively monitored while on-orbit, very little electrical characterization results have been published. The leading cause of cell degradation was meteoroid or debris impacts. This performance loss was dependent upon the size and energy of the impacts. The type of loss ranged from a decrease in fill factor, to a loss of short circuit current caused by loss of active cell area from the impact crater, to a loss of open circuit voltage due to damage to the cell structure. Minor performance loss was caused by decreased amounts of light reaching the cell. This was caused by the cumulative effects of contamination, UV degradation of the coverglass adhesive, atomic oxygen/UV degradation of the anti-reflection coatings, and/or radiation damage.

Batteries - There were no space related failures of any of the LiSO2, LiCF, or NiCd batteries flown on LDEF. All ten of the LiCF batteries used on LDEF suffered experienced an anticipated seal rupture which resulted in the leakage of the electrolyte gas. Corrosion of the glass seal interface took place on the LiSO2 batteries. However, both of these degradations were duplicated in batteries kept in ground storage and thus this effect is not attributed to the spaceflight environment. Reliability and performance of these types of batteries proved to be quite satisfactory.

Confusing, Ambiguous or Obscure Findings:
The variations in the prevailing torques during removal of tray clamp fastener assemblies are greater than would be expected.

Integrated current leakage measurements on one experiment and erratic real-time charge loss measurements on large numbers of charged sensors on another experiment indicate the possibility of a complex plasma environment. Contributing factors are speculated to include outgassing molecular contamination, solar orientation, and local thermal dynamics

Ground Simulation Testing Requirements:
A need exists for a combined effects chamber that possesses the capabilities for temperature cycling, UV, atomic oxygen, and dynamic testing of lubricants and mechanisms. Dynamic testing not only needs to be performed on lubricant specimens but on the operating mechanism.

Future Flight Experiments:
A significant concern to the spacecraft designer is the successful on-orbit replacement of hardware. LDEF is providing valuable information towards the use of fasteners and mechanisms in space. However, because LDEF was primarily a "static" satellite, additional questions remain. These questions include the possibility of coldwelding occurring due to repeated on-orbit cycling of fastener

assemblies. Even if coldwelding doesn't occur, increases in friction due to galling will cause difficulties during EVA. Because of these concerns, there is a need to know the durability of the various lubricant schemes being suggested for long term space exposure. Formidable difficulties would be encountered in testing a fastener assembly or mechanism to the combined effects of the space environment while undergoing dynamic cycling in a ground simulation chamber. Only a future flight experiment will provide the required design data.

Because the operative factors in plasma effects are not well understood, it is not possible to design a ground simulation at this time. Thus it is of significance that future flight experiments be designed to characterize these effects. It is particularly important that some degree of uniformity and consistency be assured in future plasma measurements and observations on orbit. Every flight mission, at a minimum, will have a unique contamination environment and the subsequent correlation of data from separate missions will be difficult in the best circumstances.

Databasing Requirements:
Databases should contain the following information: 1)specific lubricant, adhesive, solar cell, and fasteners flown on LDEF, 2) environment seen by the specific component, 3) results and conclusions, 4) status of testing, 5) responsible experimenter, and 6) references for additional information. The amount of material will determine whether the database would consist of a paper version (handbook) or an electronics version (floppy disc). In many areas the quantity of data is expected to be compatible with hardcopy storage and distribution.

LUBRICANTS, ADHESIVES, SEALS, FASTENERS, SOLAR CELLS, AND BATTERIES

James Mason and Joel Edelman, Co-Chairmen
Harry Dursch, Recorder

LUBRICANTS, ADHESIVES, SEALS, AND FASTENERS

- RESULTS AFFECTED SPACE APPLICATION OF ________?

  [Alternate View: What material does to environment vs. space environment effects on material]

ADHESIVES

- Failures, while few, not necessarily the result of space environment
- No evidence of failure due to space environment
  - Four solar cells fell off?
    Thermal cycling?
    Cohesive/adhesive?
    Thermal cycling?
    AO/UV/thermal/vacuum?
    Kapton?
  - Exposure Questions

    Angle of attack?
    Sacrificial layer?
  - Darkening of Solar Cells?

LUBRICANTS

- Failures did occur due to space environment
- All "protected" lubes continued to do their job
- Contamination by lubricants must be considered

SEALS

- No failures attributed to the space environment (all seals protected)
- With one exception, all seals worked (one compression failure due to contamination)

FASTENERS

- No failures due to space environment
- No space environment-induced cold welding
- Extensive galling
- Lubricants for space servicing and assembly

SOLAR CELLS

- Approximately 300 silicon and GaAs cells flown
- Over half were actively monitored

FINDINGS TO DATE:

- Most degradation of cells caused by meteoroid or space debris impacts
  - Performance loss dependent upon size and energy of impacts
- Minor degradation caused by decreased amount of light reaching cell
  - Contamination
  - UV degradation of coverglass adhesive?
  - Atomic oxygen/UV degradation of antireflection coatings?
- To date, particle radiation effects not discernible from other degradation factors

BATTERIES: $LiSO_2$, $LiCF_x$, NiCd

- No space related failures of any battery. Anomalies duplicated in ground storage samples
- Reliability and performance of these types of batteries are satisfactory in unexposed space applications
- Summary and final conclusions to be presented in Systems SIG Phase I Final Report
- No requirements for additional testing

UNDERSTANDING OF ENVIRONMENTAL PARAMETERS?

- LDEF demonstrates importance of combined thermal/vacuum/AO/UV/thermal effects
- Results suggest thermal vacuum testing is required for characterization of adhesives, lubricants, seals. Angle of attack appears to be a factor.

UNDERSTANDING OF MECHANISMS OF MATERIAL DEGRADATION?

- Not yet addressed

NEW MATERIAL DEVELOPMENTS REQUIRED?

- Seals/Adhesives--Okay if not directly exposed to environment
- Lubricants

    --Shielded, are okay

    --Exposed dry films are a concern

    --Improved dry films for exposed situations

GROUND SIMULATION TESTING REQUIREMENTS?

- Need combined T/UV/AO/Dyn Testing
- LDEF II

ANALYTICAL MODELING REQUIREMENTS?

- Still need testing

DATA BASE REQUIREMENTS

- Publish A.S.A.P.
- Final report summarizing findings and presenting references (Paper/electronic forms)

LDEF CONFERENCE RECOMMENDATIONS

- Conclusions
- Design Recommendations/Guidelines
- Set standards for viewgraphs

CLEAR FINDINGS

- No cold welding
- Shielded lubricants, adhesives, seals work
- Several exposed lubricants failed

    Everlube 620 - gone
    Braycote 601 - decreased viscosity

AMBIGUOUS FINDINGS

- High prevailing (running) torques
- Dynamic effects on cold welding and lubricants
- No statistical data on seals, lubricants, and adhesives

CONCERNS

- Lubricant duty cycle vs periods of exposure
- Material impact on environment vs environment impact on material
- Moisture and ambient oxygen exposure of materials
- Development of guidelines for design engineers
- Testing of lubricants exposed to LEO on external surfaces
- Need to continue collation and integration of experimenter results
- Solar cell round robin
- Primary structure fasteners/silver lubricants

GENERAL FINDINGS REGARDING LDEF SYSTEMS

- "Common knowledge is not all that common."
- "I wish I didn't know now what I didn't know then."

LDEF MATERIALS WORKSHOP 1991

SPONSOR: Long Duration Exposure Facility - Materials Special Investigation Group

OBJECTIVES:
- In-depth exposition of LDEF Materials Findings from Principal Investigators and MSIG
- Workshop discussions and theme reports on LDEF materials disciplines, data-basing requirements, ground simulation testing and analytical modeling needs, and future flight experiments

TUTORIAL AND WORKSHOP DISCUSSION DISCIPLINES:
- LDEF Materials, Environmental Parameters, and Data Bases
- LDEF Contamination
- Metals, Ceramics, and Optical Materials
- Lubricants, Fasteners, Adhesives, Seals
- Thermal Control Coatings, Protective Coatings, and Surface Treatments
- Polymers and Films
- Polymer-Matrix Composites

ATTENDANCE:
- ~200 technologists from the International Space Materials Community
- Spacecraft materials analysts and designers
- Space Environmental Effects research and development scientists and engineers
- Spacecraft and space experiment program managers

LDEF MATERIALS - PRELIMINARY FINDINGS

- PRELIMINARY DATA ON SIMILAR MATERIALS FROM TRAY TO TRAY IS REMARKABLY CONSISTENT:
  - Data quality is excellent
  - LDEF will provide the "benchmark" for materials design data bases for LEO/SSF
- SOME MATERIALS WERE IDENTIFIED TO BE ENCOURAGINGLY RESISTANT TO LEO SPACE ENVIRONMENTAL EFFECTS (E.G.- AO & VUV) FOR 5.8 YEARS:
  - Chromic-acid anodized aluminum, other metals, ceramics
  - Some thermal control coatings (e.g.- YB-71, Z-93, PCB-Z, D-111)
  - Composites with inorganic coatings; siloxane-containing polymers
  - Aluminum coated stainless steel reflectors
- OTHER MATERIALS DISPLAYED SIGNIFICANT ENVIRONMENTAL DEGRADATION:
  - Various thermal control coatings and silicone conformal coatings
  - Uncoated polymers and polymeric-matrix composites, silver, copper
  - Silvered Teflon thermal blankets and second-surface mirrors
- MOLECULAR CONTAMINATION WAS WIDESPREAD:
  - LDEF offers an unprecedented opportunity to provide a unified perspective of LEO spacecraft contamination mechanisms / interactions / lessons learned
- ABSOLUTELY ESSENTIAL TO SPACE STATION FREEDOM AND FUTURE SPACECRAFT DESIGNERS THAT LDEF MATERIALS RESULTS BE THOROUGHLY ANALYZED AND DOCUMENTED INTO A QUANTITATIVE DESIGN DATA BASE:
  - Requires continued adequate funding to complete Materials Principal Investigator and MSIG analyses

LDEF MATERIALS WORKSHOP '91 AGENDA

NASA Langley Research Center
H. J. E. Reid Conference Center
14 Ames Road Building 1222
Hampton, Virginia 23665-5225
November 19 - 22, 1991

Tuesday, November 19, 1991

8:30 a.m. **Introductions**

William H. Kinard, LDEF Chief Scientist
Bland A. Stein, Workshop Coordinator
Philip R. Young, Workshop Coordinator

9:00 a.m. **Technical Session**

- **LDEF Materials, Environmental Parameters, and Data Bases (Plenary Session)**

Cochairman: Bruce Banks, NASA - Lewis Research Center
Cochairman: Mike Meshishnek, The Aerospace Corporation
Recorder: Roger Bourassa, Boeing Defense & Space Group

LDEF Atomic Oxygen Fluence Update	Roger Bourassa Boeing Defense & Space Group
LDEF Yaw and Pitch Angle Estimates	Bruce Banks
LDEF Experiment M0003 Meteoroid and Debris Survey	Mike Meshishnek The Aerospace Corporation
Atomic Oxygen Erosion Yields of LDEF Materials	Bruce Banks, LeRC for John Gregory University of Alabama in Huntsville
The LDEF M0003 Experiment Deintegration Observation Data Base	Sandy Gyetvay The Aerospace Corporation
Overview of Flight Data from LDEF M0003 Experiment Power and Data System	John Coggi The Aerospace Corporation

12:00 Noon **Lunch**

Tuesday, November 19, 1991 continued

1:00 p.m. **Technical Session**

- **LDEF Contamination (Plenary Session)**

Cochairman: Steve Koontz, NASA Johnson Space Center
Cochairman: Wayne Stuckey, The Aerospace Corporation
Recorder: Russell Crutcher, Boeing Defense & Space Group

C-4

Introduction	Wayne Stuckey The Aerospace Corporation
Materials SIG Quantification and Characterization of Surface Contaminants	Russell Crutcher Boeing Defense & Space Group
Z-306 Molecular Contamination Ad-Hoc Committee Results	John Golden Boeing Defense & Space Group
LDEF Contamination Modelling	Tim Gordon Applied Science Technology and Ray Rantanen ROR Enterprises
M0003 Contamination Results	Wayne Stuckey and Carol Hemminger The Aerospace Corporation
Organic Contamination on LDEF	Gale Harvey NASA Langley Research Center

5:00 p.m. **End Session**

Wednesday, November 20, 1991

8:00 a.m. **Technical Session**

- **Thermal Control Coatings, Protective Coatings and Surface Treatments (Plenary Session)**

Cochairman: Ann Whitaker, NASA Marshall Space Flight Center
Cochairman: Wayne Slemp, NASA Langley Research Center
Recorder: John Golden, Boeing Defense & Space Group

Thermal Control Materials on Thermal Control Surfaces (TCSE) Experiment	James Zwiener, NASA MSFC for Don Wilkes AZ Technology
Vacuum Deposited Coatings	Wayne Slemp NASA Langley Research Center
Anodized Aluminum on LDEF	John Golden Boeing Defense & Space Group
Thermal Control Tape	Rachel Kamenetsky NASA Marshall Space Flight Center
Fluorescence in Thermal Control Coatings	James Zwiener NASA Marshall Space Flight Center
Thermal Control Coatings on DoD Flight Experiment	William Lehn, Nichols Research Corp. for Charles Hurley Univ. of Dayton Research Institute and Michele Jones U.S.A.F Wright Laboratories
Next Generation LDEF: Retrieval Payload Carrier	Arthur Perry American Space Technologies, Inc.

Element Material Exposure Experiment Experiment by EFFU — Yoshihiro Hashimoto, Ishikawajima- Harima Heavy Industries Co., Ltd. (IHI)

Skylab DO24 Thermal Control Coatings and Polymer Films Experiment — William Lehn, Nichols Research Corporation

12:00 Noon **Lunch**

Wednesday, November 20, 1991 **continued**

1:00 p.m. **Technical Session**

- **Polymers and Films (including Ag/FEP) (Concurrent Session)**

Cochairman: Phil Young, NASA Langley Research Center
Cochairman: David Brinza, Jet Propulsion Laboratory
Recorder: Gary Pippin, Boeing Defense & Space Group

Ag/FEP Teflon — François Levadou, European Space Research & Technology Centre

Ag/FEP: Recent MSIG Results — Gary Pippin, Boeing Defense & Space Group

Polymer Films and Resins — Philip Young, NASA Langley Research Center

Texas A & M S1006 Balloon Materials Experiment — Alan Letton and Thomas Strganac, Texas A & M University

Depth Profiling of Orbital Exposure Damage to Halar (A0171 Solar Array Materials Experiment) — William Brower, Marquette University

M0003: Recent Results on Polymer Films — Michele Jones, U.S.A.F Wright Laboratories

5:00 p.m. **End Session**

Wednesday, November 20, 1991 **continued**

1:00 p.m. **Technical Session**

- **Metals, Ceramics, and Optical Materials (Concurrent Session)**

Cochairman: Roger Linton, NASA Marshall Space Flight Center
Cochairman: John Gregory, University of Alabama
Recorder: Gail Bohnhoff-Hlavacek, Boeing Defense & Space Group

Selected Results from Metals on LDEF Experiment A0171 — Ann Whitaker, NASA MSFC

Oxidation of Copper and Silver on LDEF — Ton de Rooij, European Space Research & Technology Centre

Optical Transmission and Reflection Measurements of Thin Metal Films Exposed on LDEF — Roger Linton, NASA MSFC for John Gregory University of Alabama in Huntsville and

Oxidation of Black Chromium Coatings on LDEF — John Golden, Boeing Defense & Space Group

LANL Results from Space-and Ground-based Atomic Oxygen Exposures of Metals and Inorganic Materials — Jon Cross, Los Alamos National Laboratory (LANL)

AXAF Optical Materials and Issues — James Bilbro, NASA MSFC for Alan Shapiro, NASA Marshall Space Flight Center

Effects of Space Exposure on Pyroelectric Infrared Detectors — James Robertson, NASA Langley Research Center

Status and Results of LDEF Optical Systems SSIG Data Base — Gail Bohnhoff-Hlavacek, Boeing Defense & Space Group

5:00 p.m. **End Session**

Thursday, November 21, 1991

8:00 a.m. **Technical Session**

- **Polymer-Matrix Composites (Concurrent Session)**

Cochairman: Rod Tennyson, University of Toronto
Cochairman: Gary Steckel, The Aerospace Corporation
Recorder: Pete George, Boeing Defense & Space Group

M0003 and Other Polymer-Matrix Composites — Gary Steckel, The Aerospace Corporation

A0134: Polymer Matrix Composites — Wayne Slemp, NASA Langley Research Center

Space Environmental Effects on LDEF Low-Earth Orbit (LEO) Exposed Graphite-Reinforced Polymer- Matrix Composites — Pete George, Boeing Defense & Space Group

Long-Term Environmental Effects on Carbon-and Glass-Fiber Composites — Ann Whitaker, NASA Marshall Space Flight Center

Evaluation of Long-Duration Exposure to the Natural Space Environment on Graphite-Polyimide and Graphite-Epoxy Mechanical Properties — Richard Vyhnal, Rockwell International

Proposed Test Program and Data Base for LDEF Polymer-Matrix Composites — Pete George, Boeing Defense & Space Group and Rod Tennyson, University of Toronto

12:00 Noon **Lunch**

Thursday, November 21, 1991

8:00 a.m. **Technical Session**

- **Lubricants, Adhesives, Seals, Fasteners, Solar Cells, and Batteries (Concurrent Session)**

Cochairman: James Mason, NASA Goddard Space Flight Center
Cochairman: Joel Edelman, LDEF Consultant
Recorder: Harry Dursch, Boeing Defense & Space Group

Identification and Evaluation of Lubricants, Adhesives, and Seals Used on LDEF	Bruce Keough Boeing Defense & Space Group
Results from the Testing and Analysis of LDEF Batteries	Steve Spear Boeing Defense & Space Group
Effects of Long-Term Exposure on Fastener Assemblies	Steve Spear Boeing Defense & Space Group
Results from the Testing and Analysis of Solar Cells Flown on LDEF	Harry Dursch Boeing Defense & Space Group
System Related Testing and Analysis of FRECOPA	Christian Durin Centre National D'etudes Spatiales

12:00 Noon **Lunch**

1:00 p.m.
- Working meetings of **Theme Panels** to prepare charts for Workshop Summary Session and begin draft of panel report. **(Concurrent Session)**

5:00 p.m. **End Session**

Friday, November 22, 1991

8:00 a.m. **Technical Session**

- **LDEF Materials Workshop '91 - Summary (Plenary Session)**
  - 20-minute presentations by panel chairmen followed by question/answer periods
  - Final general discussion period moderated by workshop coordinators

12:00 Noon **End Workshop**

LDEF
MSIG
MATERIALS
SPECIAL INVESTIGATION GROUP

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13. ABSTRACT (*Maximum 200 words*)

The LDEF Materials Workshop '91 was a follow-on to the Materials Sessions at the First LDEF Post-Retrieval Symposium held in Kissimmee, Florida, June 1991. The workshop comprised a series of technical sessions on materials themes, followed by theme panel meetings. Themes included Materials, Environmental Parameters, and Data Bases; Contamination; Thermal Control and Protective Coatings and Surface Treatments; Polymers and Films; Polymer Matrix Composites; Metals, Ceramics, and Optical Materials; Lubricants Adhesives, Seals, Fasteners, Solar Cells, and Batteries. This report contains most of the papers presented at the Technical sessions. It also contains theme panel reports and visual aids. This document continues the LDEF Space Environmental Effects on Materials Special Investigation Group (MSIG) pursuit of its charter to investigate the effects of LEO exposure on materials which were not originally planned to be test specimens and to integrate this information with data generated by Principal Investigators into an LDEF Materials Data Base.

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