

SPACECRAFT CONTAMINATION ISSUES FROM LDEF: ISSUES FOR DESIGN*

Gary Pippin and Russ Crutcher
Boeing Defense & Space Group
P.O. Box 3999
Seattle, WA 98124-2499
Telephone: (206) 773-2846

INTRODUCTION

Many contamination sources have been identified on the Long Duration Exposure Facility (LDEF). Effects of contamination from these sources are being quantified and have been reported on in several papers (refs. 1 and 2).

For a designer, the essential question is how much contamination from all sources can be tolerated without causing a given spacecraft system to degrade below a critical performance level, or fail altogether. Even a rudimentary knowledge of the mechanisms by which molecular and particulate contamination can occur will allow simple design options to be chosen to circumvent potential contamination problems and reduce contamination levels.

Because of the varied nature and condition of hardware used on LDEF experiments, examples of many types of contamination were seen and these provide a useful guide to expected performance of many types of materials in space environments.

DESIGN CONSIDERATIONS

The central step in any contamination process is the transport of material from one location to another. For a designer, the choices are either to minimize the quantity of source materials or to physically block the materials from the source so it cannot redeposit on a surface which must remain clean. Low outgassing materials are chosen for space applications for various reasons, but for the long-term missions even materials which are low outgassing can build up substantial deposits over mission life. Vacuum thermal bakeout of hardware can help, but even baked out hardware will be subject to moisture reabsorption unless special (and expensive) precautions are taken.

For longer duration missions, the potential for "unexpected" events to occur increases. For such missions, designs will need to be more "fault tolerant" and provide capabilities for recovering from contamination events brought on by failure or degradation of a material by ultraviolet (UV), proton, and electron radiation, atomic oxygen (AO), vacuum, thermal cycling, and/or impact damage.

For example, cleaning a hydrocarbon from an optical sensor surface could be achieved by turning the surface to the ram direction. However other materials which also react with AO could

* Work done under NAS1-19247 and NAS1-18224.

be present. If siloxane-based films are present, these materials can be converted to nonvolatile silica type (SiO_x) species, trapping other contaminant films and leading to permanent performance degradation. Orientation of surfaces toward the Sun to increase volatility by temperature increases would also run the risk of photo-induced deposition.

Contaminant species on a spacecraft surface are likely to undergo changes in their structure and composition over time. Those products which remain on a surface for substantial amounts of time will be the more thermodynamically stable species.

LDEF RESULTS

On LDEF, two general sets of source conditions were present. At a number of leading edge sites, deterioration and/or outright failure of materials led to creation of a number of particle sources. Erosion of organic based materials by AO tended to leave these surfaces molecularly "clean."

Trailing edge conditions allowed creation of thin films as materials outgassed and redeposited. Without AO to remove these contaminants, they remain in place and may be altered by the UV exposure.

PARTICULATES

On-orbit generation of particles may be an issue for sensitive optics components. Particulate contaminants can physically obscure sensor lenses, block light from entering a detector and/or simply increase the amount of scattered light entering a camera or other detector, thereby degrading the quality of an image. Particles could interfere with moving parts, increase friction or wear on surfaces, even block the motion of a surface in a worst case. Particles could also abrade or scratch surfaces, leaving damaged areas even if the particle is dislodged.

In general, those materials which failed were largely toward the leading edge, where recession under the combined AO and UV exposure, coupled with thermal cycling, caused some materials to lose mechanical integrity and essentially disintegrate. Thus, some leading edge locations were sources of particulate contaminants. In contrast, trailing edge conditions allowed formation of thin molecular contaminant films from outgassing and redeposition processes. There was no evidence of particle generation from failed materials at trailing edge (no AO exposure) conditions.

NASA's video downlink during the recovery process showed a collection of highly reflective, thin particles had gathered in the LDEF wake. These particles were observed prior to the grapple procedure. The presence of such material traveling within the LDEF wake means, whatever the mechanism of transport, it has to explain how particles from the leading edge locations leave the surface, travel around the spacecraft, and collect again in the wake. The recovery operation approach represents a "snapshot" taken over a relatively short time. The particles may have some small momentum relative to the LDEF and actually be drifting through the wake over a period of weeks or months.

Particles such as those observed in the LDEF wake represent potential artifacts for telescopes, cameras, and/or other imaging equipment. Satellites which rotate intermittently or are reboosted periodically could have significant interactions with such contaminant particles. These motions could also be a significant source of additional particles.

FILMS

In general, contaminant films can lower the apparent AO induced material recession rate because they consume AO which would otherwise react with the material in question.

Both organic- and organic silicone-based films need to be considered. Organic-based film can be cleaned by oxidation because these processes create volatile products. Organic film may also be fixed in place by exposure to solar radiation. Silicones will be at least partially fixed in place by oxidation to SiO_x species, potentially trapping otherwise volatile species and allowing the opportunity for darkening of surfaces by radiation.

On LDEF specifically, there were many sources of both types of material producing contaminants. Organic-based potential film sources included paint solvents, polymeric thin films, and composite materials. Potential sources of silicon were adhesives, coatings for specimens, and support hardware, paints, and solar cells. Particulate sources from preflight conditions include dust, pollen, and fibers. On-orbit degradation of materials created new sources.

Thin film deposition on LDEF can be explained by line-of-sight deposition from many individual sources and with a smaller contribution from material reflecting from one surface to another. The grounding strap for blanket D11 shows a variety of contamination and environmentally induced changes. The adhesive release paper had a siloxane coating which left silicon-containing species on the copper. The silicone room temperature vulcanized (RTV) adhesive used to bond Velcro™ strips to the underside of thermal control blankets and to tray frames outgassed through vent holes at the edge of the blanket materials onto the portions of the copper grounding strap tucked down along the tray edge. Figure 1 shows a schematic of the strap with key areas of differing silicone deposition intensity shown. Areas of the copper strap exposed to significant AO show levels of silicone decreased from the levels on shielded areas and ground control specimens.

Optical properties of material were altered drastically in selected localized areas. Overall effects on anodized aluminum, which covered 60 percent of the LDEF external surface, and on silverized Teflon™ (Ag/FEP) which covered 18 percent of the surface, were minimal. Total absorptance changes on the chromic acid anodized aluminum ranged from 0 percent to about 8 percent. There was virtually no change in absorptance and very slight changes (<5 percent) in emissivity of Ag/FEP for exposed portions of these blankets. Averaged over all the blankets, the effect on thermal control performance due to contamination is at most 2 to 3 percent. This decrease shows that some oxidation processes were removing silicon containing species as well as creating nonvolatile SiO_x films.

OUTGASSING

Contamination on LDEF was extensive. Film deposits were produced in many locations. However, the molecular contamination was site specific; that is, produced by many different sources, redepositing or reflecting from surfaces until deposited on a "fixing" surface. The final redeposition of outgassed material was mostly on surfaces in the line of sight of the venting volume.

Some materials may outgas at a significant rate for an extremely long time. For these materials, short-term (24 h) outgassing tests may not be appropriate for characterizing their performance. Some materials may slowly decompose under vacuum conditions, in which case the material will outgas until it is gone. Under these conditions, the total amount of material becomes a significant consideration because the material never appears to "bake out."

Outgassed and redeposited material can undergo considerable subsequent changes under exposure to the space environment. Oxygen atoms can clean surfaces and also make nonvolatile oxide films.

Venting and outgassing of substantial amounts of material occurs early in a mission. Heavy deposits around selected vent paths from the interior of LDEF demonstrate the need for careful consideration of the location and orientation of vents relative to spacecraft surfaces. Venting should be directed normal to spacecraft surfaces. In addition, vent paths normal to the direction of motion should also minimize return flux.

One method is to minimize outgassed species contact with surfaces, where they could become attached and fixed in place by solar UV photons. Materials which outgas, such as paints, composites, thin polymeric films, or adhesives which are organic based, will likely outgas over a long period of time. Sixteen specimens of DC 6-1104 RTV silicone adhesive used to attach the Velcro™ strips on AO178 showed an average total mass loss (TML) of 0.34 wt%, as determined by ASTM E595, compared with original ground control measurements of 0.14 wt%. Specimens taken from the exposed bond line and from under the center portion of the Velcro™ showed no essential difference in the TML measurements. The conclusion is that, left indefinitely, this material will continue to outgas very slowly until it is gone. However, this process would take longer than the lifetime of any space hardware currently under design.

Similarly, heat shrink tubing used on aluminum clamps holding the wire barriers on the interior of LDEF outgassed at about 65 to 75 percent the rate of ground-based specimens. For this material the outgassing as measured by TML varies significantly with location; leading and trailing edge locations outgassing at a greater rate than all other locations. Table 1 shows the results of the outgassing measurements on the heat shrink tubing.

Fiberglass shims used between the heat shrink tubing and the aluminum wire harness clamps show outgassing rates slightly lower (85 to 95 percent) than the rates of ground control specimens.

SUMMARY

Observations made postflight on the LDEF hardware lead to the conclusion that there were significant interactions between contaminant materials and the low-Earth orbit (LEO) environmental factors during the 69 months of flight. Thermal cycling induced contaminant thin film with distinct layers were produced in some areas. Materials deposited on surfaces exposed to solar radiation were likely fixed in place by UV-assisted processes. These attached species are subject to changes over time brought about by energetic solar vacuum UV photons. AO may remove selected contaminant materials either directly or by removing the underlying substrate.

Potential consequences from exposure to contamination include degradation of optics by thin films which change the transmission characteristics and light scattering from particles which collect on detector lenses and physically block portions of the detector. Performance of thermal control surfaces may be degraded as films with increased absorptance are deposited. Contaminate films may also change surface electrostatic conditions. This subject has not been well studied during examination of LDEF. The most likely effect would be to convert conducting surfaces to insulators and allow charge buildup and create potential differences for one surface relative to another.

The particulate species produced by materials degradation on-orbit have the potential to interfere with scientific measurements being made around a spacecraft or by instruments on the spacecraft. Even if particulates do not attach to the lens, they may travel through the field-of-view and even remain in the field-of-view for long periods of time. The video downlinks showing particles collected in the LDEF wake and evidence of contamination from shuttle material dumps, obtained by postretrieval analysis, are examples of this concern.

Planned spacecraft orientation and temperature are two methods of passive contamination control. The higher the surface temperatures of the spacecraft can be maintained early in the mission, and without damaging essential components, the less opportunity for material redeposition. In LEO, ram and near-ram surfaces will be "cleaned" by exposure to AO. However, such exposure can damage the substrate, so this "cleaning" is limited in practice. Physically blocking sensitive locations from the line-of-sight of any potentially significant outgassing source is the most direct method of minimizing contamination. This solution is best considered in the design phase.

There are practical limits to cleanliness achievable at any large facilities, such as Kennedy Space Center (KSC). Improvements in methods of delivering clean hardware to KSC might be more effective, in both technical and cost terms, than seeking increased cleanliness levels at KSC.

Hardware should be cleaned prior to delivery at KSC and protected as much as possible prior to launch. Critical components should be designed so that they may be shielded until the hardware is in orbit. Maintaining the covers in place for a period of time in orbit would allow initial venting and outgassing to subside. This period might range from a day to up to a month, depending on requirements.

Contamination films on LDEF had a minimal effect on the overall thermal status of the satellite. Contaminant films did interfere with surface elemental analysis of test materials. Determination of average material recession rates must also consider the presence of contaminant films which react at different rates and/or even block recession for a period of time.

REFERENCES

1. "LDEF-69 Months in Space, First Post-Retrieval Symposium," NASA Conference Publication 3134, Part 1, Kissimmee, FL, June 2-8, 1991, section on LDEF Mission and Induced Environments.
2. "LDEF Materials Workshop '91," NASA Conference Publication 3162 Part 2, NASA LaRC, November 19-22, 1991, and contamination references therein.

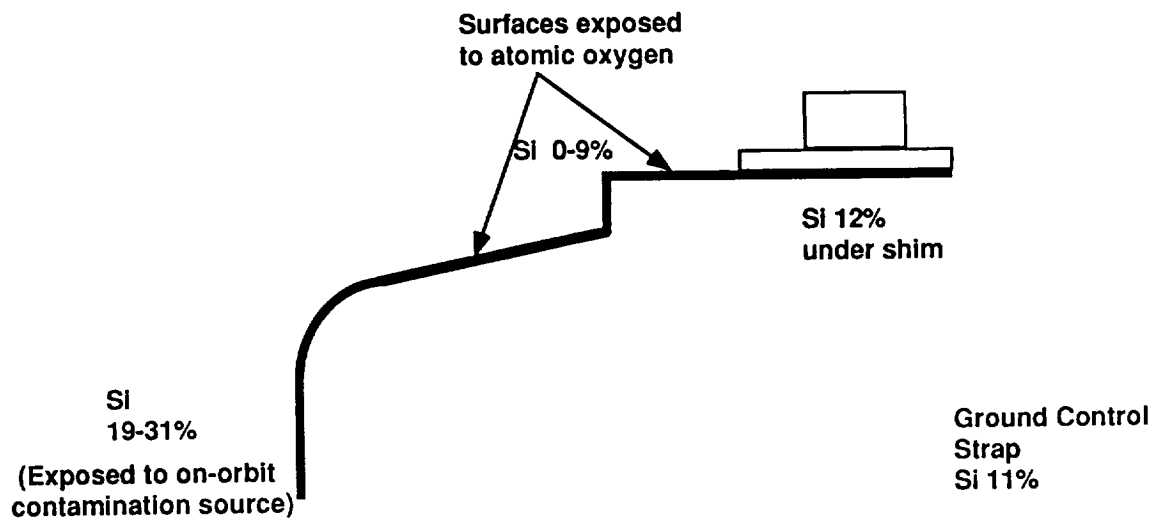


Figure 1. Cross section view of copper grounding strap, Tray D11, showing Mol% silicon on surface in different areas. (The value for the ground control strap is shown for comparison.)

Table 1. Total mass loss of heat shrink tubing as determined by ASTM E595.

Location on LDEF Bay and Longeron Between Rows	TML (Percent)
A,3-4	0.113
B,3-4	0.130
C,3-4	0.122
B,8-9	0.137
B,8-9	0.123
B,5-6	0.100
D-8, D-E	0.103
B,9-10	0.132
F,9-10	0.113
C,10-11	0.115
Space End	0.111
E,2-3	0.136
E,12-1	0.114
Earth End	0.102
F,8-9	0.126
B,3-4	0.139
Ground Control	0.170

