LONG DURATION EXPOSURE FACILITY POST-FLIGHT DATA AS IT INFLUENCES THE TROPICAL RAINFALL MEASURING MISSION

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SUMMARY

The Tropical Rainfall Measuring Mission (TRMM) is an earth observing satellite that will be in a low earth orbit (350 kilometers) during the next period of maximum solar activity. The TRMM observatory is expected to experience an atomic oxygen fluence of 8.9×10^{22} atoms per square centimeter. This fluence is ten times higher than the atomic oxygen impingement incident to the Long Duration Exposure Facility (LDEF). Other environmental concerns on TRMM include: Spacecraft glow, silicon oxide contaminant build-up, severe spacecraft material degradation, and contamination deposition resulting from molecular interactions with the dense ambient atmosphere. Because of TRMM's predicted harsh environment, TRMM faces many unique material concerns and subsystem design issues. The LDEF data has influenced the design of TRMM and the TRMM material selection process.

INTRODUCTION

The Tropical Rainfall Measuring Mission (TRMM) is a joint United States and Japan observatory program that will conduct systematic measurements of tropical rainfall required for weather and climate research. NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Maryland will design, build, and test the observatory. The observatory will be 3.6 meters in diameter and 4.6 meters in length and has a mass of 3334 kilograms. Figures 1 and 2 show the observatory configuration. The observatory will carry five instruments: Precipitation Radar (PR) supplied by the National Space Development Agency of Japan (NASDA), TRMM Microwave Imager (TMI) built by Hughes in El Segundo, Visible Infrared Scanner (VIRS) built by Santa Barbara Research Corporation, Clouds and the Earth's Radiant Energy System (CERES) managed by NASA Langley Research Center and built by TRW, and Lightning Imaging Sensor developed by NASA Marshall Space Flight Center.

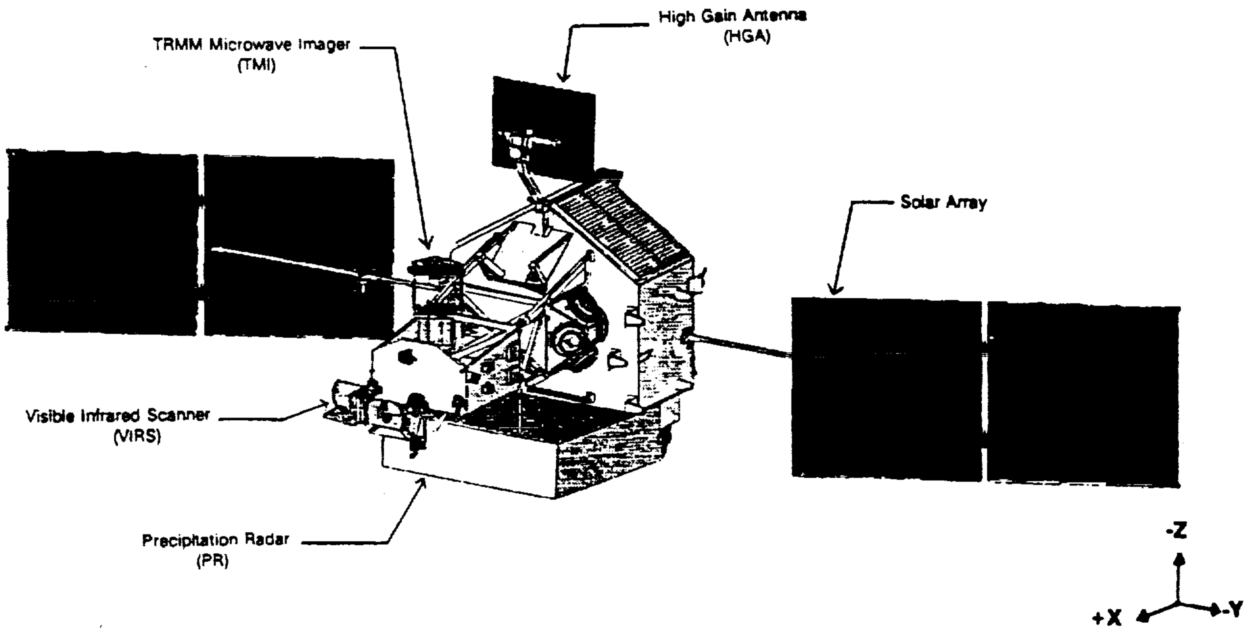

Figure 1. Tropical Rainfall Measuring Mission

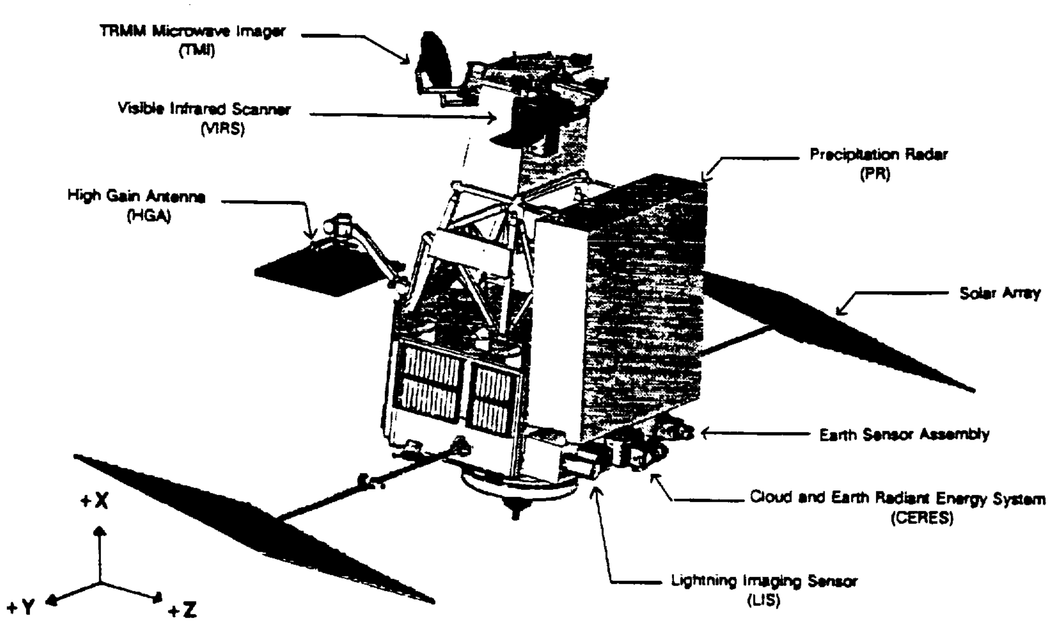

Figure 2. Tropical Rainfall Measuring Mission

TRMM is scheduled for launch in August 1997 from Tanegashima Space Center in Tanegashima, Japan. The launch vehicle is a Japanese H-II rocket. The observatory will fly in a circular orbit having an inclination of 35 degrees and an altitude of 350 kilometers (189 Nautical miles, just 10 nautical miles higher than the LDEF retrieval). TRMM's +Z axis is nadir pointing. The observatory performs a 180 degree yaw maneuver every 2 to 4 weeks to limit exposure of direct sunlight on the +Y side of the observatory.

TRMM will be in orbit during the next period of maximum solar activity (April 2000) and is predicted to experience an atomic oxygen fluence of 8.9×10^{22} atoms per square centimeter. This fluence is ten times higher than the atomic oxygen impingement incident to the Long Duration Exposure Facility (LDEF) and is almost double the space station atomic oxygen design fluence. Severe material degradation is expected resulting from material interactions with atomic oxygen or synergetic effects between atomic oxygen, solar ultra violet, and temperature. Most commonly used spacecraft outer layers will not survive TRMM's three and a half year mission. Table 1 lists the material thicknesses of common spacecraft materials required to survive the mission. The erosion rates used to calculate the material losses are based on LDEF and Shuttle erosion data[1,2]. All exterior surfaces of the observatory need to be protected against atomic oxygen since the observatory has no true "wake".

Table 1

Approximate Material Thicknesses Required for TRMM Mission

Spacecraft Material	Material Thickness Required
Kapton	>105 Mil
Chemglaze Z306	>12 Mil
Teflon	>13 Mil
Graphite Epoxy	>91 Mil
Unprotected Silver	>368 Mil

TRMM has several other low earth orbit environmental concerns. The atomic oxygen is expected to react with outgassed silicones to produce a permanent contaminant layer. This phenomena was widely observed on LDEF and has been seen on other missions like the Solar Maximum Mission (SMM), the Evaluation of Atomic Oxygen Interactions with Materials (EOIM-3) Experiment, and the European Retrievable Carrier (EURECA). Silicone oxide build-up is TRMM's major on-orbit contamination concern. Not only will the contaminant itself degrade sensitive surfaces but the mechanism exists for the silicone oxide to form in several different oxidation states making it difficult to predict the extent of degradation. In addition the silicone oxide contaminants can trap carbon based contaminants on sensitive surfaces further degrading those surfaces.

The contamination deposition problem is compounded by the dense ambient atmosphere. The ambient atmosphere at 350 km is approximately 26 times the density experienced at 600 km (a typical earth observing satellite orbit). Because of the dense ambient atmosphere, the TRMM thrusters need to fire approximately every two days during the last portion of the mission just to maintain orbit. TRMM will also experience localized pockets of ambient density build-up between the solar array and the spacecraft. As a result, outgassed contaminants from the observatory have a higher probability of colliding with the ambient atmosphere and returning back to the spacecraft. This phenomena is called return flux.

Another low earth orbit phenomena which TRMM is susceptible to is spacecraft glow. Glow is observed on shuttle flights especially after engine firings. Glow is a result of a reaction of contaminants or coatings with atomic oxygen and nitrogen. The mechanisms for glow to occur are not well defined. The impact of glow on the TRMM instruments and earth sensor will be evaluated in fiscal years 1994 and 1995.

DESIGN ISSUES

Multi-Layer Insulation Outer Layer

The TRMM Material Selection Working Group is responsible for approval of all external materials on TRMM with one of its main responsibilities being selection and testing of the observatory's multi-layer insulation (MLI) outer layer. The group consists of representatives from Contamination Engineering, Thermal Engineering, Thermal Coatings, and Materials. The group has evaluated over 50 candidate multi-layer insulation materials for use on TRMM. The materials included both instrument and spacecraft materials. The LDEF data was used in the preliminary screening process. Unfortunately, because of lack of applicable data and TRMM's harsh environmental constraints, selection of MLI outer layers has been difficult.

After preliminary screening, all candidate materials undergo environmental testing. The MLI outer layer testing program includes flex tests, optical property measurements, atomic oxygen testing, ultraviolet exposure tests, thermal cycling, and atomic oxygen testing in combination with ultraviolet irradiation. Flex tests involve flexing the materials sample over a 1/4 inch mandrel in two directions. Optical property measurements are performed by GSFC and include absorptance and emittance measurements. Atomic oxygen testing is performed at NASA Lewis Research Center (LeRC) using a directed atomic oxygen beam facility. The effective atomic oxygen fluence in this facility is calculated based on LDEF erosion rates for kapton and teflon. Ultraviolet exposure tests are performed by the GSFC. The materials are tested to 3000 solar equivalent hours in this facility. Thermal cycling tests are also performed by GSFC. The samples are cycled from -100°C to +100°C for 3000 cycles. Atomic oxygen testing in combination with ultraviolet irradiation tests will be performed by LeRC. The tests are expected to start in January 1994. Pre-test chamber characterizations have been completed.

The TRMM primary multi-layer insulation outer layer is an Optical Coating Laboratories, Inc. (OCLI) proprietary coating over VDA backed white tedlar. This selection was driven by the desire to have a diffusely reflective outer layer. The OCLI coating is custom made to the TRMM mission specifications. The proprietary coating consists of multilayers of three different types of inorganic oxides. The substrate on the MLI outer layer is white tedlar. White tedlar is a polyvinylfluoride film manufactured by DuPont in a 1.5 mil thickness. White tedlar has an absorptance value of 0.301 and an emittance of 0.890. Vapor deposited aluminum is applied to the back of the substrate for conductivity. A scrim will also be attached to the material to provide added strength. The OCLI coating over tedlar has an absorptance ranging from 0.377 to 0.612 and an emittance ranging from 0.762 to 0.778 depending on the thickness on the coating and its state of oxidation.

Several back-up materials are also being considered in case the primary material fails to pass all environmental tests. They include beta cloth with vapor deposited aluminum backing, Sheldahl silicon oxide (SiO_x) over kapton, or a composite consisting of Kapton coated with chemglaze Z306 to roughen the surface, then coated with a layer of vapor deposited aluminum, followed by aluminum oxide, and completed with an over-coat of silicon oxide. The back-up materials are not perfect solutions. The thermal properties of beta cloth woven with silicones degrade with ultraviolet radiation causing the properties to exceed observatory thermal requirements. The silicones in the beta cloth can be transferred by touch and handling of the beta cloth produces particulates. Beta cloth without silicones tends to be more brittle. Also, the teflon in the beta cloth can be eroded with atomic oxygen exposure, thus increasing its transmittance. The Sheldahl SiO_x over kapton may contain pinhole defects in the material making it susceptible to atomic oxygen erosion. Also it is difficult to detect microcracks in the SiO_x coating as a result of handling. The composite material has end of life thermal properties that exceed the spacecraft limits.

Special Radiator Surfaces

Radiator material selection is also controlled by the TRMM Material Selection Working Group. The spacecraft will use MS 74 white silicate paint on its radiator surfaces. MS 74 white silicate paint is UV and atomic oxygen stable and exhibits low outgassing properties.

Silver teflon is not an acceptable radiator material for the TRMM mission. Based on the LDEF measured erosion rates, 13 mil of teflon will be eroded during the mission.

Because the erosion of teflon is a synergetic effect between atomic oxygen, UV, and temperature and cannot be accurately reproduced in ground testing, the exact erosion rate of teflon for the TRMM mission is difficult to extract from the LDEF measured rates (the LDEF data represents only one low earth orbit long exposure data point). Rather than design teflon radiators to degrade at a certain rate and leave enough teflon to maintain the correct thermal properties, the risk of failure has been reduced by eliminating unprotected teflon from the spacecraft. Protective coatings do not adhere well to teflon.

Other radiator surfaces on the observatory include optical solar reflectors, IITRI Z-93P white silicate paint, and vapor deposited aluminum.

Blanket and Radiator Attachment Methods

Current plans are to attach the spacecraft blankets with fiberglass or stainless steel buttons. The possibility of using velcro in some protected areas of the spacecraft that are not contamination sensitive is being investigated. The edges of blankets must be turned under to prevent AO erosion of the blanket materials. The concept of joining two blankets with a french seam is being considered.

The use of tapes on external surfaces will be minimized or eliminated. There is concern that the acrylic adhesive backed tapes will experience AO undercutting and possible lifting. Silicone based adhesives represent a contamination source and need to be minimized. Silicone adhesives are currently being used to bond solar array cells to the substrates and to attach optical solar reflectors.

Future testing includes both acrylic and silicone adhesion tests in an AO environment. Undercutting of adhesives will be measured. Optical solar reflector degradation will be measured as a result of adhesive outgassing and oxidizing in an AO/UV environment. In addition, a test needs to be performed to measure the efficiency of the silicone/atomic oxygen reaction.

Solar Array Harness Protection

The baselined wire on the solar array harness has 8 mil of teflon insulation and therefore needs protection from atomic oxygen. Alternative insulations either have higher AO erosion rates or are too stiff for three dimensional deployment. Protective coatings will not adhere to the wire insulations.

Several protection methods have been proposed for the solar array harnesses. The boom harness which moves three dimensionally during deployment will be covered with a beta cloth sleeve sewn with an AO resistant thread. The interconnect harnesses will also be covered with beta cloth sleeves. The front side wire bundles with less than 10 wires will be coated with NUSIL CV1-1142. Larger bundles on the front side will be wrapped with germanium coated kapton tape. The backside wires (which experience some UV as a result of feathering the solar arrays to reduce drag) will be protected with germanium coated kapton sheets bonded with silicone adhesive or OCLI over white tedlar sheets bonded with a silicone adhesive. The terminal boards and diode boards will be covered with MS 74 painted metal covers. The backside of the arrays will be painted with MS 74 white silicate paint.

The above solar array harness protection methods need additional testing including outgassing tests, adhesion tests, thermal cycling and AO erosion tests. In addition, a study is being performed to determine if another suitable insulation is available.

Earth Sensor Concerns

The earth sensor is expected to experience several unique contamination concerns. The earth sensor has four lenses. Two of the lenses face 45° from the +X direction and two of the lenses face 45° from the -X direction. Because the observatory flies 50 percent of the time in the +X direction and 50 percent of the time in the -X direction, all lenses will face the ram direction making them susceptible to contamination and atomic oxygen environmental effects.

The earth sensor lens exterior consists of multiple layers of proprietary coatings. A sample of the lens will be tested in an atomic oxygen facility to verify the coating will remain intact in TRMM's predicted environment without pitting, eroding, or fogging. It is also planned to measure the effects of glow at the earth sensor wavelength region (12 to 18 microns) by exposing a lens sample to silicone and hydrocarbon contaminants while in the presence of atomic oxygen and nitrogen.

To determine the earth sensors susceptibility to contamination, GSFC will measure the lens sample transmittance loss as a function of SiO_x thickness, amorphous carbon thickness, and a combination of the two. There is concern that the earth sensor lenses will experience the same lens fogging problem[3] as observed on the TIROS and DMSP ram facing earth sensor lenses. The fogging phenomena is believed to be a combination of environmental and contamination effects.

External Contamination Limitations

To minimize molecular contaminants such as those observed on LDEF, the amount of silicone based materials on the observatory exterior will be limited. Outgassed silicones react with atomic oxygen to produce silicon oxide (SiO_x). Silicon oxide is a permanent contaminant layer which cannot be "baked-off" a surface. In addition, silicon oxide build-up can trap carbon based contaminants on a surface causing further degradation. Current external sources of silicones on the observatory include solar arrays (largest source), adhesives on tapes and optical solar reflectors, and protection of the TMI graphite epoxy support structure. Unfortunately, because of the lack of material alternatives and supporting flight data, silicones are being used to protect surfaces known to react with atomic oxygen.

Analytical predictions of contaminant flux to sensitive surfaces was performed using on-orbit contamination analyses and propulsion contamination analyses. Outgassing limits have been assigned to various spacecraft components. The outgassing rates of instruments, solar arrays, blankets, high gain antenna, harnesses, and electronic boxes will be certified during thermal vacuum testing using a quartz crystal microbalance. If the outgassing rates of those subsystems exceed the outgassing requirements, the respective subsystem will be baked-out. Spacecraft and instrument venting will be controlled and/or directed away from sensitive surfaces.

Internal Contamination Limitations

Contaminants originating from inside the spacecraft will be controlled. Outgassing rates of TRMM hardware will be monitored during component level thermal vacuum tests. Hardware not meeting the outgassing requirements will be baked-out.

The use of Chemglaze Z306 has been eliminated in the spacecraft cavity except for small quantities. The "nicotine" stains observed on LDEF have been attributed to outgassing from Chemglaze Z306. The equipment panels and electronic boxes will be either anodized or painted with MSA-94B black silicate paint.

Sources of silicones in the spacecraft interior will be controlled with a special spacecraft vent design. The spacecraft cavity will be tightly sealed with a layer of kapton or mylar under the thermal blankets. The vent effluent will be directed out a single vent in the least contaminating position on the spacecraft. Figure 3 shows the location of the spacecraft vent. The vent effluent will pass through a series of baffles coated with a molecular adsorber which has a high efficiency for adsorbing silicone based contaminants. The molecular adsorber is being developed by JPL. A similar venting concept was used in the Hubble Space Telescope Wide Field Planetary Camera II.

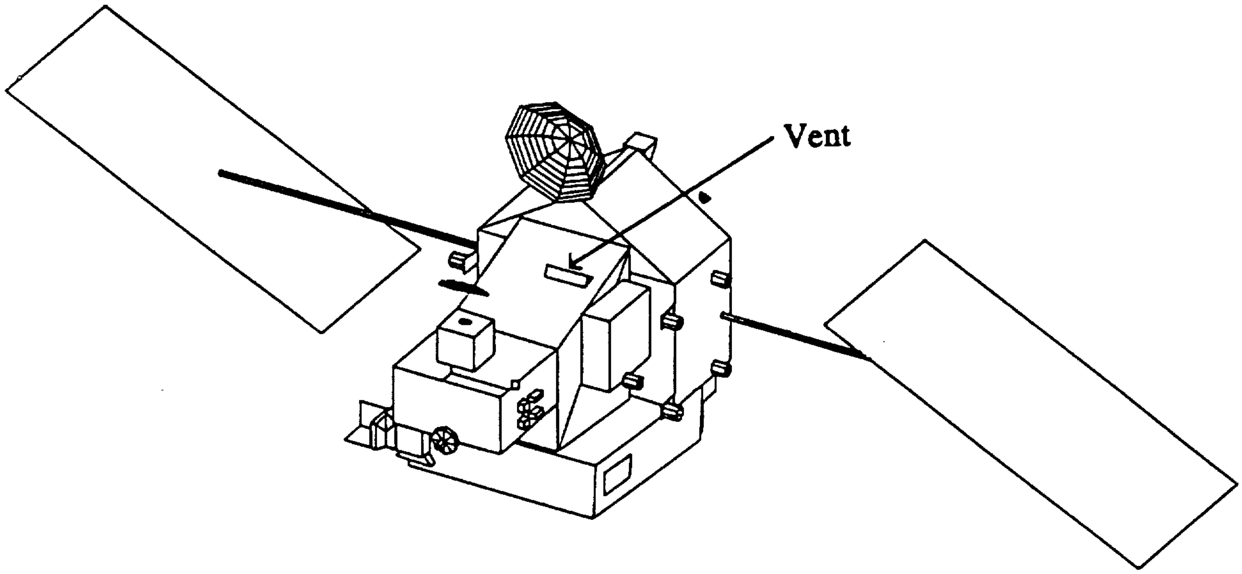

Figure 3. TRMM Vent Location

CONCLUSIONS

In conclusion, the knowledge obtained from LDEF post-flight data has been valuable in designing TRMM with respect to contamination control and material integrity. However, there exists a need for more long term data on materials, coatings and adhesives from orbits such as LDEF and TRMM, especially materials which erode by synergetic interactions with AO and UV. Because of the limited understanding of synergetic material interactions, extrapolating erosion rates from one orbital environment to another may be risky.

In addition, there are large voids in understanding how silicone based materials react with the environment, which silicones are hazardous, the efficiency of the silicone/silicon oxide reaction, and the relationship between atomic oxygen flux and silicone residence time. These material unknowns make material selection and behavior predictions difficult.

As a result of the uncertainties, the current design approach forces large margins, resulting in over-design, increased weight and increased cost. Efforts should be made to obtain environmental effects flight data from TRMM to make the follow-on mission more efficient as well as assisting in the design of similar low earth orbit satellites.

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EXPERIMENTS